North Anna Power Station
Updated Final Safety Analysis Report

Chapter 3

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CHAPTER 3 DESIGN CRITERIA - STRUCTURES, COMPONENTS, EQUIPMENT, AND SYSTEMS

3.1 CONFORMANCE WITH ATOMIC ENERGY COMMISSION (AEC) GENERAL DESIGN CRITERIA

Structures, systems, and components important to safety are designed to meet the intent of the general design criteria (GDC). The general design criteria, and explanations of how the structures, systems, and components meet the intent of the general design criteria, are found in Sections 3.1.1 through 3.1.55.

Each of the engineered safety features is designed to tolerate a single failure during the period of recovery following an incident, without loss of its protective function. This period of recovery consists of two segments, the short-term period and the long-term period.

During the short-term period, the single failure is limited to a failure of an active component to complete its function as required. Should the single failure occur during the long-term rather than the short-term period, the safety-related system is designed to tolerate an active failure or a passive failure without loss of its protective function.

The following definitions pertain to the single-failure criterion:

Period of recovery - The time necessary to bring the plant to a cold shutdown and regain access to faulted equipment. The recovery period is the sum of the short- and long-term periods defined below.

Incident - Any natural or accidental event of infrequent occurrence and its related consequences that affect the plant operation and require the use of engineered safety features (ESF) systems. Such events, which are analyzed independently and are not assumed to occur simultaneously, include the loss-of-coolant accident (LOCA), steam-line ruptures, steam generator tube ruptures, etc. A system blackout may be an isolated occurrence or may be concurrent with any event requiring engineered safeguards systems use.

Short term - Short term is the first 24 hours following initiation of ESF system operations. During the time immediately following the incident, automatic actions are performed, system responses are checked, the type of incident is identified, and preparations for long-term recovery are made.

Long term - The remainder of the recovery period following the short term. In comparison with the short term, when the main concern is to remain within Atomic Energy Commission (AEC) specified site criteria, the long-term period of operation involves bringing the plant to cold-shutdown conditions, where access to the containment can be gained and repair effected.

Active failure - The failure of a powered component, such as a piece of mechanical equipment, component of the electrical supply system, or instrumentation and control equipment, to act on command to perform its design function. Examples include the failure of a motor-operated valve to move to its correct position; the failure of an electrical breaker or relay to respond; the failure of a pump, fan, or diesel generator to start; etc.

Equipment moving spuriously from the proper safeguards position without signal, such as a motor-operated valve inadvertently shutting at the moment it is required, is not considered credible.

Passive failure - The structural failure of a static component that limits the component's effectiveness in carrying out its design function. When applied to a fluid system, this means a break in the pressure boundary resulting in abnormal leakage not exceeding 50 gpm for 30 minutes. Such leak rates are consistent with limited cracks in pipes, sprung flanges, valve-packing leaks, or pump seal failures.

The single-failure criterion applies to the following safety-related fluid systems:

System	Related General Design Criteria
Emergency core cooling system	GDC-35
Containment depressurization system	GDC-38
Service water system	GDC-44

The reactor trip system, discussed in Section 7.2, is designed to meet the single-failure criterion in conformance with IEEE Std. 279-1971.

North Anna Power Station, Units 1 and 2, was issued construction permit nos. CPPR-77 and CPPR-78 dated February 1971, based on the station design being in conformance with the *General Design Criteria for Nuclear Power Plants,* published in 1966. However, to facilitate review by the AEC, the following section discusses the design of the station relative to the new design criteria published in 1971. Following the text of each criterion is a brief discussion specific to that criterion.

Compliance with Safety Guides is discussed in Appendix 3A.

3.1.1 Quality Standards and Records, Criterion 1

3.1.1.1 AEC Criterion

Structures, systems, and components important to safety shall be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. Where generally recognized codes and standards are used, they shall be identified and evaluated to determine their applicability, accuracy, and sufficiency, and shall be supplemented or modified as necessary to ensure a quality product in keeping with the required safety function. A quality assurance program shall be established and implemented in order to provide adequate assurance that these structures, systems, and components will satisfactorily perform their safety functions. Appropriate records of the design, fabrication, erection, and testing of structures, systems, and components important to safety shall be maintained by or under the control of the nuclear power unit licensee throughout the life of the unit.

3.1.1.2 Discussion

Structures, systems, and components important to safety are designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. The codes and standards for the design, fabrication, erection, and testing of safety-related structures, systems, and components are identified in Chapters 1, 3, 4, 5, 6, 7, 8, and 9. The quality assurance program established and implemented to provide adequate assurance that these structures, systems, and components will satisfactorily perform their safety functions is described in Chapter 17. Design control activities ensure that the codes and standards are adequate and applicable, so that the performance and safety functions can be achieved. Appropriate records of the design, fabrication, erection, and testing of these structures, systems, and components are maintained by VEPCO as described in Chapter 17.

The reference sections are:

Section Title	Chapter
Introduction and General Description of Plant	1
Design Criteria - Structures, Components, Equipment, and Systems	3
Reactor	4
Reactor Coolant System	5
Engineered Safety Features	6
Instrumentation and Controls	7
Electric Power	8
Auxiliary Systems	9
Quality Assurance	17

3.1.2 Design Bases for Protection Against Natural Phenomena, Criterion 2

3.1.2.1 AEC Criterion

Structures, systems, and components important to safety shall be designed to withstand the effects of natural phenomena such as earthquakes, tornados, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions. The design basis for these structures, systems and components shall reflect:

1. Appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.
2. Appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena.
3. The importance of the safety functions to be performed.

3.1.2.2 **Discussion**

The station structures, systems, and components important to safety have been designed to withstand the effects of natural phenomena such as earthquakes, tornados, hurricanes, seiches, and floods, as described in Chapters 2 and 3. Tsunami are not applicable to the North Anna site. Appropriate considerations have been made in the design basis for the most severe natural phenomena that have been historically reported for the site and surrounding area, including a margin of error for the accuracy of such reporting and the relatively short period over which data has accumulated. The combined phenomena have been included as described in this chapter. The importance of the safety functions to be performed has been considered in developing the design basis for structures, systems, and components important to safety.

The reference sections are:

Section Title	Chapter
Site Characteristics	2
Design Criteria - Structures, Components, Equipment, and Systems	3
Reactor	4
Reactor Coolant System	5
Engineered Safety Features	6
Instrumentation and Controls	7
Electric Power	8
Auxiliary Systems	9

3.1.3 Fire Protection, Criterion 3

3.1.3.1 **AEC Criterion**

Structures, systems, and components important to safety shall be designed and located to minimize, consistent with other safety requirements, the probability and effect of fires and explosions. Noncombustible and heat-resistant materials shall be used wherever practical through the unit, particularly in locations such as the containment and control room. Fire detection and fighting systems of appropriate capacity and capability shall be provided and designed to minimize the adverse effects of fire on structures, systems, and components important to safety. Fire fighting systems shall be designed to ensure that their rupture or inadvertent operation does not significantly impair the safety capability of these structures, systems, and components.

3.1.3.2 **Discussion**

Facilities are designed to minimize the probability and effect of fires and explosions.

Structures are of fire-resistant construction, and equipment is designed to minimize fire hazards. Fire detection and protection systems are described in Section 9.5.1.

The reactor containment design minimizes the use of combustible materials. Atmospheric conditions within the containment are not of an explosive nature. A fire detection system is provided at the base of the reactor coolant pump volutes to detect possible oil fires.

The control room is of fire-resistant construction, isolated from surrounding areas by heavy concrete shielding. The control room atmosphere is not explosive. Fire protection is described in Section 9.5.1.

Waste hydrogen gas from the reactor coolant system is diluted to a concentration below its lower flammability limit when it is discharged through the process vent. Potentially hazardous systems processing hydrogen-oxygen mixtures conform to the National Electrical Code for areas of Class I, Division 2, Group B.

The fire protection system is designed so that a failure of any component will not cause a nuclear accident or significantly impair the capability of safety-related structures, systems, and components.

The reference sections are:

Section Title	Chapter
Reactor	4
Reactor Coolant System	5
Engineered Safety Features	6
Auxiliary Systems	9
Radioactive Waste Management	11

3.1.4 Environmental and Missile Design Bases, Criterion 4

3.1.4.1 AEC Criterion

Structures, systems, and components important to safety shall be designed to accommodate the effects of and to be compatible with the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents, including LOCAs. These structures, systems, and components shall be appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids, that may result from equipment failures and from events and conditions outside the nuclear power unit.

The General Design Criteria 4 (GDC-4) has undergone significant changes. The revised GDC-4 (References 14 and 15) approved the use of leak-before-break technology for eliminating the dynamic effects of postulated pipe ruptures in high energy piping including primary coolant piping from the design basis of pressurized water reactor's (PWR). Implementation of the revised rule permits the removal of pipe whip restraints, jet impingement barriers, and other related changes. The rule clearly allows removal of plant hardware which it is believed negatively affects plant performance and safety. However, as stated in the Federal Register/Vol. 15, No. 70/ of April 11, 1986, and subsequently in broad scope rule in the Federal Register/Vol. 52, No. 207/ of

October 27, 1987, containment design, emergency core cooling, and environmental qualification requirements are not influenced by the revised rule.

3.1.4.2 **Discussion**

The arrangement and design of the structures, systems, and components for the ESF systems provide protection against dynamic effects of both interior and exterior missiles, of jet impingement, and of pipe rupture, as described in this chapter.

Wherever possible, ESF systems piping and valves, except root valves and their connections to the reactor coolant piping, have been run inside the columns supporting the crane wall below the steam generator and pressurizer cubicles, or in the annulus outside of the crane wall. Since this space is completely outside of the area occupied by the reactor coolant system, the ESF equipment and piping loops are protected from the effects of a LOCA. Inside the individual cubicles, protection is by separation and/or restraint of individual lines wherever possible.

Layout and structural design specifically protects the injection lines leading to unbroken reactor coolant loops against damage as a result of the maximum reactor coolant system pipe rupture. Separation of individual injection lines is provided to the maximum extent practicable. Movement of injection lines associated with the rupture of a reactor coolant loop is accommodated by line flexibility and by design of the pipe supports, so that no damage beyond the missile barrier is credible.

Instrumentation, motors, cables, and penetrations located inside the containment are selected to meet the most adverse accident conditions to which they may be subjected. These items are either protected from containment accident conditions or are designed to withstand, without failure, exposure to the worst combination of temperature, pressure, humidity, and radiation expected during the required operational period. This qualification was substantiated by appropriate testing of the actual equipment or prototypes where practicable.

The reference sections are:

Section Title	Chapter
Design Criteria - Structures, Components, Equipment, and Systems	3
Reactor Coolant System	5
Engineered Safety Features	6
Instrumentation and Controls	7

3.1.5 Sharing of Structures, Systems, and Components, Criterion 5

3.1.5.1 **AEC Criterion**

Structures, systems, and components important to safety shall not be shared between nuclear power units unless it is shown that such sharing will not significantly impair their ability to perform their safety functions including, in the event of an accident in one unit, an orderly shutdown and cooldown of the remaining units.

3.1.5.2 **Discussion**

Structures, systems, and components that are shared between units are tabulated in Section 1.2.11, with references to sections containing specific design details.

Safety functions are not significantly impaired by the sharing of these structures, systems, and components.

The reference section is:

Section Title	Chapter
Introduction and General Description of Plant	1

3.1.6 Reactor Design, Criterion 10

3.1.6.1 **AEC Criterion**

The reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to ensure that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences.

3.1.6.2 **Discussion**

The reactor core and associated coolant, control, and protective systems are designed to function throughout the core's design lifetime without exceeding acceptable fuel damage limits. The core design, together with reliable process and decay heat removal systems, provides for this capability under all expected conditions of normal operation with appropriate margins for uncertainties and anticipated transient situations, including the effects of the loss of reactor coolant flow, trip of the turbine generator, loss of normal feedwater, and loss of all offsite power.

The reactor control and protection instrumentation system is designed to actuate a reactor trip for any anticipated combination of plant conditions when necessary to ensure a minimum departure from nucleate boiling ration (DNBR) greater than the limit value and fuel center temperatures below the melting point of UO_2.

Chapter 4 discusses the design bases and design evaluation of reactor components including the fuel, reactor vessel internals, and reactivity control systems. Details of the control and protection systems instrumentation design and logic are discussed in Chapter 7. This information supports the accident analyses of Chapter 15 showing that acceptable fuel design limits are not exceeded.

3.1.7 Reactor Inherent Protection, Criterion 11

3.1.7.1 AEC Criterion

The reactor core and associated coolant systems shall be designed so that in the power operating range the net effect of the prompt inherent nuclear feedback characteristics tends to compensate for a rapid increase in reactivity.

3.1.7.2 Discussion

Prompt compensatory reactivity feedback effects are ensured when the reactor is critical by the negative fuel temperature effect (Doppler effect) and by the nonpositive operational limit on moderator temperature coefficient of reactivity. The negative Doppler coefficient of reactivity is ensured by the use of low-enrichment fuel; the nonpositive moderator temperature coefficient of reactivity is ensured by administratively limiting the dissolved absorber concentration.

The core inherent reactivity feedback characteristics are described in Section 4.3, Nuclear Design. Reactivity control by chemical injection is discussed in Section 4.2.3, Reactivity Control System, and Section 9.3.4, Chemical and Volume Control System. The Technical Requirements Manual defines allowable absorber concentrations.

3.1.8 Suppression of Reactor Power Oscillations, Criterion 12

3.1.8.1 AEC Criterion

The reactor core and associated coolant, control, and protection systems shall be designed to ensure that power oscillations that can result in conditions exceeding specified acceptable fuel design limits are not possible, or can be reliably and readily detected and suppressed.

3.1.8.2 Discussion

Power oscillations of the fundamental mode are inherently eliminated by the negative Doppler and nonpositive moderator temperature coefficient of reactivity.

Oscillations due to xenon spatial effects, in the radial, diametral, and azimuthal overtone modes, are heavily damped due to the inherent design and to the negative Doppler and nonpositive moderator temperature coefficient of reactivity.

Oscillations due to xenon spatial effects may occur in the axial first overtone mode. Assurance that fuel design limits are not exceeded by xenon-induced axial oscillations is provided by reactor trip functions using the measured axial power imbalance as an input.

The stability of the core against xenon-induced power oscillations and the functional requirements of instrumentation for monitoring and measuring core power distribution are discussed in Section 4.3, Nuclear Design. Details of the instrumentation design and logic are discussed in Chapter 7.

3.1.9 Instrumentation and Control, Criterion 13

3.1.9.1 AEC Criterion

Instrumentation shall be provided to monitor variables and systems over their anticipated ranges for normal operation, for anticipated operational occurrences, and for accident conditions as appropriate to ensure adequate safety, including those variables and systems that can affect the fission process, the integrity of the reactor core, the reactor coolant pressure boundary, and the containment and its associated systems. Appropriate controls shall be provided to maintain these variables and systems within prescribed operating ranges.

3.1.9.2 Discussion

Instrumentation and control systems are provided in the North Anna Power Station to monitor and maintain plant variables, including those variables that affect the fission process, integrity of the reactor core, the reactor coolant pressure boundary, and the containment over their prescribed ranges for normal operation, for anticipated operational occurrences, and under accident conditions.

The following processes are controlled to maintain key variables within their normal ranges:

1. Reactor power level (manual or automatic, by controlling thermal load).
2. Reactor coolant temperature (manual or automatic, by rod control cluster assembly motion, in sequential groups).
3. Reactor coolant pressure (manual or automatic, by heaters and spray in the pressurizer).
4. Reactor coolant water inventory, as indicated by the water level in the pressurizer (manual or automatic, by charging flow).
5. Reactor coolant system boron concentration (manual or automatic, by makeup of charging flow).
6. Steam generator inventory on secondary side (manual or automatic, by feedwater control valves).
7. Containment pressure (manual, by use of containment vacuum system).

The reactor control system is designed to maintain automatically a programmed average temperature in the reactor coolant during steady-state operation, and to ensure that plant conditions do not reach reactor trip settings as the result of a transient caused by a load change. Overall reactivity control is achieved by the combination of soluble boron and rod cluster control assemblies. Long-term regulation of core reactivity is accomplished by adjusting the concentration of boric acid in the reactor coolant. Short-term reactivity control for power changes is achieved by the reactor control system, which automatically moves rod cluster control assemblies. This system uses neutron flux, coolant temperature, and turbine load input signals.

The pressurizer pressure control system limits pressure excursions that might otherwise cause reactor trip, changes in reactivity, and actuation of the relief valves.

A wide spectrum of measurements is displayed for operator information and/or is processed to provide alarms. These measurements provide notification and allow correction of conditions having the potential of leading to accident conditions. Typical indication (or alarm) measurements are rod position, rod deviation, insertion limit, rod bottom, rod control system failure, rod control system urgent failure, incore flux and temperature, protection system faults, and protection system test mode. Reactor coolant system pressure and pressurizer level are monitored to ensure that the reactor coolant system pressure is maintained within design and operating limits. Containment pressure is monitored and alarmed to enable the operator to operate the containment vacuum system as needed to maintain the design operating pressure inside the containment. In addition, instrumentation monitoring containment pressure, pressurizer pressure level, steam flow and pressure, and steam-line differential pressure provide automatic ESF actuation on sensing accident conditions.

The instrumentation and control systems are discussed in Chapter 7.

3.1.10 Reactor Coolant Pressure Boundary, Criterion 14

3.1.10.1 AEC Criterion

The reactor coolant pressure boundary shall be designed, fabricated, erected, and tested so as to have an extremely low probability of abnormal leakage, or rapidly propagating failure, and of gross rupture.

3.1.10.2 Discussion

The reactor coolant pressure boundary is designed to accommodate the system pressures and temperatures attained under all expected modes of plant operation including all anticipated transients, without exceeding the applicable stress limits. The design criteria, methods, and procedures applied to components of the reactor coolant pressure boundary are discussed in Section 5.2.3. Reactor coolant pressure boundary materials selection and fabrication techniques ensure a low probability of gross rupture or significant leakage.

In addition to the loads imposed on the system under normal operating conditions, consideration was also given to abnormal loading conditions such as pipe rupture and seismic disturbance, as discussed in Sections 3.6 and 3.7, respectively. Fracture prevention measures prevent brittle fracture. Refer to the discussion under Criterion 31 in Section 3.1.27 for additional information.

The system is protected from overpressure by the pressurizer high-pressure reactor trip (Section 7.2) and by pressure-relieving devices (Section 5.2.2).

The reactor coolant pressure boundary materials are protected by control of coolant chemistry from corrosion, which might otherwise reduce the system’s structural integrity during its service lifetime.

The pressure boundary has provisions for inspection, testing, and surveillance of critical areas to assess its structural and leaktight integrity. The reactor coolant pressure boundary leakage detection systems and inservice inspection program are discussed in Sections 5.2.4 and 5.2.5, respectively.

3.1.11 Reactor Coolant System Design, Criterion 15

3.1.11.1 AEC Criterion

The reactor coolant system and associated auxiliary, control, and protection systems shall be designed with sufficient margin to ensure that the design conditions of the reactor coolant pressure boundary are not exceeded during any condition of normal operation, including anticipated operational occurrences.

3.1.11.2 Discussion

The reactor coolant system and associated auxiliary, control, and protection systems are designed to ensure the integrity of the reactor coolant pressure boundary with adequate margins during normal operation and during anticipated operational transients. The system boundary accommodates loads due to the operating-basis earthquake during normal operation, including normal operational transients, within upset condition code stress limits. The system boundary accommodates loads due to the design-basis earthquake combined with loads due to piping failures, such as circumferential pipe ruptures of reactor coolant pipes at junctures with equipment nozzles, and connecting pipes at junctures to reactor coolant piping, without propagation of failure to remaining reactor coolant system loops, steam power conversion system, or other piping or equipment needed for emergency cooling. The components of the reactor coolant system and associated fluid systems are designed in accordance with appropriate ASME codes. These codes are identified in Chapter 5. The protection system is designed in accordance with IEEE Std. 279-1971. The protection system analyses are given in Section 7.2.2.

The selected design margins include operating transient changes due to thermal lag, coolant transport times, pressure drops, system relief valve characteristics, and instrumentation and control response characteristics.

3.1.12 Containment Design, Criterion 16

3.1.12.1 AEC Criterion

Reactor containment and associated systems shall be provided to establish an essentially leaktight barrier against the uncontrolled release of radioactivity to the environment and to ensure that the containment design conditions important to safety are not exceeded for as long as postulated accident conditions require.

3.1.12.2 Discussion

A reinforced-concrete, steel-lined containment structure, operating at a subatmospheric pressure, encloses the entire reactor coolant system. It is designed to sustain, without loss of required integrity, all effects of gross equipment failures up to and including the rupture of the largest pipe in the reactor coolant system. Engineered safety features, comprising safety injection systems and containment depressurization systems, cool the reactor core and return the containment to subatmospheric pressure, thus terminating the driving force for the release of radioactivity, and maintain the containment at subatmospheric pressure for as long as the situation requires. The containment and its associated engineered safety features, therefore, meet the required functional capability of protecting the public from the consequences of gross equipment failures.

The system is discussed in Chapter 6.

3.1.13 Electric Power Systems, Criterion 17

3.1.13.1 AEC Criterion

An onsite electric power system and an offsite electric power system shall be provided to permit functioning of structures, systems, and components important to safety. The safety function for each system (assuming the other system is not functioning) shall be to provide sufficient capacity and a capability to ensure that (1) specified acceptable fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded as a result of anticipated operational occurrences, and (2) the core is cooled and containment integrity and other vital functions are maintained in the event of postulated accidents.

The onsite electric power supplies, including the batteries and the onsite electric distribution system, shall have sufficient independence, redundancy, and testability to perform their safety functions assuming a single failure.

Electric power from the transmission network to the onsite electric distribution system shall be supplied by two physically independent circuits (not necessarily on separate rights of way) designed and located so as to minimize to the extent practical the likelihood of their simultaneous failure under operating and postulated accident and environmental conditions. A switchyard common to both circuits is acceptable. Each of these circuits shall be designed to be available in sufficient time following a loss of all onsite ac power supplies and the other offsite electric power circuits, to ensure that specified acceptable fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded. One of these circuits shall be designed to be available within a few seconds following a LOCA to ensure that core cooling, containment integrity, and other vital safety functions are maintained.

Provisions shall be included to minimize the probability of losing electric power from any of the remaining supplies as a result of, or coincident with, the loss of power from the transmission network, or the loss of power from the onsite electric power supplies.

3.1.13.2 Discussion

Onsite and offsite power systems are provided that can independently supply the electric power required for the operation of safety-related systems. This capability is maintained even with the failure of any single active component in either the onsite or offsite system. In the unlikely event of total loss of offsite power, the emergency buses are energized by the emergency diesel generators. Four diesel generators are available for two units. Two diesels are assigned to Unit No. 1 and two are assigned to Unit No. 2. There are two redundant buses in each unit serving engineered safety features; these buses ensure operation of minimum ESF equipment under all conditions, including a failure of a single component in the onsite power system. The system is described in Chapter 8.

3.1.14 Inspection and Testing of Electric Power Systems, Criterion 18

3.1.14.1 **AEC Criterion**

Electric power systems important to safety shall be designed to permit appropriate periodic inspection and testing of important areas and features, such as wiring, insulation, connections, and switchboards, to assess the continuity of the systems and the condition of their components. The systems shall be designed with a capability to test periodically (1) the operability and functional performance of the components of the systems, such as onsite power sources, relays, switches, and buses, and (2) the operability of the systems as a whole and, under conditions as close to design as practical, the full operation sequence that brings the systems into operation, including operation of applicable portions of the protection system, and the transfer of power among the nuclear power unit, the offsite power system, and the onsite power system.

3.1.14.2 **Discussion**

The redundant electric power systems important to plant safety are continuously monitored and energized during normal plant operation from redundant offsite power sources. Redundant onsite diesel generators provide automatic backup power sources.

Periodic tests of the automatic operation of the transfer system are made to ensure that station auxiliary power is supplied automatically when an offsite power source is out of service. Periodic starting and loading of each emergency generator, and its emergency bus, ensures operability of the emergency generator and the automatic sequence of activating the emergency power supply in the event of loss of electrical power.

The condition of the station batteries is periodically monitored by checking and recording battery specific gravity and voltage. The system is described in Chapter 8.

3.1.15 Control Room, Criterion 19

3.1.15.1 **AEC Criterion**

A control room shall be provided from which actions can be taken to operate the nuclear power unit safely under normal conditions and to maintain it in a safe condition under accident conditions, including LOCAs. Adequate radiation protection shall be provided to permit access and occupancy of the control room under accident conditions without personnel receiving radiation exposures in excess of 5 rem TEDE for the duration of the accident.

Equipment at appropriate locations outside the control room shall be provided (1) with a design capability for prompt hot shutdown of the reactor, including necessary instrumentation and controls to maintain the unit in a safe condition during hot shutdown, and (2) with a potential capability for subsequent cold shutdown of the reactor through the use of suitable procedures.

3.1.15.2 **Discussion**

A control room, located at grade level in the service building, contains the main control board and all controls and instrumentation necessary for safe operation of the units during normal and accident conditions, including LOCAs. All safety-related switchgear, auxiliary shutdown control panels, and battery rooms and communications equipment are located in the service building below the control room. Emergency air-conditioning equipment is provided within the envelope of the control room and associated portions of the basement. The control room also includes various auxiliary control panels, such as the switchyard control panel, electrical recording panels, fire protection panel, control panels for operation of the emergency diesel-generator system, and computer consoles.

The control panels contain those instruments and controls necessary for operation of the station functions, such as the reactor and its auxiliary systems, turbine generator, and the steam and power conversion systems.

In the event that access to the control room is restricted, the reactors can be maintained in a hot-shutdown condition at the auxiliary shutdown control panels, located outside the control room but within the protected envelope.

Sufficient shielding, distance, and structural integrity ensure that control room personnel will not receive radiation exposures in excess of 5 rem TEDE for the duration of an accident.

Makeup air for emergency conditions is available from a compressed air bank and, upon exhaustion, from emergency ventilating units supplying air through high-efficiency particulate air (HEPA) and charcoal filters to remove particulates and iodine, respectively.

The reference sections are:

Section Title	Chapter
Instrumentation and Controls	7
Auxiliary Systems	9
Radiation Protection	12
Control Room Habitability	Section 6.4

3.1.16 Protection System Functions, Criterion 20

3.1.16.1 **AEC Criterion**

The protection system shall be designed (1) to initiate automatically the operation of appropriate systems, including the reactivity control systems, to ensure that specified acceptable fuel design limits are not exceeded as a result of anticipated operational occurrences, and (2) to sense accident conditions and to initiate the operation of systems and components important to safety.

3.1.16.2 **Discussion**

The North Anna Power Station operational limits for the reactor protection system are defined by analyses of plant operating and fault conditions requiring rapid rod insertion to prevent or limit core damage. With respect to acceptable fuel design limits, the system design bases for anticipated operational occurrences are:

1. Minimum DNBR shall not be less than the limit value.
2. Clad strain on the fuel element shall not exceed 1%.
3. No centerline melt shall occur in the fuel elements.

A region of permissible core operation is defined in terms of power, axial power distribution, and coolant flow and temperature. The protection system monitors these process variables (as well as other process variables and plant conditions). If the region limits are approached during operation, the protection system will automatically actuate alarms, initiate load cutback, prevent control rod withdrawal, or trip the reactor, depending on the severity of the condition.

Operation within the permissible region and complete core protection is ensured by the overtemperature delta T and overpower delta T reactor trips in the system pressure range defined by the pressurizer high-pressure and pressurizer low-pressure reactor trips, in the event of a transient that is slow with respect to piping delays from the core to the temperature sensors. In the event that a transient faster than the delta T response occurs, high-nuclear flux and low coolant flow reactor trips provide core protection. Finally, thermal transients are anticipated and avoided by reactor trips initiated by turbine trip and primary coolant pump circuit breaker position.

The protection system operates by interrupting power to the rod control power supply. All control and shutdown rods insert by gravity as a result. The Westinghouse protection system design meets the requirements of IEEE Std. 279-1971, *Criteria for Protective Systems for Nuclear Power Generating Stations*.

The protection system measures a wide spectrum of process variables and plant conditions. All analog channels that actuate reactor trip, rod stop, and permissive functions are indicated or recorded. In addition, visual and/or audible alarms are actuated for reactor trip; partial reactor trip, any input channel; and any control variable exceeding its setpoint on any input channel. These measurements and indications provide the bases for corrective action to prevent the development of accident conditions. In the event of an accident condition, however, the reactor protection system will sense the condition, process the signals used for ESF actuation, and generate the actuation demand. The conditions leading to ESF actuation are:

1. Low-low pressurizer pressure.

2. High steam-line pressure differential between any two steam generators.
3. High steam-line flow in two out of three steam lines, coincident with either low steam-line pressure or low-low T_{avg} in two out of three loops.
4. High containment pressure.

The reactor trip system is discussed in Section 7.2, the safety injection actuation in Section 7.3.1.3.3, and the engineered safety features in Chapter 6.

3.1.17 Protection System Reliability and Testability, Criterion 21

3.1.17.1 **AEC Criterion**

The protection system shall be designed for high functional reliability and inservice testability commensurate with the safety functions to be performed. Redundancy and independence designed into the protection system shall be sufficient to ensure that (1) no single failure results in loss of the protection function, and (2) removal from service of any component or channel does not result in loss of the required minimum redundancy unless the acceptable reliability of operation of the protection system can be otherwise demonstrated. The protection system shall be designed to permit periodic testing of its functioning when the reactor is in operation, including a capability to test channels independently to determine failures and losses of redundancy that may have occurred.

3.1.17.2 **Discussion**

The North Anna Power Station protection system is designed for high functional reliability and inservice testability commensurate with the safety functions to be performed.

The system consists of a large number of input measurement channels, redundant logic trains, redundant reactor trip breakers, and redundant ESF actuation devices. It performs both indication and alarm functions, in addition to its reactor trip and ESF actuation functions. The design meets the requirements of IEEE Std. 279-1971, *Criteria for Nuclear Power Generating Station Protection Systems*. The redundant logic trains, reactor trip breakers, and safety features actuation relays are electrically isolated and physically separated. Further, physical separation of the channels is maintained within the separated trains. Either of the two logic trains will perform the protection function. All channels used in power operation are sufficiently redundant that individual testing and calibration can be performed with the reactor at power, without degradation of the protection function or violation of the single-failure criterion. Such testing will disclose failures or reduction in redundancy that may have occurred. Removal from service of any single channel or component does not result in loss of minimum required redundancy. For example, a two-of-three function is placed in one-of-two mode when one channel is removed.

Semiautomatic testers are built into each of the two logic trains. These testers have the capability of testing the major part of the protection system very rapidly with the reactor at power. Between tests, the testers continuously monitor a number of internal protection system points including train power supply voltages and fuses. The outputs of these monitor circuits are processed by logic devices to provide an alarm in the event of a single failure in either train and an automatic reactor trip in the event of one or more failures in both trains. Self-testing provisions are designed into each tester.

The protection system is discussed in Sections 7.2 and 7.3.

3.1.18 Protection System Independence, Criterion 22

3.1.18.1 AEC Criterion

The protection system shall be designed to ensure that the effects of natural phenomena and of normal operating, maintenance, testing, and postulated accident conditions on redundant channels do not result in loss of the protection function, or shall be demonstrated to be acceptable on some other defined basis. Design techniques, such as functional diversity or diversity in component design and principles of operation, shall be used to the extent practical to prevent loss of the protection function.

3.1.18.2 Discussion

The North Anna Power Station protection system has been designed to provide sufficient resistance to a broad class of accident conditions or postulated events.

The defenses against loss of the protection function through the effects of natural phenomena such as tornado, flood, earthquake, and fire are physical separation and electrical isolation of redundant channels and subsystems, functional diversity of subsystems, and safe (direction of reactor trip) component and subsystem failure modes. These defenses have been used in the design of the reactor protection system. The redundant logic trains, reactor trip breakers, and safety features actuation devices are physically separated and electrically isolated. Physically separate channel cable trays, conduit, and penetrations are maintained upstream from the logical elements of each train. Functional diversity is designed into the system. For example, the loss of one feedwater pump could actuate pressurizer high pressure, pressurizer high level, steam generator low level, overpower delta T and ovetemperature delta T, and low feedwater flow trips. The system logic is designed so that, with the exception of the reactor coolant pump interlock trips and the safety features actuation devices, a zero input represents a trip demand. Hence severed or shorted channel wiring, loss of power, and the majority of channel component failures are seen by the system as trip demands.

The factors associated with normal operation are temperature, humidity, dust or dirt, and vibration. The protection system is tested and qualified under environmental conditions in excess of the extreme normal ranges. The recommended test and maintenance procedures are adequate against simultaneous multiple failures due to wear, dust, or dirt. Further, protection of the equipment from dust or other contaminants is afforded by the cabinets in which the equipment is installed.

The possibility of loss of the protection function through improper or incorrect maintenance is minimized by a number of factors. Among these are administrative controls, maintenance records, functional diversity (a temperature channel and a flux channel are not likely to be miscalibrated in the same direction, for example), and a comprehensive indication, alarm, and status system.

Loss of the protection function through improper testing or failure of the test equipment is guarded against by interlocks that enable the testing of only one of the two trains at a time, bypass trip breakers to maintain the protection function during test, annunciation of the test mode, unambiguous tester readout, and the indication, alarm, and status systems.

The protection system has been quantitatively evaluated with respect to functional diversity and qualitatively evaluated with respect to common mode susceptibility. These studies indicate that the system is designed to have a very high probability of performing its function in any postulated occurrence.

The reactor protection system and the ESF actuation system are discussed in Sections 7.2 and 7.3, respectively.

3.1.19 Protection System Failure Modes, Criterion 23

3.1.19.1 **AEC Criterion**

The protection system shall be designed to fail into a safe state or into a state demonstrated to be acceptable on some other defined basis if conditions such as disconnection of the system, loss of energy (e.g., electric power, instrument air), or postulated adverse environments (e.g., extreme heat or cold, fire, pressure, steam, water, and radiation) are experienced.

3.1.19.2 **Discussion**

The North Anna Power Station system is designed with due consideration of the most probable failure modes of the components under various perturbations of energy sources and the environment.

Each reactor trip channel is designed on the de-energize-to-trip principle, so that a loss of power or disconnection or shorting of a channel causes that channel to go into its tripped mode. Likewise, loss of voltage to either of the two protection system output devices will trip the reactor. In addition, 15 internal points in each train are continuously monitored by the semiautomatic testers. Faults involving one logic train are annunciated; faults involving both trains automatically trip the reactor, even though such faults would not necessarily defeat the trip function. All control and shutdown rods will insert by gravity if the rod power supply is lost.

There are certain additional trips which provide input into the reactor trip channel which are designed on the energize to operate principle. These inputs are related to anticipatory trips and their operation or failure to operate does not adversely affect the ability of the de-energize-to-trip protection to function. These anticipatory trips are not considered to function in the bases for the safety analyses.

The protection system components have been tested and qualified for the extremes of the normal environment to which they are subjected. In addition, components are tested and qualified according to individual requirements for the adverse environment, specific to their location, that might result from postulated accident conditions.

In the event of a loss of the offsite power, onsite diesel generators provide power to emergency loads. Station batteries are provided to power the vital instrumentation loads. The diesels are capable of supplying the power required to operate engineered safeguards pumps and associated valves. A loss of power to one train of emergency core cooling equipment will not affect the ability of the other train to perform its function. Loss of power or control air to the containment isolation valves results in closure of the valves.

The rod control system, containment isolation system, reactor trip system, and ESF actuation systems are discussed in Sections 4.2.3, 6.2.4, 7.2, and 7.3, respectively.

3.1.20 Separation of Protection and Control Systems, Criterion 24

3.1.20.1 **AEC Criterion**

The protection system shall be separated from control systems to the extent that failure of any single control system component or channel, or failure or removal from service of any single protection system component or channel that is common to the control and protection systems, leaves intact a system satisfying all reliability, redundancy, and independence requirements of the protection system. Interconnection of the protection and control systems shall be limited so as to ensure that safety is not significantly impaired.

3.1.20.2 **Discussion**

The failure of a single control system component or channel, or the failure or removal from service of any protection system component or channel that is common to the control and protection systems, leaves intact a system satisfying all reliability, redundancy, and independence requirements of the protection system. Interconnection of the protection and control systems is limited to ensure that safety is not impaired.

Most functions performed by the reactor protection and the reactor control systems require the same process information. The design philosophy for these systems is to make maximum use of a wide spectrum of diverse and redundant process measurements. The protection system is separate and distinct from the control system. The control system is dependent on the protection system in that control input signals are derived from protection system measurements where applicable. These control signals are transferred to the control system by isolation amplifiers which are classified protection system components. No credible failure at the output of an isolation amplifier will prevent the corresponding protection channel from performing its protection function. Such failures include short circuits, open circuits, grounds, and the application of the maximum credible ac and dc voltages. The adequacy of system isolation has been verified by testing under these fault conditions. The design meets all requirements of IEEE Std. 279-1971, *Criteria for Protection Systems for Nuclear Power Generating Stations*.

The reactor protection system and the control systems are discussed in Sections 7.2 and 7.7, respectively.

3.1.21 Protection System Requirements for Reactivity Control Malfunctions, Criterion 25

3.1.21.1 AEC Criterion

The protection system shall be designed to ensure that specified acceptable fuel design limits are not exceeded for any single malfunction of the reactivity control systems, such as accidental withdrawal (not ejection or dropout) of control rods.

3.1.21.2 Discussion

The protection system design ensures that acceptable fuel design limits are not exceeded in the event of single reactivity control malfunctions including accidental withdrawal of control cluster groups. Analyses of these accidents are given in Chapter 15.

Reactor shutdown with control rods is completely independent of the control functions. The trip breakers will interrupt power to the rod drive mechanisms to trip the reactor regardless of the status of existing control function signals.

The reactor control system provides visual displays of the rod control cluster assembly positions and actuates an alarm should deviation of rods occur within their groups.

Additional information is given by the response to Criterion 10. The reactivity control systems are discussed in Section 4.2.3, the protection system is discussed in Section 7.2, and the electrical control systems are discussed in Section 7.7.

3.1.22 Reactivity Control System Redundancy and Capability, Criterion 26

3.1.22.1 AEC Criterion

Two independent reactivity control systems of different design principles shall be provided. One of the systems shall use control rods, preferably including a positive means for inserting the rods, and shall be capable of reliably controlling reactivity changes to ensure that under conditions of normal operation, including anticipated operational occurrences, and with appropriated margin for malfunctions such as stuck rods, specified acceptable fuel design limits are not exceeded. The second reactivity control system shall be capable of reliably controlling the rate of reactivity changes resulting from planned, normal power changes (including xenon burnout) to ensure that acceptable fuel design limits are not exceeded. One of the systems shall be capable of holding the reactor core subcritical under cold conditions.

3.1.22.2 Discussion

Two independent reactivity control systems of different design principles are provided in the North Anna Power Station. One of the systems uses control rods; the second system uses dissolved boron (chemical shim).

Two functional categories of rods are used, full-length shutdown and full-length control. During operation the shutdown rod banks are fully withdrawn. The control rod system automatically maintains a programmed average reactor temperature compensating for reactivity effects associated with scheduled and transient load changes.

The shutdown rod banks, along with the control banks, are designed to shut down the reactor with adequate margin under conditions of normal operation and anticipated operational occurrences, thereby ensuring that specified fuel design limits are not exceeded. The most restrictive period in core life is assumed in all analyses, and the most reactive rod cluster is assumed to stick in the out-of-core position. The reactor protection system initiates reactor trip by interrupting power to the rod control power supply. This releases the magnetic latches, and the control and shutdown rods insert by gravity.

The boron system is capable of controlling the rate of reactivity change resulting from planned normal power changes, including xenon burnout, to ensure that fuel design limits are not exceeded. This system is capable of maintaining the reactor core subcritical under cold conditions with all rods withdrawn. The control rod system and boron system are discussed in Sections 4.2.3 and 9.3.4.

3.1.23 Combined Reactivity Control Systems Capability, Criterion 27

3.1.23.1 AEC Criterion

The reactivity control systems shall be designed to have a combined capability, in conjunction with poison addition by the emergency core cooling system, of reliably controlling reactivity changes to ensure that under postulated accident conditions and with appropriate margin for stuck rods the capability to cool the core is maintained.

3.1.23.2 Discussion

The North Anna Power Station reliability controls reactivity changes to ensure applicable accident analyses acceptance criteria are met with appropriate allowances for uncertainties. Combined use of rod cluster control and chemical shim control permits the necessary shutdown margin to be maintained during long-term xenon decay and plant cooldown. The single highest-worth control cluster is assumed stuck in its fully withdrawn position in postulated accident analyses. These controls are discussed in detail in Sections 4.2.3 and 9.3.4.

Under accident conditions, when the emergency core cooling system is actuated, concentrated boric acid is injected into the reactor coolant system. Reactivity effects of emergency core cooling are discussed in Section 6.3 and evaluated for accident conditions in Chapter 15.

3.1.24 Reactivity Limits, Criterion 28

3.1.24.1 AEC Criterion

The reactivity control systems shall be designed with appropriate limits on the potential amount and rate of reactivity increase to ensure that the effects of postulated reactivity accidents can neither (1) result in damage to the reactor coolant pressure boundary greater than limited local yielding, nor (2) sufficiently disturb the core, its support structures, or other reactor pressure vessel internals to impair significantly the capability to cool the core. These postulated reactivity accidents shall include consideration of rod ejection (unless prevented by positive means), rod dropout, steam-line rupture, changes in reactor coolant temperature and pressure, and cold water addition.

3.1.24.2 Discussion

In the North Anna Power Station, core reactivity is controlled by a chemical poison dissolved in the coolant, rod cluster control assemblies, and burnable poisons. The maximum reactivity insertion rates due to withdrawal of a bank of rod cluster control assemblies or by boron dilution are limited. These limits are set such that peak heat generation rate and DNBR do not exceed the allowable limits at overpower conditions. The maximum worth of control rods and the maximum rates of reactivity insertion using control rods are limited to values that prevent rupture of the coolant pressure boundary or disruption of the core internals to a degree that would impair core cooling capacity. The reactor can be brought to the shutdown condition, and the core will maintain acceptable heat transfer geometry following postulated accidents such as rod ejection, steam-line break, etc.

The reactivity control systems are discussed in Sections 4.2.3 and 4.3.

3.1.25 Protection Against Anticipated Operational Occurrences, Criterion 29

3.1.25.1 AEC Criterion

The protection and reactivity control systems shall be designed to ensure an extremely high probability of accomplishing their safety functions in the event of anticipated operational occurrences.

3.1.25.2 Discussion

The North Anna Power Station protection and reactivity control systems are designed to ensure an extremely high probability that they will perform their required safety functions in the event of anticipated operational occurrences. Redundancy, functional and locative diversity, testability, use of safe failure modes, and analyses are design measures that are used to ensure performance of the required safety functions. Detailed probabilistic analyses of the systems verify this high reliability. The protection system is further discussed under Criteria 20 through 25 and in Section 7.2. The reactivity control systems are discussed in Sections 4.2.3 and 7.7.

3.1.26 Quality of Reactor Coolant Pressure Boundary, Criterion 30

3.1.26.1 AEC Criterion

Components which are part of the reactor coolant pressure boundary shall be designed, fabricated, erected, and tested to the highest quality standards practical. Means shall be provided for detecting and, to the extent practical, identifying the location of the source of reactor coolant leakage.

3.1.26.2 Discussion

Reactor coolant pressure boundary components are designed, fabricated, inspected, and tested in conformance with applicable design and construction codes. The design bases and evaluations of reactor coolant pressure boundary components, including code applicability, are discussed in Section 5.2.

Major components are classified as Seismic Class I and are accorded the quality measures appropriate to this classification.

Leakage is detected by an increase in the amount of makeup water required to maintain a normal level in the pressurizer. The reactor vessel closure joint is provided with a temperature-monitored leakoff between double gaskets. Leakage inside the reactor containment is drained to the containment sump where it is monitored.

Leakage is also detected by measuring the airborne activity of the containment atmosphere and by monitoring the containment pressure. Monitoring the inventory of reactor coolant in the system at the pressurizer, volume control tank, and primary drain transfer tank makes available an indication of integrated leakage.

The reactor coolant pressure boundary leakage detection system is discussed in Section 5.2.4.

3.1.27 Fracture Prevention of Reactor Coolant Pressure Boundary, Criterion 31

3.1.27.1 AEC Criterion

The reactor coolant pressure boundary shall be designed with sufficient margin to ensure that when stressed under operating, maintenance, testing, and postulated accident conditions (1) the boundary behaves in a nonbrittle manner and (2) the probability of rapidly propagating fracture is minimized. The design shall reflect consideration of service temperatures and other conditions of the boundary material under operating, maintenance, testing, and postulated accident conditions and the uncertainties in determining (1) material properties, (2) the effects of irradiation on material properties, (3) residual, steady-state, and transient stresses, and (4) size of flaws.

3.1.27.2 Discussion

Close control is maintained over material selection and fabrication for the reactor coolant system to ensure that the boundary behaves in a nonbrittle manner. Reactor coolant system materials exposed to the coolant are corrosion-resistant stainless steel or Inconel. The nil ductility transition (NDT) temperature of reactor vessel material samples are established by Charpy V-notch and drop weight tests. The materials testing is consistent with Appendices G and H to 10 CFR 50. These tests ensure the selection of materials with proper toughness properties and margins and verify as well the integrity of the reactor coolant pressure boundary.

As part of the reactor vessel specification, certain tests in addition to those specified by the applicable ASME codes are performed. These tests are:

1. Ultrasonic testing - In addition to code requirements, the performance of a 100% ultrasonic test of reactor vessel plate for shear wave, and a posthydrotest ultrasonic map of all welds in the pressure vessel is required. Cladding bond ultrasonic inspection to more restrictive requirements than code is also required to preclude interpretation problems during inservice inspection.
2. Radiation surveillance program - In the surveillance programs, the evaluation of the radiation damage is based on preirradiation and postirradiation testing of Charpy V-notch and tensile specimens. These programs monitor the effect of radiation on the fracture toughness of reactor vessel steels on the basis of the transition temperature approach and the fracture mechanics approach, and are in accord with ASTM-E-185 recommended practice for surveillance tests for nuclear reactor vessels.

The fabrication and quality control techniques used in the fabrication of the reactor coolant system are equivalent to those used for the reactor vessel. The inspections of reactor vessel, pressurizer, piping, pumps, and steam generator are governed by ASME Code and ANSI B31.7 requirements. See Section 5.2 for details.

The heatup and cooldown rates as well as the static loading stresses during plant life are determined by using conservative values for the change in ductility transition temperature due to irradiation.

Details of the various aspects of the design and testing processes are included in Chapter 5.

3.1.28 Inspection of Reactor Coolant Pressure Boundary, Criterion 32

3.1.28.1 AEC Criterion

Components which are part of the reactor coolant pressure boundary shall be designed to permit (1) periodic inspection and testing of important areas and features to assess their structural and leaktight integrity, and (2) an appropriate material surveillance program for the reactor pressure vessel.

3.1.28.2 Discussion

The design of the reactor vessel and its arrangement in the system provide accessibility during service life to the entire internal surfaces of the vessel and certain external zones of the vessel, including the nozzle to reactor coolant piping welds and the top and bottom heads. The reactor arrangement within the containment provides sufficient space for inspection of the external surfaces of the reactor coolant piping, except for the area of pipe within the primary shielding concrete. The inspection capability complements the leakage detection systems in assessing the pressure boundary integrity.

Monitoring of the NDT temperature properties of the core region plates forging, weldments, and associated heat-treated zones is performed in accordance with ASTM-E-185, *Recommended Practice for Surveillance Tests on Structural Materials in Nuclear Reactors*. Samples of reactor vessel plate materials are retained and catalogued in case future engineering development shows the need for further testing.

The material properties surveillance program includes not only the conventional tensile and impact tests, but also fracture mechanics specimens. The observed shifts in NDT temperature of the core region materials with irradiation will be used to confirm the calculated limits to start-up and shutdown transients.

To define permissible operating conditions below NDT temperature, a pressure range is established that is bounded by a lower limit for pump operation and an upper limit that satisfies reactor vessel stress criteria. To allow for thermal stresses during heatup or cooldown of the reactor vessel, an equivalent pressure limit is defined to compensate for thermal stress as a function of rate of change of coolant temperature. Since the normal operating temperature of the reactor vessel is well above the maximum expected NDT temperature, brittle fracture during normal operation is not considered to be a credible mode of failure. Additional details can be found in Section 5.2.

3.1.29 Reactor Coolant Makeup, Criterion 33

3.1.29.1 **AEC Criterion**

A system to supply reactor coolant makeup for protection against small breaks in the reactor coolant pressure boundary shall be provided. The system safety function shall be to ensure that specified acceptable fuel design limits are not exceeded as a result of reactor coolant loss due to leakage from the reactor coolant pressure boundary and rupture of small piping or other small components which are part of the boundary. The system shall be designed to ensure that for onsite electric power system operation (assuming offsite power is not available) the system safety function can be accomplished by using the piping, pumps, and valves used to maintain coolant inventory during normal reactor operation.

3.1.29.2 **Discussion**

The Chemical and Volume Control System provides a means of reactor coolant makeup and adjustment of the boric acid concentration. Makeup is added automatically if the level in the volume control tank falls below a preset level. High-pressure centrifugal charging pumps are provided which are capable of supplying the required makeup and reactor coolant seal injection flow with power available from either onsite or offsite electric power systems. These pumps also serve as high-head safety injection pumps. In the event of a loss of coolant larger than the capacity of the normal makeup path, these pumps discharge into the larger safety injection piping. A high degree of functional reliability is ensured by providing standby components and ensuring safe response to probable modes of failure. Details of system design are included in Section 9.3.4; details of the electric power systems are given in Chapter 8.

3.1.30 Residual Heat Removal, Criterion 34

3.1.30.1 **AEC Criterion**

A system to remove residual heat shall be provided. The system safety function shall be to transfer fission product decay heat and other residual heat from the reactor core at a rate such that specified acceptable fuel design limits and the design conditions of the reactor coolant pressure boundary are not exceeded.

Suitable redundance in components and features, and suitable interconnections, leak detection, and isolation capabilities, shall be provided to ensure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished, assuming a single failure.

3.1.30.2 **Discussion**

The residual heat removal system, in conjunction with the steam and power conversion system, transfers the fission product decay heat and other residual heat from the reactor core and keeps the core temperature within acceptable limits. The crossover from the steam power conversion system to the residual heat removal system occurs at approximately 350°F.

Suitable redundancy is provided below 350°F by the two residual heat removal pumps with means available for draining and monitoring of leakage, two heat exchangers, and the associated piping and cabling. The residual heat removal system operates on either onsite or offsite electrical power.

Suitable redundancy at temperatures above approximately 350°F is provided by the steam generators, auxiliary feed pumps, and attendant piping.

Details of the system design are in Section 5.5.4.

3.1.31 Emergency Core Cooling, Criterion 35

3.1.31.1 **AEC Criterion**

A system to provide abundant emergency core cooling shall be provided. The system safety function shall be to transfer heat from the reactor core following any loss of reactor coolant at a rate such that (1) fuel and clad damage that could interfere with continued effective core cooling is prevented, and (2) clad metal-water reaction is limited to negligible amounts.

Suitable redundancy in components and features, and suitable interconnections, leak detection, isolation, and containment capabilities shall be provided to ensure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished, assuming a single failure.

3.1.31.2 **Discussion**

By combining the use of passive accumulators with two centrifugal charging pumps and two low-head safety injection pumps, emergency core cooling is provided even with a failure of any component in any system. The emergency core cooling system uses a passive system of accumulators that do not require any external signals or source of power for their operation to cope with the short-term cooling requirements of large reactor coolant pipe breaks. Two independent pumping systems, each capable of the required emergency cooling, are provided for small-break protection and to keep the core submerged after the accumulators have discharged following a large break. Adequate design provisions ensure the performance of the required safety functions even with the loss of a single component, assuming the electric power is available from either the offsite or the onsite electric power sources. Borated water is injected into the reactor coolant system by accumulators, low-head safety injection pumps, and charging pumps.

The design meets the intent of the *Interim Policy Statement Criteria for Emergency Core Cooling Systems for Light Water Power Reactors*.

The primary function of the emergency core cooling system is to deliver borated cooling water to the reactor core following a LOCA. This limits the fuel clad temperature and thereby ensures that the core will remain substantially intact and in place, with its essential heat transfer geometry preserved. This protection is afforded for:

1. All pipe break sizes up to and including the hypothetical circumferential rupture of a reactor coolant loop.
2. A loss of coolant associated with a rod ejection accident.

The basic criteria for LOCA evaluations are as follows: no clad melting; Zirconium-water reactions will be limited to an insignificant amount; and the core geometry is to remain essentially in place and intact so that effective cooling of the core will not be impaired. The Zirconium-water reactions will be limited to an insignificant amount so that the accident neither interferes with the emergency core cooling function to limit clad temperatures nor produces H_2 in an amount that when burned would cause the containment pressure to exceed the design value.

For any rupture of a steam pipe and the associated uncontrolled heat removal from the core, the emergency core cooling system adds shutdown reactivity so that with a stuck rod, no offsite power, and minimum engineered safety features, there is no consequential damage to the primary system, and the core remains substantially in place and intact. With no stuck rod, no offsite power, and all equipment operating at design capacity, there is insignificant cladding rupture. The emergency core cooling system is described in Section 6.3. Sections 6.2 and 15.4 contain the analysis for the LOCA and steam-line rupture.

3.1.32 Inspection of Emergency Core Cooling System, Criterion 36

3.1.32.1 AEC Criterion

The emergency core cooling system shall be designed to permit appropriate periodic inspection of important components, such as spray rings in the reactor pressure vessel, water injection nozzles, and piping, to ensure the integrity and capability of the system.

3.1.32.2 Discussion

Design provisions are made for inspection, to the extent practical, of all components of the emergency core cooling system. Periodic inspections demonstrate system readiness.

The pressure-containing systems are inspected for leaks from pump seals, valve packing, flanged joints, and safety valves during system testing.

In addition, to the extent practical, the critical parts of the reactor vessel internals, injection nozzles, pipes, valves, and pumps are inspected visually or with a boroscope for erosion, corrosion, and vibration wear, and by nondestructive inspection, where such techniques are appropriate.

Details of the inspection program for the reactor vessel internals are included in Section 5.2.5. Inspection of the emergency core cooling system is discussed in Section 6.3.4.

3.1.33 Testing of Emergency Core Cooling System, Criterion 37

3.1.33.1 AEC Criterion

The emergency core cooling system shall be designed to permit appropriate periodic pressure and functional testing to ensure (1) the structural and leaktight integrity of its components, (2) the operability and performance of the active components of the system, and (3) the operability of the system as a whole and, under conditions as close to design as practical, the performance of the full operational sequence that brings the system into operation, including operation of applicable portions of the protection system, the transfer between normal and emergency power sources, and the operation of the associated cooling water system.

3.1.33.2 Discussion

The components of the system located outside the containment will be accessible for leaktightness inspection during appropriate periodic tests. Each active component of the emergency core cooling system may be individually actuated on the normal power source at any time during plant operation to demonstrate operability. The centrifugal charging pumps are part of the charging system; this system is in continuous operation during plant operation. Remote-operated valves are exercised and actuation circuits are tested periodically. The automatic actuation circuitry, valves, and pump breakers also may be checked during integrated system tests during a planned cooldown of the reactor coolant system.

Design provisions also include special instrumentation, testing, and sampling lines to perform tests during plant shutdown to demonstrate proper automatic operation of the emergency core cooling system. A test signal is applied to initiate automatic action. The test demonstrates the operation of the valves, pump circuit breakers, and automatic circuitry. In addition, other tests are performed periodically to verify that the safety injection pumps attain required discharge heads.

These tests are described in Section 6.3.4.

3.1.34 Containment Heat Removal, Criterion 38

3.1.34.1 AEC Criterion

A system to remove heat from the reactor containment shall be provided. The system safety function shall be to reduce rapidly, consistent with the functioning of other associated systems, the containment pressure and temperature following any LOCA and maintain them at acceptably low levels.

Suitable redundancy in components and features, and suitable interconnections, leak detection, isolation, and containment capabilities shall be provided to assure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished, assuming a single failure.

3.1.34.2 Discussion

Two quench spray subsystems, each 100%-capacity, and four separate recirculation spray subsystems, each approximately 50%-capacity, remove heat from the containment following a LOCA. Each subsystem contains a separate pump and spray header, and each recirculation spray subsystem contains a separate cooler. Two electrical buses, each connected to both offsite and onsite power, feed the pump motors and the necessary valves. Redundant remote-reading water level indication is provided in the safeguards area for leak detection of safeguards equipment. Containment isolation valves separate all outside components from the containment penetrations.

The reference sections are:

Section Title	Chapter
Engineered Safety Features	6
Electric Power	8

3.1.35 Inspection of Containment Heat Removal System, Criterion 39

3.1.35.1 AEC Criterion

The containment heat removal system shall be designed to permit appropriate periodic inspection of important components, such as the torus, sumps, spray nozzles, and piping to assure the integrity and capability of the system.

3.1.35.2 **Discussion**

Equipment comprising the containment depressurization system is so situated that periodic physical inspections can be made. All equipment can be inspected during planned refueling shutdowns. The system is described in Chapter 6.

3.1.36 Testing of Containment Heat Removal System, Criterion 40

3.1.36.1 **AEC Criterion**

The containment heat removal system shall be designed to permit appropriate periodic pressure and functional testing to assure (1) the structural and leaktight integrity of its components, (2) the operability and performance of the active components of the system, and (3) the operability of the system as a whole and, under conditions as close to the design as practical, the performance of the full operational sequence that brings the system into operation, including operation of applicable portions of the protection system, the transfer between normal and emergency power sources, and the operation of the associated cooling water system.

3.1.36.2 **Discussion**

Provision is made to permit testing the quench spray subsystem and the recirculation spray subsystem throughout the life of the unit to ensure that the systems are operable. For preoperational testing, ends of the quench spray headers were fitted with blind flanges, allowing connection of temporary drain lines for full-flow testing up to the nozzles. The recirculation spray nozzle connections were plugged for preoperational testing and temporary connections made between the spray headers and the containment sump, allowing full-flow test of the system. These provisions permitted testing of the containment depressurization system over the full range of flow and starting conditions.

Periodically during the life of the unit, the quench spray and outside recirculation spray pumps are flow tested, the motor-operated valves in the containment depressurization system are tested. The quench spray and recirculation spray subsystems are tested or inspected for the presence of particulate matter which could clog the spray nozzles following maintenance or an activity which could result in nozzle blockage. These tests verify that the containment depressurization system will respond promptly and perform its design function.

The design of the control system for the quench spray subsystems and the recirculation spray subsystems includes manual test switches for individual testing of all the equipment in the subsystems and for testing of the operational sequence of the containment spray systems. These tests may be conducted on the normal shutdown power system or may include transfer to the alternate power source.

The reference sections are:

Section Title	Chapter
Engineered Safety Features	6
Instrumentation and Controls	7

3.1.37 Containment Atmosphere Cleanup, Criterion 41

3.1.37.1 AEC Criterion

Systems to control fission products, hydrogen, oxygen, and other substances that may be released into the reactor containment shall be provided as necessary to reduce, consistent with the functioning of other associated systems, the concentration and quality of fission products released to the environment following postulated accidents, and to control the concentration of hydrogen or oxygen and other substances in the containment atmosphere following postulated accidents to ensure that containment integrity is maintained.

Each system shall have suitable redundancy in components and features, and suitable interconnections, leak detection, isolation, and containment capabilities to assure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) its safety function can be accomplished, assuming a single failure.

3.1.37.2 Discussion

Systems are provided to control fission products generated by a design basis accident. These systems are sufficiently redundant to meet the single-failure criterion and are operable with either onsite or offsite power.

The caustic sprays from the quench spray subsystem remove radioactive iodine and particulate fission products by absorption and washing action. Per Reference 1, the control of hydrogen and oxygen in a design basis accident is no longer a regulatory requirement.

The systems are discussed in Chapter 6.

3.1.38 Inspection of Containment Atmosphere Cleanup Systems, Criterion 42

3.1.38.1 AEC Criterion

The containment atmosphere cleanup systems shall be designed to permit appropriate periodic inspection of important components, such as filter frames, ducts, and piping to ensure the integrity and capability of the systems.

3.1.38.2 Discussion

Both the containment atmosphere cleanup system and the containment depressurization system are designed to permit appropriate periodic inspection of the important components, as described in Chapter 6.

3.1.39 Testing of Containment Atmosphere Cleanup Systems, Criterion 43

3.1.39.1 AEC Criterion

The containment atmosphere cleanup systems shall be designed to permit appropriate periodic pressure and functional testing to assure (1) the structural and leaktight integrity of its components, (2) the operability and performance of the active components of the systems, such as fans, filters, dampers, pumps, and valves, and (3) the operability of the systems as a whole and, under conditions as close to design as practical, the performance of the full operational sequence that brings the systems into operation, including operation of applicable portions of the protection system, the transfer between normal and emergency power sources, and the operation of associated systems.

3.1.39.2 **Discussion**

Both the containment atmosphere cleanup system and the containment depressurization system are designed to permit periodic pressure and functional testing of their components, as described in Chapter 6.

3.1.40 Cooling Water, Criterion 44

3.1.40.1 **AEC Criterion**

A system to transfer heat from structures, systems, and components important to safety to an ultimate heat sink shall be provided. The system safety function shall be to transfer the combined heat load of these structures, systems, and components under normal operating and accident conditions.

Suitable redundancy in components and features, and suitable interconnections, leak detection, and isolation capabilities, shall be provided to ensure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished, assuming a single failure.

3.1.40.2 **Discussion**

All safety-related items requiring cooling during an accident are cooled by the service water system. Heat exchangers requiring cooling during normal operation and cooldown are cooled by either the component cooling system or the service water system. The component cooling system, in turn, is cooled by the service water system.

The service water system has sufficient redundancy to meet the single-failure criterion, including the failure of an emergency generator. The service water system is in use during normal operation and during accident recovery.

The component cooling system is provided with redundant pumping and heat transfer equipment. Piping and valving ensure maximum reliability, but do not contain redundant supply and return headers. The piping that is not redundant is located in missile-protected areas and is designed to withstand seismic loadings without failure. Valves that affect the operation of both units are located in missile-protected areas and can be repacked under system pressure.

The component cooling system will operate with emergency onsite power. The systems are described in Chapter 9.

The auxiliary feedwater system is provided to supply water to the steam generators to transfer heat to atmosphere or to the condenser. Auxiliary feedwater has redundancy of design and power supplies to meet single failure criteria. Auxiliary feedwater is described in Section 10.4.3.

3.1.41 Inspection of Cooling Water System, Criterion 45

3.1.41.1 AEC Criterion

The cooling water system shall be designed to permit appropriate periodic inspection of important components, such as heat exchangers and piping, to ensure the integrity and capability of the system.

3.1.41.2 Discussion

The cooling water system referred to in this criterion transfers heat from structures, systems, and components important to safety to an ultimate heat sink. Three systems are used for this purpose: the service water system, the component cooling system, and the auxiliary feedwater system.

The majority of the header piping in the service water system is buried under 10 feet of backfill or is encased in concrete to provide the necessary missile protection. Inspection of this piping is not anticipated. The remainder of the piping, valves, equipment, and associated electrical gear in the service water system can be readily inspected.

All piping, valves, equipment, and associated electrical gear in the component cooling system can be readily inspected. Those portions of the piping inside the missile barrier of the containment structure can be inspected during refueling shutdowns.

All of the auxiliary feedwater system is accessible for inspections.

The references sections are:

Section Title	Chapter
Electric Power	8
Auxiliary Systems	9
Condensate and Feedwater Systems	10

3.1.42 Testing of Cooling Water System, Criterion 46

3.1.42.1 AEC Criterion

The cooling water system shall be designed to permit appropriate periodic pressure and functional testing to ensure (1) the structural and leaktight integrity of its components, (2) the operability and the performance of the active components of the system, and (3) the operability of the system as a whole and, under conditions as close to design as practical, the performance of the full operational sequence that brings the system into operation for reactor shutdown and for LOCAs, including operation of applicable portions of the protection system and the transfer between normal and emergency power sources.

3.1.42.2 **Discussion**

The cooling water system referred to in this criterion encompasses the service water system, the component cooling system, and the auxiliary feedwater system.

The service water system operates continuously. The service water supply to the recirculation spray heat exchangers is tested periodically to ensure that the automatic valves function as required and the structural and leaktight integrity of the pressure-containing components is retained. This test requires opening the recirculation spray heat exchanger isolation valves and the service water header isolation valves which are energized by the containment depressurization actuation signal.

The component cooling system is in continuous use, thus ensuring that the structural and leaktight integrity, operability of active components, and operability of the system in its entirety are continuously monitored. The integrity and operability of the flow path of component cooling water to the residual heat exchangers are verified by operation during refueling shutdowns.

Auxiliary Feedwater Systems are periodically flowed and tested in accordance with technical specifications.

The operational testing of the component cooling, service water, and Auxiliary Feedwater Systems also provides for the testing of the electrical portions of the system.

The reference sections are:

Section Title	Chapter
Engineered Safety Features	6
Electric Power	8
Auxiliary Systems	9
Condensate and Feedwater Systems	10

3.1.43 Containment Design Basis, Criterion 50

3.1.43.1 **AEC Criterion**

The reactor containment structure, including access openings, penetrations, and the containment heat removal system shall be designed so that the containment structure and its internal compartments can accommodate, without exceeding the design leakage rate and with sufficient margin, the calculated pressure and temperature conditions resulting from any LOCA. This margin shall reflect consideration of (1) the effects of potential energy sources that have not been included in the determination of the peak conditions, such as energy in steam generators and energy from metal-water and other chemical reactions that may result from degraded emergency core cooling functioning, (2) the limited experience and experimental data available for defining accident phenomena and containment responses, and (3) the conservatism of the calculational model and input parameters.

3.1.43.2 **Discussion**

The containment structure is designed to leak less than 0.1 volume percent of its contents per day under post-design basis accident (DBA) conditions. The containment is designed to withstand pressures and temperatures above those conservatively calculated to result from a design basis accident by a margin sufficient to ensure that design conditions are not exceeded.

The reference sections are:

Section Title	Chapter
Containment Structure	3.8.2
Engineered Safety Features	Chapter 6
Condition IV - Limiting Faults	15.4

3.1.44 Fracture Prevention of Containment Pressure Boundary, Criterion 51

3.1.44.1 **AEC Criterion**

The reactor containment boundary shall be designed with sufficient margin to ensure that under operating, maintenance, testing, and postulated accident conditions (1) its ferritic materials behave in a nonbrittle manner, and (2) the probability of rapidly propagating fracture is minimized. The design shall reflect consideration of service temperatures and other conditions of the containment boundary material during operation, maintenance, testing, and postulated accident conditions, and the uncertainties in determining (1) material properties, (2) residual, steady-state, and transient stresses, and (3) size of flaws.

3.1.44.2 **Discussion**

The design condition of the containment pressure boundary is based on the parameters derived after the design basis accident, as detailed in Section 3.8.2. For this design condition, as well as operating, testing, and maintenance conditions, the steel liner material behaves in a nonbrittle manner, minimizing the propagation of any undetected flaw, as explained in Section 3.8.2.

A fatigue analysis of the steel liner ensures that pressure and temperature variations, with their corresponding number of cycles, for the design, testing, maintenance, and operational conditions, satisfy the allowable limits.

The steel liner material was tested and certified to prove that its properties meet or exceed the minimum values as specified in the ASME Boiler and Pressure Vessel Code. The steel liner material has sufficient ductility to tolerate local deformations without rupture. For detailed information see Section 3.8.2. Fracture propagation and prevention in the containment pressure boundary is also discussed in detail in Section 3.8.2.

3.1.45 Capability for Containment Leakage Rate Testing, Criterion 52

3.1.45.1 **AEC Criterion**

The reactor containment and other equipment which may be subjected to containment test conditions shall be designed so that periodic integrated leakage rate testing can be conducted at containment design pressure.

3.1.45.2 **Discussion**

The reactor containment was subjected to a "one time only" air pressure test at 115% design pressure. The initial leakage rate test was performed at a pressure equal to the calculated peak containment atmospheric pressure (P_a) (see Section 6.2.1.4). Measurements to established leakage rates were obtained by using the leakage monitoring system (Section 6.2.7). Periodic integrated leakage rate tests will be performed as required by the Technical Specifications.

The reference sections are:

Section Title	Chapter
Containment Structure	3.8.2
Engineered Safety Features	Chapter 6
Containment Tests	Technical Specifications

3.1.46 Provisions for Containment Testing and Inspection, Criterion 53

3.1.46.1 **AEC Criterion**

The reactor containment shall be designed to permit (1) appropriate periodic inspection of all important areas, such as penetrations, (2) an appropriate surveillance program, and (3) periodic testing at containment design pressure of the leaktightness of penetrations that have resilient seals and expansion bellows.

3.1.46.2 **Discussion**

The reactor containment design includes provisions for testing the leaktightness of all penetrations, except as discussed in Section 6.2.1.4, including those that have resilient seals or expansion bellows, and other important areas. Penetrations with resilient seals will be visually inspected and pressure tested. Penetrations with expansion bellows will be pressure tested. Test channels for checking the weld between penetrations and the containment liner have been provided. These provisions, in conjunction with the leakage monitoring system, allow surveillance of the conditions inside the containment.

The reference sections are:

Section Title	Section
Containment Structure	3.8.2
Engineered Safety Features	Chapter 6

3.1.47 Piping Systems Penetrating Containment, Criterion 54

3.1.47.1 AEC Criterion

Piping systems penetrating primary reactor containment shall be provided with leak detection, isolation, and containment capabilities having redundancy, reliability, and performance capabilities that reflect the importance to safety of isolating these piping systems. Such piping systems shall be designed with a capability to test periodically the operability of the isolation valves and associated apparatus and to determine if valve leakage is within acceptable limits.

3.1.47.2 Discussion

The containment isolation system provides, during accident conditions, at least two barriers between the atmosphere outside the containment structure and either the fluid inside the reactor coolant pressure boundary or the atmosphere inside the containment structure. The operation of the containment isolation system is automatic, and failure of one valve or barrier does not prevent isolation. Means are provided to test periodically the setpoints of sensors, speed of response, operability of fail-safe features, and leakage rates of all valves, except as discussed in Section 6.2.1.4, used for containment isolation.

The reference sections are:

Section Title	Chapter
Engineered Safety Features	6
Instrumentation and Controls	7

3.1.48 Reactor Coolant Pressure Boundary Penetrating Containment, Criterion 55

3.1.48.1 AEC Criterion

Each line that is part of the reactor coolant pressure boundary and that penetrates primary reactor containment shall be provided with containment isolation valves as follows, unless it can be demonstrated that the containment isolation provisions for a specific class of lines, such as instrument lines, are acceptable on some other defined basis:

1. One locked closed isolation valve inside and one locked closed isolation valve outside containment; or
2. One automatic isolation valve inside and one locked closed isolation valve outside containment; or
3. One locked closed isolation valve inside and one automatic isolation valve outside containment (a simple check valve may not be used as the automatic isolation valve outside containment); or
4. One automatic isolation valve inside and one automatic isolation valve outside containment (a simple check valve may not be used as the automatic isolation valve outside containment).

Isolation valves outside containment shall be located as close to containment as practical, and upon loss of actuating power, automatic isolation valves shall be designed to take the position that provides greater safety.

Other appropriate requirements to minimize the probability or consequences of an accidental rupture of these lines or of lines connected to them shall be provided as necessary to ensure adequate safety. Determination of the appropriateness of these requirements, such as higher quality in design, fabrication, and testing, additional provisions for inservice inspection, protection against more severe natural phenomena, and additional isolation valves and containment, shall include consideration of the population density, use characteristics, and physical characteristics of the site environs.

3.1.48.2 **Discussion**

All pipe penetrations through the containment structure have, during accident conditions, at least two barriers between the atmosphere outside the containment and either the fluid inside the reactor coolant pressure boundary or the atmosphere inside the containment structure. A detailed description of the isolation arrangement of each piping penetration and a comparison of the arrangement with the criterion are contained in Section 6.2.4.

The design pressure of all piping and connecting components within the isolated boundary afforded by the two barriers is greater than the design pressure of the containment structure, and the piping is designed to Class I or II of the USA Standard Code for Pressure Piping - ANSI B31.7-1969, *Nuclear Power Piping*. The isolation valves outside the containment are located as close to the penetration as practical, and automatic valves take the position that provides greatest safety upon the loss of actuating power. All isolation valves and associated equipment are protected from missiles and water jets originating from the reactor coolant system. No manual action is required to activate the valves to isolate the containment, and the failure of one valve or barrier does not prevent isolation. All remotely actuated and automatic trip valves have their positions indicated in the control room. Containment isolation valves are inspected and tested in accordance with the Technical Specifications.

The system is described in Section 6.2.4.

3.1.49 Primary Containment Isolation, Criterion 56

3.1.49.1 **AEC Criterion**

Each line that connects directly to the containment atmosphere and penetrates primary reactor containment shall be provided with containment isolation valves as follows, unless it can be demonstrated that the containment isolation provisions for a specific class of lines, such as instrument lines, are acceptable on some other defined basis:

1. One locked closed isolation valve inside and one locked closed isolation valve outside containment; or

2. One automatic isolation valve inside and one locked closed isolation valve outside containment; or
3. One locked closed isolation valve inside and one automatic isolation valve outside containment (a simple check valve may not be used as the automatic isolation valve outside containment); or
4. One automatic isolation valve inside and one automatic isolation valve outside containment (a simple check valve may not be used as the automatic isolation valve outside containment).

Isolation valves outside containment shall be located as close to containment as practical, and upon loss of actuating power, automatic isolation valves shall be designed to take the position that provides greater safety.

3.1.49.2 **Discussion**

Refer to the discussion in Section 3.1.48.

3.1.50 Closed System Isolation Valves, Criterion 57

3.1.50.1 **AEC Criterion**

Each line that penetrates primary reactor containment and is neither part of the reactor coolant pressure boundary nor connected directly to the containment atmosphere shall have at least one containment isolation valve that shall be either automatic, or locked closed, or capable of remote manual operation. This valve shall be outside containment and located as close to the containment as practical. A simple check valve may not be used as the automatic isolation valve.

3.1.50.2 **Discussion**

Refer to the discussion in Section 3.1.48.

3.1.51 Control of Release of Radioactive Materials to the Environment, Criterion 60

3.1.51.1 **AEC Criterion**

The nuclear power unit design shall include means to control suitably the release of radioactive materials in gaseous and liquid effluents and to handle radioactive solid wastes produced during normal reactor operation, including anticipated operational occurrences. Sufficient holdup capacity shall be provided for retention of gaseous and liquid effluents containing radioactive materials, particularly where unfavorable site environmental conditions can be expected to impose unusual operational limitations upon the release of such effluents to the environment.

3.1.51.2 **Discussion**

Waste gas effluents are controlled by holdup of waste gases in decay tanks until the activity of tank contents and existing environmental conditions permit discharges within 10 CFR 20 and 10 CFR 50 requirements. Waste gas effluents are monitored at the point of discharge for radioactivity and rate of flow. Sufficient waste gas holdup capacity is provided, as discussed in

Section 11.3, to cope with all anticipated operational occurrences and site environmental conditions. A decay tank burst would not result in an activity release greater than 10 CFR 100 limits, based on 1% failed fuel.

Liquid waste effluents are controlled by holdup of waste liquids in storage tanks, batch processing of all liquids, and sampling before controlled rate discharge. Liquid effluents are monitored for radioactivity and rate of flow. The liquid waste disposal system, as described in Section 11.2, is sufficient to cope with all anticipated operational occurrences and unfavorable site environmental conditions.

Station solid wastes are typically shipped to offsite processors for volume reduction by approved contractors and then forwarded to approved burial sites. All shipments are in accordance with the transportation requirements of the Federal Regulations. Sufficient handling capacity is provided, as discussed in Section 11.5, to cope with all anticipated operational occurrences.

The reference sections are:

Section Title	Chapter
Radioactive Waste Management	11
Accident Analysis	15

3.1.52 Fuel Storage and Handling and Radioactivity Control, Criterion 61

3.1.52.1 AEC Criterion

The fuel storage and handling, radioactive waste, and other systems which may contain radioactivity shall be designed to ensure adequate safety under normal and postulated accident conditions. These systems shall be designed (1) with a capability to permit appropriate periodic inspection and testing of components important to safety, (2) with suitable shielding for radiation protection, (3) with appropriate containment, confinement, and filtering systems, (4) with a residual heat removal capability having reliability and testability that reflects the importance to safety of decay heat and other residual heat removal, and (5) to prevent significant reduction in fuel storage coolant inventory under accident conditions.

3.1.52.2 Discussion

Systems which may contain radioactivity, such as the reactor coolant system, the containment system, the engineered safeguards system, the containment depressurization system, the containment vacuum system, the containment atmosphere cleanup system, the boron recovery system, the component cooling system, the fuel pit cooling and refueling purification system, the Chemical and Volume Control System, the radioactive waste systems, the radiation protection system, and the residual heat removal system are designed to ensure adequate safety under normal and postulated accident conditions.

These systems are designed to permit inspection and testing as described in Chapters 5, 6, 9, and 11. Systems and components that may contain radioactivity are designed and provided with suitable shielding for radiation protection to meet the requirements of 10 CFR 20. Additional shielding is provided and barricades are used to limit personnel access in the areas adjacent to the fuel transfer canal wall during actual fuel transfers. Appropriate containment, confinement, and treatment facilities and procedures are provided to preclude gross mechanical failures which could lead to significant radioactivity releases. Reliable and testable residual heat removal and fuel pit cooling systems are provided as described in Chapter 9. Equally reliable component cooling systems are provided to ensure the safety and ultimate rejection of decay heat as described in Chapter 9. The fuel pit storage, fuel pit cooling, and fuel pit water makeup systems are designed to prevent significant reduction in the inventory fuel pit water under accident conditions, as described in Section 9.1.3.

The reference sections are:

Section Title	Chapter
Reactor Coolant System	5
Engineered Safety Features	6
Auxiliary Systems	9
Radioactive Waste Management	11
Radiation Protection	12

3.1.53 Prevention of Criticality in Fuel Storage and Handling, Criterion 62

3.1.53.1 AEC Criterion

Criticality in the fuel storage and handling system shall be prevented by physical systems and processes, preferably by the use of geometrically safe configurations. As allowed in 10 CFR 50.68(a), North Anna has chosen to comply with the requirements of 10 CFR 50.68(b) to preclude the possibility for a criticality event in the fuel storage areas and handling systems.

3.1.53.2 Discussion

The water used in the spent-fuel pit and the reactor cavity when the reactor vessel head is removed is maintained with a boron concentration greater than or equal to 2600 ppm, or a concentration not less than that required to shut down the core to a k_{eff} equal to 0.95 cold with all control rods inserted, whichever is more restrictive. This concentration ensures that k_{eff} is equal to or less than 1.0 even if all control rods are withdrawn, with appropriate allowance for calculational and measurement uncertainty.

The design and arrangement of the new- and spent-fuel handling, transfer, and storage equipment and facilities in conjunction with administrative controls provide sufficient center-to-center distance between assemblies and/or neutron poison to ensure that k_{eff} meets the applicable criteria of 10 CFR 50.68(b):

- k_{eff} must not exceed 0.95 for fresh fuel racks loaded with fuel of maximum fuel assembly reactivity and flooded with unborated water
- k_{eff} must not exceed 0.98 for fresh fuel racks loaded with fuel of maximum fuel assembly reactivity and conditions of optimum moderation (e.g., aqueous foam)
- k_{eff}, if credit for soluble boron is taken, for spent fuel racks loaded with fuel of maximum fuel assembly reactivity and flooded with borated water must not exceed 0.95 and must remain below 1.0 if flooded with unborated water.

To meet these criteria in the spent fuel pool, the boron concentration shall be greater than or equal to 2600 ppm as described in UFSAR Section 4.3.2.7. The spent fuel pool boron concentration will be monitored every 7 days. Administrative controls are in place on the placement of fuel in the spent fuel pool to ensure that the k_{eff} limit is met for unborated water. The fuel transfer equipment is designed to handle one fuel assembly at a time. The new-fuel storage racks are designed so that it is impossible to insert assemblies in other than the safe geometry lattice spacing. The fuel storage racks are designed with sufficient center-to-center distance between assemblies to ensure the above k_{eff} limits are satisfied.

Fuel storage is discussed in Section 9.1.

3.1.54 Monitoring Fuel and Waste Storage, Criterion 63

3.1.54.1 **AEC Criterion**

Appropriate systems shall be provided in fuel storage and radioactive waste systems and associated handling areas (1) to detect conditions that may result in loss of residual heat removal capability and excessive radiation levels and (2) to initiate appropriate safety actions.

3.1.54.2 **Discussion**

The spent-fuel pit water temperature is continuously monitored. The temperature is displayed in the control room, where an audible alarm sounds should the water temperature increase above a preset level. An audible alarm also sounds in the control room should the water level in the spent-fuel pit fall below a preset level. Decay heat removal from the spent fuel is provided by the heat exchangers in the fuel pit cooling system which are cooled in turn by the component cooling system. The status of the fuel pit cooling pumps and component cooling pumps is displayed at the control board. Flow indicators are provided for the component cooling water. Service water backup is available on loss of station power.

The spent-fuel pit water level monitor and alarm also warn the station operators of any potential radiation hazard. Operators can determine the radiation level by portable detectors.

A radiation monitor is located on the movable platform used for fuel handling. This monitor indicates the radiation level above the fuel pit when it is located over the pit. Higher than preset levels will initiate an audible and visible alarm locally and in the control room. Continuous surveillance of radiation levels in the waste storage and handling areas is maintained by an appropriately mounted radiation detector. Radiation levels in excess of preset levels will initiate audio and visual alarms locally and in the control room. As allowed by 10 CFR 50.68(b) these radiation monitors in conjunction with technical specifications governing storage of fuel in the new and spent fuel storage areas preclude the necessity of maintaining a monitoring system capable of detecting a criticality as described in 10 CFR 70.24.

The operator will take the appropriate safety actions on receipt of any of the above alarms.

The reference sections are:

Section Title	Chapter
Auxiliary Systems	9
Radioactive Waste Management	11
Radiation Protection	12

3.1.55 Monitoring Radioactive Releases, Criterion 64

3.1.55.1 **AEC Criterion**

Means shall be provided for monitoring the reactor containment atmosphere, spaces containing components for recirculation of LOCA fluids, effluent discharge paths, and plant environs for radioactivity that may be released from normal operations, including anticipated operational occurrences, and from postulated accidents.

3.1.55.2 **Discussion**

The reactor containment atmosphere is continually monitored during normal station operation by the containment particulate and gas monitors. The sample path for continuous monitoring of the containment atmosphere will be isolated under accident conditions. Radioactivity levels for facility effluent discharge paths are monitored during normal and accident conditions by the station radiation monitoring systems and by the radiological protection program for this facility, as described in Chapters 11 and 12. The safeguards areas are monitored by the ventilation vent sample particulate and gas monitors.

3.1 References

1. Letter from S.R. Monarque (NRC) to D.A. Christian (VEPCO), *North Anna Power Station Units 1 and 2 - Issuance of Amendments on Elimination of Requirements for Hydrogen Recombiners and Hydrogen Monitors Using CLIIP (TAC Nos. MC4391 and MC4392),* March 22, 2005 (Serial No. 05-220).

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3.2 CLASSIFICATION OF STRUCTURES, COMPONENTS, AND SYSTEMS

3.2.1 Seismic Classification

The earthquake producing the maximum vibratory accelerations at the site is designated the design-basis earthquake (DBE) (Section 2.5). The earthquake producing one-half the maximum vibratory accelerations at the site is designated the operational-basis earthquake (OBE) (Section 2.5). Seismic Class I structures, components, and systems are designed to resist the operational-basis earthquake within allowable stresses. Analyses were made to ensure that failure to function will not occur during the design-basis earthquake. The nomenclature and definitions contained herein are modified, by necessity, from those suggested in the proposed *Standard Format and Content of SARs for Nuclear Power Plants*, February 1972, to describe the plant as actually designed and constructed.

Seismic Class I design includes those structures, systems, and components:

1. Whose loss or failure by earthquake could cause a nuclear accident and thereby constitute a hazard to the general public; or
2. Whose loss or failure by earthquake could increase the severity of a nuclear accident. Radioactivity levels that constitute such a hazard to the general public are defined in 10 CFR 100.

Seismic Class I structures, components, and systems are designed for resistance to seismic loadings in accordance with Sections 3.7 and 3.8.

A list of structures, components, and systems that are designed to satisfy seismic and/or tornado criteria is given in Table 3.2-1.

3.2.2 System Quality Group Classification

North Anna Power Station, Units 1 and 2, was issued construction permit Nos. CPPR-77 and CPPR-78 in February 1971. The station design incorporates the codes and standards that were in effect when the equipment was purchased.

The codes and standards used for the design, fabrication, erection, and testing of safety-related components are commensurate with the importance of the safety functions to be performed.

The group classifications tabulated in the *Standard Format and Content of Safety Analysis Reports for Nuclear Power Reactors*, issued February 1972, and in Safety Guide No. 26, published March 1972, incorporated, in most cases, later editions of codes than those in effect when the majority of safety-related equipment was designed. Some of the equipment that would fall under a “group” as defined in Safety Guide No. 26 was designed to different codes or different editions of the same code. For example, for different components that would be in the same group, one may be designed to ASME III-1968, one to ASME III-1971, and one to ASME VIII-1968.

Therefore, pressure-containing components of safety-related systems do not fall under the group classifications listed above.

The codes and standards applicable to pressure-containing components of safety-related systems are listed in the following sections of this report, which describe these systems.

System	Reference Section
Containment liner and penetrations	3.8.2
Reactor coolant system	5
Containment depressurization system	6.2.2
Containment isolation system	6.2.4
Containment atmosphere cleanup system	6.2.5
Containment vacuum system	6.2.6
Emergency core cooling system	6.3
Fuel pit cooling and refueling purification system (portion of the system used to cool spent fuel)	9.1.3
Service water system	9.2.1
Chemical and volume control system (portion of the system used for emergency core cooling)	9.3.4
Boron recovery system (gas stripper)	9.3.5
Emergency diesel generator fuel-oil system	9.5.4
Steam and power conversion system (portions listed in Section 10.1)	10
Gaseous waste disposal system (waste gas decay tank)	11.3

Equipment that is part of the reactor coolant pressure boundary meets the requirements of 10 CFR 50.55a, except as discussed in Section 5.2.

Safety-related piping was designed in accordance with the Code for Nuclear Power Piping ANSI B31.7-1969 and the 1970 and 1971 addenda. However, reanalysis of the pressurizer surge line to account for the effect of thermal stratification and striping was performed in accordance with the requirements of ASME Boiler and Pressure Vessel Code, Section III, 1986 and addenda through 987, incorporating high cycle fatigue as required by NRC Bulletin 88-11. Original safety-related pressure retaining components other than pipe were specified by the design Engineer. The draft ASME Code for pumps and valves (dated Nov. 1968) and ASME VIII were the design codes for safety related pumps to the extent invoked by the appropriate design or procurement specification. Specific design and fabrication requirements for piping components, pumps, and pressure retaining components are described in the appropriate design for procurement specification.

Piping designed and built to B31.7, Class I is indicated on the system diagrams by the designation “Q1.” This piping includes that which is part of the reactor coolant pressure boundary as defined in 10 CFR 50.55a. B31.7 Class II piping is indicated on the system diagrams by the designation “Q2,” and B31.7 Class III piping by the designation “Q3.”

Table 3.2-1
STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

Legend
W - Westinghouse Electric Corporation SW - Stone & Webster Engineering Corporation
I - Refers to Seismic Category I T - Refers to structures that will not fail during the design tornado
P - Refers to systems and components that will not fail during the design tornado, since they are protected by tornado-resistant structures
NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Structures, see Note 3.				
Reactor containment and containment auxiliary structures				
Reinforced-concrete substructure	I	P	SW	
Reinforced-concrete superstructure	I	T		
Reinforced-concrete interior shields and walls	I	NA		
Steel plate liner	I	P [b]		
Piping, duct, and electrical penetrations	I	P		P for critical system penetrations only
Personnel access hatch	I	P [b]		
Equipment hatch platform	I	T [e]		The platform and the labyrinth portion of the personnel hatch missile shield are considered one structure
Auxiliary building				
Reinforced-concrete structure	I	T		

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to “pumps” include drivers.
d. All references to “piping and valves” include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)
STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO
SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

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NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Steel superstructure	I	NA		
Fuel building			SW	
Reinforced-concrete structure	I	T		
Steel superstructure	I	T		T for tornado winds
New-fuel storage racks	I	P		
Spent-fuel storage rack	I	P		P for horizontal missile only
Fuel building trolley support structure	I	T		Over spent-fuel pit only & T for tornado winds
Decontamination building			SW	
Below-grade enclosure for liquid waste disposal system and decontamination system equipment	I	T		
Service building			SW	
Control room	I	T		

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to “pumps” include drivers.
d. All references to “piping and valves” include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)
STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

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NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Switchgear and relay rooms	I	T		
Battery rooms	I	T		
Air-conditioning equipment room	I	T		For control room and relay room
Emergency diesel-generator cubicles				
Reinforced-concrete floor	I	T		
Walls	I	T		
Roof slab	I	T		
Turbine building	NA	NA	SW	See Note 4
Circulating water intake structure	I	T	SW	For auxiliary service water pump cubicles
Auxiliary feedwater pump house	I	T [e]		
Auxiliary feedwater pipe tunnel	I	T	SW	
Casing cooling pump house	I	NA	SW	
Service water pump house	I	T	SW	

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to “pumps” include drivers.
d. All references to “piping and valves” include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)
STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO
SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

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NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Service water valve house	I	T		
Service water tie-in vault	I	T	SW	
Boron recovery tank dikes	I	T	SW	
Fuel-oil pump house	I	T	SW	
Service water pipe expansion joint structures	I	T		
Flood protection dike	I	NA		Seismic design for OBE only
Quench spray pump house	I	T	SW	EL. 272’-0” slab and below
Main steam valve house	I	T	SW	
Safeguards area structure	I	T	SW	
Reactor coolant system				
Steam generators	I	P	W	
Steam generator supports	I	P	SW	
Reactor coolant pumps [c]	I	P	W	

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to “pumps” include drivers.
d. All references to “piping and valves” include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)
STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO
SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

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NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Reactor coolant pump supports	I	P	SW	
Pressurizer and pressurizer heaters	I	P	W	
Pressurizer support	I	P	SW	
Pressurizer relief tank	NA	P	W	
Reactor vessel				
Reactor core support structure	I	P	W	
Fuel assemblies	I	P	W	
Control rod and drive shaft assemblies	I	P	W	
Incore instrumentation thimbles	I	P	W	
Reactor vessel supports and neutron shield tank	I	P	SW	
Level indication system	I	P	-	See Section 7.9.2.2
Control-rod drive mechanisms	I	P	W	

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to “pumps” include drivers.
d. All references to “piping and valves” include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)
STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO
SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

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I - Refers to Seismic Category I
T - Refers to structures that will not fail during the design tornado
P - Refers to systems and components that will not fail during the design tornado, since they are protected by tornado-resistant structures
NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Reactor coolant piping, valves, and supports [d]	I	P	W	
Reactor coolant bypass piping, valves, and supports	I	P	W	
Reactor coolant high point vent system	I	P	-	See Section 5.5.10
Pressurizer surge line	I	P	W	
Pressurizer spray lines, valves, and supports	I	P	SW/W	
Pressurizer safety and relief valve piping	I	P	SW	
Safety Injection System				
Accumulators and supports	I	NA	W	
Low-head safety injection pumps and piping	I	P [b]	W	
Other piping, valves, and supports	I	NA	SW	Except drain/sample lines
Boron injection tank	I	P	W	
Quench spray subsystem				

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to “pumps” include drivers.
d. All references to “piping and valves” include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)

STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

Legend

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I - Refers to Seismic Category I T - Refers to structures that will not fail during the design tornado

P - Refers to systems and components that will not fail during the design tornado, since they are protected by tornado-resistant structures

NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Refueling water storage tank	I	NA	SW	Analyzed full of water
Chemical addition tank	I	NA	SW	
Quench spray pumps	I	NA	SW	
Piping, valves, and supports	I	NA	SW	Except flow test lines
Recirculation spray subsystem				
Casing cooling tank	I	NA	SW	
Recirculation spray pumps and piping	I	P [b]	SW	
Recirculation spray heat exchangers	I	P	SW	
Reactor containment sump, strainer modules and fins	I	P	SW	
Other piping, valves, and supports	I	P	SW	
Casing cooling pump and piping	I	NA	SW	
Containment vacuum system				

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to “pumps” include drivers.
d. All references to “piping and valves” include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)
STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

Legend
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SW - Stone & Webster Engineering Corporation
I - Refers to Seismic Category I
T - Refers to structures that will not fail during the design tornado
P - Refers to systems and components that will not fail during the design tornado, since they are protected by tornado-resistant structures
NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Postaccident cleanup piping and valves	I	NA	W	
Chemical and volume control system				
Boric acid storage tanks	I	P [e]	W	
Boric acid transfer pumps	I	P	W	
Boric acid blender	I	P	W	
Charging/high-head safety injection pumps	I	P	W	
Regenerative heat exchanger	I	P	W	
Nonregenerative heat exchanger	I	P	W	
Letdown filter	I	P	W	
Mixed-bed demineralizers	I	P	W	
Reactor coolant filter	I	P	W	
Volume control tank	I	P	W	
Seal-water heat exchanger	I	P	W	

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to “pumps” include drivers.
d. All references to “piping and valves” include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)
STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

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NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Seal-water filter	I	P	W	
Excess letdown heat exchanger	I	P	W	
Piping, valves and supports				
Boric acid piping	I	P [e]	SW	
Feed and bleed piping	I	P	SW	
Hydrogen, nitrogen, and vent piping for volume control tank	I	P	SW	
Residual heat removal system				
Residual heat removal pumps	I	P	W	
Residual heat exchangers	I	P	W	
Piping, valves, and supports	I	P	SW	
Boron recovery system				
Overhead gas compressors (pressure-containing parts)	I	P	SW	

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to “pumps” include drivers.
d. All references to “piping and valves” include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)
STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO
SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

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NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Stripper vent condenser	I	P	SW	
Stripper vent chiller	I	P	SW	
Stripper	I	P	SW	
Gas stripper surge tank	I	P	SW	
Piping, valves, support				
Gas stripper to waste gas system	I	P	SW	
Boron recovery tanks to dike penetrations	I	NA	SW	
Component cooling system				
Component cooling pumps	I	P	SW	
Component cooling heat exchangers	I	P	SW	
Component cooling surge tank	I	P	SW	
Piping, valves, and supports from pumps				
To residual heat exchangers	I	P	SW	

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to “pumps” include drivers.
d. All references to “piping and valves” include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)

STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

Legend

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SW - Stone & Webster Engineering Corporation
I - Refers to Seismic Category I
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P - Refers to systems and components that will not fail during the design tornado, since they are protected by tornado-resistant structures
NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
To fuel pit coolers	I	P	SW	P for horizontal missile
Fuel pit cooling system				
Fuel pit pumps	I	P	SW	P for horizontal missile
Fuel pit coolers	I	P	SW	P for horizontal missile
Piping, valves, and supports connecting above equipment to spent-fuel pit	I	P	SW	P for horizontal missile
Compressed air system				
Instrument air receivers	I	P	SW	
Instrument air compressors	I	P	SW	
Piping, valves, and supports to critical instruments and controls	I	P [e]	SW	
Service water system				
Service water reservoir	I	NA	SW	
Service water pumps	I	P	SW	

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to “pumps” include drivers.
d. All references to “piping and valves” include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)
STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO
SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

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NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Auxiliary service water pumps	I	P	SW	
Service water screen wash pumps	I	P	SW	
Service water traveling water screens	I	P	SW	
Service water piping, valves, and pipe supports for				
Recirculation spray heat exchangers	I	P	SW	
Component cooling heat exchangers	I	P	SW	
Service water pumps	I	P	SW	
Spray system	I	NA		
Supply to auxiliary steam generator feed pumps	I	P	SW	
Fire protection system				
Engine-driven fire pump	I	P	SW	
Diesel-oil tank (300 gal)	I	P	SW	

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to “pumps” include drivers.
d. All references to “piping and valves” include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)
STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO
SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

Legend
W - Westinghouse Electric Corporation SW - Stone & Webster Engineering Corporation
I - Refers to Seismic Category I T - Refers to structures that will not fail during the design tornado
P - Refers to systems and components that will not fail during the design tornado, since they are protected by tornado-resistant structures
NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Yard hydrant piping system	I	P	SW	
Fuel handling system				
Manipulator crane in containment	I	P	W	Crane will be parked and secured so no damage to reactor control-rod drive mechanisms can occur during earthquake
Movable platform with hoist in fuel building	I	NA	SW	Platform will be parked and secured so no damage to fuel can occur during earthquake or tornado
Fuel handling trolley in fuel building	I	NA	SW	Trolley will be parked and secured during tornado-warning periods so no damage to spent fuel can occur
Fuel transfer tube with isolation valve	I	P [b]	W	
Fuel elevator in fuel building	I	NA	SW	
Ventilation system				

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to “pumps” include drivers.
d. All references to “piping and valves” include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)
STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO
SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

Legend
W - Westinghouse Electric Corporation SW - Stone & Webster Engineering Corporation
I - Refers to Seismic Category I T - Refers to structures that will not fail during the design tornado
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NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Safeguards areas ventilation exhaust fans and exhaust ductwork to the fans and duct up to and including relief door	I	NA	SW	
Safeguards areas standby ventilation systems including fans and ductwork	I	P	SW	
Containment supply ventilation purge ductwork from fans at upstream or outer isolation valves including isolation valves	I	P [b]	SW	
Containment exhaust ventilation purge to fan intakes including isolation valves	I	P [b]	SW	
Containment air cooling recirculation system including ductwork and equipment	I	P	SW	
Control-rod air cooling recirculation system downstream from Elevation 291 ft. 10 in. in the steam generator cubicles	I	P	SW	

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to "pumps" include drivers.
d. All references to "piping and valves" include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)

STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

Legend
W - Westinghouse Electric Corporation SW - Stone & Webster Engineering Corporation
I - Refers to Seismic Category I T - Refers to structures that will not fail during the design tornado
P - Refers to systems and components that will not fail during the design tornado, since they are protected by tornado-resistant structures
NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Control and relay rooms air-conditioning recirculation systems including ductwork and equipment	I	P	SW	
Control and relay rooms bottled compressed breathing air systems including piping and equipment	I	P	SW	
Control and relay rooms emergency supply air system including ductwork and equipment	I	P	SW	
Auxiliary building central area exhaust to intake at fans, and discharge to above the roof	I	NA	SW	See pressure relief description in Section 9.4
Emergency diesel-generator room intake louvers and dampers	I	NA	SW	

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to "pumps" include drivers.
d. All references to "piping and valves" include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)
STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO
SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

Legend
W - Westinghouse Electric Corporation
SW - Stone & Webster Engineering Corporation
I - Refers to Seismic Category I
T - Refers to structures that will not fail during the design tornado
P - Refers to systems and components that will not fail during the design tornado, since they are protected by tornado-resistant structures
NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Auxiliary building exhaust filter assemblies including upstream and downstream duct headers, filter duct headers, filter duct connections and branch duct connections for the following systems: auxiliary building central area, Unit 1 reactor containment, Unit 1 safeguard area, Unit 2 reactor containment, Unit 2 safeguard area, fuel building exhaust within auxiliary building, decontamination building and waste solidification area exhaust within auxiliary building and auxiliary building general area	I	NA	SW	
Auxiliary building suction ducts above Elevation 291 ft. 10 in. to fan inlets	I	NA	SW	
Motor control center rooms emergency supply ventilation systems	I	P	SW	

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to “pumps” include drivers.
d. All references to “piping and valves” include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)
STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO
SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

Legend
W - Westinghouse Electric Corporation   SW - Stone & Webster Engineering Corporation
I - Refers to Seismic Category I   T - Refers to structures that will not fail during the design tornado
P - Refers to systems and components that will not fail during the design tornado, since they are protected by tornado-resistant structures
NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Auxiliary feedwater pump house ventilation system	I	P	SW	
Battery room ventilation system	I	P	SW	
Air-conditioning chiller room exhaust fans	I	P	SW	
Service water pump house ventilation system	I	P	SW	
Service water valve house ventilation system	I	P		
Screenwaste and service water pump house ventilation system	I	P	SW	
Main steam system				
Main steam piping from steam generators to and including main steam nonreturn valve	I	P	SW	
Main steam piping, valves, and supports from nonreturn valve to and including turbine stop valves	NA	NA	SW	Calculations verify that design-basis earthquake would not cause failure to function

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to “pumps” include drivers.
d. All references to “piping and valves” include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)

STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

Legend
W - Westinghouse Electric Corporation
SW - Stone & Webster Engineering Corporation
I - Refers to Seismic Category I
T - Refers to structures that will not fail during the design tornado
P - Refers to systems and components that will not fail during the design tornado, since they are protected by tornado-resistant structures
NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Turbine steam bypass piping, valves, and supports to condenser	NA	NA	SW	
Condensate and feedwater system				
110,000-gal condensate storage tank	I	P	SW	Assume full of water
Auxiliary steam generator feed pumps	I	P	SW	
Piping, valves, and supports				
From 110,000-gal condensate storage tank to auxiliary steam generator feed pumps	I	P	SW	
From auxiliary steam generator feed pumps to steam generator feed lines	I	P [e]	SW	
Steam generator feed lines inside containment to and including first isolation check valve outside containment	I	P	SW	
Primary vent and drain system				
Primary drain transfer tank	I	P	SW	

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to "pumps" include drivers.
d. All references to "piping and valves" include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)
STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO
SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

Legend
W - Westinghouse Electric Corporation
SW - Stone & Webster Engineering Corporation
I - Refers to Seismic Category I
T - Refers to structures that will not fail during the design tornado
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NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Piping, valves, and supports to primary drain transfer tank and from primary drain transfer tank to boron recovery system	I	P	SW	
Secondary vent and drain system				
Steam generator blowdown piping, valves, and supports inside containment to and including first isolation trip valve	I	P [b]	SW	
Gaseous waste disposal system				
Waste gas decay tanks	I	P	SW	
Waste gas recombiner system	I	P	SW	
Waste gas compressors	I	P	SW	
Waste gas charcoal filter	I	NA	SW	
Process vent blowers	I	NA	SW	
Waste gas piping, valves, and supports from stripper to dilution air	I	P	SW	

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to “pumps” include drivers.
d. All references to “piping and valves” include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)

STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

Legend
W - Westinghouse Electric Corporation
SW - Stone & Webster Engineering Corporation
I - Refers to Seismic Category I
T - Refers to structures that will not fail during the design tornado
P - Refers to systems and components that will not fail during the design tornado, since they are protected by tornado-resistant structures
NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Waste gas surge drum	I	P	SW	
Containment High-Range Radiation Monitoring System	I	P		
Process radiation monitoring system				
Recirculation spray heat exchanger service water monitors	I	NA	SW	
Containment gaseous and particulate monitors	I	NA	SW	See Section 5.2.4.1.1
Containment atmosphere cleanup system				
Recombiners	I	P	SW	
Hydrogen analyzers	I	P	SW	
Piping, valves, and supports	I	P	SW	
Instrumentation and control				

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to “pumps” include drivers.
d. All references to “piping and valves” include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)
STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

Legend
W - Westinghouse Electric Corporation
SW - Stone & Webster Engineering Corporation
I - Refers to Seismic Category I
T - Refers to structures that will not fail during the design tornado
P - Refers to systems and components that will not fail during the design tornado, since they are protected by tornado-resistant structures
NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Instrumentation and control to operate and monitor operation of critical system components shown above during an accident or a controlled shutdown as follows:				
Reactor protection (in part)	I	P	W	
Safeguards initiation	I	P	W/SW	
Containment isolation	I	P	W/SW	
Reactor control (in part)	I	P	W	Includes trip breakers
Steam generator water level control system	I	P	W	
Reactor makeup control	I	P	W	
Nuclear instrumentation (in part)	I	P	W	
Nonnuclear process instrumentation (in part)	I	P	W/SW	
Electrical systems				
Emergency diesel generators	I	P	SW	See note 5

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to “pumps” include drivers.
d. All references to “piping and valves” include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)
STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO
SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

Legend
W - Westinghouse Electric Corporation
SW - Stone & Webster Engineering Corporation
I - Refers to Seismic Category I
T - Refers to structures that will not fail during the design tornado
P - Refers to systems and components that will not fail during the design tornado, since they are protected by tornado-resistant structures
NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Fuel-oil day tanks	I	P	SW	
Fuel-oil transfer pumps	I	P	SW	
Underground fuel-oil storage tanks	I	P	SW	Assume 1/2 full of oil
Fuel-oil piping, valves, and supports to emergency generators	I	P	SW	P for piping to protected generators
Station service batteries and chargers	I	P	SW	
Diesel air start	I	P	SW	
Diesel lubrication	I	P	SW	
Ac vital bus panels and inverters	I	P	SW	
Emergency station service 480-V unit substations	I	P	SW	
Emergency station service 4.16-kV switchgear	I	P	SW	
Main control board	I	P	SW	
Waste disposal control board	I	P	SW	

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to “pumps” include drivers.
d. All references to “piping and valves” include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)

STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

Legend
W - Westinghouse Electric Corporation SW - Stone & Webster Engineering Corporation
I - Refers to Seismic Category I T - Refers to structures that will not fail during the design tornado
P - Refers to systems and components that will not fail during the design tornado, since they are protected by tornado-resistant structures
NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Auxiliary shutdown panels	I	P	SW	
Emergency diesel-generator panels	I	P	SW	
Auxiliary relay panels (safety-related only)	I	P	SW	
Ventilation panel	I	P	SW	
Battery distribution switchboard	I	P	SW	
Dc distribution panels	I	P	SW	
Main control board dc SOV panels	I	P	SW	
Electrical penetrations and terminal boxes	I	P	SW	
Radiation monitoring system control room cabinets	I	P	SW	
Pressurizer heater control group only	I	P	SW	
Cable runs to critical components, instruments, and controls as shown above	I	P	SW	Cable passing through unprotected areas will be in rigid conduit
Miscellaneous				

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to “pumps” include drivers.
d. All references to “piping and valves” include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)

STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO SEISMIC AND TORNADO CRITERIA

(Refer to the equipment classification list (Q-list) for a more comprehensive list of components, see Note 1.)

Legend

W - Westinghouse Electric Corporation

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I - Refers to Seismic Category I

T - Refers to structures that will not fail during the design tornado

P - Refers to systems and components that will not fail during the design tornado, since they are protected by tornado-resistant structures

NA - Not applicable

Item	Seismic Criterion	Tornado Criterion	Sponsor [a]	Notes
Reactor containment crane	I	P	SW	

a. HISTORICAL information, see Note 2.
b. To maintain containment integrity and allow plant operation following a tornado.
c. All references to “pumps” include drivers.
d. All references to “piping and valves” include root valves connecting to non-Seismic systems and valve operators.
e. Refers to SSCs that are not provided with complete physical protection from a tornado-generated missile, but have been evaluated using the Tornado Missile Risk Evaluator methodology to demonstrate that complete physical protection from tornado-generated missiles need not be provided.

Table 3.2-1 (continued)
STRUCTURES, SYSTEMS, AND COMPONENTS THAT ARE DESIGNED TO
SEISMIC AND TORNADO CRITERIA

Notes:

1. CAUTION, this table shall only be used for the classification of structures. Refer to the PAMS database for the classification of systems and components. A list of structures, systems, and components, like those in.Table 3.2-1 was provided as part of the licensing application to permit a determination to be made as to the general suitability of the classification given and the design approach applied. Since the time of original plant licensing, an equipment classification listing (Q-List), was developed and subsequently replaced with a database (PAMS) to provide a more comprehensive and up-to-date list of individual components and their classifications than does this table, which only provides a general list of systems and components. According to the NAPS current licensing basis, structures required to withstand the effects of a design basis tornado (Tornado Criterion “T”) are also required to be designed to Seismic Category I requirements (Seismic Criterion “I”). Hence, all structures classified as “T” must also be classified as “I”, but not necessarily vice versa. The Q-List and PAMS database only provide an input field for the more encompassing Seismic Category I classification for structures and do not provide a separate input field to identify those Seismic Criterion “I“ structures that must also meet the Tornado Criterion “T” classification. Hence, NAPS UFSAR, Table 3.2-1, was updated to be consistent with the NAPS current licensing basis to reflect both the Seismic Criterion “I” and Tornado Criterion “T” classifications for structures at NAPS in response to US NRC RIS 2015-06. For the classifications of all systems and components at NAPS, designed to be functional under Seismic Class I, Seismic Criterion “I”, refer to the PAMS database.
2. The information in the sponsor column designates the division of responsibility between Westinghouse and Stone & Webster for the original design of designated structures, systems, and components. These designations are considered HISTORICAL and are not intended or expected to be updated for the life of the plant.
3. Portions of structures, the failure of which potentially could cause damage of Seismic Category I components, are generally also defined as Seismic Category I; examples include the fuel building steel superstructure, auxiliary building reinforced-concrete and steel superstructure, and auxiliary service water pump cubicle. These are listed in the table.
4. The turbine building structure adjacent to the control area is designed to withstand 150-mph wind loads with roofing and siding in place. The bare steel structure, without siding and roofing, is designed to withstand 360-mph tornado wind loads without collapsing on the control area. A comparison of static seismic forces with the tornado wind loadings shows that the wind loads are the controlling design loads. Static seismic loads are assumed to equal the maximum acceleration value of 0.24g as shown in the response spectra, DBE for Rock, Figure 2.5-13, assuming 10% damping for the bolted structural steel structures as shown in Table 3.7-1.
5. The diesel generators are protected against tornado or air bottle failure missiles by missile-proof rooms. The engine is designed to contain a crankcase explosion without release of missiles. The air bottles are built to ASME Section VIII standards and are protected by two relief valves; overpressure failure is not credible. In addition, each diesel is in its own room, so that an air bottle rupture could not endanger more than one diesel.

3.3 WIND AND TORNADO DESIGN CRITERIA

3.3.1 Wind Criteria

All Seismic Class I structures listed in Table 3.2-1 are designed for the 100-year period of recurrence of the fastest mile of wind, 80 mph as determined from Figure 1b of ASCE Paper 3269 (Reference 1). The maximum normal wind loading based on this ASCE paper, the 100-year recurrence interval, and a shape factor of 1.3 for a typical building are shown in Table 3.3-1.

Gust factors selected on the basis of structure width are multiplied by the maximum normal wind loading to determine the design wind pressure. The gust factors determined from ASCE Paper 3269 are shown in Table 3.3-2.

Where other than normal wind pressures on typical rectangular building walls are considered, the maximum wind loading is adjusted for the appropriate shape or drag factor given in the ASCE paper.

Structures other than Seismic Class I structures are designed for the 50-year period of recurrence of the fastest mile of wind as given in Figure 1a of ASCE Paper 3269. The maximum normal wind loading based on this ASCE paper, the 50-year recurrence interval, and a shape factor of 1.3 for a typical building is shown in Table 3.3-3.

Wind loads for other than Seismic Class I structures are also adjusted for appropriate gust, shape, and drag factors as given in the ASCE paper.

Members of Seismic Class I and other structures subject to stresses produced by this wind load combined with live and dead loads are proportioned for stresses 33-1/3% greater than conventional working stresses, provided that the section thus required is not less than that required for the combination of dead and live loads computed without the one-third increase.

3.3.2 Tornado Criteria

Section 2.3 outlines the probability of a tornado occurring at the site. Although no structural damage is known to have resulted to a reinforced-concrete building in a tornado (Reference 2), the structures and systems so indicated in Table 3.2-1 are designed to ensure safe shutdown of the reactor when subjected to tornado loadings.

The tornado model used for design has the following characteristics:

Rotational velocity	300 mph
Translational velocity	60 mph
Pressure drop	3 psi in 3 sec
Overall diameter	1000 ft

Applicable structures are designed to resist a maximum wind velocity of 360 mph associated with a tornado, which is obtained by adding the rotational and translational velocities. These structures and systems are designed for tornado pressure loading, vacuum loading, and the combination of these two.

The tornado wind velocity is converted to an equivalent pressure, which will be applied to the structures uniformly using the formula:

$$P = 0.00256\ V^2$$

where:

P = equivalent pressure, lb/ft^2

V = wind velocity, mph

This pressure is multiplied by applicable shape factors and drag coefficients as given in ASCE Paper 3269 and applied to the silhouette of the structure.

A reduction of the full negative pressure differential is made when venting of the structures is provided. The amount of the reduction is a function of the venting area provided.

Tornado wind loads are combined with other loads as described in Section 3.8. Tornado and earthquake loads are not considered to act simultaneously. A uniform wind velocity and a nonuniform atmospheric pressure gradient are considered in the design of the containment structure.

Structural design criteria for tornado loading for the containment structure are given in Section 3.8.2.

It is assumed that a tornado could generate any of the following potential missiles:

1. Missile equivalent to a wooden utility pole 40 feet long, 12-inch diameter, with a density of 50 lb/ft^3, and traveling in a vertical or horizontal direction at 150 mph (Reference 3).
2. Missile equivalent to a 1-ton automobile traveling at 150 mph not more than 25 feet above ground grade and with a contact area of 30 ft^2.
3. 1-inch solid steel rod, 3 feet long, with a density of 490 lb/ft^3.
4. 6-inch Schedule 40 pipe, 15 feet long, with a density of 490 lb/ft^3.
5. 12-inch Schedule 40 pipe, 15 feet long, with a density of 490 lb/ft^3.

The design assumes maximum wind forces and partial vacuum to occur simultaneously with the impact of any of the missiles singly. Allowable stresses do not exceed 90% of the guaranteed minimum yield strength of structural steel, the capacity reduction factor, given in

Section 3.8, times the guaranteed minimum yield strength of the reinforcing steel, or 75% of the ultimate strength of the concrete. Allowable soil bearing values may be increased one-third for this loading condition. The allowable stress limits of 0.9 F_y (steel superstructures) and 0.9 f_y and 0.75 f'_c (reinforced concrete structures) apply to global stresses from the dynamic overall structural response. These global stresses are located outside of the tornado missile impact zone and away from any yield-line patterns that may develop during the tornado missile impact.

Typically the above-grade exterior portion of all tornado-resistant structures consist of 2-foot-thick heavily reinforced concrete. The walls and roof of such structures comprise the barrier against tornado missiles. A typical reinforcement for a 2-foot-thick barrier consists of N11 bars, on 10-inch centers, running in two perpendicular directions, in both the near and far faces of the concrete. In addition, test data and analytical studies (Reference 5) have confirmed that 2-foot thick, concrete test specimens, with similar spans and steel reinforcement as those found in NAPS Tornado Criterion "T" structures (Table), will not experience back face scabbing or a ductility ratio, , in excess of allowable applicable industry code limits (i.e., < 10), when subjected to design basis tornado load effects, as described in NAPS UFSAR, Section 3.3.2. Other combinations of concrete thickness and steel reinforcement that provide the same protection have also been provided. If a heavily reinforced concrete labyrinth was not practical as a means of egress from tornado-resistant structures, a 3-inch-thick steel plate sliding or swinging door has been provided.

It is noted that the physical configuration of certain plant components does not provide complete physical protection against tornado-generated missiles. The vulnerable surface area for each component was assessed probabilistically using the Tornado Missile Risk Evaluator methodology (Reference 6) and it was determined that the risk to the plant is acceptably low, such that complete physical protection need not be provided. Refer to Table 3.2-1 for identification of these components.

Non-tornado-resistant building superstructures are constructed from materials such as reinforced concrete, concrete block, and/or structural steel, with metal siding and roof deck. Potential missiles or debris from these materials, resulting during failure of the superstructure when subjected to excessive wind loads up to tornado intensity, are not considered to result in a more severe design criterion than that imposed by the utility pole (Reference 4).

The extent of the turbine building superstructure adjacent to, and projecting above, the portion of the service building roof over the tornado-resistant control room, has been braced against possible collapse onto the control room when subjected to excessive wind loads up to tornado intensity.

3.3 REFERENCES

1. Task Committee on Wind Forces, "Wind Forces on Structures," *Transactions of the American Society of Civil Engineers*, Paper 3269, Vol. 126, Part II, p. 1124, 1962.
2. V. C. Gilbertson and E. R. Mageanu, *Tornadoes*, AIA Technical Reference Guide, TRG 13-2, U.S. Weather Bureau.
3. D. R. Miller and W. A. Williams, *Tornado Protection for the Spent Fuel Storage Pool*, General Electric APED-5696, Class I, November 1968.
4. A. Amerckian, *Design of Protective Structures*, Bureau of Yards and Docks, Department of the Navy, Navy Docks P-51, August 1950.
5. SWECO 7703, *Missile-Barrier Interaction – A Topical Report*, Stone & Webster Engineering Corporation, Boston, MA, September 1977
6. NEI 17-02, Rev. 1B, *Tornado Missile Risk Evaluator (TMRE)*, September 2018, as implemented and approved at Shearon Harris Nuclear Power Plant (ML18347A385).

Table 3.3-1
WIND LOADING ON SEISMIC CLASS 1 STRUCTURES (Based on 100 Yr. Recurrence of 80 mph Wind Measured 30 ft Above Ground)

Height Zone (ft)	Basic Wind Velocity (mph)	Dynamic Wind Pressure (DWP) (psf)	DWP × 1.3 Shape Factor (psf)	DWP × 1.3 Shape Factor x Gust Factor (Table 3.3-2) (psf)
0-50	80	16	21	27
51-150	95	23	30	36
151-400	110	31	40	40

Table 3.3-2
GUST FACTORS

Width of Structure (ft)	Gust Factor
0-50	1.3
51-100	1.2
101-150	1.1
Greater than 150	1.0

Table 3.3-3
WIND LOADING ON OTHER THAN SEISMIC CLASS 1 STRUCTURES (Based on 50 Yr. Recurrence of 75 mph Wind Measured 30 ft Above Ground)

Height Zone (ft)	Basic Wind Velocity (mph)	Dynamic Wind Pressure (DWP) (psf)	DWP × 1.3 Shape Factor (psf)	DWP × 1.3 Shape Factor x Gust Factor (Table 3.3-2) (psf)
0-50	75	14.5	19	25
51-150	90	21	27	32
151-400	100	25.5	33	33

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3.4 WATER LEVEL (FLOOD) DESIGN CRITERIA

Finish ground grade at the station is at Elevation 271.0 ft. The normal level of Lake Anna is at Elevation 250.0 ft., and the probable maximum flood still-water level of the lake at the station site is Elevation 264.2 ft. This level results from the revised probable maximum flood analysis presented in Appendix 2A, dated June 18, 1976. Test borings indicated a ground-water level at approximately Elevation 220.0 ft. before the start of construction and flooding of the lake.

During construction, surface water was the principal source of water. This surface water was readily handled by pumping, when required, and hydrostatic loadings, which may have otherwise caused flotation, did not occur.

At the completion of the main dam construction, Lake Anna was allowed to fill to its normal pond level, and ground-water levels increased. Considering the dead weight of the various structures, hydrostatic loadings are not of sufficient intensity to result in flotation.

All below-grade walls are designed for the maximum anticipated hydrostatic loadings. All below-grade rattle spaces between structures are protected from ground-water seepage with two water stops composed of either PVC membrane attached to embedded reglets, embedded PVC expansion-type water seals, or a combination of the two. Additionally, subsurface drainage has been provided to intercept ground water and prevent hydraulic pressure at rattle spaces between the Auxiliary Building and the containment structures, and between the Auxiliary Building and the Main Steam Valve Houses.

Static and dynamic effects and consequences of all types of flooding on safety-related facilities are discussed in Section 2.4.10.

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3.5 MISSILE PROTECTION CRITERIA

3.5.1 Missiles Postulated Within Reactor Containment

The systems located inside the reactor containment have been examined to identify and classify potential missiles. The basic approach was to ensure design adequacy against generation of missiles, rather than to postulate missile formation and then try to contain their effects.

Catastrophic failure of the reactor vessel, steam generators, pressurizer, reactor coolant pump casings, and piping leading to generation of missiles is not considered credible. Massive and rapid failure of these components is not credible because of the material characteristics, scheduled inspections, quality control during fabrication, erection, and operation, conservative design, and prudent operation as applied to the particular component. The reactor coolant pump flywheel is not considered a source of missiles for the reasons discussed in Section 5.2.3.3.3. Nuts and bolts are of no concern because of the small amount of stored energy.

Components that, nevertheless, are considered to have a potential for missile generation inside the reactor containment are the following:

1. Control rod drive mechanism (CRDM) housing extension and cap, drive shaft, and the drive shaft and drive mechanism latched together.
2. Certain valve bonnets.
3. Temperature- and pressure-sensing assemblies.
4. Pressurizer heaters.

Design provisions to preclude missile damage from these sources are discussed in Section 3.5.3.

Gross failure of a control rod mechanism housing sufficient to allow a control rod to be rapidly ejected from the core is not credible for the following reasons:

1. Control rod mechanisms are shop pressure-tested at 3450 psig and 4105 psig.
2. The mechanism housings are individually hydrotested to 3107 psig as they are installed on the reactor vessel head adapters, and checked during the hydrotest of the completed reactor coolant system.
3. Stress levels in the mechanisms are not affected by system transients at power, or by thermal movement of the coolant loops.
4. The mechanism housings are made of type 304 stainless steel. This material exhibits excellent fracture notch toughness at all temperatures encountered.

However, it is postulated that the cap and extension on the top of the control rod drive mechanism housing might become loose and be forced upward by the water jet. The following sequence of events is then assumed.

The drive shaft and control rod cluster are forced out of the core by the differential pressure of 2250 psi across the drive shaft. The drive shaft and control cluster, latched together, are assumed fully inserted when the accident starts. After approximately 12 feet of travel, the rod cluster control spider hits the underside of the fuel assembly upper support plate. Upon impact, the flexure arms in the coupling joining the drive shaft and control cluster fracture, completely freeing the drive shaft from the control rod cluster. The control cluster would be completely stopped by the upper support plate; however, the drive shaft would continue to be accelerated upward until stopped by the missile shield.

Valve stems are not credible sources of missiles. All the isolation valves installed in the reactor coolant system have stems with a back seat. This effectively eliminates the possibility of ejecting valve stems even if the stem threads fail. Analysis shows that the back seat or the upset end would not penetrate the bonnet. Additional interference is encountered with air- and motor-operated valves.

Valves with nominal diameter larger than 2 inches in high-pressure systems have been designed against bonnet-body connection failure and subsequent bonnet ejection by means of:

1. Using the design practice of ASME Section VIII (1968) for bolting.
2. Using the design practice of ASME Section VIII (1968) for flange design.
3. Controlling the torque load during the bonnet-body connection stud-tightening process.

The pressure-containing parts of these valves are designed to Class I requirements established by the USAS B16.5 (1968), *Steel Pipe Flanges and Flanged Fittings*.

The proper stud torquing procedures and the use of torque wrenches limit the stress of the studs to the allowable limits established in Section VIII of the ASME Code. This stress level is far below the material yield. The complete valves are hydrotested per USAS B16.5 (1968). The stainless steel bodies and bonnets are volumetrically and surface tested to verify soundness.

Valves with nominal diameter of 2 inches or smaller are forged, and have screwed bonnet with canopy seal. The canopy seal is the pressure seal, while the bonnet threads are designed to withstand the hydrostatic end force. The pressure-containing parts are designed to criteria established by USAS B16.5 (1968).

While valve missiles are not generally postulated, for the reasons discussed above, the valves in the region where the pressurizer extends above the operating floor are exceptions. Valves in this region include the pressurizer safety valves, the motor-operated isolation valves in the relief line, the air-operated relief valves, and the air-operated spray valves. Although failure of these valves is also incredible, failure of the valve bonnet-body bolts is postulated, and provisions made to ensure integrity of the containment liner from the resultant bonnet missile. To the extent practical, all valves are also oriented such that any missile will strike a barrier.

The only credible source of jet-propelled missiles from the reactor coolant piping and piping systems connected to the reactor coolant system is that represented by the temperature and pressure sensor element assemblies. The resistance element assemblies can be of two types: “with well” and “without well.” Two rupture locations have been postulated: around the weld (or thread) between the temperature assembly and the boss for the “without well” element, and the weld (or thread) between the well and the boss for the “with well” element.

A temperature sensor element is installed on the reactor coolant pumps close to the radial bearing assembly. A hole is drilled in the gasket and sealed on the internal end by a steel plate. In evaluating missile potential, it is assumed that this plate breaks and the pipe plug on the external end of the hole becomes a missile.

In addition, it is assumed that the welded joint fails and the well and sensor assembly becomes a jet-propelled missile.

Finally, it is assumed that the pressurizer heaters become loose and become jet-propelled missiles.

3.5.2 Typical Characteristics of Missiles Postulated Within Reactor Containment

The missile characteristics of the control rod drive mechanism housing cap and extension, the control rod drive shaft, and the control rod drive shaft latched to the drive mechanism are given in Table 3.5-1. These velocities have been calculated by equating the increase in the missile momentum to the decrease in jet momentum. The reactor coolant discharge rate from the break has been calculated using the Burnell equation (Reference 1). The coolant pressure has been assumed constant at the initial value. No spreading of the water jet has been assumed.

The missile characteristics of the bonnets of the valves in the region where the pressurizer extends above the operating floor are given in Table 3.5-2.

The missile characteristics of the piping temperature sensor element assemblies are given in Table 3.5-3. A 10-degree expansion half-angle water jet has been assumed. The missile characteristics of the piping pressure element assemblies are less severe than those presented in Table 3.5-3.

The missile characteristics of the reactor coolant pump temperature element, the instrumentation well of the pressurizer, and the pressurizer heaters are given in Table 3.5-4. A 10-degree expansion half-angle water jet has been assumed.

3.5.3 Design Evaluation for Missiles Postulated Within Reactor Containment

The principal design basis is that missiles generated in coincidence with a LOCA shall not cause loss of function of any engineered safety features, or loss of containment integrity.

The missile barriers in the containment are designed to resist the missiles assumed in Section 3.5.2.

The barriers are designed so that they will not be penetrated by the postulated missiles. The steam generator shell is also ample to resist penetration of the postulated missiles.

A missile shield structure is provided within 1 inch (hot) of the top of the control rod drive mechanisms to block any missiles that might be associated with a fracture of the pressure housing of any mechanism. This shield is a 20-inch-thick concrete slab with 1-inch steel facing. It is located close to the mechanisms to limit the acceleration and momentum of the ejected missiles, to limit the movement of the drive shaft, to minimize the probability of missiles missing the shield and striking the containment liner, and to minimize the probability of missiles ricocheting and damaging other control rod drive mechanism housings.

This missile shield will stop any missiles associated with the rupture of a control rod drive mechanism housing. The worst missile case involves the housing cap and extension, followed by the drive shaft.

To protect against valve bonnet missiles postulated in the region where the pressurizer extends above the operating floor, a barrier surrounds that part of the pressurizer. This barrier will stop the postulated missiles.

The ability of reactor cubicle walls and the operating floor to stop missiles is evaluated for the postulated instrumentation assembly and pressurizer heater missiles. Generally, the minimum thickness of the reactor cubicle walls and the operating floor is 2 feet of concrete. Calculations based on this thickness and the given missile characteristics show that the critical velocity required to penetrate is at least twice the maximum calculated velocity.

Interior missile forces were not included in the design criteria of the containment liner plate. The placement of missile barriers is a basic design consideration. Interior concrete structures have been evaluated for a variety of interior missiles. Because of these analyses, and the placement of local barriers, the liner is not endangered by missiles.

Interior jet forces were not included in the design of the containment shell. Jet forces on the inside face of the containment shell could occur, since failure of main steam or feedwater lines in the annular space between the crane wall and the containment shell are now postulated. The steel-lined, 4 ft. 6 in. reinforced-concrete wall of the containment shell will not be penetrated by jet impingement loads from these high-energy lines.

All missile barriers are also designed to withstand the dynamic impact loads. The energy method (Reference 2), the momentum method (Reference 3), or an empirical method (Reference 4) is used.

A large section of 3/8-inch-thick liner was analyzed for the maximum temperature that could be imposed due to a nearby main steam line break. Since buckling of the liner is the most likely and least desirable effect, the analysis was performed using an elastic-plastic large deformation computer code, MARC.

Based on this method, it was shown that the anchor stud spacing of 12 inches is sufficient to restrain the plate from buckling. The total equivalent plastic strain was shown to be about 0.004 in./in. for a maximum liner temperature of 560°F due to jet impingement. The out-of-plane deflections are much less than the plate thickness.

3.5.4 Design for Missiles Postulated Outside of Reactor Containment

The North Anna Power Station site is approximately 26 miles from the nearest commercially serviced airport at Fredericksburg, Virginia. The closest major airport is the Orange County Airport, 18 miles from the station site. The site is not on the normal approach path to either of these air fields. Commercial aircraft pass at a horizontal distance of 1.5 miles from the site. The only aircraft that potentially would overfly the plant site would be private aircraft operating on local flight plans. Private aircraft are usually small, lightweight aircraft used for recreational purposes, and do not pose any threat to the North Anna site.

As stated in Section 3.3.2, five tornado-generated missiles have been evaluated. They are:

1. Missile equivalent to a wooden utility pole 40 feet long, 12 inches diameter, with a density of 50 lb/ft^3 and traveling in a vertical or horizontal direction at 150 mph.
2. Missile equivalent to a 1-ton automobile traveling at 150 mph.
3. 1-inch solid steel rod, 3 feet long, with a density of 490 lb/ft^3.
4. 6-inch Schedule 40 pipe, 15 feet long, with a density of 490 lb/ft^3.
5. 12-inch Schedule 40 pipe, 15 feet long, with a density of 490 lb/ft^3.

The design velocity of 150 mph for the postulated 40-foot-long, 12-inch-diameter utility pole tornado missile is based on engineering judgement, after a comprehensive review of tornado case histories. The velocity assumption is substantiated by data presented in General Electric Report APED-5696 (Reference 5); from Figure 15 of that report and associated formulas, this size utility pole would have a characteristic parameter value of 0.0254, assuming a drag coefficient of unity, and would attain a velocity of approximately 140 fps or 95 mph during a 300-mph tornado. Adding together the 300-mph rotational velocity and the 60-mph translational velocity of the design tornado increases the wind speed to 360 mph and the missile speed to approximately 130 mph. Since skin friction along the utility pole would reduce the speed to less than 130 mph, the proposed design velocity of 150 mph is considered to be conservative.

Tornado missile protection is provided to protect the safety-related structures, systems, and components indicated in Table 3.2-1. Tornado-protected structures are described in Section 3.3.2.

As also described in Section 3.3.2, the Tornado Missile Risk Evaluator methodology was used to analyze certain structures, systems, and components where it was determined that complete physical protection against tornado-generated missiles was not present.

The analytical techniques used to design missile-protected structures consist of the use of ballistic formulas. The Ballistic Research Laboratories formula is cited on page 15.2.3-3 of the PSAR. The selection of this formula as the basis for structural analysis and design of missile-protected structures was based on an engineering evaluation after review of available data on the effects of missile impact. Other formulas have also been cited and used to substantiate this analytical basis.

Analysis of the barrier thickness of heavily reinforced concrete required to prevent perforation by the utility pole indicates that 18.6 inches are required. This thickness is calculated as follows:

1. Determine penetration into an infinite barrier by Equation 4.1.14 and Equation 4.1.15 from the Ammann and Whitney report (Reference 6).
2. Determine thickness of concrete for the missile to just perforate it by Equation 30 from R. Gwaltney (Reference 7).

Similar calculations for missiles 3, 4, and 5 traveling at 200 mph give the following results:

Missile	Concrete Thickness Required to Prevent Perforation
1-in. solid steel rod, 3 ft. long, 490 lb/ft^3	4.1 in.
6-in. Schedule 40 pipe, 15 ft. long, 490 lb/ft^3	11.4 in.
12-in. Schedule 40 pipe, 15 ft. long, 490 lb/ft^3	18.5 in.

These results demonstrate that the utility pole is the most critical missile. Structures, systems, and components protected against the utility pole will also be protected from any credible missile.

None of these missiles would penetrate the reactor containment. The effect of missiles on stored fuel in the spent-fuel pit is discussed in Section 9.1.2. A list of structures that are designed to resist the impact of tornado missiles is presented in Table 3.2-1.

Secondary missiles resulting from missile impact on barriers or structures have very low energies in all cases studied, and present no hazard.

If secondary missiles develop, the fragments would be localized. All safety-related equipment is redundant and physically separated to the extent practicable, so that localized secondary missiles will not impair the required safety feature action.

3.5.5 Missiles from Compressed Gas

The location, marking, fabrication, testing, and inspection of tanks and cylinders containing compressed gases are in compliance with Subparts H and M of 29 CFR 1910, Occupational Safety and Health Administration.

Since the cylinders are equipped with pressure relief valves that are set below the design pressure, the possibility of excessive pressure buildup is precluded.

Table 3.5-5 indicates the operating pressure, vessel location, and energy release of a representative sample of cylinders containing compressed gases. The energies listed in Table 3.5-5 are based on the adiabatic expansion of the compressed gases. In the event of a localized failure, such as a valve stem, the compressed gas bottles will not become rocket-propelled missiles, since they are secured in racks. Also, in the primary gas storage area, concrete block walls separate racks of different gases.

The location of the gas storage facilities in relationship to equipment essential for initiating and maintaining a shutdown precludes the possibility of interaction in the event of an incident.

3.5 REFERENCES

1. J. Burnell, *The Flow of Boiling Water through Nozzles, Orifices, and Pipes,* The Institution of Engineers, Australia, March 1946.
2. J. M. Biggs, *Introduction to Structural Dynamics*, McGraw-Hill, 1964.
3. C. H. Norris et al., *Structural Design for Dynamic Loads*, McGraw-Hill, 1959.
4. *Protective Design - Fundamentals of Protective Design (Non-Nuclear)*, TM 5-855-1, Department of the Army Technical Manual, July 1965.
5. D. R. Miller and W. A. Williams, *Tornado Protection for the Spent-Fuel Storage Pool*, GE Company, APED 5696, November 1968.
6. Ammann and Whitney Report, *Industrial Engineering Study to Establish Safety Design Criteria for Use in Engineering of Explosive Facilities and Operations - Wall Response*, April 1963.

7. R. Gwaltney, *Missile Generation in Light-Water Cooled Power Reactor Plants*, ORNL-NS1C-22, September 1968.

Table 3.5-1
CONTROL-ROD DRIVE MECHANISM - MISSILE CHARACTERISTICS

Missile Description	Weight (lb)	Travel Outside Housing (in.)	Velocity (ft/sec)	Kinetic Energy (ft-lb)
Extension and cap	80	1	39.2	1900
Drive shaft	120	1	175.8	57,500
Drive shaft latched to drive mechanism	1500	1	8.7	1760

Table 3.5-2
VALVE-MISSILE CHARACTERISTICS

Missile Description	Weight, lb	Area, in^2	Flow Discharge Area, in^2	Impact Area, in^2	Weight to Impact Area Ratio, psi	Velocity, fps
Safety valve bonnet (3 in. x 6 in. or 6 in. x 6 in.)	350	2.86	80	24	14.0	110
3-in. motor-operated isolation valve bonnet (plus motor and stem) (3-in.)	400	5.5	113	28	14.3	135
2-in. air-operated relief valve bonnet (plus stem)	75	1.8	20	20	3.75	115
3-in. air-operated spray valve bonnet (plus stem)	120	5.5	50	50	2.4	190
4-in. air-operated spray valve	200	9.3	50	50	4	190

Table 3.5-3

PIPING TEMPERATURE ELEMENT ASSEMBLY - MISSILE CHARACTERISTICS

1. For a tear around the weld between the boss and the pipe:

Characteristics	Without Well	With Well
Flow discharge area, in^2	0.11	0.60
Thrust area, in^2	7.1	9.6
Missile weight, lb	11.0	15.2
Area of impact, in^2	3.14	3.14
Missile Weight / Impact area, psi	3.5	4.84
Velocity, fps	20	120

2. For a tear at the junction between the temperature element assembly and the boss for the “without well” element, and at the junction between the boss and the well for the “with well” element:

Characteristics	Without Well	With Well
Flow discharge area, in^2	0.11	0.60
Thrust area, in^2	3.14	3.14
Missile weight, lb.	4.0	6.1
Area of impact, in^2	3.14	3.14
Missile Weight / Impact area, psi	1.27	1.94
Velocity, fps	75	120

Table 3.5-4
CHARACTERISTICS OF OTHER MISSILES POSTULATED
WITHIN REACTOR CONTAINMENT

	Reactor Coolant Pump Temperature Element	Instrument Well of Pressurizer	Pressurizer Heaters
Weight, lb	0.25	5.5	15
Discharge area, in^2	0.50	0.442	0.80
Thrust area, in^2	0.50	1.35	2.4
Impact area, in^2	0.50	1.35	2.4
Missile Weight / Impact area, psi	0.5	4.1	6.25
Velocity, fps	260	100	55

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.5-5

STORAGE OF GASES UNDER PRESSURE

				Maximum Energy Release[a] if Ruptured (ft-lb x 10^3)		
Gas	Pressure, psi	No. of Tanks	Estimated Volume, ft^3	One Tank	All Tanks	Location
Hydrogen						
Primary	2200	20	2.3	1373	27,460	Primary gas storage area
Secondary	2450	5	64.4	43,183	215,915	North yard
Nitrogen						
Primary	2200	28	2.3	1396	39,088	Primary gas storage area
Tube Trailer	2700	29	10.9	8254	239,366	East of boron recovery building
Recombiner isolation valve operators	2490	2	1.54	1063	2126	Recombiner vault
Oxygen	2200	16	2.3	1396	22,336	Primary gas storage area
Carbon dioxide						
Fire protection	800	6	2.3	544	3264	Fuel-oil pump house
L.P. fire protection	300	1	230	17,631	17,631	Auxiliary building
Secondary	300	1	800	61,327	61,327	North yard
Halon	600	4	2.39	562	2248	Service building
Air	2400	88	2.3	1532	134,816	Service building
Halon[b]	600	4	2.39	562	2248	Office building

a. Energy release based on reversible adiabatic expansion.

b. Halon cylinders in the office building have been removed.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.5-5 (continued)
STORAGE OF GASES UNDER PRESSURE

				Maximum Energy Release[a] if Ruptured (ft-lb x 10^3)		
Gas	Pressure, psi	No. of Tanks	Estimated Volume, ft^3	One Tank	All Tanks	Location
Halon	600	2	0.30	71	142	Security building
Halon	600	2	0.30	71	142	Security control center
Halon	600	2	0.90	212	424	Security control center

a. Energy release based on reversible adiabatic expansion.
b. Halon cylinders in the office building have been removed.

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3.6 CRITERIA FOR PROTECTION AGAINST DYNAMIC EFFECTS ASSOCIATED WITH A LOSS-OF-COOLANT ACCIDENT

The containment structure and all essential equipment within the containment is adequately protected against the effects of blowdown jet forces and pipe whip resulting from a postulated pipe rupture of reactor coolant, main steam, and feedwater lines. Appropriate protective measures are also used as required to mitigate the consequences of postulated breaks in other high-energy piping.

3.6.1 Acceptance Criteria

The criteria for adequate protection permit limited damage when analysis or experiment demonstrates that:

1. Leakage through the containment will not cause offsite doses to exceed the limits specified in 10 CFR 50.67.
2. The minimum performance capabilities of the engineered safety features (ESF) systems are not reduced below those required to protect against the postulated break.
3. A pipe break that is not a loss of reactor coolant will not cause a loss of reactor coolant, or steam- or feedwater-line break. Also, a reactor coolant system pipe break will not cause a steam or feedwater system pipe break.

3.6.2 Protection Approaches

Protection is provided by a combination of the following approaches.

3.6.2.1 Placement of Piping and Components

The routing of pipe and the placement of components minimize the possibility of damage.

The polar crane wall serves as a barrier between the reactor coolant loops and the containment liner. In addition, the refueling cavity walls, various structural beams, the operating floor, and the crane wall enclose each reactor coolant loop in a separate compartment; this prevents an accident, which may occur in any loop, from affecting another loop or the containment liner. The portions of the steam and feedwater lines within the containment have been routed behind barriers that separate these lines from all reactor coolant piping except for connection to the steam generator. These barriers can withstand loadings caused by pipe rupture forces.

3.6.2.2 Movement-Limiting Restraints and Jet Barriers

Where the careful layout of piping and components cannot offer adequate protection against the dynamic effects associated with a postulated pipe rupture, restraints to prevent excessive pipe movement or special jet impingement shielding are provided to the extent practical.

Restraints offer good supplemental protection because pipe displacements are minimized and large kinetic energies are prevented. The placement of the restraints prevents excessive pipe displacements in the event of either a longitudinal split or circumferential break.

3.6.2.3 **Augmented Inspection**

In specific instances where the installation of restraints or shields is not practical, adequate assurance of protection is provided by an augmented inservice inspection program on specific welds selected on the basis of pipe stress analysis.

The augmented inservice inspection will comply, to the extent practical within the limitations of design, geometry, and materials of construction of the components, to the requirements in those editions of Section XI of the ASME Boiler and Pressure Vessel Code and addenda required for the reactor coolant system. The frequency of the augmented inservice inspection has been increased by an order of magnitude over that required by Section XI of the ASME Boiler and Pressure Vessel Code, dated January 1970, so that each weld will be inspected three times during each 10-year inspection interval.

The augmented inservice inspection program applies to the following piping runs:

1. Unit 1 pressurizer spray line
2. Unit 2 pressurizer safety valve, normally pressurized, inlet lines

3.6.2.4 **Locations of Postulated Pipe Breaks**

The probability of rupturing a primary coolant pipe is extremely small as demonstrated by the study based upon leak-before-break (LBB) technology reported in Westinghouse WCAP 11163/11164, *Technical Bases for Eliminating Large Primary Loop Pipe Rupture as a Structural Design Basis for North Anna Units 1 & 2,* August 1986 and supplement 1 to the same WCAP in January 1988. The NRC has approved the use of LBB, as allowed by an amendment to General Design Criteria 4, in License Amendment Nos. 107 and 93 for North Anna Units 1 and 2, respectively. The amendment to General Design Criteria 4 of Appendix A to 10 CFR 50 dated October 27, 1987, permits the use of LBB on the primary coolant pipe and allows the removal of the pipe rupture restraints and shields designed to mitigate the effects of primary coolant loop breaks. Thus, the dynamic effects associated with postulated ruptures of the reactor coolant loop piping are excluded from the design basis.

For analyzed piping in the containment other than primary coolant loop pipe, break location and orientation criteria are as stated in Section 3A.32, defining the extent of compliance with Regulatory Guide 1.46. Stress analysis of this piping (designed to ANSI B31.7-1969) is based on criteria and procedures specified in the ASME Boiler and Pressure Vessel Code, Section III-1971, which satisfies all the requirements of B31.7-1969.

3.6.2.5 **Methods of Analysis**

Analyses were performed for pipe impact and jet impingement. In addition, major equipment supports were analyzed to ensure adequacy under postulated pipe rupture loads transmitted by attached piping.

For the purpose of design, unless otherwise stated, the pipe break event is considered a faulted condition, and the pipe, its restraint or barrier, and the structure to which it is attached are designed accordingly.

For plastic deformation in code-related components, calculations comply with ASME Section III (1971), Paragraph NB-3225. Restraints and energy-absorbing materials that require plastic deformation are based on 50% of ultimate strain and 50% of material capacity, respectively.

The forces associated with both longitudinal and circumferential ruptures are considered in the design of supports and restraints to ensure continued integrity of vital components and engineered safety features. The break area for both postulated break types is the cross-sectional area of the pipe. The break length for the postulated longitudinal break is assumed equal to twice the pipe diameter.

The analysis takes advantage of limiting factors on the blowdown thrust force, such as line friction, flow restrictors, pipe configuration, etc.

3.6.2.5.1 Jet Impingement Forces

Calculation of the total jet force from a postulated rupture is based on Moody's theoretical model (References 1, 2 & 3) and Fauske's experimental data (Reference 4). It is assumed that the retarding action of the surrounding air on the jet is negligible, and the total jet force is constant at all locations. The jet impingement pressure on a distant object is computed by assuming that the jet stream expands conically at a solid angle of 20 degrees.

For impingement normal to a surface, the jet impingement force on a distant object is equal to the product of the jet impingement pressure and the intercepted jet area. If the object intercepts the jet stream with a curved or inclined surface area, the drag force between the jet and the object is used as the jet impingement force.

3.6.2.5.2 Jet Thrust (Forcing Function)

Because the energy balance model was used in the pipe whip restraint analysis, a steady-state jet thrust was used. The value of the force was:

$$F = PA$$

where:

P = design pressure
A = pipe area

Present criteria require amplification factors of:

1. 1.25 for saturated steam, water, and steam/water mixture.
2. 2.00 for subcooled water (nonflashing).

Although these amplification factors were not used, the restraint designs are adequate, since:

1. The above amplification factors are ideal theoretical values. In practice, friction reduces their value.
2. The amplification factors are for long-term steady state. During the period of pipe acceleration and restraint impact, the force has not built up to the above values. As the peak reaction loads during impact are well in excess of the above forces, the restraints will support these forces when they finally build up to steady-state values.
3. The restraints as designed have a large margin of safety because the permissible limits on strain have not been approached.

For the main steam and feedwater restraints, samples of lumped parameter dynamic analyses indicated that no forcing function multiplier is required to account for rebound. A detailed analysis for a main steam line restraint justifying this position is given in Section 3.6.3 below. For all other pipe rupture restraints designed by the energy balance method, a multiplier of 1.2 was used to establish the magnitude of the forcing function.

3.6.2.5.3 Summary of Results of Analyses

A summary of the analyses is provided in Reference Drawings 1 through 4 and Figures 3.6-1 through 3.6-12.

All restraints are designed to constrain pipe motions in all directions except parallel to the axis of the pipe. Drawings of typical main steam and feedwater pipe restraints are shown in Reference Drawings 1 and 2; the locations of these restraints are shown in Reference Drawings 3 and 4.

Fatigue cumulative usage factors were not calculated for the main steam and feedwater lines. The break locations were postulated on the basis of stress using the criteria discussed in Section 3.6.3. These stresses are presented in graphical form in Figures 3.6-1 through 3.6-12.

3.6.2.5.4 Design of Pipe Whip Restraints

The restraints are designed with a gap sufficient to prevent interference with the normal thermal and dynamic motion of the lines. This permits the pipe to acquire kinetic energy, which must be dissipated upon impact into the restraint. This energy was conservatively set equal to the product of peak thrust force times displacement. No energy dissipation mechanisms operating prior to impact, such as plastic deformation in the pipe, were considered. Static, elastic-plastic analyses of the deformation of the restraints and bolts provided the force displacement characteristics of the restraints. The area (energy) under this force-displacement curve was matched to the kinetic energy of the impacting pipe to determine the deformation and the equivalent static load. In view of the conservatism of the energy input assumptions and the use of calculations that do not take credit for other energy dissipation mechanisms such as pipe deformation, this approach is conservative.

3.6.2.5.5 Equipment Supports

The internal structural system of the containment is designed to mitigate loading caused by rupture in the main reactor coolant lines and the main steam and feedwater lines. Incident rupture is considered in only one line at a time. The support system is designed to preclude damage to or rupture of any of the other lines as a result of the incident. The snubber and key systems are designed to transfer rupture thrusts on the steam generator to the internal structural system. The reactor, steam generator, pressurizer, and reactor coolant pumps supports are discussed in detail in Section 5.5.9.

3.6.3 Sample Problem

The original analyses of the main steam and feedwater pipe whip restraints inside the containment were based on the energy balance method. The results of those analyses indicated that the restraint which would be most highly deformed as a result of pipe impact was attached to the top of the crane wall near an elbow in a main steam line. The analytical method and results for this restraint are provided in Section 3.6.3.1. A new analysis, using a lumped-parameter analysis model, is also presented to prove that this “worst-case” restraint is satisfactory when analyzed to the new criteria.

The physical arrangement of the restraint and pipe is shown in Figure 3.6-13.

For a circumferential break at one end of the elbow, the pipe is thrust against the restraint, pulling it away from its embedment. A 1-inch gap between the pipe and restraint is ensured by the placement of shims while the pipe is in the hot position.

3.6.3.1 **Energy Balance Model (Original Method)**

The pipe-restraint interaction was analyzed using an energy balance method in which the work done by the blowdown thrust was equated to the strain energy of the deformed restraint. The solution provided the peak reaction load in the restraint and the strains in the component parts of the restraint.

The work done by the blowdown thrust is the product of force times distance:

$E_i = F(g + x)$

where:

E_i = energy input

F = blowdown thrust

g = pipe restraint gap

x = restraint deflection at impact point for the blowdown thrust

F = pA

where:

p = design pressure

$A = \pi r_i^2$ = break area

Thus:

$E_i = \pi P_o r_i^2 (g + x)$

where:

P_o = initial pressure

r_i = pipe inside diameter

This is shown in Figure 3.6-14 for several gap dimensions. Since shims were used to ensure a 1-inch gap between the restraint and the pipe in the hot position, only one of these curves is applicable to the actual design.

The basis for the energy absorption characteristics of the restraint was a multi-stage static stress analysis. The force-deflection properties of the restraint were determined using the mathematical model shown in Figure 3.6-15. Initially, all members were considered elastic, and a load was applied in the radially outward direction. The first region to yield was the arch structure at the point of load application. The restraining structure remained fully elastic up to 900 kips.

At yield, the mathematical model was modified by placing a pin at the node where the plastic hinge had formed. A moment, corresponding to the fully plastic moment across this section, was applied across the pin. This moment remained constant throughout the remaining analysis; strain hardening was not considered. The load applied to this model was gradually increased until the bolts holding the restraint to the embedment yielded at 1300 kips.

The mathematical model was again modified to reflect the plastic properties of these long stainless steel bolts. For the bolts, which deform in simple tension, strain hardening was considered. These are the only components in which strain hardening was considered during the analysis of all the restraints.

The result of this multi-stage analysis for a radially outward load applied to this main steam pipe whip restraint is the force-deflection curve of Figure 3.6-16. Other curves were derived in a similar manner for all the restraints. In each case, three loading conditions were considered: radially outward, tangential to the base, and outward at 45 degrees to the base.

By integrating the force-deflection curve, the strain energy-deflection relationship for this restraint was determined (Figure 3.6-17). Superimposed on this figure is the energy input curve for a 1-inch gap, as shown in Figure 3.6-14. From this graphical presentation, it is readily seen that the energy absorbed by strain energy in the restraining structure equals the energy input by the blowdown thrust at a deflection of 1.6 inches. For this deflection, the maximum strain in the arch portion of the restraint is 0.004, and 0.044 in the bolt. These are 2% and 10% of the uniform ultimate strain of the materials used in these two locations. This is well below the allowable limit of 50% of uniform ultimate strain, and indicates the large degree of conservatism even in this worst-case restraint.

3.6.3.2 **Lumped-Parameter Model**

The same restraint was reanalyzed using a lumped-parameter analysis model. The solution involved a three-step analysis. The first step determined the time history of the blowdown force. The next computed the local crushing resistance of the pipe at the restraint. The last step involved the elastic-plastic dynamic analysis of the pipe-restraint system.

3.6.3.2.1 Time-Dependent Blowdown Forces

The blowdown forcing function for use with the lumped-parameter elastic-plastic dynamic analysis was derived for the specific break being analyzed (Figure 3.6-18).

Steam was treated as an ideal, single-phase gas with a constant specific heat ratio (alpha) of 1.3. Except for the case of steady-state blowdown flow, the flow was assumed to be isentropic with negligible pipe friction for the prediction of the transient-state forcing function. A graphical characteristic method due to DeHaller (Reference 5) was used to construct the state (u, c) and physical (x, t) diagrams; the result was then used to calculate the forcing functions.

For the calculation of the steady-state blowdown forcing function, the friction losses, such as pipe friction, were taken into consideration.

Although the pipe has numerous bends and straight segments, it was regarded as straight pipe of total length L (which is the sum of lengths of the bends and straight segments) for the one-dimensional fluid mechanics analysis. The corresponding blowdown end reaction forces may be superimposed on the actual pipe layout to provide segmented time-dependent loads for pipe dynamic analysis.

The analysis of the transient-state forcing function was based on the method of characteristics. A general description of the method can be found in most gas dynamics textbooks (References 6 & 7). A graphical method by DeHaller was used to construct the state and physical diagrams for steam discharge via a pipe from the steam manifold. The details can be found in References 5, 6, and 7. The result was then used to calculate the transient-state forcing functions.

Immediately following the break, a decompressive wave travels into the pipe towards the manifold. The fluid in front of the wave is at a state:

$$u = o$$

$$C = C_o$$

where u = velocity of the fluid, C = speed of sound. The fluid state behind the wave is at the sonic condition, since the initial pressure was sufficiently high (Reference 8):

$$\frac{u}{C_o} = \frac{C}{C_i} = \frac{2}{\gamma + 1} = 0.8695, \text{ for } \gamma = 1.3$$

The blowdown force can be calculated as:

$$\frac{F_B}{P_o A} = \left[P + \frac{\rho u^2}{g}\right]\frac{1}{P_o} = \frac{P}{P_o} + \frac{\rho c^2}{gp} = \frac{P}{P_o} + \frac{\rho}{\rho_o}\left(\frac{c}{C_o}\right)^2 \frac{\rho \; C_o^2}{gp_o}$$

The pressure ratio across the wave is:

$$\frac{P}{P_o} = \left(\frac{T}{T}\right)^{\frac{\gamma}{\gamma - 1}} = \left(\frac{c}{C_o}\right)^{\frac{2\gamma}{\gamma - 1}} = \frac{2}{\gamma + 1}^{\frac{2\gamma}{\gamma - 1}} = 0.298$$

and the density ratio:

$$\frac{\rho}{\rho_o}\left(\frac{P}{P_o}\right)^{\frac{1}{\gamma}} = \left(\frac{c}{C_o}\right)^{\frac{2\gamma}{\gamma - 1} \bullet \frac{1}{\gamma}} = \left(\frac{c}{C_o}\right)^{\frac{2}{\gamma - 1}} = \left(\frac{2}{\gamma + 1}\right)^{\frac{2}{\gamma - 1}}$$

Therefore the blowdown force can be reformulated as:

$$\frac{F_B}{P_oA} = \left(\frac{2}{\gamma+1}\right)^{\frac{2\gamma}{\gamma-1}} + \left(\frac{2}{\gamma+1}\right)^{\frac{2}{\gamma-1}} \bullet \left(\frac{2}{\gamma+1}\right)^2 \bullet \gamma = (1+\gamma)\left(\frac{2}{\gamma+1}\right)^{\frac{2}{\gamma-1}} = 0.685(\approx 0.7)$$

For frictionless flow, the blowdown force is constant until a return signal from the pressure source reaches the break. The approximate duration for this initial blowdown force extends (Reference 3) from L_B/C_o to 1.6L/C. After that time interval, the fluid state at the exit changes gradually to its steady-state value.

When the wave reaches the manifold, it is reflected as a compression wave. The boundary condition at the pressure reservoir lies on the steady-state ellipse.

$$\left(\frac{C_i}{C_o}\right)^2 + \frac{\gamma-1}{2}\left(\frac{u_i}{C_o}\right)^2 = 1$$

which is the energy equation applying across the vessel to the pipe inlet.

The boundary condition for this case is:

$$T_o = T_i + \frac{u_i^2}{2Cp}$$

where i refers to the state at inlet to the pipe.

If the steady state is reached, the flow in the pipe is uniform, and if the pressure in the pressure vessel remains high, the boundary condition at the break always lies on the sonic line $\frac{u}{C_o} = \frac{c}{C_o}$. Then, from the critical flow condition,

$$\frac{u^*}{C_o} = \frac{c^*}{C_o} = \sqrt{\frac{2}{\gamma+1}} = 0.9325$$

and the steady-state blowdown force with $\frac{fL}{D} = 0$ is:

$$\frac{FB}{P_oA} = \frac{P^*}{P_o} + \frac{\rho^* u^{*2}}{g} = \frac{p^*}{p_o} + \frac{\rho^*}{\rho_o}\left(\frac{u}{c_o}\right)^2 \rho_o C_o^2 / P_o$$

$$= \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}} + \left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}} \bullet \left(\frac{2}{\gamma+1}\right) \bullet \gamma = (1+\gamma)\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}} \approx 1.255$$

In actual application, the friction loss is taken into account for predicting the steady-state blowdown force. For most cases, friction losses severely affect the steady-state blowdown thrust. A curve for steady-state blowdown with friction (Figure 3.6-19) was derived as follows.

Assuming a dimensionless pipe length $\frac{L_{max}}{D} \approx 54.0$ and with friction factor $f \approx 0.01$. Then:

$$\frac{fL_{max}}{D} \approx 0.54$$

The friction factor, f, is a function of two parameters:

1. Re - Reynolds number of the flow.
2. E/D - relative surface roughness of the pipe.

The effect of these two parameters on the friction factor for any kind and size of pipe can be found in the *Pipe Friction Manual* (Reference 9).

For a very high-flow Reynolds number, such as flowdown flow due to pipe rupture, the friction factor becomes constant for a given E/D. For a 30-inch i.d. commercial steel pipe, the relative roughness, E/D, is 0.00006; therefore f = 0.01.

From tables for Fanno (Reference 10) line with $\gamma = 1.3$, the inlet Mach number is:

$$M_i \approx 0.6$$

With inlet Mach number = 0.6, the stagnation pressure at the exit plane, where the flow is accelerated to a Mach number of unity due to friction effect, is:

$$\frac{P_o*}{P_o} \approx \frac{1}{1.193} \text{ or } P_o* \approx \frac{1,050}{1.193} \approx 880 \text{ psia}$$

and the critical pressure at the exit plane, where the flow is changed due to friction, is:

$$P* = \left(\frac{P*}{P_o*}\right)_{M=1} \qquad P_o* = 0.545 \times 880 = 480 \text{ psia} > 14.7 \text{ psia}$$

where $\left(\frac{P*}{P_o*}\right)_{M=1}$ was obtained from the isentropic flow table (Reference 10).

The blowdown force at the exit plane can be obtained from the impulse function of the table:

$$\frac{F_i}{F*} = 1.11$$

and the impulse function F_i is:

$$F_i = \left[P_1 + \frac{\rho_1 u_1 2}{g}\right] A = P_1 A(1 + \gamma M_1{}^2)$$

Therefore, the blowdown force is:

$$\frac{F_B}{P_oA} = \frac{F^*}{P_oA} = \frac{1}{1.11}\ \frac{P_1}{P_o}(1 + \gamma M_1{}^2) = \frac{0.7962}{1.11} \times [1 + 1.3 \times (0.6)^2] = .053$$

Repeated use of the above formulas results in the steady-state blowdown curve (Figure 3.6-19).

Based on the above analysis, the blowdown forcing function at bend number 1 was calculated (Figure 3.6-20). Since the line is fixed at the penetration, forcing functions at the other elbows were not needed to compute the pipe whip.

3.6.3.2.2 Local Pipe Indentation

The local stiffness of the pipe was obtained by means of a large-displacement, elastic-plastic analysis using the MARC program (Appendix II). MARC library Element 8, which was used in this analysis, is an isoparametric curved triangular shell element based on Koiter-Sanders shell theory. This shell element, developed by Dupuis (References 3, 11 & 12), is a generalization of shell elements derived from basic functions of polynominal form corrected by rational functions.

The nine degrees of freedom associated with each node are three global displacements and their six derivatives with respect to two Gaussian coordinates. MARC Element 14, used to obtain the beam deflection, is a simple, closed-section, straight-beam element. Six degrees of freedom, three global displacements and three rotations, are associated with each node. The elastic-plastic analysis follows the Prandtl-Rouss equations with isotropic strain hardening. The large-displacement analysis makes use of a Lagrangian (initial coordinate) frame of reference and, therefore, the fundamental stress and strain measures are Kirchoff stress and Lagrange strain.

Figure 3.6-21 shows this force-local indentation relation obtained from 31-element mesh, and that obtained from the 16-element mesh. The finer mesh produces a force-local indentation relation which is slightly less stiff. In general, refining the mesh size has this effect on stiffness. In the present example, the results do not differ significantly, and the application of the higher stiffness derived from the coarser mesh is conservative, since higher loads will be calculated.

When the pipe impacts on the restraint, the contact area is constant in length in the longitudinal direction (Figure 3.6-22), and propagates in the circumferential direction as the applied load increases. To stimulate this contact type of loading (with spreading load area):

1. Analyses were done for the pipe with several different loading areas.
2. Each loading was assumed to have a cosine distribution in the circumferential direction and a $q_o x^\gamma$ distribution in the longitudinal direction as shown in Figure 3.6-22 (γ may range $1.5 \leq \gamma \leq 1.8$).

The coordinate system and the mesh for the quarter of the pipe (A-B-C-D) is shown in Figure 3.6-23, with symmetric boundary conditions imposed along sides AB, BC, and CD.

For each different loading area, the nodal displacement in the loading direction (Z direction) was plotted against the increasing total load. A special loading (P_c) obtained from this figure is said to be the contact loading, which produces a contact area the same as this given loading area, when P_c minimizes the quantity e, where:

$$e = \sum \frac{\bar{Z}^* - Z^*}{\bar{Z}^*}$$

$Z^* = Z + W$

$Z = r\,(1 - \cos ø)$

is the distance of any point in the loading area (such as Q) to the vertex point (such as B)

W = the displacement of that point in the loading direction

$\bar{Z}^*$= average of Z^*

The average displacement ($\overline{W}$) for P_c is then obtained from the energy principle, i.e.,

$$Pc\overline{W} = \int_A p\ W\ d\ A$$

The (P_c, $\overline{W}$) pairs obtained for different loading areas can then be plotted to obtain the P-W curve for this pipe. To proceed further, the beam deflection, which can be obtained by using MARC library Element 14, may be subtracted from $\overline{W}$ to obtain a force-local deformation relation for the pipe (Figure 3.6-24). An element with these properties was used to join the beam-element pipe with the restraint in the lumped-parameter analysis model.

It is somewhat easier to understand the physical significance of the quantity “e,” as used above, if a simpler geometry is examined. Consider the deformation of a pipe forced against a rigid half-plane. The derivation of the force-deflection relation would be reasonably straightforward if the two-body problem with changing contact geometry could be handled by the computer code. However, only position-dependent pressure distributions may be applied in the MARC code. Thus, a pressure function with a distribution and magnitude that causes the pipe to become flat over a given area must be determined. The quantity “e” is a measure of the difference between the desired contact geometry (flat) and the calculated geometry resulting from an arbitrary pressure distribution. The objective is to minimize the error “e” by varying the pressure function. The procedure used to obtain the pressure-local deformation is as follows:

1. The pipe is first modeled with a constant loading area, and several different pressure distribution patterns are assumed.

2. The deformation of the pipe model with one of the pressure distributions is then computed as the magnitude of the pressure is increased by increments. For each load, the quantity “e” is calculated. This procedure is repeated for all assumed load distributions.
3. The total load, obtained by integrating the pressure over the loading area, and the average deformation are then calculated for the load distribution and magnitude that yields the smallest “e.” Thus, one point on the force-deflection curve is obtained.

This exercise is repeated for several loading areas to generate the total force-deflection relation. By subtracting the beam deflection from the total deformation, the local force-deformation relation is obtained.

3.6.3.3 **Lumped-Parameter Dynamic Analysis**

The mathematical model of the piping system is shown in Figure 3.6-25. Initially, the pipe is stressed by internal pressure, but remains in static equilibrium. This is simulated in the mathematical model by applying forces where the pipe is curved, such as at the elbows.

For a circumferential break, as the crack propagates, the load-carrying metal area of the pipe decreases so a force unbalance results. The load in the pipe at the break is assumed to drop linearly to zero in 1 millisecond. After the break, the forces exerted on the pipe by the fluid are determined by the time-dependent blowdown force. The force was applied to the mathematical model as shown in Figure 3.6-26.

Pipe motion following rupture is analyzed by the use of an elastic-plastic lumped-mass beam element computer code called LIMITA II, described in Section 3.7.2.7. The analysis is divided into two stages, the first being the free motion of the pipe through the gap. The mathematical model is then modified to include the restraint and the connecting member simulating the local crush resistance of the pipe.

The rebound of the pipe is determined by the sign of the force in the member connecting the pipe and restraint in the mathematical model. Therefore, the rebound effects are considered by connecting and disconnecting that member for impact and rebound, respectively. Most of the analyses that have been done indicate no rebound occurred.

The pipe positions before break and at maximum deflection are shown in Figure 3.6-26. The pipeline is plastic from joint 4 to joint 8. The velocity at the impact point is 30 ft/sec; the kinetic and strain energies of the pipe are 840 in.-kips and 228 in.-kips, respectively. After impact, the loading history of the pipe indentation member is shown in Figure 3.6-27. The impact point becomes hinged at 820 kips and the bolts yield at 1060 kips. The pipe displacement at the impact point reaches its maximum (1.35 inches at 1080 kips). It is noted that no rebound of this pipe occurred throughout this period. The maximum strains in the arch portion and in the bolts were 0.003 and 0.006, respectively, corresponding to 1.5% and 1.3% of uniform ultimate strain.

3.6.4 Bolt Strain Calculational Differences

The major factors leading to the large differences in bolt strains are:

1. The blowdown load assumed in the "energy" method is larger than that in the "exact" method. The force is assumed to be constant at its initial (maximum) value. "Exact" methods use time-dependent, generally decreasing, force time histories.
2. In the energy method, it is assumed that the total system energy is absorbed by the restraint (mainly by the bolt), while the results of the "exact" method indicate that a significant amount of the energy is absorbed by pipe deformation.

3.6 REFERENCES

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13. Modification of General Design Criterion 4, Requirements for Protection Against Dynamic Effects of Postulated Pipe Ruptures, Federal Register, Vol. 51, No. 70, April 11, 1986 pp. 12502-12505.

14. Amendment to General Design Criterion 4, Broad Scope Rules, Federal Register, Vol. 52, No. 207, October 27, 1987.

15. *Technical Bases for Eliminating Large Primary Loop Rupture as a Structural Design Basis for North Anna 1 and 2*. WCAP 11163/11164 August 1986.

16. *Additional Information in Support of the Technical Justification for Eliminating Large Primary Loop Pipe Rupture as the Structural Design Basis for North Anna Units 1 and 2*. WCAP 11163/11164 Supplement 1, January 1988.

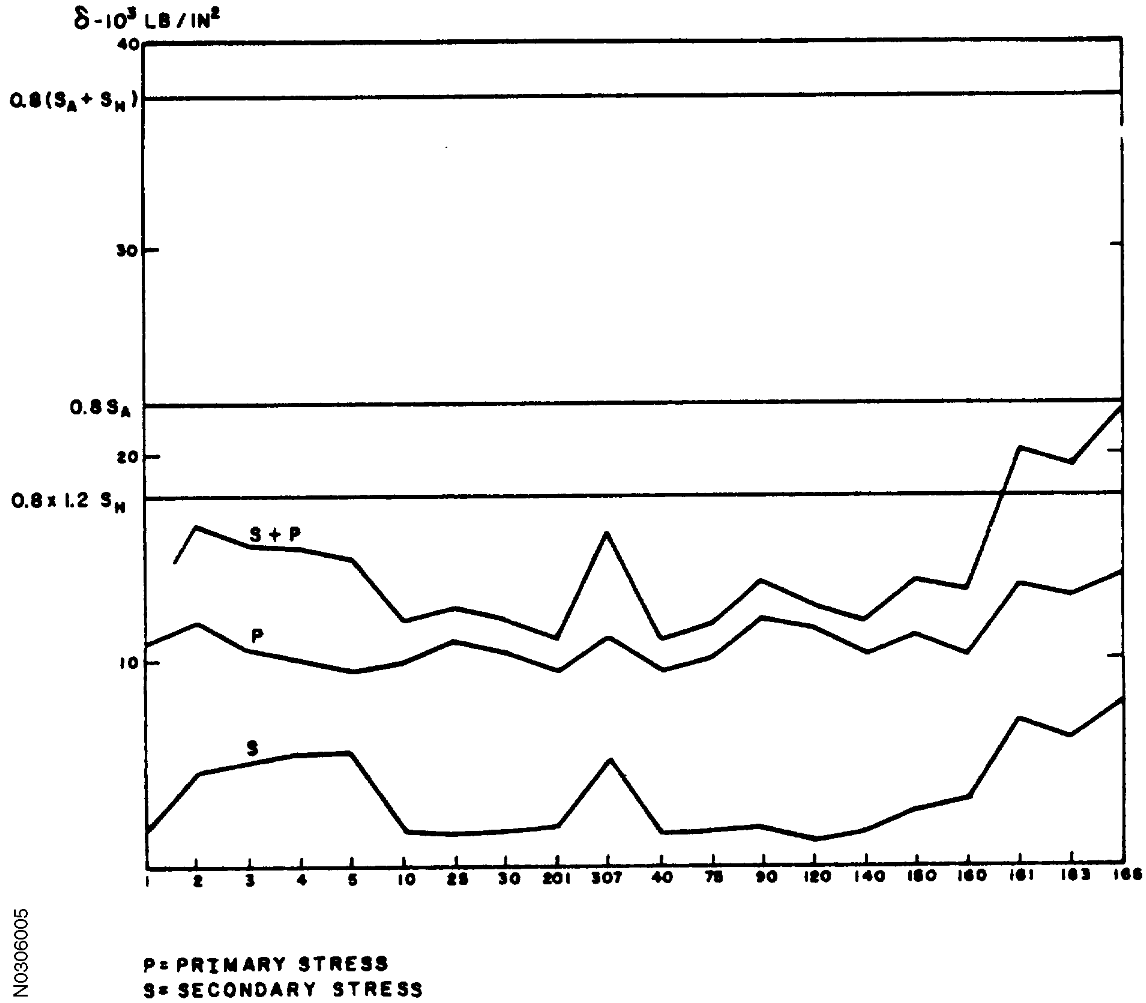
17. License Amendment Nos. 107 and 93 to Facility Operating License Nos. NPF-4 and NPF-7 for North Anna Power Station.

3.6 REFERENCE DRAWINGS

The list of Station Drawings below is provided for information only. The referenced drawings are not part of the UFSAR. This is not intended to be a complete listing of all Station Drawings referenced from this section of the UFSAR. The contents of Station Drawings are controlled by station procedure.

	Drawing Number	Description
1.	11715-FV-76B	Pipe Break Restraints, Main Steam Piping, Sheet 2
2.	11715-FV-77B	Pipe Break Restraints, Feedwater Piping, Sheet 2
3.	11715-FV-76A	Pipe Break Restraints, Main Steam Piping, Sheet 1
4.	11715-FV-77A	Pipe Break Restraints, Feedwater Piping, Sheet 1

Figure 3.6-1
MAIN STEAM LOOP A ANALYSIS: UNIT 1



N0306005

Figure 3.6-2
MAIN STEAM LOOP B ANALYSIS: UNIT 1

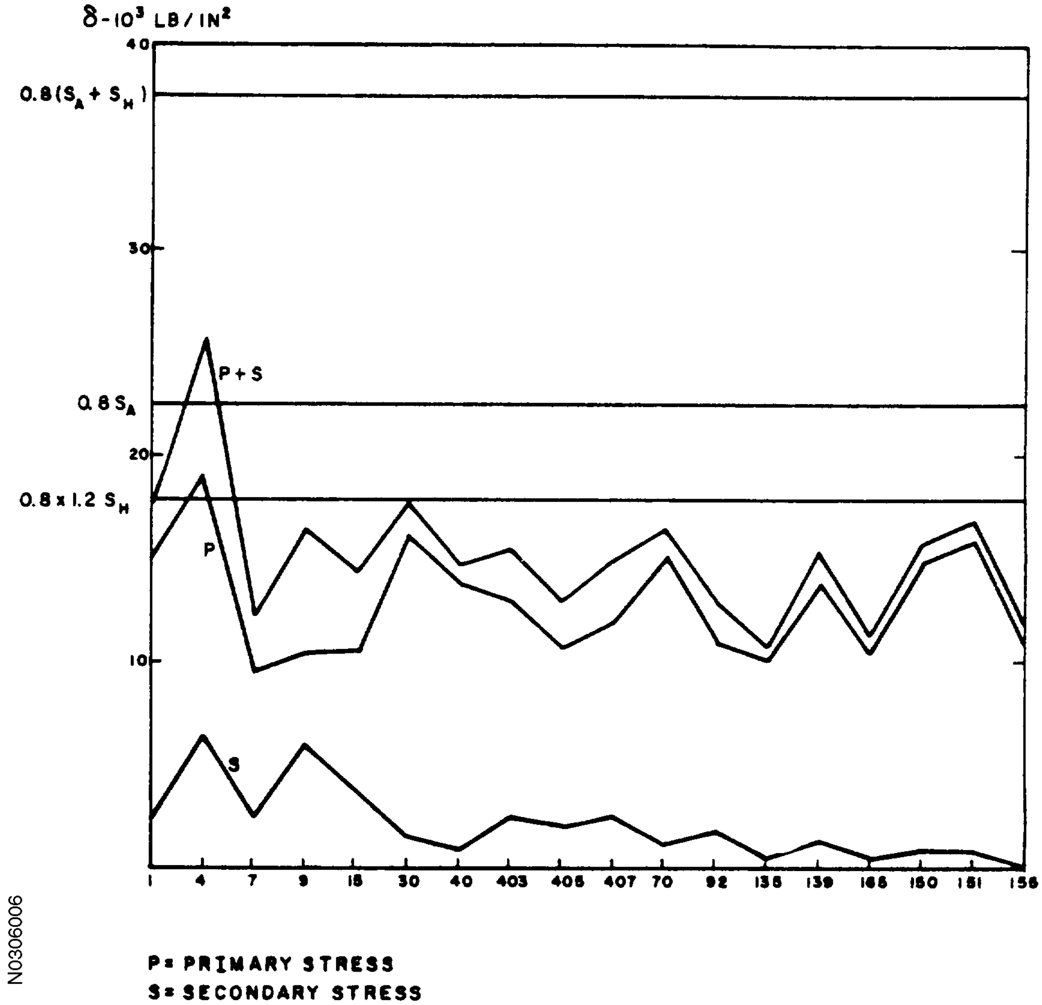


Figure 3.6-3
MAIN STEAM LOOP C ANALYSIS: UNIT 1

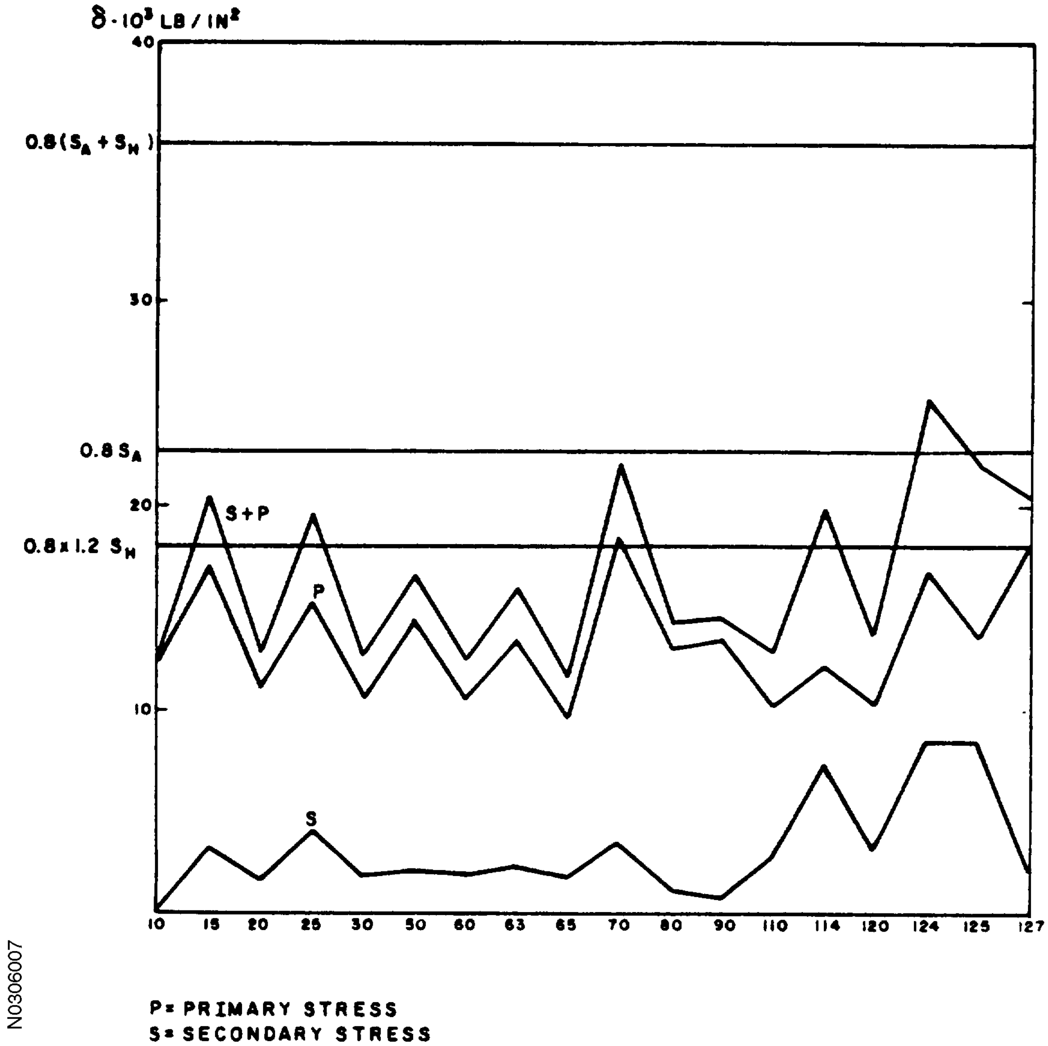
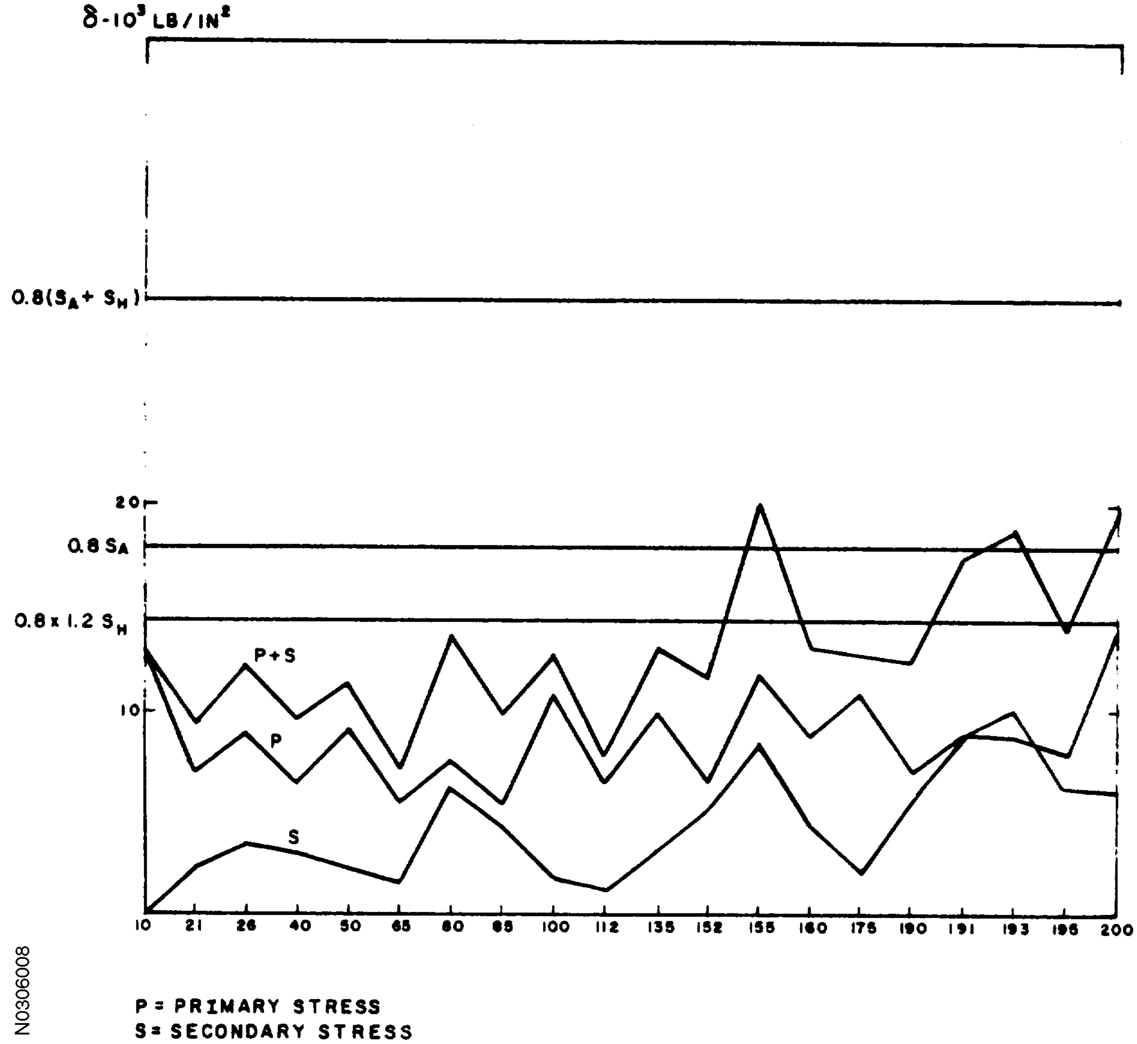


Figure 3.6-4
FEEDWATER LOOP A ANALYSIS: UNIT 1



N0306008

Figure 3.6-5
FEEDWATER LOOP B ANALYSIS: UNIT 1

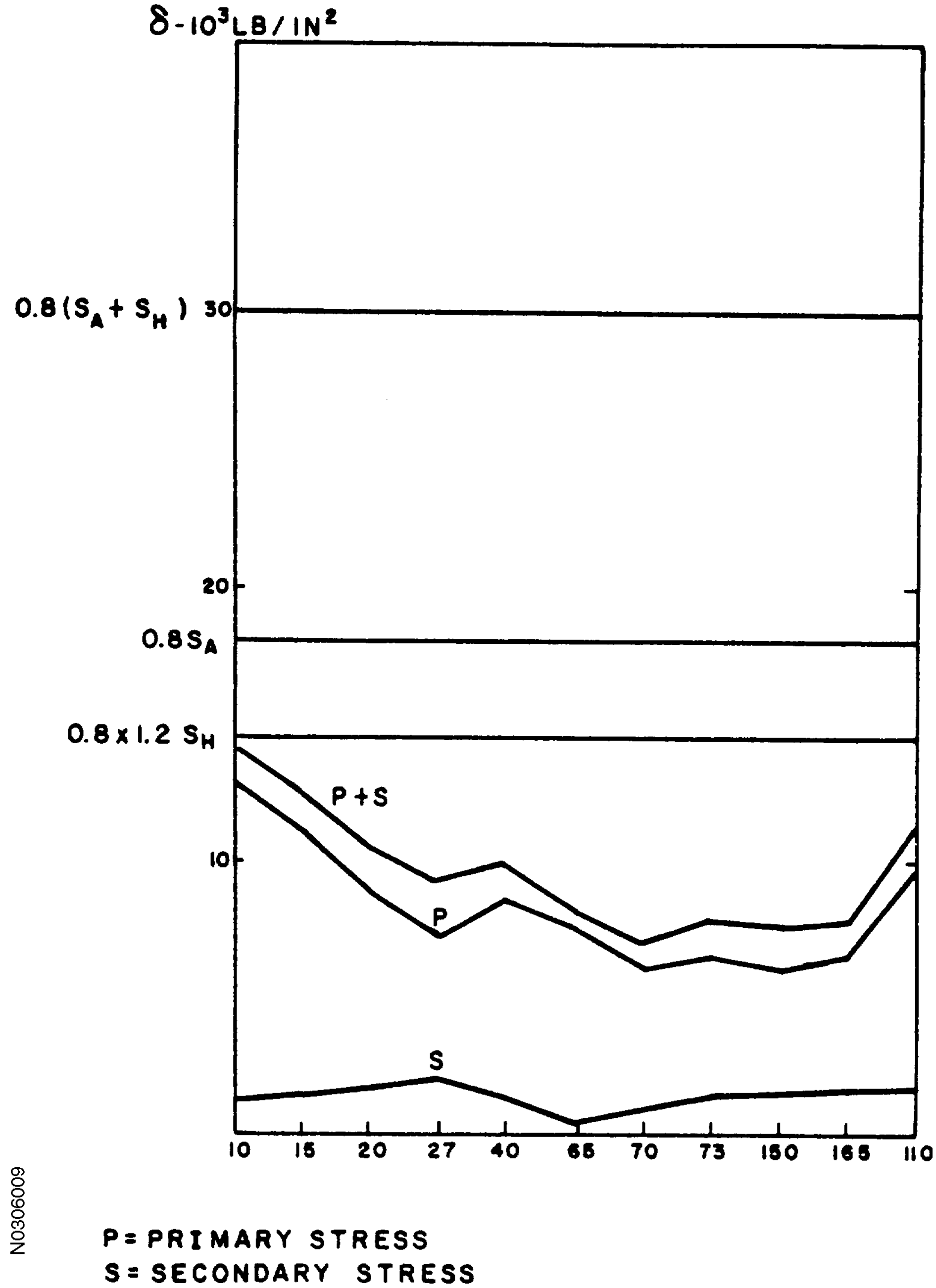


Figure 3.6-6
FEEDWATER LOOP C ANALYSIS: UNIT 1

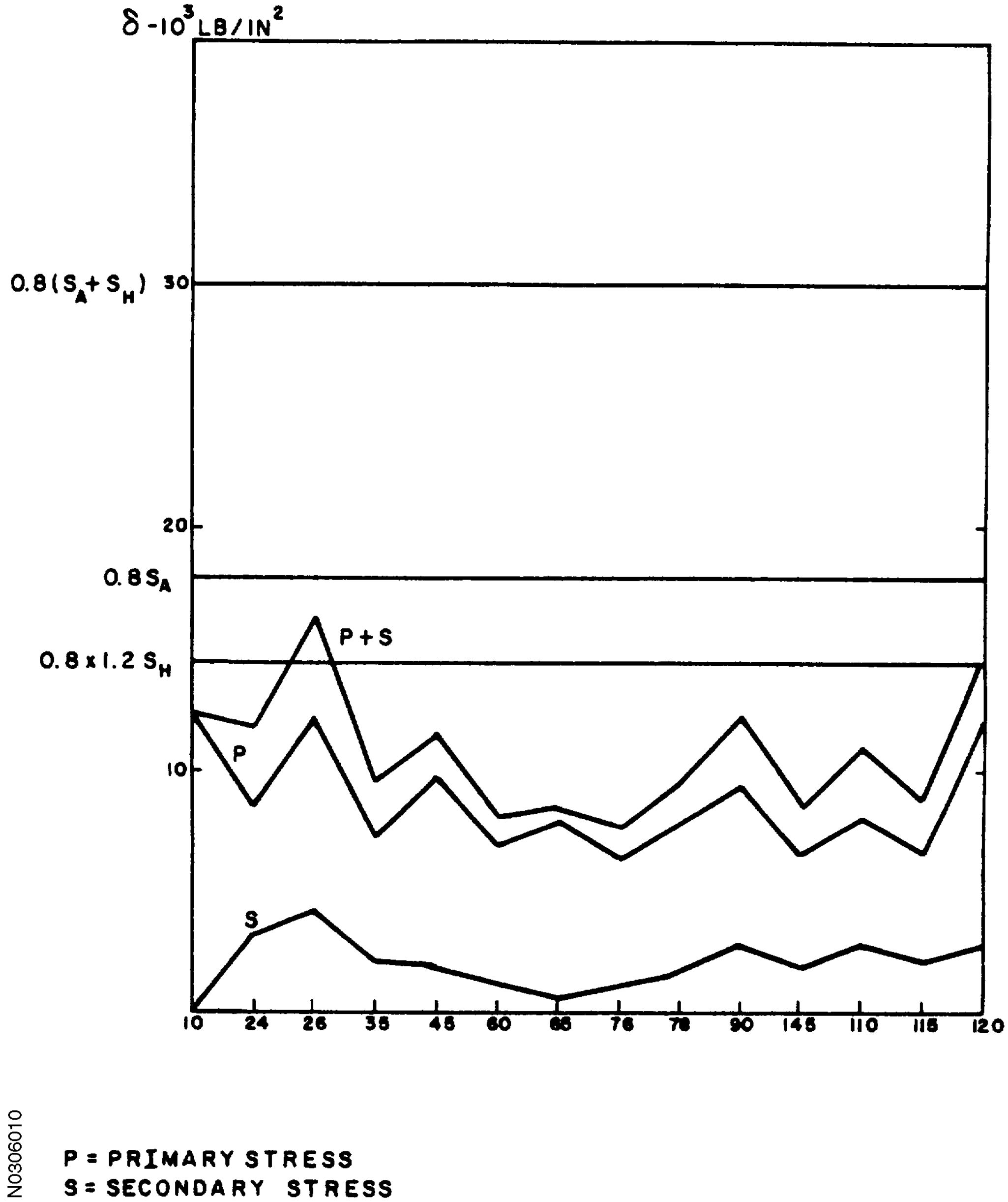


Figure 3.6-7
MAIN STEAM LOOP A ANALYSIS: UNIT 2

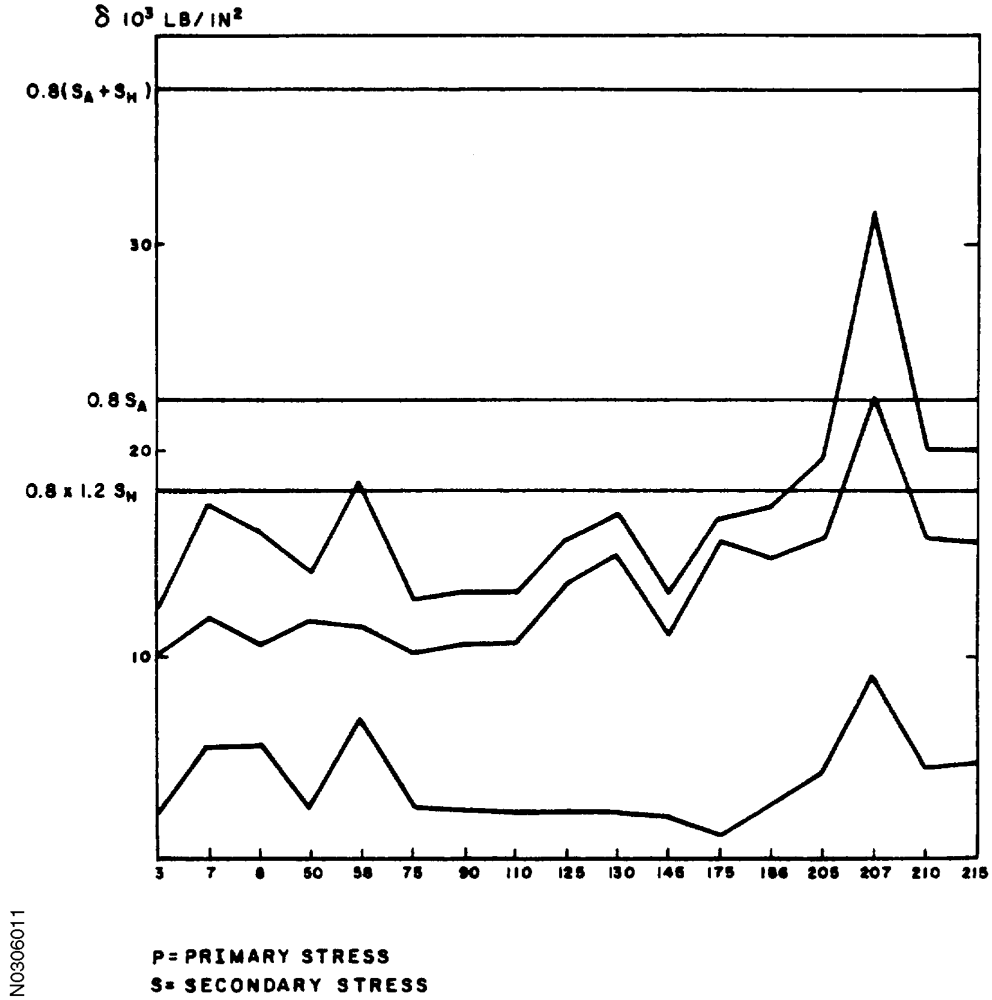


Figure 3.6-8
MAIN STEAM LOOP B ANALYSIS: UNIT 2

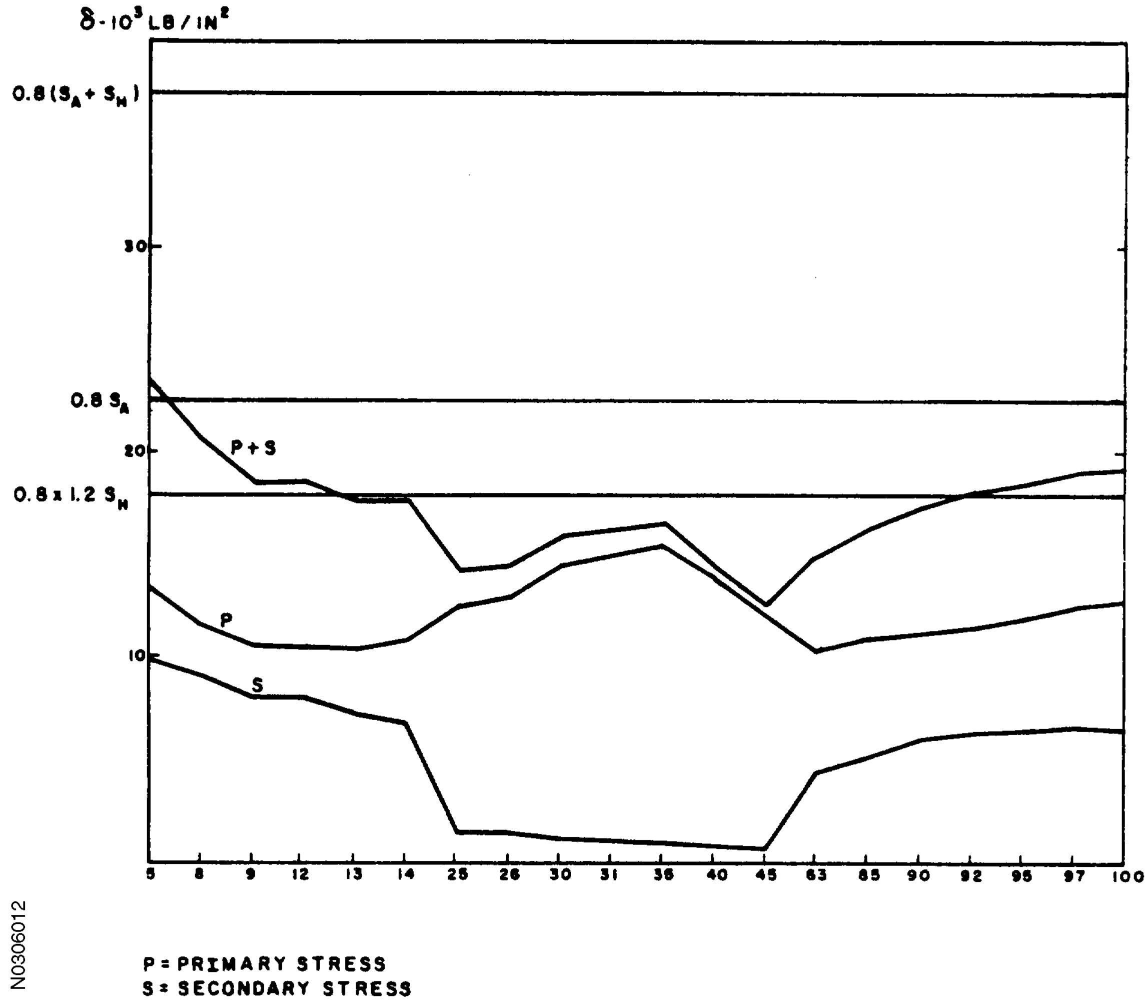


Figure 3.6-9
MAIN STEAM LOOP C ANALYSIS: UNIT 2

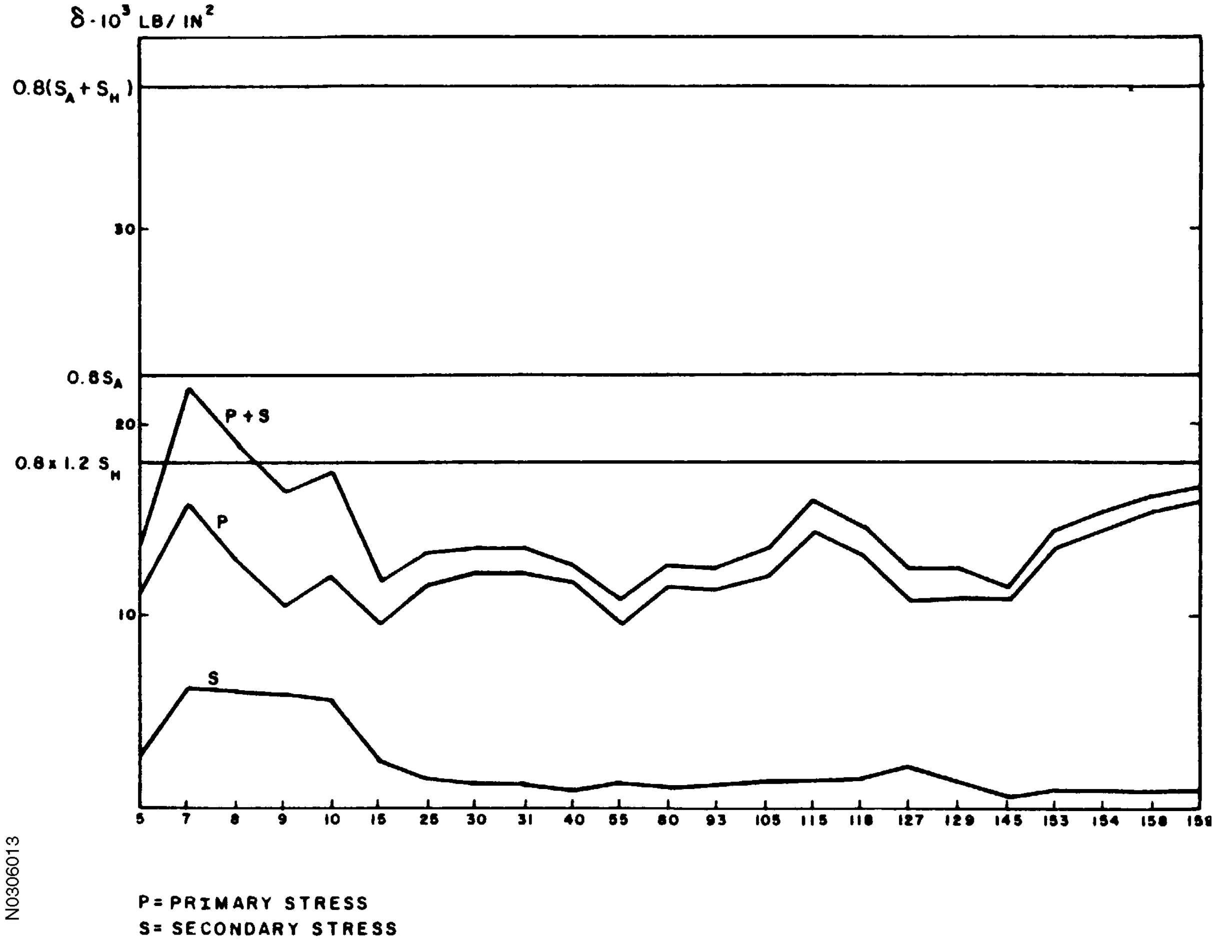


Figure 3.6-10
FEEDWATER LOOP A ANALYSIS: UNIT 2

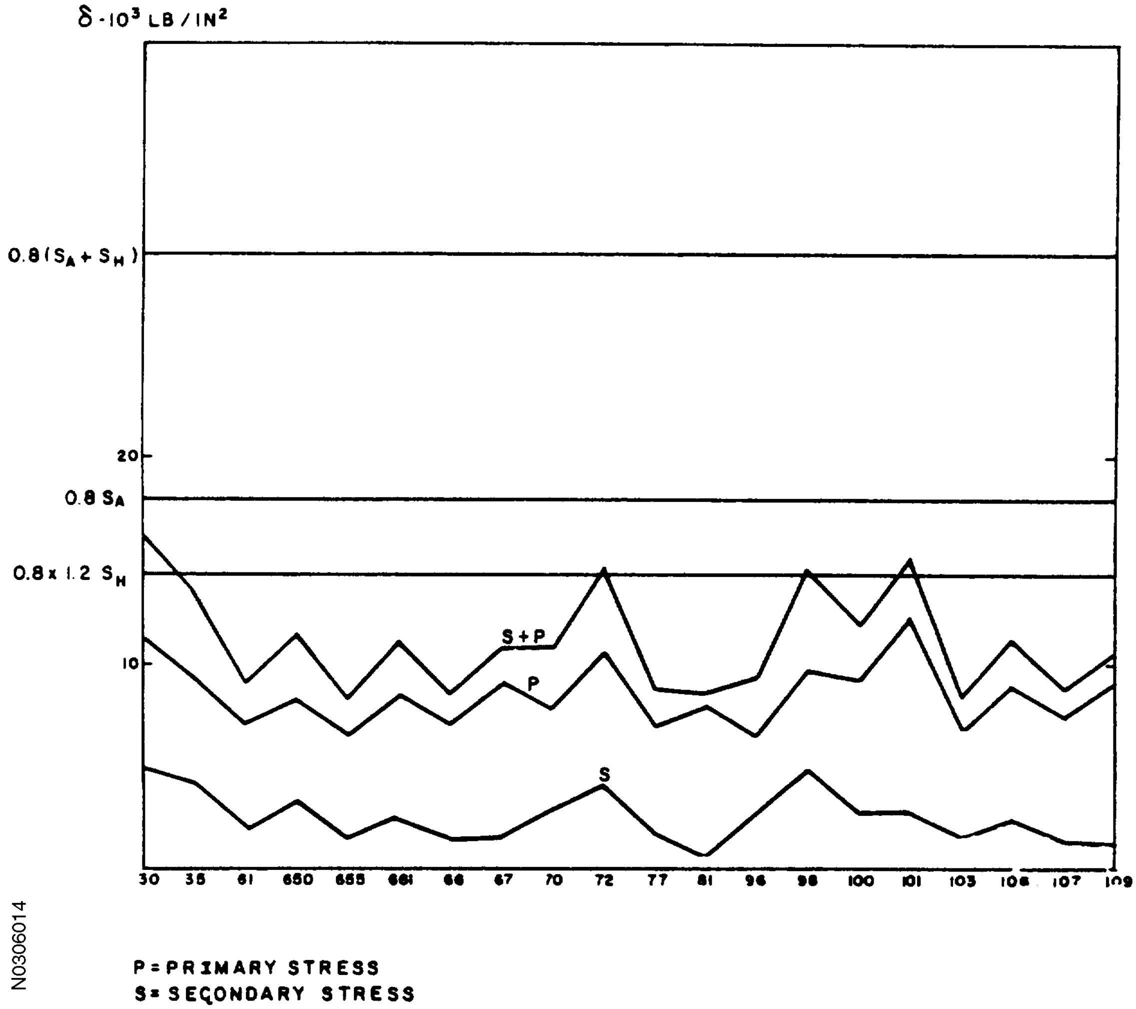


Figure 3.6-11
FEEDWATER LOOP B ANALYSIS: UNIT 2

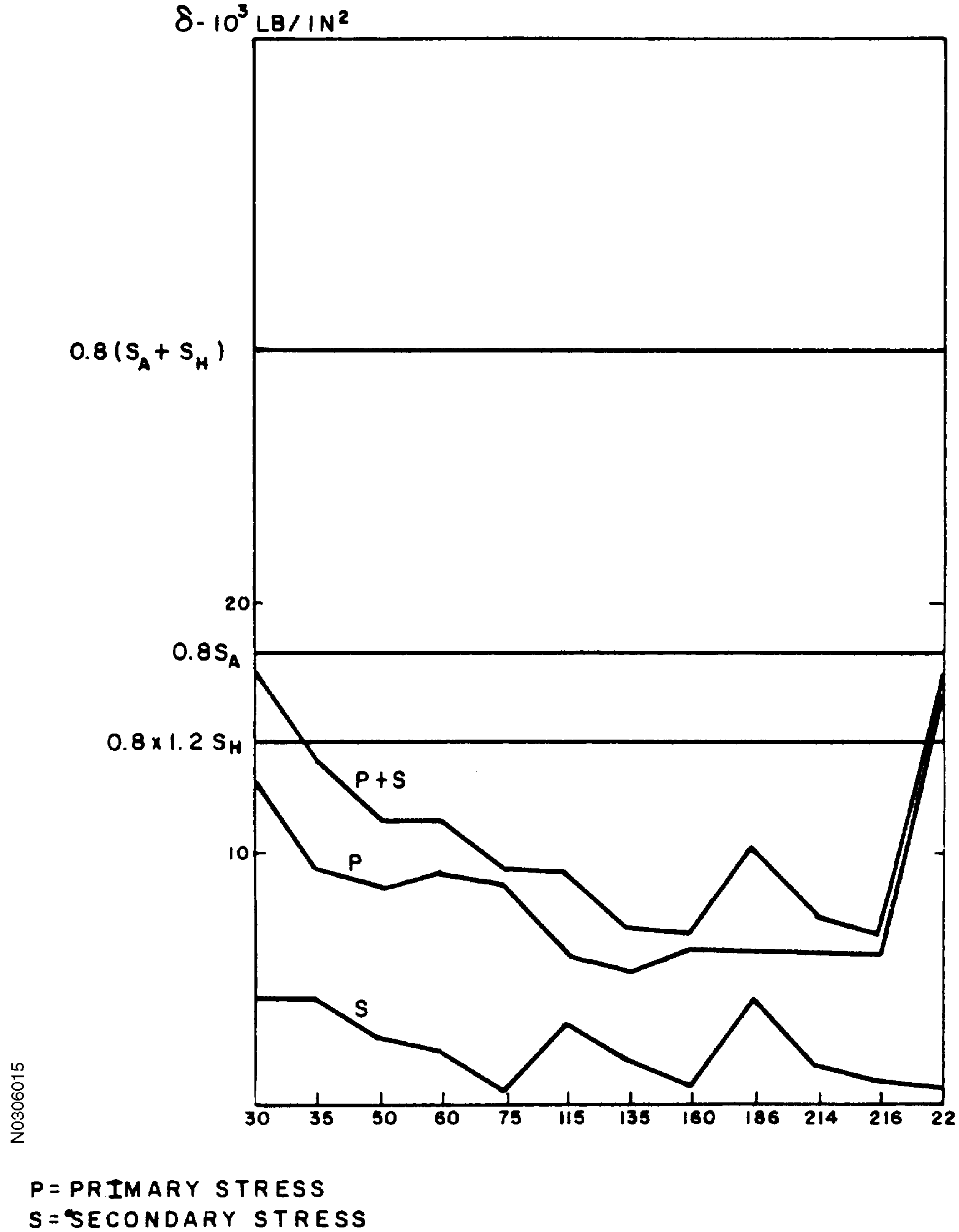
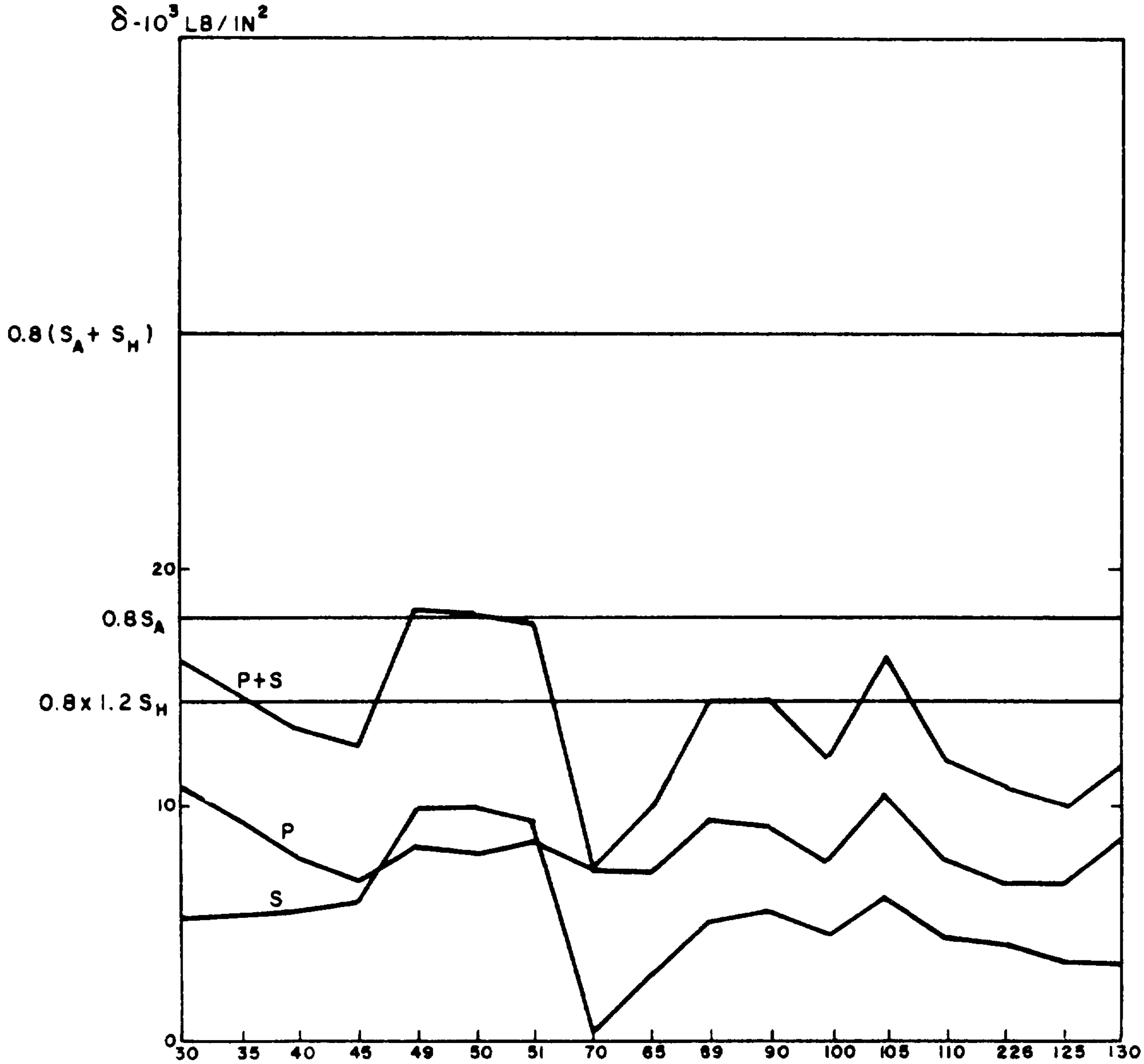


Figure 3.6-12
FEEDWATER LOOP C ANALYSIS: UNIT 2



P = PRIMARY STRESS
S = SECONDARY STRESS

N0306016

Figure 3.6-13
PIPE RESTRAINT SYSTEM

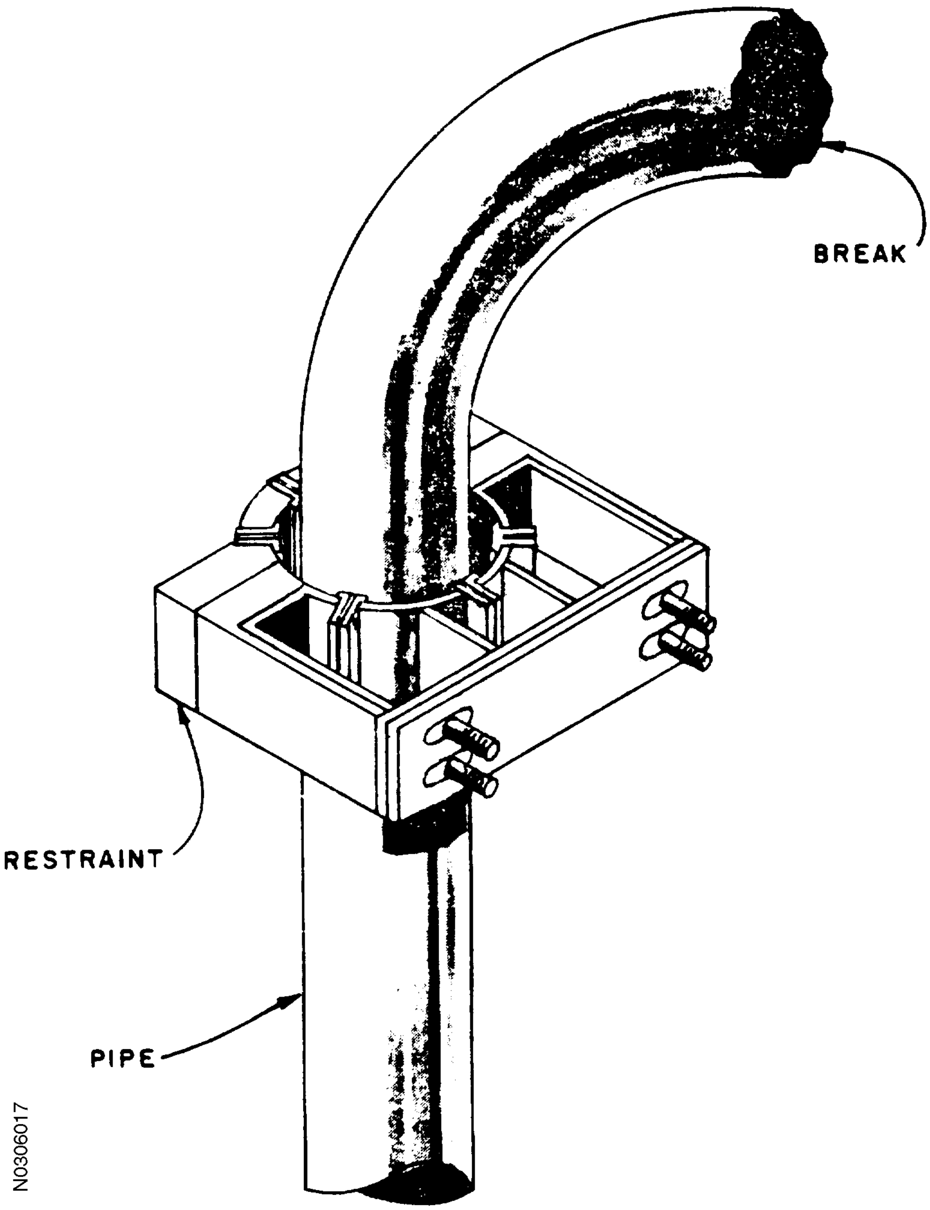


Figure 3.6-14
ENERGY FROM BLOWDOWN THRUST

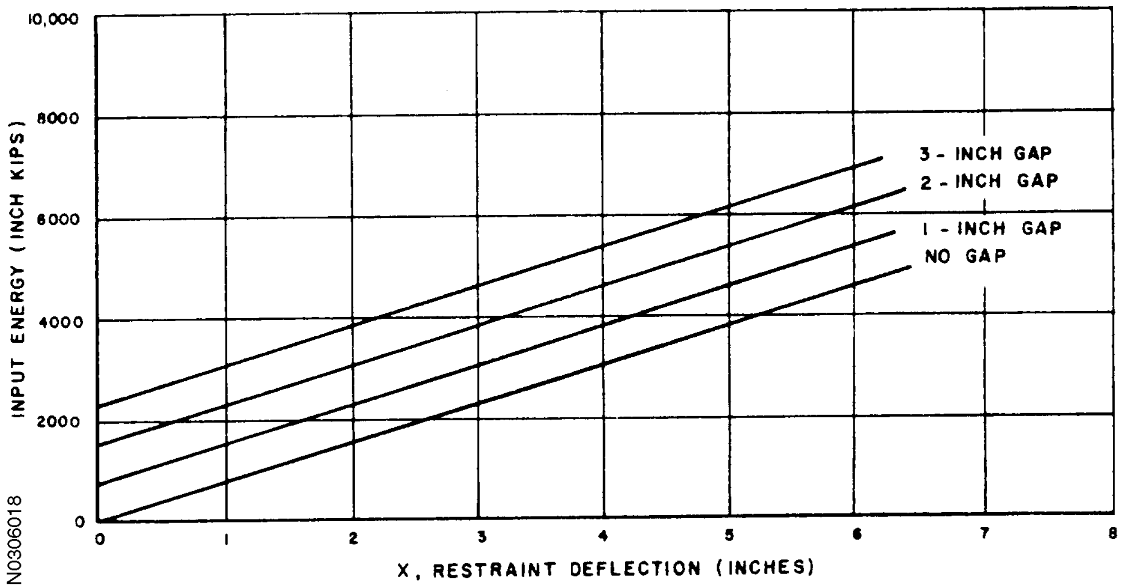


Figure 3.6-15
MATHEMATICAL MODEL OF 32 INCH PIPE WHIP RESTRAINT

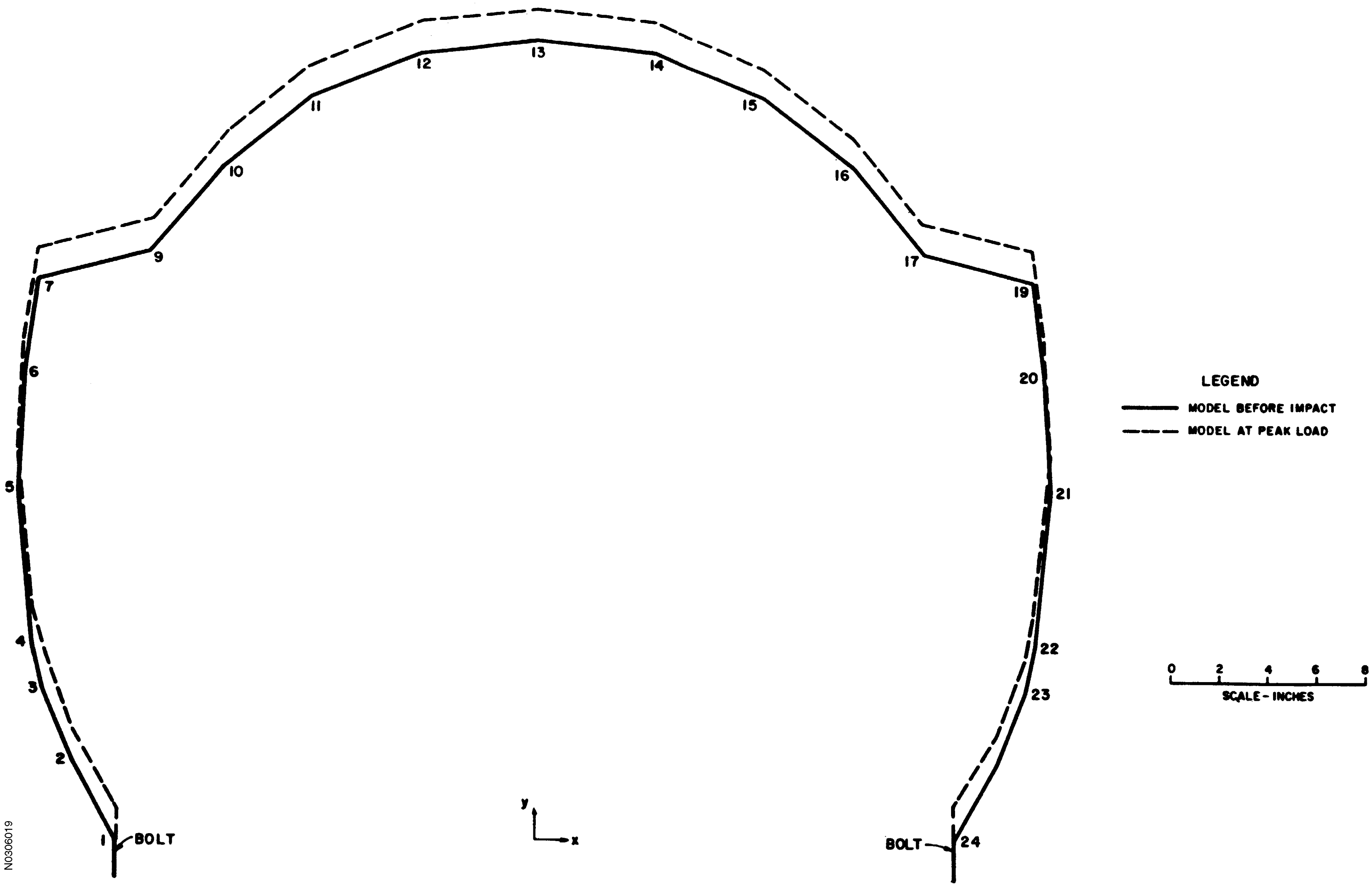


Figure 3.6-16
RESTRAINT REACTION RADIAL OUTWARD LOAD

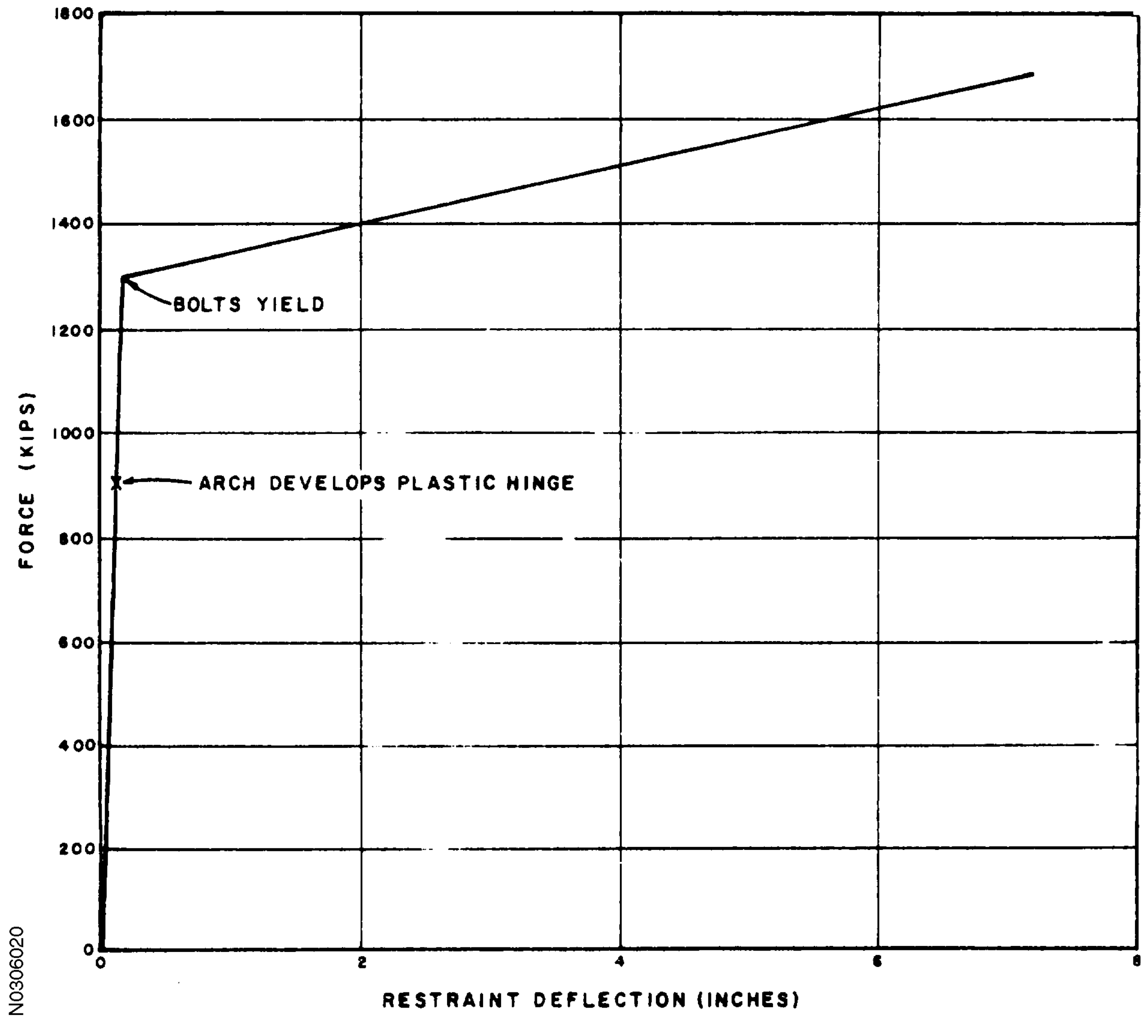


Figure 3.6-17
RESULTS OF ENERGY ABSORPTION METHOD

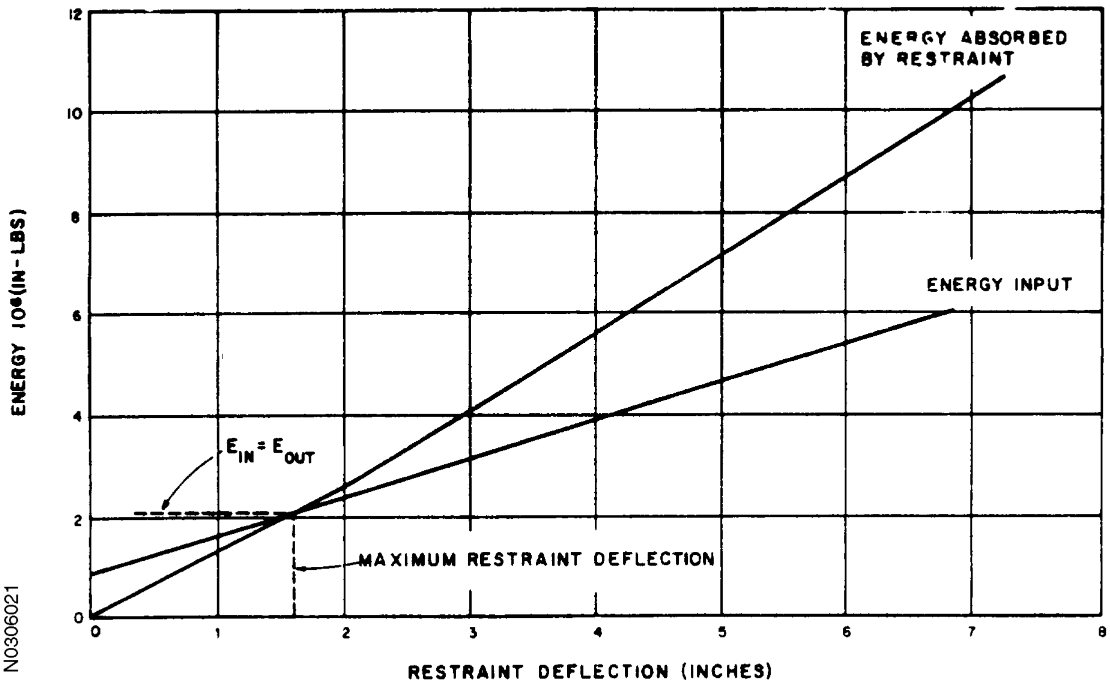
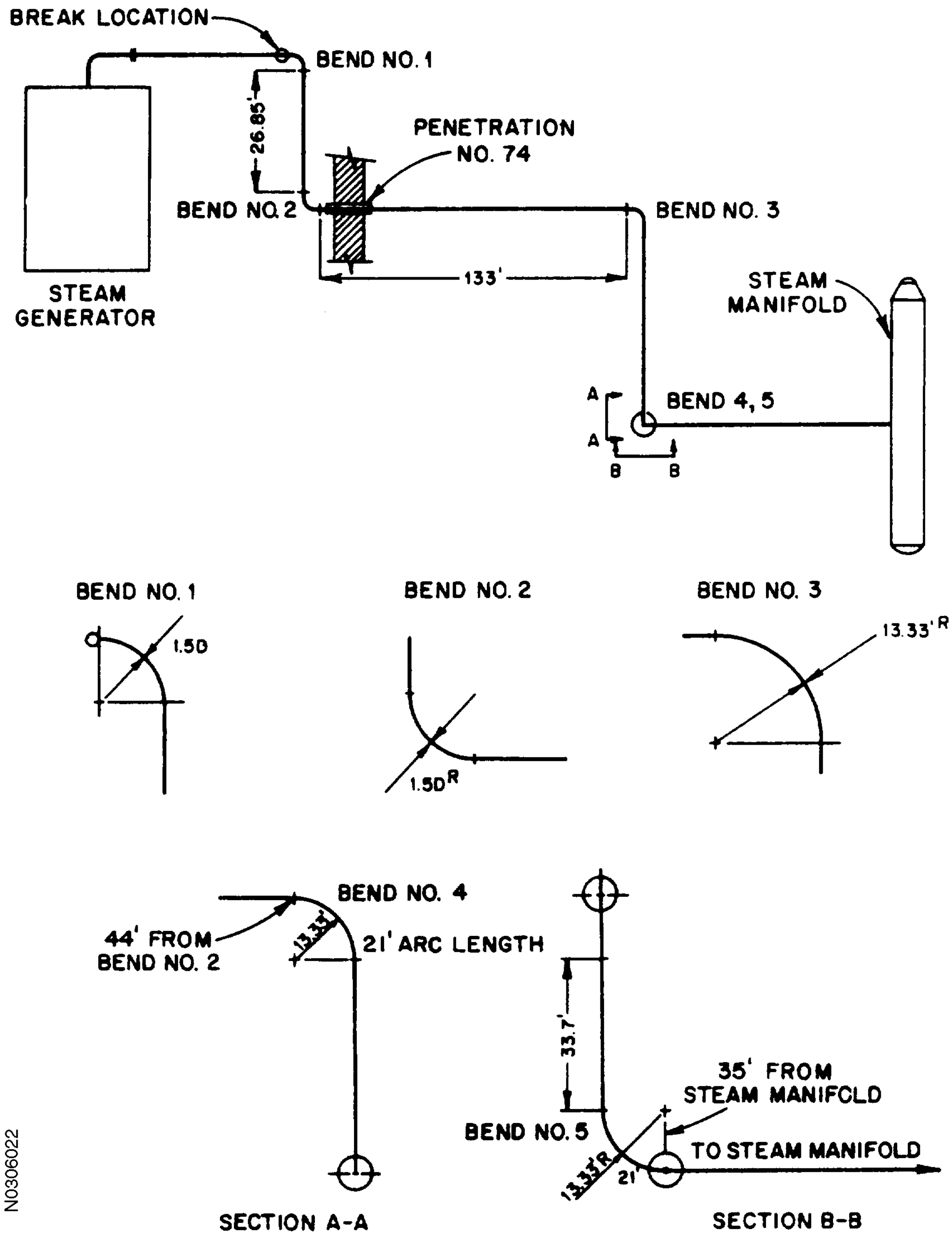
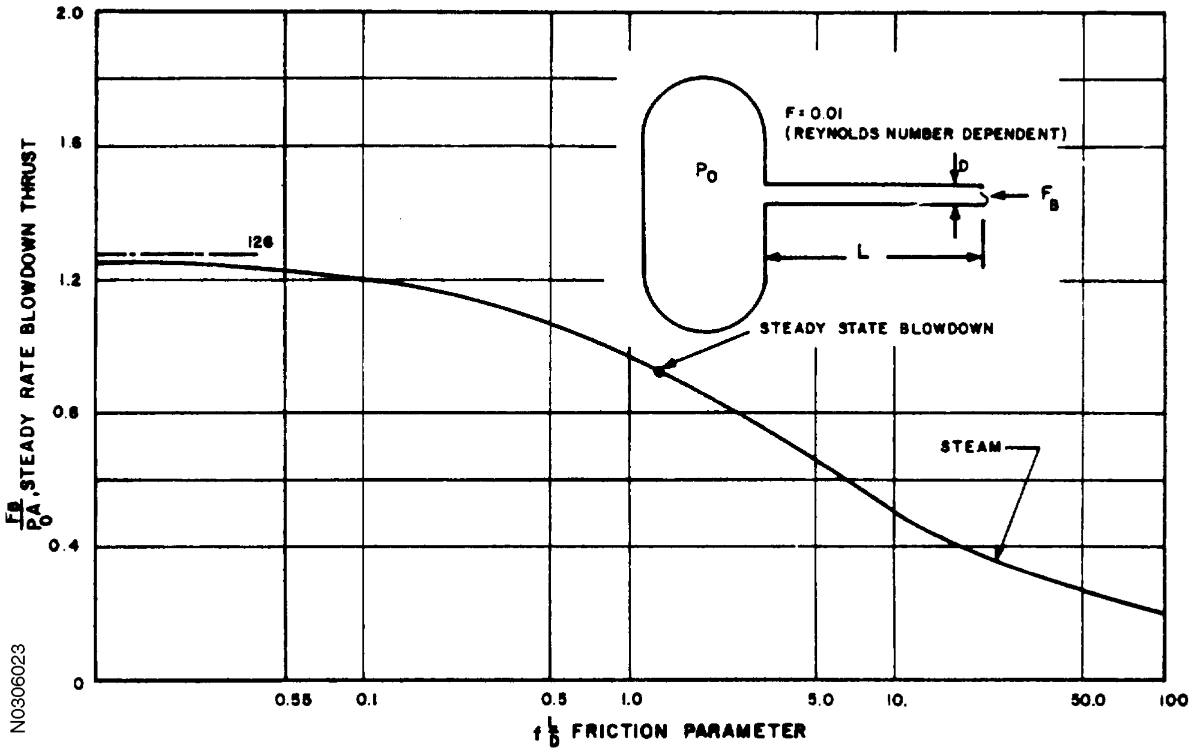


Figure 3.6-18
SCHEMATIC DRAWING OF STEAM LINE BREAK



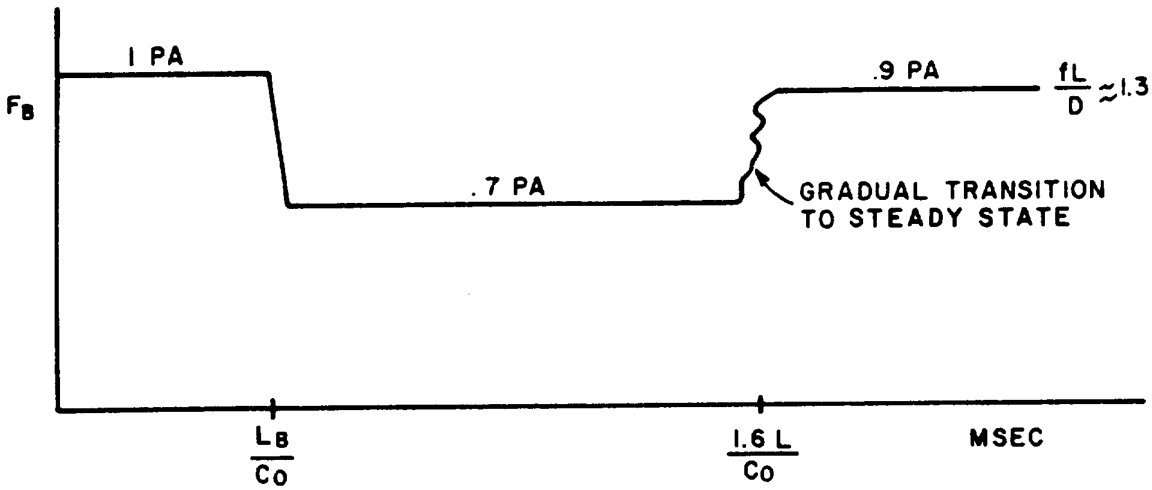
N0306022

Figure 3.6-19
THE STEADY STATE BLOWDOWN FORCES



N0306023

Figure 3.6-20
FORCING FUNCTION AT BEND NO. 1



L_B = LENGTH OF ELBOW

$$\frac{L_B}{C_0} = \frac{1.5 \times 2.5 \times \pi}{2\ (1000)} = 3.68 \text{ MSEC}$$

L = 326 FT. FROM BREAK LOCATION TO THE STEAM MANIFOLD

$$\frac{1.6L}{C_0} \approx 326 \text{ MSEC}$$

FRICTION PARAMETER $\frac{fL}{D} = \frac{.01 \times 326}{2.5} = 1.3$

(FOR THIS CALCULATION ELBOW LOSS WAS NOT CONSIDERED)

N0306024

Figure 3.6-21
FORCE: LOCAL INDENTATION RELATION

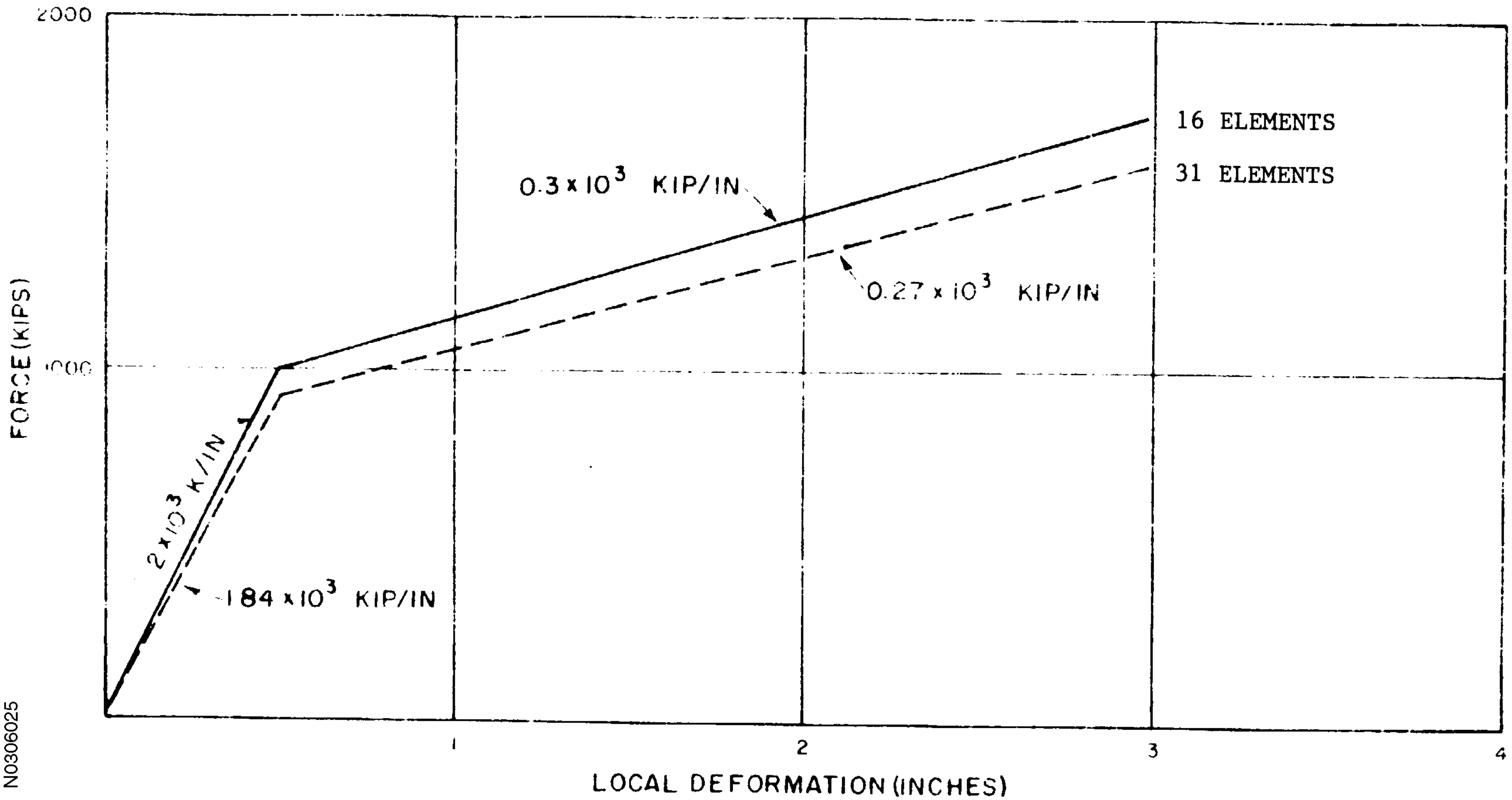
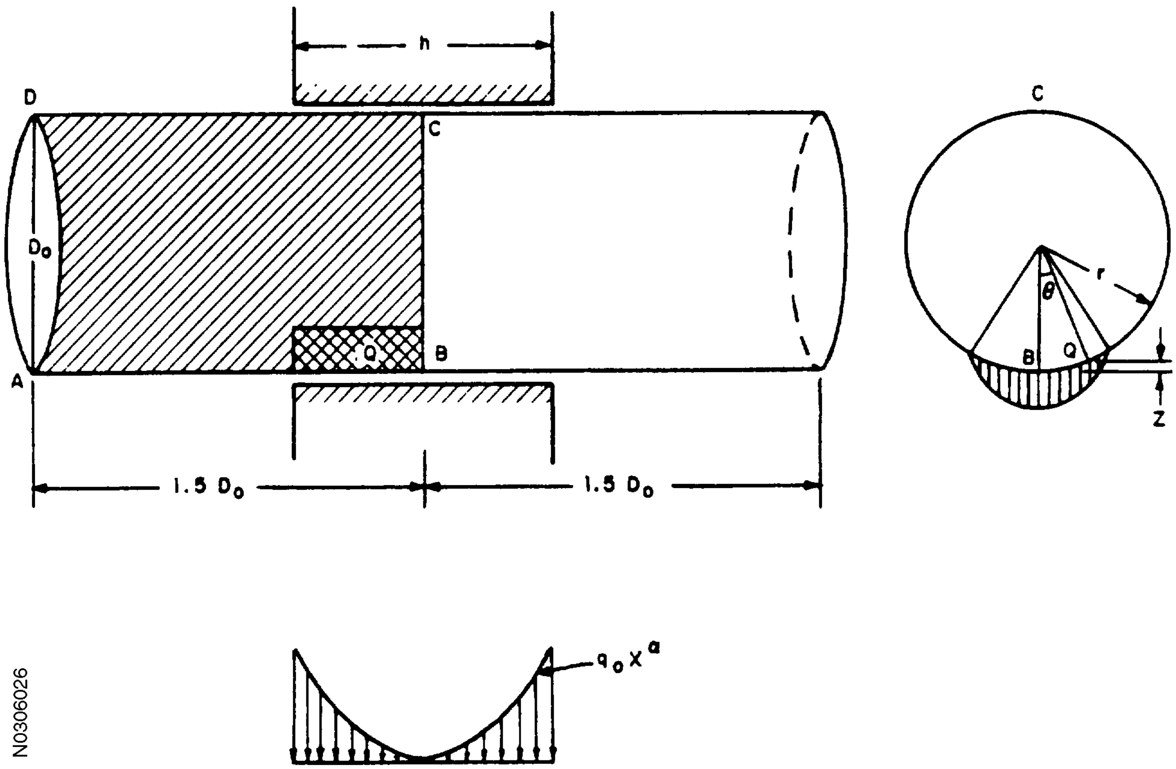


Figure 3.6-22
GEOMETRY FOR PIPE INDENTATION CALCULATION



N0306026

Figure 3.6-23
MATHEMATICAL MODEL FOR PIPE INDENTATION

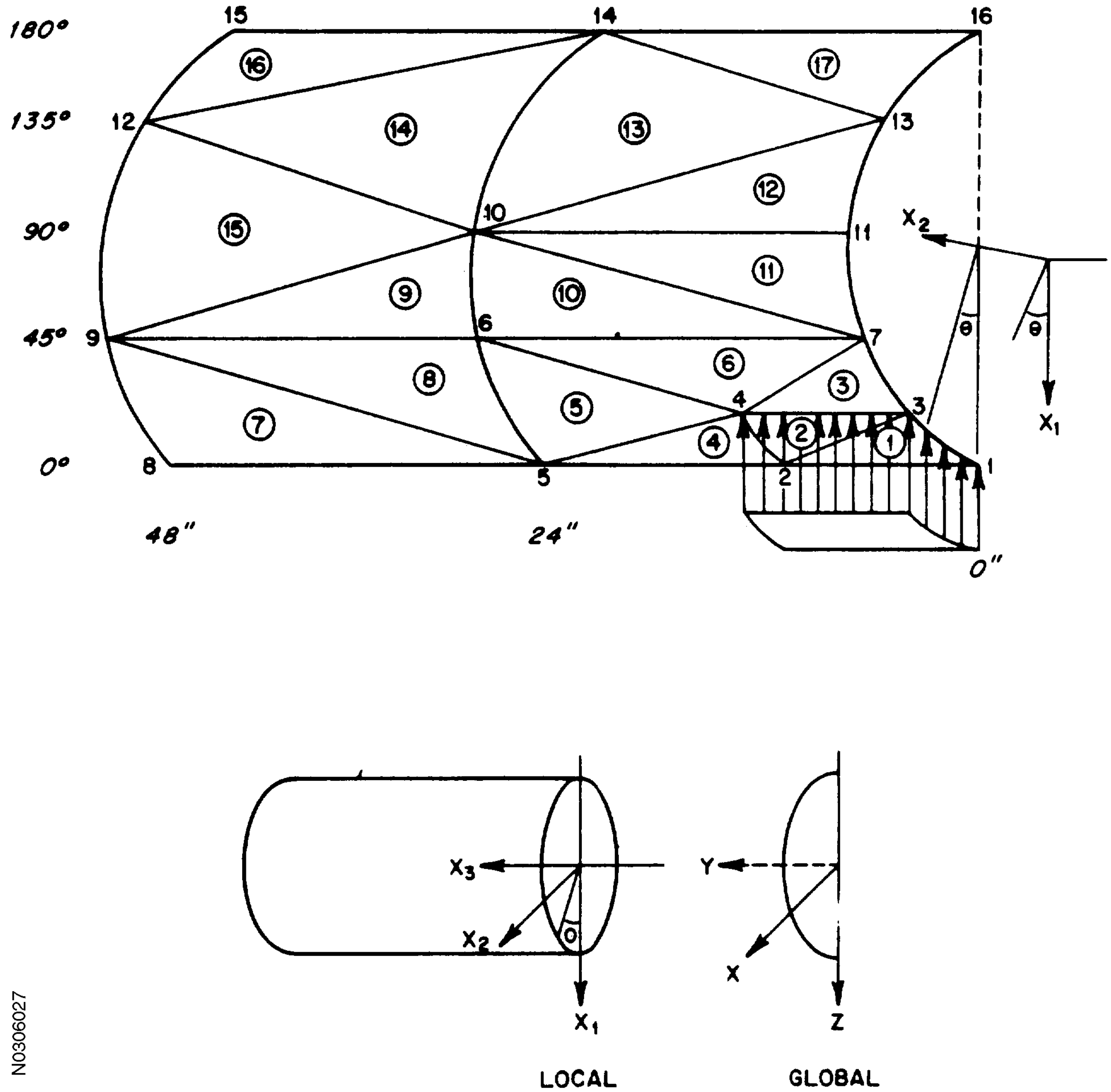


Figure 3.6-24
IDENTIFICATION STIFFNESS OF 32 INCH PIPE

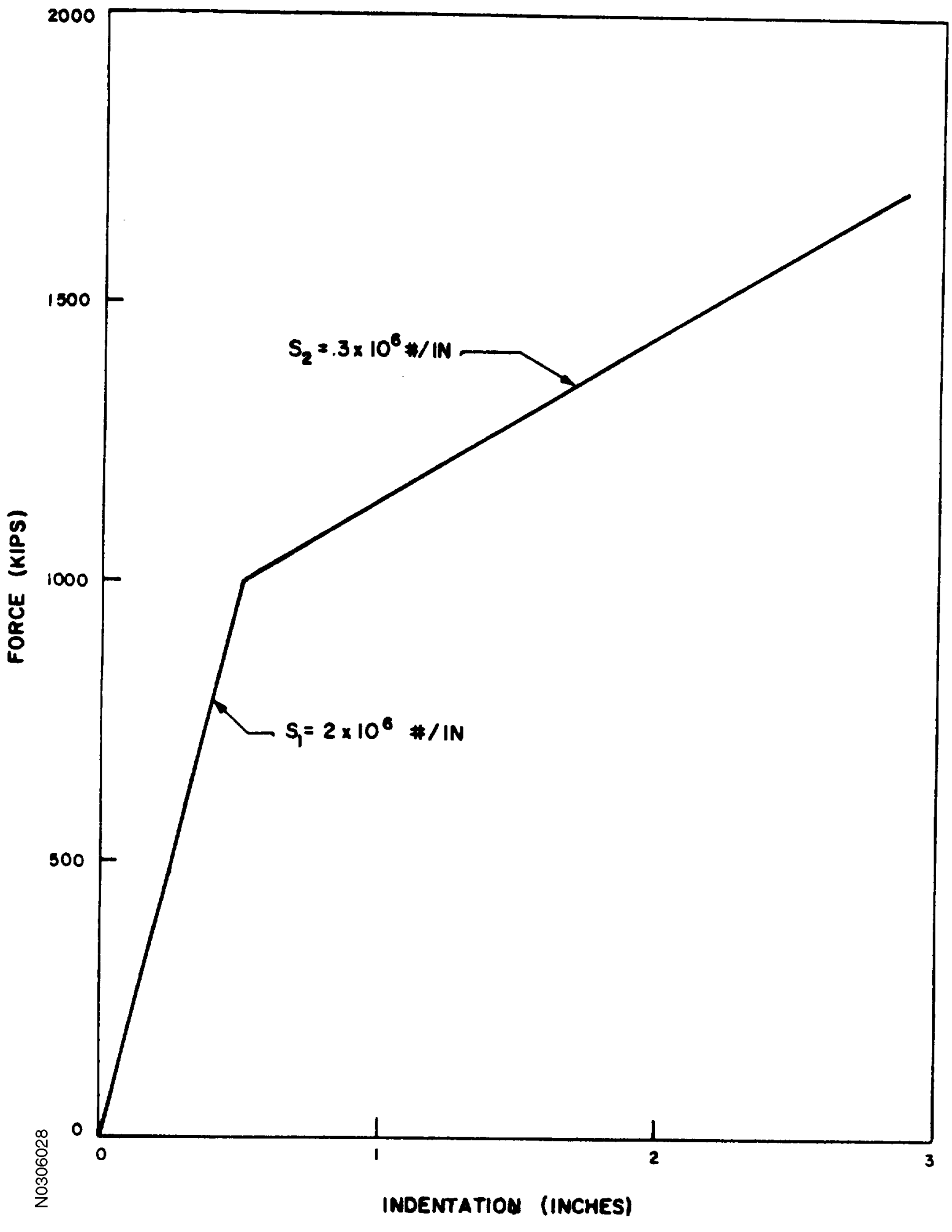


Figure 3.6-25
MATHEMATICAL MODEL OF PIPE AND RESTRAINT

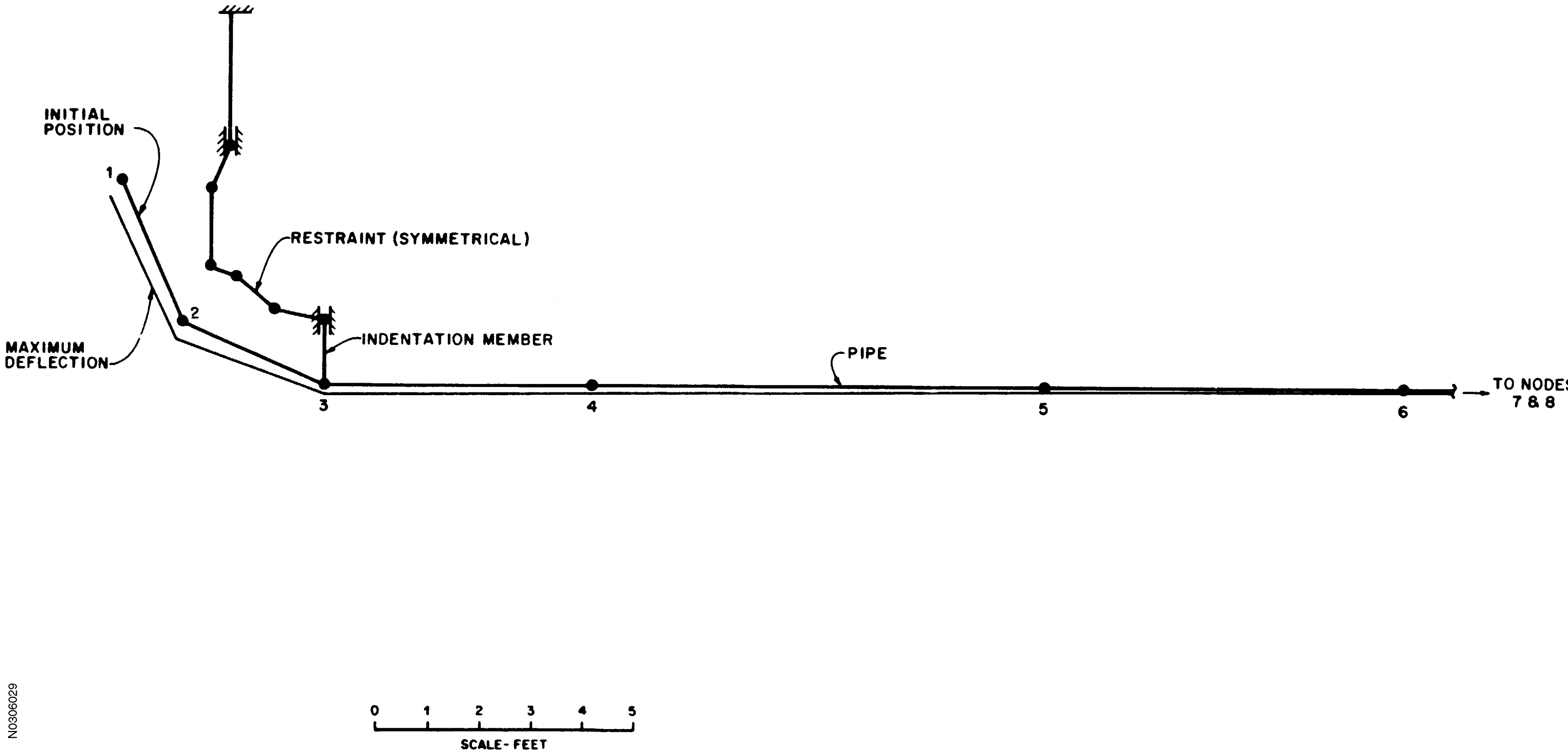


Figure 3.6-26
APPLICATION OF BLOWDOWN THRUST TO MATHEMATICAL MODEL

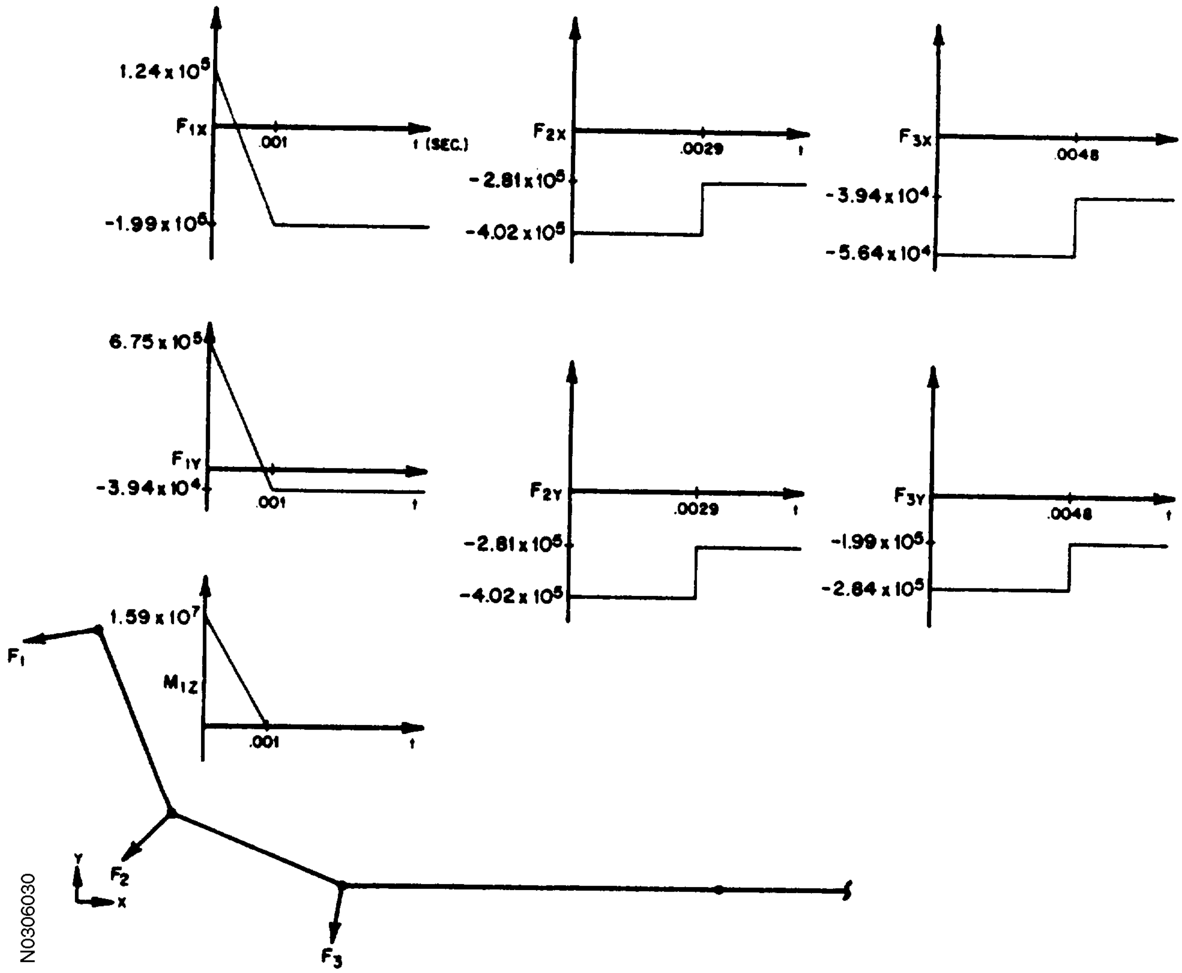
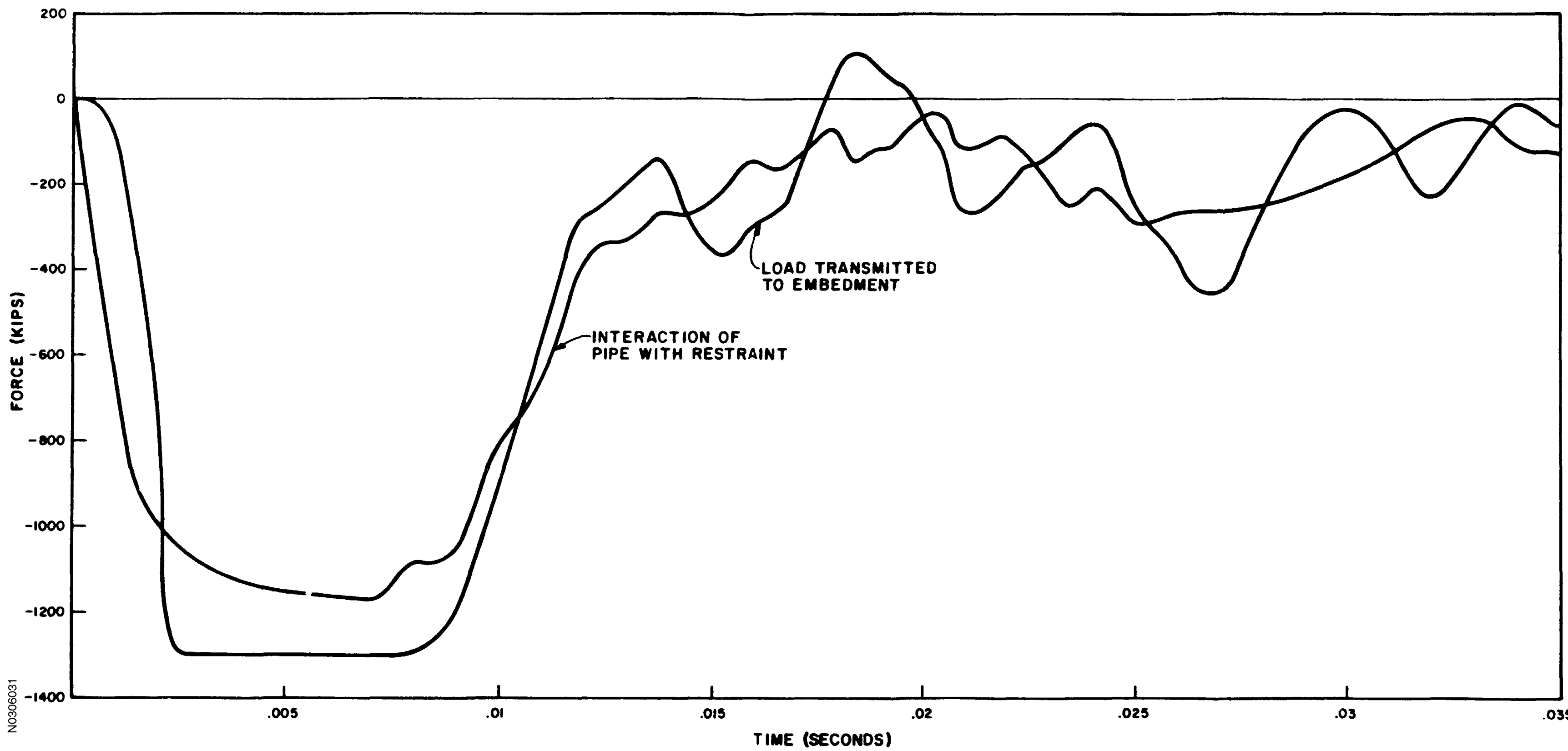


Figure 3.6-27
DYNAMIC RESPONSE OF PIPE RESTRAINT SYSTEM



3.7 SEISMIC DESIGN

3.7.1 Input Criteria

Seismic Class I structures, systems, and components that were designed to resist seismic forces are listed in Section 3.2.1. The design was based on two separate criteria, the operational-basis earthquake (OBE) and the design-basis earthquake (DBE), as described in Section 2.5. Acceleration response spectra for each earthquake are given for bedrock ground motion and for ground motion on soil overlying bedrock in Figures 2.5-11 through 2.5-14.

Damping factors for the structures, systems, and components (SSC) are given in Section 3.7.2 and Table 3.7-1.

All major soil-supported Seismic Class I structures are identified in Section 2.5.4; the depth of soil over bedrock is given for each structure.

The elastic properties of the founding media at different locations in the site are given in Section 2.5. The effect of foundation structure interaction was characterized by equivalent foundation springs attached to multi-degree-of-freedom, lumped-mass models. For more recently developed amplified response spectra, in lieu of modeling soil springs, soil structure interaction was characterized by appropriate impedance and wave scattering functions as discussed in Section 3.7.2.5. It is pointed out in Section 3.7.2 that reasonable variation of the elastic properties of the foundation was considered to determine the dynamic response of the system. Foundation parameters at this site were not sufficiently flexible to cause any filtering effect.

3.7.2 Seismic System Analysis

The earthquake ground motions are established in the form of response spectra for the operational-basis earthquake and design-basis earthquake for lateral loading. The spectrum intensity for vertical loading is assigned a value of two-thirds of the horizontal intensity for both earthquake loadings. According to the *Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants*, issued by the Atomic Energy Commission, the design-basis earthquake corresponds to the safe-shutdown earthquake (SSE), and one-half the safe-shutdown earthquake is analogous to the operational-basis earthquake in terms of relative ground motion intensity, but not to the extent of structure, system, and component design. The derivation of these earthquakes and the response spectra are discussed in Section 2.5.2. The combination of design loading conditions with seismic loading and the allowable stress levels are given in Section 3.8.2.2.

The responses of the containment structure and other Seismic Class I structures to the application of horizontal and vertical earthquake ground motions were originally determined by the frequency response method. For the frequency response method, modeling of structures is discussed in Sections 3.7.2.1 through 3.7.2.4. During original licensing, to demonstrate evidence of conservatism with the frequency response method, the AEC requested a comparison of amplified response spectra developed by the frequency response method with amplified response spectra developed by the time history method. Appendix 3B provides the results of the review of seismic design adequacy that encompassed this comparison. In addition, Section 3.7.6 discusses the seismic design validation with regard to containment mat seismic spectra.

Subsequent to the development and use of spectra from the frequency response method in the original design, the time-history modal analysis method has been employed to determine the amplified response spectra for North Anna structures. As noted above, the response spectra used to validate the frequency response method were developed by the time-history modal analysis method. As a result of NRC approval of ASME Code Case N-411 damping, new spectra were developed, as noted in Section 3.7.3, using the same method. As part of the resolution of Unresolved Safety Issue (USI) A-46, amplified response spectra were generated for several structures using time-history modal analyses as discussed in Section 3.7.2.5.

As discussed in Reference 1 and in Section 3.7.3.1.1, for piping attached to two or more structures, the differential movement of the structures is included in the seismic analysis of the piping.

Overall conclusions regarding in-structure amplified response spectra are discussed in Section 3.7.2.6.

3.7.2.1 **Containment Dynamic Model**

The dynamic models of the containment structure are shown in Figures 3.7-1 and 3.7-2.

The motion of the containment structure in the vertical direction is uncoupled from the lateral and rotational motions, which made necessary the use of two dynamic models.

The horizontal dynamic model of the containment structure is shown in Figure 3.7-1. It consists of a system of spring-connected lumped masses coupled to the subgrade by soil springs. This multi-degree-of-freedom model was used to establish the free undamped vibrational characteristics of the structural system.

Masses M1 through M8 represent the total mass of the outer structure, exclusive of a small mass at the base of the shell, which is lumped with the mass of the mat M9. Mass moments of inertia I1 through I8 represent the rotary inertia of masses M1 through M8 about their own centers of gravity.

Translation and rocking spring constants K9 and K15, respectively, are included to represent the subgrade. These constants are for a rigid circular base resting on an elastic half space.

$$\text{K8 (Translational)} = \frac{32(1-\mu)GR}{7-8\mu} \quad \text{(Bycroft 1956)} \qquad (3.7\text{-}1)$$

$$\text{K14 (Rocking)} = \frac{8\ GR^3}{3(1-\mu)} \quad \text{(Borowicka 1943)}$$

where:

G = shear modulus of subgrade

R = radius of foundation mat

μ = Poisson's ratio of subgrade

The flexural characteristics of the cylinder and dome under inertial loading are determined from beam theory, which accounts for distortion due to flexure and shear. Beam theory is valid, since the shell cross sections do not distort appreciably under inertial loading. The spring elements K1 through K8 shown in Figure 3.7-1 represent the outer structure. Springs K1 and K2 are for the dome; K3 through K8 are for the cylinder.

The internal structure is made up of the primary shield wall and the crane wall interconnected by floors and radial walls. The lumped masses M10 through M14, representing the internal structure and equipment, are also shown in Figure 3.7-1. The stiffness elements K10 through K14 are established from beam theory, which accounts for flexure and shear distortion.

To determine the free vibrational characteristics of the dynamic model, the modal equation of a multi-degree lumped-mass system may be written using matrix notation as:

$$[F]\,[M]\,[q] = \frac{1}{W_n^2}\,[q] \qquad (3.7\text{-}2)$$

where:

[F] = square flexibility matrix

[M] = a diagonal mass matrix

[q] = column matrix of displacement for the nth mode

W_n = natural frequency in rad/sec for each mode

The solution of this equation determines the natural circular frequencies (W_n) for each mode and the associated coordinate displacements (q).

The modal participation factors (p) are defined by the equations:

$$p = \frac{\sum_{i=1}^{j} M_i q_i^r}{\sum_{i=1}^{j} M_i (q_i^r)^2 + \sum_{i=1}^{j} I_i (q_i^r)^2} \qquad (3.7\text{-}3)$$

where:

i indicates the mass point

r indicates the mode

I_i indicates the mass moment of inertia of the mass i

Damped modal response is established for each mode from the following equation:

$$A_i^r = p^r q_i^r A_s^r \qquad (3.7\text{-}4)$$

where:

A_i^r = ith coordinate response for the rth mode

A_s^r = damped spectral response for the rth mode

The total response at any point is determined by taking the square root of the sum of the squares of the coordinate response for each mass for all significant modes:

$$A = \sqrt{\left(A_i^1\right)^2 + \left(A_i^2\right)^2 + \ldots \left(A_i^r\right)^2} \qquad (3.7\text{-}5)$$

where:

A = total response for mass point i for all significant modes

The dynamic model of the containment structure for vertical motion is shown in Figure 3.7-2. The lumped masses are identical to those described for lateral motions. The structural spring elements K1 through K8 and K10 through K14 represent the vertical deformation characteristics of the structural elements. The soil spring Ks is determined from:

$$k_s = \frac{4\ GR}{1 - \mu} \text{ (Timoshenko and Goodier, 1951, Reference 2)} \qquad (3.7\text{-}6)$$

Mode shapes, modal participation factors, and structural responses are determined by the previously described method.

3.7.2.2 Dynamic Models of Other Seismic Class I Structures

The dynamic models of the Seismic Class I structures, described in Section 3.8.1, consist of systems of generalized spring-connected lumped masses coupled to the subgrade by springs derived from the rock or soil stiffness. The masses consist of floor, tributary walls and columns, equipment, and piping.

Horizontal, vertical, rocking, and torsional spring constants represent the subgrade. These constants were determined from consideration of the theory of elasticity relating to rigid plates on an elastic half-space.

The floors are treated as rigid plates or diaphragms; the frames and diaphragm walls transfer earthquake inertia forces to the foundation mat and subgrade. Beam theory, which includes the effects of flexure and shear, is used to establish the stiffness characteristics of the frame wall sections.

Free vibrational characteristics of the dynamic model, modal participation factors, damped response, and total response at any mass point were determined from the general equations of motion as described previously for the containment structure.

3.7.2.3 Seismic Analysis Methods and Criteria

The lumped masses of the analytical model of a Seismic Class I structure are chosen to obtain a satisfactory representation of the dynamic behavior of the actual structure. In general, masses are lumped at floor levels and incorporate the masses of the floor, tributary walls and columns, equipment, and piping. The containment structure shell is divided into several segments, and the translatory and rotary mass properties are computed with respect to the center of gravity of the segments.

The mathematical dynamic models for all Seismic Class I structures include rocking translational and torsional springs derived from elastic properties of the subgrade.

In a concrete structure, the amount of cracking affects the stiffness and damping, and hence the response of the system. Cracking of the containment structure shell is expected due to the internal pressure. Dynamic analysis of the containment structure is accomplished using two dynamic models that represent cracked and uncracked containment structure shells. The cracked shell model is consistent with the lower bound values of the stiffness properties of the structural elements, while the uncracked shell model is consistent with the upper bound values.

The probable maximum values of moments, shears, etc., have a variation of approximately 10% between cracked and uncracked models. The probable maximum values are obtained by modal superposition. The design is based on the higher of the two values.

Seismic Class I structures other than the containment structure are not subjected to internal pressure; cracking is therefore assumed to be minimal.

The shear modulus for the rock on which the North Anna Power Station is founded has been conservatively taken as 1,000,000 psi, based on measured shear wave velocities. Examination shows that reasonable variations in this shear modulus have negligible effects on the frequencies of the rock-supported structure and amplified response spectra. A variation of ±15% in the shear modulus is considered reasonable. The shear modulus was obtained by computation from measured compressional and transverse wave velocities as described in Section 2.4.

The change in the containment system frequencies for the variation of ±15% in the subgrade shear modulus are tabulated below for eight of the 14 modes.

	Modal Frequencies, cps		
Mode	$G = 0.85 \times 10^6$ psi	$G = 10^6$ psi	$G = 1.15 \times 10^6$ psi
1	5.18	5.213	5.25
2	5.49	5.52	5.52

	Modal Frequencies, cps		
Mode	$G = 0.85 \times 10^6$ psi	$G = 10^6$ psi	$G = 1.15 \times 10^6$ psi
3	12.50	12.54	12.57
4	15.65	15.71	15.74
5	24.62	24.87	25.06
6	29.59	29.67	29.70
7	34.64	37.15	39.08
8	36.63	38.46	40.41

For soil-supported structures, the shear modulus has been taken as 14,000 psi. This value is changed by ±1/3 from the nominal value to allow for the range in variation in actual shear modulus and for uncertainties in computing soil spring constants, virtual mass embedment, and contact pressure distribution. The most conservative results are used for structure and equipment design.

Amplified response spectra are generated for all Seismic Class I structures. The method used to obtain amplified response spectra is described in detail in Section 3.7.2.4.

Seismic responses for all Seismic Class I structures are determined from the simultaneous application of horizontal and vertical earthquake ground motions using a multi-mass dynamic analysis procedure.

Seismic Class I structures may have natural torsional modes of vibration due to eccentricities between the centers of rigidity and centers of mass of the structural elements. The presence of eccentricities generates coupling between translational directions of motion, resulting in torsion. Thus, a general three-dimensional model was set up, followed by a complete dynamic analysis as described previously for the containment. The results of this analysis therefore include torsional modes.

Overturning moments resulting from seismic effects on Seismic Class I structures are determined by combining the inertia forces associated with the individual modes on the basis of the square root of the sum of the squares.

The effect of vertical earthquake motion is considered to determine the maximum and minimum vertical loads on the structure. Vertical seismic forces are determined by obtaining the vertical inertia forces of individual modes and combining them as described above.

Figures 3.7-14 provide information about the mode frequencies and mode shapes of the containment structure.

Appendix 3B compares the time-history method and the response spectrum method of analysis. The following table shows a comparison between responses obtained by the two methods.

		Acceleration of Structural Coordinates	
Structure	Elevation	Time-History Method (g)	Response Spectrum Method (g)
Containment structure	396.78	0.64	0.62
	341.98	0.35	0.34
	343.0	0.59	0.50
	291.0	0.30	0.28
Fuel building	287.67	0.16	0.15
	274.75	0.16	0.13
Auxiliary building	291.0	0.36	0.33
	273.0	0.30	0.29
	241.5	0.28	0.23

The artificial time history used to generate these structural responses corresponds to the design spectrum at structural damping of 5%. Smooth design spectrum at 5% damping was used for the response spectrum method.

Structural damping is energy loss due to internal friction within the structural material and at connections. The damping force is a function of the intensity of motion and the stress levels induced in the system. Damping is also highly dependent upon the makeup of the structural system and the energy absorption mechanisms within the system. Considerable energy will also be absorbed at cracked surfaces when the elements on each side of the crack can move relative to one another. The damping factors, as given in Table 3.7-1, are estimated to be 2% for the operational-basis earthquake and 5% for the design-basis earthquake.

The seismic stress analyses have been reviewed to verify that the damping values of 2% (OBE) and 5% (DBE) are consistent with the actual stress levels computed. For the levels of stress induced in the structure, these values are conservative.

3.7.2.4 **The Frequency Response Method for the Determination of Amplified Response Spectra for Equipment**

The response of a structural system such as a reactor containment building to seismic ground motion is made up of harmonic components of frequencies equal to the natural frequencies of the structure. Components such as equipment and piping, with elastic properties, mounted in the structure respond to the structural motion. The elastic behavior of the components is not considered in the analysis of the total structure. This does not, however, introduce a discernible inaccuracy in the dynamic analysis of the structure because the mass of the equipment is small, compared to the mass of the structure. Component mass is included in the analysis of the structure. The analysis of components must take into account the modification of the ground motion due to the response of the structure and the effects of the distortion of the structure itself.

Components mounted in the structure that are flexible as compared to the structure (in terms of natural period) will respond essentially as though supported directly on the subgrade. Distortion of the structure has very little effect on oscillatory response.

On the other hand, components that are very stiff compared to the structure experience seismic response which is the same as that of the structure at the point where the component is supported.

Where components have natural periods close to the natural periods of the structure, resonance will occur and component motion will be much greater than support motion. The extreme, of course, would be the classical situation of an elastic system responding to a sinusoidal support motion. Because of the irregular characteristics of earthquake motion and damping in the combined structure-subgrade complex, a steady state of support motion does not exist, and the harmonic components of support responses are considered to decay. Component damping also has a significant effect on the magnitude of the component response.

Using the damped ground response to determine modal responses at points of interest in the structure, structural motion is idealized as a decaying time-dependent sinusoidal motion for each mode of structural response. These discrete, time-dependent, modal structural motions are used as support motions for damped single-degree-of-freedom (SDF) oscillators to calculate amplified response spectra.

This is done by determining the maximum time-dependent oscillator response to each mode of structural response and combining these results as the square root of the sum of the squares. Noting that the terms “oscillator” and “component” can be used interchangeably, a mathematical description of the frequency response method is summarized below. A computer program has been developed to carry out the procedure.

The equation of motion of a damped SDF oscillator subjected to time-dependent support motion described by $F(\lambda)$ is:

$$M\ddot{u} + c\dot{u} + ku = - M\,F(\lambda) \qquad (3.7\text{-}7)$$

where:

M = mass

k = spring constant

c = oscillator damping constant

u = displacement of oscillator relative to the support

λ = the time function

$F(\lambda)$ = the exponentially decaying sinusoidal support motion function which represents the idealized structural motion at equipment support point

For multi-degree-of-freedom (MDF) oscillator systems such as piping and equipment,

$$F(\lambda) = e^{-rB_s\lambda} P_i A_i \sin W_i\lambda \qquad (3.7\text{-}8)$$

where:

P_i = modal participation factor for the ith structural mode

A_i = amplitude of damped ground response spectrum acceleration for the ith structural mode

B_s = structural damping

r = an empirical factor that modifies the logarithmic decay of the forcing function to provide conservative results at resonance

W_i = structure natural frequency for the ith mode

λ = time

Dividing Equation 3.7-7 by M and denoting $\Omega^2 = \frac{K}{M}$

where:

Ω = natural frequency of the oscillator

C = 2M Be (where Be is a measure of oscillator damping)

$$\ddot{u} + 2\,Be\,\dot{u} + \Omega^2 u = -F(\lambda) \qquad (3.7\text{-}9)$$

The maximum response of the oscillator is determined for each mode of structural response. For each oscillator over the range of interest (1, 2, 3,.....n), the maximum responses to each structural mode of response are combined as the square root of the sum of the squares to generate the amplified response spectrum. Curves are developed for the required levels of equipment damping for both the operational-basis earthquake and design-basis earthquake.

The procedure outlined is used for both the horizontal and vertical components of earthquake motion.

To validate the method, amplified response spectra developed by the frequency response method were compared to spectra obtained by the theoretically more rigorous time-history approach. This served to establish the factor “r” that controls the rate of amplitude decay of the sinusoidal forcing function F (λ). Comparisons were made, for an MDF structure, of amplified response spectra determined by the frequency response method and the time history method. Two earthquake records were used, Helena E. W. and Golden Gate. Both time histories were normalized to 0.06g. Structural system damping was assumed to be 2% of all modes, and oscillator damping was assumed to be 0.5%. These records were chosen because the motions were recorded at bedrock, and the principal Seismic Class I structures of the North Anna Station are rock-founded. It was demonstrated that a value of r = 0.6 controlled the assumed logarithmic decay of the F (λ) function to give conservative results as compared to the time-history method.

Amplified response spectra for all Seismic Class I structures were developed in the manner described. As examples, Figure 3.7-3 Sheets 1-3 show amplified response spectra calculated by the frequency response method superimposed on those calculated by the time-history method for Helena E. W. time history normalized to 0.06g. The response spectrum shown in Figure 3.7-3 Sheet 1 is for the operating floor of the reactor containment building internal structure at Elevation 291.83. Oscillator damping is 0.5%, and structural damping is 2%. A value of r = 0.5, the empirical factor controlling the logarithmic decay, provides a response spectrum which agrees reasonably well with that obtained using Helena E. W. time history. Similarly, Figure 3.7-3 Sheets 2 and 3 show response spectra for the auxiliary building and the fuel building, respectively. The values of the empirical factor “r” are, respectively, 1.0 and 0.6 for the auxiliary building and fuel building.

Figure 3.7-3 Sheets 4 through 6 show response spectra calculated by the frequency response method using the ground response spectra of the North Anna site for the operational-basis earthquake for the respective values of the r = 5, 1.0 and 0.6. The maximum ground acceleration for the operational-basis earthquake is 0.06g. Superimposed on Figure 3.7-3 Sheets 4 through 6 are the response spectra calculated by the time-history method using the Helena E. W. time history, normalized to 0.06g. A study of these figures demonstrates the conservatism of ground response spectra for the North Anna site concerning equipment design. Where the values of amplified response spectra obtained by the frequency response method fall below the appropriate spectra obtained by the time-history method away from resonant peaks, the former values were conservatively raised to envelop the time-history spectra.

The containment structure dynamic model has been tested for possible variations in rock shear modulus (G), conservatively rated at 10^6 psi. Examination of results shows that reasonable variation of the shear modulus (±15%) has a negligible effect on the natural frequencies of rock-founded structures. It was also shown that ±1/3 variation in soil shear modulus for structures so founded would have a significant effect on the rocking and translational frequencies. Accordingly, this is taken into account in the generation of amplified response spectra for components. It was determined that extreme variation of structural properties caused some variation in structural natural frequency and, consequently, location of the resonant peaks in the equipment response spectra.

As stated in the North Anna PSAR, Supplement Addendum Section 4.0, “To account for variations in modeling and parameters of both the structural system and the equipment, the following procedure has been adopted: Equipment response curves are developed according to the procedures outlined at the nominal rock shear modulus G = 10^6 psi with the best available assessment of structural parameters. The natural frequencies of the equipment to be analyzed will be similarly developed. Where significant equipment modes are within ±15% of the resonant peaks, those equipment modes will be arbitrarily altered to coincide with the resonant peaks and the curves as derived will be used. For structures founded in soil, the range described above will be based on a variation in soil modulus of ±1/3. Our examination of soil-mounted structures shows this will cause a spread in the natural periods of -20% and +25% as measured against the nominal resonant periods" (Reference 3).

3.7.2.5 **Amplified Response Spectra Developed as Part of the Resolution of USI A-46**

As part of the resolution of Unresolved Safety Issue (USI) A-46, amplified in-structure response spectra (ISRS) for most structures were developed for the design-basis earthquake (DBE). These spectra were generated using time-history modal analyses, with more realistic representation of soil/structure interaction for soil founded structures and with improved modeling of structures. They were developed for use in the seismic analysis and qualification of equipment and components.

The amplification of earthquake motion through the structures was computed from the DBE ground spectral shape using lumped-mass models consisting of beams and stiffness matrix elements with six degrees of freedom at each node. The ground spectral shapes used in these analyses are plotted in Figure 2.5-12 for rock and Figure 2.5-14 for soil. In accordance with Section 2.5.2.6, 0.12g horizontal peak ground acceleration and 0.18g horizontal peak ground acceleration were used for rock and soil founded structures respectively, with 2/3 of these values in the vertical direction. Previous structural models and founding conditions were evaluated and refined or recreated as necessary. Time-history modal analyses were performed by first determining the dynamic characteristics (mode shapes, natural frequencies and participation factors) of the structures.

Synthetic time-histories, the spectra from which closely envelop the rock and soil target DBE ground response spectrum (GRS) shapes of Figures 2.5-12 and 2.5-14 respectively, were developed. These time histories were of 20-second duration defined at a 0.01-second interval and were statistically independent for each of the three orthogonal directions. Consistent with Table 3.7-1, a structural damping value of 5% was used. Spatial combination was in accordance with NRC Regulatory Guide 1.92.

For most of the soil-founded structures, new soil-structure interaction (SSI) analyses were performed. In the SSI analyses, building models were used together with appropriate impedance and scattering functions. Three SSI analyses were performed, one for each of the following conditions: lower bound, best estimate, and upper bound soil properties. The determination of best-estimate low strain properties was based on Section 2.5. To estimate the lower and upper bound low-strain characteristics from the best estimate properties, the following factors were used:

$G_{lower} = 0.5 * G_{best}$ $V_{lower} = 1/\sqrt{2} * V_{best}$

$G_{upper} = 2.0 * G_{best}$ $V_{upper} = \sqrt{2} * V_{best}$

where G represents the shear modulus and V the shear wave velocity.

The impedance and scattering of the embedded foundation were only computed with the DBE spectrum – best estimate high strain soil properties. The resulting spectra from the SSI analyses at each nodal point in the structural model were enveloped from these three cases. The structures founded on rock (e.g., the Containment Building) were modeled as fixed base and no translational or rocking spring constants were used to represent the subgrade.

ISRS were developed for 3% and 5% equipment damping at each elevation for each structure, whether founded on soil or rock. These ISRS were peak broadened +15% and -15% to account for uncertainty and variability in the structural and equipment frequencies in accordance with Section 3.7.2.4.

In addition to the development of in-structure spectra for the design basis spectral shapes of Figures 2.5-12 and 2.5-14, median-centered in-structure response spectra were generated based on the ground response spectrum shapes defined in NUREG/CR-0098 (Reference 59). The peak ground acceleration levels (pga) in these analyses were the same as the pga for the design-basis earthquake, i.e., per Section 2.5.2.6, the horizontal pga values were 0.12g and 0.18g for rock and soil founded structures respectively with 2/3 of these values in the vertical direction. These in-structure spectra were developed using the same methodology as discussed above. The median-centered in-structure response spectra may only be used for seismic evaluation of equipment performed via the USI A-46 methodology discussed in Section 3.7.3.2.2.4 and in accordance with the rules discussed in the Generic Implementation Procedure (Reference 61).

3.7.2.6 **Summary and Conclusions**

The original development of in-structure response spectra for all Seismic Class I structures was via the use of frequency response method. Structures, systems and components were designed and qualified using these spectra. Subsequently, the spectra obtained from this method were verified against the spectra developed from time-history modal analyses of structures. Actual and synthetic earthquake records were used. This comparison confirmed the validity of the original spectra. Later, response spectra for ASME Code Case N-411 damping were generated using the time-history modal analysis method. The amplified spectra developed as part of the resolution of USI A-46 were also based on the same method, with refined modeling of structures and state-of-the-art soil-structure interaction techniques. The methods utilized for the development of in-structure response spectra are sound and the results from these analyses are valid for use in seismic design and qualification of systems, structures and components.

3.7.2.7 **Validation of Computer Programs**

This section describes computer programs that were used by Stone & Webster and Westinghouse for the original dynamic and static analyses of Class I equipment and components. Subsequent analyses may be performed using additional computer programs in accordance with Virginia Power administrative procedures and the design control program.

3.7.2.7.1 Programs Within Stone & Webster Scope

The following computer programs were used in dynamic and static analyses for Seismic Class I Stone & Webster designed equipment and components:

1. STRUDL II - multipurpose mechanics program.
2. STARDYNE - dynamic analysis program.
3. ST-176 - seismic spectra response calculations.
4. SHELL 1 - shell analysis program.
5. Stress Analysis of Shells of Revolution.
6. MARC - nonlinear finite element program, static.
7. LIMITA II - nonlinear transient dynamic analysis.
8. MAT 5 - foundation mat analysis.
9. Time-History Program - seismic response spectra.
10. PRATO - mixed finite element with curved surfaces.
11. NUPIPE-SW- performs a linear elastic analysis of three dimensional piping systems subjected to thermal, static, and dynamic loads.
12. STRUDL-SW- multipurpose static and/or dynamic analysis program.
13. STEHAM- determines flow induced forcing functions on piping systems during a steamhammer event.

3.7.2.7.1.1 *STRUDL II.* STRUDL II has been designed as a modified subsystem of the Integrated Civil Engineering System (ICES) (Reference 4) which was designed and formulated at the Massachusetts Institute of Technology, Department of Civil Engineering.

The finite element method (Reference 5) provides for the solution of a wide range of solid mechanics problems. Its use within the context of the STRUDL analysis facilities expands these for the treatment of plane stress, plane strain, plate bending, shallow shell, and three-dimensional stress analysis problems.

STRUDL II also provides a dynamic analysis capability for linear elastic structures undergoing small displacements. Either free or forced vibrational response may be obtained; in the latter case, the forcing function may be in the form of time histories or response spectra.

The three-dimensional finite element capability of STRUDL is used to analyze the containment at the regions of the personnel and equipment hatches and other specific regions of interest.

Seismic Class I structures are analyzed for seismic effect using the dynamic analysis capability of STRUDL. The analysis yields frequencies of vibration, mode shapes, displacements, velocities, accelerations, and forces.

STRUDL II is a recognized program in the public domain. Version 2, Modification 2 (June 1972) of STRUDL is used. The software system is IBM-MVT - Release 20.7. The hardware configuration is IBM-370 - Model 165.

3.7.2.7.1.2 *STARDYNE.* The STARDYNE structural analysis system, written by Mechanics Research, Inc., of Los Angeles, California, is a fully warranted and documented computer program available at Control Data Corporation's 6600 data centers. The latest version became available August 1, 1973.

The MRI STARDYNE analysis system consists of a series of compatible digital computer programs designed to analyze linear elastic structural models. The system encompasses the full range of static and dynamic analyses. The static capability includes the computation of structural deformations and member loads and stresses caused by an arbitrary set of thermal, nodal applied loads, and prescribed displacements. Using the normal mode technique, dynamic response analyses can be performed for a wide range of loading conditions, including transient, steady-state harmonic, random, and shock spectra excitation types. Dynamic response results can be presented as structural deformations and internal member loads.

3.7.2.7.1.3 *ST-176 Seismic Spectra Response Calculations.* This computer program is designed to supplement STRUDL program capability in seismic analysis by computing the participation factors and modal forces from the given ground response spectra, eigenvectors, and inertias of the structural system. The first step in the analysis is to determine the eigenvalues and eigenvectors of the structure using the STRUDL dynamic program. The modal data output from the STRUDL dynamic program is input to ST-176 along with the amplified response spectra representing the postulated earthquake. The output of the ST-176 program produces forces applied to the structure at the mass points. This force system is input to the STRUDL static program to calculate loads and stresses in the various members of the structure. The computer code ST-176 is not a lumped-mass dynamic analysis program.

The program functions as follows.

Given the modal shapes (from STRUDL punch-out) and the inertia of structural model, the participation factors are computed as:

$$\Gamma_{ni} = \frac{-\sum M_i \phi_{ni}}{\sum M_j (\phi_{nj})^2} \qquad (3.7\text{-}10)$$

where n is the mode, i varies over the degrees of freedom corresponding to assumed earthquake directions (for instance, an earthquake in the X1 direction, i will vary over all degrees of freedom in the X2 direction), and j varies over all degrees of freedom.

The modal forces are given by:

$$F_{jn} = ø_{jn} R_n \Gamma_n M_j \quad (3.7\text{-}11)$$

where:

ø = modal shape

R = response acceleration

Γ = participation factor

M = inertia

n = nth mode

j = degree of freedom

The absolute-sum equivalent static forces are computed as:

$$F_{ABSj} = \sum_{m} |F_{nj}| \quad (3.7\text{-}12)$$

The algebraic-sum equivalent static forces are computed as:

$$F_{ALGj} = \sum_{m} F_{nj} \quad (3.7\text{-}13)$$

The RMS-sum equivalent static forces are computed as

$$F_{RMSj} = \sqrt{\sum (F_{nj})^2} \quad (3.7\text{-}14)$$

3.7.2.7.1.4 *SHELL I.* The SHELL I computer program is a further development of a computer program written at AVCO Corporation. The program is based on the general numerical procedure, proposed by D. Budiansky and P. P. Radkowski (References 6 & 7), to analyze a shell of revolution subjected to arbitrary loadings. The analysis is based on the general first or linear theory of thin shells by J. L. Sanders, Jr. (Reference 8).

This program is used to obtain the membrane forces and bending moments in the reactor containment structure wall and reactor support wall due to the temperature and pressure loads. Discontinuity forces applied at the foundation mat are obtained from the computer program MAT 5.

This is a finite-difference stress analysis computer code. It can be used to determine the forces, moments, shears, displacements, rotations, and stresses in a thin shell of revolution subject to arbitrary loads expanded in Fourier series of up to 150 terms. Single-layer shells with up to 30 simply connected branches may be analyzed. Poisson's ratio may change at discontinuity points, and Young's modulus and the thermal coefficient of expansion may be different at each point. The allowed types of loading include elastic restraints, pressures in three orthogonal directions, temperature changes that may have a gradient through the shell thickness, and simplified input for weight of the shell or earthquake forces.

The equilibrium equations for a thin shell are based on the linear theory of Sanders. Sanders' equations are expanded and modified slightly to handle a broader range of problems. All pertinent load, stress, and deformation variables are expanded into Fourier series. The individual Fourier components of stress and deflection are found separately by solution of the finite-difference forms of the appropriate differential equations. The algorithm used to solve these equations is a minor modification of the Gaussian elimination method.

3.7.2.7.1.5 *Stress Analysis of Shells of Revolution.* This is a finite element computer code. It can be used to determine the forces, moments, shears, displacements, rotations, and stresses in a thin shell of revolution subject to axisymmetric loads. Different orthotropic material properties may be input for each element in a model. The allowed types of loading include internal pressure, temperature changes that may have a gradient through the shell thickness, and simplified input for weight of the shell.

The explicit stiffness relations for the axisymmetric shell elements are based on the classical theorem of potential energy and the usual approximations of thin shell theory. The direct stiffness method (a simple modification of the displacement method) is used to assemble the equilibrium equations. The algorithm used to solve these equations is derived by applying the Gauss-Jordan method of elimination to a tridiagonal system of equations.

3.7.2.7.1.6 *MARC.* The MARC nonlinear finite element analysis program, used to obtain the local pipe indentation stiffness, came into the public domain in December 1971. It is written FORTRAN IV in a general form with variable dimensions passed down to the subroutines. A library of elements is available directly in the program.

The elastic-plastic and large displacement analysis is done in a series of piecewise linear increments. Creep and thermal effects that cause initial strains are analyzed as a series of steps in which an increment of initial strain occurs at the start of each step. Optional facilities enable the lowest eigenvalue to be obtained after each applied increment of load. This eigenvalue furnishes the factor that must be used to scale the next increment of load to cause collapse.

Controls have been added that allow the specification of loading or creep for a total number of increments or time steps, respectively. These controls are referred to as automatic load controls. The automatic load control for creep selects the time step for each increment so that the resulting stress and strain changes remain within a specified limit. A higher order step-by-step integration in time, known as the residual load correction, may be specified for creep problems. This residual load correction feature stabilizes creep solutions.

The behavior is the classical theory of isotropic, elastic-plastic, time-independent materials, with a von Mises yield criterion, isotropic strain hardening, temperature-dependent elastic properties, and equivalent yield stress. Perfect plasticity is assumed when no strain hardening is specified.

The theoretical basis of the computer code has been presented in a series of papers published by P. V. Marcal (References 10 through 19). The accuracy of the code has been demonstrated by comparison with both theoretical and experimental results. A typical example is shown in Figures 3.7-4 and 3.7-5.

3.7.2.7.1.7 *LIMITA II - Mathematical Model.* LIMITA II is a plane frame, nonlinear, transient dynamic analysis computer code. The major differences between this program and others commonly used for dynamic elastic analysis are the provisions for large displacements and inelastic deformation. The geometry is modified for large deflection analysis. Two versions of geometry updating are available in the code. The first approach updates the geometry at every time increment, and the second only when plastic flow occurs. For analysis of restrained piping, large deflections are not encountered except due to plastic deformation. Thus the latter option is used, and this is shown in the flow chart.

A plane frame is simulated as an assembly of discrete lumped masses connected by beam elements. Under any loading, the equilibrium at each mass point is ensured by the equation of motion:

$$[m]\{\ddot{U}\} + [c]\{\dot{U}\} + [k]\{U\} = \{f(t)\} \qquad (3.7\text{-}15)$$

where:

$[m]$ = mass matrix

$[c]$ = damping coefficient matrix

$[k]$ = stiffness matrix

$\{\dot{U}\}$ = displacement vector

$\{\ddot{U}\}$ = velocity vector

$\{U\}$ = acceleration vector

$\{f(t)\}$ = external load vector

The displacement, velocity, and acceleration vectors are comprised of all the nonrestrained movements of each mass point. The external load vector f(t) is comprised of the external loads applied to the mass points in all nonrestrained directions of movement. The mass matrix is a diagonal matrix. An element of the matrix, m_{ij}, is the mass associated with the ith degree of freedom. An element of the damping coefficient matrix, [c], is applied to the jth velocity in the ith equation of motion. An element of the stiffness matrix, $[k_{ij}]$, is defined as the force necessary to hold the structural element from moving in the ith degree of freedom when the jth degree of freedom is given a unit displacement and all of the other degrees of freedom of the structural element are restrained from moving.

For the total structure, the governing equations of motion are:

$$[m]\{\ddot{U}\} + [c]\{\dot{U}\} + [k]\{U\} = \{f(t)\} \qquad (3.7\text{-}16)$$

where $\{\ddot{U}\}$, $\{\dot{U}\}$, $\{U\}$, and $\{f(t)\}$ are vectors comprised of all the total structure, and [m], [c], and [k] are the assembly matrices of all the element matrices.

This system of second-order differential equations is solved by a linear acceleration integration method, starting from some known initial state of the system at time zero. The nonlinear effects, such as plasticity and large deflections, are included by varying [k] and [c] at each necessary time step.

In the numerical integration procedure, the following relations are used:

$$\{U\} = f(U_t, U_{t-1}, U_{t-2}....)$$

$$\{U\} = g(U_t, U_{t-1}, U_{t-2}....) \qquad (3.7\text{-}17)$$

$$\{U\} = h(U_t, U_{t-1}, U_{t-2}....)$$

where f is a cubic function and the acceleration is a linear function across the time interval. Making these substitutions into Equation 3.7-17 gives:

$$[c_1 [m] + c_2 [c] + [k]] \{U\} = \{f(t)\} + \{f([t],[m], \{U_{t-1}\},\{U_{t-2}\},....\} \qquad (3.7\text{-}18)$$

where c_1 and c_2 are functions of $(t\text{-}t_{-1})$ and $(t_{-1}\text{-}t_{-2})$, etc.

The damping function can be more easily understood by rewriting the motion Equation 3.7-15 in the form:

$$M_r\ddot{U}_r + \sum^{i} c_{ri}\dot{U}_r + \sum^{i} k_{ri}\dot{U}_r = f_r \qquad (3.7\text{-}19)$$

where:

$\sum^{i}$ indicates a series with one term for each of the displacements

c_{ri} is the damping coefficient for the ith velocity in the rth equation of motion

The damping forces are approximately determined by two sets of dampers, one associated with the member stiffnesses and the other with the masses. The damping forces are assumed to be proportional to relative velocity in the former and absolute velocity in the latter. Therefore, the damping coefficient c_{ri} in Equation 3.7-19 is given by:

$$c_{ri} = c_k k_{ri} + c_m m_r \delta_{ri} \qquad (3.7\text{-}20)$$

where δ_{ri} is the Kronecker delta. The values of c_k and c_m are assumed constant, and may be determined either by an approximate analytical approach or experimental data.

K_{ri} is the member stiffness, defined as the force necessary to hold the structural member from moving in the rth degree of freedom when the ith degree of freedom is given a unit displacement and all other degrees of freedom are restrained from moving. In the elastic range, the derivation of these stiffnesses is given in References 20 and 21. The method used to provide for changes in stiffness during inelastic deformation is described below.

Since no external loading is applied to a member between nodes, the maximum value of the internal forces acting on the member occurs at its ends. The transition from the elastic to the fully plastic state is disregarded, and the section is assumed to remain linearly elastic up to the fully plastic yield surface. This yield surface is defined by a scalar function Φ of the internal member forces, Q, of the form:

$$\Phi(Q) = 1 \qquad (3.7\text{-}21)$$

Here the function Φ is obtained by integrating the stress across the section with the stress fully developed over the section and satisfying the von Mises (or Tresca) yield criterion:

$$\sigma^2 + \gamma^2 Z^2 = \sigma^2{}_c \qquad (3.7\text{-}22)$$

where:

σ = normal stress

Z = shear stress

σ_c = yield stress in simple tension

γ^2 = 3 (von Mises) or 4 (Tresca)

Thus the function Φ depends on the shape of the cross section and the force components being considered.

The yielding normally occurs due to either a predominant bending moment (pipe or arch of restraint) or to predominant tension or compression (bolt or special pipe indentation member). These two yield models are provided.

Since a section is either elastic or fully plastic, there are four possible states for a bending member: (1) both ends γ and β are elastic, (2) end γ is yielding and β is elastic, (3) end γ is elastic and β is yielding, (4) both ends γ and β are yielding. A plastic hinge is introduced at any end section which is yielding. The force-displacement relation of the plastic hinge follows an ideal bilinear curve (References 22 & 23). In situations where force reversal occurs, the stiffness of the hinged member is restored, providing unloading along the elastic line (isotropic strain hardening model).

There are only two possible states for a tension (or compression) member: either the entire member is elastic or the entire member is plastic. When the member yields, the member elastic Young's modulus and the force displacement curve follows a bilinear curve. If the member unloads, the elastic modulus is restored.

In LIMITA II, Equation 3.7-18 is solved at each time point in the dynamic transient. Since [m], [c], and [k] can be recalculated at each time point, they can vary with time in any desired fashion.

The von Mises yield surface is used along with the PRANDTL-REUSS flow relations. The stress-strain curve is assumed to be isothermal B-linear with isotropic hardening and kinematic hardening models.

For large deflection analysis, the geometry is modified (if necessary) at the end of each load increment so that the total loading is applied to the deformed structure of the next load increment. This procedure thus follows the large-deflection load-deflection curve.

The computation procedures of the LIMITA II program are given in a flow chart, Figure 3.7-6.

3.7.2.7.1.8 *MAT 5*. This program analyzes a symmetrically loaded circular plate on an elastic foundation, and maintains compactibility between (1) the plate (foundation mat) and the subgrade, and (2) the plate and the circular walls supported thereon. The program (Reference 25) computes the discontinuity effects at the interface of the mat and the circular walls, and includes these effects in the analysis.

This program is used to analyze the foundation mat and to provide the contact pressure and the discontinuity forces at the junction of the mat and superstructure.

The solutions to test problems using MAT 5 are substantially identical to those obtained by hand calculations. It is to be understood that the complexity of the hand calculations tend to limit their accuracy. The test problems used are actual containment structures.

Included are plots of the radial and tangential bending moments and the radial shear in the mat for a MAT 5 solution vs. hand calculations. Also shown are the discontinuity forces at the interface of the mat and circular walls. This particular mat is on soil (Figure 3.7-7).

Similar plots are submitted for a MAT 5 solution versus a hand solution done in accordance with Reference 26 for a mat on rock (Figure 3.7-8). The comparison, particularly at the junction of the containment wall and mat, is excellent. The hand calculations show a somewhat larger radial shear near the edge because the cantilever effect (5 feet) of the mat beyond the containment wall was not included. Other minor discrepancies occur at the lift-off point for the mat between the two solutions, but these are due to assumptions inherent in the Timoshenko solution (i.e., at the point of mat lift-off, the radial moment, displacement, and slope of mat equal zero).

3.7.2.7.1.9 *Time-History Program.* The time-history program computes time-history response and amplified response spectra at any mass point location of a lumped-mass spring-connected system due to a synthetic earthquake time-motion record input. The responses are computed by integration of the modal equations of the system by the "exact method" (Reference 27). The program's main application is the generation of amplified response spectra used for the design of Seismic Class I equipment and piping.

The time-history program solution to a test problem is substantially identical to the solution obtained using STRUDL II. The test problem uses an actual containment structure subjected to an earthquake time-motion record input of Helena E. W. normalized to 0.06g. The time-history response of the structure is computed at the operating floor level by the time-history program and STRUDL II. The results of these two analyses (Figures 3.7-9 and 3.7-10, respectively) agree extremely well with each other.

3.7.2.7.1.10 *PRATO.* The PRATO program is based on a mixed finite element formulation described in Reference 28. It allows for triangular and quadrilateral curved shell elements on the cylindrical surface or on an arbitrary shallow surface. The nodal variables are the three translation components referred to in the local curvilinear reference frame, and the three stress couples. Both displacements (i.e., translation) and moment boundary conditions can be imposed. This program uses linear expansions for the translations and stress couples over the element domain. A simpler version (linear displacement constant moment) is discussed in Reference 29, and a more refined version (quadratic displacement, linear moment) is described in Reference 30.

A pressurized cylindrical shell having a circular cutout illustrates the relative accuracy of the PRATO program vs. the finite element displacement model (Rodriguez) (Reference 31) and an approximate analytical solution. Figure 3.7-11 shows the definition and treatment of boundary conditions. Stress results are plotted in Figures 3.7-12 and 3.7-13. Close agreement with the displacement model solution is obtained. A number of other comparison studies are listed in Reference 32.

3.7.2.7.1.11 *NUPIPE-SW.* The NUPIPE-SW piping program performs a linear elastic analysis of three dimensional piping systems subjected to thermal, static, and dynamic loads. NUPIPE-SW utilizes the finite element method of analysis with special features incorporated to accommodate specific requirements in piping analysis. These features include simplified input for piping system description, use of special curved elements to represent piping elbows, and analytical conformance to the ASME Section III Nuclear Power Plant Components Code.

NUPIPE-SW will handle all loading conditions required for complete nuclear piping analyses. A given piping configuration may be analyzed successively for a number of static and dynamic load conditions in a single computer run. Separate load cases, such as thermal expansion and anchor displacements, may be combined to form additional analysis cases. The piping deadload analysis considers both distributed weight properties of the piping and any added concentrated weights.

The NUPIPE-SW program is designed to perform analysis in accordance with the ASME Boiler and Pressure Vessel Code Section III, Nuclear Power Plant Components (Code). Features insuring Code conformance include use of accepted analysis methods, incorporation of specified stress indices and flexibility factors, proper combination of moment resultants, and provision to (automatically) generate results of combined loading cases. A program option is available to specify Class 1 analysis per Article NB-3600 of the Code, Class 2 analysis per Article NC-3600 of the Code, analysis per ANSI B31.1.0 Power Piping Code, analysis per ANSI B31.3 Petrochemical Code, and combined Class 1 and Class 2 analysis per Articles NB-3600 and NC-3600 of the Code.

3.7.2.7.1.12 *STRUDL-SW.* STRUDL-SW performs a static and/or dynamic analysis of a structure composed of members. The capability also exists (for a static analysis) to check or design structural members based on various code requirements. This program is a completely documented and qualified subset of STRUDL-II (ST-015).

STRUDL-SW may be applied to a wide range of structural problems using the same basic input. It handles two-dimensional trusses, frames, and grids, as well as three-dimensional trusses and frames. Only elastic, small displacement analysis is available.

The solution method used is the displacement method for structural analysis. This procedure requires the specification of member properties in some acceptable form and treats the joint displacements as unknowns. Stiffness and mass matrices (for dynamics) of the structure are assembled or input and the static and/or dynamic problem is solved.

3.7.2.7.1.13 *STEHAM.* The STEHAM program determines the flow induced forcing functions on piping systems during a steamhammer event for the use of subsequent piping dynamic analysis.

The analysis is based upon the method of characteristics with finite difference approximations for solutions of unsteady one-dimensional homogeneous adiabatic, compressible fluid flows.

The required program input consists of numerical codes representing the flow network of the piping system, pipe dimensions, valve flow characteristics, valve operation characteristics, initial steam flow conditions in the piping system, and flow frictional coefficients.

The program output will generate the following: time values of flow pressure, density, velocity, nodal forces for all nodes, and segment forces for all segments of the flow network at each time increment.

3.7.2.7.2 Programs within Westinghouse Scope

The following computer programs have been used in dynamic and static analyses to determine mechanical loads, stresses, and deformations of Seismic Class I components and equipment:

1. WESTDYN (or WESDYN-7) - static and dynamic analysis of redundant piping systems.
2. FIXFM - time-history response of three-dimensional structures.
3. WESDYN-2 - piping system stress analysis from time-history displacement data.
4. STHRUST - hydraulic loads on loop components from blowdown information.
5. STRUDL - structural analysis under thermal or static loads.
6. THESSE - RCL equipment support structures analysis and evaluation.
7. WECAN - finite element structural analysis.
8. ANSYS - finite element structural analysis.

A description of the basis, capabilities, and extent of application of each program follows.

The verification and qualification of computer codes FIXFM, STHRUST, THESSE, and WECAN are addressed in the Westinghouse topical report WCAP-8252, *Documentation of Selected Westinghouse Structural Analysis Computer Codes* (Reference 33).

3.7.2.7.2.1 *WESTDYN (or WESDYN-7).* WESTDYN, a Westinghouse adapation of the A. D. Little Company program (Reference 34), is a special-purpose program for the static and dynamic analysis of redundant piping systems with arbitrary loads and boundary conditions. It computes, at any point in the piping system, the forces, deflections, and stresses that result from the imposed anchor or junction loads, thermal gradients in the system, and gravity loads, in any combination of the three orthogonal axes. The piping system may contain a number of sections, a section being defined as a sequence of straight and/or curved members lying between two network points. A network point is (1) a junction of two or more pipes, (2) an anchor or any point at which motion is prescribed, or (3) any arbitrary point.

Any location in the system may sustain prescribed loads or may be subject to elastic constraint in any of its six degrees of freedom. For example, hangers may be arbitrarily spaced along a section, and may be of the rigid, flexible, or constant force type.

The response to seismic excitation is analyzed by normal mode, response spectral superposition technique with a lumped-mass system. The eigenvalue routines used are the Jacobi rotation and the Givens-Householder schemes (Reference 35). The maximum spectral acceleration is applied for each mode at its corresponding frequency from response spectra to obtain the amplitude of the modal coordinate for each mode. A basic assumption is that the maximum modal excitation of each mode occurs simultaneously. The forces, deflections, support reactions, and stresses are calculated for each significant mode. The total response is computed by combining the contributions of the significant modes by several methods, one of which is the square root of the sum of the squares method.

3.7.2.7.2.2 *FIXFM.* FIXFM (Reference 33) is a digital computer program that determines the time-history response of a three-dimensional structure excited by arbitrary, time-varying forcing functions. The input for FIXFM (obtained from the WESTDYN program) consists of normalized mode shapes, natural frequencies, forcing functions, and an initial deflection vector. The program sets up the modal differential equations of motion. The modal differential equations are solved numerically by a predictor-corrector technique of numerical integration. The modal contributions are then summed at various mass points throughout the structure to obtain the actual time-history response. FIXFM, like WESTDYN, is applied to redundant piping systems.

3.7.2.7.2.3 *WESTDYN-2.* WESTDYN-2 is a slightly modified version of the WESTDYN program. The program treats the input of time-history displacement vectors at mass points (from FIXFM) as an imposed deflection condition, and proceeds to a usual WESTDYN static solution. In addition to the usual stress solution, the program also calculates axial stress, shear stress, and stress intensity.

3.7.2.7.2.4 *STHRUST.* The STHRUST (Reference 33) code computes hydraulic loads on primary loop components from the blowdown information calculated by the SATAN (Reference 41) code, i.e., density, internal energy, and mass flow rate. The entire primary system, including special elements such as the reactor core, pressurizer, and accumulators, is represented by the same two-loop model used in the SATAN blowdown calculation.

The force nodes are selected along the two-loop geometric model of a reactor plant where the vector forces and their components in a global coordinate system are calculated. Each force node is associated with a control volume that may contain one or two blowdown (SATAN) control volumes, depending on the location of the force node in the system. Each force control volume, in turn, has one or two associated apertures (flow area). STHRUST calculates the time history of forces at locations where there is a change in either direction or flow area within the reactor coolant loop.

The major input information required for the code is:

1. Blowdown hydraulic information, which is read directly from the SATAN result tape.
2. The orientation of the force node in the system, which is input as three projection coefficients along the three coordinate axes of the global coordinate system.

3.7.2.7.2.5 *STRUDL.* STRUDL, part of the ICES civil engineering computer system (Reference 42), is a general-purpose matrix structural analysis program that can solve for stresses and deflections of structures subjected to static or thermal loads. The basis of the program is the general beam finite element. It is applicable to linear elastic two- and three-dimensional frame or truss structures, e.g., steam generator lower, steam generator upper lateral, and reactor coolant pump lower support structures. STRUDL uses the stiffness formation, and is valid only for small displacements. Structure geometry, topology, and element orientation and cross section properties are described in free format. Member and support joint releases, such as pin and rollers, are specified. Otherwise, six restraint components are assumed at each end of each member and at each support joint.

The STRUDL system performs structural stability and equilibrium checks during the solution process, and prints error messages if these conditions are violated. However, the system cannot detect geometry or topology errors. Type, location, and magnitude of applied loads or displacements are specified for any number of loading conditions. These can be combined as desired during the solution process.

One important feature of STRUDL is that any desired changes, deletions, or additions can be made to the structural model during the solution process. This produces results for a number of structure configurations, each with any number of loading conditions.

The output includes member forces and distortions, joint displacements, support joint reactions, and member stresses.

3.7.2.7.2.6 *THESSE.* The THESSE (Reference 33) computer program was developed by Westinghouse to accomplish RCL equipment support structures analyses and evaluation. Two versions are used, one for normal and upset condition loading using AISC-69 allowable stress equations, and one for faulted condition loading where LOCA loads are read in time-history form and ultimate stress equations are used.

Westinghouse has expanded the output capabilities of STRUDL to include selective punch card data that are used as input in the THESSE program. The input includes

1. Six components of forces acting on the support structure for each of the thermal, weight, pressure, seismic, and LOCA loadings.
2. Member geometry and material.
3. 6 x 6 member influence coefficient array for each end of each member.

Loads on the structure are combined, transformed to the structure-coordinate system, and multiplied by member influence coefficients. The resulting member forces are then used with member properties in stress and interaction equations to determine the adequacy of each member in the structure. THESSE calculates all member internal forces and moments and determines when the highest stresses occur in each member. These maximum stresses are expressed as a ratio of the maximum stress to the limiting values.

3.7.2.7.2.7 *WECAN.* WECAN (Reference 33), a one-, two-, and three-dimensional finite element program, is capable of solving elastic-plastic static structural problems, transient and steady-state thermal problems, and linear and nonlinear dynamic structural problems. Its library of finite elements includes spars, beams, pipes, plane and axisymmetric triangles, three-dimensional solids, plates, plane and axisymmetric shells, three-dimensional shells, friction interface elements, springs, masses, dampers, thermal conductors, hydraulic conductors, convection elements, and radiation elements.

WECAN is capable of predicting mode shapes and natural frequencies, maximum response to harmonic excitation, or complete time-history response to arbitrary forcing functions. The matrix displacement method is applied to each finite element in the idealized structure. A “wave front” direct solution technique is used to give accurate results in a minimum of computer time. The analysis solution output includes geometry plots, nodal displacements, element stresses, and nodal forces.

3.7.2.7.2.8 *ANSYS.* ANSYS (Reference 83) is a commercial large-scale, general purpose finite element computer program with applications to many classes of engineering problems. Structural analysis methods include static options for the solution of elastic, plastic, and nonlinear large and small deflection problems. Also, dynamic options are available to perform nonlinear transient, harmonic response and mode-frequency analysis. The finite element library is extensive and includes beam, spar, plant, shell, and nonlinear gap elements.

The matrix displacement method of finite element analysis is used in the formulation of the problem, and equations are solved by the wave front and direct time integration methods.

3.7.2.7.3 Programs within Framatome Scope

This section describes computer programs that were used by Framatome ANP for the dynamic and static analysis of Class 1 equipment and components during the process of qualifying the replacement reactor vessel closure heads to ASME Section III requirements. These computer programs meet the requirements of the Dominion and Framatome ANP software validation programs. The validation program meets the requirements of 10 CFR 50 Appendix B, ASME NQA 1 and ANSI N45.2. The software validation compliance was verified during an onsite quality audit of the replacement closure head vendor. Audit results and objective evidence of the software validation are available in the Framatome ANP audit file. These programs provide results that are essentially the same or more conservative than the analyses of record.

3.7.2.7.3.1 *BIJLAARD.* BIJLAARD (Reference 78) is designed to calculate local stresses in a cylindrical or spherical shell induced by a nozzle or support.

3.7.2.7.3.2 *FERMETURE.* FERMETURE (Reference 79) is designed to calculate the loadings used for the closure analysis. FERMETURE calculates the stud load components for a given set of temperature and pressure values. Additionally, FERMETURE verifies the leak tightness of the vessel closure.

3.7.2.7.3.3 *SYSTUS.* SYSTUS (Reference 80) is designed to analyze the thermal-mechanical behavior of beams and solid structures in two or three dimensions.

3.7.2.7.3.4 *RCCM-ASME.* RCCM-ASME Program (Reference 81) is a special postprocessor of SYSTUS that allows manipulation of SYSTUS results for stress analyses in accordance with the rules defined by the ASME Code Section III including stress linearization, usage factor calculation and thermal ratchet analysis.

3.7.3 Seismic Analysis for Piping Systems

3.7.3.1 **Stone & Webster Analyses and Design Criteria of Seismic Class I Piping**

3.7.3.1.1 General Analytical Procedure

Analyses of Seismic Class I piping systems are based on criteria and procedures specified in the ASME Boiler and Pressure Vessel Code, Section III (including the 1971 Winter Addenda), which satisfies all the requirements of ANSI-B31.7, Nuclear Power Piping Code (1969 edition). Reanalysis of the pressurizer surge line to account for the effect of thermal stratification and striping was performed in accordance with the requirements of ASME Boiler and Pressure Vessel Code, Section III, 1986 and addenda through 1987, incorporating high cycle fatigue as required by NRC Bulletin 88-11.

Seismic analyses of Class I piping, which include all ASME Code Classes 1, 2, and 3 piping systems, are performed by the modal analysis response spectra method. Original plant pipe stress analyses utilized a combination of SHOCK3, PIPESTRESS, NCCODE, and STRESSCOMBINER computer programs as required. Certain subsequent pipe stress analyses have utilized the NUPIPE-SW computer program (Reference 55) which can perform a complete piping analysis/qualification. A majority of the discussion in Section 3.7.3.1.1 (General Analytical Procedure) and Section 3.7.3.1.2 (Basic Steps and Equations Used in the Analytical Procedure) contains specific reference to analytical techniques used by the SHOCK3, PIPESTRESS, NCCODE, and STRESSCOMBINER computer programs. However, reference to code equations and damping values within these sections is applicable to all analyses regardless of which computer program is being utilized. A description of the NUPIPE-SW computer program is contained in Section 3.7.3.1.2.5. Each piping system is idealized mathematically as an elastically coupled dynamic structural model in three-dimensional space. Inertial characteristics of the piping system are simulated by discrete masses of piping components, including all eccentric masses such as valves and valve operators, lumped at selected nodes. For piping analyses which utilize the NUPIPE-SW program, the complete qualification/analysis is performed by the NUPIPE-SW computer program. For other analyses, the following programs are used. The stiffness matrix of the piping system is calculated by Stone & Webster's computer program, PIPESTRESS (Reference 43). Modal seismic responses at each node of the piping system, due to amplified response spectra excitation applied at its support points, are calculated by Stone & Webster's computer program, SHOCK3. The modal analysis technique used in SHOCK3 computes the peak response quantities for each mode. These quantities are then combined in Equation 3.7-29 of Section 3.7.3.1.2.4. Normal mode, linear elastic, and small displacement theory are incorporated in SHOCK3 and PIPESTRESS.

Structural response spectra, consisting of peak responses of a family of seismic loadings for the piping systems, are the amplified response spectra, obtained for discrete locations in the structure where the piping system is supported. (See Section 3.7.2 for the development of the amplified response spectra.) Damping factors used for critical piping and components are 0.5% for the operating-basis earthquake and 1% for the design-basis earthquake. As an alternative, the following damping values given in the ASME Code Case N-411 may be used for both the operating-basis earthquake and the design-basis earthquake. These values specifically are: 5% below frequency of 10 Hz; linear reduction from 5% to 2& between 10 Hz and 20 Hz and 2% above 20 Hz. These damping values are used in the following situations and the following additional considerations:

1. For seismic analyses in cases where new piping is added, existing systems are modified, existing systems are re-evaluated and for support optimization.
2. For seismic analyses using response spectrum methods and not for seismic analyses using time-history analyses methods.
3. When these alternate damping values are used, they are used in a given analysis in their entirety.
4. When these damping values are used together with changes in the support arrangement that increases the flexibility of piping systems, the predicted maximum displacements are reviewed to ensure that such displacements do not cause adverse interaction with adjacent structures, components or equipments.
5. When these damping values are used, the ±15% peak broadening criteria of Regulatory Guide 1.122, *Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components*, are used.

The uncertainties in the calculated values of fundamental structural frequencies due to expected variations in subgrade and structural material properties are taken into account. The peak resonant period value(s) in the amplified response spectra developed in Section 3.7.2 are subject to variations of 15% for Units 1 and 2 and its site. Accordingly, piping systems designed using amplified response spectra having modal periods within ±15% of the peak resonant period(s) are assigned the peak response value(s). Outside this range, the amplified response spectra are used exactly as stated.

Where a piping system is subjected to more than one amplified response spectrum, such as support points located in different parts of the structure, the amplified response spectrum closest to and higher in elevation than the center of mass of the piping system is applied to the system.

Relative seismic structural displacements between piping supports and anchor points (i.e., between floor penetrations and equipment supports at different elevations within a building, and also between buildings) are used as inputs of equivalent static boundary displacement conditions in SHOCK3. Relative seismic displacements between pipe support points in different buildings are always considered to be out of phase, to obtain the most conservative piping responses.

Internal moments and forces in all Seismic Class I piping systems, due to relative seismic motion between piping supports for each of the three orthogonal directions, are computed separately at each mass node by SHOCK3. The square root of the sum of the squares of the internal moments and displacements, due to all three differential seismic motions, are superimposed at each mass node with the moments and displacements due to inertial effects computed in Equation 3.7-29 (Section 3.7.3.1.2.4), resulting in the total seismic response in each global coordinate direction of the piping system.

Internal moments and forces computed by SHOCK3 as the seismic responses of the piping system are combined with responses from deadweight, pressure, thermal, and other mechanical loads to complete the stress analysis of all Seismic Class I piping. For ASME Code Class 1 piping, stress intensities and cumulative usage factors of the piping system are computed by Stone & Webster's computer program NCCODE, based on formulations specified in Subarticle NB-3600. For ASME Code Class 2 and Class 3 piping, maximum stresses are computed by Stone & Webster's computer program, STRESSCOMBINER, based on formulations specified in Subarticles NC-3600 and ND-3600.

The seismic design and analysis criteria for ASME Code Classes 1, 2, and 3 are defined in Table 3.7-2. The design loading combinations and stress limits for Seismic Class I piping systems are defined in Table 3.7-3.

3.7.3.1.2 Basic Steps and Equations Used in the Analytical Procedure

3.7.3.1.2.1 *Flexibility/Stiffness Influence Coefficient Matrix.* The flexibility influence coefficient matrix, [δ], as defined here, gives the deflections in the structure due to unit loads at each static degree of freedom. This matrix is related to the stiffness matrix by the following:

$$[\delta]\,[K] = [I] \qquad (3.7\text{-}23)$$

where:

[K] = the square stiffness matrix of all mass nodes of the piping system obtained by combining the stiffness of individual piping elements

[I] = unit matrix

The flexibility matrix of each beam element includes the coupled axial, bending, shear, and torsional flexibilities. The size of the stiffness matrix for each piping structural element is 12 x 12, since six forces and moments and six deflections and rotations are considered by the piping flexibility program in each of the two nodes of an element.

The unrestrained general stiffness matrix [K] of a dynamic structural model is condensed to a square reduced-stiffness matrix [k]. This procedure excludes rigid constraints and condenses rotational stiffness coordinates into dependent coordinates of the translational displacement stiffness matrix (Reference 44).

3.7.3.1.2.2 *Normal Mode Frequencies and Mode Shapes.* After development of stiffness and mass matrices, natural frequencies and their associated mode shapes are determined by solution of the following equations:

$$[[k] - w_i^2 [m]] [Q_i] = 0 \qquad (3.7\text{-}24)$$

where:

[k] = square reduced-stiffness matrix

$[w_i]$ = natural frequencies of system (i = 1, 2,.....n)

[m] = mass matrix

$[Q_i]$ = mode shape vector associated with the ith mode

Through the use of SHOCK3, the w values and $[Q_i]$ matrix for each of the n modes are computed (i = 1, 2.....n, where n equals degrees of freedom of the piping system dynamic structural model).

3.7.3.1.2.3 *Modal Response Quantities.* For the acceleration response spectrum method of analysis, the maximum displacements in global coordinates are:

$$\{y_{max}\}_n = [Q]\{q_{max}\} \qquad (3.7\text{-}25)$$

where:

[Q] = square matrix containing an eigenvector for each mode

$\{q_{max}\}$ = maximum generalized displacement vector

$$= [w_n^2]^{-1} [S_a][M_n]^{-1} [Q]^T [m] \{D\} \qquad (3.7\text{-}26)$$

and:

$[M_n]$ = generalized mass = $[Q]^T[m] [Q]$

{D}= direction vector

$[S_a]$ = matrix of spectral acceleration values

Equation 3.7-25 is rewritten as:

$$\{y_{max}\} = [Q] [w_n^2]^{-1} [S_a] [\Gamma]_n \qquad (3.7\text{-}27)$$

where:

$[\Gamma]_n$ = participation factor of the system

$= [M_n]^{-1} [Q]^T [m] \{D\}$ in Equation 3.7-26

Inertia forces for each mass point are then calculated:

$$\{F_{max}\}_n = \underset{(nxn)}{[M]} \; \underset{(nxd)}{[Q]} \; \underset{(dxd)}{[W_d^2]} \; \underset{(dxi)}{q_{max}} \qquad (3.7\text{-}28)$$

where:

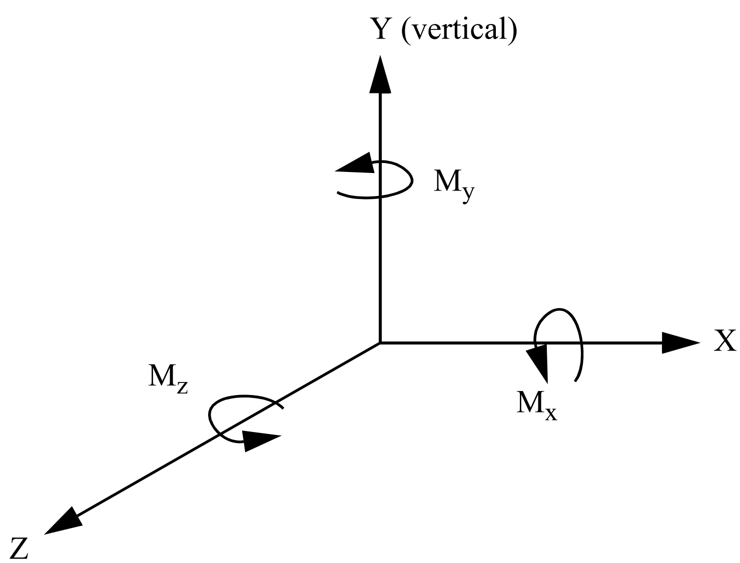
d = number of modes considered

3.7.3.1.2.4 *Combined Response Quantities.* To predict maximum responses due to seismic excitation, modal responses are combined by one of the following procedures.

1. Compute modal internal moments due to dynamic responses of inertial forces by X-direction input spectrum for each mode. Repeat it for Y-direction and Z-direction input spectra, respectively. The notation of the internal moment of ith mass around the x-axis due to jth mode dynamic responses of system by X-direction earthquake spectrum is $(M_{ix})_{jx}$ where:

   i = number of mass, i = 1, 2, 3....N

   j = number of modes employed, j = 1, 2, 3....d



Nine arrays (sizes N x d) of internal moments are computed:

$(M_{ix})_{jx}$	$(M_{iy})_{jx}$	$(M_{iz})_{jx}$
$(M_{ix})_{jy}$	$(M_{iy})_{jy}$	$(M_{iz})_{jy}$
$(M_{ix})_{jz}$	$(M_{iy})_{jz}$	$(M_{iz})_{jz}$

Internal moments for each ith mass are combined statistically in Equation 3.7-29:

$$M_x = \sqrt{\sum_{j=1}^{d} \left[\sqrt{(M_{ix})^2_{jx} + (M_{ix})^2_{jz}} + \left|(M_{ix})_{jy}\right| \right]^2}$$

$$M_y = \sqrt{\sum_{j=1}^{d} \left[\sqrt{(M_{iy})^2_{jx} + (M_{iy})^2_{jz}} + \left|(M_{iy})_{jy}\right| \right]^2} \qquad (3.7\text{-}29)$$

$$M_z = \sqrt{\sum_{j=1}^{d} \left[\sqrt{(M_{iz})^2_{jx} + (M_{iz})^2_{jz}} + \left|(M_{ix})_{jy}\right| \right]^2}$$

The procedure used for combining maximum modal responses of seismic subsystems is based on the square root of the sum of squares (SRSS) of the vectorial sum of two orthogonal horizontal modal responses, and the vertical modal responses.

For a single-degree-of-freedom linear system oriented arbitrarily with respect to horizontal directions, the vectorial sum of the responses by considering both horizontal components of the spectra is an upper bound of the response of the system (Reference 45). Since the seismic analysis of the piping system is based on eigensolutions of the system's dynamic structural model, this method is conservative in computing both piping seismic responses and seismic reactions on equipment and supports.

2. The seismic inertia calculations are performed for each of the three component directions of earthquake individually. To combine the responses due to each earthquake within each mode, the method of SRSS combination is used. The modal responses are summed by the grouping method. Two consecutive modes are defined as closely spaced if their frequencies differ from each other by ten percent or less of the lower frequency.

   The effects of each of the three components of earthquake (two horizontal and one vertical) are combined by the SRSS method.

The SRSS method is an acceptable procedure if certain approximations in random vibration analysis for earthquake effects in the amplified response spectra are made (Reference 46). Justifications of the applicable amplified response spectra in comparison to the time-history analysis of primary systems are presented in Appendix 3B.

The approach used in the SRSS method—both in Reference 46 and in the Stone & Webster analyses—is based on the assumption that an earthquake is a stationary random process, with no need for any special consideration of the spacing of the modes of the secondary systems.

Section 3.7.3.1.2.2 shows a comparison of responses obtained by the time-history method and the response spectrum method for structures. Examination of mode frequencies reveals that closely spaced frequencies occur at higher modes that have an insignificant contribution to the total response of the structure.

3.7.3.1.2.5 *Description of NUPIPE-SW Computer Program.* The following is a brief description of the analytical procedure used in the NUPIPE-SW computer program. A detailed description of the subject computer program can be obtained in the NUPIPE-SW users manual which is on file at Stone and Webster Engineering Corporation offices.

3.7.3.1.2.5.1 *General Description.* The basic method of analysis used is the finite element stiffness method. The continuous piping is mathematically idealized as an assembly of elastic structural members (simple beam elements) connecting discrete nodal points. System loads and displacements such as deadweight, equivalent thermal forces, earthquake inertia forces, and anchor displacement are applied at the nodal points. Piping system restraints are represented by stiffness values.

Analysis for each type of load is performed individually, either statically or dynamically, and results superimposed on the results of other load analyses as required to meet stress requirements of the appropriate codes. Loadings such as pressure, thermal expansion, deadweight, and building and support point motions are typically evaluated by static analysis. Response of a piping system to seismic excitation and other occasional loads, such as flow-induced transients, is commonly determined utilizing dynamic methods of analysis.

3.7.3.1.2.5.2 *Static Analysis.* The static events to be considered in the design and analysis of a nuclear piping system include the loads resulting from deadweight, applied forces, thermal expansion, uniform acceleration, and anchor movement conditions. For static loadings representing these conditions, the following equation is used:

$$F = Ku \quad \text{......................................} \quad \text{A-1} \qquad (3.7\text{-}30)$$

where F = The applied nodal force

K = The global stiffness matrix

u = The unknown displacement

The global stiffness matrix is formulated by adding the contributions of the element and support stiffnesses. Depending on the load case, NUPIPE may form appropriate types of static stiffness matrices.

The unknown nodal displacements are obtained in NUPIPE by solving the simultaneous equations resulting from equation A-1, using the Gauss method. These nodal displacements are then applied to the individual members, and the member stiffness used to determine the internal forces. The nodal displacements at support locations can be used along with the stiffnesses to determine support reactions.

3.7.3.1.2.5.3 *Dynamic Analysis.*

3.7.3.1.2.5.3.1 *Response Spectra Method.* The mathematical model utilized for static analysis is supplemented through addition of concentrated mass points at suitable locations (nodal points) to provide response to the particular type of dynamic loading being considered.

The eigenvalues (natural frequencies) and the eigenvectors (mode shapes) for each of the natural modes are calculated by solving the frequency equation. The natural mode shapes are then used to effect an orthogonal transformation of equation of equilibrium. This yields a series of independent equations of motion uncoupled in the system modes. The uncoupled equations are solved by either the step-by-step integration or the response spectrum method to obtain system response within each mode, and the individual modal results are combined to determine the total system dynamic response.

System response to seismic disturbance is obtained using the method of modal superposition. The inertia forces are calculated for each of the system natural modes and applied as static forces in the same manner as the weight or equivalent thermal forces in order to find internal forces and moments in each mode. A system response is then obtained.

3.7.3.1.2.5.3.2 *Time History with Modal Superposition.* The stress analysis for dynamic forces resulting from safety or relief valve blowdown or steam and waterhammer analysis is generally performed by direct time history integration using the same discrete beam element model described above. The equation of motion is written for each normal mode. It is solved directly in finite time increments for the generalized displacement. The total generalized displacement is transformed using the mode shape vector to form the system total displacement vector. This transformation is performed for each mode for each time step. These modal displacements are then applied to the system to determine internal forces, moments, and reactions for each mode for each time step. Finally, the modal responses at each time step are combined directly to form total response for each time step.

3.7.3.1.3 Analytical Procedure and Design Criteria

3.7.3.1.3.1 *ASME Code Class 1 Piping.* The ASME Code Class 1 piping systems are analyzed using NUPIPE-SW or NCCODE, based on formulations and criteria specified in Subarticle NB-3650. Subarticle NB-3112.3(b) requires a number of earthquake cycles and seismic events used in the analyses of the ASME Code Class 1 components to be specified as part of the piping design criteria. The specifications are as follows:

1. A total of five operational-basis earthquake (OBE) (one-half safe-shutdown earthquake) and one design-basis earthquake (DBE) (safe-shutdown earthquake) seismic events will occur during the life of plant.
2. One hundred seismic stress cycles are imposed on the piping system during each operational-basis earthquake.

3.7.3.1.3.2 *ASME Code Class 2 and Class 3 Piping.* The ASME Code Class 2 and Class 3 piping systems are analyzed using NUPIPE-SW or STRESSCOMBINER, based on formulations specified in Subarticles NC-3600 and ND-3600. The seismic stresses are governed by the following allowables:

Pressure stress (S_{1p}) + dead load stress $(S_{d1}) \leq S_L$ (3.7-31)

Pressure stress + dead load stress + OBE stress $\leq 1.2\ S_h$ (3.7-32)

Pressure stress (S_{1p}) + dead load stress (S_{d1}) + DBE stress $\leq 1.8\ S_h$ (3.7-33)

Thermal stress $\leq (1.25\ S_c + 0.25\ S_h)\ f + (S_h - |\ S_{1p} + S_{d1}\ |)$ (3.7-34)

where:

S_h = allowable stress of material at hot temperature (Tables I-7.1, I-7.2, I-8.1, and I-8.2 of ASME Code Section III)

S_c = allowable stress of material at cold temperature (Tables I-7.1, I-7.2, I-8.1, I-8.2 of ASME Code Section III)

f = stress range reduction factor for cyclic condition (Table NC-3611.1(b)(3)-1 of ASME Code Section III)

Equation 3.7-31 is based on Subarticle NC-3611.(c) for normal condition.

Equation 3.7-32 is based on Subarticles NC-3611.(c) and NC-3612.3, which state that seismic events of operational-basis earthquake for normal and upset conditions occur for less than 1% of the operating period. The stress limit is increased 20%.

Equation 3.7-33 is based on Subarticles NB-3652 and NB-3655, which state that a stress limit of 2.25 S_m for emergency condition (during DBE occurrence) is 1.5 times greater than the stress limit of 1.5 S_m for normal and upset conditions (during OBE occurrence). Based on the stress limit of 1.2 S_h for ASME Code Class 2 and Class 3 piping, in normal and upset conditions, the stress limit for emergency/faulted condition is thus derived to be 1.5 times 1.2 S_h, or 1.8 S_h.

Equation 3.7-34 is based on Subarticles NC-3611.(b)(3) and (b)(4).

All stress calculations for ASME Code Class 2 and Class 3 piping are based on equations given in Subarticle NC-3672.9, including bending and torsional effects. All inertial effects of eccentric mass, such as valve and valve operators connected to the piping system, are included in the dynamic structural model for the stress analysis.

Dynamic force loadings, resulting from sudden closure of an isolation valve or a turbine throttle valve on the piping system (for example, transient loading on steam line due to turbine trip), are to be included as occasional mechanical loads in piping analysis. For the steam generator replacement efforts at North Anna, the STEHAM computer program was utilized to determine dynamic force loads resulting from a main steam line break. Constraints or hydraulic snubbers are used as required to control excessive displacements or moments due to these transient loadings.

Field located seismic supports and constraints for Seismic Class I piping systems, including snubbers and dampers, are installed in accordance with seismically designed piping shown on approved construction drawings. Inspections are conducted to verify that these seismic restraints are fabricated and located in accordance with the construction plan and other applicable documents.

3.7.3.1.3.3 *Buried Seismic Class I Piping.* Responses of buried Seismic Class I piping to differential ground motion, due to particle motions caused by seismic wave propagations, are calculated by a method reported by N. M. Newmark (Reference 45). It can be shown that in the rock-founded site of the plant, the transverse bending stress due to shear wave propagation along buried pipe will be negligible. Axial tension and compression, due to differential ground motion on buried pipes, are minimal in rock-founded site.

Reactions and bending moments of buried Seismic Class I piping, due to differential motion at structural penetrations, are calculated by considering a buried pipe as a semi-infinite beam on an elastic soil foundation with full restraint at structural penetrations. The maximum expected seismic displacements at the structural penetration and the maximum modulus of the soil foundation are used to calculate the stress. The results are superimposed with axial tension-compression stress to meet the requirements defined in Subarticles NC-3600 and ND-3600. If these stresses are found to be excessive, the seismic design of the underground piping within concrete or steel conduits (unattached to any structure), with or without expansion joints, is incorporated into the system.

3.7.3.1.3.4 *Seismically Induced Effects of Other Piping on Seismic Class I Piping.* To prevent propagation of failure from seismically induced effects of non-Seismic Class I piping to Seismic Class I piping, each non-Seismic Class I piping system is isolated from any Seismic Class I piping system by either a constraint or barrier, or is remotely removed from the location of the Seismic Class I piping system. If it is not practical to isolate the Seismic Class I piping system from the non-Seismic Class I piping system, adjacent non-Seismic Class I piping is seismically designed according to the same criteria as applicable to the Seismic Class I piping.

3.7.3.1.3.5 *Small-Size Seismic Class I Piping.* ASME Code Class 1 piping systems 1-inch NPS or below, such as sample, drain, and instrument lines, and ASME Code Class 2 and Class 3 systems, 6-inch NPS and smaller, are subjected to analyses using acceleration values from the amplified response spectra. The length of span between supports is selected so that the fundamental frequency is removed from the resonant band of the amplified shock spectra as specified in Section 3.7.3.1.3.7.

The combined stresses are also checked by Equations 3.7-31, 3.7-32, 3.7-33, and 3.7-34, as defined in Section 3.7.3.1.3.2.

3.7.3.1.3.6 *Pressure Relief Piping.* The installation criteria for mounting of all pressure relief devices (safety and relief valves) and for governing materials, fabrication, examination, testing, inspection, stamping, and reporting are in accordance with the rules in Subsections NB, NC, and ND of ASME Code Section III, applicable to the classification of the piping system involved.

The design criteria for all safety relief valves are in accordance with the rules in Subarticles NB-3677 and NC-3677, applicable to the classification of the piping system involved. In particular, the design criteria and analyses used to calculate maximum stresses and stress intensities are in accordance with Subarticles NB-3600 and NC-3600. Maximum stresses on each valve nozzle are calculated based on full-discharge loads (thrust and bending) and internal design pressure. Maximum stress intensity in the run pipe, or header, under full-discharge loads (thrust, bending, and torsion) and internal design pressure is also computed by Stone & Webster's PITRUST computer program (Reference 47).

In the case of safety or relief valve(s) mounted on a common header and full discharge occurring concurrently, the additional stresses induced in the header are combined with the previously computed local and primary membrane stresses to obtain the maximum stress intensity.

3.7.3.1.3.7 *Simplified Analysis of Seismic Class I Piping.* The basic approach to the design of small-size ASME Class 1 piping (1-inch NPS and smaller), and ASME Class 2 and Class 3 piping (6-inch NPS and smaller), is to make the system relatively rigid whenever engineering design criteria dictate.

The space between pipe constraints is selected so that the fundamental frequency, fp, of the piping section is always greater than 1.5 fs where fs is the highest peak resonant frequency of the structure, as determined from applicable amplified response spectra. Inertial loads ("g" factor) from the operational-basis earthquake and the design-basis earthquake are conservatively set at one-half the peak acceleration of the operational-basis earthquake and the design-basis earthquake response spectra, respectively, using this predetermined span. The dead weight stresses are multiplied by the applicable "g" factor in the X, Y, and Z directions, as specified, which are set at one-half the peak acceleration, or 0.5g minimum; this multiplication produces the seismic stress induced by the operational-basis earthquake and the design-basis earthquake, respectively, in all three directions. The seismic stress calculation is based upon equations in Subarticle NC-3672.9. The "g" factors for the X, Y, and Z directions are specified explicitly for each problem. Pressure stress is calculated as per Subarticle NC-3611.1.(4).(b).

Allowable thermal stresses, based on Subarticle NC-3611.1, of the piping sections are calculated under applicable boundary conditions.

This simplified analytical approach is to perform stress calculations for small-size pipes in a sectionalized "between supports" manner without using computer analyses. This is justifiable because a rigid system with sufficient pipe supports represents many one-dimensional, straight-beam problems, wherein the coupling effects of the three-dimensional piping systems are eliminated. Constraints are placed near elbows, tees, and concentrated masses, such as valves, etc., so that coupling effects are negligible. These calculations of maximum combined stresses provide sufficient and conservative data to satisfy the requirements of Subarticle NC-3600 as specified by Equations 3.7-31, 3.7-32, 3.7-33, and 3.7-34 in Section 3.7.3.1.3.2.

3.7.3.2 **Summary of Equipment Design Procedures**

Seismic Class I systems and components are those necessary to ensure:

1. The integrity of the reactor coolant pressure boundary.
2. The capability to shut down the reactor and maintain it in a safe-shutdown condition.
3. The capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposures comparable to the guideline exposure of 10 CFR 50.67.

All Seismic Class I equipment is evaluated for seismic adequacy. Depending on equipment location, the basic source of seismic design data is either the ground response spectra or the amplified response spectra derived through a dynamic analysis of the relevant structure (see Section 3.2.1) including amplification, if any, through the intervening system or component (e.g., through piping or cabinets).

These spectra are developed and used for equipment consistent with the damping factors tabulated in Table 3.7-1, or as justified by test. The uncertainties in the calculated values of fundamental structural frequencies due to reasonable variations in subgrade and structural properties are taken into account. The peak resonant period value(s) in the amplified response spectra developed as described in Section 3.7.1 are subject to variations of +15% and -15% for this plant and site. Accordingly, equipment designed using these amplified response spectra having modal periods within +15% and -15% of the peak resonant period(s) are assigned the peak resonant response value(s). Beyond this range, the amplified response spectra are used exactly as shown.

These requirements pertain to all Seismic Class I equipment regardless of industry code or code classification. The requirements for seismic qualification are intended either to supplement existing industry analytical requirements where applicable, or to provide documentation of component adequacy to combined normal plus earthquake loads where no documentation requirements currently exist. All acceleration ("g") factors and analyses are based on elastic analysis exclusively.

Four principal categories of evaluation are considered. These are:

1. Static analysis.
2. Dynamic analysis
3. Testing.
4. Earthquake experience-based method developed for Unresolved Safety Issue (USI) A-46.

3.7.3.2.1 Static Analysis

Static analysis is used for equipment that can be characterized as a relatively simple structure. This type of analysis involves the multiplication of the equipment or component total weight by the specified seismic acceleration component (direction-dependent loading) to produce forces that are applied at the center of gravity in the horizontal and vertical directions. A stress analysis of equipment components such as feet, hold-down bolts, and other structural members, is performed to determine their adequacy.

In the specification of equipment for static analysis, two or more sets of acceleration data are provided, the choice of which set to use depending on the fundamental equipment natural frequency. For the particular or "worst" equipment location, the relevant response curves are reviewed to determine a "cutoff frequency," which bounds the rigid range from the resonance range of the response curves. Components having fundamental natural frequencies above the cutoff frequency are analyzed to rigid range response accelerations. For components having a fundamental natural frequency below the cutoff frequency, analysis is based on response accelerations that are not less than those indicated by the curves over the full-frequency range of the component. If the fundamental mode of the component falls within any of the "broadened" resonant response peaks existing in the component frequency range, the resonant response acceleration is increased by 30% as an arbitrary factor for conservatism to account for all significant dynamic modes under a resonant situation.

3.7.3.2.2 Dynamic Analysis

A detailed dynamic analysis is performed when component complexity or dynamic interaction precludes static analysis, or when static analysis is too conservative.

3.7.3.2.2.1 *Modeling.* To describe fully the behavior of a component subjected to dynamic loads, infinite numbers of coordinates would be required. Since calculation at every point of a complex model is impractical, the analysis is simplified by a judicious selection of a limited number of mass points. The lumped-mass or the consistent-mass approach is used in the dynamic analysis. In the lumped-mass and in the consistent-mass idealization, the main structure is divided into substructures and the masses of these substructures are concentrated at a number of discrete points. The nature of these substructures and the stiffness properties of the corresponding modeling elements determine the minimum spacing of the mass points and the degrees of freedom to associate to each point. In accordance with the minimum spacing requirements, the analyst can then choose, for the model, particular mass points that reflect predominant masses of components that are believed to give significant contribution to the total response.

In cases for which some dynamic degrees of freedom do not contribute to the total response, static or kinematic condensation is used in the analysis.

3.7.3.2.2.2 *Method of Analysis.* The normal mode approach is used for seismic analysis of components. Natural frequencies, eigenvectors, participation factors, and modal member end forces and moments of the undamped structure are calculated. The system of equations that describe the free vibrations of an n-degree-of-freedom, undamped structure is:

$$[M]\ \{\ddot{x}\} + [K]\ \{x\} = 0 \qquad (3.7\text{-}35)$$

where:

[M] = mass matrix

[K] = stiffness matrix

$\{x\}$, $\{\ddot{x}\}$ = displacement, acceleration vectors

The mode shapes and frequencies are solved in accordance with

$$[K - w_n^2 M] \qquad \{\phi\}_n = 0 \qquad (3.7\text{-}36)$$

where:

w_n = frequency of the nth mode

$\{\phi\}_n$ = mode shape vector for the nth mode

Eigenvector, eigenvalue extraction routines such as Householder-QR, Jacobi Reduction, and Inverse Iteration are used, depending on the total number of dynamic degrees of freedom and the number of modes desired.

For each mode, the participation factor for the specific direction i is defined by:

$$\Gamma_{ni} = \frac{\{\phi\}^T[M]\{D\}_i}{\{\phi\}^T[M]\{\phi\}} \qquad (3.7\text{-}37)$$

where:

$\{\phi\}^T$ = transpose of mode shape vector for the nth mode

$\{D\}_i$ = earthquake direction vector referring to direction i

The modal member-end forces and moments are determined by:

$$\{F_m\}_n = [K_m]\ \{\phi\}_n \qquad (3.7\text{-}38)$$

where:

$[K_m]$ = member stiffness matrix

For each modal frequency, the corresponding response acceleration is determined for a given level of equipment damping from the applicable response curve.

The maximum response for each mode is found by computing:

$$\{\ddot{x}\} = \Gamma_{n_i} R_{n_i}\{\phi\}_n \qquad (3.7\text{-}39)$$

$$\{\dot{x}\} = \frac{1}{W_n}\{\ddot{x}\}_n \qquad (3.7\text{-}40)$$

$$\{x\} = \frac{1}{W_n^{\ 2}}\{\ddot{x}\}_n \qquad (3.7\text{-}41)$$

$$\{F\}_n = \frac{\Gamma_n R_{n_i}}{W_n^{\ 2}}\{F_m\}_n \qquad (3.7\text{-}42)$$

where:

$\{\ddot{x}\}_n$ = modal acceleration

$\{\dot{x}\}_n$ = velocity

$\{x\}_n$ = displacement

$\{F_m\}$ = member-end force

R_{n_i} = spectral acceleration for the nth mode in the i direction

The total combined seismic results are obtained by taking the square root of the sum of the squares of each parameter under consideration.

$$\{x\}_{srss} = \sqrt{\sum_n \{x\}_n^{\ 2}} \qquad (3.7\text{-}43)$$

$$\{\dot{x}\}_{srss} = \sqrt{\sum_n \{\dot{x}\}_n^{\ 2}} \qquad (3.7\text{-}44)$$

$$\{\ddot{x}\}_{srss} = \sqrt{\sum_n \{\ddot{x}\}_n^{\ 2}} \qquad (3.7\text{-}45)$$

$$\{F\}_{srss} = \sqrt{\sum_n \{F\}_n^{\ 2}}$$

where the summation Σ_n includes all significant modes.

Tables 3.7-4 and 3.7-5 present margins for the actual calculated stress levels to the allowable stress levels for Stone & Webster-supplied mechanical and structural equipment that was qualified by analysis. These stress levels are not failure levels, but conservative allowables, permitted by codes and standards. Thus, substantial additional margin exists beyond code limitations to that which would compromise equipment functions.

3.7.3.2.2.3 *Testing.* Equipment that is tested is qualified in accordance with plant owner's designated engineer's general instructions for earthquake requirements. For tested equipment, these requirements either supplement other applicable industry standards (such as the IEEE Standard for Seismic Qualification of Class I Electric Equipment for Nuclear Power Generation Stations, STD-344-1971, 1975, or 1987) or provide guidance for testing where no such codes are available. Equipment packages or components are shown adequate either by being tested individually, as part of a simulated structural section, or as part of an assembled module or unit. In any case, the minimum acceptance criterion must include:

1. No loss of function, or ability to function, before, during, or after the proposed test.
2. No structural/electrical failure (i.e., connections and anchorages) that would compromise component integrity.
3. No adverse or maloperation before, during, or after the proposed test that could result in an improper safety action.

Equipment vendors and suppliers are required to formulate a program for qualifying the equipment in accordance with the conditions specified in the earthquake requirements.

General testing guidance criteria specified for components include the following:

1. A frequency scan (standard logarithmic sweep) at a constant acceleration level is performed for as much of the range between 2 and 50 Hz as practicable or justified. The objective of this test is to determine the natural frequencies and amplification factors of the tested equipment and its critical components or appurtenances and to ensure general seismic adequacy over the full frequency range of interest. The acceleration inputs used are the maximum rigid-range accelerations indicated by the relevant response spectrum curves (damping independent).
2. A "dwell test" of the equipment at its fundamental natural frequency is included at the acceleration values specified in 1, above. Additionally, other frequencies are selected if amplification factors of 2.0 or more are indicated. A 20- to 60-second duration is considered acceptable for each "dwell."
3. The test is conducted in three orthogonal directions individually, or in a manner that adequately represents vertical and horizontal forcing simultaneously for each of two orthogonal horizontal directions.

Qualification programs for random or sinusoidal beat excitation are considered acceptable alternatives to the sinusoidal vibration test criteria outlined above. Also given consideration are laboratory shock results, in-shipment shock data, or adequate historical dynamic adequacy data (i.e., previous relevant test or environmental data). The method of test selected must demonstrate the adequacy of principal structural and functional components of the equipment.

Table 3.7-6 provides historical information on representative safety-related components within Stone & Webster scope of supply that have been qualified by seismic tests. Included is pertinent information regarding the equipment, testing facilities, testing programs, and results. All of the equipment was concluded to be adequate for the North Anna 1 and 2 site with adequate margin. Details of the test results, i.e., the location, number, and type of acceleration and performance monitors, and the capability of test machines, are very lengthy and have not been incorporated into this table. These specific details are contained in the test reports.

Substantial margin is available with reference to an increase in seismic loads for the majority of the equipment identified in Table 3.7-6. Margin, as noted herein, is defined as the ratio of test acceleration to required acceleration. The majority of qualified equipment has been shown to have test margins in excess of 20%, while much of the equipment has been shown to have the capability to withstand an earthquake of at least twice the design accelerations. For other equipment for which large margins are not evident, additional information, entitled “Comments,” is provided. It should be noted that this information, as well as experience with other similar tested equipment installed at other job sites, provides the basis for the rationale in presenting engineering judgements.

3.7.3.2.2.4 *Earthquake Experience-based Method Developed for Unresolved Safety Issue (USI) A-46*. In response to U.S. Nuclear Regulatory Commission Generic Letter 87-02 on USI A-46, Verification of Seismic Adequacy of Mechanical and Electrical Equipment in Operating Reactors, a Generic Implementation Procedure (GIP) was developed by the Seismic Qualification Utilities Group (SQUG). The criteria and methodology in Revision 3 of the GIP (Reference 61), as modified and supplemented by the NRC Supplemental Safety Evaluation Report (SSERs) 2 and 3, (References 62 & 63) may be used, with certain additional considerations, as an alternative to other licensing basis methods for seismic design and verification of existing, modified, new and replacement equipment classified as safety-related, NSQ or seismic category 1. Considerations that are additional to the GIP pertain to the following issues:

- Use of GIP Method A for estimating seismic demand.
- Additional criteria applicable for the design and analysis of new flat bottom vertical tanks.
- Applicability of Part II, Section 5 of the GIP and damping values and static coefficient for conduit and cable tray raceways evaluation.
- Use of criteria associated with damping, static coefficient and expansion anchor safety factors for equipment anchorage evaluations conforming to current, conservative, licensing basis commitments.

- Documentation of the results of the Screening Verification and Walkdown in Section 4.6 of the GIP may be limited to the use of walkdown checklists. It is not necessary to complete the Screening Verification Data Sheets (SVDS).
- It is not necessary to identify “essential relays” and perform functionality screening as defined in Section 6 of the GIP. Relays designated as Class 1E are evaluated by comparing seismic capacity to seismic demand.
- The GIP method is generally applicable only for equipment located in mild environment. However, with case-by-case justification, it may be used for equipment in harsh environment.

Guidance for the use of the GIP for the seismic design and verification of mechanical and electrical equipment, including a discussion of the above considerations, is provided in an engineering procedure (Reference 77).

3.7.3.2.3 Specification Requirements

Within these three general categories, all Seismic Class I equipment furnished is shown to meet the requirements for the operational-basis earthquake and design-basis earthquake. These requirements are as follows.

3.7.3.2.3.1 *Operational-Basis Earthquake.* Equipment is designed to be capable of continued operation, with the normal operating loads acting simultaneously with both horizontal and vertical components of the OBE loads (see Section 2.5.2). Horizontal and vertical seismic loads are added, considering a horizontal-direction earthquake acting concurrently with the vertical-direction earthquake. One or more directions of the horizontal earthquake are considered on a “most-severe basis.” The stress levels due to these combined loading conditions are kept within maximum working stress limits permitted under applicable design standards, AISC Manual of Steel Construction, ASME Boiler and Pressure Vessel Code, AWWA Standards, or other codes or specifications. If no codes are used, the stress level under the combined loading is limited to 90% of the minimum yield strength of the material, per the ASTM Specification.

3.7.3.2.3.2 *Design-Basis Earthquake.* The equipment is designed to withstand the combined effects of all normal operating loads acting simultaneously with DBE loads (Section 2.5.2) without loss of function or structural integrity. Horizontal and vertical seismic loads are added, considering a horizontal-direction earthquake acting concurrently with the vertical-direction earthquake, again on the “most-severe basis.” It is permissible to allow strain limits in excess of yield strain in safety-related components during the design-basis earthquake and under postulated concurrent conditions, provided the necessary safety functions are maintained. These limits were defined and used only with reference to specific design codes, such as ASME Section III, which allow such limits for this loading.

3.7.3.2.3.3 *Coupled Items.* In the course of analysis, a comparison of relative mass and stiffness properties between connected components is performed. If this comparison indicates that the possibility of dynamic interaction is small, the interface is assumed to be an anchor. For this to be valid, the natural frequencies of connected components must be separated by a factor not less than 2, and the floor-connected component (related to amplified response curve) must be nonresonant. If, however, adverse dynamic coupling is concluded to be possible, the problem is resolved by two general methods. Either additional restraints are provided to suitably alter stiffness parameters, and thus dynamically uncouple the system, or the analytical model is formulated to include the connected components to actually determine the coupling effects of the combined system. The principal purpose for such considerations is to accurately or conservatively define component interface loads (specifically nozzle loads) for inclusion in component adequacy documentation.

3.7.3.3 **Seismic Design of Westinghouse Mechanical Equipment**

In addition to the loads imposed on the system under normal operating conditions, the design of equipment and equipment supports required that consideration also be given to abnormal loading conditions such as an earthquake. Two types of seismic loadings were considered: operational-basis earthquake and design-basis earthquake.

For the OBE loading condition, the nuclear steam supply system is designed to be capable of continued safe operation. Therefore, for this loading condition, equipment and equipment supports are required to operate within design limits. The seismic design for normal-plus-DBE and normal-plus-DBE-plus-DBA loading conditions is intended to provide a margin in design that ensures capability to shut down and maintain the nuclear facility in a safe condition. In this case, it is only necessary to ensure that required equipment and equipment supports do not lose their capability to perform their safety function. This has come to be referred to as the “no loss of function” criterion.

Not all critical components have the same functional requirements for safety. For example, no loss of function requires that rotating equipment will not seize, and components required to respond actively, such as valves and relays, will respond properly. On the other hand, many components can experience significant permanent deformation without loss of function. Piping and vessels are examples of the latter; they are principally required to retain their contents and allow fluid flow.

The design of Seismic Class I mechanical equipment is covered in this section. The seismic design of Seismic Class I instrumentation and electrical equipment is covered in Section 3.10. Seismic classifications of particular equipment are given in Section 3.2.1.

Tables 3.7-7 and 3.7-8 provide seismic design margins for representative safety-related equipment within the Westinghouse Electric Corporation scope of supply.

3.7.3.3.1 Operating Conditions Categories

These categories are defined in accordance with the ASME Boiler and Pressure Vessel Code, Section III, Summer 1968 Addenda:

1. "*Normal Conditions*. Any condition in the course of system start-up operation in the design power range, and system shutdown, in the absence of upset, emergency, or faulted conditions.
2. "*Upset Conditions*. Any deviations from normal conditions anticipated to occur often enough that design should include a capability to withstand the conditions without operational impairment. The upset conditions include those transients that result from any single operator error or control malfunction, transients caused by a fault in a system component requiring its isolation from the system, transients due to loss of load or power, and any system upset not resulting in a forced outage. The estimated duration of an upset conditions shall be included in the design specifications—the upset conditions include the effect of the specified earthquake for which the system must remain operational or must regain its operational status.
3. "*Emergency Conditions*. Any deviations from normal conditions that require shutdown for correction of the conditions or repair of damage in the system. The conditions have a low probability of occurrence but are included to provide assurance that no gross loss of structural integrity will result as a concomitant effect of any damage developed in the system. The total number of postulated occurrences for such events shall not exceed 25.
4. "*Faulted Conditions*. Those combinations of conditions associated with extremely low-probability postulated events whose consequences are such that the integrity and operability of the nuclear energy system may be impaired to the extent where considerations of public health and safety are involved. Such considerations require compliance with safety criteria as may be specified by jurisdictional authorities. Among the faulted conditions may be a specified earthquake for which safe shutdown is required."

3.7.3.3.2 Input Criteria

Horizontal and vertical seismic umbrella spectra were generally prepared, which encompass the floor response spectra at the elevations where the system attaches to the building structure. The umbrella spectra were compared with the horizontal and vertical floor response spectra developed from the results of the building time-history analysis to ensure their conservatism.

The effect of differential seismic movement of interconnected components between floors and buildings was considered in the analysis.

The damping values used in seismic analyses are given in Table 3.7-1.

3.7.3.3.3 Seismic System Analysis

3.7.3.3.3.1 *Analysis of Seismic Class I Mechanical Equipment.* The seismic response of Seismic Class I mechanical equipment within Westinghouse scope of responsibility is determined as part of a multi-degree-of-freedom model that includes the support characteristics. This model is a multi-mass mathematical representation of the system. A sufficient number of masses are included to ensure an accurate determination of the dynamic response. A single mass model is used to determine vertical response loads for the seismic design when justified by the equipment design characteristics and/or the conservatism of the assigned loadings.

The system is evaluated for the simultaneous occurrence of horizontal and vertical motions. For the reactor pressure vessel, the pressurizer, the steam generator, and the reactor coolant pump the spatial combination of seismic loadings were performed as follows:

Reactor Pressure Vessel: The results of the vertical excitation, evaluated as a single degree of freedom model, are added absolutely to the results of the horizontal excitation.

Pressurizer: The total seismic response was obtained by combining the three components of earthquake motion by the absolute summation method.

Reactor Coolant Pump: The three components of earthquake motion were combined by the square root of the sum of the squares method.

Steam Generator: The total seismic response was obtained by combining the three components of earthquake motion by the square root sum of the squares method.

In a coupled system with different structural elements, either the lowest damping value of the system is used for all modes, or equivalent modal damping values are determined according to the energy distribution in each mode.

The materials used in Seismic Class I mechanical equipment under Westinghouse scope of supply are standard. The material properties that can effect a variation in modal period are well known, and the known variation in these properties does not account for any measurable or significant shift in period or increase in seismic loads.

The response spectrum method of analysis is used. Further details are covered in Section 3.7.3.3.4.

3.7.3.3.3.2 *Analysis of Reactor Vessel Internals.* The mathematical model of the reactor pressure vessel (RPV) system is a three-dimensional nonlinear finite element model which represents dynamic characteristics of the reactor vessel/internals /fuel in the six geometric degrees of freedom. The RPV system model was developed using the ANSYS computer code. The ANSYS finite element model consists of three concentric structural sub-models connected by non-linear impact elements and stiffness matrices. The first sub-model represents the reactor vessel shell and associated components. The reactor vessel is restrained by reactor vessel supports and by the attached primary coolant piping. The reactor vessel support system is represented by stiffness matrices.

The second sub-model represents the reactor core barrel assembly (core barrel and thermal shield), lower support plate, tie plates, and secondary core support components. The sub-model is physically located inside the first, and is connected to it by a stiffness matrix at the internal support ledge. Core barrel to vessel shell impact is represented by non-linear elements at the core barrel flange, core barrel nozzle, and lower radial key support locations.

The third sub-model represents the upper support plate, guide tubes, support columns, upper and lower core plates, and the fuel. This sub-model includes the specific properties of the Westinghouse 17 x 17 Robust Fuel Assembly 2 (RFA-2) with intermediate flow mixing (IFM) grids. The use of Westinghouse fuel properties in the third sub-model bounds the transition cores containing Advanced Mark-BW fuel. The third sub-model is connected to the first and second sub-model by stiffness matrices and nonlinear elements.

The following typical discrete elements from the ANSYS finite element library are used to represent the reactor vessel and internals components:

- Three-dimensional elastic pipe
- Three-dimensional mass with rotary inertia
- Three-dimensional beam
- Three-dimensional linear spring
- Concentric impact element
- Linear impact element
- 6x6 card stiffness matrix
- 18 card stiffness matrix
- 18 card mass matrix
- Three-dimensional friction element

3.7.3.3.4 Seismic Subsystem Analysis

3.7.3.3.4.1 *Analysis of Seismic Class I Mechanical Equipment.* Westinghouse-supplied Seismic Class I mechanical components are checked for seismic adequacy as follows:

1. If a component falls within one of the many categories previously analyzed using a multi-degree-of-freedom model and shown to be relatively rigid, the equipment specification for that component is checked to ensure that the equivalent static “g” values specified are larger than the appropriate response spectrum values, and therefore are conservative. Rigid equipment is that which has a fundamental frequency in the rigid range of the building elevation spectrum curves. The rigid range corresponds to frequencies greater than 20 to 30 cps.
2. If the component cannot be categorized as similar to a previously analyzed component that has been shown to be relatively rigid, an analysis is performed as described below.

Seismic analyses of typical Westinghouse-supplied Seismic Class I mechanical equipment, including heat exchangers, pumps, tanks, and valves were performed using a multi-degree-of-freedom modal analysis. Appendages, such as motors attached to motor-operated valves, are included in the models. The natural frequencies and normal modes are obtained using analytical techniques developed to solve eigenvalue-eigenvector problems. A response spectrum analysis is then performed based on the simultaneous occurrence of horizontal and vertical input motions. The response spectra are combined with the modal participation factors and the mode shapes to give the structural response for each mode from which the modal stresses are determined. The combined total seismic response is obtained by adding the individual modal responses using the square root of the sum of the squares method. Combined total response for closely spaced modal frequencies whose eigenvectors are perpendicular are handled in the above-described manner. In the rare event that two significantly closely-spaced in-phase modes occur, the combined total response is obtained by adding the square root of the sum of the squares of all other modes to the absolute value of one of the closely spaced modes.

Hydrodynamic analysis of tanks is performed using the methods described in Chapter 6 of the U. S. Atomic Energy Commission - TID-7024. Bridge and trolley structures are designed so that restraints prevent derailing due to the design-basis earthquake. The manipulator crane is designed to prevent disengagement of a fuel assembly from the gripper under the design-basis earthquake.

Components and supports of the reactor coolant system are designed for the loading combinations given in Section 5.2. These components are designed in complete accordance with the ASME Code, Section III, Nuclear Vessels, and the USAS B31.7 Code for Nuclear Power Piping. For the steam generator replacement efforts at North Anna, the STRUDL-SW computer program was utilized to qualify the steam generator lower support structure. The allowable stress limits for these components and supports are also given in Section 5.2.

The loading combinations and stress limits for other components and supports are given in Section 3.9.

3.7.3.3.4.2 *Analysis of Reactor Vessel Internals.* Nonlinear dynamic seismic analysis of the RPV system (RPV, internals, and fuel) includes the development of the system finite element model and the synthesized time history accelerations.

The basic mathematical model for seismic analysis is essentially similar to the LOCA model except that the seismic model includes the hydrodynamic mass matrices in vessel/barrel annulus to account for the fluid interactions. The RPV system finite element model for the nonlinear time history seismic analysis consists of three concentric structural sub-models connected by nonlinear impact elements and linear stiffness matrices. The first sub-model represents the reactor vessel shell and its associated components. The reactor vessel is restrained by the reactor vessel support system; this is represented in the system finite element model by stiffness matrices.

The second sub-model represents the reactor core barrel, thermal shield, lower support plant, tie plates, and the secondary core support components. These sub-models are physically located inside the first, and are connected to them by stiffness matrices at the vessel-internals interfaces. Core barrel to reactor vessel shell impact is represented by nonlinear elements at the core barrel flange, upper support plate flange, core barrel outlet nozzles, and the lower radial restraints.

The third and innermost sub-model represents the upper support plate assembly consisting of guide tubes, upper support columns, upper and lower core plates, and the fuel. The fuel assembly simplified structural model incorporated in to the RPV system model preserves the dynamic characteristics of the entire core for each type of fuel design the corresponding simplified fuel assembly model is incorporated in to the system model. The third sub-model is connected to the first and second sub-model by stiffness matrices and nonlinear elements.

The fluid structure or hydroelastic interaction is include in the RPV model for seismic evaluations. The horizontal hydroelastic interaction is significant in the cylindrical fluid flow region between the core barrel and the reactor vessel annulus. Mass matrices with off-diagonal terms (horizontal degrees of freedom only) attach between nodes on the core barrel, thermal shield, and the reactor vessel. The diagonal terms of the mass matrix are similar to the lumping of water masses to the vessel shell, thermal shield, and core barrel. The off diagonal terms:

1. reflect the fact that all of the water mass does not participate when there is no segmentation of the reactor vessel and the core barrel
2. allow inclusion of radial variations along their heights, and
3. approximate the effects of beam mode information

It should be pointed out that the hydrodynamic mass matrix has no artificial virtual mass effect and is derived in a straight forward, quantitative manner.

The matrices are a function of the properties of concentric cylinders with the fluid in the cylindrical annulus, specifically, inside and outside radius of the annulus, density of the fluid and length of the cylinders. Vertical segmentation of the reactor vessel and the core barrel allows inclusion of the radii variations along their heights and approximates the effects of beam mode deformation. These mass matrices were inserted between the selected nodes on the core barrel, thermal shield, and the reactor vessel.

The seismic evaluations are performed by including the effects of simultaneous application of time history accelerations in the three orthogonal directions. The ANSYS computer code, which is used to determine the response of the reactor vessel and its internals, is a general purpose finite element code. In the finite element approach, the structure is divided into a finite number of discrete members or elements. The inertia and stiffness matrices, as well as the force array, are first calculated for each element in the local coordinates. Employing appropriate transformations, the element global matrices and arrays are assembled into global structural matrices and arrays, and used for dynamic solution of the system equations.

3.7.3.3.5 Seismic Design Control Measures

The following procedure is used for Westinghouse-supplied Seismic Class I mechanical equipment that falls within one of the many categories analyzed as described in Sections 3.7.3.3.3 and 3.7.3.3.4 and shown to be rigid as defined in Section 3.7.3.3.4.

1. Equivalent static acceleration factors for the horizontal and vertical directions are included in the equipment specification. The vendor must certify the adequacy of the equipment to meet the seismic requirements as described in Section 3.7.3.3.4.
2. When the floor response spectra are developed, the cognizant engineer responsible for the particular component checks to ensure that the acceleration factors are less than those given in the equipment specification.

All other Westinghouse-supplied Seismic Class I equipment is analyzed or tested as described in Sections 3.7.3.3.3, 3.7.3.3.4, and 3.10. For new and replacement equipment, the evaluation methodology described in Section 3.7.3.2.2.4 may be used as an alternative. Westinghouse design control generally and seismic design control specifically is discussed in detail in Chapter 17.

3.7.3.4 **Analysis of Seismic Class I Piping Systems Using Other Computer Codes**

The piping analysis may be performed using computer codes in addition to the codes mentioned in Sections 3.7.3.1, 3.7.3.2 and 3.7.3.3, provided these computer codes are verified to meet applicable NRC requirements.

3.7.4 Criteria for Seismic Instrumentation Program

Data from seismic instrumentation and a walkdown of the nuclear power plant are used to make the initial determination of whether the plant must shut down after an earthquake. A seismic instrumentation program that complies with RG 1.12 (Reference 84) and RG 1.166 (Reference 85) is provided to monitor and record input motion and behavior of structures and components of the North Anna Power Station during a seismic event. RG 1.12 describes seismic instrumentation and RG 1.166 provides plant shutdown criteria that are acceptable to the NRC staff to support prompt evaluations after an earthquake.

3.7.4.1 **Location and Description of Instrumentation**

Seismic recording stations, each comprised of an acceleration sensor and a motion recorder, are installed at various site locations. The acceleration sensor picks up vibration and transforms it into an electrical signal that is sent to a motion recorder via cable. The motion recorders can be mounted locally near their associated acceleration sensor, or remotely in another location.

Consistent with the guidance of RG 1.12, acceleration sensors are installed at the following locations:

- Meteorological Tower (free-field recording station)

- Unit 1 Containment at elevation 216 feet (foundation-level)
- Unit 1 Containment at elevation 262 feet
- Unit 1 Containment at elevation 291 feet
- Auxiliary Building at elevation 244 feet (foundation-level)
- Auxiliary Building at elevation 274 feet

These recording stations are linked to a network control center (NCC) located in the Main Control Room (MCR). The NCC and motion recorders each have seismically qualified battery backups that permit continued operation of the system upon loss of normal external power. This instrumentation allows the processing of data at the plant site within 4 hours after an earthquake to determine if operating-basis earthquake (OBE) ground motion was exceeded. Each recording station may be accessed locally through the use of a laptop configured for data retrieval.

The system is configured such that triggering of the free-field or foundation-level instrumentation is annunciated at the NCC in the MCR of the plant. The triggers of the motion recorders will be set for a threshold acceleration of not more than 0.02g.

Although not required to satisfy RG 1.12, Dominion has elected to install some autonomous recording stations (i.e., not networked to the NCC) at various locations in the station. The autonomous recording stations will collect data at other structures in the event of an earthquake. This data is not needed for plant shut down determination, but may be used for subsequent evaluations to better characterize the impact of a seismic event on other structures and address potential plant restart issues.

3.7.4.2 **Use of Data from Seismic Instrumentation**

In accordance with paragraph V(a) of Appendix A to 10 CFR 100, an orderly and sequential shutdown of the North Anna units will be carried out according to detailed written station procedures if a seismic event with vibratory ground motion equal to or exceeding that of the OBE occurs. Prior to resuming operations, it will be demonstrated to the NRC that no functional damage has occurred to those features necessary for continued operation without undue risk to the health and safety of the public, or that the necessary repairs to those features have been completed.

The data from the free-field seismic instrumentation, coupled with information obtained from a plant walkdown, are used to make the initial determination of whether the plant must be shut down due to an earthquake. After an earthquake, a response spectrum check and the cumulative absolute velocity (CAV) will be calculated based on the recorded motions at the free field instrument in accordance with RG 1.166 to determine if OBE was exceeded. OBE exceedance is annunciated in the Main Control Room. If the OBE ground motion is exceeded or significant plant damage is identified during plant walkdowns, the plant must be shutdown in an orderly manner.

As per RG 1.166, if the response spectrum check and the CAV check were exceeded at the free-field seismic instrumentation, the OBE was exceeded and plant shutdown is required. If either check does not exceed the criterion, the earthquake motion did not exceed the OBE. If only one check can be performed, the other check is assumed to be exceeded. If the OBE was not exceeded and walkdown inspections indicate no damage to the nuclear power plant which would require shutdown, then shutdown of the plant is not required and the plant may continue to operate (or may restart following a post-trip review, if it tripped off-line due to the earthquake).

The Containment and Auxiliary Building foundation-level instrumentation are used for shutdown consideration only in the event that data from the free-field instrumentation is unavailable. In this case, the determination of OBE exceedance is based on a response spectrum check. A comparison is made between the foundation-level design response spectra and data obtained from the foundation-level instruments. If the response spectrum check at either foundation is exceeded, the OBE is exceeded and the plant must be shut down. The CAV check is not applicable to the data recorded at the foundation-level instrumentation.

In the event that data from the free-field instrumentation and foundation-level instrumentation is unavailable, then the guidance of RG 1.166 Appendix A will be followed.

The other instrument locations in the plant, including the autonomous recording stations, collect data that is not needed for plant shutdown determination, but may be used for subsequent evaluations to better characterize the impact of a seismic event on other structures and address potential plant restart issues.

If the plant is shutdown due to OBE exceedance, the guidelines for inspections, tests, long-term evaluations, and documentation specified in RG 1.167 (Reference 86) will be followed prior to restart.

3.7.5 Seismic Design Control Measures

Components and equipment requiring seismic input are specified in Section 3.2.1. When equipment specifications are prepared, a check is made to ensure that they are in full compliance with the North Anna 1 & 2 UFSAR. All designers and vendors of Seismic Class I equipment are provided the necessary seismic information for the design and verification of components and equipment. This information is either amplified (floor) acceleration data (in the form of either response spectra or acceleration "g" constants) or dynamic model data necessary to incorporate coupling effects.

Components not specifically affecting structural response are specified in accordance with procedures outlined in Section 3.7.3.2, and are designed to meet a specific criterion (code allowable or other). All vendor-supplied documentation is reviewed to ensure component adequacy with respect to specified criteria. The vendor-proposed methods for documenting seismic adequacy are reviewed prior to implementation, and reviewed in detail for approval upon submittal of completed documentation.

3.7.6 Containment Basemat Reevaluation

In 1980, the NRC expressed concern about the validity of the frequency response method, described in Section 3.7.2, for determining the response of the containment basemat. Consequently, the containment basemat amplified response spectrum was generated using a lumped-mass spring model and time-history analysis method as described in Appendix 3B. These spectra are shown in Figures 3.7-16 and 3.7-17.

The containment basemat amplified response spectra calculated from this time-history analysis are very conservative with respect to the smooth ground response spectra, because the artificial earthquake chosen to represent free-field time history is conservative (Figure 3.7-18). This figure also compares the mat response spectra and the ground response spectra generated from artificial time history.

At all elevations above the containment mat, the amplified response spectra remain as originally calculated by the frequency response method. Evaluation of safety-related components has now been completed for smooth ground response spectra, and all have been found acceptable without any design modifications.

3.7.7 Seismic Margin Management Plan for Design Changes and Qualification of New and Replacement Equipment

Following North Anna's shutdown and subsequent restart as a result of the Magnitude 5.8 Mineral, Virginia earthquake of August 23, 2011, Dominion implemented a long term seismic margin management plan (SMMP) to address the impact of the August 23, 2011 earthquake. The SMMP provides additional assurance that North Anna can operate safely in the long-term and is capable of withstanding another earthquake. Detailed guidance and examples for evaluating piping systems and supports, and for the seismic qualification of new and replacement equipment under the SMMP are described in General Engineering Nuclear Standard STD-GN-0038 (Reference 77).

The design change process for North Anna Power Station has been revised to require an assessment of seismic margins based on the August 23, 2011 earthquake. The loads and in-structure response spectra (ISRS) calculated from the recorded time-histories of this earthquake shall be used as an additional DBE case, but not as another OBE case. As an alternative, it is acceptable to envelop the ISRS from DBE and the August 23, 2011 earthquake. The applicable codes, standards, and other criteria for the SMMP shall be the same as those being used for North Anna's design basis. For dynamic analyses using the ISRS developed from the August 23, 2011 earthquake motions, damping values from NRC Regulatory Guide (RG) 1.61, Revision 1 (Reference 82) can be used as an alternative to the current design basis damping values such as ASME Code Case N411. As an example, 4% of critical damping for piping systems can be used in evaluations under SMMP. Damping values from the Seismic Qualification Utility Group's Generic Implementation Procedures can also be used, as appropriate, for the evaluation of equipment using the USI A-46 procedures.

The ISRS for the August 23, 2011 earthquake for the Containment, Auxiliary Building, and other buildings containing safety related SSCs will be developed based on the time-histories recorded at the Containment basemat during the August 23, 2011 event. The ISRS will be developed using the same models, methods, and properties that were used for the design basis for the USI A-46 effort. These ISRS shall be used in the SMMP evaluations for design changes and for the seismic qualification of new and replacement equipment. Until the ISRS for the August 23, 2011 event are developed and available for use, DBE ISRS in each horizontal direction will be increased by a factor of 1.10 and the vertical direction DBE ISRS will be increased by a factor of 1.20 in the entire frequency range for design change and new/replacement equipment evaluations. These factors are based on the average spectral exceedances of the August 23, 2011 event over the DBE spectra at the Containment basemat in the damaging frequency range of 2 to 10 Hz.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

3.7.8 Evaluation and Results of Analyses Performed for Seismic Motions Recorded During M5.8 Mineral Virginia Earthquake of August 23, 2011

A M5.8 earthquake occurred with its epicenter in Mineral, Virginia on August 23, 2011 and the North Anna plant was shut-down immediately following this event. The plant underwent extensive inspections, examinations, testing, and a series of surveillances and evaluations per the guidance in EPRI NP-6695 (Reference 87) prior to restart in November 2011. As part of the long-term evaluations following the restart, analyses were performed for structures, systems and components (SSCs) as required by RG 1.167 (Reference 86 and EPRI NP-6695 (Reference 87). The following evaluations were performed:

- Calculation of seismic loads (i.e., floor response spectra based on actual ground motion records from the earthquake).
- Comparison of actual seismic loads of August 23, 2011 and design basis seismic loads
- Seismic re-evaluation of equipment, piping systems and structures where calculated loads may have exceeded design basis loads

For selected piping and components, if the calculated stresses or responses were found to be less than the allowables for ASME Code Level C Service Limits (for piping systems) or the allowable values for equipment (typically faulted condition or test response spectra for tested equipment) then the item was considered acceptable. For selected structures, if the calculated forces and moments were found to be less than the ultimate design strength capacity, as allowed by the corresponding design code, then the item was considered acceptable. If not, the acceptability of the item would be based on: (a) results of a detailed visual examination, (b) evaluating the effect of stresses on the functionality of the item, (c) results of operability tests, or other examinations or (d) repair/replacement of potentially damaged areas.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

The evaluations used the codes, standards, and/or specification applicable for the structure, piping system or equipment. Median values of the properties were considered acceptable per EPRI NP-6695 guidelines (Reference 87. The following were considered as appropriate median damping values (Reference 89):

- Massive low stressed components (Pumps, Motors etc.) → 3%
- Piping systems → 5%
- Fluid containing tanks (Impulsive Mode) → 3% to 5%
- Welded and Bolted Steel Components/Supports, Electrical Cabinets → 5%

The evaluations and results to comply with the above steps and criteria are discussed below.

3.7.8.1 **Development of In-Structure Response Spectra**

The first step in this evaluation was the development of in-structure response spectra (ISRS) for each of the safety related structures. The time-histories in three directions recorded at the containment basemat at elevation 216' from Kinemetrics recorders were used as the starting point since no free-field data was available for the August 23, 2011 earthquake. Using the recorded motions and the sub-surface properties, time-histories were developed at the hard rock location which is about 60' below the Containment basemat. For this section, hard rock is defined where the shear wave velocity (SWV) is about 9200 ft/sec. These time-histories were used in a soil-structure interaction (SSI) analysis using the best estimate SWV profiles of rock below the containment to develop in-structure response spectra (ISRS) for the Reactor Containment Internal and External Structures. For each elevation of the internal structure, spectra from the SSI analysis were conservatively enveloped with the interpolated/extrapolated spectra derived from the recorded motions at the basemat and the operating deck.

The remaining rock-founded structures were analyzed as fixed base structures. The existing lumped mass model of these structures were reviewed and considered adequate to develop the ISRS. Hard rock time histories developed from the Containment base mat recorded motions were used as input in these dynamic analyses to develop the ISRS at each floor location of these structures.

The soil founded structures were analyzed using time-history soil-structure interaction (SSI) analyses with the best estimate SWV profiles. The Auxiliary building, which is partially on soil, was analyzed using soil springs, which was consistent with the previous design basis analyses.

In all of the above analyses, 5% structural damping was used and the ISRS were developed for several spectral (or equipment) damping values ranging from 1% to 7% of critical damping.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

3.7.8.2 Comparison of Seismic Loads/Spectra from August 23, 2011 Earthquake to Design Basis Loads/Spectra

For each structure and floor elevation and in each direction, the ISRS developed from the above analyses were compared to the existing ISRS from the design-basis earthquake (DBE), prior to selecting equipment or piping systems for detailed reevaluation. If the calculated floor response spectra for the actual earthquake were less than the OBE/DBE floor spectra at all frequencies of interest, then the equipment or piping systems mounted on that floor would not require any additional review. If it was determined that the calculated ISRS at floors of various structures from the August 23, 2011 earthquake exceeded the DBE spectra then representative SSCs would require seismic re-evaluation.

A review of these comparisons for each structure/floor elevation indicated that the August 23, 2011 spectra exceeded the OBE/DBE spectra at most locations in certain isolated frequency bandwidths. Therefore, the floor mounted equipment and piping systems were reviewed for the applicable August 23, 2011 floor spectra. Where needed, credit was taken for the spectra used in the actual qualification of the equipment and/or piping systems.

3.7.8.3 Evaluation of Structures

Evaluations were performed to determine potential areas of high load demand in select safety-related structures at NAPS. Methodologies used in these evaluations included direct comparison of generated building response spectra, equivalent static coefficient analysis, as well as the response spectrum method. The hard-rock time-histories or response spectra developed from the recorded motions for the August 23, 2011 event, as described in Subsection 3.7.8.1, were used in conjunction with the lumped mass stick models (LMSM) and other finite element models to obtain the worst-case seismic load demand at critical locations within the selected safety-related structures at NAPS. These evaluations provided a conservative estimate of the maximum forces and moments that acted on these selected NAPS safety-related structures on August 23, 2011, for the purposes of identifying potential areas of high seismic load demand.

The following North Anna safety-related structures were selected for Long-Term Evaluations:

- Fuel Building
- Auxiliary Building
- Containment Building
- Intake Structure
- Safeguards Building
- Unit 1 Main Steam Valve House

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

- Service Water Valve House
- Auxiliary Feed Water Pump House
- Service Water Reservoir

The selected safety-related structures that were evaluated are representative of the structure types that exist at North Anna and include the reinforced concrete and structural steel plant structures that house irradiated spent fuel, as well as an earthen type structure. The analyses showed that the calculated forces and moments at various locations in the above structures were well below their ultimate strength design capacities. The results of these Long-Term Evaluations corroborate the results of the extensive plant inspections and functional tests that were performed in support of the plant restart effort; and for which no physical or functional damage was observed in any safety-related structure. No area of abnormally high load demand was identified for the selected NAPS safety-related structures. Hence, no further plant inspections or surveillance tests were required.

3.7.8.4 **Evaluation of Piping Systems and Pipe Supports**

Representative piping systems were selected for re-evaluation for the spectra from the August 23, 2011 event. Consistent with EPRI NP-6695 guidelines, the piping re-evaluations were limited to ASME Class 1 piping. The piping reanalysis was performed on a sampling basis. The following considerations were used to select the piping systems for seismic re-evaluation:

1. Piping systems were selected where the spectral acceleration was exceeded at contributing natural frequencies.
2. Piping systems with highest calculated stresses were reviewed on a best effort basis. Engineering judgment was used based on the configuration of the piping systems, if the detailed stress analysis results were not available.

A number of piping models (analysis configurations) were selected for re-evaluation. Since the pre start-up damage assessment was based upon 100% inspection of the entire population of ASME Class 1 piping, using a sampling for re-evaluation provided confidence for the Class 1 piping population. The total numbers of Class 1 piping models covering North Anna Units 1 and 2 are about 120; therefore, it was reasonable to select thirteen representative systems or about 10% of total number of piping models for re-evaluation. The sampling covered pipe sizes from 2" diameter to 31" and was biased towards the level of the highest stress in the design-basis evaluation.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Piping models were analyzed for Design Pressure, Dead weight, and the applicable response spectra and building displacements due to August 23, 2011 earthquake. For comparison purposes, the OBE and DBE results were typically extracted from the existing run of record analyses. The calculated stresses from the spectra corresponding to the August 23, 2011 earthquake were significantly below the ASME Section III, Level C allowable. Thus, the results indicated that the piping components had adequate margin to accommodate an earthquake of the intensity of August 23, 2011 event and no gross deformation in the piping was expected.

The resultant seismic moment in fatigue sensitive locations were also tabulated and compared with the resultant seismic moment used in the existing fatigue evaluations. The comparison indicated that the August 23, 2011 earthquake had insignificant effects on component fatigue.

Loads on equipment nozzles and branch line nozzles at RCL were tabulated for August 23, 2011 earthquake and were compared with the loads used in qualification of equipment nozzles and RCL branch nozzles. The results indicated that the August 23, 2011 earthquake did not affect the structural integrity of the nozzles.

Loads on the pipe supports during the August 23, 2011 earthquake were collected from the analysis and compared with the seismic loads used in the pipe support qualification. If the seismic load during August 23, 2011 was lower than the seismic load used in the support design, the structural integrity for loads during August 23, 2011 is automatically established. If the seismic load during August 23, 2011 was higher than the seismic load used in the support design, then the combined load combination together with the loads from the August 23, 2011 earthquake was reviewed. The combined loads resulting from thermal expansion, deadweight, seismic inertia and seismic anchor movements (SAM) on the pipe supports during the August 23, 2011 earthquake were compared with the loads used in the support design. The results showed that the structural integrity of the pipe supports was not affected by the August 23, 2011 earthquake. The support loads during the August 23, 2011 earthquake remained below the criteria set in the EPRI NP-6695 guidelines (Reference 87).

The analyses of piping systems and pipe supports validate the conclusions of the results of inspections performed after the August 23, 2011 earthquake that identified no gross deformation of piping systems.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

3.7.8.5 Evaluation of Equipment

Representative safety-related equipment items were selected for reevaluation to the ISRS developed for the August 23, 2011 earthquake. These included:

- Major equipment and Supports in the Reactor Building
- Mechanical and Electrical Equipment
- Tanks and Heat Exchangers

Other than major equipment and supports, the scope of safety-related mechanical and equipment and tanks and heat exchangers for re-evaluation was based on the composite USI A-46/Individual Plant Examination of External Events (IPEEE) Safe Shutdown Equipment List (SSEL), which is documented in Appendix A to Reference 88. The sample process for seismic re-evaluation was based on selecting equipment items as follows: (a) items representative of each Class of Twenty [Reference 61], with a few exceptions, (b) items in each of the safety-related structures, and (c) the low capacity items with a high-confidence-of-low-probability-of-failure (HCLPF) capacity less than 0.3g that were identified in the IPEEE program. A large portion of the equipment sample was previously qualified using the SQUG-GIP methodology; however, the sample population selected for re-evaluation also included representative equipment items qualified by seismic shake-table testing. The Class of Twenty equipment items excluded from the sample were: Class 7 (Fluid-operated valves); Class 8A (Motor-operated valves); and Class 8B (Solenoid-operated valves) and Class 19 (Temperature Sensors). Valves are typically pipe mounted and are generally considered seismically rugged. Similarly, Temperature Sensors were found to be rugged and well installed during the USI A-46 program. It is noted that the North Anna SSEL does not contain any item of equipment in a few Classes of Twenty; also items of equipment previously classified as seismically rugged in the composite SSEL were excluded.

The major Nuclear Steam Supply System (NSSS) equipment items are, in general, considered seismically rugged and were exempted from the USI A-46 review because large margins existed to accommodate an earthquake significantly larger than the SSE. However, as a part of this evaluation, major equipment, such as the Reactor Pressure Vessel (RPV), Steam Generator (SG), Reactor Coolant Pump (RCP) and Pressurizer were reviewed using the existing analyses and additional analyses were performed, where required. The structural integrity of the equipment was verified by comparing all the interface (nozzles, support attachments) loads at the equipment during August 23, 2011 earthquake with the loads due to design basis loading at the same locations. The comparisons indicated that the loads during August 23, 2011 earthquake were less than the loads from a design-basis earthquake. No major equipment or their supports were identified with excessive stress or deformation requiring further evaluation, inspections or testing.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

An approximately 10% sample of electrical and mechanical equipment, heat exchangers and tanks was selected for evaluation using the ground spectra or in-structure response spectra, as appropriate from the August 23, 2011 event. With two exceptions, the evaluation of the sample components, including their anchorages, showed that the stresses remained within the allowable values. For a sample of electrical equipment qualified by shake-tests, the in-structure response spectra calculated from the recorded motions of the August 23, 2011 earthquake were adequately enveloped by the corresponding site-specific or generic test response spectra.

The exceptions included two groups of components that were in the IPEEE low capacity component list - the 120V Vital AC bus cabinets and the refueling water storage tank (RWST) for both units. Using the response spectra derived from the August 23, 2011 earthquake motions, the shear-tension interaction of the anchorage of the vital bus cabinets was calculated to be greater than unity from a conservative static analysis with peak spectral accelerations, and the overturning moment of the RWST exceeded the capacity of the anchorage of this tank. The anchorages of these components were inspected. No deformation or anomalies were found in these inspections and it is concluded that the August 23, 2011 earthquake did not cause any damage to these components or their anchorages.

The evaluation of equipment validates the results of the comprehensive inspections performed after the August 23, 2011 earthquake that found no damage to equipment or supports.

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63. *Supplemental Safety Evaluation Report No. 3 (SSER No. 3) on the Review of Revision 3 to the Generic Implementation Procedure for Seismic Verification of Nuclear Power Plant Equipment, Updated May 16, 1997*, U.S. Nuclear Regulatory Commission, December 4, 1997.

64. Virginia Power Letter Serial Number 92-384 to U. S. Nuclear Regulatory Commission, *Virginia Electric and Power Company, Surry Power Station Units 1 and 2, North Anna Power Station 1 and 2, Response to Supplement 1 of Generic Letter 87-02 - SQUG Resolution of Unresolved Safety Issue A-46*, September 16, 1992.

65. NRC Letter to Virginia Power, Serial No. 92-763, *Safety Evaluation of NAPS Units 1 and 2 and SPS Units 1 and 2, 120 day response to Supplement No. 1 to Generic Letter 87-02,* November 20, 1992.

66. Virginia Power Letter to Document Control Desk (NRC), *North Anna Power Station, Units 1 and 2, Summary Report for Resolution of Unresolved Safety Issue (USI) A-46,* May 27, 1997.

67. NRC letter to Virginia Power, *North Anna Power Station, Units 1 and 2 - Request for Additional Information on the Resolution of Unresolved Safety Issue A-46 (USI A-46),* February 16, 1999.

68. Virginia Power letter to NRC, *North Anna Power Station, Units 1 and 2 - Response to Request for Additional Information dated February 16, 1999 on USI A-46 Summary Report (GL 87-02),* June 1, 1999.

69. NRC letter to Virginia Power, *North Anna Power Station, Units 1 and 2 - Request for Additional Information on the Resolution of Unresolved Safety Issue A-46 (USI A-46),* January 6, 1999.

70. Virginia Power letter to NRC, *North Anna Power Station, Units 1 and 2 - Response to Request for Additional Information dated January 6, 1999 on USI A-46 Summary Report (GL 87-02),* April 1, 1999.

71. Virginia Power letter to NRC, *North Anna Power Station, Units 1 and 2 - Response to Request for Additional Information on USI A-46 Summary Report,* October 18, 1999.

72. Virginia Power letter to Document Control Desk (NRC), *North Anna Power Station, Units 1 and 2, Completion of Outlier Resolution - USI A-46 Program, GL 87-02 - Verification of Seismic Adequacy of Mechanical and Electrical Equipment*, May 26, 2000.

73. NRC Letter to Virginia Power, Serial Number 00-600, *Transmitting Safety Evaluation by the Office of Nuclear Reactor Regulation for USI A-46 Program Implementation at North Anna Power Station, Units 1 and 2, Operating License Nos. NPF-4 and NPF-7*, Docket Nos. 50-338 and 50-339, November 3, 2000.

74. NRC (Brian Sheron) letter to SQUG (Neil Smith), *Clarification of the Staff's Position Regarding Incorporation of the GIP Method as a Revision to the Plant Licensing Basis,* June 19, 1998.

75. NRC letter to SQUG, *Review of Seismic Qualification Utility Group's Report on the Use of the Generic Implementation Procedure for New and Replacement Equipment and Parts*, June 23, 1999.

76. *Implementation Guidelines for Seismic Qualification of New and Replacement Equipment/Parts (NARE) Using the Generic Implementation Procedure (GIP)*, Revision 4, Prepared for EPRI and SQUG by MPR Associates, July 2000.

77. Dominion General Engineering Nuclear Standard STD-GN-0038, *Seismic Qualification of Equipment.*

78. BIJLAARD *Local Shell Stress Calculation,* Version 1.0, Developed by Framatome ANP.

79. FERMETURE *Closure Analysis,* Version AXP 2.2, Developed by Framatome ANP.

80. SYSTUS *General Finite Element System,* Developed by Framatome ANP; Module SYSNUKE Version 233 AXP 3 for Closure Head Stress and Fatigue Analysis; Module NUKE Version 1.03 SGI for Adapter Tube and Vent Pipe Stress and Fatigue Analysis.

81. RCCM-ASME *Pressure Retaining Boundary Analysis,* according to ASME Code Developed by Framatome ANP, Version AXP 2.3.12 for Closure Head Stress and Fatigue Analysis; Version 2.3.13 SGI and 2.3.14 SGI for Adapter Tube and Vent Pipe Stress and Fatigue Analysis.

82. NRC Regulatory Guide 1.61, Revision 1, *Damping Values for Seismic Design of Nuclear Power Plants,* March 2007.

83. ANSYS Version 10.0 General Purpose Finite Element Code as Configured for Westinghouse Use in Westinghouse Letter, LTR-SST-06-21, *Release of ANSYS 10 for XP, HPUX 11.0, and HPUX 11.23 and ANSYS Error Reports*, July 12. 2006.

84. NRC Regulatory Guide 1.12, Revision 2, *Nuclear Power Plant Instrumentation for Earthquakes*, March 1997.

85. NRC Regulatory Guide 1.166, *Pre-Earthquake Planning and Immediate Nuclear Power Plant Operator Postearthquake Actions*, March 1997.

86. NRC Regulatory Guide 1.167, *Restart of a Nuclear Power Plant Shut Down by a Seismic Event*, March 1997.

87. EPRI NP-6695, *Guidelines for Nuclear Plant Response to an Earthquake*, December 1989.

88. North Anna Power Station Units 1 and 2 response to USNRC GL 88-20, *Report on Individual Plant Examination of External Events (IPEEE) - Seismic*, May 31, 1997.

89. EPRI Report NP-6041-SL, Rev.1, *A Methodology for Assessment of Nuclear Plant Seismic Margin*, August 1991.

Table 3.7-1
DAMPING FACTORS

Stress Level	Type and Condition of Structure, System, or Component	Percent of Critical Damping
Low stress, well below proportional limit. Stresses below 0.25 yield point.	Steel, reinforced concrete; no cracking and no slipping at joints	0.5-1.0
Working stress limited to 0.5 yield point stress.	Welded steel, well-reinforced concrete (with only slight cracking)	2.0
	Bolted steel	5.0
At or just below yield point.	Welded steel	5.0
	Reinforced concrete	5.0
	Bolted steel	7.0

Table 3.7-2

DESIGN LOADING COMBINATIONS AND STRESS LIMITS FOR SEISMIC CLASS I PIPING SYSTEM (ELASTIC ANALYSIS)

Condition	ASME Section III Code Class	Design Loading Combinations	Primary Stress $P_m(P_1) + P_b$	Primary + Secondary Stress $P_m(P_1) + P_b + Q$	Peak Stress $P_m(P_1) + P_b + Q + P$
Normal and upset	1 (NB-3600)	Design pressure, weight OBE, and other mechanical loads. Design thermal gradients (steady-state and transient)	$1.5S_m$	$3S_m$	S = K S /2 Cumulative usage factor less than 1
Emergency	1 (NB-3600)	N/A	N/A	N/A	N/A
Faulted	1 (NB-3600)	Pressure, weight, DBE, and DBA loads	$3S_m$	N/A	N/A
		Design Loading Combinations			
Normal and upset	2(NC-3600) and 3(ND-3600)	Design pressure, weight, and other sustained loads.	Design pressure, other sustained loads OBE, and occasional mechanical loads	Design thermal gradients (steady-state)	
		S_h	$1.2\ S_h$	$(1.25S_c + 0.25S_h)\ f + S_h - S_{1p} + S_{d1}$	
Emergency/ Faulted	2(NC-3600) and 3(ND-3600)	Design pressure and weight	Design pressure, weight, DBE, and occasional mechanical loads	Design thermal gradients (steady-state)	
		S_h	$1.8\ S_h$	$(1.25S_c + 0.25S_h)\ f + S_h - S_{1p} + S_{d1}$	

Note: The nomenclature, conditions, and applications of the above limits are in accordance with ASME, Section III, Boiler and Pressure Vessel Code, Subarticles NB-3000 and 1C-3000.

Table 3.7-3
PIPING SYSTEM SEISMIC DESIGN AND ANALYSIS CRITERIA

ASME Code, Class	Type of Earthquake	Type of Seismic Analyses	Combined Stress Calculations and Stress Criteria
1 (sizes 1.05 in. NPS and larger)	DBE	Dynamic response spectra	ASME Code, Section III, Subarticle NB-3600
	OBE	Dynamic response spectra	ASME Code, Section III, Subarticle NB-3600
1 (sizes 1 in. NPS and below)	DBE	Simplified dynamic analyses or dynamic response spectra	ASME Code, Section III, Subarticle NC-3600
			Eq.3.7-31 through 3.7-34 of Section 3.7.3.1.3.2[a]
	OBE	Simplified dynamic analyses or dynamic response spectra	ASME Code, Section III, Subarticle NC-3600
			Eq.3.7-31 through 3.7-34 of Section 3.7.3.1.3.2[a]
2 and 3 (sizes 8 in. NPS and larger)	DBE	Dynamic response spectra	ASME Code, Section III, Subarticle NC-3600
			Eq.3.7-31 through 3.7-34 of Section 3.7.3.1.3.2[a]
	OBE	Dynamic response spectra	ASME Code, Section III, Subarticle NC-3600
			Eq.3.7-31 through 3.7-34 of Section 3.7.3.1.3.2[a]
2 and 3 (sizes 6 in. NPS and below)	DBE	Simplified dynamic analysis or dynamic response spectra	ASME Code, Section III, Subarticle NC-3600
			Eq.3.7-31 through 3.7-34 of Section 3.7.3.1.3.2[a]
	OBE	Simplified dynamic analysis or dynamic response spectra	ASME Code, Section III, Subarticle NC-3600
			Eq.3.7-31 through 3.7-34 of Section 3.7.3.1.3.2[a]

a. These refer to this UFSAR, not ASME-III.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-4

REPRESENTATIVE LISTING OF SEISMIC DESIGN MARGINS

STONE AND WEBSTER SCOPE OF SUPPLY (MECHANICAL ITEMS)

System/Component	Total Loading Combination	Max Seismic Stress, psi		Total Max Combined Stress, psi		Allowable Stress, psi		Design Margin[a]	
		OBE	DBE	OBE	DBE	OBE	DBE	OBE	DBE
Reactor Coolant System									
Steam generator supports	Normal[b] +SRSS (EQ& pipe rupture)	---	5790	---	16,880	---	17,000	---	1.01
Reactor coolant pump supports	Normal[b] +SRSS (EQ& pipe rupture)	---	53,160	---	57,720	---	70,200	---	1.21
Recirculation spray system									
Recirculation spray heat exchanger	DL+EQ+Oper	12,400	15,467	25,335	28,150	25,380	36,720	1.01	1.30
Recirculation spray heat exchanger seismic restraint (main support structure)	DL+EQ+Oper	2180	3580	10,520	11,950	35,000	35,000	3.33	2.93
Component cooling system									
Component cooling pumps	DL+EQ+Oper	2520	3390	21,750	20,380	32,400	32,400	1.49	1.59
Compressed air system									
Main instrument air receivers	DL+EQ	485	833	485	833	5047	9270	10.40	11.10

a. Design margin = $\frac{\text{allowable stess}}{\text{total max. combined stress}}$

b. Normal = deadweight + thermal + internal pressure

c. Test only.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-4 (continued)
REPRESENTATIVE LISTING OF SEISMIC DESIGN MARGINS
STONE AND WEBSTER SCOPE OF SUPPLY (MECHANICAL ITEMS)

System/Component	Total Loading Combination	Max Seismic Stress, psi		Total Max Combined Stress, psi		Allowable Stress, psi		Design Margin[a]	
		OBE	DBE	OBE	DBE	OBE	DBE	OBE	DBE
Service water system									
Service water pumps	DL+EQ+Oper	500	830	16,200	16,300	32,400	32,400	2.0	2.0
Ventilation systems									
HVAC 1 & 2 air-handling units (NA 269/1269 NAS-294) service building elevation 277	DL+EQ+Oper	7000	7500	14,665	15,200	28,800	28,800	1.95	1.9
Main steam system									
Main steam safety valves	DL+EQ+Oper	1415	2125	11,950	12,660	17,500	23,940	1.46	1.9
Condensate plus feedwater system									
Auxiliary feedwater pumps (steam-driven plus motor-driven)	DL+EQ+Oper	1350	2700	27,750	29,100	32,400	32,400	1.17	1.11
Process radiation monitoring systems									

a. Design margin = $\frac{\text{allowable stess}}{\text{total max. combined stress}}$

b. Normal = deadweight + thermal + internal pressure

c. Test only.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-4 (continued)
REPRESENTATIVE LISTING OF SEISMIC DESIGN MARGINS
STONE AND WEBSTER SCOPE OF SUPPLY (MECHANICAL ITEMS)

System/Component	Total Loading Combination	Max Seismic Stress, psi		Total Max Combined Stress, psi		Allowable Stress, psi		Design Margin[a]	
		OBE	DBE	OBE	DBE	OBE	DBE	OBE	DBE
Containment gaseous plus particulate monitor	DL+EQ	1285	1760	1500	2000	13,700	13,700	9.1	6.85
Electrical systems									
Station batteries[c] Battery racks DC dist. panels[c] Static inverters[c] 4160V switchgear[c]	DL+EQ	18,720	25,125	20,000	27,000	32,400	32,400	1.62	1.20
Quench spray system									
Refueling water storage tank	DL+EQ+Oper	15,780	31,450	18,540	34,220	29,400	42,700	1.59	1.25
Quench spray pumps	DL+EQ+Oper	575	820	4100	4300	7000	32,400	1.7	7.5

a. Design margin = $\frac{\text{allowable stess}}{\text{total max. combined stress}}$

b. Normal = deadweight + thermal + internal pressure

c. Test only.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-5

REPRESENTATIVE LISTING OF SEISMIC DESIGN MARGINS FOR STONE AND WEBSTER SCOPE OF SUPPLY (STRUCTURAL ITEMS)

Component	Failure Mode Controlling Design Margin at Interface of Component/Structure	Criteria for Allowable Capacity (FA)	Criteria Reference	Maximum Reaction, F	Design Margin, FA/F	Seismic Event	Estimated% of Reaction Due to Seismic Event
Steam generator supports	Punching shear in concrete	FA = 4 f'c b_od	ACI 318-63, Section 1707 (c)	1207 kips	1.89	DBE	55
Reactor coolant pump supports	Punching shear in concrete	FA = 4 f'c b_od	ACI 318-63, Section 1707 (c)	1023 kips	2.06	DBE	42
Safety injection accumulator supports	Combined shear and tension on ASTM A307, Gr. A bolts	FA = 1.33 (28.0-1.6 fv) 27.0	AISC 69 Spec., Section 1.6.3 plus 1/3 increase	20.64 ksi tens. 3.59 ksi shear	1.31	DBE	46
Refueling water storage tank	Tank sliding on concrete foundation	FA = 1.1 (sliding force)	SRP 3.8.5, Section II.3.c	701 kips	1.54	DBE	100
Quench spray pump anchor	Combined shear and tension on ASTM A307, Gr. A bolts	FA = 1.33 (28.0-1.6 fv) 27.0	AISC 69 Spec., Section 1.6.3 plus 1/3 increase	1.83 ksi tens. 91 ksi shear	14.75	DBE	100

Note: The table addresses the concerns of the USNRC as they pertain to the anchorage of safety-related components to the building structure. The computed seismic design margins are based on the allowable capacity for a local failure at the component/structure interface. The controlling failure mode is identified for that interface as well as the criteria for defining allowable capacities. Maximum reactions are given in terms of force or stress, depending on what appeared to be more meaningful for the stated failure mode. Loads from the operational-basis earthquake generally do not control and, thus, were omitted from the presentation. The estimated percentage of the reaction which is due to the design-basis earthquake is provided.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-5 (continued)

REPRESENTATIVE LISTING OF SEISMIC DESIGN MARGINS FOR STONE AND WEBSTER SCOPE OF SUPPLY (STRUCTURAL ITEMS)

Component	Failure Mode Controlling Design Margin at Interface of Component/Structure	Criteria for Allowable Capacity (FA)	Criteria Reference	Maximum Reaction, F	Design Margin, FA/F	Seismic Event	Estimated% of Reaction Due to Seismic Event
Residual heat exchanger supports							
Main	Tension on ASTM A307, Gr. A bolts	FA = 0.9 F_y	Section 3.8.1.4	25.44 K	1.14	DBE	75
Upper	Tension on drilled-in anchor	FA = 3K for 7/8-in.-diam. anchor	S&W STD-MS-13-3	2.3 K	1.3	DBE	50
Main instrument air receivers	Base sliding on concrete	FA = 1.1 (sliding force)	SRP 3.8.5, Section II,3,c	494 lb	1.2	DBE	100
Service water pump supports	Combined shear and tension on ASTM A307, Gr. A bolts	FA = 1.33 (28.0-1.6 fv) 27.0	AISC 69 Spec., Section 1.6.3 plus 1/3 increase	9.5 ksi tens. 2.04 ksi shear	2.8	DBE	90
Control and relay room ac coil assembly support	Combined shear and tension on drilled-in anchor	$(T/TA)^{5/3}$ + $(S/SA)^{5/3}$ 1.0 TA = 1500 lb, SA = 1500 lb for 5/8-in.-diam. anchor	S&W STD-MS-13-3	980 lb tens 946 lb shear	1.05	DBE	100

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-5 (continued)

REPRESENTATIVE LISTING OF SEISMIC DESIGN MARGINS FOR STONE AND WEBSTER SCOPE OF SUPPLY (STRUCTURAL ITEMS)

Component	Failure Mode Controlling Design Margin at Interface of Component/Structure	Criteria for Allowable Capacity (FA)	Criteria Reference	Maximum Reaction, F	Design Margin, FA/F	Seismic Event	Estimated% of Reaction Due to Seismic Event
Process instrumentation rack supports	Combined shear and tension on drilled-in anchor	$(T/TA)^{5/3}$ + $(S/SA)^{5/3}$ 1.0 TA = 1000 lb, SA = 1000 lb for 0.5 in.-diam. anchor	S&W STD-MS-13-3	181 lb tens. 147 lb shear	5.3	DBE	100
Battery racks	Combined shear and tension on drilled-in anchor	$(T/TA)^{5/3}$ + $(S/SA)^{5/3}$ 1.0 TA = 1000 lb, SA = 1000 lb for 0.5 in.-diam. anchor	S&W STD-MS-13-3	520 lb tens. 260 lb shear	1.81	DBE	100
Dc distribution panels	Combined shear and tension on drilled-in anchor	$(T/TA)^{5/3}$ + $(S/SA)^{5/3}$ 1.0 TA = 700 lb, SA = 700 lb for 3/8 in.- diam. anchor	S&W STD-MS-13-3	146 lb tens. 149 lb shear	4.46	DBE	100
Reactor coolant gas and particulate monitor	Shear on drilled-in anchor	SA = 1/4 avg. ult. shear	Manufacturer's recommendation	525 lb	2.88	DBE	100

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-5 (continued)

REPRESENTATIVE LISTING OF SEISMIC DESIGN MARGINS FOR STONE AND WEBSTER SCOPE OF SUPPLY (STRUCTURAL ITEMS)

Component	Failure Mode Controlling Design Margin at Interface of Component/Structure	Criteria for Allowable Capacity (FA)	Criteria Reference	Maximum Reaction, F	Design Margin, FA/F	Seismic Event	Estimated% of Reaction Due to Seismic Event
Static inverters							
15 kVA	Shear on drilled-in anchor	SA = 1/4 avg. ult. shear	Manufacturer's recommendation	940 lb	1.44	DBE	100
20 kVA				1410 lb	1.08	DBE	100
Recirculation spray heat exchanger							
Lower support	Combined shear and tension on drilled in anchor	(T/TA) + (S/SA) 1.0	Manufacturer's recommendation	T = 6.2 K, S = 2.2 K	1.29	DBE	80
Main support	Tension on ASTM A307, Gr. A bolts	FA = 0.9 F_y	Section 3.8.1.4	10.48 K	1.73	DBE	90
4160V switchgear	Shear at channel embedment producing bearing on concrete	FA = 0.85 f'c	ACI 318-71, Section 10.14	2.75 K	3.27	DBE	100
Component cooling water pump support	Tension on ASTM A307, Gr. A bolts	FA = 0.9 F_y	Section 3.8.1.4	6.93 K	1.44	DBE	90

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-6

EQUIPMENT TEST SUMMARY, STONE & WEBSTER SCOPE OF SUPPLY

Equipment Description	Req'd Test "g" (ZPA)		Experienced Test						
	Horizontal	Vertical	"g" Horizontal	"g" Vertical	Frequency Range and Resonant Frequency	Tested in Operation	Test Lab Facilities	Notes	Margin
1. Flow indicators, ITT/Barton	0.34	0.28	3.0	2.0	Freq. scan: 1.60 Hz Res. freq.: 29 Hz, 38 Hz, 58 Hz	Yes	Wyle Labs, Huntsville, Alabama, October 1972	Sinusoidal input for frequency scan and dwell, three axes individually scan at 6.0 sec/cycle 2 min dwell at resonance freq.	a
2. Radiation monitoring system, Westinghouse	0.43	0.28	0.50	0.35	Freq. scan: 1-35 Hz Res. freq.: 5 Hz, 7 Hz, 23 Hz	Yes	Westinghouse Aerospace Test Labs Pittsburgh, Pennsylvania, May, 1972	Six accelerometers used, mounted at various locations. Sinusoidal input for frequency scan, sine beat for dwell; three axes individually. Scan at every odd frequency. Sine beat of 5 beats, 10 cycles/beat.	a
3. Main control board instrumentation, Wolfe & Mann	0.36	0.24	0.4	0.4	Freq. scan: 1-33 Hz Res. freq.: 13 Hz, 29 Hz, 33 Hz	Yes	Wyle Labs, Huntsville, Alabama, May 1972	Seven accelerometers used, mounted at various locations. Sinusoidal input for dwell and scan. Three axes tested individually. Inst. mounted on test panel. Freq. scan 10 min each axis and dwelled for 1 min at each resonant frequency.	a

Notes:

1. A 0.2g or higher input acceleration was used for all frequency scans except in the range of 1-5 Hz, where machine limitations prevailed.
2. Capabilities of the test machines are available in their vendor's test reports.
3. Location, number, and type of acceleration and performance monitors are too lengthy for incorporation into this table. Details are available in the test reports.
4. When devices are separately tested, they are mounted on rigid brackets or on a support structure that simulates the actual design configuration.

a. Substantial margin exists, as shown by examination of data.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-6 (continued)

EQUIPMENT TEST SUMMARY, STONE & WEBSTER SCOPE OF SUPPLY

Equipment Description	Req'd Test "g" (ZPA)		Experienced Test			Tested in Operation	Test Lab Facilities	Notes	Margin
	Horizontal	Vertical	"g" Horizontal	"g" Vertical	Frequency Range and Resonant Frequency				
4. Batteries (control storage), C&D batteries	0.25	0.15	0.51	0.41	Freq. scan: 1-50 Hz Res. freq.: several	Yes	TII Labs, College Point, New York, November 1972	Two cells mounted in a test rack, four accelerometers located on table, rack, and cells. Sinusoidal input for frequency scan and dwell. Three axes tested individually. Frequency scan and dwell at 20 sec/Hz (min).	a
5. Dc distribution panels, General Electric	0.18	0.12	0.39	0.39	Freq. scan: 4-50 Hz Res. freq.: 7 Hz, 11 Hz, 14 Hz, 26 Hz, 32 Hz, 48 Hz	Yes	Dayton T. Brown, Long Island, New York, September 1972	Eight accelerometers used, mounted at various location. Sinusoidal input for frequency scan and dwell, three axes individually. Frequency at scan 0.73 octaves/min. Dwell for 20 seconds minimum.	a
6. Static battery charger, Gould, Inc.	0.18	0.12	0.39	0.26	Freq. scan: 1-50 Hz Res. freq.: several	Yes	Acton Labs, Acton, Massachusetts, January 1973	Ten accelerometers used, mounted at various locations. Sinusoidal input for frequency scan and sine beat for dwell; three axes individually. Scan test at 2 octaves/min maximum. Sine beat at 10 cycles per beat, 5 beats.	a

a. Substantial margin exists, as shown by examination of data.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-6 (continued)

EQUIPMENT TEST SUMMARY, STONE & WEBSTER SCOPE OF SUPPLY

Equipment Description	Req'd Test "g" (ZPA) Horizontal	Req'd Test "g" (ZPA) Vertical	Experienced Test "g" Horizontal	Experienced Test "g" Vertical	Experienced Test Frequency Range and Resonant Frequency	Tested in Operation	Test Lab Facilities	Notes	Margin
7. Control panel relays for emer. diesel generator, Fairbanks Morse, Inc.	0.18	0.12	2.0	1.45	Freq. scan: 1-30 Hz Res. freq.: none	Yes	MTS Systems Research Lab, July 1971	Sinusoidal input for frequency scan and dwell, two axes simultaneously. Scan at 20 sec/Hz. Also subjected to narrow band random and sine beat for dwell. Horizontal axis and vertical axis individually.	a
8. Resistance temperature detectors, Electric Thermometers, Trinity, Inc.	0.30	0.15	12.0	12.0	Res. freq.: 8.9 Hz, 20 Hz, and higher than 100 Hz	Yes	Electric Thermometers Trinity, July 1971	Equipment was tested at 12 g for 1 hour at 120 Hz, and at 2.8 g for 1 hour at 60 Hz. Sinusoidal input, 2 axes individually.	a
9. Transmitters, Foxboro Co.	0.61	0.36	1.50	0.61	Freq. scan: 1-100 Hz Res. freq.: none	Yes	Acton Labs, Acton, Massachusetts, October 1971	Six accelerometers used; three on top cover, two on transmitter, one on table. Sinusoidal input frequency scan and sine beat for dwell. Three axes individually. Normal service mounting. Scan at one octave/min 10 cycles/beat for 10 beats.	a

a. Substantial margin exists, as shown by examination of data.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-6 (continued)

EQUIPMENT TEST SUMMARY, STONE & WEBSTER SCOPE OF SUPPLY

Equipment Description	Req'd Test "g" (ZPA) Horizontal	Req'd Test "g" (ZPA) Vertical	Experienced Test "g" Horizontal	Experienced Test "g" Vertical	Experienced Test Frequency Range and Resonant Frequency	Tested in Operation	Test Lab Facilities	Notes	Margin
10. 15 and 20 KVA static inverters, Solid State Controls, Inc.	0.18	0.12	0.39	0.26	Freq. scan: 1-33 Hz Res. freq.: several	Yes	Gaynes Labs, Chicago, Illinois, March 1973	Four accelerometers used at various locations. Sinusoidal input for frequency scan and dwell. Three axes tested individually. Scans at 2 octaves/min minimum, dwells for 20 seconds. Normal service mounting.	a
11. Control room instrumentation, Westinghouse	0.36	0.24	Varies 0.43 min 3.36 max	Varies 0.43 min 3.36 max	Freq. scan: 1-60 Hz Res. freq.: 58 Hz, 60 Hz	Yes	Westinghouse, Pittsburgh, Pennsylvania, January 1973	Sinusoidal input for frequency scan and dwell. Three axes tested individually. Scan for 30 seconds at each frequency. Dwell for 1 min at 60 Hz. Accelerometer manually moved.	
12. Control and protective relays, General Electric	0.40	0.27	Varies 0.50 min 5.0 max	Varies 0.50 min 5.0 max	Freq. scan: 1-33 Hz Res. freq.: none	Yes	General Electric, Philadelphia, Pennsylvania, November 1976	Random input. Test response spectra enveloped required response spectra. No malfunction based upon failure criteria.	a
13. Contractor for backup pressurizer heaters, Klockner Moeller	0.30	0.20	0.30	0.25	Freq. scan: 2-55 Hz Res. freq.: 14, 16, 20, 34, 46, 52 Hz	Yes	TII Labs, College Point, New York, August 1973	Six accelerometers used, two on table and four on the equipment at various locations. Sinusoidal input for one horizontal plus vertical simultaneously for frequency scan and dwell. Scan rate at 20 sec/Hz. Dwell for 1 min minimum.	(Ref. Expl. Note 12)

a. Substantial margin exists, as shown by examination of data.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-6 (continued)

EQUIPMENT TEST SUMMARY, STONE & WEBSTER SCOPE OF SUPPLY

Equipment Description	Req'd Test "g" (ZPA)		Experienced Test			Tested in Operation	Test Lab Facilities	Notes	Margin
	Horizontal	Vertical	"g" Horizontal	"g" Vertical	Frequency Range and Resonant Frequency				
14. Auxiliary control and relay panels instrumentation, Wolfe & Mann	0.18	0.12	0.30	0.38	Freq. scan.: 1-33 Hz Res. freq.: none	Yes	Wyle Labs, Huntsville, Alabama, March 1973	Seven accelerometers used at various locations. Sinusoidal input for frequency scan and dwell. Three axes individually. Devices mounted on test panel (actual panels have been shown to be rigid). Frequency scan at 1 octave/min; dwell for 1 min minimum.	a
15. Motor control center, Klockner Moeller	0.34	0.28	0.39	0.28	Freq. scan: 1-50 Hz Res. freq.: 6 Hz, 13 Hz, 20 Hz & 26 Hz	Yes	TII Labs, College Point, New York, May 1974	Sinusoidal input for frequency scan and dwell. Two axes simultaneously. Frequency scan at 1 octave/min. Dwell for 20 sec energized and 20 sec de-energized at resonant frequencies.	(Ref. Expl. Note 14)
16. Pressure switches, Barksdale Valves	0.35	0.28	0.50	0.50	Freq. scan: 2-33 Hz Res. freq.: none	Yes	Ogden Labs, California, December 1973	Sinusoidal input for frequency scan and dwell. Three axes individually. Dwelled for 30 seconds at 2, 5, 10, 15, 20, 25, 30 Hz. Scan rate 0.8 octave/min.	a

a. Substantial margin exists, as shown by examination of data.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-6 (continued)

EQUIPMENT TEST SUMMARY, STONE & WEBSTER SCOPE OF SUPPLY

Equipment Description	Req'd Test "g" (ZPA) Horizontal	Req'd Test "g" (ZPA) Vertical	Experienced Test "g" Horizontal	Experienced Test "g" Vertical	Experienced Test Frequency Range and Resonant Frequency	Tested in Operation	Test Lab Facilities	Notes	Margin
17. Ac distribution panel, General Electric	0.18	0.12	0.39	0.39	Freq. scan: 2-30 Hz Res. freq.: 21, 22, 31, 35, 39, 43, 44 Hz	Yes	Dayton T. Brown, Inc., New York, January 1973	Ten accelerometers used at various locations. Sinusoidal input used for scan and dwell. Three axes individually. Frequency scan at 0.73 octaves/min. Dwell for 20 sec minimum at resonance frequencies. Normal service mounting.	a
18. 480V switchgear, I-T-E Imperial	0.40	0.30	Varies .80 min 4.0 max	Varies .80 min 4.0 max	Freq. scan: 1-33 Hz	Yes	Wyle Labs, Huntsville, Alabama, July 1975	Random input. Test response spectra enveloped required response spectra. Biaxial.	a
19. 4160V switchgear, I-T-E Imperial	0.40	0.30	Varies .80 min 4.5 max	Varies .80 min 4.5 max	Freq. scan.: 1-33 Hz	Yes	Wyle Labs, Huntsville, Alabama, May 1975	Random input. Test response spectra enveloped required response spectra. Biaxial.	a
20. Air-conditioningself-cleaning strainers, Elliott Co.									
1) Component flushing valves, Contromatics Corp.	0.33	0.32	6.0	6.0	Freq. scan: 5-200 Hz Res. freq.: 90 Hz, 95 Hz	Yes	York Research Corp., Stamford, Connecticut, January 1974	Three axes individually sinusoidal input. Dwell for 15 min.	a

a. Substantial margin exists, as shown by examination of data.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-6 (continued)

EQUIPMENT TEST SUMMARY, STONE & WEBSTER SCOPE OF SUPPLY

Equipment Description	Req'd Test "g" (ZPA) Horizontal	Req'd Test "g" (ZPA) Vertical	Experienced Test "g" Horizontal	Experienced Test "g" Vertical	Experienced Test Frequency Range and Resonant Frequency	Tested in Operation	Test Lab Facilities	Notes	Margin
2) Component motor control center, Allen Bradley Co.	0.18	0.12	0.39	0.39	Freq. scan: 2-60 Hz Res. freq.: several	Yes	TII Labs, College Point, New York, January 1974	Three axes individually. Sinusoidal input for frequency scan and dwell. Scan at 2 octaves/min. Dwell for 30 seconds at each frequency.	a
21. Bimetallic thermometers, Moeller Instrument Co.	0.43	0.28	1.0	1.0	Freq. scan: 5-200 Hz Res. freq.: several	No	Delevan Electronics Corp., East Aurora, New York, November 1971	Three axes individually. Scan at 1/3 octave/min. Dwell at 1.0 g for 1 min with sinusoidal input.	a
22. Rotork motor operator, Rotork Company	0.50	0.35	0.50	0.35	Freq. scan: 1-33 Hz Res. freq.: several	No	Aero Nav Lab, College Point, New York, September 1975	Three axes individually, sinusoidal scan held 20 seconds at each frequency. Scan rate 3 Hz/min. 30 seconds dwell. Accelerometers on fixture, electrical box and motor. No malfunction.	(Ref. Expl. Note 21)

a. Substantial margin exists, as shown by examination of data.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-6 (continued)

EQUIPMENT TEST SUMMARY, STONE & WEBSTER SCOPE OF SUPPLY

Equipment Description	Req'd Test "g" (ZPA) Horizontal	Req'd Test "g" (ZPA) Vertical	Experienced Test "g" Horizontal	Experienced Test "g" Vertical	Experienced Test Frequency Range and Resonant Frequency	Tested in Operation	Test Lab Facilities	Notes	Margin
23. Level transmitters, Delaval Gems Sensor Division	0.12	0.12	0.36	0.30	Freq. scan: 1-33 Hz Res.freq.: Type XM-36925 level Transmitter: 8 Hz Type XM-36490 level Transmitter: 12 Hz	Yes	TII Testing Lab, College Point, New York, January 1974	Sinusoidal scan three axes individually held 20 seconds at each freq. Scan rate 3 Hz/min. Dwell 60 seconds biaxial in 2 directions. Accelerometers on fixture and transmitter. No malfunction.	a
24. Receiver, Delaval Gems Sensor Division	0.12	0.12	4.2	3.4	Freq. scan: 1-33 Hz Res. freq.: none	Yes	TII Testing Lab, College Point, New York, January 1974	Same as above.	a
25. Damper operator motor, Barber Colman	0.65	0.36	1.0	0.75	Freq. scan: 1-35 Hz Res. freq.: 21 Hz, 31 Hz	No	Gaynes Engineering and Testing Lab, Chicago, Illinois, October 1974	Accelerometers on base and top of damper assembly. Sinusoid input for scan and dwell. Three axes individually. 20 seconds dwell at 1-10, 13, 15, 17, 20, 25, 30, 35 Hz plus additional resonance. Functional test after vibration test. No malfunction.	a

a. Substantial margin exists, as shown by examination of data.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-6 (continued)

EQUIPMENT TEST SUMMARY, STONE & WEBSTER SCOPE OF SUPPLY

Equipment Description	Req'd Test "g" (ZPA) Horizontal	Req'd Test "g" (ZPA) Vertical	Experienced Test "g" Horizontal	Experienced Test "g" Vertical	Experienced Test Frequency Range and Resonant Frequency	Tested in Operation	Test Lab Facilities	Notes	Margin
26. Valve accessories, Fisher Controls, Marshalltown	3.0	3.0	4.0	4.0	Freq. scan: 5-60 Hz Res. freq.: none	Yes	Fisher Controls, Marshalltown, Iowa, November, 1972	Three axes individually. Sinusoid input. Scan at 1 g. Dwell for 60 seconds at 10, 17, 25, & 33 Hz.	a
27. Valve controller, Fisher Controls, Marshalltown	0.18	0.12	0.52	0.35	Freq. scan: 5-60 Hz Res. freq.: none	Yes	Fisher Controls, Marshalltown, Iowa, December 1972	Three axes individually. Sinusoid input. 60 seconds dwell at 5, 10, 17, 25, 33 Hz. Well mounted. No malfunction. Accelerometer on shaker table.	a
28. Valve positioner, Fisher Controls, Marshalltown	3.0	3.0	4.0	4.0	Freq. scan: 5-60 Hz Res. freq.: 48 Hz	Yes	Fisher Controls, Marshalltown, Iowa, May 1973	Three axes individually. Sinusoid input. 60 seconds dwell at 10, 17, 25, 33, 48 Hz. No malfunction. Accelerometer on shaker table.	a
29. Pressure reducing valve and self-contained relief valve, Fisher	3.0	3.0	4.0	4.0	Freq. scan: 5-60 Hz Res. freq.: none	Yes	Fisher Controls, Marshalltown, Iowa, April 1975	Three axes individually. Sinusoid input. 60 seconds dwell at 10, 17, 25, and 33 Hz. No malfunction.	a
30. Solenoid valve, ASCO	3.0	3.0	9.1	12.2	Freq. scan: 5-40 Hz Res. freq.: none	Yes	ASCO Valve Lab, October 1976	One valve tested 3 axes individually and 1 valve tested biaxially. Sinusoid input. Scan rate 2 octaves/min. Constant 15-in. double amplitude displacement (.62 g at 9 Hz - 12 g at 50 Hz).	a

a. Substantial margin exists, as shown by examination of data.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-6 (continued)

EQUIPMENT TEST SUMMARY, STONE & WEBSTER SCOPE OF SUPPLY

Equipment Description	Req'd Test "g" (ZPA) Horizontal	Req'd Test "g" (ZPA) Vertical	Experienced Test "g" Horizontal	Experienced Test "g" Vertical	Experienced Test Frequency Range and Resonant Frequency	Tested in Operation	Test Lab Facilities	Notes	Margin
31. Solenoid valve, Atkomatic Valve Co./ Fisher	2.4	1.6	3.0	2.0	Freq. scan: 2-200 Hz Res. freq.: 120 Hz and 125 Hz	Yes	Gaynes Engineering, Chicago, Illinois, September 1976	Biaxial - scan rate octaves/min at 0.72 g. 60 seconds dwell. Sinusoid input. Accelerometers on base and valve. No malfunctions.	a
32. Indicating and alarm instrument, International	.18	.12	2.0	1.4	Freq. scan: 5-30 Hz Res. freq.: none	Yes	Dayton T. Brown, Long Island, New York, October 1973	Sine beat - 2 beats each freq. min 10 cycles/beat. 3 axes individually.	a
33. Electric heat tracing, Nelson Electric									
1) 47 point thermocouple controller cabinet	0.43	0.28	0.61	0.28	Freq. scan: 1-40 Hz Res. freq.: several	Yes	Aero Nav Labs, College Point, New York, April 1976	Ten accelerometers used at various locations. Sinusoidal input for frequency scan and dwell, three axes individually. Dwell at each frequency for 60 seconds. No malfunction.	(Ref. Expl. Note 32)

a. Substantial margin exists, as shown by examination of data.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-6 (continued)

EQUIPMENT TEST SUMMARY, STONE & WEBSTER SCOPE OF SUPPLY

Equipment Description	Req'd Test "g" (ZPA)		Experienced Test						
	Horizontal	Vertical	"g" Horizontal	"g" Vertical	Frequency Range and Resonant Frequency	Tested in Operation	Test Lab Facilities	Notes	Margin
2) 24 pole distribution panel	0.61	0.28	0.80	0.30	Freq. scan: 1-40 Hz Res. freq.: 12, 18, 22, 27 and 33 Hz	Yes	Aero Nav Labs, College Point, New York, September 1975	Same as above.	(Ref. Expl. Note 32)
3) 30 kVA heavy-duty transformer	0.61	0.28	0.80	0.50	Freq. scan: 1-40 Hz Res. freq.: several	Yes	Aero Nav Labs, College Point, New York, March 1976	Same as above.	(Ref. Expl. Note 32)
4) 3-phase, 70 amp breaker	0.61	0.28	0.80	0.28	Freq. scan: 1-40 Hz Res. freq.: 24, 30, 36, and 37 Hz	Yes	Aero Nav Labs, College Point, New York, September 1975	Seven accelerometers used at various locations. Sinusoidal input for frequency scan and dwell. Three axes individually. Dwell at each frequency for 60 seconds. No malfunction.	(Ref. Expl. Note 32)
5) 16-point controller	0.61	0.28	0.80	0.28	Freq. scan: 1-40 Hz Res. freq.: 28, 33, and 35 Hz	Yes	Aero Nav Labs, College Point, New York, December 1975	Same as above	(Ref. Expl. Note 32)

a. Substantial margin exists, as shown by examination of data.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-6 (continued)

EQUIPMENT TEST SUMMARY, STONE & WEBSTER SCOPE OF SUPPLY

Equipment Description	Req'd Test "g" (ZPA) Horizontal	Req'd Test "g" (ZPA) Vertical	Experienced Test "g" Horizontal	Experienced Test "g" Vertical	Experienced Test Frequency Range and Resonant Frequency	Tested in Operation	Test Lab Facilities	Notes	Margin
6) 24-point master annunciator panel	0.25	0.15	0.61	0.28	Freq. scan: 1-40 Hz Res. freq.: several	Yes	Eagle-Picher Industries, Missouri, May 1976	Eight accelerometers used at various locations. Sinusoidal input for frequency scan and dwell. Three axes individually. Dwell at each frequency for 20 seconds. No malfunction.	(Ref. Expl. Note 32)
7) 72-point annunciator	0.43	0.28	0.61	0.28	Freq. scan: 1-40 Hz Res. freq.: several	Yes	Aero Nav Labs, College Point, New York, April 1976	Same as above.	(Ref. Expl. Note 32)
34. Valve operator, Limitorque/ Crane									
1) SMB-00-25	3.0	3.0	5.0	4.6	Freq. scan: 1-35 Hz Res. freq.: 33 Hz	Yes	Lockheed Electronics Company, Ogden Technology Lab, Aero Nav Labs, Franklin Institute, January 1975	Five accelerometers used at various locations. Sinusoidal input for frequency scan and dwell. Three axes individually. Dwell for 1 min at 33 Hz. No malfunction.	a

a. Substantial margin exists, as shown by examination of data.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-6 (continued)

EQUIPMENT TEST SUMMARY, STONE & WEBSTER SCOPE OF SUPPLY

Equipment Description	Req'd Test "g" (ZPA) Horizontal	Req'd Test "g" (ZPA) Vertical	Experienced Test "g" Horizontal	Experienced Test "g" Vertical	Experienced Test Frequency Range and Resonant Frequency	Tested in Operation	Test Lab Facilities	Notes	Margin
2) SMB-00-15	3.0	3.0	6.3	6.5	Freq. scan: 1-35 Hz Res. freq.: none	Yes	Aero Nav Labs, New York, New York, January 1975	Six accelerometers used at various locations. Sinusoidal input for frequency scan and dwell. Three axes individually. Dwell for 30 seconds at 33 Hz. No malfunctions.	a
35. Emergency manual operator fire pumps, Pearless/ FMC Corp.	0.51	0.36	0.55	0.36	Freq. scan: 1-40 Hz Res. freq.: 25 Hz	Yes	Gaynes Engineering and Testing Lab, August 1975	Two accelerometers used at various locations. Three axes individually. Sinusoidal input for frequency dwell and scan. Dwell for 20 seconds at resonant frequencies.	(Ref. Expl. Note 34)
36. Leak detection system, Nutec, Inc.	0.18	0.12	0.30	0.15	Freq. scan: 1-60 Hz Res. freq.: 9, 22.5, 33.5, 48, 55, 57 Hz	Yes	Wyle Lab, May 1976	Two axes simultaneously. Six accelerometers used at various locations. Sinusoidal input for frequency scan and dwell. Dwell for 20 seconds at resonant frequencies.	a
37. Centrifugal fans--damper motors #331-2707, Buffalo Forge/Power Regulators	0.48	0.30	0.67	0.67	Freq. scan: 1-40 Hz Res. freq.: 4 Hz and 25 Hz	No	Gaynes Engineering and Testing Lab, December 1971	Three axes individually. Sinusoidal input for frequency scan and dwell. Acceleration held at 11 discrete frequencies for 20 seconds or more. Equipment tested after vibration test, no malfunction.	a

a. Substantial margin exists, as shown by examination of data.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-6 (continued)

EQUIPMENT TEST SUMMARY, STONE & WEBSTER SCOPE OF SUPPLY

Equipment Description	Req'd Test "g" (ZPA)		Experienced Test						
	Horizontal	Vertical	"g" Horizontal	"g" Vertical	Frequency Range and Resonant Frequency	Tested in Operation	Test Lab Facilities	Notes	Margin
38. Damper operator, Power Regulators Company #331-2779	0.55	0.35	1.0	1.0	Freq. Scan: 3-40 Hz Res. Freq.: 18, 28, 30, 40 Hz	No	Gaynes Engineering and Testing Lab, August 1974	Two tests were conducted. three axes individually and two axes simultaneously. Acceleration held at each frequency for 20 seconds. Sinusoidal input for frequency scan and dwell.	a
39. Electric air duct heating, CVI Corp.									
1) heater control cabinet	0.43	0.28	0.55	0.55	Freq. Scan: 2-50 Hz Res. freq.: 5, 9, 10, 15, 18, 21, 29, 34 and 44 Hz	Yes	Boyd Lab, Ohio State University, April 1976	Three axes individually. Sinusoidal input for frequency scan and dwell. Scan rate at 0.270 octave/min. Dwell at each resonant frequency.	a
2) 100-kV heater control cabinet	0.43	0.28	0.55	0.55	Freq. scan: 2-50 Hz Res. freq.: 5, 7, 9, 13 and 26 Hz	Yes	Boyd Lab, Ohio State University, April 1976	Same as above.	a
40. Hydrogen- oxygen analyzer system, Bendix Corp.	0.38	0.27	0.44	0.30	Freq. scan: 1-33 Hz Res. freq.: 8, 12, 15, 19 and 29 Hz	Yes	Aerospace Research Corp., August 1976	Six accelerometers used in various locations. Sinusoidal input for frequency scan and dwell. Three axes individually. Dwell at resonant frequencies for 20 to 25 seconds.	(Ref. Expl. Note 39)

a. Substantial margin exists, as shown by examination of data.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-6 (continued)

EQUIPMENT TEST SUMMARY, STONE & WEBSTER SCOPE OF SUPPLY

Equipment Description	Req'd Test "g" (ZPA) Horizontal	Req'd Test "g" (ZPA) Vertical	Experienced Test "g" Horizontal	Experienced Test "g" Vertical	Experienced Test Frequency Range and Resonant Frequency	Tested in Operation	Test Lab Facilities	Notes	Margin
41. Agastat relay model, 7012 and 7022, Colt Industries	0.38	0.27	Varies 2.2g min 10g max	Varies 2.2g min 10g max	1-33 Hz Frequency Bathwidth:	Yes	Wyle Lab, Huntsville, Alabama, September 1976	Biaxial random input for 30 seconds. Fragility response spectra greater than required response spectra.	a
42. Automatic temperature control systems, Honeywell									
1) Humidity controller	0.43	0.28	0.55	0.36	Freq. scan: 5-40 Hz Res. freq.: several	Yes	Wyle Labs, August 1976	Two axes simultaneously. Sinusoidal input for frequency dwell and scan.	a
2) Heavy-duty thermostat								Sweep at 1 octave/min. Dwell test performed at 1/2 octave intervals over the frequency range 0.5 Hz	
3) Pneumatic damper operator								- 40 Hz for a duration of 30 seconds per frequency.	
4) Dampers & operator assembly	0.18	0.12	0.33	0.55	Freq. scan: 2-100 Hz Res. freq.: several	Yes	Honeywell, September 1972	Twelve accelerometers used at various locations. Three axes individually. Dwell at 18, 20, 28, 33, 45, 61, and 69 Hz for 20 seconds each.	a
5) Temperature control module									

a. Substantial margin exists, as shown by examination of data.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-6 (continued)

EQUIPMENT TEST SUMMARY, STONE & WEBSTER SCOPE OF SUPPLY

Equipment Description	Req'd Test "g" (ZPA) Horizontal	Req'd Test "g" (ZPA) Vertical	Experienced Test "g" Horizontal	Experienced Test "g" Vertical	Experienced Test Frequency Range and Resonant Frequency	Tested in Operation	Test Lab Facilities	Notes	Margin
6) Motor control module	0.18	0.12	0.18	0.15	Freq. scan: 5-100 Hz Res. freq.: 12, 15, 18, 23, and 85 Hz	Yes	Honeywell, September 1973	Three axes individually. Sinusoidal input for scan and dwell. Duration of dwell test was minimum of 30 seconds at each resonant frequency.	(Ref. Expl. Note 41)
7) Temperature indication module								Three axes individually. Sinusoidal input for scan and dwell. Duration of dwell test was minimum of 30 seconds at each resonant frequency.	(Ref. Expl. Note 41)

Explanatory Notes

3. Main Control Board Instrumentation

The instrumentation was subjected to a series of sinusoidal scan tests and dwell tests at a maximum input acceleration level of 0.4g over the frequency range from 1 to 33 Hz. The required input acceleration for this instrumentation, based upon its location and site-related conditions, is 0.36g horizontal and 0.24g vertical. All instrumentation remained functional throughout the test. The demonstrated margin is in excess of 11%.

It is believed that this instrumentation can easily withstand greater accelerations than those to which it has been qualified.

12. Contractor for Backup Pressurized Heaters

The equipment was subjected to a sinusoidal frequency scan test at input accelerations ranging from 0.16g to 1.4g horizontal and for 0.17g to 1.2g vertical with the acceleration held at each frequency for at least 30 seconds to record the accelerometer readings. This test was conducted, however, with the equipment not energized. Dwell tests were conducted at the resonant frequencies for a 60-second duration and minimum input acceleration of 0.30g horizontal and 0.25g vertical. The equipment functioned satisfactorily during and after the tests.

The equipment margins existing beyond the demonstrated level are not known.

a. Substantial margin exists, as shown by examination of data.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-6 (continued)

EQUIPMENT TEST SUMMARY, STONE & WEBSTER SCOPE OF SUPPLY

Equipment Description	Req'd Test "g" (ZPA) Horizontal	Req'd Test "g" (ZPA) Vertical	Experienced Test "g" Horizontal	Experienced Test "g" Vertical	Experienced Test Frequency Range and Resonant Frequency	Tested in Operation	Test Lab Facilities	Notes	Margin

14. Motor Control Center

Motor control centers were subjected to a series of three tests, with the minimum input acceleration ranging from 0.39g horizontal and 0.26g vertical to 0.49g horizontal and 0.36g vertical. Dwell tests were conducted for a minimum of 40 seconds (up to 2 minutes for two of three tests) at all the identified resonant frequencies and at frequencies where the transmissibility was higher than 2. It is also noted that during the frequency search tests, the input accelerations exceeded the required input accelerations by a very large margin, and these input accelerations were held at each frequency for at least 30 seconds. Although the equipment was not energized during the frequency search tests and, therefore, does not constitute a dwell test, the capability of the equipment to withstand higher accelerations for long duration is evident. The equipment successfully passed performance tests after undergoing the vibration tests.

This observation, in conjunction with experience with other manufacturer's equipment, leads to the belief that this equipment can easily withstand seismic accelerations at least 15% greater than those to which it has been qualified.

21. Rotork Motor Operator

The Rotork motor operator type 7AZ SPC was subjected to sinusoidal frequency scan and dwell tests with minimum input accelerations of 0.5g horizontal and 0.35g vertical. The frequency scan was conducted from 1 to 33 Hz. For the range from 5 to 33 Hz, each frequency was held for a minimum of 20 seconds. Therefore, the frequency scan can be considered a dwell test. Additional 30-second dwell tests were conducted at 5, 10, 15, 17, 20, 25, 30 and 33 Hz in one horizontal direction and 9 Hz in the vertical direction. The equipment was tested in the nonoperating mode. It is not a requirement that these motor operators function during an earthquake. The motor operator was tested to required acceleration levels. Additional margin exists based on testing of similar equipment.

32. Electric Heat Tracing Equipment

All the components of this equipment were tested in energized condition on a constant displacement machine, with the input acceleration held at each frequency for at least 20 seconds. Use of the constant displacement machine resulted in much higher input acceleration than the minimum required, noted as "experienced," at all the frequencies beyond 10 Hz. Study of the experienced accelerations demonstrated that all the components of this equipment can easily withstand 50 to 100% higher accelerations than those indicated.

34. Emergency Manual Operator for Fire Pumps

The operator was tested to the required acceleration levels. However, due to its compact makeup, substantial margin is believed to exist.

a. Substantial margin exists, as shown by examination of data.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-6 (continued)

EQUIPMENT TEST SUMMARY, STONE & WEBSTER SCOPE OF SUPPLY

Equipment Description	Req'd Test "g" (ZPA) Horizontal	Req'd Test "g" (ZPA) Vertical	Experienced Test "g" Horizontal	Experienced Test "g" Vertical	Experienced Test Frequency Range and Resonant Frequency	Tested in Operation	Test Lab Facilities	Notes	Margin

39. Hydrogen Analyzer System

The hydrogen analyzer system was tested to specification requirements of 0.44g horizontal and 0.30g vertical with no indication of structural or functional failure. Results of frequency scan tests indicate that the equipment is more sensitive to horizontal excitation than vertical excitation. A similar unit was tested by the same manufacturer to levels of 0.61g horizontal and 0.22g vertical without structural or electrical failure. Based on the observation that the equipment is more susceptible to horizontal excitation than vertical, and that a similar unit was successfully tested to levels 33% higher than the North Anna specification requirements, it can reasonably be assumed that the equipment purchased for North Anna can withstand an acceleration level significantly in excess of the required level.

41. Automatic Temperature Control Systems

Items 1 through 4 have been shown to have substantial margins. However, items 5, 6, and 7 were tested only to the required accelerations and, therefore, do not provide evidence of available margin.

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a. Substantial margin exists, as shown by examination of data.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-7

NORTH ANNA UNITS 1 AND 2 SEISMIC DESIGN MARGINS, PERCENTAGE OF ALLOWABLES FOR MOST HIGHLY STRESSED LOCATIONS

Component	OBE	SSE	SSE & LOCA	Location
Steam generator	a	a	a	
Reactor coolant pump	72%	72%[c]	98%	OBE-SSE main closure bolts SSE-LOCA pump casing at support foot
Pressurizer	a	a	a	
Reactor coolant loop piping	90%	50%	90%	OBE-SSE at RPV inlet nozzle SSE-LOCA at SG inlet elbow
Reactor vessel	b	b	b	
Reactor vessel internals	6%	6%	63%	Core barrel girth weld
Fuel	10%	16%	57%	Fuel assembly grids
CRDM	53%	53%[c]	90%	RPV head adaptor

a. Component analyzed to multi-plant envelope response spectra and design loads. The actual spectra are shown to be below envelope spectra. The actual loads are shown to be below envelope loads.
b. The reactor pressure vessel is designed and analyzed for conservative design loads consisting of simultaneously applied static seismic loads on the vessel and system-imposed nozzle loads generate by dynamic system analyses.
c. Seismic SSE loads compared with OBE allowables.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.7-8
SEISMIC DESIGN MARGINS

					Qualification Level					
				Response Spectra[a]			Acceleration		Percent of Response Spectra	
Component	Building	Elevation	Component Frequency	Elevation	H	V	H	V	H	V
1. Safety injection accumulator tank	Containment	217 ft 5 in.	21.3 Hz	239.42 ft	0.5g	0.4g	0.7g	0.46g	71%	87%
2. Residual heat removal heat exchanger	Auxiliary	233 ft 4.5 in.	36.5 Hz	241.5 ft	0.33g	0.27g	0.7g	0.45g	47%	60%
3. Centrifugal charging pump	Auxiliary	244 ft 6 in.	33 Hz	259.0 ft	0.33g	0.3g	0.75g	0.5g	44%	60%
4. Low-head safety injection pump	Auxiliary	259 ft 7.25 in.	33 Hz	259.0 ft	c	c	c	c	c	c
5. Process instrumentation and control rack	Control room	252 ft 0 in.	b	b	b	b	b	b	b	b

a. 1% equipment damping.
b. The process instrumentation and control racks were qualified to the generic seismic requirements presented in WCAP 7821. This WCAP presents requirements for qualifications for high seismic plants (i.e., 0.2 to 0.4g ground acceleration). Therefore, considering the relatively low ground acceleration of 0.12g for the North Anna site, design margins in excess of 2 are shown.
c. The low-head safety injection pumps were seismically qualified by comparison to an equivalent pump that had been generically qualified by dynamic modal analysis and response spectrum methods. The North Anna response spectrum at the elevation of the pumps and within the frequency range of the pumps was shown to be conservatively enveloped by the design spectra used for the reference pump, thereby confirming the applicability of the results of the reference analysis for the North Anna pumps.

Figure 3.7-1
HORIZONTAL DYNAMIC MODEL FOR SEISMIC ANALYSIS OF
CONTAINMENT STRUCTURE

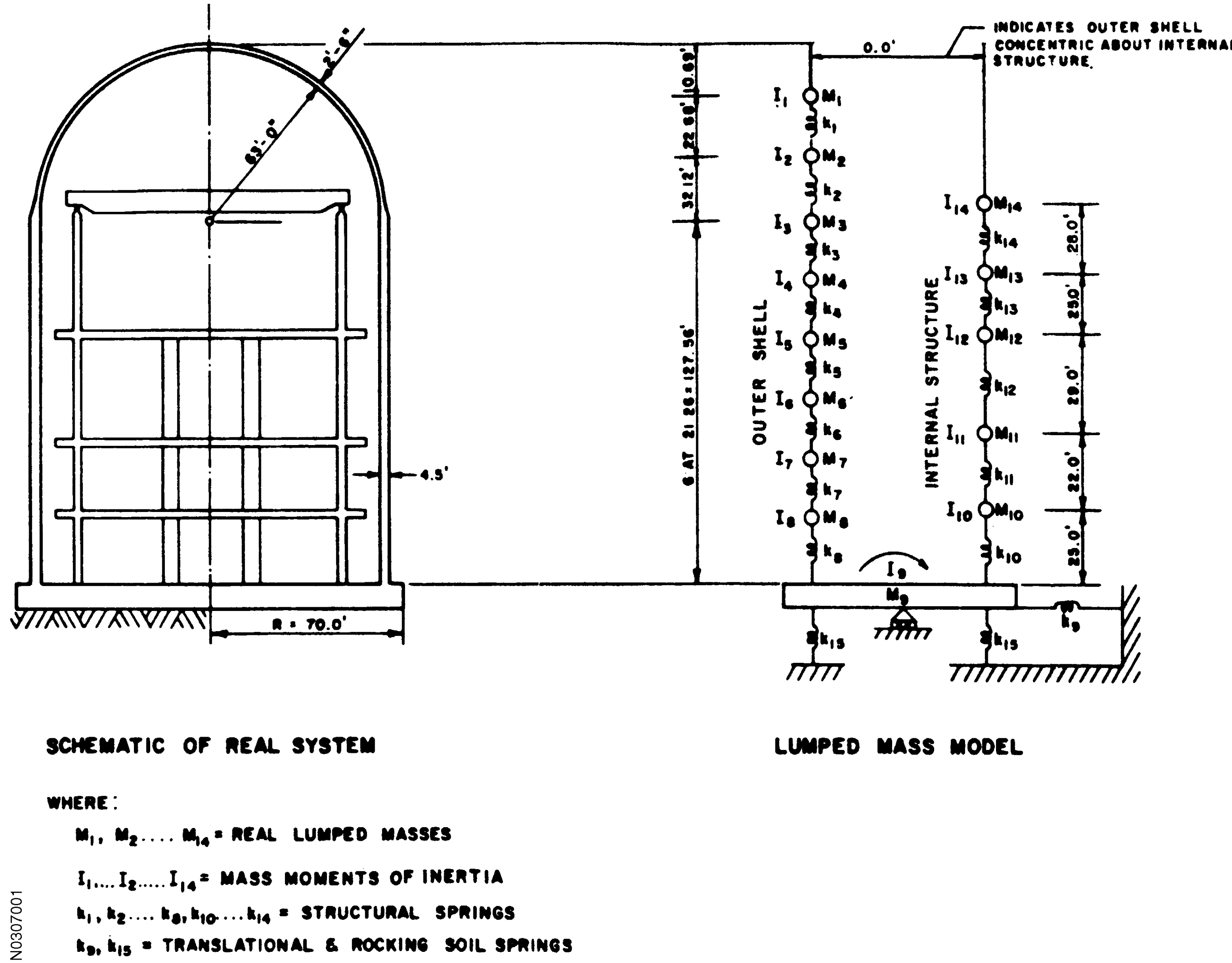
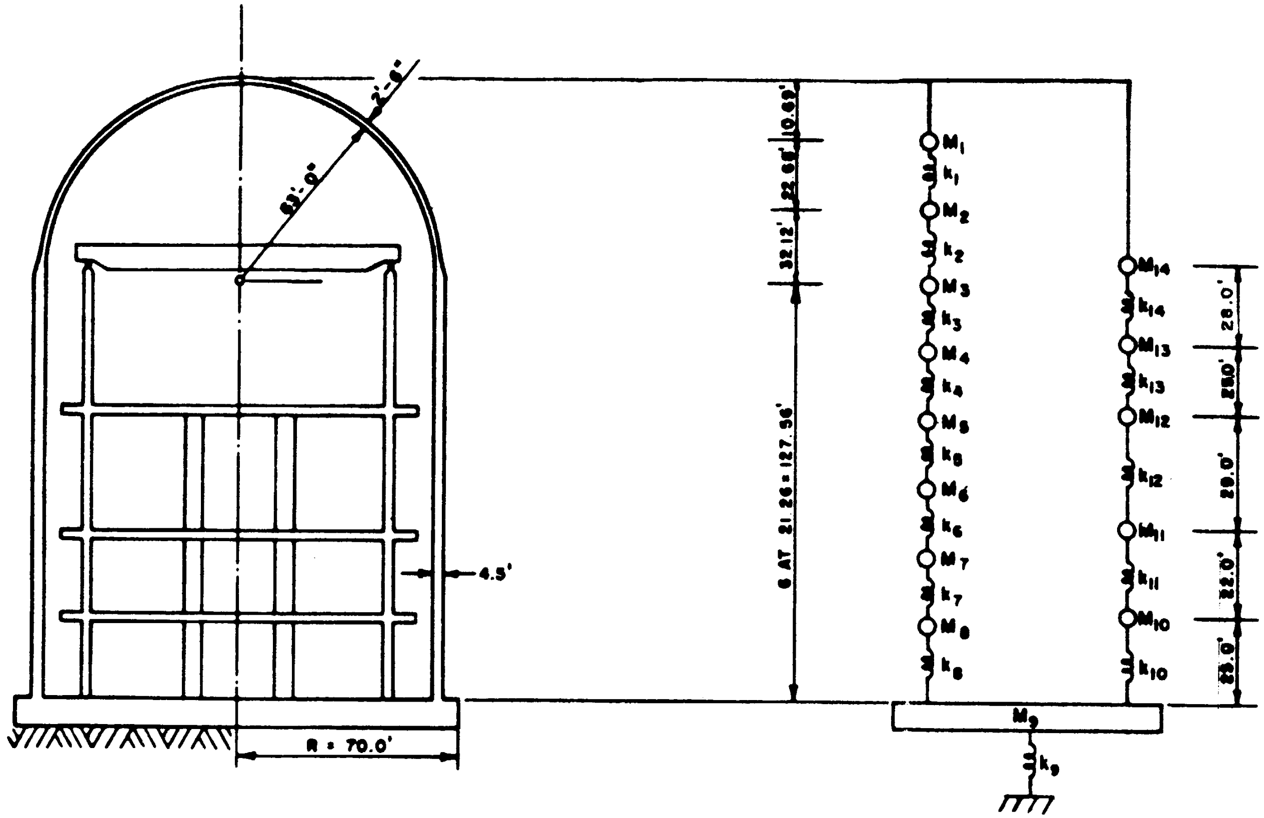


Figure 3.7-2
VERTICAL DYNAMIC MODEL FOR SEISMIC ANALYSIS OF CONTAINMENT STRUCTURE



SCHEMATIC OF REAL SYSTEM

LUMPED MASS MODEL

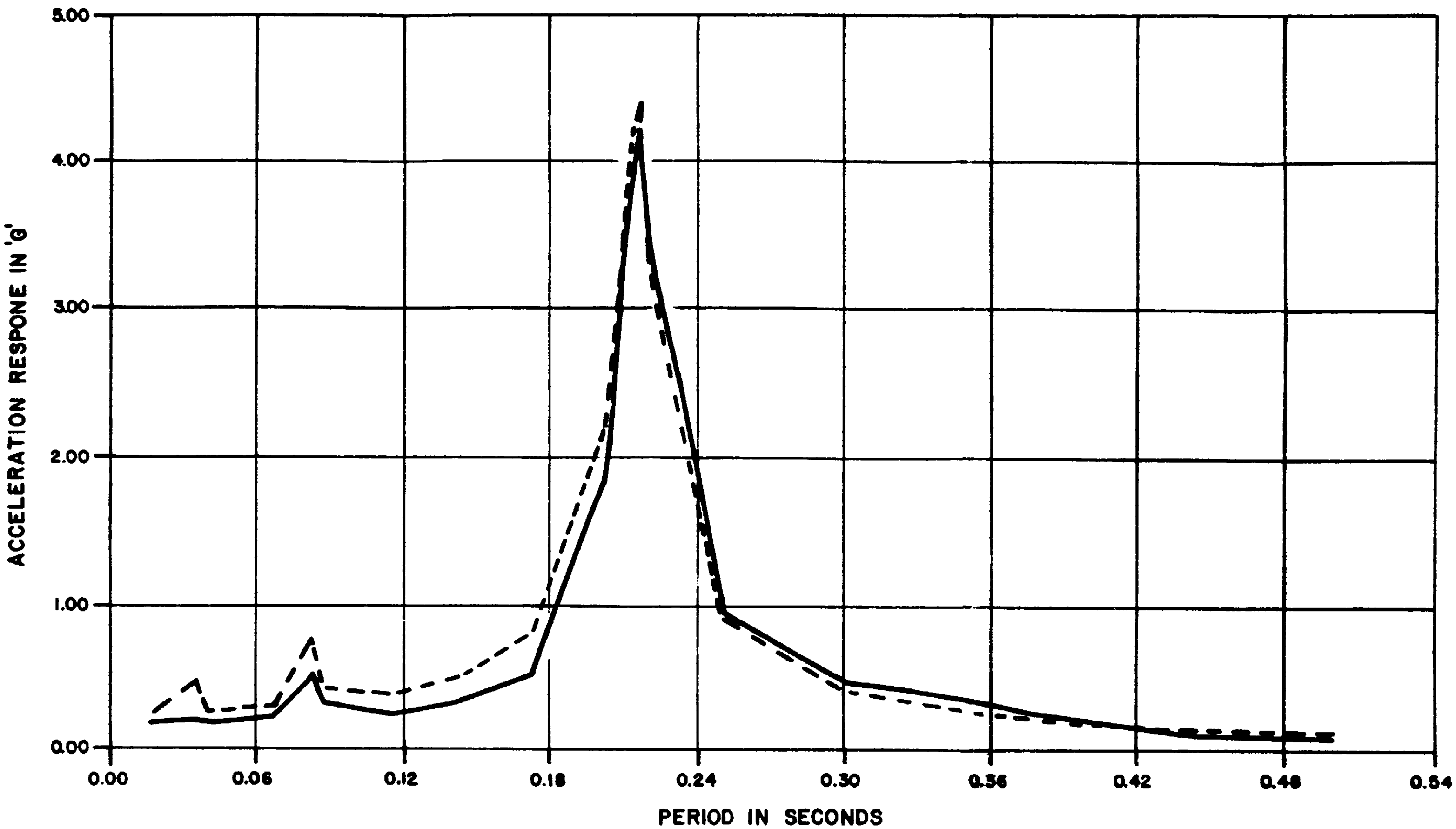
WHERE:

M_1, M_2.... M_{14} = REAL LUMPED MASSES

k_9 = VERTICAL SOIL SPRING

307002

Figure 3.7-3 (SHEET 1 OF 6)
AMPLIFIED RESPONSE SPECTRA



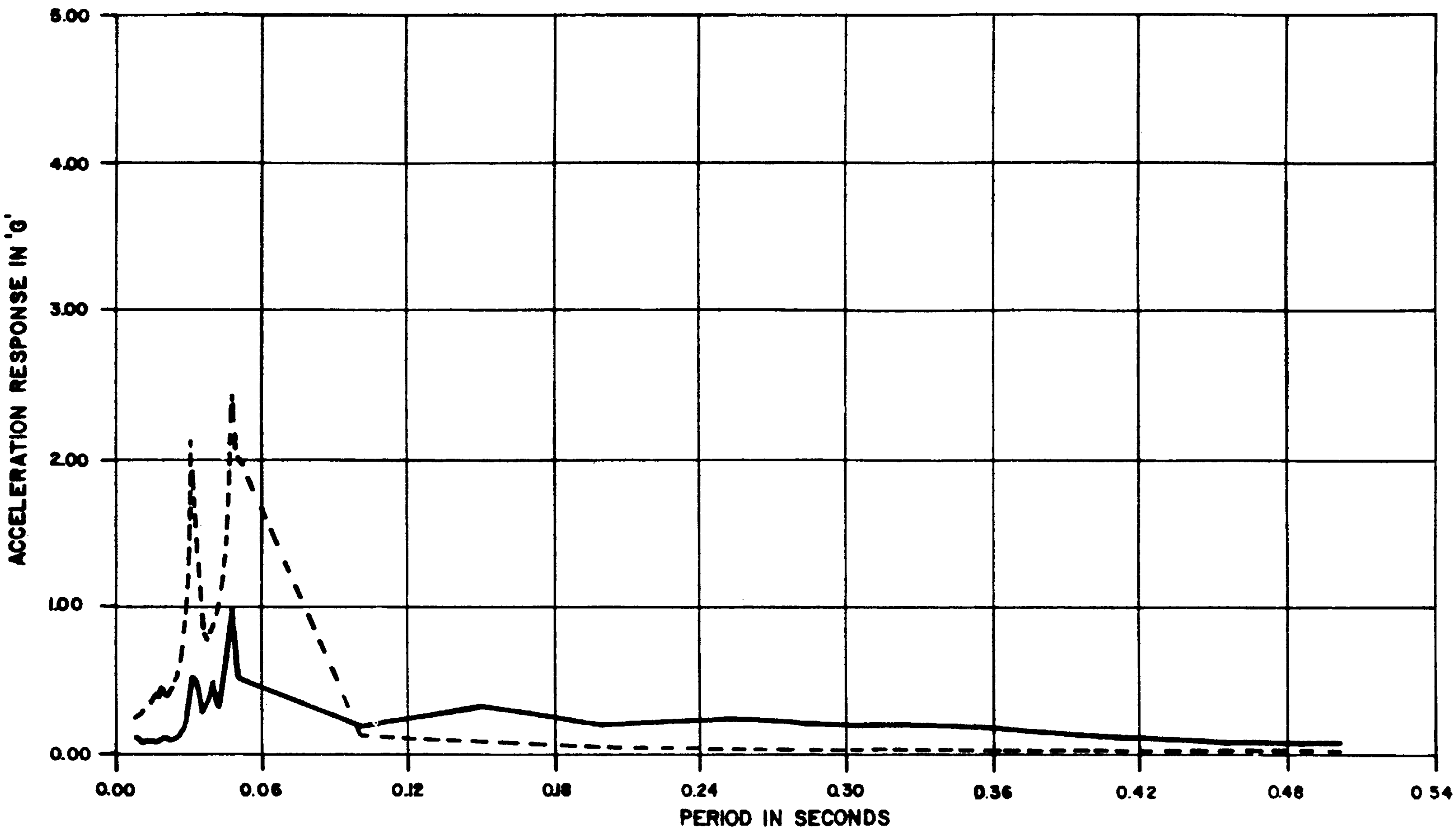
NOTES:

COMPARISON OF TIME HISTORY AND FREQUENCY RESPONSE METHODS AT CHARGING FLOOR ELEVATION 291 FT. 10 IN. INTERNAL STRUCTURE, CONTAINMENT BUILDING.
EQUIPMENT DAMPING .005 STRUCTURAL DAMPING .02

– – – – – FREQUENCY RESPONSE METHOD R=.5
———— TIME HISTORY METHOD FOR HELENA EW NORMALIZED TO .066

N0307003

Figure 3.7-3 (SHEET 2 OF 6)
AMPLIFIED RESPONSE SPECTRA

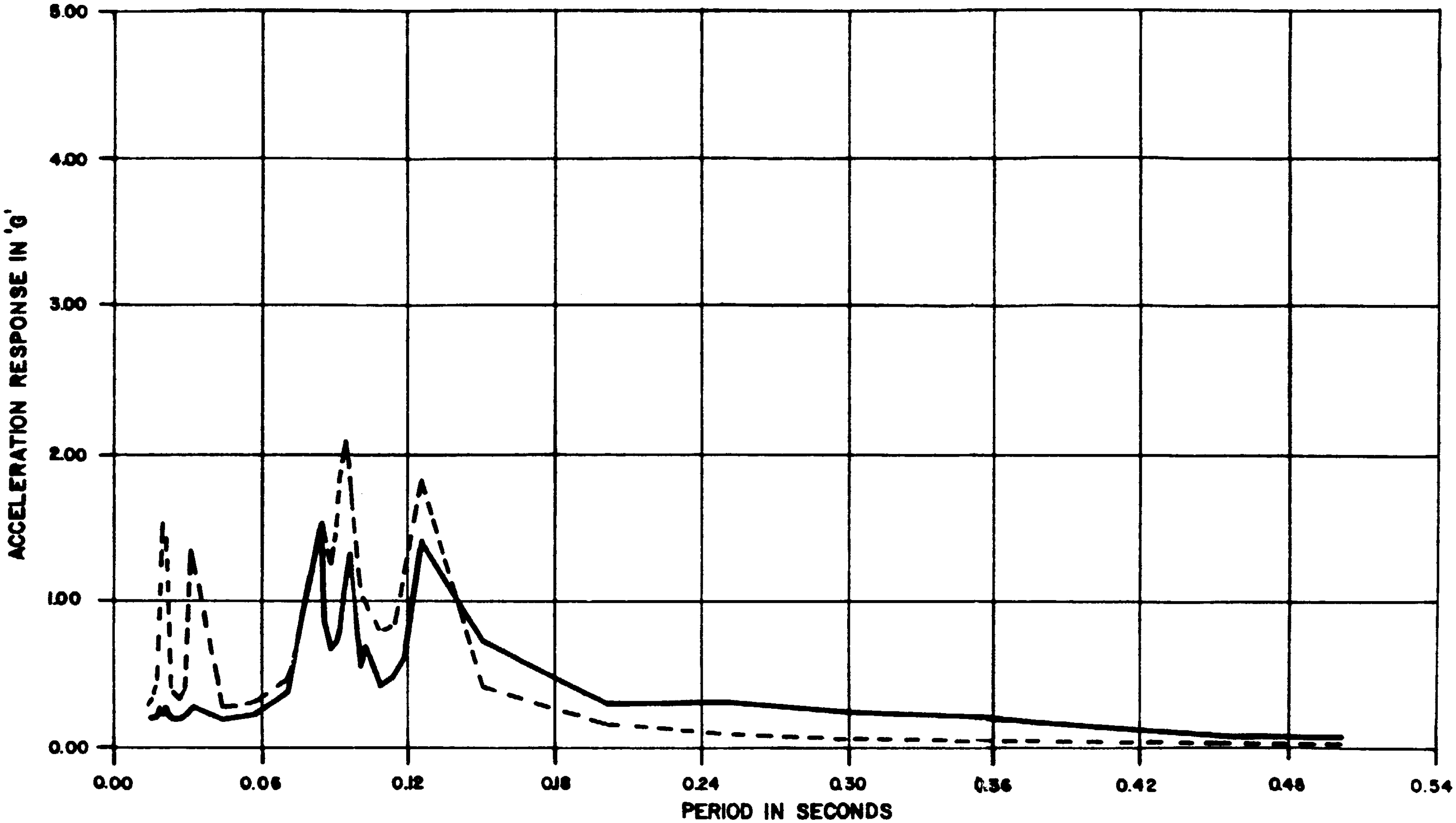


NOTE:
COMPARISON OF TIME HISTORY AND FREQUENCY RESPONSE METHODS AT EL. 310.5 FT. AUXILIARY BUILDING
EQUIPMENT DAMPING .005 STRUCTURAL DAMPING .02

------ FREQUENCY RESPONSE METHOD. R = 1.
——— TIME HISTORY METHOD FOR HELENA EW NORMALIZED TO .066

N0307004

Figure 3.7-3 (SHEET 3 OF 6)
AMPLIFIED RESPONSE SPECTRA

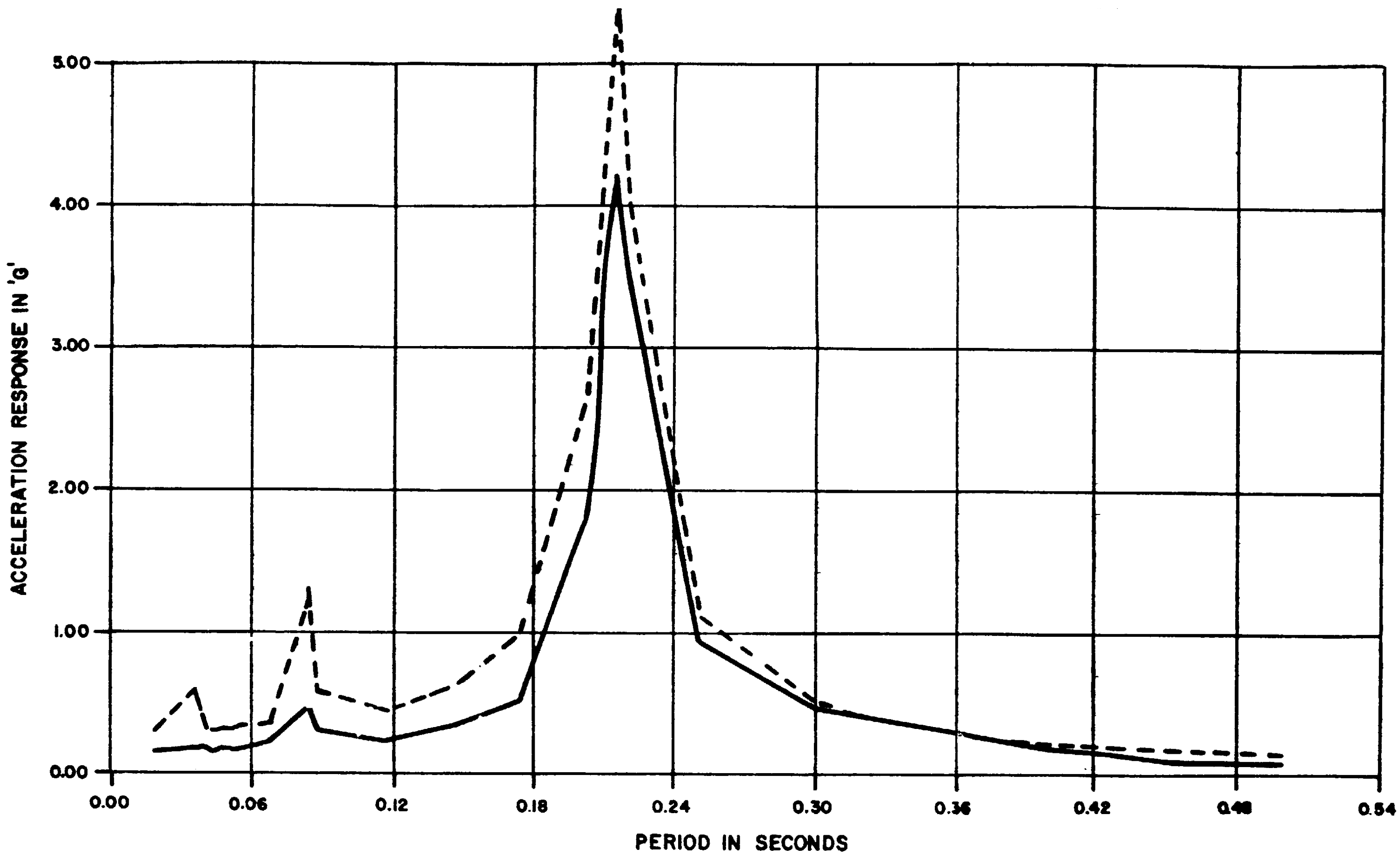


NOTE:
COMPARISON OF TIME HISTORY AND FREQUENCY RESPONSE METHODS AT EL. 322.83 FT. FUEL BUILDING.
EQUIPMENT DAMPING .005 STRUCTURAL .02

– – – – – FREQUENCY RESPONSE METHOD. R=.6
———— TIME HISTORY METHOD FOR HELENA EW NORMALIZED TO .0.6G

N0307005

Figure 3.7-3 (SHEET 4 OF 6)
AMPLIFIED RESPONSE SPECTRA

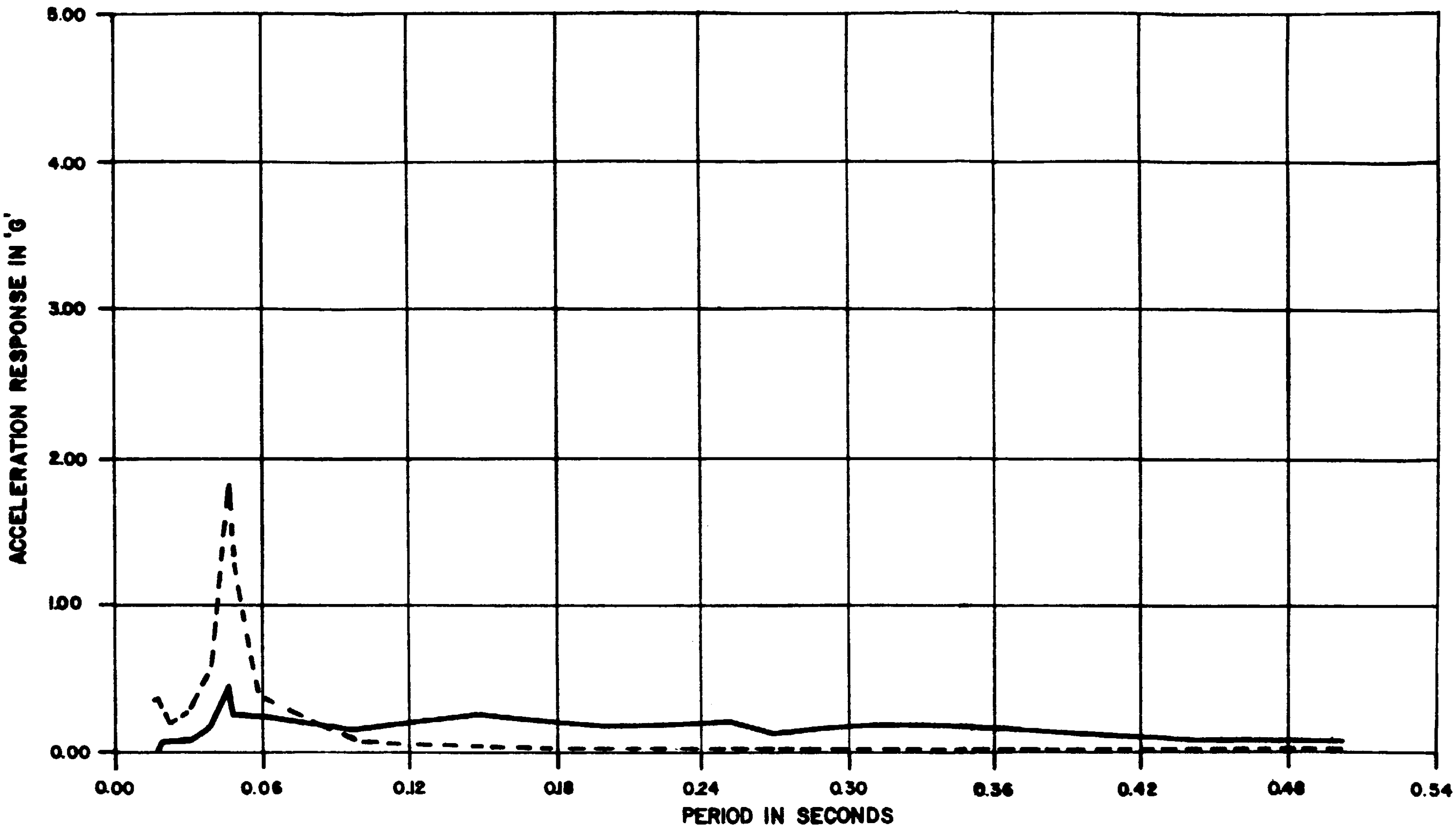


NOTE:
COMPARISON OF TIME HISTORY AND FREQUENCY RESPONSE METHODS AT CHARGING FLOOR ELEVATIONS 291 FT. 10 IN. INTERNAL STRUCTURE, CONTAINMENT BUILDING. EQUIPMENT DAMPING .005 STRUCTURE DAMPING .02

– – – – – FREQUENCY RESPONSE METHOD R=.5 OBE JOB SPECTRA
———— TIME HISTORY METHOD FOR HELENA EW NORMALIZED TO .066

N0307006

Figure 3.7-3 (SHEET 5 OF 6)
AMPLIFIED RESPONSE SPECTRA



NOTE:

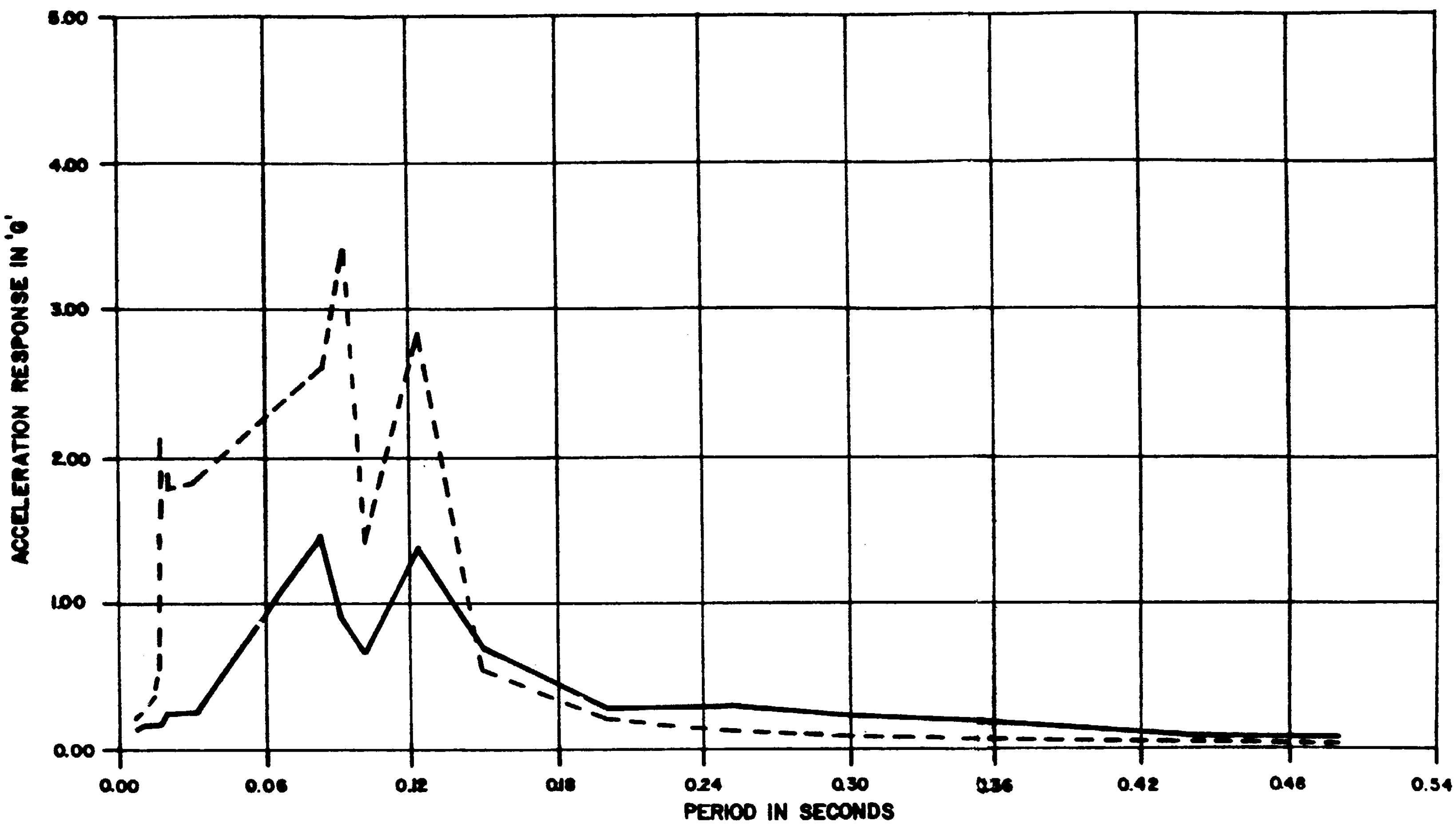
COMPARISON OF TIME HISTORY AND FREQUENCY RESPONSE METHODS AT EL. 291 FT. AUXILIARY BUILDING
EQUIPMENT DAMPING .005 STRUCTURAL DAMPING .02

– – – – – – FREQUENCY RESPONSE METHOD. R=1., OBE JOB SPECTRA

———————— TIME HISTORY METHOD FOR HELENA EW NORMALIZED TO .06G

N0307007

Figure 3.7-3 (SHEET 6 OF 6)
AMPLIFIED RESPONSE SPECTRA

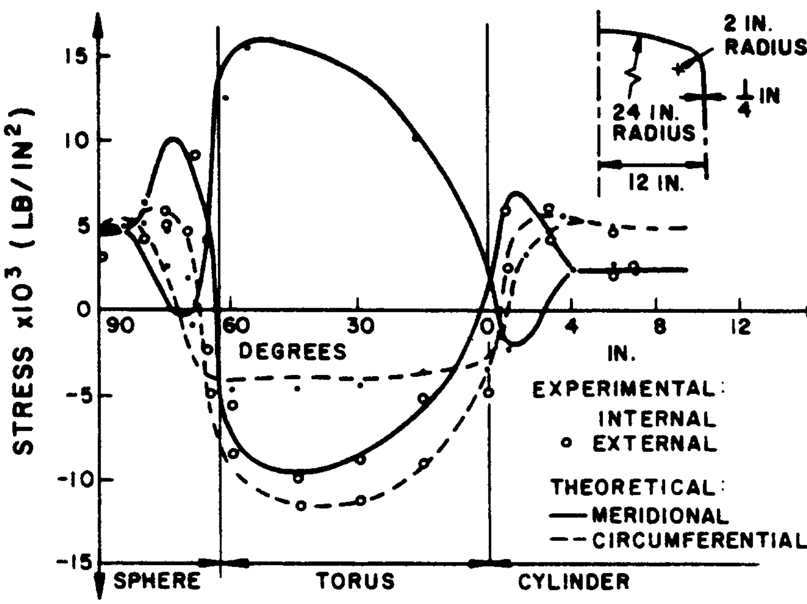


NOTE:
COMPARISON OF TIME HISTORY AND FREQUENCY RESPONSE METHODS AT EL. 322.83 FT. FUEL BUILDING.
EQUIPMENT DAMPING .005 STRUCTURAL DAMPING .02

– – – – – FREQUENCY RESPONSE METHOD. R=.6, OBE JOB SPECTRA
——— TIME HISTORY METHOD FOR HELENA EW NORMALIZED TO .066

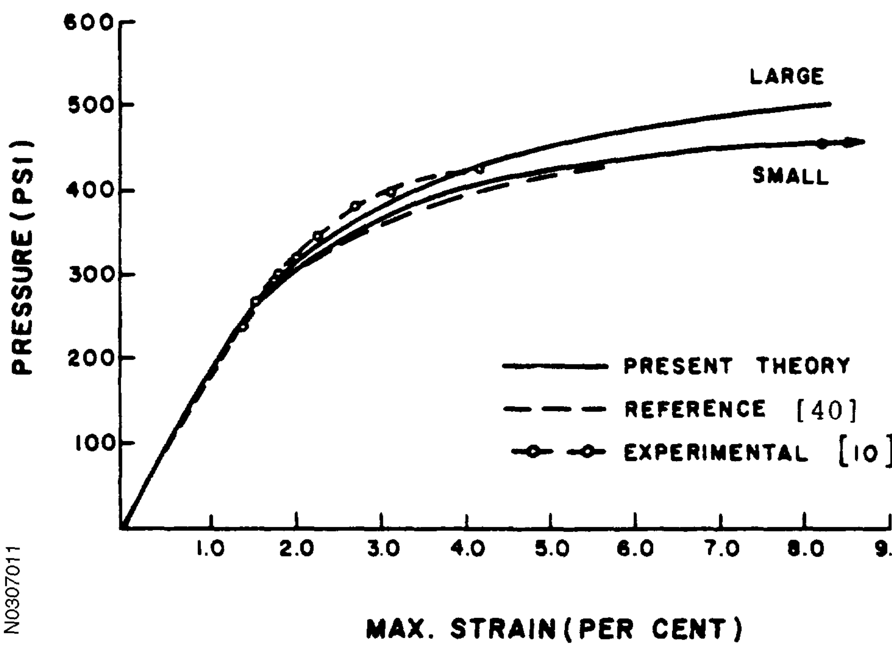
N0307008

Figure 3.7-4
STRESS DISTRIBUTION FOR TORISPHERICAL VESSEL, 100 lbf/in^2



N0307009

Figure 3.7-5
PRESSURE: MAXIMUM STRAIN IN TORISPHERE



N0307011

Figure 3.7-6
FLOW CHART: LIMITA II

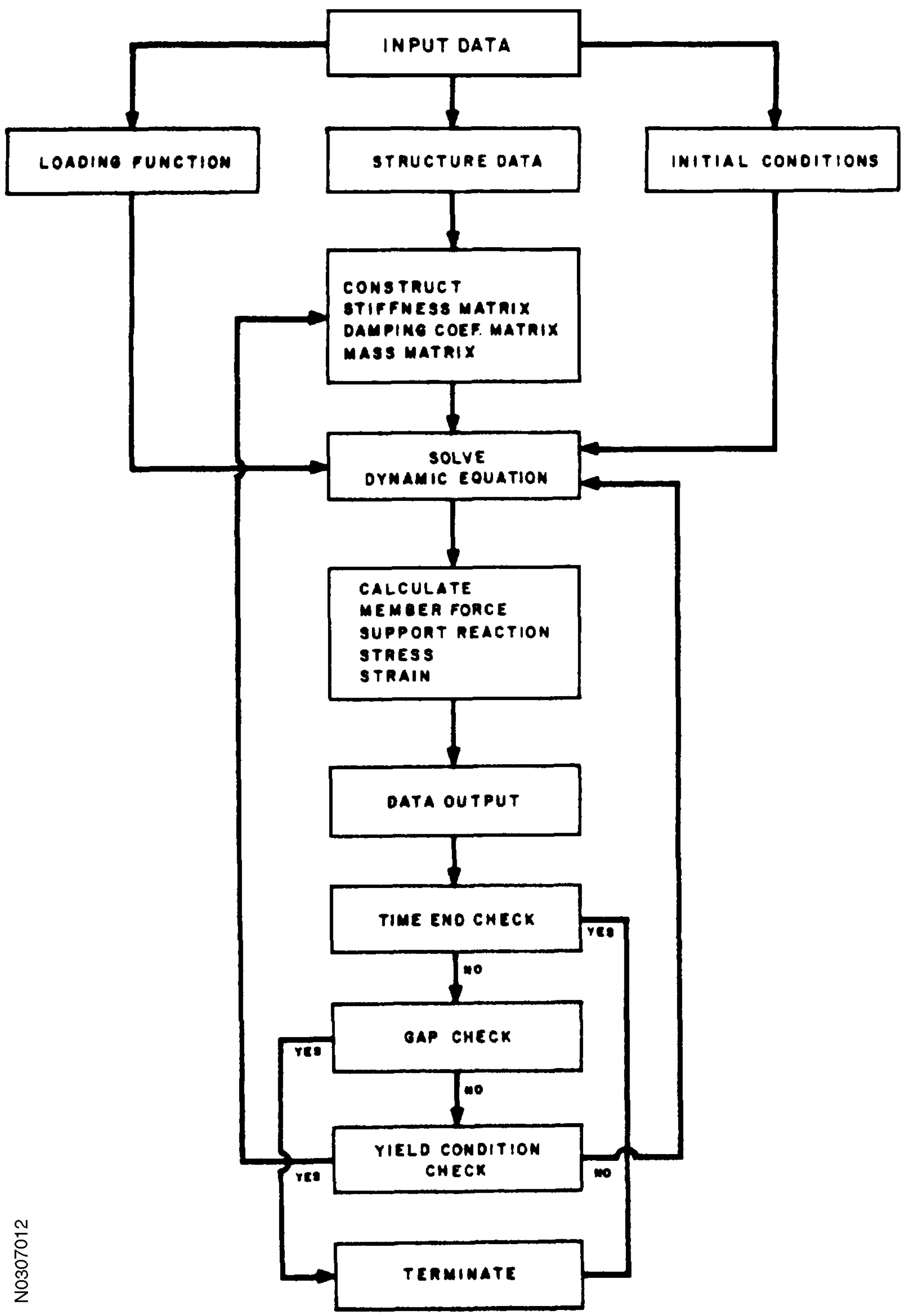


Figure 3.7-7
COMPARISON OF MAT 5 OUTPUT TO HAND CALCULATIONS
FOR A TEN FT CIRCULAR MAT ON SOIL

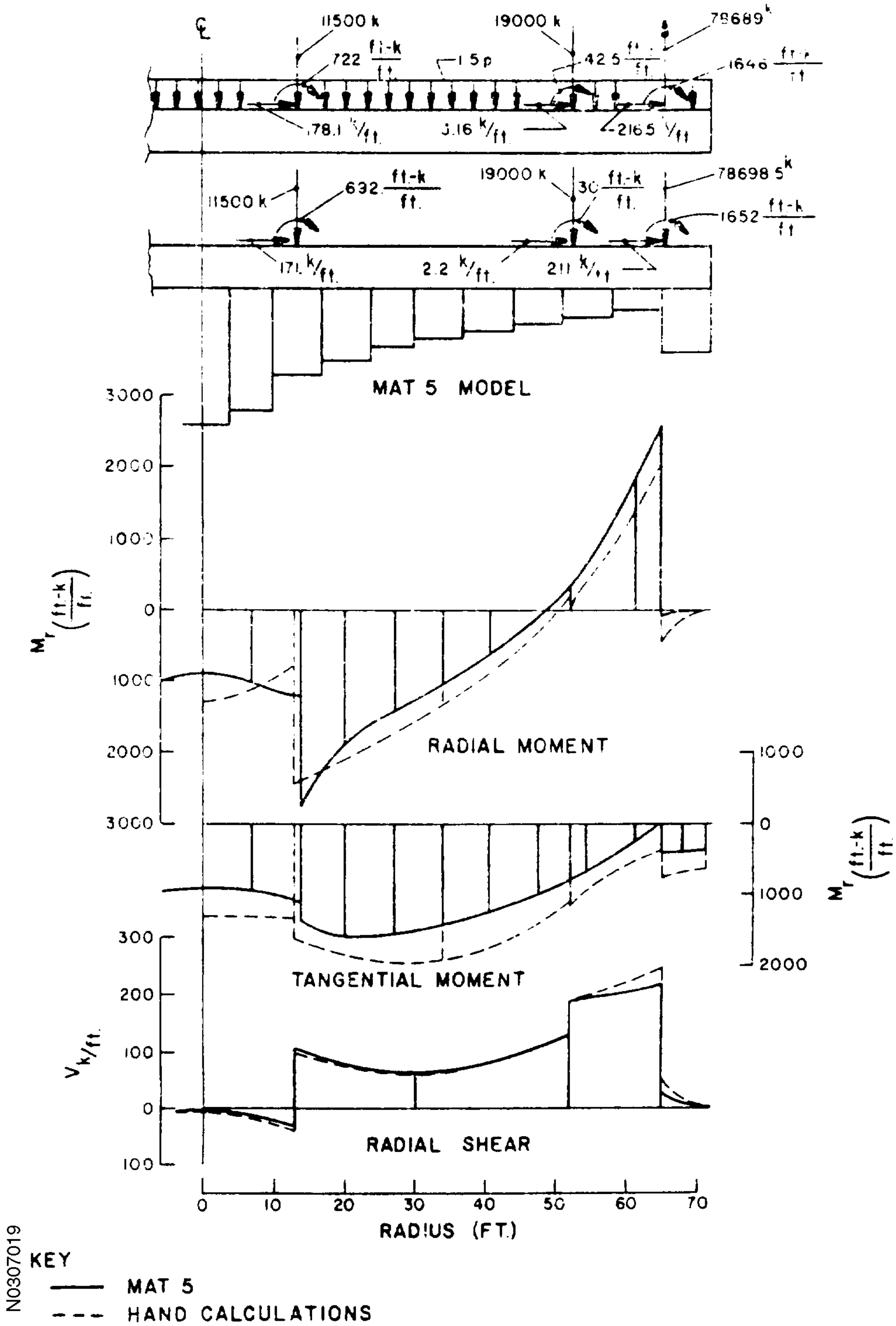


Figure 3.7-8
COMPARISON OF MAT 5 OUTPUT TO HAND CALCULATIONS
FOR A TEN FT THICK CIRCULAR MAT ON ROCK

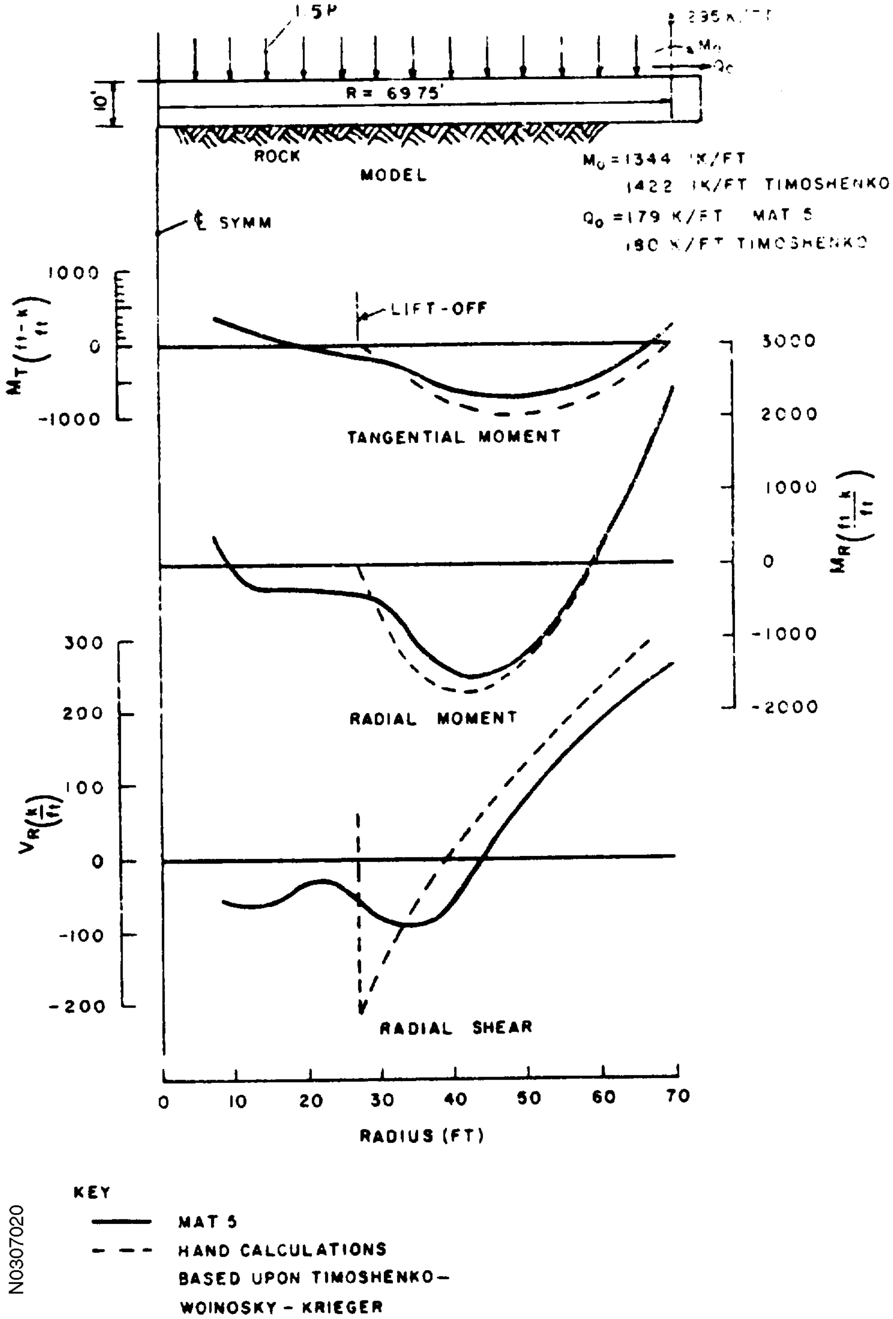


Figure 3.7-9
RESULTS OF TIME HISTORY PROGRAM: CONTAINMENT STRUCTURE:
OPERATING FLOOR LEVEL: TIME HISTORY OF STRUCTURAL RESPONSE

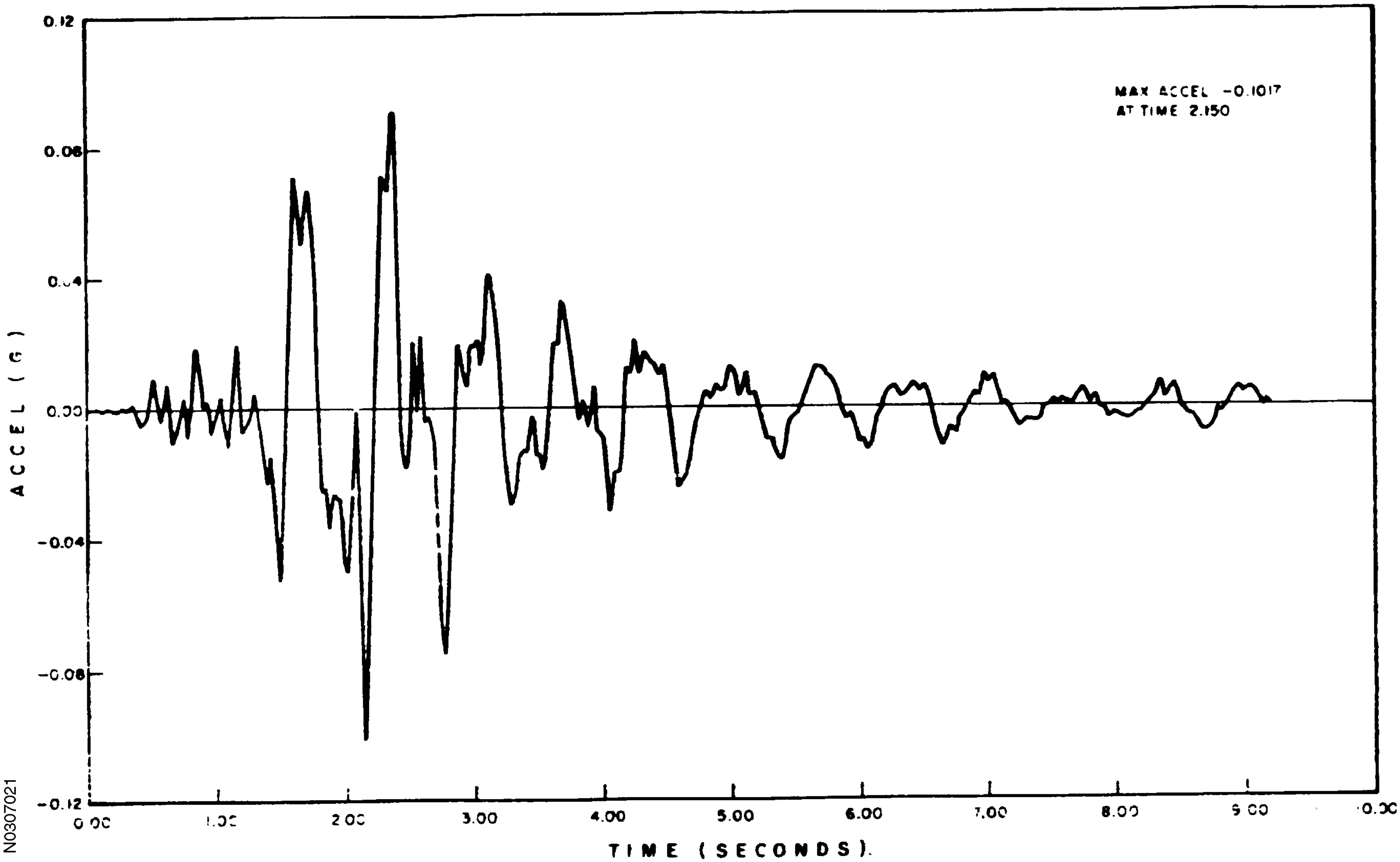


Figure 3.7-10
RESULTS OF STRUDL II ANALYSIS: CONTAINMENT STRUCTURE:
OPERATING FLOOR LEVEL: TIME HISTORY OF STRUCTURAL RESPONSE

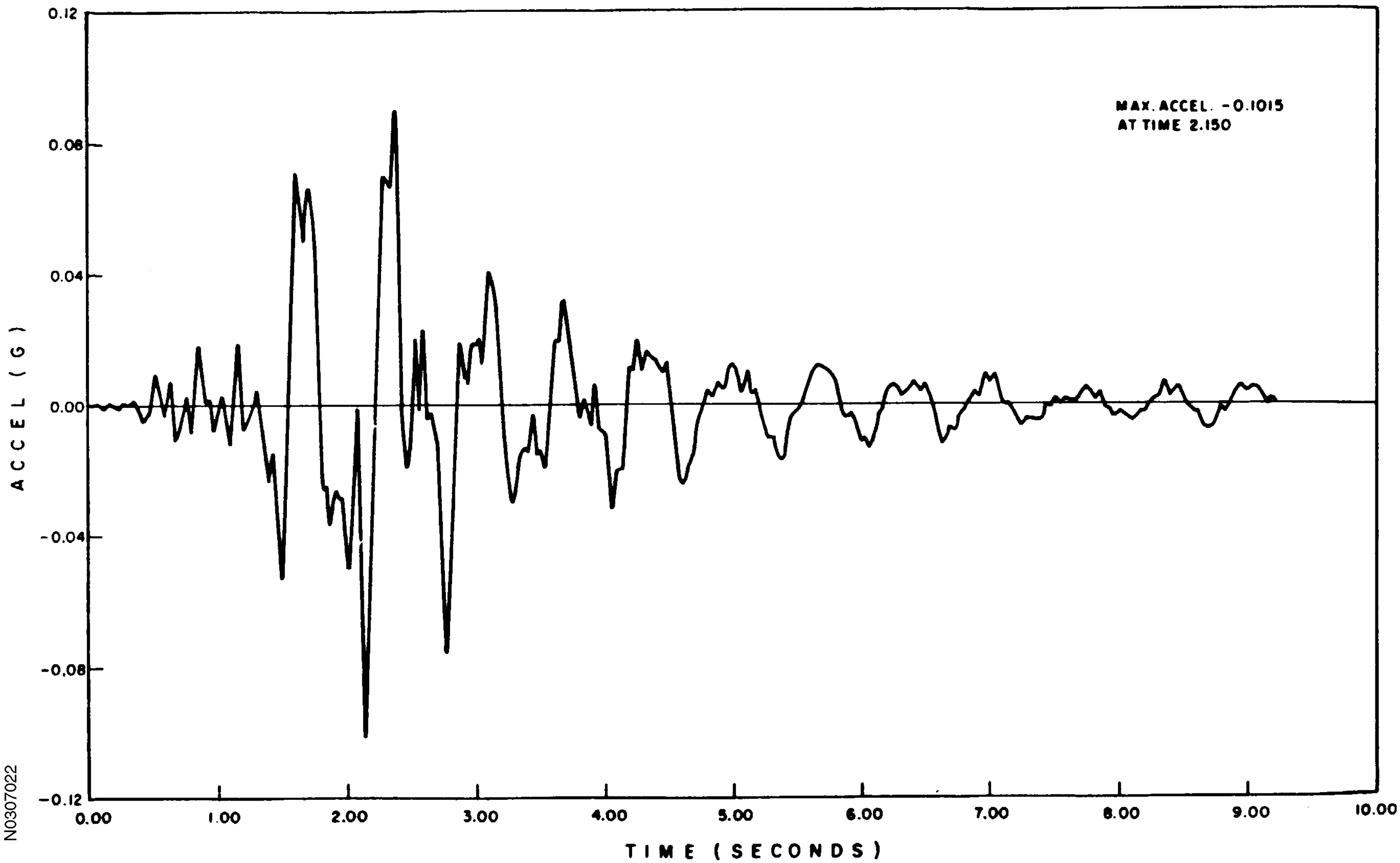


Figure 3.7-11
CYLINDRICAL SHELL WITH A HOLE

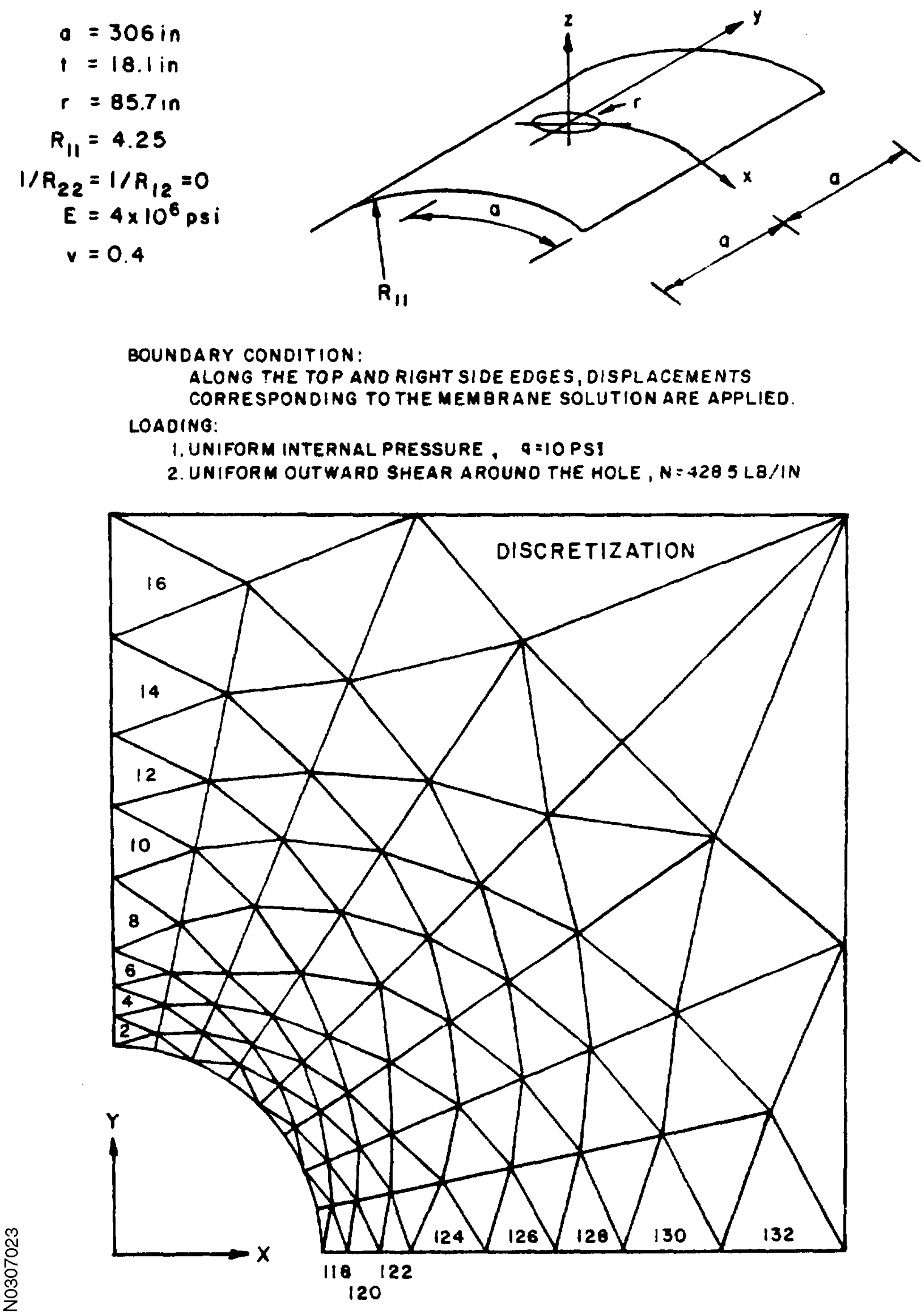
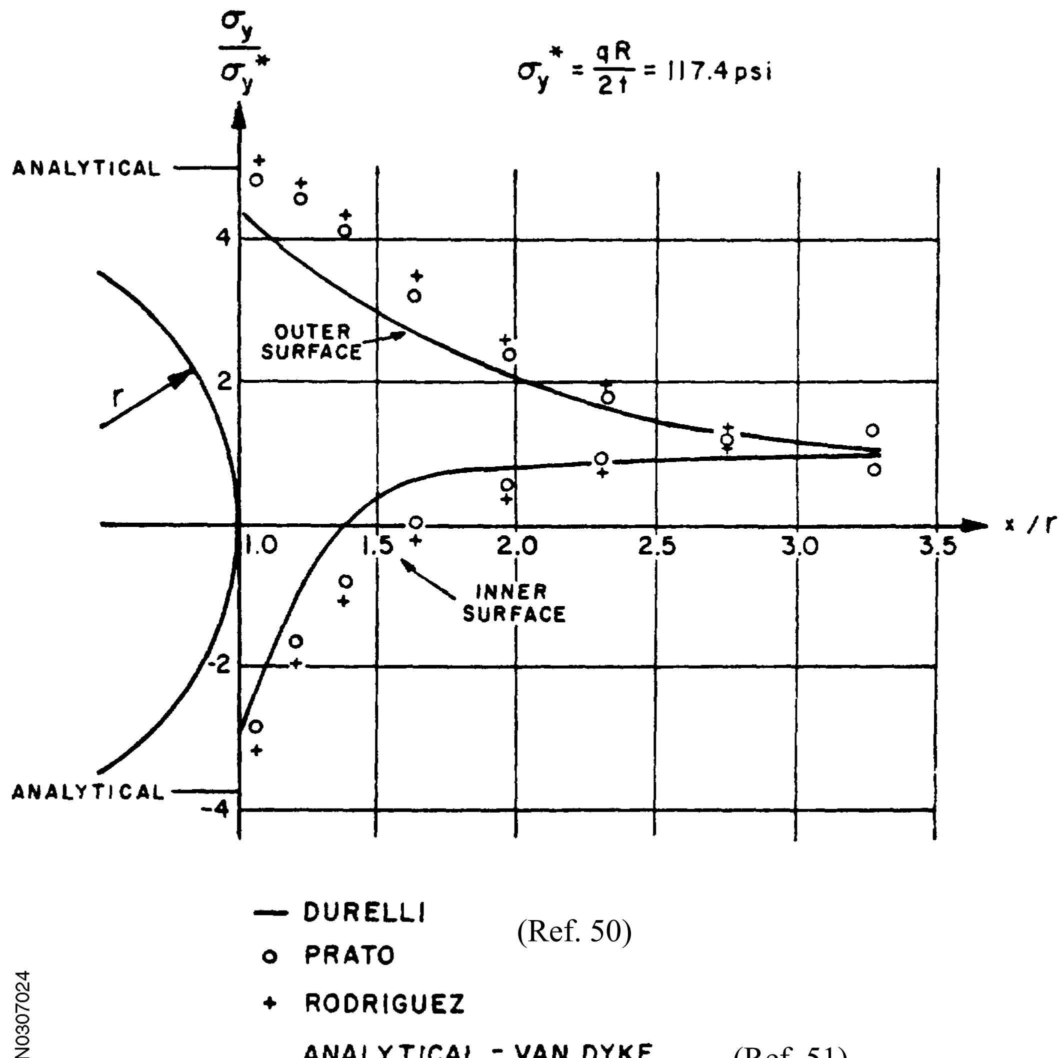


Figure 3.7-12
RESULTANT STRESSES ALONG X AXIS



(Ref. 50)

(Ref. 51)

Figure 3.7-13
RESULTANT STRESSES ALONG Y AXIS

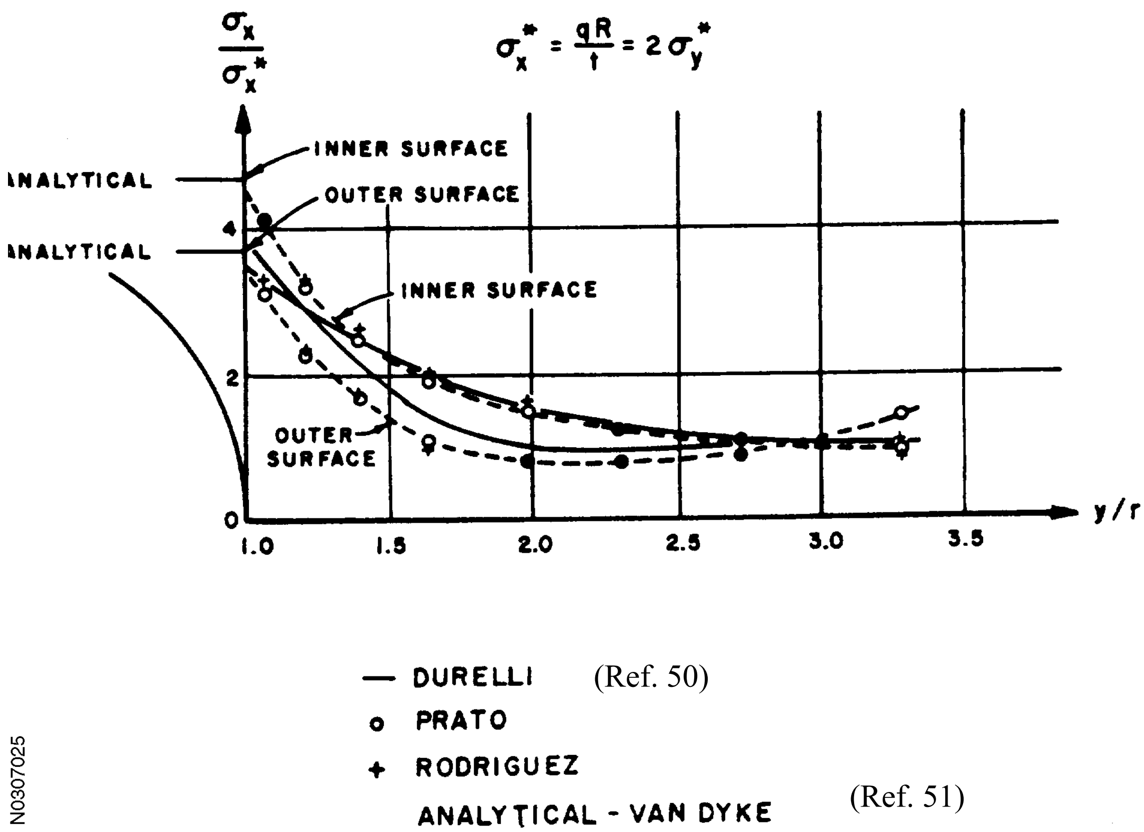


Figure 3.7-14 (SHEET 1 OF 2)
SEISMIC ANALYSIS: REACTOR CONTAINMENT

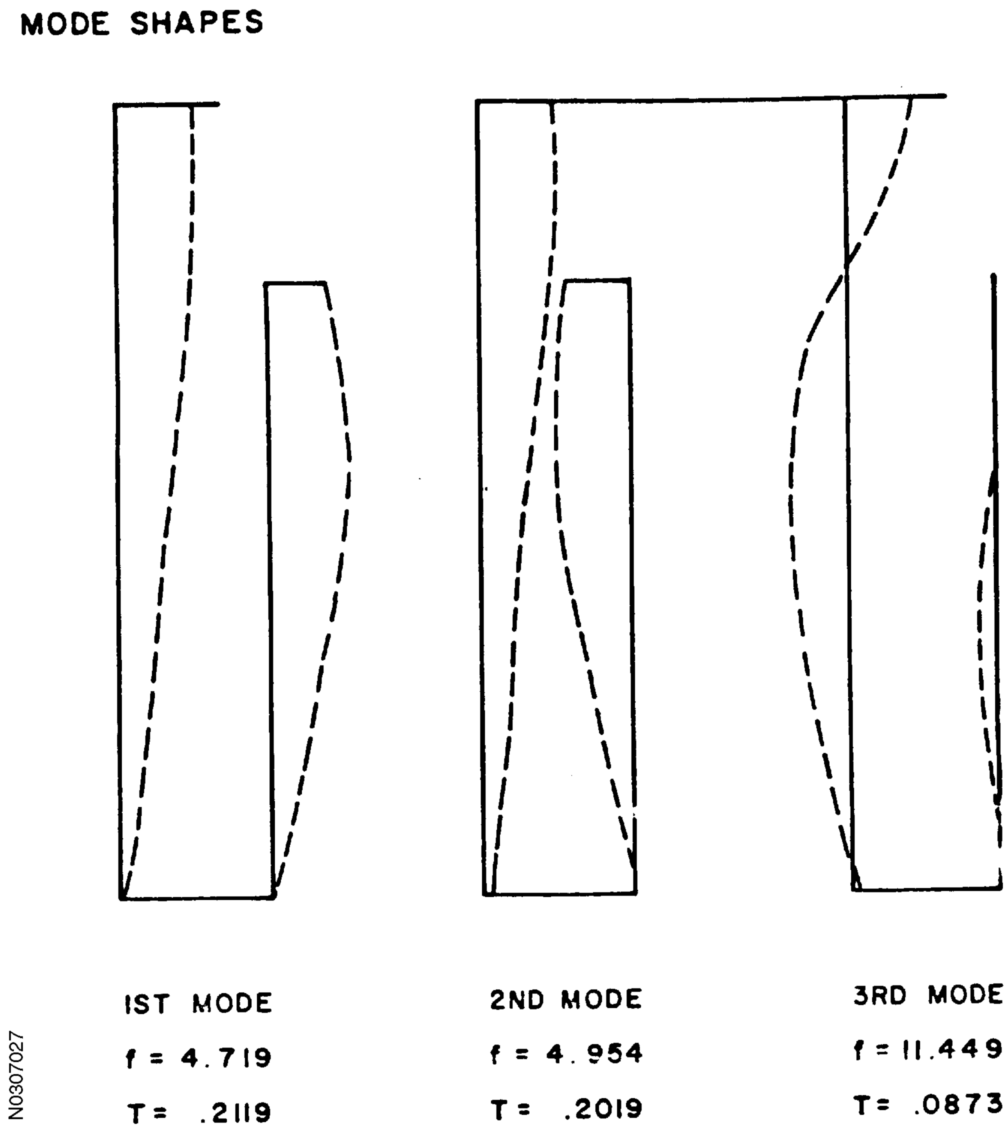


Figure 3.7-14 (SHEET 2 OF 2)
SEISMIC ANALYSIS: REACTOR CONTAINMENT

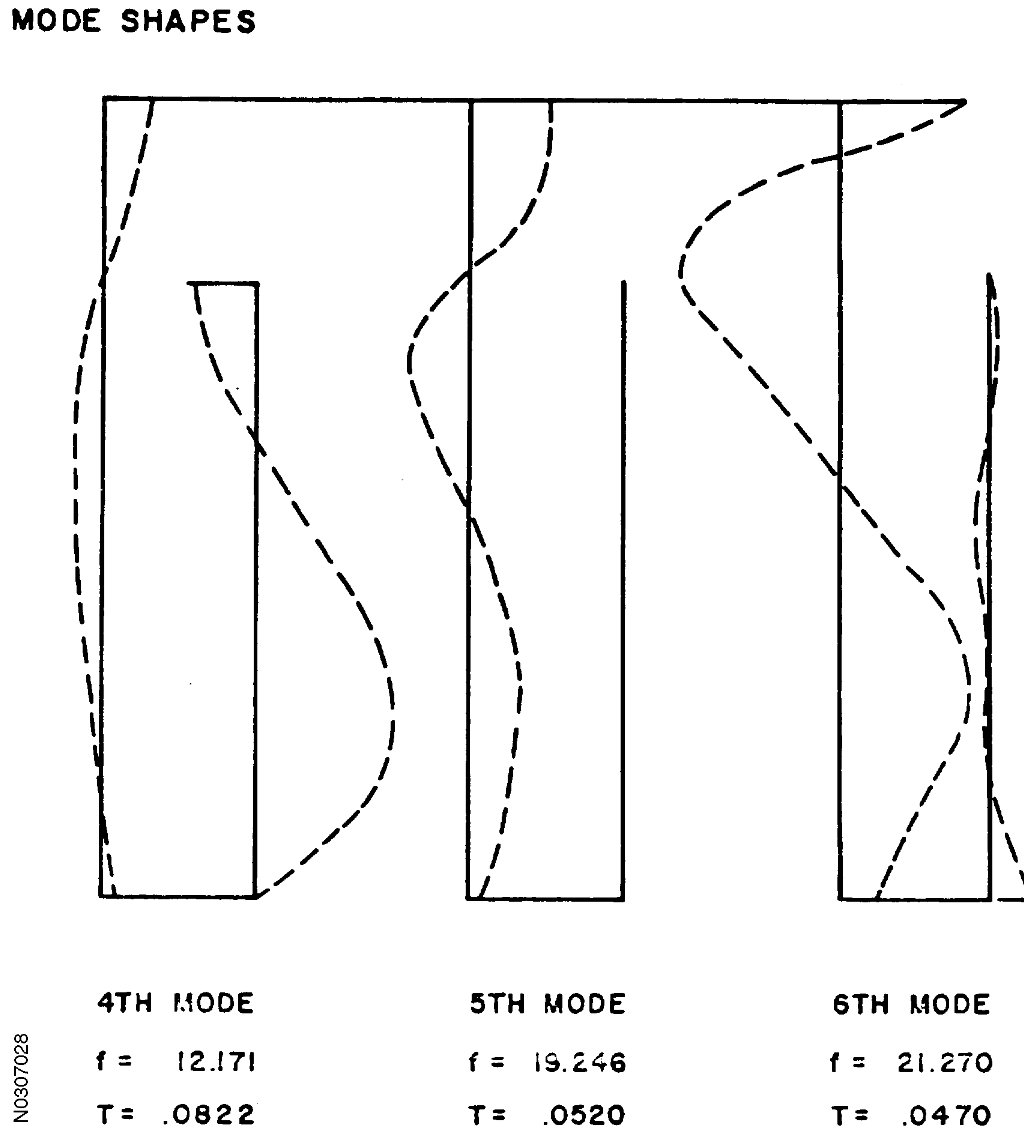


Figure 3.7-15
MATHEMATICAL MODEL OF REACTOR INTERNALS

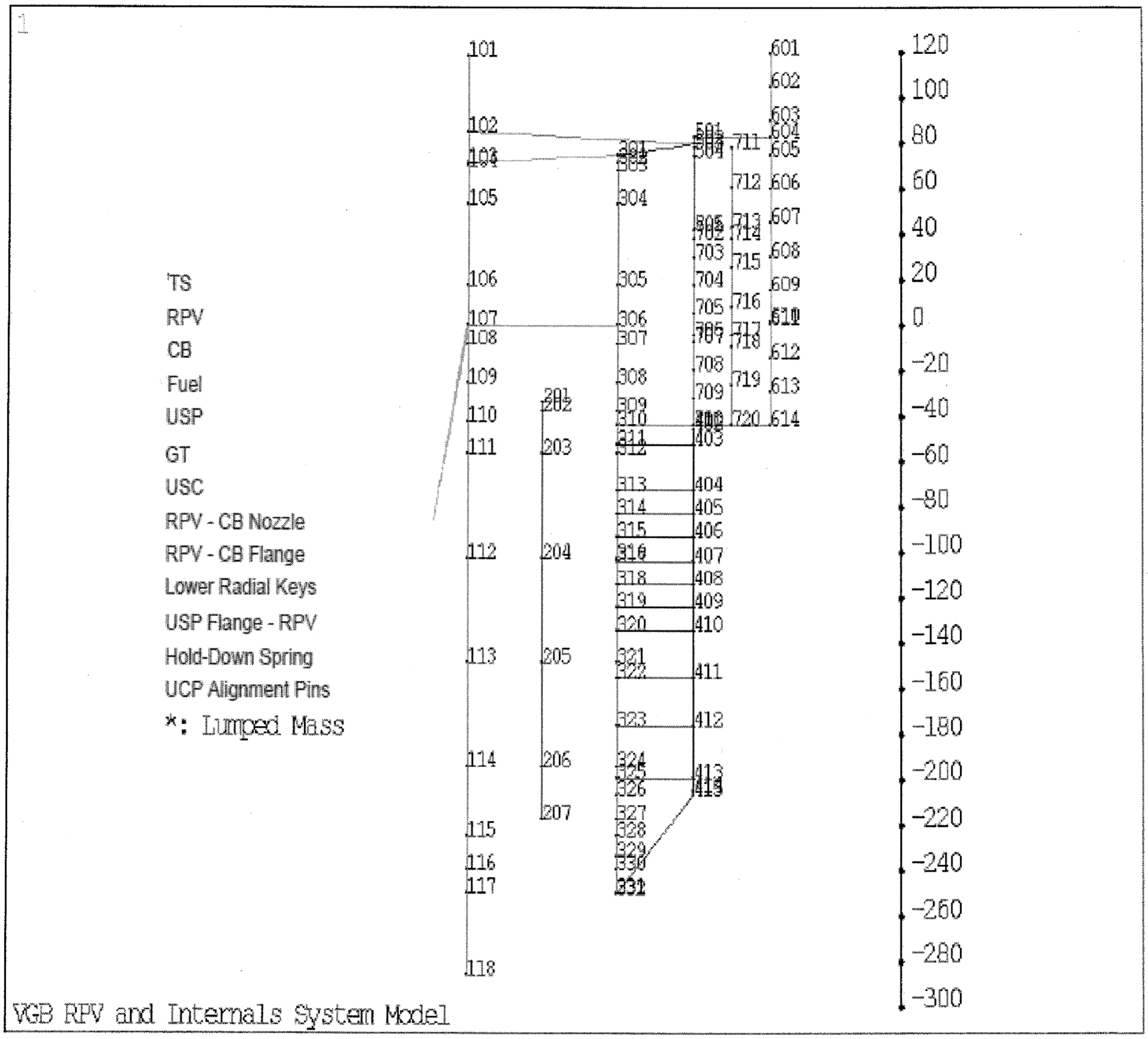


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Figure 3.7-16 (SHEET 1 OF 2)
SEISMIC ANALYSIS: REACTOR BUILDING: JOINT 9: ELEVATION 204.42 FT: N-S AND E-W
EXIT: OBE UNCRACKED AMPLIFIED RESPONSE SPECTRA BY TIME HISTORY

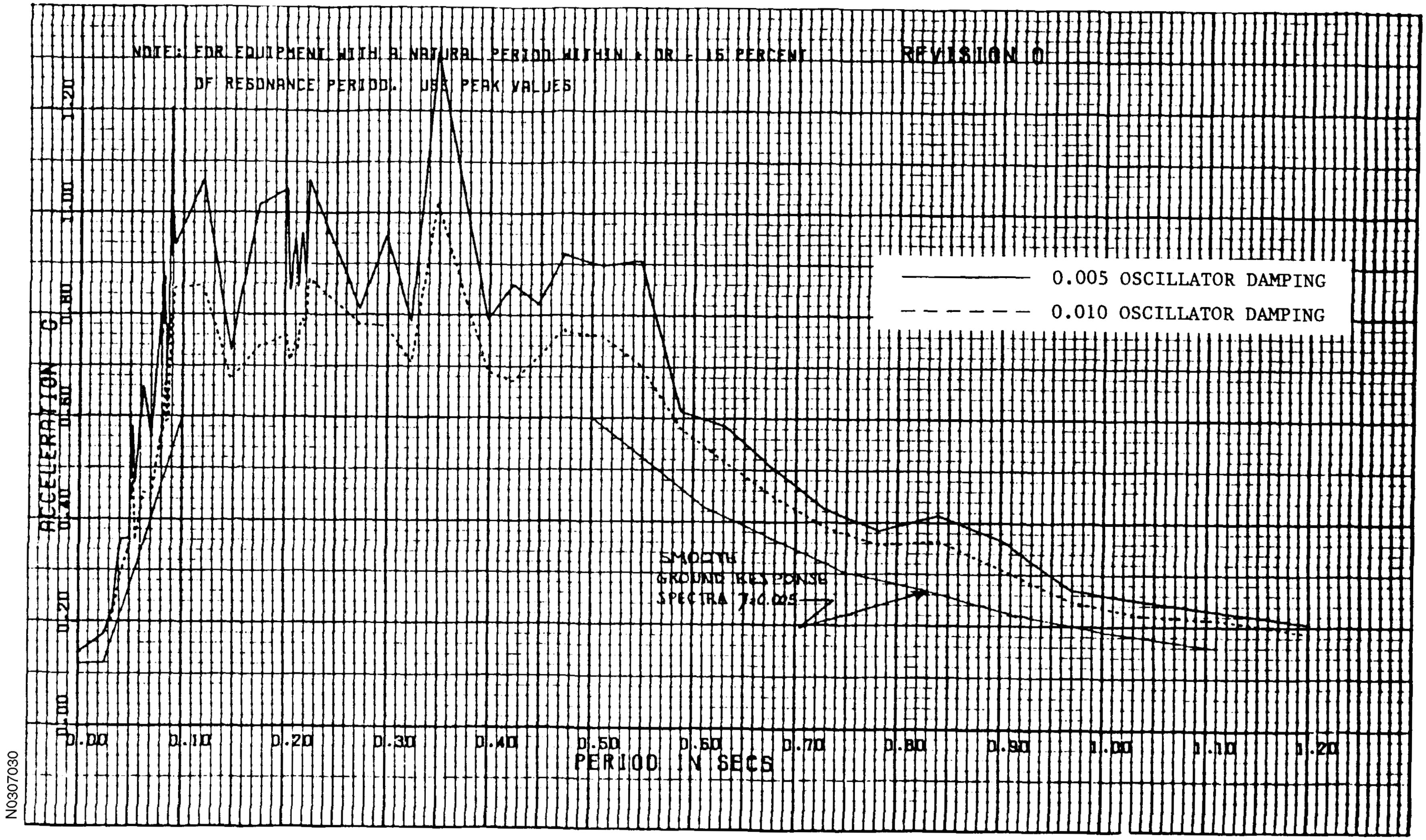
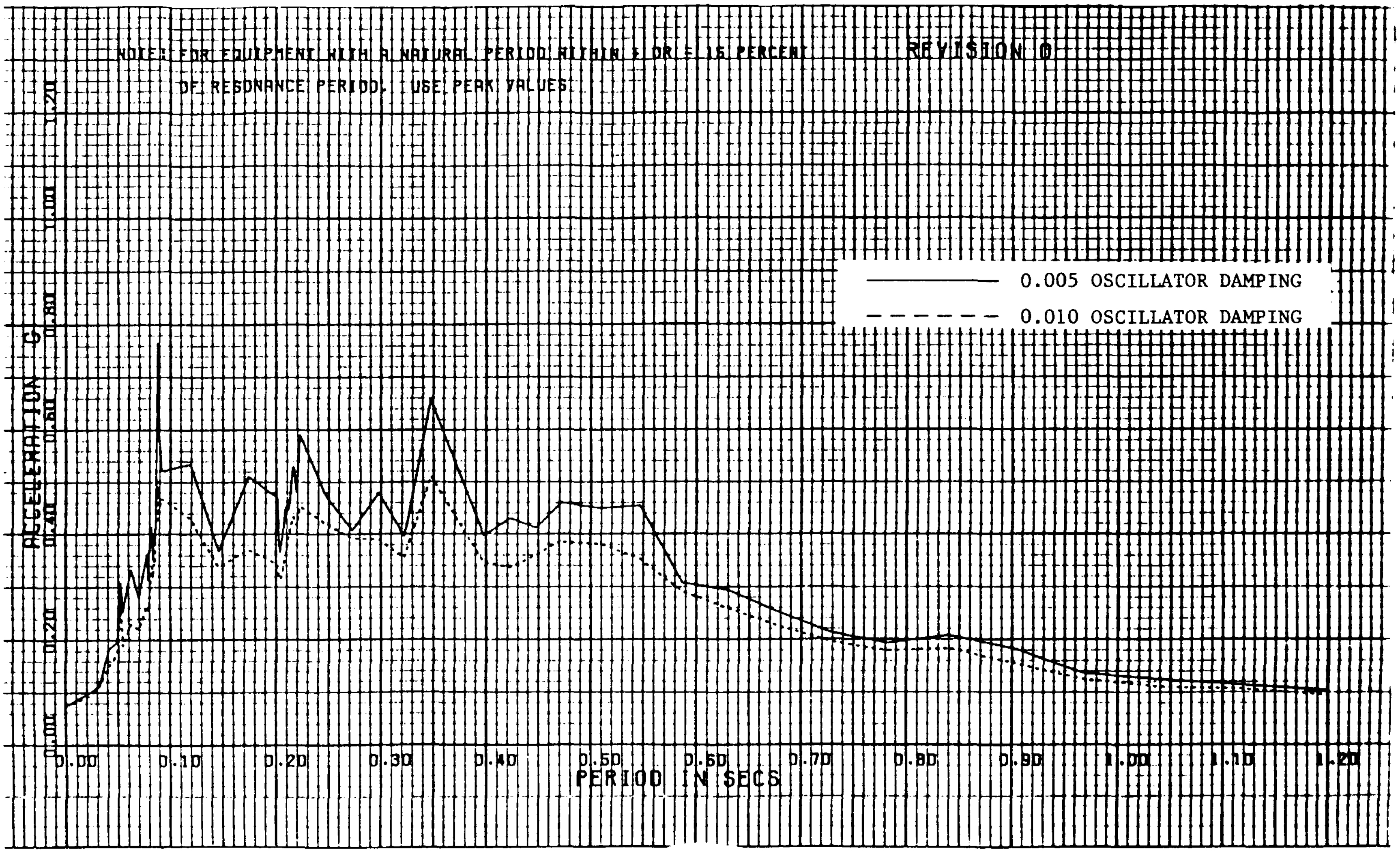
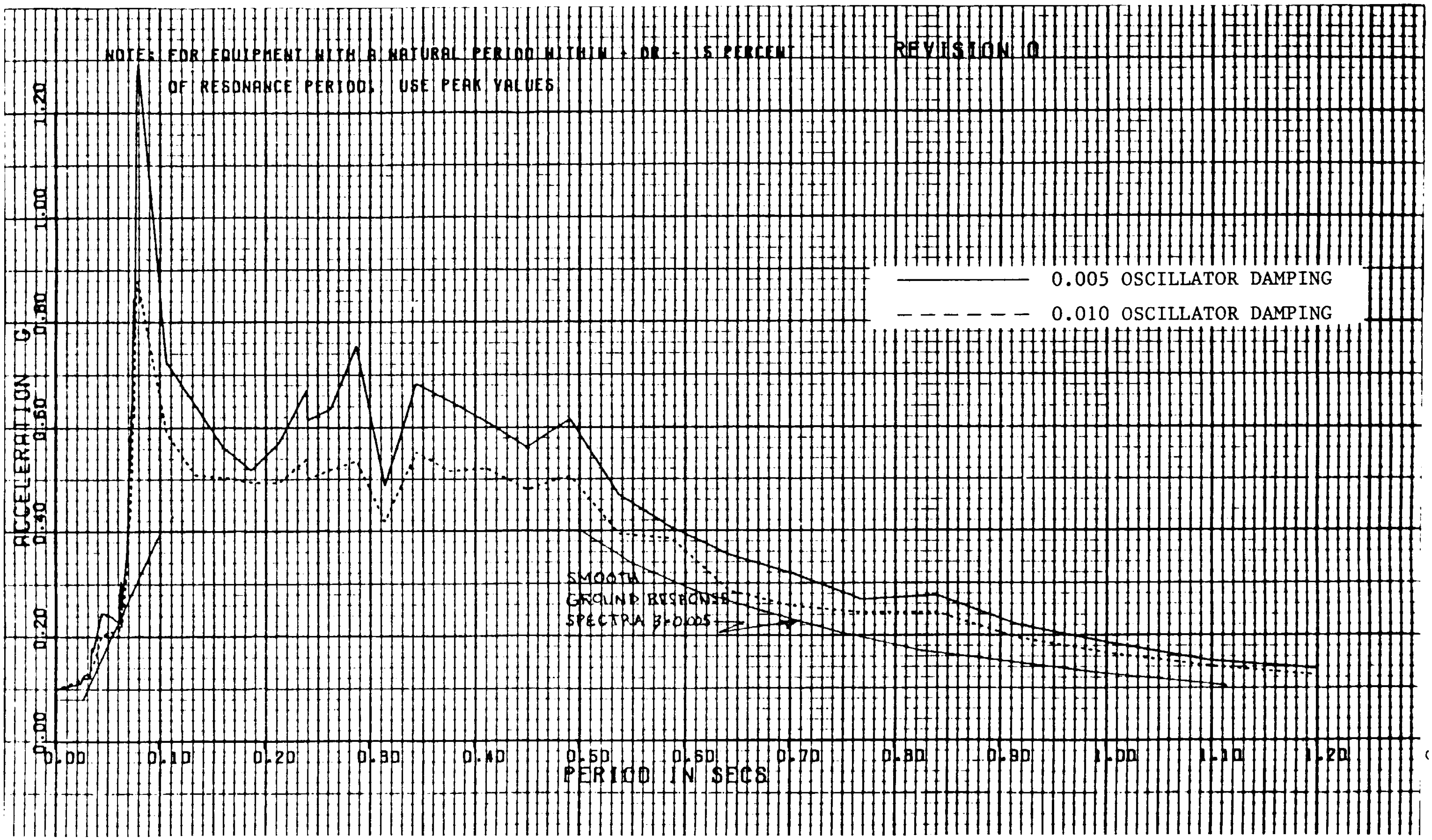


Figure 3.7-16 (SHEET 2 OF 2)
SEISMIC ANALYSIS: REACTOR BUILDING: JOINT 9: ELEVATION 204.42 FT: N-S AND E-W EXIT:
OBE UNCRACKED AMPLIFIED RESPONSE SPECTRA BY TIME HISTORY



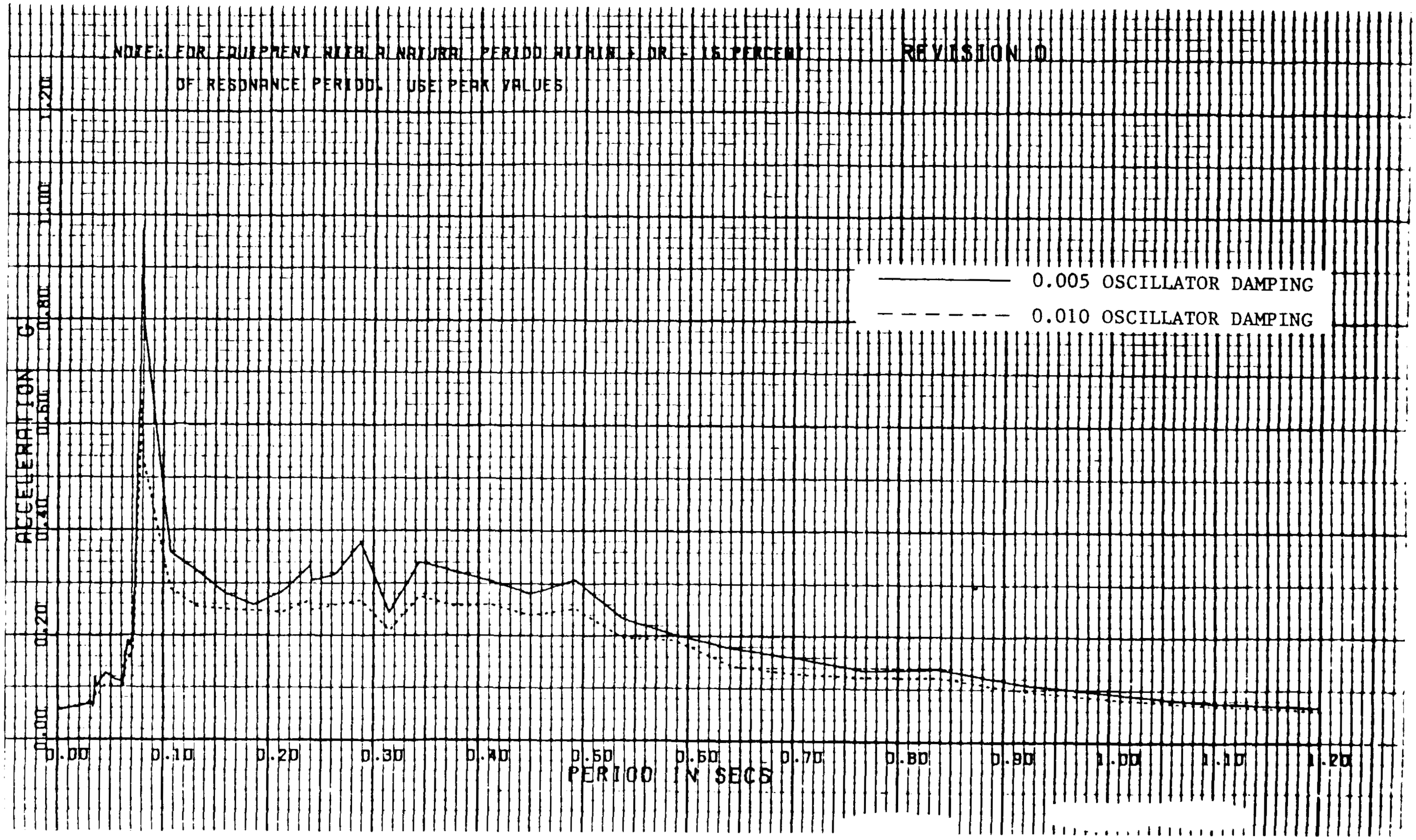
N0307031

Figure 3.7-17 (SHEET 1 OF 2)
SEISMIC ANALYSIS: REACTOR BUILDING: JOINT 9: ELEVATION 204.42 FT:
VERTICAL EXIT: OBE UNCRACKED AMPLIFIED RESPONSE SPECTRA
BY TIME HISTORY



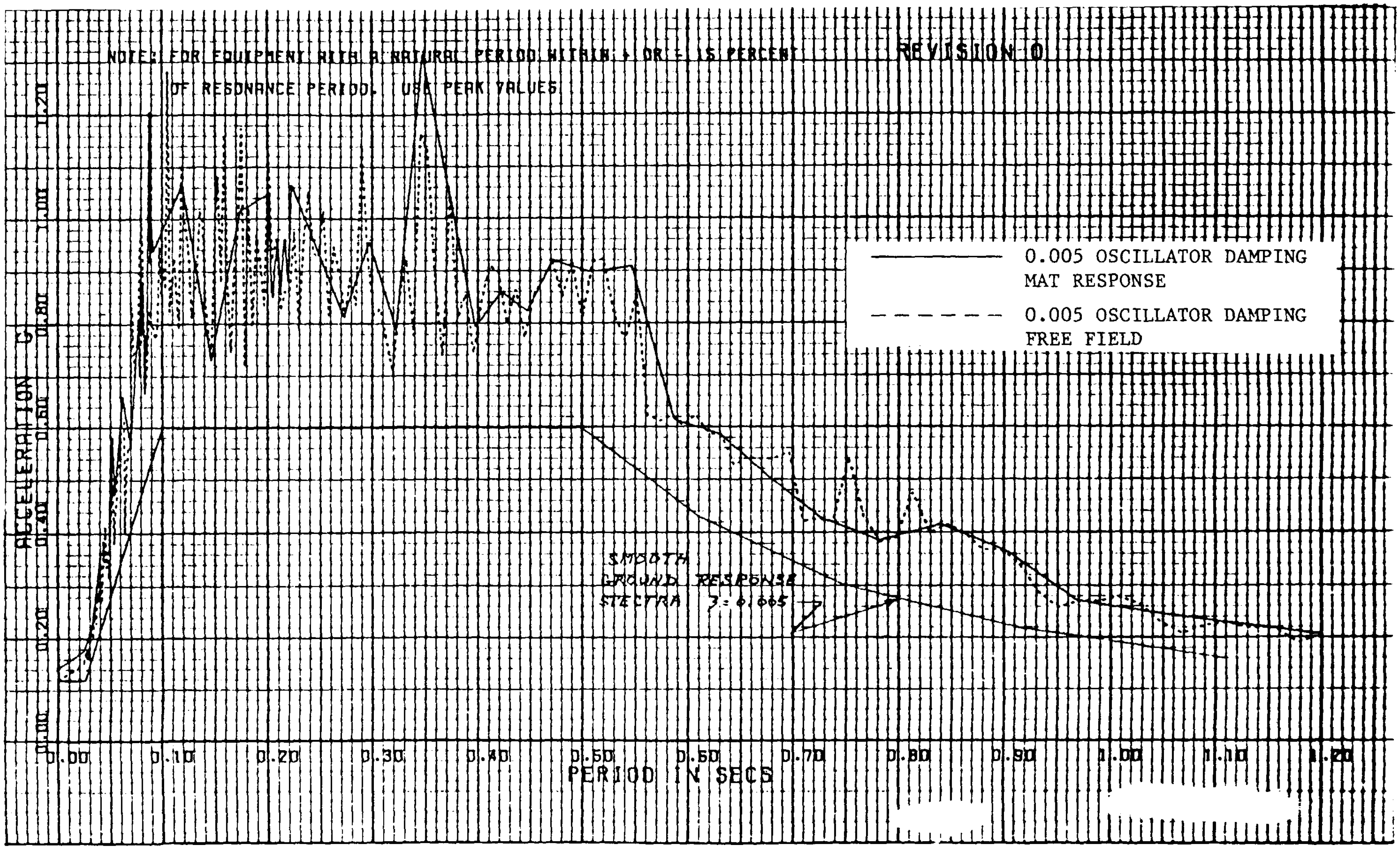
N0307032

Figure 3.7-17 (SHEET 2 OF 2)
SEISMIC ANALYSIS: REACTOR BUILDING: JOINT 9: ELEVATION 204.42 FT: VERTICAL EXIT:
OBE UNCRACKED AMPLIFIED RESPONSE SPECTRA BY TIME HISTORY



N0307033

Figure 3.7-18
SEISMIC ANALYSIS: REACTOR BUILDING: BASE G(T) — FREE FIELD ACCELERATION:
AMPLIFIED RESPONSE SPECTRA BY TIME HISTORY



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3.8 DESIGN OF SEISMIC CLASS I STRUCTURES

3.8.1 Structures Other Than Containments, Main Dam, and Service Water Reservoir

3.8.1.1 Design Basis and Physical Description

The design basis for Seismic Class I structures other than containments is shown in Table 3.2-1. In addition to seismic loading, or tornado loading if applicable, structures are designed to adequately support all dead, live, normal wind, hydrostatic, and lateral earth pressure loadings.

To allow for unimpeded relative motions between Seismic Class I structures, and between these and nonseismic structures, under any loading condition, a minimum 2-inch rattlespace is provided where such structures abut each other. Rattlespaces are located to separate the following:

1. The fuel building and the:
   a. Decontamination building.
   b. Below-grade pipe tunnel along its south wall.
2. The containments and the:
   a. Auxiliary building.
   b. Fuel building.
   c. Decontamination building.
   d. Containment auxiliary structures around the periphery of the containment.
3. The auxiliary building and the:
   a. Fuel building.
   b. Containment auxiliary structures around the periphery of the containment.
   c. Service building.

Below-grade rattlespaces are kept free of backfill or other material that might minimize unimpeded relative motions by polystyrene foam board formwork, which is left in place after concrete placement, and by polyvinyl chloride waterseals. The compressive strength of foam board is not considered sufficient to impede relative motion.

Section 1.2.2 presents outline and arrangement figures of the above structures.

3.8.1.1.1 Auxiliary Containment Structures

Auxiliary containment structures are a group of irregularly shaped, heavily reinforced, concrete structures extending both above and below grade, located radially around the north side of and adjacent to the reactor containment structure. These structures house and protect critical equipment.

The auxiliary containment structures include the following:

	Size (ft)
Safeguards area	74 x 21
Main steam valve housing	45 x 32
Quench spray pump housing	40 x 32
Purge air duct and motor control center area	60 x 20

The structures are supported on concrete mats or slabs at various elevations. Access to the various floor levels is provided by steel ladders and grating walkways. Exterior walls and roofs of all these structures except the quench spray pump housing are heavy concrete sections to resist missiles. Walls of the quench spray pump housing are of concrete, and the roof has steel framing covered by metal roof deck, insulation, and single-ply, mechanically attached membrane roofing.

3.8.1.1.2 Cable Vault and Cable Tunnel

The cable vault is a reinforced-concrete portion of the auxiliary building adjacent to the outside of the containment structure around the major electric penetrations, above the pipe tunnel. The cable tunnel extends from the cable vault through the auxiliary building to the electric control area below the main control room in the service building.

The cable vault is enclosed by a reinforced-concrete superstructure, approximately 20 feet wide by 60 feet long by 19 feet high, the roof of which serves as the floor for the purge air duct and motor control center area. The cable tunnel is approximately 18 feet wide by 12 feet high. Walls and roof are of heavy concrete sections.

3.8.1.1.3 Auxiliary Building

This structure has a reinforced-concrete foundation mat with monolithic finish. Substructure walls are of reinforced concrete. The superstructure has a structural steel frame supported by above-grade reinforced-concrete walls, with uninsulated metal siding. Rolling steel and hollow metal doors are provided for access. Roofing is supported by steel framing covered with insulated metal roof deck and a single-ply, mechanically attached membrane roofing system.

The ground floor level and the supported floor level below it have reinforced-concrete floor framing and columns. The ground floor level slab is adequate to provide protection against the assumed tornado missile and to support a fork lift truck. The second floor is a monolithic concrete slab supported on steel framing.

Reinforced-concrete walls and slabs are provided for enclosing the volume control tanks, component cooling surge tank, component cooling heat exchangers, and the personnel hatches of the containment structures for biological and missile shielding. Other areas requiring biological shielding are enclosed with the necessary thickness of concrete. Heavy aggregate concrete is used in some areas to conserve space. Other partitions are of hollow concrete block. Pass doors are hollow metal type. A motor-operated rolling steel door provides access for handling of equipment.

Precast concrete hatch covers are provided over the ion exchange cubicles and in other locations in the ground floor for handling equipment.

The steel superstructure of the auxiliary building is designed to resist seismic loads. Parts of the superstructure that enclose the volume control tanks and component cooling water equipment are concrete enclosures designed to withstand both seismic and tornado loads, including tornado-generated missiles. The charcoal filters and ventilation fans for the auxiliary building are located on the 3-foot-thick ceiling of the volume control tank enclosure, which is adequate to support this equipment during either an earthquake or tornado. Equipment installed on the supported steel framing consists of ventilation fans for the nuclear auxiliary systems. The motor for the largest fan supported on the steel superstructure would develop less energy than the postulated tornado missile if the motor fell freely from a height equivalent to its height above the 2-foot-thick floor slab at finish ground grade, which is designed to prevent penetration by the tornado missile. Consequently, the equipment and piping below the missile shield provided by the ground floor concrete slab would not be damaged by collapse of the superstructure or the equipment supported by the superstructure. The decision to design the steel superstructure for seismic loads was made to facilitate operation after an earthquake and is not based on safety requirements.

3.8.1.1.4 Fuel Building

The fuel building contains the new fuel, spent fuel, and spent-fuel cask and related equipment. The building is sized for two units. The structure is approximately 136 feet long by 41 feet wide. The top of the foundation mat is approximately 21 ft. 8 in. below grade. The main roof area is approximately 48 feet above finish grade, and the roof of the trolley bay is approximately 20 feet higher. The spent-fuel storage area has clear inside dimensions approximately 29 ft. 3 in. wide by 72 ft. 6 in. long by 42 ft. 6 in. deep. Narrow canals connect to Units 1 and 2. New fuel racks are mounted in the new-fuel area above the slab at Elevation 274 ft. 9 in. This area is accessible to the platform crane. The lowest level slab supports the fuel pit coolers and cooling pumps. The fuel is stored vertically in stainless steel racks, which provide separation to preclude criticality.

The spent-fuel pool contains a 3 ft. 6 in. reinforced-concrete wall, extending from the foundation mat to the top of the pool. This wall separates the spent-fuel cask handling area from the spent-fuel racks and is designed for a cask impact accident, as discussed in Appendix 9B.

The fuel building structure is supported by a concrete mat founded on rock. Walls of the spent-fuel storage pit are 6-foot-thick reinforced concrete for biological shielding. Exterior and interior walls enclosing the fuel pit coolers are of concrete for missile shielding. Exterior walls above the concrete work are covered with insulated metal siding on structural steel framing. A large T-shaped rolling steel door permits moving the trolley and spent-fuel cask through the door opening. Another similar rolling steel door is provided for bringing new fuel into the structure. Passage doors are of the hollow metal type.

The superstructure walls and the roof are supported on steel framing. The roof is covered with insulated metal deck and a single-ply, mechanically attached membrane roofing system. Intermediate platforms in the new-fuel area are concrete slabs on steel framing. Stairs have steel framing with grating treads and grating platforms.

Movable gates between the spent-fuel pit and each canal permit dewatering the canals for access to the fuel transfer mechanisms without dewatering the entire pit. The interior walls and floor of both the pit and the fuel transfer canals are lined with 0.25-inch stainless steel plate.

Rails embedded in the concrete are provided for operation of the motor-driven platform with hoists for transferring fuel.

3.8.1.1.5 Service Building (Partially Seismic Class I)

As is shown in Table 3.2-1, only certain portions of the service building are designed to tornado and seismic criteria. These portions consist of the control room, switchgear and relay rooms, battery rooms, air-conditioning equipment rooms, and emergency diesel-generator cubicles.

The service building is a multistory structure on the south side of the turbine building. It is approximately 70 feet wide by 660 feet long, to serve two units. Emergency switchgear, instrumentation rooms, and air-conditioning equipment rooms are located in an approximately 272 feet by 70 feet area below ground grade under the control room, locker room, and shops area. Warehouse, shops, control room, locker area, emergency generator rooms, and auxiliary boiler room are located at ground level. Mechanical equipment and cable tray rooms are located on the second floor. Non-safety-related switchgear for each unit is located on the third floor directly above the cable tray rooms.

In general, foundations consist of a structural mat between the “4” and “12” lines, and strip footings in adjacent areas. The control room area is supported on continuous wall-bearing foundations. Where necessary, the walls span across the circulating water discharge tunnels. Substructure walls are of reinforced concrete. The control room, emergency generator area, instrumentation rooms, and emergency switchgear areas are enclosed by concrete walls and slabs for tornado and missile protection and biological shielding. Screens or labyrinths to prevent penetration of missiles are provided at air inlet and outlet openings of the emergency generator areas. The air-conditioning equipment rooms below ground are also designed for missile protection. The remainder of the structure has steel framing with monolithic concrete floor slabs, an insulated metal roof deck, and single-ply, mechanically attached, membrane roofing. Granolithic floor finish is provided in the areas occupied by switchgear cabinets.

Exterior walls are covered with uninsulated metal siding. Rolling steel and hollow metal doors are provided for access. Pass doors are, in general, of the hollow metal type.

The control room, including the office, computer rooms, and toilet room, has vinyl tile floor finish with a cove base and a suspended aluminum honeycomb luminous ceiling. Hollow metal pass doors of the control cubicle are furnished with neoprene gaskets to reduce air leakage and thus maintain positive pressure within the control area cubicle. Special steel plate doors are furnished to provide biological shielding at personnel access openings in concrete walls. This entire control area concrete cubicle from Elevation 254.0 to and including the concrete slab at Elevation 291.5 over the control room, and the vertical extension of the interconnecting stairwell, is designed to provide both biological protection required after a maximum credible incident, and tornado protection.

The laboratory and locker area consists of hot and cold laboratories, storage and supplies, laundry, locker room, count room, instrument repair shop, clean and contaminated showers and washrooms, and offices for health physics, chemistry, and general purposes.

Cabinets, work tables, and hoods are furnished for the hot and cold laboratories. The count room walls and ceiling are of poured concrete for radiation shielding. Sheet vinyl floors are provided in the hot and cold laboratories, count room, and health physics area. The floor of the laundry and shower room is lined with stainless steel sheet. Two stainless steel shower stalls are provided. Ceramic floor tile and dados are furnished in the toilet and laundry area. Other areas have monolithic floors and painted concrete block walls. Acoustic tile ceilings are provided.

3.8.1.1.6 Decontamination Building (Partially Seismic Class I)

As is shown in Table 3.2-1, only the below-grade enclosure for the liquid waste disposal system and decontamination system equipment is designed to tornado and seismic criteria.

The decontamination building is approximately 30 feet wide and 65 feet long, with its roof 20 feet above ground level. There is a basement in the north end of the building, and the elevation of the floor slab is approximately 20 feet below ground grade. The north end of the building extends upwards to the elevation of the fuel building roof.

Three manually operated hatches are installed in the roof to allow lowering of the spent-fuel casks by the trolley running over the roof.

The building is supported by a reinforced-concrete mat. The substructure walls and floors are reinforced-concrete construction. The walls aboveground are a steel frame covered with insulated metal siding. The roof is a metal deck with insulation and a single-ply, mechanically attached, membrane roofing system.

The floor in the three areas where a cask may be placed is covered with a 0.25-inch stainless steel plate liner, and is sloped toward a sump. This liner extends 4 feet up the surrounding walls. The remaining interior surfaces are covered with a decontaminable epoxy paint.

A work platform to provide access to the upper portion of the spent fuel cask is located at Elevation 281 ft. 6 in. This platform is steel framed with stainless steel checkered plate. An exterior stair from the Elevation 271 ft. to Elevation 291 ft. allows access to the upper decontamination bay without using the work platform ladder.

3.8.1.1.7 Service Water Pump House

A service water pump house (SWPH) is provided to house service water system equipment for Units 1 and 2. The building is of 2-foot-thick reinforced concrete, 64 feet long, 62 feet wide, and 45 feet high, located at the edge of the service water reservoir. Equipment installed in this structure includes: vertical electric-motor-driven service water pumps; traveling water screens; screen wash pumps; service water motor-operated strainers; pump discharge headering, valving, and instrumentation; radiation monitoring equipment (abandoned); water screen differential level control equipment; diesel-driven fire pump; service water air compressors with receiver tank; and sumps discharging to the Service Water Reservoir. Screen wells are provided with stop logs on the intake. A monorail system is provided for lifting the traveling screens' basket. Pump missile barriers are provided between the service water pumps.

The wing walls were structurally designed to withstand static plus seismic forces due to the design-basis earthquake, and have an adequate factor of safety against sliding and overturning. Therefore, it is concluded that a complete wing wall failure is not possible.

The reinforced-concrete wing walls were designed as cantilevered retaining walls to stand independently of the service water pump house. The design assumed there would be no transfer of stress along the horizontal surface where the wing wall concrete was placed directly on the lip of the SWPH mat, nor along the vertical surface where wing wall concrete was placed in contact with the wall of the service water pump house. These surfaces are unreinforced, unkeyed, cold joints.

Differential settlement of the wing wall and service water pump house has resulted in transfer of stress, however, as indicated by the cracks reported in VEPCO letter dated July 11, 1975, Serial No. 594. The settlement is discussed in Section 3.8.4.

The east wing wall is shown in Figure 3.8-1. Detail A shows the extent of the cracking detected on June 23, 1975, where the wall bears on the 12-inch-wide lip of the service water pump house footing. This cracking was apparently the result of differential settlement between the wing wall and pump house footing. To prevent future propagation of these cracks, the wing wall and pump house have been decoupled vertically by chipping away the wing wall concrete to create a 4-inch separation between them. A compressible material has been installed in this separation to ensure that it does not plug with debris and to prevent possible erosion of backfill materials. Horizontal decoupling of the wing wall already exists, as evidenced by the separation shown in Detail A of Figure 3.8-1, which was apparently the result of tilting of the service water pump house.

Two elevations of the west wing wall are shown in Figure 3.8-1. Elevation #1 shows the wing wall configuration and cracking across its south face as of the inspection on June 23, 1975. This cracking was apparently the result of differential settlement and tilting of the pump house. Subsequently, at the request of the NRC staff, the backfill behind the wall was excavated down to the top of the wing wall footing. An inspection by Stone & Webster, NRC, and VEPCO personnel on October 10, 1975, indicated that there were no cracks in the north face of the wing wall, nor were there any cracks in the top surface of the wing wall footing adjacent to the north and south faces of the wing wall.

Elevation #2 shows the west wing wall configuration after repair. The wing wall and pump house have been decoupled vertically and horizontally by chipping away the wing wall concrete, which was bearing on the 36-inch-wide lip of the SWPH footing, and placing a new wall section that is tied with drilled and grouted reinforcing to the pump house footing and wall. To further prevent propagation of existing cracks or the formation of new ones, due to differential settlement and/or binding, a 2-inch separation has been created between the wing wall and the new wall section of the service water pump house. This separation is also filled with a compressible material to ensure that it does not plug with debris, and to prevent possible erosion of backfill materials.

The initial intention was to chip out and replace the entire portion of the west wing wall above the crack shown in Elevation #1, since, prior to the inspection of October 10, 1975, the crack was assumed to extend completely through the wall to its north face. Inspection proved that this was not the case; the crack was found to be generally hairline in width on the south face only, and no greater than 1/32 inch at its widest point. Therefore, it was decided to investigate the magnitude of the horizontal shear stresses that must be safely transmitted from the upper portion of the wall, across the crack to the lower portion, and to the footing. Acceptable stress levels would indicate that repair of the crack was unnecessary.

It was also decided to start the repair of the west wing wall, in advance of this investigation, on the assumption that the entire wing wall above the crack would have to be removed. The earliest possible start on this work, if it was to be required, would minimize possible delays to the filling of the service water reservoir.

On October 21, 1975, it was concluded that removal of reinforced concrete of the west wing wall, above the crack, need only be accomplished for the 3-foot section of wing wall immediately adjacent to the southwest corner of the service water pump house, shown as new wall pour “A” in Elevation #2. Section A-A shows the details of that repair. At that time the reinforced concrete shown as new wall pour “B” in Elevation #2 had already been cut out for removal. Section B-B shows the details of how the full design capability of the wing wall was restored at that location.

The remaining portion of the wing wall above the crack was left as is. The surface of the wall was patched along the crack with an epoxy gel for cosmetic purposes only.

Investigation of the magnitude of horizontal shear stress at the base of the wing wall under seismic conditions shows that these stresses are acceptable. The following load equations were used in the analysis:

OBE: 1.4D + 1.7L + 1.9E

DBE: D + L + E'

where:

D = dead load, including hydrostatic load

L = live load, including soil pressure

E' = design-basis earthquake soil and wall inertia loads

E = operational-basis earthquake

The maximum average shear stresses at the base of the wall have been calculated to be 26.1 psi for the DBE case, and 39.2 psi for the OBE case. These values are within the allowables of 60 psi and 40 psi, respectively.

The maximum average shear stress values were calculated based on a section of the wall that includes the full height. The west wing wall has a maximum height of 11 ft. 6 in. and a total length of 16 ft. 7 in. The full height of the wall exists for only a 4-inch portion, and then begins to slope down at a rate of 3.8 in/ft. This 4-inch portion of the wall will not act independently of the balance of the length, necessitating inclusion of a portion of the remaining length for calculation of the average shear stress. This condition was included in the calculation. Based on this analysis, further repair of the wing wall is unwarranted.

3.8.1.1.8 Boron Recovery Tank Dikes

The boron recovery tank building is a single-story structure located in the south yard adjacent to the waste disposal building. The structure is approximately 110 feet long, 38 feet wide, and 43 feet high.

The dikes are supported by reinforced-concrete footings. Concrete walls rise to a height of 15 feet above grade and divide the building into three cubicles, each of which houses one boron recovery tank. An additional 12 feet of concrete wall above the dike wall extends around the building perimeter for radiation shielding. The remaining upper wall structure is noninsulated metal siding.

An elevated platform approximately 32 feet above the building floor permits access to each cubicle. Entrance into the building and platform is through the waste disposal building by an elevated platform at approximately 16 feet above building floor. The boron recovery tank dikes are designed to Seismic Class I criteria and their 2-foot thickness also provides tornado missile protection. The dikes serve to contain the entire volume of the tanks in the event of tank failure. A tank failure would result in no radiological consequences on the waters of the North Anna Reservoir, the Waste Heat Treatment Facility, or the potable water supply for the site.

3.8.1.1.9 Circulating Water Intake Structure (Partially Seismic Class I)

As shown in Table 3.2-1, only the auxiliary service water pump cubicles are designed to tornado and seismic criteria.

The circulating water intake structure is a reinforced-concrete building approximately 64 feet wide by 187 feet long by 47 feet high. It is supported on a 3-foot-thick mat. Exterior walls vary in thickness from 2 feet to 5 ft. 5 in.

Eight trash racks, with cleaning device, and steel plate stop logs for dewatering are provided. Eight traveling water screens are installed with screen wash equipment consisting of pumps, piping, and automatic control equipment. Eight electric-motor-driven circulating water pumps discharge through individual 90-inch steel pipes to the concrete tunnel leading to the station. A rubber expansion joint and motor-operated butterfly valve are installed at the discharge of each pump.

Two auxiliary service water pumps, one motor-driven fire pump, and two circulating water screenwash pumps that are used to make up to the Service Water Reservoir are also installed at the intake structure.

3.8.1.1.10 Fuel-Oil Pump House

The fuel-oil pump house is constructed of reinforced concrete with walls and roof 2 feet thick to resist tornado missiles. The building is constructed at ground grade. An exhaust fan is provided to remove fumes. A sump pump discharges to a holding tank equipped with level alarms. A CO_2 fire protection system, described in Section 9.5.1.2.2, is installed.

3.8.1.1.11 Turbine Building Superstructure (Partially Tornado-Resistant)

As shown in Table 3.2-1, the full extent of the turbine building structure is not designed for seismic or tornado loads. However, the turbine building columns between the 6 to 10 lines, inclusive, and their supporting bracing system, including the structural steel framing of the service building on column lines 6, 7, 8, 9, and 10 (the area adjacent to the main control room), is designed for tornado loads to prevent its collapse on the main control room. Structural requirements to satisfy tornado loads are greater than for seismic loads; consequently, the framing in this area will withstand the earthquake loadings postulated for this project.

3.8.1.1.12 Casing Cooling Pump House

The casing cooling pump house is a Seismic Class I reinforced-concrete structure, constructed on a common 28 feet by 56 feet mat foundation with the 26-foot-diameter casing cooling tank. The mat is founded directly on bedrock.

The pump house provides a weather-protected enclosure for the casing cooling systems, motors, and other equipment. Its walls are 12-inch-thick reinforced concrete. The roof consists of a 6-inch-thick concrete slab on metal decking that is supported by a structural steel frame. The pump house is not tornado-resistant.

3.8.1.1.13 Service Water Valve House

A service water valve house (SWVH) is provided to house service water system valves and related equipment for Units 1 and 2. The building superstructure consists of 2 feet thick reinforced concrete. The building is 58 ft. 6 in. long, 45 feet wide and 52 feet high and is located at the northwest edge of the service water reservoir.

The SWVH was constructed in two phases. Phase one, which consisted of construction up to Elevation 326 ft. 0 in., was performed when the structure was intended to serve as a Unit 3 and 4 pump house. Construction materials used in phase one conform to the description in Section 3.8.1.5 for original plant construction. Phase two, consisting of completion of all civil, structural, mechanical, and electrical work, converted the structure into a Unit 1 and 2 valve house. Construction materials used in phase two conform to the description in Section 3.8.1.7 under Service Water Reservoir Improvements.

A reinforced concrete expansion joint access pit is located along the north side of the SWVH. This pit serves to enclose, protect, and provide access to the two rubber expansion joints in the service water return headers entering the valve house.

Equipment installed in the SWVH includes: piping, valves, and expansion joints for the service water spray and bypass system, electrical motor control centers, distribution panels, etc., radiation monitoring equipment, heating and ventilation equipment, and sump pumps with associated discharge piping to the service water reservoir.

3.8.1.1.14 Service Water Tie-In Vault

A reinforced concrete vault, approximately 31 feet x 30 feet x 27 feet high, is provided at the tie-in to the original buried service water lines to protect the four service water headers and access hatches from the adverse effects of tornado generated missiles.

The tie-in piping, buried piping, and access hatches are designed to nuclear safety-related, ANSI B31.7, Class 3 piping requirements. Seismic pipe supports are provided for piping inside the tie-in vault to maintain the integrity of the service water system.

The tie-in vault houses the pipe access hatches, v-cone flow measurement devices, and the associated cathodic protection equipment. Platforms for gaining access to the pipe access hatches are provided. A 36-inch diameter, 3-inch thick steel manhole is located in the vault roof for personnel access into the tie-in vault. A 9 ft. by 20 ft. (approx.) four-piece removable equipment hatch is provided for construction and permanent access for equipment installation and removal.

A floor sump is located on the south side of the pit. A sump pump and discharge line are installed to allow drainage of the tie-in vault. The drain piping is 2-inch diameter, stainless steel and is embedded in the tie-in vault wall and discharges to grade outside the vault.

Forty-two inch diameter sleeves allow for unanticipated settlement of the tie-in vault without impacting the piping. The pipe sleeves are sealed and the sleeve seals allow differential movement between the piping and walls and maintain a sufficient seal to minimize soil and water inleakage into the pit.

3.8.1.2 Codes and Specifications

The original design and construction of the seismic Class I structures described in Section 3.8.1.1 conformed to the codes and specifications listed below. Subsequent modifications or reanalysis of these structures may have been performed using later industry codes and standards in accordance with administrative procedures and the design control program.

ACI 301-66	*Structural Concrete for Buildings*, and all specifications of the American Society for Testing and Materials referred to in Section 105 and declared to be a part of ACI 301-66 as if fully set forth therein
ACI 614-59	*Recommended Practice for Measuring, Mixing, and Placing Concrete*
ACI 605-59	*Recommended Practice for Hot Weather Concreting*
ACI 306-66	*Recommended Practice for Cold Weather Concreting*
ACI 318-63	*Building Code Requirements for Reinforced Concrete*
ACI 347-63	*Recommended Practice for Concrete Formwork*
AISC	*Specification for the Design, Fabrication, and Erection of Structural Steel for Building*, 1963 issue
BOCA	*Basic Building Code of the Building Officials Conference of America*, 1966 issue

Section III, Class B, of the ASME Boiler and Pressure Vessel Code for Nuclear Vessels was used as a guide in the selection of materials, design stresses, and fabrication of the steel containment liner.

ACI 301-66, *Specifications for Structural Concrete for Buildings*, together with ACI 347-63, *Recommended Practice for Concrete Formwork*, and ACI 318-63, *Building Code Requirements for Reinforced Concrete*, formed the basis for the project concrete specifications.

ACI 301-66 was supplemented as necessary with mandatory requirements relating to types and strengths of concrete, including minimum concrete densities, proportioning of ingredients, reinforcing steel requirements, joint treatments, and testing agency requirements.

The proposed ACI-ASME (ACI-359) Code for concrete containments was not used. Admixtures, types of cement, bonding of joints, embedded items, concrete curing, additional test specimens, additional testing services, cement and reinforcing steel mill test report requirements, and additional concrete test requirements were specified in detail.

Concrete protection for reinforcement, preparation and cleaning of construction joints, concrete mixing, delivering, placing, and curing, were equal to or exceeded the requirements of ACI 301, with the following exceptions:

Section 1404(a) - Maximum slump was 4.5 inch to permit placing concrete in the heavily reinforced containment structures. The samples for the slump tests were taken at the end of the last conveyor, chute, or pipeline before the concrete was placed in the forms.

Section 1404(b) - Maximum placing temperature of the concrete when deposited conformed to the requirements of ACI 605-59, *Recommended Practice for Hot Weather Concreting*.

Section 1404(c) - Minimum placing temperature of the concrete when deposited conformed to the requirements of ACI 306-66, *Recommended Practice for Cold Weather Concreting*.

3.8.1.2.1 Codes and Specifications - Service Water Reservoir Improvements

The original design and construction of the service water valve house and service water tie-in vault conformed to the codes, specifications, and other documents listed below. Subsequent modifications or reanalysis may have been performed using later industry codes and standards in accordance with administrative procedures and the design control program.

AASHTO T-26-79	*Quality of Water to be used in Concrete*
ACI 301-84	*Structural Concrete for Buildings*
ACI 318-83	*Building Code Requirements for Reinforced Concrete*
ACI 318-71	*Building Code Requirements for Reinforced Concrete*
ACI 349-80	*Code Requirements for Nuclear Safety Related Concrete Structures*
ANSI N45.2.5	*Supplementary Quality Assurance Requirements for Installation*
(1974)	*Inspection, and Testing of Structural Concrete and Structural Steel during the Construction Phase of Nuclear Power Plants* (including all referenced documents)
AISC	*Specification for the Design, Fabrication and Erection of Structural Steel for Buildings,* 8th Edition

NRMCA-1984	*Quality Control Manual - Section 3 Certification of Ready Mix Concrete Production Facilities*
Reg. Guide	*Quality Assurance Requirements for Installation, Inspection, and*
1.94 (1976)	*Testing of Structural Concrete and Structural Steel during the Construction Phase of Nuclear Power Plants*
Reg. Guide 1.142 (1981)	*Safety Related Concrete Structures for Nuclear Power Plant* (other than Reactor Vessel and Containments)

ANSI N45.2.5-1974, together with ACI 349-80 and ACI 301-84 formed the basis for the project concrete specifications. The latest edition of documents referenced by ANSI N45.2.5-1974, ACI 349-80 and ACI 301-84 were used.

3.8.1.3 **Structural Loading Combinations**

Seismic and tornado or normal wind loads are not considered to act on a structure simultaneously. Seismic loads were considered to act in combination with dead, live, hydrostatic, and lateral earth pressure loads. Tornado loads were considered to act in combination with dead, live, hydrostatic, and lateral earth pressure loads.

3.8.1.3.1 Definitions

D - Dead load of structure, equipment, piping, and snow or ice load, including the effect of hydrostatic and lateral earth pressures

L - Live load

E - Operational-basis earthquake (OBE) load

HE - Design-basis earthquake (DBE) load

C' - Load due to horizontal wind velocity resulting from the design wind

C - Load due to negative pressure, horizontal wind velocity, and airborne missile resulting from the design tornado

S - Required section strength for structural steel based on the elastic design methods and allowable stresses defined in Part 1 of the AISC Standard, *Specification for the Design, Fabrication and Erection of Structural Steel for Buildings*, April 17, 1963

Fy - Minimum yield stress for structural steel

W - Working stress design section strength for reinforced concrete based on the elastic design methods and allowable stress defined in Part IV A of the ACI Standard, *Building Code Requirements for Reinforced Concrete*, ACI 318-63

U - Ultimate strength design section strength for reinforced concrete based on ultimate design methods defined in Part IV B of the ACI Standard, *Building Code Requirements for Reinforced Concrete*, ACI 318-63

ø - Capacity reduction factor defined in Section 1504(b) of ACI 318-63

3.8.1.3.2 Load Equations

Seismic Class I reinforced-concrete and structural steel structures are proportioned to satisfy each of the following:

W or S = D + L + E

øU or 0.90 Fy = D + L + HE

1.33 W or 1.33 S = D + L + C'

øU or 0.90 Fy = D + L + C

3.8.1.3.3 Service Water Valve House

The partially completed Units 3 and 4 reinforced concrete service water pump house was completed with modifications to utilize the structure as a valve house. The original and modified, completed design was based on the requirements of ACI-318, using the following load combinations:

U = 1.4 D + 1.7 L

U = 0.75 (1.4 D + 1.7 L + 1.7 W)

U = 1.4 D + 1.7 L + 1.9 OBE

U = 0.9 D + 1.9 OBE

U = 1.0 D + 1.0 L + 1.0 DBE

U = 0.9 D + 1.0 DBE

U = 1.0 D + 1.0 L + 1.0 C

U = 1.0 D + 1.0 C

U = 1.0 D + 1.0 F

where:

U = Section strength required to resist the design loads based on the strength design method

D = Dead load of structure, equipment, piping and snow or ice load, including the hydrostatic and lateral earth pressures

L = Live load

OBE = Operating-basis earthquake load

W = Load due to horizontal wind velocity resulting from the design wind

DBE = Design-basis earthquake loads

F = Maximum possible flood loads

C = Load due to negative pressure, horizontal wind velocity, and airborne missile resulting from the design tornado

3.8.1.3.4 Spray Array Support Structures

Service water reservoir spray array support structures were designed in accordance with the load combinations and stress limits set forth in Section 3.8.4 of the Standard Review Plan, NUREG-0800, July 1981.

3.8.1.3.5 Service Water Tie-In Vault

The service water tie-in vault was designed in accordance with the load combinations and stress limits set forth in Section 3.8.4 of the Standard Review Plan, NUREG-0800, July 1981.

3.8.1.4 **Analytical Techniques**

Seismic loads, in combinations described in Section 3.8.1.3, are treated as static loads, in the form of acceleration profiles in the direction of a set of orthogonal axes of Seismic Class I structures, for both the operational-basis earthquake and the design-basis earthquake. Acceleration profiles are generated by dynamic analysis of mathematical models using appropriate response spectra and damping values.

Tornado loads, in combinations described in Section 3.8.1.3, are treated as static loads whose magnitude is equal to the dynamic wind pressure, times appropriate shape factors and drag coefficients.

The Seismic Class I structures discussed in Section 3.8.1 are primarily of reinforced-concrete construction. The principal components that transmit horizontal and vertical loads to the foundation are the reinforced-concrete roof and floor slabs, and both interior and exterior reinforced-concrete walls. Since these components act as diaphragms, tending to minimize stress concentrations that might otherwise occur (in a column, for example), and their thicknesses are usually controlled by requirements for biological shielding or tornado and interior missile protection, stresses and strains are generally not significant. For these reasons, calculated stresses and strains for selected principal structural components have been omitted in this report.

Seismic loads have a basic allowable stress for structural steel and reinforced concrete, given by the normal working stress, for the operational-basis earthquake. A check was then made for the design-basis earthquake to ensure that the maximum stress did not exceed 90% of the minimum yield strength for structural steel, the capacity reduction factor times either the compressive strength for concrete, or the minimum yield strength for reinforcing steel. Under either the operational-basis earthquake or design-basis earthquake, no increase in allowable soil or rock bearing values was permitted.

Tornado loads have a basic allowable stress of 90% of the minimum yield for structural steel, the capacity reduction factor times either the compressive strength for concrete, or the minimum yield for reinforcing steel. Allowable soil and rock bearing values were increased by one-third. A discussion of allowable stresses for tornado loads is provided in Section 3.3.2.

Initial structural designs were based on specified 28-day compressive strengths for concrete of 3000 psi, or as otherwise noted on the engineers' drawings (e.g., concrete used as backfill had a specified 28-day compressive strength of 1000 psi, and concrete used for the spent-fuel pool cask drop wall and counterfort had a specified 28-day compressive strength of 4000 psi). In those instances where initial design loads were revised or new loading conditions were postulated, it was necessary to reevaluate the existing design. If that evaluation required 28-day compressive strength for concrete greater than originally specified (e.g., for shear, bearing, or compression considerations), and if the concrete for that structure had been previously placed, the cylinder tests were researched to determine the actual 28-day compressive strength of that mix as placed at that time, in accordance with the methods of ACI-318-71, Section 4.3.3. This procedure was required in the following structures or portions of structures for the reasons indicated.

3.8.1.4.1 Spent-Fuel Pool

The spent-fuel pool structure was redesigned as a result of a deficiency in the original design. This activity was reported to the USNRC, Region II Office of Inspection and Enforcement, on July 19, 1976, and the final report on the structural analysis of this structure is submitted as Appendix 9A.

The reanalysis, which confirmed that the original design was deficient, used a 28-day compressive strength of 4500 psi for the walls. This was based on a review of 25 cylinder tests for the mix used, for which the average 28-day compressive strength was 4763 psi. Only 10 of these test cylinders broke at values less than 4500 psi, and only four of these broke at values less than 4000 psi. This reanalysis used a 28-day compressive strength of 5000 psi for the foundation mat. This was based on a review of seven cylinder tests for the mix used, for which the average 28-day compressive strength was 5063 psi. Only three of these cylinders broke at values less than 5000 psi, and only one of those broke below 4950 psi.

The reanalysis that evaluated the spent-fuel pool, with the added counterfort feature stiffening the north wall, used these same values of 28-day compressive strength, i.e., 4500 psi for the walls and 5000 psi for the mat, as a matter of analytical convenience. The structural design is not dependent on these 28-day values, however, since the primary overstress in the original design was due to flexural tension in reinforcing bars.

3.8.1.4.2 Evaluation of Possible Damage to Embedded Reinforcing Steel During Installation of Drilled-In Anchors

Various plant structures were evaluated for the structural significance of possible reinforcing steel damage that could have occurred when the holes for drilled-in anchors for pipe supports were drilled using diamond-tipped drill bits. This problem was reported to the USNRC, Region II Office of Inspection and Enforcement, on October 12, 1976, and the evaluation report submitted on October 16, 1978. This report demonstrated that the damage to rebar would not prevent the structures from performing their intended functions.

During this evaluation, there was one instance when the reactor containment cranewall column analysis required the use of actual 28-day compressive strengths for concrete. The loading combinations for this analysis are contained in Section 3.8.2.2.

There are two columns involved, designated as 7-8 and 18-1. Each column was poured in two lifts, and the test cylinder 28-day compressive strengths were as follows:

Column	Lift #1	Lift #2	Average, 28 days
7-8	3696	4168	3932 psi
18-1	4026	4168	4097 psi

The columns were slightly over the allowable stress, using a 28-day compressive strength of 3650 psi, but were well within the allowable using a strength of 4000 psi. To provide added assurance that the in-place strengths were satisfactory, core samples were taken and tested in accordance with ASTM C42 in February 1977, with results as follows:

Column	Lift #1	Lift #2	Average, 2/77
7-8	5307	6139	5723 psi
18-1	6400	5515	5958 psi

Results of core samples for concrete compressive strength were used only to supply additional assurance that the concrete would satisfy the required revised structural design criteria for these columns.

3.8.1.4.3 Circulating Water Tunnels

The circulating water tunnels were reanalyzed to evaluate the structural consequences of hydraulic transient pressure and vacuum loadings that resulted from various postulated events other than steady-state flow.

In the safety-related portion of the discharge tunnel, the Unit 1 and Unit 2 tunnels are separated by an 18-inch-thick, reinforced-concrete wall. When postulating the peak pressure transient to occur in one tunnel simultaneously with the peak vacuum transient in the other, the moment and shear resistance of the wall required a 28-day compressive strength of 4000 psi in order to satisfy the following equation:

Service Load

$U= 1.4 (D + W) + 1.9E'$

where:

U = required section strength, which includes the capacity reduction factors defined in Chapter 9 of ACI 318-71

D = dead load

W = vacuum or pressure load due to hydraulic transients

E' = operational-basis earthquake loads

The use of a 28-day compressive strength of 4000 psi is based on tests of concrete core samples taken and tested in accordance with the requirements of ACI 318-71, Section 4.3.5.

The concrete that comprises the common wall of the safety-related portion of the discharge tunnel was placed in two pours. The first was from a point 6 ft. 0 in. east of 4-line westward to a point 8 ft. 6 in. west of 5-line (Pour No. 292), and the second continued westward to a point 17 ft. 9 in. west of 0-line (Pour No. 264). Concrete was placed in one lift from the top of the tunnel floor at Elevation 236 ft. 6 in. to the underside of the roof slab at Elevation 246 ft. 6 in. Three concrete core samples were taken from each pour, and the results are given below:

Test Values

Pour No.	1	2	3	Test Avg.
292	6348	6139	6243	6243
264	6243	6087	6139	6156

In accordance with the provisions of ACI 318-71, Section 4.3.5.1, the use of a compressive strength of 4000 psi is justified.

3.8.1.4.4 Evaluation of Effects of High-Energy Pipe Break

The qualification of portions of buildings to withstand the effects of postulated high-energy-line pipe breaks often required that the compressive strength of concrete be higher than initially specified. A postulated pipe break requires analysis of the effects of jet impingement loads, pipe whip impact loads against a restraint or structural target, and pressurization loads acting in the volume within the structural boundary enclosing the broken pipe.

The load combinations used to evaluate pipe rupture effects inside the reactor containment are contained in Section 3.8.2.2. All effects of pipe break loads are included in the term “R” (i.e., jet impingement, pipe whip, or restraint reactions), except pressurization loads, which are denoted by the term “P.” Pipe break effects were treated either as equivalent static loads with an appropriate dynamic load factor to account for the dynamic nature of the load, or as dynamic loads with a dynamic model of the structure and a time-history analysis.

The load combinations used to evaluate pipe rupture effects outside the reactor containment are contained in Section 3C.2.5.4.

The following are examples of structures for which compressive strengths of concrete were required that were higher than initially specified.

The primary shield wall was checked and shown acceptable using a compressive strength of concrete of 3760 psi at the base to satisfy design requirements for the effects of a reactor pressure vessel cold-leg break, as discussed in Appendix 5A. Bending moment resistance is needed in the wall near the wall/mat intersection to resist the combined effects of a cold-leg rupture plus the design-basis earthquake. Concrete test cylinders show that the 28-day compressive strengths equal or exceed this value, and thus the design is acceptable (see Table 3.8-1).

The analyses of the pressurizer cubicle floor slab at Elevation 262 ft. 10 in., and cranewall and radial walls up to Elevation 291 ft. 10 in., have assumed a compressive strength of concrete of 4000 psi to satisfy design requirements for the effects of a pressurizer surge line pipe break. Concrete cylinder test results show 28-day compressive strengths that justify this assumption (see Tables 3.8-2 and 3.8-3).

The analysis of the steam generator cubicle floor slab at Elevation 242 ft. 6 in., and radial walls up to Elevation 291 ft. 10 in., assumed a compressive strength of concrete of 4000 psi to satisfy design requirements for the effects of the primary coolant loop pipe breaks occurring inside the cubicle. Concrete cylinder test results show 28-day compressive strengths that justify this assumption (see Tables 3.8-3 and 3.8-4).

The analysis of the cranewall between Elevation 291 ft. 10 in. and Elevation 342 ft. 4 in., which supports the main steam and feedwater pipe break restraints, has assumed a compressive strength of concrete of 5200 psi to satisfy design requirements. Concrete cylinder test results show 28-day compressive strengths that justify this assumption (see Table 3.8-5).

3.8.1.4.5 Spent-Fuel Rack Embedments

The structural capability of the embedments that support the spent-fuel racks was reevaluated for comparison with loads imposed on them from newly designed, high-density storage racks. The existing embedment designs were checked using a compressive strength of concrete of 4815 psi. Concrete cylinder test results show 28-day strengths that justify this value (see Table 3.8-6).

The neutron absorber spent fuel storage racks which replace the high-density storage racks do not utilize all of the existing embedments. The pool structure was analyzed to ensure that the neutron absorber spent fuel storage racks can be accommodated by the structure during a seismic event.

3.8.1.4.6 Fuel Pit Walls in Fuel Building

The difference in temperature between the water in the spent-fuel pit and the lower ambient temperature develops bending forces in the walls. These forces cause compression in the concrete at the inside face, and tension at the outside face, because of the restraint provided by the plate liner. The pool is lined with 0.25-inch-thick stainless steel plate, butt-welded and protected with leak test channels, to prevent leakage.

The forces due to the thermal gradient are evaluated on the basis of a cracked section for flexural rigidity and reduced value of modulus of elasticity of the concrete. The Portland Cement Association publication, *Circular Tanks Without Prestressing*, was used as a design guide.

The 6-foot thickness of the walls of the spent-fuel pit is dictated by biological shielding requirements. This large thickness limits deflection. The design is in accordance with paragraph 1508 of ACI-318 63, *Control of Cracking*. Since temperature is a factor in the design of the fuel pit, reinforcement is provided and distributed so that strains are controlled. In addition, the reinforced-concrete structure of the fuel building is designed as a Seismic Class I structure.

3.8.1.4.7 Masonry Walls; IE Bulletin 80-11

At the completion of the response to IE Bulletin 80-11, all identified masonry block walls were evaluated and modified, as required, to meet the acceptance criteria. The results of this reevaluation program were transmitted to the Nuclear Regulatory Commission. In compliance with IE Bulletin 80-11 (Reference 1), both seismic and non-seismic masonry walls were re-evaluated to determine whether they could fail under seismic or other extreme loading, and to determine the effects on safety-related systems of possible failures. Fifty-five safety-related masonry walls were determined to be acceptable by the re-evaluation either as is or after modifications were completed. An additional 15 safety-related masonry walls in the fuel building were not acceptable under extreme loading conditions and were replaced with blow-off siding. Over three hundred walls in non-seismic areas of the plant were also reviewed to ensure that they did not endanger safety-related equipment. Conduits on some walls were relocated so that failure of the walls would not endanger them. Following the approval of responses to IE Bulletin 80-11 by the Nuclear Regulatory Commission, all subsequent modifications involving masonry block walls are evaluated under the Nuclear Design Control Program, which continues to invoke the technical requirements of IE Bulletin 80-11 (References 49 & 50).

3.8.1.5 **Construction Materials**

3.8.1.5.1 Concrete

See Section 3.8.2.9.4 for the description of the concrete used for the Reactor Pressure Vessel Head Replacement Project.

3.8.1.5.1.1 *Cement.* All cement used was an approved American brand conforming to the *Specification for Portland Cement*, ASTM Designation C150, Type II, low alkali. It is suitable for Seismic Class I structures because of its lower heat of hydration and improved resistance to sulphate attack. The low alkali was specified to minimize the possibility of reaction with aggregates. Certified copies of mill tests, showing that the cement met or exceeded the ASTM requirements for Portland Cement, were furnished by the manufacturer. An independent testing laboratory performed tests on the cement for compliance with the specifications.

In the fall of 1975, the transition between using approved concrete mixes and specifications that were developed for Units 1 and 2, and using approved mixes and specifications that were developed for Units 3 and 4, was completed. Concrete placed in Unit 1 and 2 structures from that time forward conformed to the descriptions given in Section 15.3.1 of the North Anna Units 3 and 4 PSAR.

3.8.1.5.1.2 *Admixtures.* An air-entraining agent was used in the concrete in an amount sufficient to entrain from 3 to 5% of air, by volume, of normal-weight concrete. This agent conformed to the requirements of *Standard Specification for Air-Entraining Admixtures for Concrete*, ASTM C260, when tested in accordance with *Standard Method of Testing Air-Entraining Admixtures for Concrete*, ASTM C233. The air-entraining agent was added separately to the batch in solution in a portion of the mixing water or with nonabsorbent or water-saturated aggregates. The solution was batched by means of a mechanical dispenser capable of accurate measurement, and in a manner ensuring uniform distribution of the agent throughout the batch during the specified mixing period. A fixed procedure was adopted for the control of the dispensing operation. No admixtures were used in heavy-weight, ilmenite concrete.

3.8.1.5.1.3 *Water.* Mixing water was furnished from the North Anna River, and was kept clean and free from injurious amounts of oils, acids, alkalies, salts, organic materials, or other substances deleterious to concrete or steel. The quality of the water was the equivalent of that suitable for drinking. The water was checked and tested for compliance with the above requirements by an independent testing laboratory.

3.8.1.5.1.4 *Aggregates.* Fine and coarse aggregates conformed to the requirements of the *Standard Specifications for Concrete Aggregates*, ASTM C33. Aggregates were evaluated for potential chemical alkali reactivity. Aggregates were free from any materials that would be deleteriously reactive in any amount sufficient to cause excessive expansion of mortar or concrete. All aggregates were tested for compliance with the above requirements by an independent testing laboratory.

3.8.1.5.1.5 *Proportioning.* Proportioning of structural concrete conformed to ACI 301, Chapter 3. Working stress type concrete and ultimate strength type concrete conformed to the requirements of ACI 301, Paragraph 302. Ultimate strength type concrete was used in the construction of the foundation mat, exterior wall, and dome of the reactor containment, and in general site construction. Working stress type concrete was used in the dam construction.

In general, concrete mixes have a 28-day specified strength of 3000 psi, except as otherwise noted on the engineer’s drawings.

Concrete used for biological shielding purposes, that is, the majority of concrete used in floors, walls, roof, and dome of the containment structure, the fuel building, and auxiliary building, weighs at least 140 lb/ft^3, air-dried at 7 days in accordance with ACI 301, Section 303(b).

Reference to lightweight concrete in Section 303(b) was construed as applicable to regular structural concrete for the purpose of these requirements. In some cases, where space was not available, it was necessary to use heavy aggregate concrete having a density of 230 lb/ft^3 or greater to provide biological shielding.

Proportions of ingredients were determined and tests conducted by an independent laboratory in accordance with the method detailed in ACI 301, Paragraph 308, for combinations of materials to be established by trial mixes.

The maximum slump of mass concrete, as defined in ACI 301, Chapter 14, did not exceed 4.5 inch. Slump of other concrete conformed to ACI 301, Paragraph 305. The samples for the slump tests were taken at the end of the last conveyor, chute, or pipeline at the point where concrete was placed in the forms.

3.8.1.5.1.6 *Mixing and Placing.* Batching and mixing conformed to Chapter 7 of ACI 301. Concrete ingredients were batched in a batch plant and transferred to transit mix trucks for mixing, agitating, and delivering to the point of placement. Water was added to the mix with the other ingredients before the truck left the batch plant area.

Placing of concrete was by bottom dump buckets, concrete pump, and by conveyor belt. Bottom dump buckets did not exceed 4 yd^3 in size. The discharge of concrete was controlled so that concrete was effectively compacted around embedded items and near the forms.

Vertical drops greater than 6 feet for any concrete were not permitted, except where suitable equipment was provided to prevent segregation.

After the initial concrete set had occurred, but before the concrete reached its final set, the surfaces of all construction joints were thoroughly cleaned to remove all laitance and to expose clean, sound aggregate using the air-water jet. After cutting, the surface was washed and rinsed. All excess water that was not absorbed by the concrete was removed.

Where the use of an air-water jet was not advisable in any specific instance, that surface was roughened by hacking with hand tools or other satisfactory means to produce the requisite clean surface. Horizontal construction joints were covered by a 0.5-inch-thick layer of sand/cement grout of the same sand/cement ratio as the concrete, and new concrete was then placed immediately against the fresh grout.

Curing and protection of freshly deposited concrete conformed to ACI 301, Chapter 12, with the following supplementary provisions:

1. Concrete to be cured with water was kept wet by covering with an approved water-saturated material, by a system of perforated pipes or mechanical sprinklers, or by other approved methods that kept all surfaces continuously wet. Where wood forms were used and left in

place for curing, they were kept wet at all times to prevent opening at the joints and drying out of the concrete. Water used for curing was generally clean and free from any elements that might cause objectionable effects.

2. The structural engineer indicated the surfaces on which curing compounds could be used. Curing compounds were not used on surfaces to which additional concrete was bonded.
3. For the procedures used for curing of the top surface of the containment foundation mat, see Section 3.8.2.

Concrete strength tests were performed in accordance with ACI 301, Chapter 16, Section 1602(a), Paragraph 4, supplemented as follows.

No fewer than two sets of compression test specimens for each design of concrete were made during the first 2 days of placing concrete, and at least one set of test specimens was made per 8-hour shift, or for each 100 yd^3 of concrete for Seismic Class I structures, and each 250 yd^3 of concrete for other than Seismic Class I structures, whichever gave the greatest number of specimens. In addition, one set of specimens was made whenever, for any reason, the materials, methods of concreting, or proportioning was changed.

The test specimens for compressive strength were 6-inch-diameter and 12-inch-long cylinders. Each set consisted of five specimens, at least one of which was tested at 7 days and three at 28 days age. The remaining cylinder was retained at the laboratory for further tests at 60 days age, if the result of the previous tests made such a test desirable.

Concrete strength tests were evaluated by the engineers in accordance with ACI 214-65, *Recommended Practice for Evaluation of Compression Test Results of Field Concrete*, and ACI 301-66, Chapter 17.

Strengths of working stress type concrete were considered satisfactory if the average of any five consecutive strength tests of the laboratory-cured specimens at 28 days age was equal to or greater than the specified compressive strength, f'c, of the concrete.

Strengths of ultimate strength type concrete were considered satisfactory if the average of any three consecutive strength tests of the laboratory-cured specimens at 28 days age was equal to or greater than the specified compressive strength, f'c, of the concrete.

When and if tests for individual cylinders or group of cylinders failed to reach the specified compressive strength, f'c, of the concrete, the Stone & Webster engineers were immediately notified to determine if further action was required.

The field tests for slump of Portland Cement concrete were in accordance with ASTM C143. Any batch not meeting specified requirements was rejected. Slump tests were made frequently during concrete placement and each time concrete test specimens were made.

Statistical quality control of the concrete was maintained by a computer program. The program was based on an article in ACI Publication SP-16, *Computer Applications in Concrete Design and Technology*. This program analyzes compression test results reported by the testing laboratory in accordance with methods established by ACI 214, *Recommended Practice for Evaluation of Compression Test Results of Concrete*.

3.8.1.5.2 Reinforcing Steel

See Section 3.8.2.9 for the description of the reinforcing steel used for the Reactor Pressure Vessel Head Replacement Project.

3.8.1.5.2.1 *General.* Except for N14 and N18 reinforcing bars, all reinforcing conforms to Grade 40 of ASTM A615, *Standard Specification for Deformed Billet-Steel-Bars for Concrete Reinforcement*. Special large-size reinforcing bars, No. 14 and No. 18, used in the construction of Seismic Class I structures, are steel of 50,000 psi minimum yield point, conforming to Grade 40 of the *Standard Specification for Deformed Billet-Steel Bars for Concrete Reinforcement*, ASTM A615, as modified to meet the following chemical and physical requirements:

Carbon	0.35% maximum
Manganese	1.25% maximum
Silicon	0.15 to 0.25%
Phosphorus	0.05% maximum
Sulphur	0.05% maximum
Yield strength	50,000 psi minimum
Elongation	13% minimum in an 8-inch test sample
Tensile strength	70,000 psi minimum

In areas limited to some containment interior walls, a small amount of Grade 60 reinforcing steel was used to maintain construction schedules. These bars were stored separately from all other reinforcing to ensure their traceability to the point of placement in the containment interior walls.

See Section 3.8.2.9 for the description of the reinforcing steel used for the Reactor Pressure Vessel Head Replacement Project.

3.8.1.5.2.2 *Fabrication.* For special chemistry bars, all ingots were identified and all billets were stamped with identifying heat numbers. All bundles of bars were tagged with the heat number as they came off the rolling mill. A special stamp marking was rolled into all bars conforming to this special chemistry to identify them as possessing the chemical and mechanical qualities specified.

On a random basis, the pouring of the heats and the physical and chemical tests performed by the fabricator were witnessed. Bars containing inclusions or failing to conform to the required chemistry and physical requirements were rejected.

Both the ASTM A615 40,000-psi minimum yield strength reinforcement heats and the special chemistry reinforcement heats contained approximately 100 tons per heat. The conventional 40,000-psi reinforcement and the special chemistry reinforcement had mill reports on chemical and physical tests performed on each heat.

3.8.1.5.2.3 *Tension Testing.* Reinforcing tests were those required by ASTM A-615, performed and certified by the fabricator.

A tension test was performed for each heat of Grade 40, Grade 40 modified, and Grade 60 reinforcing steel furnished. The tension tests conformed to ASTM A370, *Standard Methods and Definitions for Mechanical Testing of Steel Products*. The loading for the tension test to yield was applied at a rate of from 2000 to 5000 lb/min.

For Grade 40 modified reinforcing steel (N14 and N18 bars), the fabricator's standard practice was to perform the required tension test on a full-diameter specimen. For all other reinforcing steel, i.e., Grade 40 and 60, the tension test sample was either a full-diameter or standard 0.505-inch-diameter specimen, as allowed by ASTM A-615-68. Additionally, for N14 and N18 reinforcing, one full-diameter by 2 ft. 0 in. length specimen from each heat was furnished to permit independent verification of chemical and mechanical properties. See Section 3A.14 for supplemental information.

3.8.1.5.2.4 *Placing.* Placing of reinforcing steel conformed to the requirements of Chapter 5 of ACI 301, *Structural Concrete for Buildings*, and Chapter 8 of ACI 318, *Building Code Requirements for Reinforced Concrete*.

3.8.1.5.2.5 *Welding.* Welding was performed using the *Metallic Arc Welding Process* with coated electrodes, or the *Metallic Inert Gas Shielded Welding Process* (MIG) using bare wire. The filler metal for the Metallic Arc Welding Process conformed to AWS A-316, *Coated Arc Welding Electrodes* (identical to ASTM A-233 and ASTM A-316, *Coated Arc Welding Electrodes,* respectively), Classification E-10016-D2, E-10018-D2, or E7018.

The filler metal for the "MIG" welding process was a spooled bare wire, 0.30-inch or 0.35-inch-diameter Linde or Arches Type 515. The shielding gas used for the "MIG" welding process was Line C-25, a mixture of 75% argon and 25% carbon dioxide.

The ends of the bars to be jointed by butt welding were prepared by sawing or flame cutting, and dressed by grinding, where necessary, to form a single vee butt joint.

Mill test reports of the heats of steel used for making rebars were obtained to confirm the grade of steel to be welded. Where preheating was required, temperatures were checked with Tempilstiks.

To qualify welders for work on the reinforcing steel bars, each welder made a reinforcing bar test weld in the horizontal fixed position, welding vertically up. Each test weld was sectioned through the center of the weld by power sawing and machining. The cross-sectional surface was etched with a solution of nitric acid and water. The etched surface was examined to determine the qualification of the welding operator.

All welds were visually inspected. Any cracks, porosity, or other defects were removed by chipping or grinding until sound metal was reached, and then repaired by welding. Peening was not permitted.

3.8.1.5.3 Cadwelds

See Section 3.8.2.9 for the description of Cadwelds, including operator qualification and tensile testing, used for the Reactor Pressure Vessel Head Replacement Project.

3.8.1.5.3.1 *General.* Bar sizes N14 and N18 were spliced using the Cadweld T-series rebar splices in accordance with the instructions for their use issued by the manufacturer, Erico Products, Inc., Cleveland, Ohio.

The ends of the rebars to be joined by the Cadweld process splices were saw-cut or flame-cut. The ends of the bars were thoroughly cleaned of all rust, scale, grease, oil, water, or other foreign matter before splicing.

All Cadweld process joints were visually inspected for dryness and cleanliness prior to fitting the sleeve over the ends. The completed joints were inspected for properly filled joints with filler metal visible at both ends of the sleeve and at the top hole in the center of the sleeve. Randomly selected splices were removed and strength-tested for compliance with the specifications.

The following Cadweld process filler metal casting conditions were not normally considered cause for rejection or repair of the Cadweld joint:

1. Shrinkage bubbles, shrinkage cracks, and pinholes, usually visible at the ends of the sleeve, and bubbles at the top hole in the center of the sleeve.
2. Concavity of the filler metal at the sleeve ends caused by the asbestos packing bulging into the openings between the sleeve and the bar.

Defective Cadweld joints were completely removed, and rejoined using the correct procedure.

During the Reactor Vessel Head Replacement Project, a temporary construction opening was cut in the containment building and the subsequent repair and testing of Cadweld splices was made in accordance with ASME Section III, Division 2, 1995, as described in Section 3.8.2.9.

3.8.1.5.3.2 *Operator Qualification.* To qualify operators for making Cadweld splices, each operator demonstrated his ability to make an acceptable fixed joint using the Cadweld process procedures in accordance with the manufacturer's recommendation. Operators were qualified after every 200 Cadwelds.

3.8.1.5.3.3 *Tensile Testing.* Randomly selected production Cadweld splices were removed from each Seismic Class I structure and tensile-tested to meet the following statistical requirements: one of the first 10 splices, three of the next 100 splices, and two of each subsequent group of 100 splices.

Sister splices were selected only when removal of production splices was impractical.

Tensile tests were considered satisfactory if the average value of two or more successive splices developed at least the minimum guaranteed ultimate strength of the reinforcing bar, and no single splice failed to develop 90% of the minimum guaranteed ultimate strength of the rebar.

In the event that Cadweld splices did not meet these requirements, three additional production splices, made by the operator of the substandard splice, were tested to these same requirements, and the operator requalified. If any of these additional three productions splices were substandard, the design of the portions of the Seismic Class I structure in the areas of these Cadweld splices would be reassessed to determine its ability to accept the reduced average ultimate strength.

3.8.1.6 **Structural Testing and Surveillance**

No structural preoperational testing was performed on Seismic Class I structures other than containments. Structural surveillance programs consist only of seismic instrumentation surveillance, as discussed in Section 3.7.4, and periodic elevation surveys to detect and monitor foundation settlement.

3.8.1.7 **Construction Materials for Service Water Reservoir Improvements**

3.8.1.7.1 Concrete

3.8.1.7.1.1 *Cement.* All cement used was an approved American brand conforming to the *Specification for Portland Cement*, ASTM Designation C150, Type II. It is suitable for Seismic Class I structures because of its lower heat of hydration and improved resistance to sulphate attack. Certified copies of mill tests, showing that the cement met or exceeded the ASTM *Requirements for Portland Cement,* were furnished by the manufacturer. An independent testing laboratory performed tests on the cement for compliance with the specifications.

3.8.1.7.1.2 *Admixtures.* An air-entraining agent was used in the concrete in an amount sufficient to entrain air so that the air content of the concrete was in accordance with Table 4.5.1 of ACI 318-83. This agent conformed to the requirements of *Standard Specification for Air-Entraining Admixtures for Concrete,* ASTM C260, when tested in accordance with *Standard Method of Testing Air-Entraining Admixtures for Concrete,* ASTM C233.

A retarding admixture was used to delay the concrete setting time. The admixture conformed to the requirements of *Standard Specification for Chemical Admixtures for Concrete,* ASTM C494, when tested in accordance with ASTM C494.

The admixtures were added separately to the batch in solution in a portion of the mixing water. The solutions were batched by means of a mechanical dispenser capable of accurate measurement, and in a manner ensuring uniform distribution of the agent throughout the batch during the specified mixing period.

3.8.1.7.1.3 *Water.* Mixing water was potable water furnished from the town of Orange, Virginia municipal supply. The water was clean with a total solids content of not more than 2000 ppm as determined by ASTM D1888, *Standard Test Methods for Particulate and Dissolved Matter, Solids, or Residue in Water*. The mixing water did not contain more than 250 ppm of chloride ion as determined by ASTM D512, *Standard Test Methods for Chloride Ion in Water.* In addition, a comparison of the mixing water was made with distilled water by performing the following tests:

a. Compressive Strength, in accordance with ASTM C109, *Standard Test Method for Compressive Strength of Hydraulic Cement Mortars* (using 2-inch or 50-mm Cube Specimens).

b. Setting Time, in accordance with ASTM C191, *Standard Test Method for Time of Setting of Hydraulic Cement by Vicat Needle.*

c. Soundness, in accordance with ASTM C151, *Standard Test Method for Autoclave Expansion of Portland Cement.*

The water was checked and tested for compliance with the above requirements by an independent testing laboratory.

3.8.1.7.1.4 *Ice.* Ice was used for hot weather batching and was made from water meeting the same requirements as identified in Section 3.8.1.7.1.3.

3.8.1.7.1.5 *Aggregates.* Fine and coarse aggregates conformed to the requirements of the *Standard Specifications for Concrete Aggregates,* ASTM C33. Aggregates were evaluated for potential chemical alkali reactivity. Aggregates were free from any materials that would be deleteriously reactive in any amount sufficient to cause excessive expansion of mortar or concrete. All aggregates were tested for compliance with the above requirements by an independent testing laboratory.

3.8.1.7.1.6 *Proportioning.* Proportioning of structural concrete conformed to ACI 211.1 and ACI 349. In general, concrete mixes have a 28-day specified compressive strength of 3000 psi.

Proportions of ingredients were determined and tests conducted by an independent laboratory in accordance with the methods detailed in ACI 211.1 and ACI 349 for combinations of materials to be established by trial mixes. Slump of concrete conformed to ACI 301, Section 3.5.

3.8.1.7.1.7 *Mixing and Placing.* Batching and mixing conformed to ASTM C94, Standard Specification for Ready-Mixed Concrete, except as otherwise noted in the engineer's specifications. Concrete ingredients were batched in a batch plant and transferred to transit mix trucks for mixing, agitating, and delivering to the point of placement. Water was added to the mix with the other ingredients before the truck left the batch plant area.

Placing of concrete was by bottom dump buckets, concrete pump, and directly from truck chute. Bottom dump buckets did not exceed 4 yd^3 in size. The discharge of concrete was controlled so that concrete was effectively compacted around embedded items and near the forms.

Vertical drops greater than 6 feet for any concrete were not permitted, except where suitable equipment was provided to prevent segregation.

After the initial concrete set had occurred, but before the concrete reached its final set, the surfaces of construction joints were thoroughly cleaned to remove all laitance and to expose clean, sound aggregate using the air-water jet. After cutting, the surface was washed and rinsed. All excess water that was not absorbed by the concrete was removed. Construction joints with keyways were cleaned but were not required to be roughened.

Where the use of an air-water jet was not advisable in any specific instance, that surface was roughened by hacking with hand tools or other satisfactory means to produce the requisite clean surface. Horizontal construction joints were covered by a 0.5 inch to 1.0 inch thick layer of sand/cement grout and new concrete was then placed immediately against the fresh grout.

Curing and protection of freshly deposited concrete conformed to ACI 301, Chapter 12.

3.8.1.7.1.8 *Testing.* Concrete testing was conducted upon delivery at the site. All concrete sampling for testing was done in accordance with ASTM C172. Concrete material for preparing compression cylinders and performing slump, air content, concrete temperature and density tests were taken from the discharge end of pipelines or from the discharge chute of the truck mixer if pipelines were not used.

Compressive strength specimens were prepared in accordance with ASTM C31 and tested in accordance with ASTM C39. Six 6-inch diameter by 12-inch long cylinders were prepared at a minimum frequency of every 100 cubic yards placed or fraction thereof per day, for each mix design placed. Two cylinders were tested at 7 days; two cylinders at 28 days, and two cylinders were retained for future testing. If the compressive strengths of the 28 day tests exceeded the design requirements, the remaining cylinders were discarded.

Strengths of concrete were considered satisfactory if the average of any three consecutive strength tests of the laboratory cured specimens at 28 days was equal to or exceeded the specified compressive strength, f'c, of the concrete and if no individual cylinder break result falls more than 500 psi below f'c. Each test result was the average strength of two (minimum) cylinder breaks at 28 days.

Slump, air content, air temperature and concrete temperature were tested (or measured) at a minimum frequency of the first batch and every 50 cubic yards placed per day for each mix design placed. Slump was tested in accordance with ASTM C143. Air content was tested in accordance with ASTM C231. Concrete was rejected unless all specified requirements of slump, air content, and temperatures were met. Unit weight was also tested daily during production in accordance with ASTM C138.

3.8.1.7.2 Reinforcing Steel

3.8.1.7.2.1 *General.* All reinforcing conforms to Grade 60 of ASTM, A615 Standard Specification for Deformed Billet-Steel-Bars for Concrete Reinforcement.

3.8.1.7.2.2 *Placing.* Placing of reinforcing steel conformed to the requirements of Section 5.4.2.2, 5.4.2.4, and 5.5 of ACI 301, *Structural Concrete for B*uildings, and Section 7.5 of ACI 349, *Code Requirements for Nuclear Safety Related Concrete Structures*.

3.8.1.7.3 Dywidag Threaded Rebar Splices

3.8.1.7.3.1 *General.* In the service water tie-in vault #11 reinforcing bars were spliced using the Dywidag threadbar splice in accordance with the instructions for their use issued by the manufacturer, Dywidag Systems International, USA, Incorporated, Lincoln Park, New Jersey.

The ends of the rebars to be joined by the Dywidag splices were sheared or saw cut with a tolerance of 1/8 inch. The ends of the bars were cleaned and deburred to the extent necessary to facilitate threading of coupler and hex nut onto the bar.

All completed splices received a visual inspection for proper installation. A random sample of splices that passed the visual inspection were torque checked.

Splices not properly made or torqued were either retorqued or disassembled, reassembled and retorqued.

3.8.1.7.3.2 *Operator Qualification.* To qualify operators for making Dywidag splices, each operator demonstrated his ability to make an acceptable joint using the Dywidag procedures in accordance with manufacturer's recommendations. Requalification of the operators was not required unless the time limit between production splices or number of incorrect splices exceeded the limits specified in the procedures.

3.8.1.7.3.3 *Tensile Testing.* Tensile testing was performed on sister splices made with straight bars.

The required number of tensile tests were as follows:

1 of first 10 splices

1 of the next 90 splices

2 of the next and subsequent 100 splices

All splices meet the acceptance criteria of ACI 318-83 Section 12.14.3.4 which requires the mechanical splice shall develop in tension or compression, as required, at least 125% of the specified yield strength of the bar.

3.8.2 Containment Structures

See Section 3.8.2.9 for the description of the restoration of the construction opening used for the Reactor Pressure Vessel Head Replacement Project (Unit 2 only).

3.8.2.1 **Physical Description**

3.8.2.1.1 General

For arrangement of the containment structure, see Reference Drawings 3 through 9.

The reactor containment structure is similar in design and construction to that of the Surry Power Station of the Virginia Electric and Power Company, in Surry County, Virginia (Docket Nos. 50-280 and 50-281). It is a steel-lined, heavily reinforced concrete structure with vertical cylindrical wall and hemispherical dome, supported on a flat basemat. Below grade the containment structure is constructed inside an open cut excavation in rock. The structure is rock-supported. The base of the foundation mat is located approximately 67 feet below finished ground grade.

The containment structure has an inside diameter of 126 ft. 0 in. The bend line of the dome is 127 ft. 7 in. above the top of the foundation mat. The inside radius of the dome is 63 ft. 0 in. The interior vertical height is 190 ft. 7 in. measured from the top of the foundation mat to the center of the dome. The cylindrical wall is 4 ft. 6 in. thick, the dome is 2 ft. 6 in. thick, and the basemat is 10 ft. 0 in. thick. The steel liner for the wall is 3/8 inch thick. The steel liner for the mat consists of a 0.25-inch plate, except in the incore instrumentation area, where an exposed 0.75-inch plate is used; the inside recirculation spray pump sumps, where an exposed 0.5-inch plate is used; and the containment drainage sumps, where an exposed 8-inch schedule 40S capped pipe is used. The steel liner for the dome is 0.5 inch thick. A waterproof membrane, as shown on Figure 3.8-2, was placed below the containment structural mat and carried up the containment wall to above ground-water level. Attached to and entirely enveloping the structure below grade, the membrane protects concrete reinforcing from ground-water corrosion, and the steel liner from external hydrostatic pressure.

Access to the containment structure is provided by a 7 ft. 0 in. i.d. personnel hatch and a 14 ft. 6 in. i.d. equipment hatch. Other smaller containment structure penetrations include hot and cold pipes, main steam and feedwater pipes, the fuel transfer tube, and electrical conductors.

The reinforced-concrete structure is designed to withstand all loadings and stresses anticipated during the operation and life of the plant. The steel liner is attached to and supported by the concrete. The liner functions primarily as a gastight membrane, and transmits loads to the concrete. During construction, the steel liner served as the inside form for the concrete wall and dome. The containment structure does not require the participation of the liner as a structural component. No credit is taken for the presence of the steel liner in the design of the containment structure to resist seismic forces or other design loads.

The steel wall and dome liner are protected from potential interior missiles by interior concrete shield walls. The basemat liner is protected by a 21- to 30-inch-thick concrete cover, except in the incore instrumentation area, the inside recirculation spray pump sumps, the containment drainage sumps, the low end of the containment sump trench, where the slope results in a minimum of approximately 12 inches of concrete cover, and the bottom of the containment sump.

3.8.2.1.2 Construction Procedure and Practice

3.8.2.1.2.1 *Preparation of Excavation.* After performing the general excavation, the circular excavation for the containment structures was taken to approximately Elevation 204 feet to found the containment mat on fresh, crystalline, metamorphic rock. The sidewall of this excavation was presplit and the interior rock excavated under rigid control, using careful blasting procedures. Explosive charge weights per delay and per shot were controlled to ensure a minimum of disturbance to rock outside the excavation limits. To ensure stability of the excavation, the sidewall was reinforced, as required, with ungrouted rock bolts and reinforced gunite. As an additional precaution, grouted rock bolt reinforcement was installed in the sidewall of the containment structure excavation, where the adjacent fuel and auxiliary building fuel structures are founded directly on the surrounding rock. This reinforcement provided an additional factor of safety against loosening of the rock along joint or foliation planes during the construction period. The details are shown on Figure 3.8-2.

The bottom of the containment structure excavation was thoroughly cleaned, and a 6-inch layer of porous concrete was placed directly on this prepared rock surface. Porous concrete is discussed in Section 3.8.2.7.4. To prevent clogging of this construction drainage layer, its surface was sealed by screeding and slush grouting. A waterproof membrane was laid directly on this construction drainage layer and covered with a second layer of porous concrete 4 inches thick. Waterproof membrane is discussed in Section 3.8.2.7.5. The surface of this drainage layer was also screeded and slush grouted to minimize clogging during placement of the mat reinforcing steel. The vertical surface of the lower 10 feet of the containment excavation was brought to a smooth, even surface with fill concrete, to which the waterproof membrane was applied. The inner face of the vertical membrane was covered with a layer of 4-inch concrete block, to serve as both protection for the waterproof membrane, and as drainage. The exposed surface of the completed membrane at the top of the foundation mat was covered with concrete backfill to provide protection. If necessary, drainage of the upper 4-inch-thick layer of porous concrete will be accomplished by permanent pumps. The membrane generally extends to 6 inches below ground grade.

After the porous concrete and concrete block was placed to protect the waterproof membrane, the reinforcing for the foundation mat was placed as described in Section 3.8.2.7.2. The concrete of the mat was cured by ponding water above the surface.

Steel bridging bars described in Section 3.8.2.1.4 and other miscellaneous steel inserts were set and cast in the concrete mat during the mat construction.

Before applying the vertical membrane, the concrete surfaces were worked as necessary to remove all fins, projections, and loose materials. Tie-bolt holes and other voids were filled to provide a smooth backup surface.

A 2-inch layer of compressible material was then placed against the waterproof membrane on the containment wall, up to the elevation where concrete backfill was discontinued, to isolate the containment structure from adjacent concrete backfill. Compressible material is discussed in Section 3.8.2.7.7. Concrete backfill was placed in the annular space between the compressible material and the vertical line of rock excavation to support the wall of the excavation with a compression ring structure, preventing any movement or yielding of the material adjoining the excavation under the surcharge of structures adjacent to the containment. Concrete backfill is discussed in Section 3.8.2.7.8. This fill extends upward to the underside of adjacent foundations or to the top of the rock surface at approximately Elevation 246 feet.

3.8.2.1.2.2 *Liner Erection.* Erection of the steel liner followed the completion of the concrete mat. The 3/8-inch-thick steel wall liner was erected to the bend line. The 0.25-inch-thick mat liner plate was installed on top of the concrete mat during this period. On completion of the wall liner to the bend line, and completion of the mat liner, all welds were checked for compliance with the approved weld inspection and gas test requirements. The containment interior concrete structure was built, and the polar crane erected, during the construction of the wall liner. Construction of the exterior concrete wall to approximately finish ground grade followed completion of the wall liner.

The liner was then completed, finishing with the construction of the 0.5-inch-thick steel dome, with all welds inspected and gas tested.

The completed steel wall liner was braced to prevent distortion during concrete placement. The exterior concrete forms were supported from the preceding concrete using cantilever formwork and strongbacks.

Cantilevered steel strongbacks were used in the construction of the concrete dome to support the steel dome liner, reinforcing steel, formwork, and wet concrete against deformation. Strongbacks were cantilevered from the completed concrete of the wall or the dome.

3.8.2.1.2.3 *Concrete Placement.* In general, concrete in the wall and dome of the containment structures was placed in uniform 6-foot lifts around the entire circumference. Each lift was deposited in approximately 18-inch layers at such a rate that concrete surfaces did not reach their initial set before additional concrete was placed. See Section 3.8.2.9 for the description of concrete placement for the Reactor Pressure Vessel Head Replacement Project.

Concrete forms were used on the exterior of the concrete dome to a line approximately 50 degrees above the horizontal plane at the bend line. The permanent steel liner served as the inner form for concrete placement.

Concrete was placed in the containment mat and walls by bottom dump buckets, belt conveyor, or by pumping. Prior to the placement of concrete in the mats, walls, and dome of the containment structure, the procedure for placing this concrete was reviewed and approved by the Stone & Webster Engineering Corporation structural engineer. In cold weather, the concrete temperature was maintained at the temperature recommended in Table 1.4.1 of ACI 306, and for the number of days recommended by Table 1.4.2. In hot weather, the concrete was delivered to the form with a maximum temperature of 70°F. Generally, most concrete as placed was at approximately 65°F. This was effected by using chipped ice in the concrete mix during hot weather.

All concrete samples for testing were taken at the point of placement, if feasible.

3.8.2.1.2.4 *Reinforcing Steel Placement.* The foundation mat of the containment structure is reinforced with both top and bottom layers of reinforcing. Bottom mat reinforcing was placed in a rectangular grid pattern with layers at 90 degrees to each other. Reinforcing for the top of the mat consists of concentric circular bars combined with radial bars. The reinforcement pattern for the top of the mat is arranged to permit a uniform spacing of the vertical wall rebars that extend into the mat. Splices in adjacent parallel rebars in the mat are in general not less than 4 feet apart.

Hoop tension in the cylinder is resisted by horizontal bars located near both the outer and inner surfaces of the wall. All horizontal circumferential bars, including those in the dome, have their joints staggered a minimum of 3 feet.

See Section 3.8.2.9 for the description of the splicing scheme used for the Reactor Pressure Vessel Head Replacement Project.

Longitudinal tension in the cylinder wall is resisted by two groups of vertical bars, one near the interior face and the other near the exterior face of the wall. Vertical bars are placed in three groups of 20 bars of equal length along the circumference. These are arranged so that no adjacent group in the same or opposite face of the wall will have splices closer than 6 feet vertically. The dome reinforcing consists of layers of rebar placed meridianally, extending from the vertical reinforcing of the cylindrical wall and horizontal layers of circumferential hoop bars. Layers are located near both the inner and outer faces of the concrete. The radial pattern of the meridianal reinforcing steel terminating in the containment dome results in a high degree of redundancy of reinforcing steel in the dome. Bars are terminated beyond a point where there is more than twice the amount of steel required for design purposes. The rate of convergence of these bars and low stress requirements dictated by the arrangement produces a relatively low bond stress. In a limited number of cases where bars are terminated close to the center of the dome, anchorage stresses are more critical, and bars are hooked to provide the required anchorage. Near the crown, the meridianal rebars were welded to a concentric steel ring cast in the concrete.

Radial shear loads generated by internal pressure resulting from the design basis accident are primarily resisted by shear assemblies, i.e., 4-inch x 0.75-inch flat bars, inclined at 45 degrees with the horizontal, and welded to the surfaces of an additional layer of vertical reinforcing in the interior face, and vertical reinforcing in the exterior face of the cylinder wall. This radial shear varies from a maximum at the base of the wall, where the foundation mat restrains the independent movement of the wall, to zero at some level above the mat. Four-foot-long deformed bar anchors are welded perpendicular to the surface of the liner to prevent splitting between the two layers of vertical reinforcing in the interior face in this region. Conventional bent bars are also used to resist radial shear loads, but only in areas of diminished shear intensity.

The tangential shears resulting from the earthquake loadings will be resisted by a combination of rebars inclined at approximately 45 degrees in each direction in the plane of the wall parallel to the main reinforcing steel, and by aggregate interlock. Minimum concrete cover for all principal reinforcing steel of the containment structure exceeds the requirements of ACI 318, paragraph 808(d), which states, “Concrete protection for reinforcement shall in all cases be at least equal to the diameter of the bars.” The largest and principal reinforcing bar is a No. 18, which would, therefore, require a minimum cover of only 2-3/8 inch by the code.

Figure 3.8-3 shows a typical detail of reinforcing steel in the foundation mat and base. Figure 3.8-4 shows a typical detail of the dome/cylinder junction. Figure 3.8-5 shows the detail of the concentric steel ring embedded in the concrete at the apex of the dome.

Figure 3.8-6 shows diagonal rebars in the containment cylinder. The diagonal reinforcement indicated is based on the recommendations contained in Report SWND-5, *Design of Orthogonally Reinforced Concrete Nuclear Containment Shells for Local Membrane Shear Resistance*, by M. J. Holley, Jr., and *Behavior of Precracked Concrete Subjected to Reversing Shearing Stresses*, by R. N. White, and modifications of their recommendations at meetings with the technical staff of the DRL on other projects on January 20, 27, 28, February 22, and March 18, 1970. The reinforcing shown is predicated on furnishing sufficient diagonal reinforcing to resist the tangential seismic shears induced by the design-basis earthquake, which are in excess of the maximum shear induced by 1.25 times the operational-basis earthquake. It is assumed that aggregate interlock resists the seismic shear induced by 1.25 times the operational-basis earthquake. Computations assume that the concrete has been precracked by the pressure resulting from the design basis accident. The computations ignore all dowel action from the orthogonally placed vertical and horizontal rebars, and assume that the liner does not assist in resisting pressure or seismic effects.

3.8.2.1.3 Ground-Water Corrosion Protection

The ground-water elevation external to the membrane protection of the exterior surfaces of the containment structure will probably be several feet higher than the level of Lake Anna, normally at Elevation 250 feet In the unlikely event that water penetrates or otherwise circumvents the membrane, it will drain to a layer of porous concrete directly below the mat and inside the membrane. This 4-inch-thick layer of porous concrete serves as a horizontal drain under the entire structure. The porous layer is vented by four 10-inch-diameter pipe sleeves that extend from the underside of the mat into two access shafts adjacent to the outside of the containment structure. These shafts are inside the waterproof membrane, and house permanent pumps operated by level control switches. Access is from ground level. Drainage past the vertical edge of the mat is assisted by a layer of 4-inch-thick concrete masonry blocks placed against the inside surface of the membrane.

Cathodic protection is not provided, since adequate corrosion protection of the embedded reinforcing is otherwise provided. Research by the National Bureau of Standards (Reference 2) and others (References 3 & 4) indicates that cathodic currents damage the bond between the reinforcing steel and concrete. This bond softening is due to the gradual concentration of sodium and potassium ions. In time, the alkali concentration becomes strong enough to attack the steel.

The surface of the steel liner in contact with concrete is not subject to corrosion because of the alkaline nature of the concrete, and therefore has no other protective coating.

3.8.2.1.4 Containment Liner

3.8.2.1.4.1 *Physical Description.* The containment liner includes the liner plates, penetrations, insert plates, anchors, and access openings. Detailed illustrations of the steel liner and penetrations are shown in Figures 3.8-7 through 3.8-15.

Liner Plate

The liner plate is a continuous steel membrane supported by and anchored to the inside of the primary containment structure.

The basic shape of the liner plate consists of a cylindrical portion attached to a skirt anchored at its base to the foundation mat. The liner plate cylinder is closed at the upper end with a hemispherical dome.

The cylindrical portion of the liner plate is 3/8 inch thick, the hemispherical dome liner plate is 0.5 inch thick, and the flat floor covering the mat is 0.25 inch thick, with the exception of areas where the transfer of loads requires a reinforced thickness.

The 0.25-inch-thick floor liner plates were assembled in place and continuously welded at their periphery to cruciform steel inserts, which are cast in the reinforced concrete basemat (Figure 3.8-7).

The 3/8-inch-thick liner plate served as the internal form for the concrete containment during construction. All liner seams are double butt welded or equal full penetration joint. Two materials are used for the liner plates. SA-537 Grade B, quenched and tempered, is used for the first 28 ft. 5 in. above the mat, and SA-516 Grade 60, fine-grained and normalized, is used for the rest of the cylinder, the dome, and the mat liner. See below for liner plate materials used for repair.

All welded seams in the mat, cylindrical liner wall, hemispherical dome, and liner penetrations are covered with continuously welded test channels except for the welded seams of local repair areas. These channels are zoned into test areas by dams welded to the ends of the sections of the channels. The channels are used to check tightness of welds during liner erection to ensure that the overall leak rate test requirement is met on completion. However, should the overall leak rate exceed specification in initial or periodic tests, the channels may be used to assist in locating the source of leakage. Typical liner plate details are shown in Figure 3.8-8.

Since the containment liner is covered on the exterior with concrete, repair methods may differ somewhat from original construction. Repairs to the liner are made from the containment interior using full penetration welds and SA/A-516 Grade 60, 65, or 70, fine grained and normalized material. A local pressure test and/or Containment Type A test is performed on completed repair welds to verify leaktight integrity.

All bolted closures are double gasketed, with means for introducing a pressurized gas between the gaskets so that the closures may be examined for leaks.

The steel containment liner is anchored to the concrete wall and dome with steel anchor studs and deformed anchor bars. In addition to the concrete stud anchors, the wall and basemat section are anchored and joined at the intersection of the vertical wall and the basemat with a steel skirt embedded and anchored in the concrete, as shown in Figure 3.8-9.

For missile and thermal protection, the bottom liner plate is overlaid with a reinforced-concrete slab approximately 2 feet thick. This slab is anchored to the bottom concrete mat through the steel liner, except at the incore instrumentation area and the sump areas. In these areas, the mat liner is not covered with concrete. The plates are 0.75 inch thick to compensate for the lack of a concrete covering in the instrumentation area. Gratings are used to protect the sump areas.

The concrete slab covering the floor liner plate is anchored through the steel liner plate by 7-inch x 0.5-inch bridging bars, as shown in Figure 3.8-7. These bars form an integral part of the steel liner, and conform to the material and workmanship specifications of the steel liner.

Bridging bars, shown in Figure 3.8-10, are welded through the floor liner plate where transfer of loads through the floor is required. Vertical reinforcing steel bars are welded to the top and bottom of the 3-inch side, thus providing bar continuity without creating multiple penetrations through the liner.

Penetrations

Penetrations are used to carry piping, mechanical systems, and electrical services through the containment walls. These penetrations can be classified as follows:

1. Piping systems - Two basic types of penetrations are used for piping systems:

   a. Unsleeved - These penetrations consist of piping installed through the containment wall without a sleeve around the outside of the piping. Unsleeved penetrations are used for cold piping systems (temperature of the fluid in the piping is less than 150°F) when only one pipe passes through the penetration.

   b. Sleeved - These penetrations have a sleeve around the outside of the piping. Sleeved penetrations are used for all multiple piping systems passing through one penetration and for all thermally hot (over 150°F) piping systems, both single and multiple. Typical piping penetrations are shown in Figure 3.8-11.

2. Mechanical system

   a. Fuel transfer tube enclosure - A fuel transfer tube enclosure is provided for the fuel transfer tube, which connects the refueling canal in the containment structure and the spent-fuel pit in the fuel building. The penetration consists of a stainless steel pipe installed inside a sleeve, as shown in Figure 3.8-11. The fuel carriage rides on rails inside the inner pipe. The outer pipe is welded to the containment liner, and compensates for any differential movement between the two end points and between the two pipes. The outer pipe, called the enclosure, has provisions for Freon gas leak-testing of all welds essential to the integrity of the penetration.

3. Electrical service penetrations - There are approximately 120 electrical penetrations through the containment. They are spaced 2 feet apart on centers, in an arrangement shown in Figure 3.8-12 and Reference Drawing 13. Penetrations used for redundant channels are separated by at least one other penetration and, hence, are a minimum of 4 feet apart. The cables, upon leaving the penetrations, enter a terminal box or conduit for maintaining separation, and then enter the cable trays. No piping is located in or near the penetration area on the cable vault side. The reactor containment side penetrations are separated from the piping by a checkered plate platform. Protection against internal missiles is provided by (1) separation of redundant vital components, (2) use of missile shielding, (3) location and orientation of potential missile sources, and (4) conservative design of pressurized components that may become missile sources. The penetration area is separated from the main containment area by the crane wall, which is designed to provide missile protection for components outside the crane wall.

   Provisions have been made for fire detection and protection for the electrical penetrations, as described in Section 9.5.1.

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Should an explosion occur, the force will be directed outward in a line perpendicular to the plane of the cable trays. The rating of the sleeves or flange of the penetration is designed to prevent the generation of a missile, but, if one is generated, the arrangement of the trays will limit the damage to one cable tray and to one channel, due to the separation criteria applied.

All cable insulating and jacketing materials used in these areas were specified and tested to ensure that they are flame-retardant and nonpropagating. Fire protection and detection equipment, including smoke detection apparatus, is installed as well.

Should a fire develop at a penetration or in a cable tray, it would be limited to the one penetration or tray, since there are no combustibles in the areas to sustain a fire and cause it to spread, and the cable itself is flame-retardant and nonpropagating. In addition, the fire detection and protection equipment would ensure prompt corrective action to minimize the duration and effects of a fire.

Electrical conductors penetrating the containment structure range in size from those used for thermocouple leads to those used for 4160V power circuits. Each penetration group passes through an 8-inch- or 12-inch-diameter steel sleeve. The sleeves are welded into the containment liner with a test channel around the weld for leak testing, as shown on Figure 3.8-13.

The electrical penetrations are shown on Figure 3.8-13, and generally consist of an 8-inch or 12-inch steel sleeve with bolted-on flanges. The penetrations are of three basic types: medium voltage, triax, and low voltage, control, and instrumentation. The medium voltage type consists of a sleeve with a flange at each end and bushing for connections. The triax type is a canister consisting of a flange on the cable vault side through which passes the connector for the triax cable and a moisture-resisting connector that is supported on the containment side. The remaining types are canister type, with one flange on the cable vault side through which pass conductors embedded in a resilient sealant matrix encased in compression fittings. Tests were performed in the factory and after installation to ensure complete leaktightness.

Each penetration is held in place with bolts that draw each flange against a sealing o-ring. An electrical connector may be replaced, if necessary, without welding or cutting of the containment liner or sleeve.

Connections for pressurizing each electrical penetration, and a pressure gauge for monitoring the degree of pressurization, are provided. During plant operation, the penetrations will normally be pressurized a few psi above atmospheric. The pressurization and pressure gauge installations assist in the early detection and repair of leaking penetration.

Electrical penetrations meet the requirements of IEEE 317-1971, *IEEE Standard for Electrical Penetrations Assemblies in Containment Structures for Nuclear Fueled Power Generating Stations*, with the exception of the installation leak test, which will be in accordance with the method described in Section 6.2, meeting Appendix J requirements.

Secondary overload protection has been installed in circuits associated with the Unit 2 Containment electrical penetrations to meet the requirements of condition 2.C(10) of Operating License NPF-7, Position C.1 of Regulatory Guide 1.63, Revision 2, July 1978, *Electric Penetration Assemblies in Containment Structure for Light-Water-Cooled Nuclear Power Plants*, and subsequent correspondence between the Nuclear Regulatory Commission and Virginia Electric and Power Company. The addition of secondary overload protection devices to all normally-energized power and control circuits which enter the Unit 2 Containment Building will adequately protect the mechanical integrity of the electrical penetrations (see Reference 33) in the event of the short-circuit current versus time condition that may occur, given a single random failure of the circuit’s overload protective device. Secondary overload protection to instrumentation circuits entering the Unit 2 Containment Building are not provided, since their maximum short-circuit current versus time condition will not exceed the rating of their electrical penetration assemblies. This exemption is also taken for control circuits which are self-protecting by the added impedance of the control loop offered by the length of the intervening cable. The postulated short circuit current at the entrance of the electrical penetration is limited by the total loop length of the circuit to a value that is less than the ampacity of the penetration feed-through.

The secondary overload protection devices, consisting of either circuit breakers, fuses, overload relays, or additional protective relays, are installed in series with existing overload protection devices in all normally-energized power and control circuits entering the Unit 2 Containment Building. Their function is to de-energize the circuit in the event of a short-circuit current versus time condition which may damage the mechanical integrity of the electrical penetration assembly.

Access Openings

The containment structure contains the following access openings:

1. Equipment hatch - The equipment hatch is mounted in the containment wall, as shown in Figure 3.8-14. This hatch has an inside diameter of 14 ft. 6 in. It is equipped with one hatch cover mounted on the inside of the containment structure.

2. Personnel air lock - A personnel air lock is installed for entry into the reactor containment structure. The personnel air lock has an inside diameter of 7 ft. 0 in., with hatch covers at both ends. It is installed in the containment wall as shown in Figure 3.8-14.
3. Dome ventilation opening - A dome ventilation opening for use during construction is installed at the apex of the containment structure, as shown on Figure 3.8-5. The dome ventilation opening has a hatch cover located on the outside of the containment, and is filled with concrete.

Insert Plates

Steel insert plates are used in the liner plate to attach brackets for the support of equipment such as the quench spray piping and headers.

Anchors

Steel anchors are provided to attach the liner plates and the insert plates to the concrete containment structure.

3.8.2.1.4.2 *Functional Design Bases - Liner Plate.* The liner plate acts as a gastight membrane under any one of the conditions that can be encountered throughout the operating lifetime of the station. The liner plate is designed to resist all direct loads and accommodate deformation of the concrete containment without jeopardizing its leaktight integrity. It is anchored to the concrete at close intervals so that the overall deformation of the liner will be essentially the same as that of the concrete containment.

The skirt-to-liner juncture and the skirt-to-mat anchorage is proportioned to develop the full strength of the liner. Under DBA conditions, the liner will be under a state of biaxial compressive strain due to thermal effects. During containment leakage and structural test conditions, the liner plate is under a state of biaxial tensile strain.

Penetrations

1. Piping system penetrations - All containment piping penetrations are anchored to the reinforced-concrete containment wall so that loads can be transferred from the piping to the reinforced concrete.
   a. Unsleeved penetrations - The pipes are welded to reinforcement plates, as shown in Figure 3.8-11, anchored to the concrete wall. This type of penetration is used for single pipes carrying cold fluids.
   b. Sleeved penetrations - An attachment plate joins the sleeve with the piping, as shown in Figure 3.8-11. The sleeve is welded to reinforcement plates anchored to the containment reinforced concrete so the piping loads can be transferred to the containment wall. The sleeved piping penetration is used for all penetrations carrying multiple pipe lines, and for piping systems carrying thermally hot (over 150°F) fluids.

Thermally hot pipes are insulated to prevent the temperature of the concrete adjacent to the sleeve from exceeding 200°F. Two water-cooled cooling units were originally installed on the sleeve for thermally hot penetrations in which the insulation alone would not be sufficient to maintain the concrete below 150°F. One cooler is located on the inside of the penetration (inner unit), encompassing the full length of the sleeve, and the other is located on the outside of the sleeve near the liners. The outside (outer) cooler has been removed on hot pipe penetrations. The outside cooler was not removed from installed spare penetrations with coolers. These coolers have been removed from service.

The CC System supply and return connections to the outer penetration coolers have been sealed as shown in Figure 3.8-15 for all ten Unit 1 and 2 thermally hot penetrations (1-PEN-PN-28, 39, 40, 41, 73, 74, 75, 76, 77, 78, and 2-PEN-PN-28, 39, 40, 41, 73, 74, 75, 76, 77, and 78).

Cooling water supply and return header piping has been cut and capped for all active hot pipe penetration coolers. The inner coolers have been isolated, drained and dried to eliminate/minimize any active corrosion mechanism. Analyses have been performed which demonstrate the concrete temperature will remain below the allowable temperature of 200°F. Cooling water to the coolers is no longer required.

2. Mechanical system penetration - The outer enclosure of the fuel transfer tube consists of sections of cylinder connected by bellows. There are two main requirements for this structure: (1) the bellows are designed to accommodate the maximum deflections, including offset between the spent-fuel pit in the fuel building and the refueling canal in the containment structure; (2) the entire structure is a part of the containment, and can withstand external pressure and temperature during the test and emergency (DBA) conditions.

   The bellows were selected on the basis of deflections caused by thermal expansion, seismic motions, and radial movement of the containment building wall due to internal pressure and temperature.

3. Electrical penetrations - Electrical conductors penetrating the containment structure range in size from No. 16 AWG thermocouple leads to 1000 MCM conductor for 4160V power circuits. Each penetration assembly passes through 8-inch or 12-inch steel pipe sleeves. The sleeves are welded into the containment liner plates with a leak test angle around the inner reinforcement plate and a leak test channel around the flange seal weld, for leak testing after installation. The assemblies are constructed to withstand DBA and seismic conditions and, where required, short-circuit forces.

   The flanges with the electrical feedthroughs are held in place with bolts that draw each flange against o-ring seals in a flange welded to the sleeve. Each flange is tapped for leak testing between the o-rings, and can be tested for leakage as required by the Technical Specifications.

Access Openings

1. Equipment hatch - The equipment hatch is a single closure hatch with an inside diameter of 14 ft. 6 in., as shown in Figure 3.8-14. The hatch cover is double gasketed with a leakage test tap between the o-rings. The enclosed space between the o-rings can be pressurized to containment design pressure to test for leakage when the access door is bolted in place. The equipment hatch cover is provided with a hoist with two-point suspension and a sliding rail for storage. A concrete tornado missile shield protects the equipment hatch.

   The equipment hatch includes a 5 ft. 9 in. inside diameter emergency personnel escape lock, as shown on Figure 3.8-14. The emergency personnel escape lock is a double closure penetration, and incorporates features used in the 7-foot personnel air lock. The escape lock is attached to the equipment hatch head by double gasketed bolted flanges. Test taps for conducting leakage measurements are provided.

2. Personnel air lock - The personnel air lock is a double closure penetration. It has an inside diameter of 7 ft. 0 in., as shown on Figure 3.8-14. Each closure head is hinged and double gasketed, with a leakage test tap between the o-rings. The enclosed space between the o-rings can be pressurized to containment design pressure to test for leakage through the access door when it is locked in place. The personnel air lock can be independently pressurized up to containment design pressure for testing. Both doors are hydraulically latched. Both doors are interlocked so that, if one door is open, the other cannot be actuated. Each door is furnished with a pressure-equalizing connection. The equalizing valves are manual or push-button operated by the person entering or leaving the personnel air lock. The interior door of the lock can be remotely closed from outside the containment structure.

3. Dome ventilation opening - A ventilation opening is provided at the containment dome apex.

   A conical cap protects the junction between the concrete and sleeve ring from rain water seeping in.

   The welded upper closure plate protects the opening itself from inclement weather. This opening is primarily for use during the construction period.

Insert Plates

All major mechanical loads generated within the containment, except pipe loads at containment wall penetrations, are carried by the internal concrete structures. The loads derived from the support of quench spray piping next to the liner wall are transferred to the containment concrete wall through insert plates and their anchors. The anchors are designed in number and size to be within the limits specified for the anchors in Table 3.8-7. The thickness of the insert plates provides a rigid base for the attached studs and pipe supports.

Sufficient anchorage is provided so that the liner plate adjacent to insert plates is isolated from loads applied to brackets or attachments, and leaktight integrity is maintained.

Anchors

The steel containment liner is anchored to the concrete wall and dome with concrete anchor studs. The anchorage layout is in a diamond pattern. The location tolerance of each stud is 1.5 inch in any direction from its theoretical location, as dimensioned on the erection drawings, to clear possible interferences with reinforcement bars or other embedded parts.

To verify the capabilities of the anchor studs, tests were conducted at Northeastern University, Boston, Massachusetts, using 5/8-inch-diameter studs and 3/8-inch-thick plate. These tests showed that shear failure occurs in the stud adjacent to the weld connecting the stud to the plate. In no instance was the plate damaged. Tests conducted by one stud manufacturer indicate that, with the manufacturer's recommended depth of embedment of the stud in concrete, the ultimate strength of the stud material can be developed in direct tension.

3.8.2.1.4.3 *Applicable Codes.* The ASME Boiler and Pressure Vessel Code, Section III, Nuclear Vessels, was used as a guide in the selection of materials and fabrication of the steel containment liner. Liner plates conform to the respective requirements stated in ASTM Standards, 1969 revisions.

There were no applicable codes for the design of concrete containment liners. However, ASME Sections III and VIII, with Code Addenda through summer 1969, were used as guides to develop the load combinations, load categories, and design allowables (Tables 3.8-7 and 3.8-8). Compliance with applicable AEC Safety Guides is described in Appendix 3A.

Documents related to the Quality Assurance Program are contained in Chapter 17.

The personnel hatch is designed, fabricated, tested, and stamped in accordance with the ASME Boiler and Pressure Vessel Code, Section III, Class B, Nuclear Vessels, 1968.

The piping system penetrations are designed, fabricated, and stamped in accordance with the Nuclear Power Piping Code, USAS B31.7-1969.

Brackets and attachments are designed and constructed using industry-accepted techniques such as the AISC Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings, February 12, 1969.

3.8.2.1.4.4 *Load Combinations - Liner Plate.* The containment liner plate was designed for the load combinations presented in Table 3.8-7.

Regulatory Guide 1.46, *Protection Against Pipe Whip Inside Containment*, position C.3.b, indicates that piping 1 inch in diameter and less does not require postulation of high-energy pipe break. Therefore, no specific mathematical analysis has been performed to calculate adequacy of the exposed liner plate to a postulated incore instrumentation tube rupture. It is considered that tubing of this size and wall thickness would cause no hazard to the liner, which is greater in thickness and is buttressed by many feet of concrete.

Penetrations

1. Piping system penetrations - The load combinations used for both sleeved and unsleeved penetrations are listed in Table 3.8-8.

   The penetration load combinations include pipe internal design pressure and temperature, plus M or T, where M and T are the bending and torsional moments that would cause the attached pipe to yield fully across the entire cross section. Each penetration assembly is designed to withstand these loading combinations within the limits set by ASME Section III.

   Whether the source of the penetration loading is a normal, seismic, or pipe rupture force, the defined criterion considers the maximum loading that the attached pipe can transmit to the penetration, regardless of the source of loading. Therefore, no separate calculation of seismic forces is needed.

2. Mechanical system penetration - fuel transfer tube enclosure - As described in Section 3.8.2.1.4.2, the significant design loads include the external loads due to containment test pressure, design pressure and temperature effects, and seismic loads.

Access Openings

Access openings are designed for the load combinations presented in Table 3.8-7.

Insert Plates

The mechanical loads for the insert plates are derived from pipe support analysis for the quench spray subsystem. Load combinations for piping subsystems are contained in Section 3.7.3.

Anchors

Anchors are designed for the loads given in Table 3.8-7.

3.8.2.1.4.5 *Analytical Techniques.* The computer programs are explained in more detail at the end of this section. Certain portions of these computer programs are considered proprietary to Stone & Webster Engineering Corporation.

Liner Plate

The containment liner plate was analyzed using the computer code, *Stress Analysis of Shells of Revolution*, for orthotropic shells axisymmetrically loaded. Included in the analysis are the effects of the reinforced-concrete wall, dead weight, internal pressure, and temperature.

The junction of the mat liner and wall liner was analyzed with the computer code SHELL 1.

Allowable seismic stresses in the liner are given in Table 3.8-7 for the DBE loads. The maximum seismic loads were determined from the seismic analysis of the containment building, as described in Section 3.8.2.4. In this analysis the total wall loads are calculated. Manual calculations were then performed on the total wall loads to determine what percentage of these loads is seen by the liner.

In cases where a shear stress and membrane stresses occur concurrently, principal stresses were determined manually using the Mohr's circle equation for stresses.

Penetrations

1. Piping System Penetrations

   a. Unsleeved - The basic sizing of these penetrations was done manually for the load combinations of the design conditions in Table 3.8-8. There are no attachment plates or sleeves for these pipes. For evaluation of the pipes, refer to Section 3.7.3.1.

   b. Sleeved - The basic sizing is the same as for the unsleeved penetrations, with the added computations for the sleeve and the attachment to the plate.

      Some of the penetration sleeves operate at temperatures above 150°F. Penetrations with process fluids operating above 150°F have been analyzed using heat balance methodology and conservation of energy to establish that the concrete surrounding the penetration does not exceed the Construction Code allowables (200°F). These penetrations have also been analyzed using strength of materials methodology to establish their structural adequacy at temperatures up to the design temperature of the process fluid.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

The thermal analysis of the pipe, attachment plate, and sleeve was done by a heat balance computer code.

The analytical evaluation of the penetration discontinuities was done using the computer code SHELL 1, a Stone & Webster proprietary computer program that analyzes axisymmetric thin shells of revolution under symmetric and unsymmetric loading.

SHELL 1 was used to analyze the combined effects of pressure and temperature and to determine the stresses.

2. Mechanical system penetration - fuel transfer tube enclosure - The enclosure is designed for external pressure using the technique described by ASME Code, Section III, 1968. The largest external pressure is the containment test pressure.

   The most critical parts of the enclosure, the bellows assemblies, are designed for the maximum deflections expected between the two anchored ends. These deflections include seismic, pressure, and thermal expansion effects. Experience has shown that bellows must be selected on the basis of experiment as well as analysis. Consequently, the techniques were derived from the manufacturers, combining deflections and conditions as defined in Section 3.8.2.1.4.2.

3. Electrical penetrations - There are two main groupings of penetrations, from a gross structural standpoint: the medium-voltage power (MVP) type, which have canister tubes, and the LVP (containing low-voltage power, instrumentation, triax control), which do not have canister tubes.

   Stress analysis was performed on one MVP type and two LVP types, penetrations with center feedthrough support plates, and those without support plates. Penetrations without support plates were further broken down into categories based on feedthrough sheath size, for which worst-case stresses were calculated. Design conditions were based on DBA pressure and temperature.

   For purposes of seismic analysis, MVP types were treated as fixed-end, supported-end beams, combining steady-state and seismic loads. LVP types were treated as uniformly loaded, single-span, fixed-end beams. Each type was analyzed combining steady-state and seismic loads. All stress levels were calculated on maximum load basis, even where qualified for reduced loading.

Access Openings

Access openings were analyzed by the computer program SHELL 1, which includes the effects of the concrete as well as containment pressure and temperature.

Insert Plates

Pipe supports are welded to the insert plates. The loads determined from the pipe system analysis were manually transferred to the anchor studs for each insert plate. Table 3.8-7 gives the anchor allowables for general liner conditions. These are also applied to the maximum anchor stresses calculated for the insert plates.

The pipe supports, including the attachment point to the insert plates, were analyzed for stresses along with the piping system, and are not included in the liner analysis.

Anchors

Anchors for the 3/8-inch and 0.5-inch liner plates are exposed to the following loading conditions: (1) the containment is under vacuum, and this negative pressure times the pitch area of influence of that stud is applied to the anchor as a tensile load; (2) the containment is under the consequences of the design basis accident with the studs at the lower edge of the liner subjected to a shear load derived from the liner computer evaluation mentioned above. The stud anchors are designed for both loading conditions. The resultant shear due to earthquake results in negligible loads on the anchor studs.

Since the forces associated with the emergency condition are compressive, the anchor studs are spaced throughout the liner wall and dome to prevent buckling. Pitch dimensions were determined by the procedure set forth in the text by Timoshenko and Genes, *Theory of Elastic Stability*, for a cylindrical shell under combined axial and uniform lateral pressure.

Compressive forces that tend to buckle the liner were obtained from the liner plate analysis and were transformed into the axial load and lateral pressure required by the referenced text.

The following paragraphs describe the computer codes mentioned in this section.

Stress Analysis of Shells of Revolution (References 5 and 6)

This is a finite element computer code. It can be used to determine the forces, moments, shears, displacements, rotations, and stresses in a thin shell of revolution subject to axisymmetric loads. Different orthotropic material properties may be input for each element in a model. The allowed types of loading include internal pressure, temperature changes that may have a gradient through the shell thickness, and simplified input for weight of the shell.

The explicit stiffness relations for the axisymmetric shell elements are based on the classical theorem of potential energy and the usual approximations of thin-shell theory. The direct stiffness method (a simple modification of the displacement method) is used to assemble the equilibrium equations. The algorithm used to solve these equations is derived by applying the Gause-Jordan method of elimination to a tridiagonal system of equations.

SHELL 1

This is a finite difference stress analysis computer code. It can be used to determine the forces, moments, shears, displacements, rotations, and stresses in a thin shell of revolution subject to arbitrary loads expanded in Fourier Series of up to 150 terms. Single-layer shells with up to 30 simply-connected branches may be analyzed. Poisson's ratio may change at discontinuity points, and Young's modulus and the thermal coefficient of expansion may be different at each point. The allowed types of loading include elastic restraints, pressures in three orthogonal directions, temperature changes that may have a gradient through the shell thickness, and simplified input for weight of the shell or earthquake forces.

The equilibrium equations for a thin shell are based on the linear theory of Sanders (Reference 7). Sander's equations are expanded and modified slightly to handle a broader range of problems (References 8 & 9). All pertinent load, stress, and deformation variables are expanded into Fourier Series. The individual Fourier components of stress and deflection are found separately by solution of the finite difference forms of the appropriate differential equations. The algorithm used to solve these equations is a minor modification of the Gaussian elimination method.

3.8.2.1.4.6 *Design Allowables - Liner Plate.* The liner was designed to meet the allowables presented in Table 3.8-7.

Penetrations

1. Piping system penetrations - Table 3.8-8 contains the allowables that were used for the evaluation of the sleeved and unsleeved penetrations.

2. Mechanical system penetrations - fuel transfer tube enclosure - The outer sleeve of the fuel transfer tube meets the external pressure requirements for thickness set by ASME Section III. The bellows are designed to accommodate the maximum deflections calculated for the fuel and reactor buildings at the tube attachment points.
3. Electrical penetrations - No stress levels were found to exceed the allowable 90% of yield strength.

Access Openings

The access openings are designed to meet the allowables presented in Table 3.8-7.

Insert Plates and Anchors

The stresses for the concrete anchors that are attached to both the liner plates and the insert plates meet the allowables listed in Table 3.8-7.

3.8.2.1.4.7 *Construction - Tolerances.* The cylindrical portion of the liner is plumb within 1/300 of the height measured from an established vertical line extending up from the base of the liner. The maximum plus or minus deviation of the containment shell from true circular form, measured radially on the inside of the liner, does not exceed 3 inches. The maximum plus or minus deviation of the containment dome from true spherical form, measured radially on the inside of the dome liner, does not exceed 0.5% of the nominal radius.

The maximum deviation from true circular form measured between any two points 14 inches apart in a circumferential direction does not exceed 0.25 inch.

The maximum deviation from a straight line between any two adjacent points 14 inches apart in the meridianal direction does not exceed 0.25 inch.

All measurements are taken on parent metal at least 12 inches from welds. Flat spots or sharp angles were not allowed in curved surfaces.

Careful attention was given to the actual circumference of the shell, to ensure that all shell rings mated properly. The tolerance of alignment of the liner plates is in accordance with ASME III-1968, paragraph N-525.

The allowable deviation from true form does not affect the elastic stability of the containment liner, because of the restraint provided by the studs that tie it to the reinforced-concrete shell.

Materials

Ferritic materials for the reactor containment boundary were specified so that when the liner is exposed to the emergency, test, normal, and upset conditions, the corresponding and resultant stress level will be below the maximum stress level at this temperature permitted by the “CAT” curve of the NRL Report 6900.

The liner materials are ASTM-A537-Gr. B (quenched and tempered) for the first four shell rings (about 29 feet above the mat), and SA-516-Gr. 60 (fine-grain practice) for the remainder. The SA-537-Gr. B has a specified minimum tensile strength of 80,000 psi, a minimum guaranteed yield strength of 60,000 psi, and a guaranteed minimum elongation of 22% in a standard 2-inch specimen.

The SA-516-Gr. 60 has a specified minimum tensile strength of 60,000 psi, a minimum guaranteed yield strength of 32,000 psi, and a guaranteed minimum elongation of 25% in a standard 2-inch specimen. The material nil-ductility transition temperature (NDTT) for both materials was tested not to exceed -20°F. The plates of SA-516-Gr. 60 are heat treated for improved notch toughness, and both materials are certified to the mechanical and chemical limits specified in the ASME Code, Section II, 1968.

The liner plates conform with standard mill practice as given in ASTM-20 with regard to thickness tolerance.

Ferritic steel items, except backing plates and anchors, gas-testing channels (formed shape), and equipment hatch bolts and nuts, are made to fine-grain practice, and normalized, quenched, and tempered to the appropriate material specification.

Testing

Ferritic steel items, except backing plates, anchors, gas-testing channels, and access hatch bolts and nuts, are NDTT-tested in accordance with the following specifications to determine the resistance capabilities of these steels toward embrittlement as the temperature of the steel drops.

1. Material 5/8-inch and thicker was tested by the drop weight test method in accordance with ASTM E208.
2. Material less than 5/8-inch thick was tested in accordance with the ASTM proposed method for drop weight tear tests of ferritic steels.
3. NDTT test data are available on certified documents only on material below 5/8-inch thickness.
4. Plates from a given heat that were heat treated together have only one set of NDTT test data.
5. Plates from a given heat that are individually heat treated have one set of NDTT test data for each plate.
6. Heat treatments of each plate or set of plates are described in detail and their NDTTs are recorded on notarized documents submitted as part of the contract records.
7. Copies of temperature certification charts marked with the heat number and plate identification are included with the above certified documents.

8. As part of the welding procedures, NDTT determinations are performed on the weld metal and heat-affected zone for each different type of welding procedure used.
9. For all plate and piping materials, each individual piece is permanently marked for identification and traceability to required documentation.

All welding procedures and tests required in Section IX of the ASME Boiler and Pressure Vessel Code for Welding Qualifications are met in the selection of weld rod material, weld rod flux, heat treatment, the qualification of the welding procedures, and the performance of welding machine and welding operators who are engaged in the construction of the containment liner. The welding qualifications included 180-degree bend tests of weld material. These procedures ensure that the ductility of welded seams is comparable to the ductility of the containment liner plate material.

3.8.2.1.4.8 *Liner Tests and Surveillance Programs.* The containment leakage rate tests, both preoperational and postoperational, are described fully in Section 6.2.1.4. The liner is also involved in, but not a main feature of, the structural acceptance test described in Section 3.8.2.8.

3.8.2.2 **Design Basis**

The design of the containment structures is based on: (1) biological shielding requirements, (2) the temperature and pressure generated by the design basis accident (Section 15.4), (3) the operational- and design-basis earthquake (Section 2.5), (4) severe weather phenomena, and (5) a maximum core power level of 2951 MWt (100.37% of 2940 MWt rated thermal power). The design basis accident was selected as the design basis for the containment structure, since all other bases would result in lower temperatures and pressures. The containment structure was also designed for the normal subatmospheric operating conditions. Further, the containment structure is designed for a leakage rate not to exceed 0.1% of the contained volume per day at 45 psig.

The operating air partial pressure for the containment is maintained in accordance with the Technical Specifications, and varies from 10.3 to 12.3 psia. This corresponds to an assumed range of containment analysis initial conditions for a total containment pressure of approximately 10.0 to 14.1 psia when the effects of instrument uncertainty and vapor partial pressure (selected over the range of anticipated air temperature and humidity values) are included. The average bulk air temperature of the containment air fluctuates between a maximum temperature of 115°F and a minimum of 86°F during normal operation, and 60°F during shutdown. The normal operating pressure was selected so that the containment is accessible for inspection and minor maintenance during operation without requiring containment pressurization.

3.8.2.2.1 Containment Structure Interior

The interior cubicles within the containment structure are designed and constructed to withstand the localized pressure pulse effects of the energy released by the blowdown caused by a double-ended rupture of a reactor coolant pipe. This rupture is assumed to be either in one of the three steam generator cubicles, the pressurizer cubicle, or within the primary shielding. Since the volume of each of these cubicles is less than the entire containment structure, initial differential pressures are developed until the energy passes through cubicle vent spaces to the remaining volume of the structure. All structural components, walls, floors, and beams enclosing these cubicles are designed to withstand this differential pressure.

The design of the structural components of the steam generator cubicles and primary shielding is based on a load factor design similar to that used for the reactor containment shell. The load capacity is adequate to resist:

$(1.0 \pm 0.05)\ D + 1.0\ R + 1.0\ T + 1.0\ P + 1.0\ E$

where:

D = dead load of structure and equipment

R = double-ended pipe rupture thrust on structure

T = load due to maximum temperature gradient through the concrete from increased temperatures resulting from the pipe rupture and pressure buildup

P = pressure buildup from the expansion of the fluid released from the ruptured pipe as a function of time

E = design-basis earthquake loading, with applicable damping factors from Table 3.7-1.

For design purposes, the maximum values of R and P are assumed to occur concurrently.

Allowable stresses for reinforced concrete are equal to the compressive strength of the material times the applicable coefficient of reduction, as defined in Section 1504 of ACI 318-63. For structural steel, the allowable stress is 0.9 times the guaranteed minimum yield strength. For additional information on compressive strengths, see Section 3.8.1.5.

Within the primary shield area, the reactor vessel is supported on the steel neutron shield tank, which transfers the vessel weight directly to the containment foundation mat. The neutron shield tank will not be damaged by the design differential pressure of 130 psi within the primary shield resulting from a design basis accident, nor will resulting deflections impair the functioning of the reactor supports, which are designed to withstand resulting reaction forces. The neutron shield tank is grouted into and dependent on the reinforced-concrete primary shield cavity wall for lateral support. This wall is designed for a differential pressure of 130 psi.

3.8.2.2.2 Containment Structure Exterior

The containment structure exterior is designed by ultimate strength methods conforming to ACI 318-63, Part IV-B. Design load criteria based on ACI requirements and others given below conform to current containment design practice. The combination of dead, pressure, temperature, and earthquake or tornado loading expressed in the criteria contains varying load factors for pressure, temperature, and earthquake forces. The total loading resulting from the summation of any one of the combinations will cause a maximum stress condition, depending on the type of stress and member under consideration.

Loads imposed on the containment shell include:

1. Dead load.
2. DBA pressure.
3. Temperature rise in liner associated with the design basis accident.
4. Normal operating temperature gradients.
5. Earthquake.
6. Wind loads, including tornado winds.

Loads imposed on the containment mat include

1. Weight of mat and interior structures during construction.
2. Dead load for complete structure.
3. Dead load, and DBA pressure and liner loads.
4. Dead load, DBA pressure, liner loads, and earthquake.
5. Dead load and earthquake.

The ultimate load capacity of the containment structure as modified by the safety provisions of ACI 318-63, Section 1504, which requires the application of varying reduction factors for different types of stress, is not less than that required to satisfy the structural loading criteria tabulated in Table 3.8-9.

Buoyancy caused by ground water does not control the design. Normal wind forces, as obtained from ASCE Paper No. 3269, *Wind Forces on Structures*, do not control the design. For a description of wind loading, see Section 3.3.

The seismic design coefficients and critical damping factors used in the design of the reactor containment structure are given in Section 3.7.2. The response spectra curves are included in Section 2.5. The earthquake loads include the effects of horizontal acceleration, vertical acceleration, or a combination of both where the effects, as measured by the stresses resulting from the separate acceleration components, of horizontal and vertical ground accelerations are combined algebraically to produce maximum stress intensities, taking into account any potential adverse effect due to phase of the separate accelerations.

The load capacity of tension members is based on the guaranteed minimum yield strength of the reinforcing steel. Load capacities of flexural and compression members are first determined in accordance with the Building Code Requirements for Reinforced Concrete, ACI 318. The load capacity so determined was decreased by a reduction factor multiplier, "Ø," to compensate further for small adverse variations in material and workmanship. The reduction factors are:

Tension and flexure	0.90

Diagonal tension, bond, and anchorage 0.85

The load capacity reduction factor for stresses in concrete produced by tornado-carried missiles, in combination with other tornado-produced stresses as given in Table 3.8-9, is 0.75.

The dominant design load is the 45-psi design basis accident pressure, which creates major tensile membrane stresses in the reinforcing steel, coincident with moments at the junction of the containment wall and mat.

The design tornado wind loading and pressure criteria are stated in Section 3.3.

Since the DBA pressure load is greater than the negative pressure load of tornados, the containment structure is able to maintain its integrity should a tornado strike the structure.

The containment design is checked by calculating stress levels in the structural components due to design loads, using elastic straight-line theory.

Missile protection criteria and the criteria for protection against dynamic effects associated with a LOCA are discussed in Sections 3.5 and 3.6, respectively.

3.8.2.3 **Codes and Specifications**

In general, the same codes and specifications discussed in Section 3.8.1 were also used for the containment structures. Some modifications of load factors and allowable stress were required because of the unique containment structural loading combinations, and these are incorporated in the discussion of analytical techniques (see Section 3.8.2.5).

See Section 3.8.2.9.1 for the description of the codes and specifications used for the Reactor Pressure Vessel Head Replacement Project.

3.8.2.4 **Structural Loading Combinations**

Information regarding structural loading combinations is incorporated in the discussion of analytical techniques.

3.8.2.5 **Static Analysis**

The containment structure was designed for the loading conditions with appropriate load factors given in Section 3.8.2.2. Since the containment superstructure is a thin shell composed of a cylindrical section capped by a hemisphere, membrane stresses induced by pressure and thermal loads were calculated by traditional shell formulas. The base moment and shear at the cylinder wall foundation mat junction were calculated as a part of the mat analysis. For this analysis, the containment pressure loads, the stiffnesses of the containment wall and internal structures connected to the mat, the dead loads, and the characteristics of the mat supporting rock were used.

In the membrane portion of the shell, i.e., the areas not in the influence of the bending moments due to the discontinuities of the mat-cylinder and the dome-cylinder intersections, the pressure applied to the containment was the factored DBA pressure plus an equivalent pressure, which is the force exerted by the liner as it is heated. Under the DBA conditions, it was assumed that the temperature rise is sudden, and all of the DBA temperature rise occurs in the liner, the concrete shell remaining at the operating temperature.

The procedure used for computing the stresses due to the DBA thermal load and pressure is

Let

A_{vi}, A_{vo} be areas of reinforcement in the vertical direction on the inner and outer faces, respectively.

A_{hi}, A_{ho} be areas of reinforcement in the hoop direction on the inner and outer faces, respectively.

A_{lh}, A_{lv} be the areas of the liner plate in the hoop and vertical direction, respectively.

R_l be the radius to the center of the liner plate from the center of the containment.

R_{hi}, R_{ho} be the radii from the center of the shell to the centers of inner and outer hoop reinforcement, respectively.

R_{vi}, R_{vo} be the radii from the center of the shell to the centers of inner and outer vertical reinforcement, respectively.

σ_{lh}, σ_{lv} be the stresses in the liner plate in the hoop and vertical directions, respectively.

σ_{vi}, σ_{vo} be the stresses in the vertical reinforcing steel in the inner and outer faces, respectively.

σ_{hi}, σ_{ho} be the stresses in the hoop reinforcing steel in the inner and outer faces, respectively.

E be the modulus of elasticity of steel.

P be the design pressure inside the containment due to the design basis accident.

ΔT be the temperature rise in the liner plate due to the design basis accident.

α be the thermal coefficient of expansion of liner plate.

ν be Poisson's ratio for steel.

w be the weight of containment shell per unit circumference at the elevation under consideration.

From compatibility of displacements:

Radial displacement of liner = radial displacement of outer hoop steel:

or

$$R_1 \frac{\sigma_{lh}}{E} - \nu \frac{\sigma_{lv}}{E} + \Delta T = R_{ho} \frac{\sigma_{ho}}{E}$$

Radial displacement of outer hoop steel = radial displacement of inner hoop steel:

or $R_{ho} \frac{\sigma_{ho}}{E} = R_{hi} \frac{\sigma_{hi}}{E}$

From compatibility of strains:

Vertical strain of liner plate = vertical strain of inner vertical steel

or $\frac{\sigma_{lv}}{E} - \nu \frac{\sigma_{lh}}{E} + \Delta T\alpha = \frac{\sigma_{vi}}{E}$

Vertical strain of inner vertical steel = vertical strain of outer vertical steel

or $\frac{\sigma_{vi}}{E} = \frac{\sigma_{vo}}{E}$

From equilibrium of forces:

$A_{lh}\,\sigma_{lh} + A_{hi}\,\sigma_{hi} + A_{ho}\,\sigma_{ho} = pR_1$

$A_{lv}\,\sigma_{lv} + A_{vi}\,\sigma_{vi} + A_{vo}\,\sigma_{vo} = \frac{pR_1}{2} - W$

From the preceding six equations, the different unknown stresses were evaluated. From the stress in the liner, the equivalent pressure on the concrete shell was calculated.

At the junction of the mat and the shell, it was assumed that the compressive strain in the liner plate is equal to $\alpha\Delta T$. This compressive strain in the liner plate was converted into equivalent pressure on the concrete shell. This equivalent pressure was added to the DBA pressure in calculating the radial displacement of the containment shell, for use in the mat analysis.

The containment mat was analyzed by a computer program that has the capability to calculate bending moments, shears, and soil pressures for a symmetrically loaded circular plate on an elastic foundation. The general method used is described in *Practical Methods for Analysis of Beams and Plates on Elastic Foundations*, by Boris N. Zhomochkin, which is for a plate on a semi-infinite elastic half space. This method is an adaptation of the Boussinesq approach.

The cylindrical containment wall, crane wall, and primary shield wall are elastically fixed to the mat and therefore produce discontinuity moments and shears that are applied to the mat as external forces. The magnitudes of the discontinuity forces were determined by enforcing compatibility conditions at the wall/mat interfaces. For the purpose of calculating the discontinuity forces at the base, the containment cylinder was assumed to be completely cracked vertically, and cracked horizontally to the neutral axis of the transformed section. The containment, therefore, has the hoop stiffness of the circumferential rebars and the meridianal bending stiffness of the transformed section.

The crane wall and reactor support have stiffnesses as calculated by Equations 279 and 280 of Reference 11. The discontinuity forces (base moments and shears) calculated as a part of the mat solution were applied to the end of the shell. Using the solution for a long cylinder, the variation of moment and shear with increasing elevation was computed.

The mat was analyzed for the effects of seismic loads using a finite difference computer program. The loads, which are applied to the mat antisymmetrically, are the result of overturning moments in the containment and internals.

3.8.2.5.1 Diagonal Reinforcing for Earthquake

Seismic analysis provided the accelerations that the containment would receive during an earthquake. These accelerations were applied as a static load to the containment, and it was analyzed for forces by a finite difference computer program. The tangential shears caused by the earthquake load are resisted by both the concrete and diagonal reinforcing. The concrete was assumed to have a shear resistance of 60 psi. Diagonal reinforcement, as shown in Figure 3.8-6, is provided for shear in excess of the 60 psi allowable; also, some diagonal reinforcement was continued to the dome/cylinder intersection. In calculating the steel requirement, compatible strains were considered, so that the effect of pressure-induced stresses was included; it was assumed that the liner does not provide any shear resistance.

3.8.2.5.2 Tornado Loading

Wind pressure was assumed to be distributed over the containment dome in accordance with the methods given by Gondikas and Salvadori (Reference 11). This method provides for the discontinuity stresses at the junction of the dome and cylinder. Wind pressure was assumed to be distributed over the containment cylindrical shell in accordance with ASCE Paper No. 3269. With this approach, a statically indeterminate circular ring of unit width was analyzed for a varying wind load resisted by tangential shear. This produces bending moment, axial load, and shear around the ring.

No torsional loading from tornado was investigated, since the necessary friction or surface drag was considered to be negligible. Overturning of the structure due to tornado is not a factor, because the dead load of the structure is sufficient to overcome the wind force. The equivalent static force of wind was obtained from formulas in the ASCE Paper No. 3269 referred to in Section 3.3.

3.8.2.5.3 Scaled Load Plots

Figures 3.8-16 through 3.8-18 are scaled load plots of moment, shear, and membrane forces for the containment structure under the design loading conditions.

Earthquake forces in the mat are shown separately from those forces that are pressure-induced. Tornado forces in the containment are shown separately from the operating condition. Operating temperature effects are not shown on the plots, but are considered in the design. Compression forces are plotted as negative values. Moments are plotted to the tension side. Load plot nomenclature is given in Figure 3.8-17.

Containment structure dynamic analysis is discussed in Section 3.7.2.

3.8.2.6 Design Methods and Allowable Stress

3.8.2.6.1 General

Information regarding general design methods and allowable stress has been incorporated in the discussion of analytical techniques (Section 3.8.2.5).

3.8.2.6.2 Penetrations

Penetrations through the exterior walls of the containment structure are divided into the following three categories:

1. Pipe penetrations 9 inches in diameter or less - No special structural reinforcing is provided for these penetrations.

   Penetrations in this category are located to avoid interference with the reinforcing steel.

2. Pipe penetrations greater than 9 inches and up to 3 ft. 9 in. in diameter - Supplementary reinforcement is provided for these penetrations in amount and distribution such that area requirements for reinforcement are satisfied.

   At all these penetrations, reinforcing steel interrupted by the openings was terminated at each side of the opening. Supplementary reinforcing was placed parallel to the interrupted bars to provide bar continuity. Horizontal, diagonal, and vertical bars were used to effectively frame the opening. The total area of reinforcement provided in any plane is not less than twice the area of steel interrupted or cut by the opening, with one-half of this placed on each side of the opening.

   Anchorage of this additional reinforcement is determined by using a conservative bond stress of 75% of that allowed by ACI-318, to provide 90% of the guaranteed minimum yield strength of the added rebar. This design approach is consistent with the practice used and pressure-tested at the Connecticut Yankee facility at Haddam Neck, Connecticut, Units 1 and 2 of the Surry Power Station at Surry, Virginia, and the Maine Yankee facility at Wiscasset, Maine.

3. Openings larger than 3 ft. 9 in. in diameter - The two openings in this category are the 7 ft. 0 in. diameter personnel access hatch and the 14 ft. 6 in. diameter equipment access hatch. Details of the additional reinforcement provided around the equipment access hatch and personnel access hatch are shown on Figures 3.8-19 through 3.8-22.

These penetrations are analyzed by means of computer programs using the finite element method. These programs, because they maintain compatibility between the ring beam and cylinder wall, are used to supplement Stone & Webster's computer program, *Nuclear Containment Structure Access Opening*, which analyzes, by the method of virtual work, an isolated, doubly-curved beam (Reference 12).

The equipment hatch opening (14.5-foot i.d.) is analyzed using a computer program based upon the Ph.D thesis (June 1968) by C. A. Prato entitled, *A Mixed Finite Element Method for Thin Shell Analysis*. The personnel hatch opening (7-ft. 1-in. i.d.), which has a projecting ring on the outside of the wall, is analyzed by using the three-dimensional finite element capability of STRUDL, since this program could more accurately investigate an eccentric ring beam. Results from both these programs were compared with the Stone & Webster computer program.

To obtain more meaningful results, the ring beam and cylinder wall for both hatches are assumed to be cracked, and to have the extensional stiffness of the reinforcing bars only. The analyses show that sizeable tangential (in plane) shears exist in the wall near the ring beam. These shears are resisted by special reinforcing bars placed parallel to the typical earthquake shear bars.

The ring beam is designed to resist the axial tension and shears resulting from the loading criteria listed in Section 3.8.2.2. The axial tension is assumed to be resisted by the reinforcing bars only. The shears, including torsional shear, are resisted entirely by stirrups placed radially around the penetrations.

In effect, any concrete resistance to tension and shear is neglected. The principal circumferential and meridianal reinforcing bars, as designed, are extended to the inner face of the ring beam, hooked 90 degrees, and Cadwelded to each other, thereby providing additional shear resistance to that provided in the design.

The normal pattern of membrane forces (meridianal and circumferential) in the containment wall is disrupted in the region of the hatch openings. The redistribution of these forces is provided by the finite element computer programs and extra reinforcement added to areas of marked deviation from the normal pattern.

3.8.2.7 **Construction Materials**

See Section 3.8.2.9 for the description of the construction materials used for the Reactor Pressure Vessel Head Replacement Project.

3.8.2.7.1 Concrete

The discussion of concrete (Section 3.8.1.5.1) applies as well to the concrete placed in the containment structure. See Section 3.8.2.9 for the description of the concrete used for the Reactor Pressure Vessel Head Replacement Project. No differentiation was made in the parameters for concrete for Seismic Class I structures relative to the particular Seismic Class I structure in which this material was placed, except for placement procedures.

3.8.2.7.2 Reinforcing Steel

The discussion of reinforcing steel (Section 3.8.1.5.2) applies as well to the steel placed in the containment structure. See Section 3.8.2.9 for the description of the reinforcing steel used for the Reactor Pressure Vessel Head Replacement Project. No differentiation was made in the parameters for reinforcing steel for Seismic Class I structures relative to the particular Seismic Class I structure in which this material was placed, except for the limited amount of Grade 60 used in containment interior walls only.

3.8.2.7.3 Cadwelds

The discussion of Cadwelds (Section 3.8.1.5.3) applies as well to the Cadwelds placed in the containment structure. See Section 3.8.2.9 for the description of Cadwelds, including operator qualification and tensile testing, used for the Reactor Pressure Vessel Head Replacement Project. No differentiation was made in the parameters for Cadwelds for Seismic Class I structures relative to the particular Seismic Class I structure in which this material was placed.

3.8.2.7.4 Porous Concrete

Porous concrete is used under the basemat to provide drainage for the containment structure, as discussed in Sections 3.8.2.1.2 and 3.8.2.1.3. This type of concrete is formed by the omission of the fine aggregate from a standard structural concrete mix. The mix is designed to have a 28-day compressive strength greater than 1000 psi.

Water porosity tests were performed earlier in an independent laboratory for porous concrete, using 6-inch by 12-inch cylinders prepared in the laboratory by compacting the material in three layers with standard tamping rods. A varying number of strokes, ranging from 10 to 40 for each layer, were used for different cylinders. After the concrete test cylinders had been properly cured, the amount of water that would flow through the 12-inch length of specimen during a 3-minute period with a constant head of 4 inches of water above the top of each cylinder was determined. Results indicated water porosities of from 28 to 47 gpm/ft^2, depending upon the amount of compaction and resulting density of the cylinders.

3.8.2.7.5 Waterproof Membrane

The waterproof membrane is used to envelope the containment and exterior walls for ground-water corrosion protection, as discussed in Sections 3.8.2.1.2 and 3.8.2.1.3. The waterproof membrane is a flexible polyvinyl chloride sheet with a minimum thickness of 40 mils. Adhesives and tapes are the manufacturer’s recommended material for the application conditions.

Field splices have a minimum 2-inch lap at all joints. Adhesive was applied to both surfaces at each joint, and coated areas were then pressed together with a roller. Joints were inspected 1 hour later, and any loose edges were recoated and rerolled. At joints between horizontal and vertical sheets of membrane, an L-shaped piece was used to close the joint, with adhesives applied in the manner previously described. Vertical sheets were terminated 6 inches below ground grade, with a continuous Nob-Lock Termination strip embedded in the concrete.

3.8.2.7.6 Protective Coatings (Paints)

3.8.2.7.6.1 *Inside Containment Coating Applications.*

3.8.2.7.6.1.1 *General.* Protective coatings for exposed concrete and carbon steel surfaces within the containment liner boundary are required for corrosion mitigation, and to obtain a relatively impervious film on permanent surfaces that is decontaminable in the event of accidental spillage of radioactive fluids. It is also necessary that protective coatings remain intact if subjected to the environment associated with postulated LOCAs. Assurance that proposed protective coating systems would meet this additional requirement was obtained by exposing test panels to a simulated environment representative of the design basis accident.

3.8.2.7.6.1.2 *Construction Phase.*

3.8.2.7.6.1.2.1 *Test Panels.* Test panels representative of all major surfaces within the containment liner boundary were prepared with the proposed coating system. Surface preparation and coating application was performed by Stone & Webster Engineering Corporation construction personnel and inspected by its field quality control organization. The American National Standards Institute, Inc., (ANSI) standard entitled, *Quality Assurance for Protective Coatings Applied to Nuclear Facilities*, ANSI N101.4, provided the basis for the quality assurance criteria.

3.8.2.7.6.1.2.2 *Testing.* Simulated DBA environment testing was performed by an independent testing laboratory. The test consisted of subjecting all test panels to the temperature, pressure, and radiation levels experienced during the first 7 days of the design basis accident while partially immersed in, and sprayed with, a solution identical in chemistry to that provided by the recirculation spray subsystem. The ANSI standard entitled, *Protective Coatings for Light Water Nuclear Reactor Containment Facilities*, ANSI N101.2 provided the basis for the test program criteria. The test duration was selected to envelop the most severe temperature, pressure, and radiation levels, which occur during the first hour after the design basis accident, and to continue the lower levels of these exposures, which occur after this period, for an additional 167 hours.

3.8.2.7.6.1.2.3 *Test Results.* A report on simulated DBA environment test results was prepared (see Appendix 3D).

This report includes the following:

1. A description of test panel coating systems and testing criteria.
2. A description of the test apparatus and procedures.
3. Performance evaluations of each coating system in terms of:
    a. Flaking by ASTM D772.

b. Blistering by ASTM D714.

c. Chalking by ASTM D659.

d. Delamination, peeling, or any other changes associated with the release of an individual coat or all coats from the substrate.

e. Photographs of test panels before and after testing.

3.8.2.7.6.1.2.4 *Application - Coatings by Stone & Webster.* The stability of containment coatings in the event of a LOCA is documented in Appendix 3D. A description of the qualified coatings that were specified for the containment interior painting is given in Table 3.8-10.

The temperatures of the ambient air and of the substrate was maintained within the limits established by the coating manufacturer until the time-to-recoat period had elapsed. The time-to-recoat period was similarly established by the coating manufacturer. During this period, adequate ventilation was provided to permit proper solvent release and removal.

The extent to which unqualified coatings were used for containment interior painting during construction is given in Table 3.8-11. Approximately 8140 ft^2 of unqualified coating applied by Virginia Power are on the containment ring duct. The ring duct and supports are covered by a stainless steel wire mesh designed to contain coating particles greater than 120 mils in size which may separate from the ductwork under post LOCA conditions. Therefore, the coating is not considered to be a source for debris for sump blockage.

3.8.2.7.6.1.2.5 *Operations Phase.* The preceding discussion pertains to the coating systems originally used within the reactor containment. NAS 3000, *Specification for Inside Containment Protective Coatings*, specifies the coating systems to be used and the application requirements to be followed during any post-construction in-containment coating application. This specification applies to the maintenance of existing coating and the application of coating on new uncoated components or structures. All coatings specified for use meet the technical performance requirements for simulated DBA testing set forth in ANSI N101.2-72, *Protective Coatings (Paints) for Light Water Nuclear Reactor Containment Facilities*. Coatings selected for future use were DBA tested to determine acceptability. Refer to Reference 35. Once qualification was determined, surface preparation and application procedures were developed for each coating material.

3.8.2.7.6.2 *Vendor Supplied Coating of Components for Installation Inside Containment.*

3.8.2.7.6.2.1 *General.* Protective Coating for components installed inside the containment are required for two purposes: to provide corrosion protection for steel surfaces and to provide a more easily decontaminable surface. It is essential that the coating integrity remain in place in order not to adversely impact post-accident containment sump performance.

3.8.2.7.6.2.2 *Construction Phase.* Vendor coatings on components installed inside the containment during the construction phase met one of the following criteria: the vendor provided documentation that the coating system was qualified for DBA environmental conditions, the coating system was qualified by NAPS qualification testing, the component was primed by the vendor and top coated on site in accordance with NAS-1016, *Application of Protective Materials within the Containment,* or an unqualified coating system was judged to be the best available (e.g., post manufacturing stripping and repainting was not sensible due to the potential risk to component performance, the relatively small coated surface area involved and the high quality of the coating system used).

3.8.2.7.6.2.3 *Operations Phase.* Coated components supplied by vendors to be installed inside the containment are purchased for both design change and maintenance use. Coated components for design change installation inside containment are purchased to meet or exceed the original requirements discussed above. Coating by the vendor of replacement components or refurbished components to be installed inside the containment are purchased to meet or exceed the coating requirements of the original procurement specification.

3.8.2.7.6.3 *Generic Safety Issue (GSI) - 191 Coating Review.* Updated inventories of Qualified Coatings in the Steam Generator Loop Rooms and Unqualified Coatings in containment were developed as a result of the design changes implemented from Generic Safety (GSI) - 191. The coating systems listed in Tables 3.8-19, 3.8-20, 3.8-21 comprise the design input for determining the debris generation relating to coatings in containment following a LOCA. The inventory of Qualified Coatings in the ZOI contained in Table 3.8-19 is based on a North Anna Unit 1 Steam Generator Loop Room break of the 31-inch intermediate leg. Tables 3.8-20 and 3.8-21 document the Unqualified Coatings identified within Units 1 & 2 containment.

3.8.2.7.7 Compressible Material

A unique compressible material is used around the containment structure, between the exterior wall and concrete backfill, to maintain isolation. This compressible material is Rodofoam, soft grade No. 300, as manufactured by Electrovert, Inc. It is a polyvinyl chloride plastic that requires a force of 2 to 5 psi to compress elastically to 75% of its original thickness, and a force of 13 to 16 psi to compress elastically to 50% of its original thickness. These elastic properties ensure that structural response of the containment during the structural acceptance test will be unrestrained by the concrete backfill and will therefore be representative of the DBA design parameters. Additionally, these properties ensure that structural response of the containment during seismic events will be representative of the OBE and DBE design parameters.

3.8.2.7.8 Concrete Backfill

Concrete backfill is used to support the wall of the containment rock excavation from postconstruction surcharge loads, as discussed in Section 3.8.2.1.2. The mix is designed to have a 28-day compressive strength greater than 1000 psi. Concrete backfill was placed in horizontal layers of approximately 12 inches, and at a vertical rate not to exceed 1 ft/hr. These controls ensured minimal precompression of the compressible material due to hydraulic pressure. Additionally, backfill concrete was rodded in place and not vibrated. These additional controls were to prevent damage to the compressible material and/or the waterproof membrane during placement.

3.8.2.8 **Structural Testing and Surveillance**

3.8.2.8.1 Structural Acceptance Test

3.8.2.8.1.1 *General.* The structural acceptance test for the containment structures equalled or exceeded the requirements of Safety Guide 18, *Structural Acceptance Test for Concrete Primary Reactor Containments,* U.S. Atomic Energy Commission, dated October 27, 1971, pertaining to nonprototype containments.

3.8.2.8.1.2 *Pressure Cycles.* The completed containments were tested for structural integrity by an air pressure test with a maximum pressure of 52 psig, which is 115% of the design pressure. The levels of the pressurization and depressurization cycles were atmospheric, 13 psig, 26 psig, 39 psig, and 52 psig. Deflections, strains, and cracks were observed and recorded at each level of each cycle after that level was maintained for a minimum of 1 hour.

3.8.2.8.1.3 *Deflections.* Radial deflections of the containment wall, with respect to the containment horizontal centerlines, were measured at each of the following approximate locations:

1. 13 ft. 6 in. up from the top of the mat, at midheight, and at the springline of the dome, each of these three points being measured on six equally spaced meridians, 18 locations total.
2. At the equipment hatch along its horizontal and vertical axes, at distances of R, 2R, and 2.5R, 12 locations total.

Vertical deflections of the containment dome were measured at each of the following approximate locations:

1. At the springline on six equally spaced meridians, six locations total.
2. At the apex.

3.8.2.8.1.4 *Strains.* Strains in the containment liner wall were measured to determine principal stress in the liner plate at locations of typical wall response.

3.8.2.8.1.5 *Cracks.* Crack patterns were mapped during the pressurization cycle on containment wall at each of the following locations:

1. At the mat/wall intersection, at midheight, and at the springline of the dome.
2. At one quadrant of the equipment hatch.

Areas that were mapped were observed before, during, and after the test, and cracks exceeding 0.01 inch were recorded.

3.8.2.8.1.6 *Environmental Conditions.* The daily average temperature was recorded inside and outside the containment for 1 week prior to the test. During the test, atmospheric temperature, pressure, and humidity inside and outside the containment were continuously monitored, and recorded at hourly intervals. There were no extreme weather conditions during the test.

3.8.2.8.1.7 *Predicted Response.* The predicted response of the containments at the 52-psig maximum test pressure was as follows:

1. Radial deflection of wall, generally +0.75 in.
2. Radial deflection of wall at equipment hatch, +0.75 in.
3. Vertical deflection of dome at springline, +0.6 in.
4. Vertical deflection of dome at apex, +1.0 in.
5. Width of a new crack or increase in an existing crack, 0.03 in.

The basis for these predicted responses was an elastic analysis of the behavior of the containment under the maximum test pressure.

3.8.2.8.1.8 *Test Results.* Containment structural acceptance test results are documented in reports written and furnished by Stone & Webster for Unit 1 in 1977 and for Unit 2 in 1979.

3.8.2.9 **Reactor Pressure Vessel Head Replacement Project**

The Reactor Pressure Vessel (RPV) Head Replacement Project created and restored a construction opening in the reactor containment structure in accordance with administrative procedures and the design control program. The opening was used to facilitate the movement of original and replacement RPV heads in and out of the reactor containment structure. The opening was restored to meet the original design bases of the containment structure.

3.8.2.9.1 Codes and Specifications

ACI 318-63 is the design code for the restored containment structure. The restored structure meets all applicable design loads and load combinations required by ACI 318-63.

Concrete placement, curing, and repair were in accordance with ACI 301-99 with the incorporation of Cold Weather Concreting per ACI 306.1/ACI 306R, as appropriate. The use of ACI 301-99 is in accordance with Section 2.2 of ANSI N45.2.5-74.

Concrete mix proportioning was per ACI 211.1-91 (reapproved 1997) in accordance with Table A of ANSI N45.2.5-74.

Bechtel specifications (References 40-47) address:

- reinforcing steel procurement, testing, and placement
- Cadweld reinforcing steel splices procurement, testing, and installation

- concrete mix design, testing, and placement
- structural steel and materials

3.8.2.9.2 Liner Restoration

The cut section of the containment liner plate was rewelded to the liner plate with a full penetration weld. The weld was tested to ensure no leakage. In addition, the full penetration weld was covered by a seal welded leak chase channel to facilitate testing.

Replacement material was purchased for the liner plate, Nelson studs, and leak chase channels. The Nelson studs, and leak chase channels were used for reinstallation of the plate and the leak chase channel system. Reference 47 requires the liner plate material to be ASTM A-516-Grade 60 (or better), fine-grained and normalized.

3.8.2.9.3 Reinforcing Steel Restoration

The reinforcing steel bars cut during the creation of the opening were re-installed using Cadweld splices or welding, as required, in accordance with References 43, 44, and 48. Reinforcing steel bars that were damaged during the creation of the opening were repaired in accordance with References 42 and 48 or were replaced with reinforcing steel procured in accordance with Reference 41. New N14 and N18 reinforcing steel used for containment wall restoration conforms to either ASTM A615 Grade 60 and/or ASTM A706 Grade 60, and meets the additional elongation and chemical composition requirements described in Section 3.8.1.5.2.1 for the containment structure existing reinforcing steel.

In-process testing of Cadweld splices was done in accordance with Sub subparagraph CC-4333.5.2 of ASME B&PVC Section III Division 2, 1995 Edition with 1996 Addenda. This differs from the testing protocol, based on Safety Guide No. 10, that was used during the original construction (described in Section 3A.9). It also differs from (Section 4.9.3 of) ANSI N45.2.5-74, the quality standard used by Dominion during the plant operational phase. Additional differences relative to ANSI N45.2.5-74 are as follows:

- Splice System Qualification: Per subparagraph CC-4333.2 of ASME B&PVC Section III Division 2 (1995 Edition, 1996 Addenda)
- Operator Qualification: Per subparagraph CC-4333.4 of ASME B&PVC Section III Division 2 (1995 Edition, 1996 Addenda) instead of Section 4.9.1 of ANSI N45.2.5-74
- Testing Frequency: Per sub subparagraph CC-4333.5.3 of ASME B&PVC Section III Division 2 (1995 Edition, 1996 Addenda) instead of Section 4.9.4 of ANSI N45.2.5-74

Dominion's Operational Quality Assurance Program Topical Report was revised to reflect the above exceptions of ANSI N45.2.5-74.

To minimize the size of the construction opening, the Cadweld splice locations were not staggered as described in Section 3.8.2.1.2.4. Section 805 of ACI 318-63 does not require staggered Cadweld splices if the splice can develop in tension at least 125 percent of the specified yield strength of the reinforcing steel bar. The minimum acceptance criteria for the Cadweld splice testing in Reference 44 is that the minimum tensile strength of each sample tested shall be equal to or exceed 125 percent of the yield strength of the reinforcing steel bar. Also, the splicing scheme for the RPV Head Replacement Project construction opening is similar to that used during the closure of the original construction opening.

3.8.2.9.4 Construction Restoration

As discussed in Dominion's Operational Quality Assurance Program Topical Report commits to ANSI N45.2.5-74 (with clarifications) for satisfying the quality assurance requirements for installation, inspection, and testing of structural concrete during the operational phase of North Anna Power Station. Section 2.2 of ANSI N45.2.5-74 requires that the installation, inspection, and test activities be performed in accordance with the latest codes. Tables A and B of ANSI N45.2.5-74 provide the requirements for the qualification and in-process testing of the concrete ingredients and concrete mix.

The concrete was replaced and the restored structure tested in accordance with ASME B&PVC Section XI, Articles IWL 4000 and IWL 5000, respectively. In accordance with the guidance of Table A of ANSI N45.2.5-74 concrete mix design is based on ACI 211.1-91 (reapproved 1997). The activities associated with placement of concrete were performed in accordance with References 40 and 46, which meet the requirements of ACI 301 and ANSI N45.2.5-74. In-process sampling, testing, and acceptance requirements for all repair material were in accordance with Table B of ANSI N45.2.5-74. Reference 40 provides the testing frequencies, sampling and testing standards, and acceptance criteria for concrete ingredients and concrete mix. The concrete had a minimum 5-day strength of 3000 psi.

The water used for concrete mix was evaluated in accordance with the requirements of AASHTO T-26, as specified in Table A of ANSI N45.2.5-74. The water testing and acceptance criteria included in Reference 40 required that the water used during the restoration was free of harmful levels of contaminants.

The cement used in the new concrete was Type II Low Alkali (as defined in ASTM C 150).

Test results for the cement chemical composition for Unit 1 and Unit 2 indicated that the Tricalcium Aluminate (C3A) content is 1% higher than the specified amount. However, an engineering evaluation concluded that the cement is acceptable and that the C3A content will have no adverse effect on the quality of the concrete. The conclusion is based on an assessment of the heat-of-hydration and the service environment that is not subject to sulfate attack.

For the RPV Head Replacement Project, the restoration of the containment wall used smaller coarse aggregate, size 57 (25 mm to 4.75 mm) because of the limited size of the opening and due to the use of pour ports/bird mouths for concrete placement. Both fine and coarse aggregates were tested in accordance with the requirements of ANSI N45.2.5-74 to ensure acceptable physical characteristics and that they were free of harmful levels of alkali reactivity and deleterious substances (acceptance criteria are defined in ASTM C 33).

Test results for the fine aggregate for Unit 1 and Unit 2 indicated that it was slightly outside the acceptance threshold. An engineering evaluation concluded that the fine aggregate is acceptable for use. The conclusion is based on an assessment of the mitigating effect of low alkali cement and the documented long-term service record of the fine aggregate; and that the concrete will not be subject to extended periods of saturation, the kind experienced by water-front and intake structures, which can aggravate the problem of aggregate reactivity. Also, the restored portion of the wall is not in contact with soil and the climate at North Anna does not cause an extended exposure to a humid atmosphere.

Admixtures used to modify the concrete mix properties met the requirements of ASTM standards and were used in accordance with the manufacturer's written procedures and applicable ACI standards (primarily ACI 211.1-91 (reapproved 1997) for mixing and ACI 301-99 for placement). Reference 45 prohibited the use of admixtures with chlorides. Uniformity of admixture lots was verified with Infrared Spectrophotometry in accordance with Table B of ANSI N45.2.5-74.

In its ready mix state, the new concrete had an air content of 4.5% (±1.5%) at the point of placement. This is consistent with Table 6.3.3 of ACI 211.1-91 (reapproved 1997) for the maximum aggregate size being used in the concrete mix (1" for Size No. 57 coarse aggregate) and air-entrained concrete.

The slump of the concrete in its ready mix state, without admixtures, was between 2 and 4 inches in accordance with the recommended values in Table 6.3.1 of ACI 211.1-91 (reapproved 1997). For admixture-treated concrete, the slump was between 2.5 and 8 inches based on the footnote to Table 6.3.1 of ACI 211.1-91 (reapproved 1997), which approves higher concrete slump when chemical admixtures are used provided that there are no signs of segregation or excessive bleeding.

3.8.2.9.5 Post Modification Testing

The nondestructive examination of the containment liner was in accordance with Safety Guide 19, Nondestructive Examination of Primary Containment Liners with the following changes: after vacuum box testing of the liner seam weld and installation of the channel, the channel to liner weld was tested by a static pressure test (decay test) with an acceptance criteria of zero leakage. Soap bubble testing was used to identify leakage. Leaking areas of the joint were repaired and retested. In addition, following the containment building pressure test, the channel was re-pressurized and an "as-found" LLRT, meeting ANS 56.8-1994 requirements, was performed.

Prior to placing the containment structure in-service, a containment pressure test that bounds the calculated peak containment internal pressure was performed in accordance with IWL

Article 5000 of the ASME B&PVC Section XI. The surface of the replacement concrete at the temporary construction opening was examined in accordance with IWL-5250 prior to pressurization, at test pressure, and following completion of pressurization.

3.8.3 Main Dam

Withhold under 10 CFR 2.390 (d) (1)

[redacted]

The high central portion of the earth dam has a vertical chimney drain of free-draining sand connecting with a blanket drain immediately over the bedrock, which in turn connects to a downstream rock toe, as shown on Figure 3.8-24. On the abutment sections, where the dam is of lesser height (the general height of dam from ground surface to normal pool level is 25 to 30 feet), the dam is provided with a pervious downstream toe, as shown on Figure 3.8-25. A line of relief wells, located at approximately 50-foot intervals along the toe of the dam, extends through the overburden to bedrock. Profiles showing the installed wells with stainless steel screens and chlorinated polyvinyl chloride drainage collection system are given in Figures 3.8-26 and 3.8-27. Relief well details are shown on Figure 3.8-28. Except for these drain systems, the dam embankment is constructed of residual soils placed and compacted under careful control. The residual soils were obtained from borrow areas within the reservoir. Borrowing of soil did not encroach upon the dam embankment foundation, since an upstream blanket of the residual soil profile was retained within the limits on Figure 3.8-23. The surface of this blanket was compacted to form an upper seal. The edges of the blanket, in proximity to the natural river channel, were sealed using a slurry trench construction. The dam is faced on the upstream side with riprap for its full height and on the downstream side with riprap to above tailwater level for probable maximum flood.

3.8.3.2 **Basis for Design**

Design development of the dam was based on subsurface investigations: the sampling of foundation materials and borrow materials, the sampling of portions of the compacted embankment, and extensive laboratory testing to evaluate material properties. The results of the investigation, testing programs, and the material properties are presented in a report entitled, *Report on Design and Stability of North Anna Dam for Virginia Electric and Power Company* (Reference 13), dated May 7, 1971, which was submitted as Amendment 15 to the North Anna Units 1 and 2 PSAR.

A detailed analysis of the dam was made to determine its stability under various loading conditions, including severe earthquake. This analysis is given in the same report. This report includes a description of the analytical procedures used in evaluating the design of the dam. The basis for vibratory ground motion used in analysis of the dam is the same as described for the station site in Section 2.5.2 of this report.

Studies of stability and behavior under static and dynamic loadings included:

1. Stability of slopes downstream at completion of construction.
2. Stability of slopes under long-term static loadings both upstream and downstream.
3. Stability of slopes upstream for drawdown conditions.
4. Stability of slopes both upstream and downstream for the design-basis earthquake, assuming normal operating level for the pool.
5. Stability of retaining walls at the spillway under the design-basis earthquake.
6. Shear stresses in the soil parallel to the spillway retaining walls, resulting from distortions of the earth dam sections relative to the spillway under earthquake loads.
7. Evaluation of stresses in and stability of the spillway structure and gates.

In all cases, the dam was found to be safely and conservatively designed.

For the analysis of the embankment section under dynamic conditions, dynamic finite element techniques were used to determine the accelerations that would exist in various portions of the dam.

Analyses were made for the highest section of the dam on the rock foundation near the spillways, Station 22+00, and for a typical embankment section on the abutments, Station 28+70. For both locations, the dam was modeled, including its foundation to the surface of the bedrock, and earthquake motions applied using several earthquake records normalized to 0.12g horizontally and 0.08g vertically to determine the accelerations that would exist within the dam. Using these accelerations and pseudo-static analytical techniques employing Bishop's method (Reference 14) for slope stability, factors of safety against sliding under earthquake were computed. As a result of these computations, it was concluded that the embankment portions of the dam could safely withstand an earthquake at least one order of intensity greater than the design-basis earthquake, and probably more than this, without serious distortions or shear failures. Stability analyses for static loading conditions and for rapid drawdown showed conditions well within accepted limits. Shearing strengths of soils used in these analyses were based on both static and dynamic testing of soil to determine the behavior under long-term and short-term loadings. Procedures and results are described in detail in Reference 13.

Analyses of the stability of the retaining wall of the spillway for earthquake conditions were made by using two different approaches. These were the Monobe-Okabe seismic coefficient analysis (Seed and Whitman, Reference 15) and the dynamic finite element analysis. Both were made using maximum horizontal acceleration at rock level of 0.12g horizontal and 0.08g vertical, acting simultaneously. Results of the two methods were in good agreement. These analyses showed that, for the design-basis earthquake, the resultant forces would stay well within the base of the retaining wall. They also show that contact pressures at the toe of the wall upon the rock would be less than 250 psi (approximately one-third of the allowable bearing capacity for sound rock), and that the coefficient of total horizontal loads to total vertical loads would be less than 0.7. These values indicate that the wall is stable and safe under the DBE conditions.

Under transverse earthquake forces, the embankment section of the dam will deflect in an upstream-downstream direction. The spillway, however, is essentially a rigid structure in this direction, and will move with the foundation rock. Bending distortions, therefore, will develop in the upper portion of the dam under earthquake conditions, since the portion close to the spillway will tend to be restrained, while portions further away will deflect essentially as a vertical shear beam.

If the shearing stresses associated with this bending were excessive, cracking of the soil could occur, particularly along the face of the spillway retaining walls. Analyses indicate that shearing stresses along the face of the spillway walls, necessary to restrain relative motion between the embankment and the walls, are on the order of 100 psf. This stress is only a small fraction of the shear strength available to resist motion. This analysis indicates that cracking along the face of the spillway retaining walls would not be a hazard under earthquake conditions.

An evaluation has been made of the stability of the spillway structure and radial gates. These analyses were made for normal operating Lake Anna level and for the design-basis earthquake, using procedures of Westergaard and Von Karman (Reference 16) to ascertain dynamic loadings. Friction values, overturning factors, and bearing pressures between rock and concrete were all found to be well within acceptable limits, indicating that the spillway is safely and conservatively designed.

Stresses in the radial gates, considering both static and dynamic loads, are well within acceptable stress levels. Stresses in the piers of the gate structure under earthquake conditions, considering both hydrodynamic and inertia loads, are also well within acceptable limits.

Thus, in the various cases considered, the dam was found to be conservatively designed, with adequate stability for the dynamic loads from the design-basis earthquake.

3.8.3.3 **Construction of Dam**

Construction of the dam was closely controlled to ensure compliance with specification and design objectives.

On excavation of overburden materials to sound rock under the central high portion of the embankment, the bedrock surface was carefully cleaned, examined for joints and open cracks, and the rock structure mapped. Beneath the core section of the embankment upstream from the chimney drain, the rock surface was treated with dental concrete and slush grout to provide a relatively uniform sealed surface on which the base of the embankment was bonded.

Joints within the sound bedrock beneath the embankment core section were sealed with a neat cement grout curtain approximately 50 feet deep. This curtain extends across the main valley upstream from the centerline of the dam and continues beneath the spillway, as shown on Figure 3.8-23.

Each end of the grout curtain terminates at the limits of the upstream blanket in combination with the north and south slurry trenches, which seal the ends of the blanket to bedrock. On detailed evaluation of the grouting program, it is concluded that joints within the sound bedrock have been effectively sealed.

3.8.3.4 **Quality Control**

An extensive quality control program was carried out to ensure the quality of the constructed dam. Special provisions relating to the embankment construction are summarized as follows:

1. The borrow areas were inspected daily to detect moisture conditions, deleterious materials, and any obvious changes in borrow material properties.
2. Continuous inspection was made to determine the need for excavation, including unsuitable foundation materials and compacted embankment materials not meeting specified requirements.
3. Continuous inspection was made of fill material quality and properties.
4. Continuous inspection was made of fill placement methods and procedures.
5. Testing was conducted daily to evaluate fill compaction and moisture content. The measured results were compared with specified requirements, and removal, reworking, or additional compaction was required where compaction or moisture content did not meet specified requirements.

An unusually high standard of moisture and compaction control was achieved for an earth dam embankment. The cumulative results of compaction and moisture variation within the completed embankment are presented in the form of a histogram of test results shown on Figures 3.8-29 and 3.8-30. Where test results did not comply with specified values, the material involved was either removed or reworked and recompacted. Testing of the reworked material was found to meet specifications.

3.8.3.5 **Instrumentation of Dam**

A program of continuing surveillance has been established to (1) monitor the alignment and settlement of the centerline crest of the dam, (2) monitor the quantity of discharge from the collector drainage system, (3) monitor the pore water pressure within the embankment foundation at selected locations to determine the long-term steady-state seepage conditions, (4) monitor the head of water within the blanket drain at five locations beneath the high central portion of the dam embankment to determine seepage discharge gradients through the blanket drain, and (5) monitor the water level within or flow from each relief well along the toe of the dam to aid in evaluating seepage conditions through the foundation.

The locations of instrumentation devices used in monitoring the performance of the dam are shown on Figure 3.8-23. A summary of the monitoring program to be followed and the evaluation of data to be made is presented in Table 3.8-12.

3.8.4 Service Water Reservoir and Pump House

3.8.4.1 **Description of Reservoir**

The Service Water Reservoir is located approximately 500 feet south of the station site area, as shown on Figure 1.2-1 and Reference Drawing 10. This reservoir was constructed by diking an area between two adjacent gullies and excavating from the area behind the dikes to provide the required volume of emergency cooling water. The reservoir shown in Figure 3.8-31 has a bottom surface area of approximately 7.9 acres and a storage capacity of 88 acre-ft. below Elevation 315. Approximately 500 feet of the 3000-foot perimeter is formed by excavated slopes, with an impounding dike forming the remaining 2500 feet.

The cross sections developed for the excavated slopes and impounding dikes are shown in Figure 3.8-33. Areas below Elevation 305 were filled with impervious earth fill. The overburden beneath the dikes and lining was stripped and grubbed or excavated, as required, and thoroughly compacted before any fill was placed. The impervious core and lining were founded directly on this compacted surface, which was scarified before fill placement to ensure bonding. The material for the compacted impervious fill to Elevation 305 for low areas and for the core of the dike was residual soil, excavated from the station area, which was placed and compacted under careful control. The width of the impervious dike core is variable, and connects directly with the select earth lining. The Service Water Reservoir lining has a minimum thickness after compaction of 2 feet, and extends up all excavated slopes to above maximum water level. This select earth lining material, derived from the upper portion of the residual soil profile, has a high clay content, a very low permeability, and is plastic in nature. This plastic nature permits deformation without cracking.

Immediately downstream of the impervious dike core is a transition filter zone of sand filter and coarse filter, which provides internal drainage and forms a transition zone between the impervious core and the compacted rock shell on the exterior portion of the dike.

Material for the rock shell was obtained from excavation of slightly weathered to fresh hornblende gneiss and granite gneiss in the station site area. The rock was processed and sized to form a durable, dense rock fill with high shear strength.

The inboard faces of the impounding dikes and excavated slopes are protected against erosion with a layer of dumped rock slope protection.

3.8.4.2 **Foundation Exploration**

The service water reservoir site was investigated by 10 borings. Eight of these borings (41 through 48) were drilled in and near the reservoir area, and the logs of these borings are included in a document entitled, *Report, Site Environmental Studies, Proposed North Anna Power Station, Louisa County, Virginia, Virginia Electric and Power Company* (Reference 17). Two additional borings, SWR-1 and SWR-2, were drilled at the pump house location and are presented on Figure 3.8-34. In general, these borings show that the service water reservoir is underlain by granitic gneiss that has weathered to fine to medium silty sand and micaceous fine silty sand. Borings and refraction seismic surveys indicate that the depth to bedrock varies from 60 to 80 feet.

Further detailed investigations are reported in Appendix 3E.

3.8.4.3 **Material Properties**

The physical properties and strength parameters of the principle materials of construction are listed in Table 3.8-13. The properties and parameters of the impervious core material were determined by laboratory tests. In general, the testing program included the determination of index properties, grain size distribution, moisture density relationships, and the evaluation of total and effective and consolidation stress strength parameters by the triaxial testing prepared samples.

Physical properties and strength parameters of the rock shell and filter materials were selected on the basis of empirical formulas and prior experience. The selected values are conservative for materials of similar gradation and density.

The effective and consolidation stress strength parameters for postulated relic surfaces within saprolite foundation materials were based on test results reported by Horn & Deere (Reference 18). These values were considered to be conservative.

Results of field and laboratory investigations of material properties related to strength, consolidation, permeability, and liquefaction potential are reported in Appendix 3E.

3.8.4.4 **Analysis of Stability**

Stability analyses of critical dike sections were made to evaluate the factors of safety for all anticipated operating conditions of the service water reservoir. To assess the stability of the dike under both static and dynamic loading conditions, two types of failure patterns were analyzed. Using various radii with centers selected over a grid pattern, the critical circular failure surface was found to pass through both dike and foundation materials, which had the factor of safety as shown in Table 3.8-14. Circular failure surfaces were analyzed using the *Simplified Bishop Method*, while wedge failure surfaces were analyzed using the *Morgenstern-Price Method*. Since the factor of safety for dynamic loading conditions is greater than 1.0, slope displacements during the design-basis earthquake will be negligible (Reference 19).

An evaluation of the possible effects of relic joint surfaces in the saprolite soil structure was made using wedge-shaped failure surfaces. It was assumed that a segment of the failure surface passed along a postulated relic joint surface. The strength along such a seam was taken to be considerably lower than that of the surrounding saprolite, as shown in Table 3.8-13. The bottom surface elevation of the central wedge was varied to determine the critical pattern. This pattern shows an acceptable minimum factor of safety, as given in Table 3.8-14.

In this method, a computed factor of safety of 1.0 under combined static and dynamic loads indicates initiation of inelastic distortions. Since the analysis is made for a single peak acceleration, a number of cycles of loading to dynamic loads sufficient to produce computed factors of safety less than unity would be required to develop significant distortions in the structure. Acceleration values of 0.18g horizontal and 0.12g vertical were used in the calculation of the dynamic factors of safety. These values are conservative, and allow for 50% amplification of the design-basis earthquake value of 0.12g horizontal input at bedrock.

The calculated factors of safety of the service water reservoir dikes under static and dynamic loading for the anticipated operating conditions of the reservoir are given in Table 3.8-14. The values of dynamic factors of safety given in the table are based on an analysis using total, undrained, or consolidation stress strength parameters, which is appropriate for the short-term loading under earthquake forces. In all cases, the calculated factors of safety were considered conservative.

The design of this reservoir and dike system was approached conservatively, using design procedures, methods of analysis, and considerations typical of those used for major earth dams.

Differential distortions of the dikes under static and dynamic loading conditions are negligible. Cracking of the reservoir bottom due to differential settlement under static or dynamic loading is not anticipated. Relative displacement along the centerline of dikes due to earthquake ground waves will not exceed 3 inches. This is computed from the ground displacement spectrum normalized to 0.18g, taking the total relative displacement, peak to peak, for a half wave length for the shear wave equal to the distance between points considered. The impervious core will sustain this relative displacement without cracking.

Additional information on soil stability is given in Appendix 3E.

3.8.4.5 Settlement of the Service Water Pump House

3.8.4.5.1 Original Bases

The dikes and pump house are founded on moderately dense, well-graded sandy silt or silty fine sand and clayey silt. General depth to bedrock beneath the dikes and pump house is approximately 60 to 80 feet. Because of the varying height of the dikes, differential settlement along the crest was anticipated.

The service water reservoir pump house is located within an enlarged section of the dike and is supported on a reinforced-concrete mat founded directly on the compacted impervious reservoir lining. This lining is underlain by approximately 65 feet of moderately dense sandy silt.

Because of the nonuniform loading imposed by the dike and pump house on foundation materials, it was anticipated that the pump house would experience greater settlements under its northern edge (near center line of dike) than along is southern edge (toe of dike). Because of the monolithic nature of the pump house, this angular rotation about its base will not cause any structural distress.

3.8.4.5.2 Additional Settlement

In 1975 it was observed that the service water pump house was settling more than anticipated. In accordance with numerous communications with the NRC, the following actions were taken:

1. Additional soil testing has been performed. Results of a series of tests are reported in Appendix 3E.
2. The relatively unpredictable response of the saprolite soil appeared to be sensitive to ground water. Consequently, an extensive network of horizontal drains has been installed, as described in Section 3.8.4.6.
3. A program was developed for periodic monitoring of settlement, with frequency, limits, and responses described in the Technical Requirements Manual (TRM).
4. Because settlement of the pump house causes deflection of the piping attached to the structure, changes were made, as described in Section 3.8.4.5.4, including installation of expansion joints in the 24-inch service water piping. Deflections at these joints are monitored in accordance with the TRM.

Reference 20, in response to NRC questions related to a request for changes in the original Technical Specifications, reported in considerable detail on amounts of settlement measured and structural details of the pump house.

As the pump house is located within the Service Water Reservoir and is surrounded either by impervious lining or core, this settlement will have no effect on the watertightness of the reservoir. Lateral soil loads on the walls of the pump house under dynamic conditions have been considered in its design.

3.8.4.5.3 Monitoring of Settlement

At intervals defined in the TRM, the elevations of points of interest are measured by accurate survey. Points located on structures at the service water reservoir and at the main plant, including the service water pump house, service water lines, service water valve house, service water tie-in vault, service building, and main steam valve house, have been monitored for settlement in some cases since 1975. Most of the points are no longer monitored since minimal movement had occurred. The structures and components which are being monitored are listed in Table 3.8-15. This table also provides the initial baseline elevations for these points. These baseline elevations are periodically compared to current values: if the change exceeds prescribed limits given in the TRM, appropriate action is taken. Settlement markers located at or near the service water reservoir are shown on Figures 3.8-31 and 3.8-60. Four settlement markers are provided for both the service water valve house and service water tie-in vault. Settlement markers at the main plant are shown on Figure 3.8-59.

The baseline surveys meet the accuracy requirements of a second-order, Class II survey as defined by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Survey.

3.8.4.5.4 Effect on Piping

3.8.4.5.4.1 *Service Water Piping to Main Steam Valve House.* The NRC Office of Inspection and Enforcement, Region II, was notified by VEPCO on December 15, 1976, that the service water piping between the main steam valve house and the service building for Unit 2 may be overstressed due to differential settlement between these two buildings. This notification was made under the provisions of 10 CFR 50.55(e). Subsequently, a final report was filed on January 14, 1977 (Serial No. 002), in which it was stated that the service water lines would be replaced in this area to preclude any possible deleterious stress development due to differential settlement.

1. Foundation conditions along the 14 line are shown in Figure 3.8-35. Foundation contact pressures (based on dead loads only) at the service water line connections (14 line) are 4500 psf for the service building and 2500 psf for the main steam valve house.

2. The elevations of the service building and the main steam valve house were not monitored continuously from the time immediately following construction; therefore, measured values of actual settlement, rate of settlement, and tilt over a long time period are not available.

3. The differential settlement used to analyze the service water lines was based on the total apparent settlements of the service building and main steam valve house given above. The settlement of 0.224 foot for the service building was extrapolated backward in time, using the same rate of settlement as has actually been measured at the northwest corner of the

service building. From this extrapolation, it was calculated that the differential settlement between the two structures during the time period between installation of the pipes and the end of 1976 was 1.1 inch.

4. When the service building settled, the building settlement imposed deformation boundary conditions on the composite structure of the service water piping and the concrete encasement. The theory of beams on elastic foundations and NUPIPE II (computer program ME-110, *Computer Code for Stress Analysis of Nuclear Piping*, Stone & Webster Engineering Corporation) were used to compute stresses in the pipe.

   The actual computation was done by using the NUPIPE II program (Reference 21). The composite beam of piping, concrete, and rebars was converted into an equivalent pipe of a homogeneous material. See Figures 3.8-36 through 3.8-38 for construction details and equivalent pipe details. The concrete was assumed to take compression only when the composite beam was subjected to bending. The effects of soil stiffness were represented by a series of elastic "soil springs" acting along the pipe. The spacing of the springs was calculated based on the theory of beams on elastic foundations to ensure that the pipe length in between any two consecutive soil springs falls within the short beam range. In other words, each pipe element is a sufficiently small element for numerical computation.

   Building settlements, as discussed above and as predicted for the future, were applied as differential settlements between the buried pipe and building. The anchor at the service building was conservatively assumed as a rigid anchor to the buried pipe. The settlement of the service building becomes the deformation boundary conditions of the buried pipe. Bending moments were obtained from the NUPIPE II program. Stresses in the pipe were then calculated from the bending moments. The calculation performed that indicated a possible overstress condition in the pipes was based on the NUPIPE II model shown in Figure 3.8-37.

   To compute the total future stresses for the service water lines after a section of pipe was replaced, two calculations were made. The first calculation was performed to obtain the stresses in the pipes without the section that was replaced. The settlement to date (1976) was applied to the cantilever beam, which had a free end boundary condition assumed at the point where the pipe was replaced. The second calculation was performed to obtain the stresses in the pipes after repair.

   The future settlement was applied to the NUPIPE II model (Figure 3.8-38) of the complete service water lines between the service building and the Unit 2 main steam valve house. The sum of stresses from the first and second calculations—namely, from the settlement to date and future settlement—were checked against the allowable stress and were found to be within the allowable limit.

In accordance with Section NC3652.3(b) of the ASME Boiler and Pressure Vessel Code, Section III, Winter 1976 Addendum, the effects of any single and repeated anchor movement (e.g., building settlement) shall meet the requirements of Equation 10a, for which the allowable stress is $3S_c$. No dynamic loadings are included in Equation 10a, since such dynamic effects are cyclic in nature.

5. For the analysis of possible existing stresses prior to repair, values for the moduli of vertical subgrade reaction were assumed to be 100 and 300 tons/ft^3 for the saprolite and structural fill, respectively, based on Figure 11-8 of NAVDOCKS DM-7. These are similar to the values used for the analysis of the service water lines at the service water pump house. Analysis of the service water lines between the service building and the main steam valve house indicated a possible overstressed condition even for the lower modulus of 100 tons/ft^3.

   The stress analysis used a modulus of 300 tons/ft^3 under the pipe encasement not disturbed by the repairs, and a modulus of 100 tons/ft^3 under the section of pipes that was replaced. Backfill specifications called for lightly compacted fill to minimize future settlement stresses.

   To prevent the possible overstress, a portion of the concrete encasement was removed along the main steam valve house wall, as shown on Figure 3.8-39, and a section of each pipe was replaced. The extent of the excavation needed for the repairs is shown on Figure 3.8-40.

3.8.4.5.4.2 *Mathematical Model for Buried Piping Near the Service Water Pump House.* A detailed sketch of the mathematical model used in the recent stress calculations is shown in Figure 3.8-41. The beam on an elastic foundation and NUPIPE piping stress program are used as the model to perform stress calculations. The buried piping is regarded as a beam, whereas the soil stiffness effects are represented by a series of elastic “soil springs” acting along the beam (pipe). The coefficients of subgrade reaction and the spacing of the soil springs are the same as those used in the analyses performed in 1975. The spacing of the springs, d = 3.0 ft., was chosen so that the pipe length between any two consecutive soil springs falls inside the “short beam” range (Reference 22).

Except near the pump house, the springs were used in pairs: one perpendicular to the pipe in the horizontal plane, and one perpendicular to the pipe in the vertical plane. Near the pump house, the first kind was omitted because that area is beyond the range of influence of the bending moments produced at the buried elbows. The formulas used for the spring constants were:

$$K_H = K_{OH} D_O d \text{ and } K_V = D_O\, d\, (K_{OH} \sin^2\Theta - + K_{OV} \cos^2\Theta)$$

where:

d = spacing of springs, in.

D_O = outside diameter of pipe, in.

K_{OH}, K_{OV}= coefficients of subgrade reaction

Θ = slope of pipe, degrees

K_H= horizontal spring constant

K_V= vertical spring constant

Internal spring constants represented the stiffness of the expansion joints. As one boundary condition, the piping was assumed to be fixed at a point far from the 47-degree elbow in which the peak stress occurs. This point is in nonsettling soil. As a second boundary condition, the soil springs along the pipe were caused to settle according to the settlement profile (Figure 3.8-42). The penetration of the pipe through the north face of the service water pump house was considered as the other terminal fixed end of the model. A settlement value equal to the largest settlement experienced by the four service water lines at their penetrations through the north face of the service water pump house was imposed at that fixed end of the mathematical model. No other boundary conditions were imposed. The restraining effect of friction was modeled as an axial force applied to the pipe.

The analysis of the model was carried out in two parts. First, the stresses due to the action of the soil settlement were computed. This run also provided conservative values for expansion joint movements. Second, a computer run was made with zero settlement, but with an axial force acting near the point where the pipe enters the soil, representing friction of the buried pipe up to the first buried elbow. Friction forces beyond this elbow will not affect moments and stresses there. Stress levels throughout the pipe were considered to be the sum of the stresses computed separately by the two runs.

The conservatisms in the analysis are:

1. The stress at each point was calculated from the sum of the resultants of the moments from the two runs described above, rather than adding the moments by components and then calculating the stress.
2. The vertical coefficient of subgrade reaction was twice that of a reasonable estimate.
3. In calculating friction, the soil lateral pressure due to soil overburden was assumed equal to the soil vertical pressure. Generally, the lateral pressure is significantly less.
4. The assumed soil density of the dike was 135 pcf.
5. The soil/pipe coefficient of friction used was 0.6 for the dike material and to 0.4 for the material beyond the dike. This and items 3 and 4 ensure that the calculated value of the friction force is conservatively high.
6. The method of calculating differential motion across the expansion joint assembly was conservative because it assumed that friction was not present. The effect of friction is to oppose motion at the joint due to settlement. The canceling effect will make the actual movements much smaller than those provided to the expansion joint vendor for evaluation.

3.8.4.5.4.3 *Resistance to Collapse.* The service water piping can withstand effects of loads and movements generated by the 0.66-foot settlement allowable. This conclusion is based on a comparison of stress levels with the allowable stress in the piping materials for settlement loading conditions.

A second basis for confidence is a comparison of compressive stress levels against those required for local elastic instability. The compressive stress caused by frictional forces is about 10,000 psi. The compressive stress required for instability (Reference 23) is on the order of 100,000 psi. Thus, deformation initiated by elastic instability is not expected.

A third basis is the effect of the soil in which the pipe is buried. The restraining action of the soil, combined with the internal pressure in the pipe, serve to augment the natural stability of the pipe wall. (The external soil pressure is only one-quarter of internal pressure.) The surrounding soil will also prevent Euler buckling.

Additionally, it can be demonstrated that, should instability be arbitrarily postulated, the effects would be limited by the secondary nature of the forces involved.

The friction force is generated by soil movement relative to the pipe, so piping movements cannot exceed soil movements. If instability were postulated, and if the pipe were assumed to move the maximum amount possible, the resulting deformation and flow area change would be insignificant to system performance.

Figure 3.8-43 illustrates the above rationale. The maximum movement possible is equal to the total soil compression along the pipe that is generated by the settlement gradient, as shown in Diagram "A" on Figure 3.8-43. If the instability points are postulated to occur at three adjacent stress peaks, as shown in Diagram "B" on Figure 3.8-43, the rotation that can occur at the elbow is no greater than 2.2 degrees. This worst-case value for the amount of distortion in the elbow would result in a flow area change of less than 1%.

It is concluded that no general collapse is possible, and that any conceivable deformations of the piping would still allow the system to operate at the required capacity.

3.8.4.5.4.4 *Code Stress Limits.* The ASME Code stress limit for "single, nonrepeated anchor movements" is stated in Equation 10a to be $3S_c$, where S_c is listed in Appendix I to the section. For the pipe and fitting material used in the service water system, $S_c = 13{,}700$ psi, which gives a settlement stress allowable of 41,100 psi. This value does not include the benefit of measurements on the actual material. For example, the measured yield strength of the 47-degree elbow is 37,000 psi (Reference 24), as compared to 30,000 psi listed in the Code Appendix I.

3.8.4.5.4.5 *Expansion Joint.* Prior to February 2002, metal expansion joints were installed in the service water supply piping near Service Water Pump House (SWPH) to accommodate settlement of SWPH and piping.

In February 2002, it was identified that the expansion joint 1-SW-15A1C was damaged due to corrosion. In an interim configuration, the metal expansion joints were replaced with 36-inch diameter 0.375-inch thick spool pieces on a temporary basis to justify temporary operation until permanent resolution was implemented. The permanent resolution was implemented through design change to install rubber expansion joints in place of original metal expansion joints to accommodate future settlement.

Technical Requirements Manual (TRM) Table 3.7.7-1 limits the allowable differential settlement between SWPH (monitoring points 7, 10) and service water piping (monitoring points 17, 18) to 0.22 foot as measured since July 1977. The settlement data indicated a cumulative differential settlement of 0.103 foot measured from July 1977 until February 2002. Thus, a future differential settlement of (0.22 foot - 0.103 foot) = 0.117 foot will be within the limits of the TRM.

The rubber expansion joints have four open arch convolutions and can safely accommodate 0.292 foot of differential movement in lateral direction. The projected differential settlement at the expansion joint is 0.117 foot, which is 40 percent of the allowable. This leaves enough available movement in the expansion joint for dead weight and seismic conditions. These rubber expansion joints can also accommodate 0.583 foot of movement in compression and 0.292 foot in elongation. However, the elongation is restricted by control rod settings in the field. The allowable cycles of loading for these rubber expansion joints far exceed the expected lifetime cycles. Therefore, fatigue for these rubber expansion joints is not a concern. The piping system was reanalyzed with rubber expansion joints and the stresses in the piping system remained within the allowable limits of applicable code in all loading conditions including seismic.

The plant maintenance program monitors aging of the rubber expansion joints and replaces them periodically.

3.8.4.5.4.6 *Effects on Service Water Pumps.* The manufacturer's requirement for alignment of the service water pumps of 0.10 in/ft (0.5 degrees) maximum allowable tilt is a "rule of thumb" to ensure that the pump shaft is plumb. The manufacturer's requirement of alignment for the 26-foot-long pumps corresponds to 2.6-inch displacement. The manufacturer has indicated that a displacement of 0.5 degrees would not adversely affect pump operability. The long-term results of operating at the maximum allowable displacement would be a slight bowing of the pump shaft.

After initial installation of the service water (SW) pumps into the service water pump house (SWPH) there was some concern about a change in alignment due to the settlement of the SWPH. Almost twenty years of measurements on the SW pump base plate determined that settlement of the pump house was not causing significant change in pump alignment. Also movement of the SWPH has decreased substantially. SW pump tilt methodology was determined in Virginia Power Calculation ME-0532 and it was determined that direct measurements of the SW pump are no longer required. The tilt could be conservatively determined from the SWPH settlement measurement and this change in methodology could be made following pump replacement (realignment of pump) per DC-95-015.

Due to the design of the system, the effects of pipe settlement will not be transmitted to the pump nozzles. The combination of the expansion joint on the pump discharge nozzle and the piping anchor 2.5 feet downstream effectively isolates the pump from piping-induced loads. Therefore, the maximum tilt angle is only a function of pump house differential settlement, and is independent of piping system interactions.

3.8.4.5.4.7 *Spray Piping Stress Evaluation.* The service water reservoir piping stress analysis, was performed in accordance with ND-3600, Section III of the ASME Boiler and Pressure Vessel Code up to 1971 addenda. The requirements for analysis of piping in accordance with ND-3600 (same as for NC-3600) are:

Condition 1: The sum of stresses due to effects of pressure, weight, and other sustained mechanical loads within S_h (allowable stress range for material in the hot condition).

Condition 2: The sum of stresses due to effects of pressure, weight, other sustained loads, and occasional loads, including operating basis earthquake, within 1.2 S_h.

Condition 3: The sum of stresses due to effects of pressure, weight, other sustained loads, and occasional loads, including design-basis earthquake, within 1.8 S_h.

Condition 4: The stresses due to the effects of thermal expansion within S_A=1.25 S_c + 0.25 S_h (where S_c = allowable stress range for material at room temperature), or the sum of stresses due to effects of pressure, weight, other sustained loads, and thermal expansion within S_A + S_h.

Besides the above requirements, the stresses in the piping due to the effects of one time relative settlements were calculated independently of any other loading and kept within 3 S_c.

Each of the two 36-inch carbon steel return headers with expansion joints outside the north wall of the valve house, branches into two 24-inch headers inside the valve house. The expansion joints allow for a relative settlement of 1/2 inch between the buried return headers and the valve house structure. Each 24-inch header then branches into two 18-inch headers that exits the valve house south wall. There are eight 18-inch headers that exit the valve house south wall and enter the Service Water Reservoir. Each 18-inch header is supported above the reservoir water level and contains a pair of hinged expansion joints. Each pair of hinged expansion joints acts as a toggle to accommodate relative settlement of 3 inches between the valve house and the first vertical support located in the reservoir. Each of these eight 18-inch headers supply service water to the corresponding spray array in the reservoir.

To address the potential for long-term settlement of the Service Water Reservoir piping support structures, 3/4 inches of relative settlement between two adjacent supports 25 feet apart was considered in the settlement analysis.

For the spray piping stress evaluation, thermal flexibility, deadweight, seismic, water hammer and settlement analyses were performed. For the dynamic analysis of the underwater winter bypass piping attached to the south wall of the valve house, hydro-dynamic masses equal to the weight of the volume of water displaced by it were added to the weight of the pipe and its contents.

3.8.4.5.4.8 *Abandoned Spray Piping Near the Pump House.* Four 24-inch steel pipes extend from the south wall of the pump house to hangers, approximately 35 feet to the south, mounted on a common footing. These lines were abandoned following tie-in of the new service water spray and bypass system. The four lines will retain their seismic qualification in order to not affect any safety-related components in the Service Water Reservoir, however, the lines will no longer be classified as safety-related.

3.8.4.5.4.9 *Erosion of the SWR Liner Material.* Material could possibly be eroded by one of two methods in the service water reservoir:

1. Material could be eroded by the flow of water over the surface of the liner to the pump intakes. Tests performed at MIT with soil from the North Anna service water reservoir indicate that flow rates greater than .55 ft/sec are necessary to start erosion of the liner. A concrete apron has been placed around the intake to the service water pump house to a radius of approximately 82 feet. With this apron, the maximum flow rate expected across the impervious liner is 0.2 ft/sec. Therefore, this type of erosion is not expected.
2. Material could be eroded as a result of operation of the underwater winter bypass headers at the service water valve house. The bypass piping was designed such that exit velocities would be minimized. A coarse aggregate erosion liner apron has been placed on the reservoir bottom in the vicinity of the bypass piping discharge. The apron was sized to ensure that velocities over the clay liner are within the limits described in Item 1 above. Therefore, this type of erosion is not expected.

3.8.4.6 Ground-Water Control Beneath the Service Water Pump House

In response to a request by the NRC, design and field work was performed for a system to maintain the average ground-water level beneath the service water pump house at Elevation 275 MSL. The purpose of this system, as outlined by the NRC, is to minimize or avoid additional settlement and/or loss of stability that might be caused by increases in ground-water levels due to seepage from the service water reservoir.

Initially, a system of vertical wells located near the pump house was investigated. Three test wells were installed, and pumping tests were conducted to determine final design parameters. Details of test wells are shown in Figure 3.8-44, and locations are shown in Figure 3.8-45.

After installation of the three test wells, TW-1 was pumped at various rates during an 8-day period to observe the effect of pumping on other wells, piezometers, and water levels in slope indicator casings. At a pumping rate of 1.25 gpm, the inflow capacity of TW-1 was exceeded, with water level in the well dropping about 25 feet in a 40-minute period.

Two types of pump tests were conducted. Initial "step-drawdown" tests consisted of pumping TW-1 at rates of 1, 0.8, and 0.5 gpm, and observing rate of drawdown and elevation at which water level in TW-1 stabilized. Following this, TW-1 was pumped at a constant rate for 74 hours, and the effect on adjacent wells, piezometers, and slope indicator casings was measured. Distance vs. drawdown and time vs. drawdown data are shown in Figures 3.8-46 and 3.8-47, respectively.

The pumping tests generally confirmed the expectation that foundation soil permeability is low and that control of the water table beneath the pump house would require either a large number of wells or, with a limited number of wells, an excessive drawdown at each well. Placement of additional wells through the pump house floor was not possible, and locating wells along the outside periphery of the pump house would require penetrating the impervious clay liner. Although methods of sealing well penetrations through the clay liner are available, to obtain complete assurance of the effectiveness of such seals would be difficult in advance of Service Water Reservoir filling.

A scheme was investigated that would involve two clusters of wells (approximately five in each cluster) located at the northeast corner and the northwest corner of the pump house, which would not involve penetrating the impermeable liner. This arrangement could maintain a constant but sloping phreatic surface beneath the pump house. It was estimated that to maintain the ground water at Elevation 275 (approximate existing elevation) beneath the south edge of the pump house, the ground-water level 15 feet away from each well cluster would be at approximately Elevation 265. The disadvantage of this approach is the potential for inducing increased settlement along the north side of the pump house. However, well clusters located at the northeast and northwest corners of the pump house were considered to be the best method of ground-water control using vertical wells. The design of additional wells would be the same as the three initial wells, except that the well screen diameter would be reduced to 4 inches.

During installation of the test wells, it proved impossible to drill through the rock fill zone at the dike surface, and it was necessary to excavate this material by backhoe. Replacement of the fill material to its original density was difficult and, in this respect, installation of vertical wells was proven undesirable from the standpoint of dike integrity. Pipes in the vicinity of the pump house in some cases would prevent location of additional wells at desirable points.

Because of the disadvantages of vertical wells, a system of horizontal drains, of the type used for drainage of permanent cut slopes, was designed. A trial drain (Drain 1) was installed for the purpose of testing feasibility of available construction and survey methods, and confirming the ability of the drains to remove ground water without loss of fines.

Horizontal drains offer the advantage of maintaining a relatively uniform ground-water surface with minimum potential for induced differential settlement. At the designed maximum spacing of 16 feet, the maximum drawdown, measured from the midpoint between drains, is 1.5 foot. This estimate is based on an inflow rate equal to the estimated seepage quantity from the entire reservoir of 15 gpm, using standard design methods for spacing of drains (Reference 25). It is recognized that the nonhomogeneity of foundation materials will result in minor local variations in ground-water level.

Installation of Drain 1 was completed on October 8, 1976. Location of the drain is shown in Figures 3.8-48 and 3.8-49, and water quality data collected during the first 10 days of operation are plotted in Figure 3.8-50. At the initial flow rate of 3.8 gpm, the drain flowed one-third full, and outflow appeared to be clear within a few hours after completion of installation.

Drain 1 was installed by advancing BW casing by rotary drilling to the planned depth, inserting the 1.5 inch i.d. slotted PVC drain pipe within the casing, and removing the casing. The annulus between drain pipe and soil was grouted at the outlet end to prevent seepage around the drain pipe.

It was concluded that the additional drains could be safely installed by basically the same method used for the initial drain, with some modifications in drilling tools and techniques. The horizontal alignment of Drain 1 could not be measured with the prototype survey instrument available at the time of installation. Measurement of the alignment of the remaining drains became possible by modifying the “Deflectometer” survey instrument manufactured by Terrametrics, Inc., to permit its use in a range of casing sizes. This instrument can reliably measure drill casing location with an estimated accuracy of ±6 in/100 ft depth.

Water quality tests to supplement visual observation of the Drain 1 outflow showed that no removal of fines occurred and that turbidity and suspended solids in the drain outflow were both considerably lower than in samples taken from the service water reservoir. (For comparison with values shown by Figure 3.8-50, a water sample from the reservoir on October 9, 1976, had a turbidity of 3.4 ppm and suspended solids of 5.5 ppm.) Outflow from Drain 1 was collected and allowed to settle in a drum for the initial 10 days of flow. The quantity of sediment collected was not measurable and probably represented material introduced into the drain by rods used to insert survey instruments.

Figure 3.8-51 shows a comparison of drain slot size (0.010 inch) with gradation of typical saprolite. The size is adequate from the standpoint of both prevention of loss of fines and drain capacity requirements. This slot size is about equal to the D_{50} size of the middle range of foundation soil gradations. Sizing of well screen slots equal to or less than the D_{50} size of adjacent materials is general practice, although the applicability of this criterion (References 26 & 27) depends on the soil type and its resistance to piping. Experience with Drain 1 indicated that the slot size is satisfactory.

The additional five horizontal drains required to complete the ground- water control system were installed during the period of June through August 1977, as shown in Figures 3.8-48 and 3.8-49. The procedure developed for drilling the holes for the drains consisted of, first, advancing 40 feet of HW casing (4-inch i.d.) at an initial upward slope of twice the planned final slope of the drain; this heavy casing would drop over this 40-foot length to the correct slope. Then a total length of 100 feet of NW casing (3-inch i.d.) was drilled through the HW casing and, after every 10 to 20 feet of penetration, the “Aquaducer” survey instrument was used to measure the slope of the casing. Whenever the casing departed from the planned slope, the drilling technique was altered to correct the attitude of the casing or, in many instances, the casing was withdrawn 30 feet or more and redrilled very slowly. Finally, BW casing (2-3/8-inch i.d.) was drilled through the NW casing to the planned depth, with frequent slope measurements and redrilling where required. Before inserting the PVC drain pipe and withdrawing the casing, the “Deflectometer” was used to survey the horizontal departure of the BW casing from the planned direction.

The success of the painstaking installation procedure is obvious in Figures 3.8-48 and 3.8-49. At a depth equivalent to the center of the pump house, the average spacing of the drains is about 15 feet, and the average vertical position of the six drains is Elevation 274.6.

Following the installation of the drains, a similar drilling procedure was used to install a 3-inch PVC outlet pipe 130 feet to the northeast beneath the emergency dike. This pipe extends another 35 feet to a subsurface drain that empties into Canal “A.” A concrete gallery collects the flow from the six drains and diverts it to the outlet pipe. Access to the drains for monitoring and maintenance is provided by a manhole to the gallery.

Figure 3.8-52 summarizes the installation sequence of Drains 2 through 6 and the measurements of flow from each drain after it was installed. In addition, this figure shows the ground-water elevations (on the right-hand scale) measured in two piezometers and one test well in the vicinity of the drains (as shown in Figure 3.8-48). The time at which each drain was completed is shown at the top of the figure by the same symbol used to indicate the flow from that drain. (The installation of Drain 4 was interrupted when grouting was required to correct the slope.) A general relationship can be seen between the flow from each drain and the ground-water elevations as additional drains were installed, but it is obscured by an overall lowering of the ground-water table due to the lack of rain during this period.

Results of water quality tests on the flow from the six horizontal drains are shown in Table 3.8-16. These results reflect the influence of installing adjacent drains and should be considered with reference to Figure 3.8-52. Following the installation of all drains, the turbidity and suspended solids of the flow stabilized at very low or unmeasurable levels.

Monitoring of the outflow from the drains was performed on a monthly frequency, and a permanent program of monitoring and maintenance was established. Water quality tests were made at 3-month intervals for 1 year and at 6-month intervals thereafter. The water quality tests to be run will be suspended solids and turbidity. The Technical Requirements Manual requires a visual inspection of the clarity of the outflow from each drain to be performed in conjuction with the flow monitoring effort.

The monitoring of the rate of flow from the drains is continuing on a 6-month frequency. The requirement to monitor the turbidity and suspended solids was deleted as recommended in Reference 34.

3.8.4.7 **Dike Design and Evaluation**

3.8.4.7.1 Design Objectives

In the conclusion to his treatise on earth dams, Middlebrooks (Reference 28) lists design and construction criteria considered essential for the construction of an earth dam (or dikes) that will be unquestionably safe.

Of these, pertinent criteria used in the design of the North Anna service water reservoir were as follows:

1. Freeboard should be sufficient to prevent overtopping when the maximum possible flood occurs.
2. Seepage through impounding dikes should be controlled by proper zoning of materials or by pervious drains. The use of pipe drains within the embankment section should be avoided. Development of cracks in the embankment due to foundation or fill settlement should be avoided by proper consideration of slopes and abutments and by proper placement of fill material. Special attention should be given to the impervious core or lining to ensure that it will be sufficiently plastic to deform without cracking.
3. Foundation and embankments should not be overstressed in shear (slide potential).
4. The impervious section should be compacted to a density that will not produce settlement on saturation.
5. Slope protection should be provided to the crest of the dike to protect against breaching during a major storm.

Conformance of the service water reservoir design with the above objectives gives assurance of adequate conservatism to ensure safety of this critical structure.

3.8.4.7.2 Overtopping Failure

The most common cause of complete catastrophic failure of earth dams has been water flowing over the tops during great river floods when spillway capacities were inadequate. Overtopping of the dikes of the service water reservoir could only occur in two ways. The first would be by flooding during a great rain storm. Maximum probable precipitation for the North Anna area would produce 27.5 inch of rain in 48 hours. Since there is no contributing drainage area other than the area of the pond itself, the 60-inch freeboard provided in the design precludes overtopping from this cause. The second would be by overfilling of the reservoir due to runaway of the makeup pump. For such a runaway to occur, both the level control system and the level control alarm would have to fail. In the incredible event that both systems failed, pump runaway would have to continue unchecked for over 7 days before overtopping would occur. Should overtopping occur from some unknown reason, the design of the dikes using an outer rock shell is such that limited overtopping could occur without catastrophic failure. Such overtopping would be directed into Canal A and away from the plant site by the emergency dike shown on Figure 3.8-48.

3.8.4.7.3 Seepage Failures (Piping)

Piping, or progressive erosion of concentrated leaks, has caused a larger number of catastrophic failures than any other action except overtopping.

Piping most commonly occurs in homogeneous dams as a result of poor construction control, which can result in inadequately compacted material or pervious layers in the embankment, inferior compaction adjacent to concrete outlet pipes or other structures, or poor compaction and bond between the embankment and the foundation or abutments. Embankment leaks through differential settlement cracks have also been a major source of piping failures. However, many of the modern techniques of earth dam design and construction have been developed to prevent piping failures. The following techniques have been considered and incorporated into the service water reservoir design: (1) construction of the impervious lining of the dike with materials that by their nature have a high resistance to piping and are sufficiently plastic to accommodate differential settlement without cracking; (2) the introduction into the downstream portion of the dike of filter layers that form a transition in gradation; and (3) stringent requirements for uniformly compacted embankments, with emphasis on control of construction water content and density.

The material properties of the construction materials for the impounding dikes of the service water reservoir are listed in Table 3.8-13. With the exception of the graded sand and coarse filters, all materials were obtained on site. Lining material was obtained by selective borrowing from required excavations for the plant and appurtenant facilities. In particular, select earth-lining materials were obtained from selective excavation for the switchyard. These materials are described and classified in logs (Reference 17) of Borings 52, 53, and 54. In general, the materials selected and stockpiled are classified according to the Unified Soil Classification System as inorganic clays (CH), inorganic silts (MH), and clayey sands (SC). They are generally well graded, as shown in Figure 3.8-53, and have high to very high resistance to piping (Reference 29). These materials have sufficient plasticity to sustain the anticipated minor differential settlements without cracking (Reference 30). Also, because of relatively uniform foundation conditions underlying the reservoir, differential settlements and cracking at the abutments are not anticipated. After careful stockpiling, the stockpile was randomly sampled and the samples tested and reclassified to ensure that proper materials had been obtained and that no segregation existed.

Impervious earth fill materials were obtained from excavation of residual soils in the upper portion of the service water reservoir cut areas and generally consist of fine sandy silt with a low permeability.

The sand and coarse filters were obtained from a commercial source meeting gradation requirements, as shown on Figure 3.8-54. This gradation was established in accordance with universally accepted quantitative criteria developed in extensive studies by the United States Corps of Engineers, the United States Bureau of Reclamation, and other researchers. The results of these studies have demonstrated conclusively that properly designed filters provide complete protection against piping (Reference 31).

Rockfill for the construction of the downstream shell was obtained from the excavation of granite gneiss. The material is generally well graded, hard, angular, durable, and very pervious. Rockfill material was processed before placement to be sufficiently free of fines to ensure a free-draining downstream rock shell of maximum strength.

Another major source of piping failures has been along conduits built into or under an embankment. Such a failure will not be possible in the case of the North Anna service water reservoir because all service water piping was brought above the normal saturation level within the core section of embankment. Nor can a piping failure develop at the juncture of the impervious core and the pump house, as this structure is located completely within the reservoir and is totally surrounded by the select earth-lining material, which is plastic in nature.

3.8.4.7.4 Slide Failures

Calculated factors of safety for all operating conditions of the service water reservoir are given in Table 3.8-14. The strength parameters used in the stability analyses are listed in Table 3.8-13 and are considered conservative. The total, effective, and consolidation stress strength parameters selected for impervious core materials and foundation soils were lower bounding values from results of several controlled, undrained triaxial shear tests with pore pressure measurements. These tests were performed under careful supervision using the most advanced techniques and equipment, and the results are considered reliable. The strength parameters for the relic joint material were selected after reviewing pertinent mineralogical literature. The values used for design were based on laboratory tests run by Horn and Deere (Reference 18). Strength parameters selected for sand and gravel filter materials as well as the compacted rock shell are also considered conservative. Values for angle of internal friction, Ø, for well-graded sand and gravel mixtures compacted to a relative density greater than 70% are typically 40 to 45 degrees, and for well-graded compacted rock, 45 to 50 degrees or more. Thus the input to the stability analysis is conservative.

An additional conservatism used in the stability analysis is the input with respect to pore pressures. Pore pressures that exist within an embankment at any given time are generated as the result of two actions that can be considered independent for practical purposes: gravity seepage flow, and changes in pore volume due to changes in total stress. The stability of the dike slopes for the full-reservoir steady-state flow condition was analyzed using the effective stress method of analysis, and the pore pressures assumed to be acting were those governed by gravity flow through the embankment. However, for most well-compacted embankment materials, such as those specified for construction of the service water reservoir dikes, this approach is conservative, since shear strains, which may be imposed on the embankment after construction is completed and the reservoir is full, cause the soil to dilate and to reduce the pore water pressures temporarily. This dilation also imparts an apparent cohesion to granular materials; thus, factors of safety reported for downstream full-pool conditions under dynamic loading must be considered very conservative. The triaxial tests have clearly shown these soils to be strongly dilative when sheared.

The factors of safety reported in Table 3.8-14 are based on several hundred calculations using very sophisticated analytical procedures. In all cases, the factors of safety computed using extremely conservative input demonstrate that foundation and embankments are not overstressed in shear and, in fact, exceed factors of safety considered satisfactory for earth and rockfill dams several hundred feet in height.

3.8.4.7.5 Other Sources of Failure

The compactive effort and moisture content range specified for placement of compacted impervious fill are such that settlement will not occur during saturation of the embankment.

Slope protection is provided to and on the crest to protect the dike against breaching during a major storm.

An additional source of potential failure that has been considered is that of intentional sabotage. To cause a failure that would result in loss of cooling water, a section of the impounding dike would have to be breached. Considering the size of breach required to cause complete loss of the Service Water Reservoir, the compacted rock fill shell covering the dike, and the amount of explosives needed using commercially available high-density gelatin dynamites, it is not considered credible for such a sabotage attempt to occur unnoticed and unprevented.

To provide additional conservatism for flooding protection of the station, an emergency dike and intercepting channel has been constructed on the south side of the station. The channel is sized to safely divert the flow from a triangular breach in the Service Water Reservoir wall with the apex at the bottom line of the reservoir and the breach assumed to be instantaneous. The calculated flow through this assumed breach would be approximately 800 cfs. For design purposes, the flow was assumed to be 1000 cfs.

3.8.4.7.6 Construction of Reservoir

Construction of the service water reservoir dike and lining was closely controlled to ensure conformance with specifications and design objectives.

An extensive quality control program was carried out to ensure the quality of the constructed embankment and select earth lining. Special provisions relating to the embankment construction are summarized as follows:

1. The borrow areas were inspected daily to detect moisture conditions, deleterious materials, and any obvious changes in borrow material properties.
2. Continuous inspection was made to determine the need for excavation, including unsuitable foundation materials and compacted embankment materials not meeting specified requirements.
3. Continuous inspection was made of fill material quality and properties.
4. Continuous inspection was made of fill placement methods and procedures.
5. Testing was conducted daily to evaluate fill compaction and moisture content. The measured results were compared with specified requirements, and removal, reworking, or additional compaction was required when compaction or moisture content did not meet specified requirements.

A high standard of moisture and compaction control was achieved for the earth dike embankment and reservoir lining. The cumulative results of compaction and moisture variation within the completed embankment are presented in the form of a histogram of test results for compacted select earth lining, shown on Figures 3.8-55 and 3.8-56, and for impervious fill, shown on Figures 3.8-57 and 3.8-58.

3.8.4.7.7 Instrumentation of Dikes

A program of combining surveillances has been established to monitor the settlement of centerline crest of the dike and the pore water pressure at selected locations to determine the long-term steady-state seepage conditions.

The locations of past and current instrumentation and monitoring devices used in monitoring the performance of the dike are shown on Figures 3.8-31 and 3.8-32, respectively. A summary of the monitoring program currently followed and the evaluation of data made is presented in Table 3.8-17 and in Section 3.8.4.8. The current monitoring program was modified based on findings presented in References 34, 38, and 39.

3.8.4.8 **Reservoir Loss Monitoring**

A direct measurement of the leakage from the service water reservoir is not possible. Such a system would require that all seepage water be intercepted and collected by underdrains, and all normal ground-water flow be excluded from the collectors. Collectors located near the reservoir bottom or dike toe would collect ground water but would be of limited effectiveness, since they could be bypassed by some seepage tending to move to the lower ground-water table. A deep collector system would gather reservoir seepage more effectively but would also receive unknown quantities of ground-water inflow.

Piezometers can indicate changes in seepage rates but do not provide a means of measuring actual seepage quantities. Leakage rates predicted are on the order of only 1.5% of total expected water losses due to spray evaporation, surface evaporation, and spray drift. This calculated seepage rate is confirmed by more recent analyses (Report on Geotechnical Investigations of Service Water Reservoir, dated December 23, 1975), which considered outflow both with liner intact and with a portion of the liner removed. It was estimated that seepage losses with liner intact would be approximately 0.36 gpm per 100 ft of effective dike length, and that with a 50-foot-wide liner strip parallel to the dike removed (representing approximately 18% of the Service Water Reservoir area), seepage rates would be approximately 0.60 gpm per 100 ft, an increase of only 66%.

However, seepage losses under this postulated severe condition would still total only 2.3% of total expected normal losses, which is insignificant. Seepage in quantities that would threaten either the integrity of the dike or the Service Water Reservoir balance would be detectable by visual inspection of the dikes and surrounding ground.

Service Water Reservoir Loss-Monitoring Procedure

The loss evaluation shall be based on an established time interval and include the reservoir inventory based on the reservoir levels, rainfall, makeup and blowdown information during the interval.

Data for calculating the loss from the SW reservoir shall be obtained and recorded with frequency specified in the Technical Requirements Manual.

3.8.4.9 Current Frequency for Monitoring of Settlement and Groundwater Levels

Extensive monitoring has been performed since the issuance of the Operating License for Unit 1. This monitoring has provided a large data base which has been used to establish trends related to performance of the SWR, pumphouse, and their components.

Evaluation of this data base has led to applying a single 6-month frequency to all monitoring retained and deletion of certain monitoring. Details are contained in Reference 34.

3.8.5 Settlement of Service Building

Monitoring of the settlement of all Class I structures was initially required by Technical Specifications. Total settlement of the west end of the service building and differential settlement of the service building with respect to the main steam valve house/quench spray pump house are the only settlements in the main plant that are currently being monitored. The service water lines run beneath the structures which limits the amount of differential settlement allowed between the buildings.

3.8.5.1 **Background**

The western end of the service building (especially in the area of the four emergency diesel-generator rooms) is underlain by a variable thickness of compressible, soil-like, decomposed rock called “saprolite.”

Figure 3.8-59 shows a plan of this area, together with column lines and the locations of pertinent settlement monitoring points. Under the southern wall of the service building (along the E Line), the saprolite may be as much as 15 feet thick, whereas it may be 20 feet thick or more under the northern wall (along the C Line, 68 feet north of the E Line). The presence of this compressible material has resulted in settlement of the service building to the west of the 10 Line and especially from the 14 Line to the 17 Line.

3.8.5.2 **Settlement Record**

The record of differential settlement between the service building, the Unit 2 Quench Spray Pump House (QSPH), and the main steam valve house (MSVH) has been kept since July 1977. The 24-inch diameter service water lines run between buildings at this point. The variability in the elevations of the two structures does not reflect their individual behavior but, rather, the inaccuracies of measurements from one survey to the next. Regardless of this variability, the difference between the two changes in elevation for each survey is a valid measure of the differential settlement between the two points, as long as both elevations are measured from the same position of the surveying instrument, or at least from two positions separated by a minimum number of turns. Since November 1992, the differential settlement between the two building has been determined by direct survey measurement utilizing a single instrument set-up.

3.8.5.3 **Service Water Piping**

As described previously, the safety-related piping affected by the differential settlement consists of four buried service water lines running southerly from beneath the service building, under the 25-foot-wide roadway, and through the northern wall of the main steam valve house. These four buried lines are 24-inch-diameter, carbon steel pipes encased in reinforced concrete. The line members for this piping are identified as 24-WS-426, 428, 434, 436-151-Q3.

The remedial action taken in April 1977 to improve the stress conditions consisted of permanently removing a portion of the concrete encasement adjacent to the main steam valve house, cutting the pipes, and then rewelding. For input to the pipe stress analysis at that time, the future differential settlement from April 1977 was assumed to be 3/8 inch (0.031 foot). This additional settlement resulted in a calculated stress due to total differential settlement in the service water lines of 39,285 psi, as compared to an allowable stress for this load case of $3S_c$ = 45,000 psi.

As can be seen from Table 3.8-18, a differential settlement of 9/16 inch (0.047 foot) from April 1977 is required to develop a stress of 44,176 psi, which more closely approaches but does not exceed the allowable stress of 45,000 psi. The analysis to calculate the capacity of the piping to withstand this 50% additional differential settlement is performed without any change to the analytical model and assumptions for the analysis that was performed earlier. The linear extrapolation performed to more closely approach the allowable stress is valid for this analytical model.

3.8.5.4 **Conclusions**

As demonstrated above, the current differential settlement between the service building and the MSVH/QSPH does not require any immediate remedial action. The differential settlement has essentially stabilized. However, monitoring of movement between the two buildings will continue to assure that the differential settlement between them will not exceed 9/16-inch (0.047 foot).

3.8.6 Flood Protection Dike

3.8.6.1 **Description of Dike**

The earthen flood protection dike west of the Unit 2 turbine and service buildings was built to a crest elevation of approximately 271.0, with side slopes that are 2.0 horizontal to 1 vertical or 2.5 horizontal to 1 vertical. In order to provide storm drainage to the area between the dike and the Unit 2 turbine building, a drainpipe was installed within the dike. Station requirements exist that the valve in this drainage pipe be closed when the lake level exceeds Elevation 252.0.

3.8.6.2 **Design Basis**

Analyses were performed to determine the stability of the upstream and downstream slopes for the condition at the completion of construction as well as the condition where the water level on the outside of the dike has reached the PMF lake level of Elevation 264.2. In both cases, the dike was found to have adequate factors of safety.

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3.8 REFERENCE DRAWINGS

The list of Station Drawings below is provided for information only. The referenced drawings are not part of the UFSAR. This is not intended to be a complete listing of all Station Drawings referenced from this section of the UFSAR. The contents of Station Drawings are controlled by station procedure.

	Drawing Number	Description
1.	11715-FP-5Y	Service Water Reservoir, Spray Pipe Support and Concrete Pad Locations, Sheet 2
	12180-FZ-19D	Service Water Reservoir, Spray Pipe Support and Concrete Pad Locations, Sheet 2
2.	11715-FP-5X	Service Water Reservoir, Spray Pipe Support and Concrete Pad Locations, Sheet 1
	12180-FZ-19C	Service Water Reservoir, Spray Pipe Support and Concrete Pad Locations, Sheet 1
3.	11715-FM-1A	Machine Location: Reactor Containment, Plan, Elevation 291'- 10", Unit 1
4.	11715-FM-1B	Machine Location: Reactor Containment, Plan, Elevation 262'- 10", Unit 1
5.	11715-FM-1C	Machine Location: Reactor Containment, Plan, Elevation 241'- 0", Unit 1
6.	11715-FM-1D	Machine Location: Reactor Containment, Plan, Elevation 216'- 11", Unit 1
7.	11715-FM-1E	Machine Location: Reactor Containment, Sections 1-1 & 5-5, Unit 1
8.	11715-FM-1F	Machine Location: Reactor Containment; Sections 2-2, 6-6, 7-7, & 10-10; Unit 1
9.	11715-FM-1G	Machine Location: Reactor Containment, Sections 3-3 & 4-4, Unit 1
10.	11715-FY-1B	Site Plan, Units 1 & 2
11.	11715-FP-5AM	Service Water Valve House Piping, Plan and Sections, Units 1 & 2
12.	11715-FP-5AN	Service Water Valve House Piping, Plan and Sections, Units 1 & 2
13.	11715-FE-35A	Arrangement: Electrical Penetrations, Reactor Containment, Unit 1
	12050-FE-35A	Arrangement: Electrical Penetrations, Reactor Containment, Unit 2

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.8-1

REACTOR CONTAINMENT PRIMARY SHIELD WALL CONCRETE COMPRESSIVE STRENGTHS BASED ON 28-DAY CYLINDER TESTS

Location	Pour	Mix	Test	28-Day psi	Moving 3 Avg.(Min.) (psi)	Low (psi)	Remarks
Unit 1							
214 ft. 5 in. to 222 ft. 6 in.	P950	1BK	333	3979	4002	3867	
222 ft. 6 in. to 228 ft. 6 in.	P989	1BK	340	4256	4000	3696	P993 actual
228 ft. 6 in. to 235 ft. 6 in.	P103B	1BK	353	3625	3839	3625	P1019 actual
235 ft. 6 in. to 243 ft. 0 in.	(Pour records not available; use f'c = 3000 psi)						
243 ft. 0 in. to 247 ft. 4 in.	P1412	1BK	562	4280	4224	3748	
247 ft. 4 in. to 252 ft. 10 in.	P1466	1BK	584	4191	4341	4191	
252 ft. 10 in.to 257 ft. 10 in.	P1735	1BK	633	4321	4396	4321	
257 ft. 10 in.to 262 ft. 10 in.	P1953	11A	93	5264	5396	5264	
Unit 2							
214 ft. 5 in. to 222 ft. 6 in.	P1167	1BK	423	4144	3759	3537	
222 ft. 6 in. to 228 ft. 6 in.	P1212	1BK	448	3932	3908	3796	
228 ft. 6 in. to 235 ft. 6 in.	P1242	1BK	488	3842	3799	3701	
235 ft. 6 in. to 243 ft. 0 in.	(Pour records not available; use f'c = 3000 psi)						
243 ft. 0 in. to 252 ft. 10 in.	P1970	17A	211	4350	4464	4350	
252 ft. 10 in.to 257 ft. 10 in.	P2176	11A	135	5694	6003	5694	
257 ft. 10 in.to 262 ft. 10 in.	P2706	11A	(Not available; use f'c = 3000 psi)				

Notes: See notes appended to Table 3.8-6.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.8-2

REACTOR CONTAINMENT PRESSURIZER CUBICLE FLOOR SLAB (262 FT. 10 IN.) AND CRANEWALL CONCRETE COMPRESSIVE STRENGTHS BASED ON 28-DAY CYLINDER TESTS

Location	Date Pour	Mix	Test	28-Day psi	Moving 3 Avg.(Min.) (psi)	Low (psi)	Remarks
Unit 1 Cranewall							
279 ft. 10 in. to 287 ft. 10 in.	7-20-72 2029	11A	105	5535	5568	5535	
269 ft. 10 in. to 297 ft. 10 in.	5-24-72 1850	11A	172	5046	4841	4716	Not actual pour
262 ft 10 in. to 269 ft 10 in.	4-10-72 1743	17A	117	4898	4442	4144	
Slab							
262 ft 10 in.	3-31-72 1711	17A	110	4439	4327	4056	
Unit 2 Cranewall							
279 ft 10 in. to 287 ft 10 in.	12-5-73 2672	11A	227	6001	5763	5394	
269 ft 10 in. to 279 ft 10 in.	11-13-73 2594	11A	209	5983	5928	5665	
262 ft 10 in. to 269 ft. 10 in.	11-6-72 2553	11A	202	6019	5675	5924	Not actual pour
Slab							
262 ft. 10 in.	10-23-72 2464	11A	188	5318	5722	5317	

Notes: See notes appended to Table 3.8-6.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.8-3

REACTOR CONTAINMENT STEAM GENERATOR/PRESSURIZER CUBICLE RADIAL WALL CONCRETE COMPRESSIVE STRENGTHS BASED ON 28-DAY CYLINDER TESTS

Location	Pour	Mix	Test	28-Day (psi)	Moving 3 Avg.(Min.) (psi)	Low (psi)	Remarks
Unit 1							
Cubicle A	11-9-71 1267	11A	8	4815	4907	4149	
Cubicle A	11-24-71 1301	1BK	534	3902	4369	3902	
Cubicle A	12-16-71 1374	1BK	549	4097	4098	3884	
Cubicle A	1-7-72 1410	1BK	559	3842	4136	3842	
Cubicle A	2-10-72 1473	17A	33	4775	4854	4757	Not actual pour (1499)
Cubicle A	3-1-72 1570	17A	54	4846	4372	4132	
Cubicle A	3-16-72 1630	17A	84	4545	4437	4132	Not actual pour (1633)
Cubicle A	4-13-72 1754	1BK	634	4356	4384	4286	
Cubicle A	6-7-72 1903	17A	183	5258	4839	4474	
Cubicle B	11-19-71 1305	11A	13	4668	4840	4662	
Cubicle B	12-8-71 1354	1BK	539	4510	4215	3919	Not actual pour (1347)
Cubicle B	12-14-71 1369	1BK	545	4227	4093	3884	Not actual pour (1351)
Cubicle B	1-10-72 1396	1BK	561	4421	4136	3842	
Cubicle B	2-16-72 1524	17A	37	5435	5085	4061	
Cubicle B	3-1-72 1578	17A	56	4132	4372	4132	

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.8-3 (continued)

REACTOR CONTAINMENT STEAM GENERATOR/PRESSURIZER CUBICLE RADIAL WALL CONCRETE COMPRESSIVE STRENGTHS BASED ON 28-DAY CYLINDER TESTS

Location	Pour	Mix	Test	28-Day (psi)	Moving 3 Avg.(Min.) (psi)	Low (psi)	Remarks
Unit 1 (continued)							
Cubicle B	3-16-72 1630	17A	84	4595	4437	4132	Not actual pour (1633)
Cubicle B	5-10-72 1809	11A	63	5830	5608	5023	
Cubicle B	6-16-72 1937	11A	89	6077	5823	5382	
Cubicle C	12-3-71 1342	11A	18	5223	4855	5504	
Cubicle C	12-14-71 1369	1BK	545	4227	4093	3884	
Cubicle C	1-19-72 1441	1BK	574	4840	4846	4209	
Cubicle C	2-23-72 1541	17A	41	4522	4207	4038	
Cubicle C	3-10-72 1609	17A	72	5695	5180	4009	Not actual pour (1611)
Cubicle C	5-15-72 1822	11A	71	5205	5262	5046	
Cubicle C	6-28-72 1961	11A	96	4733	5496	4733	Not actual pour (1960)

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.8-3 (continued)

REACTOR CONTAINMENT STEAM GENERATOR/PRESSURIZER CUBICLE RADIAL WALL CONCRETE COMPRESSIVE STRENGTHS BASED ON 28-DAY CYLINDER TESTS

Location	Pour	Mix	Test	28-Day (psi)	Moving 3 Avg.(Min.) (psi)	Low (psi)	Remarks
Unit 2							
Cubicle A	3-29-72 1697	1BK	613	4474	4480	4339	
Cubicle A	4-7-72 1738	1BK	630	4657	4079	3732	
Cubicle A	4-24-72 1788	11A	57	5900	5629	5376	
Cubicle A	8-7-72 2096	11A	122	5918	5641	5341	
Cubicle A	6-28-72 1961	17A	202	4816	4164	3749	
Cubicle A	7-19-76 2001	17A	236	5010	4509	4197	
Cubicle B[a]	5-12-72 1820	11A	69	5211	5391	5205	
Cubicle B	2-6-73 2926	11A	(No cylinder taken for 11A this date)				
Cubicle B	2-13-73 2940	11A	274	6083	6132	5924	Not actual pour (2941)
Cubicle B	2-13-73 2940	11A	274	6083	6132	5924	
Cubicle B	2-21-73 2981	11A	284	6861	5946	4727	Not actual pour (2902)
Cubicle B	2-21-73 2981	11A	284	6861	5946	4727	
Cubicle B	5-17-72 1828	11A	75	5423	5239	5046	Not actual pour (1834)

a. One of the two radial walls of steam generator cubicles B and C, in each reactor containment, also constitutes the pressurizer cubicle radial wall, i.e., they share a common wall with the pressurizer cubicle.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.8-3 (continued)

REACTOR CONTAINMENT STEAM GENERATOR/PRESSURIZER CUBICLE RADIAL WALL CONCRETE COMPRESSIVE STRENGTHS BASED ON 28-DAY CYLINDER TESTS

Location	Pour	Mix	Test	28-Day (psi)	Moving 3 Avg.(Min.) (psi)	Low (psi)	Remarks
Unit 2 (continued)							
Cubicle B	6-9-72 1908	17A	184	5096	4885	4586	Not actual pour (1912)
Cubicle B	9-9-72 2251	11A	149	5529	5474	5099	
Cubicle B	9-19-72 2301	17A	337	5399	5103	4674	
Cubicle B	10-25-72 2485	17A	399	3961	4423	3961	
Cubicle B	12-11-72 2696	11A	231	6378	5909	5394	
Cubicle C	2-15-73 2940	11A	274	6083	6132	5924	Not actual pour (2939)
Cubicle C[a]	6-1-72 1976	17A	178	4244	4252	4179	Not actual pour (1877)
Cubicle C	6-6-72 1893	17A	181	4474	4329	4179	
Cubicle C	6-26-72 1752	17A	198	5612	4875	4350	
Cubicle C	9-9-72 2250	11A	148	5706	5470	5187	
Cubicle C	9-20-72 2209	17A	154	5117	4714	4486	Not actual pour (2300)

a. One of the two radial walls of steam generator cubicles B and C, in each reactor containment, also constitutes the pressurizer cubicle radial wall, i.e., they share a common wall with the pressurizer cubicle.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.8-3 (continued)

REACTOR CONTAINMENT STEAM GENERATOR/PRESSURIZER CUBICLE RADIAL WALL CONCRETE COMPRESSIVE STRENGTHS BASED ON 28-DAY CYLINDER TESTS

Location	Pour	Mix	Test	28-Day (psi)	Moving 3 Avg.(Min.) (psi)	Low (psi)	Remarks
Unit 2 (continued)							
Cubicle C	11-6-72 2531	11A	201	5317	5486	5317	Not actual pour (2550)
Cubicle C	11-16-72 2606	11A	213	5104	5604	5104	
Cubicle C	12-8-72 2695	11A	230	5954	5909	5394	

Notes: See notes appended to Table 3.8-6.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.8-4

REACTOR CONTAINMENT STEAM GENERATOR CUBICLE FLOOR SLAB (ELEVATION 242 FT. 6 IN.) CONCRETE COMPRESSIVE STRENGTHS BASED ON 28-DAY CYLINDER TESTS

Location	Pour	Mix	Test	28-Day (psi)	Moving 3 Avg.(Min.) (psi)	Low (psi)
Unit 1						
Cubicle A	P1267	11A	8	4816	4907	4149
Cubicle A	P1267	11A	7	5759	4737	4149
Cubicle B	P1305	11A	12	5192	4840	4662
Cubicle B	P1305	11A	13	4668	4840	4662
Cubicle B	P1305	11A	14	4662	4840	4638
Cubicle C	P1342	11A	20	4840	4855	4504
Cubicle C	P1342	11A	19	4503	4855	4504
Cubicle C	P1342	11A	18	5223	4855	4504
Unit 2						
Cubicle A	P1670	11A	48	5434	5673	5435
Cubicle A	P1670	11A	49	6354	5932	4993
Cubicle A	P1670	11A	50	6814	5734	4993
Cubicle B	P1785	11A	58	5611	5340	5034
Cubicle B	P1785	11A	59	5376	5340	5034
Cubicle B	P1785	11A	60	5033	5340	5023
Cubicle C	P1834	11A	77	5140	5590	5141

Notes: See notes appended to Table 3.8-6.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.8-5

REACTOR CONTAINMENT CRANEWALL (ABOVE ELEVATION 291 FT. 10 IN.) CONCRETE COMPRESSIVE STRENGTHS BASED ON 28-DAY CYLINDER TESTS

Location	Pour	Mix	Test	28-Day (psi)	Moving 3 Avg.(Min.) (psi)	Low (psi)	Remarks
Unit 1							
291 ft. 10 in. to 320 ft. 0 in.	8-5-72 2085	11A	118	6007	5851	5723	
291 ft. 10 in.t o 320 ft. 0 in.	8-7-72 2086	11A	119	5723	5629	5341	
291 ft. 10 in. to 320 ft. 0 in.	8-17-72 2152	11A	129	6166	5614	5205	
291 ft. 10 in. to 320 ft. 0 in.	8-28-72 2194	11A	139	5606	5582	5223	Not actual pour
291 ft. 10 in. to 320 ft. 0 in.	8-28-72 2195	11A	139	5606	5582	5223	
291 ft. 10 in. to 320 ft. 0 in.	9-21-72 2310	11	160	6773	6321	5642	
291 ft. 10 in. to 320 ft. 0 in.	9-23-72 2326	11	162	6413	6176	5983	
291 ft. 10 in. to 320 ft. 0 in.	10-3-72 2375	11	169	6190	6017	5900	
291 ft. 10 in. to 320 ft. 0 in.	11-17-72 2611	11	214	6343	5775	5104	Not actual pour
320 ft. 0 in. to top	8-24-72 2185	11A	137	6083	5802	5606	
320 ft. 0 in. to top	9-1-72 2230	11	144	5169	5250	4704	
320 ft. 0 in. to top	9-18-72 2292	11	156	5794	5735	5642	
320 ft. 0 in. to top	9-28-72 2345	11	166	5612	5761	5541	
320 ft. 0 in. to top	10-5-72 2384	11	173	5571	5916	5571	
320 ft. 0 in. to top	10-11-72 2409	11	179	6838	6382	5912	
320 ft. 0 in. to top	10-31-72 2521	11	198	5954	5698	5453	
320 ft. 0 in. to top	11-6-72 2553	11	202	6019	5675	5317	

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.8-5 (continued)

REACTOR CONTAINMENT CRANEWALL (ABOVE ELEVATION 291 FT. 10 IN.)
CONCRETE COMPRESSIVE STRENGTHS BASED ON 28-DAY CYLINDER TESTS

Location	Pour	Mix	Test	28-Day (psi)	Moving 3 Avg.(Min.) (psi)	Low (psi)	Remarks
Unit 1 (continued)							
320 ft. 0 in. to top	11-7-72 2556	11	203	5924	5753	5317	
320 ft. 0 in. to top	11-10-72 2586	11	206	6130	5977	5765	
320 ft. 0 in. to top	11-10-72 2586	11	207	5765	5928	5765	
320 ft. 0 in. to top	11-28-72	11	219	5747	5928	5747	Not actual pour
320 ft. 0 in. to top	12-18-72	11	240	5706	5826	5706	Not actual pour
320 ft. 0 in. to top	12-22-72	11	245	5641	5698	5511	Not actual pour
Unit 2							
291 ft. 10 in. to 320 ft. 0 in.	1-25-73 2855	11	264	6543	6234	5736	
291 ft. 10 in. to 320 ft. 0 in.	1-25-73 2856	11	264	6543	6234	5736	Not actual pour
291 ft. 10 in. to 320 ft. 0 in.	1-25-73 2858	11	264	6543	6234	5736	Not actual pour
291 ft. 10 in. to 320 ft. 0 in.	2-6-73 2913	11	(No cylinders taken this date)				
291 ft. 10 in. to 320 ft. 0 in.	2-7-73 2912	11	(No cylinders taken this date)				
291 ft. 10 in. to 320 ft. 0 in.	2-16-73 2952	11	277	6119	5690	5028	
291 ft. 10 in. to 320 ft. 0 in.	2-20-73 2955	11	279	6054	5733	5028	
291 ft. 10 in. to 320 ft. 0 in.	3-6-73 3020	11	295	5841	5800	5376	
291 ft. 10 in. to 320 ft. 0 in.	3-15-73 3066	11	305	5724	5967	5724	
291 ft. 10 in. to 320 ft. 0 in.	3-15-73 3066	11	306	6236	5967	5724	
320 ft. 0 in. to top	2-16-73 2952	11	277	6119	5690	5028	

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.8-5 (continued)

REACTOR CONTAINMENT CRANEWALL (ABOVE ELEVATION 291 FT. 10 IN.)
CONCRETE COMPRESSIVE STRENGTHS BASED ON 28-DAY CYLINDER TESTS

Location	Pour	Mix	Test	28-Day (psi)	Moving 3 Avg.(Min.) (psi)	Low (psi)	Remarks
Unit 2 (continued)							
320 ft. 0 in. to top	2-23-73 2995	11	286	5924	5397	5034	
320 ft. 0 in. to top	3-2-73 3010	11	292	5824	5783	5682	Not actual pour
320 ft. 0 in. to top	3-9-73 3037	11	297	6531	6097	5841	Not actual pour
320 ft. 0 in. to top	3-13-73 3051	11	303	6549	6303	5724	
320 ft. 0 in. to top	3-19-73 3079	11	311	6655	5735	5205	
320 ft. 0 in. to top	3-26-73 3098	11	313	6243	5771	5511	
320 ft. 0 in. to top	3-26-73 3102	11	314	5559	5771	5511	
320 ft. 0 in. to top	3-29-73 3136	11	319	6614	6085	5706	
320 ft. 0 in. to top	4-3-73 3151	11	323	5323	5928	5323	
320 ft. 0 in. to top	4-6-73 3170	11	325	6207	6068	5323	Not actual pour
320 ft. 0 in. to top	4-9-73 3177	11	326	5824	6235	5824	Not actual pour
320 ft. 0 in. to top	4-16-73 3220	11	336	6313	6097	5553	

Notes: See notes appended to Table 3.8-6.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.8-6

SPENT-FUEL RACK EMBEDMENT CONCRETE COMPRESSIVE STRENGTHS BASED ON 28-DAY CYLINDER TESTS

Location	Pour	Mix	Test	28-Day (psi)	Moving 3 Avg.(Min.) (psi)	Low (psi)	Remarks
Unit 2 (continued)							
320 ft. 0 in. to top	4-19-73 3235	11	342	5995	5767	5553	
Pour 1	6-12-72 1918	17A	186	4969	4885	4586	
Pour 1	6-12-72 1918	17A	187	5570	5042	4586	
Pour 1	6-12-72 1918	17A	188	5175	4973	4315	
Pour 4	8-12-72 2123	17A	282	5010	5195	5010	
Pour 4	6-12-72 2123	17A	285	5240	5077	4993	
Pour 4	6-12-72 2123	17A	286	4999	4928	4792	

Notes: Tabulated information for concrete pours is listed under various headings as follows.

Location: Under this heading is a brief description of the limits of the pour as defined by elevations or other appropriate references.

Pour: This is the number assigned by the field forces to the concrete placed in the location of interest, except as noted under Remarks.

Mix: This is the number assigned to the specific approved mix (proportions) used for the pour.

Test: This is the number assigned to a set of cylinders taken from a given pour for compressive testing.

28-Day: This is the average 28-day compressive strength based on three 28-day cylinder breaks from the set.

Moving 3 Average: This is the average of any three consecutive tests of which the listed test is a part, as taken from computerized statistical analysis data.

Low: This is the lowest test value of any individual test within the data used to compute the moving 3 average.

Remarks: Entries in this column are generally made for the purpose of identifying pours which, because of their small volume, did not require a set of cylinders to be taken. The number given in the Pour column is for concrete placed in another location, but of the same type, supplied on the same day, by the same supplier, under comparable conditions. The number corresponding to the actual pour, which was not sampled, is provided in the Remarks column.

Table 3.8-7
LOAD COMBINATIONS FOR LINER PLATE AND ACCESS OPENINGS

Category	Load Combinations	Stress Allowables (Per ASME III Nomenclature)
Emergency	$D + P_d + T_d + DBE$	$P_m + P_b + Q < 3\ S_m$
Test	$D + 1.15\ P_d$	$P_m < 0.9\ S_y$ $P_m + P_b < 1.35\ S_y$ + "CAT" curve considerations, per NRL report 6900
Normal (Cyclic)	$D + P_o + T_o + DBE$	Use method of paragraph N-415, Analysis for Cyclic Operation
Upset	$D + P_{min} + T_{min}$	$P_m + P_b + Q < 3\ S_m$
	Load Combinations for Anchors	
Emergency	$D + P_d + T_d$	$0.425\ S_w$ (max shear)
Upset	$D + P_{min} + T_{min}$	$0.45\ S_w$ (max tensile)

Notes:

D =	Dead load effect of reinforced-concrete structure acting on the liner, plus dead load of the liner, or, for access openings, dead weight of doors.
P_d =	Design pressure (pressure resulting from design basis accident plus safety margin).
T_d =	Load due to thermal expansion resulting when the liner is exposed to the design temperature.
DBE =	Stresses in the liner derived from applying the effect of the design-basis earthquake.
P_o =	Differential pressure between operating pressure and atmospheric pressure (P_o = 5.2 psi). The design limit for operating pressure variations is 1500 cycles. The anticipated number of cycles (150) is based on 2.5 refueling cycles per year on a 60-year span.
T_o =	Load due to thermal expansion resulting when the liner is exposed to the differential temperature between operating and seasonal refueling temperatures. The design limit for operating temperature variations is 6000 cycles. The anticipated number of cycles (600) is based on 10 such variations per year on a 60-year span.
P_{min} =	Minimum pressure resulting during operation of the containment.
T_{min} =	Load due to thermal expansion resulting when the liner is exposed to the minimum pressure.
S_y =	Yield strength of the material.
S_m =	Basic allowable stress from ASME III.
S_w =	Ultimate strength of anchor stud material.

Table 3.8-8
LOAD COMBINATIONS FOR PIPING PENETRATIONS

Location	Condition	Load Combinations	Allowables (Per ASME III Nomenclature)
Shear lugs	Design	T_p	Shear < 0.6 S_y Bending < 0.9 S_y Bearing on concrete < 2400 psi
Sleeve and attachment plate	Design	M_p or T_p or J_{ax}	$P_m < 0.9\ S_y$ $P_m + P_b < 0.9\ S_y$
	Normal	$M_p + P_g$	$P_m + P_b < 1.5\ S_m$
	Normal	$M_p + P_g + T_g$	$P_m + P_b + Q < 3\ S_m$
Juncture of pipe and attachment	Design	M_p or T_p or J_{ax}	$P_m < 0.9\ S_y$ $P_m + P_b < 0.9\ S_y$
	Normal	$P_g + T_g$	$P_m + P_b + Q < 3\ S_m$

Notes:

J_{ax} = Axial jet force = P_g times pipe inside area.

T_p = Yielding torque: produces stresses equal to the yield strength of the pipe material.

M_p = Yielding moment: produces stresses equal to the yield strength of the pipe material.

P_g = Pipe internal design pressure.

T_g = Pipe design temperature.

S_y = Yield stress from ASME III.

S_m = Basic stress limit from ASME III.

Table 3.8-9

CONTAINMENT STRUCTURAL LOADING CRITERIA

Loading Combination	Required Load Capacity of Structure
Operating plus 1.5 DBA	$(1.0 \pm 0.05)\ D + 1.5\ P + 1.0\ (T + TL)$
Operating plus DBA plus 1.5 OBE	$(1.0 \pm 0.05)\ D \pm 1.0\ P \pm 1.0\ (\underline{T} + \underline{TL}) + 1.5\ E$
Operating plus DBA plus DBE	$(1.0 \pm 0.05)\ D + 1.0\ P + 1.0\ (\underline{T} + \underline{TL}) + 1.0\ HE$
Operating plus 1.25 DBA and 1.25 OBE	$(1.0 \pm 0.05)\ D + (1.25\ P) + (T' + TL') + 1.25\ E$
Operating plus tornado loading	$(1.0 \pm 0.05)\ D + 1.0\underline{T'} + 1.0\ C$

Notes:

C = Load due to negative pressure and horizontal wind velocity resulting from tornado, including the effects of tornado-generated missiles. For description of tornado design criteria, refer to Section 3.3.

D = Dead load of structure, including effect of earth and hydrostatic pressures, buoyancy, ice, and snow loads. To provide for variations in the assumed dead load, the coefficient for the dead load components is adjusted by ±5% as indicated in the above formulas to provide the maximum stress levels.

P = Pressure load from DBA. DBA pressure will be 45 psig, as described in Section 15.4.

T = Load due to maximum temperature gradient through the concrete shell and mat based on temperature associated with 1.5 DBA pressure.

$\underline{T'}$ = Load due to maximum temperature gradient through the concrete shell and mat based on normal operating temperature.

TL = Load exerted by the exposed liner based upon temperature associated with 1.5 times DBA pressure.

T' = Load due to maximum temperature gradient through the concrete shell and mat based on temperatures associated with 1.25 times DBA pressure.

TL’ = Load exerted by the exposed liner based on temperatures associated with 1.25 times DBA pressure.

$\underline{T}$ = Load due to maximum temperature gradient through the concrete shell and mat based on temperature associated with 1.0 times DBA pressure.

$\underline{TL}$ = Load exerted by the exposed liner based on temperature associated with 1.0 times DBA pressure.

E = Operational-basis earthquake loading. Based on a ground acceleration of 0.06 g horizontally at zero period and a damping factor of 2%. For description of the operational-basis earthquake refer to Section 2.5.

HE = Design-basis earthquake loading. Based on a ground acceleration of 0.12 g horizontally at zero period and a damping factor of 5%. For description of the design-basis earthquake, refer to Section 2.5.

Normal wind loadings replace earthquake loads where they exceed earthquake loadings. Normal wind or tornado loads are not considered coincident with earthquake loads.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.8-10

QUALIFIED COATINGS USED INSIDE CONTAINMENT

Product/Manufacturer	Dry Density (pcf)	Surface Area (ft^2)	Approximate DFT (mils)	Surface Type
Qualified Steel Primers				
Carbo Zinc 11	453	75,000	5.0	Containment
Carboline	453	20,000	5.0	Liner equipment
7107 Epoxy White Primer	215	100,000	3.0	Struc. and misc.
Keeler & Long, Inc.	215	25,000	3.0	Steel equipment
Qualified Steel Finish Coats				
Corlar Epoxy Chemical Resistant Enamel (gloss), E.I. duPont deNemours & Co.	208	75,000	4.0	Containment
823-Line	208	20,000	4.0	Liner equipment
7475 Epoxy White Enamel	149	100,000	2.5	Struc. and misc.
Keeler & Long, Inc.	149	25,000	2.5	Steel equipment
Corlar Epoxy Chemical Resistant Enamel (gloss), E.I. duPont deNemours & Co.	208	130,000	4.0	Formed concrete
823-Line	208	20,000	6.0	Concrete flatwork

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.8-11

UNQUALIFIED COATINGS USED INSIDE CONTAINMENT

Product/Manufacturer, Unqualified Coatings	Surface Area (ft^2)	Surface Type
Coatings applied by Stone and Webster		
Alkyd enamel	1000	Elevator
Zinc chromate and alkyd enamel	150	Communications handsets
Chromox 13-R-50/Mobil	300	Uninsulated valves
Dimecote Primer #2/Amercoat	35	Transmitters
Lacquer	20	Sump pump
Zinc chromate	10	Sump pump
Alkyd enamel	25	Transfer pump
Carboline 4674/Carboline Co.	25	Transfer tank support
Zinc chromate and alkyd	10	Sampling pumps
Plasite 7155H/Wisconsin Protective Coating Corp.	215	Refueling seal ring-Unit 1
Organic zinc-based	1500	Cut and threaded areas of galvanized materials
Total area	3290 [a]	

Paint Type	Manufacturer's Designation	Dry Film Thickness (mil)	Surface Area Covered (ft^2)	Surface Estimated Volume (gal)	Curing Procedure
Coatings on components supplied by Westinghouse					
Inorganic zinc-based	Dimecote-2	2	3070	-	30 minute at 50°F to 95°F
Silicon (organic) modified base	Carboline 4674 (black only)	3	2900	15	a) 2 hours at 75°F between coats b) Air-dry in 204 hours at 75°F c) Coating cures in service
Silicon [b] aluminum	Aluminum Paint TT-P-28	1.5 to 2.0	11,700	-	24 hours at 50°F to 95°F
Polyamide cured epoxy	Amercoat-66	5	1125	10	Finish coat dry for 7 days at 70°F

a. The total surface area represents approximately 1.3 ft^3, assuming the coatings were applied at an average of 5 mils DFT

b. Quantities provided are based on the original steam generators coatings. The replacement steam generator lower assemblies are unpainted and the steam domes have had most of the unqualified paint removed as a result of decontamination activities.

Table 3.8-12
GEOTECHNICAL INSTRUMENTATION SUMMARY

		Measurements to Be Made				
Item to Be Monitored	Location	Item	Method	Units	Frequency	Evaluation Required
Alignment-settlement markers	Crest of dam	Displacement and settlement	Precision survey	ft	Once a year and when reservoir level exceeds Elevation 255	A qualified engineering review of measurements made and the significance of any apparent movement of the structure at least once in 5 years
Drainage collector system	Downstream toe of dam	Discharge from manholes a, b, and c	60° V notched weir	gpm	Every 3 months and when reservoir level exceeds Elevation 255	
Relief wells	Downstream toe of dam	Water levels in relief wells	Water level indicator	ft	Every 6 months and when reservoir level exceeds Elevation 255	A qualified engineering review of measurements made, the condition and functioning of the drainage system, and the need for maintenance or alterations at least once in 5 years
		Accumulated sediment	Weighted tape	ft	At least once a year and when reservoir level exceeds Elevation 255	
Piezometers	Blanket drain, dam foundation, and toe of slope	Piezometric elevation	Water level indicator	ft	Every 6 months[a] and when reservoir level exceeds Elevation 255	A qualified engineering review of measurements made and seepage conditions as they affect the safety of the dam at least once in 5 years.

a. Monitoring frequencies may be modified as recommended by engineering evaluations. This includes recommendations resulting from each 18 CFR 12.37 (c) independent consultant report performed every five years.

Table 3.8-13

MATERIAL PROPERTIES AND STRENGTH PARAMETERS, SERVICE WATER RESERVOIR

			Effective Stress Parameters		Consolidation Stress Strength Parameters		
Material	Saturated Density, γs (pcf)	Dry Density, γd (pcf)	Ø' (deg)	C' (psf)	$Ø'_c$ (deg)	C'_c (ps f)	Permeability (cm/sec)
Compacted impervious core and select lining	116	95	32	0	26	720	1×10^{-6}
Transition filters	130	115	38	0	38	0	1×10^{-2}
Compacted rock shell	140	120	43	0	43	0	Free draining
Foundation saprolite	125	105	30	0	26	720	1×10^{-6}
Foundation relic joint	-	-	12	0	12	-	-

Table 3.8-14
FACTORS OF SAFETY (F.S.), SERVICE WATER RESERVOIR DIKES

Operating Condition	Slope Failure Mode	Static F.S.	Dynamic F.S.[a]
Reservoir full (W.S. El. 315)	U/S - circular failure	1.9	2.0
Reservoir full (W.S. El. 315)	D/S - shallow circular failure[b, c]	1.9	1.2
Reservoir full (W.S. El. 315)	D/S - deep circular failure[b]	1.5	1.3
Rapid drawdown (W.S. El. 305)	U/S - circular failure	4.2	2.2
Reservoir full (W.S. El. 315)	D/S - wedge failure along relic joint surface	1.5	1.2

Legend: W.S. - water surface
U/S - upstream side of dike
D/S - downstream side of dike

a. Based on undrained strength parameters.
b. Shallow failure is defined as a failure surface located entirely within the rock fill or filter blankets. Deep failures penetrate into the impervious core or foundation soil.
c. The factor of safety for the shallow failure through the rock fill or filter blankets is based on an infinite slope failure.

Table 3.8-15
SETTLEMENT MONITORING POINTS FOR SEISMIC CLASS I STRUCTURES AT THE MAIN PLANT AND SERVICE WATER RESERVOIR

Mark No	Elevation (ft.)	Baseline (Date Established)	Structure/Location
113R	272.631	(5/87)	Unit 2 Main Steam Valve/Quench Spray Pump House
314 [a]	271.997	(11/92)	West End of Service Building
315 [a, b]	272.030	(11/92)	West End of Service Building
316 [a]	271.979	(11/92)	West End of Service Building
317 [a]	271.933	(11/92)	West End of Service Building
SAM-1 [b]	319.474	(11/75)	Crest of Service Water Reservoir
SAM-2 [b]	318.969	(11/75)	Crest of Service Water Reservoir
SAM-3 [b]	318.966	(11/75)	Crest of Service Water Reservoir
SAM-4 [b]	318.995	(11/75)	Crest of Service Water Reservoir
SAM-6 [b]	319.556	(11/75)	Crest of Service Water Reservoir
SM-7	327.585	(7/77)	Service Water Pump House
SM-8 [b]	327.841	(11/75)	Service Water Pump House
SM-9 [b]	327.690	(11/75)	Service Water Pump House
SM-10	327.397	(7/77)	Service Water Pump House
SM-17R	321.861	(7/77)	Expansion Joint on Service Water Line
SM-18R	321.666	(7/77)	Expansion Joint on Service Water Line
SM-19 [b]	315.387	(1/78)	West Wing Wall, Service Water Pump House
SM-20 [b]	314.983	(1/78)	East Wing Wall, Service Water Pump House
SM-25	325.954	(4/87)	Service Water Valve House
SM-26	326.018	(4/87)	Service Water Valve House
SM-27	326 034	(4/87)	Service Water Valve House
SM-28	326.146	(4/87)	Service Water Valve House
SM-29	303.028	(4/87)	Service Water Tie-in Vault
SM-30	303.030	(4/87)	Service Water Tie-in Vault
SM-31	303.057	(4/87)	Service Water Tie-in Vault
SM-32	303.026	(4/87)	Service Water Tie-in Vault

SAM - Settlement Alignment Marker
SM - Settlement Marker

a. Settlement monitoring points 114, 115, 116, and 117 were relocated in 11/92 due to obstructions. The relocated points were renumbered as 314, 315, 316, and 317 respectively. Baseline elevations were assigned to the relocated points.
b. These settlement points monitored for information only.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.8-16

WATER QUALITY OF FLOW FROM HORIZONTAL DRAINS[c]

Drain No.	Date	Days After Installation	Turbidity, ppm	Suspended Solids, ppm
1	7/11/77	276	≤ 0.5	0.1
	8/5/77	301	≤ 0.5	0.2
	8/26/77	322	≤ 0.5	0.2
	10/7/77	364	≤ 0.5	0.4
2	7/28/77	1	≤ 0.5	0.7
	8/5/77	9	≤ 0.5	0.5
	8/12/77	16	≤ 0.5	0
	8/22/77	26	≤ 0.5	0.1
	8/23/77	27	Stopped flowing	
3	8/26/77	4	≤ 0.5	0.1
	9/8/77[a]	17	≤ 0.5	0.1
	10/7/77	46	≤ 0.5	0
4	7/15/77	2	≤ 0.5	0.6
	7/22/77	9	0	1.3
	7/29/77	16	≤ 0.5	0.5
	8/5/77	23	≤ 0.5	1.0
	8/12/77	30	≤ 0.5	0
	8/22/77	40	≤ 0.5	0.5
	8/26/77	44	≤ 0.5	0.4
	10/7/77	86	0.9	0.4
5	8/12/77	2	≤ 0.5	0.8
	8/22/77	12	0.6	0.6
	8/26/77	16	0.6	0.6
	10/7/77	58	≤ 0.5	0.3
6	7/6/77	5	2.3	4.5
	7/15/77	14	≤ 0.5	2.0
	7/22/77	21	0	0
	7/29/77	28	≤ 0.5	0.4
	8/5/77[b]	35	≤1.6	2.6
	8/12/77	42	≤ 0.5	0.3
	8/22/77	52	≤ 0.5	0
	8/26/77	56	≤ 0.5	0
	10/7/77	98	≤ 0.5	0

a. pH determined to be 7.45.
b. Influenced by installation of Drain 5; sample contained bluish “Revert” drilling fluid.
c. Requirement to monitor turbidity and suspended solids was deleted based on recommendations contained in Reference 34.

Table 3.8-17

GEOTECHNICAL INSTRUMENTATION SUMMARY SERVICE WATER RESERVOIR

Items to Be Monitored	Location	Required Measurements	Measurement Method	Units	Frequency of Measurements
Reference monuments	See Figure 3.8-31	Elevations and coordinates	Surveying, third order	ft	Initial establishment
Alignment -settlement markers	See Figure 3.8-31	Settlement	Surveying, second order	ft	Monthly prior to filling reservoir and for 12 months after filling, and then annually. Requirement to monitor horizontal movements deleted and settlement monitored on 6-month frequency[1]
Settlement markers on Units 1 & 2 pump house	See Fig. 3.8-31 & 3.8-60	Settlement	Surveying, second order	ft	Monthly until 12 months after filling, at 18 months, and then annually. Settlement presently monitored on 6-month frequency[1]
Settlement markers on Units 1 & 2 service water valve house	See Fig. 3.8-31 & 3.8-60	Settlement	Surveying, second order	ft	Monthly for 12 months and on 6-month frequency thereafter
Settlement markers on Units 1 & 2 service water tie-in vault	See Figure 3.8-31	Settlement	Surveying, second order	ft	Monthly for 12 months and on 6-month frequency thereafter
Piezometers (pneumatic) 10, 11, 15	See Figure 3.8-32	Piezometric elevation	Slope Indicator Co. Model 51411 indicator	ft	Monthly until 5 years after filling, and then as established by engineering review of data. Presently monitored on 6-month frequency[1]

Table 3.8-17 (continued)
GEOTECHNICAL INSTRUMENTATION SUMMARY SERVICE WATER RESERVOIR

Items to Be Monitored	Location	Required Measurements	Measurement Method	Units	Frequency of Measurements
Piezometers (open tube) P-19, P-20, P-21, P-22, P-14, P-18, P-10, P-23 [2], P-24 [2]	See Figure 3.8-32	Piezometric elevation	Measuring head of water in open tube	ft	Every 6 months
Horizontal drains	Beneath Units 1 and 2 pump house	Flow rate	Measuring time to fill container of known volume	gpm	Daily for 10 days after installation, weekly for 1 month, monthly until 12 months after installation, and then every 6 months
Horizontal drains	Beneath Units 1 and 2 pump house	Turbidity and suspended solids in out-flow	Chemistry Procedures CP-86 and CP-95	ppm	Weekly during installation, every 3 months until 12 months after installation, and then every 6 months. Requirements to monitor deleted 1 although visual inspection retained during flow measurement
Condition of dike	Crest and toe of dike	Cracks, erosion, or seepage	Visual inspection		Every 6 months

Note: Engineering review of data to be conducted when limiting values are approached and/or at maximum intervals of 5 years.

1. An engineering review and evaluation was performed in February, 1983. Results and details are contained in Reference 34.
2. Piezometers P-23 and P-24 are monitored for information only (See References 38 and 39).

Table 3.8-18

CALCULATED STRESSES IN SERVICE WATER LINES

	Stress, psi			
Load Case	Northern End of 4-Ft-Thick Encasement[a]	Southern End of 4-Ft-Thick Encasement[b]	North Wall of Main Steam Valve Housing[c]	Explanation of Stress
Load Case I	29,504[a]	0	0	Stress immediately after cutting lines
Load Case II	9781	27,053	2486	Stress due to 3/8-inch additional settlement since cutting lines
Total, Load Cases I and II	39,285	27,053	2486	Total stress after 3/8-inch additional settlement
Load Case III[d]	14,672	40,580	3729	Stress due to 9/16-inch additional settlement since cutting lines
Total, Load Cases I and III	44,176	40,580	3729	Total stress after 9/16-inch additional settlement

a. 8.0 ft south of E line (node 5 in NUPIPE model).

b. 20.5 ft south of E line (node 30 in NUPIPE model).

c. 25.0 ft south of E line (node 40 in NUPIPE model).

d. Load Case III is linear extrapolation of Case II for additional settlement of 9/16 in. and equals (9/16) (8/3) (II) = 1.5 (II).

Table 3.8-19
QUALIFIED COATINGS USED INSIDE ZONE OF INFLUENCE (ZOI) IN CONTAINMENT[a]

Coating System	Total Thickness (mils)	Surface Area (ft^2)	Volume of Coating Debris for Limiting Break (ft^3) Maintenance w/ Surfacer (9%)	Maintenance w/o Surfacer (9%)	Original Coating (90%)
Concrete Systems					
Original					
Dupont Corlar Epoxy Chemical Resistant Enamel (Vertical Surfaces)	4.0	5025.5			1.675
Dupont Corlar Epoxy Chemical Resistant Enamel (Horizontal Surfaces)	6.0	770.4			0.385
Maintenance					
Carboline Carboguard 2011S & Carboline Carboguard 890N (2 Coats)	32	64.4	0.172		
Carboline Carboguard 890n (2 Coats)	12	579.6		0.580	
Total			0.17	0.580	2.06
Total Concrete		6439.89		2.81	
Steel Systems				Maintenance (10%)	Original Coating (90%)
Original					
Carboline CarboZinc 11 (CZ-11)	3.0	6355.35			1.59
Dupont Corlar Epoxy Chemical Resistant Enamel	4.0	6355.35			2.12
Maintenance					
Carboline Carboguard 890N (2 Coats)	12	838.15		0.84	3.71
Total					
Total Steel		7193.5			4.55
Total w/ miscellaneous Steel Margin 10%					5.00

a. The Zone of Influence considered a break of the 31" Intermediate Leg for determining the Concrete and Steel Surface Area for maximum debris generation.

Table 3.8-20
NORTH ANNA UNIT 1 UNQUALIFIED/UNACCEPTABLE (DAMAGED) COATINGS
USED INSIDE OF CONTAINMENT[a]

System, Structure, or Component	Coating Material	Surface Area (ft^2)	DFT (mils)	Substrate	Volume (cu. Ft.)
Three Steam Generator Supports (Heat Damaged)	DuPont Corlar top coat (Epoxy)	1559[b]	4.0	Steel	1.56
Total	DuPont Corlar top coat (Epoxy)				1.56
Carbon steel fasteners, Cut Edges of Galvanize Steel	Carboline CZ10	1500	2.0	Steel	0.25
Total	Carboline CZ10				0.25
Elevator Enclosure	Alkyd Enamel	1000	1.5	Steel	0.125
Residual Heat Removal (RHR) Pump Motors and Junction Box Covers	Alkyd Enamel	290	1.5	Steel	0.036
Electrical Junction Boxes	Alkyd Enamel	278	1.5	Steel	0.035
Loud Speakers	Alkyd Enamel	200	1.5	Steel	0.025
Limitorque Operators	Alkyd Enamel	197	1.5	Steel	0.025
“Hear Here” Telephone Boxes	Alkyd Enamel	180	1.5	Steel	0.023
Miscellaneous Electrical and Electronic Equipment	Alkyd Enamel	86	1.5	Steel	0.011
Total	Alkyd Enamel				0.28
Total Unqualified and Heat Damaged Coatings					2.09

a. Includes Heat Damaged Qualified Coatings.
b. Surface area shown is the amount of heat damaged area on each Steam Generator.

Table 3.8-21
NORTH ANNA UNIT 2 UNQUALIFIED/UNACCEPTABLE (DAMAGED) COATINGS
USED INSIDE OF CONTAINMENT[a]

System, Structure, or Component	Coating Material	Surface Area (ft^2)	DFT (mils)	Substrate	Volume (cu. Ft.)
Three Steam Generator Supports (Heat Damaged)	DuPont Corlar top coat (Epoxy)	1559[b]	4.0	Steel	1.56
Total	DuPont Corlar top coat (Epoxy)				1.56
Carbon steel fasteners, Cut Edges of Galvanize Steel	Carboline CZ10	1500	2.0	Steel	0.25
Total	Carboline CZ10				0.25
Elevator Enclosure	Alkyd Enamel	1000	1.5	Steel	0.125
RHR Pump Motors and Junction Box Covers	Alkyd Enamel	290	1.5	Steel	0.036
Electrical Junction Boxes	Alkyd Enamel	331	1.5	Steel	0.041
Loud Speakers	Alkyd Enamel	200	1.5	Steel	0.025
Limitorque Operators	Alkyd Enamel	157	1.5	Steel	0.020
“Hear Here” Telephone Boxes	Alkyd Enamel	275	1.5	Steel	0.034
Miscellaneous Electrical and Electronic Equipment	Alkyd Enamel	156	1.5	Steel	0.020
Total	Alkyd Enamel				0.30
Total Unqualified and Heat Damaged Coatings					2.11

a. Includes Heat Damaged Qualified Coatings.
b. Surface area shown is the amount of heat damaged area on each Steam Generator.

Figure 3.8-1 (SHEET 1 OF 3)
WING WALLS: SERVICE WATER PUMP HOUSE

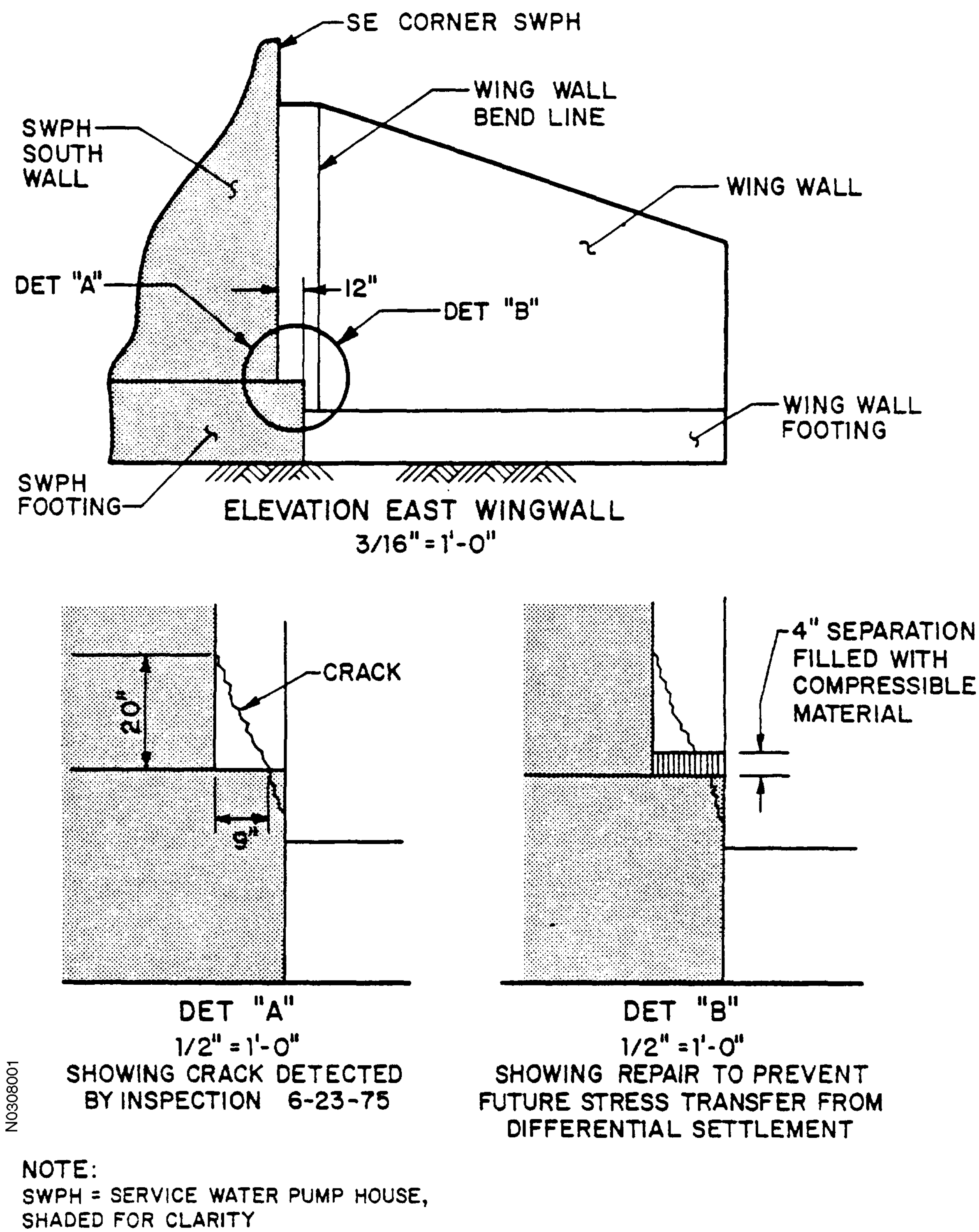


Figure 3.8-1 (SHEET 2 OF 3)
WING WALLS: SERVICE WATER PUMP HOUSE

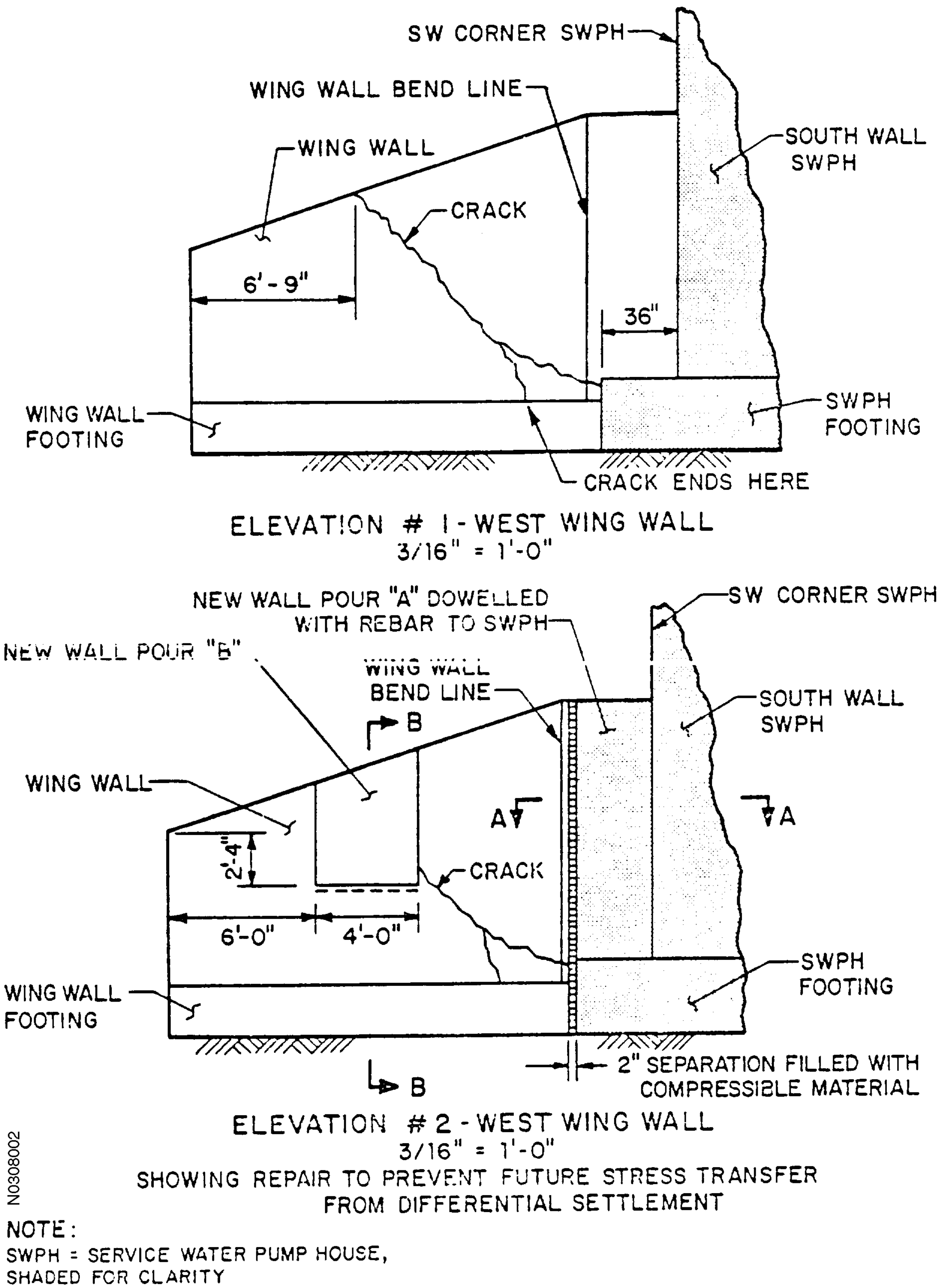


Figure 3.8-1 (SHEET 3 OF 3)
WING WALLS: SERVICE WATER PUMP HOUSE

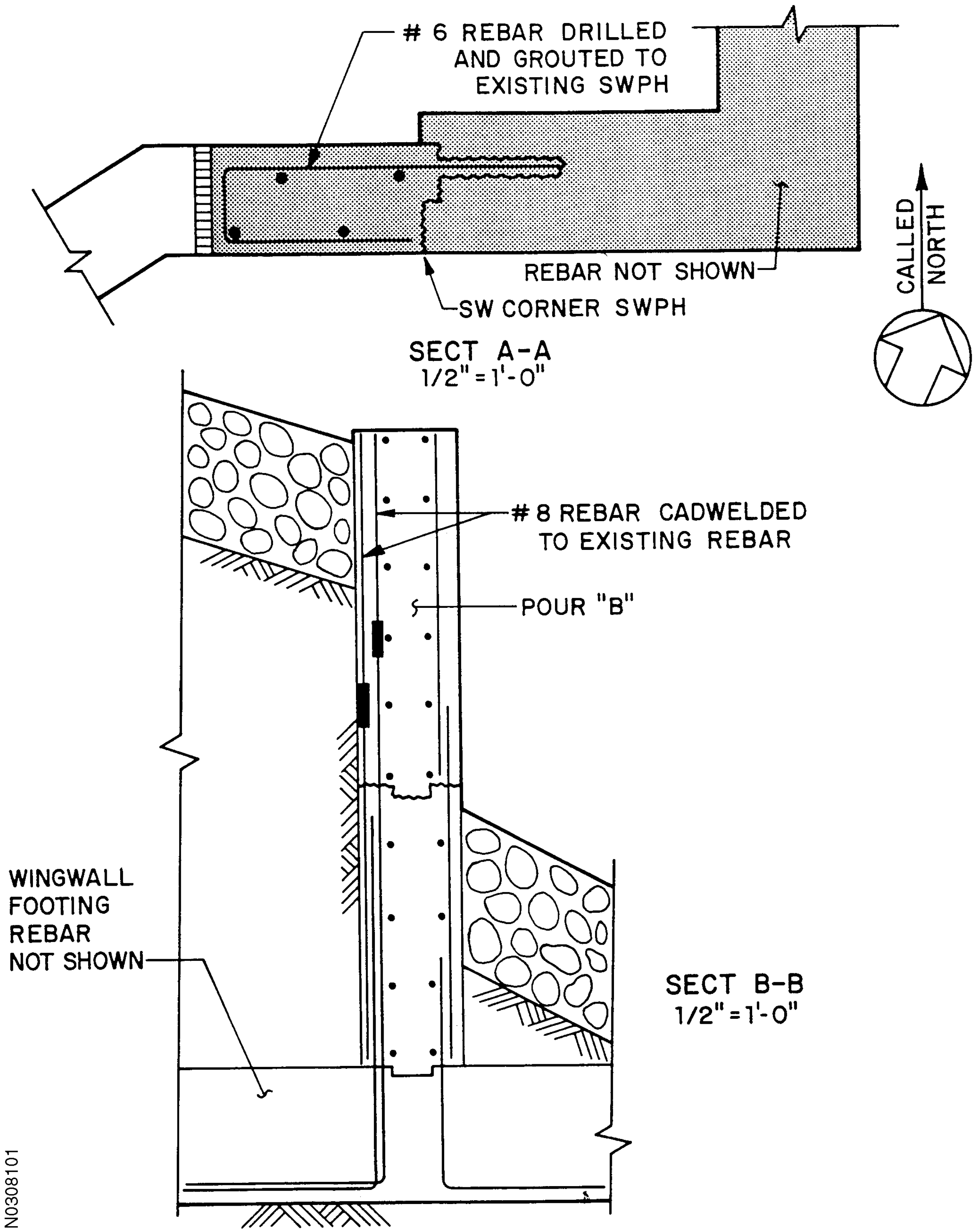


Figure 3.8-2
FOUNDATION DETAIL: CONTAINMENT STRUCTURE

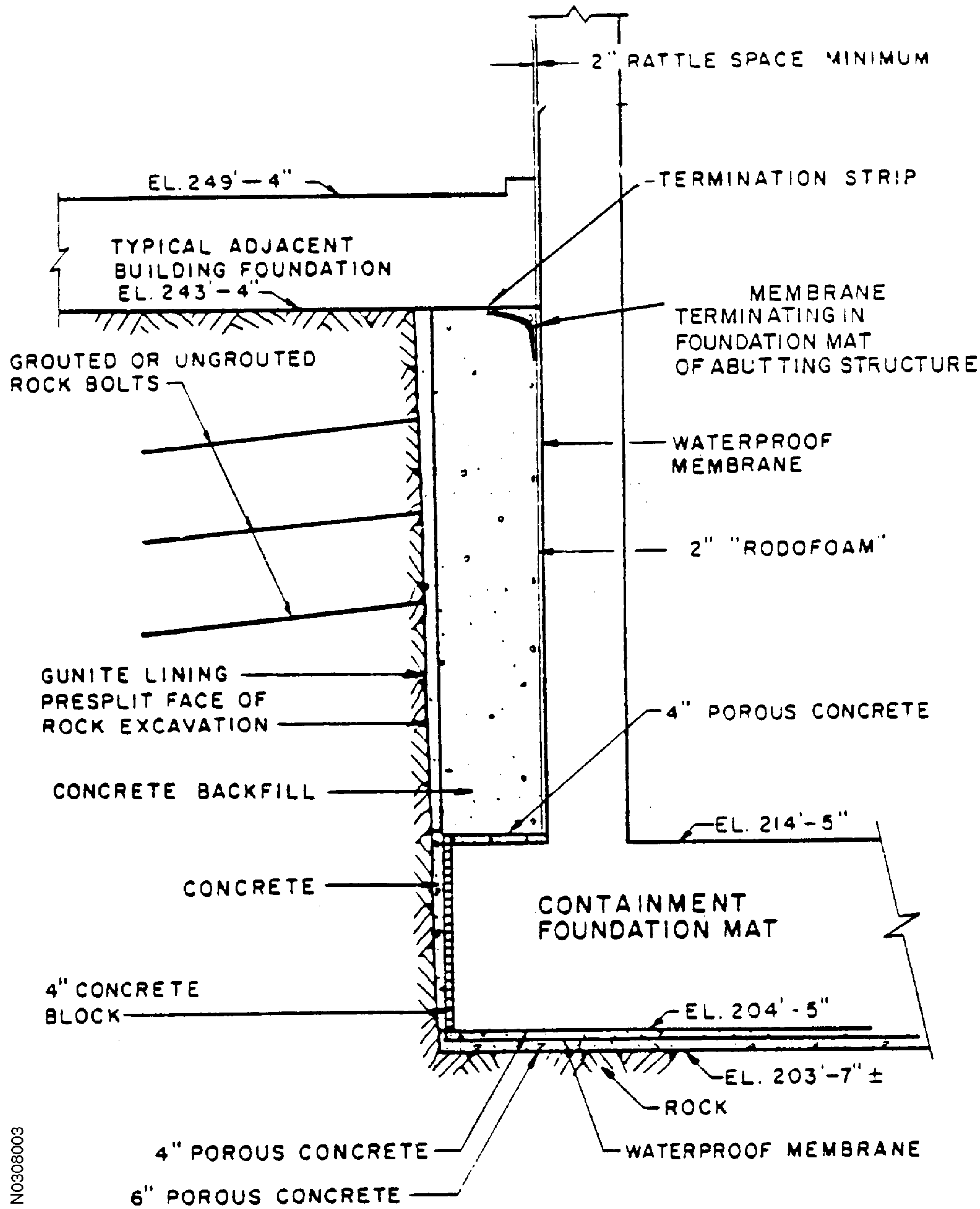


Figure 3.8-3
TYPICAL DETAIL: FOUNDATION MAT AND BASE

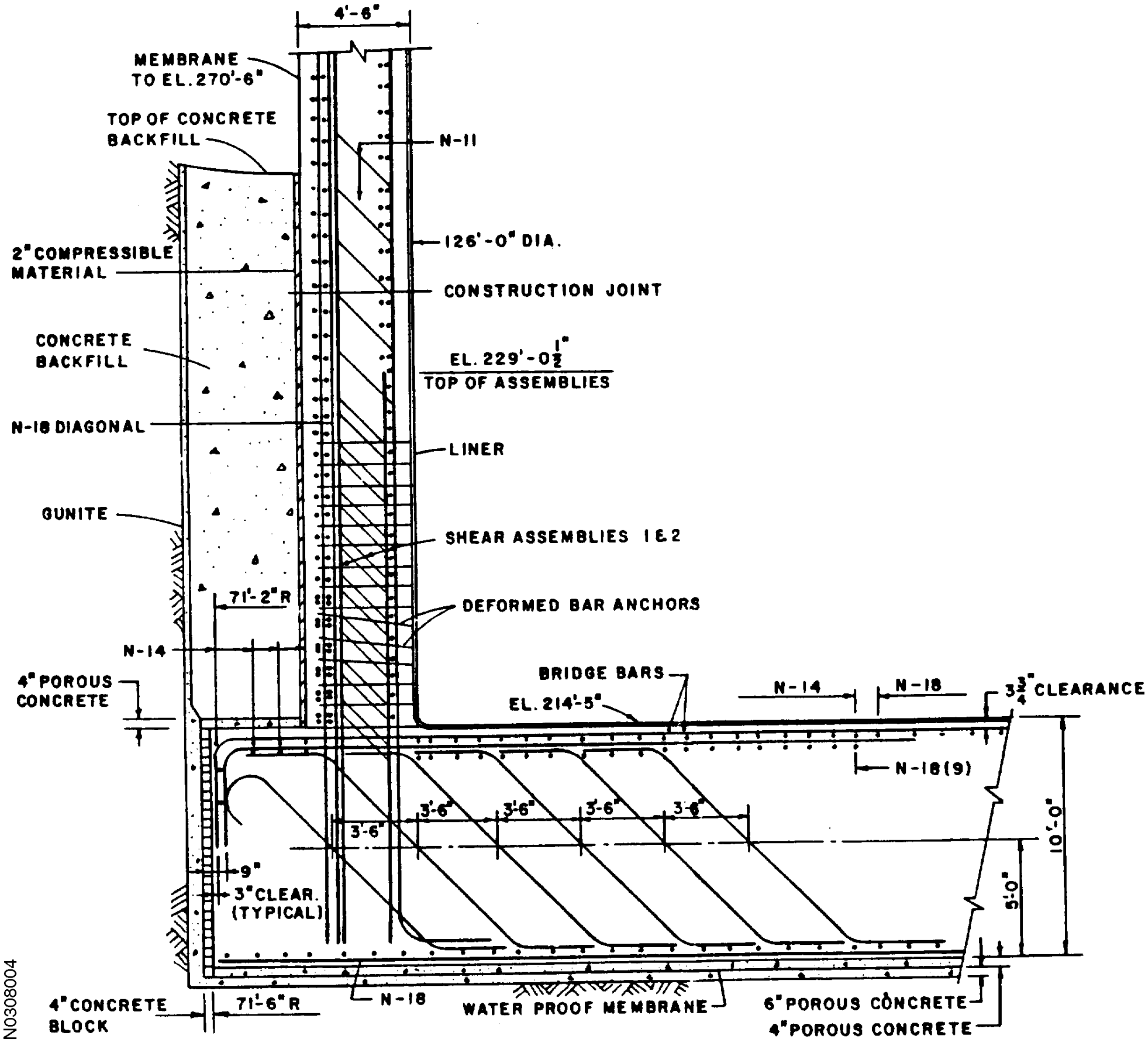


Figure 3.8-4
TYPICAL DETAIL OF DOME: CYLINDER JUNCTION

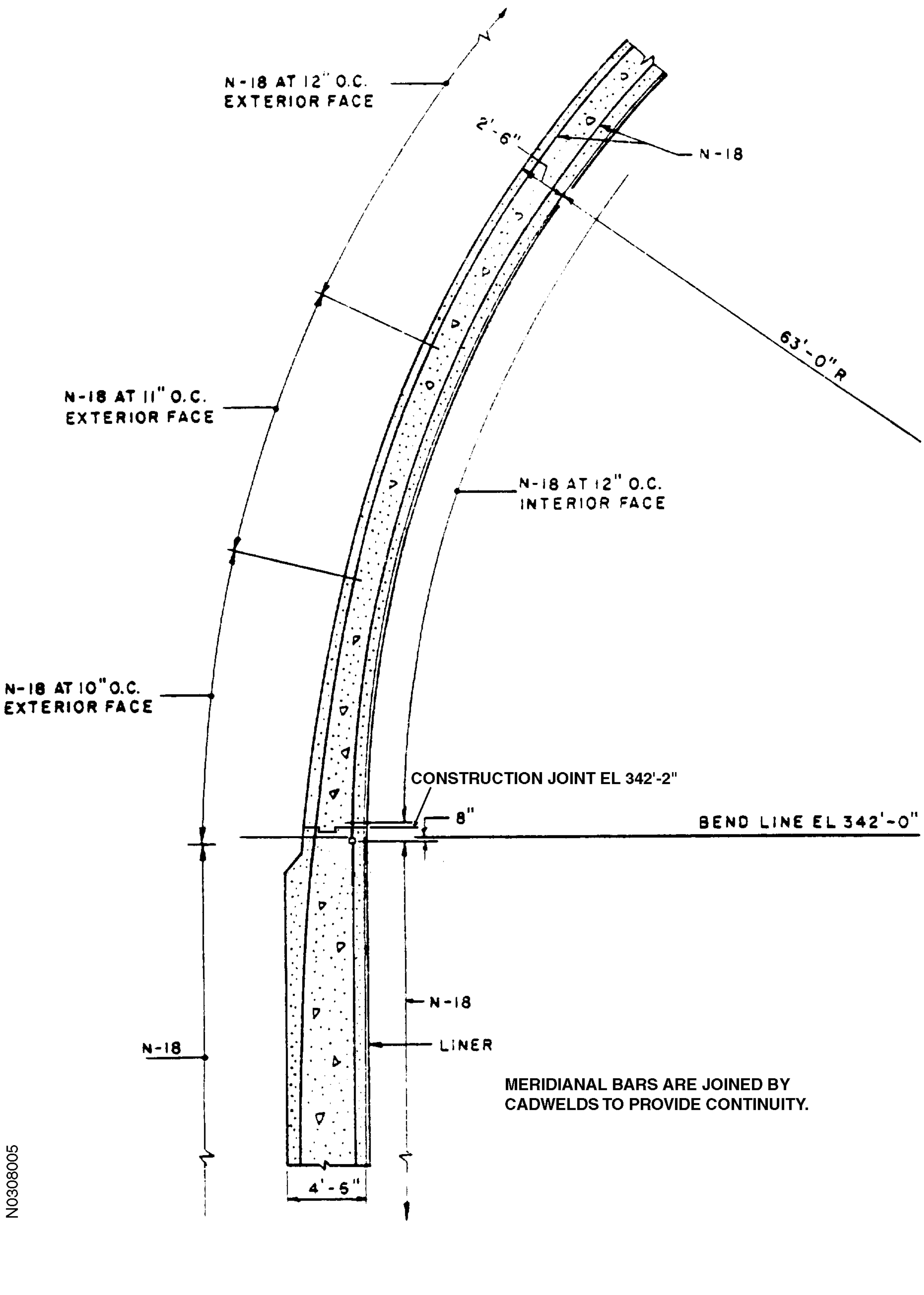


Figure 3.8-5
CONCENTRIC RING AT APEX OF DOME

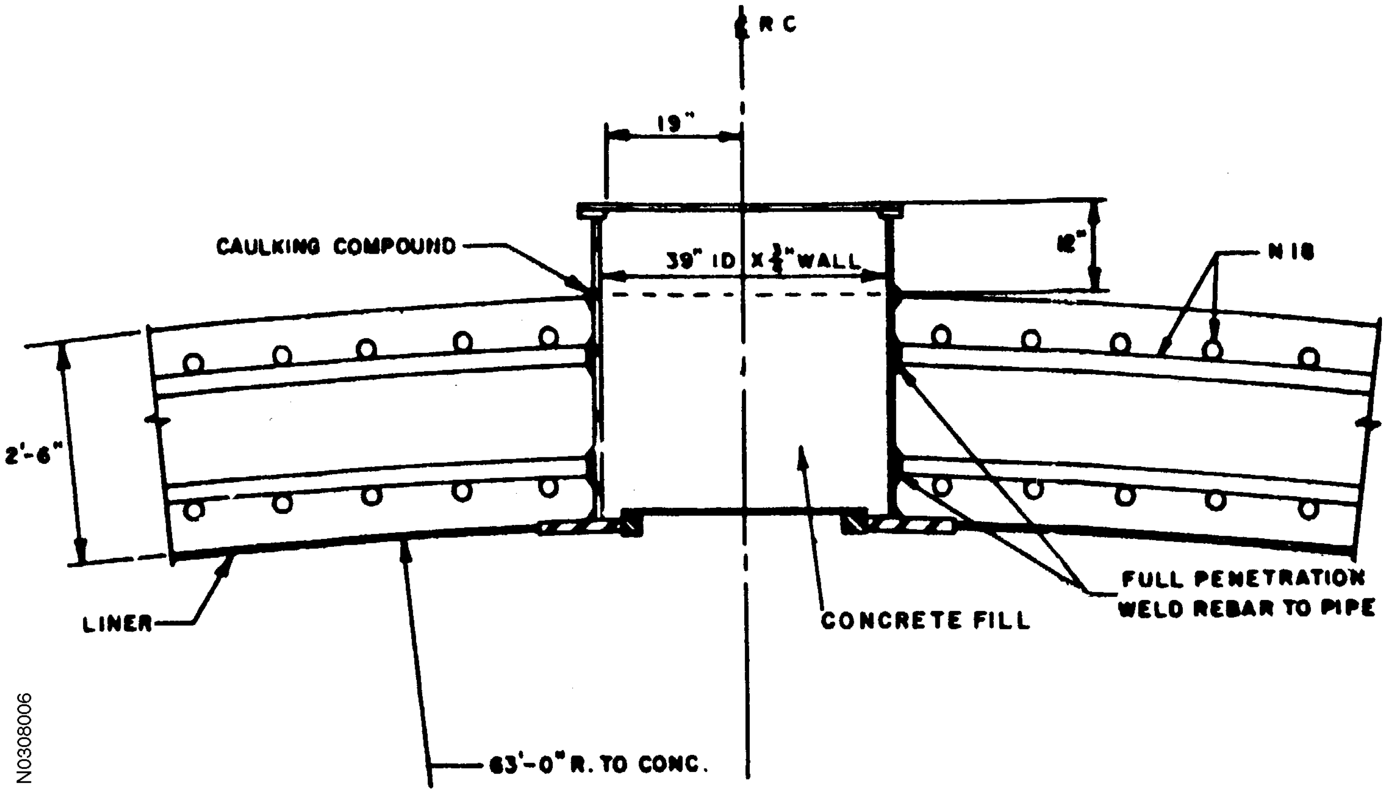


Figure 3.8-6
CONTAINMENT DIAGONAL REINFORCING

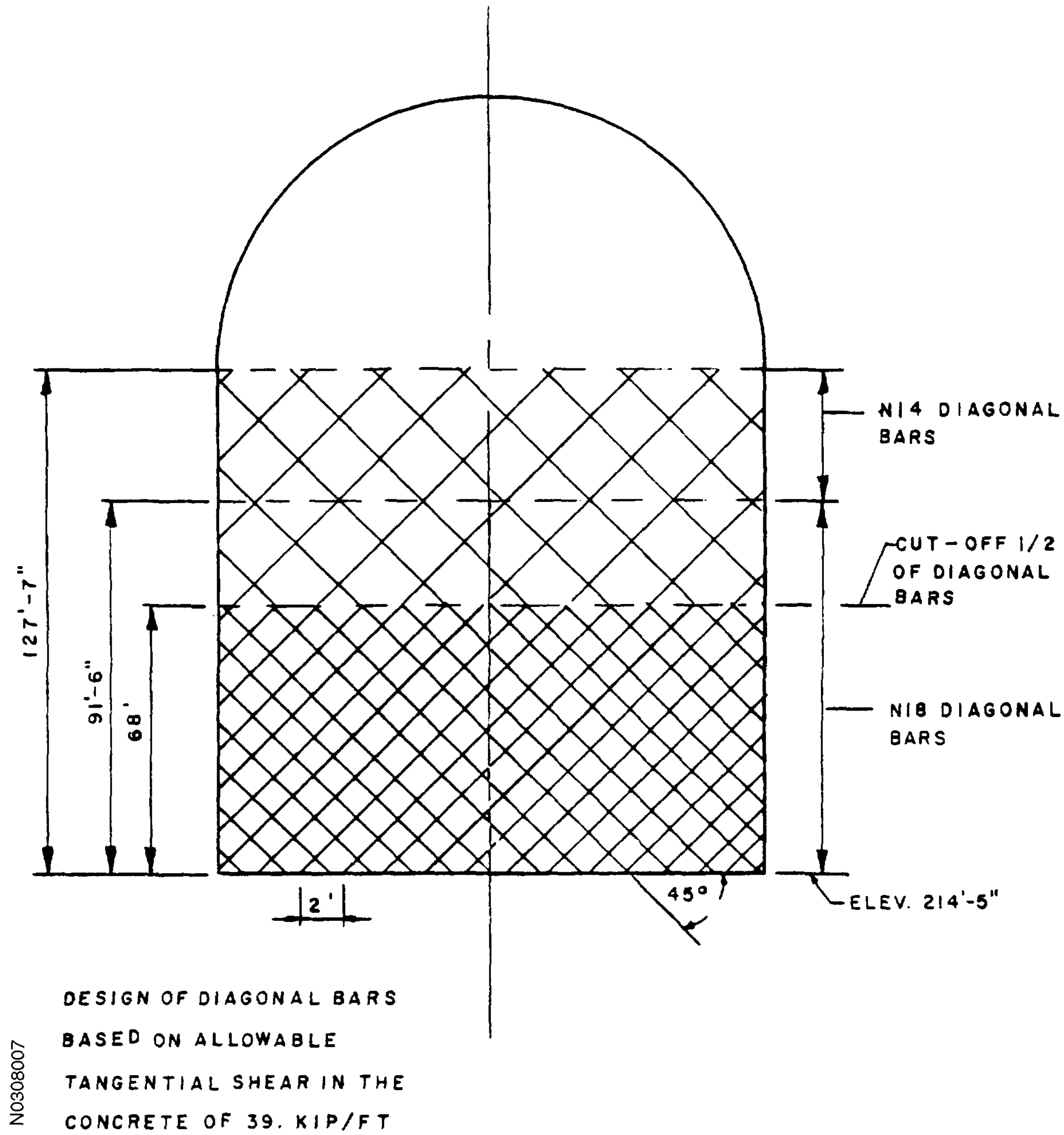
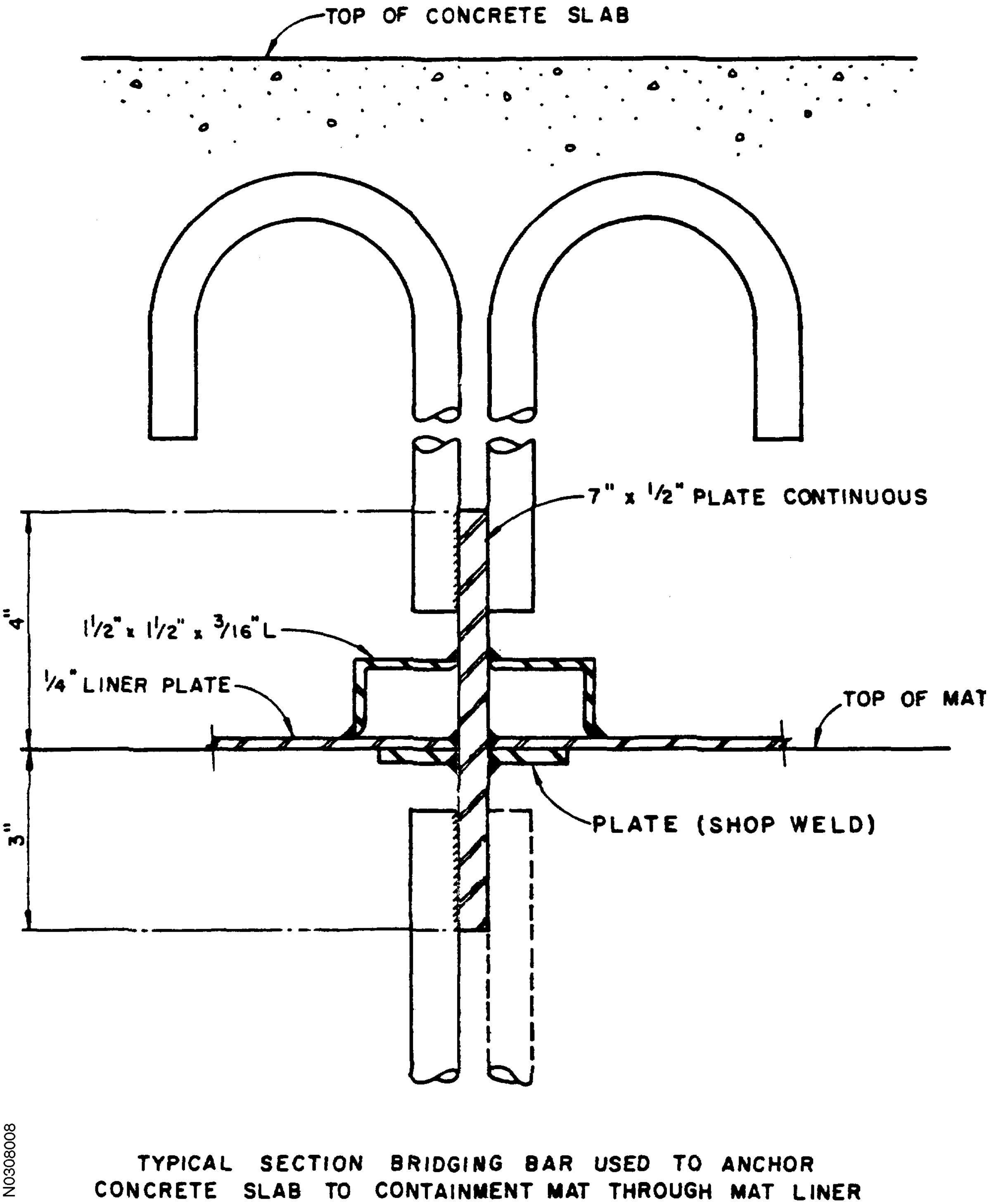


Figure 3.8-7
SECTION: TYPICAL BRIDGING BAR



TYPICAL SECTION BRIDGING BAR USED TO ANCHOR CONCRETE SLAB TO CONTAINMENT MAT THROUGH MAT LINER

Figure 3.8-8
TYPICAL LINER DETAILS

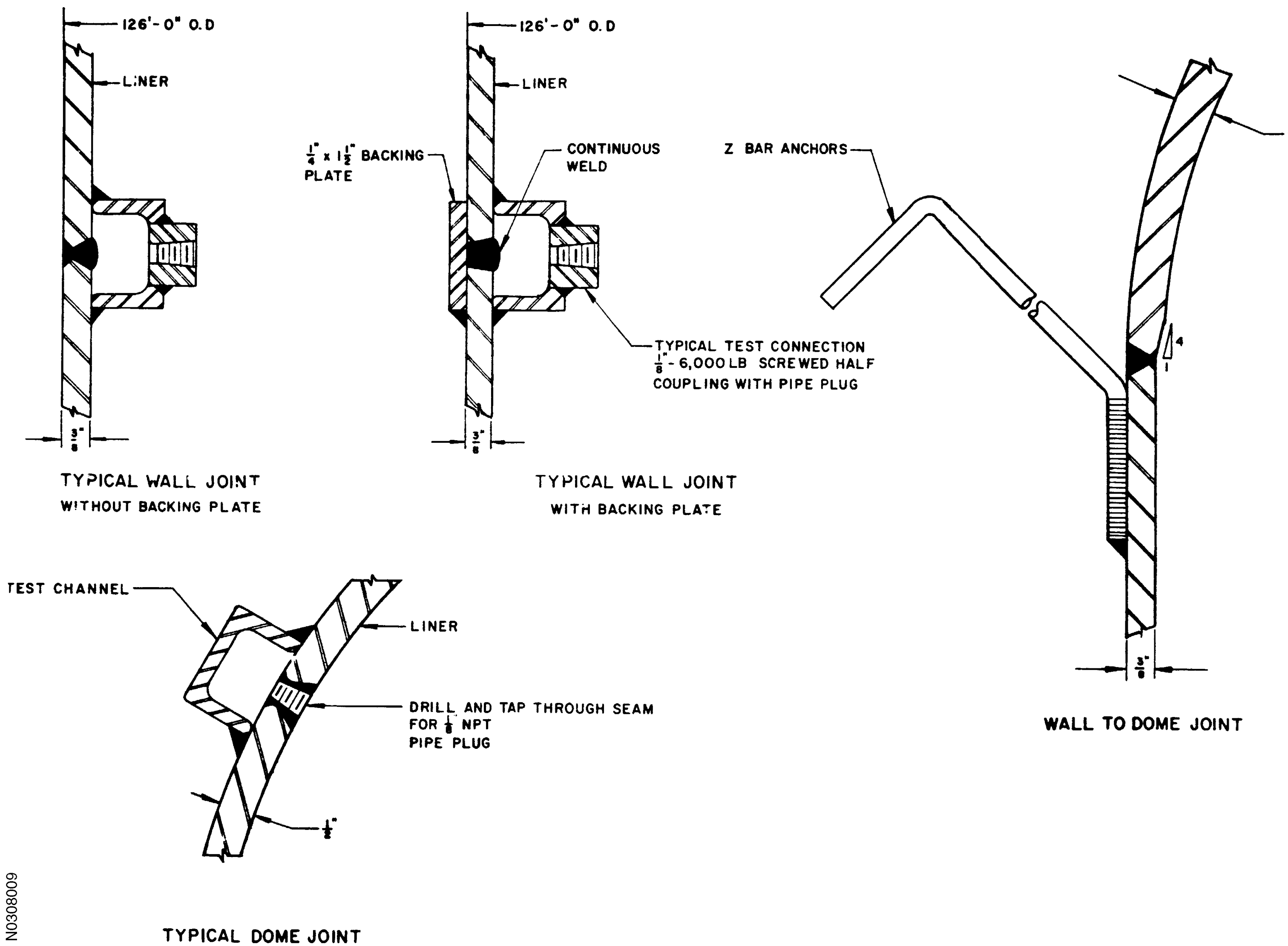


Figure 3.8-9
WALL AND MAT JOINT

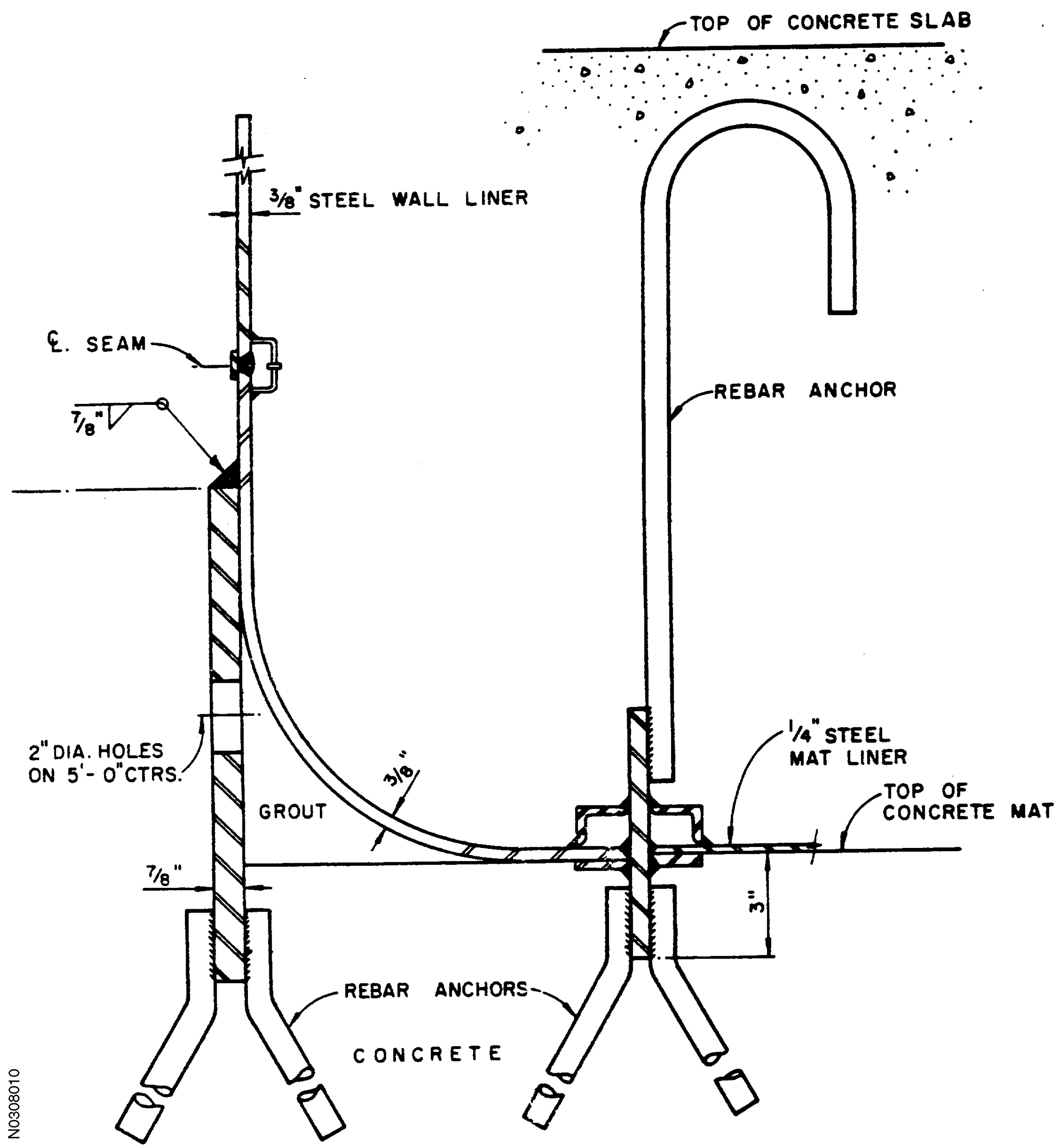
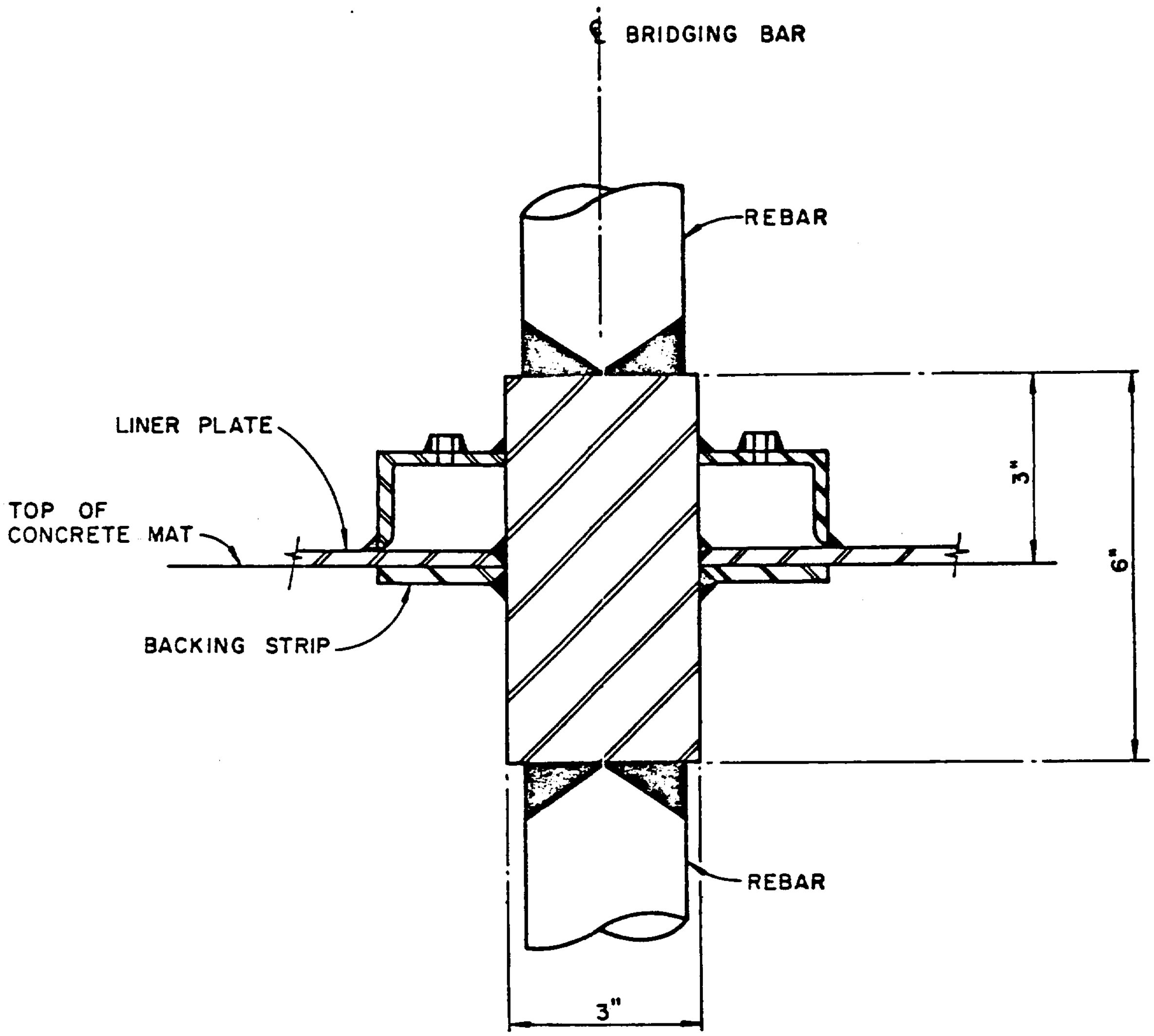


Figure 3.8-10
SECTION: TYPICAL BRIDGING BAR (SHEET 2)



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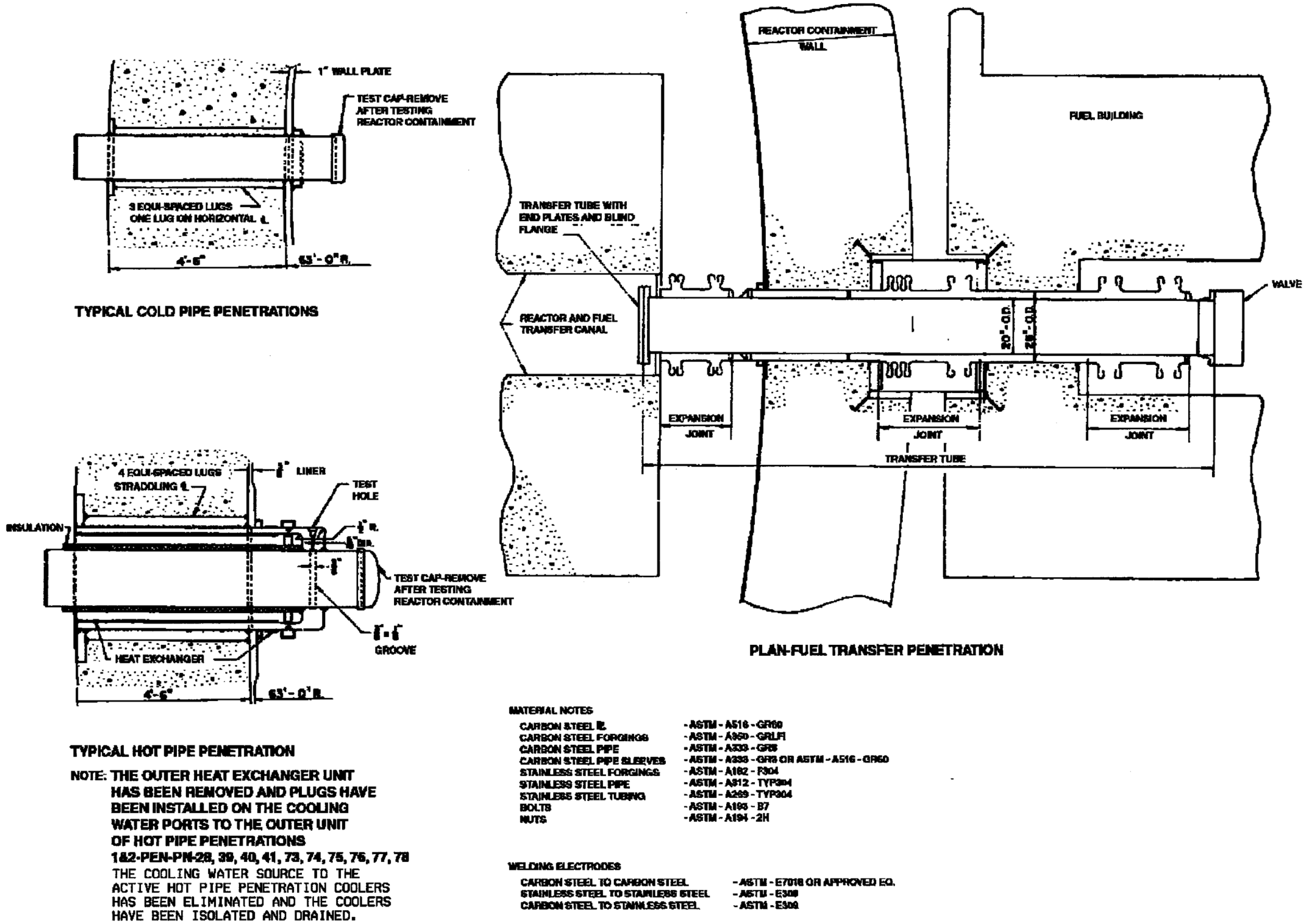
TYPICAL SECTION THROUGH BRIDGING BAR USED TO PROVIDE MAIN REINFORCING STEEL CONTINUITY THROUGH MAT LINER

Figure 3.8-11
TYPICAL PIPING PENETRATIONS



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N0308012.DGN

Figure 3.8-12
REACTOR CONTAINMENT ELECTRICAL PENETRATIONS AREA

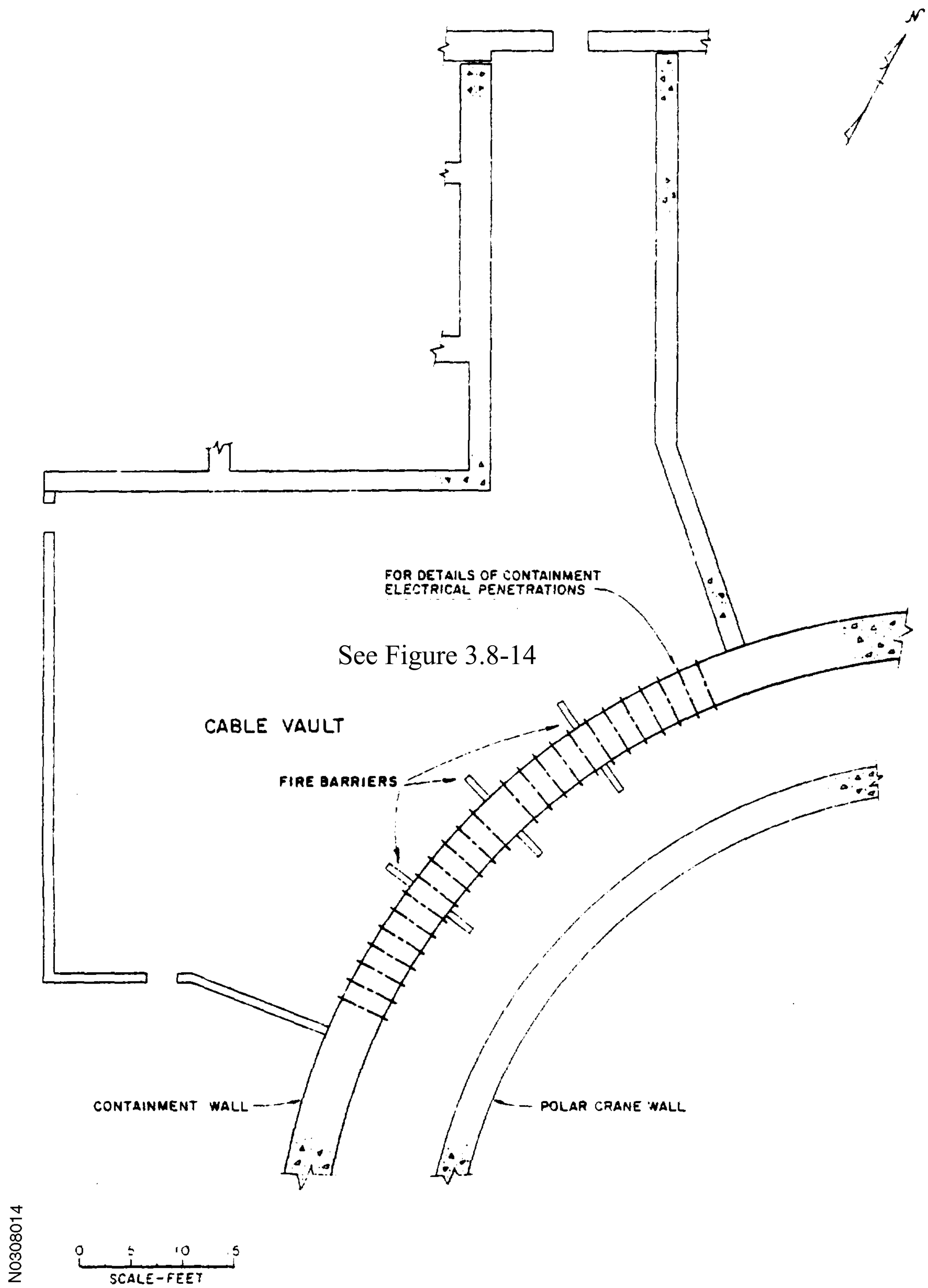
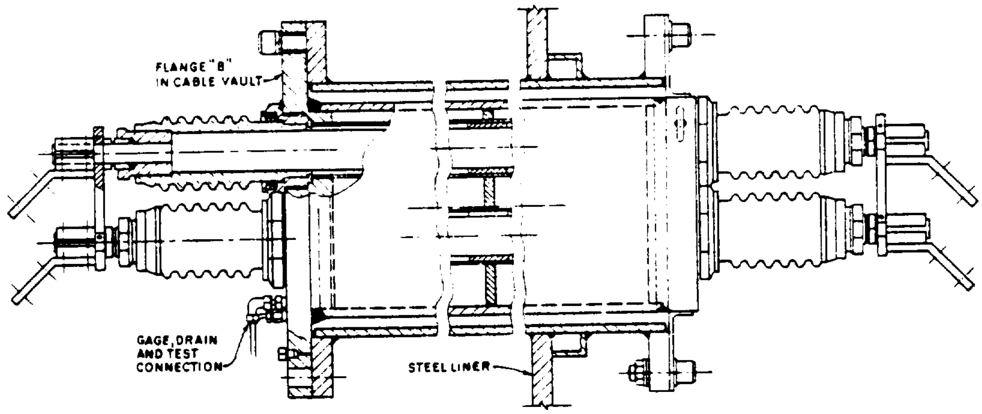
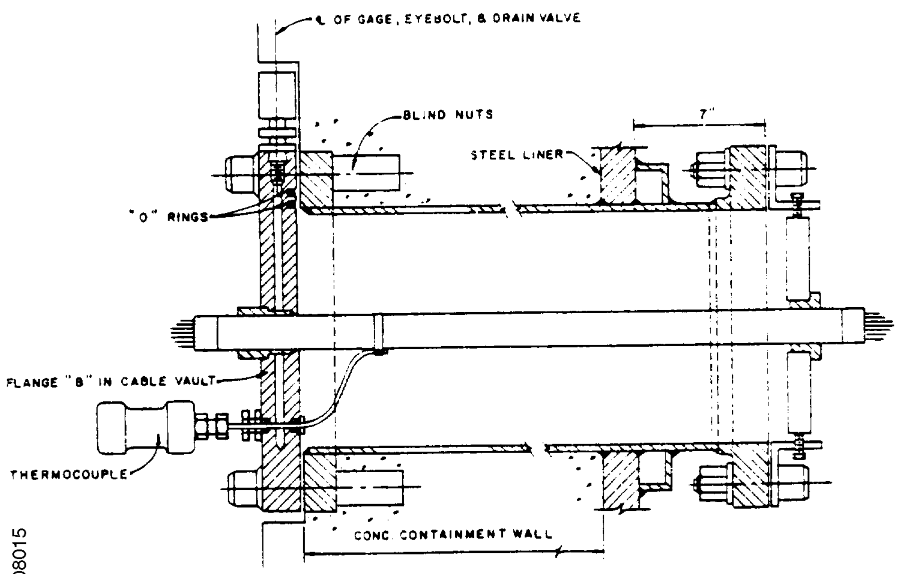


Figure 3.8-13
ELECTRICAL PENETRATIONS



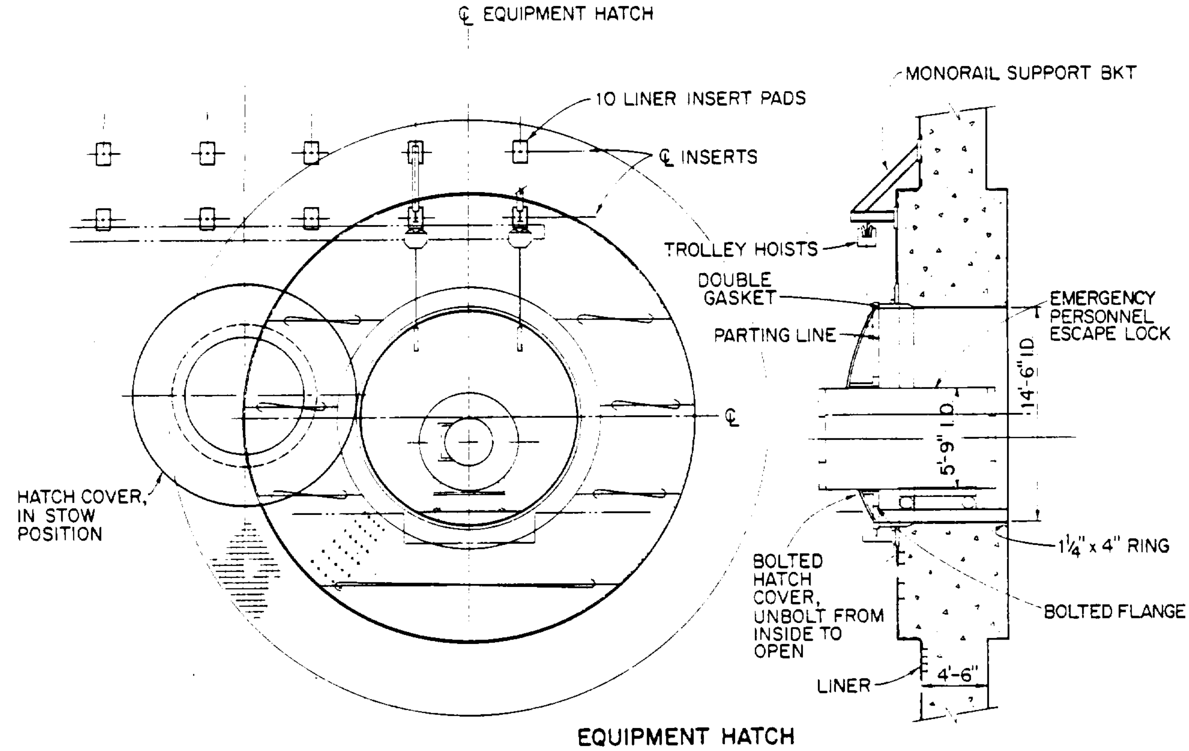
MEDIUM VOLTAGE TYPE



LOW VOLTAGE TYPE

N0308015

Figure 3.8-14
PERSONNEL AND EQUIPMENT HATCH ASSEMBLIES



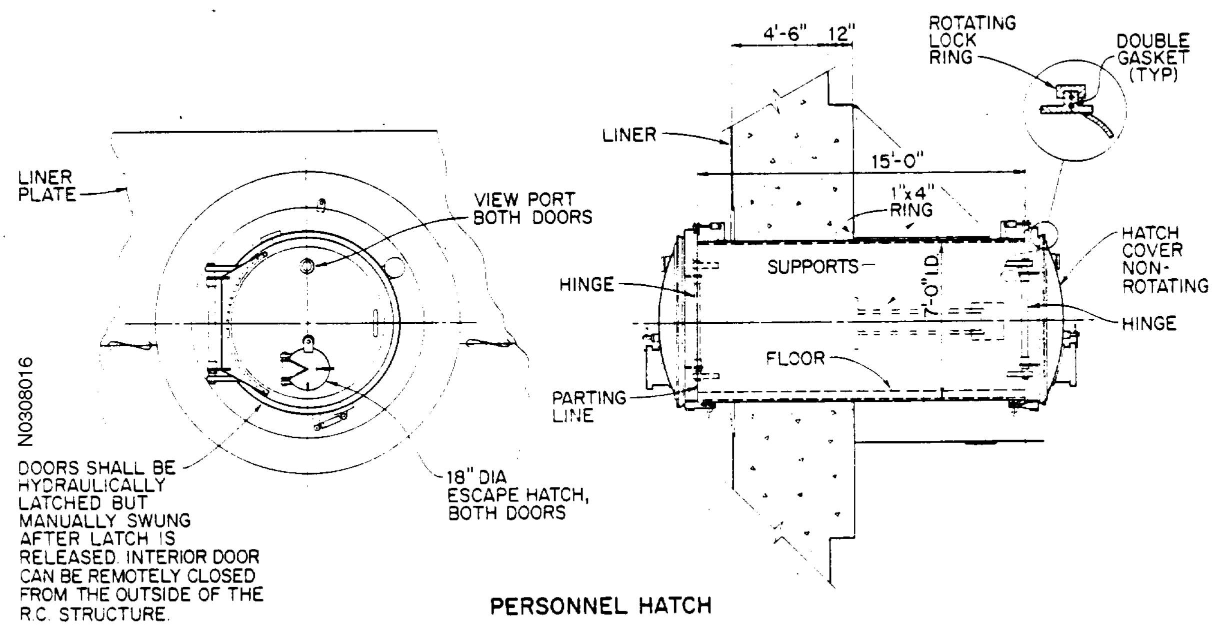


Figure 3.8-15
TYPICAL PIPING PENETRATION WITH COOLERS

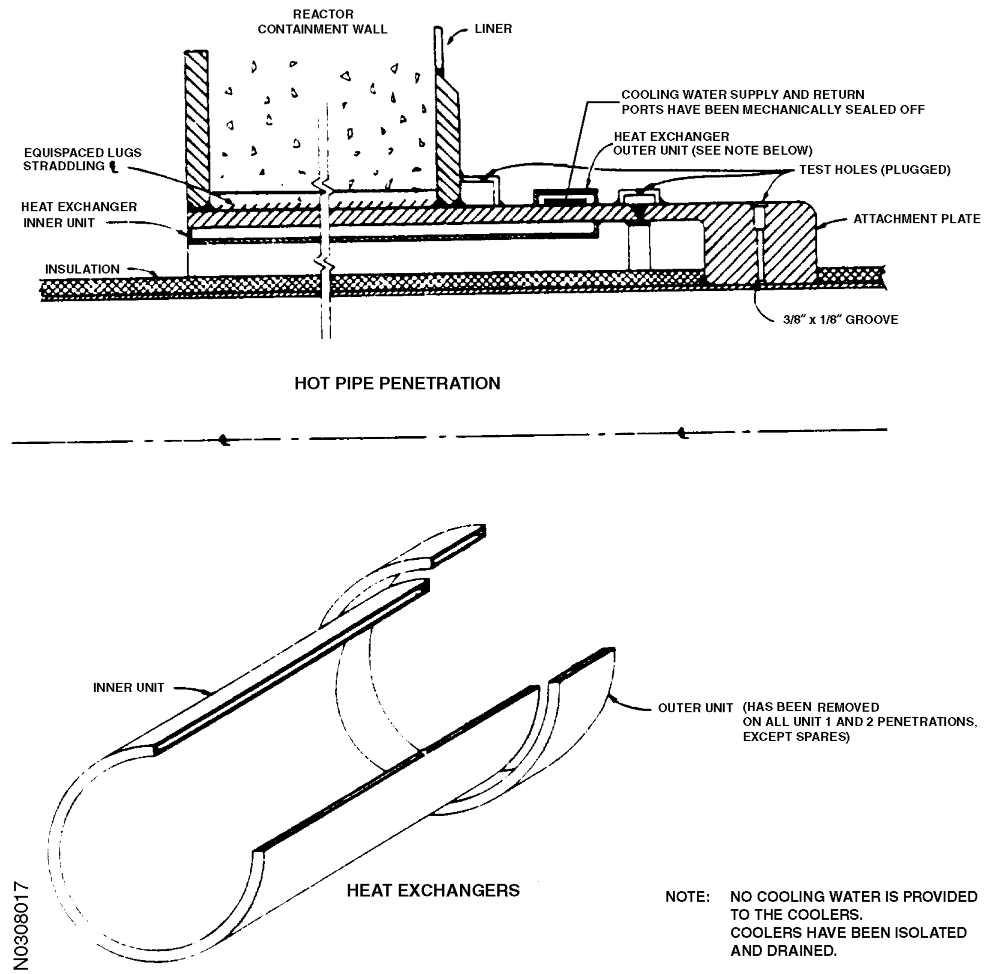
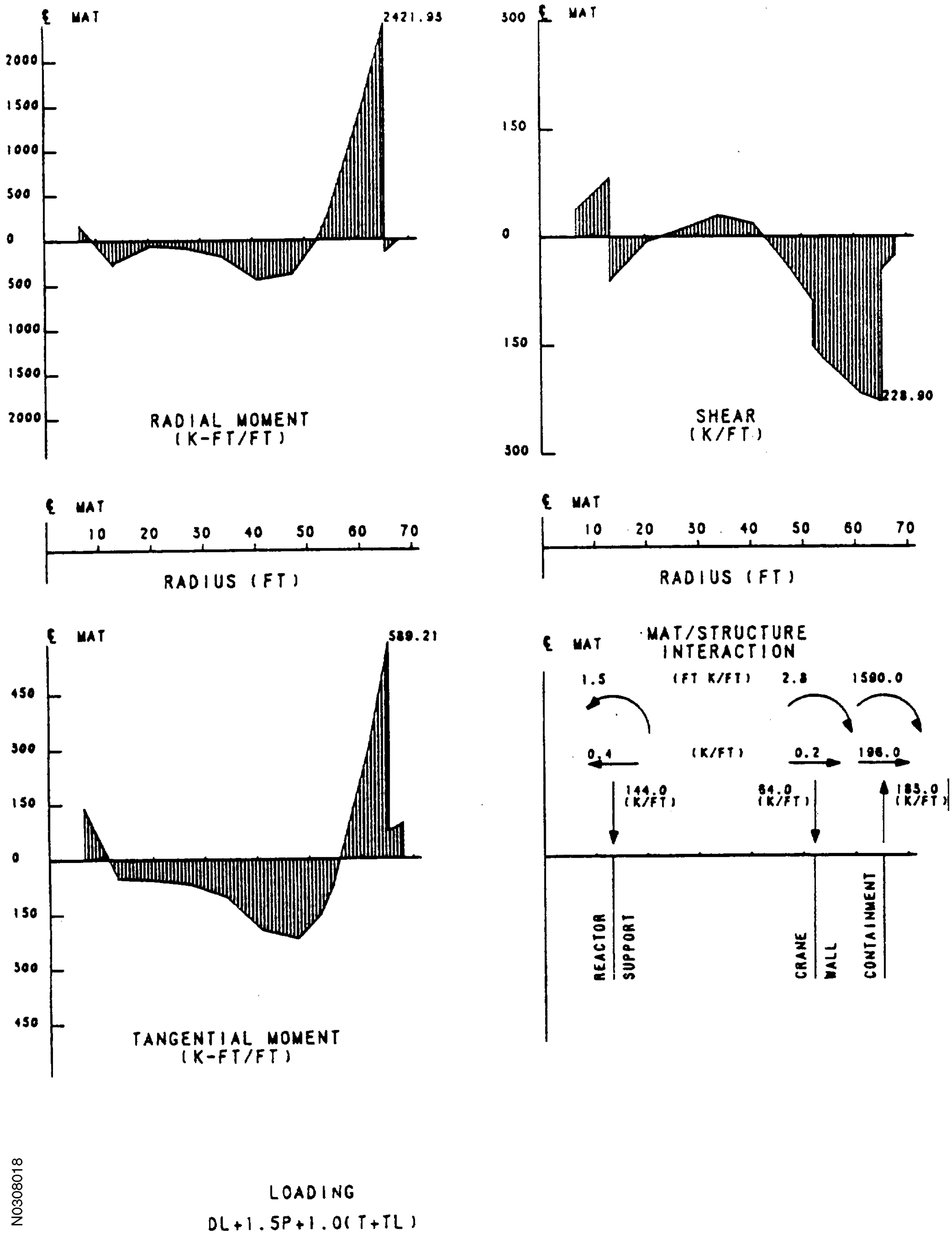
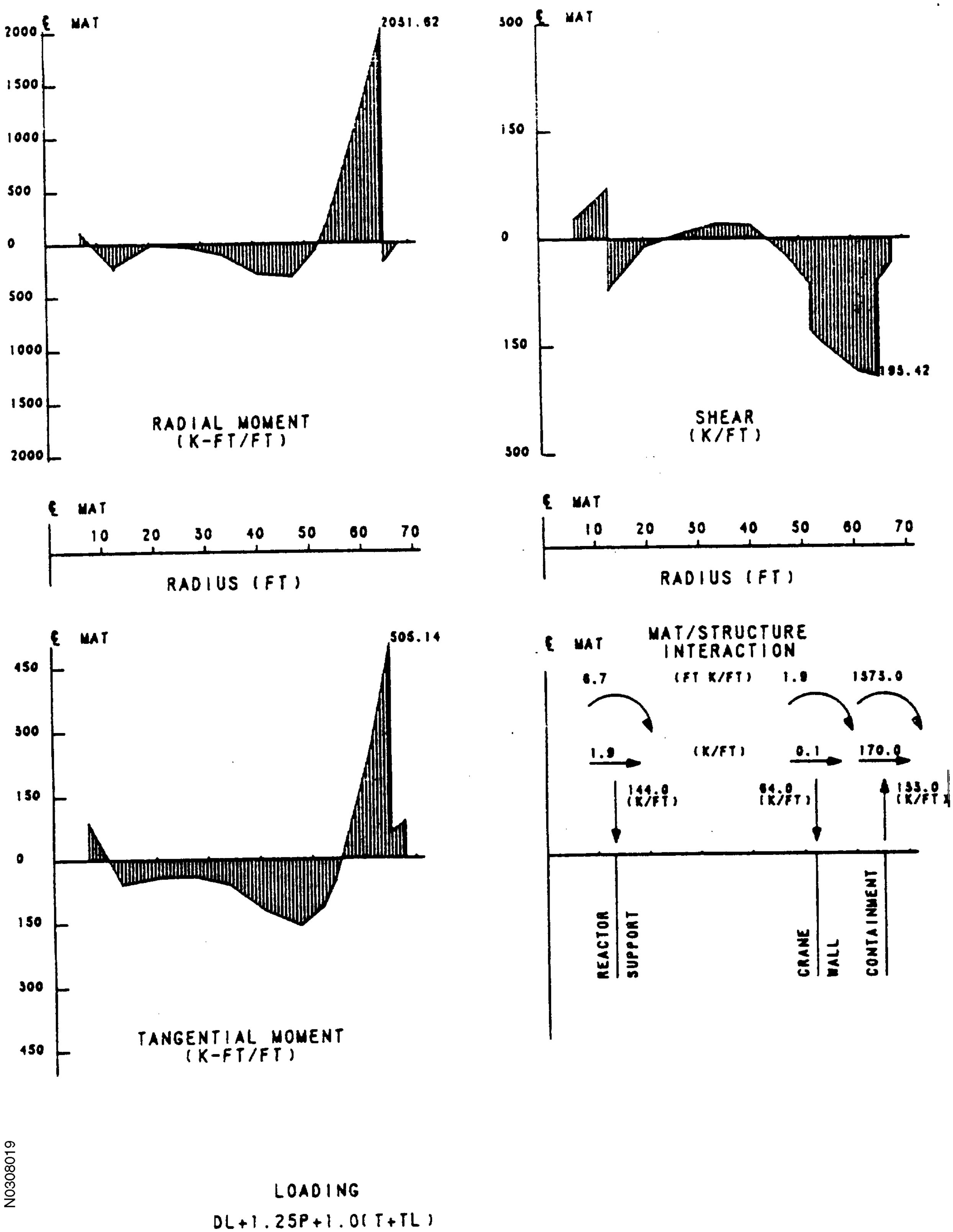


Figure 3.8-16 (SHEET 1 OF 7)
CONTAINMENT MAT MOMENT AND SHEAR DIAGRAMS



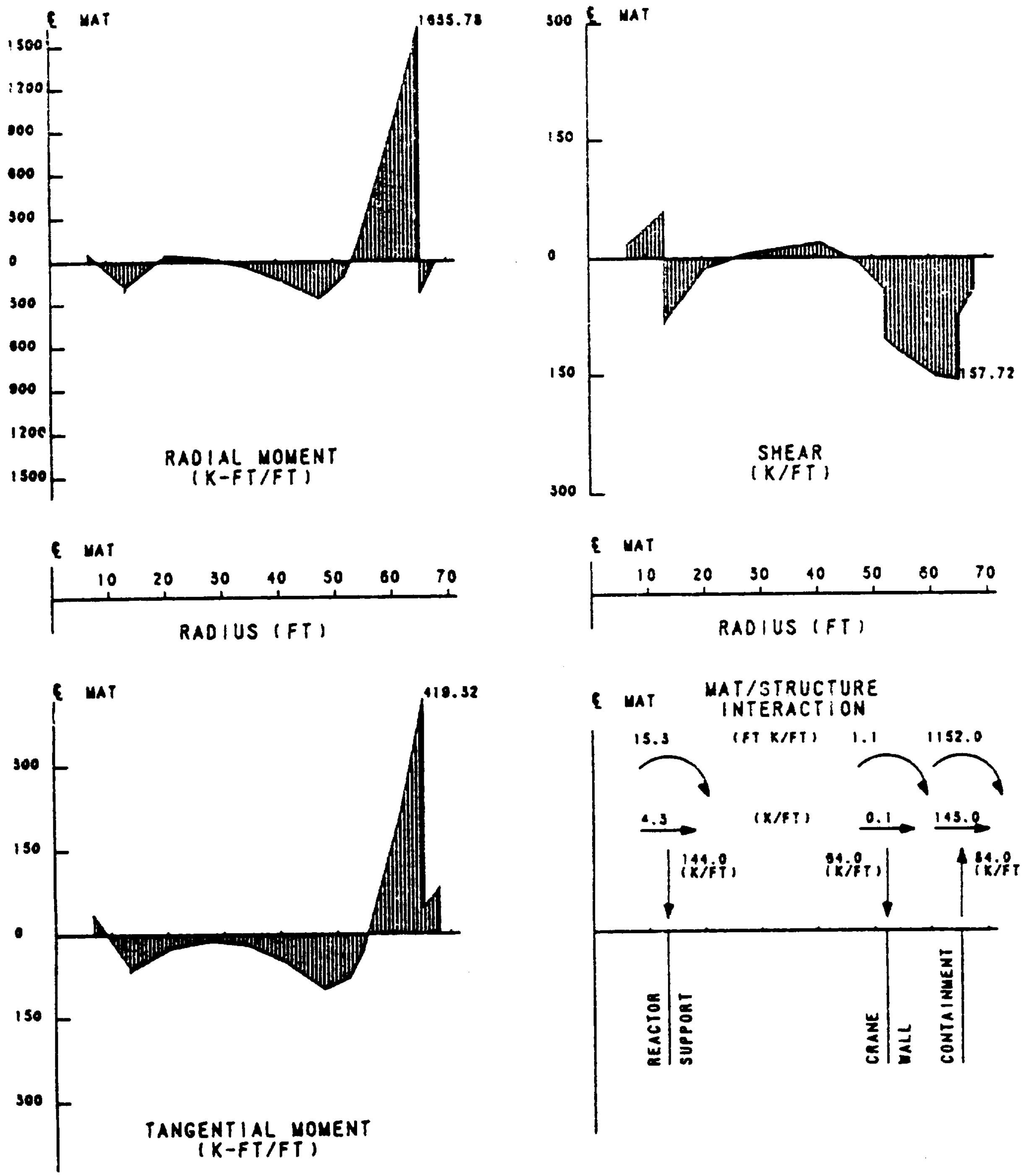
LOADING
DL+1.5P+1.0(T+TL)

Figure 3.8-16 (SHEET 2 OF 7)
CONTAINMENT MAT MOMENT AND SHEAR DIAGRAMS



N0308019

Figure 3.8-16 (SHEET 3 OF 7)
CONTAINMENT MAT MOMENT AND SHEAR DIAGRAMS



N0308020

LOADING
DL+1.0P+1.0(T+TL)

Figure 3.8-16 (SHEET 4 OF 7)
CONTAINMENT MAT MOMENT AND SHEAR DIAGRAMS

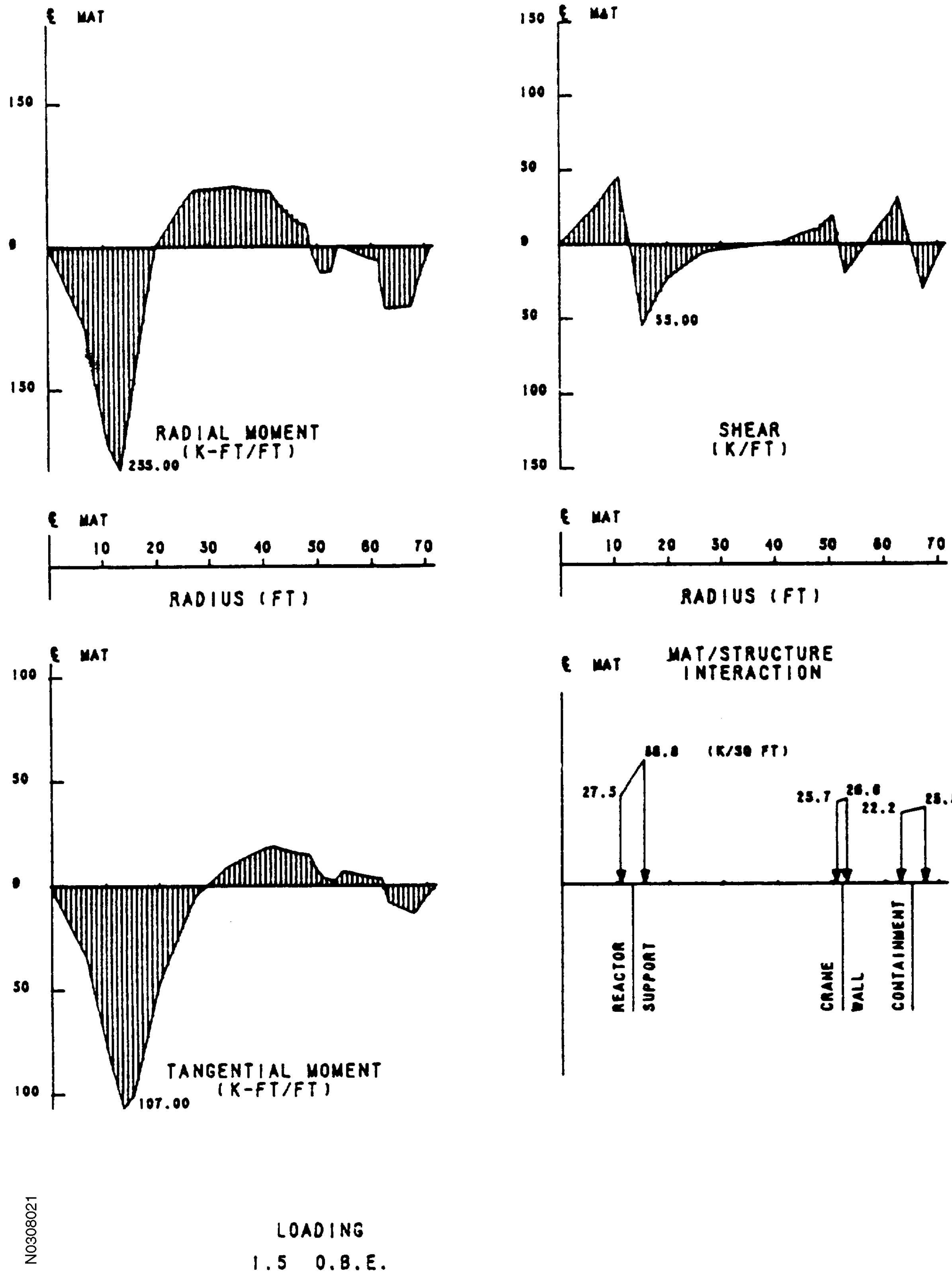


Figure 3.8-16 (SHEET 5 OF 7)
CONTAINMENT MAT MOMENT AND SHEAR DIAGRAMS

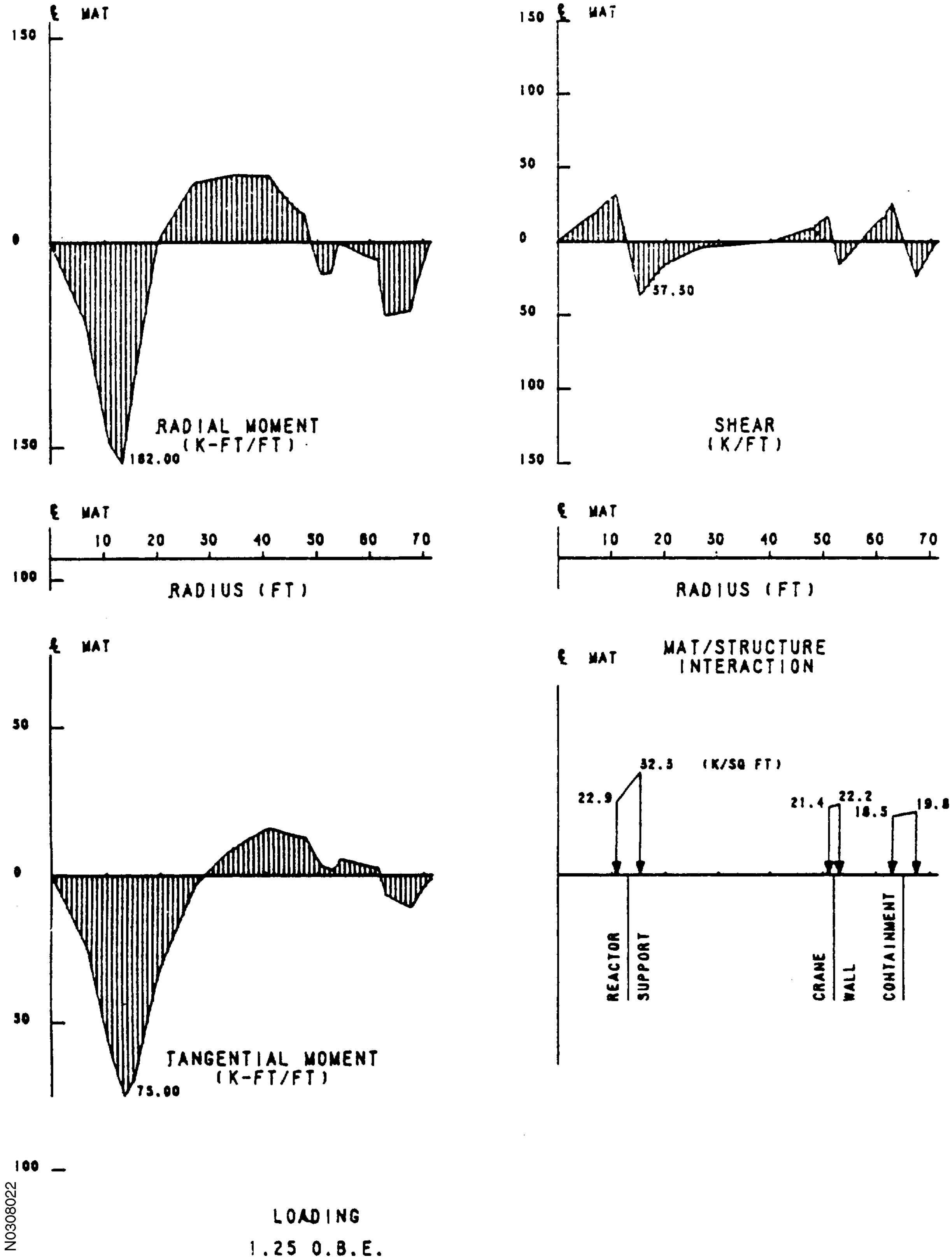
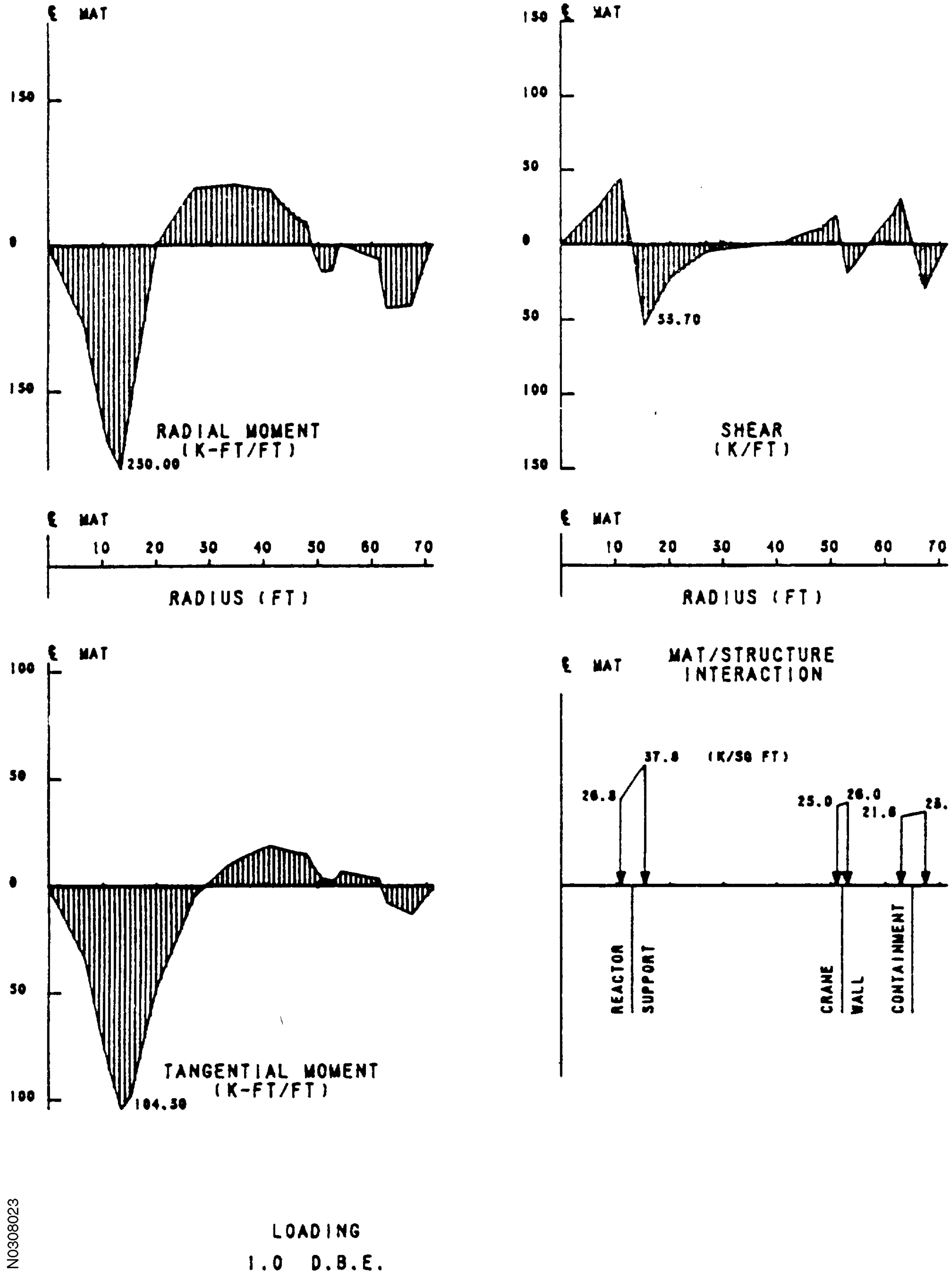


Figure 3.8-16 (SHEET 6 OF 7)
CONTAINMENT MAT MOMENT AND SHEAR DIAGRAMS



LOADING
1.0 D.B.E.

Figure 3.8-16 (SHEET 7 OF 7)
CONTAINMENT MAT MOMENT AND SHEAR DIAGRAMS

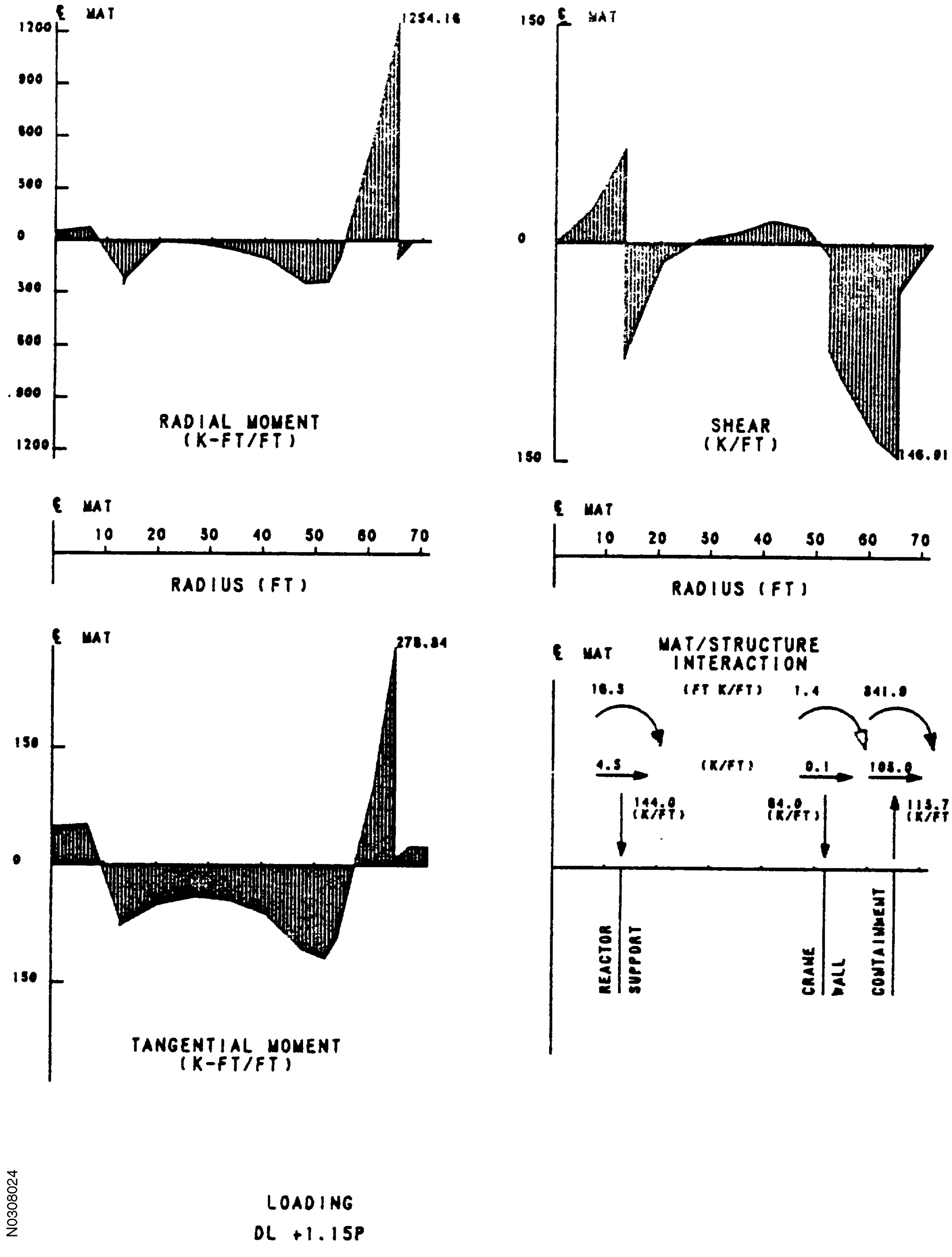


Figure 3.8-17
LOAD PLOT NOMENCLATURE

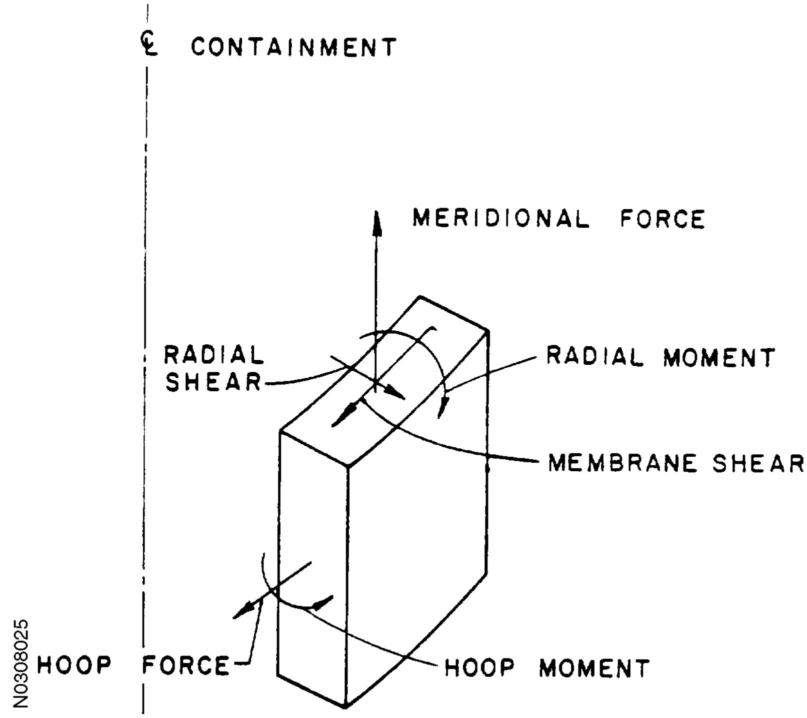


Figure 3.8-18 (SHEET 1 OF 28)
SCALED LOAD PLOTS

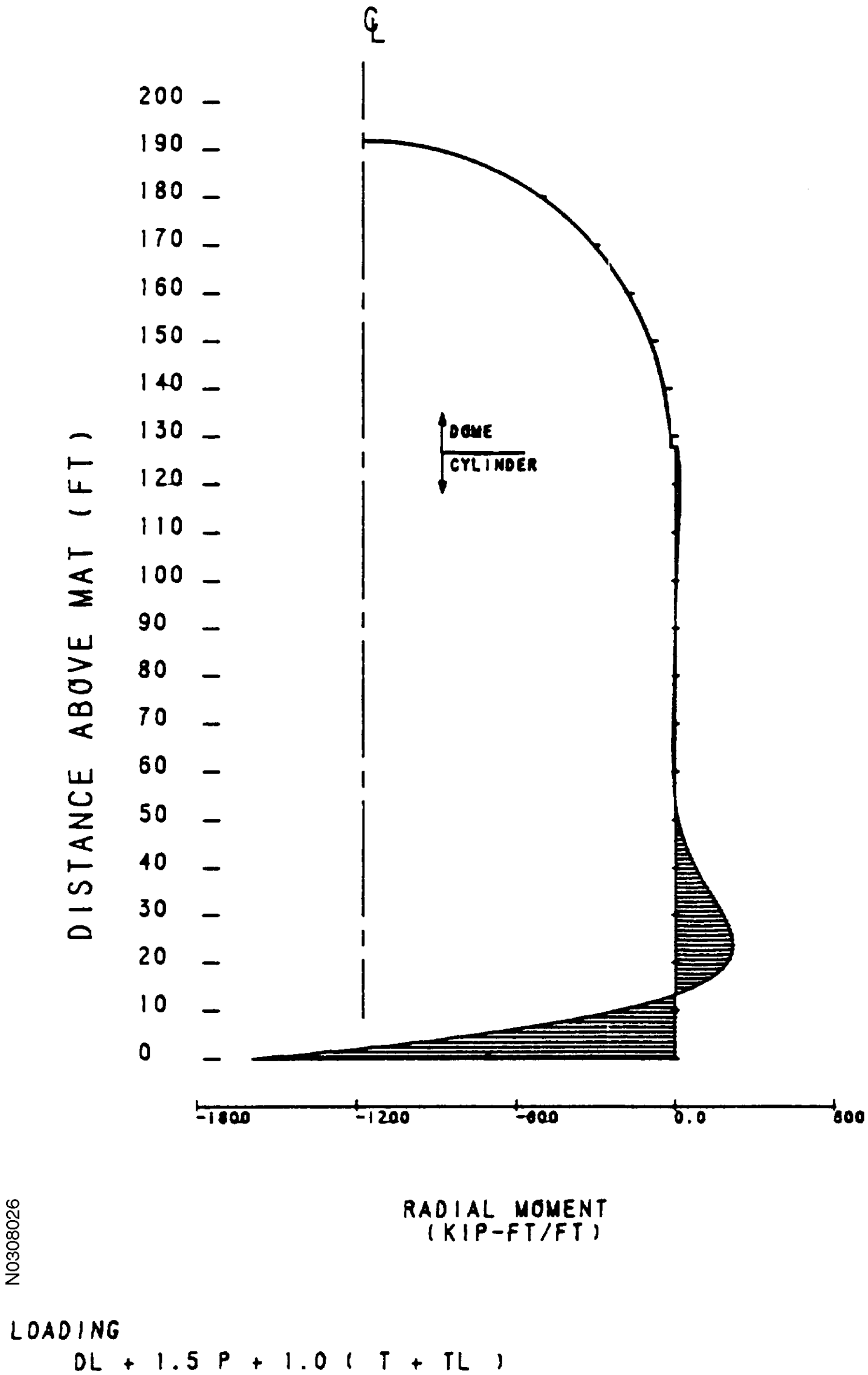
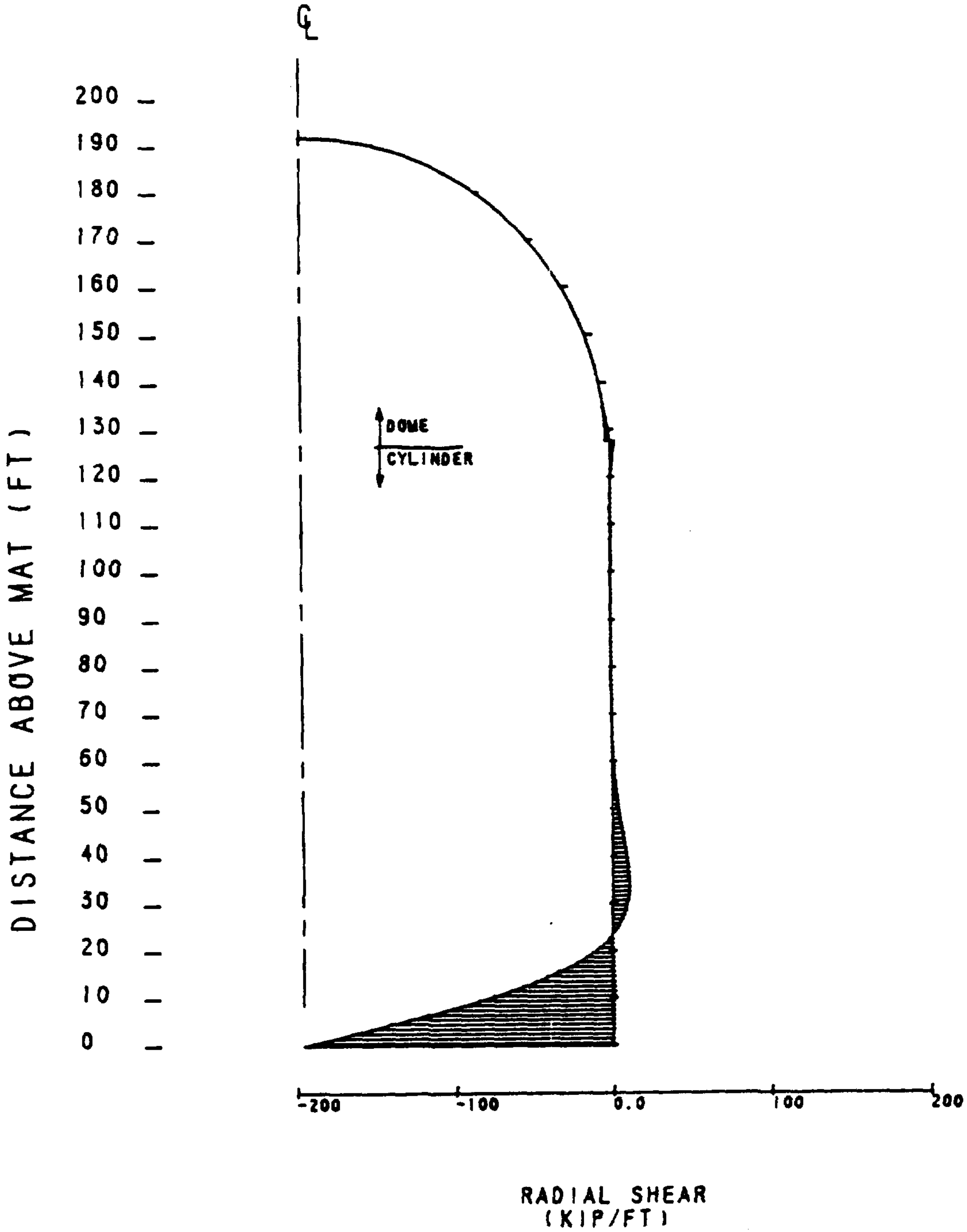


Figure 3.8-18 (SHEET 2 OF 28)
SCALED LOAD PLOTS



N0308027

LOADING
DL + 1.5 P + 1.0 (T + TL)

Figure 3.8-18 (SHEET 3 OF 28)
SCALED LOAD PLOTS

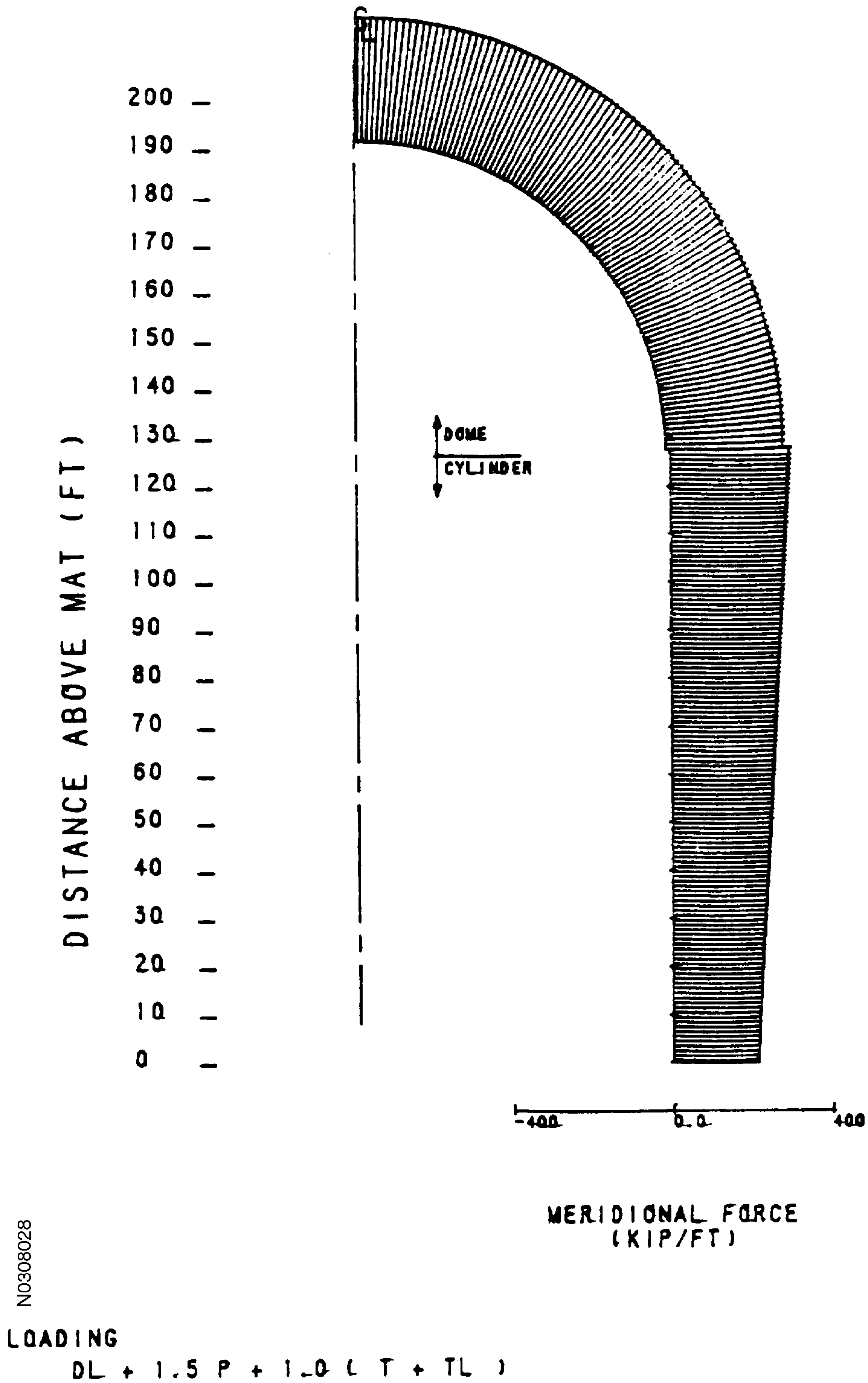
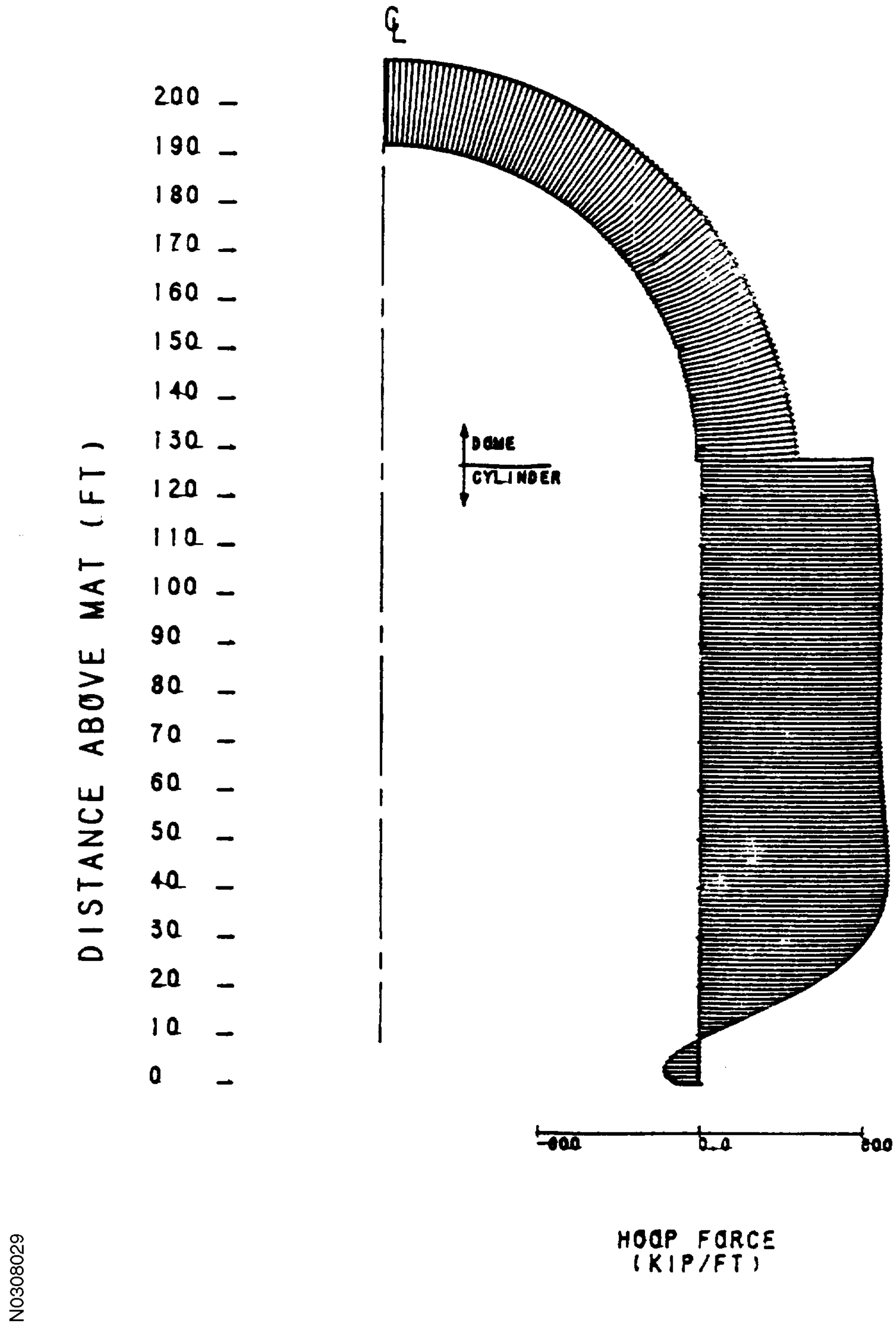
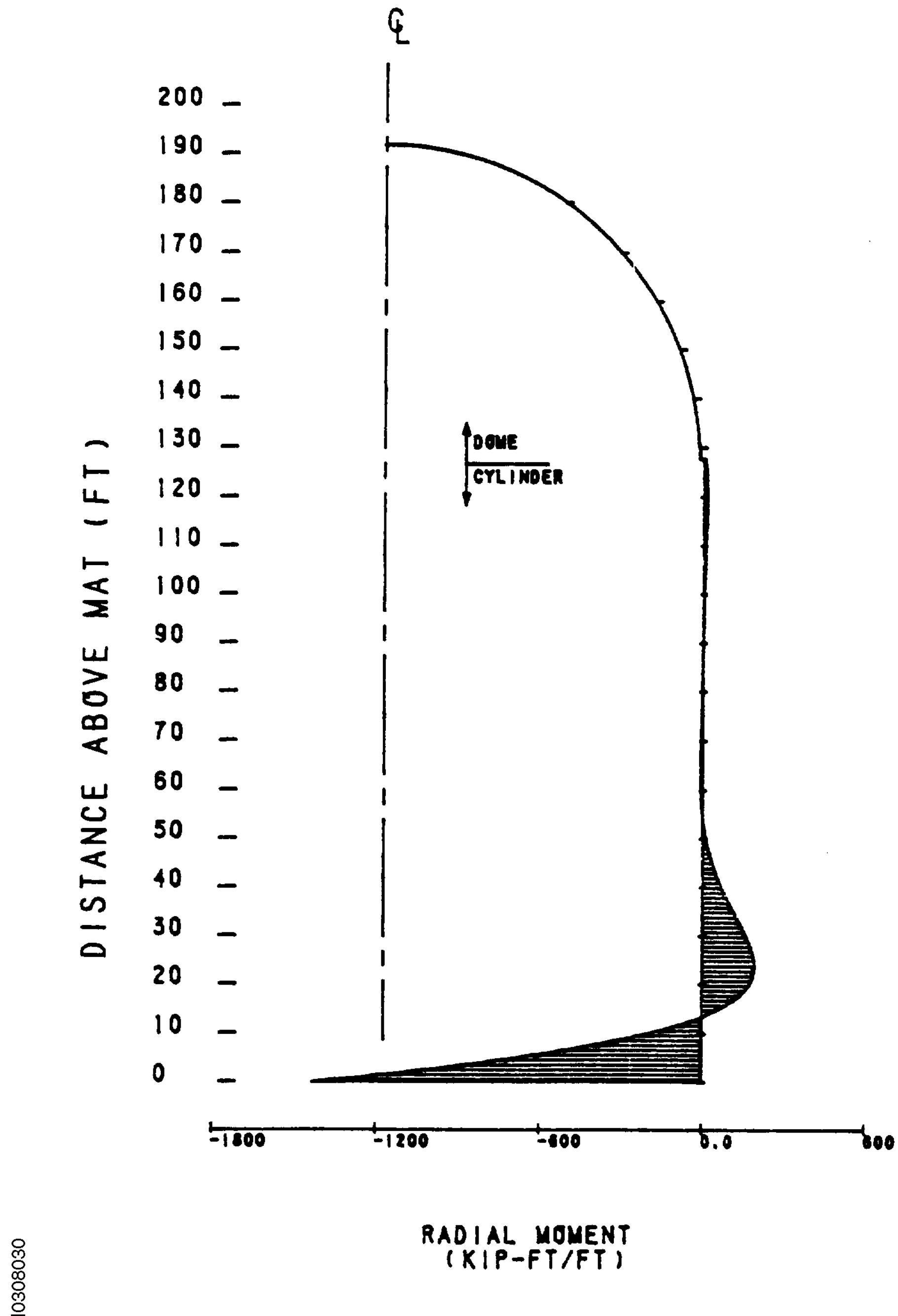


Figure 3.8-18 (SHEET 4 OF 28)
SCALED LOAD PLOTS



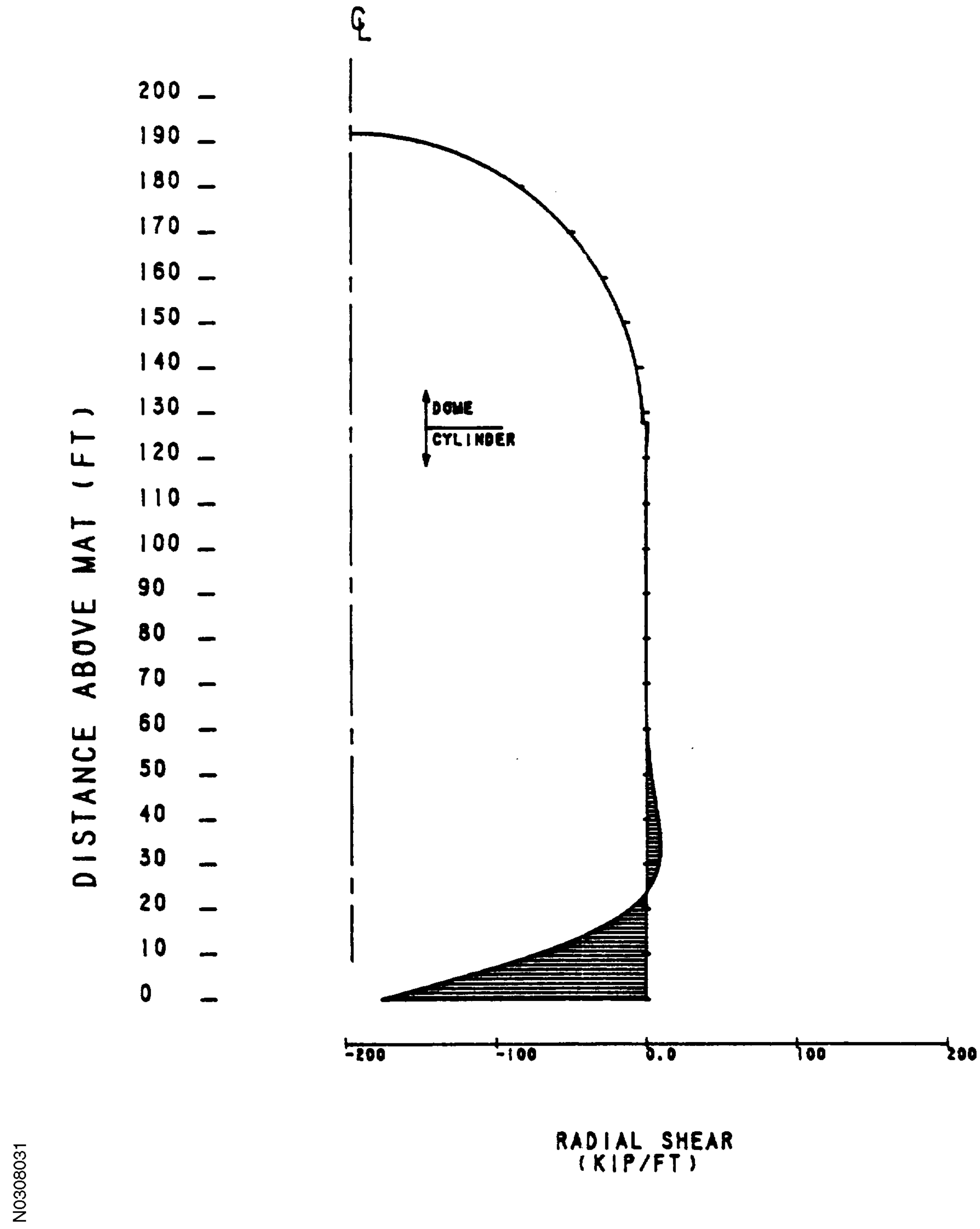
LOADING
DL + 1.5 P + 1.0 (T + TL)

Figure 3.8-18 (SHEET 5 OF 28)
SCALED LOAD PLOTS



LOADING
DL + 1.25 P +1.0 (T + TL) + 1.25 OBE

Figure 3.8-18 (SHEET 6 OF 28)
SCALED LOAD PLOTS



LOADING
DL + 1.25 P +1.0 (T + TL) + 1.25 OBE

Figure 3.8-18 (SHEET 7 OF 28)
SCALED LOAD PLOTS

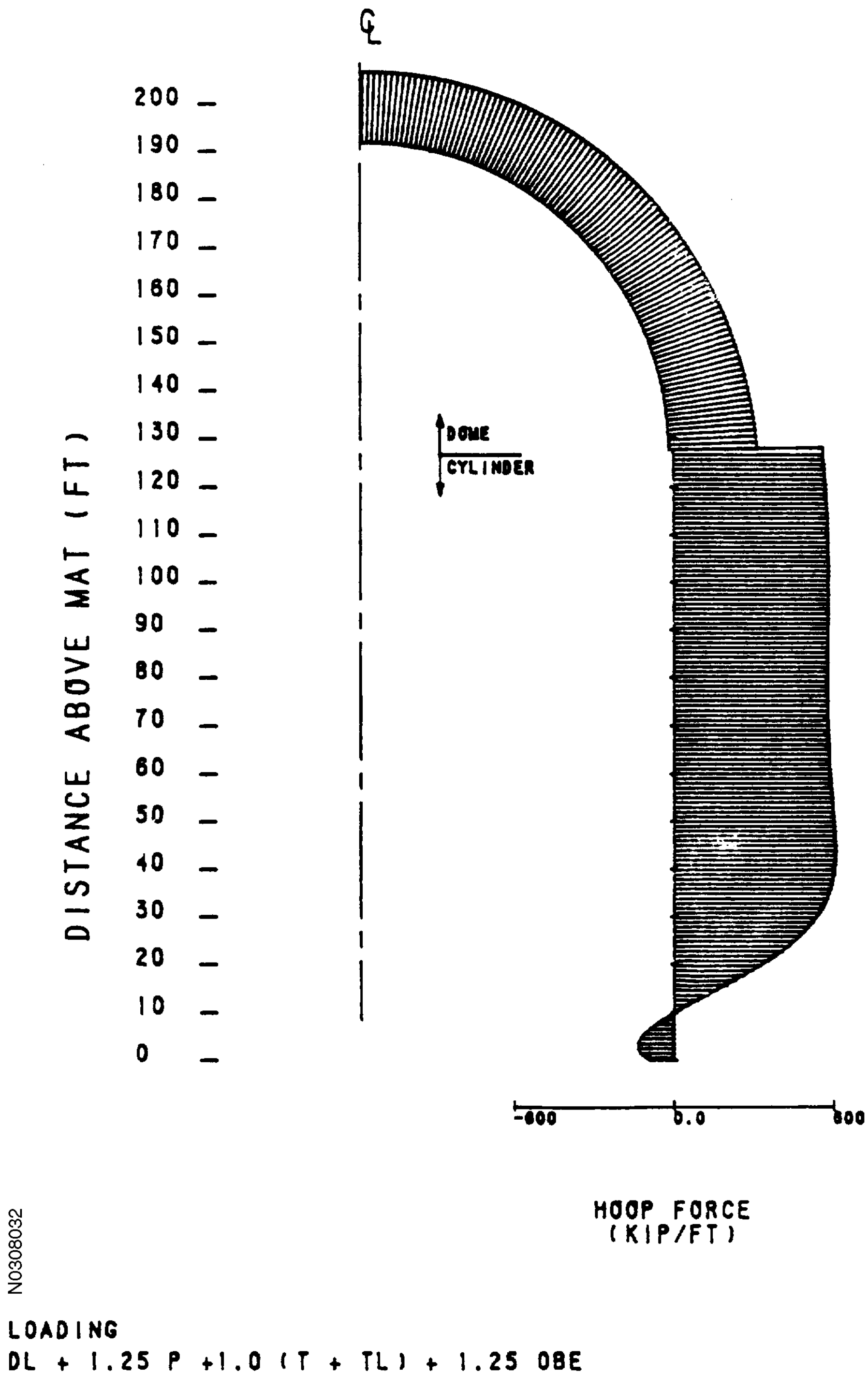


Figure 3.8-18 (SHEET 8 OF 28)
SCALED LOAD PLOTS

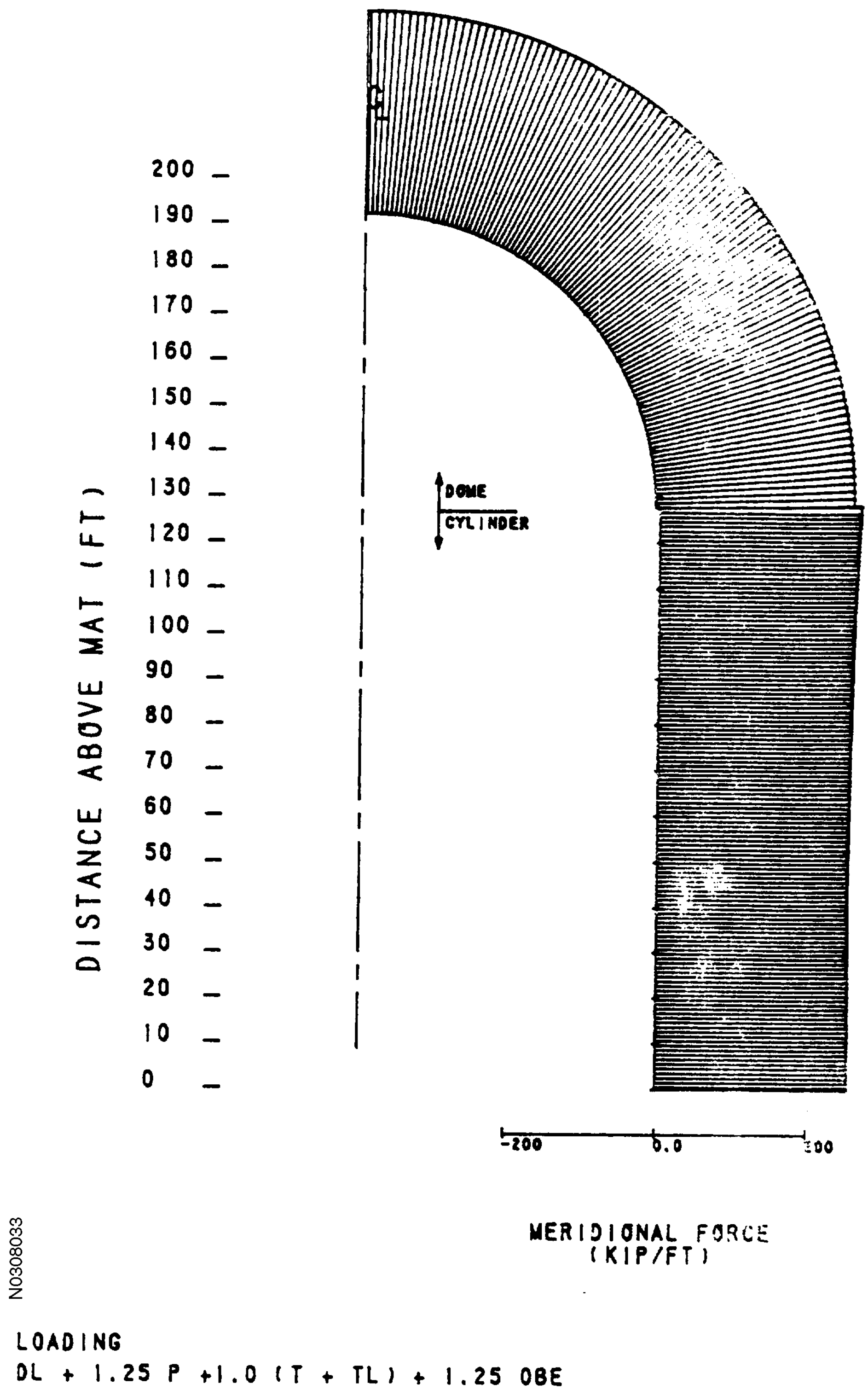
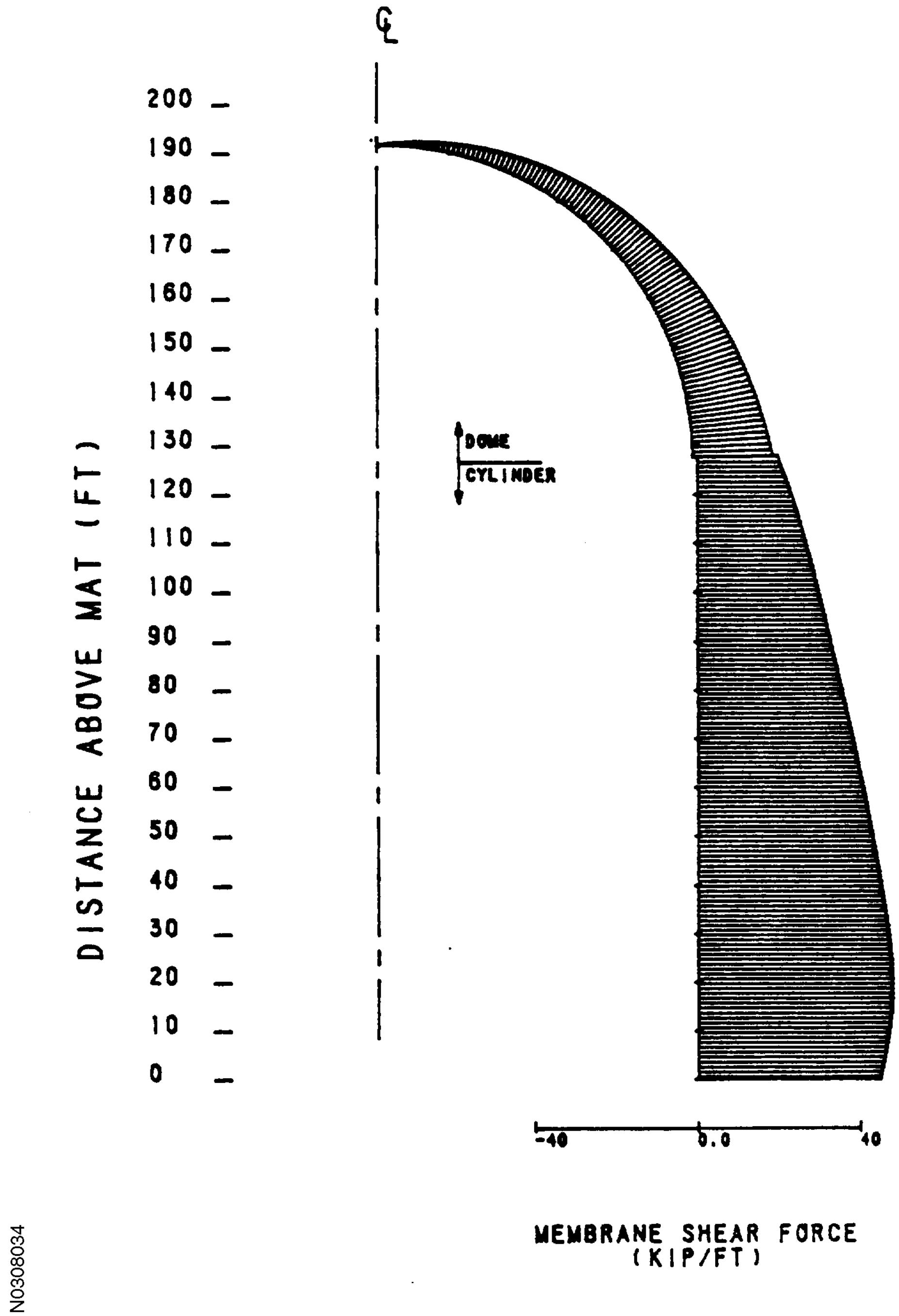


Figure 3.8-18 (SHEET 9 OF 28)
SCALED LOAD PLOTS



LOADING
DL + 1.25 P +1.0 (T + TL) + 1.25 OBE

Figure 3.8-18 (SHEET 10 OF 28)
SCALED LOAD PLOTS

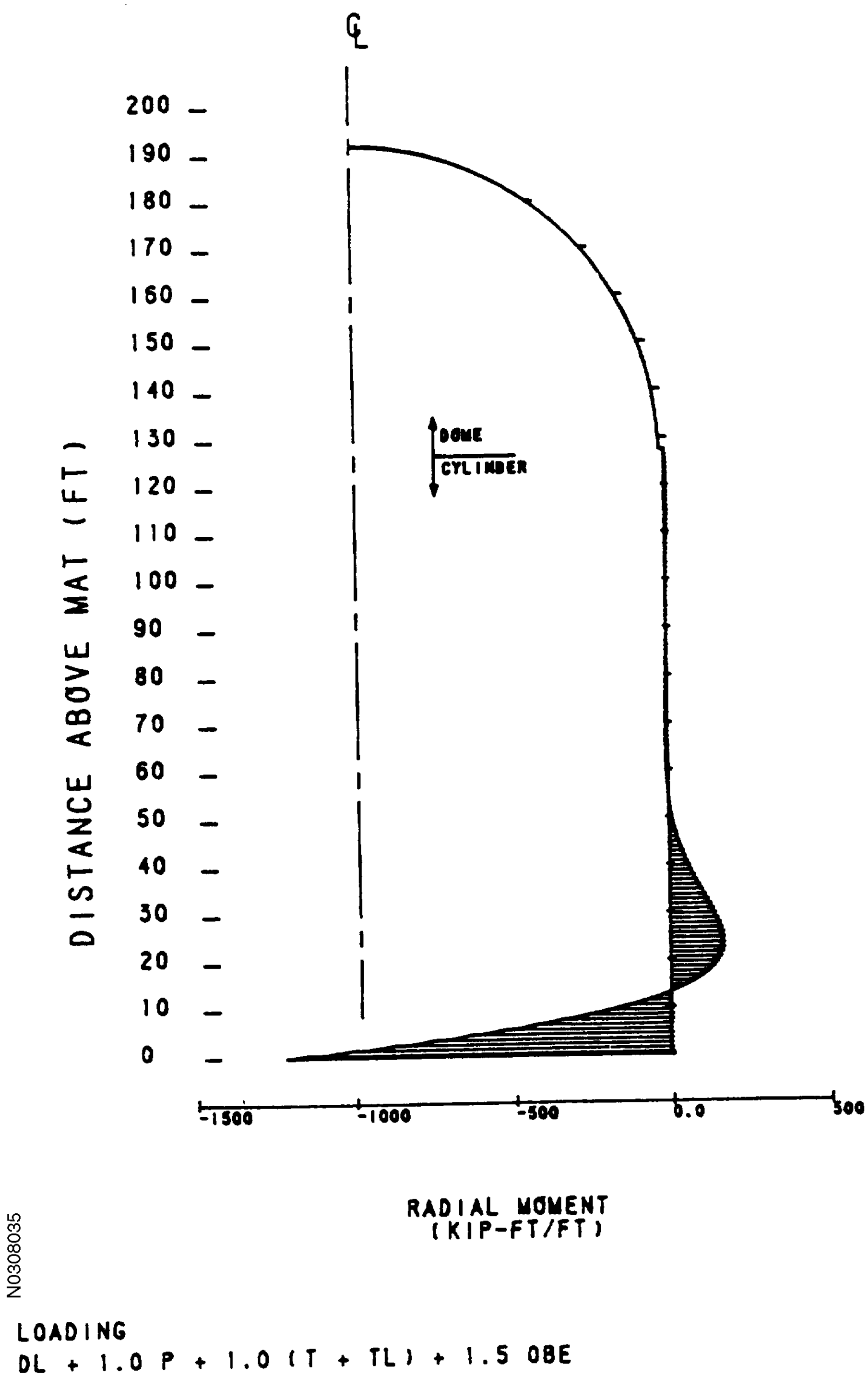
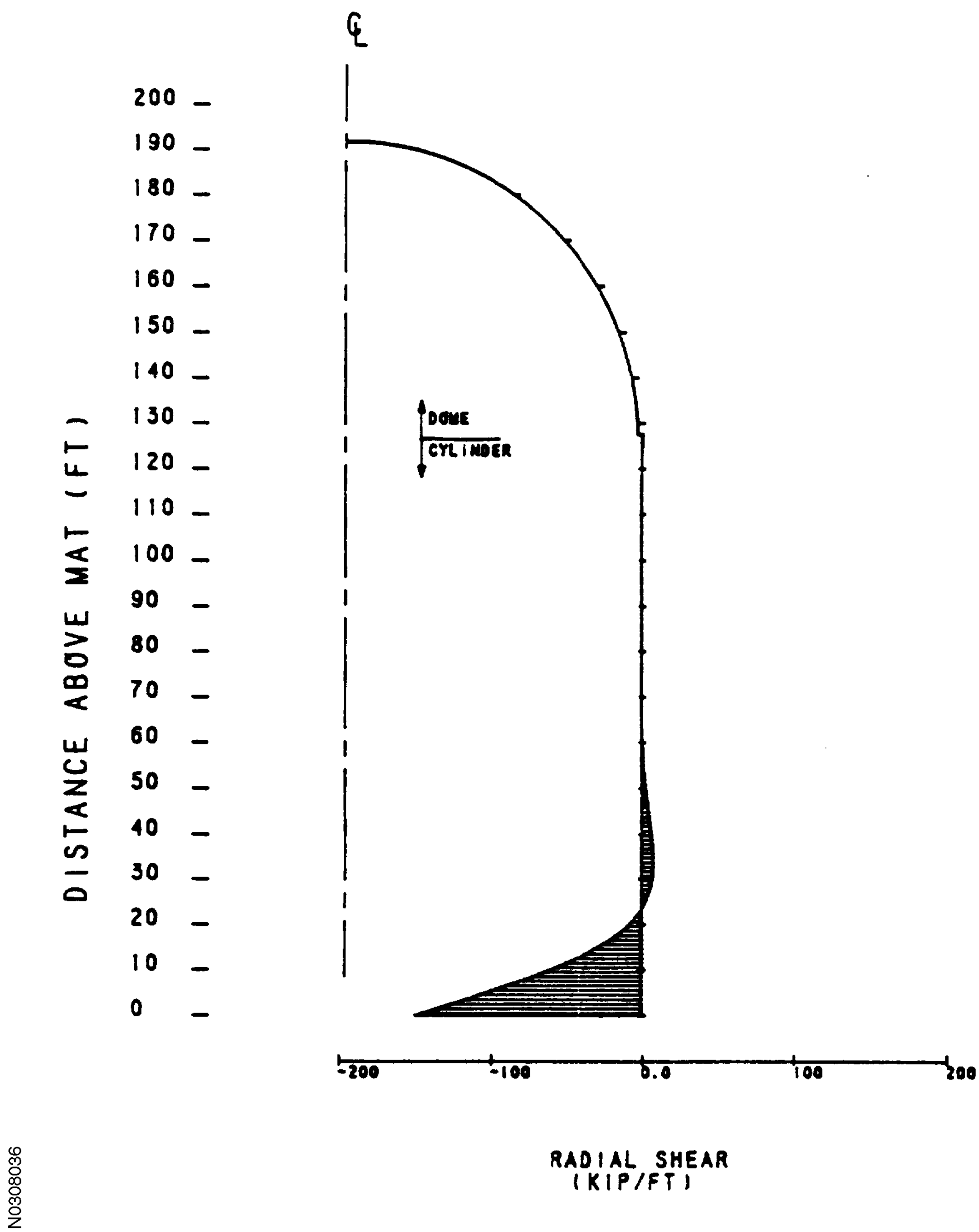
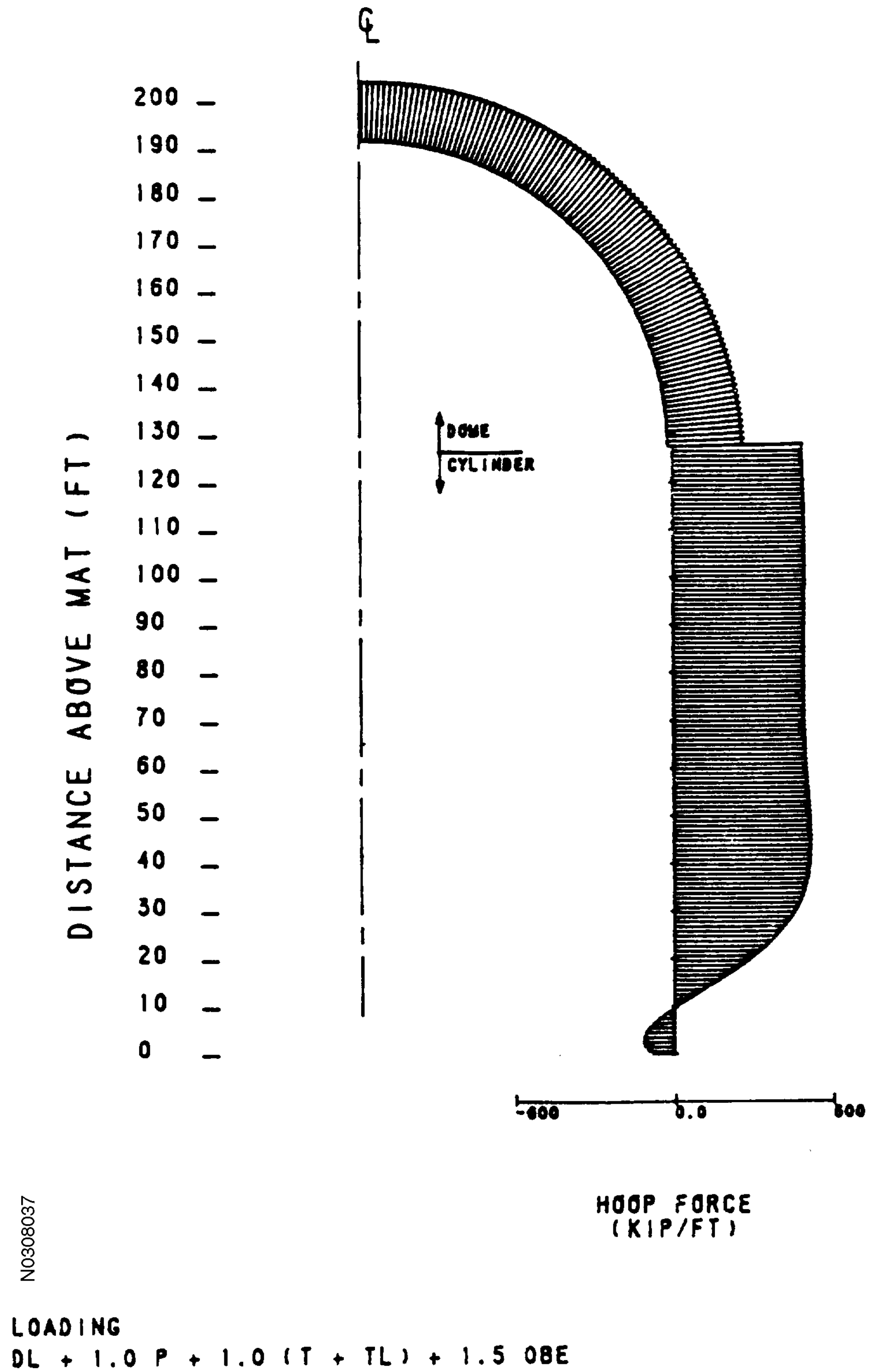


Figure 3.8-18 (SHEET 11 OF 28)
SCALED LOAD PLOTS



LOADING
DL + 1.0 P + 1.0 (T + TL) + 1.5 OBE

Figure 3.8-18 (SHEET 12 OF 28)
SCALED LOAD PLOTS



SCALE:

Figure 3.8-18 (SHEET 13 OF 28)
SCALED LOAD PLOTS

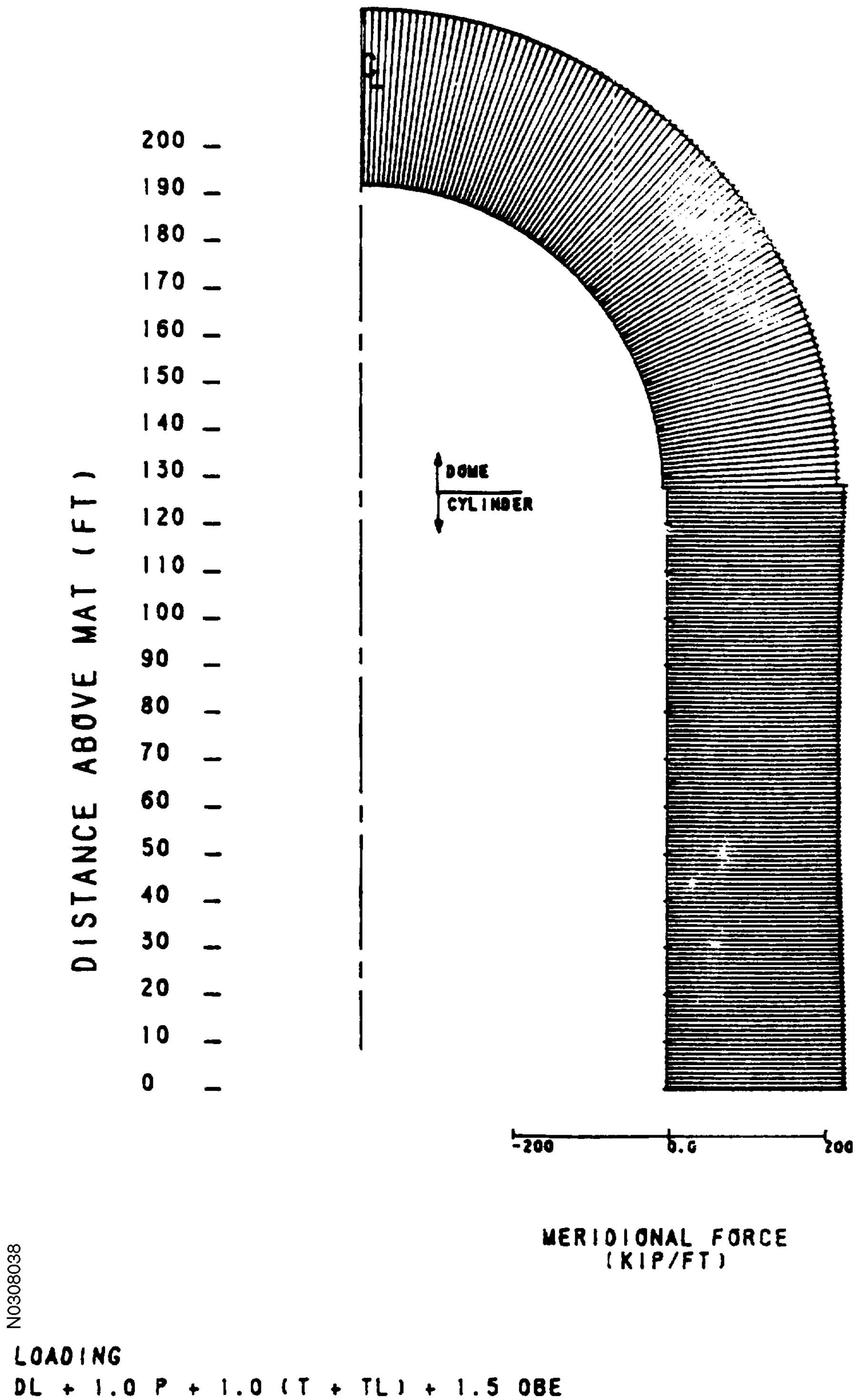
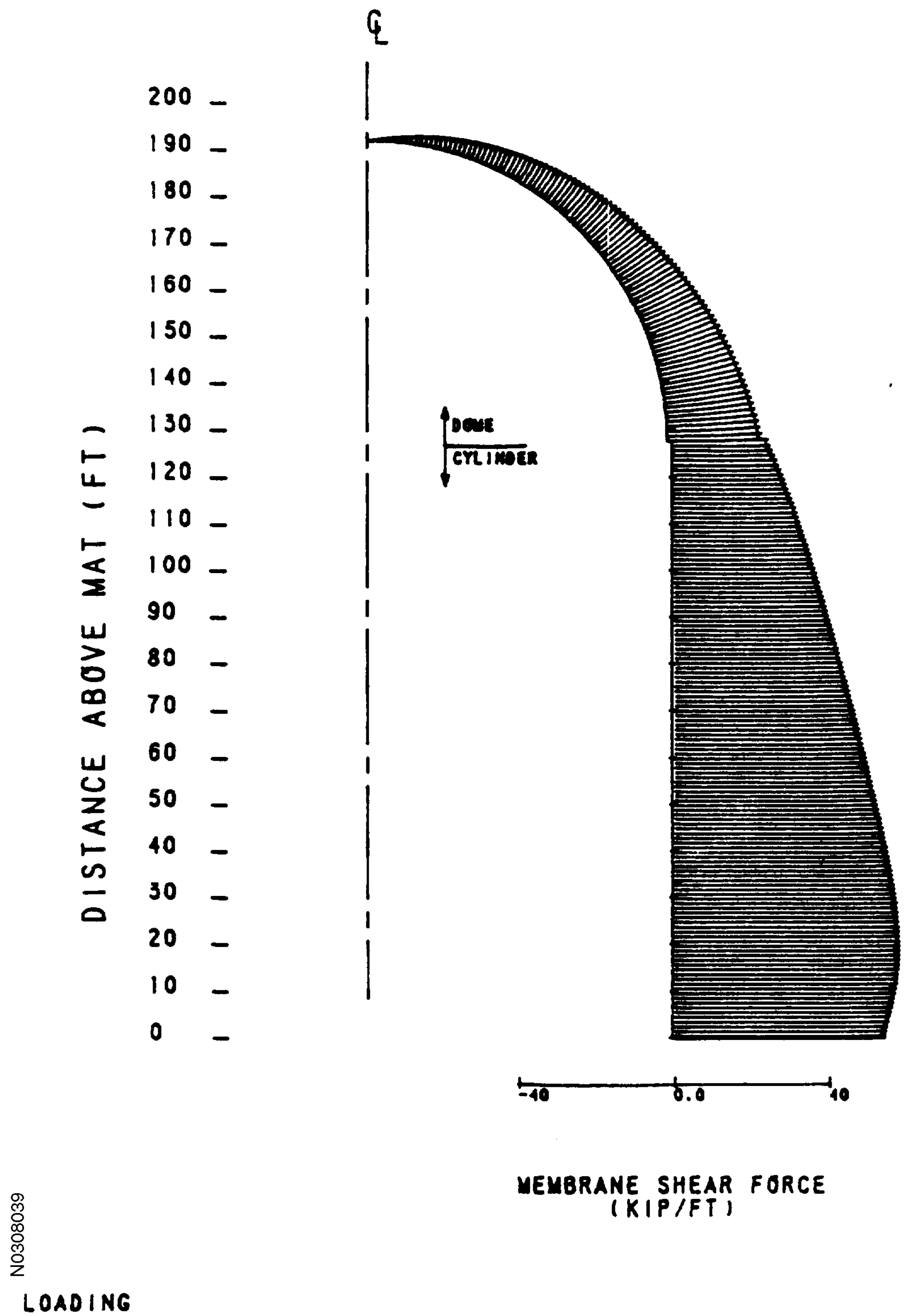


Figure 3.8-18 (SHEET 14 OF 28)
SCALED LOAD PLOTS



LOADING
DL + 1.0 P + 1.0 (T + TL) + 1.5 OBE

Figure 3.8-18 (SHEET 15 OF 28)
SCALED LOAD PLOTS

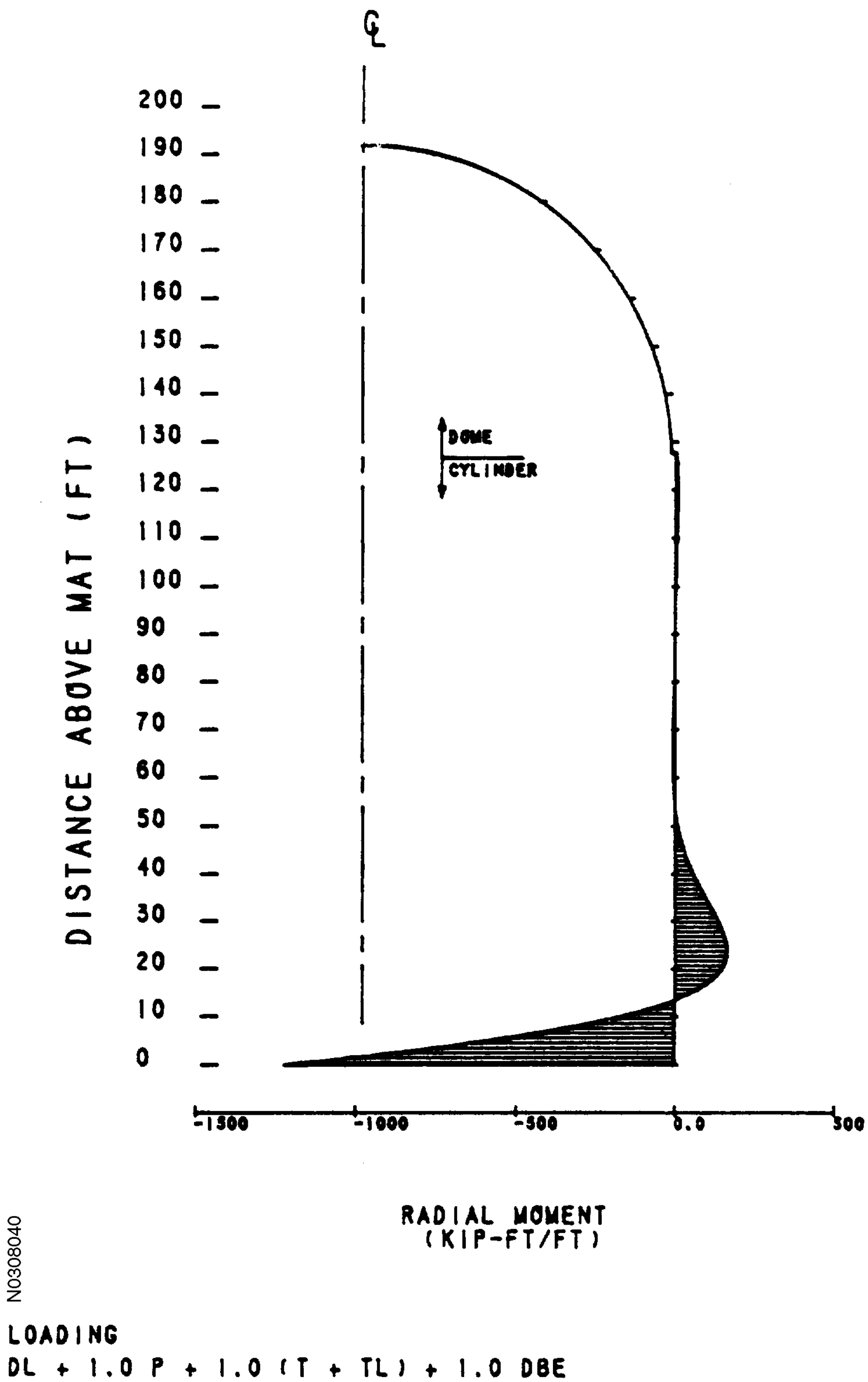
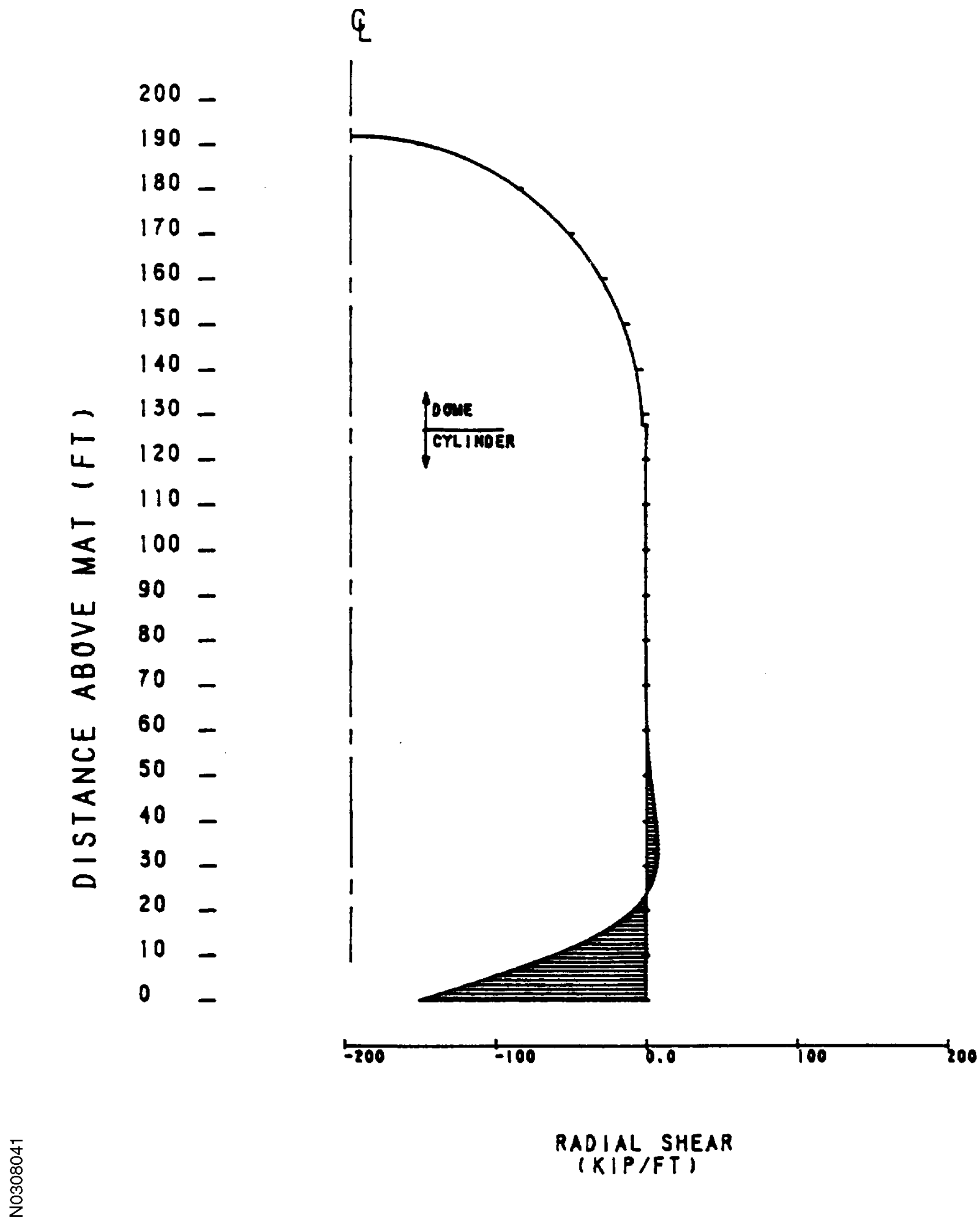
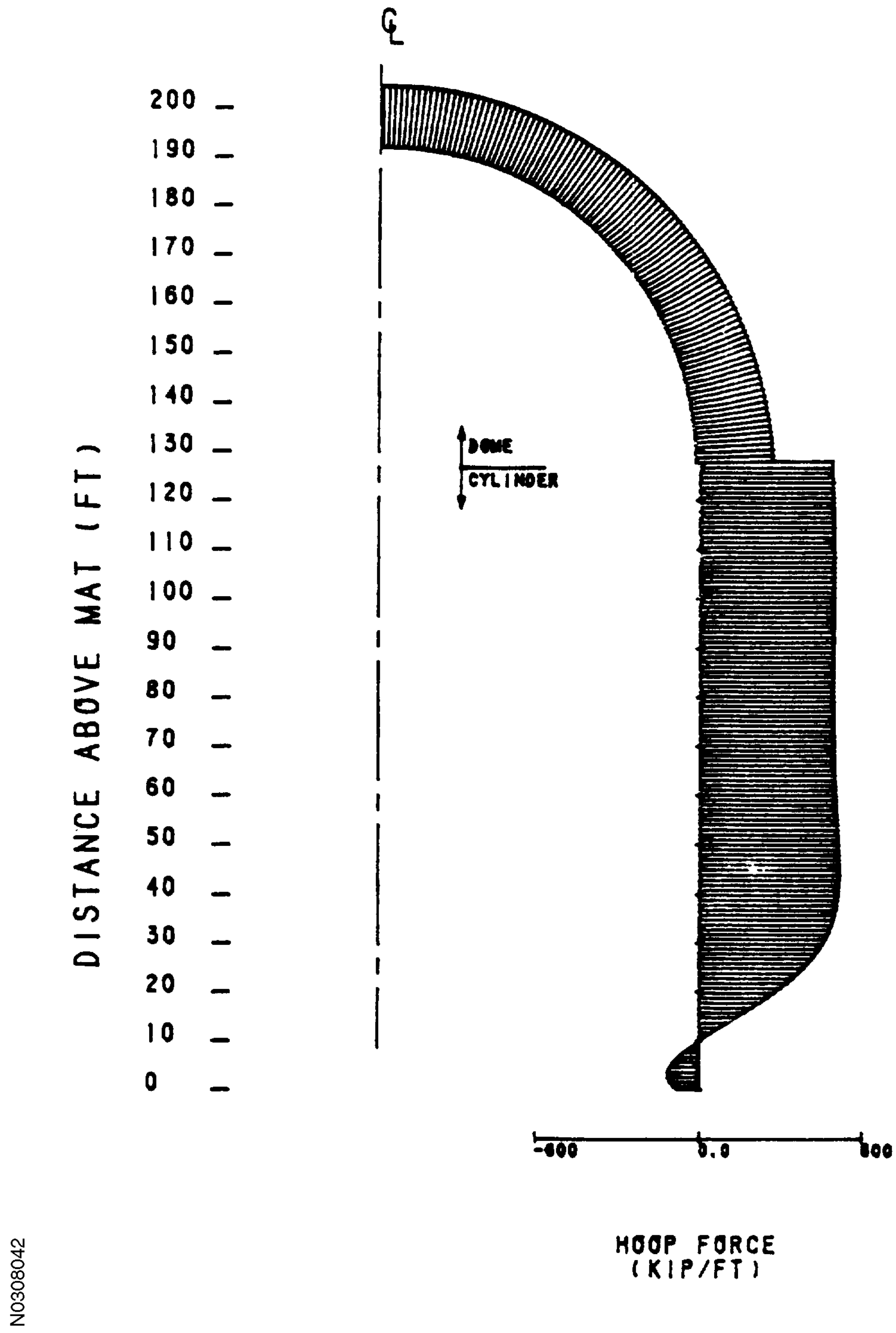


Figure 3.8-18 (SHEET 16 OF 28)
SCALED LOAD PLOTS



LOADING
DL + 1.0 P + 1.0 (T + TL) + 1.0 DBE

Figure 3.8-18 (SHEET 17 OF 28)
SCALED LOAD PLOTS



LOADING
DL + 1.0 P + 1.0 (T + TL) + 1.0 DBE

Figure 3.8-18 (SHEET 18 OF 28)
SCALED LOAD PLOTS

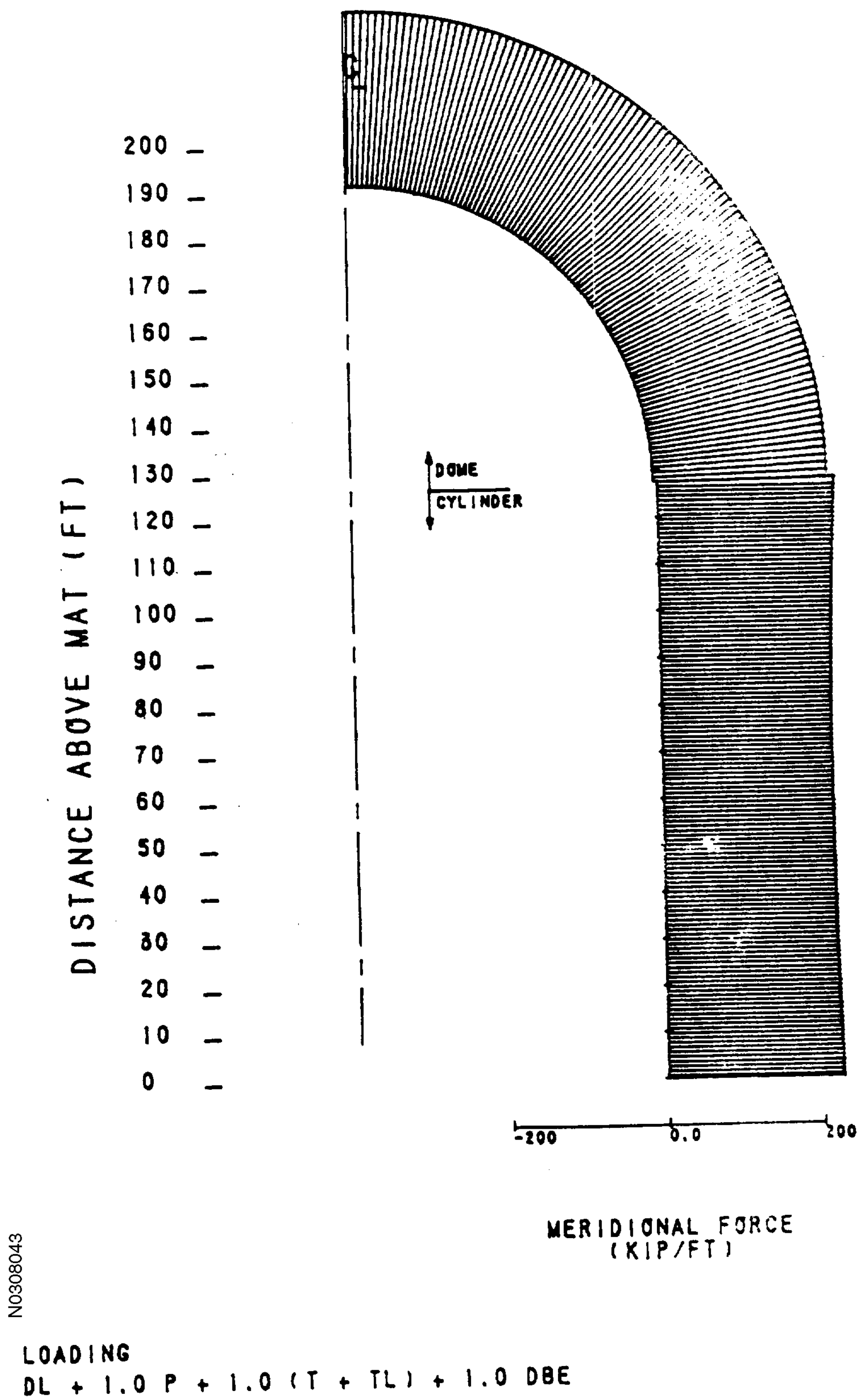
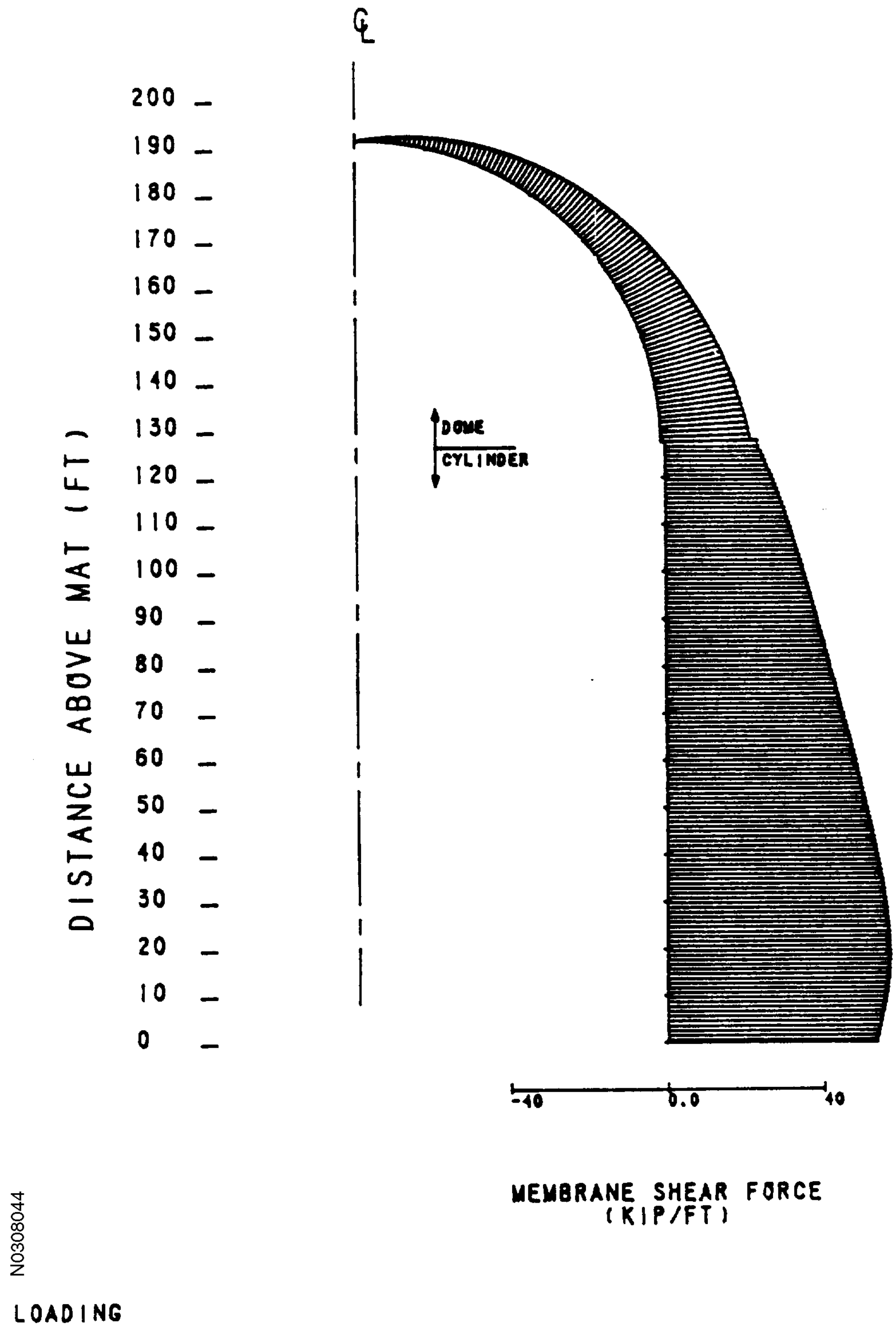


Figure 3.8-18 (SHEET 19 OF 28)
SCALED LOAD PLOTS



LOADING
DL + 1.0 P + 1.0 (T + TL) + 1.0 DBE

Figure 3.8-18 (SHEET 20 OF 28)
SCALED LOAD PLOTS

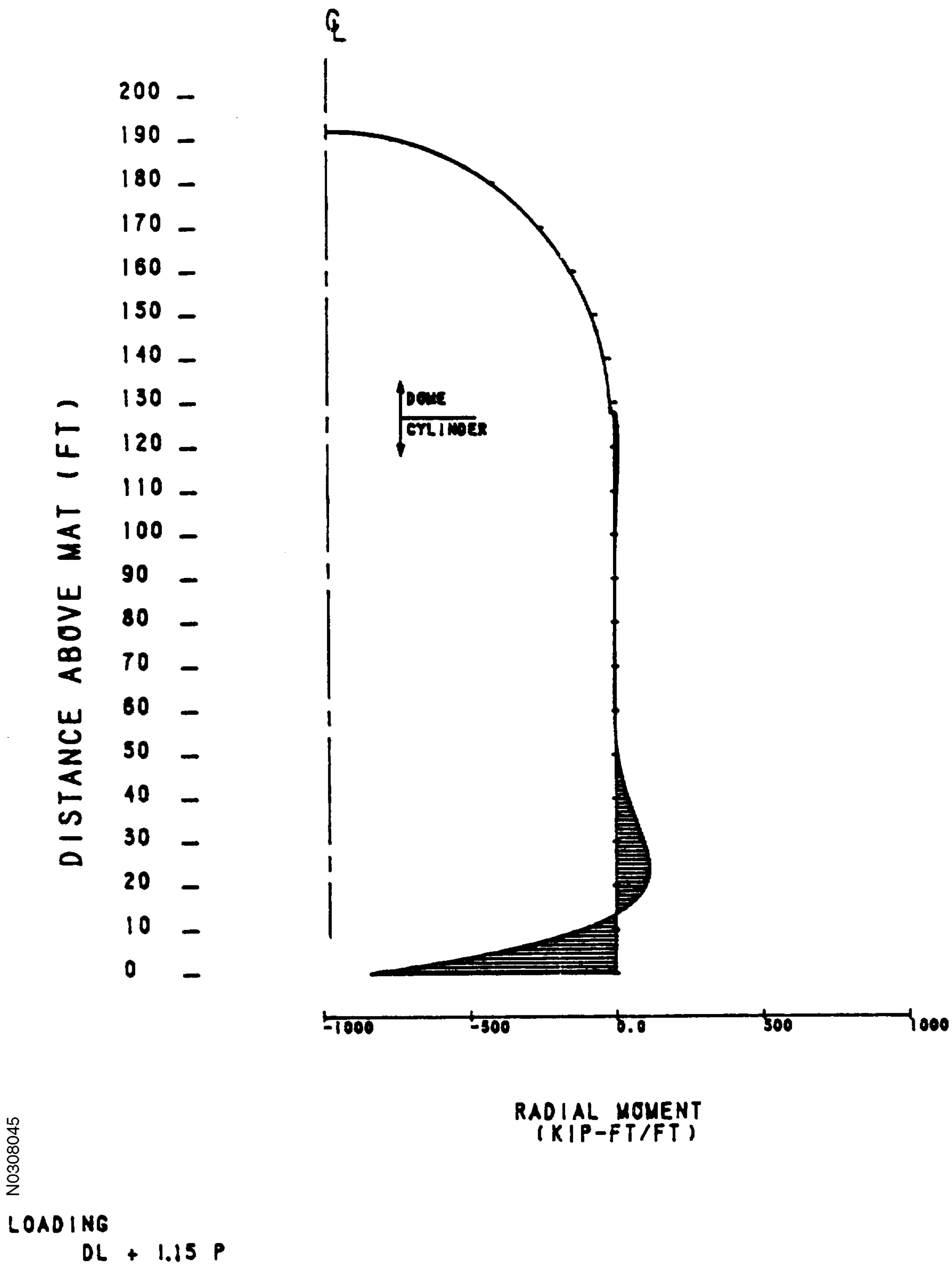
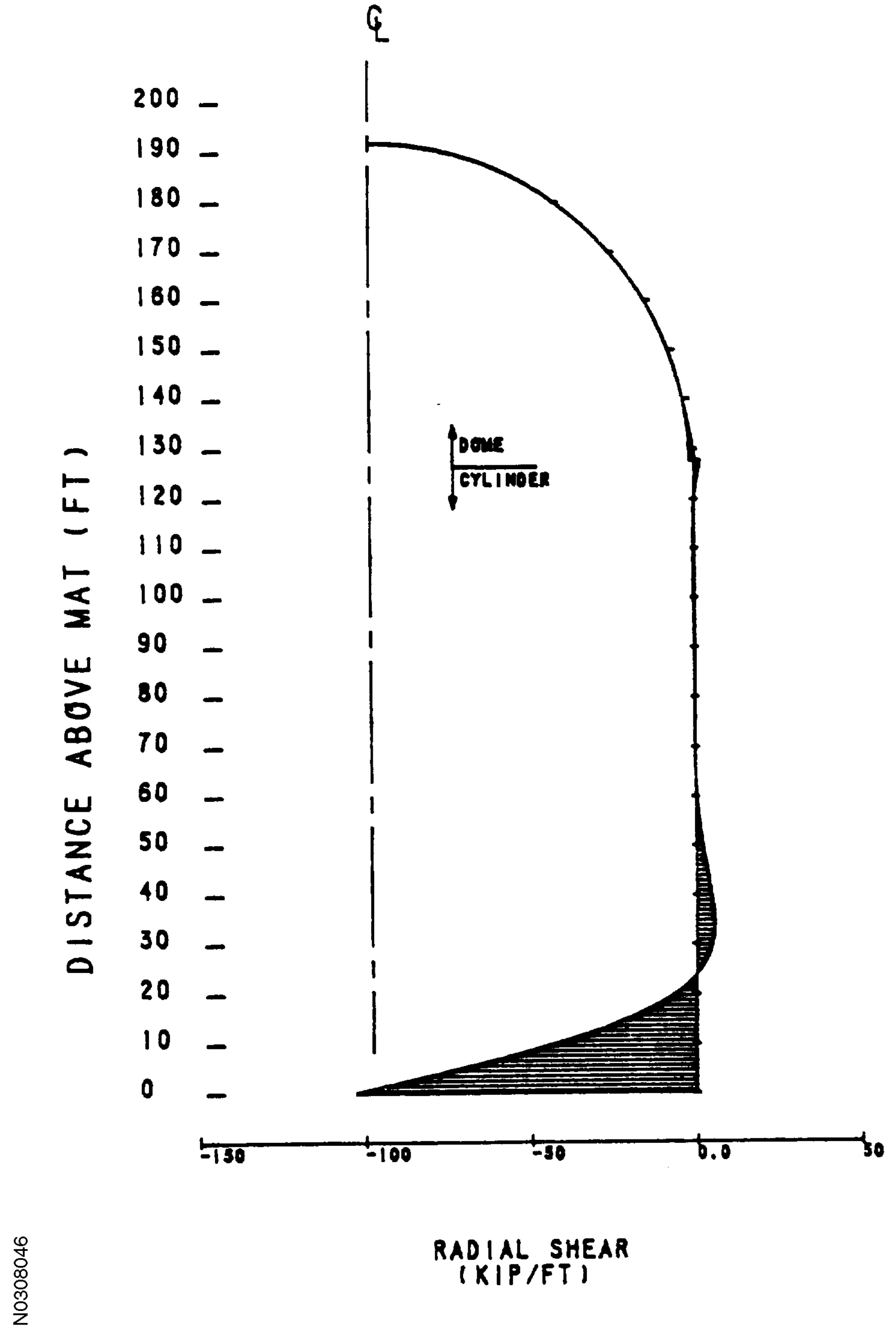


Figure 3.8-18 (SHEET 21 OF 28)
SCALED LOAD PLOTS



LOADING
DL + 1.15 P

Figure 3.8-18 (SHEET 22 OF 28)
SCALED LOAD PLOTS

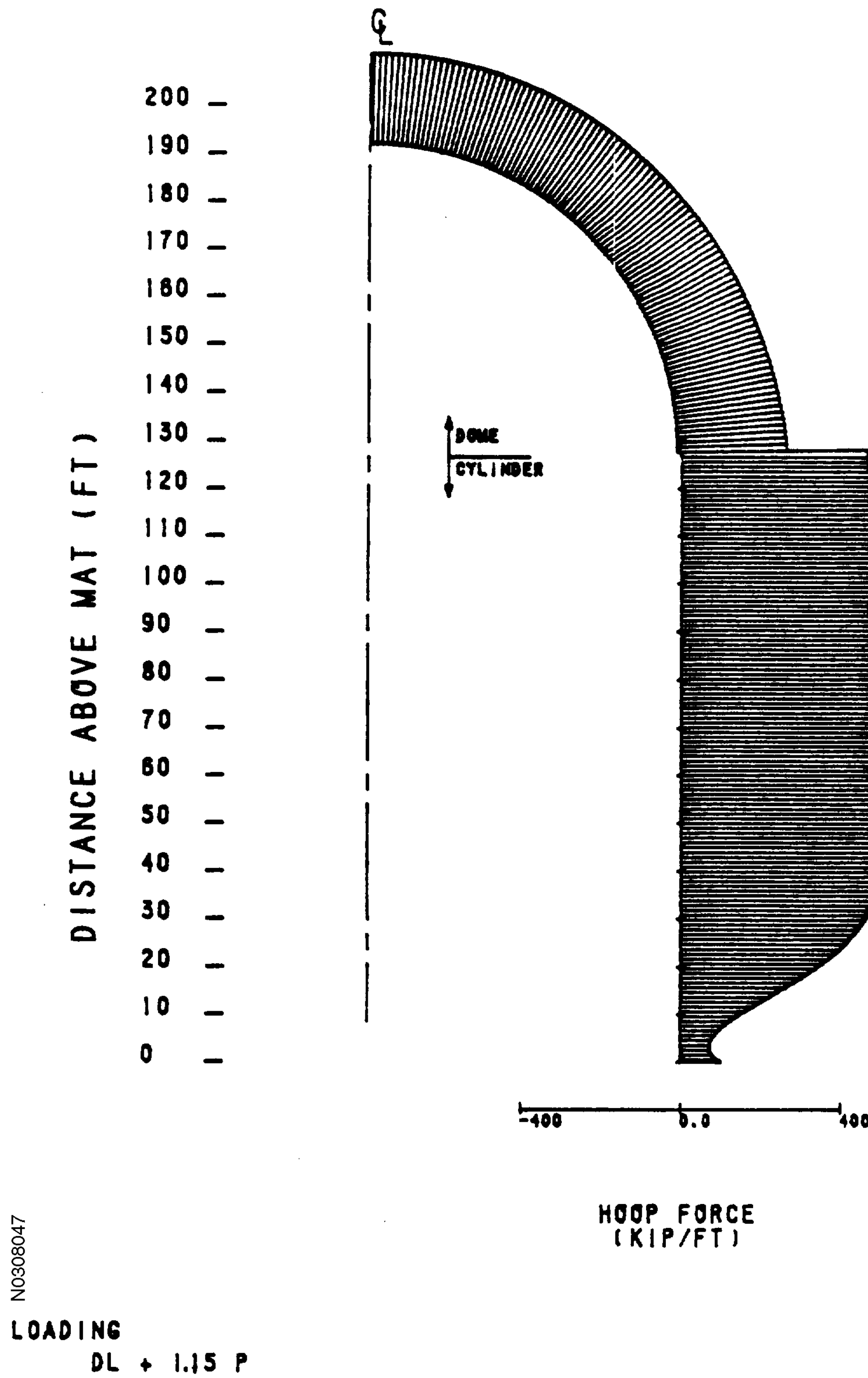


Figure 3.8-18 (SHEET 23 OF 28)
SCALED LOAD PLOTS

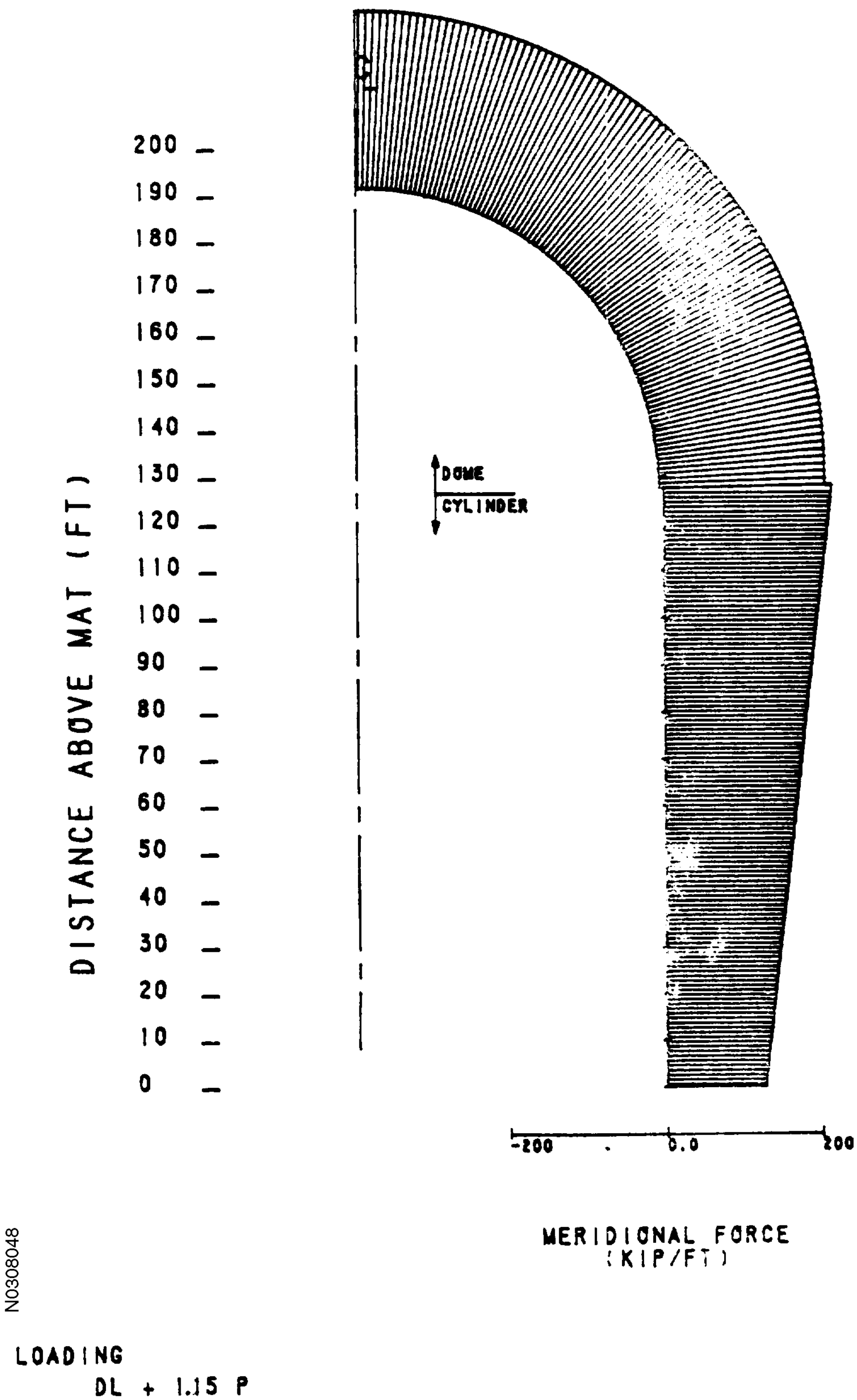


Figure 3.8-18 (SHEET 24 OF 28)
SCALED LOAD PLOTS

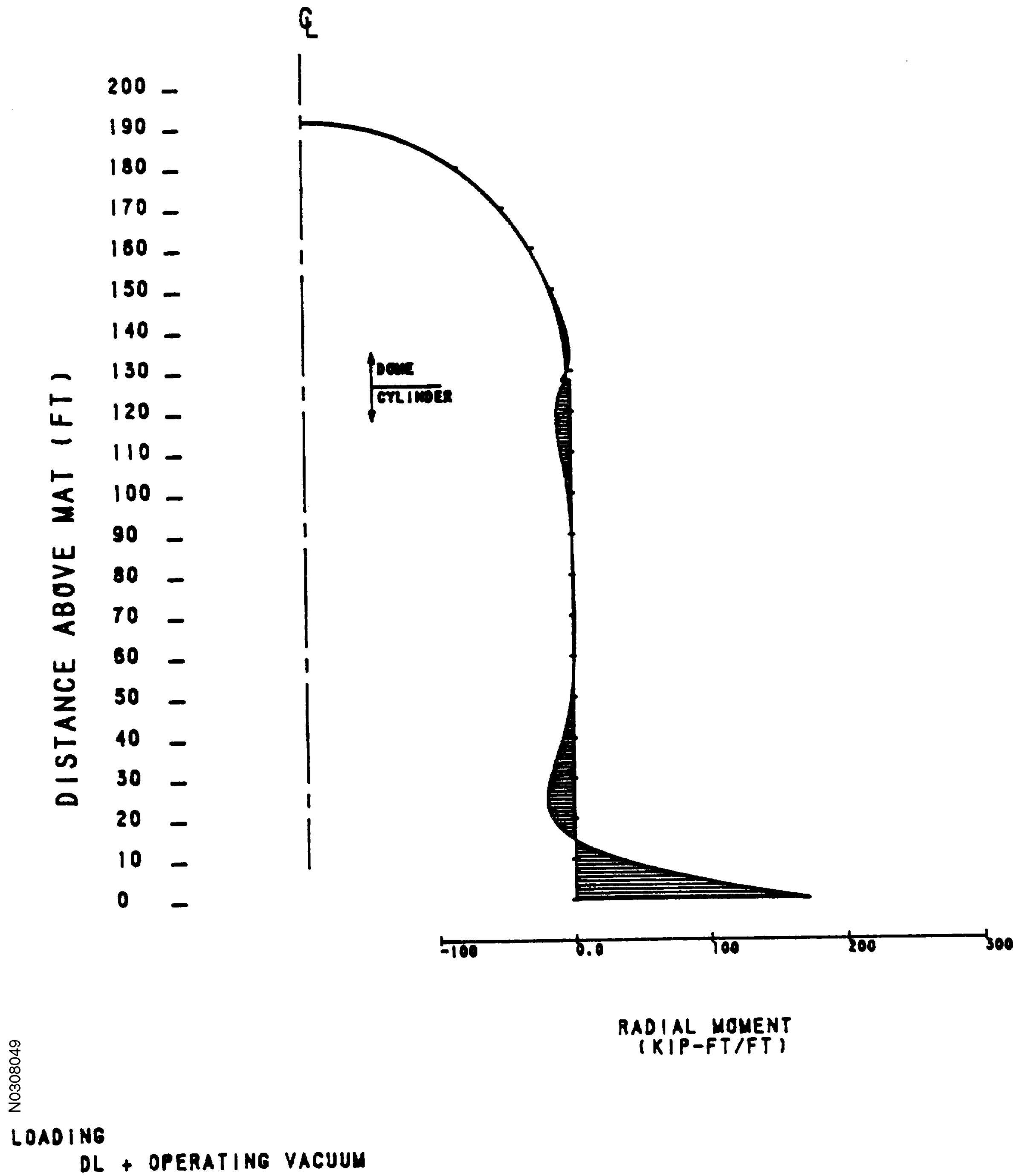


Figure 3.8-18 (SHEET 25 OF 28)
SCALED LOAD PLOTS

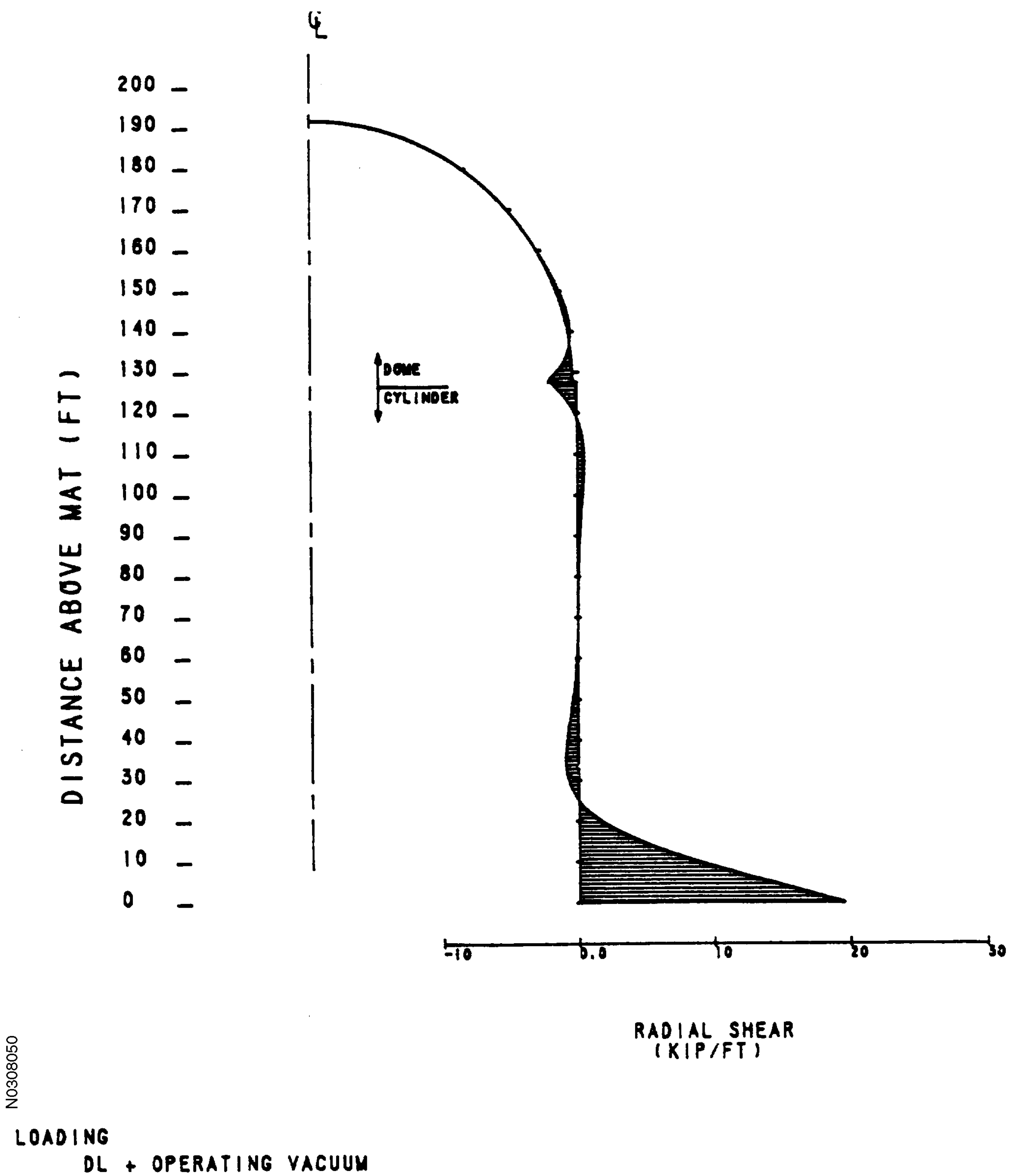


Figure 3.8-18 (SHEET 26 OF 28)
SCALED LOAD PLOTS

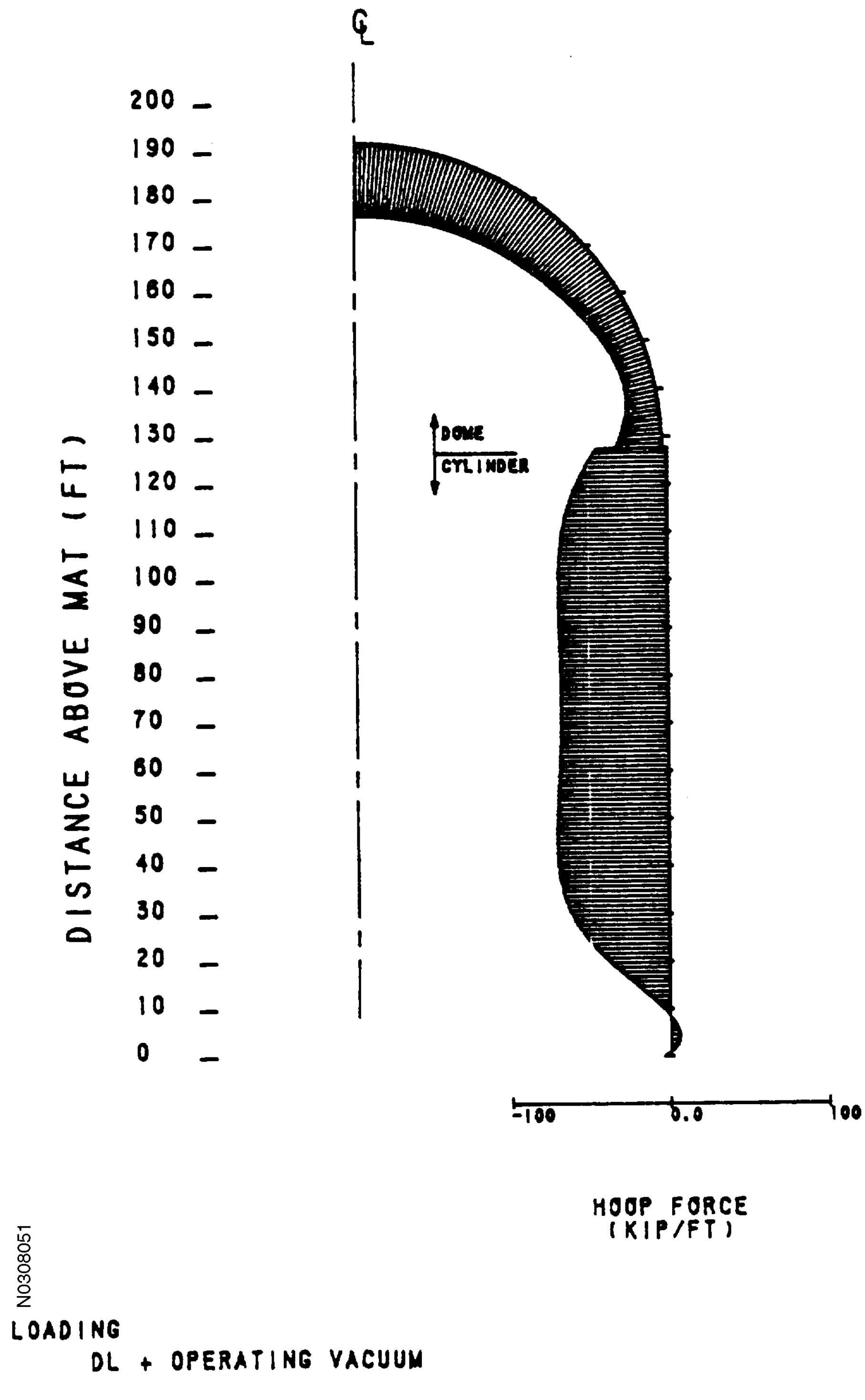
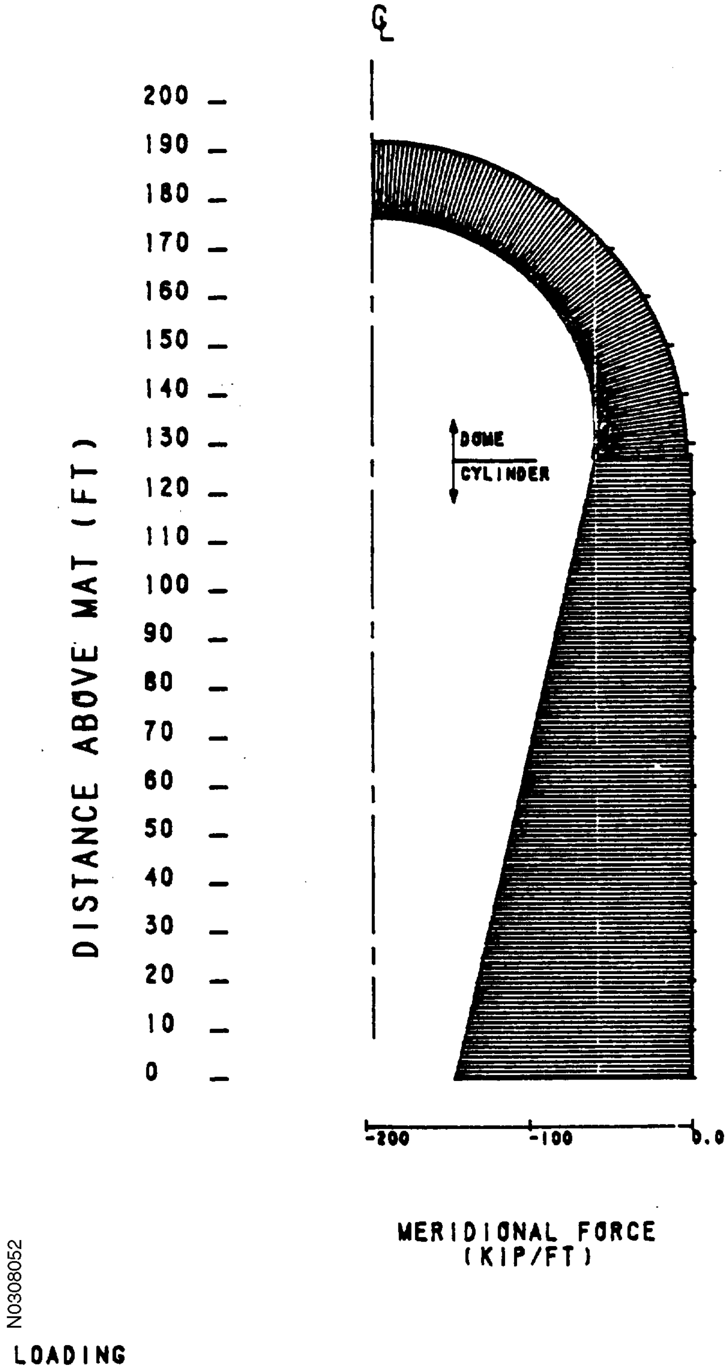
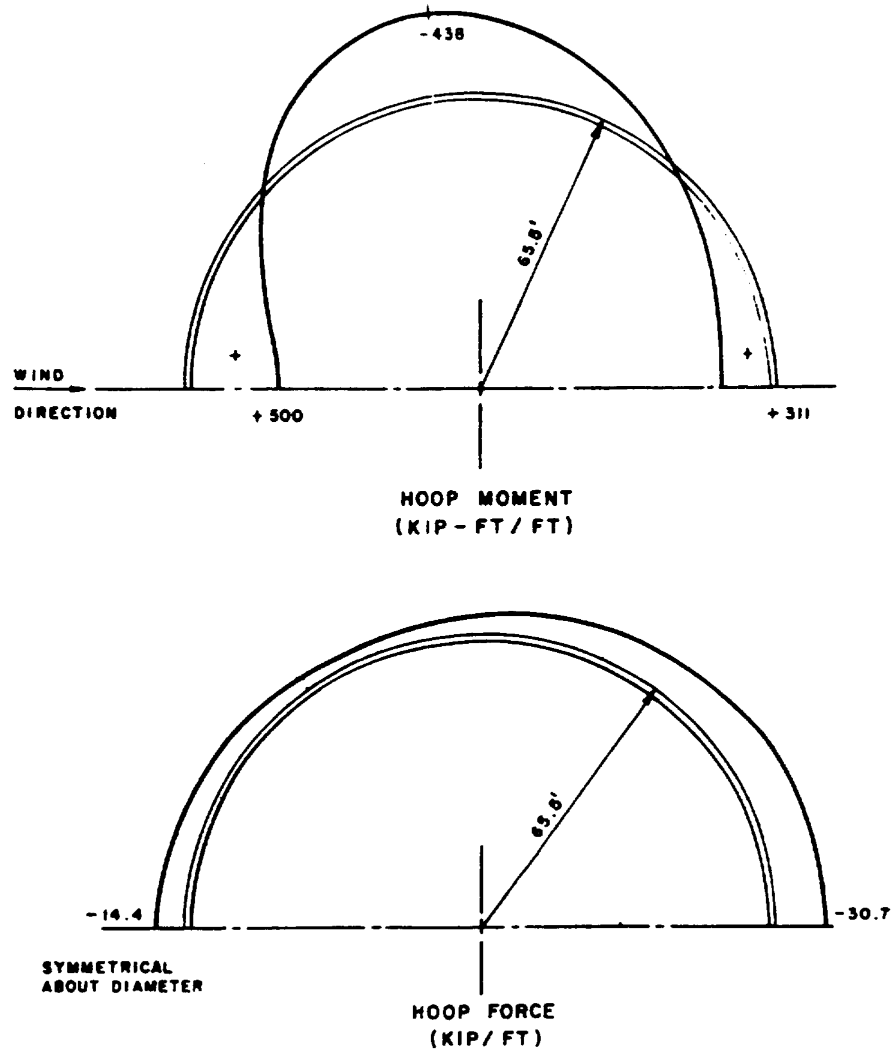


Figure 3.8-18 (SHEET 27 OF 28)
SCALED LOAD PLOTS



LOADING
DL + OPERATING VACUUM

Figure 3.8-18 (SHEET 28 OF 28)
SCALED LOAD PLOTS



N0308053

PLAN OF CONTAINMENT CYLINDER

LOADING: TORNADO WINDS

VELOCITY = 360 MPH,
EQUIVALENT TO LOAD OF 0.33 K/FT^2

LOAD DISTRIBUTION BASED ON
ASCE PAPER No. 3269

Figure 3.8-19
REINFORCING DETAILS: EQUIPMENT ACCESS HATCH OPENING

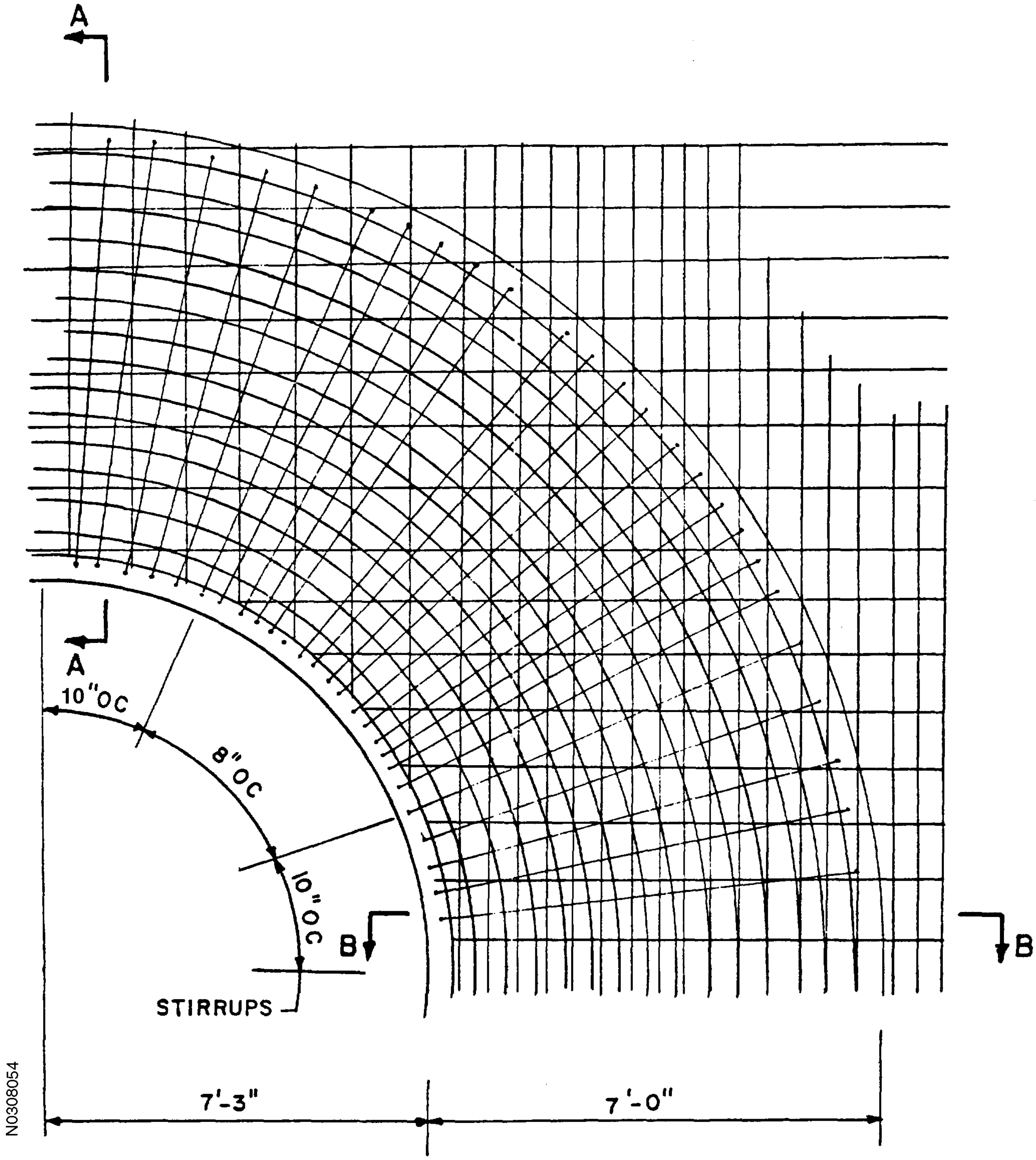


Figure 3.8-20
REINFORCING DETAILS: SECTIONS THROUGH RING BEAM TO EQUIPMENT ACCESS HATCH

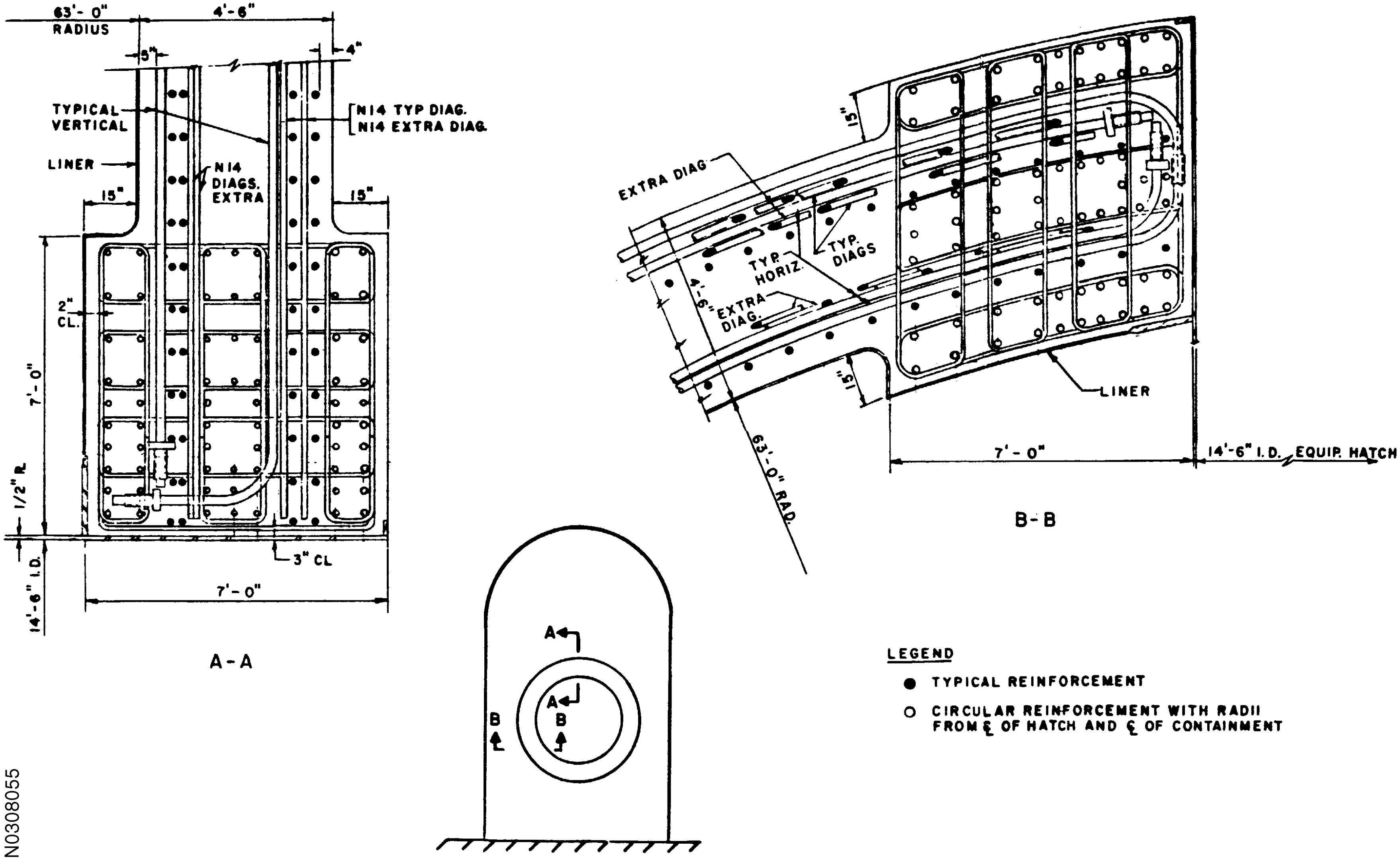


Figure 3.8-21
REINFORCING DETAILS: PERSONNEL HATCH OPENING

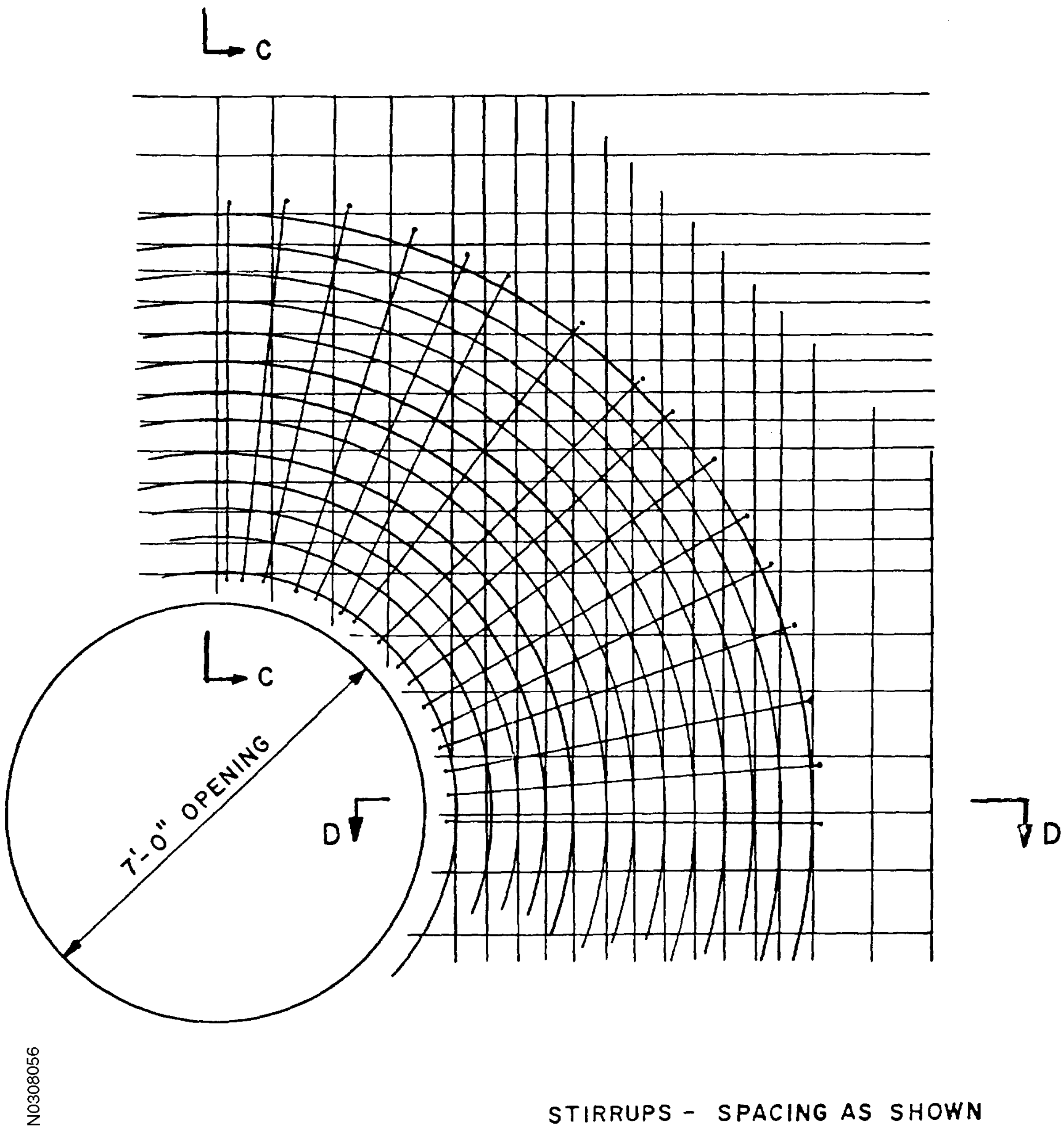


Figure 3.8-22
REINFORCING DETAILS: SECTIONS THROUGH RING BEAM TO
PERSONNEL ACCESS HATCH

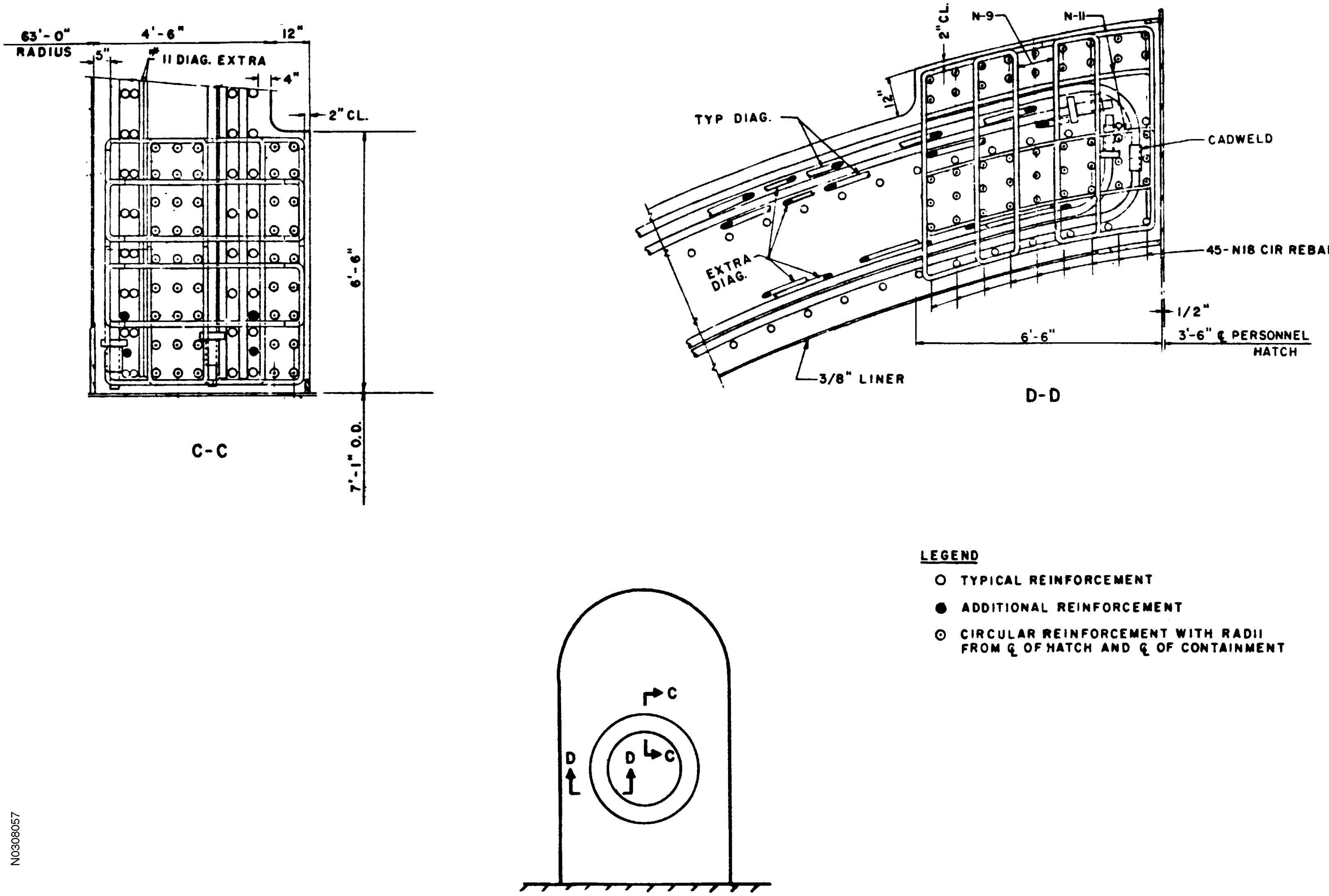
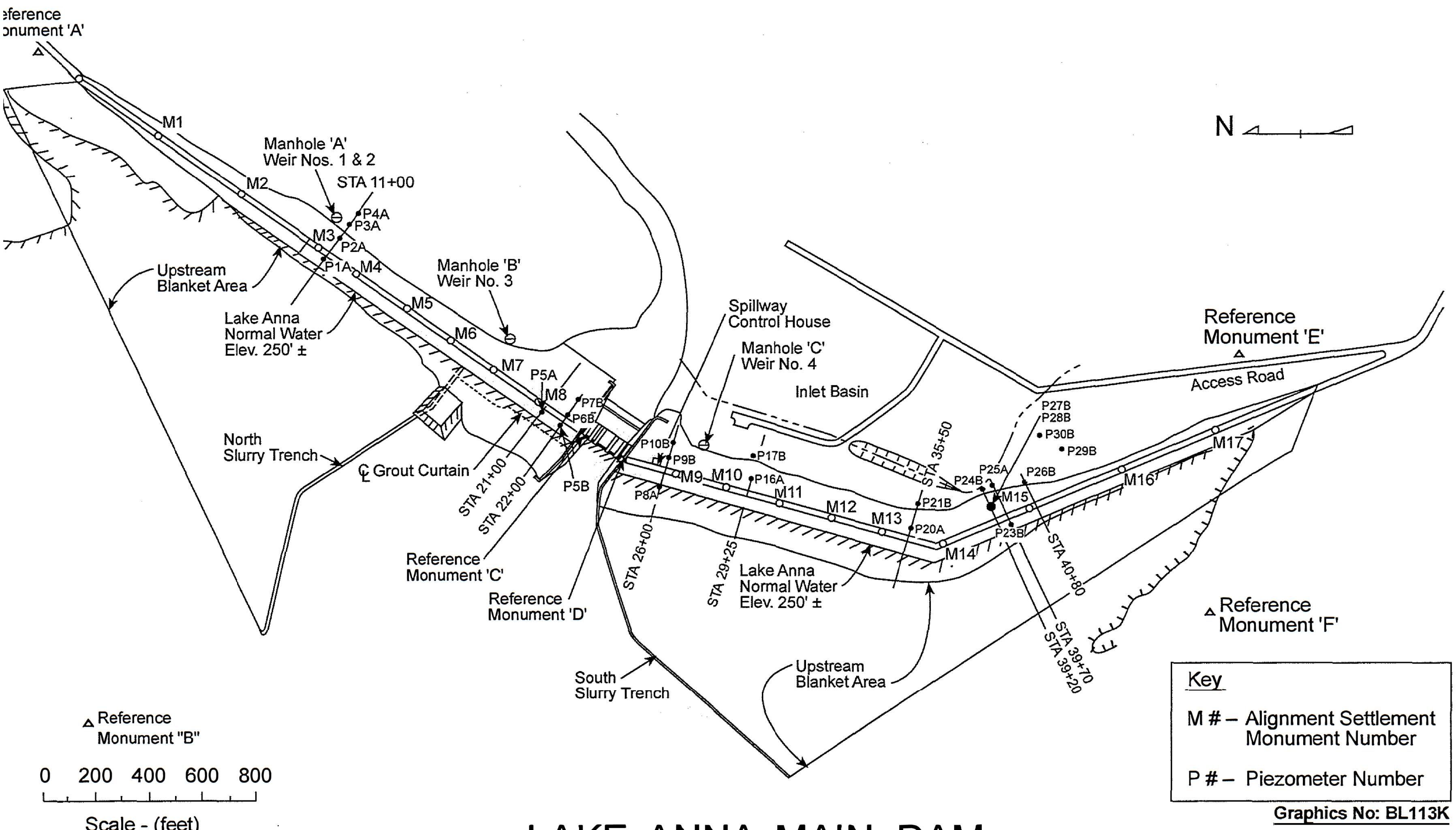


Figure 3.8-23
GENERAL LAYOUT AND PLAN SHOWING INSTRUMENTATION: LAKE ANNA DAM



LAKE ANNA MAIN DAM

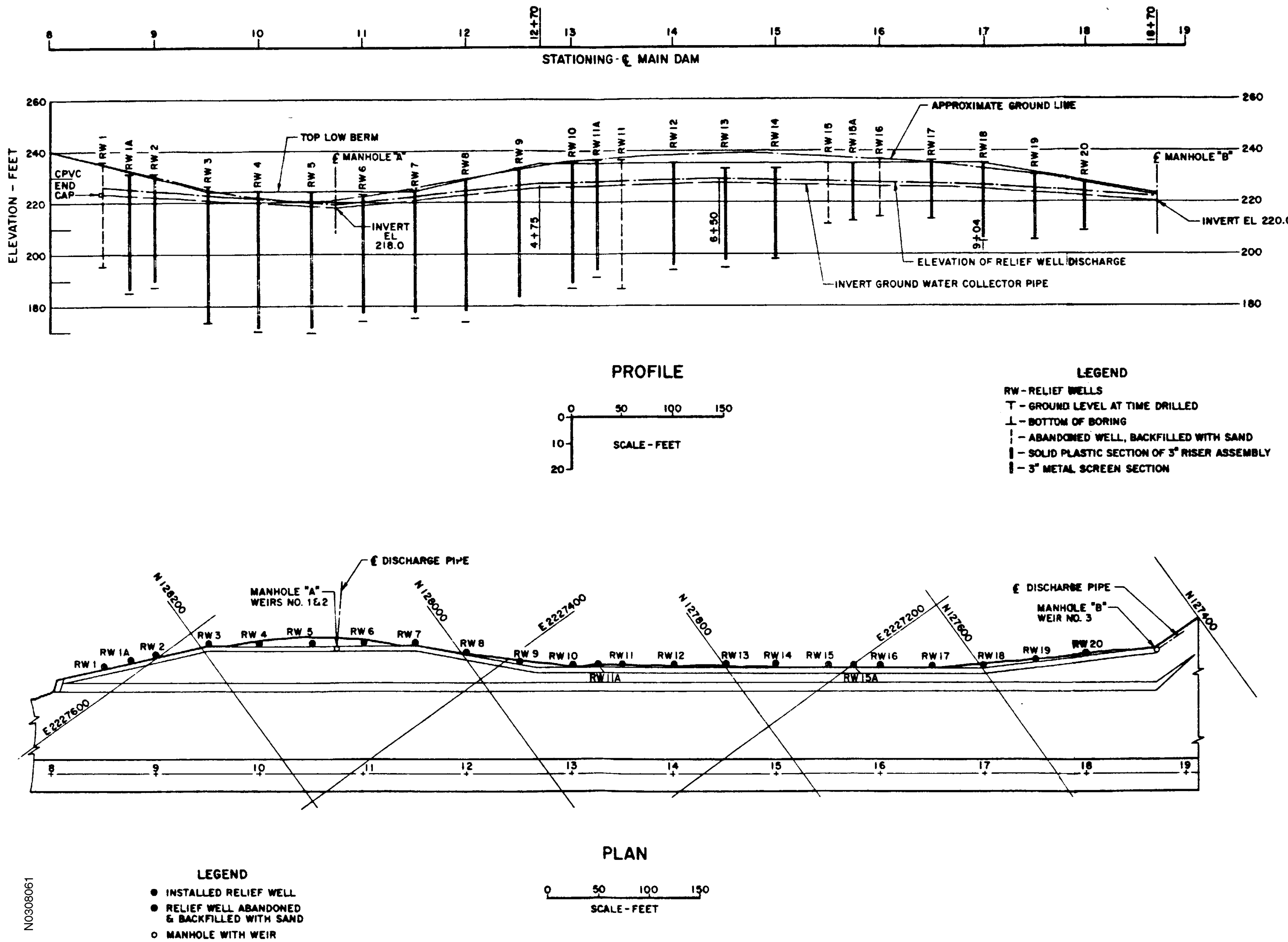
Withhold under 10 CFR 2.390 (d) (1)

[redacted]

Withhold under 10 CFR 2.390 (d) (1)

[redacted]

Figure 3.8-26
RELIEF WELL SYSTEM: NORTH EMBANKMENT: LAKE ANNA DAM



N0308061

Figure 3.8-27
RELIEF WELL SYSTEM: SOUTH EMBANKMENT: LAKE ANNA DAM

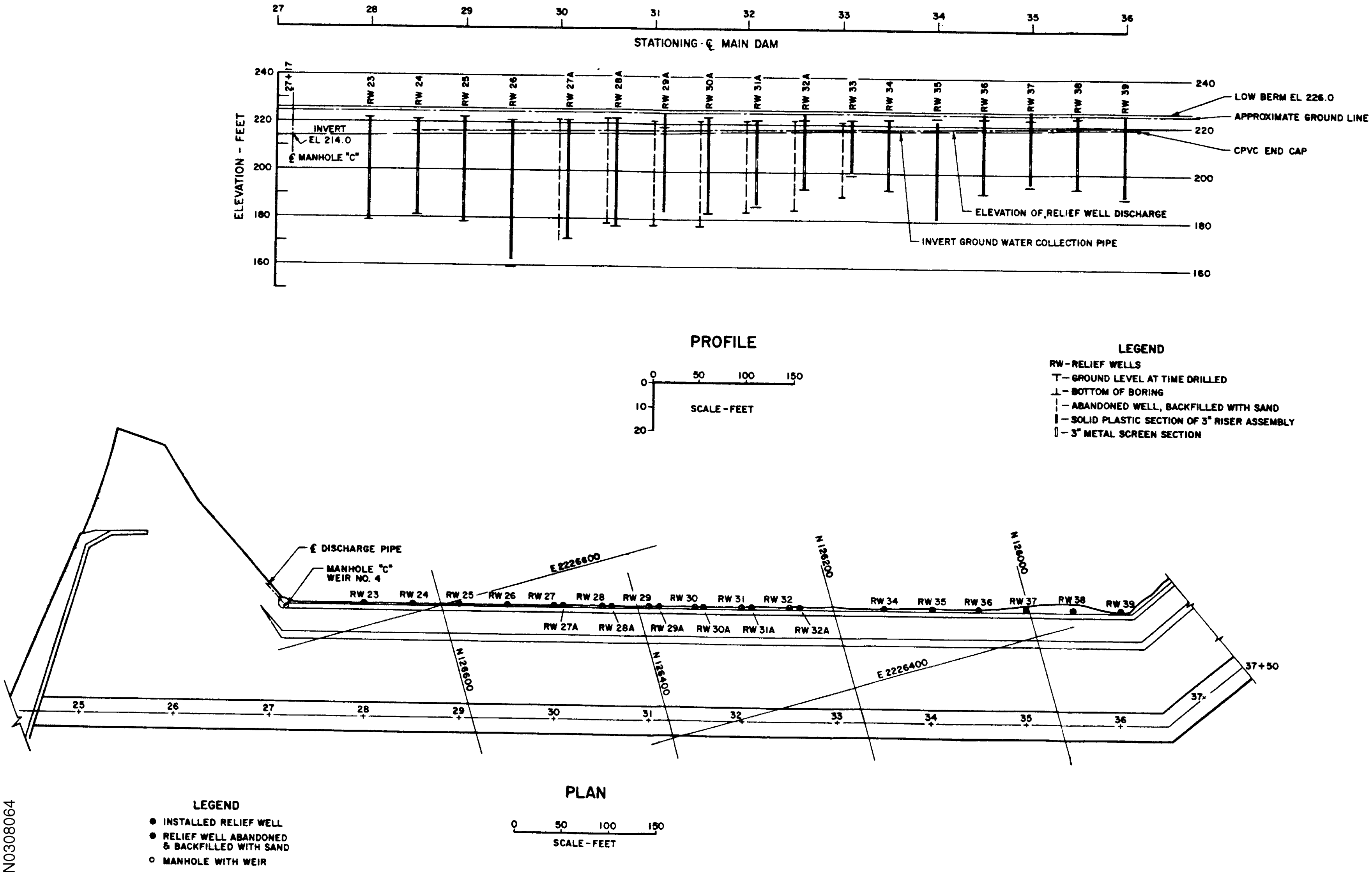
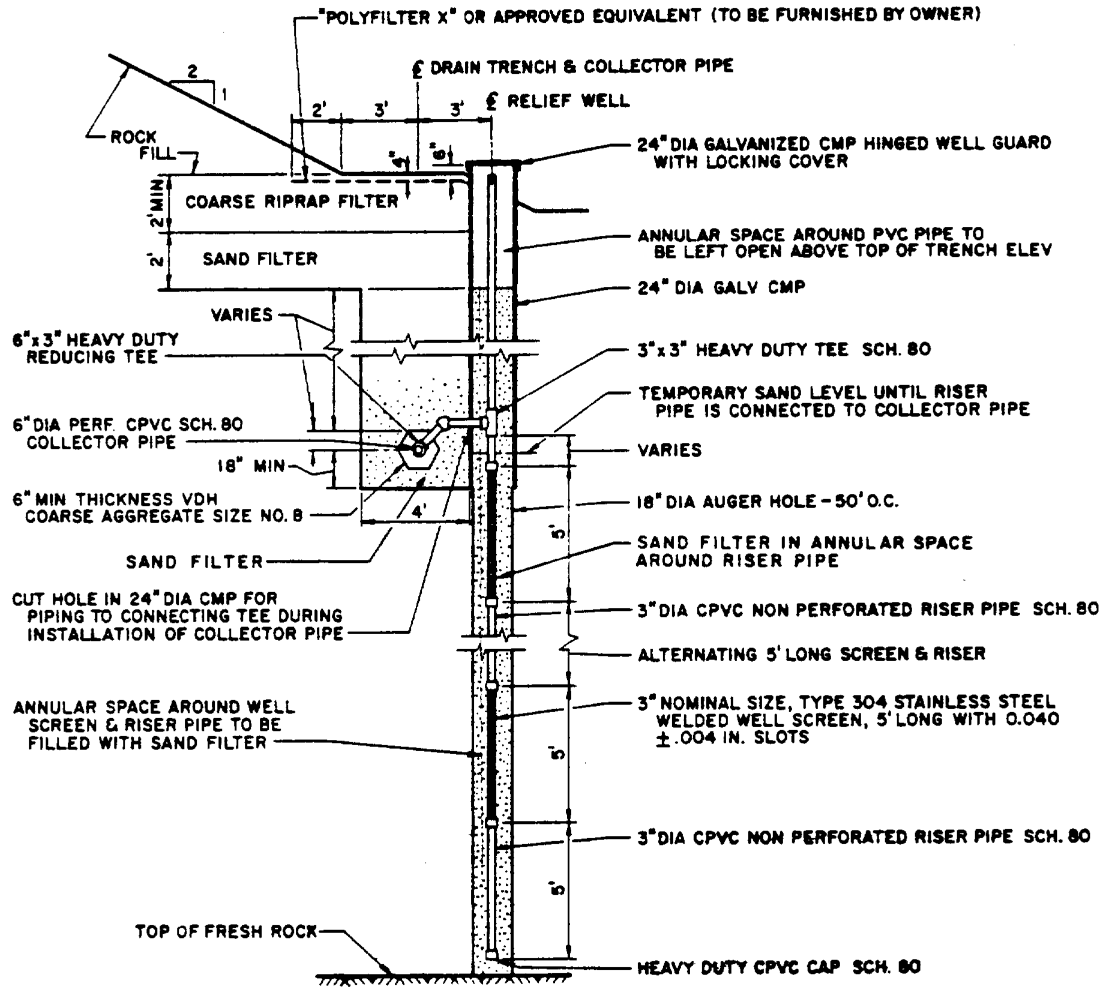


Figure 3.8-28
DETAIL OF RELIEF WELL: LAKE ANNA DAM

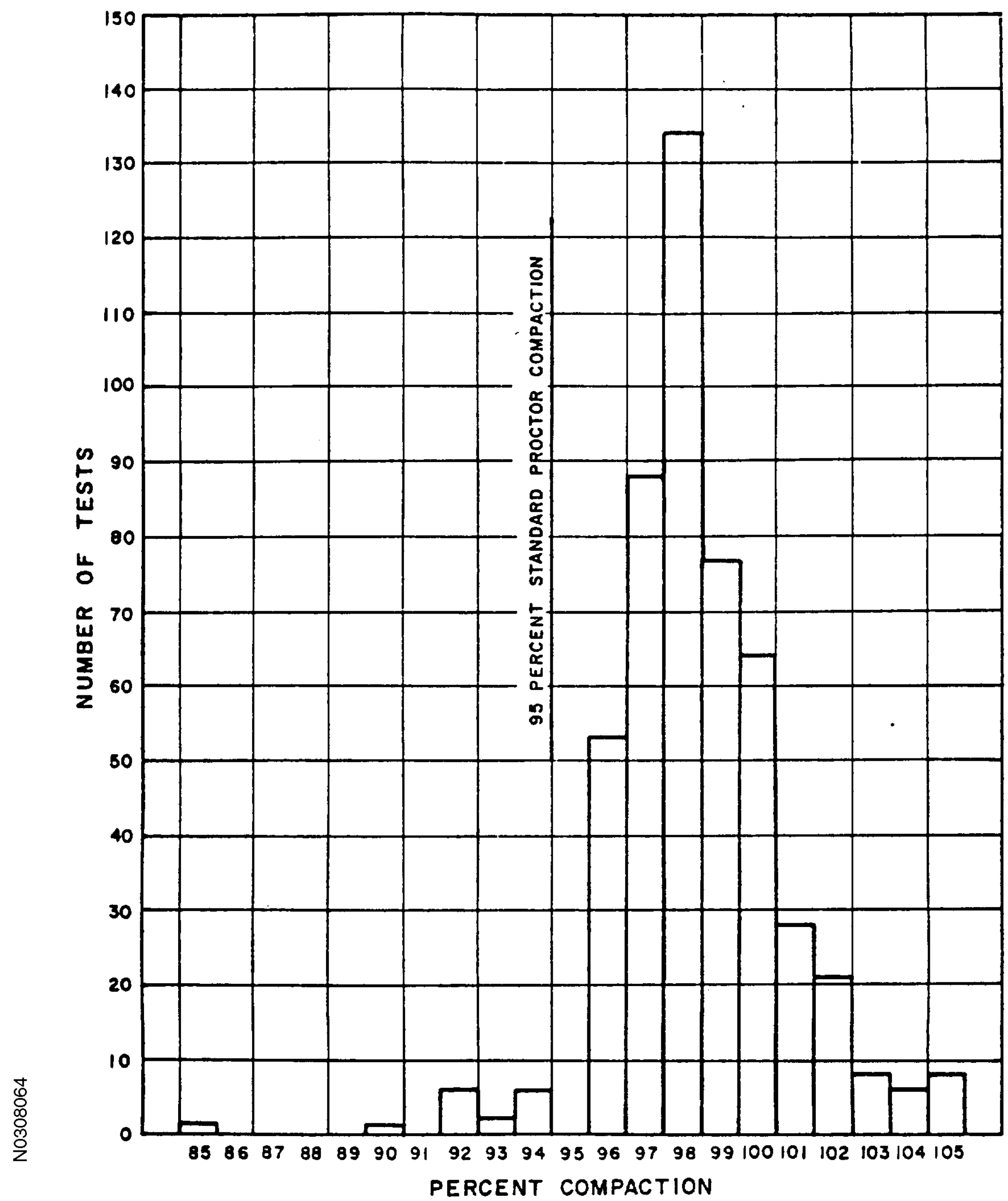


TYPICAL RELIEF WELL
NO SCALE

NOTE
FIVE FOOT STAINLESS STEEL WELL SCREENS ASSEMBLED ALTERNATELY WITH FIVE FOOT SECTIONS OF RISER PIPE FROM WELL BOTTOM TO CONNECTING TEE AS SHOWN.
RISER PIPE & SCREENS ASSEMBLED USING THREADED CONNECTIONS IN CONFORMANCE WITH PIPE MANUFACTURER'S RECOMMENDATIONS.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.8-29
HISTOGRAM OF COMPACTION CONTROL TESTS: LAKE ANNA DAM



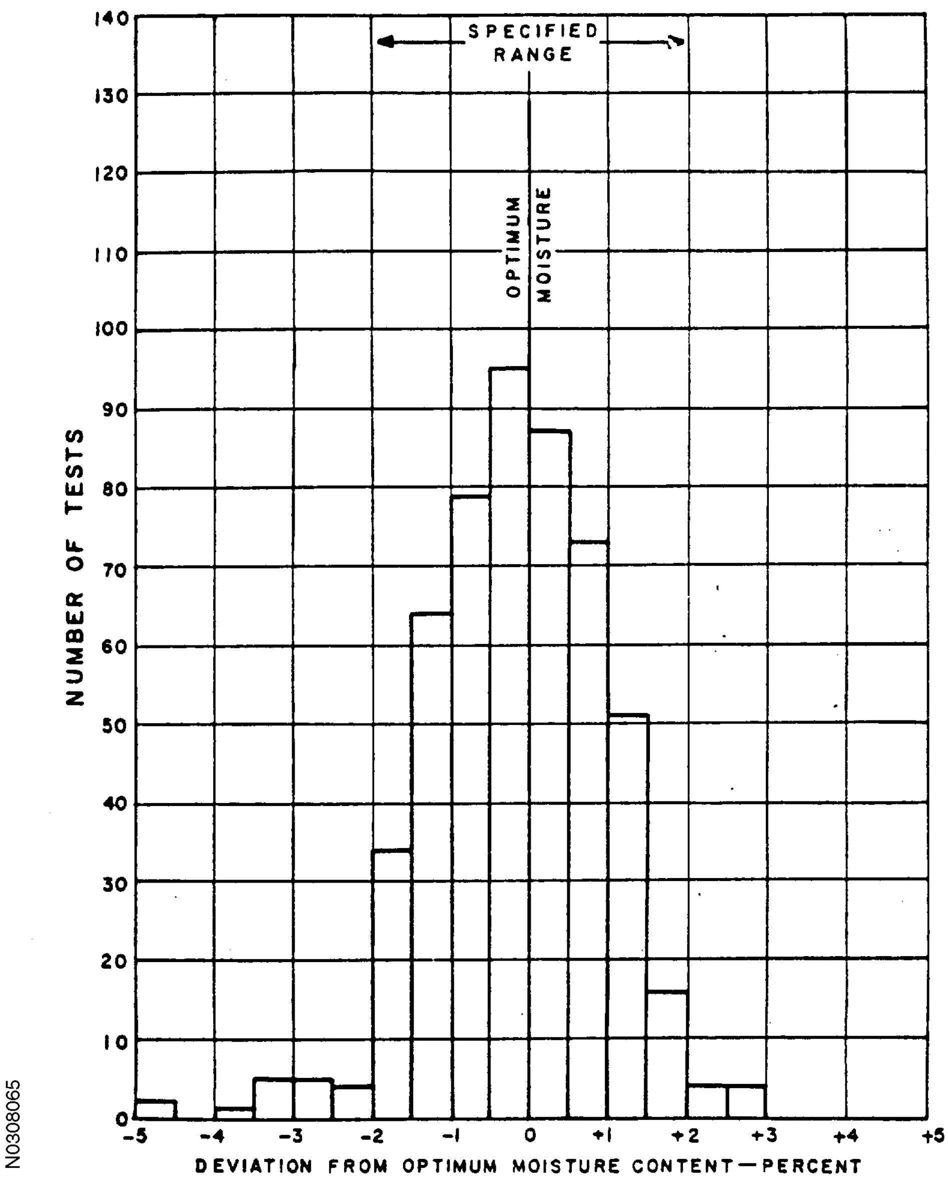
NOTES:

(1) MINIMUM SPECIFIED COMPACTION WAS 95 PERCENT STANDARD PROCTOR PER ASTM DESIGNATION DG98 METHOD A

(2) MATERIAL REPRESENTED BY TEST RESULTS LESS SPECIFIED MINIMUM WAS REWORKED OR REPLACED AND RETESTED

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

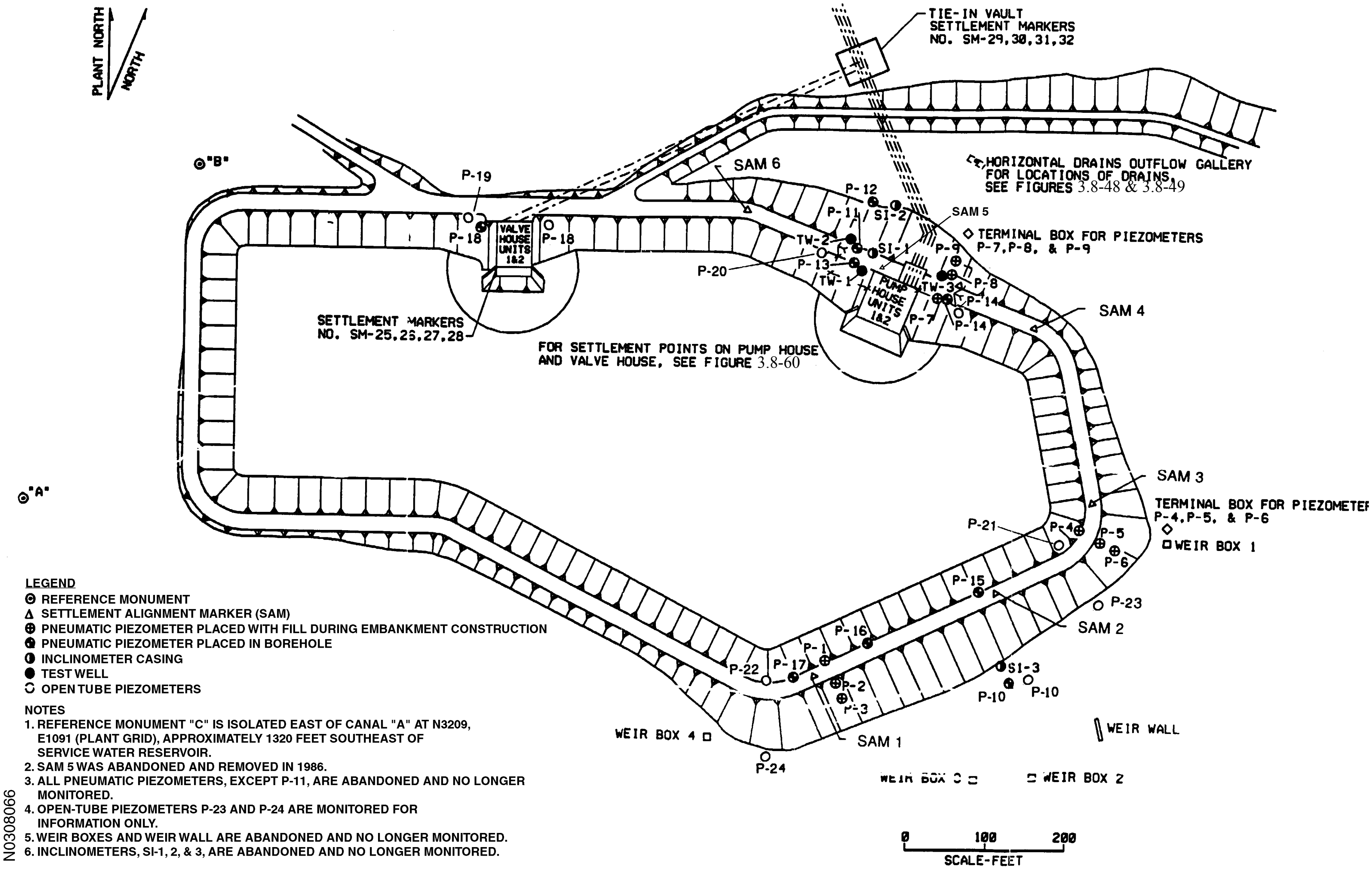
Figure 3.8-30
HISTOGRAM OF MOISTURE CONTENT CONTROL TEST: LAKE ANNA DAM



NOTE:

MATERIAL REPRESENTED BY TESTS RESULTS OUTSIDE OF SPECIFIED RANGE WAS REWORKED OR REPLACED AND RETESTED

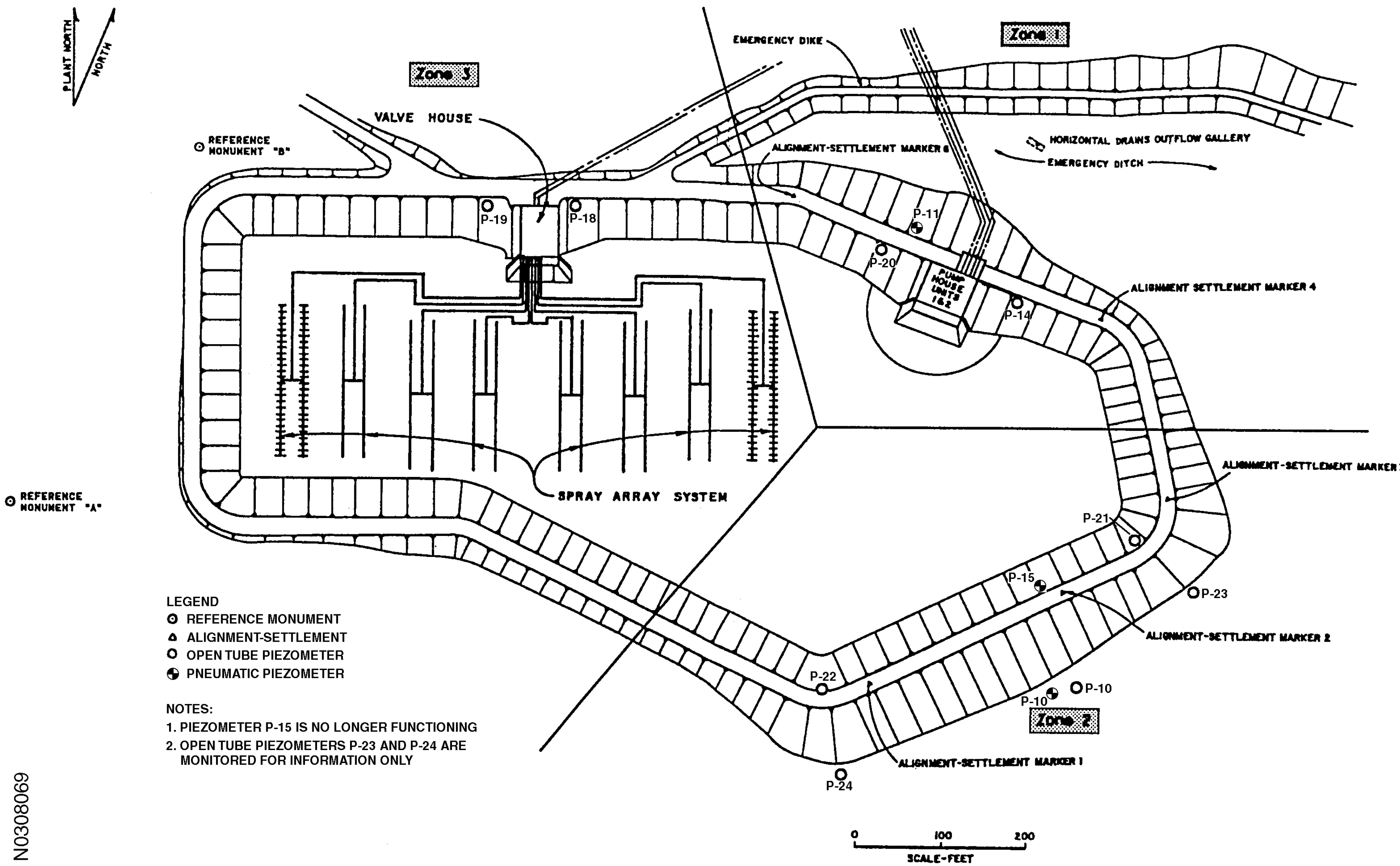
Figure 3.8-31
INSTRUMENTATION: SERVICE WATER RESERVOIR



LEGEND
- REFERENCE MONUMENT
- SETTLEMENT ALIGNMENT MARKER (SAM)
- PNEUMATIC PIEZOMETER PLACED WITH FILL DURING EMBANKMENT CONSTRUCTION
- PNEUMATIC PIEZOMETER PLACED IN BOREHOLE
- INCLINOMETER CASING
- TEST WELL
- OPEN TUBE PIEZOMETERS

NOTES
1. REFERENCE MONUMENT "C" IS ISOLATED EAST OF CANAL "A" AT N3209, E1091 (PLANT GRID), APPROXIMATELY 1320 FEET SOUTHEAST OF SERVICE WATER RESERVOIR.
2. SAM 5 WAS ABANDONED AND REMOVED IN 1986.
3. ALL PNEUMATIC PIEZOMETERS, EXCEPT P-11, ARE ABANDONED AND NO LONGER MONITORED.
4. OPEN-TUBE PIEZOMETERS P-23 AND P-24 ARE MONITORED FOR INFORMATION ONLY.
5. WEIR BOXES AND WEIR WALL ARE ABANDONED AND NO LONGER MONITORED.
6. INCLINOMETERS, SI-1, 2, & 3, ARE ABANDONED AND NO LONGER MONITORED.

Figure 3.8-32
CURRENT INSTRUMENTATION LOCATIONS: SERVICE WATER RESERVOIR



N0308069

Withhold under 10 CFR 2.390 (d) (1)

[redacted]

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.8-34
BORING LOGS: SERVICE WATER RESERVOIR: PUMP HOUSE

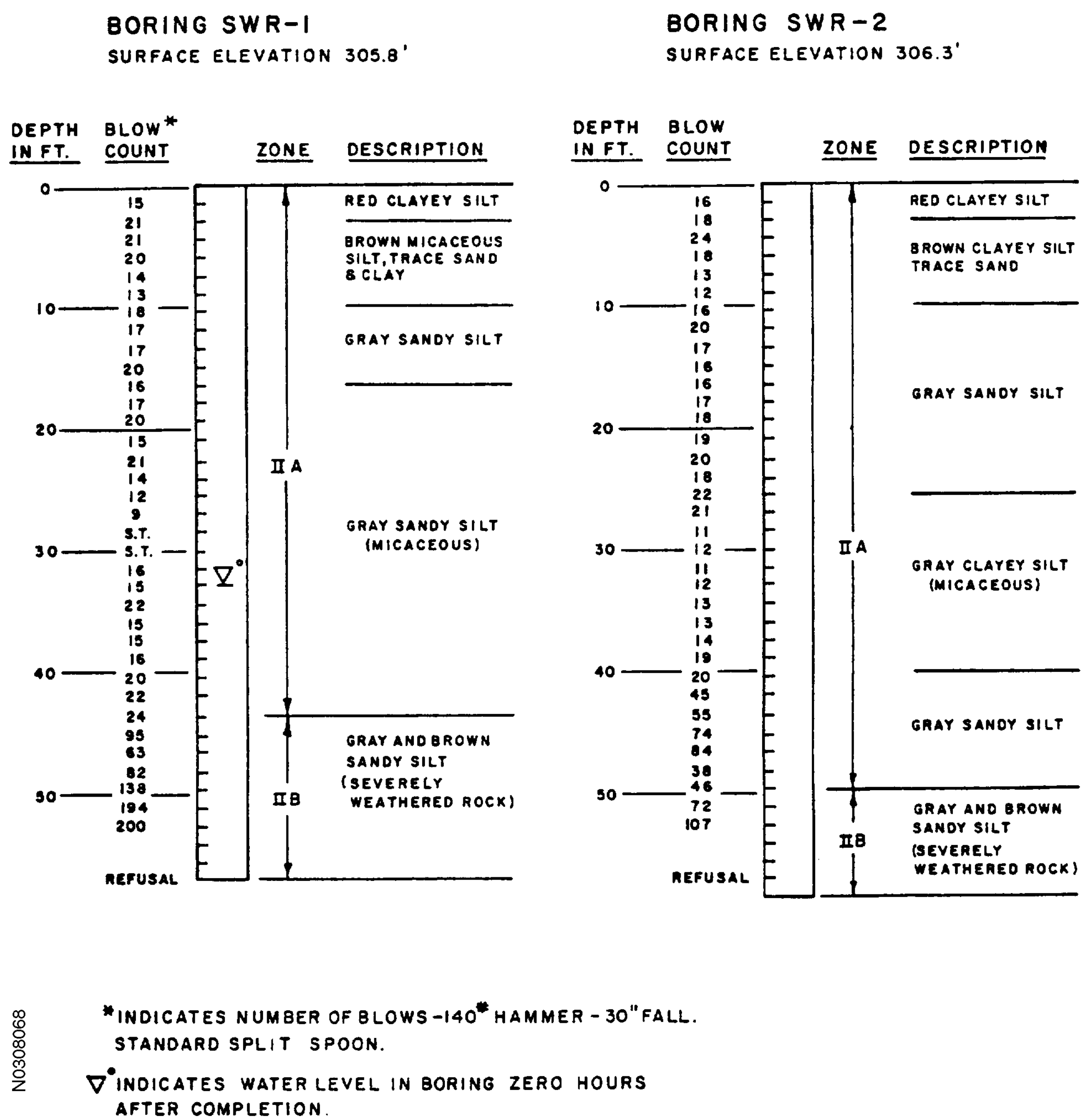


Figure 3.8-35
PROFILE ALONG 14 LINE SHOWING FOUNDATION OF SERVICE WATER LINES

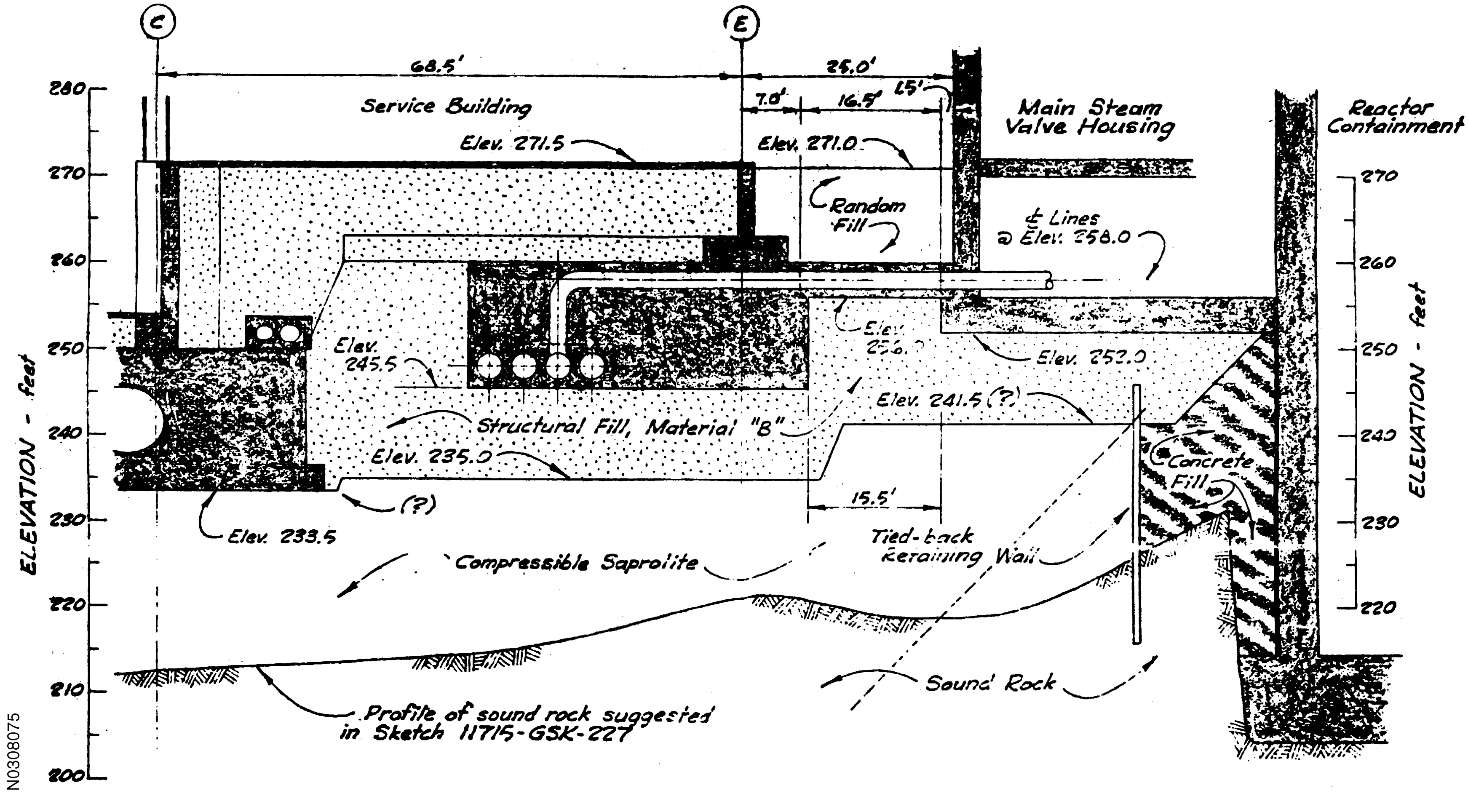
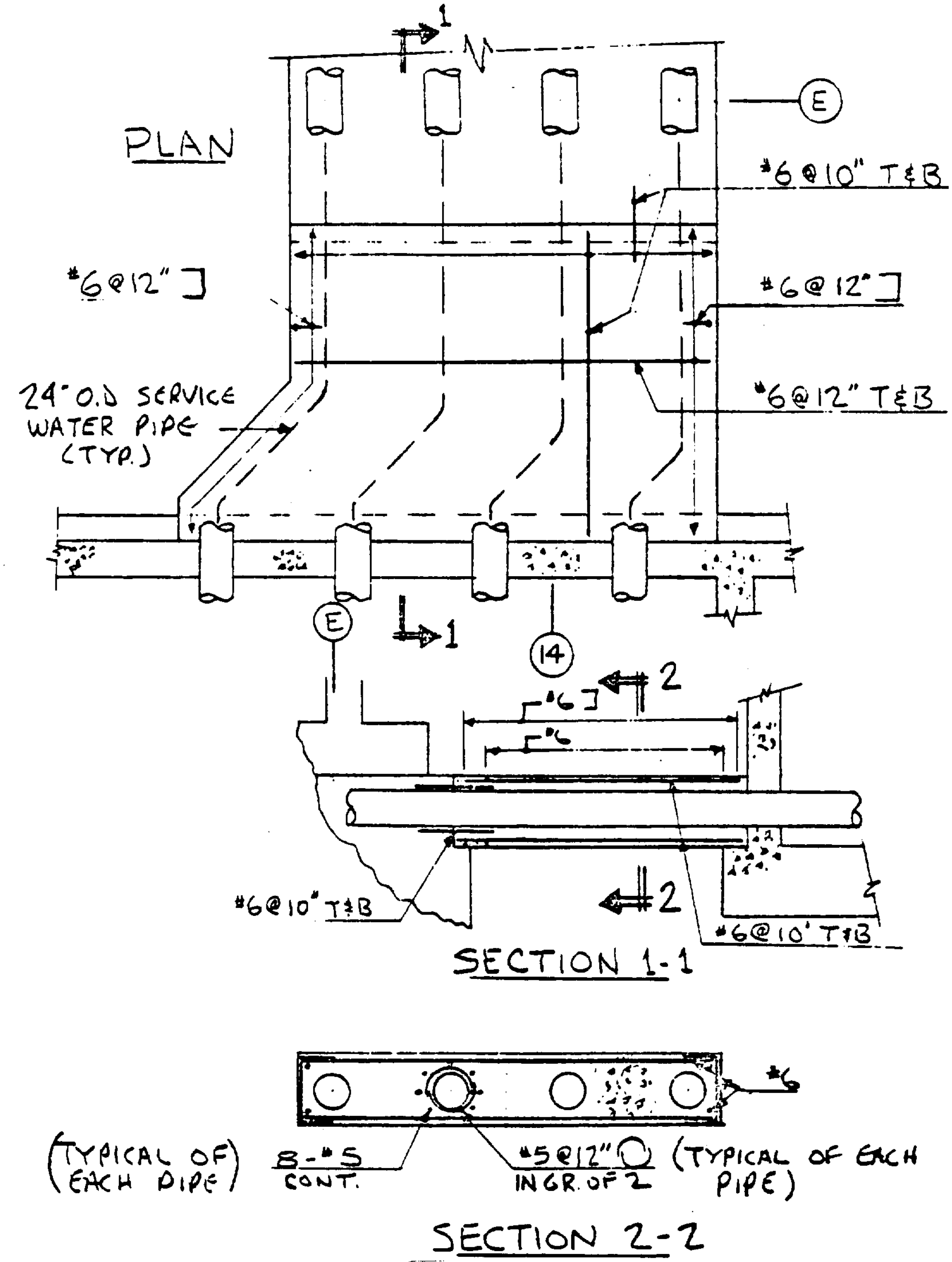


Figure 3.8-36
SERVICE WATER PIPING BEFORE MODIFICATION



NOTE: THIS FIGURE SHOWS THE ORIGINAL ARRANGEMENT. THE EXTENT OF THE REMOVED CONCRETE ENCASEMENT AND REINFORCING STEEL IS SHOWN ON FIGURE 3.8-79.

N0308076

Figure 3.8-37
SERVICE WATER PIPING WITH CONCRETE ENCASEMENT

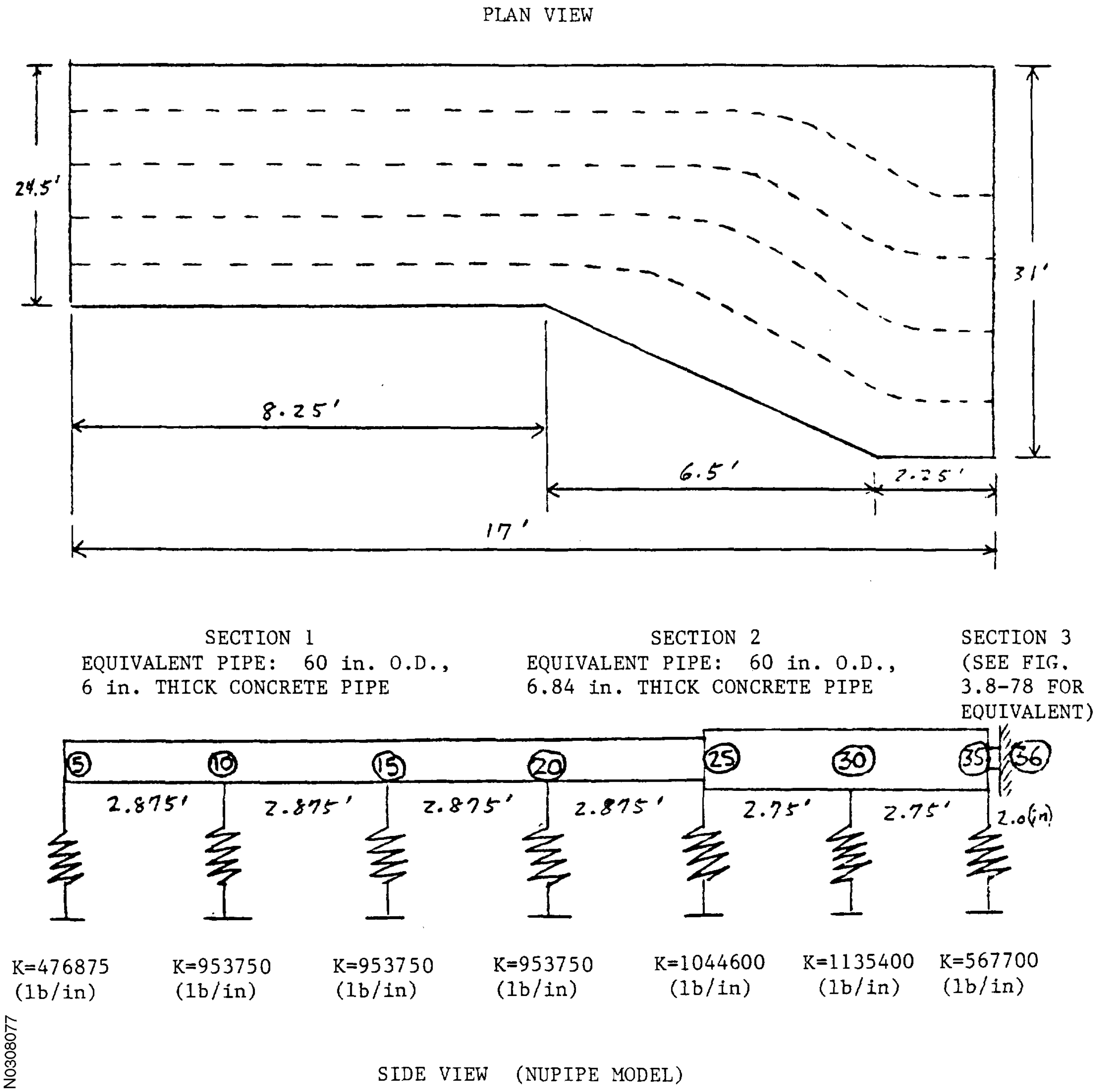


Figure 3.8-38
SERVICE WATER PIPING: PARTIALLY ENCASED

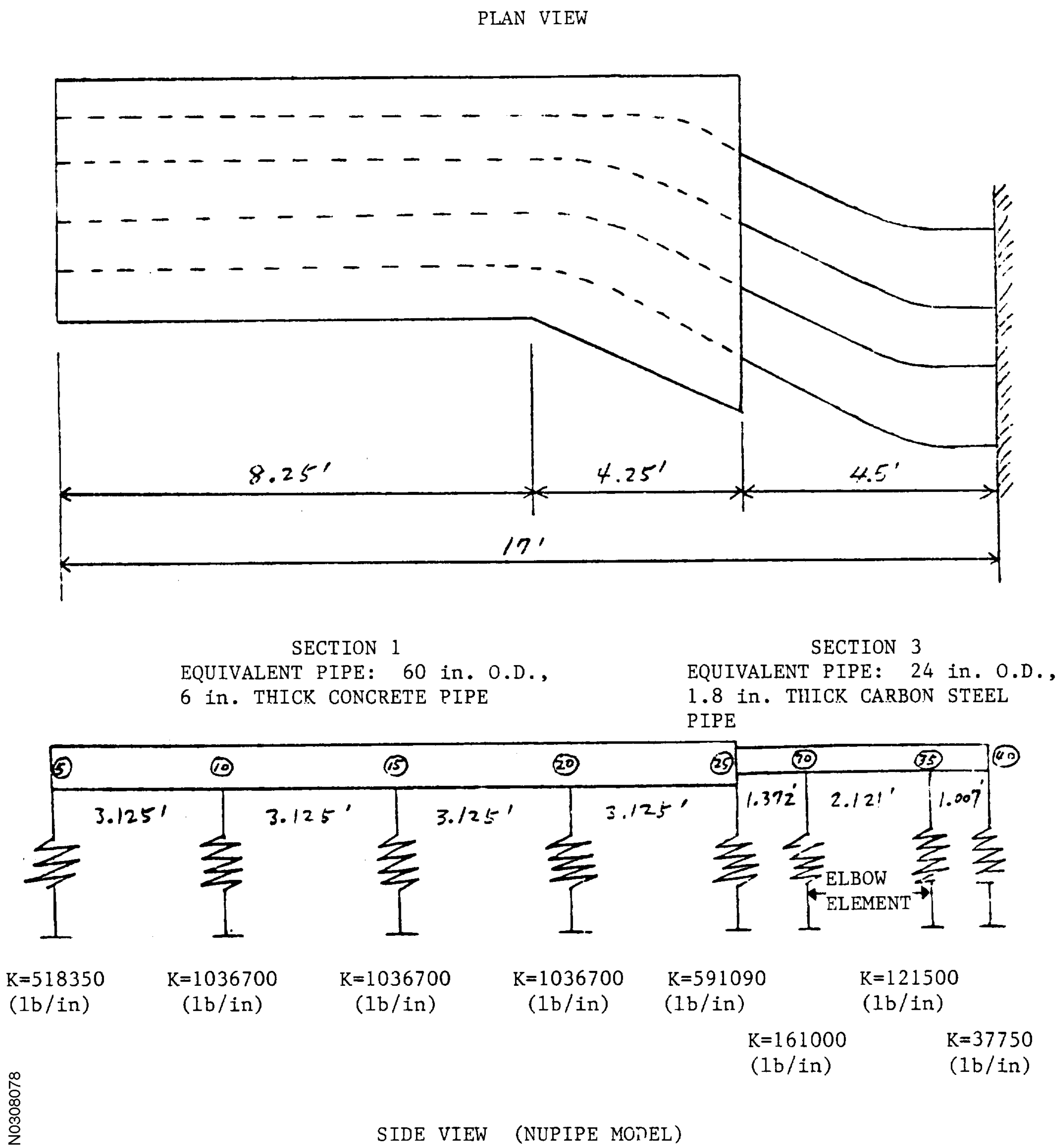


Figure 3.8-39
PLAN OF REPAIR OF SERVICE WATER LINES

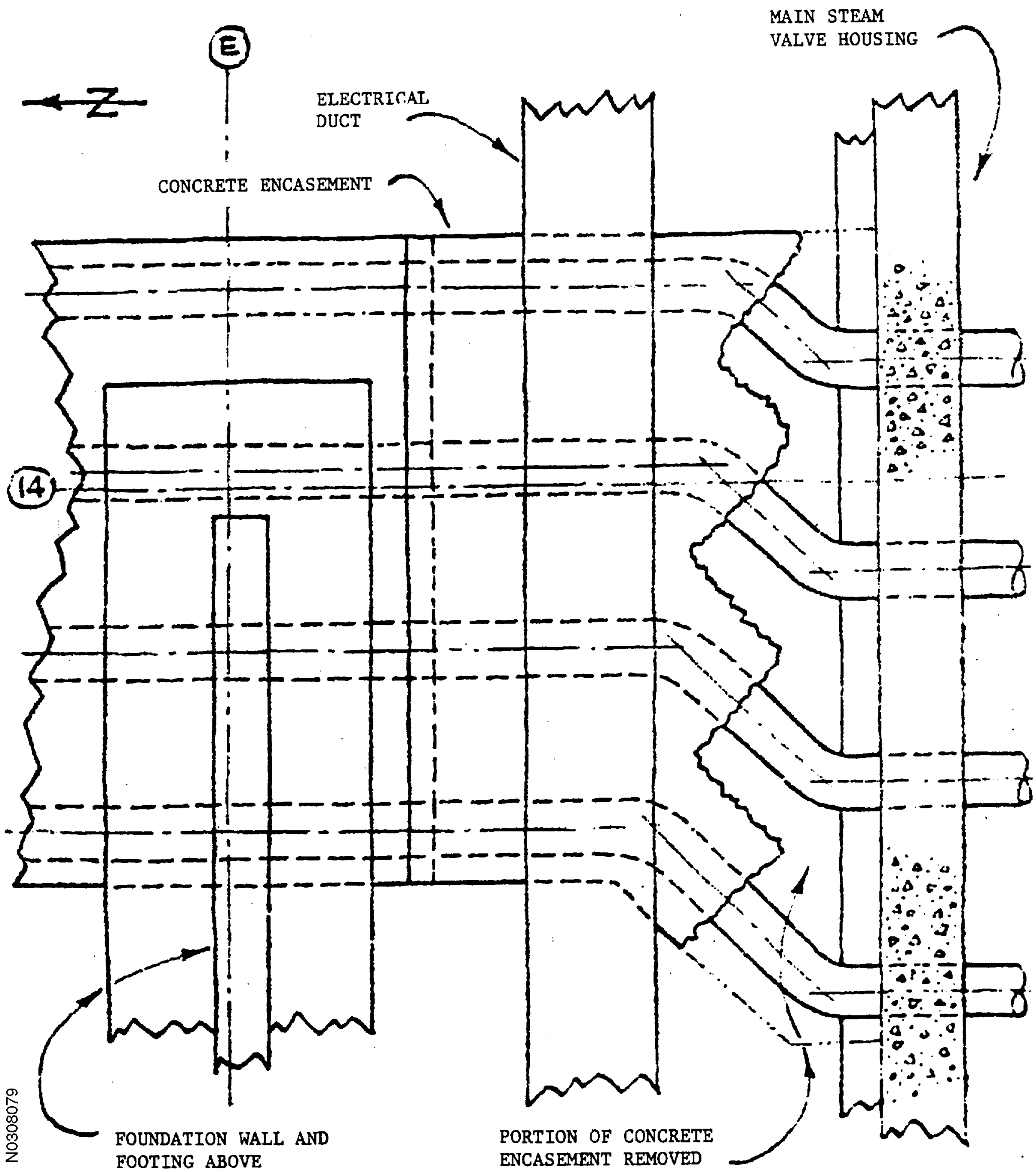
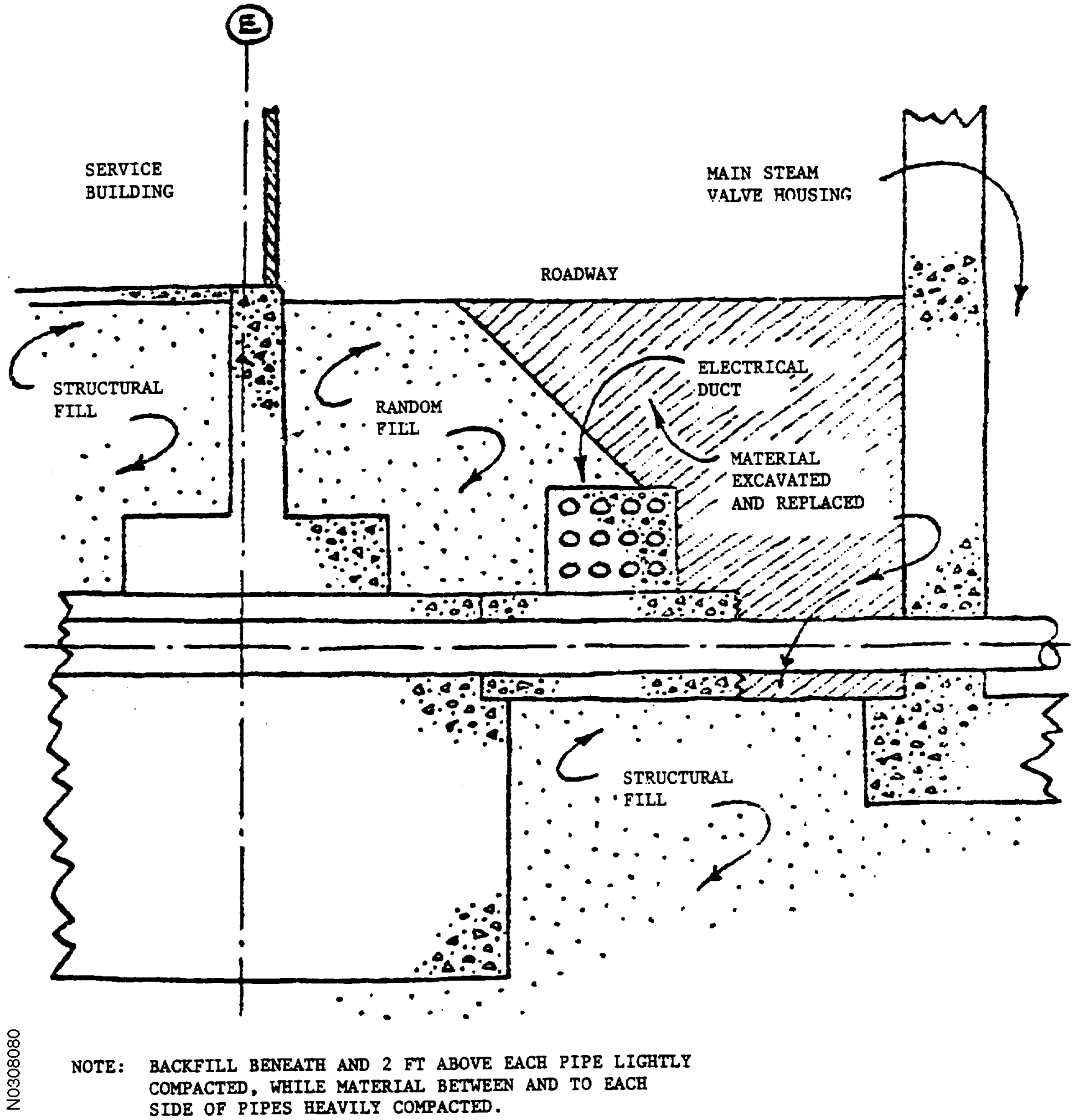


Figure 3.8-40
SECTION THROUGH REPAIR OF SERVICE WATER LINES



NOTE: BACKFILL BENEATH AND 2 FT ABOVE EACH PIPE LIGHTLY COMPACTED, WHILE MATERIAL BETWEEN AND TO EACH SIDE OF PIPES HEAVILY COMPACTED.

Figure 3.8-41
SERVICE WATER PIPING REANALYSIS: MATH MODEL

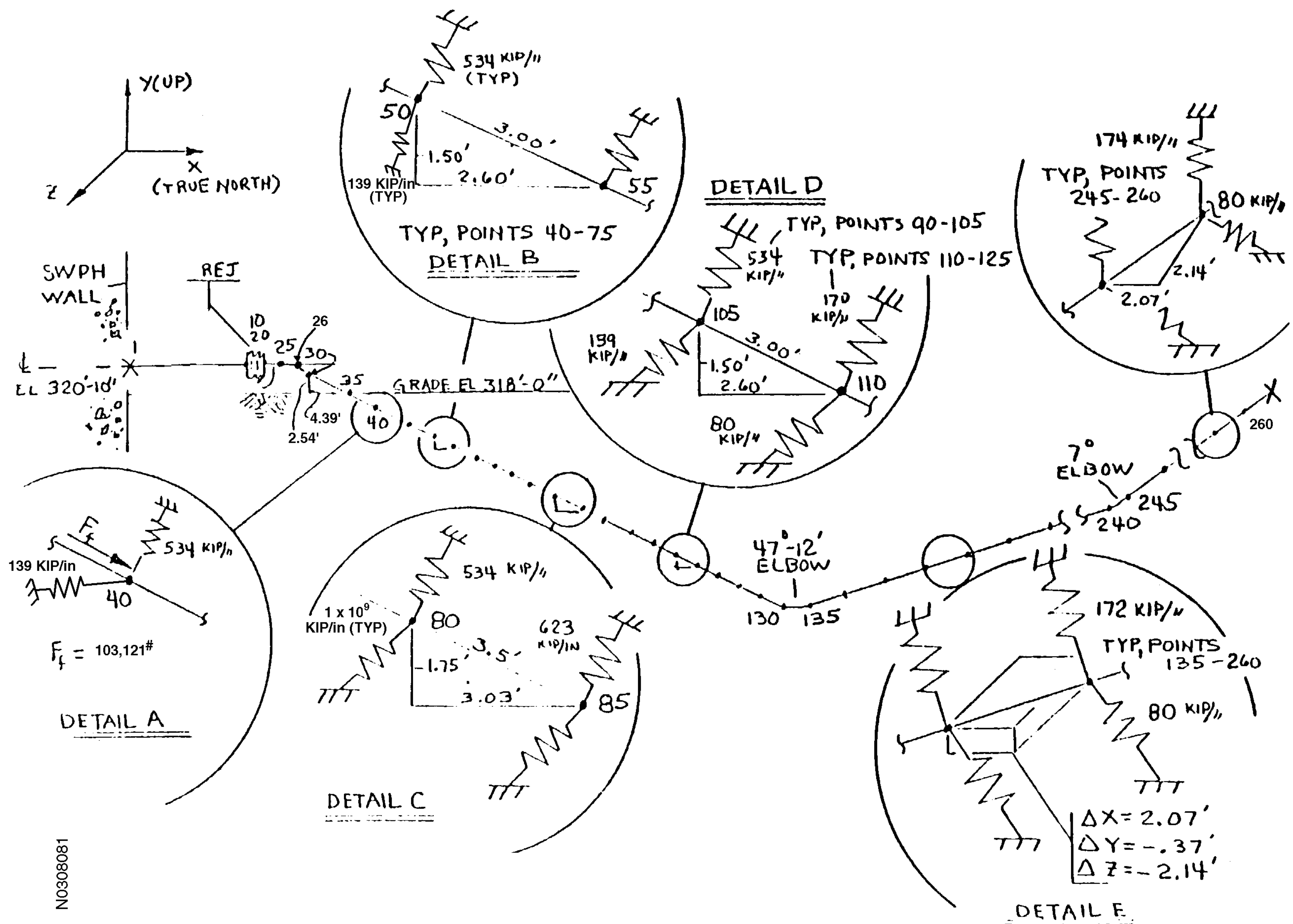
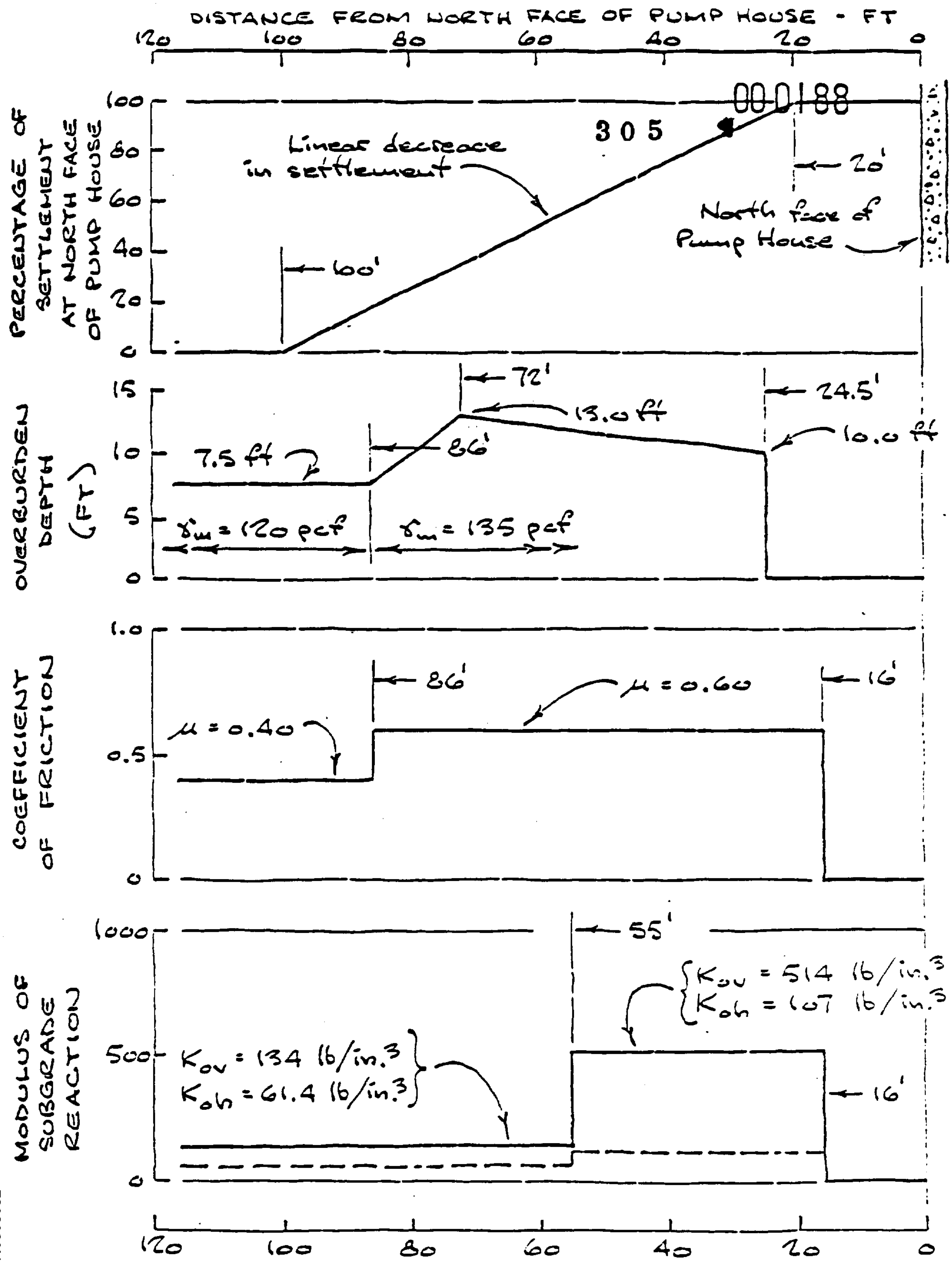
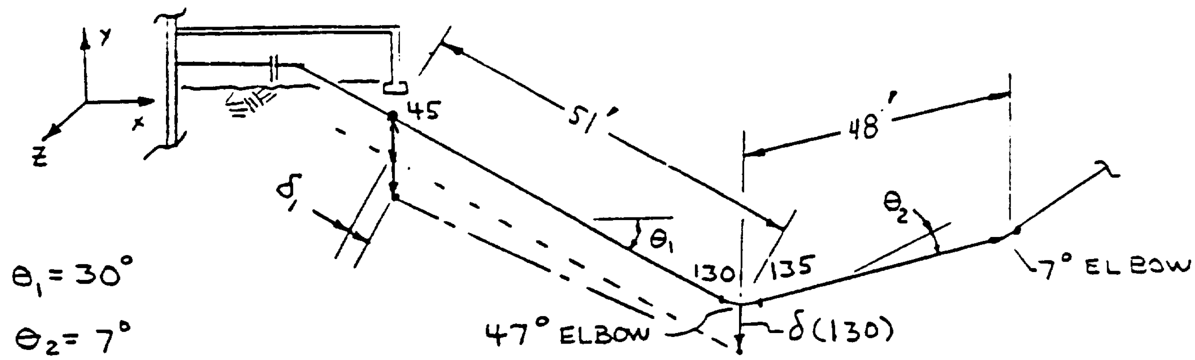


Figure 3.8-42
SERVICE WATER PIPING REANALYSIS: SOIL PROPERTIES



N0308082

Figure 3.8-43
SERVICE WATER PIPING REANALYSIS: SOIL SETTLEMENT AND INSTABILITY

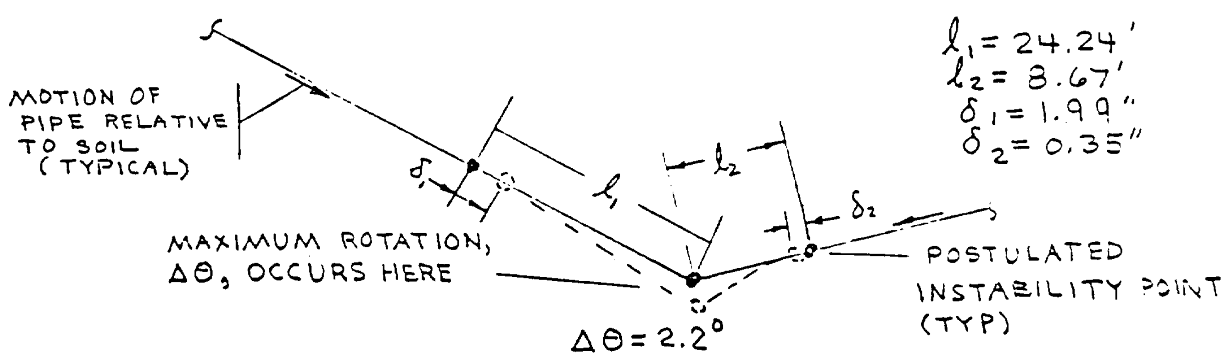


$$\delta_1 = (\delta(45) - \delta(130)) \sin\theta_1$$
$$= 1.99''$$

$$\delta_2 = \delta(130) \sin\theta_2$$
$$= 0.35''$$

MAXIMUM MOVEMENT OF PIPE
DUE TO SOIL SETTLEMENT

Diagram "A"



CONFIGURATION OF
POSTULATED INSTABILITY

Diagram "B"

N0308083

Figure 3.8-44
TYPICAL TEST WELL INSTALLATION: SERVICE WATER RESERVOIR

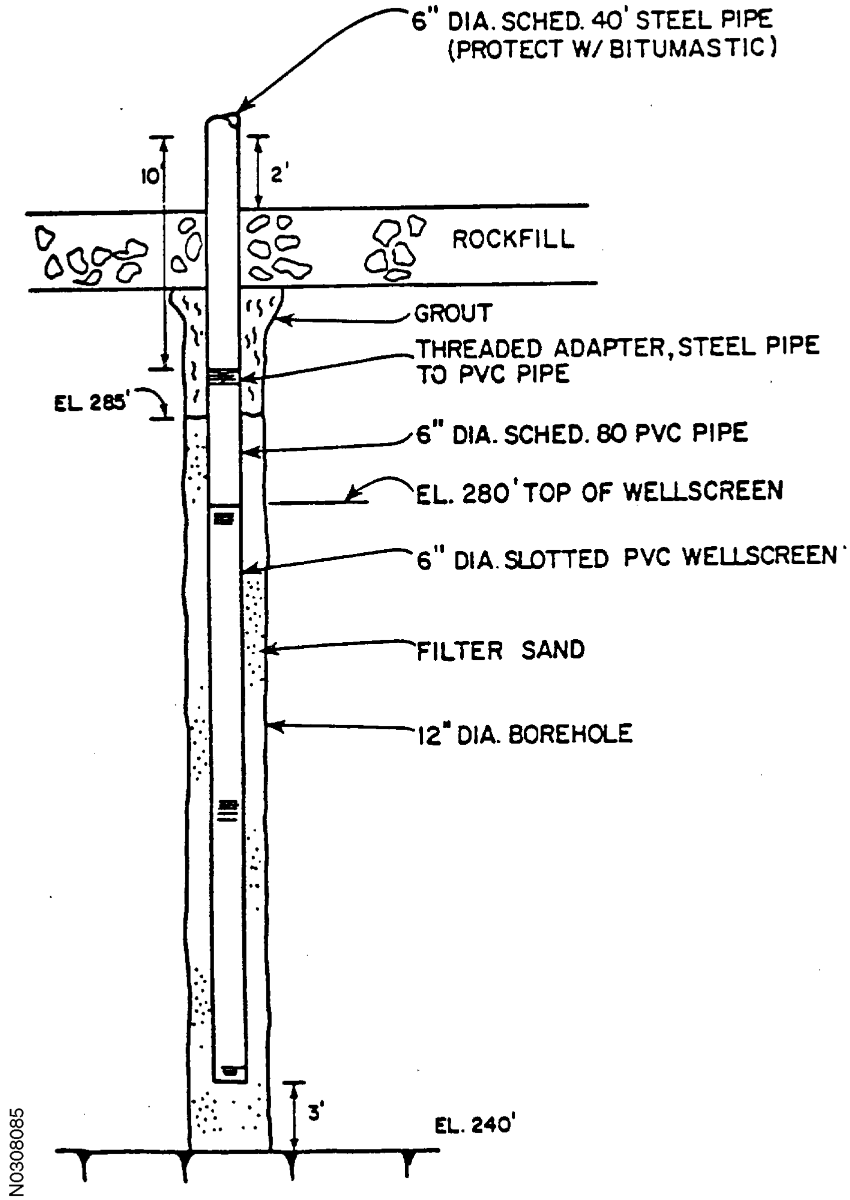


Figure 3.8-45
LOCATIONS OF TEST WELLS: SERVICE WATER RESERVOIR

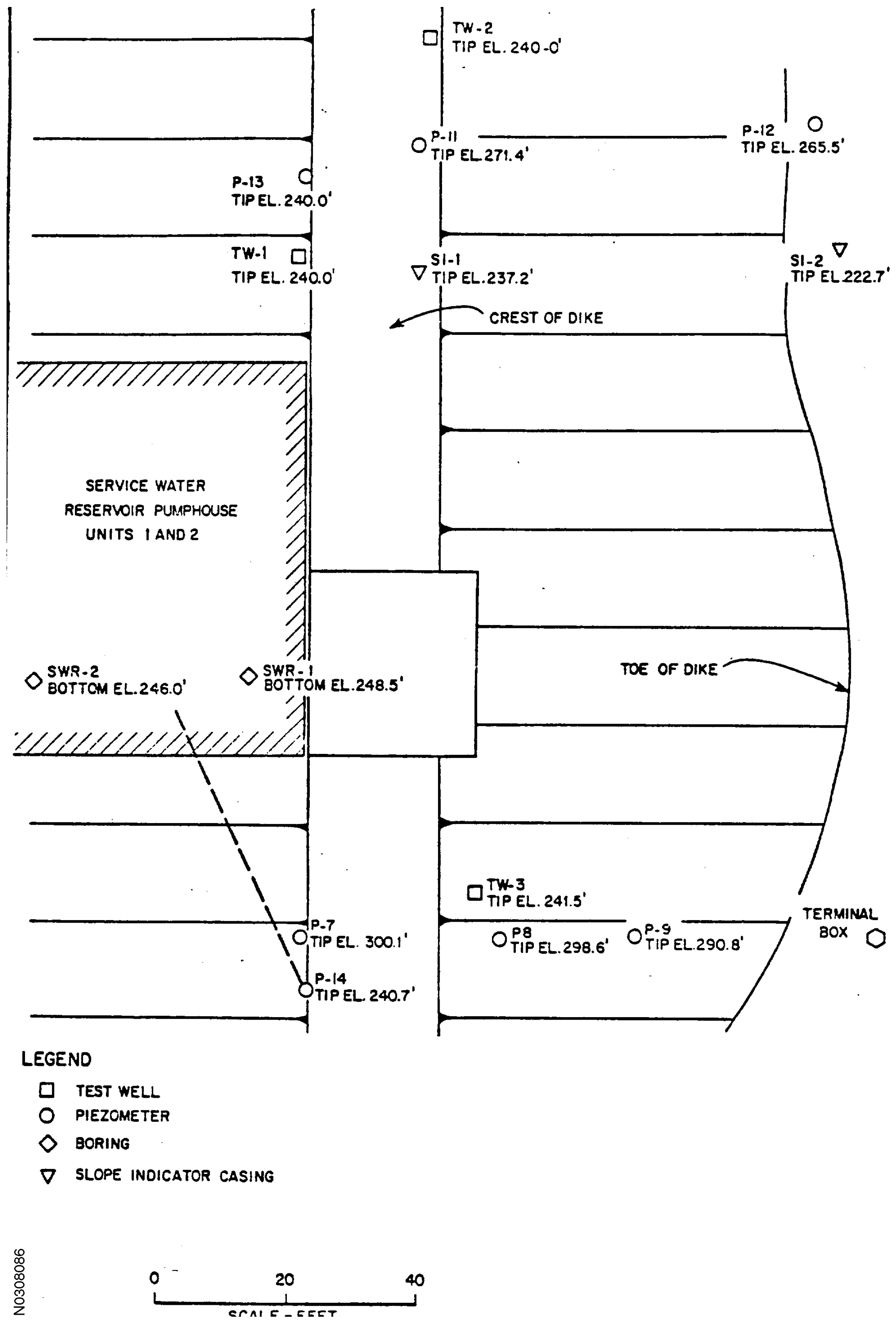


Figure 3.8-46
DISTANCE: DRAWDOWN ANALYSIS: WELL PUMPING TEST:
SERVICE WATER RESERVOIR

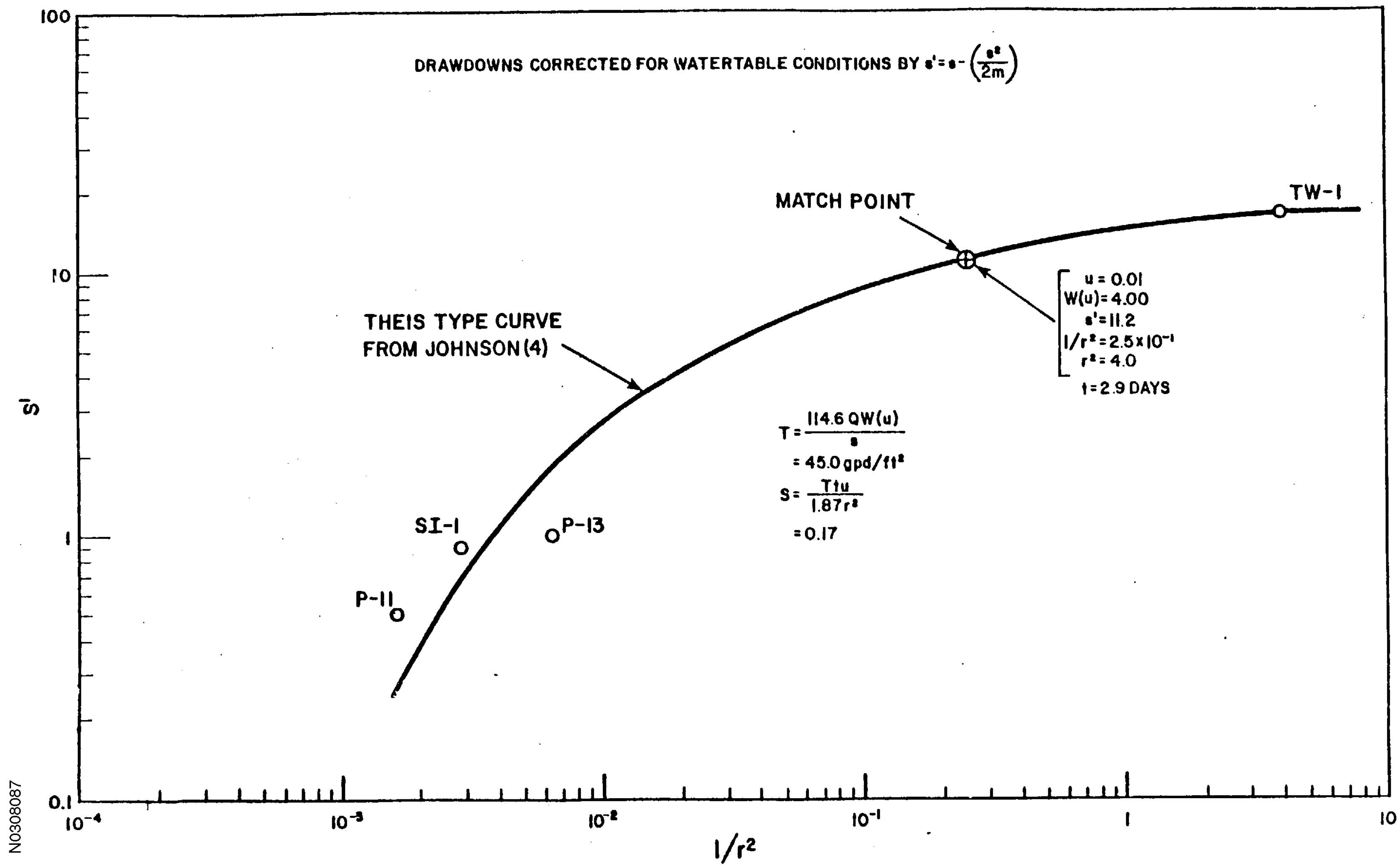


Figure 3.8-47
TIME: DRAWDOWN ANALYSIS: WELL PUMPING TEST:
SERVICE WATER RESERVOIR

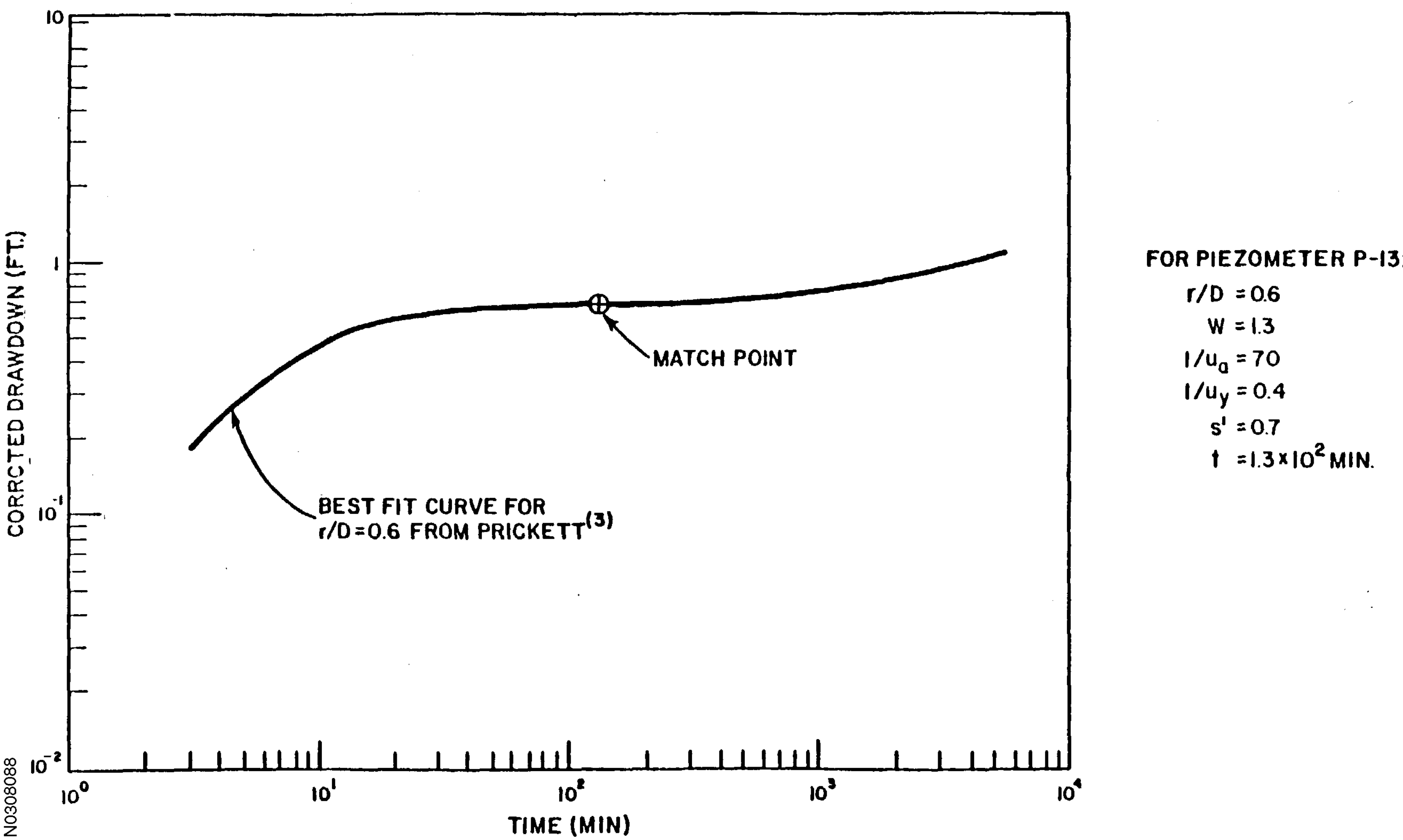


Figure 3.8-48
PLAN OF HORIZONTAL DRAINS: SERVICE WATER RESERVOIR

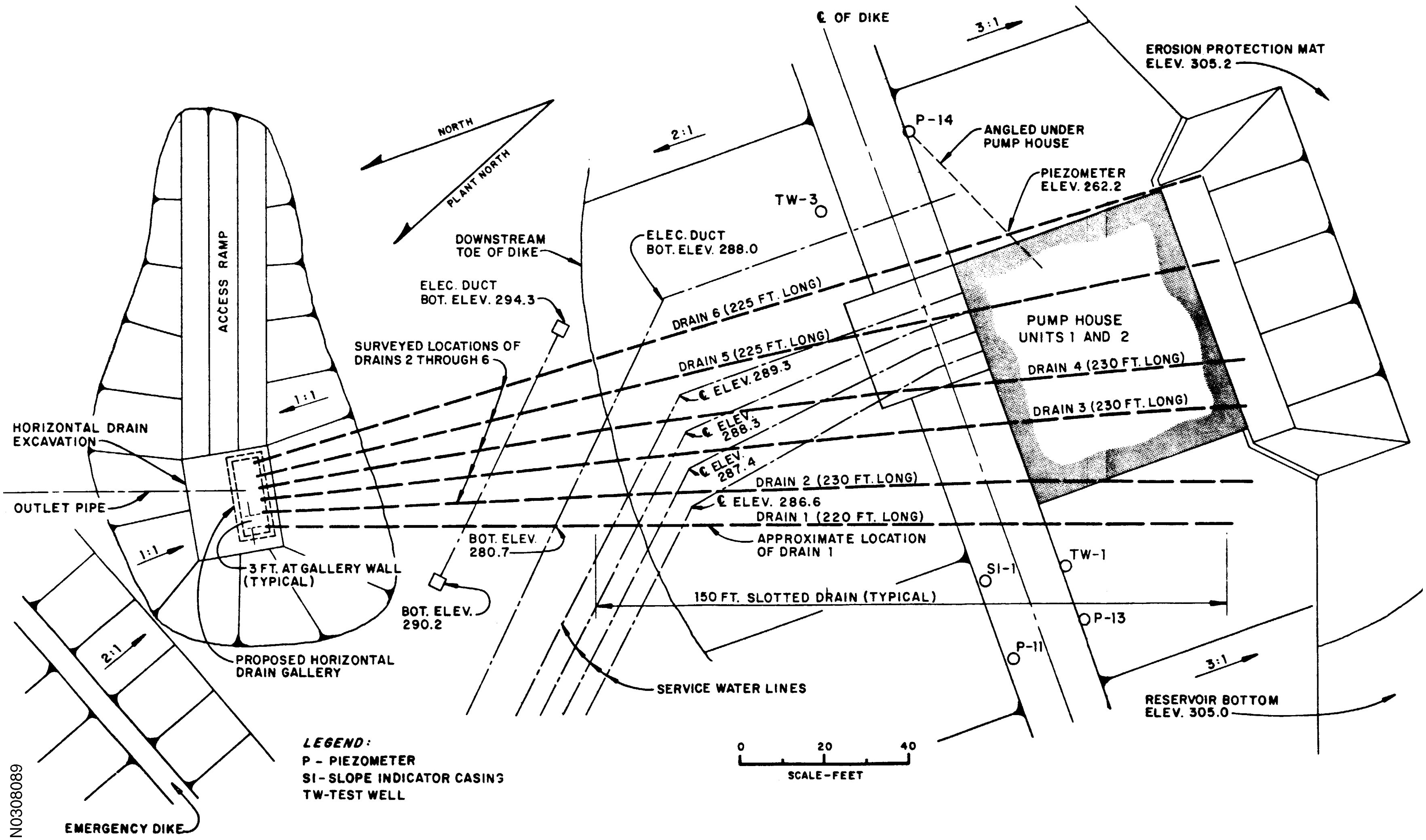
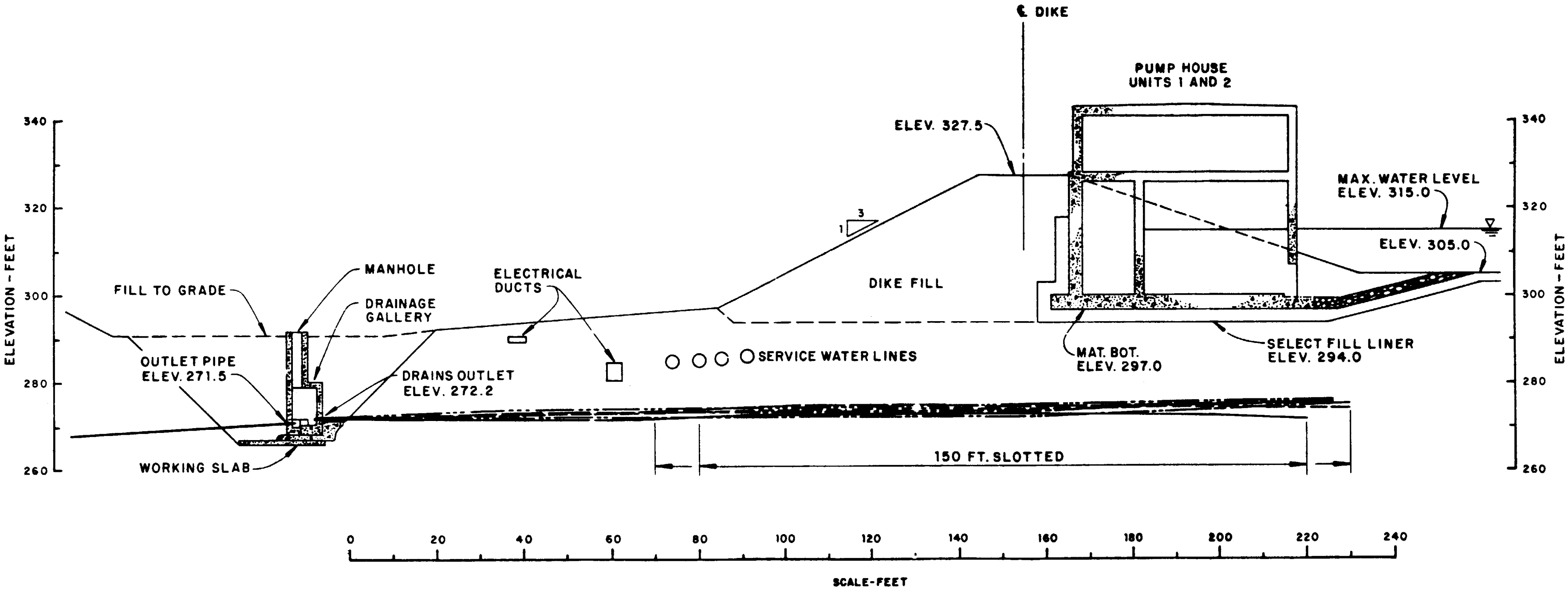


Figure 3.8-49
PROFILE OF HORIZONTAL DRAINS: SERVICE WATER RESERVOIR



LEGEND:

DRAIN 1
DRAIN 2
DRAIN 3
DRAIN 4
DRAIN 5
DRAIN 6

NOTES:

FOR CORRECT LOCATIONS OF PUMP HOUSE, SERVICE WATER LINES, AND ELECTRICAL DUCTS WITH RESPECT TO INDIVIDUAL DRAINS, SEE FIG.

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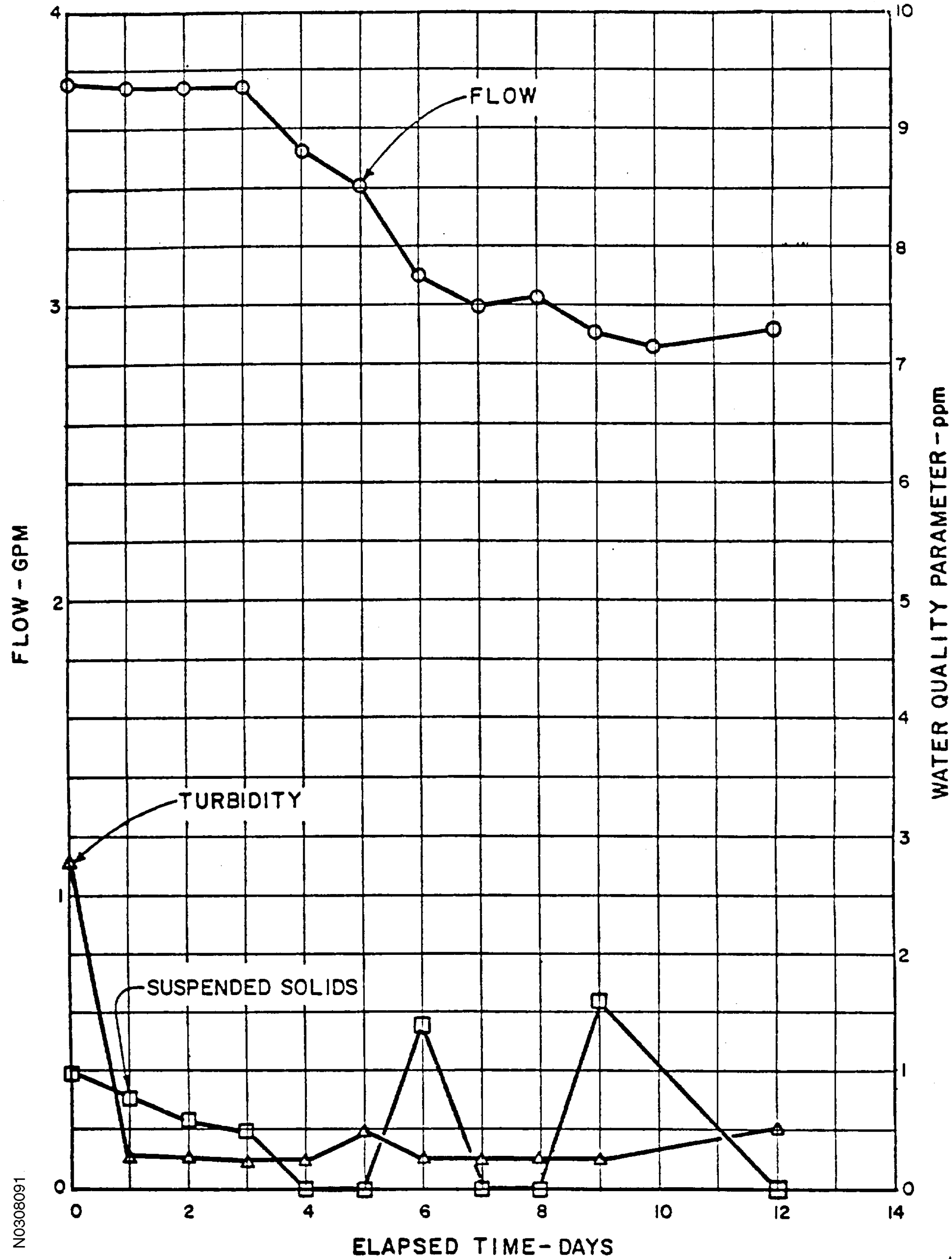
The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

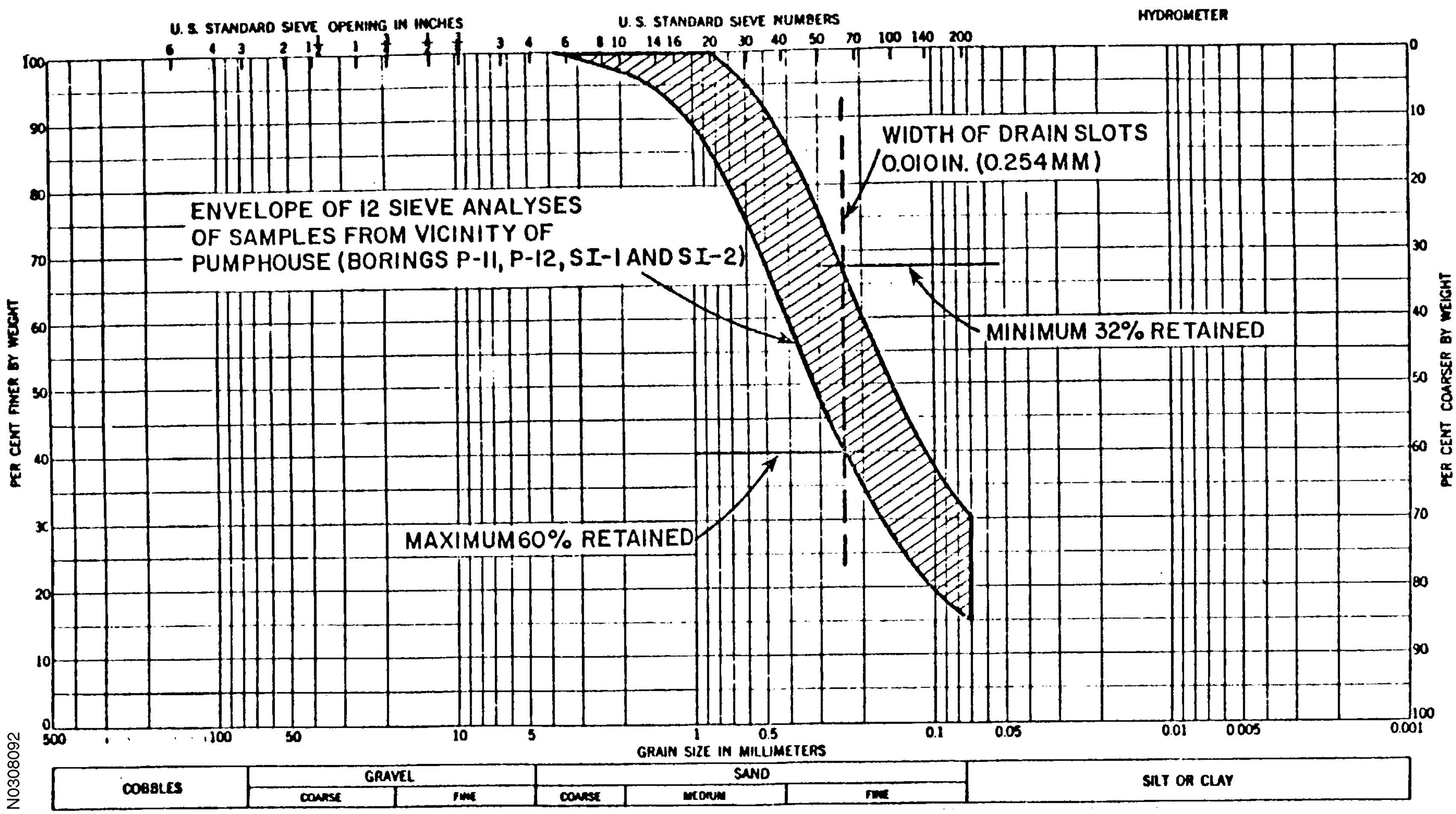
Figure 3.8-50
QUANTITY AND QUALITY OF WATER FROM HORIZONTAL DRAIN: SERVICE WATER RESERVOIR



The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.8-51

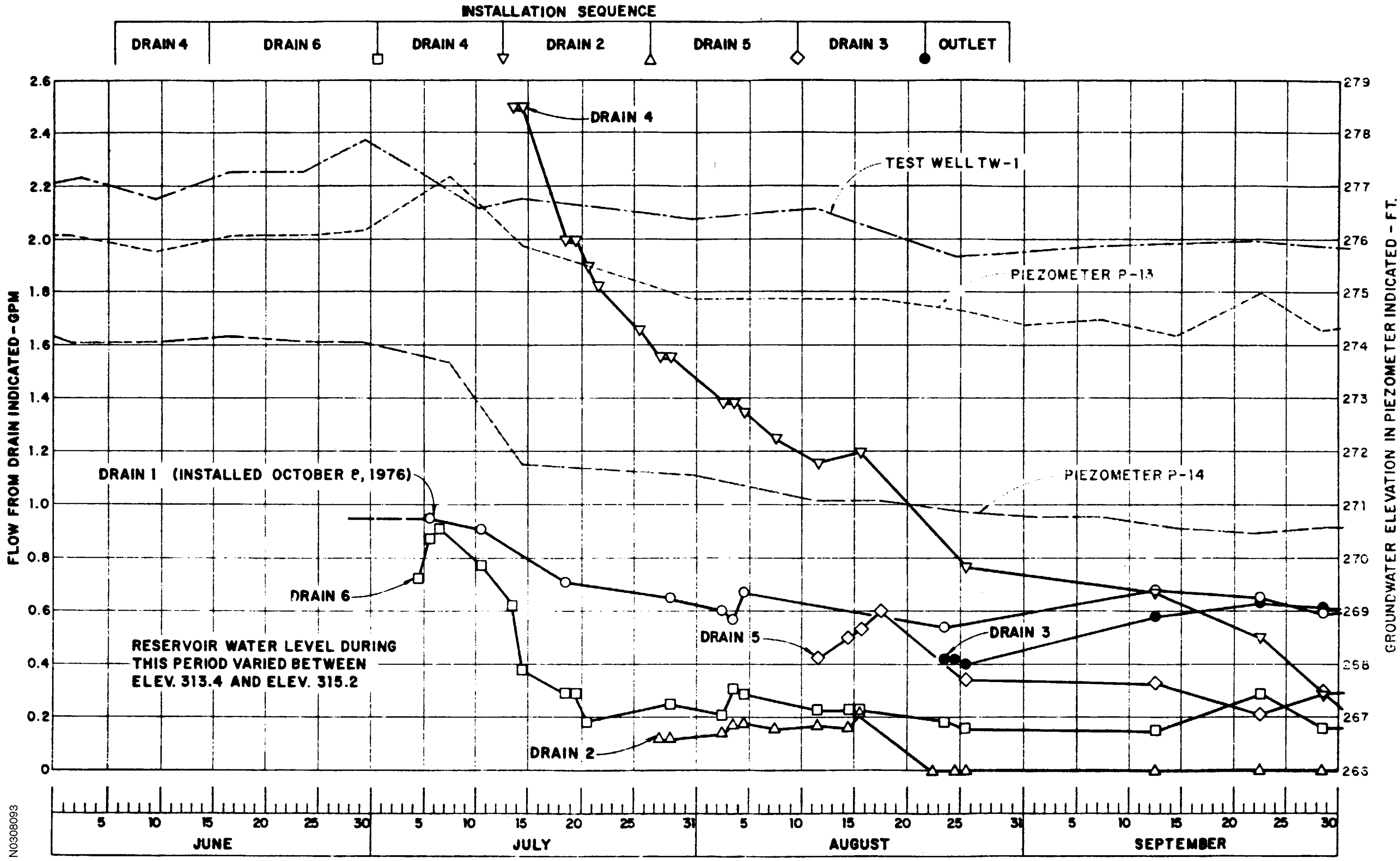
COMPARISON OF DRAIN SLOT WIDTH TO GRADATION OF SAPROLITE



The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.8-52

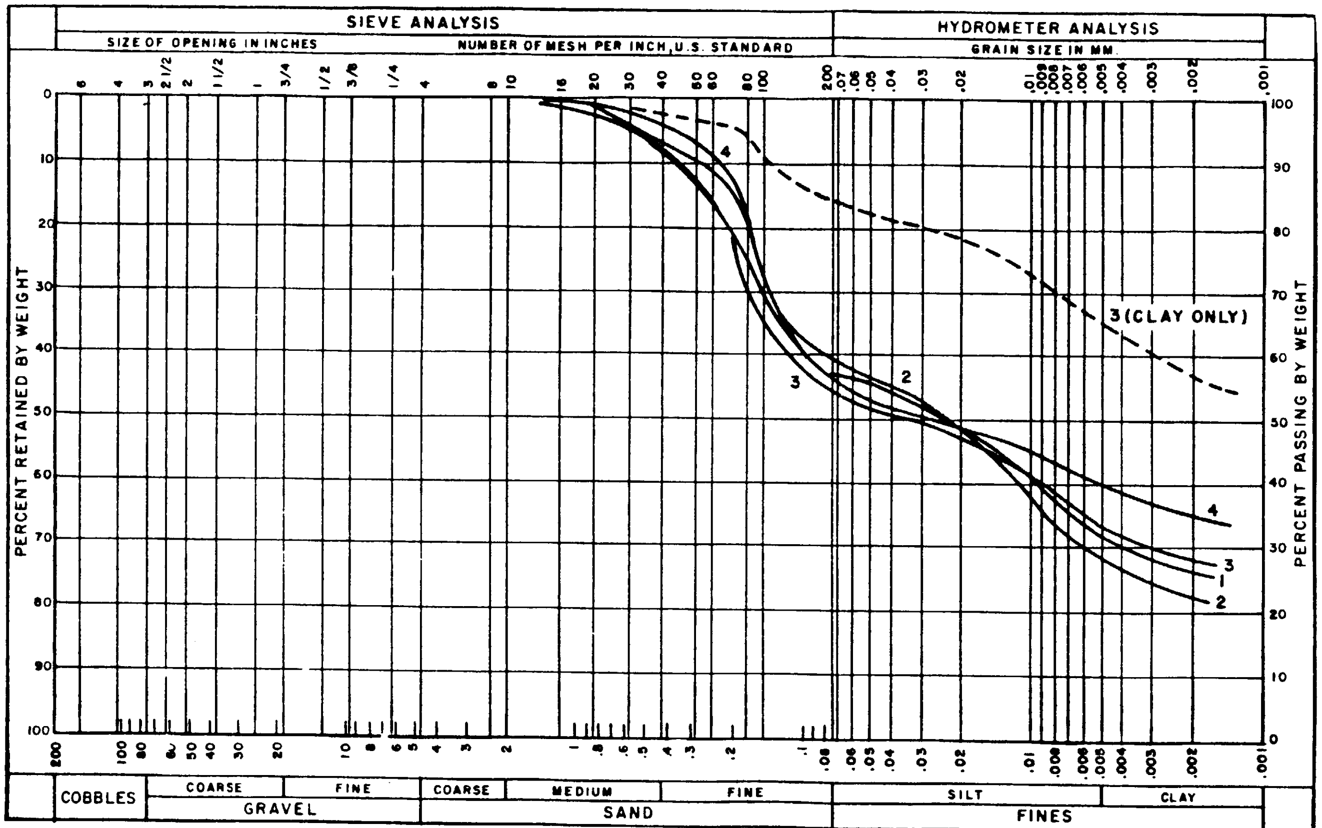
FLOWS FROM HORIZONTAL DRAINS AND GROUNDWATER ELEVATIONS DURING INSTALLATION: SERVICE WATER RESERVOIR



The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.8-53

GRADATION CURVES: SERVICE WATER RESERVOIR



FIELD SAMPLE NO.	KEY	SAMPLE DEPTH	SAMPLE DESCRIPTION
1			COMPOSITE – SELECT STOCKPILE FOR LINING
2			COMPOSITE – SELECT STOCKPILE FOR LINING
3			COMPOSITE – SELECT STOCKPILE FOR LINING
3			CLAY PORTION ONLY
4			COMPOSITE – SELECT STOCKPILE FOR LINING

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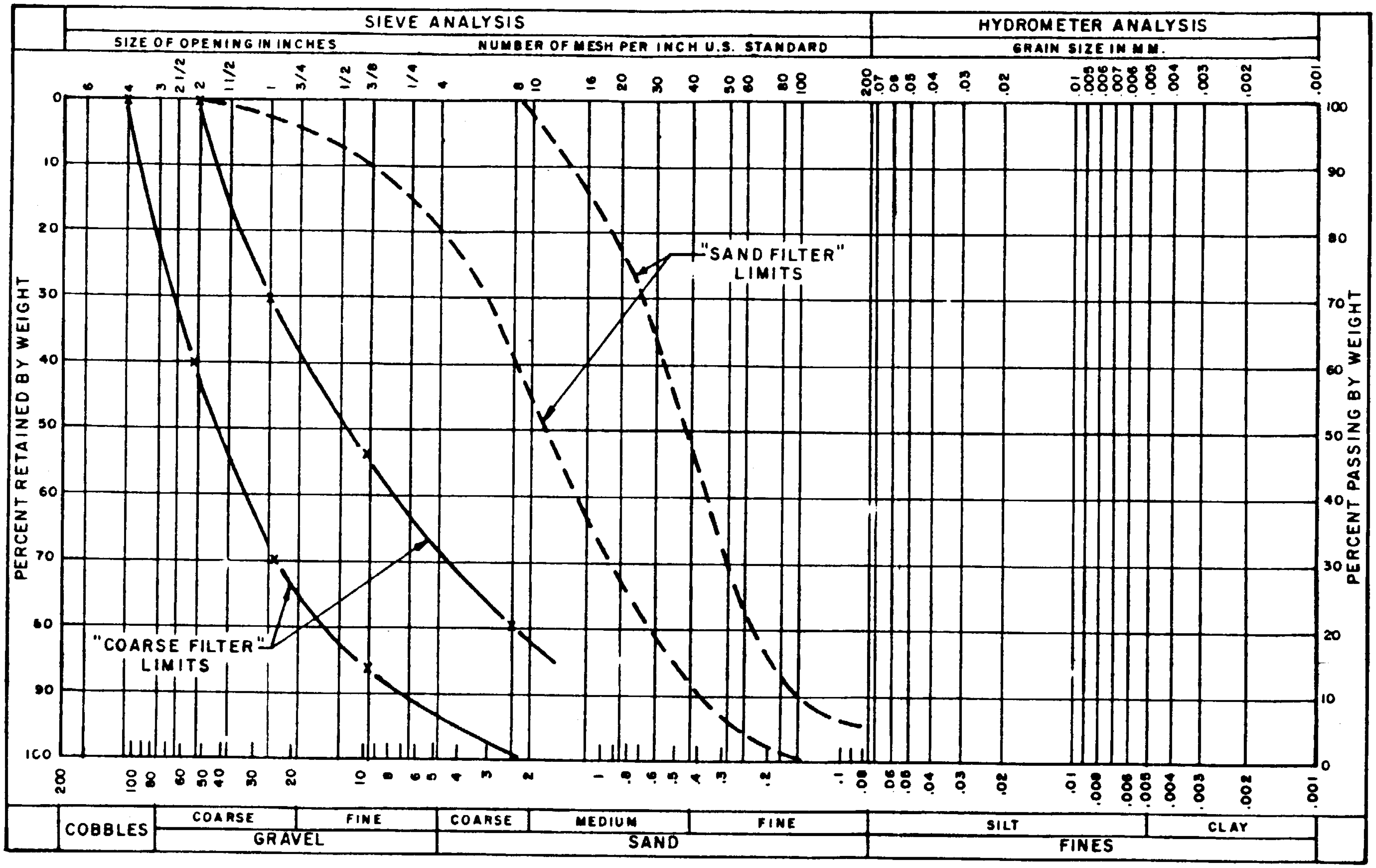
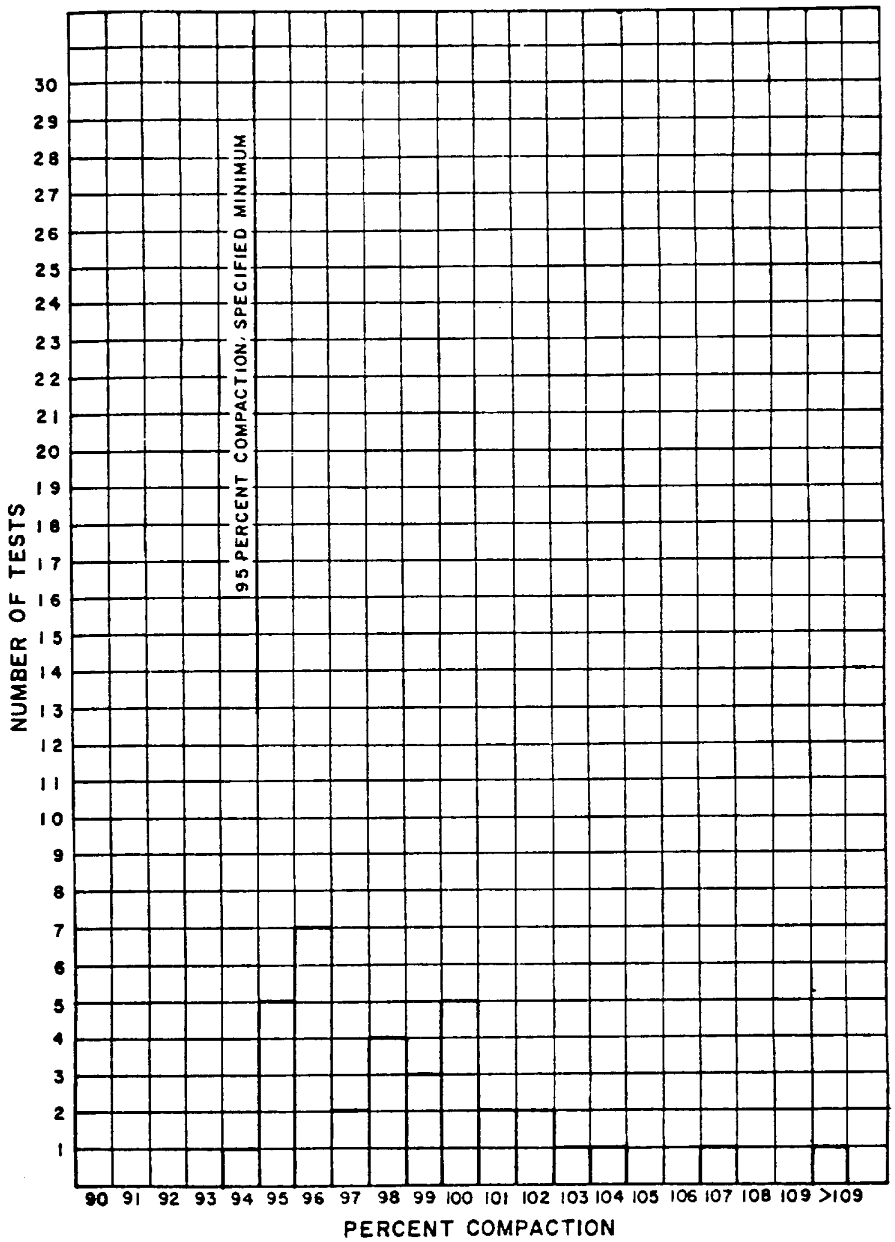
Figure 3.8-54

GRADATION LIMITS OF SAND FILTER AND COARSE FILTER



The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.8-55
HISTOGRAM OF RECORD TESTS FOR COMPACTION CONTROL
OF SELECT EARTH LINING: SERVICE WATER RESERVOIR



NOTES:

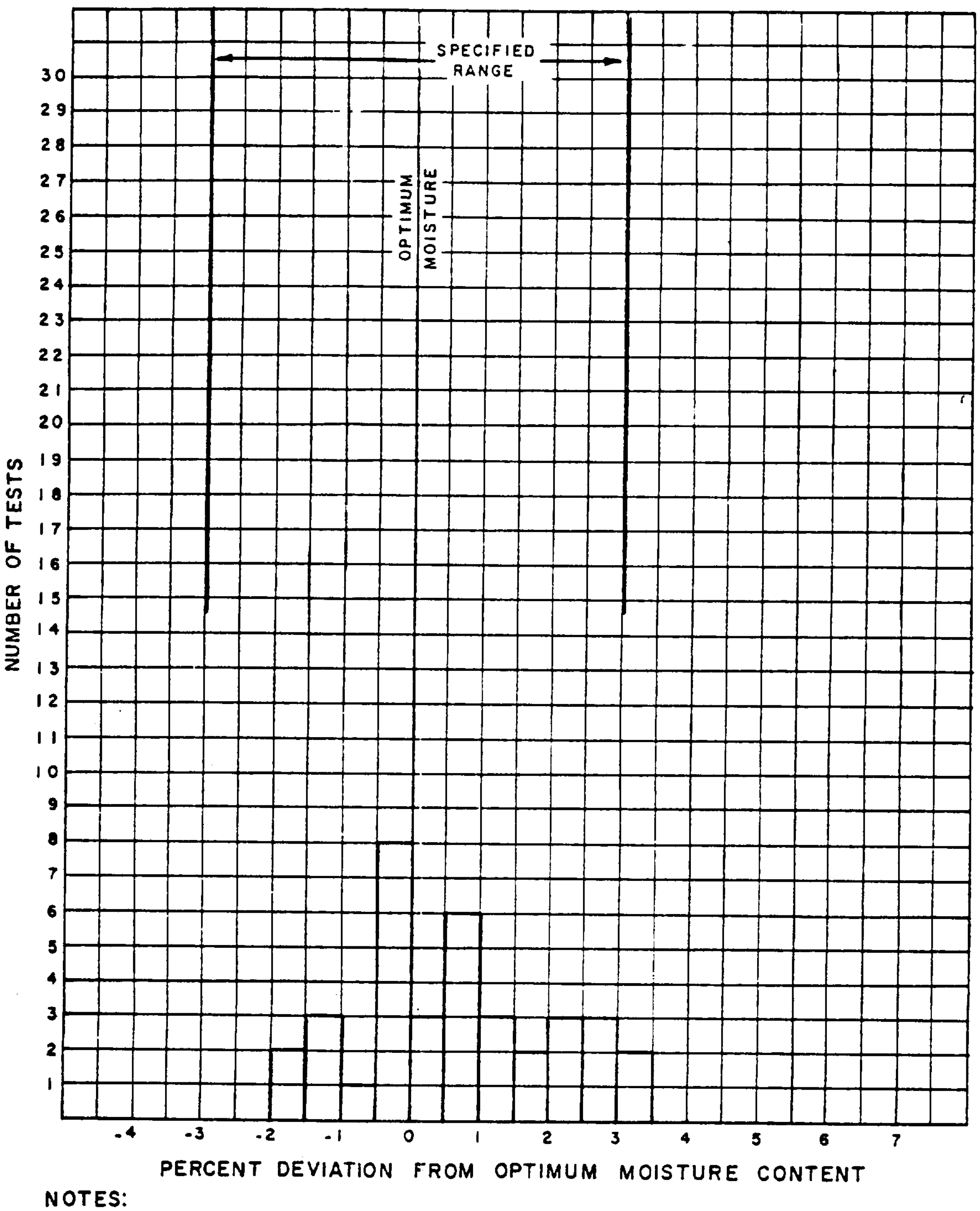
(1) TEST RESULTS ARE FOR FILL PLACED PRIOR TO SEPT. 16, 1972

(2) MATERIAL REPRESENTED BY ONE TEST HAVING 94% COMPACTION AT 20% DEVIATION FROM OPTIMUM MOISTURE IS ACCEPTABLE

N0308096

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.8-56
HISTOGRAM OF RECORD TESTS FOR MOISTURE CONTENT CONTROL OF SELECT EARTH LINING: SERVICE WATER RESERVOIR



NOTES:

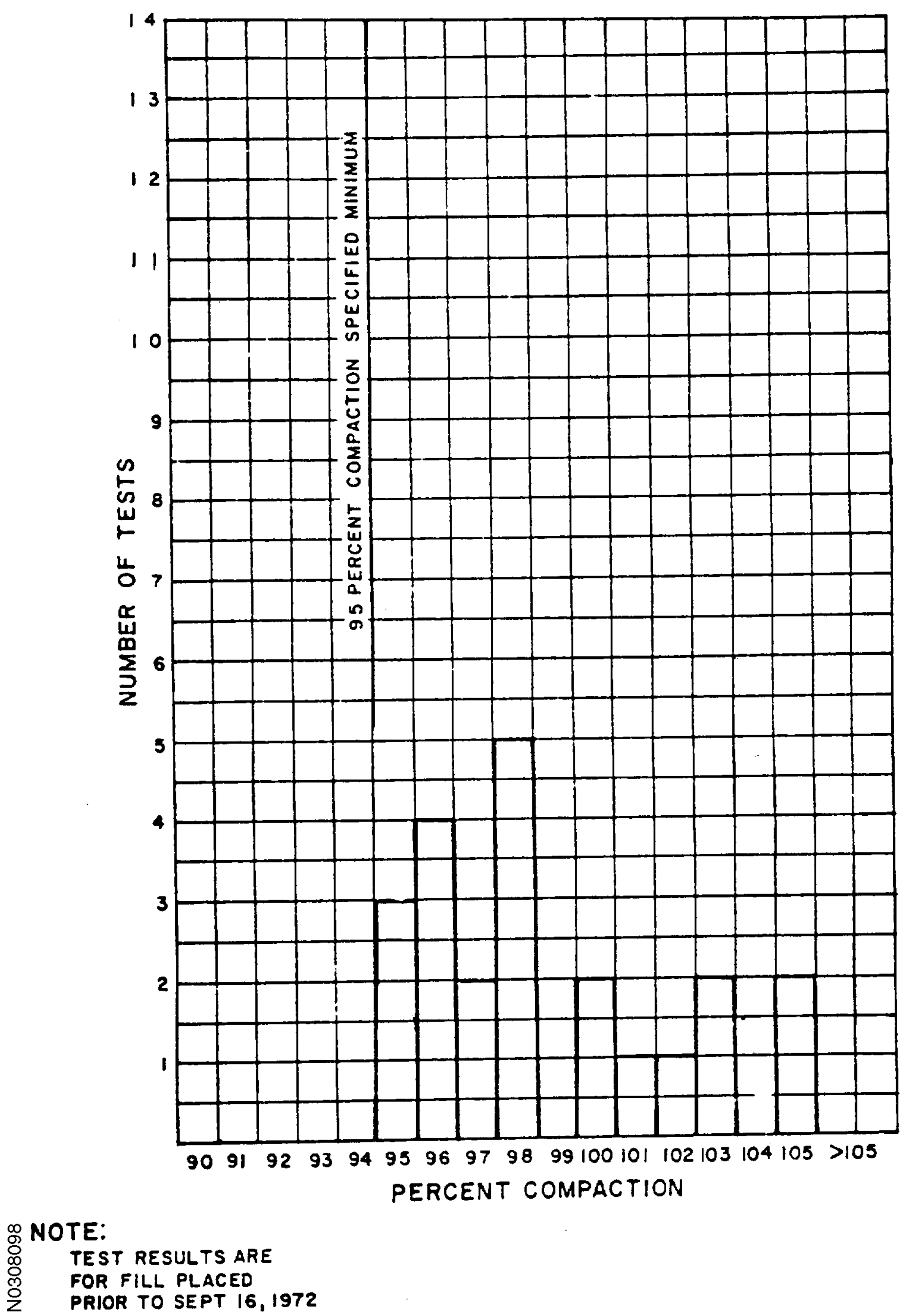
(1) TEST RESULTS ARE FOR FILL PLACED PRIOR TO SEPT. 16, 1972

(2) MATERIAL REPRESENTED BY TWO TESTS HAVING +3.2 % DEVIATION FROM OPTIMUM AND COMPACTED TO 95.0 AND 96.1% COMPACTION IS ACCEPTABLE

N0308097

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.8-57
HISTOGRAM OF RECORD TESTS FOR COMPACTION CONTROL
OF COMPACTED IMPERVIOUS FILL: SERVICE WATER RESERVOIR



The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.8-58
HISTOGRAM OF RECORD TESTS FOR MOISTURE CONTENT CONTROL OF COMPACTED IMPERVIOUS FILL: SERVICE WATER RESERVOIR

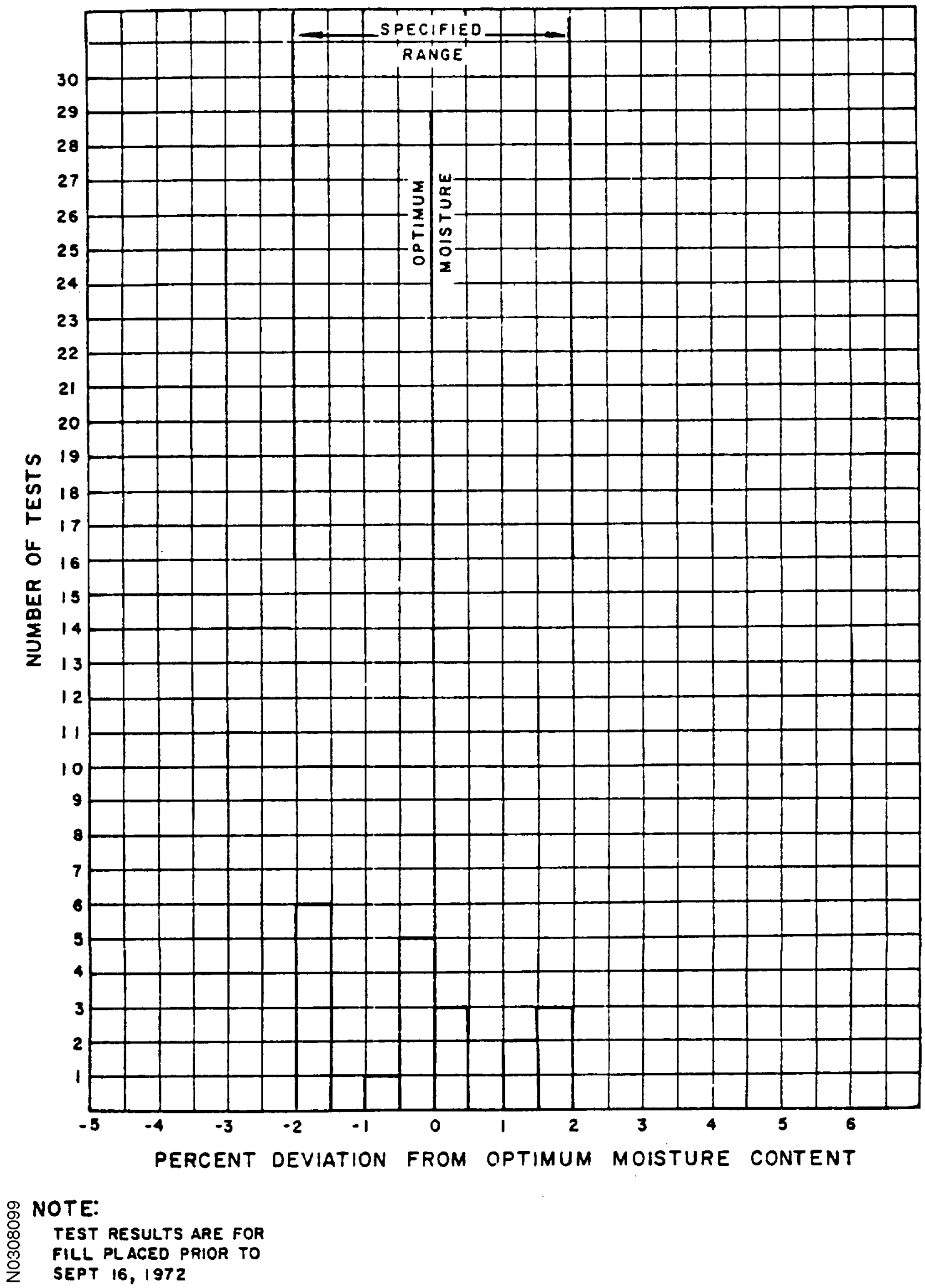


Figure 3.8-59
LOCATIONS OF SETTLEMENT MONITORING POINTS

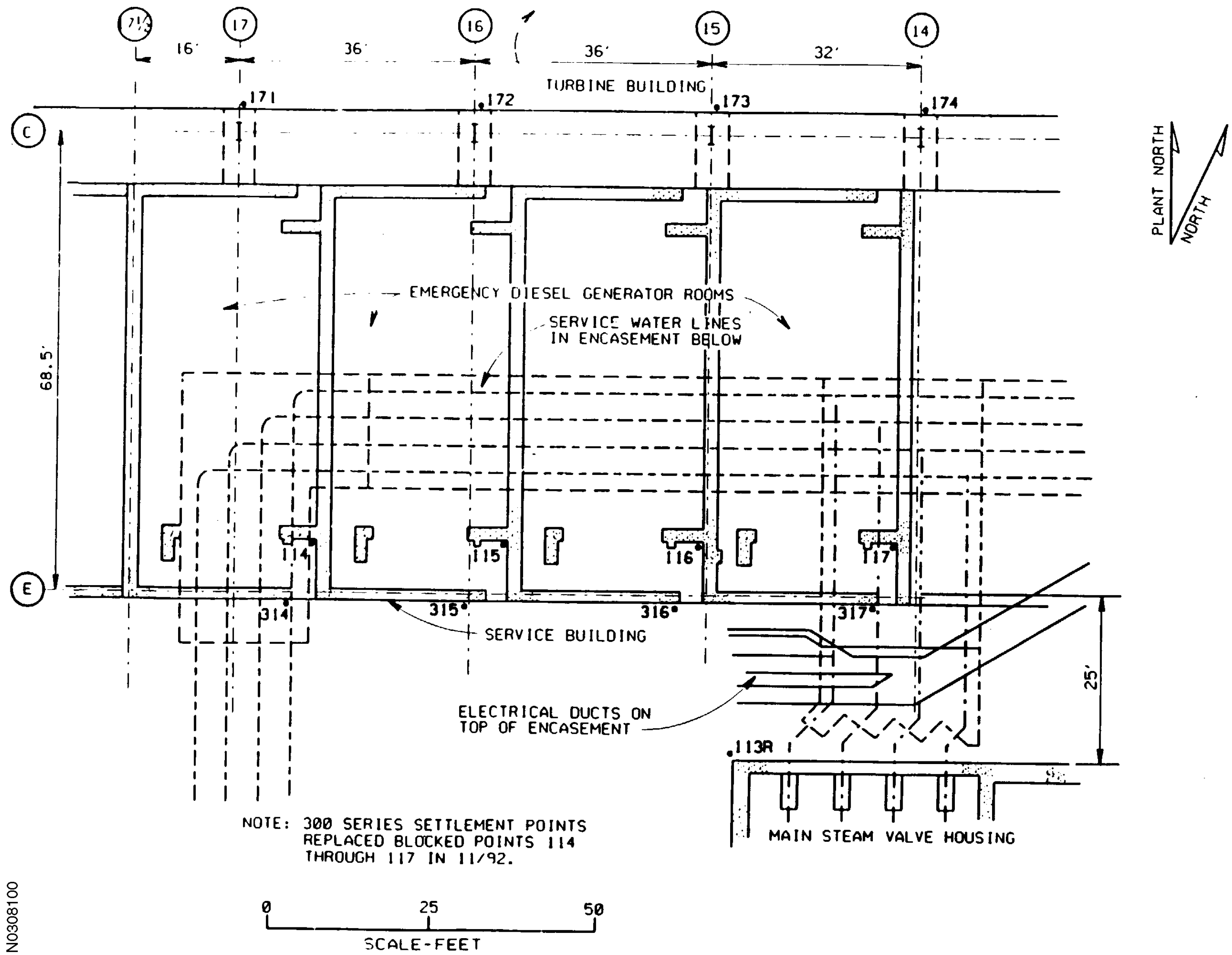
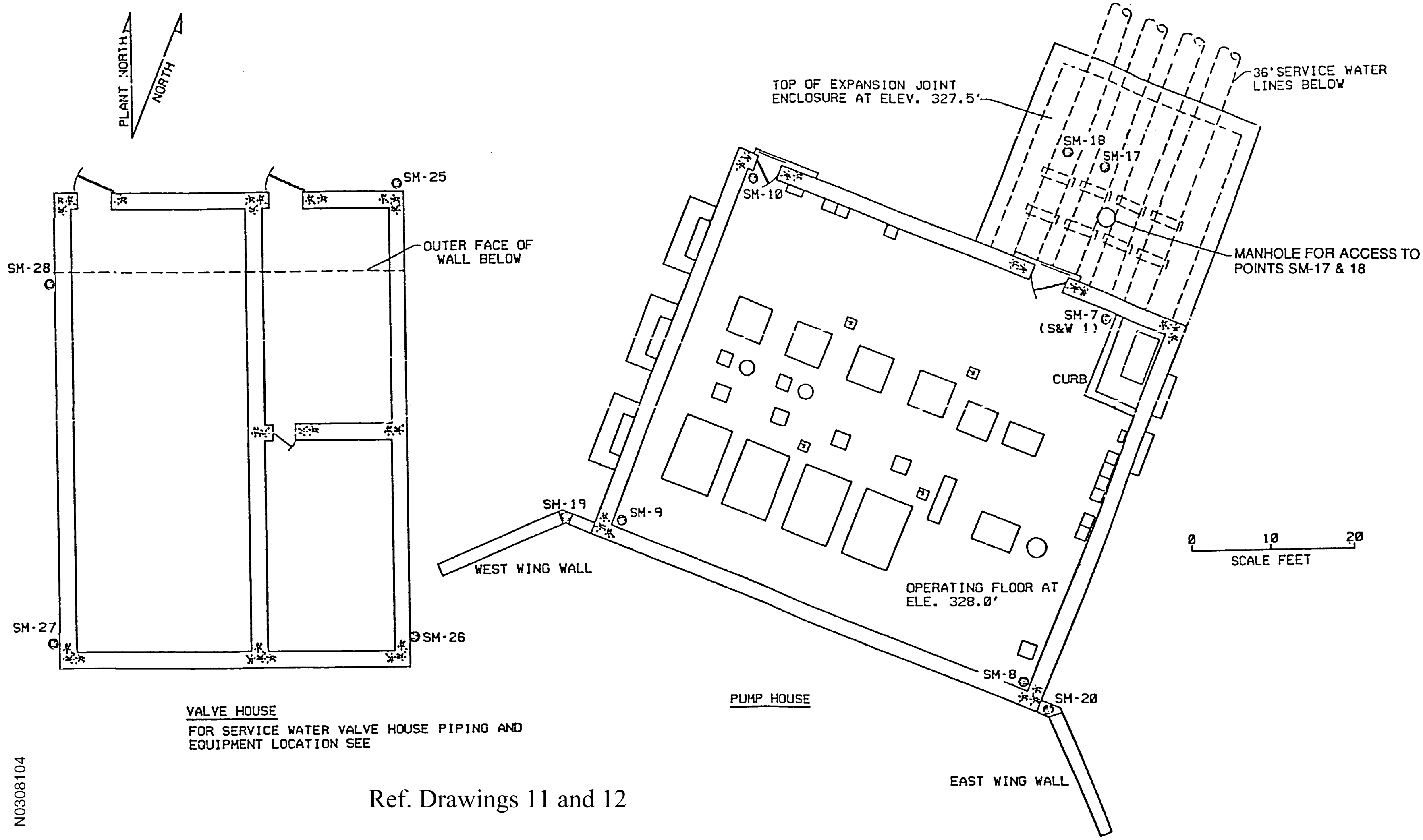
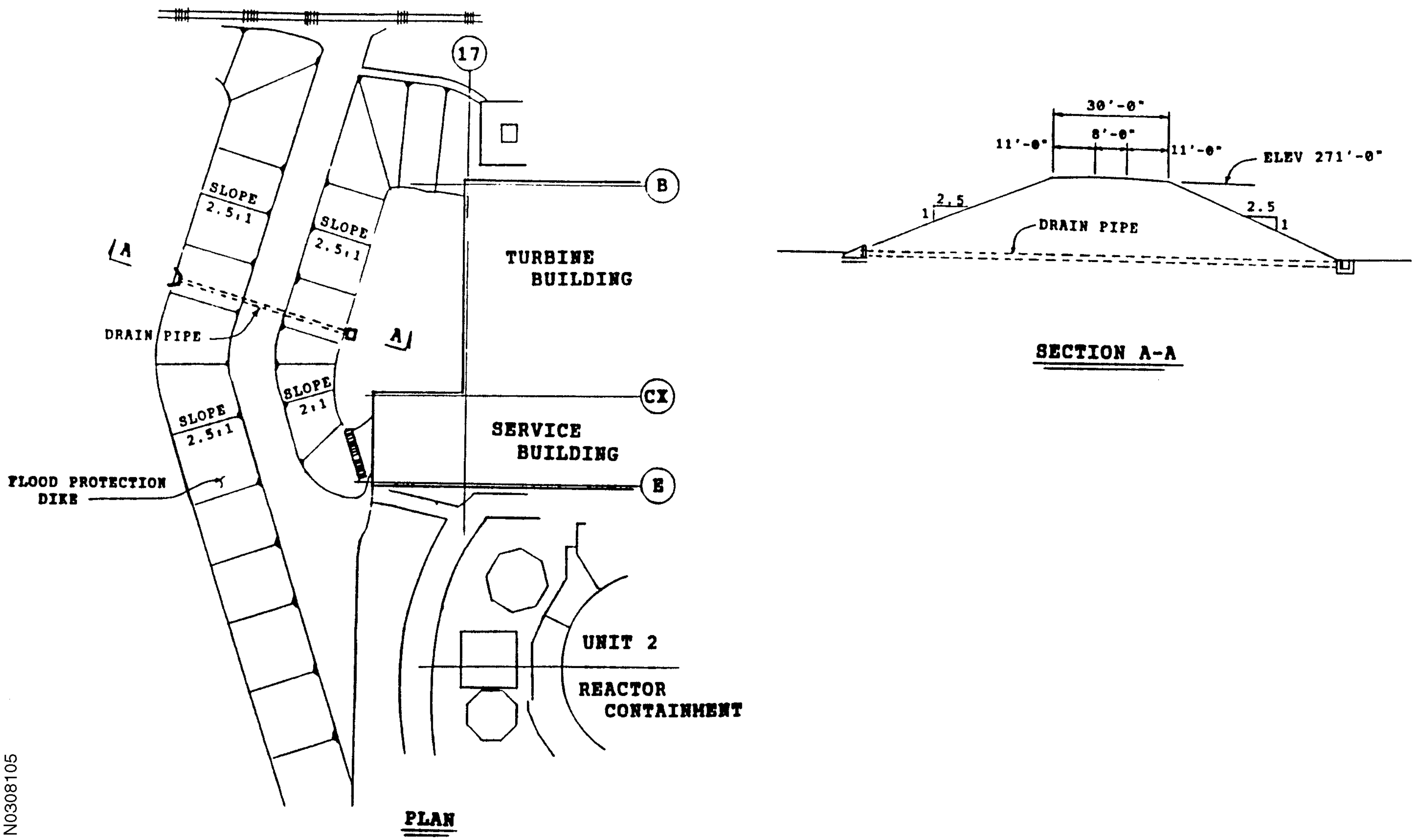


Figure 3.8-60
SETTLEMENT POINTS: SERVICE WATER PUMP HOUSE



Ref. Drawings 11 and 12

Figure 3.8-61
FLOOD PROTECTION DIKE



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3.9 MECHANICAL SYSTEMS AND COMPONENTS

3.9.1 Dynamic System Analysis and Testing

3.9.1.1 Summary of Stone & Webster Design Procedures

All Seismic Class I mechanical equipment such as fans, pumps, and heat exchangers are qualified as seismically adequate in accordance with the criteria and procedures outlined in Section 3.7.3.2. Generally, all equipment is specified for qualification in the operating mode unless it can be shown that an alternative condition is a more severe case. Compliance with these criteria is intended to ensure that the equipment will function when subjected to seismic loading.

Seismic Class I cranes have been dynamically analyzed to ensure structural adequacy. In addition, restraints have been designed and installed to prevent the crane from becoming dislodged during an earthquake.

Dynamic effects on piping systems under start-up or initial operating conditions due to turbine trips, valve closures, pump trips, etc., are minimized by optimally designed piping restraints. Dynamic analysis methods and criteria for piping systems are presented in Section 3.7.3.1. Transient conditions and the associated actions (pump trips, valve actuations, etc.) are listed in the preoperational and initial start-up testing programs in Section 14.1. Dynamic responses under the transient conditions during the preoperation and initial start-up conditions on piping systems are observed to ensure that the vibration is within acceptable limits.

A preoperational vibration test program on Q1 and Q2 piping systems was conducted under simulated transients that are credible within the normal and upset operating modes of the systems. Selected locations on the following piping systems were subjected to visual inspection and instrumented measurements (if needed) by the piping engineer during these tests:

1. Start and stop reactor coolant pumps.
2. Closure of main steam line trip valves during pre-core-loading testing.
3. Start and stop residual heat removal (RHR) pumps with normal operation of the valves used to control flow.
4. Start and stop high-pressure safety injection/charging pumps.
5. Operation of pressurizer relief valves and their associated discharge piping system.
6. Start and stop auxiliary feedwater pump with normal operation (closure/openings) of the associated motor-operated and hand-control discharge valves in the auxiliary feedwater piping system.

For instrumented testing, the measure of dynamic piping responses was converted to a dynamic stress intensity equivalence, to be combined with other primary stresses. The acceptable criteria for Q1 piping were based on the allowable combined stress limit of 1.5 Sm for ASME

Class 1 piping, as specified in paragraph NB-3642 of ASME Code Section III. The acceptable criteria for Q2 piping were based on the allowable combined stress limit of 1.2 Sh for ASME Class 2 piping, as specified in paragraph NC-3652.2 of ASME Code Section III (1972 Winter Addendum).

3.9.1.1.1 Pressure Relief Valves and Associated Piping Systems

The design criteria for piping systems associated with safety and relief valves are in accordance with the rules in Subarticles NB-3677 and NC-3677 of ASME Code Section III, 1971, applicable to the classification of the piping system involved. For open relief systems, the design criteria and analyses used to calculate maximum stresses and stress intensities are in accordance with Subarticles NB-3600 and NC-3600 of ASME Code Section III (1972 Winter Addendum). Maximum dynamic stresses on attached piping sections are calculated based on full discharge loads (thrust and bending) and internal design pressure. Maximum stress intensity in the run, pipe, or header, under full discharge loadings (thrust, bending, and torsion) and internal design pressure is also computed.

3.9.1.1.1.1 *Open Relief System.* The total steady-state discharge thrust load for an open system discharge is expressed as the sum of the pressure and momentum forces, as follows:

$$\frac{F}{A} = 144P + \frac{V^2 d}{g} \qquad (3.9\text{-}1)$$

where:

F = total reaction force (lb)

A = exit flow area (ft^2)

P = exit pressure (psig)

V = exit fluid velocity (ft/sec)

d = exit fluid density (lb/ft^3)

g = 32.3 ft/sec^2

To ensure consideration of the effects of the suddenly applied load, a dynamic load factor is computed by dynamic analysis. The calculation of the dynamic load factor is based on modeling the valve and nozzle as a single- degree-of-freedom dynamic system. The lumped mass of this system corresponds to the weight of the valve and nozzle, and is assumed to be at the valve center of gravity. The rotational degree of freedom of this system is considered to be in the direction that causes maximum bending stress in the nozzle at the junction of the nozzle and run-pipe. Rotational flexibility of the system is computed by a series combination of nozzle flexibility and local run-pipe flexibility (at the junction of the nozzle and run-pipe).

The rise time of the discharge force at the outlet of the safety valve is assumed to be the minimum valve opening time, and the discharge force is assumed to rise linearly with time. The ratio of maximum dynamic rotations predicted by this single-degree-of-freedom system to the static rotation caused by the steady-state discharge force represents the dynamic load factor.

When more than one valve is mounted on the same common header, full discharge is assumed to occur concurrently. The additional stresses induced in the header are combined with the previously computed local and primary membrane stresses to obtain the maximum stress intensity.

3.9.1.1.1.2 *Closed Relief System.* For relief valves discharging into a closed system, an analytical model of one-dimensional transient flow characteristics following the blow-off of the upstream safety/relief valve into the discharging piping is established. The time-dependent pressure, temperature, density, and velocity, and hence the momentum of the downstream pipe flow, is computed from this conservative hydrodynamic/thermodynamic flow model. The phenomena of flow restrictions, frictional resistance, and flow discontinuities (shock waves) are considered. This model also considers the influence of valve opening time and the effect of loop seal-water, if any is contained upstream of the valve seat.

The unbalanced transient hydraulic forcing function acting on the piping system computed from the flow model is used to determine the transient dynamic responses of the piping structural model. Adapting the lumped-parameter method incorporated with the modal analysis of piping system, the time-history modal response is computed. Computations of maximum stress intensities for ASME Code Class 1 piping or maximum stress levels for ASME Code Class 2 and 3 piping are based on the dynamic analysis of the system. Dynamic load factors are determined as described in Section 3.9.1.1.1.1.

3.9.1.1.2 Code Class 1 Analysis

ASME Code Class 1 components within the Stone & Webster scope of supply have been analyzed on an elastic system and elastic component basis. Inelastic component stress analyses have not been used. Analytical methods are compatible with the system used.

3.9.1.2 **Summary of Westinghouse Design Procedures**

3.9.1.2.1 Dynamic System Analysis and Testing

The scope of the different dynamic analysis techniques and methods used to evaluate mechanical systems and components of the Westinghouse pressurized water reactor is very extensive. However, the more important, pertinent methods are presented as an overview of the type of methods used.

3.9.1.2.2 Main Piping System, Flow-Induced Vibrations

Flow-induced vibrations in the main piping systems of the reactor coolant loop may be caused by pressure pulses from the reactor coolant pump impeller.

The perturbating frequency of the reactor coolant pump is quite high when compared to the piping natural frequency. Frequency separation, therefore, ensures a very small probability of self-excited or sympathetic vibration. This is borne out by satisfactory operation of several similar coolant loops.

The piping natural frequencies are calculated using a finite element computer model of a reactor coolant loop. This loop, for North Anna Unit 1, has 78 dynamic degrees of freedom (DOF). A unique frequency is associated with each degree of freedom. Since the loop model consists of both piping and components, and the components are large equipment (e.g., steam generator, RCL pump, and stop valves), the lower modes reflect the bending modes of these components, with the piping acting as elastic coupling between components.

The frequencies associated with the piping modes are higher than the component modes (e.g., 36 Hz and higher). However, the effect of flow-induced vibrations from the RCL pump impeller on the piping has been studied empirically on installed RCL piping during plant start-up, cold hydro, and hot-functional testing.

The experimental studies indicate that pipe vibration results from the excitation produced by the pump and the fluid flowing in the system. Measurements indicate that the pipe vibration has narrow band response at certain system natural frequencies superimposed on a broad band response. In addition, certain deterministic responses have been measured on the system and have been identified as frequencies associated with RCL pump shaft rotation (19.8 Hz) and multiples of this frequency up to 544 Hz, the fourth blade-passing frequency. Additional measurements have been taken on European plants where the pump shaft rotation frequency is 24 Hz and the responses of the blade-passing frequency appear as high as 336 Hz. During all of the Westinghouse test experience, no abnormal vibration has been observed related to any of the frequencies generated from the pump operation. The response of the reactor coolant loop has been reported in WCAP 7920 (Reference 1).

The tubes in the steam generator may be subjected to flow-induced vibration that does not exist in the primary coolant loop. This excitation might result from vortex shedding due to flow across the tubes. To ensure that no sympathetic vibration is generated by the vortex shedding, there is a wide frequency separation between the vortex frequency of the fluid and the beam frequency of the tube. Parallel flow vibration is analyzed using the correlations of Burgreen, and the amplitude of vibration is shown to be low enough that neither stress, banging, nor fatigue is a problem. Flow-induced vibration of the reactor internals is discussed in Section 3.9.1.2.5.

3.9.1.2.3 Dynamic Analysis of Reactor Internals

The reactor internals are modeled to determine dynamic loads produced by a reactor coolant loop (RCL) branch line pipe rupture (for both cold-leg and hot-leg breaks), and for the response due to a design-basis earthquake.

The structural analysis considers simultaneous application of the time-history loads on the reactor vessel resulting from the RCL mechanical loads and internal hydraulic pressure transients. The vessel is restrained by reactor vessel support pads and shoes beneath the reactor vessel nozzles and the RCL piping with the primary supports of the steam generators and the RCPs.

Following a postulated pipe rupture, the reactor vessel is excited by time-history forces. As previously mentioned, these forces are the combined effect of reactor coolant loop mechanical loads and reactor internal hydraulic forces.

The RCL mechanical forces are derived from the elastic analysis of the loop piping for the postulated break. The reactions on the nozzles of the RCL piping are applied to the vessel in the RPV blowdown analysis.

The reactor internals hydraulic pressure transients were calculated including the assumption that the structural motion is coupled with the pressure transients. This phenomena has been referred to as hydroelastic coupling or fluid-structure interaction. The hydraulic analysis considers the fluid-structure interaction of the core barrel by accounting for the deflections of constraining boundaries which are represented by masses and springs. The analytical methods used to develop the reactor internals hydraulic forces are described in References 8 and 10.

3.9.1.2.3.1 *Reactor Vessel and Internals Modeling.* The reactor vessel is restrained by two mechanisms: (1) the attached reactor coolant loops with the SG and RCP primary supports; and (2) reactor vessel supports, beneath each reactor vessel inlet nozzle and outlet nozzle. The support shoe provides restraint in the horizontal directions for reactor vessel motion.

The mathematical model of the RPV is a three-dimensional nonlinear finite element model which represents the dynamic characteristics of the reactor vessel and its internals in the six geometric degrees of freedom. The model was developed using the ANSYS computer code. The model consists of three concentric structural submodels connected by nonlinear impact elements and stiffness matrices. The first submodel, Figure 3.9-4, represents the reactor vessel shell and associated components. The reactor vessel is retrained by the reactor vessel supports and by the attached primary coolant piping. Each reactor vessel support is modeled by a linear horizontal stiffness and a vertical nonlinear element with lift-off capability. The attached piping is represented by a stiffness matrix.

The second submodel, Figure 3.9-5, represents the reactor core barrel, thermal shield, lower support plate, and secondary core support components. This submodel is physically located inside the first and is connected to it by a stiffness matrix at the internals support ledge. Core-barrel-to-vessel impact is represented by nonlinear elements at the core barrel flange, core barrel nozzle, and lower radial support locations.

The third and innermost submodel, Figure 3.9-6, represents the lower core support plate, guide tubes, support columns, upper core plate, and fuel. The third submodel is connected to the first and second by stiffness matrices and nonlinear elements.

3.9.1.2.3.2 *Analytical Methods.* The time-history effects of internals loads and loop mechanical loads are combined and applied simultaneously to the appropriate nodes of the mathematical model of the reactor vessel and internals. The analysis is performed by direct time integration with the ANSYS computer code. The output of the analysis includes the displacements of the reactor vessel and the loads in the reactor vessel supports which are combined with other applicable faulted condition loads and subsequently used to calculate the stresses in the supports. Also, the reactor vessel displacements are applied as a time-history input to the dynamic reactor coolant loop analysis. The resulting loads and stresses in the piping components and supports include both RCL branch pipe loop blowdown loads and reactor vessel displacements. Thus, the effect of vessel displacements upon loop response and the effect of RCL branch pipe blowdown upon vessel displacement are both evaluated.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

3.9.1.2.4 Preoperational Tests

The program to establish internals integrity used extensive design analysis, model testing, and post-hot-functional inspection. Additionally, Westinghouse instrumented (Reference 1) full-size reactors to measure the dynamic behavior of the first of a kind of each plant size, and compared measurements with predicted values.

This program was instituted as part of a basic Westinghouse philosophy to instrument the internals of the first of a kind of the current nuclear steam supply system designs for power plants. The previous first-of-a-kind plants that were instrumented were: Jose Cabrera Station, one-loop; Robert Ginna Station, two-loop; H. B. Robinson Unit No. 2, three-loop; and Indian Point Unit No. 2, four-loop. The Indian Point II (IPP) plant was the most thoroughly instrumented plant to date. The magnitude of that test program was much greater than the intent of the philosophy, and was established as part of an extensive plan to develop theories and basic concepts related to internals vibration under various operating conditions. Thus, not only was added assurance obtained that all of the hardware would operate in the manner for which it was designed, but these data also assisted in the development of increased capability for the prediction of the dynamic behavior of PWR internals.

The H. B. Robinson (CPL) reactor was established as the prototype for the Westinghouse three-loop plant internals verification program.

Subsequent three-loop plants were similar in design. Past experience with other reactors indicated that plants of similar designs behave in a similar manner. For this reason, an instrumentation program was conducted on the H. B. Robinson plant to confirm the behavior of the reactor components. The main objective of this test was to increase confidence in the adequacy of the internals by determining stress or deflection levels at key locations.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

The only significant difference between the North Anna units' internals and the H. B. Robinson prototype internals was that 17 x 17 fuel assemblies were in North Anna, while the Robinson plant used 15 x 15 fuel assemblies. This internals change was manifested only in the design of guide tubes located in the upper core support structure. The new 17 x 17 guide tubes were stronger and more rigid, and therefore less susceptible to flow-induced vibration. The Trojan Nuclear Plant of the Portland General Electric Company was the first operational Westinghouse pressurized water reactor to use 17 x 17 fuel assemblies. Operation of this plant preceded the North Anna units. The 17 x 17 guide tube in the Trojan plant was instrumented and the vibration behavior confirmed in accordance with Regulatory Guide 1.20. The instrumentation of the Trojan plant also confirmed guide tube vibration behavior on the North Anna plants in accordance with Regulatory Guide 1.20.

In the final analysis, the proof that the internals are adequate, free from harmful vibrations, and have performed as intended, is obtained through component observations and examinations during service. Thus, CPL, the three-loop prototype, was subjected to a thorough visual and dye-penetrant examination by a qualified Westinghouse quality assurance engineer before and after the hot-functional test. This inspection was in addition to the normal inspection of the internals in the shop, and before and after shipment.

For the particular case of the three-loop plants, the following operating experiences, gained up to the time of North Anna licensing, offered additional assurance of the adequacy of this design:

1. Southern California Edison, San Onofre plant was a three-loop plant with a slightly different design. This plant had been in operation since 1967 with no internals vibration problems. The internals had been inspected on various occasions.
2. H. B. Robinson (CPL), after completion of the hot-functional inspection, had been at power operation since 1970 with no internals vibration problems.
3. Florida Power and Light (FPL) had successfully completed the post-hot-functional inspection, with results indicating no internals vibration problems.
4. Virginia Electric and Power Company, Surry Power Station (VPA), had also successfully completed the post-hot-functional inspection, with similar results.

The CPL, FPL, and VPA internals had the same configuration as the other Westinghouse three-loop plants, thus providing important evidence of the reliability of the internals.

Regulatory Guide 1.20, Paragraph D, "Regulations for Reactor Internals Similar to the Prototype Design," was satisfied for these three-loop plants in the following manner.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

The internals were subjected to a thorough examination before and after preoperational flow tests. This examination included the 35 points shown on Figure 3.9-1. These 35 points included the following:

1. All major load-bearing elements of the reactor internals relied on to retain the core structure in place.
2. The lateral, vertical, and torsional restraints provided within the vessel.
3. Locking and bolting devices whose failure could adversely affect the structural integrity of the internals.
4. Other locations on the reactor internal components that were examined on the prototype design.

The interior of the reactor vessel was also examined for evidence of loose parts or foreign material.

Specifically, the inside of the vessel was inspected before and after the hot-functional test, with all the internals removed, to verify that no loose parts or foreign material were in evidence.

3.9.1.2.4.1 *Lower Internals.* A particularly close inspection was made on the following items or areas, using a 5X or 10X magnifying glass or a particle test where applicable. The locations of these areas are shown in Figure 3.9-1.

1. Upper barrel flange and girth weld.
2. Upper barrel to lower barrel girth weld.
3. Upper core plate aligning pin. Examined for any shadow marks, burnishing, buffing, or scoring. Checked for the soundness of lockwelds.
4. Irradiation specimen basket welds.
5. Baffle assembly locking devices. Checked for lockweld integrity.
6. Lower barrel to core support girth weld.
7. The flexible tie connections (flexures) at the lower end of the thermal shield.
8. Radial support key welds to barrel.
9. Insert locking devices. Examined for soundness of lockwelds.
10. Core support columns and instrumentation guide tubes. All the joints checked for tightness and soundness of the locking devices.
11. Secondary support assembly welds.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

12. Lower radial support lugs and inserts. Examined for any shadow marks, burnishing, buffing, or scoring. Checked for the integrity of the lockwelds. These members supplied the radial and torsion constraint of the internals at the bottom relative to the reactor vessel while permitting axial growth between the two. One would have expected to see, on the bearing surfaces of the key and keyway, burnishing, buffing, or shadowing marks that would have indicated pressure loading and relative motion between the two parts. Some scoring of engaging surfaces was also possible and acceptable.
13. Bearing surfaces of upper core plate radial support key.
14. Mounting blocks thermal shield to core barrel. Connections examined for evidence of change in tightness or lockweld integrity.
15. Gaps at baffle joints. Checked for gaps between baffle and top former and at baffle-to-baffle joints.

3.9.1.2.4.2 *Upper Internals.* A particularly close inspection was made on the following items or areas, using a 5X or 10X magnifying glass where necessary. The locations of these areas are shown in Figure 3.9-1.

1. Thermocouple conduits, clamps, and couplings.
2. Guide tube, support column, and thermocouple column assembly locking devices.
3. Support column and conduit assembly clamp welds.
4. Radial support keys and inserts between the upper core plant and upper core barrel. Examined for any shadow marks, burnishing, buffing, or scoring. Checked for the integrity of lockwelds.
5. Connections of the support columns and guide tubes to the upper core plate. Checked for tightness.
6. Thermocouple conduit gusset and clamp welds.
7. Thermocouple end-plugs. Checked for tightness.
8. Guide tube closure welds, tube-transition plate welds, and card welds.

Acceptance standards were the same as required in the shop by the original design drawings and specification.

During the hot-functional test, the internals were subjected to a total operating time at greater than normal full-flow conditions (all pumps operating) of at least 10 days, or 240 hour. This provided a cyclic loading of approximately 1×10^7 cycles on the main structural elements of the internals. In addition, there was some operating time with only one and two pumps operating.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Therefore, when no signs of abnormal wear were found, no signs of harmful vibration present in the core support structures, and with no apparent structural changes taking place, the three-loop core support structures were considered adequate. They performed their function as intended, free from harmful vibrations.

3.9.1.2.5 Flow-Induced Vibration

The dynamic behavior of reactor components has been studied using experimental data obtained from operating reactors, along with results of model tests and static and dynamic tests in the fabricator's shops and at plant site. Extensive instrumentation programs to measure vibration of reactor internals (including prototype units of various reactors) have been carried out during preoperational flow tests and reactor operation.

From scale model tests, information on stresses, displacements, flow distribution, and fluctuating differential pressures is obtained. Studies have been performed (Reference 1) to verify the validity and determine the prediction accuracy of models for determining reactor internals vibration due to flow excitation. Similarity laws were satisfied to ensure that the model response can be correlated to the real prototype behavior.

Vibration of structural parts during preoperational tests is measured using displacement gauges, accelerometers, and strain transducers. The signals are recorded with F.M. magnetic tape records. Onsite and offsite signal analysis is done using both hybrid real-time and digital techniques to determine the (approximate) frequency and phase content. In some structural components, the spectral content includes nearly discrete-frequency or very narrow-band signals, usually due to excitation by the main coolant pumps and other components that reflect the response of the structure at a natural frequency to broad bands and mechanically induced and/or flow-induced excitation. Damping factors are also obtained from wave analyses.

It is known from the theory of shells that the normal modes of a cylindrical shell can be expressed as sine and cosine combinations, with indices m and n indicating the number of axial half-waves and circumferential waves, respectively. The shape of each mode and the corresponding natural frequencies are functions of the numbers m and n. The general expression for the radial displacement of a simply supported shell is:

$$w(x, \psi, t) = \sum_{n=0}^{''} \sum_{m=1}^{''} [A_{nm}(t)\cos n\psi + B_{nm}(t)\sin n\psi] \quad \sin\frac{m\pi x}{L} \qquad (3.9\text{-}2)$$

The shell vibration at a natural frequency depends on the boundary conditions at the ends. The effect of the ends is negligible for long shells or for higher-order m modes, and long shells will have the lowest frequency for n = 2 (elliptical mode). For short shells, the effects of the ends are more important, and the shell will tend to vibrate in modes corresponding to values of n greater than 2.

With these previous considerations as a basis, the following procedures have been performed in the study of thermal shield vibration:

1. During a test program performed with a one-seventh-scale model, the natural frequencies of the thermal shield in water and the maximum vibration amplitude were measured.
2. Shaker test programs performed on a prototype thermal shield with the actual boundary conditions provided full-scale natural frequencies and mode shapes in air. These modes were established by measuring accelerations at the center, top (support elevation), and bottom of the shield. In Figure 3.9-2, the results obtained are plotted for $n = 4$, and correspond to a thermal shield with eight supports, which are indicated in the same figure. The amplitudes of vibration are fitted with a curve $y = A \sin 4\theta$.
3. Maximum displacements were measured during the preoperational reactor test and were correlated with the information obtained in the one-seventh-scale model and shaker test.
4. In Figure 3.9-3, the maximum amplitudes of vibration are plotted as measured on a thermal shield with six supports. The experimental points have been least squares fitted with a curve $y = A \sin 3\theta$.

In general, the study follows two parallel procedures: obtain frequencies and spring constants analytically, and confirm these values from the results of the tests. Damping coefficients are established experimentally, and forcing functions are estimated from pressure fluctuations measured during operation and in models. Once these factors are established, the response can be computed analytically. In parallel, the responses of important reactor structures are measured during preoperational reactor tests, and the frequencies and mode shapes of the structures are obtained. Once all the dynamic parameters are obtained, as explained above, the forcing functions can be estimated. These two procedures are not independent; both are performed simultaneously, and when combined they provide indications of the internals behavior during reactor operation. Finally, it should be mentioned that internals behavior during reactor operation has been measured using mechanical devices and nuclear noise methods. The last method involves the frequency spectral analysis of signals from ex-core ion chambers. Information is obtained on the frequency, amplitude, and damping of the vertical and lateral vibrations of the core because relative motions of the core cause reactivity perturbations and fluctuations in the neutron flux signal level.

Some components, such as control rod guide tubes, fuel rods, and incore instrumentation tubes, are subjected to cross flow and parallel flow with respect to the axis of the structure. In these cases there are numerous theoretical and experimental studies directed toward establishing the response of the structure (Reference 1). These studies also provide information on the added apparent mass of the water, which decreases the natural frequency of the component. For both cases, cross and parallel, the response is obtained after the forcing function and the damping of the system is determined.

Cross flow may excite the structure with periodic vortex-shedding, which gives rise to a lateral oscillatory lift force perpendicular to the flow direction, and a drag force in the flow direction. The dimensionless vortex-shedding frequency, or Strouhal number S = fd/V, is a function of the Reynolds number and is known for different cross sections. The structure is usually designed so that its natural frequency in water is considerably higher than the vortex-shedding frequency, to avoid coincidence. The lateral force per unit length is given by:

$$F(x, t) = C_L\, [1/2\, d_f (V_x)^2] D \cos \omega t \qquad (3.9\text{-}3)$$

where C_L is the oscillatory lift coefficient, including correlation length effects (C_L depends on the Reynolds number), d_f is fluid density, V_x is cross-flow velocity, D is the characteristic diameter, and ω is the vortex- shedding circular frequency.

Data obtained from preoperational and shop tests are used to confirm the coefficients used.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

3.9.1.2.6 Vibration Monitoring

Since internals of a given type (i.e., two-, three-, or four-loop) are designed and manufactured to essentially the same procedures and processes, and to similar drawings, the response of these structures within a pressurized water reactor environment is similar.

Performance data from the instrumentation of actual reactors, as well as mechanical and flow scale models, are available (References 1, 2, 3 & 4).

For example, preoperational flow test on the Indian Point II Plant, the four-loop prototype plant, has been completed. The pre- and post- preoperational flow test examination of the internals has been completed, indicating that all the components performed as predicted. No evidence of damage or incipient failures has been found.

The testing programs consisted of measurements of the stresses, deflections, and responses of select key points in the internals structures during hot-functional and low-power physics tests. The main purpose of this testing program was to ensure that no unexpected large amplitudes of vibration existed in the internals structure during operation.

These tests, however, were by no means designed or intended to detect possible incipient failures of all the various components within the core support structures. They were designed with the purpose of giving data and results on what were assumed to be indicators of overall cores support structure performance, and to verify particular stress and deflection quantities.

3.9.1.2.7 Dynamic Analysis of Safety-Related Mechanical Equipment

A description of the analyses used in the design of safety-related mechanical equipment such as pumps and heat exchangers is given in Section 3.7.3.3.

3.9.1.2.8 Inelastic Stress Analysis

No plastic instability allowable limits given in ASME Section III are used when dynamic analysis is performed. The limit analysis methods have the limits established by ASME Section III for Normal, Upset, and Emergency Conditions. For these cases, the limits are sufficiently low to ensure that the elastic system analysis is not invalidated. For faulted conditions, the limits are specified in Section 5.2.1. These limits are established so that there is an equivalence with the adopted elastic limits, and consequently the elastic system analysis will not be invalidated. Particular cases of concern are checked by readjusting the elastic system analysis.

3.9.1.2.9 Core Components

Stainless steel clad silver-indium-cadmium alloy absorber rods are resistant to radiation and thermal damage, thereby ensuring their effectiveness under all operating conditions. Rods of similar design have been successfully used in the original and reload cores of San Onofre, Connecticut Yankee, and others.

Two burnable poison (Reference 5) rods of smaller length than, but similar in design to, the borosilicate glass design initially used in North Anna were exposed to inpile test conditions in the Saxton Test Reactor in October 1967. A visual examination of the rods was made in early June 1968, and a visual and profilometer examination was made on July 30, 1968, after an exposure of 1900 effective full-power hour (approximately 25% B^{10} depletion). The rods were found to be in excellent condition, and profilometry results showed no dimensional variation from the initial condition.

An experimental verification of the reactivity worth calculations for borosilicate glass tubing was completed prior to use of this material in the original North Anna burnable absorber rods. Similar rods were successfully operated in the Ginna (Reference 6) reactor prior to the startup of North Anna with no evidence of deficiency.

Testing was performed during fabrication and assembly of these components to ensure that manufacturing defects did not appear during the hot-functional tests. The basic program that was used to ensure adequacy of manufacturing practices for the initial core components consisted of:

1. Extremely thorough nil-ductility temperature and quality assurance program at the internals vendors.
2. Extensive visual examination at the plant site prior to hot-functional testing of the primary system.
3. Running the hot-functional test with full flow for 240 hours, which accumulates approximately 10^7 cycles on the majority of the core structure components.
4. Reexamining all areas of the internals after the 240-hour hot-functional test.

3.9.1.3 Earthquake Experience-based Method Developed for Unresolved Safety Issue (USI) A-46

The USI A-46 methodology can be used to verify the seismic adequacy of Seismic Class I mechanical equipment in accordance with Section 3.7.3.2.2.4.

3.9.2 ASME Code Class 2 and Class 3 Components

Active components are those whose operability is relied upon to perform a safety function, such as a safe shutdown of the reactor or mitigation of the consequences of an accident.

The code applicability dates for North Anna Units 1 and 2 are such that Section III, Nuclear Power Plant Components, of the ASME-1971 Code, does not apply. Nor do the proposed ANS criteria for the design of stationary pressurized water reactor power plants apply to the design and classification of the North Anna Units 1 and 2 systems and components. However, to assist in the safety evaluation of Units 1 and 2, the information below is provided.

3.9.2.1 Stone & Webster Scope

Table 3.9-1 lists pumps and valves required to operate as stated above that are not part of the reactor coolant pressure boundary, are supplied by Stone & Webster, and which, if ASME III-1971 were applicable, would be classified as ASME Class 2 or 3 in accordance with the guidelines of Regulatory Guide 1.26.

All motor-operated valves (MOV), manual valves, and check valves listed are built to ANSI B16.5-1968 or later edition. All motor-operated, manual, check, and control valves are built with the following quality control requirements, with acceptable limits as specified in individual valve specifications:

1. Hydrostatic and seat leakage test.
2. Performance test (motor-operated valves and control valves only).
3. Radiography required for cast valves designed for greater than 300-psi service.
4. Material certification.
5. Magnetic particle inspection required for carbon and low-alloy steel valves rated at 600 psi and greater, which are not radiographed.
6. Liquid penetrant inspection required for stainless steel valves rated at 600 psi and greater, which are not radiographed.

   In addition to the above, the following valves require 100% liquid penetrant testing:

   MOV-RS-155A, B

   and 100% radiography and 100% liquid penetrant testing for these valves:

   MOV-RS-156A, B

MOV-QS-101A, B

Valve motors conform to the standards of USAS for intermittent duty, and are totally enclosed. Motors to be used in the containment have Class H insulation.

Main steam safety valves are designed in accordance with the functional requirements of ASME III-1968 Edition with Addenda through Winter 1970 in addition to the above requirements.

All valves and all pumps listed are designed to Seismic Class I requirements.

3.9.2.2 **Westinghouse Scope**

Table 3.9-2 lists components required to operate as stated above, which, if the aforementioned design codes and criteria were applicable, would be classified as ASME Code Section III, Class 2 or 3, under the criteria contained therein or in the proposed ANS criteria (for Safety Class 2 or 3 systems or components) and the associated Westinghouse criteria.

The listed valves were designed in accordance with MSS-SP-66 and ANSI B16.5, and tested in accordance with MSS-SP-61.

3.9.2.3 **Nuclear Steam Supply System**

3.9.2.3.1 Design Bases

Design pressure, temperature, and other loading conditions that provide the bases for design of fluid systems other than ASME Class A components are presented in the corresponding sections that describe the system in which the component is installed.

3.9.2.3.2 Design Loading Combinations and Stress Limits

The design criteria for ASME Class 2 and 3 components are given in Table 3.9-3.

Stress limits, selected following the code intent, are sufficiently low to ensure that no gross deformation will occur in active components, and that the active components will operate as required following the event. The limits established for passive components ensure that violation of the pressure-retaining boundary will not occur.

3.9.2.4 **Stone & Webster Supplied Equipment**

ASME Code Class B and C (1968) components were specified in accordance with guidelines and stress criteria outlined in Section 3.7.3.2. ASME Code Class 2 and 3 piping systems and components were specified in accordance with guidelines and stress criteria outlined in Section 3.7.3.1.

The design approach and the criteria used to ensure the integrity of critical systems (and the containment structure) from the effects of pipe whip (for piping other than within the reactor coolant pressure boundary) are presented in Section 3.6.

All the applicable nonmandatory code case interpretations for ASME Section III (Nuclear Power Plant Components), Section VIII (Pressure Vessels, Division 1 and Division 2), ANSI-B31.7 (Nuclear Power Piping), ANSI-B31.1 (Power Piping), and ANSI-B16.5 (Valves) that are approved by the American Society of Mechanical Engineers are used as the criteria for design, analysis, fabrication, installation, and examination of components not within the reactor coolant pressure boundary. In addition, all mandatory addenda to ASME Section III and Section VIII codes, up to and including the 1971 Winter Addenda, are included in the design of ASME Class 2 and Class 3 piping components.

The design pressure, temperature, and other loading conditions that provide the bases for design of ASME Code Class 2 and 3 piping systems are defined in certified design specifications as identified in NA-3250 of the ASME Code, Section III. The design and installation criteria for the mounting of pressure-relieving devices on the main steam lines outside the containment are presented in Section 3.7.3.1.

3.9.3 Components Not Covered By ASME Code

3.9.3.1 **Nuclear Steam Supply System**

3.9.3.1.1 Core and Internals Integrity Analysis (Mechanical Analysis)

3.9.3.1.1.1 *Requirements.* The response of the reactor core and vessel internals under excitation produced by a RCL branch pipe rupture and seismic excitation for a typical Westinghouse pressurized water reactor plant internals has been determined. The following mechanical functional performance requirements apply:

1. Following the design basis accident, the basic operational or functional requirement to be met for the reactor internals is that the plant shall be shut down and cooled in an orderly fashion so that fuel cladding temperature is kept within specified limits. This implies that the deformation of certain critical reactor internals must be kept sufficiently small to allow core cooling.

2. For large breaks, the reduction in water density greatly reduces the reactivity of the core, thereby shutting down the core whether the rods are tripped or not. The subsequent refilling of the core by the emergency core cooling system uses borated water to maintain the core in a subcritical state. Therefore, the main requirement is to ensure effectiveness of the emergency core cooling system. Insertion of the control rods, although not needed, further ensures the ability to shut the plant down and keep it in a safe-shutdown condition.

3. The functional requirements for the core structures during the design basis accident are shown in Table 3.9-4. The inward upper barrel deflections are controlled to ensure no contact with the nearest rod cluster control guide tube. The outward upper barrel deflections are controlled to maintain an adequate annulus for the coolant between the vessel inner diameter and core barrel outer diameter.

4. The rod cluster control guide tube deflections are limited to ensure operability of the control rods.
5. To ensure no column loading of rod cluster control guide tubes, the upper core plate deflection is limited to the value shown in Table 3.9-4.
6. The reactor has mechanical provisions that are sufficient to maintain the core and internals design, and to ensure that the core is intact, with acceptable heat transfer geometry, following transients arising from the design basis accident operation conditions.
7. The core internals are designed to withstand mechanical loads arising from the operating-basis earthquake, design-basis earthquake, and pipe ruptures (References 1, 2, 3 & 7).

3.9.3.1.1.2 *Faulted Conditions.* The following events are considered in this category:

1. Loads produced by a RCL branch pipe rupture for both cases: cold-leg and hot-leg break.
2. Response due to a design-basis earthquake, as described previously in the seismic analysis.
3. Maximum stresses obtained in each case are added in the most conservative manner.

Maximum stress intensities are compared to allowables for each condition. When fatigue is of concern, the applicable stress concentration factors are determined and peak stresses are used to establish the usage factor. For faulted conditions, the Code permits the stresses to be above yield. For these cases only, when deformation requirements exist, a plastic analysis is independently performed to ensure that functional requirements are maintained (guide tubes deflections and core barrel expansion).

These analyses show that the stresses and deflections that would result following a faulted condition are less than those that would adversely affect the integrity of the structures. Also, the natural and applied frequencies are such that resonance problems do not occur.

3.9.3.1.1.3 *Reactor Internals Response Under Blowdown and Seismic Excitation.* A LOCA would result from a rupture of reactor coolant piping. During the blowdown, reactor internal components are subjected to vertical and horizontal excitation as rarefaction waves propagate inside the reactor vessel.

For large breaks, the reduction in water density greatly reduces the reactivity of the core, thereby shutting down the core whether the rods are tripped or not. The subsequent refilling of the core by the emergency core cooling system uses borated water to maintain the core in a subcritical state. Therefore, the main requirement is to ensure effectiveness of the emergency core cooling system.

The pressure waves generated within the reactor are highly dependent on the location and nature of the postulated pipe failure. In general, the more rapid the severance of the pipe, the more severe the imposed loadings on the components. A 1-millisecond severance time is taken as the limiting case.

In the case of the hot-leg break, a rarefaction wave propagates through the reactor hot-leg nozzle into the interior of the upper core barrel. Since the wave has not reached the flow annulus on the outside of the barrel, the upper barrel is subjected to an impulsive compressive wave. Thus, dynamic instability (buckling) or large deflections of the upper core barrel, or both, are possible responses of the barrel during hot-leg blowdown. In addition to the above effects, the hot-leg break results in transverse loading on the upper core components as the fluid exits the hot-leg nozzle.

In the case of the cold-leg break, a rarefaction wave propagates along a reactor inlet pipe arriving first at the core barrel at the inlet nozzle of the broken loop. The upper barrel is then subjected to a non-axisymmetric expansion radial impulse that changes as the rarefaction wave propagates, both around the barrel and down the outer flow annulus between vessel and barrel. After the cold-leg break, the initial steady-state hydraulic lift forces (upward) decrease rapidly (within a few milliseconds) and then increase in the downward direction. These cause the reactor core and lower support structure to move initially downward.

If a simultaneous seismic event with the intensity of the design-basis earthquake is postulated with the LOCA, the imposed loading on the internals component may be additive in certain cases; therefore, the combined loading must be considered. In general, however, the loading imposed by the earthquake is small compared to the blowdown loading.

3.9.3.1.2 Acceptance Criteria

The criteria for acceptability in regard to mechanical integrity analyses are that adequate core cooling and core shutdown must be ensured. This implies that the deformation of the reactor internals must be sufficiently small so that the geometry remains substantially intact. Consequently, the limitations established on the internals are concerned principally with the maximum allowable deflections and/or stability of the parts, in addition to a stress criterion, to ensure integrity of the components.

3.9.3.1.2.1 *Allowable Deflection and Stability Criteria.* For the loss of coolant plus the maximum potential earthquake condition, deflections of critical internal structures are limited to the values given in Table 3.9-4.

In a hypothesized downward vertical displacement of the internals, energy-absorbing devices limit the vertical downward displacement of the internals.

Upper Barrel

The upper barrel deformation has the following limits:

1. To ensure a shutdown and cooldown of the core during blowdown, the basic requirement is a limitation on the outward deflection of the barrel at the locations of the inlet nozzles connected to the unbroken lines. A large outward deflection of the barrel in front of the inlet nozzles, accompanied by permanent strains, could close the inlet area and stop the cooling water coming from the accumulators. Consequently, a permanent barrel deflection in front of the unbroken inlet nozzles larger than a certain limit, called the "no loss of function" limit, could impair the efficiency of the emergency core cooling system.
2. To ensure rod insertion and to avoid disturbing the control rod cluster guide structure, the barrel should not interfere with the guide tubes. This condition also requires a stability check to ensure that the barrel will not buckle under the accident loads.

Control Rod Cluster Guide Tubes

The guide tubes in the upper core support package house the control rods. The deflection limits were established from tests.

Fuel Assembly

The limitations for this case are related to the stability of the thimbles in the upper end. The upper end of the thimbles must not experience stresses above the allowable dynamic compressive stresses. Any buckling of the upper end of the thimbles due to axial compression could distort the guide line and thereby affect the free fall of the control rod.

Upper Package

The local vertical deformation of the upper core plate, where a guide tube is located, shall be less than 0.100 in. This deformation will cause the plate to contact the guide tube, since the clearance between plate and guide tube is 0.100 inch. This limit prevents the guide tubes from undergoing compression. For a plate local deformation of 0.150 inch, the guide tube will be compressed and deformed transversely to the upper limit previously established; consequently, the value of 0.150 inch is adopted as the "no loss of function" local deformation, with an allowable limit of 0.100 inch. These limits are given in Table 3.9-4.

3.9.3.1.2.2 *Allowable Stress Criteria.* The allowable stress limits during the design basis accident used for the core support structures are based on the limits specified in Section 5.2.1. This section defines various criteria based on their corresponding method of analysis.

3.9.3.1.3 Methods of Analysis

The internal structures are analyzed for loads corresponding to normal, upset, emergency, and faulted conditions. The analysis performed depends on the mode of operation under consideration.

The scope of the stress analysis problem is very large, requiring many different techniques and methods, both static and dynamic. A comprehensive explanation of all the techniques and analytical methods used cannot be included in the scope of this document. The more important and relevant methods are presented as an overview in Section 3.9.1, and summarized in the following.

3.9.3.1.4 Blowdown Forces Due to Cold-Leg and Hot-Leg Break

Reactor Internals Analysis

The evaluation of the reactor internals is composed of two parts. The first part is the three-dimensional response of the reactor internals resulting from the RCL branch pipe break conditions. The reactor internals response is taken from the ANSYS RPV and internals system response. The second part of this evaluation is the core-barrel shell response which consists of the various n = 0, 2, 3, etc., ring mode response occurring in the horizontal plane. This second part, or ring mode evaluation, is independent of the loop forces.

Analysis of the reactor internals for blowdown loads resulting from an RCL branch pipe break is based on the time-history applied blowdown forcing functions. For the North Anna Units, the limiting auxiliary line breaks that were considered were the pressurizer surge line (98.35 in^2) and the accumulator line break (86.59 in^2). The forcing functions are defined at points in the system where differential loads are generated during the blowdown transient. The dynamic mechanical analysis can employ the displacement method, lumped parameters, and stiffness matrix formulations, and assumes that all components behave in a linearly elastic manner.

In addition, because of the complexity of the system and the components, it is necessary to use finite element stress analysis codes to provide more detailed information at various points.

MULTIFLEX 3.0 is a blowdown digital computer program (Reference 10), which was developed for the purpose of calculating local fluid pressure, flow, and density transients that occur in pressurized water reactor coolant systems during a LOCA, is applied to the subcooled, transition, and saturated two-phase blowdown regimes. Version 3.0 of the MULTIFLEX code shares a common hydraulic modeling scheme with the NRC approved MULTIFLEX (1.0) computer code (Reference 8), with the differences being confined to a more realistic downcomer hydraulic network and a more realistic core barrel structural model that accounts for nonlinear boundary conditions and vessel motion. Generally, this improved modeling results in more realistic, but still conservative, hydraulic forces on the core barrel. This in contrast to programs such as WHAM (Reference 9) which are applicable only to the subcooled region and which, due to their method of solution, could not be extended into the region in which larger changes in the sonic velocities and fluid densities take place. MULTIFLEX 3.0 is based on the method of characteristics wherein the resulting set of ordinary differential equations, obtained from the laws of conservation of mass, momentum, and energy, are solved numerically, using a fixed mesh in both space and time. The NRC staff has accepted the use of MULTIFLEX 3.0 for calculating the hydraulic forces on reactor vessel internals, including the reactor core, for the baffle barrel bolt program (Reference 11) and to demonstrate control rod insertability (Reference 12).

Although spatially one-dimensional, conservation laws are employed, the code can be applied to describe three-dimensional system geometries by use of the equivalent piping networks. Such piping networks may contain any number of pipes or channels of various diameters, dead ends, branches (with up to six pipes connected to each branch), contractions, expansions, orifices, pumps, and free surfaces (such as in the pressurizer). System losses such as friction, contraction, and expansion, as well as some effects of the water/solid interaction, are considered.

The MULTIFLEX 3.0 code evaluates the pressure and velocity transients for a maximum of 5000 locations throughout the system. Each reactor component for which calculations are required is designated as an element and assigned an element number. Forces acting upon each of the elements are calculated, summing the effects of:

1. The pressure differential across the element
2. Flow stagnation on, and unrecovered orifice losses across, the element
3. Friction losses along the element

Input to the calculation code, in addition to the blowdown pressure and velocity transients, includes the effective area of each element on which the force acts due to the pressure differential across the element, a coefficient to account for flow stagnation and unrecovered orifice losses, and the total area of the element along which the shear forces act.

The reactor internals analysis has been performed using the following assumptions:

- The analysis considers the effect of hydroelasticity.
- The reactor internals are represented by concentric pipes, beams, concentrated masses, linear and nonlinear springs, and dashpots simulating the nonlinear response of the components.
- The model described is considered to have a sufficient number of degrees of freedom to represent the most important modes of vibration in both the horizontal and vertical directions.

The pressure waves generated within the reactor are highly dependent on the location and nature of the postulated pipe failure. In general, the more rapid the severance of the pipe, the more severe the imposed loadings on the components. A 1-millisecond time is taken as the limiting case.

In the case of a hot leg branch pipe break, a rarefaction wave propagates through the reactor hot leg nozzle into the interior of the upper core barrel. Since the wave has not reached the flow annulus on the outside of the barrel, the upper barrel is subjected to an impulsive compressive wave. Thus, dynamic instability (buckling) or large deflections of the upper core barrel, or both, are possible responses of the barrel during hot leg blowdown. In addition to the above effects, the hot leg break results in transverse loading on the upper core components as the fluid exits the hot leg nozzle.

In the case of a cold-leg branch pipe break, a rarefaction wave propagates along a reactor inlet pipe, arriving first at the core barrel at the inlet nozzle of the affected loop. The upper barrel is then subjected to a non-axisymmetric expansion radial impulse which changes as the rarefaction wave propagates both around the barrel and down the outer flow annulus between vessel and barrel. After the cold leg branch pipe break, the initial steady-state hydraulic lift forces (upward) decrease rapidly (within a few milliseconds) and then increase in the downward direction.

If a simultaneous seismic event with the intensity of the SSE is postulated with the LOCA, the combined effect of the maximum stresses for each case is considered. In general, the loading imposed by the earthquake is small compared to the blowdown loading.

A summary of the analysis for major components is presented in the following paragraphs. References 8 and 10 provide the basis methodology used in the reactor internals blowdown analysis.

1. Core Barrel

   For the hydraulic analysis of the pressure transients during hot-leg branch pipe blowdown, the maximum pressure drop across the barrel is uniform radial compressive impulse.

   The barrel is then analyzed for dynamic buckling using the following conservative assumptions:

   a. The effect of the fluid environment is neglected.

   b. The shell is treated as simply supported.

During a cold-leg branch pipe blowdown, the upper barrel is subjected to a non-axisymmetric expansion radial impulse which changes as the rarefaction wave propagates both around the barrel and down the outer flow annulus between vessel and barrel.

   The analysis of transverse barrel response to a cold-leg branch pipe blowdown is performed as follows:

   a. The core barrel is analyzed as a shell with two variable sections to model the core barrel flange and core barrel.

   b. The core barrel is modeled as a beam elastically supported at the top and at the lower radial support. The thermal shield is modeled as a beam elastically supported at the top support blocks and at the flexures. The dynamic response is then obtained.

2. Guide Tubes

   The dynamic loads on Rod Cluster Control (RCC) guide tubes are more severe for a LOCA caused by hot-leg branch pipe rupture than for an accident caused by cold-leg branch pipe rupture, since the cold-leg break leads to much smaller changes in the transverse coolant flow over the Rod Cluster Control Assembly (RCCA) guides. The guide tubes in closest proximity to the outlet nozzle for a hot-leg branch pipe break are the most severely loaded. The transverse guide tube forces during a blowdown decrease with increasing distance from the ruptured nozzle location.

   A detailed structural analysis of the RCC guide tubes is performed to establish the equivalent cross section properties and elastic end support conditions. An analytical model is verified by subjecting the RCC guide tube to a concentrated force applied at the midpoint of the lower guide tube. In addition, the analytical model has been previously verified through numerous dynamic and static tests performed on the 17 x 17 guide tube design.

   The response of the guide tubes to the transient loading from blowdown resulting from hot-leg branch pipe breaks is found by representing the guide tube as an equivalent three-dimensional beam in which each node of the beam has six degrees of freedom.

3. Upper Support Columns

   Upper support columns located close to the nozzle of the affected hot-leg will be subjected to transverse loads due to cross flow. The loads applied to the columns are computed with a method similar to the one used for the guide tubes; i.e., by taking into consideration the increase in flow across the column during the accident. The columns are studies as beams with variable sections and the resulting stresses are obtained using the reduced section modulus and appropriate stress risers for the various sections.

4. Results of Reactor Internals Analysis

   Maximum stresses due to the SSE (vertical and horizontal components) and a LOCA were obtained and combined. All core support structure components were found to be within acceptable stress and deflection limits for both hot-leg and cold-leg branch pipe LOCAs occurring simultaneously with the SSE; the stresses and deflections which would result following a faulted condition are less than those which would adversely affect the integrity of the core support structures. The barrel does not buckle during a hot-leg branch pipe break and it meets the allowable stress limits during all specified transients.

   The results obtained from the analyses indicate that for certain interfacing components, the relative displacement between the components will close the gaps, and consequently the structures will impact each other. The effects of the gaps that could exist between vessel and barrel, between fuel assemblies, and between fuel assemblies and baffle plates, were considered in the analysis using non-linear analysis. The stress intensities are within acceptable limits.

Even though control rod insertion is not required for plant shutdown following a large break LOCA, this analysis shows that most of the guide tubes will deform within the limits established to assure control rod insertion. For the guide tubes deflected above the no-loss-of-function limit, it must be assumed that the rods will not drop. However, the core will still shut down due to the negative reactivity insertion in the form of core voiding. Shutdown will be aided by the great majority of rods that do drop. Seismic deflections of the guide tubes are generally negligible by comparison with the no-loss-of-function limit.

3.9.3.2 **Stone & Webster Supplied Equipment**

Safety-related mechanical components (Seismic Class I) not covered by the ASME Boiler and Pressure Vessel Code are seismically qualified within the criteria and procedures of Section 3.7.3.2. Non-ASME Code components typically include diesel generators and emergency ventilation equipment. Cranes are seismically qualified in accordance with a criterion that precludes the possibility of the crane being dislodged by a seismic disturbance.

Except as noted elsewhere, if any code is used for the design of a component, the guidelines of Section 3.7.3.2 generally require addition of the operational-basis earthquake load with no increase in code-allowable stress. The general criteria for analysis of the design-basis earthquake and pipe rupture (if applicable) loads require that deformation of components be allowed only with no loss of function. Generally, stress limits are set for the design-basis earthquake so that lower bound limit loads are not exceeded (as in Section 3.9.2).

3.9.3.3 **Operability of Valve Appurtenances**

To ensure that a non-Code appurtenance (e.g., position switch) will not prevent the proper operation of valves, such devices are also seismically qualified to limits comparable to the valve.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

The following cases are typical examples of seismic qualification testing of appurtenances vital to the operation of active pumps and valves.

3.9.3.3.1 Seismic Qualification Test of National Acme Company Snap-Lock Electric Switch No. D 2400X-2

A seismic qualification test program of National Acme snap-lock electric switch No. D 2400X-2 was conducted by Fisher Controls Company and reported in document No. 1529, dated November 2, 1975. Testing was conducted with the switch assembly fastened to a metal plate, which in turn was attached to a shaker table. All tests were conducted with the switch in an operating condition. The following is a summary of the test procedure and results.

Test Procedure

1. Conduct a continuous frequency sweep for each of the three axes from 5 to 60 Hz at an acceleration level of 1.0g in no less than 31 seconds.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

2. If the resonant frequency is less than 33 Hz, conduct a 4g 1-minute dwell at the resonant frequency and at 10 and 33 Hz.
3. If the resonant frequency is greater than 33 Hz, conduct a 4g 1-minute dwell at 10, 17, 25 and 33 Hz and at the resonant frequency if it is less than 60 Hz.

Test Results

The snap-lock electric switch performed satisfactorily with no malfunctions noted, and meets or exceeds the specifications outlined in the test procedure.

3.9.3.3.2 Seismic Qualification of Solenoid Valves

ASCO valves were tested during a seismic qualification test program for the solenoid valves used on the Westinghouse-supplied active air-operated valves. The test dynamic input forces were of 3g horizontal and 2g vertical. Also, frequency search and dwell tests, with the unit in its operational mode, were conducted. Additional information on component qualification can be found in Section 3A.33.

3.9 REFERENCES

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Table 3.9-1
TYPES OF PUMPS AND VALVES - STONE & WEBSTER SCOPE

Pumps (Units 1 and 2)

Number	Description	Type
1,2 SW-P-1A,B	Service water pumps	Vertical turbine
1,2 SW-P-2	Service water screenwash pump	Vertical turbine
1,2 SW-P-4	Auxiliary service water pump	Vertical turbine
1,2 SW-P-5,6,7,8	Radiation monitor recirculation spray	Turbine
1,2 CC-P-1A,B	Component cooling pump	Centrifugal
1 RS-P-1A,B	Inside recirculation spray pump	Vertical turbine
1 RS-P-2A,B	Outside recirculation spray pump	Vertical turbine
1 QS-P-1A,B	Quench spray pumps	Centrifugal
1 FC-P-1A,B	Fuel pit cooling pumps	Centrifugal
1 FW-P-2 1 FW-P-3A,B	Auxiliary steam generator feed pumps	Centrifugal
1 CW-P-2B 2 CW-P-2A	Circulating water screenwash pumps	Vertical turbine

Valves, Component Cooling System
(Unit 1 Valves Listed, Unit 2 Valves Identical)

Number	Line	Type	Size
TV-CC-104A,B,C	Cooling water supply to reactor coolant pump	Butterfly	8 in.
TV-CC-102A,B,C,D,E,F	Cooling water return from reactor coolant pump	Butterfly	8 in.
CC-106A,B,C	Coolant water supply to reactor coolant pumps	Globe	4 in.
MOV-CC-100A,B	Cooling water return residual heat removal	Butterfly	18 in.
TV-CC-101A,B	Thermal barrier cooling water return	Globe	4 in.
TV-CC-103A,B	Cooling water return residual heat removal	Butterfly	18 in.
TV-CC-115A,B,C	Chilled water to/from recirculation air coolers	Butterfly	8 in.
TV-CC-100A,B,C TV-CC-105A,B,C	Recirculation air cooler cooling water return	Butterfly Butterfly	6 in. 6 in.
1 CC-193, 198 [a]	Cooling water supply to residual heat removal heat exchanger	Check	18 in.

a. Unit 2 valves are similar with different mark numbers.
b. MOV-RS-256A, B are similar but not identical to MOV-RS-156A, B. The service requirements for both units MOVs are identical.
c. These twelve valves were specified, procured and installed by Virginia Power. They replaced the original four MOV-SW-100A, B and 200A, B valves.

Table 3.9-1 (continued)
TYPES OF PUMPS AND VALVES - STONE & WEBSTER SCOPE

Valves, Component Cooling System
(Unit 1 Valves Listed, Unit 2 Valves Identical) (continued)

Number	Line	Type	Size
1 CC-84, 119, 154 [a]	Cooling water supply to reactor coolant pump	Check	8 in.
1 CC-546, 559, 512 [a]	Cooling water to recirculation air coolers	Check	6 in.

Recirculation Spray and Quench Spray Systems
(Unit 1 Valves Listed, Unit 2 Valves Identical)

Number	Line	Type	Size
MOV-RS-155A,B	Outside recirculation spray pump suction	Gate	12 in.
MOV-RS-156A,B [b]	Outside recirculation spray pump discharge	Gate	10 in.
MOV-QS-100A,B	Quench spray suction	Gate	10 in.
MOV-QS-101A,B	Quench spray pump discharge	Gate	8 in.
1 RS-18, 27 [a]	Recirculation spray containment isolation check valves	Check	10 in.
1 QS-11, 19 [a]	Quench spray containment isolation check valves	Check	8 in.

Main Steam System
(Unit 1 Valves Listed, Unit 2 Valves Identical)

Number	Line	Type	Size
PCV-MS-101A,B,C	Atmospheric steam dump globe	Angle globe	6 in.
HCV-MS-104	Decay heat release	Globe	4 in.
TV-MS-110	Main steam line to steam generator blowoff	Gate	1-1/2 in.
TV-MS-101A,B,C	Steam generator isolation valves	Check	32 in.
NRV-MS-101A,B,C	Nonreturn valves	Angle stop check	32 in.
TV-MS-113A,B,C	Main steam bypass line	Globe	3 in.
TV-MS-111A,B	Steam to auxiliary feed pump drive	Globe	3 in.
HCV-FW-100A,B,C	Auxiliary feed header isolation	Globe	3 in.

a. Unit 2 valves are similar with different mark numbers.
b. MOV-RS-256A, B are similar but not identical to MOV-RS-156A, B. The service requirements for both units MOVs are identical.
c. These twelve valves were specified, procured and installed by Virginia Power. They replaced the original four MOV-SW-100A, B and 200A, B valves.

Table 3.9-1 (continued)
TYPES OF PUMPS AND VALVES - STONE & WEBSTER SCOPE

Main Steam System
(Unit 1 Valves Listed, Unit 2 Valves Identical) (continued)

Number	Line	Type	Size
MOV-FW-100A,B,C, D	Auxiliary feed header isolation	Globe	3 in.
TV-BD-100A,B,C, D, E, F	Steam generator blowdown	Globe	3 in.
TV-MS-109	Drain main steam to condenser	Globe	3 in.
SV-MS-101A,B,C SV-MS-102A,B,C SV-MS-103A,B,C SV-MS-104A,B,C SV-MS-105A,B,C	Main steam safety valves		6 x 10 in.
1 FW-162, 180 (4") 1 FW-145, 160, 173, 229, 230 (6") 1 FW-143 (8") [a]	Auxiliary feed supply	Gate	4, 6, and 8 in.
1 FW-142 [a]	100,000-gal condensate storage tank cross-connect to 300,000-gal condensate storage tank	Gate	6 in.
1 FW-166, 172, 184, 190 (4") 1 FW-149, 155 (6") [a]	Auxiliary feed pump discharge	Gate	4 and 6 in.
1 FW-47, 79, 111 [a]	Feedwater isolation	Check	16 in.

Service Water System

Number	Line	Type	Size
MOV-SW-101A,B,C,D	Recirculation spray cooling supply	Butterfly	24 in.
MOV-SW-105A,B,C,D	Recirculation spray cooling discharge	Butterfly	24 in.
MOV-SW-201A,B,C,D	Recirculation spray cooling supply	Butterfly	24 in.
MOV-SW-205A,B,C,D	Recirculation spray cooling discharge	Butterfly	24 in.
MOV-SW-110A,B	Service water recirculation air cooling supply	Butterfly	8 in.
MOV-SW-114A,B	Service water recirculation air cooling discharge	Butterfly	8 in.
MOV-SW-210A,B	Service water recirculation air cooling supply	Butterfly	8 in.
MOV-SW-214A,B	Service water recirculation air cooling discharge	Butterfly	8 in.

a. Unit 2 valves are similar with different mark numbers.
b. MOV-RS-256A, B are similar but not identical to MOV-RS-156A, B. The service requirements for both units MOVs are identical.
c. These twelve valves were specified, procured and installed by Virginia Power. They replaced the original four MOV-SW-100A, B and 200A, B valves.

Table 3.9-1 (continued)
TYPES OF PUMPS AND VALVES - STONE & WEBSTER SCOPE

Service Water System (continued)

Number	Line	Type	Size
MOV-SW-113B, 213B	Service water to fuel pit coolers	Butterfly	10 in.
MOV-SW-113A, 213A	Service water from fuel pit coolers	Butterfly	10 in.
MOV-SW-121A,B[c] MOV-SW-221A,B[c] MOV-SW-122A,B[c] MOV-SW-222A,B[c]	Service Water Reservoir Spray system - spray array piping	Butterfly	18 in.
MOV-SW-123A,B[c] MOV-SW-223A,B[c]	Service Water Reservoir spray system-bypass piping	Butterfly	24 in.
MOV-SW-103A,B,C,D	Recirculation spray heat exchanger supply	Butterfly	16 in.
MOV-SW-104A,B,C,D	Recirculation spray heat exchanger discharge	Butterfly	16 in.
MOV-SW-203A,B,C,D	Recirculation spray heat exchanger supply	Butterfly	16 in.
MOV-SW-204A,B,C,D	Recirculation spray heat exchanger discharge	Butterfly	16 in.
MOV-SW-102A,B MOV-SW-202A,B	Recirculation spray supply cross connection	Butterfly	24 in.
MOV-SW-106A,B MOV-SW-206A,B	Recirculation spray discharge cross connection	Butterfly	24 in.
MOV-SW-108A,B MOV-SW-208A,B	Service water to component cooling	Butterfly	24 in.
MOV-SW-119,219	Service water makeup	Butterfly	8 in.
MOV-SW-117,217 MOV-SW-115A,B MOV-SW-215A,B	Auxiliary service water supply	Butterfly	24 in.
MOV-SW-120A,B MOV-SW-220A,B	Auxiliary service water discharge	Butterfly	24 in.
TV-SW-101A,B TV-SW-201A,B	Service water recirculation air cooling coils	Butterfly	8 in.
1 SW-120, 130, 140, 150 [a]	Service water to recirculation spray coolers	Check	16 in.

a. Unit 2 valves are similar with different mark numbers.
b. MOV-RS-256A, B are similar but not identical to MOV-RS-156A, B. The service requirements for both units MOVs are identical.
c. These twelve valves were specified, procured and installed by Virginia Power. They replaced the original four MOV-SW-100A, B and 200A, B valves.

Table 3.9-2
TYPES OF PUMPS AND VALVES - WESTINGHOUSE SCOPE

Pumps

Mark Number [a]	Description	Type
1-CH-P-1A,B,C	Charging/high-head injection pumps	Centrifugal
1-SI-P-1A,B	Low-head safety injection pumps	Centrifugal
1-RH-P-1A,B	Residual heat removal pumps	Centrifugal

Valves
Chemical and Volume Control System

Mark Number [a]	Line	Type	Size
1-CH-HCV-1311	Auxiliary spray	Globe	2 in.
1-CH-TV-1204A,B	Letdown line containment isolation	Globe	2 in.
1-CH-MOV-1350	Emergency boration	Gate	2 in.
1-CH-FCV-1113A	Boric acid blender	Globe	1 in.
1-CH-FCV-1113B	Boric acid blender to VCT outlet	Diaphragm	2 in.
1-CH-MOV-1115C,E	Volume control tank outlet isolation	Gate	4 in.
1-CH-MOV-1115B,D	Emergency makeup from refueling water storage tank	Gate	8 in.
1-CH-MOV-1275A,B,C	Charging pump minimum flow recirculation line	Globe	2 in.
1-CH-MOV-1373	Charging pump minimum flow recirculation header isolation	Gate	3 in.
1-CH-MOV-1289B	Charging header isolation	Globe	3 in.
1-CH-MOV-1370	Reactor coolant pump seal injection line isolation	Gate	3 in.
1-CH-MOV-1380 1-CH-MOV-1381	Reactor coolant pump seal-water return line	Gate	3 in.
1-CH-HCV-1137	Excess letdown flow control	Globe	3/4 in.
1-CH-HCV-1142	Letdown flow control from residual heat removal system	Globe	2 in.
1-CH-HCV-1186	Seal injection flow control	Globe	3 in.
1-CH-FCV-1122	Charging control valve	Globe	3 in.
1-CH-PCV-1145	Letdown low-pressure control	Globe	2 in.

a. Unit 1 equipment is identified. Unit 2 equipment is similar.
b. Unit 1 valves are 12 inches. Unit 2 valves are 10 inches.

Table 3.9-2 (continued)
TYPES OF PUMPS AND VALVES - WESTINGHOUSE SCOPE

Safety Injection System

Mark Number [a]	Line	Type	Size
1-SI-MOV-1885A,B	Low-head safety injection (LHSI) pump minimum flow isolation	Globe	2 in.
1-SI-MOV-1885C	Minimum flow and test line (return to RWST) isolation	Globe	2 in.
1-SI-TV-1884A,B	Boric acid from boron injection tank (BIT) to boric acid storage tank (BAST)	Globe	1 in.
1-SI-TV-1884C	Boric acid from BAST isolation to BIT	Globe	1 in.
1-SI-MOV-1890C,D	LHSI cold leg injection	Gate	10 in.
1-SI-MOV-1890A,B	LHSI hot leg injection	Gate	10 in.
1-SI-MOV-1864A,B	LHSI pump header isolation	Gate	10 in.
1-SI-MOV-1869A,B	High-head hot leg recirculation	Gate	3 in.
1-SI-MOV-1867A,B	BIT inlet isolation	Gate	3 in.
1-SI-MOV-1867C,D	BIT outlet isolation	Gate	3 in.
1-SI-MOV-1860A,B	Containment sump isolation	Gate	12 in.
1-SI-MOV-1862A,B	LHSI pump inlet from RWST	Gate	12 in. [b]
1-SI-MOV-1863A,B	Low-head to high-head pump recirculation isolation	Gate	8 in.

Residual Heat Removal System

Mark Number [a]	Line	Type	Size
1-RH-FCV-1605	Residual heat exchanger bypass flow	Butterfly	12 in.
1-RH-HCV-1758	Residual heat exchanger flow control	Butterfly	12 in.

a. Unit 1 equipment is identified. Unit 2 equipment is similar.
b. Unit 1 valves are 12 inches. Unit 2 valves are 10 inches.

Table 3.9-3

DESIGN CRITERIA FOR ASME CLASS 2 AND 3 COMPONENTS[a]

Load	Vessel/Tanks	Pumps		Valves		Piping
Pressure + deadweight + thermal (nozzle loads only)	ASME III/ ASME VIII	ASME III/ performance testing in accordance with standards of the Hydraulic Institute procedures		ASME III/ANSI B16.5		ASME III/ ANSI B31.1
		Structural	Functional[b]	Structural	Functional[b]	
Pressure + deadweight + design-basis earthquake	ASME III/ ASME VIII g loading specified in purchase specification	Ensured by integrity of connecting piping	Rigid (fn > 33), within working conditions by dynamic analysis	Ensured by integrity of connecting piping	Rigid (fn > 33), within working conditions by dynamic analysis	Proposed 1972 Winter Addenda of ASME III
Pressure + deadweight + main steam line break	Westinghouse pipe whip criteria applied to main steam line					

a. Suitable tests subject to review may be substituted for analysis.

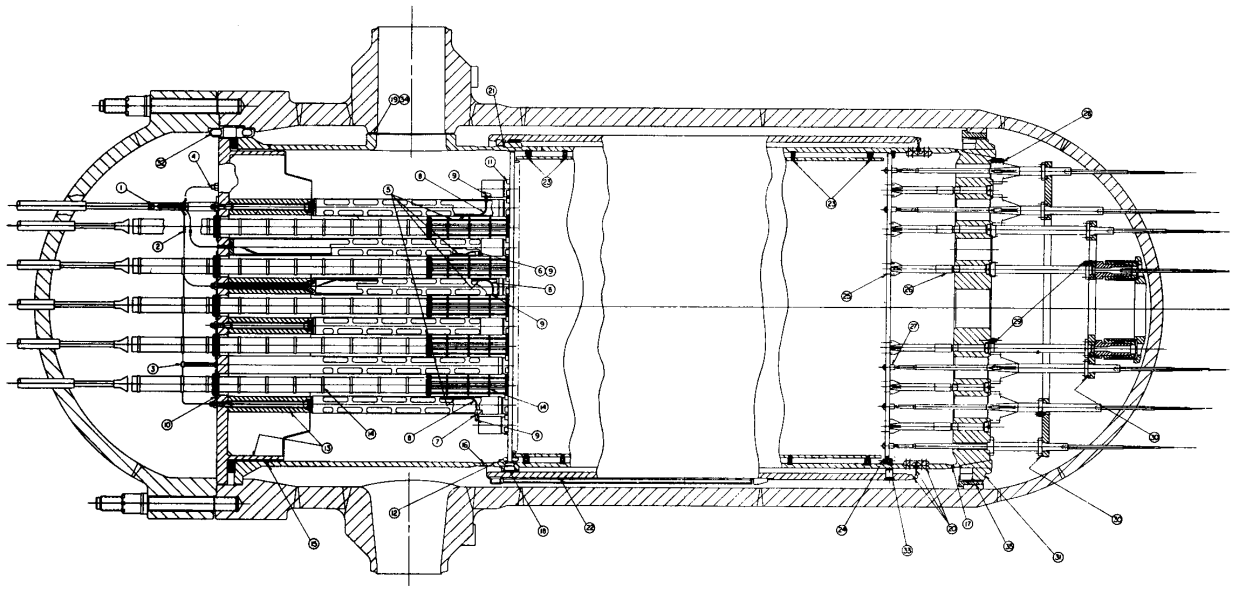
b. Functional design requirements apply only to active components whose operability is relied on to perform a safety function (as well as reactor shutdown function) during the transients or events considered in the respective operating categories.

Table 3.9-4
MAXIMUM DEFLECTIONS SPECIFIED FOR REACTOR INTERNAL SUPPORT STRUCTURES

Component	Allowable Deflections (in.)	No-Loss-of-Function Deflection (in.)
Upper barrel		
Radial inward	4.38	8.77
Radial outward	1.0	1.5
Rod cluster control		
Guide tubes	1.0	1.6
Upper package	0.1	0.150

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.9-1
VIBRATION CHECKOUT FUNCTIONAL TEST INSPECTION DATA (686J544)



	No.	FEATURES TO BE EXAMINED
UPPER INTERNALS	1	THERMOCOUPLE CONDUIT CLAMPS INSIDE THE THERMOCOUPLE COLUMN.
UPPER INTERNALS	2	CONDUIT SWAGELOK FITTINGS, THEIR BANDINGS, AND THE TAB-TYPE LOCKS.
UPPER INTERNALS	3	CLAMP ARRANGEMENTS AT THE MOUNTING BRACKET LOCATIONS.
UPPER INTERNALS	4	PLUG TO CONDUIT WELD AT THE FOUR SUPPORT COLUMNS ADJACENT TO THE THERMOCOUPLE COLUMNS
UPPER INTERNALS	5	ACCESSIBLE ANGLE CONDUIT CLAMPS INSIDE THE UPPER SUPPORT COLUMNS.
UPPER INTERNALS	6	ACCESSIBLE WELD JOINTS AT THE THERMOCOUPLE STOP FOR THE SELF INSTRUMENTED COLUMNS.
UPPER INTERNALS	7	WELD JOINTS ON ACCESSIBLE SUPPORT COLUMN AND MIXING DEVICE GUSSETS (THERMOCOUPLE SUPPORT HARDWARE.)
UPPER INTERNALS	8	RIGIDITY OF EXPOSED PORTION OF THERMOCOUPLE CONDUIT RUNS, AT ACCESSIBLE LOCATIONS. (INSIDE SUPPORT COLUMNS-LOWER END)
UPPER INTERNALS	9	RIGIDNESS OF THE ACCESSIBLE PROTRUDING THERMOCOUPLE TIPS.
UPPER INTERNALS	10	THERMOCOUPLE COLUMN AND GUIDE TUBE SCREW LOCKING DEVICES.
UPPER INTERNALS	11	ACCESSIBLE SUPPORT COLUMN, MIXING DEVICE, ORIFICE PLATE, AND CORE PLATE INSERT SCREW LOCKING DEVICES.
UPPER INTERNALS	12	UPPER CORE PLATE INSERTS.
UPPER INTERNALS	13	DEEP BEAM WELDS AT THE SKIRT AND AT THE OUTER HOLLOW ROUNDS.
UPPER INTERNALS	14	ACCESSIBLE GUIDE TUBE WELDS.
LOWER INTERNALS	15	UPPER BARREL TO FLANGE GIRTH WELD.
LOWER INTERNALS	16	UPPER BARREL TO LOWER BARREL GIRTH WELD.
LOWER INTERNALS	17	LOWER BARREL TO CORE SUPPORT GIRTH WELD.
LOWER INTERNALS	18	UPPER CORE PLATE ALIGNING PIN WELDS AND BEARING SURFACES
LOWER INTERNALS	19	OUTLET NOZZLE INTERFACE SURFACE CONDITION.
LOWER INTERNALS	20	THERMAL SHIELD FLEXURE ARM, ATTACHMENTS TO BARREL, AND WELD TO THE THERMAL SHIELD, DYE PENETRANT INSPECT ALL SIX.
LOWER INTERNALS	21	THERMAL SHIELD INTERFACE AT THE HANG OFF PADS.
LOWER INTERNALS	22	IRRADIATION SPECIMEN BASKET WELDS.
LOWER INTERNALS	23	BAFFLE ASSEMBLY SCREW LOCKING ARRANGEMENTS AT THE TWO TOP AND THE TWO BOTTOM FORMER ELEVATIONS.
LOWER INTERNALS	24	LOWER CORE PLATE TO CORE BARREL FLANGE SCREW LOCKING DEVICES ACCESSIBLE AT THE 0°, 90°, 180°, AND 270° AXES.
LOWER INTERNALS	25	CORE SUPPORT COLUMN TO LOWER CORE PLATE SCREW LOCKING DEVICES. (24 RANDOMLY CHOSEN)
LOWER INTERNALS	26	CORE SUPPORT COLUMN ADJUSTING SLEEVES.
LOWER INTERNALS	27	ACCESSIBLE (2) INSTRUMENTATION GUIDE COLUMN LOCKING COLLARS NEAREST THE MANWAY.
LOWER INTERNALS	28	LOCKING DEVICES AND CONTACT OF THE CRUCIFORM SHAPED BOTTOM INSTRUMENTATION GUIDE COLUMNS WHERE ATTACHED TO THE CORE SUPPORT AND TIE PLATES.
LOWER INTERNALS	29	LOCKING DEVICES OF THE SECONDARY CORE SUPPORT BUTT COLUMNS AT THE CORE SUPPORT AND AT THE TIE PLATE.
LOWER INTERNALS	30	WELD OF TIE PLATES TO THE OUTER INSTRUMENTATION COLUMNS (4 PER TIE PLATE)
LOWER INTERNALS	31	RADIAL SUPPORT KEY LOCKING ARRANGEMENTS AND BEARING SURFACES.
LOWER INTERNALS	32	HEAD AND VESSEL ALIGNING PIN SCREW LOCKING DEVICES AND BEARING SURFACES.
LOWER INTERNALS	33	ADJUSTMENT PLUG WELDS
VESSEL	34	VESSEL NOZZLE INTERFACE SURFACE CONDITION.
VESSEL	35	VESSEL CLEVIS LOCKING ARRANGEMENTS AND BEARING SURFACES.

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Figure 3.9-2
THERMAL SHIELD: MODE SHAPE N=4: OBTAINED FROM SHAKER TEST

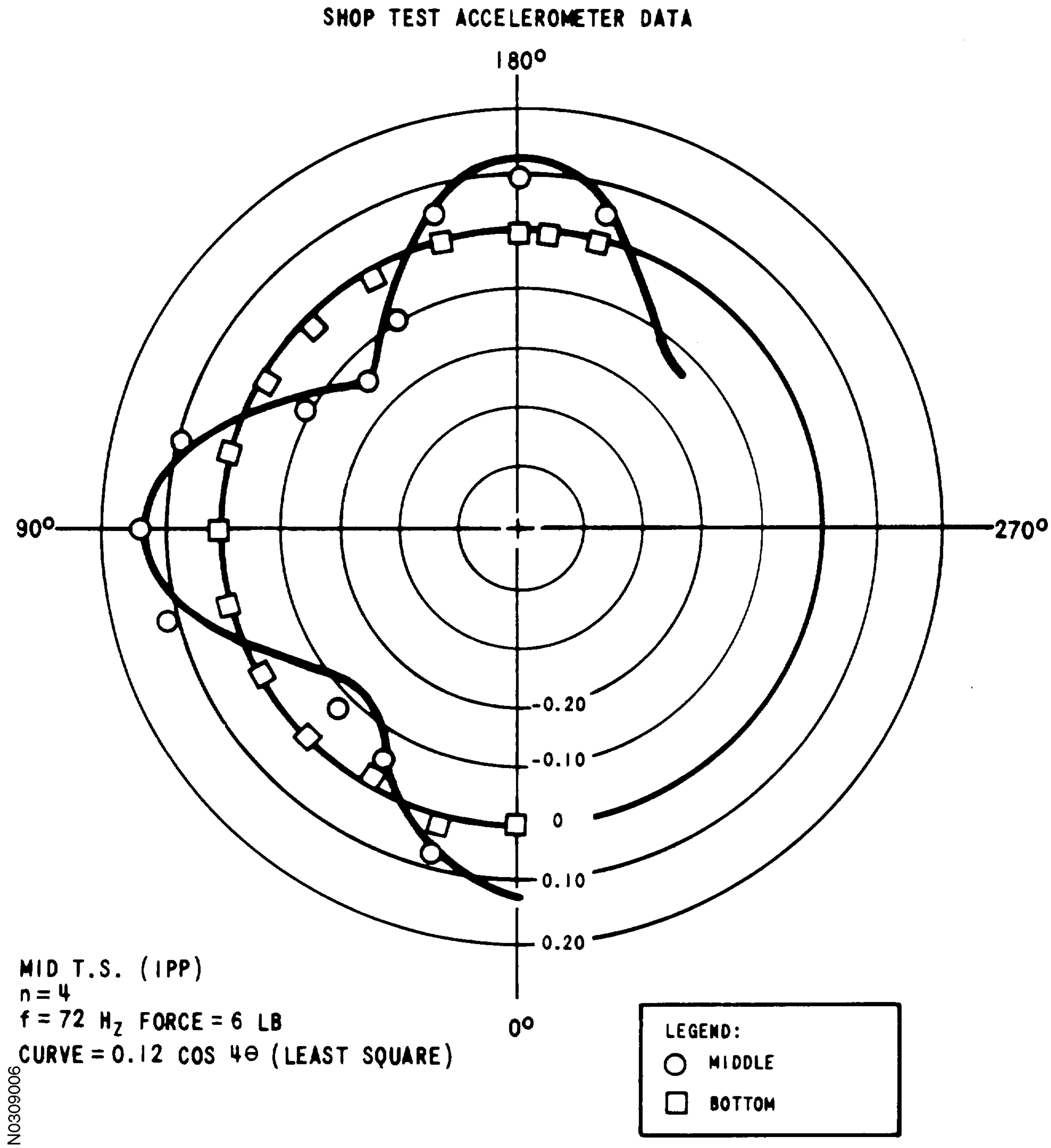


Figure 3.9-3
THERMAL SHIELD: MAXIMUM AMPLITUDE OF VIBRATION DURING PREOPERATIONAL TESTS

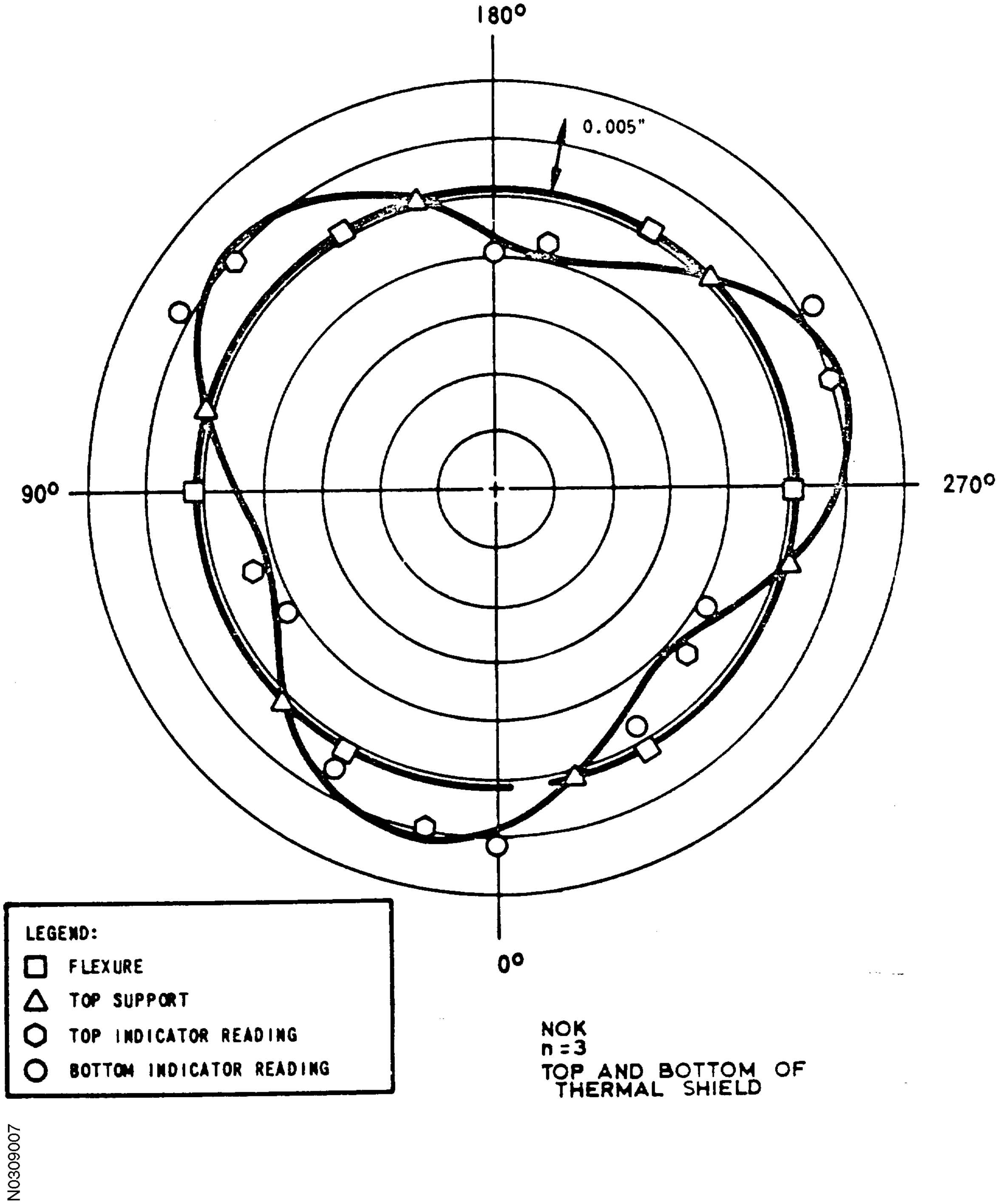


Figure 3.9-4
REACTOR VESSEL AND TYPICAL SUPPORTED NOZZLE

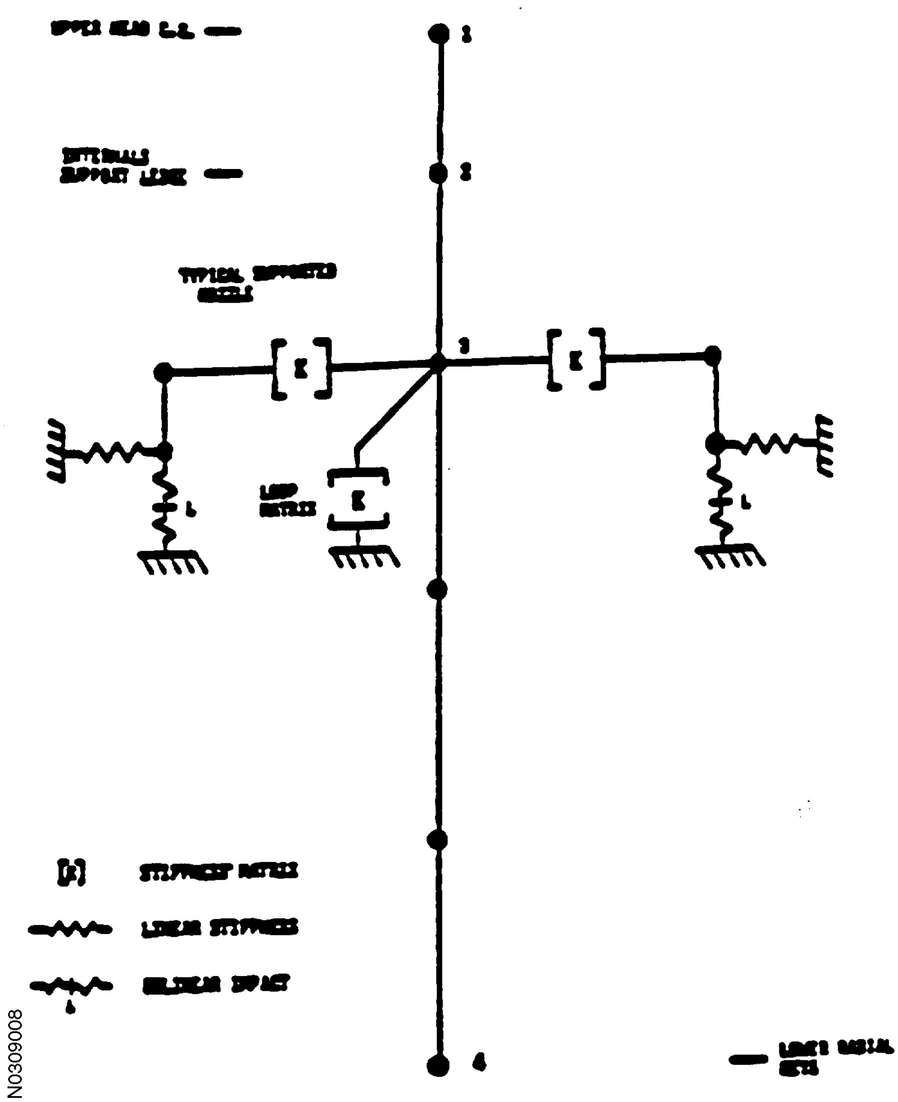


Figure 3.9-5
CORE BARREL SUBMODEL

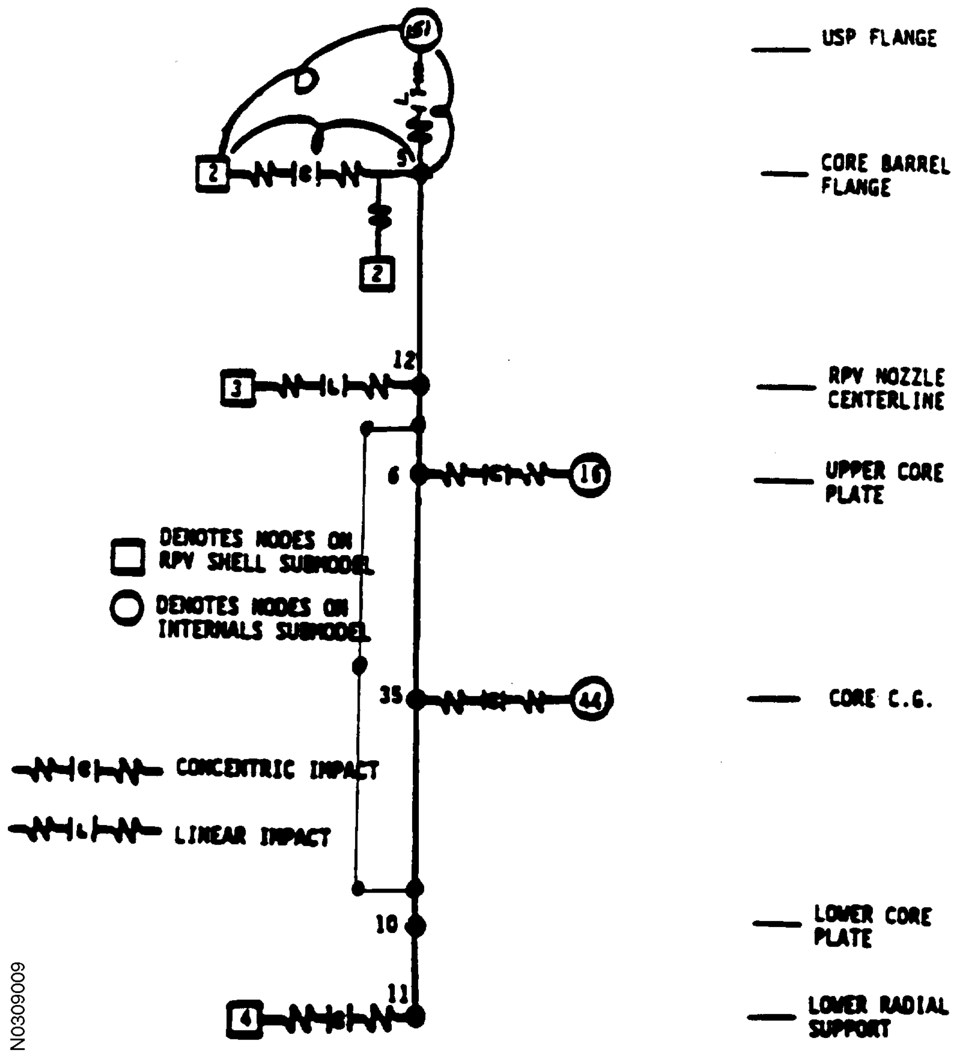
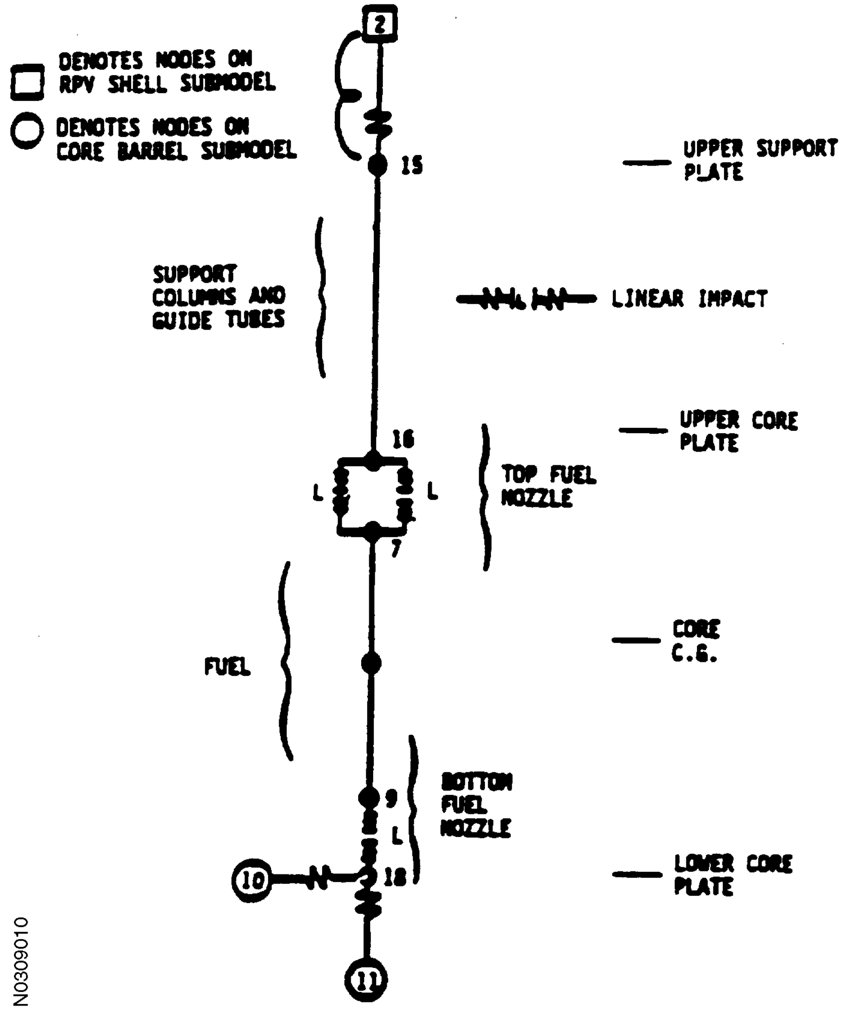


Figure 3.9-6
INTERNALS SUBMODEL



3.10 SEISMIC DESIGN OF CLASS I INSTRUMENTATION AND ELECTRICAL EQUIPMENT

3.10.1 Nuclear Steam Supply System

For either earthquake (operating or design-basis), the equipment will be demonstrated to maintain its functional capability, i.e., shut the plant down and maintain it in a safe-shutdown condition.

For the design-basis earthquake, there may be permanent deformation of the equipment provided that the capability to perform its function is maintained.

Typical protection system equipment is subjected to type tests under simulated seismic motion consisting of sine beats to demonstrate its ability to perform its functions.

Type testing has been done on this equipment by using conservatively large accelerations and applicable frequencies. This testing conforms to the IEEE Standard 344-1971, *IEEE Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations*. Analyses such as are performed for structures are not used for the reactor protection system equipment. However, the peak accelerations used are checked against those derived by structural analyses of operating and design-basis earthquake loadings.

Seismic analysis or testing of new electrical equipment or modifications to existing electrical equipment can be performed in accordance with IEEE 344-1975 as endorsed by Regulatory Guide 1.100, Revision 1 and IEEE 344-1987 as endorsed by Regulatory Guide 1.100, Revision 2. As an alternative, the experience-based methodology of USI A-46 can be used in accordance with Section 3.7.3.2.2.4.

References 1 through 7 provide the seismic evaluation of Seismic Class I instrumentation and electrical equipment. The results show that there were no electrical irregularities that would leave the plant in an unsafe condition even though some trips were initiated.

The reactor trip switchgear, Type DB50, has been seismically tested over the range of 1 to 35 Hz. The tests were conducted during the month of December 1973 at the Westinghouse Astronuclear Laboratory, and are reported in Supplement 6 to WCAP-7817 (Reference 6).

Modifications to the reactor trip switchgear were performed to satisfy NRC Generic Letter 83-28 dated July 8, 1983, to improve reactor trip switchgear reliability. The modifications included replacing the reactor trip switchgear shunt trip attachment and the installation of a shunt trip panel and electrical components to perform automatic actuation of the shunt trip attachment. The replacement shunt trip attachment and all components associated with the automatic actuation of the shunt trip attachment have been seismically qualified in accordance with IEEE-344-1975 and were installed such that the original qualification of the reactor trip switchgear was not compromised.

Resistance temperature detectors used to sense the temperature in the main coolant loops have been seismically qualified by type testing in accordance with IEEE 344-1975.

The nuclear instrumentation system power range neutron detector has been sinusoidally tested in both the transverse (horizontal) direction and the longitudinal (vertical) direction. The performance of the chamber was evaluated by checking resistance, capacitance, and neutron sensitivity before and after the tests. No significant changes were seen. There was no mechanical damage to the detector.

3.10.2 Stone & Webster Furnished Equipment

Seismic Class I (Safety related) instrumentation and electrical equipment are designed to maintain their capability to:

1. Initiate a protective action during the design-basis earthquake and the operating-basis earthquake.
2. Withstand seismic disturbances during postaccident operation.

Instrumentation and electrical equipment are seismically qualified in accordance with Stone & Webster's general instructions for earthquake requirements. These Stone & Webster requirements either supplement the requirements of applicable industry codes, such as IEEE STD 344-1971, or provide guidance for testing where no such codes are available. Seismic analysis or testing of new electrical equipment or modifications to existing electrical equipment can be performed in accordance with IEEE 344-1975 as endorsed by Regulatory Guide 1.100, Revision 1, and IEEE 344-1987, as endorsed by Regulatory Guide 1.100, Revision 2. As an alternative, the experience-based methodology of USI A-46 can be used in accordance with Section 3.7.3.2.2.4. Class I instrumentation and electrical equipment may be qualified as an individual component, as part of a simulated structural section, or as part of a completely assembled module or unit.

The response of racks, panels, cabinets, and consoles is considered in assessing the capability of instrumentation and electrical equipment. Mounted components are qualified, as a minimum, to acceleration levels consistent with those transmitted by their supporting structure. A design objective is to minimize amplification of floor acceleration by supporting members to mounted components.

Determination of amplification and seismic adequacy of instruments and electrical equipment was implemented by the analysis and testing methods outlined in Section 3.7.3.2.2.

Cable tray systems are designed for static acceleration loads equal to 1.3 times the applicable peak amplified resonant response at the support points, using a value of 5% damping.

The adequacy of the 1.3 dynamic amplification factor is justified by the results of analysis of a typical cable tray system, which indicates the conservatism of the factor. The model and results are shown in Figure 3.10-1. Results are based on a flat response spectrum of 1g and indicate factors below 1.0 for both square-root-of-sum-of-squares and absolute-sum modal combinations. The criterion outlined in Section 3.7.3.2 is used in this evaluation. Support systems are designed (or purchased already designed) so that no adverse deformation or failure is allowed for the design-basis earthquake. For the operating-basis earthquake, normal working stresses are maintained.

Conduit support systems are designed since 1982 for static acceleration loads equal to the applicable peak amplified resonant response at the support points, using a value of 1/2% damping for OBE and 1% damping for DBE. The use of conservative damping justifies the use of the 1.0 dynamic amplification factor. For cases where 5% damping factor is used, a dynamic amplification factor of 1.3 is used. The justification for the use of 1.0 Dynamic Amplification Factor is provided in the resolution to ECR-0165.

Standard safety-related conduit supports are provided in the Specification NAS-2016.

Control Storage Batteries 1-I, 1-II, 1-III, 1-IV, 2-I, 2-II, 2-III and 2-IV are Exide type 2-GN-23 cells. The cells and two tier battery rack were subjected to simulated seismic testing dynamic analysis (Reference 73).

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

The main control board instrumentation (Wolfe & Mann) and panels of auxiliary control and relays (Wolfe & Mann) were qualified by component testing. The test input to each component device was based on the assumption that the boards and panels were analytically verified as rigid bodies. Details of the analysis and results demonstrating that the boards and panels are rigid are given in References 8 through 17.

Verification for other specific equipment is given in the following references.

Equipment	References
Circuit breakers on distribution panels (General Electric)	18-25
Clark Relays (714 UP. 6X, Model 7314) and electric governor control logic unit on the control panels of emergency diesel generator (Fairbanks Morse, Inc.)	26-29
15- and 20-kVA static inverters (Solid State Controls, Inc.)	30-35
Control and protective relays (General Electric)	36-46
HGA relays (General Electric) on auxiliary control and relays (Wolfe & Mann)	14-17
Valve operators (Limitorque, Crane)	47-52
Pressure switches (Barksdale)	53-61

Test reports that verify the effect of connecting piping on operability for the air-conditioning self-cleaning strainers are given by References 62 through 67, and for the Foxboro Transmitters by References 68 through 72.

A tabulation of the requirements and results of seismic testing of equipment within the Stone & Webster scope of supply is given in Table 3.10-1. Pertinent information regarding the equipment, testing facilities, testing programs, and results is included. Equipment was concluded to be seismically adequate under the conditions described.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

A tabulation of the requirements and results of seismic testing of this equipment is given in Table 3.10-1. The “Required Test” g levels in this table are the Zero Period Acceleration (ZPA) values obtained from the design-basis earthquake response spectra of the building/elevation where the equipment is mounted. The “g horizontal” value indicates higher of the two horizontal acceleration values. The “Experienced Test” column indicates either the acceleration levels that were used in single frequency tests or the ZPA levels of the Test Spectra when random, multi-frequency tests were used. Other pertinent information regarding the equipment, testing facilities, testing programs, and results are also included. Equipment was concluded to be seismically adequate under the conditions described.

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Note: References 1 through 25 and 31 through 65 were forwarded to the NRC in VEPCO's letter of March 31, 1977 (Serial No. 007A/011277). References 26 through 30 were forwarded to the NRC in VEPCO's letter of June 24, 1977 (Serial No. 007B/011277).

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.10-1
EQUIPMENT TEST SUMMARY

Description	Required Test		Experienced Test			Tested in Operation	Test Lab[a] Facilities	Notes
	g Horizontal	g Vertical	g Horizontal	g Vertical	Frequency Range and Resonant Frequency			
Resistance temperature detectors (Electric Thermometers Trinity, Inc.)	0.70	0.30	2.8 & 12.0	2.8 & 12.0	Res. Freq.: > 100 Hz Dwell 60 Hz @ 2.8g and 120 Hz @ 12	Yes	York Research Corp. (18)	Equipment was tested at 12g for 1 hour, w/sinusoidal input, 2 axes individually.
Control and protective relays (Westinghouse)	0.32	0.19	0.2	0.2	1.5 to 35 Hz Fragility tests	Yes and No	Westinghouse Pittsburgh, Pa. (2)	Three axes individually, sinusoidal scan, sine beat test to establish fragility from 1.5 to 35 Hz with 5 cycles per beat, 5 beats. Awaiting documentation submittal.
Radiation monitoring system (Westinghouse)	0.19	0.13	0.2 1.0	0.2 0.7	Freq. Scan: 1-35 Hz Res. Freq.: 5 Hz, 7 Hz, 23 Hz	Yes	Westinghouse Aerospace Test Labs (3)	Six accelerometers used, mounted at various locations. Sinusoidal input for frequency scan, sine beat for dwell; three axes individually. Scan at every odd frequency. Sine beat of 15 beats, 10 cycles/beat.
Main control board instrumentation (Wolfe & Mann)	0.19	0.13	0.4 0.4	0.4 0.4	Freq. Scan: 1-13 Hz Res. Freq.: 13 Hz, 29 Hz, 33 Hz	Yes	Wyle Labs (4)	Seven accelerometers used, mounted at various locations. Sinusoidal input for dwell and scan. Three axes tested individually. Inst. mounted on test panel (rigid). Scan 1-33 Hz in 10 minutes and dwelled for 1 minute @ each resonant frequency.

a. Numbers in parentheses refer to section numbers in Appendix 1 of the table.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.10-1 (continued)

EQUIPMENT TEST SUMMARY

Description	Required Test		Experienced Test			Tested in Operation	Test Lab[a] Facilities	Notes
	g Horizontal	g Vertical	g Horizontal	g Vertical	Frequency Range and Resonant Frequency			
Batteries (Control storage) C&D Batteries	0.18	0.12	0.51 0.51	0.41 0.41	Freq Scan: 1-50 Hz Res. Freq.: 12 Hz, 16 Hz, 26 Hz	Yes	TII Labs College Point, N.Y. (5)	Two cells mounted in a test rack, four accelerometers located on table, rack, and cells. Sinusoidal input, three axes individually. Dwell test for 60 sec minimum.
Dc distribution panels (General Electric)	0.3	0.23	0.39 0.39	0.3 0.3	Freq.Scan: 4-50 Hz Res.Freq.: 7 Hz, 11 Hz, 32 Hz	Yes	Dayton T. Brown Long Island, N.Y(6)	Eight accelerometers used, mounted at various locations. Sinusoidal input for frequency scan and dwell, three axes individually. Frequency scan @ 0.73 octaves/min. Dwell for 20-second minimum.
Static battery charger (Gould, Inc.)	0.18	0.12	0.39 0.39	0.26 0.26	Freq. Scan: 1-50 Hz Res. Freq.: 1.5 Hz, 5.5 Hz, 7.7 Hz	Yes	Acton Labs, Acton, Mass. (11)	10 accelerometers used, mounted at various locations. Sinusoidal input for frequency scan and sine beat for dwell; three axes individually. Scan test at 2 octaves/min maximum. Sine beat at 10 cycles per beat, 5 beats.
Control panels - emer. diesel generator (Fairbanks Morse, Inc.)	0.18	0.12	> 1.5	> 1.5	Freq. Scan: 1-30 Hz Res. Freq.: None reported Scan held each freq. ≥ 20 sec	Yes	MTS Systems Research Lab	Also subjected to narrow band random and sine beat for dwell. Horizontal axis and vertical axis individually.
Flow indicators (ITT/Barton)	0.35	0.35	1.5	1.0	Freq. Scan: 5-33 Hz No resonance observed	Yes	General Electric San Jose, Calif.	Sinusoidal scan 5-33 Hz in 7 minutes. Three axes individually. Normal service mounting.

a. Numbers in parentheses refer to section numbers in Appendix 1 of the table.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.10-1 (continued)

EQUIPMENT TEST SUMMARY

Description	Required Test g Horizontal	Required Test g Vertical	Experienced Test g Horizontal	Experienced Test g Vertical	Experienced Test Frequency Range and Resonant Frequency	Tested in Operation	Test Lab[a] Facilities	Notes
Transmitters (Foxboro Co.)	0.35	0.35	0.3 > 0.5	0.3 > 0.5	Freq. Scan: 1-5 Hz 6-100 Hz Res. Freq.: None in range	Yes	Acton Labs Acton, Mass. (12)	Six accelerometers used; three on top cover, two on transmitter, one on table. Sinusoidal input for frequency scan and sine beat for dwell. Three axes individually. Normal service mounting. Scan at one octave/min. 10 cycles/beat for 10 beats.
Valve operator (Limitorque/Crane)	0.20	0.12	1.0 3.0	1.0 3.0	Freq. Scan: 1-35 Hz Res. Freq.: None in frequency range, dwelled 2-35 Hz	Yes	Franklin Research Inst. (13) Ogden Tech Labs. (14)	Sinusoidal input for frequency scan and dwell; three axes tested individually. Five accelerometers used in various locations. Normal service mounting. Additional 10-second dwells 2-34 Hz, 5.3g at 35 Hz.
15 and 20 kVA static inverters (Solid State Controls, Inc.)	0.39	0.26	0.39 min 0.39	0.26 min 0.26	Freq. Scan: 1-35 Hz Res. Freq.: At many freq. between 2-35 Hz	Yes	Gaynes Labs. Chicago, Ill. (15)	Four accelerometers used at various locations. Sinusoidal input for frequency scan and dwell. Three axes tested individually. Scans at 2 octaves/min minimum, dwells for 20 sec/min. Normal service mounting.
Control room instrumentation (Westinghouse)	0.36	0.24	0.36 0.36	0.24 0.24	Freq. Scan: 10-60 Hz Res. Freq.: 60 Hz	Yes	Westinghouse Pittsburgh, Pa. (16)	Sinusoidal input for frequency scan and dwell. Three axes tested individually. Scan for 30 seconds at each frequency. Dwell for 1 minute at 60 Hz. Accelerometer manually moved.

a. Numbers in parentheses refer to section numbers in Appendix 1 of the table.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.10-1 (continued)

EQUIPMENT TEST SUMMARY

Description	Required Test g Horizontal	Required Test g Vertical	Experienced Test g Horizontal	Experienced Test g Vertical	Experienced Test Frequency Range and Resonant Frequency	Tested in Operation	Test Lab[a] Facilities	Notes
Control and protective relays (General Electric)	0.4	0.27	0.5 3.0	0.5 2.6	Freq. Scan: 5-33 Hz Dwelled at 33 Hz	Yes	General Electric Philadelphia, Pa.	Sinusoidal input. Scan at 1 Hz per 15 seconds. Dwell tests at 10g or to 100 microsec. Discontinuity of contacts for 120 seconds. Three axes individually.
Contactor for backup pressurizer heaters (Klockner Moeller)	0.30	0.20	> 0.30 > 0.30	> 0.20 > 0.20	Freq. Scan: 2-55 Hz Res. Freq.: 14, 16, 20, 34, 46, 52 Hz	Yes	TII Labs College Point, N.Y. (7)	Six accelerometers used, two on table and four on the equipment at various locations. Sinusoidal input for one horizontal plus vertical simultaneously for frequency scan and dwell. Normal service mounting.
Auxiliary control and relay panels inst. (Wolfe & Mann)	0.36	0.30	0.40 0.40	0.40 0.40	Freq. Scan: 1-33 Hz Res. Freq.: None in this range; dwell at 33 Hz	Yes	Wyle Labs Huntsville, Ala. (8)	Seven accelerometers used at various locations. Sinusoidal input for frequency scan and dwell. Three axes individually. Devices mounted on test panel (actual panels have been shown to be rigid). Frequency scan at 1 octave/min; dwell for 1 minute minimum.
Motor control centers (Klockner Moeller)	0.45	0.35	0.49 0.49	0.36 0.36	Freq. Scan: 5-50 Hz Res. Freq.: 10 Hz, 20 Hz	Yes	TII Labs College Point, N.Y. (9)	Four accelerometers used, mounted at various locations. Simultaneous vertical and horizontal sinusoidal input for each horizontal axis @ 1 Hz intervals. Sinusoidal dwell for 2 minutes.

a. Numbers in parentheses refer to section numbers in Appendix 1 of the table.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.10-1 (continued)

EQUIPMENT TEST SUMMARY

Description	Required Test g Horizontal	Required Test g Vertical	Experienced Test g Horizontal	Experienced Test g Vertical	Experienced Test Frequency Range and Resonant Frequency	Tested in Operation	Test Lab[a] Facilities	Notes
Motor control center - control switch (Westinghouse)	0.45	0.35	0.2	0.2	Freq. Scan: 1-25 Hz	Yes	Wyle Labs	Sinusoidal scan. Dwell with sine beat. Five cycles per beat, two beats. Three axes individually. Normal service mounting. Awaiting documentation submittal.
Pressure switches (Barksdale Valves)	0.33	0.16	400	400	High impact shock	Yes	Hughes Aircraft (1)	Post-shock testing indicated function capability was not impaired due to high impact shock testing.
Ac distribution panel (General Electric)	0.39	0.26	0.39 0.39	0.30 0.30	Freq. Scan: 2-50 Hz Res. Freq.: 21, 22, 31, 35, 39, 43, 44 Hz	Yes	Dayton T. Brown, Inc. (10)	Ten accelerometers used at various locations. Sinusoidal input used for scan and dwell. Three directions individually. Frequency scan at 0.73 octaves/min. Dwell for 20 seconds minimum at resonant frequencies. Normal service mounting.
480-V switchgear (I-T-E Imperial)	0.45	0.15	0.14 0.14, 0.22, 0.53, 0.71	0.1 0.1, 0.15, 0.36, 0.48	Freq. Scan: 2-35 Hz Res. Freq.: 7, 19 Hz	Yes	Wyle Labs	Twenty-four accelerometers used at various locations. Sinusoidal input for scan and dwell. Scan rate 2 octaves/min, dwells at 0.14g H, 0.1g and 0.22g H and 0.15g V for 200 cycles minutes. Dwells at (0.53, 0.36) and (0.71, 0.48) for 3 seconds. Three axes simultaneously. Total unit tested.

a. Numbers in parentheses refer to section numbers in Appendix 1 of the table.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.10-1 (continued)

EQUIPMENT TEST SUMMARY

Description	Required Test		Experienced Test			Tested in Operation	Test Lab[a] Facilities	Notes
	g Horizontal	g Vertical	g Horizontal	g Vertical	Frequency Range and Resonant Frequency			
4160V switchgear (I-T-E Imperial)	0.45	0.15	0.25 0.25, 0.40, 0.53, 0.71	0.17 0.17, 0.27, 0.36, 0.48	Freq. Scan: 2-35 Hz Res. Freq.: 9, 19 Hz	Yes	Wyle Labs	Twenty-three accelerometers used at various locations. Sinusoidal input for frequency scan and dwell. Scan rate 2 octaves/min, dwells for 0.25g H and 0.17g V, and 0.40g H and 0.27g V for 20 cycles minimum. Dwells at 0.53g H and 0.36g V and 0.71g H and 0.48g V for 3 seconds. Three axes simultaneously. Total unit tested.
Air conditioning self-cleaning strainers Seller: Elliot Co.								
Component: Flushing valves Mfg.: Contromatics Corp.	0.35	0.25	0.35	0.25	Freq. Scan: 1-50 Hz	Yes	York Research Corp. Stamford, Conn.	Three axes individually. Sinusoidal input. Scan at 0.35g horizontal and 0.35g vertical at 2 octaves/min maximum. Dwells at 0.35g horizontal and 0.25g vertical for 20 seconds minimum. Awaiting vendor documentation.
Component: Relays Mfg.: Allen Bradley Co.	0.35	0.25	0.35	0.25	Freq. Scan: 2-100 Hz	Yes	Allen Bradley Co.	Three axes individually. Sinusoidal input. Scans and dwells at 0.35g horizontal and 0.25g vertical. Scan at 2 octaves/min maximum. Dwells for 20 seconds minimum. Awaiting vendor documentation.

a. Numbers in parentheses refer to section numbers in Appendix 1 of the table.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.10-1 (continued)

EQUIPMENT TEST SUMMARY

Description	Required Test g Horizontal	Required Test g Vertical	Experienced Test g Horizontal	Experienced Test g Vertical	Experienced Test Frequency Range and Resonant Frequency	Tested in Operation	Test Lab[a] Facilities	Notes
Component: Motor control centers Mfg.: Allen Bradley Co.	0.35	0.25	0.35	0.25	Freq. Scan: 2-33 Hz	Yes	Allen Bradley Co.	Three axes individually. Sinusoidal input. Scans and dwells at 0.35g horizontal and 0.25g vertical. Scan at 2 octaves/min maximum. Dwells for 20 seconds minimum. Awaiting vendor documentation.
Bimetallic thermometers (Moeller Instrument Co.)	1.0	0.3	0.38-1.54 1.0 1.0	0.38-1.54 1.0 1.0	Freq. Scan: 5-10 Hz 10-200 Hz Res. Freq.: 28, 55, 78, 82, 84, 76, 118, 120, 128, 132, 100, 170 Hz	No	Delevan (17)	Three axes individually. Scan at 1/3 octave/min. 0.3-inch disp. 5-10 Hz, 1g 10-200 Hz. Dwell at 1.0g for 1 minute with sinusoidal input. At least one accelerometer used.

a. Numbers in parentheses refer to section numbers in Appendix 1 of the table.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

APPENDIX 1 TO TABLE 3.10-1

1. **Hughes Aircraft Company**

   Fullerton, California

   Test Apparatus:

   1. Navy lightweight high-impact shock machine, BUSHIPS drawing 10-T-2145-L

   Equipment Tested: Pressure switches

2. **Westinghouse Research Laboratories**

   Pittsburgh, Pennsylvania

   Equipment:

   1. Shaker - Unholtz Dickie Model 6
   2. Accelerometer - Unholtz Dickie Model 75D21
   3. Accelerometer amplifier - Unholtz Dickie Model CV11M-LF-1
   4. Function generator - Wavetek Models 112, 136
   5. Recorder - Midwestern Instr. 10 Channel Oscillograph

   Capabilities:

   Frequency - dc to 1000 Hz

   Stroke - 6 in. peak to peak

   Waveshape of generated motion - all standard, as well as sine beat

   Direction of motion - one, two, or three directions simultaneously in phase

   Motion sensing - three accelerometers and amplifiers

   Motion recording - ten channel oscillograph

   Equipment tester - control and protective relays

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

3. **Westinghouse Aerospace Test Laboratories**

Item	Description	Mftr.	Model	Serial	Comments
8.3.2.1	Shaker table	M.B.	C25	963	5000#
8.3.2.2	Driver	B. & K.	1018	Ogden 2130	
8.3.2.3	Accelerometer	Endevco	2213	9218	Control=A1
8.3.2.4	Accelerometer	Endevco	2213	9299	Response=A2
8.3.2.5	Accelerometer	Endevco	2213	9266	Response=A3
8.3.2.6	Accelerometer	Endevco	2242C	JB92	Response=A4
8.3.2.7	Accelerometer	Endevco	2226	KC53	Response=A5
8.3.2.8	Accelerometer	Endevco	2226	VK43	Response=A6
8.3.2.9	Charge amp	Unholtz Dickie	8PMCV	Ogden 1049	A1
8.3.2.10	Charge amp	Unholtz Dickie	8PMCV	Ogden 570	A2
8.3.2.11	Charge amp	Unholtz Dickie	8PMCV	Ogden 571	A3
8.3.2.12	Charge amp	Unholtz Dickie	8PMCV	Ogden 573	A4
8.3.2.13	Charge amp	Unholtz Dickie	8PMCVA	Ogden 2464	A5
8.3.2.14	Charge amp	Unholtz Dickie	8PMC	Ogden 1048	A6
8.3.2.15	Adhesive	Eastman	910	None	
8.3.2.16	Catalyst	L. D. Caulk Co.	Liq. Caulk	None	Use with adhesive
8.3.2.17	Fixture	Ogden	None	None	
8.3.2.18	X-Y plotter	Mosely	5	431	
8.3.2.19	Pulse generator	Datapulse	110A	17217	Process mod. signal source
8.3.2.20	Recorder	Southern Inst. Ltd.	10-513/50	617	
8.3.2.21	Scaler	Hewlett Packard	5233 L	413-01109	

Equipment Tested: Radiation Monitoring System

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

4. Wyle Laboratories

No. Instrument	Manufacturer	Model No.	Serial No.	Wyle or Gov't No.	Range	Accuracy	Calibration On	Calibration Due
1. Accelerometer	Endevco	2226	1585	95-185	1000g	±5%	2-5-72	5-5-72
2. Accelerometer	Endevco	226	PA53	97370	1000g	±5%	2-5-72	5-5-72
3. Accelerometer	Endevco	2226	PA56	96006	1000g	±5%	3-6-72	6-6-72
4. Accelerometer	Endevco	2226	KB81	NA	1000g	±5%	3-6-72	6-6-72
5. Accelerometer	Endevco	2226	HA42	NA	1000g	±5%	2-5-72	5-5-72
6. Accelerometer	Endevco	2226	HA76	NA	1000g	±5%	2-5-72	5-5-72
7. Accelerometer	Endevco	2226	JC51	81416	1000g	±5%	3-6-72	6-6-72
8. Accelerometer	Endevco	2213	NA11	G3876	1000g	±5%	2-5-72	5-5-72
9. Charge amp	Dynamics	7102PH	NA	1596	500g	±2%	12-21-71	6-21-72
10. Charge amp	Dynamics	7302PH	NA	1669	500g	±2%	12-21-71	6-21-72
11. Charge amp	Dynamics	7302PH	NA	1523	500g	±2%	12-21-71	6-21-72
12. Charge amp	Dynamics	7302PH	NA	1579	500g	±2%	12-21-71	6-21-72
13. Charge amp	Dynamics	7302PH	NA	1618	500g	±2%	12-21-71	6-21-72
14. Charge amp	Dynamics	7302PH	NA	1554	500g	±2%	12-21-71	6-21-72
15. Charge amp	Dynamics	7302PH	NA	1509	500g	±2%	12-21-71	6-21-72
16. Charge amp	Dynamics	7302PA	NA	1572	500g	±2%	12-21-71	6-21-72
17. Visicorder	Honeywell	1508	NA	81026	2 dc Hz	±5%	3-7-72	9-2-72
18. Digi work	Chadwick Helmuth	429	NA	97694	±1 count	±1 count	2-17-72	6-21-72
19. Galvo amps	Honeywell	TGA-600	—	96035	-1:1	±5%	1-31-72	7-31-72
20. Sweep oscillator	Dynamics	50104A	—	97435	0-50 Hz	±4%	2-7-72	5-7-72
21. Amplitude servo	Dynamics	50105	—	605F08	0-1000g	±4%	3-20-72	6-20-72
22. Chaf detector	Wyle	1-100	—	NA	1 μsec to 100 μsec	±3%	Prior to use	
23. Hydro servo control	Wyle	1003	—	NA	0-6V dc	±2%	Prior to use	
24. Power supply	Kepco	KS36-10M	—	98723	0-36V dc 0-10A	.01% Reg	5-1-72	8-1-72

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

4. **Wyle Laboratories (continued)**

No. Instrument	Manufacturer	Model No.	Serial No.	Wyle or Gov't No.	Range	Accuracy	Calibration On	Calibration Due
25. Oscilloscope	Tektronix	535A	—	80256	5 sec .1 µsec	±3%	2-19-72	5-19-72
26. Preamp.	Tektronix	53/54C	—	80272	0.5V	±3%	2-19-72	5-19-72
27. LVDT	Schaevitz	10,000 HR	115	97032	±10 in.	±0.25%	Prior to use	
28. RFL	Boonton	829D	1200	80190	.05 to 20A	±.5%	4-17-72	10-17-72
29. Milliammeter	Weston	81284	20754	81284	0 to 1000 ma	±1%	3-12-72	6-12-72

Equipment Tested: main control board instrumentation

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

5. **TII Laboratories**

   College Point, New York

   Test Apparatus:

   Vibration Table and Control System,
   Type RVH-72-5000, Serial No. 51402,
   manufactured by L.A.B. Corporation.
   Calibration Due: 21 September 1972.

   Accelerometers, Model 2213, Serial Nos.
   M-849, M-862, and PB38,
   manufactured by Endevco Corporation.
   Calibration Due: 22 November 1972.

   Amplifier, Model 261B, Serial No. KA07,
   manufactured by Endevco Corporation.
   Calibration Due: 12 December 1972.

   Power Supply, Model No. 057, Serial No. 1,
   manufactured by TII Testing Laboratories, Inc.
   Calibration Due: 12 December 1972.

   Ultra-Low Frequency Band Pass Filter,
   Model No. 330M, Serial No. 2116,
   manufactured by Krohn-Hite Corporation.
   Calibration Due: 9 February 1973.

   True R.M.S. Vacuum Tube Voltmeter, Model No. 320A,
   Serial No. 8622, manufactured by Ballantine Labs.
   Calibration Due: 9 December 1972.

   Amplifier, Model 2614, Serial No. 4246,
   manufactured by Endevco Corporation.
   Calibration Due: 12 December 1972.

      Type LCU-13
      8 Hr. Cap. 900 A.H.
      09 CON 72

      Type LCU-21
      8 Hr. Cap. 1500 A.H.
      09 CON 72

   Equipment Tested: control storage batteries

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

6. **Dayton Brown Inc., Long Island, New York**

Test Equipment							
Item	Manufacturer	Model	S/N	Cal. Period	Date of Last Cal.	Accuracy	Remarks
X-Y recorder	F. L. Moseley	7035A	604-00122	3 months	16 May 72	±1% Ind.	
Magnetic tape recorder	Sanborn	3914A	104	6 months	23 May 72	±3dB Response	
Charge amplifier	Unholtz Dickie	11MGV SLF1	EO 48	3 months	21 Jun 72	±5% Ind.	
Charge amplifier	Unholtz Dickie	11MGV SLF1	EO 51	3 months	6 Jun 72	±5% Ind.	
Dynamic analyzer	Spectral Dynamics	SD101B	53	6 months	17 Mar 72	±.25dB fso .25dB dc	
Electronic counter	Anadex	CF603R	31326	3 months	18 May 72	±1 Count	
Charge amplifier	Unholtz Dickie	8PMCV	50-70	3 months	26 Jun 72	±5% Ind.	
Charge amplifier	Unholtz Dickie	8PMCV	C468	3 months	28 Jun 72	±5% Ind.	
Charge amplifier	Unholtz Dickie	8PMCV	C466	3 months	28 Jun 72	±5% Ind.	
Charge amplifier	Unholtz Dickie	8PMCV	C467	3 months	28 Jun 72	±5% Ind.	
Charge amplifier	Unholtz Dickie	8PMCV	C470	3 months	28 Jun 72	±5% Ind.	
Charge amplifier	Unholtz Dickie	8PMCV	C469	3 months	18 May 72	±5% Ind.	
Charge amplifier	Unholtz Dickie	8PMCV	50-64	3 months	17 Jul 72	±5% Ind.	
Charge amplifier	Unholtz Dickie	8PMCV	50-65	3 months	17 Jul 72	±5% Ind.	
Charge amplifier	Unholtz Dickie	11MGV SLF1	EO 41	3 months	17 May 72	±5% Ind.	
Charge amplifier	Unholtz Dickie	11MGV	EO 43	3 months	18 May 72	±5% Ind.	
Accelerometer	Unholtz Dickie	5D21-8	243	3 months	11 May 72	±5% Flatness	
Accelerometer	Unholtz Dickie	5D21-8	244	3 months	11 May 72	±5% Flatness	
Accelerometer	Unholtz Dickie	5D21-8	245	3 months	9 May 72	±5% Flatness	
Accelerometer	Unholtz Dickie	5D21-8	246	3 months	9 May 72	±5% Flatness	
Accelerometer	Unholtz Dickie	5D21-8	254	3 months	9 May 72	±5% Flatness	

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

6. **Dayton Brown Inc., Long Island, New York (continued)**

Test Equipment (continued)

Item	Manufacturer	Model	S/N	Cal. Period	Date of Last Cal.	Accuracy	Remarks
Accelerometer	Unholtz Dickie	5D21-8	248	3 months	10 May 72	±5% Flatness	
Accelerometer	Unholtz Dickie	5D21	266	3 months	10 May 72	±5% Flatness	
Accelerometer	M. B. Electronics	303	149209	3 months	11 May 72	±5% Flatness	
Charge amplifier	Unholtz Dickie	8PMCV	50-53	3 months	17 Jul 72	±5% Ind.	
Charge amplifier	Unholtz Dickie	8PMCV	50-56	3 months	17 Jul 72	±5% Ind.	
Accelerometer	Unholtz Dickie	5D21	199	3 months	9 May 72	±5% Flatness	
Accelerometer	Unholtz Dickie	5D21	244	3 months	9 May 72	±5% Flatness	
Accelerometer	Endevco	2272M20	TA 08	3 months	11 May 72	±5% Flatness	
Oscilloscope	Tektronix	RM 564	003043	3 months	6 Jul 72	±3% Ind.	
Oscilloscope	Tektronix	R564B	B020140	3 months	7 Jul 72	±3% Ind.	
Oscilloscope	Hewlett Packard	122AR	032-04903	3 months	15 May 72	±3% Ind.	
Vibration exciter	M. B. Electronics	C-210	222	TRANSFER	INSTRUMENT		USN: 000269
Power amplifier	M. B. Electronics	T-999A	112	TRANSFER	INSTRUMENT		

Equipment Tested: dc distribution panels

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

7. **TII Laboratories**

College Point, New York

Description of Test Apparatus:

Vibration Machine and Control System,
Type RW-72-5033, Serial No. 51402,
manufactured by L.A.B. Corporation.
Calibration Due: 30 September 1973.

Vertical Bulkhead Vibration Fixture.

Accelerometer, Model 2213E, Serial No. CP4S,
manufactured by Endevco Corporation.
Calibration Due: 23 January 1974.

Accelerometers, Model 2213E, Serial Nos.
CP36, CP37, CP43, CP47 and CP48,
manufactured by Endevco Corporation.
Calibration Due: 16 January 1974.

Amplifier, Model 2616B, Serial No. KA07,
manufactured by Endevco Corporation.
Calibration Due: 29 December 1973.

Amplifier, Model 2616, Serial No. CA13,
manufactured by Endevco Corporation.
Calibration Due: 29 December 1973.

Power Supply, Model 057, Serial No. 1,
manufactured by TII Testing Laboratories, Inc.
Calibration Due: 29 December 1973.

Power Supply, Model 2622, Serial No. CA 24,
manufactured by Endevco Corporation.
Calibration Due: 29 December 1973.

Band Pass Filter, Model No. 330M, Serial No. 2118,
manufactured by Krohn-Hite Corporation.
Calibration Due: 13 February 1974.

True R.M.S. VTVM, Model 320A, Serial No. 8400,
manufactured by Ballantine Labs.
Calibration Due: 19 November 1973.

Power Supply, Model LA-100-03BM, Serial No. 14464,
manufactured by Lambda Electronics Corporation.
Oscillograph Recorder, Model 800R25MIT, Serial No. 283,
manufactured by Midwestern Instruments, Inc.
Calibrated prior to use.

Equipment Tested: contactor for backup pressurized heaters

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

8. Wyle Laboratories

No.	Instrument	Manufacturer	Model No.	Serial No.	Wyle or Gov't No.	Range	Accuracy	Calibration On	Calibration Due
1.	Accelerometer	Endevco	2213C	LB08	03751	1000	5%	2-19-73	5-19-73
2.	Accelerometer	Endevco	2226	YS85	95185	1000	±5%	2-21-73	5-21-73
3.	Accelerometer	Endevco	2226	HA42	NA	1000	±5%	2-21-73	5-21-73
4.	Accelerometer	Endevco	2226	PA53	97370	1000	±5%	2-21-73	5-21-73
5.	Accelerometer	Endevco	2226	PE91	98022	1000	±5%	2-12-73	5-12-73
6.	Accelerometer	Endevco	2226	JC70	81418	1000	±5%	2-12-73	5-12-73
7.	Accelerometer	Endevco	2226	JC51	81416	1000	±5%	2-12-73	5-12-73
8.	Accelerometer	Endevco	2226	K881	NA	1000	±5%	2-12-73	5-12-73
9.	Charge amp	Dynamics	7302	NA	1619	500	±2%	12-26-72	6-26-73
10.	Charge amp	Dynamics	7302	NA	1540	500	±2%	12-26-72	6-26-73
11.	Charge amp	Dynamics	7302	NA	1516	500	±2%	12-26-72	6-26-73
12.	Charge amp	Dynamics	7302	NA	1613	500	±2%	12-26-72	6-26-73
13.	Charge amp	Dynamics	7302	NA	1637	500	±2%	12-26-72	6-26-73
14.	Charge amp	Dynamics	7302	NA	1589	500	±2%	12-26-72	6-26-73
15.	Charge amp	Dynamics	7302	NA	1686	500	±2%	12-26-72	6-26-73
16.	Galvo amps	Honeywell	T6HA-600	NA	Rental		±2%	2-7-73	8-7-73
17.	Galvo amps	Honeywell	117 AccuPATA	NA	95190	1 to 10	±2%	2-15-73	5-15-73
18.	Digi-Mark	Chadwick Helmuth	425	NA	97694	999.9	±1 Count	1-2-73	4-2-73
19.	Oscilloscope	HP	122AR	NA	80604	10 V/cm	±3%	11-28-72	2-29-73
20.	Oscillator	Exact	505 B	BA	96005	10 kHz	±3%	2-16-73	5-16-73
21.	Voltmeter	B&K	2416	NA	80380	1 kV	±2%	11-29-72	2-29-73
22.	Visicorder	Honeywell	1508	NA	81026	2 kHz	±5%	2-21-73	Prior to use
23.	Manometer	Dwyer	1226	NA	NA	-.2 to +2.6 in. W.G.	NA	NA	NA
1.	Voltmeter (ac)	Weston	433		81390	0-150V	±2%	11-27-72	2-27-73
2.	Visicorder	Honeywell	1508		96056			Prior to use	
3.	Chatter	Wyle	1-100		NA	10 µsec	±3%	Prior to use	
4.	Power Supply	Kepco	R536-15M		98581	0-50 V	±1%	12-7-72	3-7-73

Equipment Tested: auxiliary control and relay panel instrumentation

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

9. **TII Laboratories, Inc.**

   College Point, New York

   Description of Test Apparatus:

   Vibration Table and Control System,
   Type RVM-72-5000, Serial No. 51402,
   manufactured by L.A.B. Corporation.

   Accelerometers, Model No. 2213,
   Serial Nos. M-818, M-849 and M-855,
   manufactured by Endevco Corporation.
   Calibration Due: 12 December 1971.

   Amplifier, Model No. 2614,
   Serial Nos. 4246, 4247 and 4248,
   manufactured by Endevco Corporation.
   Calibration Due: 12 December 1971.

   Power Supply, Model No. 2621, Serial No. 9026,
   manufactured by Endevco Corporation.
   Calibration Due: 12 December 1971.

   Ultra-Low Frequency Band Pass Filter,
   Model No. 330M, Serial No. F-101,
   manufactured by Krohn-Hite Corporation.
   Calibration Due: 21 January 1972.

   True RMS Vacuum Tube Voltmeter,
   Model No. 320A, Serial No. 8400,
   manufactured by Ballantine Labs.
   Calibration Due: 23 October 1971.

   Oscillograph, Model 000R25MIT, Serial No. 203,
   manufactured by Midwestern Company.
   Calibrated immediately prior to test.

Equipment Tested: motor control centers

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

10. **Dayton Brown, Inc., Long Island, New York**

Test Equipment

Item	Manufacturer	Model	S/N	Cal. Period	Date of Last Cal.	Accuracy	Remarks
X-Y recorder	F. L. Moseley	7035B	845-02965	3 months	14 Nov 72	±1% Ind.	
Sweep oscillator	Spectral Dynamics	SD104A-5	187	6 months	8 Aug 72	±2%	
Servo monitor	Spectral Dynamics	SD105A	140	6 months	8 Aug 72		
Accelerometer	Endevco	2233	MA 17	3 months	22 Nov 72	±5% Flatness	
Accelerometer	Unholtz Dickie	4D21	242	3 months	18 Nov 72	±5% Flatness	
Accelerometer	Unholtz Dickie	5D21-8	245	3 months	21 Nov 72	±5% Flatness	
Accelerometer	Unholtz Dickie	5D21-8	246	3 months	21 Nov 72	±5% Flatness	
Accelerometer	Unholtz Dickie	5D21-8	252	3 months	18 Nov 72	±5% Flatness	
Accelerometer	Unholtz Dickie	5D21	266	3 months	21 Nov 72	±5% Flatness	
Charge amplifier	Unholtz Dickie	11MGV SLF1	EO 45	3 months	7 Sept 72	±5% Ind.	
Charge amplifier	Unholtz Dickie	11MCV SLF1	EO 50	3 months	30 Aug 72	±5% Ind.	
Charge amplifier	Unholtz Dickie	11MGV SLF1	EO 51	3 months	7 Sept 72	±5% Ind.	
Dynamic analyzer	Spectral Dynamics	SD101B	53	6 months	13 Oct 72	±.25 dB fso ±.25 dB dc	
Log converter	F. L. Mosley	c)D	531-01597	3 months	1 Sept 72	±.5 dB Ind. 20 cps-10ke	
Timer	Dimco Gray	165	47-121	6 months	13 Oct 72	±1 second	
Charge amplifier	Unholtz Dickie	11MGV SLF1	EO 40	3 months	13 Oct 72	±5% Ind.	
Charge amplifier	Unholtz Dickie	11MGV SLF1	EO 41	3 months	1 Sept 72	±5% Ind.	
Charge amplifier	Unholtz Dickie	11MGV SLF1	EO 42	3 months	5 Sept 72	±5% Ind.	

Equipment Tested: ac distribution panels

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

11. **Acton Laboratories, Acton, Massachusetts**

Equipment	Manufacturer	Model	S/N	Inv. No.	Range	Acc.	Cal. Freq.
Accelerometer	B&K	4335	362081	AC371	2 Hz to 6 KHz	±2%	3 months
Accelerometer	B&K	4335	135138	AC334	2 Hz to 6 KHz	±2%	3 months
Accelerometer	B&K	4335	362084	AC372	2 Hz to 6 KHZ	±2%	3 months
Accelerometer	B&K	4335	354734	AC354	2 Hz to 6 KHz	±2%	3 months
Accelerometer	B&K	4335	354735	AC355	2 Hz to 6 KHz	±2%	3 months
Accelerometer	B&K	4335	362079	AC370	2 Hz to 6 KHZ	±2%	3 months
Accelerometer	MB	305	163303	AC349	2 Hz to 6 KHz	±2%	3 months
Accelerometer	MB	305	185768	AC348	2 Hz to 6 KHz	±2%	3 months
Accelerometer	MB	305	163291	AC351	2 Hz to 6 KHz	±2%	3 months
Accelerometer	B&K	4335	170873	AC332	2 Hz to 6 KHz	±2%	3 months
Chatterbox	ALI	10	-	PE329	10 µsec to 5 sec	±5%	6 months
Brush recorder	Brush	MKII	-	RE401	DC to 100 Hz, 2 ch.	±2%	3 months
Visicorder, 12-ch.	Minn-Honey	99334	99334	RE311	DC to 2 KHz	±1 dB	3 months
Visicorder, 12-ch.	Minn-Honey	906	9-5235	RE332	DC to 2 KHz	±1 dB	3 months
Oscilloscope	Tektronix	564	11562	OS309	DC to 10 MHz	±2%	3 months
Sweep oscillator	Spec Dynamics	SD104-5	21	SG315	.005 Hz to 50 KHz	2%	3 months
Tone brush generator	G.R.	1396	1052	SG326	DC to 2 MHz	N/A	6 months
Low freq. oscillator	H.P.	202B	397	SG319	0.01 Hz to 1 KHz	±5%	6 months
Controller	MTS	443.11S	-		DC to 2000 Hz	±1%	
Ac transistor voltmeter	Hewlett Packard	403A	-	MV322	10 Hz to 1 MHz 0-300V, 12 ranges	±3%	3 months

Equipment Tested: static battery charger

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

12. Acton Laboratories, Acton, Massachusetts

Equipment	Manufacturer	Model	Ser. No.	Range	Accuracy	Inv. No.	Cal. Freq.
Accelerometer	B&K	4335	135133	2 Hz to 6 KHz	±2%	AC331	1 yr
Accelerometer	B&K	4335	227725	2 Hz to 6 KHz	±2%	AC327	1 yr
Accelerometer	B&K	4335	227726	2 Hz to 6 KHz	±2%	AC329	1 yr
Accelerometer	B&K	4335	155036	2 Hz to 6 KHz	±2%	AC326	1 yr
Accelerometer	B&K	4335	135119	2 Hz to 6 KHz	±2%	AC328	1 yr
Accelerometer	B&K	4335	135138	2 Hz to 6 KHz	±2%	AC334	1 yr
Accelerometer	Endevco	2215L	TC28	2 Hz to 6 KHz	±2%	AC314	1 yr
Sweep oscillator	Spec Dynamics	SD104-5	21	.005 Hz to 50 KHz	2%	SG315	
Oscilloscope	Tektronix	564	9027	DC to 10 MC		OS311	
Amplifier charge	Unholtz Dickie	D11MGSV	1-12	1-1000 2 Hz to 20 KHz	±5%	AM333	
Hydraulic actuator	MTS	204.63		DC to 300 Hz 25,000 force lbs 25" DA max	2% Freq. 5% amplitude		
Hydraulic actuator controller	MTS	443.115		DC to 2000 Hz	1%		
Hydraulic power supply	Vickers	PVA120		120 gpm to 170 gpm max, 3000 to 5000 psi max 250 hp	N/A		
Visicorder	Honeywell	90002	99334	DC to 2 KHz 12-ch.	±1 db	RE311	
Power supply	Foxboro	NO140XL		75 V DC Nominal			
Resistors	Foxboro	NO116ST		100 ohm	±1.01%		
Air dead weight tester	Mansfield & Green			4-800" H_20	±0.025% of reading		
Audio generator	HEA	1672		10 Hz to 100 KHz	±5%	SG316	

Equipment Tested: transmitters

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

13. **Franklin Institute Research Laboratories**

1. Honeywell-Brown Electronik 2-pen recorder, Model No. Y153X(22)-VV-X-IV-K-(G)(V), Ranges: 0 to 500 F with Type J thermocouples: 0 to 200 psig with Ametek Pressure Transducer. (Calibrated 4/13/72)
2. Honeywell-Brown Electronik Multipoint Recorder, Model No. 15305846-24-02-2-000-030-10 097, 0 to 500 F with Type T thermocouples. (Calibrated 4/13/72)
3. Westinghouse Industrial Analyzer, Type PG-191, 25 to 150 Hz, Style 292B948A09. Connected for 25 A, 600V, and 25 kW full-scale readings. (Calibrated 3/13/72)
4. Westinghouse AC Wattmeter, Type PF-44, Style PH 10632N3 2, used in conjunction with Weston Potential Transformers, Model 311, No. 3283 and No. 3284, and Universal Current Transformers, Serial Nos. 56975 and 56976, for 25 kW full scale. (Calibrated 3/13/72)
5. Sanborn 150, 4-channel recorder, with DC Coupling Pre-Amplifier, Model 150-300. (Calibrated 6/29/72)
6. James G. Biddle Megger, Insulation Tester, No. 325603, 500V d-c. (Calibrated 4/13/72)
7. Ametek Pressure Transducer, Model 50-200-G-B/C. (Calibrated 12/16/71)
8. 2 Giannini & Co. Pressure Transmitters, 0 to 300 psig. (Calibrated 7/30/72)
9. Lonergan Maximon Gage, Type OA, 0 to 200 psig. (Calibrated 4/14/72)

Equipment Tested: valve operator

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

14. **Ogden Technical Laboratories**

Test Equipment:

Electro-Hydraulic Vibration Machine
Ogden Technology Laboratories, Inc.
Type: 6"/25K
Calibration: None required

Data Track
Research, Inc.
Model: FGE-5110
Calibration: Before each use

Servo Amplifier
1600g
Model: 82-104
Calibration: None required

Function Generator
Hewlett-Packard Corp.
Model: 202A
Calibration Interval: 6 months
Last Calibration: 3/27/72

Recording Oscillograph
Consolidated Electrodynamics Corp.
Model: 5-124
Calibration: System calibration prior to use

Signal amplifier
Unholtz Dickie Corporation
Model: 607-HMG-3A
Calibration Interval: 6 months
Last Calibration: 4/16/72

Accelerometer (5)
Endevco Corporation
Model: 2215C
Calibration Interval: 6 months
Last Calibration: 12/6/71

Equipment Tested: valve operator

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

15. **Gaynes Engineering and Testing Laboratories, Inc.**

Instrumentation

Instrument or Equipment	**Manufacturer**	**Model No.**
Vibration machine	Gaynes Engr.	2000VH
Vibration machine	L.A.B. Corp.	RVH 72-2500
Accelerometers	Endevco Corp.	2213
Amplifiers	Endevco Corp.	2614
Power Supply	Endevco Corp.	2621
Filters	Spencer-Kennedy	302
Tachometer	Jones-Motorola	3200
Oscilloscope	Tektronix	549
Strobotac	General Radio	1531A
Voltmeters, ac	Ballantine Labs.	300
Amplifier	Honeywell Inc.	117-06
Recorder	Honeywell Inc.	1508B

Load - furnished by Solid State Controls, Inc.

Equipment Tested: 15 & 20 kVA static inverters

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

16. **Westinghouse Labs**

Test Equipment:

1. Digital Voltmeter: H.P. Model 3460B, Serial No. D813-00522
   Accuracy: ±.003% of scale plus ±.007% of reading
   Resolution: (10V scale) 10 microvolts
   Calibrated: 12/15/72
2. Oscilloscope: Tektronix Model 545A, Serial No. 039665;
   CA type plug-in, Serial No. 065604
   Calibrated: 11/1/72
   1A7A Differential Plug-In, Serial No. B040999
   Calibrated: 11/1/72
   P6023 Differential Probes, Serial No. 010-168
   Model K5-0 Scope Camera, Serial No. 2298
3. Charge Amplifier: Columbia Model 4102, Serial No. 122
   Range: 1 to 10,000g psi, accuracy ±2%
   Calibrated: 9/11/70 (Factory)
4. Accelerometer: Columbia Model 606-2, Serial No. 4073
   Range: 0.1 to 10 kg, Charge Sensitivity: 1.27 PK-PCMB/KP-g
   Calibrated: 9/18/70 (Factory)
5. Strobotac: General Ratio Model 631-B
   Accuracy: ±1%
6. Vibration Tables: All American Tool Co.
   Vertical Table, Model 100V, Serial No. 8016
   Max capacity 239 or 100 lb at 10G
   Table movement 0 to 0.125" double amplitude
   Table size: 15 x 18 in.
   Frequency Range: 10 to 60 Hz
   Horizontal table, model 100HL, Serial No. 7889

17. **Delevan Electronics Corp.**

East Aurora, New York

Equipment:

1. Shaker - Unholtz Dickie Vibration System No. 73
   Serial No. 110
2. Tektronix 531A Oscilloscope

Equipment Tested: bimetallic thermometers

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

18. **York Research Corp.**

Random Vibration Systems

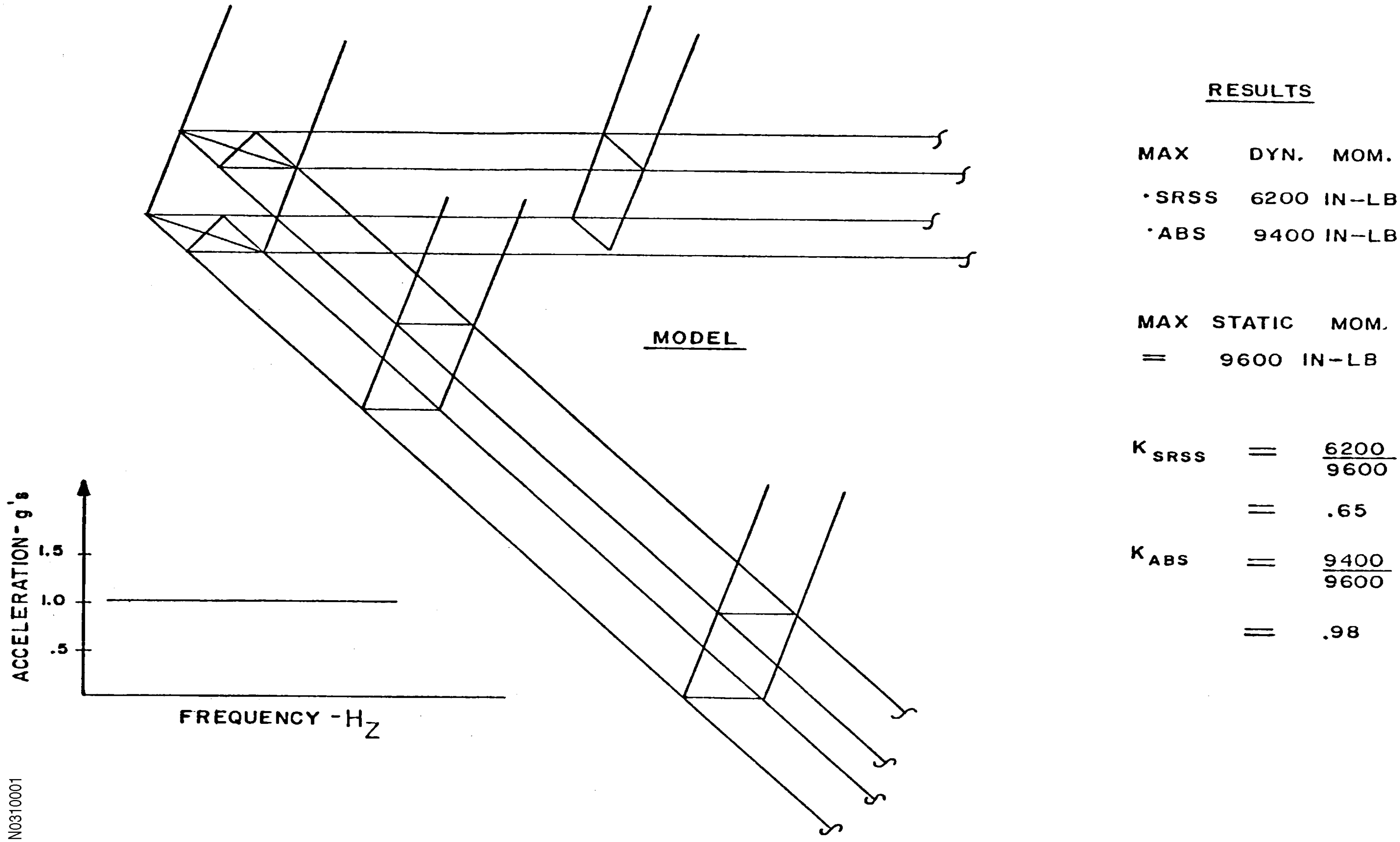
M.B. Electronics:	80-channel (mixed crystal filter array)
	10,000-lb force (C-126)
	Automatic equalization (1 sec)
	Amplitude protector (overtest prevention)
	Automatic program
Unholtz Dickie:	80-channel (mixed crystal filter array)
	2750-lb force (89F)
	Automatic equalization (1 sec)
	Automatic program

Sinusoidal Vibration Systems

M.B. Electronics:	10,000-lb force (C-126)
	5 to 5000 cps - automatic cycling
	5 to 10,000 cps - external accelerometer
	Amplitude protector (overtest prevention)
	Automatic program
Unholtz Dickie:	2750-lb force (89F)
	5 to 5000 cps - automatic cycling
	5 to 10,000 cps - external accelerometer
M.B. Electronics:	1250-lb force (C-10)
	5 to 5000 cps - automatic cycling
Calidyne:	1250-lb force
	0 to 2000 cps - manual program

Equipment Tested: resistance temperature detectors

Figure 3.10-1
RESPONSE SPECTRA



3.11 ENVIRONMENTAL DESIGN OF MECHANICAL AND ELECTRICAL EQUIPMENT

3.11.1 Nuclear Steam Supply System

3.11.1.1 Equipment Required to Operate During and Subsequent to the Design Basis Accident

In the event of a rupture in the reactor coolant system, or of secondary system equipment located inside the containment, a large release of energy, in the form of steam, would occur. The steam release and consequent heatup of the original containment atmosphere would result in an increase in both the temperature and pressure inside the containment. In addition to the steam release to the containment, a reactor coolant system rupture might also result in the release of large quantities of radioactive fission products to the containment atmosphere. The activity released into the containment would result in a large field of ionizing radiation within the containment atmosphere.

The equipment or components required to operate in the postaccident environment have been categorized as engineered safeguards equipment. The equipment required to operate in the postaccident environment is presented in Appendix 3F, which also presents the environmental temperatures associated with the limiting main steam line break (MSLB). The operating status of the emergency core cooling system components is given in the Technical Specifications.

A tabulation of Westinghouse-furnished valves in the reactor pressure boundary whose operation is considered necessary is presented in Table 3.11-1.

3.11.1.2 Qualification Tests and Analyses

A comprehensive testing program was conducted for all equipment systems and system controls vital to the functioning of engineered safeguards equipment. The program consists of performance tests of individual equipment in the manufacturer’s shop, integrated tests of the system as a whole, and periodic inspection tests of the activation circuitry and mechanical components to ensure reliable performance, upon demand, throughout the plant lifetime.

The initial qualification tests of individual components and the integrated tests of the systems as a whole complement each other to ensure performance of the system as designed and to prove proper operation of the actuation circuitry. For engineered safeguards equipment located inside the containment, qualification testing is performed under the combined effects of the expected temperature, pressure, humidity, and radiation—the postaccident environment.

The normal operating temperature for the protective equipment in the containment will be maintained below 120°F (except that, for ex-core neutron detectors, the normal operating temperature will be maintained below 135°F). The protective equipment is designed for continuous operation within design tolerance in this environment.

The neutron detectors will be designed for continuous operation at 135°F (the normal operating environment is designed to be always below this value) and will be capable of operation at 175°F for 8 hours.

Temperature control equipment is designed to maintain the temperature in the control room and relay rooms during normal operation at 75°F. Design specifications for equipment in these rooms require that no loss of protective function should result when operating in temperatures up to 120°F and humidity up to 95%, which may occur upon the loss of air conditioning and/or the ventilation system. Thus there is a wide margin between the design limit and the normal operating environment for the control room equipment.

Routine periodic inspection testing of the engineered safety features equipment is performed. Should one of the components require maintenance as a result of failure to perform during the test according to prescribed limits, the necessary corrections or minor maintenance are made and the unit retested immediately. Satisfactory performance of the remaining redundant component(s) is proof of the availability of that safety feature, and it is not necessary to adjust plant load during the brief period that a safety feature component may be out of service.

3.11.1.3 **Qualification Test Results**

Qualification testing has been performed on the various protective system equipment. This testing included demonstrating operation of safety functions at elevated ambient temperatures up to 120°F and a relative humidity up to 85% for control room and relay room electronic equipment. Detailed results of these tests are retained by suppliers.

Type testing has also been performed on Westinghouse safety-related equipment required to operate in the post-DBA environment (see , Table). This testing has demonstrated that Westinghouse-supplied safety-related equipment has been designed to complete its protective functions in the environment in which it must operate. The results of these tests are outlined below.

3.11.1.3.1 Safety-Related Motor-Operated Valves

Motor operators supplied by Limitorque that are included in the Equipment Qualification program are qualified to the environmental parameters included in qualification documentation review (QDR) package N-3.1 and N-3.3 (References 1 & 2). The vendor test reports referenced in QDR-N-3.1 and N-3.3 envelope the environmental parameters to which the operator will be exposed.

3.11.1.3.2 Pressurizer Pressure and Level Instrumentation

The pressurizer level instrumentation used at the North Anna site have been type tested in the design basis accident environment in which they must operate. The vendor testing is in compliance with the requirements of IEEE 323 1974. A supporting Virginia Power analysis of the vendor test reports are referenced in QDR-N-8.5. (Reference 3).

During testing, the performance of the transmitter was monitored. The performance requirement and demonstration that the requirements have been met is demonstrated in Technical Report EE-0031 (Reference 4).

3.11.1.3.3 Resistance Temperature Detectors

The Weed RTD's used for the wide and narrow range reactor coolant system channels have been type tested to the design basis accident environment in which they must operate. The vendor testing is in compliance with IEEE 323-1974. A supporting Virginia Power analysis of the vendor test reports are referenced in QDR-N-8.24 (Reference 5).

3.11.2 Stone & Webster Supplied Equipment

The engineered safety features and safety-related devices not within Westinghouse scope, required to function during and after any of the hypothesized accidents, are listed in Table 3.11-2.

Items that must perform an engineered safety feature function or a safety-related function are designed to withstand the environmental conditions during the life of the plant and during the accident environment. Corrosion- and radiation-resistant materials are specified. Items that have not been previously used under the hypothesized environmental conditions have been subjected to environmental type tests.

A tabulation of Stone & Webster-furnished valves in Seismic Class I systems whose operation is considered necessary is presented in Table 3.11-3.

3.11.2.1 **Quench Spray Subsystem**

As indicated in Table 3.11-2, the only components of the quench spray subsystem that would experience the combined high temperature, pressure, humidity, and radiation environment are the check valves inside the containment, and the piping and spray nozzles. No environmental testing or analysis is necessary for the piping or spray nozzles. The piping is 150-lb schedule 40 stainless steel. The nozzles are fabricated from brass.

The check valves inside the containment are weight-loaded to remain closed with a differential pressure of -2 psig on the downstream containment side, and atmospheric pressure on the upstream side. The body, disk, cap, and stuffing boxes for the weight arms are constructed of stainless steel. The disk seat and shaft seal are made of either nitrile rubber or ethylene-propylene rubber. These materials have been shown (Reference 7) to be resistant to radiation damage for doses up to 5×10^7 R.

Equipment outside the containment is seismically analyzed. The quench spray (QS) pump discharge MOVs, located in the Safeguards Area, are included in the environmental qualification program and will function in the environmental conditions of a design basis accident.

3.11.2.2 **Recirculation Spray Subsystem**

In addition to piping, spray nozzles, and positive closure check valves (discussed under the quench spray subsystem above), the recirculation spray subsystem components located inside the containment are the inside recirculation spray pumps and motors, and the recirculation spray coolers.

The inside recirculation spray motors were qualified for this application by subjecting a motor of identical design and rating to complete environmental tests using methods in IEEE Standard 334-1971. The entire motor, complete with motor lead seals and grease, was subjected to gamma radiation to a cumulative exposure of 2×10^8 rads. The motor was run at full load in an accident environment simulation chamber.

The motors were also vibration-tested in accordance with IEEE-344-1971.

The design radiation dose is calculated to be 3.5×10^4 R gamma over the original 40-year license period design life, with a maximum dose of 7.5×10^6 R gamma experienced during a design basis accident. The radiation doses for equipment located inside the containment have been calculated assuming an instantaneous release of 100% of the noble gas and 50% of the halogen inventory to the containment atmosphere. The impact of increased dose associated with an additional 20 years of normal operation (1.8×10^4 R gamma) is accounted for in the environmental qualification of the recirculating spray pump motor.

The results of the environment test of the recirculating spray pump motor are the subject of a topical report submitted under Docket Nos. 50-280 and 50-281.

The power to the inside recirculation spray motors is provided by three-conductor, stranded copper cable with heat- and flame-resistant insulation and asbestos jacket rated for a maximum 125°C ambient temperature. The cable used to terminate the inside circulation spray pump motor was environmentally qualified to the requirements of IEEE 383-1974. The vendor testing envelopes the environment in which the cables are expected to operate in. A supporting Virginia Power analysis of the vendor test reports are referenced in QDR-N-6.3 (Reference 9).

The recirculation spray coolers have been designed to withstand the DBA environmental pressures and seismic loads. They are fabricated from stainless steel and therefore are not affected by radiation.

The containment sump level transmitters were supplied by Gems-Transamerica Delaval and are environmentally qualified to the requirements of IEEE 323-1974. The tested parameters envelope the required as demonstrated in QDR-N-8.3 (Reference 6).

The cable associated with the level transmitters is identified in QDR-N-8.3 and they are also environmentally qualified.

3.11.2.3 Containment Vacuum and Leakage Monitoring System

There are no leakage monitoring system components located within the containment, with the exception of pressure-sensing lines. The containment vacuum system contains some check valves that are located within containment. These check valves are not required for containment isolation and therefore, are not required to withstand an accident environment. Consequently, environmental testing of these components is not required.

3.11.2.4 Containment Isolation Valves

Air-operated trip valves and check valves used for containment isolation inside the containment have been designed to withstand the containment environment. There are no materials in these valves susceptible to failure from environmental conditions that could prevent the valve from closing; therefore, no environmental test is required.

The electric solenoid operators that control air to the air-operated isolation valves have been environmentally qualified to meet the requirements of IEEE 323-1974. Qualification of these solenoid valves is demonstrated in QDR-N-35.1 (Reference 8).

3.11.2.5 Service Water System

As indicated in Table 3.11-2, the only components of the service water system that are subjected to the combined high temperature, pressure, humidity, and radiation environment are the check valves and piping going to the recirculation spray heat exchangers located in containment. No environmental testing or analysis is necessary for the carbon steel piping. The check valves meet the criteria specified in NUREG-0578, Section 2.1.6.b, for increased cumulative radiation resistance.

3.11.2.6 Feedwater Systems

No environmental testing is required, as these are outside the containment.

3.11.2.7 Control and Electrical Equipment

Section 7.7 discusses electronic instrumentation, including environmental effects.

3.11.2.8 Diesel-Generator Control Panels and 480V Motor Control Centers

Qualification information for the diesel-generator control panels and the 480V motor control centers is contained in References 10, 11, and 12.

Qualification test information, References 13 through 31, for balance of plant class 1E equipment was forwarded to the NRC by Reference 32, and is outlined in Table 3.11-4.

3.11.2.9 Electrical Equipment Qualification

The Virginia Power Equipment Qualification Program encompasses the complex process of environmental qualification which demonstrates that certain safety-related equipment which is subjected to a harsh environment will meet or exceed its performance requirements during and following a design-basis event (DBE) throughout its installed life.

The qualification of electrical equipment is the result of the issuance of IE Bulletin 79-01B in January 1980. Subsequently, on January 21, 1983, the NRC issued the EQ Rule (10 CFR 50.49).

As identified in IE Bulletin 79-01B, Supplement 2, all reactors with operating licenses as of May 23, 1980, will be evaluated against the DOR Guidelines (included with IEB 79-01B). Those plants with a construction permit granted after July 1, 1974 and operating license granted after May 23, 1980, the equipment will be qualified to the requirements of NUREG 0588, Category II. Therefore, the equipment qualification basis is IEB 79-01B for Unit 1 and NUREG 0588, Category II for Unit 2. The results of Virginia Power's review of IEB 79-01B and NUREG 0588 were reported in References 33 and 34, respectively.

Paragraph (k) of 10 CFR 50.49 grandfathered the qualification basis such that the utility did not have to re-qualify the equipment if it was previously qualified to the DOR Guidelines or NUREG 0588. However, paragraph (1) of 10 CFR 50.49 requires the replacement equipment of that grandfathered be upgraded to the requirements of the EQ Rule unless there are sound reasons to the contrary.

The electrical equipment qualified to the requirements of 10 CFR 50.49 is identified on the Equipment Qualification Master List (EQML). There is an EQML for each unit at North Anna.

3.11.3 Corrosion Prevention for Underground Piping

The following portions of systems, and components within these systems, are located underground and are required to attain a safe shutdown:

1. Service water system - underground piping, carbon steel.
2. Quench spray system - underground piping, stainless steel.
3. Safety injection system - underground piping, stainless steel.
4. Fuel-oil system - underground fuel tank, carbon steel; underground piping, carbon steel, and Stainless Steel.
5. Fire main - underground piping, cast iron, and ductile iron.
6. Condensate piping - underground piping, carbon steel.

The protective steps and measures taken are in accordance with National Association of Corrosion Engineers (NACE) Recommended Practice RP-01-69. All underground steel pipelines and tanks are coated and wrapped in accordance with Section 5, Coatings, of the above standard. The standard does not address itself to stainless steel piping. Analysis indicates that no protective coating is required. However, to provide additional protection for the buried stainless steel Fuel Oil piping an approved coating will be applied.

In addition, insulating flanges and/or cathodic protection systems are being used, as required, for each particular piping system. The determination of which method of corrosion control to use was based upon a corrosion survey in accordance with Section 3, Determination of Need for Corrosion Control, of NACE RP-01-69.

An impressed current cathodic protection system was installed to protect the buried service water piping headers. The cathodic protection system is divided into 4 subsystems. Each of the four subsystems will protect a specific portion of Service Water piping. The subsystems are divided as follows:

Subsystem A: Four 36" supply and return (abandoned) lines from the service water pump house to the Tie-in Vault.

Subsystem B: Two 32-1/4" return lines from the Tie-in Vault to the Service Water Valve House expansion joint pit.

Subsystem C: Four 36" supply and return lines from the Tie-in Vault to the Auxiliary and Safeguards buildings.

Subsystem D: Two 24" auxiliary supply line from the Auxiliary Service Water Valve Pit to the Turbine Building Valve Pit.

Buried piping adjacent to the service water headers is also bonded into the cathodic protection system to mitigate the corrosive effects of stray currents of the service water cathodic protection. Piping that is bonded in the subsystems includes: (1) 6" and 12" fire mains; (2) 4" domestic water mains; (3) 2" well water mains; (4) instrument air lines; and (5) 10- 1-1/2" fuel oil lines. Test stations are installed on unbonded sections of buried pipe to allow monitoring for stray currents and subsequently assure adequate pipe protection.

The design, installation, and maintenance of the service water cathodic protection is in accordance with NACE RP-01-69 (1983). Cathodic protection of the service water lines is achieved through impressed current from a series of anodes installed parallel to each piping subsystem. Each cathodic protection subsystem utilizes a dedicated rectifier for the anode current power supply. All cable connections to the service water piping are made in the S.W. Tie-in Vault or Auxiliary S.W. Valve Pit (as applicable). Test cables and reference cells are provided to permit testing of the service water piping and the effectiveness of the Cathodic Protection Subsystems.

3.11 REFERENCES

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Table 3.11-1

VALVES IN THE REACTOR COOLANT PRESSURE BOUNDARY-WESTINGHOUSE SCOPE

System	Function	Mark Number[a]	ValveType	Valve Size (in.)	Actuation Type	Environmental Design Criteria Note
RC	Pressure safety valve	1-RC-SV-1551A, B, C	Safety	6	Pressure-spring loaded	--
CH	Letdown line	1-CH-LCV-1460A, B	Globe	2	Air	1
CH	Charging line	1-CH-322, 1-CH-325, 1-CH-496	Check	3	ΔP	3
CH	Letdown line orifice isolation	1-CH-HCV-1200A, B, C	Globe	2	Air	1
CH	Letdown line containment isolation	1-CH-TV-1204A, B	Globe	2	Air	1
CH	Seal return isolation	1-CH-MOV-1380	Gate	3	Motor	2
CH	Seal return isolation	1-CH-MOV-1381	Gate	3	Motor	2
CH	Seal return line pressure relief	1-CH-402	Check	3/4	ΔP	--
CH	Seal injection	1-CH-336, 1-CH-339, 1-CH-358, 1-CH-361, 1-CH-380, 1-CH-383	Check	2	ΔP	--
CH	Charging	1-CH-MOV-1289A	Globe	3	Motor	2
CH	Loop fill header	1-CH-330	Check	2	ΔP	--
CH	Loop fill header	1-CH-FCV-1160	Globe	2	Air	1
RH	Discharge isolation	1-RH-MOV-1720A, B	Gate	10	Motor	2
RH	Hot leg isolation	1-RH-MOV-1701	Gate	14	Motor	2
RH	Hot leg isolation	1-RH-MOV-1700	Gate	14	Motor	2

a. Unit 1 equipment is listed. Unit 2 equipment is similar.

Table 3.11-1 (continued)
VALVES IN THE REACTOR COOLANT PRESSURE BOUNDARY-WESTINGHOUSE SCOPE

System	Function	Mark Number[a]	ValveType	Valve Size (in.)	Actuation Type	Environmental Design Criteria Note
SI	Cold legs	1-SI-190, 1-SI-192, 1-SI-194	Check	2	ΔP	--
SI	Boron injection tank containment isolation	1-SI-79	Check	3	ΔP	3
SI	Boron injection tank containment isolation	1-SI-MOV-1867C, D	Gate	3	Motor	2
SI	Cold legs	1-SI-127, 1-SI-144, 1-SI-161	Check	12	ΔP	3
SI	Cold legs	1-SI-125, 1-SI-142, 1-SI-159	Check	12	ΔP	3
SI	Hot legs	1-SI-95, 1-SI-99, 1-SI-103	Check	6	ΔP	3
SI	Hot legs	1-SI-209, 1-SI-211, 1-SI-213	Check	6	ΔP	3
SI	Hot leg isolation	1-SI-MOV-1869A, B	Gate	3	Motor	2
SI	Cold legs	1-SI-195, 1-SI-197, 1-SI-199	Check	6	ΔP	3
SI	Cold leg isolation	1-SI-185	Check	3	ΔP	3
SI	Cold leg isolation	1-SI-83, 1-SI-86, 1-SI-89	Check	6	ΔP	3
SI	Cold leg isolation	1-SI-MOV-1836	Gate	3	Motor	2
SI	Hot leg isolation	1-SI-90, 1-SI-201	Check	3	ΔP	3
SI	SI test	1-SI-TV-1842	Globe	3/4	Air	1
SI	SI test	1-SI-TV-1859	Globe	3/4	Air	1
SI	LHSI cold leg isolation	1-SI-MOV-1890C, D	Gate	10	Motor	2

a. Unit 1 equipment is listed. Unit 2 equipment is similar.

Table 3.11-1 (continued)
VALVES IN THE REACTOR COOLANT PRESSURE BOUNDARY-WESTINGHOUSE SCOPE

System	Function	Mark Number[a]	ValveType	Valve Size (in.)	Actuation Type	Environmental Design Criteria Note
SI	LHSI hot leg isolation	1-SI-MOV-1890A, B	Gate	10	Motor	2
SI	LHSI hot leg	1-SI-206, 1-SI-207	Check	6	ΔP	--

Notes

1. T_{avg}: 120°F
   Normal pressure 8-15 psia
   50 R/hr gamma radiation.
2. T_{avg}: 120°F
   Accident Environment: Saturated steam-air mixture with 0.2% boric acid 1.8% boric acid spray with sodium hydroxide.
3. T_{avg}: 120-150°F
   Normal pressure 8-15 psia
   15-20 R/hr gamma radiation
   100% relative humidity.
4. Valve nomenclature used in the table is:
   MOV - motor-operated valve
   TV - trip valve
   HCV - hand control valve
   PCV - pressure control valve
   NRV - non-return valve
   SV - safety valve

a. Unit 1 equipment is listed. Unit 2 equipment is similar.

Table 3.11-2
LOCATION OF ESF OR SAFETY RELATED DEVICES

Engineered Safety Feature	Location	Use
1. Quench spray subsystem		
a. Refueling water storage tank	Yard adjacent to Quench Spray Pump House	Storage tank for water for containment depressurization and emergency core cooling
b. Quench spray pumps	Quench Spray Pump House	Containment depressurization
c. Quench spray pump discharge strainers	Quench Spray Pump House	Prevent containment spray nozzle clogging
d. Piping[a]	Yard, Quench Spray Pump House, containment	Containment depressurization
e. Nozzles[a]	Inside containment on dome	Spray dispersion
f. Motor-operated valves	Quench Spray Pump House	Open in Containment Depressurization Actuation (CDA); close on depletion of refueling water
g. Check valves[a]	Quench Spray Pump House, inside containment	Containment isolation
h. Refueling water chemical addition tank	Yard adjacent to refueling water storage tank	Storage tank for addition of NaOH for improving iodine removal
2. Recirculation spray subsystem		
a. Outside recirculation spray pumps and motors[b]	Safeguards Building	Remove containment heat
b. Inside recirculation spray pumps and motors[a]	Inside containment	Remove containment heat
c. Recirculation spray coolers[a]	Inside containment	Remove containment heat
d. Motor-operated valves[b]	Safeguards Building	Open on CDA

a. Equipment located inside containment must withstand the containment environment up to and during their time of operation.
b. Equipment located outside the containment but exposed to containment atmosphere or containment sump water.

Table 3.11-2 (continued)
LOCATION OF ESF OR SAFETY RELATED DEVICES

Engineered Safety Feature	Location	Use
e. Check valves[a]	Inside containment	Containment isolation
2. Recirculation spray subsystem (continued)		
f. Nozzles[a]	Inside containment	Containment cooling
g. Piping[a]	Safeguards Building, containment	Spray water for containment heat removal
h. Outside pump seal water tank level switch[b]	Safeguards Building	Alarm - seal water tank low level
i. Casing cooling pumps	Casing Cooling Building	Cooling water to outside recirc. spray suction piping
j. Casing cooling tank	Yard adjacent to Casing Cooling Building	Storage for cooling water to outside recirculation spray (ORS) pump suction
k. Motor-operated valves	Safeguards Building	Open on CDA; close when casing cooling tank empty, and containment isolation
l. Piping	Casing Cooling Building, Safeguards Building, yard adjacent to Casing Cooling Building	Cooling water from tank to ORS pump suction
3. Containment vacuum and leak monitoring system		
a. Pressure transmitters[b]	Auxiliary Building	Containment depressurization actuation signal
4. Containment isolation valves		
a. Trip valves[a]	Inside and outside of containment penetration	Containment isolation
b. Check valves[a]	Inside containment	Containment isolation
5. Auxiliary feedwater system		

a. Equipment located inside containment must withstand the containment environment up to and during their time of operation.
b. Equipment located outside the containment but exposed to containment atmosphere or containment sump water.

Table 3.11-2 (continued)
LOCATION OF ESF OR SAFETY RELATED DEVICES

Engineered Safety Feature	Location	Use
a. Auxiliary steam generator feed pumps	Auxiliary Feedwater Pump House	Provide water for decay heat removal
5. Auxiliary feedwater system (continued)		
b. Emergency condensate storage tanks	Yard adjacent to Auxiliary Feedwater Pump House	Feed water for auxiliary steam generator feed pump steam
c. Control valves	Auxiliary Feedwater Pump House	Control steam generator feedwater
6. Service water system components		
a. Service water pumps	Service Water Pump House	Containment and reactor heat removal
b. Auxiliary service water pumps	Main circulating water intake structure	Back-up for service water pumps
c. Service water screen wash pumps	Service Water Pump House	Clean screens
d. Service water screens	Service Water Pump House	Remove leaves and debris
e. Service water make-up pumps (CW screenwash)	Main circulating water intake structure	Maintain service water reservoir level
f. Service water MOVs	Service water valve house, turbine building, auxiliary building, quench spray pump house, and main circulating water intake structure	Isolate service water to component cooling heat exchangers, open service water to recirculation spray heat exchangers on accident plant, isolate service water to bypass header, and open service water to spray arrays

a. Equipment located inside containment must withstand the containment environment up to and during their time of operation.
b. Equipment located outside the containment but exposed to containment atmosphere or containment sump water.

Table 3.11-2 (continued)
LOCATION OF ESF OR SAFETY RELATED DEVICES

Engineered Safety Feature	Location	Use
6. Service water system components (continued)		
g. Service water check valves[a]	Containment, service water pump house, auxiliary building, main circulating water intake structure, quench spray pump house, turbine building, and service building	Continuous isolation
h. Service water piping[a]	Containment, service water pump house, main circulating water intake structure, yard, auxiliary building, turbine building, service water valve house, quench spray pump house, and service building.	Cooling water for recirculation spray heat exchangers and various plant water systems
i. Service water radiation monitor pumps	Quench spray pump house	Sample service water from recirculation spray heat exchangers
j. Service water radiation monitors	Quench spray pump house shielded room	Detect recirculation spray heat exchanger leakage
k. Nozzles	Service water reservoir	Spray cooling water in spray pond

a. Equipment located inside containment must withstand the containment environment up to and during their time of operation.
b. Equipment located outside the containment but exposed to containment atmosphere or containment sump water.

Table 3.11-3
VALVES IN SEISMIC CLASS I SYSTEMS (STONE & WEBSTER SCOPE)

System	Valve Identification [a, b]	Valve Type	Valve Size (in.)	Actuation Type	Environmental Design [c]
Steam generator blowdown	TV-BD-100A	Globe	3	Air/spring	2
	TV-BD-100B	Globe	3	Air/spring	2
	TV-BD-100C	Globe	3	Air/spring	2
	TV-BD-100D	Globe	3	Air/spring	2
	TV-BD-100E	Globe	3	Air/spring	2
	TV-BD-100F	Globe	3	Air/spring	2
	TV-BD-100G	Globe	3	Air/spring	2
	TV-BD-100H	Globe	3	Air/spring	2
	TV-BD-100J	Globe	3	Air/spring	2
Component cooling	TV-CC-100A	Butterfly	6	Air/spring	2
	TV-CC-100B	Butterfly	6	Air/spring	2
	TV-CC-100C	Butterfly	6	Air/spring	2
	TV-CC-101A	Globe	4	Air/spring	2
	TV-CC-101B	Globe	4	Air/spring	2
	TV-CC-102A	Butterfly	8	Air/spring	2
	TV-CC-102B	Butterfly	8	Air/spring	2
	TV-CC-102C	Butterfly	8	Air/spring	2
	TV-CC-102D	Butterfly	8	Air/spring	2
	TV-CC-102E	Butterfly	8	Air/spring	2
	TV-CC-102F	Butterfly	8	Air/spring	2
	TV-CC-103A	Butterfly	18	Air/spring	2
	TV-CC-103B	Butterfly	18	Air/spring	2
	TV-CC-104A	Butterfly	8	Air/spring	2
	TV-CC-104B	Butterfly	8	Air/spring	2
	TV-CC-104C	Butterfly	8	Air/spring	2
	TV-CC-105A	Butterfly	6	Air/spring	2
	TV-CC-105B	Butterfly	6	Air/spring	2
	TV-CC-105C	Butterfly	6	Air/spring	2
	TV-CC-115A	Butterfly	8	Air/spring	2
	TV-CC-115B	Butterfly	8	Air/spring	2
	TV-CC-115C	Butterfly	8	Air/spring	2
Containment vacuum	TV-CV-150A	Globe	2	Air/spring	2
	TV-CV-150B	Globe	2	Air/spring	2
	TV-CV-150C	Globe	2	Air/spring	2
	TV-CV-150D	Globe	2	Air/spring	2
Screenwash	TV-CW-100	3-way	8	Air/spring	2
Vent and drain	TV-DA-100A	Globe	2	Air/spring	2
	TV-DA-100B	Globe	2	Air/spring	2
	TV-DG-100A	Globe	2	Air/spring	2
	TV-DG-100B	Globe	2	Air/spring	2

Table 3.11-3 (continued)
VALVES IN SEISMIC CLASS I SYSTEMS (STONE & WEBSTER SCOPE)

System	Valve Identification [a, b]	Valve Type	Valve Size (in.)	Actuation Type	Environmental Design [c]
Gas waste	TV-GW-102A	Globe	2	Air/spring	2
	TV-GW-102B	Globe	2	Air/spring	2
Leakage monitoring	TV-LM-100A	Globe	3/8	Air/spring	2
	TV-LM-100B	Globe	3/8	Air/spring	2
	TV-LM-100C	Globe	3/8	Air/spring	2
	TV-LM-100D	Globe	3/8	Air/spring	2
	TV-LM-100E	Globe	3/8	Air/spring	2
	TV-LM-100F	Globe	3/8	Air/spring	2
	TV-LM-100G	Globe	3/8	Air/spring	2
	TV-LM-100H	Globe	3/8	Air/spring	2
	TV-LM-101A	Globe	3/8	Air/spring	2
	TV-LM-101B	Globe	3/8	Air/spring	2
Main steam	TV-MS-101A	Check	32	Air/spring	3
	TV-MS-101B	Check	32	Air/spring	3
	TV-MS-101C	Check	32	Air/spring	3
	TV-MS-109	Globe	3	Air/spring	2
	TV-MS-110	Globe	1 1/2	Air/spring	2
	TV-MS-111A	Globe	3	Air/spring	2
	TV-MS-111B	Globe	3	Air/spring	2
	TV-MS-113A	Globe	3	Air/spring	2
	TV-MS-113B	Globe	3	Air/spring	2
	TV-MS-113C	Globe	3	Air/spring	2
Radiation monitoring	TV-RM-100A	Globe	1	Air/spring	2
	TV-RM-100B	Globe	1	Air/spring	2
	TV-RM-100C	Globe	1	Air/spring	2
Safety injection	TV-SI-100	Globe	1	Air/spring	2
	TV-SI-101	Globe	1	Air/spring	2
Sampling	TV-SS-100A	Globe	3/8	Air/spring	2
	TV-SS-100B	Globe	3/8	Air/spring	2
	TV-SS-101A	Globe	3/8	Air/spring	2
	TV-SS-101B	Globe	3/8	Air/spring	2
	TV-SS-102A	Globe	3/8	Solenoid/spring	2
	TV-SS-102B	Globe	3/8	Solenoid/spring	2
	TV-SS-103A	Globe	3/8	Solenoid/spring	2
	TV-SS-103B	Globe	3/8	Solenoid/spring	2
	TV-SS-104A	Globe	3/8	Air/spring	2
	TV-SS-104B	Globe	3/8	Air/spring	2
	TV-SS-106A	Globe	3/8	Solenoid/spring	2
	TV-SS-106B	Globe	3/8	Solenoid/spring	2

Table 3.11-3 (continued)
VALVES IN SEISMIC CLASS I SYSTEMS (STONE & WEBSTER SCOPE)

System	Valve Identification [a, b]	Valve Type	Valve Size (in.)	Actuation Type	Environmental Design [c]
Sampling (continued)	TV-SS-112A	Globe	3/8	Air/spring	2
	TV-SS-112B	Globe	3/8	Air/spring	2
Auxiliary steam	TV-SV-102-1	Globe	6	Air/spring	2
Service water	TV-SW-101A	Butterfly	8	Air/spring	2
	TV-SW-101B	Butterfly	8	Air/spring	2
Vent and drain	TV-VG-100A	Globe	1 1/2	Air/spring	2
	TV-VG-100B	Globe	1 1/2	Air/spring	2
Component cooling	MOV-CC-100A	Butterfly	18	Motor	1
	MOV-CC-100B	Butterfly	18	Motor	1
Feedwater	MOV-FW-100A	Globe	3	Motor	1
	MOV-FW-100B	Globe	3	Motor	1
	MOV-FW-100C	Globe	3	Motor	1
	MOV-FW-100D	Globe	3	Motor	1
Quench spray	MOV-QS-100A	Gate	10	Motor	1
	MOV-QS-100B	Gate	10	Motor	1
	MOV-QS-101A	Gate	8	Motor	1
	MOV-QS-101B	Gate	8	Motor	1
	MOV-QS-102A	Gate	6	Motor	1
	MOV-QS-102B	Gate	6	Motor	1
Recirculation spray	MOV-RS-155A	Gate	12	Motor	1
	MOV-RS-155B	Gate	12	Motor	1
	MOV-RS-156A	Gate	10	Motor	1
	MOV-RS-156B	Gate	10	Motor	1
Service water	MOV-SW-101A	Butterfly	24	Motor	1
	MOV-SW-101B	Butterfly	24	Motor	1
	MOV-SW-101C	Butterfly	24	Motor	1
	MOV-SW-101D	Butterfly	24	Motor	1
	MOV-SW-102A	Butterfly	24	Motor	1
	MOV-SW-102B	Butterfly	24	Motor	1
	MOV-SW-103A	Butterfly	16	Motor	1
	MOV-SW-103B	Butterfly	16	Motor	1
	MOV-SW-103C	Butterfly	16	Motor	1
	MOV-SW-103D	Butterfly	16	Motor	1

Table 3.11-3 (continued)
VALVES IN SEISMIC CLASS I SYSTEMS (STONE & WEBSTER SCOPE)

System	Valve Identification [a, b]	Valve Type	Valve Size (in.)	Actuation Type	Environmental Design [c]
Service water (continued)	MOV-SW-104A	Butterfly	16	Motor	1
	MOV-SW-104B	Butterfly	16	Motor	1
	MOV-SW-104C	Butterfly	16	Motor	1
	MOV-SW-104D	Butterfly	16	Motor	1
	MOV-SW-105A	Butterfly	24	Motor	1
	MOV-SW-105B	Butterfly	24	Motor	1
	MOV-SW-105C	Butterfly	24	Motor	1
	MOV-SW-105D	Butterfly	24	Motor	1
	MOV-SW-106A	Butterfly	24	Motor	1
	MOV-SW-106B	Butterfly	24	Motor	1
	MOV-SW-108A	Butterfly	24	Motor	1
	MOV-SW-108B	Butterfly	24	Motor	1
	MOV-SW-110A	Butterfly	8	Motor	1
	MOV-SW-110B	Butterfly	8	Motor	1
	MOV-SW-113A	Butterfly	10	Motor	1
	MOV-SW-113B	Butterfly	10	Motor	1
	MOV-SW-114A	Butterfly	8	Motor	1
	MOV-SW-114B	Butterfly	8	Motor	1
	MOV-SW-115A	Butterfly	24	Motor	1
	MOV-SW-115B	Butterfly	24	Motor	1
	MOV-SW-117	Butterfly	24	Motor	1
	MOV-SW-119	Butterfly	8	Motor	1
	MOV-SW-120A	Butterfly	24	Motor	1
	MOV-SW-120B	Butterfly	24	Motor	1
	MOV-SW-121A[d]	Butterfly	18	Motor	4
	MOV-SW-121B[d]	Butterfly	18	Motor	4
	MOV-SW-122A[d]	Butterfly	18	Motor	4
	MOV-SW-122B[d]	Butterfly	18	Motor	4
	MOV-SW-123A[d]	Butterfly	24	Motor	4
	MOV-SW-123B[d]	Butterfly	24	Motor	4
Main steam	NRV-MS-101A	Angle stop check	32	Self actuated	3
	NRV-MS-101B	Angle stop check	32	Self actuated	3
	NRV-MS-101C	Angle stop check	32	Self actuated	3
	NRV-MS-103A	Angle stop check	3	Self actuated	3
	NRV-MS-103B	Angle stop check	3	Self actuated	3
	NRV-MS-103C	Angle stop check	3	Self actuated	3
	PCV-MS-101A	Angle globe	6	Air/spring	4
	PCV-MS-101B	Angle globe	6	Air/spring	4
	PCV-MS-101C	Angle globe	6	Air/spring	4

Table 3.11-3 (continued)
VALVES IN SEISMIC CLASS I SYSTEMS (STONE & WEBSTER SCOPE)

System	Valve Identification [a, b]	Valve Type	Valve Size (in.)	Actuation Type	Environmental Design [c]
Main steam (continued)	SV-MS-101A	Safety	6x10	Self actuated	3
	SV-MS-101B	Safety	6x10	Self actuated	3
	SV-MS-101C	Safety	6x10	Self actuated	3
	SV-MS-102A	Safety	6x10	Self actuated	3
	SV-MS-102B	Safety	6x10	Self actuated	3
	SV-MS-102C	Safety	6x10	Self actuated	3
	SV-MS-103A	Safety	6x10	Self actuated	3
	SV-MS-103B	Safety	6x10	Self actuated	3
	SV-MS-103C	Safety	6x10	Self actuated	3
	SV-MS-104A	Safety	6x10	Self actuated	3
	SV-MS-104B	Safety	6x10	Self actuated	3
	SV-MS-104C	Safety	6x10	Self actuated	3
	SV-MS-105A	Safety	6x10	Self actuated	3
	SV-MS-105B	Safety	6x10	Self actuated	3
	SV-MS-105C	Safety	6x10	Self actuated	3
	HCV-MS-104	Globe	4	Air/spring	4
Safety injection	PCV-SI-100	Globe	3/4	Self actuated	3
Feedwater	HCV-FW-100A	Globe	3	Air/spring	4
	HCV-FW-100B	Globe	3	Air/spring	4
	HCV-FW-100C	Globe	3	Air/spring	4
	PCV-FW-159A	Globe	4	Air/spring	4
	PCV-FW-159B	Globe	4	Air/spring	4
Ventilation	MOV-HV-111A	Gate	4	Motor	3
	MOV-HV-111B	Gate	4	Motor	3
	MOV-HV-111C	Gate	4	Motor	3

a. Identification is for Unit 1; Unit 2 valves are identical.
b. Valve nomenclature used in the table is:
MOV - motor-operated valve TV - trip valve
HCV - hand control valve PCV - pressure control valve
NRV - non-return valve SV - safety valve
c. Environmental Design:
1. Motor is built to USASI standards for intermittent duty. The motor type is TENV. The valve and its operator are seismically designed.
2. These valves are capable of operation under normal containment atmospheric conditions and to a total radiation of 3×10^5 rads. The containment isolation valves are designed to close upon receipt of an actuation signal or loss of power or air. These valves are seismically designed.
3. These valves are seismically designed.
4. These valves and operators are seismically designed.

d. These six valves were specified, procured and installed by Virginia Power. They replaced the original valves MOV-SW-100A and B. Also, see Footnote a.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.11-4

QUALIFICATION OF ESF DEVICES

Category	Qualification Requirement	Qualification Tests and/or Analysis
Emergency diesel generator control equipment	Seismic requirements are outlined on page 13 (paragraph 28) and on form QCD-101-EA 10/70 of Reference 13.	Seismic analysis: Reference 14.
Switchgear (4160V)	Seismic requirements are outlined on page 16 (paragraph 55) and on form QCD-101 of Reference 15.	Seismic test: References 16, 17, and 18.
Motor control centers	Seismic requirements are outlined in section entitled Motor Control Center Earthquake Requirements and on form QCD-101-EA 10/70 of Reference 19.	Seismic test: References 20, 21, and 22.
Cable	Special test requirements are outlined on pages 1-13 and on form QCD-100 of Reference 23.	Special Tests: Reference 24.
Control valves	Seismic requirements are outlined in section entitled Earthquake Requirements of Reference 25.	Seismic analysis: Reference 26. In addition, the electric solenoid operators that control air to the air operated isolation valves are environmentally qualified.
Motors	Seismic requirements are outlined in section entitled Earthquake Requirements and on form QCD-101 of Reference 27. Note that the inside recirculation spray pump motors for North Anna were ordered under the same specification as that for Surry 1 and 2.	Seismic analysis: Reference 28 and Topical Report on G.E. Vertical Induction Motors Inside Containment, Recirculation Spray Pump Motors, dated 6/12/73 and by Mr. M. W. Sheets of General Electric Company. 73 copies of this Topical Report were forwarded to the Commission in VEPCO letter of July 17, 1973 (Serial No. 03773) under Docket Nos. 50-280 and 50-281, and License Nos. DPR-32 and 37.
Logic equipment (W 7300 Series)	Seismic requirements are outlined in section entitled Earthquake Requirements of Reference 29.	Seismic test: References 30 and 31. In addition, the W 7300 Series Logic Equipment was seismically tested as described in the July 10, 1975 (Serial No. NS-CE-692) Westinghouse letter to the Commission.

Appendix 3A
Compliance with Safety Guides

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APPENDIX 3A COMPLIANCE WITH SAFETY GUIDES

North Anna Power Station Units 1 and 2 were issued Construction Permit Nos. CPPR-77 and CPPR-78 in February 1971, based on the station design presented in the Preliminary Safety Analysis Report. At this time only Safety Guides 1 through 4 had been issued; however, this section was added to discuss compliance with safety guides to facilitate the Atomic Energy Commission's operating license stage review. This Appendix is not intended to be a comprehensive review of regulatory guides to date.

The sections of this Appendix are numbered so as to correspond with the numbering of the Safety Guides. Therefore, since some Safety Guides are omitted, the section numbering is not always sequential.

3A.1 NET POSITIVE SUCTION HEAD FOR EMERGENCY CORE COOLING AND CONTAINMENT HEAT REMOVAL SYSTEM PUMPS (SAFETY GUIDE NO. 1)

The intent of Safety Guide No. 1 is met with the subatmospheric containment design.

3A.1.1 Regulatory Position

Emergency core cooling and containment heat removal systems should be designed so that adequate net positive suction head (NPSH) is provided to system pumps, assuming maximum expected temperatures of pump fluids and no increase in containment pressure from that present prior to postulated LOCAs.

3A.1.2 Discussion

The operation of the emergency core cooling system is not dependent on containment pressure. Water for safety injection is initially drawn from the refueling water storage tank (RWST).

Recirculation safety injection occurs prior to the refueling water storage tank becoming empty. The point at which the switch to the recirculation safety injection mode occurs ensures that adequate NPSH is available for the pumps from either water source. Transferal of the contents of the refueling water storage tank via safety injection and quench sprays into the containment results in pump water temperatures of approximately 150°F, even without recirculation spray cooling. This ensures sufficient net positive suction head for the recirculation safety injection mode.

Minimum net positive suction head occurs without containment impairment when the containment pressure returns to subatmospheric after the design basis accident. Section 6.2.2 presents the net positive suction head available and states the pump NPSH requirements.

The recirculation sprays are started by containment pressure and are only required if an increase in containment pressure to the CDA setpoint occurs. Although the initial operation of the recirculation spray pumps requires containment pressure to provide sufficient net positive suction head, the recirculation spray system meets the requirements of Safety Guide 1; that is, to provide containment cooling and recirculation spray flow when required.

The design of the recirculation spray subsystem for the North Anna (Units 1 and 2) Power Station (see Section 6.2.2) is similar to that for the Surry Power Station (Units 1 and 2, Docket Nos. 50-280 and 50-281) and the Beaver Valley Power Station (Unit 1, Docket No. 50-334).

3A.2 THERMAL SHOCK TO REACTOR PRESSURE VESSELS (SAFETY GUIDE NO. 2)

The following section no longer represents the current licensing basis for North Anna Power Station Units 1 and 2. As of June 17, 1991, Safety Guide 2 (and its successor Regulatory Guide 1.2) was withdrawn, and superseded by 10 CFR 50.61, *Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock Events.* Pressurized Thermal Shock is discussed in more detail in Section 5.2.2.4.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Current Westinghouse research programs and pressure vessel design conform with the intent of Safety Guide No. 2.

Westinghouse is continuing to obtain fracture toughness data through participation in the Heavy Section Steel Technology (HSST) Program at the Oak Ridge National Laboratory. The fracture toughness data obtained include tests on irradiated and unirradiated material using specimens up to 12 inches thick. In addition, new testing techniques have evolved, which allow the measurement of valid fracture toughness data with much smaller specimens than have been used in the past. These unirradiated data correspond to start-up or beginning of life of the plant.

Postirradiation data obtained from thick specimens and the newly evolved elastic-plastic test procedure simplify the problem of obtaining and evaluating irradiated fracture toughness data. Westinghouse is also engaged in an extensive materials irradiation surveillance program from which irradiated fracture toughness data are obtained for actual vessel material.

The present data were used in a rigorous linear-elastic fracture mechanics analysis of the reactor vessel thermal shock problem. The results of this analysis have shown that under the postulated accident conditions, the integrity of the reactor vessel would be maintained throughout the life of a plant. Westinghouse's continuing participation in the HSST Program will yield confirmatory information on material properties and fracture mechanics analytical methods.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

If additional margin against brittle failure is required, or if the remaining data from the HSST Program do not confirm the present analysis, the reactor vessel could be annealed. Westinghouse is engaged in a research program to determine the optimum annealing time and temperature. No hardware for vessel annealing has yet been designed, but appropriately designed space heaters could be used as one conceivable method of annealing. The design of Westinghouse reactor vessels does not preclude postirradiation heat treatment.

3A.3 ASSUMPTIONS USED FOR EVALUATING THE POTENTIAL RADIOLOGICAL CONSEQUENCES OF A LOCA FOR BOILING WATER REACTORS (SAFETY GUIDE NO. 3)

This safety guide is not applicable to North Anna Power Station Units 1 and 2.

3A.4 ASSUMPTIONS USED FOR EVALUATING THE POTENTIAL RADIOLOGICAL CONSEQUENCES OF A LOCA FOR PRESSURIZED WATER REACTORS (SAFETY GUIDE NO. 4)

The assumptions used for the LOCA analysis are consistent with Safety Guide No. 4 as clarified below:

Regulatory Position	Reference Section	Regulatory Position	Reference Section
C.1.a	15.4.1.9	C.2.b	15.4.1.9
C.1.b	15.4.1.9	C.2.c	15.4.1.9
C.1.c	15.4.1.9	C.2.d	15.4.1.9
C.1.d	15.4.1.9	C.2.e	15.4.1.9
C.1.e	15.4.1.9	C.2.f	15.4.1.9
C.2.a	15.4.1.9		

An analysis of the behavior of a chemical spray as a function of the pertinent parameters that are expected in the containment atmosphere following the design basis accident is described in Section 6.2.3.1.

3A.5 ASSUMPTIONS USED FOR EVALUATING THE POTENTIAL RADIOLOGICAL CONSEQUENCES OF A STEAM-LINE BREAK FOR BOILING WATER REACTORS (SAFETY GUIDE NO. 5)

This safety guide is not applicable to North Anna Power Station Units 1 and 2.

3A.6 INDEPENDENCE BETWEEN REDUNDANT STANDBY (ONSITE) POWER SOURCES AND BETWEEN THEIR DISTRIBUTION SYSTEMS (SAFETY GUIDE NO. 6)

The design of the unit's power sources complies, in all respects, to Safety Guide No. 6.

Regulatory Position	Reference Section
D.1	8.3.1
D.2	8.3.1
D.3	8.3.2

Regulatory Position	Reference Section
D.4	8.3.1
D.5	8.3.1

3A.7 PERSONNEL SELECTION AND TRAINING (SAFETY GUIDE NO. 8)

Personnel selection and training for North Anna Units 1 and 2 conform with the requirements of Safety Guide No. 8 as clarified in Sections 13.1 and 13.2.

3A.8 SELECTION OF DIESEL-GENERATOR SET CAPACITY FOR STANDBY POWER SOURCES (SAFETY GUIDE NO. 9)

The selection of the diesel-generator sets conforms to Safety Guide No. 9 with the following clarification:

Regulatory Position	Reference Section
C.1	8.3.1
C.2	8.3.1
C.3	8.3.1

Regulatory Position	Reference Section
C.4	8.3.1
C.5	8.3.1

The initial load block causes a momentary dip in generator voltage of approximately 40%. Voltage regulator action restores motor terminal voltage to above 70% in less than 1 second. Since all motors have a guaranteed 70% voltage acceleration capability, the motors accelerate successfully. Generator voltage is restored to 100% through voltage regulator action and because inrush loads have ended before the next load block.

Subsequent load blocks never cause the generator voltage to dip below 75% with recovery to 90% within 40% of each designed load sequence time interval. The diesel-generator set is capable of starting and accelerating to rated speed all of the required engineered safety features and shutdown loads.

3A.9 MECHANICAL (CADWELD) SPLICES IN REINFORCING BARS OF CONCRETE CONTAINMENTS (SAFETY GUIDE NO. 10)

Cadweld splices conform to the regulatory positions of Safety Guide No. 10, except for the modifications discussed below:

Regulatory Position	Reference Section	Regulatory Position	Reference Section
C.1	3.8.1.5.3	C.4	3.8.1.5.3
C.2	3.8.1.5.3	C.5	3.8.1.5.3
C.3	3.8.1.5.3		

In lieu of the requirements of C.1, Cadweld operators are qualified by demonstrating the ability to make one acceptable fixed joint by using Cadweld process procedures in accordance with the manufacturer's instructions. Operators are requalified every 200 Cadwelds.

In lieu of the requirements of C.3, the average value of the tensile test of two or more successive splices is required to develop not less than the minimum guaranteed ultimate strength of the reinforcing bar, and no single splice is permitted to develop less than 90% of the minimum guaranteed ultimate strength of the reinforcing bar.

In lieu of the requirements of C.4, test frequency for production splices, and sister splices if used, is as follows:

One of the first 10 splices.
Three of the next 100 splices.
Two of each subsequent group of 100 splices.

In lieu of the requirements of C.5, in the event of substandard tensile test results, three additional production splices, made by the operator of the substandard splice, were tensile tested to the requirements above, and the operator requalified. If any of these additional three production splices were substandard, the design of the portions of the Seismic Class I structure, in the areas of these Cadweld splices, would be reassessed to determine its ability to accept the reduced average ultimate strength.

For the description of Cadwelds, including operator qualification and tensile testing, used for the Reactor Pressure Vessel Head Replacement Project, see Section 3.8.2.9.3.

3A.10 INSTRUMENT LINES PENETRATING PRIMARY REACTOR CONTAINMENT (SAFETY GUIDE NO. 11)

Instrument lines penetrating the containment meet the intent of Safety Guide 11. The specific sections related to the safety guide are listed below.

Regulatory Position	Reference Section	Regulatory Position	Reference Section
C.1.a	7.3	C.1.e	See below
C.1.b	See below	C.2.a	Not applicable
C.1.c	See below	C.2.b	Not applicable
C.1.d	See below		

The only protection system instrument lines penetrating the containment are the pressure-sensing lines for containment depressurization actuation. Redundancy is provided in this system by providing four pressure-sensing lines to produce a matrix of which two are required for containment depressurization actuation and containment isolation (Section 7.3).

The rapid response required of the pressure detectors to containment pressure requires that the sensing lines be 3/8-inch tubing. Any further restrictions on these lines would be detrimental to the system's operation.

It should be noted that if, during normal reactor operation, a failure should occur in the lines outside the containment, there would be no outleakage from the subatmospheric containment. The failure would be detected by a high-pressure detector reading in comparison with the other pressure detectors, so that the operators could take manual action. The inleakage rate is sufficiently slow that well over a day is available to locate and stop the leak before the containment would rise to atmospheric pressure.

These same lines are pressurized during the first period of a LOCA for approximately 50 minutes. A possible failure is assumed to be incredible during this period, but is assumed to be possible in the long-term recovery period. To provide positive isolation and prevent the containment from repressurizing and consequently leaking to the environment, a manual stop valve is provided outside the containment.

The stop valve and instrument tubing up to and including the trip valves downstream of the pressure detectors are located in the auxiliary building pipe tunnel, where missile protection is provided by concrete walls.

There are no other sensing lines or instrument lines that do not conform to the standard containment penetration isolation criteria.

3A.11 NUCLEAR POWER PLANT INSTRUMENTATION FOR EARTHQUAKES (REGULATORY GUIDE 1.12)

Instrumentation for earthquakes meets or exceeds the requirements of Regulatory Guide 1.12, Revision 2, dated March 1997.

The seismic instrument program for North Anna is discussed in Section 3.7.4.

3A.12 FUEL STORAGE FACILITY DESIGN BASIS (SAFETY GUIDE NO. 13)

The intent of Safety Guide No. 13 is met as amplified in the sections listed below.

Regulatory Position	Reference Section
C.1	3.2.1, 3.8.1, 9.1.2
C.2	9.1.2, 9.1.3
C.3	9.1.2
C.4	3.2.1, 15.4.3
C.5a	9.1.2, 9.1.3

Regulatory Position	Reference Section
C.5b	9.1.2, 9.1.3
C.6	9.1.3
C.7	9.1.3, 12.1.4
C.8	9.1.3

With regard to regulatory position C.2, it is impossible for small, fast- moving missiles traveling downward to impact on one fuel assembly upper nozzle. This is discussed in Section 9.1.2, and the radiological consequences of this occurrence are discussed in Section 15.4.5.

With regard to regulatory position C.7, the filtration system is not automatically actuated by a high-radiation alarm; however, when irradiated fuel is being handled in the fuel building, the fuel building ventilation exhaust may be diverted through HEPA/charcoal filters.

3A.13 REACTOR COOLANT PUMP FLYWHEEL INTEGRITY (SAFETY GUIDE NO. 14)

The design of the North Anna reactor coolant pump flywheels conforms with the intent of Safety Guide No. 14. The shaft and the bearings supporting the flywheel are capable of withstanding any combination of the normal operating loads, anticipated transients, the design-basis LOCA and the design-basis earthquake loads.

The flywheel integrity is described in Section 5.2.

3A.14 TESTING OF REINFORCING BARS FOR CONCRETE STRUCTURES (SAFETY GUIDE NO. 15)

Testing of reinforcing bars of concrete structures conforms to the regulatory positions of Safety Guide 15, except for the following modifications:

Regulatory Position	Reference Section	Regulatory Position	Reference Section
C.1.a	3.8.1.5.2	C.1.c	3.8.1.5.2
C.1.b	3.8.1.5.2	C.2	3.8.1.5.2

In lieu of the requirements of C.1.a, a tension test was performed for each heat of Grade 40, Grade 40 modified, and Grade 60 reinforcing steel furnished. For Grade 40 modified reinforcing steel (N14 and N18) the fabricator's standard practice was to perform the required tension test on a full-diameter specimen. For all other reinforcing steel, i.e., Grade 40 and Grade 60, the tension test sample was either a full-diameter, or standard 0.505-inch-diameter specimen, as allowed by ASTM A-615-68. The tension test was that required by ASTM A-615, and was conducted in conformance with ASTM A-370, performed and certified by the fabricator. Additionally, one full-diameter by 2-feet-length specimen from each heat of N14 and N18 was furnished to permit independent verification of chemical and mechanical properties by the engineers.

In lieu of the requirements of this Safety Guide, the Reactor Pressure Vessel Head Replacement Project used the reinforcing steel testing requirements described in Section 3.8.2.9.3.

3A.15 REPORTING OF OPERATING INFORMATION

The reporting requirements established in Administrative Procedures are consistent with the requirements of Section 50.72 of 10 CFR Part 50 and Section 50.73 to 10 CFR Part 50.

3A.16 PROTECTION AGAINST INDUSTRIAL SABOTAGE (SAFETY GUIDE NO. 17)

The Industrial Security Program for North Anna Power Station Units 1 and 2 is consistent with the objectives and proposed security measures outlined in Safety Guide No. 17. Particulars of this program are discussed in Section 13.7.

3A.17 STRUCTURAL ACCEPTANCE TEST FOR CONCRETE PRIMARY REACTOR CONTAINMENT (SAFETY GUIDE NO. 18)

The structural acceptance test for the reactor containment structures conforms to the regulatory positions of Safety Guide 18, for nonprototype containment, except for the modifications discussed below:

Regulatory Position	Reference Section	Regulatory Position	Reference Section
C.1	3.8.2	C.8	3.8.2
C.2	3.8.2	C.9	3.8.2
C.3	3.8.2	C.10	3.8.2
C.4	3.8.2	C.11	3.8.2
C.5	3.8.2	C.12	3.8.2
C.6	3.8.2	C.13	3.8.2
C.7	3.8.2		

In lieu of the requirements of C.3, radial deformations with respect to the containment horizontal centerlines of the containment wall around the equipment hatch are measured at 12 points. These points are located along the horizontal and vertical equipment hatch centerlines at approximate distances equal to R, 2R, and 2.5R, and were selected to account for the increased wall thickness, which forms a concentric ring around the opening. The distance R is defined as the inside radius of the equipment hatch opening.

In lieu of the requirements of this Safety Guide, the Reactor Pressure Vessel Head Replacement Project used the examination requirements of ASME B&PVC Section XI described in Section 3.8.2.9.5.

3A.18 NONDESTRUCTIVE EXAMINATION OF PRIMARY CONTAINMENT LINERS (SAFETY GUIDE NO. 19)

The nondestructive examination of the primary containment liners is consistent with Safety Guide 19 except as clarified below:

Regulatory Position	Reference Section	Regulatory Position	Reference Section
C.1.a	3.8.2.8	C.6	3.8.2.8
C.1.b	3.8.2.8	C.7.a	3.8.2.8
C.1.c	3.8.2.8	C.7.b	3.8.2.8
C.1.d	3.8.2.8	C.7.c	3.8.2.8
C.2.a	3.8.2.8	C.7.d	3.8.2.8
C.2.b	3.8.2.8	C.8.a	3.8.2.8
C.2.c	3.8.2.8	C.8.b	3.8.2.8
C.3	3.8.2.8	C.8.c	3.8.2.8
C.4	3.8.2.8	C.8.d	3.8.2.8
C.5	3.8.2.8	C.9	3.8.2.8

The nondestructive examination of liner seam welds was performed in the following steps.

Every liner seam weld was either dye-penetrant or magnetic particle tested to determine the surface integrity of the welds. In addition, all liner seam welds were tested in accordance with a vacuum box test procedure where joint configuration allowed use of a standard vacuum box. Test channels were then welded over all liner seam welds, including all containment liner piping penetration and hatch welds, and the test channel seal and liner seam welds were strength tested with an air pressure of 50 psig. Also, all test channel seam welds were solution film tested for any gross leakage path. After solution film testing, the test channels were evacuated to 1 psia or less and pressurized with halogen gas to 50 psig. All the test channel seam welds were then tested with a halogen leak detector capable of detecting leakage of 1.8×10^{-5} Std. cm^3/sec.

A more severe test than recommended by Safety Guide 19, Section C.1.c, was performed by pressurizing the test channels instead of using a vacuum box. This subjected the liner seams and the test channel seam welds to a greater pressure differential than is possible with a vacuum box test. By using halogen leak detection instead of pressure drop detection (C.1.d), a more sensitive leak test was accomplished.

For the Reactor Pressure Vessel Head Replacement Project (Section 3.8.2.9), after vacuum box testing of the liner seam weld and installation of the channel, the channel to liner weld was tested by a static pressure test (decay test) and the weld was soap bubble tested for leakage with an acceptance criteria of zero leakage. Leaking areas of the joint were repaired and retested. In addition, following the containment building pressure test, the channel was re-pressurized and an LLRT, meeting ANS 56.8-1994 requirements, was performed.

3A.19 VIBRATION MEASUREMENTS ON REACTOR INTERNALS (SAFETY GUIDE NO. 20)

Westinghouse will comply with the requirements of Safety Guide No. 20. If for some overriding reason deviations from this guide are permitted, noncompliance will be justified to the AEC.

For each prototype reactor internals design, a program of vibration analysis, measurement, and inspection will be developed and reviewed by the AEC prior to the performance of the scheduled preoperational functional test. Westinghouse has prepared the vibrational analysis and test programs for prototype two-, three-, and four-loop plants. The status of these programs at the time of the submittal of the FSAR for the North Anna units is given in Table 3A-1.

3A.20 MEASURING, EVALUATING, AND REPORTING RADIOACTIVITY IN SOLID WASTES AND RELEASES OF RADIOACTIVE MATERIALS IN LIQUID AND GASEOUS EFFLUENTS FROM LIGHT-WATER-COOLED NUCLEAR POWER PLANTS (REGULATORY GUIDE 1.21, REVISION 1)

The measuring, evaluating, and reporting requirements for radioactivity in solid wastes and releases of radioactive materials in liquid and gaseous effluents, as outlined in the Offsite Dose Calculation Manual, are in accordance with Revision 1 of Regulatory Guide 1.21, dated June 1974.

3A.21 PERIODIC TESTING OF PROTECTION SYSTEM ACTUATION FUNCTIONS (SAFETY GUIDE NO. 22)

The protection system is designed in accordance with IEEE Std. 279, 1971. All safety actuation circuitry is provided with a capability for testing with the reactor at power. The protection system design, including the engineered safety features test cabinet, complies with Safety Guide No. 22. Under the present design, there are protection functions that are not tested at power. These are as follows:

1. Generation of a reactor trip by tripping the main coolant pump breakers.
2. Generation of a reactor trip by tripping the turbine.
3. Generation of a reactor trip by use of the manual trip switch.
4. Generation of a reactor trip by manually actuating the safety injection system.
5. Generation of a safety injection signal by use of the manual safety injection switch.
6. Generation of the containment depressurization signal by use of the manual spray actuation switch.

Exception to on-line testing of the (6) protection functions listed above is taken, as allowed by Safety Guide No. 22, where it has been determined that:

1. "There is no practicable system design that would permit operation of the equipment without adversely affecting the safety or operability of the plant."

   The present position is that it is not a "practicable system design" to provide equipment to bypass a device such as a reactor coolant pump breaker or a main steam line stop valve solely to test the device. In the case of manual initiation switches, the design for test capability would require that switches be provided on a train or sequential basis. This increases the operation action required to manually actuate the function.

2. "The probability that the protection system will fail to initiate the operation of the equipment is, and can be maintained, acceptably low without testing the equipment during reactor operation."

   Probabilities have been established by the use of general failure data based on continuous operation. Specific probability analyses will be provided on a plant basis at the request of the Commission.

3. The equipment can routinely be tested when the reactor is shut down.

Based on the cases discussed above, none of the (6) protection functions require on-line testing. A further discussion of the periodic testing appears in Sections 7.2 and 7.3.

3A.22 ONSITE METEOROLOGICAL PROGRAMS (SAFETY GUIDE NO. 23)

The North Anna onsite meteorological program, described in Section 2.3.3.2, complies with Safety Guide No. 23.

3A.23 ASSUMPTIONS USED FOR EVALUATING THE POTENTIAL RADIOLOGICAL CONSEQUENCES OF A PRESSURIZED WATER REACTOR RADIOACTIVE GAS STORAGE TANK FAILURE (SAFETY GUIDE NO. 24)

The waste gas decay tank burst analysis is consistent with Safety Guide No. 24.

Regulatory Position	Reference Section
C.1.a	15.3.5
C.1.b	15.3.5
C.1.c	15.3.5
C.1.d	15.3.5
C.2.a	15.3.5

Regulatory Position	Reference Section
C.2.b	15.3.5
C.2.c	15.3.5
C.2.d	15.3.5
C.3.a	15.3.5
C.3.b	15.3.5

3A.24 ASSUMPTIONS USED FOR EVALUATING THE POTENTIAL RADIOLOGICAL CONSEQUENCES OF A FUEL-HANDLING ACCIDENT IN THE FUEL HANDLING AND STORAGE FACILITY FOR A PRESSURIZED WATER REACTOR (SAFETY GUIDE NO. 25)

The fuel-handling accident analysis is consistent with Safety Guide No. 25, as clarified in the sections listed below:

Regulatory Position	Reference Section
C.1 (Assumption a)	11.1
C.1 (Assumption b)	11.1
C.1 (Assumption c)	11.1
C.1.b	11.1
C.1.c	12.1.2.5

3A.25 QUALITY GROUP CLASSIFICATIONS AND STANDARDS (SAFETY GUIDE NO. 26)

The design of the North Anna Power Station, Units 1 and 2, meets the intent of Safety Guide No. 26, in that pressure-containing components of safety-related systems are designed, fabricated, erected, and tested to codes and standards commensurate with the importance of the safety functions to be performed.

The impracticality of classifying these components for North Anna Units 1 and 2 into the groups listed in this safety guide is discussed in Section 3.2.2, as is a listing of the safety-related systems and the section of this report in which the codes and standards applied to the components may be found.

3A.26 ULTIMATE HEAT SINK (REGULATORY GUIDE 1.27)

The cooling water systems comply in all respects to Regulatory Guide 1.27, March 1974, as discussed in Section 9.2.5.

3A.27 QUALITY ASSURANCE REQUIREMENTS FOR THE INSTALLATION, INSPECTION, AND TESTING OF INSTRUMENTATION AND ELECTRICAL EQUIPMENT (REGULATORY GUIDE 1.30)

The regulatory positions are met as described in the sections listed below:

Regulatory Position	Reference Section	Regulatory Position	Reference Section
C.1	8.3.1	C.2 (6)	Chapters 3, 5, 9, 10 & 11
C.2 (1)	7.1	C.2 (7)	7.1
C.2 (2)	8.3.1, 7.1	C.2 (8)	7.1, 8.3.1
C.2 (3)	3.8, 7.1	C.2 (9)	7.1, 8.3.1
C.2 (4)	7.1, 8.3.1	C.2 (10)	3.10.1, 7.1
C.2 (5)	3.1		

3A.28 USE OF IEEE STD. 308-1971, "CRITERIA FOR CLASS 1E ELECTRIC SYSTEMS FOR NUCLEAR POWER GENERATING STATIONS" (REGULATORY GUIDE 1.32)

The regulatory positions are met as described in the sections listed below:

Regulatory Position	Reference Section
C.a	8.3.1
C.b	8.3.2

3A.29 QUALITY ASSURANCE PROGRAM REQUIREMENTS (OPERATION) (REGULATORY GUIDE 1.33)

The recommendations of Regulatory Guide 1.33, Appendix A, as applicable to pressurized water reactors (PWR) have been considered in the development of the station safety-related procedures. Plant procedures are discussed in Section 13.5.

3A.30 PREOPERATIONAL TESTING OF REDUNDANT ON-SITE ELECTRIC POWER SYSTEMS TO VERIFY PROPER LOAD GROUP ASSIGNMENTS (REGULATORY GUIDE 1.41)

North Anna's Units 1 and 2 preoperational testing program relative to the emergency power system complies with Regulatory Guide 1.41 (refer to Table 14.1-1).

3A.31 REACTOR COOLANT PRESSURE BOUNDARY LEAKAGE DETECTION SYSTEMS (REGULATORY GUIDE 1.45, MAY 1973)

Compliance with Regulatory Guide 1.45, dated May 1973, is discussed in Section 5.2.4.1.

3A.32 PROTECTION AGAINST PIPE WHIP INSIDE CONTAINMENT (REGULATORY GUIDE 1.46)

3A.32.1 Westinghouse Scope

The probability of rupturing a primary coolant loop pipe is extremely small as demonstrated by the study based upon leak-before-break (LBB) technology reported in Westinghouse WCAP 11163/11164, *Technical Bases for Eliminating Large Primary Loop Pipe Rupture as a Structural Design Basis for North Anna Units 1 & 2,* August 1986 and supplement 1 to the same WCAP in January 1988. The NRC has approved the use of LBB, as allowed by an amendment to General Design Criteria 4, in License Amendment Nos. 107 and 93 for North Anna Units 1 and 2, respectively. The amendment to General Design Criteria 4 of Appendix A to 10 CFR 50 dated October 27, 1987, permits the use of LBB on the primary coolant pipe and allows the removal of the pipe rupture restraints and shields designed to mitigate the effects of primary coolant loop breaks. Thus, the dynamic effects associated with postulated ruptures of the reactor coolant loop piping are excluded from the design basis.

3A.32.2 Stone & Webster Scope

3A.32.2.1 **Original Break Location Criteria**

The criteria listed below were formulated for Class 2 and 3 piping, and were utilized in the pipe break analysis on the main steam and feedwater lines inside the containment prior to the issuance of Regulatory Guide 1.46. The break locations for Class 2 and 3 piping were postulated based on the following criteria:

1. The terminal points.
2. The points where a) the primary-plus-secondary stress exceeds 80% of its allowable (0.8 ($S_A + S_h$)); b) the secondary stress exceeds 80% of its allowable (0.8 S_A); and c) the primary stress exceeds 80% of its allowable ($0.8 \times 1.2\ S_h$).
3. If the number of break points selected by the above criteria is less than four, additional points were chosen at points of:
    a. Maximum primary-plus-secondary stress.
    b. Maximum primary stress.
    c. Maximum secondary stress.
4. If more than two intermediate breaks could not be chosen by the above criteria, locations were chosen that were potentially most damaging to nearby Class I structures, systems, or components.

Both circumferential and longitudinal breaks were considered at all postulated break locations. The break area for both break types was the cross-sectional area of the pipe. The break length for the postulated longitudinal breaks was assumed to equal twice the pipe diameter.

3A.32.2.2 Present Break Location Criteria

The pipe break location criteria for all high-energy systems within the containment, except the main steam and feedwater systems, are consistent with the provisions of Regulatory Guide 1.46. Specifically, break location criteria are as follows.

For Code Class 1 piping, break locations are chosen at:

1. The terminal ends.
2. Any intermediate locations between terminal ends where the primary-plus-secondary stress intensities (circumferential or longitudinal) derived on an elastically calculated basis under the loadings associated with specified seismic events and operational plant conditions exceed 2 S_m for ferritic steel and 2.4 S_m for austenitic steel, where stress intensities are calculated by either Equation (12) or (13) in Paragraph NB-3653 of the ASME Code, Section III.
3. Any intermediate locations between terminal ends where the cumulative usage factor, U, derived from the piping fatigue analysis under the loadings associated with specified seismic events and operational plant conditions exceeds 0.1.
4. At intermediate locations in addition to those determined by positions 2 and 3 above, selected on a reasonable basis as necessary to provide protection. As a minimum, there are two intermediate locations for each piping run or branch run.

For Code Class 2 and 3 piping, break locations are chosen at:

1. The terminal ends.
2. Any intermediate locations between terminal ends where either the circumferential or longitudinal stresses derived on an elastically calculated basis under the loadings associated with specified seismic events and operational plant conditions exceed 0.8 (S_h + S_A).
3. Intermediate locations in addition to those determined by regulatory position 2 above, selected on a reasonable basis as necessary to provide protection. As a minimum, there should be two intermediate locations for each piping run or branch run.

3A.32.2.3 Break Types and Orientation

The following types of breaks are postulated to occur at the break locations selected:

1. Circumferential breaks - Circumferential breaks in piping runs and branch runs exceeding 1-inch nominal pipe size, except where the maximum stress range exceeds the limits of 2 above for Code Class 1, 2, and 3, but where the circumferential stress range is at least 1.5 times the axial stress range.

2. Longitudinal breaks - Longitudinal breaks in piping runs and branch runs 4-inch nominal pipe size and larger, except where the maximum stress range exceeds the limits of 2 above for Code Class 1, 2, and 3, but where the axial stress range is at least 1.5 times the circumferential stress range, subject to the following provisions of Branch Technical Position MEB 3-1:

   a. Longitudinal breaks are not postulated at terminal ends, provided the piping at the terminal ends contains no longitudinal pipe welds.

   b. Longitudinal breaks are not postulated at intermediate locations where the criterion for a minimum number of break locations must be satisfied.

   c. Longitudinal breaks are oriented (but not concurrently) at two diametrically opposed points on the piping circumference so that the jet reaction causes out-of-plane bending of the piping configuration. Alternatively, a single split will be assumed at the section of highest stress, as determined by detailed stress analysis (e.g., finite element analysis).

The break area for postulated breaks is assumed to be equal to one pipe cross-sectional area. The flow area feeding the break is equal to the effective cross-sectional flow area upstream of the break for a circumferential break, and the sum of the effective cross-sectional flow area upstream and downstream of the break for a longitudinal break. The break length for the longitudinal break is assumed to be equal to twice the pipe diameter.

3A.32.2.4 **Comparison with Regulatory Guide 1.46**

The above original break location criteria are in full compliance with Regulatory Guide 1.46. In addition to postulating break points at locations where the primary-plus-secondary stress exceeds 80% of its allowable, as required by Regulatory Guide 1.46, break locations were also postulated at points where the primary stress exceeds 80% of its allowable, or the secondary stress exceeds 80% of its allowable. A point-by-point comparison is presented in Table 3A-2.

Present break location criteria are consistent with the provisions of Regulatory Guide 1.46.

The only exceptions to Regulatory Guide 1.46 are in Guide Footnotes 10 and 11.

Footnote 10 states that the break area is “equal to the sum of the effective cross-sectional flow area upstream of the break location and downstream of the break location, or is equal to a break area determined by test data which define the break geometry.” The original criteria assumed that the break area is equal to the pipe cross-sectional area. This method is consistent with the previously issued drafts of Regulatory Guide 1.46, which had been in force as late as March 1973.

Footnote 10 states that “longitudinal breaks are parallel to the pipe axis and oriented at any point around the pipe circumference.” The present break location criterion is more specific in defining longitudinal break orientation. Furthermore, in the present criterion longitudinal breaks are excluded from seamless piping at terminal ends and from the intermediate points that have low stresses, but are selected to satisfy the requirement for a minimum number of break locations.

Footnote 11 requires the presumption of pipe whipping normal to the pipe axis for a circumferential break. This presumption is inconsistent with the basic principles of mechanics. The pipe will move in the direction consistent with the geometry and flexibility of the severed runs, and the restraints were designed to contain the pipe whipping in these directions.

In conclusion, the Stone & Webster criteria are concluded to satisfy the intent and the requirements of Regulatory Guide 1.46.

3A.33 DESIGN LIMITS AND LOADING COMBINATIONS FOR SEISMIC CLASS I FLUID SYSTEM COMPONENTS (REGULATORY GUIDE 1.48)

Westinghouse equipment was designed to comply with the intent of Regulatory Guide 1.48, i.e., it was designed and analyzed to ensure structural integrity and operability. However, the load combinations and stress limits that were used reflect AEC requirements that were in effect when the construction permit for this plant was issued and when the components were purchased and subsequently designed. Furthermore, the codes and procedures that were available when the components were purchased are based on conservative design requirements rather than detailed stress analyses. These codes and procedures have been widely used by the nuclear industry for the design of components that are installed in plants that are presently operating.

The valves were designed to function at normal operation conditions, maximum design conditions, and DBE conditions. The requirements of ANSI B31.1, ANSI B16.5, and MSS-SP-66 were adhered to in the design. The allowable stresses in the above codes are considerably less than the limits presently proposed by the ASME Task Group on Design Criteria for Class 2 and 3 components, e.g., the allowable stress in ANSI B16.5 is 7000 psi, as opposed to the maximum limit accepted by the ASME task group of 2.4 times the ASME Section VIII allowable stress.

Prior to shipment, the valves were subjected to hydrostatic leak tests in accordance with MSS-SP-61, and functional tests to show that the valves will open and close within the specified time limits when subjected to the design differential pressure. In addition, representative valves were checked for wall thickness to ANSI B16.5 and MSS-SP-66 requirements, and subjected to nondestructive tests in accordance with ASME and ASTM codes. After installation of the valves, they underwent cold hydrostatic tests, hot-functional tests to verify operation, and periodic inservice testing and operation as required.

Active pumps were designed in accordance with the ASME Code for Pumps and Valves for Nuclear Power Plants. The stress levels in the pumps did not exceed those allowed by the code. Forces resulting from seismic accelerations in the horizontal and vertical directions were included in the analyses of the pumps and their supports.

The pumps were subjected to a series of tests before installation and after installation in the plant. In-shop tests included hydrostatic tests to 150% of the design pressure, seal leakage tests, and net positive suction head tests to qualify the pumps for the minimum available net positive suction head. For the net positive suction head and functional performance tests, the pumps were placed in a test loop and subjected to operating conditions. After installation of the pumps in the plant, they underwent cold hydrostatic tests, hot-functional tests to verify operation, and periodic inservice testing and operation as required.

The above design procedures and qualification tests are, therefore, adequate to ensure the structural integrity and operability of the pumps and valves for this plant.

3A.34 DESIGN, MAINTENANCE, AND TESTING CRITERIA FOR ATMOSPHERIC CLEANUP SYSTEM AIR FILTRATION AND ADSORPTION UNITS OF LIGHT-WATER-COOLED NUCLEAR POWER PLANTS (REGULATORY GUIDE 1.52)

Compliance with Revisions 1 and 2 of Regulatory Guide 1.52, dated July 1976 and March 1978, respectively, is discussed in Section 6.2.3 and detailed in Table 6.2-45.

3A.35 QUALIFICATION OF NUCLEAR POWER PLANT INSPECTION, EXAMINATION, AND TESTING PERSONNEL (REGULATORY GUIDE 1.58, REVISION 1, 1980)

Compliance with Regulatory Guide 1.58 is applicable to non-destructive test personnel as of January 1982 as clarified in Dominion’s Operational Quality Assurance Program Topical Report.

3A.36 ELECTRIC PENETRATION ASSEMBLIES IN CONTAINMENT STRUCTURES FOR LIGHT-WATER-COOLED NUCLEAR POWER PLANTS (REGULATORY GUIDE 1.63, REVISION 2, JULY 1978)

The regulatory positions regarding Secondary Protection of Electrical Penetrations for Unit 2 are met as described in the section referenced below:

Regulatory Position	Reference Section
C-1	3.8.2.1.4

3A.37 NONDESTRUCTIVE EXAMINATION OF TUBULAR PRODUCTS (REGULATORY GUIDE 1.66)

For the reasons stated below, the reactor coolant pressure boundary will not comply fully with the Guide. The procedures below, however, ensure quality at least as well as would the Guide requirements.

Westinghouse regards the Guide position concerning defect shape, orientation, and location detection capability as impractical, and the axial testing requirements as technically unnecessary. Since the Guide refers primarily to ultrasonic testing and flow orientation, it must be assumed that the Guide is concerned with the detection of metallurgical defects and that the mechanically produced surface defects will be detected by surface methods of nondestructive testing. This discussion, therefore, is confined to the volumetric nondestructive testing methods for detecting metallurgical flaws.

The Guide states that “nondestructive examination applied to tubular products used for components of the reactor coolant pressure boundary and other safety-related systems… should be capable of detecting unacceptable defects regardless of defect shape, orientation or location in the product.” Conformance to this Guide position is impractical, as it would require 1) ultrasonic testing at 10-degree increments from the circumferential to the axial direction, 2) equivalent size standard defects or notches at comparable angles, and 3) a complicated correction system to compensate for the varying responses expected due to angular misalignments produced by the changing curvature. Because equivalent size standard defects or notches are not mechanically feasible, test reproducibility, and therefore reliability, cannot be certified.

In addition, the Guide position regarding angle beam scanning in the axial direction is technically unnecessary, since any flaws that might be developed by the processes employed in tubular product manufacture are invariably oriented in the axial direction, and the probability of developing metallurgical flaws of other than axial orientation is virtually nil. Flaws of transverse or circumferential orientation that might be developed would normally be mechanically induced surface defects, which should be detected by surface nondestructive testing procedures.

Westinghouse believes that the nondestructive examinations performed in the normal procurement of the tubular products covered by the Guide achieve the same purpose as the Guide requirements. The primary pressure boundary and safety-related tubular products within the Westinghouse scope of supply and the nondestructive testing applied are described below. In all cases, the volumetric nondestructive testing is maximized to detect the flaws inherent to the manufacturing process or processes employed.

3A.37.1 Thin-Wall Austenitic Heat Exchanger Tubing

Angle beam ultrasonic testing is performed in two directions circumferentially, referenced to a 0.004-inch-deep notch. The ultrasonic testing is supplemented by an omnidirectional eddy current test that is referenced to a circumferential notch and drilled hole. The o.d. surfaces are also examined by penetrant testing.

3A.37.2 Thick-Wall Austenitic Instrumentation Nozzles

Angle beam ultrasonic testing is performed in two directions circumferentially, referenced to a 5% T (T = wall thickness) axial notch. These 0.3-inch-minimum wall tubes are manufactured by extrusion or machined from rolled bar stocks. When made from rolled bar, the individual bars are also examined axially from the end faces.

Penetrant tests are performed on the o.d. surfaces of the finished items.

3A.37.3 Thick-Wall Austenitic CRDM Housings and Adaptor Flanges

Angle beam ultrasonic testing is performed in two directions circumferentially, referenced to a 3% T, axial vee-notch. Axial testing is performed on the forged and/or rolled bar stock from which these CRDM components are made. Penetrant tests are performed on both the i.d. and o.d. surfaces of the finished item.

3A.37.4 Nozzle Forgings - Ferritic and Austenitic

All nozzle forgings within the Westinghouse scope of supply are ultrasonically examined axially from the end faces and in two directions circumferentially, using angle beam techniques references to 3% T, axial vee-notch. Magnetic particle and/or penetrant tests are performed on all surfaces of the finished item.

3A.37.5 Primary Coolant, Loop Bypass, and Surge Lines Austenitic Piping

All forged and/or extruded piping within the Westinghouse scope of supply is ultrasonically examined in two directions circumferentially, using angle beam (45-degree) techniques referenced to a 3% T vee-notch, and, in the radial, through-thickness direction, using straight beam (0-degree) techniques.

Cast piping components are 100% radiographically examined for the shrinkage conditions inherent to the casting processes.

Penetrant tests are performed over 100% of both the i.d. and o.d. surfaces of both product forms (wrought or cast).

3A.37.6 Austenitic Support Columns (Reactor Internals)

Tubular supports and columns are ultrasonically examined in the circumferential and axial directions using angle beam (45-degree) techniques referenced to 3% T notches. When these tubular components are made from rolled or forged bar stock, the angle beam test is augmented by axial tests from the end faces of the bar.

Penetrant tests are performed over 100% of the i.d. and o.d. surfaces of the finished item.

3A.38 PREOPERATIONAL AND INITIAL START-UP TEST PROGRAMS FOR WATER-COOLED POWER REACTORS (REGULATORY GUIDE 1.68)

The preoperational and initial start-up test programs, as outlined in Tables 14.1-1 and 14.1-2, respectively, comply with Regulatory Guide 1.68 as clarified below:

Regulatory Position	Table 14.1-1, Section	Regulatory Position	Table 14.1-1, Section	Regulatory Position	Table 14.1-1, Section
A.1.a	II.2, II.3	A.4.e	V.2.d	A.6.d	VII.4
A.1.b(1)	II.4.a	A.4.f	V.2.e	A.6.e	VII.5
A.1.b(2)	II.4.b	A.4.g	II.4.e	A.7.a	VIII.1
A.1.b(3)	II.4.c	A.4.h	V.2.f	A.7.b	a
A.1.b(4)	II.4.d	A.5.a	VI.1	A.7.c	VIII.2
A.1.b(5)	II.4.d	A.5.b	a	A.7.d	VIII.3
A.1.b(6)	II.4.e	A.5.c	VI.2	A.7.e	VIII.4
A.1.b(7)	II.4.f	A.5.e	VI.4	A.7.f	VIII.5
A.1.c	II.1, II.4.b.b, II.4.g, II.4.h, V.1.a, V.2.b, VI.5, X.1	A.5.f A.5.g A.5.h	VI.5 VI.6 VI.7	A.8 A.9.a A.9.b	IX X.1 X.2
A.1.d	II.5	A.5.i	VI.8	A.9.c	X.3
A.2.a	III.1	A.5.j	VI.9	A.9.d	VIII.3
A.2.b	III.2	A.5.k	VI.10	A.9.e	X.4
A.2.c	III.3	A.5.l	a	A.10.a	XI.1
A.2.d	III.4	A.5.m	a	A.10.b	XI.2
A.2.e	III.5	A.5.n	VI.11	A.10.c	XI.3
A.2.f	III.6	A.5.o	VI.12	A.10.d	XI.4
A.3	IV	A.5.p	VI.13	A.10.e	XI.5
A.4	V.1.b	A.5.q	VI.15	A.11	XII
A.4.a	V.1.b	A.5.r	I.3	A.12.a	XIII.1
A.4.b	V.2.a	A.6.a	VII.1	A.12.b	XIII.2
A.4.c	V.2.b	A.6.b	VII.2	A.12.c	XIII.3
A.4.d	V.2.c	A.6.c	VII.3	A.13	XIV

a. This is not applicable to North Anna Power Station Units 1 and 2.

Regulatory Position	Table 14.1-2, Section	Regulatory Position	Table 14.1-2, Section
B.1.a	I.1	C.1.j	II.12
B.1.b	I.2	D.1.a	III.1
B.1.c	I.3	D.1.b	III.2
B.1.d	I.4	D.1.c	III.3
B.1.e	I.5	D.1.d	III.3
B.1.f	I.6	D.1.e	III.4
B.1.g	I.7	D.1.f	III.5
B.1.h	I.8	D.1.g	III.6
B.1.i	I.9	D.1.h	III.8
B.1.j	I.10	D.1.i	III.9
C.1.a	II.2	D.1.j	III.10
C.1.b	II.3	D.1.k	III.11
C.1.c	II.4	D.1.l	III.12
C.1.d	II.5	D.1.m	III.13
C.1.e	II.7	D.1.n	III.14
C.1.f	II.8	D.1.o	III.17
C.1.g	II.9	D.1.p	III.15
C.1.h	II.10	D.1.q	III.16
C.1.i	II.11	D.1.r	III.18

3A.39 ASSUMPTIONS FOR EVALUATING THE HABITABILITY OF A NUCLEAR PLANT CONTROL ROOM DURING A POSTULATED HAZARDOUS CHEMICAL RELEASE (REGULATORY GUIDE 1.78)

Compliance with Regulatory Guide 1.78 is discussed in Section 6.4.1.3.3.

3A.40 PREOPERATIONAL TESTING OF EMERGENCY CORE COOLING SYSTEMS FOR PRESSURIZED WATER REACTORS (REGULATORY GUIDE 1.79)

The preoperational testing of the emergency core cooling systems conforms to Regulatory Guide 1.79, dated June 1974, with the following clarifications.

1. Regulatory Position C.3.a(2) - The capability of the high-head safety injection pumps (charging pumps) to deliver flow to the primary system at operating pressure and temperature conditions is demonstrated constantly during normal unit operation. Therefore, a specific test is not necessary for this purpose.

2. Regulatory Position C3.b(2) - Preoperational testing of the low-head safety injection pumps was done in two phases. The first phase was a system test, pumping water from the refueling water storage tank through the normal flow path into the reactor coolant loops. This phase

verified the performance of the entire system when using the refueling water storage tank as a suction source, and verified the performance of the portion of the system from the pump discharge, which is the same for all suction conditions.

The second phase was a test of the suction conditions only, when taking a suction from the containment sump. A portable dike was erected around the sump and filled with water. The test was conducted with the cylindrical mesh screens in place. During the test, the inlet was checked to prove the absence of vortexing. The pump discharge was piped back into the portable dike through temporary connections attached to the bonnets of the check valves. Pump suction pressure and casing pressure were measured to verify hydraulic head inside the pump casing. Sump level and temperature were measured, and suction losses compared to the calculated values. Pump discharge pressure and flow were measured. The test was conducted at approximately 3000 gpm flow rate.

The Phase 1 test (from the refueling water storage tank) was done on both units. The Phase 2 test was done on only one pump on Unit 1, and was used as the basis for proving flow, pressure drop, and NPSH calculations for all pumps, as the arrangement is identical in both units.

In addition, scale model tests of the containment sump were performed by Alden Research Laboratories in Holden, Massachusetts. The final report was submitted with VEPCO letter, Serial No. 400, dated September 13, 1977, and indicated that with only minor modifications the sump will be free of any harmful vortices for any postulated operating conditions. The modifications made to the sump involve the installation of two layers of floor grating in the sump and the installation of perforated vortex breakers inside the cylindrical screens.

3. Regulatory Position C.3.c(1) - Each safety injection accumulator was discharged individually into the reactor vessel, with the head removed, by pressurizing the accumulator to 100 psig and rapidly opening the isolation motor-operated valve.

3A.41 PREOPERATIONAL TESTING OF INSTRUMENT AIR SYSTEMS (REGULATORY GUIDE 1.80)

The intent of Regulatory Guide 1.80 is met as described below.

A loss-of-instrument-air test was conducted by securing the makeup air to each dedicated air accumulator supplying each safety-related component that is required to operate following a loss of instrument air. The capacity of each dedicated air accumulator was verified by operating the safety-related component a specified number of times over a specified time interval.

Air-operated components used for safety-related functions are tested to ensure that they fail in the safe mode upon loss of operating pressure (refer to Table 14.1-1, VI.10).

3A.42 PROTECTION OF NUCLEAR POWER PLANT CONTROL ROOM OPERATORS AGAINST AN ACCIDENTAL CHLORINE RELEASE (REGULATORY GUIDE 1.95)

Compliance with Regulatory Guide 1.95 is discussed in Section 6.4.1.3.3.

3A.43 INSTRUMENTATION FOR LIGHT-WATER-COOLED NUCLEAR POWER PLANTS TO ACCESS PLANT CONDITIONS DURING AND FOLLOWING AN ACCIDENT (REGULATORY GUIDE 1.97)

Compliance with Regulatory Guide 1.97 is discussed in Section 7.1.4.

3A.44 EMERGENCY PLANNING AND PREPAREDNESS FOR NUCLEAR POWER REACTORS (REGULATORY GUIDE 1.101, NOVEMBER 1975)

VEPCO has formulated a comprehensive emergency plan, contained in a separately bound document. The plan is consistent with Regulatory Guide 1.101, dated November 1975.

3A.45 PERIODIC TESTING OF DIESEL GENERATOR UNITS USED AS ONSITE ELECTRIC POWER SYSTEMS AT NUCLEAR POWER PLANTS (REGULATORY GUIDE 1.108, REVISION 1, AUGUST 1977)

The criteria for determining valid tests and failures of the emergency diesel generators are based on those found in Regulatory Position C.2.e of Regulatory Guide 1.108 and incorporated into the Technical Specifications. The requirements of Regulatory Guide 1.108 were subsequently replaced by Regulatory Guide 1.9, Revision 3, July 1993. Quarterly surveillance testing of the Station Emergency Diesel Generators was evaluated under Surveillance Test Interval Evaluation STI-N12-2017-003 and implemented in accordance with Technical Specification Section 5.5.17 Surveillance Frequency Control Program.

3A.46 CALCULATION OF ANNUAL DOSES TO MAN FROM ROUTINE RELEASES OF REACTOR EFFLUENTS FOR THE PURPOSE OF EVALUATING COMPLIANCE WITH 10 CFR PART 50, APPENDIX I (REGULATORY GUIDE 1.109, MARCH 1976)

The evaluation of compliance with 10 CFR Part 50, Appendix I, appears in Appendix 11C. All dose calculations were performed using models and assumptions consistent with Regulatory Guide 1.109 (March 1976).

3A.47 METHODS FOR ESTIMATING ATMOSPHERIC TRANSPORT AND DISPERSION OF GASEOUS EFFLUENTS IN ROUTINE RELEASES FROM LIGHT-WATER-COOLED REACTORS (REGULATORY GUIDE 1.111, MARCH 1976)

The evaluation of compliance with 10 CFR Part 50, Appendix I, appears in Appendix 11C. Meteorological dispersion and deposition analyses were based on models, assumptions, and parameter values as provided in Regulatory Guide 1.111 (March 1976).

3A.48 CALCULATION OF RELEASES OF RADIOACTIVE MATERIALS IN GASEOUS AND LIQUID EFFLUENTS FROM LIGHT-WATER-COOLED POWER REACTORS (REGULATORY GUIDE 1.112)

The evaluation of compliance with 10 CFR Part 50, Appendix I, appears in Appendix 11C. Radioactive release estimates for this analysis are based in the guidance of Regulatory Guide 1.112 except as noted in Section 11.1.1.3.

3A.49 INSPECTION OF WATER-CONTROL STRUCTURES ASSOCIATED WITH NUCLEAR POWER PLANTS (REGULATORY GUIDE 1.127)

In accordance with the NRC letter of March 28, 1979, inspection and surveillance of the dam and water impoundments will be in accordance with Regulatory Guide 1.127.

3A.50 QUALIFICATION OF QUALITY ASSURANCE PROGRAM AUDIT PERSONNEL OF NUCLEAR POWER PLANTS (REGULATORY GUIDE 1.146, AUGUST 1980)

Compliance with the requirements set forth in Regulatory Guide 1.146 has been achieved at the North Anna Power Station.

3A.51 PRE-EARTHQUAKE PLANNING AND IMMEDIATE NUCLEAR POWER PLANT OPERATOR POST-EARTHQUAKE ACTIONS (REGULATORY GUIDE 1.166, MARCH 1997)

Criteria for a timely evaluation after an earthquake of the recorded instrumentation data and for determining whether plant shutdown is required are in compliance with Regulatory Guide 1.166 and are incorporated in station procedures.

3A.52 RESTART OF A NUCLEAR POWER PLANT SHUT DOWN BY A SEISMIC EVENT (REGULATORY GUIDE 1.167, MARCH 1997)

Criteria for performing inspections and tests of nuclear power plant equipment and structures prior to restart of a plant that has been shut down by a seismic event are in compliance with Regulatory Guide 1.167 and are incorporated into station procedures.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3A-1

PROTOTYPE REACTORS INTERNALS ASSURANCE PROGRAM STATUS

Prototype Reactors		Topical Reports			
Number of Loops	Plant (Operating Utility)	Title	WCAP No.	Class	Status
2	Robert Emmett Ginna (Rochester Gas & Electric Corporation)	*Westinghouse PWR Internals Vibration Summary, 2-Loop Internals Assurance*	7845 7718	2 3	AEC accepted 10/2/72 AEC accepted 10/2/72
3	H. B. Robinson No. 2 (Carolina Power and Light Company)	*Westinghouse PWR Internals Vibration Summary, 3-Loop Internals Assurance*	7765-L	2	AEC accepted with additional information
			7765	3	AEC accepted with additional information
			7765-L-AR[a] 7765-AR[a]	2 3	AEC accepted 10/2/72
4	Indian Point No. 2 (Consolidated Edison Company of New York)	*Four-Loop PWR Internals Assurance and Test Program*	7879	2	AEC accepted 10/2/72

a. AR = Acceptance Review, notation used to designate report with additional information reviewed and accepted by the AEC; now this information is incorporated into the report and the report reissued.

Table 3A-2
COMPARISON OF PIPE BREAK LOCATION CRITERIA

Criteria for Class 2 and 3 Piping	Regulatory Guide 1.46	Stone & Webster Original Criteria
Minimum number of breaks	4	4
Terminal points	Yes	Yes
Primary and secondary stress $0.8(S_A + S_h)$	Yes	Yes
Usage factor $0.1 \times 1.2\ S_h$	Not mandatory	Not required
Primary stress $0.8 \times 1.2\ S_h$	Not required	Yes
Secondary stress $0.8\ S_A$	Not required	Yes
Additional intermediate points	Reasonable basis	Maximum primary-plus-secondary stress; maximum primary stress; maximum secondary stress; potentially most damaging location

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Appendix 3B
Comparison Between Time - History and Frequency Response Methods

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APPENDIX 3B COMPARISON BETWEEN TIME-HISTORY AND FREQUENCY RESPONSE METHODS

The time-history method of analysis was used to generate the amplified response spectra for comparison with the frequency response method. In this approach, the multi-degree-of-freedom structural system, modeled to incorporate subgrade structure interaction, is subjected to a time-dependent base acceleration. The acceleration time history used was an artificial earthquake that yielded a ground response spectrum that envelops the 0.5% smooth ground response spectrum. The artificial time history had a total duration of 10.24 second. The matching of the ground response spectrum was established for 250 oscillator periods distributed logarithmically over the range of 0.03 second (33.0 Hz) to 3.33 second (0.3 Hz). A typical comparison between the ground response spectrum obtained from the artificial time history and the smooth site ground response spectrum is shown in Figure 3B-1.

The amplified response spectra generated by the frequency response method did not envelop those generated by the time-history method over the entire frequency range. Because of this difference between the response spectra generated by the two different methods, a review and analysis was performed on critical Seismic Class I piping systems and on Seismic Class I equipment. The systems and equipment included in this review are located in the containment structure, auxiliary building, and the fuel building.

For the purpose of this review, the amplified response spectra were generated for the design-basis earthquake condition with 5% structural damping and 1% equipment damping. It is emphasized that, although the ground response spectrum obtained from the artificial time history was more conservative than the smooth site ground response spectrum at the matching damping value of 0.5%, no modification or periodwise scaling down of the amplified spectra was done. Plots of representative amplified response spectra actually used for the review are compared with those obtained by the frequency response method in Figure 3B-2.

The amplified response spectra in the high-frequency range are influenced by the structural damping. Thus, in order to establish conservatism in the high-frequency range, another artificial time history (5% artificial time history) that envelops the 5% smoothed ground response spectrum was also used to generate the amplified response spectra for design-basis earthquake condition at 5% structural damping and 1% equipment damping. A comparison of these amplified response spectra with those generated by the frequency response method demonstrates that there are no significant penetrations of these amplified response spectra curves (generated using 5% artificial time history) through the amplified response spectra curves generated by the frequency response method. The effect of these penetrations in terms of increase in stresses over those indicated in Table 3B-1 is negligible.

Inspection of the amplified response spectra curves indicates that the time-history response spectra are generally more conservative in the lower frequency range, while in the higher frequency range, in which the majority of the piping fundamental frequencies occur, the frequency response method is generally more conservative.

The justification of the frequency response method for the Seismic Class I piping systems analyses was based on a review of the worst cases of critical seismically stressed systems. The most highly stressed Code Class 1 piping system (safety injection) and Class 2/3 piping systems anchored on containment internal structure (main steam, feedwater), containment external structure (main steam), auxiliary building (component cooling water), and fuel building (spent-fuel pit cooling) were reviewed. Dynamic analyses of these piping systems were performed again, using amplified response spectra based upon the time-history method. The newly computed stresses caused by the design-basis earthquake (S_{DBE}) were then combined with the stresses caused by dead loading (S_{DL}) and the stresses caused by internal pressure (S_{LP}). The resultant stresses were all within the allowable stress limit of 3 S_m for Class 1 piping systems and 1.8 Sh for Class 2/3 systems, respectively.

A comparison of the combined stress ($S_{DBE} + S_{DL} + S_{LP}$) for the critical Seismic Class I piping based on the frequency response method and the time-history method is presented in Table 3B-1. Only the “Main Steam - Outside Containment Wall” line shows increased combined stress over the original value, an increase attributable to the high flexibility of the line. The “Main Steam - Outside Containment Wall” line has first and second mode natural frequencies of 2.09 Hz and 3.15 Hz, respectively, and it is the only piping system having high seismic stress with a fundamental natural frequency below 3 Hz. The conclusion from these results is that critical Seismic Class I piping systems have been adequately designed for seismic loading.

Similarly, Seismic Class I equipment located in the containment structure, fuel building, and auxiliary building has been reviewed on a worst-case basis for adequacy to time-history amplified response spectra. On the basis of characteristic equipment natural frequencies, acceleration values were selected from the time-history amplified response spectra and compared with those used for the original seismic design. In general, the equipment natural frequencies were found to lie in the portion of the curves where the frequency response method is conservative in comparison to the time-history method. A list of equipment reviewed is presented in Table 3B-2. In all cases investigated, the original designs were found to be conservative when compared with time-history requirements. This conclusion is based on two factors:

1. The data that have been placed into specifications for equipment were based upon 0.5% equipment damping for the design-basis earthquake. The review of component adequacy using the time-history curves was based upon an assumed equipment damping of 1.0%. With few exceptions, this resulted in resonant peak values at or below the original specified values. At all locations where the 1.0% (new) curve exceeded the 0.5% (old) curve peak values, no component was found to exceed allowable stresses.

2. The new amplified response spectra by the time-history method are characteristically less conservative, regardless of damping, in the higher frequency ranges above the predominant resonant peak frequency. The so-called “rigid range” accelerations are thus, by comparison, always lower than those specified by the original spectra. A corollary to this is the conclusion that rigidity requirements necessary to keep components within the originally specified values are not as severe.

In addition to the review described above, equipment coupled to piping systems has been reviewed for nozzle loading effects. Piping system time-history nozzle loads were compared with those developed by the frequency response method, and, in all cases, the nozzle loads used as a design basis were found to be conservative. A determination was also made of the ability of the equipment to withstand nozzle loads locally, using the methods outlined in Welding Research Council Bulletin No. 107, as applicable. The attached nozzle loads were then used in determining equipment structure and support acceptability under combined loading conditions. Again, the original design bases were found to be conservative.

The conclusion from the results of the equipment reviews is that all Seismic Class I equipment has been adequately designed for seismic loading.

It is further concluded that the frequency response method, for the particular areas of investigation, yielded generally more conservative design bases than the time-history method.

Table 3B-1
GROUND RESPONSE SPECTRUM COMPARISON

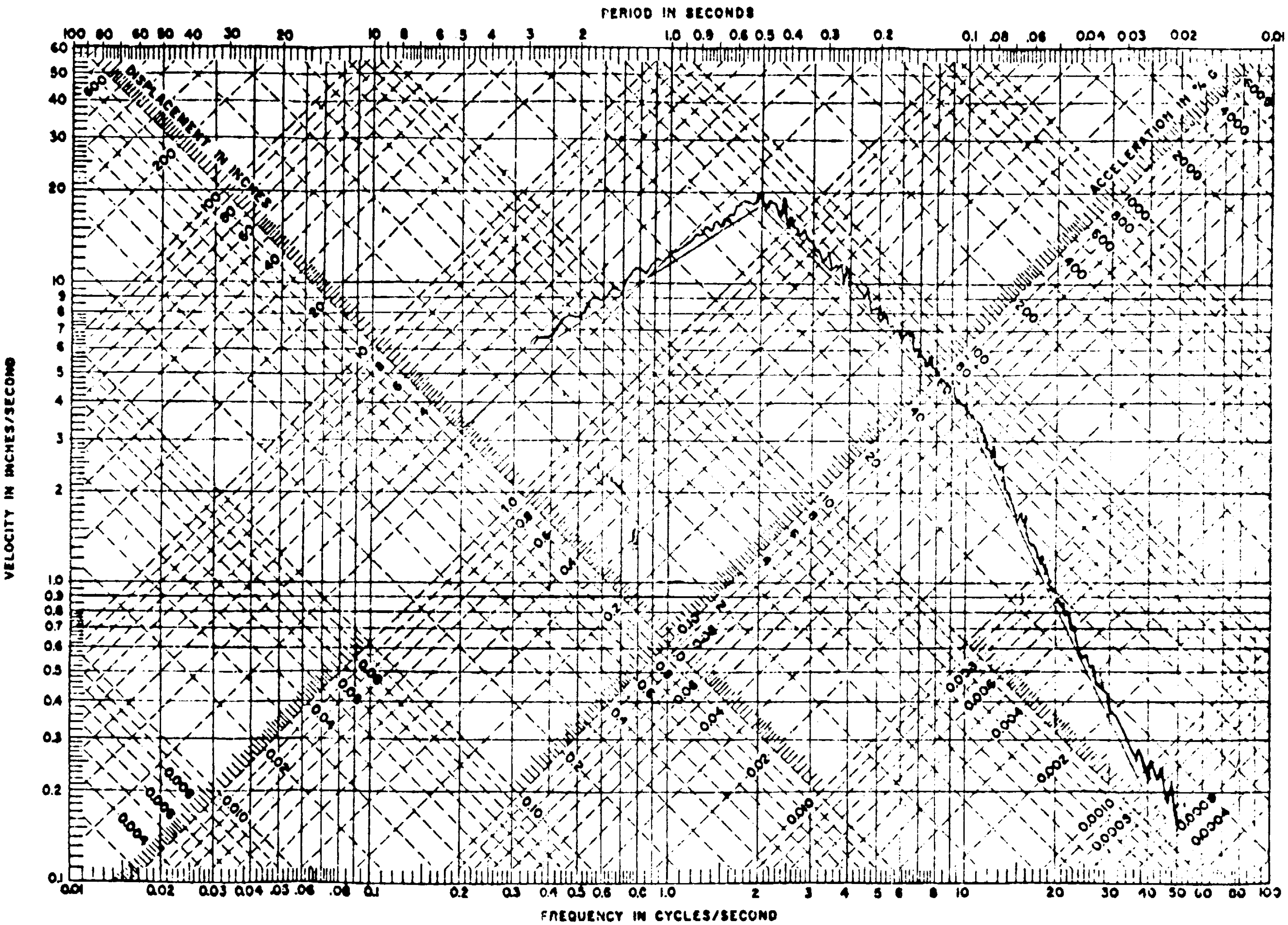
No.	System Name	ASME Code Class	Allowable Stress[a]	Seismic Excitation Location	Frequency Response Method SDBE + SDL + SLP	Percent Allowable	Time-History Method, SDBE + SDL + SLP	Percent Allowable
1	Reactor containment safety injection	1	60,000 psi	React. cont. int. struct. El. 241 ft. 0 in.	21,553 psi	35.9	18,499 psi	30.8
2	Main steam - reactor containment - Loop C	2	33,750 psi	React. cont. int. struct. El. 316 ft. 0 in	21,898 psi	64.9	19,264 psi	57.1
3	Steam generator - feedwater - Loop C	2	27,000 psi	React. cont. int. struct. El. 316 ft. 0 in.	22,144 psi	82.0	21,277 psi	78.8
4	Main steam - outside containment wall	2	33,750 psi	React. cont. ext. struct. El. 275 ft. 0 in. horiz., 296 ft. 0 in. vert.	19,214 psi	56.9	27,023 psi	80.1
5	Component cooling water (east lead)	2	27,000 psi	Aux. building El. 291 ft. 0 in.	16,445 psi	60.9	9405 psi	34.8
6	Spent-fuel pit cooling	2	29,580 psi	Fuel building El. 323 ft. 0 in.	14,982 psi	50.7	9048 psi	30.6

a. Allowable stress limit for DBE of ASME Code Class 1 piping system is 3 Sm based on Equation (9) of subparagraphs NB-3652 and NB-3656.2. Sm is the design stress-intensity value (Tables I-1.1. and I-1.2 of ASME Code Section III). Allowable stress limit for DBE of ASME Code Class 2/3 piping system is 1.8 Sh, 1.8 Sh = 150% by 1.2 Sh; the 150% is based upon accepted criteria of ASME Section III Committee; 1.2 Sh is the allowable stress limit for OBE specified by ND-3612.3 of ASME Code Section III. Sh is the allowable stress for pipe at temperature (Tables I-7.1 and I-7.2, ASME Code Section III). All references are to ASME, 1971.

Table 3B-2
LIST OF EQUIPMENT REVIEWED

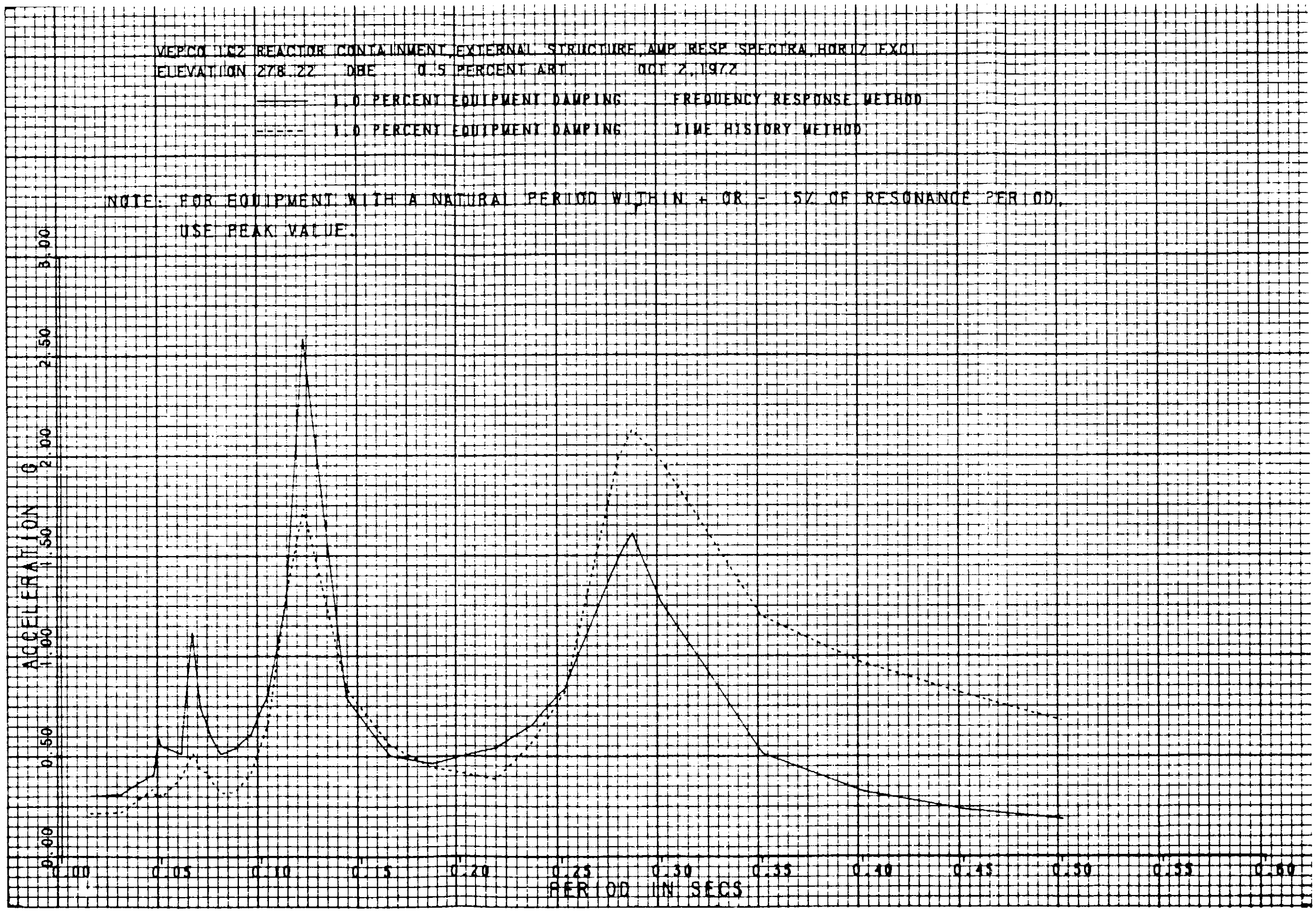
Reactor containment polar crane
Fuel building trolley
Fuel elevator
Fuel pit coolers
Spent-fuel pit pump
Containment mat drainage pumps
Air compressor (type A2, reciprocating)
Air compressor (horizontal, reciprocating)
Safety relief valves (size 3 x 4)
Air-operated sample valves (3/8 in., type 20000)
Butterfly valves (8 in., 18 in., 36 in., motor-operated)
Axial flow fans (vaneaxial, 130,000 cfm)
Containment cooling coils
Flow indicators (Barton Model 288)
Pressure transmitters
Temperature detectors (resistance type, various)

Figure 3B-1
ARTIFICIAL TIME HISTORY FOR 0.5 PERCENT DAMPING



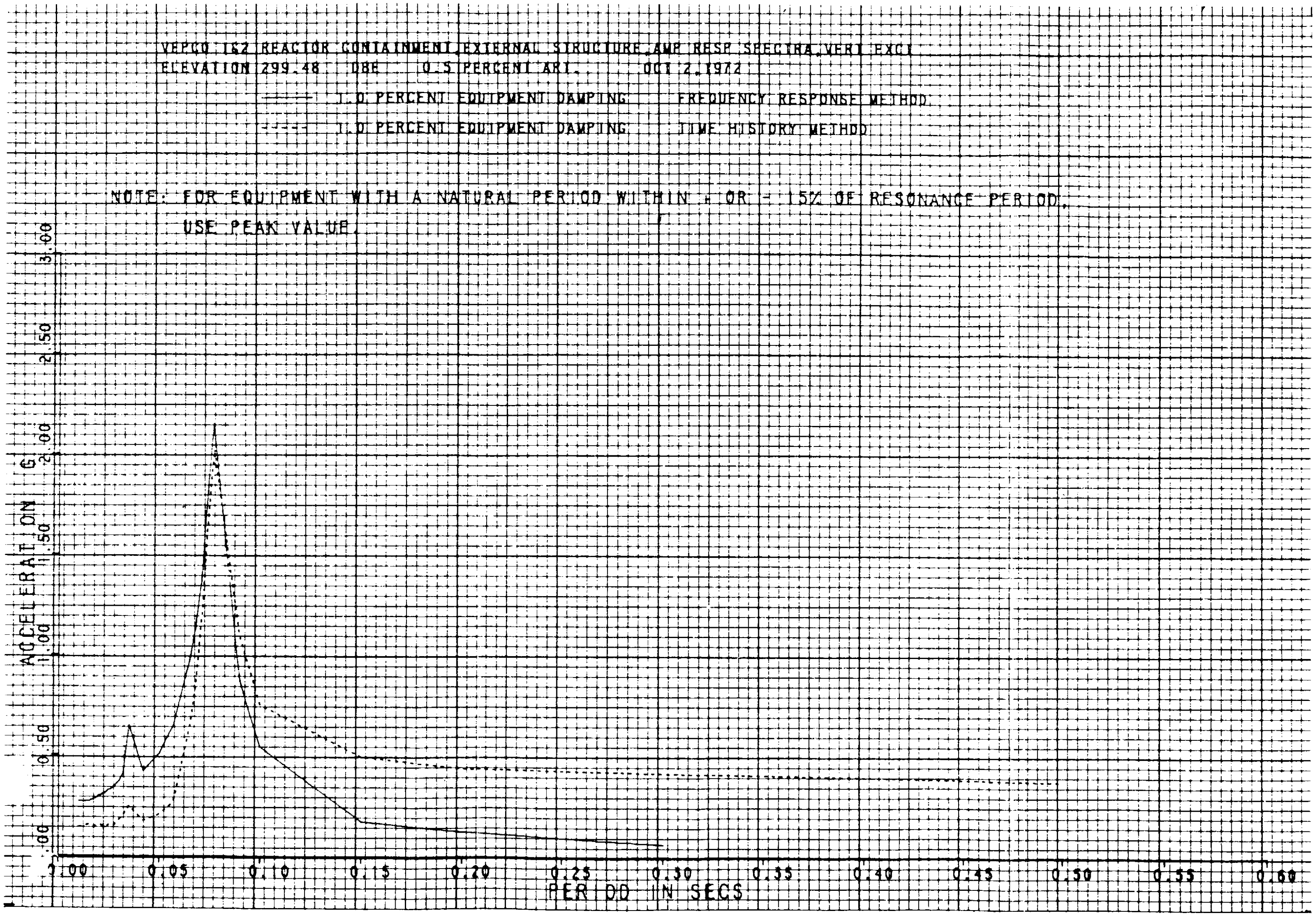
N03B0001

Figure 3B-2 (SHEET 1 OF 14)
AMPLIFIED RESPONSE SPECTRA



N03B0002

Figure 3B-2 (SHEET 2 OF 14)
AMPLIFIED RESPONSE SPECTRA



N03B0003

Figure 3B-2 (SHEET 3 OF 14)
AMPLIFIED RESPONSE SPECTRA

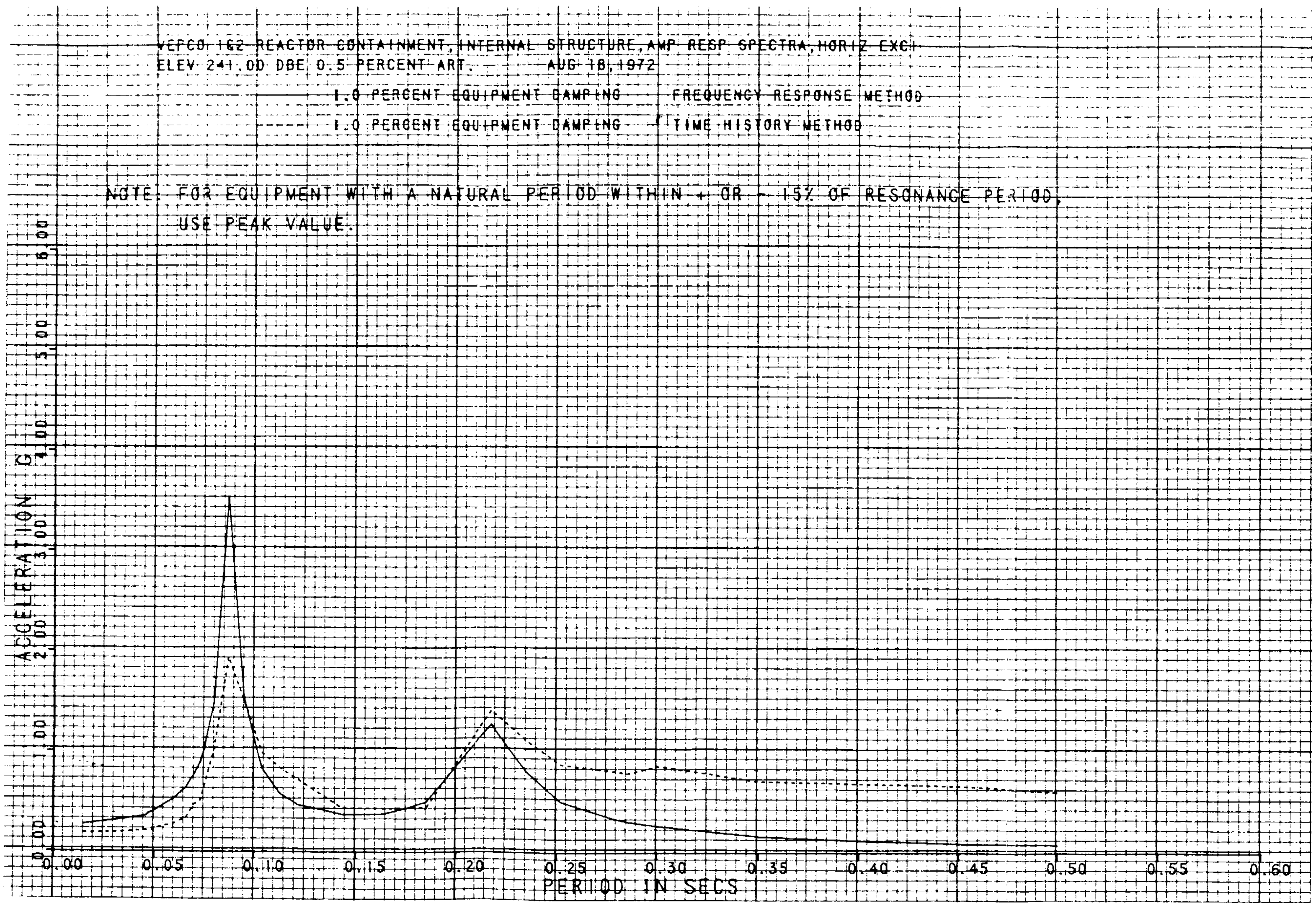


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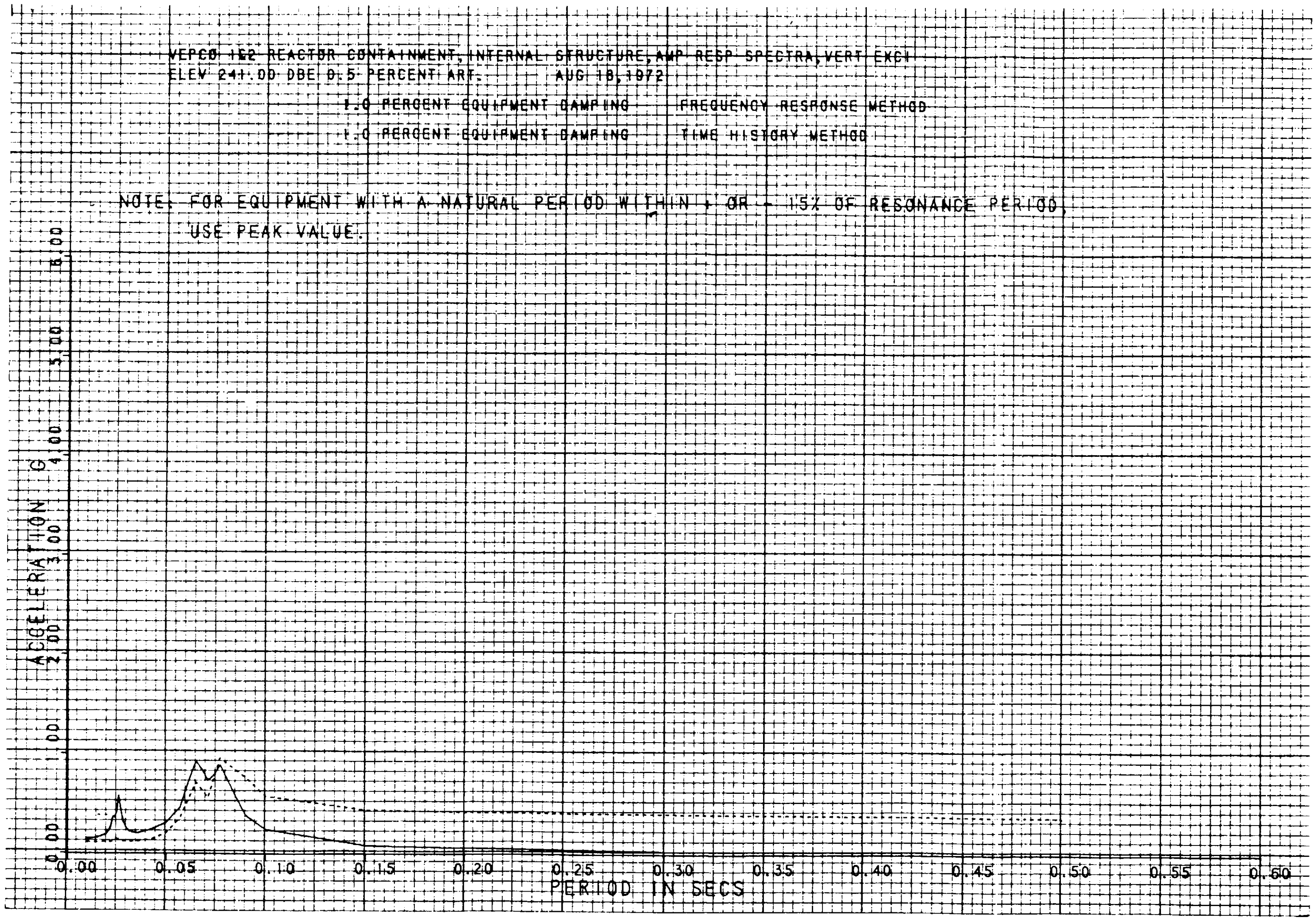
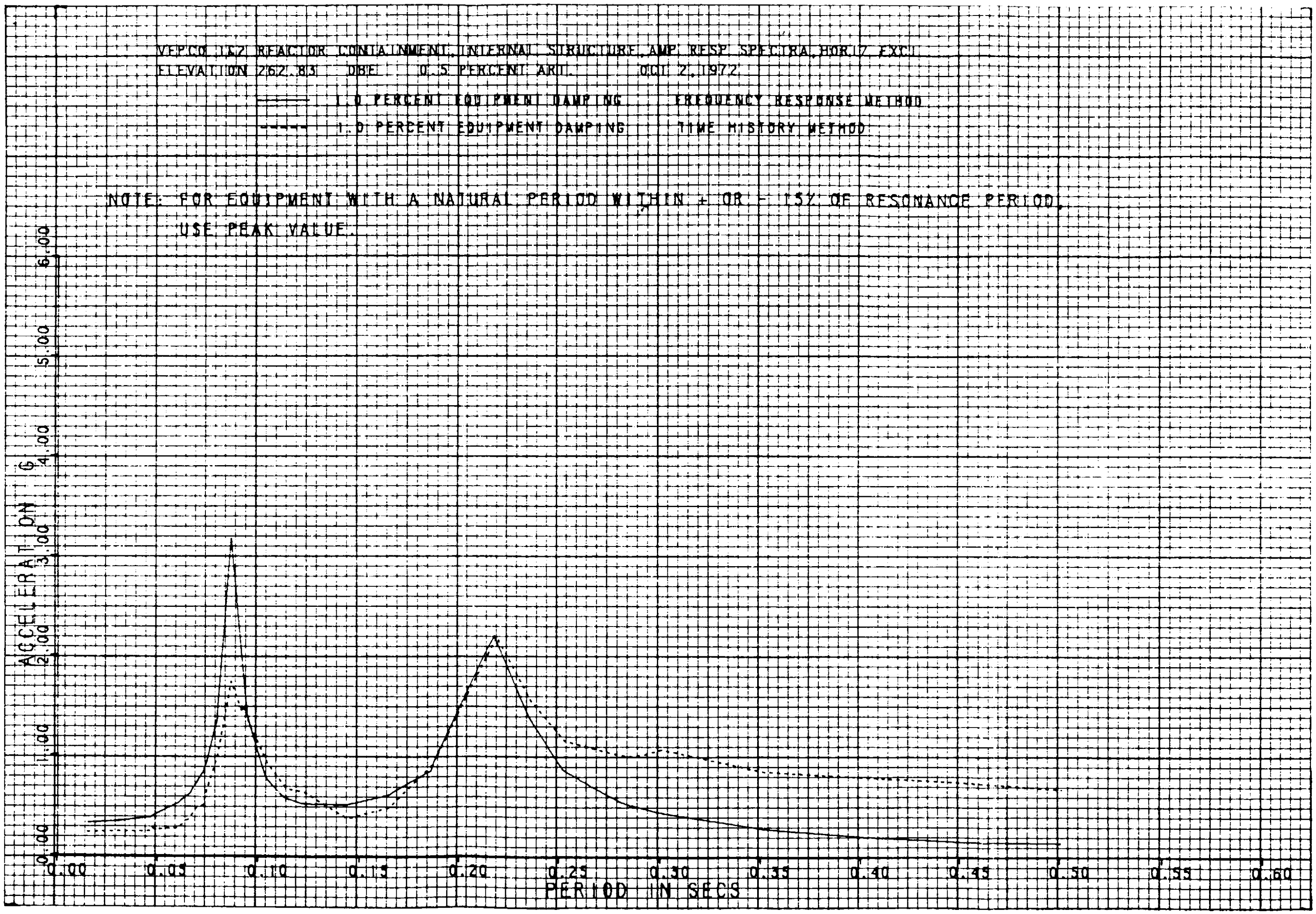
Figure 3B-2 (SHEET 4 OF 14)
AMPLIFIED RESPONSE SPECTRA



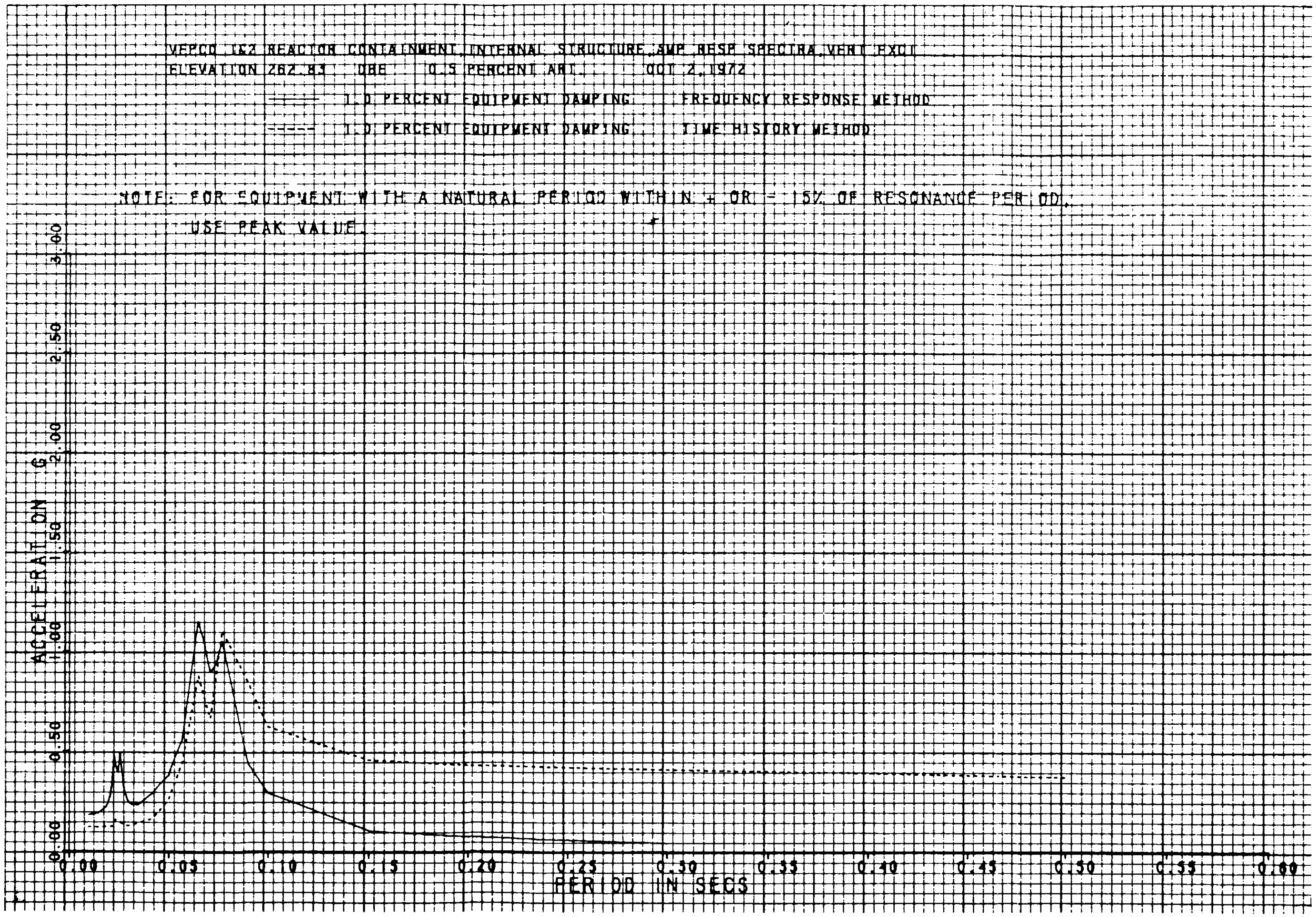
N03B0005

Figure 3B-2 (SHEET 5 OF 14)
AMPLIFIED RESPONSE SPECTRA



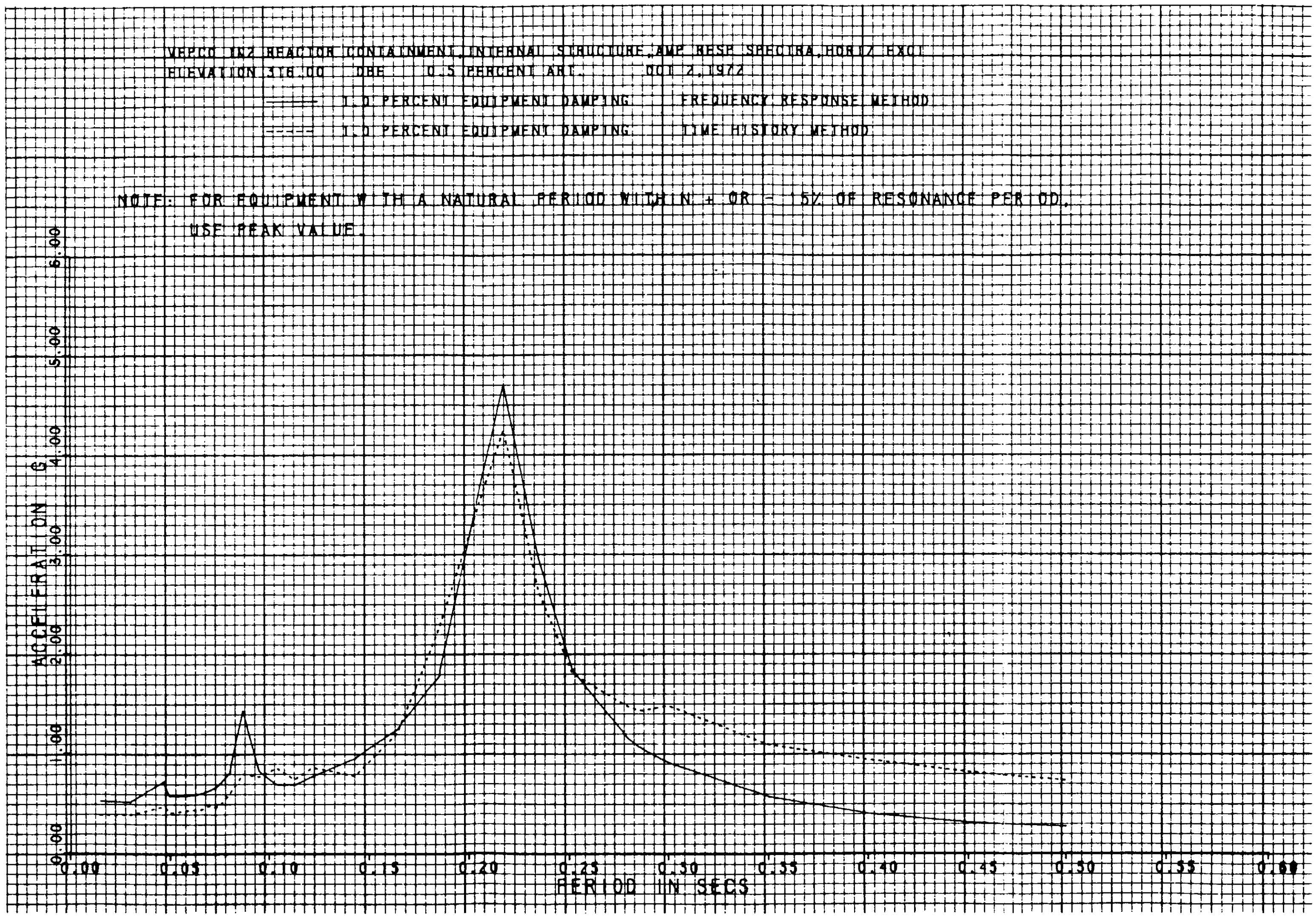
N03B0006

Figure 3B-2 (SHEET 6 OF 14)
AMPLIFIED RESPONSE SPECTRA



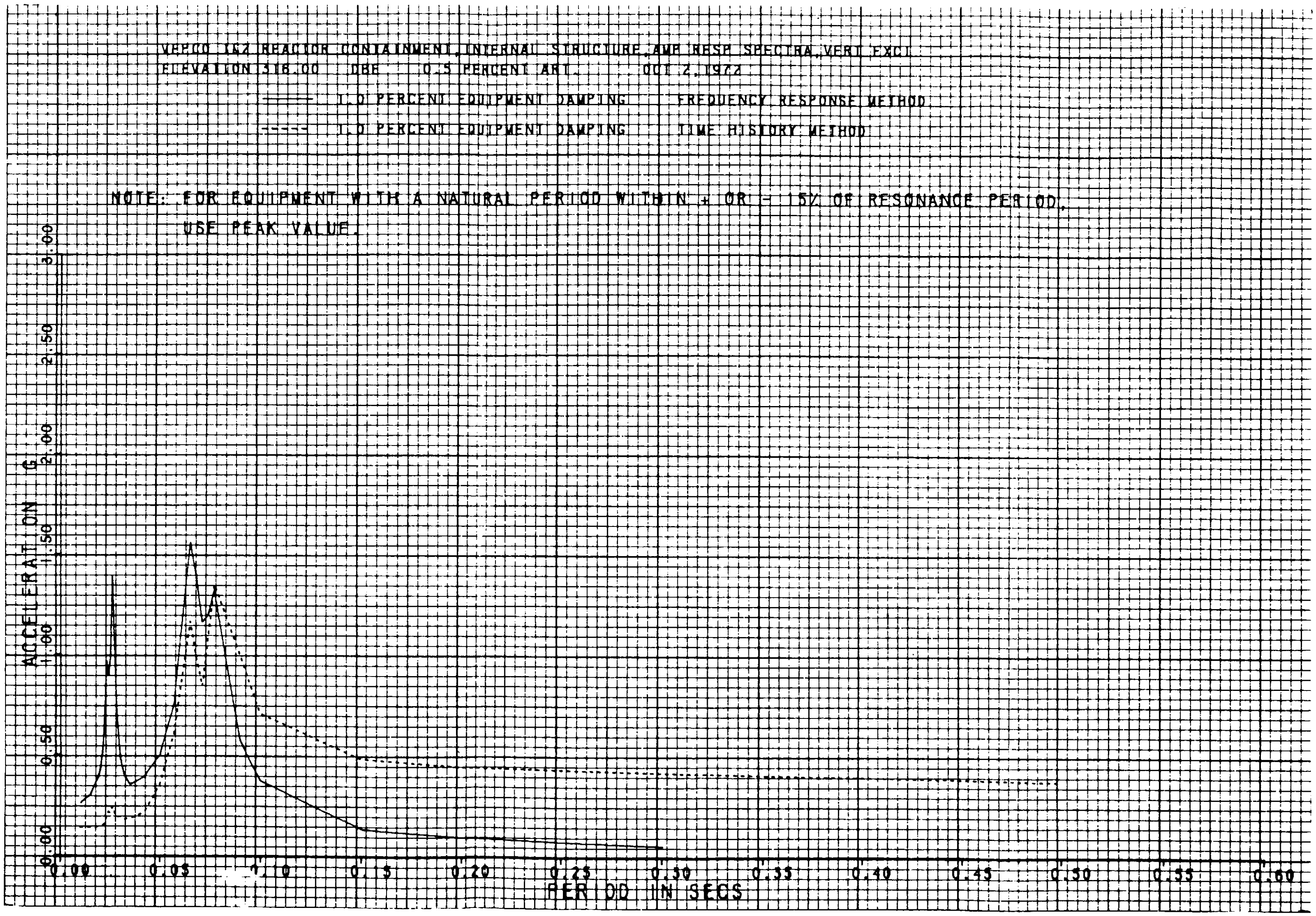
N03B0007

Figure 3B-2 (SHEET 7 OF 14)
AMPLIFIED RESPONSE SPECTRA



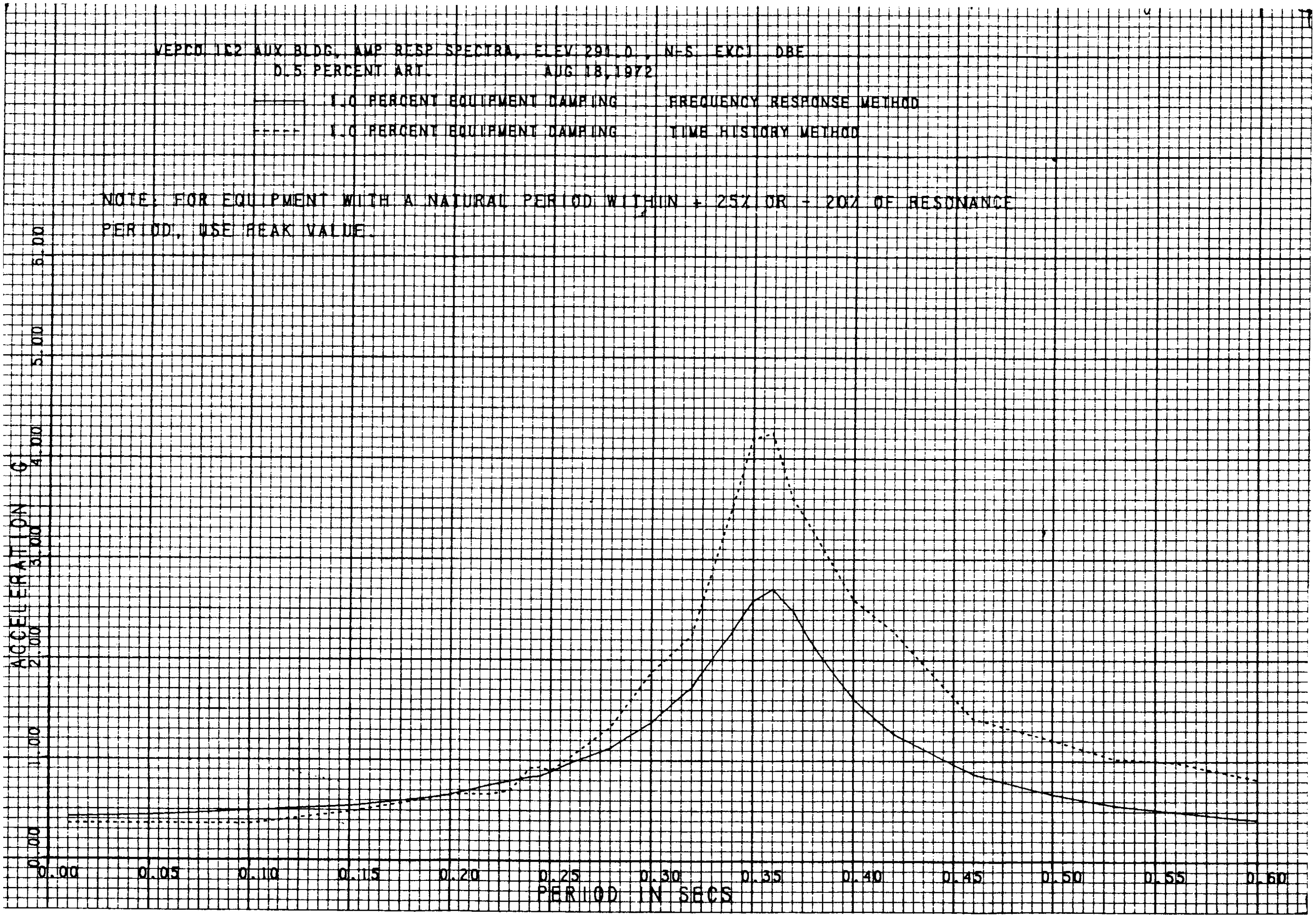
N03B0008

Figure 3B-2 (SHEET 8 OF 14)
AMPLIFIED RESPONSE SPECTRA



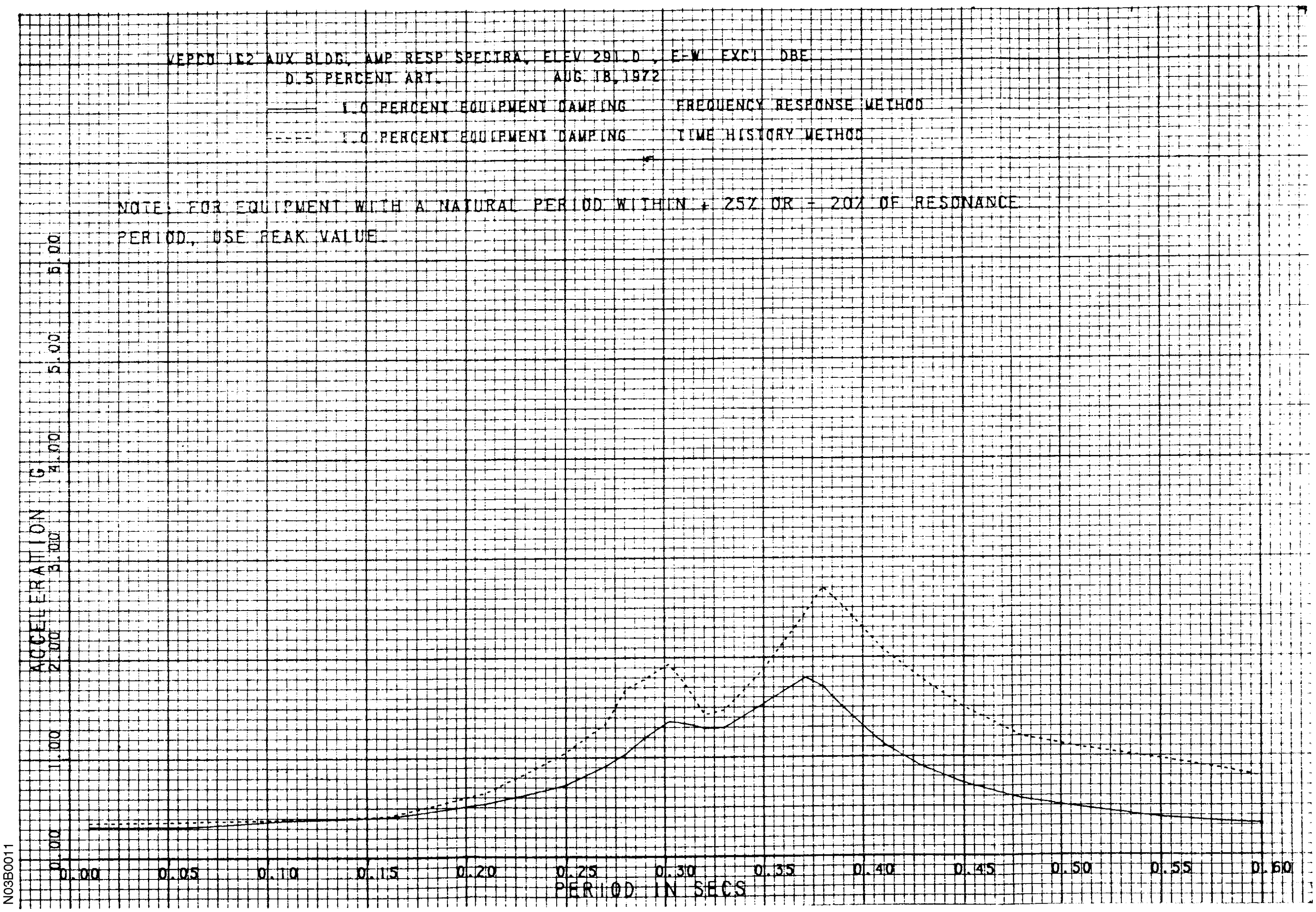
N03B0009

Figure 3B-2 (SHEET 9 OF 14)
AMPLIFIED RESPONSE SPECTRA



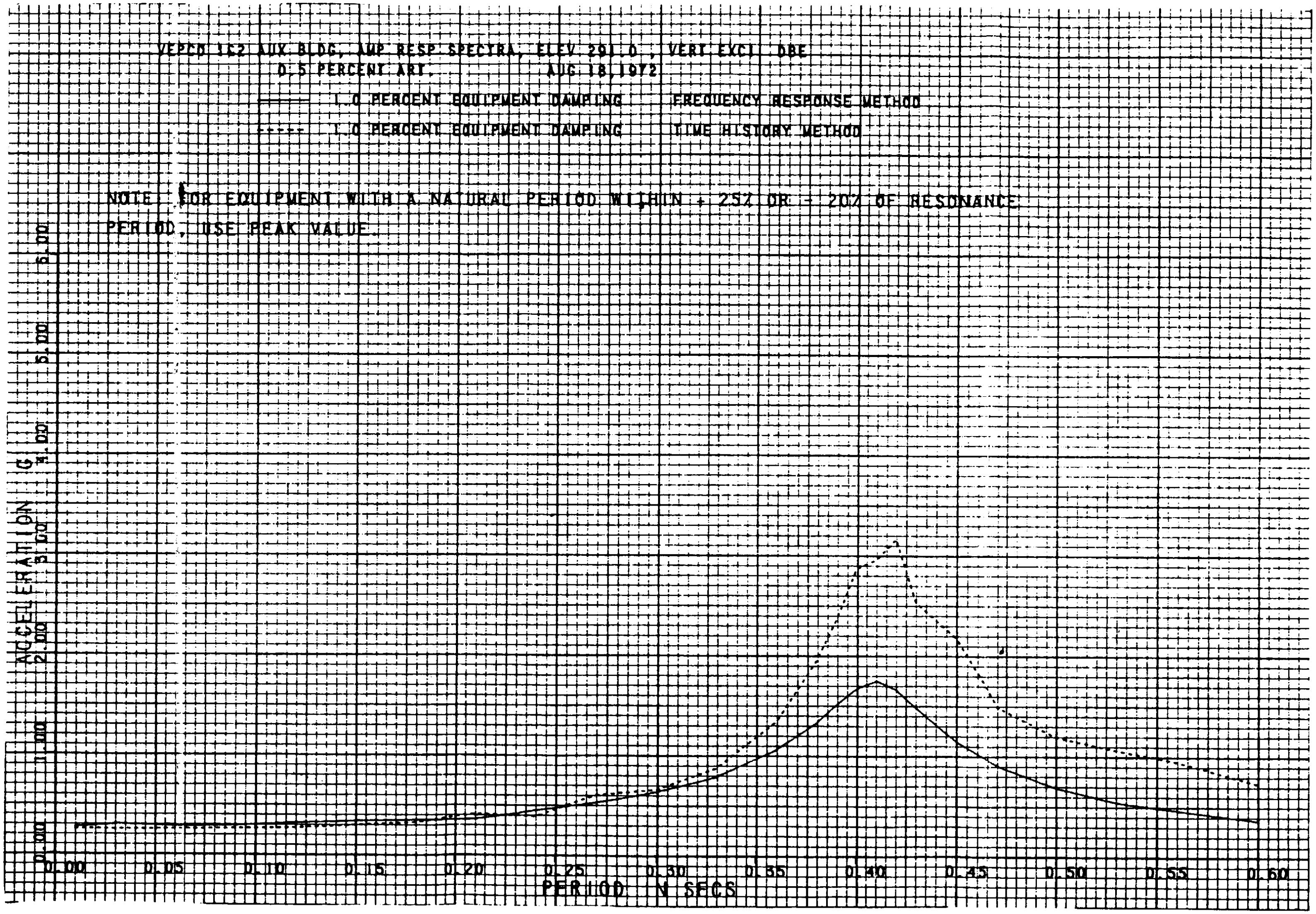
N03B0010

Figure 3B-2 (SHEET 10 OF 14)
AMPLIFIED RESPONSE SPECTRA



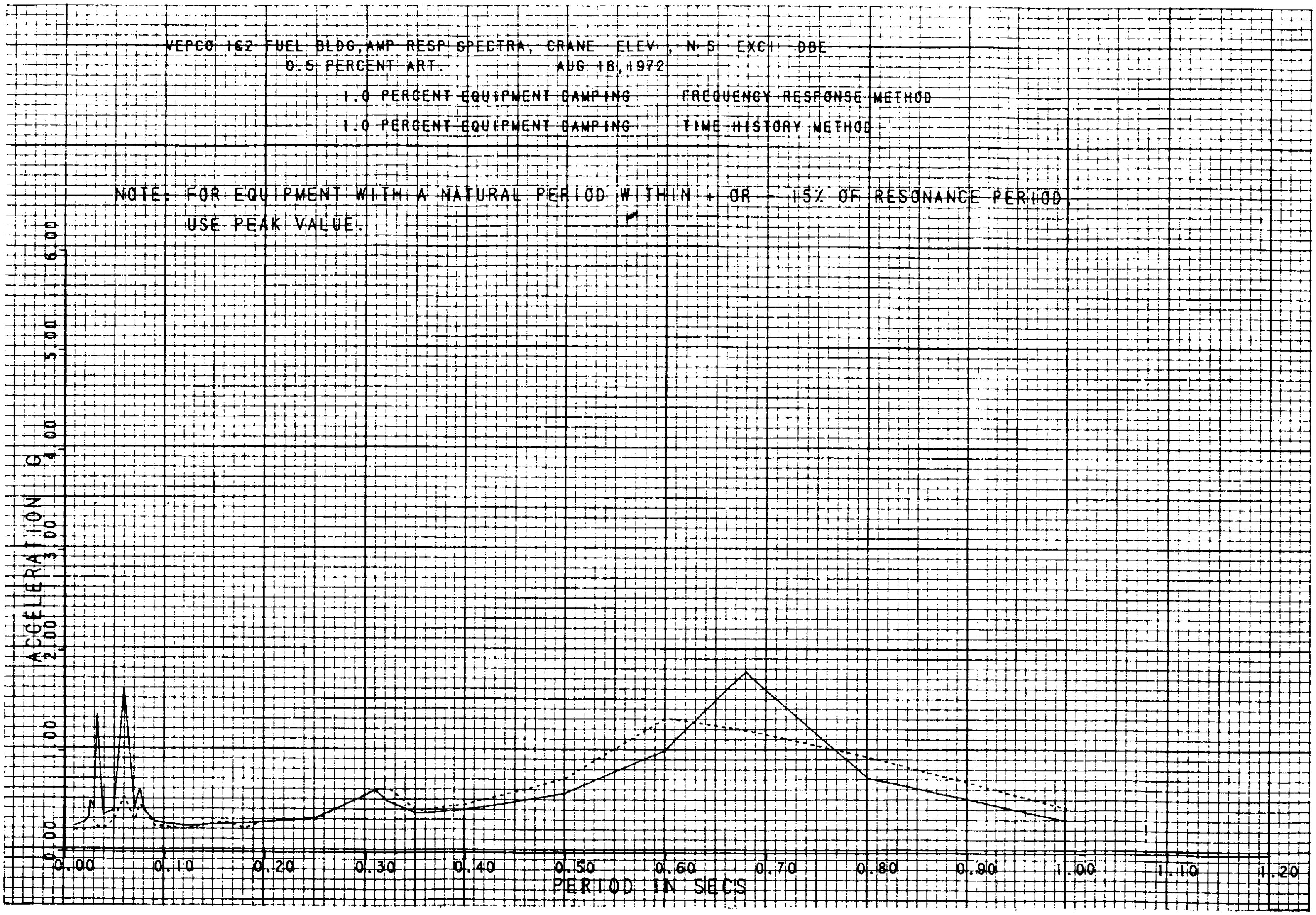
N03B0011

Figure 3B-2 (SHEET 11 OF 14)
AMPLIFIED RESPONSE SPECTRA



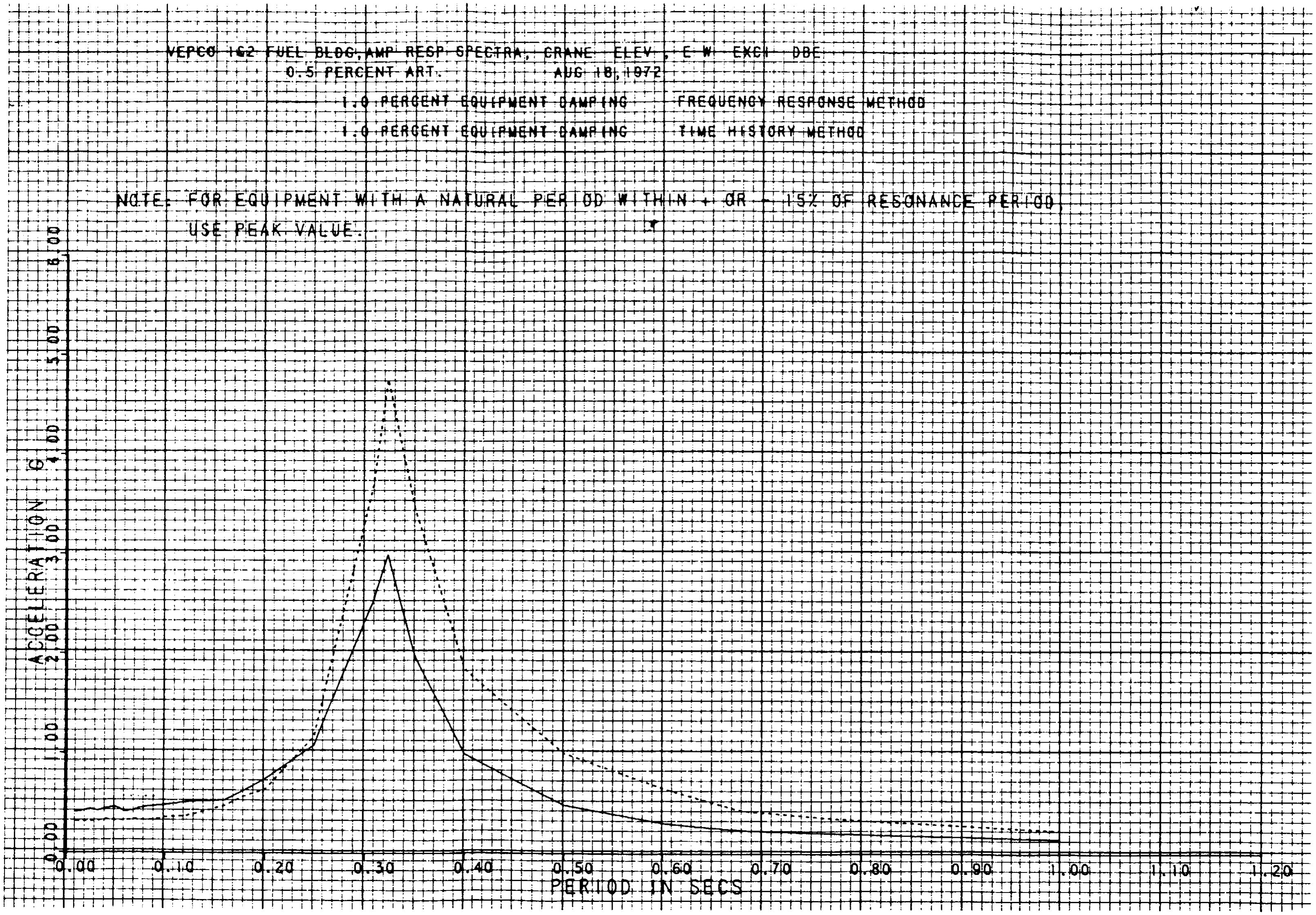
N03B0012

Figure 3B-2 (SHEET 12 OF 14)
AMPLIFIED RESPONSE SPECTRA



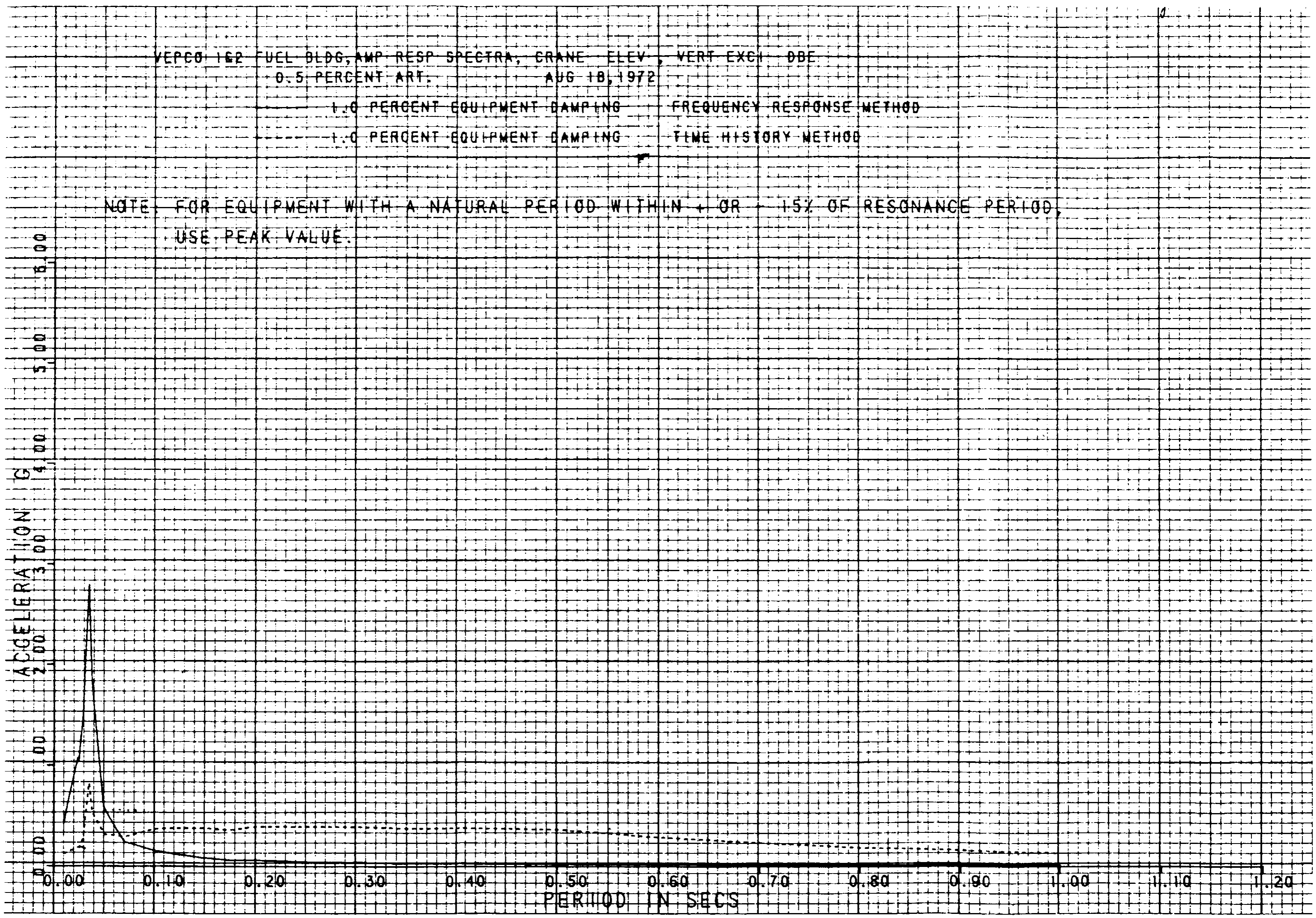
N03B0013

Figure 3B-2 (SHEET 13 OF 14)
AMPLIFIED RESPONSE SPECTRA



N03B0014

Figure 3B-2 (SHEET 14 OF 14)
AMPLIFIED RESPONSE SPECTRA



N03B0015

Appendix 3C[1]
Effects of Piping System Breaks Outside Containment

1. Appendix 3C was submitted as Appendix C in the original FSAR.

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APPENDIX 3C 1EFFECTS OF PIPING SYSTEM BREAKS OUTSIDE CONTAINMENT

3C.1 INTRODUCTION

3C.1.1 Report Coverage and Summary

This Appendix provides the response required by Mr. A. Giambusso's letter of December 18, 1972, and its attached document, entitled *General Information Required for Consideration of the Effects of Piping System Break Outside Containment*, later revised in January 1973. The inservice inspection program supports pipe line integrity as discussed in Section 3C.2.7. This program was reevaluated and adjusted according to NRC approval letter dated July 7, 1998.

This Appendix presents an analysis of the consequences of postulated pipe breaks outside the containment. In addition to the direct effects on safety resulting from the postulated break of a high-energy line, the analysis shows that North Anna Units 1 and 2 can be shut down and maintained in a safe-shutdown condition with the modifications described herein. The postulated break of a high-energy line is shown not to negate the function of any structures or systems important to safety, and not to negate any redundancy of any system or component required to operate as a result of the postulated failure.

The analysis ensures that the AEC General Design Criterion No. 4 is met, i.e., that all structures, systems, and components important to safety are designed to accommodate the effects of and are compatible with the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents. These structures, systems, and components are protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids that may result in equipment failures, and from events and conditions outside the nuclear power unit.

To provide assurance that these criteria are met, the following modifications have been made:

1. Main steam and feedwater restraints have been added to the piping within the main steam valve house.
2. The main steam valve house structure has been redesigned to accommodate the pipe whip restraints and their associated loads; to limit pressure buildup and flooding; to accommodate jet impingement loads associated with high-energy line breaks; and to limit the environmental effects of such breaks to the portion of the main steam valve house housing these lines.

3. Some piping within the main steam valve house has been rerouted to accommodate additional structural steel. This piping was routed to avoid jet impingement zones. However, where these zones are unavoidable, impingement shields are provided.
4. The auxiliary feedwater pumps and their associated instrumentation and controls have been relocated from the main steam valve house to a new, separate Seismic Class I structure which provides significant, but not comprehensive, protection against tornado-generated missiles.
5. For certain postulated high-energy line break locations in the service building, an augmented inservice inspection program, as discussed in Section 3C.2.7 will ensure line integrity during the life of the facility. In addition, the main steam and feedwater piping in the mechanical equipment rooms is included in the Secondary Piping and Component Inspection Program. Also, operators inspect these lines for leakage on a daily basis.
6. Automatic isolation valves have been added to the steam generator blowdown system to protect equipment important to safety located in the auxiliary building.
7. Temperature sensors have been provided in various areas of the auxiliary building to provide individual temperature indication and an alarm in the control room.
8. Isolation valves operable from the control room have been added to the auxiliary steam line feeding the auxiliary building.
9. Level indication and an alarm have been provided in the control room to alert the operator of flooding in the auxiliary building.
10. Containment pressure actuation devices have been moved to a different level of the auxiliary building.

3C.1.2 Report Organization

The sectional organization of this Appendix is shown in Figure 3C-1. The approach used to analyze the consequences of pipe failure is to identify and locate the high-energy “sources,” identify and locate the safety-related “targets,” determine and evaluate the physical effects, and make design modifications as required to meet the criteria. The criteria for determining pipe break locations and methods of analysis are presented in Section 3C.2. The identification and location of high-energy systems is discussed in Section 3C.3. Safety-related equipment is identified, and locations listed, in Section 3C.4. Results of calculations and the evaluation of physical effects from a pipe system break are described in Section 3C.5. Section 3C.6 presents the conclusions.

3C.1.3 Cross Reference to AEC General Information Requirements

Table 3C-1 cross-references the sections of this Appendix with the required general information requested by Mr. A. Giambusso’s letter to the Virginia Electric and Power Company, dated December 18, 1972, and later revised in January 1973.

3C.2 CRITERIA FOR PIPE BREAKS AND ANALYSIS

3C.2.1 General Discussion

High-energy systems that require analysis for the consequences of pipe break were identified based on the fluid in the pipe, the pressure, and the temperature during normal station operation.

The fluids considered were water, steam, and water solutions. High-pressure nonflashing gas lines were not included in this analysis.

The temperatures and pressures used for determination of high-energy systems are the maximum normal operating temperatures and pressures. The type of analysis required was based on the temperature and pressure conditions as shown in Figure 3C-2. The lines that were both high-temperature and high-pressure were postulated to experience a longitudinal or circumferential break, and were analyzed for pipe whip, jet impingement, and environmental effects. The pipes that were low-pressure and high-temperature, or low-temperature and high-pressure, were postulated to crack, and were analyzed for environmental effects only.

The analysis of these effects (environmental, pipe whip, fluid jets, etc.) involved consideration of the "source" and the "target." The "source" included the postulated pipe failure and the resulting reactions of the failure. The "target" included structures, systems, or components that were required to cope with the postulated pipe break and/or bring the unit to and maintain the unit at a safe-shutdown condition. Systems that require automatic initiation by safety system actuation and are required for that accident were protected from a loss of redundancy. A high-energy line break that did not cause automatic initiation of safety systems was not allowed to cause a loss of function of a feature required for safe shutdown. If such an accident resulted merely in the loss of one or more components, while 100% redundancy of its function exists elsewhere, the design of the system was considered adequate. In such a case, however, plant operations would be governed by the requirements of the Technical Specifications.

To analyze the consequences of the postulated break, the "targets" were identified, and are tabulated in Section 3C.4.

Once the high-energy break points and "targets" were identified and located, the consequences of pipe whip and jet impingement were determined. The criteria and methods of analysis for determining these effects are discussed below. As a part of the analysis of each break point, it was determined if the consequences were acceptable or if pipe whip protection and/or jet impingement protection was required.

Protection from pipe whip was not provided if any of the following conditions existed:

1. The whipping pipe was physically separated (or isolated) from structures, systems, or components important to safety by protective barriers, or restrained from whipping by plant design features such as restraints.
2. Following a single break, the unrestrained movement of either end of the pipe in any direction about a plastic hinge formed at the nearest pipe whip restraint could not impact any structure, system, or component important to safety.
3. The internal energy level associated with the whipping pipe could be demonstrated to be insufficient to impair the safety function of any structure, system, or component to an unacceptable level.
4. It can be demonstrated that the design is acceptable on some other basis.

The internal energy level associated with the pipe break reaction takes into account any line restrictions (e.g., flow limiters) between the pressure source and break location, and the effects of either single-ended or double-ended flow conditions as applicable. The energy level in a whipping pipe was considered as insufficient to rupture an impacted pipe of equal or greater nominal pipe size and equal or heavier wall thickness.

Protection from jet impingement was not provided if any of the following conditions existed:

1. The piping was physically separated (or isolated) from structures, systems, or components important to safety by protective barriers.
2. The energy associated with jet impingement was demonstrated to be insufficient to impair the safety function of any structure, system, or component to an unacceptable level.
3. It can be demonstrated that the design is acceptable on some other basis.

3C.2.2 Criteria on Pipe Breaks and Cracks

3C.2.2.1 Definition of High-Energy Lines

Design-basis pipe breaks were postulated in piping for which the maximum operating pressure exceeded 275 psig and the maximum operating temperatures equalled or exceeded 200°F. Pipe cracks ($d/2 \times t/2$) were postulated in piping for which either the operating pressure exceeded 275 psig or the operating temperature equalled or exceeded 200°F. If both operating pressure and temperature were below these specified levels, breaks and cracks were not postulated (see Figure 3C-2).

Operating temperature and pressure are defined as the maximum temperature and pressure in the piping system, during occurrences that are expected frequently in the course of power operation, start-up, shutdown, standby, refueling, or maintenance of the plant.

3C.2.2.2 Location of Breaks and Cracks

Design-basis break and crack locations were postulated in accordance with the following criteria. However, where pipes carrying high-energy fluids were routed in the vicinity of structures and systems necessary for safe shutdown of the nuclear plant, supplemental protection of these structures and systems was considered and provided, where necessary, to cope with the environmental effects (including effects of jet impingement) of a single postulated open crack at the most adverse location with regard to these essential structures and systems. For definition of terms used refer to Section 3C.2.2.3.

1. Code Class 1 piping breaks were postulated to occur at the following locations in each piping run or branch run:

   a. The terminal ends.

   b. Any intermediate locations between terminal ends where the primary-plus-secondary stress intensities S_m (circumferential or longitudinal) derived on an elastically calculated basis under the loadings associated with the operating-basis earthquake and operational plant conditions exceed 2.0 S_m for ferritic steel and 2.4 S_m for austenitic steel.

   c. Any intermediate locations between terminal ends where the cumulative usage factor "U" derived from the piping fatigue analysis and based on all normal, upset, and testing plant conditions exceeds 0.1.

   d. At intermediate locations in addition to those determined by b and c above, selected on a reasonable basis as necessary to provide protection. At a minimum, two intermediate locations were selected for each piping run or branch run, on the basis of maximum combined primary and secondary stress.

2. Code Class 2 and 3 piping breaks were postulated to occur at the following locations in each piping run or branch run:

   a. The terminal ends.

   b. Any intermediate locations between terminal ends where either the circumferential or longitudinal stresses derived on an elastically calculated basis under the loadings associated with an operating-basis earthquake event and operational plant conditions exceed 0.8 (S_h + S_a) or the expansion stresses exceed 0.8 S_a.

   c. Intermediate locations in addition to those determined by b above, selected on a reasonable basis as necessary to provide protection. At a minimum, two intermediate locations were selected for each piping run or branch run, on the basis of maximum combined primary and secondary stress.

3. For non-safety-class piping systems, breaks were postulated to occur at the following locations in each piping run or branch run:

   a. The terminal ends.

   b. Any intermediate locations between terminal ends where either the circumferential or longitudinal stresses derived on an elastically calculated basis under the loading associated with operational plant conditions exceed 0.8 ($S_h + S_a$) or the expansion stresses exceed 0.8 S_a.

   c. Intermediate locations in addition to those determined by b above, selected on a reasonable basis as necessary to provide protection. At a minimum, two intermediate locations were selected for each piping run or branch run, on the basis of maximum expansion stress. (Where stress values were not available, intermediate locations were selected at each pipe fitting.)

4. Cracks were postulated to occur in all high-energy lines at the most adverse location with respect to “targets.”

The requirement to consider arbitrary intermediate locations was eliminated by Generic Letter 87-11. The main steam and feedwater lines have been reanalyzed and intermediate locations, as described by 2c and 3c were eliminated.

The criteria used to determine the pipe break orientation at the break locations, as determined per Section 3C.2.2.2, were as follows:

1. Longitudinal breaks in piping runs and branch runs, 4-inch nominal pipe size and larger.

2. Circumferential breaks in piping runs and branch runs exceeding 1-inch nominal pipe size.

3C.2.2.3 **Terminology**

1. Piping is a pressure-retaining component consisting of straight or curved pipe and pipe fittings (e.g., elbows, tees, and reducers).

2. A piping run interconnects components such as pressure vessels, pumps, and rigidly fixed valves that may act to restrain pipe movements beyond that required for design thermal displacement. A branch run differs from a piping run only in that it originates at a piping intersection, as a branch of the main pipe run.

3. S_m is the design stress intensity as specified in the USA Standard Code for Pressure Piping, ANSI B31.7.0-1969.

4. “U” is the cumulative usage factor as specified in the USA Standard Code for Pressure Piping, ANSI B31.1.0-1967.

5. S_h is the basic material allowable stress at elevated temperature as defined in ANSI B31.1.0-1967.

6. S_a is the allowable stress range for expansion stress calculated by the rules of ANSI B31.1.0-1967.
7. Longitudinal breaks are parallel to the pipe axis and oriented at any point around the pipe circumference. The break area is equal to the effective cross-sectional flow area upstream of the break location. The length of the break is assumed to be twice the outside diameter of pipe. Dynamic forces resulting from such breaks are assumed to cause lateral pipe movements in the direction normal to the pipe axis.
8. Circumferential breaks are perpendicular to the pipe axis, and the break area is equivalent to the internal cross-sectional area of the ruptured pipe. The dynamic (blowdown) forces resulting from a circumferential break act to separate the piping axially—there is no transverse force during a circumferential break event.
9. A tee-joint that connects a branch run and main piping is not necessarily a break location for the main piping, if it does not qualify as a high-stress and/or high-cumulative-usage-factor location in this main piping run; however, at its welding junction to the branch run, which is a terminal point of the branch run, a break location has been postulated (see Figure 3C-3).
10. If one of the computed stresses and/or cumulative usage factors of the various points of an elbow, tee, or reducer was high enough to be qualified as an intermediate break location, and the other(s) were within ±10% of it, all these points were considered as a single break location.

3C.2.3 Methods and General Results

3C.2.3.1 **Whipping Pipes**

The motion of a pipe subsequent to a postulated break is analyzed with a finite element mathematical model using a computer code for nonlinear dynamic deformation. Time-dependent forces are applied to the model to represent the forces produced by the fluid. These forces account for both momentum and decompression wave effects, and include the influence of flow restrictors, friction, and pipe geometry. The code, LIMITA II, is described in Section 3.7.2.7.1.7.

3C.2.3.2 **Restrained Pipes**

The design and analytical justification of pipe whip restraints consists of two distinct phases. The first is a conservative analytical method, based on energy dissipation, used to design and size the restraints. The other consists of a nonlinear dynamic analysis of the pipe-restraint interaction to verify the design adequacy.

The first phase of the analysis either computes the motion of a whipping pipe to obtain the kinetic energy-displacement characteristics, or uses more elementary and conservative energy functions, based on pipe displacement times the peak blowdown forces during the interval immediately after the break, with approximate corrections for energy dissipation in the pipe prior to restraint impact. These energy functions are derived for several directions of pipe motion corresponding to different break conditions and locations. Peak quasi-steady-state forces are also determined for each direction of loading. These energies and forces are the basis for the preliminary restraint design. Figures 3C-4 and 3C-5 illustrate the general concept of restraints.

The gap between the pipe and pipe whip restraint is selected to prevent contact under any condition except pipe break. Allowance is made for maximum thermal and seismic pipe displacements and installation tolerances. The elastic-plastic energy-absorbing capability of a restraint design is evaluated on a static basis for each of the loading conditions, and is equated to the energy gained by the pipe in moving from its initial position (the maximum normal operating condition) to its final position against the deformed restraint. The capability of the deformed restraint to support the quasi-steady-state loads is also examined. The restraint design is sized to limit deformations to 50% of the uniform ultimate strain of the materials used.

The restraint design evolved by the above methods is analyzed for its dynamic interaction with the pipe. A finite element mathematical model of the pipe and restraint, including the local elastic-plastic stiffness of the pipe, represents the system. Using a computer code for dynamic nonlinear deformation, the time-dependent interaction of the pipe and restraints is analyzed. The results are checked to ensure that the strain criteria are met. A description of the dynamic analysis methods is provided in Section 3C.2.3.3.

3C.2.3.3 **Whipping Pipe and Wall Interactions**

3C.2.3.3.1 Introduction

The velocity and geometry of a whipping pipe and the impact of a pipe into a pipe whip restraint can be accurately predicted. However, pipe impact into a concrete wall is somewhat more complex due to the brittle nature of the concrete.

In all cases, wall thicknesses used in normal plant construction are sufficient to stop whipping pipes, although local damage to the wall may occur. Protection features such as cover plates were added if spalling concrete surfaces would adversely affect equipment important to safety.

The following sections describe the analytical techniques used.

3C.2.3.3.2 Pipe Acceleration Prior to Impact

The velocity of a whipping pipe is dependent on:

1. The blowdown forces.
2. The pipe and break geometry and size.
3. The distance traveled.

The motion of the pipe subsequent to a break is computed using a finite element mathematical model of the piping system, which is analyzed dynamically for elastic-plastic deformation using the appropriate time-dependent forces. A typical mathematical model is shown in Figure 3C-6. At time zero, before the break occurs, the system is in a state of stress due to internal pressure, but these pressure forces are in static equilibrium with the loads in the pipe. For a circumferential break, as the fracture propagates, the load-carrying metal of the pipe decreases, so an unbalanced force results. The load in the pipe at the break is assumed to drop linearly to zero in 1 msec. After the break, the forces exerted on the pipe by the fluid are determined by the time-dependent pressure and momentum effects, which are controlled by the location of the travelling decompression wave(s). The result of the above method of determining fluid dynamic forces is the product of a "net" jet thrust, which has a rise time of 1 msec, with an initial pulse peak of 1.0 PA, where P is the pipe internal pressure and A is the break flow area.

For a longitudinal break, the blowdown jet force is assumed to rise linearly to 1.0 PA in 1 msec. Thereafter, the magnitude of the force is again determined by the location of the decompression wave(s).

For both break types, if pipe friction and flow restrictions are neglected, the maximum jet force (at steady state) is equal to 1.26 PA for steam and saturated water lines and 2.0 PA for subcooled water lines.

3C.2.3.3.3 Concrete Wall Impact

The crushing resistance of the pipe is modeled as a "spring" (connected to the wall, which is assumed fixed) in the mathematical model. Displacements in the wall do not have to be considered since the great inertia of the wall prevents any appreciable movement prior to the moment that the peak forces occur. The peak force computed in this "spring" during the dynamic analysis is the maximum load transmitted to the wall during the impact. The effects of the continuing blowdown forces and the inertia of the pipe away from the impact point are included in the analysis.

Since the load is applied to the concrete wall in a short time compared to the natural period of a concrete wall, the application of a dynamic load factor is required when using static design equations. A punching shear failure analysis is performed to evaluate the concrete wall.

3C.2.3.4 **Fluid Jets and Interactions on Reinforced-Concrete Walls and Metal Plates**

All safety-related components and barriers, reinforced-concrete walls, and steel plates located in the fluid jet path of postulated pipe breaks are considered susceptible to jet impingement. To evaluate the local punch shear effect on the reinforced-concrete walls due to the jet from a pipe break, the following steps are taken:

1. For circumferential pipe break, a family of curves, Figures 3C-7 through 3C-8, representing the resistance of reinforced-concrete walls to jet impingement is presented. Four basic parameters, i.e., the pipe diameter, the fluid pressure P, the reinforced-concrete wall thickness, and the distance between wall and pipe break location, are plotted based on the following conservative assumptions:

   a. The pressure drop due to pipe friction and flow restrictions is negligible. The magnitude of the jet force is the upper bound of the steady-state value, 1.26 PA for steam line and 2.0 PA for nonflashing water line, where A is the break area.

   b. The friction between air and jet fluid is negligible.

   c. The concrete wall intercepts the whole jet normal to the wall.

   d. A dynamic load factor of 2.0 is applied to the jet force to the concrete walls, assuming instantaneous jet impingement load.

   e. The strength characteristics of concrete wall are based on American Concrete Institute Standard 318-71.

   If a case is judged safe as indicated by these curves, the judgement is regarded as conclusive. Otherwise, a more detailed analysis, as described in step 2, is performed.

2. The steady-state jet force is calculated with the effects of pipe flow friction and flow restrictions taken into consideration. The magnitude of jet force obtained in this step is expected to be less than that in the first step. The curves used in the first step are used again by simply reducing the fluid pressure P in proportion to the reduction in the magnitude of jet force. However, if the steady-state jet force is less than 1.0 PA, the initial value of jet force 1.0 PA is used.

   If the result is still unsatisfactory, a third step is taken.

3. The time history of the jet force is determined and a dynamic analysis is performed.

   If the concrete wall is shown unsafe by this third step, either the concrete wall is strengthened or jet impingement shields are installed. Within the same distance and within the same expansion angle, a jet from a longitudinal break will expand to a larger area than that from a circumferential break. Therefore, in the longitudinal break case, the use of the above-mentioned curves will give a slightly more conservative result. To analyze the jet impingement on metal plates designed to protect some equipment or structures, an approach similar to that for the concrete walls is used.

3C.2.3.5 **Pressure and Environment**

The pressure buildup from the postulated rupture of a high-energy pipe in a cubicle or building is calculated using the computer program CUPAT.

3C.2.3.5.1 Introduction

CUPAT is a computer program used to calculate pressure and temperature transients in various nuclear power plant cubicles resulting from a postulated high-energy pipe break. The output is used mainly for design purposes in establishing the peak pressure differentials across the cubicle walls.

This program was derived from the LOCTIC computer program (Reference 1), used to calculate pressure and temperature transients for the primary containment. There are two major differences between LOCTIC and CUPAT:

1. LOCTIC includes the effects of heat transfer by providing subroutines to handle sources and sinks. CUPAT assumes a volume that receives heat and mass from a ruptured piping source and discharges heat and mass to its surroundings, but aside from that there are no other heat sources or sinks (adiabatic assumption).
2. CUPAT allows for flow out of the volume considered as well as flow in.

To calculate the transients within a compartment, CUPAT numerically solves finite difference equations defining heat and mass flows into and out of the compartment. The program uses the same basic assumptions as those used in LOCTIC, namely:

1. Mass and energy added or removed during each small time step are based on rates determined at the start of the time step; i.e., during any time interval, the thermodynamic state is assumed to be steady, and the response of the flow out of the volume to changes in the thermodynamic state is instantaneous (quasi-steady-state assumption).
2. The atmosphere in the compartment mixes instantaneously and homogeneously, i.e., at each point in time, the atmosphere is in a state of thermodynamic equilibrium.

A detailed description of the approach to the problem is presented below.

3C.2.3.5.2 Calculational Approach

The calculational approach used in CUPAT is summarized in the block diagram shown in Figure 3C-9. Blocks (1) through (5) are traversed once for each time step.

3C.2.3.5.2.1 *Quasi-Steady-State Assumption.* Analyzing for the transient effects of a pipe break is very complex. The thermodynamic state of the cubicle atmosphere is continuously changing. This state depends on the mass and energy flows into and out of the cubicle. The flows, in turn, are dependent on the thermodynamic state within the cubicle. A numerical solution requires that the following simplifying assumptions be made.

The system is defined as the cubicle atmosphere at any given time. This includes any air, steam, and water droplets present, but not the walls, equipment, or internal structure of the cubicle itself. If the time step is small enough, the net rate of mass and energy addition to the system will not vary appreciably during the time step. Thus, the flow rates are calculated assuming that the thermodynamic state does not change during the time step; this assumption eliminates the need to iterate and converge on the inflow and outflow for each time step. This approach is used in LOCTIC (which also includes heat flows) for the primary containment transients, and is also used in CUPAT.

3C.2.3.5.2.2 *Mass and Energy Flow Rates into Cubicle.* The mass and energy flow rates into the cubicle are supplied as input to the program in tabulated form. These blowdown rates into the cubicle may be obtained from the output of a LOCTIC or LOCTVS (Reference 2) computer run or from the assumption of Moody (Reference 3) flow with a known pressure blowdown.

The flow of fluid from a piping rupture is relatively insensitive to the back pressure in the cubicle, since the pressure in the high-energy line is above 275 psig. Thus, the mass and energy inflow data specified as input are close to the actual flow, but are conservatively high.

3C.2.3.5.2.3 *Calculation of the Thermodynamic State of the Cubicle.* In each time step of the numerical calculation, equilibrium temperature and pressure in the cubicle are determined based on new values of mass and internal energy. Properties of water are obtained from the steam tables. The detailed procedure by which the pressure and temperature of the cubicle atmosphere are found from the updated values of mass and internal energy is described below.

Initially, the equilibrium state is considered to be a two-phase mixture of air, saturated steam, and saturated liquid. However, if the energy content for the given mass is greater than that required for saturation, a single-phase mixture of air and superheated steam is determined.

To arrive at the correct equilibrium conditions, a curve of internal energy of the air, steam, and liquid in the volume versus temperature is generated. The basis for the curve is that the mass of water present in the cubicle is at a saturated equilibrium state for each temperature, and the total internal energy of the system at this temperature is calculated accordingly. The actual total internal energy is used to enter this curve and find the true temperature. The total pressure is then determined by adding the vapor pressure to the air partial pressure calculated by the ideal gas law at this temperature.

In the case where the contents form a superheated vapor, the superheat section of the steam tables is used to match the specific volume of the steam and the internal energy to find the equilibrium temperature and pressure.

3C.2.3.5.2.4 *Calculation of Flow Rate Out of Cubicle.* The CUPAT computer program uses the LOCTVS (Reference 4) vent flow model to determine the flow rate out of the cubicle. A homogeneous flow model is used in LOCTVS to calculate flow out of the drywell through the vents of a pressure suppression containment. Although flow through the vents is characterized by slip between the gaseous and liquid phases, a homogeneous model yields lower flow rates and is used for conservatism. The ability of the vent flow model to conservatively predict flow through the vents has been checked against the Bodega Bay and Humboldt Bay pressure suppression tests.

3C.2.4 Protection Against Whip

Where pipe whip analysis indicated that the consequences of allowing a high-energy pipe to whip were unacceptable with respect to the criteria of Section 3C.2.1, the pipe was restrained, a barrier wall was placed between the pipe and the equipment, or the pipe and/or equipment was relocated.

The exact method of protection depended on the circumstances of the individual break location.

3C.2.5 Analysis of Seismic Class I Structures

3C.2.5.1 General

A discussion of the structural analysis of Seismic Class I structures is contained in Section 3.8.1. That discussion is herewith expanded to include consideration of the structural effects of pipe failure loads such as pipe whip restraint forces, jet impingement forces, and steam pressure or hydraulic flooding.

3C.2.5.2 Methods of Evaluation Stresses

3C.2.5.2.1 Structural Steel

Stresses in structural steel members were evaluated by the methods of Part 1 of the AISC Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings, issued February 12, 1969.

3C.2.5.2.2 Reinforced Concrete

Stress in reinforced-concrete members were evaluated by the methods of Part 4 of the ACI Building Code Requirements for Reinforced Concrete, issued 1971.

3C.2.5.3 Load Combinations and Allowable Design Stress: Definitions

D Dead loads and their related moments and forces, including any permanent equipment loads, and prestressing loads, if any

L Live loads, present during the pipe rupture event, and their related moments and forces

T_o Thermal loads during normal operating conditions

R_o Pipe reactions during normal operating conditions

E Operational-basis earthquake (OBE) load (see Section 2.5.2.6)

HE Design-basis earthquake (DBE) load (see Section 2.5.2.6)

P_a Pressure equivalent static load within or across a compartment and/or building, generated by a postulated break, and including an appropriate dynamic factor to account for the dynamic nature of the load

T_a Thermal loads under thermal conditions generated by a postulated break and including T_o

R_a Pipe reactions under thermal conditions generated by a postulated break and including R_o

Y_r Equivalent static load on a structure generated by the reaction of the broken high-energy pipe during a postulated break, and including an appropriate dynamic factor to account for the dynamic nature of the load

Y_j Jet impingement equivalent static load on a structure generated by a postulated break, and including an appropriate dynamic factor to account for the dynamic nature of the load

Y_m Missile impact equivalent static load on a structure generated by or during a postulated break, like pipe whipping, and including an appropriate dynamic factor to account for the dynamic nature of the load

S For the structural steel, S is the required section strength based on the elastic design methods and the allowable stresses defined in Part 1 of the AISC Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings, February 12, 1969

U For concrete structures, U is the section strength required to resist design loads, based on methods described in ACI 318-71

3C.2.5.4 Seismic Class I Structures

Concrete structures have been checked to satisfy the following load combinations:

$$U = D + L + T_a + R_a + 1.5\ P_a$$

$$U = D + L + T_a + R_a + 1.25\ P_a + 1.0\ (Y_r + Y_j + Y_m) + 1.25\ E$$

$$U = D + L + T_a + R_a + 1.0\ P_a + 1.0\ (Y_r + Y_j + Y_m) + 1.0\ HE$$

Steel structures have been checked to satisfy the following load combinations:

$$1.6\ S = D + L + T_a + R_a + P_a$$

$$1.6\ S = D + L + T_a + R_a + P_a + 1.0\ (Y_j + Y_r + Y_m) + E$$

$$1.6\ S = D + L + T_a + R_a + P_a + 1.0\ (Y_j + Y_r + Y_m) + HE$$

Local stresses due to the loads Y_r, Y_j, and/or Y_m were permitted to exceed allowable, provided there was no loss of function of any safety-related system. Appropriate dynamic load factors were included in all dynamic loads unless a time-history analysis was used.

3C.2.6 Electrical and Controls and Environmental Capability

The electrical and control equipment that must remain operable to control and power engineered safety features systems or systems to provide for safe shutdown following a postulated high-energy line break are not endangered by postulated high-energy line breaks because (1) physical plant arrangement provides protection by separation from areas occupied by the high-energy lines, or (2) equipment that could be influenced by failure of high-energy lines is “fail safe,” in that loss of the equipment or voltage causes safety equipment to be operated in the safe direction or causes a signal loss which initiates safeguards actuation, or (3) methods are used to detect and isolate the break before detrimental damage can occur.

3C.2.7 Augmented Inservice Inspection

An augmented inservice inspection program of welds at postulated break locations has been initiated for the main steam and feedwater systems from the 40-inch main steam and 26-inch feedwater headers to the main steam valve house. Twenty-five percent of the welds at postulated break locations in the main steam and feedwater piping located in the mechanical equipment room will be examined in accordance with the rules of ASME Section XI (IWC, Class 2), edition and addenda corresponding to the currently approved ASME Section XI program. The inspection locations will be changed each inspection period, such that a different twenty-five percent of the locations will be inspected. This program provides 75% weld inspection each ASME Section XI interval. (See References 9, 10, & 11). In addition, the main steam and feedwater piping in the mechanical equipment rooms is included in the Secondary Piping and Component Inspection Program. Also, operators inspect these lines for leakage on a daily basis.

3C.2.7.1 **Inservice Inspection**

The augmented inservice inspection program will comply, to the extent practical within the limitations of design, geometry, and materials of construction of the components, to the requirements in the editions of Section XI of the ASME Boiler and Pressure Vessel Code and

Addenda required for the reactor coolant system. The frequency of inspections for the augmented inservice inspection program has been increased over those required by ASME Section XI, 1970 Edition, as outlined below.

For welds (at the postulated break locations):

1. A baseline examination providing 100% coverage was performed prior to commercial operation to establish system integrity and baseline data.
2. Thereafter, inservice inspection of the welds will be performed in accordance with the following schedule. (The inspection intervals identified below sequentially follow baseline examination above.)

First 10-Year Inspection Program Intervals

a. First 3-1/3 years (or nearest refueling outage	100% volumetric inspection of all welds
b. Second 3-1/3 years (or nearest refueling outage)	100% volumetric inspection of all welds
c. Third 3-1/3 years (or nearest refueling outage)	100% volumetric inspection of all welds

Successive Inspection Intervals

Every 10 years thereafter (or nearest refueling outage)	Nondestructive inspection of one-fourth of the welds at the expiration of each period of the inspection interval with a cumulative 75% coverage of all welds each interval.

Note: The welds selected during the successive inspection intervals shall be distributed among the total number to be examined to provide a representative sampling of the conditions of the welds.

3. Examinations that reveal unacceptable defects in a weld during an inspection shall be extended to require an additional inspection of another one-fourth of the welds. If further unacceptable defects are detected in the second sampling, the remainder of the welds shall be inspected.

The nondestructive examination procedures will include the examination of the welds and heat-affected zones using either surface and ultrasonic methods or radiograph methods. Examination methods will be in accordance with ASME XI IWC-2000.

Alternative examination methods, a combination of methods, or newly developed techniques may be substituted for the method specified above, provided the results are demonstrated to be equivalent or superior to those of the specified method.

3C.2.7.2 Basis for the Inservice Inspection Program

As shown in a PVRC report (Reference 5), and Virginia Power technical report (Reference 8), toughness of nuclear power plant piping materials is sufficient to prevent brittle fracture at operating conditions. This conclusion is supported by fracture mechanics calculations. Furthermore, from the following fracture mechanics techniques and calculations, the critical size of surface and internal flaws exceeds the thickness of the piping material. Consequently, a surface or an internal flaw will extend through the wall thickness and form a subcritical through-wall crack, which will leak before it reaches its critical size.

Main steam line material is ASTM A155 grade CMS 75, Class 1, outside diameter 32 inches, wall thickness 1 inch, plate material for piping ASTM A299. Fittings were fabricated from ASTM A299 steel plate stock, using the ASTM A234 Grade WPB specification. Fitting material equivalent to ASTM A691, Grade CMS 75, Class 32: carbon-manganese-silicon alloy steel can be used as replacement material for pipe and fittings.

Feedwater line material is ASTM A106 grade B, outside diameter 16 inches, wall thickness 1.031 inch for Schedule 100 and 0.844 inch for Schedule 80. Fittings are SA234 WPB. ASTM A335, Grade P11 or P22: Chromium - Molybdenum steel can be used as replacement material for fittings. ASTM A691 Grade 2 1/4 CR, Class 42; ASTM A387, Grade 22 (plate): Chromium - Molybdenum steel can be used as replacement materials for headers of optional rolled and welded design. ASTM A691 Grade 2 1/4 CR, Class 42 can be used as alternate material for fittings.

For both main steam and feedwater piping, the ASME SA equivalent material can be used as a preferred substitute for ASTM materials.

3C.2.7.3 Fracture Mechanics

The application of fracture mechanics techniques allows prediction of the critical flaw size that can cause fast or unstable fracture in a stressed structure.

When the critical flaw size is established for a nominal stress level, it is possible to determine the acceptable defect size. One of the criteria is the leak-before-fracture criterion, which states that the defect will propagate slowly through the wall of the pipe and that the pipe will leak before the crack is large enough to trigger the fast fracture.

Fabricated structures may contain several types of defects, such as surface flaws, internal flaws, and through-the-wall cracks. The critical flaw size can be calculated for each of these flaws using fracture mechanics relationships. The required formulas were used in two published papers (References 5 & 6) treating similar problems. As emphasized in the PVRC Recommendations on Toughness Requirements for Ferritic Materials, pipe wall section thickness is usually not thick enough to support plane strain fracture propagation, which can be properly analyzed by the fracture mechanics methods. In other words, the load limits and critical flaw size calculated using fracture mechanics will in general be more conservative for pipe than for the thick section structures where the plane stress conditions can exist. Fracture will occur when the value of the stress intensity factor K_I reaches the critical value K_{IC}. The critical flaw size is related to the K_{IC} in several different formulas, depending on geometry of structures, flaws, shape, and environmental factors. The following assumptions have been made about factors affecting the relation between the K_{IC} and the critical flaw size:

1. Material properties (toughness and strength) of the weld metal and the heat-affected zone in the longitudinal and circumferential weldments are the same as in the base material.
2. The lowest and the highest temperatures in the main steam line are approximately 520°F and 540°F. The lowest and the highest temperatures in the feedwater line are approximately 290°F and 440°F. However, only the lowest temperatures are used in calculations of fracture toughness because they give more conservative values for critical crack size.
3. Because of uncertainty involved in evaluating the possible stress state, Irwin's (Reference 7) suggestion was accepted that the membrane stress is equal to the yield strength. Therefore a value of 31,100 psi at 290°F was used for ASTM A106 Grade B material, and 36,900 psi at 520°F for ASTM A155 Grade CMS 75 material, based on stress data of ANSI B31.7.
4. The critical stress intensity factor of 300,000 psi $\sqrt{\text{in.}}$ was used in Reference 6 for A106B pipe. In this work, a lower value of 200,000 psi $\sqrt{\text{in.}}$, which would correspond to the reference stress intensity factor K_{IR} at the temperature NDT +180°F, has been used. The lowest temperature for A106B pipe is 290°F and for A155 pipe 520°F, which means that the NDT temperature in the first case would be 290 - 180 = 110°F, and in the second case 520 - 180 = 340°F. This is a conservative assumption, because the NDT temperature for these materials is below room temperature.

   Toughness of replacement materials is documented in Reference 8. This reference provides technical justification for use of replacement materials based upon fracture toughness of these materials. The replacement materials are assessed using linear-elastic fracture mechanics, elastic-plastic fracture mechanics, and load limit methods.

3C.2.7.4 **Internal Flaw**

The internal flaw is assumed to be ellipsoid, as shown in Figure 3C-10 (A), and is located in the center of the pipe wall. The flaw can be axial (the major axis parallel to the pipe axis) or circumferential (the major axis perpendicular to the pipe axis). A further assumption is that the flaw is small compared to the pipe radius. Thus the curvature effect can be neglected and the pipe can be approximated with an infinite plate under uniform applied stress. The stress intensity factor K_I for this model is given by Reference 6.

$$K_I = \left[\sin^2\beta + \frac{a^2}{b^2}\cos^2\beta\right]^{\frac{1}{2}} \frac{\sigma(\pi a)^{\frac{1}{2}}}{\phi} \qquad (3C.2\text{-}1)$$

where σ is the applied stress, β is the angle at which the stress intensity is calculated, and ϕ is the elliptic integral,

$$\phi = \int_{o}^{\frac{\pi}{2}} \left[1 - \left(\frac{b^2 - a^2}{b^2} \right) \sin^2\theta \right]^{\frac{1}{2}} d\theta \qquad (3C.2\text{-}2)$$

At the tip of the major axis, $\beta = 0$, while, at the tip of the minor axis, $\beta = \pi/2$.

If it is assumed that the major axis of the ellipsoid is twice as long as the minor axis, Equation 3C.2-1 becomes:

$$K_{IC} = 0.826\ \sigma\ (\pi\ a_{cr})^{1/2} \qquad (3C.2\text{-}3)$$

It has been shown that for an elongated crack (b>>a), the critical stress intensity factor is given by:

$$K_{IC} = 1.2\ \sigma\ (\pi\ a_{cr})^{1/2} \qquad (3C.2\text{-}4)$$

Substituting the values for the stress intensity factor and applied stress (yield strength at the temperature) in Equations 3C.2-3 and 3C.2-4:

Material	Temperature, °F	Equation	2 a_{cr} (Critical Flaw Size), in.
SA106B	290	3C.2-3	38.6
SA106B	290	3C.2-4	18.3
SA155	520	3C.2-3	27.4
SA155	520	3C.2-4	13.0

The maximum nominal wall thicknesses of the main steam and feedwater lines within the service building are 1 inch. All 2 a_{cr} values are much greater than the wall thickness, which means that the flaws would extend through the wall without becoming critical. In other words, the internal flaw will become a through-the-thickness crack and will leak.

3C.2.7.5 **Surface Flaw**

The surface flaw is assumed to be a semi-ellipsoid, as shown in Figure 3C-10(B). The flaw can be axial or circumferential, as in the previous case. Again the curvature effect is neglected, and the stress intensity factor is given by Reference 5.

$$K_{IC} = 1.12\,\sigma\,(\pi\,a_{cr})^{1/2} \qquad (3C.2\text{-}5)$$

Material	Temperature, °F	a_{cr} (Critical Flaw Size), in.
SA106B	290	10.5
SA155	520	7.5

As in the case of the internal flaw, the surface flaw will penetrate the pipe wall without becoming critical.

3C.2.7.6 **Axial Through-Wall Crack**

The simplest formula for axial through-wall cracks is obtained when the pipe is assumed to be an infinite plate; that is, the diameter is much greater than the thickness. Equation 3C.2-6 gives the critical crack size for such a simple case (Reference 5):

$$K_{IC} = \sigma\,(\pi\,b_{cr})^{1/2} \qquad (3C.2\text{-}6)$$

where 2 b_{cr} is the critical crack length. The geometry is shown in Figure 3C-10(C). When the pipe diameter decreases, corrections are necessary. As a result of tests at Battelle Memorial Institute on SA106B piping, the critical size of the axial through-wall crack is given by Reference 6:

$$b_{cr} = \left\{ \frac{Rt}{1.61}\left[\left(\frac{\sigma^*}{\sigma}\right) - 1\right]\right\}^{\frac{1}{2}} \qquad (3C.2\text{-}7)$$

where b_{cr} is the critical half length, * is the flow stress, R the average pipe radius, and t the thickness.

Material	Temperature, °F	Equation	2 b_{cr} (Critical Flaw Size), in.
SA106B	290	6	26.4
SA106B	290	7	1.9 (16-in. o.d. Schedule 80)
SA106B	290	7	2.6 (16-in. o.d. Schedule 100)
SA155	520	6	18.8
SA155	520	7	3.46

3C.2.7.7 **Circumferential Through-Wall Crack**

It is shown in Reference 6 that the critical length of a circumferential through-wall crack is greater than the critical length of an axial crack.

3C.2.7.8 **Flaw Growth**

Under the influence of cyclic loads, small defects can grow to critical size. It has been shown that an empirical expression accurately describes the flaw growth.

$$\frac{da}{dn} = C(\Delta K)^m \qquad (3C.2\text{-}8)$$

where $\frac{da}{dn}$ is the flaw growth rate, ΔK is the change in stress intensity factor per cycle, and C and m are constants.

The following calculation taken from Reference 6 describes the growth of the code allowable internal and surfaces flaws into through-wall cracks. Since the size of these flaws is small, pipe curvature can be neglected, and there is no difference between axial and circumferential flaws. Surface defects in Seismic Class I piping allowed by the code are defects with a maximum depth of 5% of the wall thickness. Therefore the maximum flaw depth should not exceed 0.05x (thickness). The material constants equation have values: $C = 1.6 \times 10^{-4}$ in.$^{-1}$ and m = 4 (at 550°F). Note that the value of the exponent m is conservative. The exponent varies between 2 and 4 for different steels and, using its maximum value, the growth rate will be the fastest.

Integration of Equation 3C.2-8 gives the number of cycles:

$$n = \int_{a_i}^{a_x} \frac{da}{C(\Delta K)^4} \qquad (3C.2\text{-}9)$$

where a_i is 0.05 times the thickness, and is the initial flaw depth (the code allowable defect), and a_x is the final flaw depth. For a surface flaw, integral 3C.2-9 becomes:

(3C.2-9)

$$n = \frac{1}{C}\int_{a_i}^{a_x} \frac{da}{\left[1.12(\pi a)^{\frac{1}{2}}\right]^4}$$

If a = thickness, then n is the number of cycles to develop a through-wall crack. When Equation 3C.2-10 is applied to SA 155 pipe, $a_i = 0.05 \times 1 = 0.05$ in. and $a_x = 1$ inch.

σ = yield stress at 550°F (the flaw growth will be faster at higher temperatures).

$$n = 4.13 \times 10^9 \times \frac{1}{(27.7)^4}\left(\frac{1}{0.05} - 1\right) = 132{,}000 \text{ cycles} \qquad (3C.2\text{-}10)$$

It has been shown (Reference 6) that the growth of an internal flaw is even slower than in the above case. The number of cycles during the lifetime of a nuclear power plant can be obtained taking into account daily and weekly power reductions, start-ups, shutdowns, and other changes in pressure. An estimate made in Reference 6 gives the number of cycles at about 13,000, which is much smaller than the value for the formation of a through-wall crack.

3C.2.7.9 **Leak Detection**

The main steam and feedwater lines located in each unit's mechanical equipment room are inspected daily during operator tours for the purpose of detecting leakage from through-wall cracks before they reach critical flaw size. Specific guidance for the examination of the main steam and feedwater lines has been provided for operator use. Leakage through the insulation and protective sheet metal will be identified by observation of water or steam. If a leak is detected, it will be immediately investigated and repaired if caused by a through-wall crack. The leakage detection system described below is no longer required to be in service.

A leak detection system monitors circumferential welds of the main steam and feedwater lines in the mechanical equipment rooms. The general concept of the leak detection system is shown on Figure 3C-11. The system consists of a multichannel indicating device connected by electrical cables to moisture-sensitive tape located on the pipe insulation in the area to be monitored.

When the sensing element is dry (the normal operating condition), the indicator lamp in that channel flashes at an approximate rate of 10 to 15 times per minute. Should a leak occur in the monitored area, the flashing ceases and the indicator glows steadily. If a leak is detected, it will be investigated and repaired if caused by a through-wall crack. The location of a leak is pinpointed by the channel of the indicator lamp.

3C.3 HIGH-ENERGY SYSTEMS

3C.3.1 System Identification

The following systems contain "high-energy lines," as defined in Section 3C.2.2:

- Auxiliary steam
- Steam generator blowdown
- Boron recovery
- Chemical feed
- Condensate
- Chemical and volume control

- Extraction steam
- Feedwater
- Gland steam
- High-pressure heater drains and vents
- Low-pressure heater drains and vents
- Liquid waste disposal
- Main steam
- Safety injection
- Sample

Table 3C-2 identifies individual high-energy lines in these systems.

3C.3.2 Quality Assurance and Inspection

The quality assurance programs used for North Anna Units 1 and 2 are described in Chapter 17.

Table 3C-2 provides additional quality assurance information for each high-energy line. Those lines with a designation of Q_1, Q_2, and Q_3 have been designed, fabricated, and inspected in accordance with the requirements of Class I, II, and III, respectively, of ANSI B31.7-1969 and addenda through 1970. All other lines have been designed, fabricated, and inspected in accordance with ANSI B31.1-1967.

3C.3.3 Detection of Failures

Detection of main steam pipe breaks is described in Sections 15.2.13, 15.3.2, and 15.4.2. Detection of breaks in feedwater lines is discussed in Section 15.2.8. Detection of breaks in lines containing radioactive fluids is discussed in Section 12.1.4. Detection for breaks in lines routed through the Auxiliary Building is discussed in Section 3C.5.4.6.2.

3C.4 PLANT SHUTDOWN AND EQUIPMENT IMPORTANT TO SAFETY

3C.4.1 Introduction

Table 3C-3 lists the major equipment outside the containment that is required either to mitigate the consequences of a postulated break in a high-energy line or to bring the plant to and maintain the plant at a safe-shutdown condition. Associated instrumentation, power supplies, etc., are included with this equipment. The following assumptions have been made to determine equipment available for safe shutdown:

1. Loss of outside power, if the initiating event results in a trip of the turbine generator or the reactor protection system.
2. No design basis accident.
3. Only Seismic Class I equipment is available unless otherwise noted.

3C.4.2 Plant Shutdown Equipment

Main steam or feedwater breaks outside the containment are discussed in Sections 15.2.8, 15.3.2, and 15.4.2. Subsequent to a main steam or feedwater break, assuming offsite power is unavailable, plant shutdown is achieved by actuation of the emergency core cooling system (Section 6.3), removal of core decay and sensible heat via steam release through the atmospheric dump valves (Section 10.3), and maintenance of steam generator water inventories by means of the auxiliary feedwater system (Section 10.4.3).

Shutdown equipment is normally controlled from the control room. However, should evacuation of the control room be necessary, shutdown equipment can be controlled from an auxiliary shutdown panel as described in Section 7.4.

3C.4.3 Relationship of High-Energy Lines to Plant Shutdown and Equipment Important to Safety

The locations of equipment important to safety are shown on Reference Drawings 1 through 10. Machine and piping location drawings were used to evaluate which high energy lines were close to equipment important to safety. Table 3C-2 lists the high energy pipes; the locations can be reviewed on controlled drawings. Examples of the auxiliary building high energy piping can be found in Reference Drawings 11 through 35.

3C.5 EFFECTS OF PIPE BREAKS AND CRACKS

3C.5.1 Main Steam

3C.5.1.1 **Break Locations**

Reference Drawings 36 and 37 show the main steam lines. Break locations were postulated in the main steam lines from the containment to the turbine building in accordance with Section 3C.2.2. For the main steam line, 0.8 of the allowable thermal stress is 22,500 psi, and 0.8 of the allowable combined stress is 0.8 $(S_h + S_a)$ = 37,500 psi. Piping downstream of the manifold common to the three steam lines was not analyzed seismically. For this piping, intermediate locations were determined on the basis of maximum thermal stress. At all break points, both circumferential and longitudinal breaks were postulated. Cracks were selected in the vicinity of all identified “targets.”

3C.5.1.1.1 Main Steam Valve House

The break points for the main steam lines in the main steam valve house are listed in Table 3C-4. The break locations are shown on Reference Drawing 51.

3C.5.1.1.2 Service Building

The break points for the main steam lines in the service building are listed in Table 3C-4. The break locations are shown on Reference Drawing 51.

3C.5.1.1.3 Turbine Building

The break points for the main steam lines in the turbine building are listed in Table 3C-4. The break locations are shown on Reference Drawing 51.

3C.5.1.2 **Separation**

3C.5.1.2.1 Main Steam Valve House

The main steam valve house has been redesigned to ensure that the effects of postulated breaks within the main steam valve house are limited to the main steam valve house itself. This was done by removing doorways between adjacent structures, providing doorways directly to the outside, sealing all penetrations (piping, etc.) leading to or from adjacent structures, providing additional thickness and/or reinforcement in walls and floors, etc.

The analysis of pipe breaks within the main steam valve house indicated that adequate separation did not exist between the postulated pipe breaks and the auxiliary feedwater equipment located in that same structure. Therefore, the auxiliary feedwater pumps and their instrumentation and controls have been relocated to their own separate Seismic Class I, partially tornado-missile-protected structure adjacent to the 110,000-gallon condensate storage tank (refer to Section 3C.5.4.9).

3C.5.1.2.2 Service Building

An augmented inservice inspection program, as described in Section 3C.2.7, provides assurance of line integrity during the life of the facility. In addition, the main steam and feedwater piping in the mechanical equipment rooms is included in the Secondary Piping and Component Inspection Program. Also, operators inspect these lines for leakage on a daily basis.

3C.5.1.2.3 Turbine Building

The steam lines in the turbine building were analyzed; satisfactory separation exists between steam lines and any structures, systems, or components important to safety.

3C.5.1.3 **Restrained Pipes**

In the event that a main steam line ruptures in the main steam valve house, it is required that damage be limited primarily to blowdown of the affected steam generator and that the lines to and from the auxiliary feedwater system be protected.

Analyses indicated that whip restraints are required. These restraints are provided as shown in Figure 3C-12. It is assumed that during the initial moments after a break, steam flows from both ends of the severed pipe. For a circumferential rupture at points 150, 152, and 153, the restraint at C prevents the downstream section of pipe from whipping northward. Whipping normal to the pipe axis is limited by the containment for a longitudinal break at point 150 and by restraints B and C for a break at point 152 or 153. For a circumferential break at the elbow, restraint C limits downward whipping and restraint D prevents upward whipping of the severed pipe ends.

For a circumferential rupture in the riser at point 151 or point 461, the restraint at F restricts upward travel of the manifold. For a longitudinal break at point 461, the restraint at E prevents the manifold and riser from whipping.

The main steam pipe rupture restraints are designed to deform inelastically so that the impact energy due to the whipping rupture pipe is efficiently absorbed by the restraint to minimize the impact load transmitted to the restraint support structure (see Section 3C.2.3.2 for details pertaining to the method of analysis applied to the restraint, including the impact energy criteria and the limiting strain criteria).

Main steam line restraints B, C, D, and E consist of a restraint base, an arch, a honeycomb panel, and four long studs that fasten the restraint base to the intermediate (or attachment) structure.

By deformation in the plastic range, the studs serve as the primary energy absorption mechanism for a ruptured pipe impacting the restraint in the radially outward or tangential directions, while the honeycomb panel is the primary energy absorption mechanism for pipe impact loads in the radially inward directions.

Restraint F consists of steel straps installed over the safety valve manifold. The straps are designed to take load in the upward direction only. Energy will be absorbed by elongation of the straps.

3C.5.1.4 **Pipe Whip**

Mathematical models of pipe whip for specific pipe runs have been developed where required.

3C.5.1.5 **Fluid Jet Effects - Main Steam Valve House**

For each postulated rupture within the main steam valve house, the jet impingement loadings on the walls, valves, and piping important to safety have been calculated. The time-history results of the jet force from pipe breaks in the main steam lines have been calculated and are shown in Figure 3C-13.

The initial jet force was calculated as:

$$F = K \times P \times A$$

where:

K = thrust coefficient = 1.0

P = hot standby pressure = 1005 psig

A = flow area = 706.9 in^2

F = 710 kips

Due to the frictional effects and flow restrictions, the steady-state thrust coefficient is less than unity for this particular system. However, an initial thrust coefficient of 1.0 was applied to obtain a conservative jet force.

For the longitudinal breaks, the break size was taken as 64×11 inches with the jet diverging at a 20-degree solid angle. For circumferential break, it is assumed that the jet will impinge mainly on the adjacent section of pipe or manifold, which will be held in line within a few inches with the pipe axis by the whip restraints. For the postulated breaks, the impingement areas and jet pressures are listed in Table 3C-5.

Local damage to the walls and floors was checked. Calculations indicate that walls, floors, and roof are capable of withstanding the jet impingement loads without failure.

For the postulated main steam line breaks, jet impingement loads on the valves important to safety within the main steam valve house were calculated. The calculations indicate that the valves do not lose their ability to function.

The maximum impingement loadings on the valves are given by:

$$F = \frac{C \times P \times A \cos^2 \alpha}{1000}$$

where:

C = shape factor (0.6 for flow around a cylindrical valve)

P = initial jet pressure at the target (psig)

A = impingement area (in^2)

α = jet incident angle

The impingement pressures and normal forces on each valve are listed in Table 3C-6. It should be noted that these loads drop instantaneously to a fraction of their initial levels (see Figure 3C-13). Valves not listed in Table 3C-6 are either not important to safety, not in the path of the steam jet, or protected by a barrier or impingement shield.

An evaluation has been performed on the effects of jet impingement on piping within the valve house. Since a pipe is not damaged by impact from another whipping pipe of equal size and schedule, it follows that it will not be damaged by jet impingement from pipe of equal size and schedule. Therefore, impingement from one main steam line will not damage another main steam line, nor will impingement from a feedwater line damage a main steam or an adjacent feedwater line. However, in the case of a longitudinal rupture in the main steam riser at point 151, the jet could impinge on a variety of targets. A shield at the source is provided to direct the jet away from equipment important to safety. The general design of this shield is shown in Figure 3C-14.

3C.5.1.6 **Pressure and Environment**

3C.5.1.6.1 Turbine Building

The environmental impact on the adjacent EQ rooms resulting from the worst case turbine building high-energy line break (HELB) have been determined. The temperatures into these rooms were calculated as a function of a breach size into these EQ barriers. These rooms include the control room envelope and the emergency diesel generator rooms. The size of these breaches into the above rooms is limited based on the average internal room temperature of 120°F (see Section 9.4.1).

3C.5.1.6.2 Main Steam Valve House

The pressure and temperature transients for the main steam valve house were calculated using the computer program CUPAT discussed in Section 3C.2.3.5.

The main steam valve house has been designed with 625 ft^2 of vent area. This vent area was selected by design study to produce the maximum free passage area while maintaining structural strength and providing for missile shield requirements. The vent area is based on postulated double-ended rupture of a main steam line (32-inch o.d. with 1-inch wall thickness).

If a double-ended rupture of a 32-inch main steam line occurs in the main steam valve house, at any of the postulated break points, the effluent from one end of the break will be zero because of the immediate closure of the main steam nonreturn valve (NRV-MS-101A, B, or C). Flow from the other end of the break will be limited by the Venturi flowmeter (within the containment), which has a 16-inch inside diameter. The effective break area is therefore 1.4 ft^2. For this accident, the pressure difference across the wall of the main steam valve house is calculated using frictionless Moody flow limited by the cross-sectional area of the Venturi flowmeter. Figure 3C-15, which shows transient pressure differences for vent areas of 200, 350, and 500 ft^2, indicates relatively low pressure buildup because backflow to the break from the two unaffected steam generators is effectively prevented by the nonreturn valve. A plot of peak pressure differential versus the 625 ft^2 of vent area provided is shown in Figure 3C-16. The maximum pressure differential at this vent area is 0.32 psi.

The pressure transients shown in Figures 3C-15, 3C-17, and 3C-18 were calculated as described in Section 3C.2.3.5, and the peak differential pressures corresponding to 625 ft^2 of vent area were used to recheck the structural adequacy of the main steam valve house for each case.

For the cases shown in Figures 3C-17 and 3C-18, the main steam trip valves and the main steam nonreturn valve are assumed open. In the case of Figure 3C-15, the trip valve is assumed open and the nonreturn valve is assumed closed.

In the above analysis, credit was taken for the nonreturn valve closing for the following reasons:

1. As described in Section 3C.5.1.5, jet impingement will not impair the performance of the valve.
2. There are no instrumentation or electrical components required for operation of the valve. The nonreturn valves require only reverse steam flow for their operation.
3. In the worst case, where blowdown is the greatest following the postulated steam-line break, the unit is at the hot standby condition. Blowdown is greatest for this case since the steam-line pressures are at a maximum. At this condition there is little or no steam flow to hold the disk in the open position; therefore, the valve is performing its required function even before the postulated failure. In all cases, when the system pressure is high with respect to the pressure at 100% power, the flow rates are low and the valve is in a nearly closed position before the postulated incident occurs. Therefore, failure of the nonreturn valve is considered an incredible incident.

Should a single failure of the nonreturn valve be assumed in conjunction with a 32-inch steam-line double-ended rupture, flow to the break will come from the steam generator associated with the broken line and also from the remaining two steam generators, until isolation valves close. Flow from the other two steam generators will encounter significant resistance through piping and fittings leading to the break. When this friction is considered and a single failure of the nonreturn valve is considered, the pressure transients shown in Figure 3C-17 result. Flow from the steam generator associated with the break is sonic at the Venturi flowmeter, but flow from the other two steam generators is sonic at the break. Peak pressure values for this condition are shown on Figure 3C-16. A value of 1.1 psi has been calculated for the 625 ft^2 of vent area provided.

If the nonreturn valve is considered to fail and pipe friction in all lines is not considered, the pressure transients are as shown in Figure 3C-18. Flow is sonic in the Venturi flow nozzles of all three steam generators. For this case, the resulting peak pressure shown in Figure 3C-16 is 1.5 psi. The temperature transient for this case is shown in Figure 3C-19.

Instruments associated with the operation of the main steam trip valves and atmospheric dump valves are located in the adjacent quench spray pump house, which is not subject to the effects of a pipe break in the main steam valve house. The valve operators themselves are not subject to pipe whip effects and have been found satisfactory for the environmental conditions of the main steam valve house following a pipe break. The compressed-air lines associated with these valves are routed to protect them from pipe whip effects.

The solenoid-operated pneumatic pilot valves for the main steam trip valves, and the pneumatic converter (transducer) and pressure transmitters for the atmospheric dump valves, are located in the quench spray pump house; thus, the instrumentation for these valves is not subjected to the effects of a pipe break in the main steam valve house.

Due to the fast-acting design (5-second closure time) of the main steam trip valves and the absence of any electrical components located in the main steam valve house that are required to operate for closing the valves, valve operation is independent of the overall environmental conditions in the main steam valve house following a postulated pipe break.

Valves of similar design to the atmospheric dump valves have been tested by the valve manufacturer in the following environment:

1 hour - 320°F and 90 psig saturated steam

12 hours - 290°F and 56 psig saturated steam

The valves operated satisfactorily during and after the test. These tests demonstrate the suitability for operation in a steam environment of the atmospheric dump valves when compared with the environmental conditions that exist in the main steam valve house following a postulated break.

To ensure the ability to safely shut down the plant following a postulated pipe rupture in the main steam valve house, the pneumatic system for providing control air to the atmospheric dump valves has been designed and arranged so that the air system will remain integral following all postulated pipe breaks within the main steam valve house. This design precludes the necessity of entrance by operating personnel into the main steam valve house following a postulated break for the purpose of controlling plant shutdown.

3C.5.1.7 **Structural Analysis**

3C.5.1.7.1 General

A discussion of the methods of evaluating stress, the structural loading combinations, and the allowable design stress is contained in Section 3C.2.5.

3C.5.1.7.2 Main Steam Valve House

3C.5.1.7.2.1 *Physical Description.* Sketches of the main steam valve house are shown on Reference Drawings 43, 44, 45, and 46. Modification of some portions of the valve house configuration and details were required to safely sustain pipe failure loads.

Main steam and feedwater lines are restrained from whipping as shown on Figure 3C-12. Pipe whip restraints are supported from interior structural steel framing. Reactions from these restraints are transmitted by this framing to the exterior reinforced-concrete walls, and to the reinforced-concrete mat foundation. Modification of the interior structural steel framing consists of the addition of structural steel trusses, in the planes of the restraint reactions, spanning to the exterior reinforced-concrete walls. Additionally, continuous structural steel members are embedded around the periphery of the exterior walls, on the inside face, to support truss connections and reduce local stress concentrations in the concrete.

Main steam and feedwater pipe failure jet forces will impinge on the inside face of the reinforced-concrete roof, exterior walls, and ground-grade floor slab of the valve house. Modifications of the reinforced-concrete consist of thickening these sections to prevent punch shear failure, and the placement of additional reinforcing steel, beyond that required for tornado missile protection, to prevent flexural failure.

Pressurization intensity due to a main steam line pipe failure has been minimized by providing additional vent area. Modifications of the valve house to minimize pressurization consist of raising the roof elevation approximately 10 feet and extending its horizontal dimensions to create an overhang, with tornado-missile-protected openings on the west, east, and north sides. Additionally, the net overturning force resulting from internal pressurization is effectively eliminated by modifying the structure to include a fourth reinforced-concrete wall along its south side, adjacent to the containment.

The steam environment during and after a main steam pipe failure will be confined to the above-grade portion of the valve house. Modifications to achieve this include those previously discussed to sustain jet impingement forces, and revision of the ground-grade door configuration to eliminate egress to the adjacent quench spray pump house.

The main steam valve house ground-grade floor slab is capable of supporting the weight of water associated with a feedwater line pipe failure. Additionally, the ground-grade door, with direct egress to the outside, permits water runoff.

The Unit 1 main steam valve house is founded on concrete backfill capable of supporting increased design bearing pressures due to pipe failure loads within the normal allowable stress. The Unit 2 main steam valve house is founded on compacted granular backfill. It was necessary to increase the effective bearing area to maintain design bearing pressures within the normal allowable stress. Modifications to accomplish this consist of extending the reinforced-concrete foundation mat approximately 20 feet to the north and tying it back to the existing north wall with below-grade reinforced-concrete counterforts.

3C.5.1.7.2.2 *Structural Design Loads.* Dead loads, D, include the weights of the reinforced concrete, structural steel, and equipment. Also included are the effects of earth and hydrostatic pressures, and ice or snow loads, if any. The total dead load, including that of the adjacent quench spray pump housing, which is founded on the same reinforced-concrete mat, is approximately 9000 kips.

Live loads, L, during the pipe rupture event are neglected, since they would consist of loads associated with occupancy, and the main steam valve house and the quench spray pump house will usually be unoccupied during normal operating conditions.

Thermal loads, T_o and T_a, are not included, since temperature gradients across the reinforced-concrete superstructure are not large for either normal operating or pipe break conditions.

The pressure transient generated by the postulated pipe break event is shown in Figures 3C-15, 3C-17, and 3C-18. Pressure loads, P_a, after the pipe break event result from pressurization of the valve house in accordance with these transients.

Static pipe reactions, R_o, during normal operation are treated as pipe hanger dead loads for pipes unaffected by the postulated break. In pipes experiencing the postulated break, it is conservatively assumed that R_a is zero, since normal pipe hangers are not designed for dynamic loads.

An example of a typical dynamic pipe load reaction Y_r is shown in Figure 3C-20 in terms of its reaction on the pipe whip restraint, the structural steel supporting the restraint, and the reinforced-concrete superstructure, all as a function of time. This time history assumes that the reinforced concrete is rigid, and models a typical pipe whip restraint and supporting structural steel.

Dynamic pipe load Y_j is discussed in Section 3C.2.5.

Dynamic pipe load Y_m is nonexistent due to the pipe whip restraints employed in the main steam valve house.

3C.5.1.7.2.3 *Effect on Adjacent Structures.* The main steam valve house is immediately adjacent to the containment structure and the auxiliary building, and has a common reinforced-concrete wall separating it from the quench spray pump house. The design of the main steam valve house is such that it will not fail when subjected to the specified load combinations of Section 3C.2.5.4. Therefore, the structural performance of the main steam valve house during the postulated pipe break will have no effect on adjacent structures.

3C.5.1.8 **Conclusions for Main Steam Line Rupture Analysis**

The main steam lines outside the containment are shown on Reference Drawing 38.

3C.5.1.8.1 Main Steam Valve House

The lower left corner of Reference Drawing 38 show the cutaway view of the redesigned main steam valve houses as seen from the containments. Analyses have resulted in the following conclusions:

1. Pipe whip restraints and jet impingement shields are required to limit the consequences of postulated pipe breaks within the main steam valve house.
2. Redesign of the main steam valve house was required to accommodate the restraint loads and to limit the environmental effects of the postulated breaks.
3. Relocation of the auxiliary feedwater pumps and their associated instrumentation and controls to a newly designed separate Seismic Class I missile-protected structure was necessary.

The following discussion of auxiliary feedwater equipment locations is based on Unit 2 design and drawings. The equipment locations are similar on Unit 1.

The auxiliary feedwater discharge line check valves are indicated on Reference Drawing 47. These valves are indicated as VCW-60A check valves on lines WAPD-427, 428, and 429, and are immediately adjacent to the 16-inch main feed lines WFPD-424, 423, and 422. These valves are located in the main steam valve house. The normally closed auxiliary feedwater turbine steam supply air-operated isolation valves TV-MS-211A and B are also located in the main steam valve house and are shown on Reference Drawing 47.

Because of the placement of the steam supply isolation valve behind a barrier, as indicated on Reference Drawing 47, the steam supply to the auxiliary feedwater system is not subjected to any adverse environmental effects from a line break within the main steam valve house. Analysis indicates that the auxiliary feedwater line check valves are not subjected to adverse environmental effects. Proper operation of the auxiliary feedwater system is ensured by the above, and by electrical and control design criteria described in Section 3C.2.6.

3C.5.1.8.2 Service Building

An augmented inservice inspection program, as described in Section 3C.2.7, provides assurance of line integrity during the life of the facility. In addition, the main steam and feedwater piping in the mechanical equipment rooms is included in the Secondary Piping and Component Inspection Program. Also, operators inspect these lines for leakage on a daily basis.

3C.5.1.8.3 Turbine Building

Analysis has shown that no design changes were required for postulated breaks in main steam lines within the turbine building.

3C.5.2 Feedwater

3C.5.2.1 **Break Locations**

Reference Drawing 39 shows the main feedwater lines. Break locations were postulated in the feedwater lines from the feedwater pumps in the turbine room to the containment in accordance with Section 3C.2.2. For the feedwater lines, 0.8 of the allowable thermal stress is 18,000 psi and 0.8 of the allowable combined stress is 30,000 psi. For each line considered, none of the calculated thermal or combined stresses exceeded 0.8 of their respective allowables. Piping upstream of the manifold was not analyzed seismically, so that intermediate points were selected on the basis of maximum thermal stress. At all break points, both circumferential and longitudinal ruptures were considered. Cracks were considered in the vicinity of all identified “targets.”

The break points are listed in Table 3C-7. The break locations are shown on Reference Drawing 52.

3C.5.2.2 **Separation**

3C.5.2.2.1 Main Steam Valve House

The same degree of separation provided between equipment important to safety and postulated steam-line breaks exists for the postulated feedwater line breaks.

3C.5.2.2.2 Service Building

An augmented inservice inspection program, as described in Section 3C.2.7, will ensure line integrity during the life of the facility. In addition, the main steam and feedwater piping in the mechanical equipment rooms is included in the Secondary Piping and Component Inspection Program. Also, operators inspect these lines for leakage on a daily basis.

3C.5.2.2.3 Turbine Building

The feedwater lines in the turbine building were analyzed and satisfactory separation was found to exist between the feedwater lines and any structures, systems, or components important to safety.

3C.5.2.3 **Restrained Pipes - Main Steam Valve House**

To prevent pipe whip within the main steam valve house, it has been necessary to provide feedwater restraint as shown in Figure 3C-12. Restraint H prevents whipping of the feedwater line in the event of a rupture at the containment terminal point 1, with the containment wall restraining the free end in the direction normal to the pipe axis. This restraint is typical for all three feedwater lines within the main steam valve house.

The feedwater line restraint consists only of a base structure and a honeycomb panel. An arch will not be necessary since postulated pipe rupture locations for the feedwater lines are located so that the rupture pipe travels only in the radial inward direction relative to the restraint; therefore, only a honeycomb panel is necessary for absorbing pipe impact energy.

3C.5.2.4 **Pipe Whip**

Math models of pipe whip for specific pipe runs have been developed where required.

3C.5.2.5 **Fluid Jet Effects - Main Steam Valve House**

The feedwater line failure postulated in the main steam valve house is located at the containment penetration. The jet results in no direct impingement on equipment important to safety in the main steam valve house.

3C.5.2.6 **Pressure and Environment**

3C.5.2.6.1 Main Steam Valve House

The redesigned main steam valve house will withstand the pressure and temperature buildup from a postulated feedwater line break. Environmental effects, with the exception of flooding, are similar to the main steam line break but less severe.

Flooding has been limited to the main steam valve house by the sealing of all floor and wall penetrations. The water will drain outdoors through a newly designed doorway isolated from the adjacent quench spray pump house.

3C.5.2.6.2 Turbine Building

A feedwater line break within the turbine building cannot cause flooding of any structures important to safety.

3C.5.2.7 **Structural Analysis - Main Steam Valve House**

See Section 3C.5.1.8.1 for a discussion of the ability of the main steam valve house to withstand the effects of a feedwater break.

3C.5.2.8 **Conclusions for Feedwater Rupture Analysis**

The feedwater lines run adjacent to the main steam lines as shown in Reference Drawing 38.

3C.5.2.8.1 Main Steam Valve House

The conclusions reached in Section 3C.5.1.8.1 for main steam lines are also applicable for the feedwater lines.

3C.5.2.8.2 Service Building

An augmented inservice inspection program, as described in Section 3C.2.7 ensures line integrity during the life of the facility. In addition, the main steam and feedwater piping in the mechanical equipment rooms is included in the Secondary Piping and Component Inspection Program. Also, operators inspect these lines for leakage on a daily basis.

3C.5.2.8.3 Turbine Building

Analysis has shown that no design changes were required for postulated breaks in feedwater lines within the turbine building.

3C.5.3 Miscellaneous Systems - Turbine Building

High-energy lines of the following systems within the turbine building have been analyzed:

- Auxiliary steam
- Condensate
- Extraction steam
- High-pressure drains and vents
- Sample system

Satisfactory separation exists between all high-energy lines and any structures, equipment, etc., important to safety. The blowdown and condensate system lines added by the upgrades to the high-capacity blowdown system are, by inspection, bounded by the existing analysis.

3C.5.4 Miscellaneous Systems - Auxiliary Building

3C.5.4.1 **Break Locations**

Lines capable of pipe whip within the auxiliary building are:

3"-WGCB-14-601-Q2	3"-WGCB-22-601	3"-WGCB-420-601
3"-WGCB-15-601-Q2	2"-CH-6-602-Q2	3"-WGCB-421-601
3"-WGCB-16-601-Q2	3"-WGCB-414-601-Q2	3"-WGCB-422-601

3"-WGCB-20-601	3"-WGCB-415-601-Q2	2"-CH-943-602-Q2
3"-WGCB-21-601	3"-WGCB-416-601-Q2	
2"-CH-264-602-Q2	2"-CH-664-602-Q2	

These lines are shown in Reference Drawings 12, 15, 27, and 28. Postulated break locations were selected in accordance with Section 3C.2.2 and are shown on Figures 3C-21 and 3C-22. Temperature and pressure conditions for these lines are given in Table 3C-2.

3C.5.4.2 **Separation**

With the modifications outlined herein, adequate separation exists between high-energy lines within the auxiliary building and equipment important to safety. In addition to the provisions outlined in later sections, it was necessary to relocate the safety actuation containment pressure detectors.

3C.5.4.3 **Restrained Lines**

Analysis indicates that a number of restraints are required within the auxiliary building. A description of the restraints required is given in Table 3C-8, and their locations are shown on Figures 3C-21 and 3C-22.

3C.5.4.4 **Pipe Whip**

Mathematical models of pipe whip for specific pipe runs have been developed where required.

3C.5.4.5 **Fluid Jet Effects**

Breaks in lines with pressures greater than 275 psig and temperatures greater than 200°F have been analyzed for the effects of their jet impingement on safety-related equipment. Other environmental breaks have been studied for potential damage caused by their sprays.

Potential jet impingement targets have been determined, and the shield locations determined by visual inspection upon completion of piping installation.

The susceptibility of safety-related valves to water damage has been determined, and protective shields installed to protect valves where required.

3C.5.4.6 **Pressure and Environment**

3C.5.4.6.1 Pressure Effects

Pressure increases due to postulated breaks and cracks within the auxiliary building were found to be negligible.

3C.5.4.6.2 Temperature Effects

Postulated pipe breaks or cracks may result in high ambient temperatures within the auxiliary building; therefore, temperature sensors are provided in various areas of the auxiliary building to provide individual temperature indication and an alarm in the main control room to alert the operators to a potential problem. The column locations of the temperature sensors are shown on Reference Drawings 53 and 54, which can be compared to the physical arrangements on Reference Drawings 4 through 7.

The following lines are the only potential sources of high-temperature conditions in the auxiliary building:

- Steam generator blowdown lines
- Auxiliary steam lines
- Chemical and Volume Control System (CVCS) letdown lines
- CVCS charging lines

The temperature indicators in the main control room will enable the operator(s) to determine the approximate location of the break and therefore the most probable source of that break. Automatic isolation of the steam generator blowdown lines is accomplished within 30 seconds in the event of a piping break. Also, manual isolation associated with other breaks or cracks must be made within 30 minutes to meet the environmental qualification requirements of certain Class 1E components in the Auxiliary Building.

3C.5.4.6.2.1 *Steam Generator Blowdown Lines.* The following modifications were made to cope with a break in a steam generator blowdown line.

An excess-flow measuring device and two trip valves were installed inside the containment to mitigate the consequences of a line break. If the blowdown flow exceeds a predetermined value, the trip valves in that line will automatically close. No manual action will be required.

3C.5.4.6.2.2 *Auxiliary Steam Lines.* The pressure conditions within the auxiliary steam system are such that only the environmental effects of cracks are considered. Protection from the effects of such cracks have been provided for by:

1. The addition of the temperature sensors, etc., described previously.
2. The addition of double isolation valves, operable from the main control room.

3C.5.4.6.2.3 *Chemical and Volume Control System.* Protection from the effects of a break in a chemical volume control system have been provided by:

1. The addition of temperature sensors in various parts of the auxiliary building as previously described.

2. The use of existing instrumentation and valving to detect and isolate the break.

3C.5.4.6.3 Flooding Effects

Flooding within the auxiliary building has been investigated to demonstrate that essential equipment is not endangered by water from any postulated pipe break.

A system of floor drains within the auxiliary building will direct the water from a break to the auxiliary building sump, located within the floor of the 244 ft. 6 in. elevation. High water level within the sump will initiate an alarm in the control room. For breaks that exceed the 900 gallons capacity of the sump, the water will run out onto the 244 ft. 6 in. level. The large floor area of the auxiliary building at this elevation requires approximately 8800 gallons of water to attain a water level of 1 inch above the floor. The minimum height above floor level of equipment essential to safety was found to be 15 inches. Therefore, the water required to reach this height would be approximately 132,000 gallons.

The sump alarm, combined with visual inspection, will initiate detection and isolation of the water source in time to ensure safety, considering the large amount of water required to cause damage.

3C.5.4.7 **Structural Analysis**

The overall structural stability of the auxiliary building is not impaired by any potential pipe breaks.

3C.5.4.8 **Conclusions for Auxiliary Building Line Rupture Analysis**

With the modifications described in the preceding sections made to the auxiliary building, combined with the originally designed redundant features, safe plant shutdown is ensured for all postulated failures of high-energy piping.

3C.5.4.9 **Rupture of Refueling Water Storage Tank**

Should a major rupture of the refueling water storage tank occur, assuming in the worst case that the flow is directed toward the corner of the auxiliary feedwater pump house on the door side and the tank water level is at the maximum allowed, no significant leakage into the pump house would occur. Refer to Reference Drawing 40. Personnel doors and other openings are shielded and/or elevated well above ground level.

Any minor leakage caused by backup of the water toward the doors would collect in the trenches inside the pump house and subsequently drain to the storm sewer. Prolonged leakage past the door is not expected because of the rapid water runoff in the area.

The elevation at the top of the tank foundation is 271 ft. 6 in., and the area immediately surrounding the tank foundation is 271 ft. 0 in. The bases of the auxiliary feedwater pumps are at an elevation of 272 ft. 0 in.

Even if a massive leak into either the room containing the motor-driven pumps or the room containing the turbine-driven pump is postulated, the other room will be unaffected, as the rooms are physically isolated by a concrete missile-protection wall with all penetrations sealed.

For these reasons, flooding of the auxiliary feedwater pump house is not credible and, therefore, the rupture of the refueling water storage tank would have no effect on the capability for a safe shutdown of the plant.

The layouts for the auxiliary feedwater pump house and system are provided on Reference Drawings 40 through 50. The auxiliary feedwater system was designed so that there are no high-energy lines in the system; therefore, no separation criteria were required. There is, however, a concrete wall separating the two motor-driven auxiliary feedwater pumps from the turbine-driven auxiliary feedwater pump. This concrete wall is part of the auxiliary feedwater pump house, a tornado-missile-protected structure.

The pumps are protected from leakage from components inside the rooms by trenches connected to the storm sewer.

The auxiliary feedwater pump turbine steam supply lines run from the main steam valve house through a pipe tunnel to the auxiliary feedwater pump house. All these structures are seismic and tornado missile protected.

3C.6 CONCLUSIONS

It has been shown that North Anna Units 1 and 2 are designed so that the reactor can be shut down and maintained in a safe-shutdown condition in the event of a postulated rupture, outside the containment, of a pipe containing a high-energy fluid, including the double-ended rupture of the largest pipe in the main steam and feedwater systems. Plant structures, systems, and components important to safety have been designed and located to accommodate the effects of such postulated pipe failures to the extent necessary to ensure that a safe-shutdown condition of the reactor can be accomplished and maintained.

3C REFERENCES

1. *LOCTIC - A Computer Code to Determine the Pressure and Temperature Response of Dry Containments to a Loss-of-Coolant Accident*, SWND-1, Stone & Webster Engineering Corp., September 1971.
2. *LOCTVS - A Computer Code to Determine the Pressure and Temperature Response of Pressure Suppression Containments to a Loss-of-Coolant Accident*, SWND-2, Stone & Webster Engineering Corp., October 1969.
3. F. J. Moody, *Maximum Two-Phase Vessel Blowdown from Pipes*, APED-4827, General Electric Co., April 20, 1965.
4. *LOCTVS - A Computer Code to Determine the Pressure and Temperature Response of Pressure Suppression Containments to a Loss-of-Coolant Accident*, SWND-2, Supplement No. 1, Stone & Webster Engineering Corp., March 1973.
5. *PVRC Recommendations on Toughness Requirements for Ferritic Materials*, WRC Bulletin 175, August 1972.
6. W. E. Senchak and O. E. Widera, "Application of Fracture Mechanics to Nuclear Piping Systems," *Engineering Fracture Mechanics*, Vol. 4, p. 877, 1972.
7. H. Liebowitz, Ed., *Fracture - An Advanced Treatise*, Vol. V, p. 211.
8. *Evaluation of the Toughness of Alternate Materials for Feedwater and Main Steam Piping at Surry and North Anna Power Stations*, Technical Report No. MT-0003, Rev. 0, Materials Engineering, Nuclear Engineering Services, Virginia Power, March 1992.
9. Letter from Virginia Power to USNRC, Serial No. 96-444A, dated February 5, 1997, *Protection Against Dynamic Effects Associated with the Postulated Rupture of High Energy Lines Outside Containment.*
10. Letter from Virginia Power to USNRC, Serial No. 98-123, dated March 25, 1998.
11. Letter from NRC to Virginia Power, dated July 7, 1998, Docket Nos. 50-338 and 50-339, *Safety Evaluation by the Office of Nuclear Reactor Regulation, Request for Change in ISI Commitment on Protection Against Pipe Breaks Outside Containment.*

3C REFERENCE DRAWINGS

The list of Station Drawings below is provided for information only. The referenced drawings are not part of the UFSAR. This is not intended to be a complete listing of all Station Drawings referenced from this section of the UFSAR. The contents of Station Drawings are controlled by station procedure.

	Drawing Number	Description
1.	11715-FM-11A	Arrangement: Service Building, Safety Related Equipment, Sheet 1
2.	11715-FM-11B	Arrangement: Service Building, Safety Related Equipment, Sheet 2
3.	11715-FM-11C	Arrangement: Service Building, Safety Related Equipment, Sheet 3
4.	11715-FM-7A	Arrangement: Auxiliary Building, Safety Related Equipment, Plan, Elevation 244'- 6"
5.	11715-FM-7B	Arrangement: Auxiliary Building, Safety Related Equipment, Plan, Elevation 259'- 6"
6.	11715-FM-7C	Arrangement: Auxiliary Building, Safety Related Equipment, Plan, Elevation 274'- 0"
7.	11715-FM-7D	Arrangement: Auxiliary Building, Safety Related Equipment, Plan, Elevation 291'- 10"
8.	11715-FM-7E	Arrangement: Auxiliary Building, Safety Related Equipment, Sections 1-1 & 2-2
9.	11715-FM-7F	Arrangement: Auxiliary Building; Safety Related Equipment; Sections 3-3, 4-4, & 5-5
10.	11715-FM-7G	Arrangement: Auxiliary Building, Safety Related Equipment, Sections 6-6 & 7-7
11.	11715-FP-81A	Piping Assembly: Tunnel #1, Reactor Containment to Auxiliary Building, Sheet 1, High Energy Lines
12.	11715-FP-81B	Piping Assembly: Tunnel #1, Reactor Containment to Auxiliary Building, Sheet 2, High Energy Lines
13.	11715-FP-81C	Piping Assembly: Tunnel #1, Reactor Containment to Auxiliary Building, Sheet 3, High Energy Lines
14.	11715-FP-82A	Piping Assembly: Tunnel #2, Reactor Containment to Auxiliary Building, Sheet 1, High Energy Lines
15.	11715-FP-82B	Piping Assembly: Tunnel #2, Reactor Containment to Auxiliary Building, Sheet 2, High Energy Lines

16.	11715-FP-82C	Piping Assembly: Tunnel #2, Reactor Containment to Auxiliary Building, Sheet 3, High Energy Lines
17.	11715-FP-83A	Composite Assembly: Auxiliary Building Elevation 259'- 6", Sheet 1, High Energy Lines
18.	11715-FP-83B	Composite Assembly: Auxiliary Building Elevation 259'- 6", Sheet 2, High Energy Lines
19.	11715-FP-83C	Composite Assembly: Auxiliary Building Elevation 259'- 6", Sheet 3, High Energy Lines
20.	11715-FP-83D	Composite Assembly: Auxiliary Building Elevation 259'- 6" & Section 17-17, Sheet 4, High Energy Lines
21.	11715-FP-83E	Composite Assembly: Auxiliary Building Elevation 259'- 6"; Sections 1-1, 2-2, & 3-3; Sheet 5; High Energy Lines
22.	11715-FP-83F	Composite Assembly: Auxiliary Building Elevation 259'- 6"; Sections 1-1, 4-4, & 15-15; Sheet 6; Energy Lines
23.	11715-FP-83G	Composite Assembly: Auxiliary Building Elevation 259'- 6"; Sections 5-5, 6-6, & 7-7; Sheet 7; High Energy Lines
24.	11715-FP-83H	Composite Assembly: Auxiliary Building Elevation 259'- 6", Sections 8-8 & 9-9, Sheet 8, High Energy Lines
25.	11715-FP-83J	Composite Assembly: Auxiliary Building Elevation 259'- 6"; Sections 10-10 & 11-11; Sheet 9; High Energy Lines
26.	11715-FP-83K	Composite Assembly: Auxiliary Building Elevation 259'- 6"; Sections 12-12, 13-13, 14-14, & 16-16; Sheet 7; High Energy Lines
27.	11715-FP-84A	Steam Generator Blowdown System, Auxiliary Building Sheet 1, High Energy Lines
28.	11715-FP-84B	Steam Generator Blowdown System, Auxiliary Building Sheet 2, High Energy Lines
29.	11715-FP-84C	Steam Generator Blowdown System, Auxiliary Building Sheet 3, High Energy Lines
30.	11715-FP-85A	Waste Disposal System, Auxiliary Building Sheet 1, High Energy Lines
31.	11715-FP-85B	Waste Disposal System, Auxiliary Building Sheet 2, High Energy Lines
32.	11715-FP-85C	Waste Disposal System, Auxiliary Building Sheet 3, High Energy Lines
33.	11715-FP-85D	Waste Disposal System, Auxiliary Building Sheet 4, High Energy Lines

34.	11715-FP-85E	Waste Disposal System, Auxiliary Building Sheet 5, High Energy Lines
35.	11715-FP-85F	Waste Disposal System, Auxiliary Building Sheet 6, High Energy Lines
36.	11715-FP-1B	Main Steam, Reactor Containment to Turbine Room, Sheet 1
	12050-FP-1B	Main Steam, Reactor Containment to Turbine Room, Sheet 1
37.	11715-FP-1C	Main Steam, Reactor Containment to Turbine Room, Sheet 2
	12050-FP-1C	Main Steam, Reactor Containment to Turbine Room, Sheet 2
38.	11715-FP-76A	Main Steam, Feedwater Pipe Rupture Analysis
	12050-FP-76A	Main Steam, Feedwater Pipe Rupture Analysis, Unit 2
39.	11715-FP-2C	Steam Generator, Feedwater Lines, Reactor Containment to Turbine Room, Sheet 1
	12050-FP-2B	Steam Generator Feedwater Lines, Reactor Containment to Turbine Room, Sheet 1
40.	11715-FC-12A	Foundation Plan and Details; Refueling Water, Condensate Storage Tanks & Misc. Equipment, Sheet 1
41.	11715-FP-2J	Steam Generator, Auxiliary Feedwater Lines, Sheet 1
	12050-FP-2J	Steam Generator, Auxiliary Feedwater Lines, Sheet 1, Unit 2
42.	11715-FP-2K	Steam Generator, Auxiliary Feedwater Lines, Sheet 2
	12050-FP-2K	Steam Generator, Auxiliary Feedwater Lines, Sheet 2, Unit 2
43.	11715-FM-1A	Machine Location: Reactor Containment, Plan, Elevation 291'-10", Unit 1
	12050-FM-1A	Machine Location: Reactor Containment, Plan, Elevation 291'-10", Unit 2
44.	11715-FM-1B	Machine Location: Reactor Containment, Plan, Elevation 262'-10", Unit 1
	12050-FM-1B	Machine Location: Reactor Containment, Plan, Elevation 262'-10", Unit 2
45.	11715-FM-1C	Machine Location: Reactor Containment, Plan, Elevation 241'-0", Unit 1
	12050-FM-1C	Machine Location: Reactor Containment, Plan, Elevation 241'-0", Unit 2
46.	11715-FM-1E	Machine Location: Reactor Containment, Sections 1-1 & 5-5, Unit 1
	12050-FM-1F	Machine Location: Reactor Containment; Sections 2-2, 5-5, & 6-6; Unit 2

47.	11715-FP-7C	Yard Piping, North Reactor Containment, Sheet 3
	12050-FP-7C	Yard Piping, North Reactor Containment, Sheet 3
48.	11715-FP-7A	Yard Piping, North Reactor Containment, Sheet 1
	12050-FP-7A	Yard Piping, North Reactor Containment, Sheet 1
49.	11715-FP-7B	Yard Piping, North Reactor Containment, Sheet 2
	12050-FP-7B	Yard Piping, North Reactor Containment, Sheet 2
50.	11715-FP-7D	Yard Piping, North Reactor Containment, Sheet 4
	12050-FP-7D	Yard Piping, North Reactor Containment, Sheet 4
51.	11715-WMKS-0101A-4	Inservice Inspection Isometric SHP SYS: 28" & 32" Main Steam from Containment, Unit 1
	12050-WMKS-0101A-4	Inservice Inspection Isometric SHP SYS: 28" & 32" Main Steam from Containment, Unit 2
52.	11715-WMKS-0102D	Inservice Inspection Isometric WFPD SYS: 16" & 6" Feedwater from Containment, Unit 1
	12050-WMKS-0102D	Inservice Inspection Isometric WFPD SYS: 16" & 6" Feedwater from Containment, Unit 2
53.	11715-AM-001	Auxiliary Building Ambient Air Temperature Indication and Alarm, Channel I
54.	11715-AM-002	Auxiliary Building Ambient Air Temperature Indication and Alarm, Channel III

Table 3C-1

RELATIONSHIP OF REPORT SECTIONS AND AEC 21 CRITERIA

Relationship between information requested in AEC/DOL *General Information Required for Consideration of the Effects of a Piping System Break Outside the Containment*, revised January 1973, and outline for amendment “Covering Effects of a Piping System Break Outside of Containment”:

Piping Break Item No. and Content Summary	Appendix Section (An “X” indicates various systems)	
1. System requiring protection be identified	3C.2.1	General Discussion
2. Criteria for selection of piping break locations in plants 1, 2, and 3 system	3C.2.2	Criteria on Pipe Breaks and Cracks
3. Criteria for break orientation	3C.2.2	Criteria on Pipe Breaks and Cracks
4. Summary of dynamic analysis applicable to Seismic Class I piping	3C.2.3	Methods and General Results
	3C.2.3.1	Whipping Pipes
	3C.2.3.2	Restrained Pipes
	3C.5	Effects of Pipe Breaks and Cracks
	3C.5.X.1	Break Location
	3C.5.X.2	Separation
	3C.5.X.4	Pipe Whip
5. Description of measures to protect against pipe whip, blowdown, etc.	3C.2.1	General Discussion
	3C.2.3.2	Restrained Pipes
	3C.2.3.3	Whipping Pipes and Wall Interactions
	3C.2.3.4	Fluid Jet and Interactions on Reinforced - Concrete Walls and Metal Plates
	3C.2.4	Protection Against Whip
	3C.5.X.1	Break Location
	3C.5.X.2	Separation
	3C.5.X.3	Restrained Pipes
	3C.5.X.4	Pipe Whip
	3C.5.X.5	Fluid Jets Effects

Table 3C-1 (continued)

RELATIONSHIP OF REPORT SECTIONS AND AEC 21 CRITERIA

Relationship between information requested in AEC/DOL *General Information Required for Consideration of the Effects of a Piping System Break Outside the Containment*, revised January 1973, and outline for amendment "Covering Effects of a Piping System Break Outside of Containment":

Piping Break Item No. and Content Summary		Appendix Section (An "X" indicates various systems)	
6.	Procedures for structural design of Category I	3C.2.5	Analysis of Seismic Class 1 Structures
7.	Presentation of the structural design loads	3C.5.X.7	Structural Analysis
8.	Design of Category I structures for eventual load reversal	3C.2.5	Analysis of Seismic Class 1 Structures
9.	Design analysis of redesigned structures	3C.5.X.7	Structural Analysis
10.	Review of all failures and their effect	3C.5.X.7	Structural Analysis
11a.	Verification that rupture will not prevent cold shutdown	3C.4.3	Relationship of High-Energy Line to Plant Shutdown and Equipment Important to Safety
		3C.5.X.6	Pressure and Environment
		3C.5.X.8	Conclusions
11b.	Effect of break or rupture on environmentally sensitive components	3C.4.3	Relationship of High-Energy Line to Plant Shutdown and Equipment Important to Safety
		3C.5.X.6	Pressure and Environment
		3C.5.X.8	Conclusions
12.	Control room habitable or alternate provided	3C.5.X.6	Pressure and Environment
13.	Environmental qualifications of electrical and control equipment (items a and b)	3C.2.6	Electrical and Controls and Environmental Capability
		3C.5.X.6	Pressure and Environment
14.	Design and routing drawings of steam and feedwater lines including safety-related equipment	3C.4.3	Relationship of High-Energy Lines to Plant Shutdown and Equipment Important to Safety
15.	Discussion of flooding of safety-related equipment from ruptures	3C.5.X.6	Pressure and Environment

Table 3C-1 (continued)

RELATIONSHIP OF REPORT SECTIONS AND AEC 21 CRITERIA

Relationship between information requested in AEC/DOL *General Information Required for Consideration of the Effects of a Piping System Break Outside the Containment*, revised January 1973, and outline for amendment "Covering Effects of a Piping System Break Outside of Containment":

Piping Break Item No. and Content Summary		Appendix Section (An "X" indicates various systems)	
16.	Quality control and inspection on outside containment piping	3C.3.2	Quality Assurance and Inspection
17.	Description of leak detection method	3C.2.7.9	Leak Detection
18.	Emergency procedures following each event	3C.4.2	Plant Shutdown Equipment
19.	Seismic and QC classifications of high energy piping	3C.3.1	System Identification
20.	Description of assumptions, methods, and results of accident analysis	3C.2.3.5 3C.5.X.6	Pressure and Environment (Methods) Pressure and Environment (Results)
21.	Containment analysis due to pipe rupture	3C.5.X.7	Structural Analysis

Table 3C-2
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Nomenclature

System	Type of Pipe Break Evaluation	Location of Piping	Seismic Class
AS - auxiliary steam	1 - pipe break plus environmental	AB - auxiliary building	1 - Seismic Class I
BD - steam-generator blowdown	2 - environmental		NS - non-seismic
BR - boron recovery		MSVH - main steam valve house	
		SB - service building	
CF - chemical feed		TB - turbine building	
CN - condensate		TUN - pipe tunnel	
CH - chemical and volume control			
ES - extraction steam			
FW - feedwater			
GS - gland steam			
HPDV - high-pressure heater drains and vents			
LPDV - low-pressure heater drains and vents			
LW - waste disposal			
MS - main steam			
SI - safety injection			
SS - sample			

Note: 400 and above series piping represents Unit 2.

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
BR-6	Borated water	3.00	50	219	2	AB	NS	-	BR
BR-9	Borated water	3.00	50	219	2	AB	NS	-	BR
BR-10	Borated water	3.00	50	240	2	AB	1	Q3	BR
BR-11	Borated water	6.00	4	219	2	AB	NS	-	BR
BR-12	Borated water	6.00	4	219	2	AB	NS	-	BR
BR-13	Borated water	3.00	105	219	2	AB	NS	-	BR
BR-14	Borated water	3.00	105	219	2	AB	NS	-	BR
BR-24	Condensate	1.00	2	211	2	AB	1	Q3	BR
BR-25	Steam	0.75	2	211	2	AB	1	Q3	BR
BR-31	Steam	4.00	50	250	2	AB&TUN#1	1	Q3	BR
BR-33	Borated water	3.00	50	240	2	AB&TUN#1	1	Q3	BR
BR-42	Borated water	3.00	50	240	2	AB	1	Q3	BR
BR-43	Distillate	1.00	2	211	2	AB	1	Q3	BR
BR-45	Borated water	12.00	25	252	2	AB	NS	-	BR
BR-46	Borated water	8.00	40	253	2	AB	NS	-	BR
BR-47	Borated water	8.00	40	263	2	AB	NS	-	BR
BR-48	Steam	10.00	15	250	2	AB	NS	-	BR
BR-49	Distillate	3.00	15	250	2	AB	NS	-	BR
BR-50	Distillate	2.00	20	250	2	AB	NS	-	BR
BR-51	Distillate	1.00	35	250	2	AB	NS	-	BR
BR-52	Distillate	0.75	35	250	2	AB	NS	-	BR
BR-53	Steam	0.75	2	211	2	AB	1	Q3	BR
BR-58	Borated water	12.00	25	253	2	AB	1	-	BR
BR-59	Borated water	8.00	40	253	2	AB	NS	-	BR

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
BR-60	Borated water	8.00	40	263	2	AB	NS	-	BR
BR-61	Steam	10.00	15	250	2	AB	NS	-	BR
BR-62	Distillate	3.00	15	250	2	AB	NS	-	BR
BR-63	Distillate	2.00	20	250	2	AB	NS	-	BR
BR-64	Distillate	1.00	35	250	2	AB	NS	-	BR
BR-65	Distillate	0.75	35	250	2	AB	NS	-	BR
BR-70	Borated water	2.00	25	250	2	AB	NS	-	BR
BR-71	Borated water	2.00	25	250	2	AB	NS	-	BR
BR-72	Borated water	2.00	25	250	2	AB	NS	-	BR
BR-73	Borated water	1.50	50	250	2	AB	NS	-	BR
BR-74	Borated water	1.50	50	250	2	AB	NS	-	BR
BR-81	Steam	4.00	50	250	2	AB	1	Q3	BR
BR-99	Borated water	3.00	4	219	2	AB	NS	-	BR
BR-101	Borated water	1.00	4	219	2	AB	NS	-	BR
BR-102	Borated water	6.00	4	219	2	AB	NS	-	BR
BR-113	Borated water	6.00	4	219	2	AB	NS	-	BR
BR-205	Borated water	0.75	105	219	2	AB	NS	-	BR
BR-206	Borated water	0.75	105	219	2	AB	NS	-	BR
BR-207	Borated water	0.75	105	219	2	AB	NS	-	BR
BR-208	Borated water	0.75	105	219	2	AB	NS	-	BR
BR-209	Borated water	0.75	105	219	2	AB	NS	-	BR
BR-210	Borated water	0.75	105	219	2	AB	NS	-	BR
BR-215	Borated water	0.75	105	219	2	AB	NS	-	BR
BR-216	Borated water	0.75	105	219	2	AB	NS	-	BR
BR-221	Borated water	1.00	35	250	2	AB	NS	-	BR

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
BR-222	Borated water	1.00	35	250	2	AB	NS	-	BR
BR-223	Borated water	1.00	35	250	2	AB	NS	-	BR
BR-224	Borated water	1.00	35	250	2	AB	NS	-	BR
BR-225	Borated water	1.00	40	253	2	AB	NS	-	BR
BR-226	Radioactive gas	1.00	40	253	2	AB	NS	-	BR
BR-227	Borated water	1.00	40	253	2	AB	NS	-	BR
BR-228	Radioactive gas	1.00	40	253	2	AB	NS	-	BR
BR-229	Borated water	1.00	50	219	2	AB	NS	-	BR
BR-230	Borated water	1.00	50	219	2	AB	NS	-	BR
BR - 231	Borated water	1.00	50	219	2	AB	NS	-	BR
BR - 232	Borated water	1.00	50	219	2	AB	NS	-	BR
BR - 233	Borated water	0.75	105	219	2	AB	NS	-	BR
BR - 234	Borated water	0.75	105	219	2	AB	NS	-	BR
BR - 238	Distillate	0.75	35	250	2	AB	NS	-	BR
BR - 239	Distillate	0.75	35	250	2	AB	NS	-	BR
BR - 244	Steam	3.00	2	250	2	AB	1	Q3	BR
BR - 245	Steam	3.00	2	250	2	AB	1	Q3	BR
BR - 248	Borated water	3.00	50	219	2	AB	NS	-	BR
BR - 266	Borated water	3.00	50	240	2	AB	NS	-	BR
BR - 267	Borated water	3.00	50	240	2	AB	NS	-	BR
BR - 268	Borated water	3.00	50	219	2	AB	NS	-	BR
BR - 269	Borated water	3.00	50	219	2	AB	NS	-	BR
BR - 270	Borated water	3.00	105	219	2	AB	NS	-	BR
BR - 271	Borated water	3.00	105	219	2	AB	NS	-	BR
CFPD - 1	Phosphate	0.75	1700	100	2	AB&TUN# 1	1	Q2	CF

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
CFPD - 2	Phosphate	0.75	1700	100	2	AB&TUN# 1	1	Q2	CF
CFPD - 3	Phosphate	0.75	1700	100	2	AB&TUN# 1	1	Q2	CF
CFPD - 401	Phosphate	0.75	1700	100	2	AB&TUN# 1	1	Q2	CF
CFPD - 402	Phosphate	0.75	1700	100	2	AB&TUN# 1	1	Q2	CF
CFPD - 403	Phosphate	0.75	1700	100	2	AB&TUN# 1	1	Q2	CF
CH-2	Borated water	3.00	2500	130	2	AB	1	Q2	CH
CH-3	Borated water	3.00	2500	130	2	AB&TUN# 1	1	Q2	CH
CH-6	Borated water	2.00	335	283	1	AB&TUN# 1	1	Q2	CH
CH-7	Borated water	2.00	280	115	2	AB&TUN# 1	1	Q2	CH
CH-8	Borated water	2.00	2500	130	2	AB&TUN# 1	1	Q1	CH
CH-11	Borated water	3.00	2500	130	2	AB&TUN# 1	1	Q2	CH
CH-12	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH-13	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 20	Borated water	0.75	2500	130	2	AB	1	Q2	CH
CH - 21	Borated water	0.75	2500	130	2	AB	1	Q2	CH
CH - 22	Borated water	0.75	2500	130	2	AB	1	Q2	CH
CH - 66	Borated water	3.00	100	290	2	AB	1	Q3	CH
CH - 69	Borated water	3.00	2500	130	2	AB	1	Q2	CH
CH - 70	Borated water	3.00	2500	130	2	AB	1	Q2	CH
CH - 71	Borated water	3.00	2500	130	2	AB	1	Q2	CH
CH - 74	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 75	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 76	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 77	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 78	Borated water	0.75	2500	130	2	AB	1	Q2	CH

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
CH - 79	Borated water	3.00	2500	130	2	AB&TUN# 1	1	Q1	CH
CH - 80	Borated water	4.00	2500	130	2	AB&TUN# 1	1	Q2	CH
CH - 81	Borated water	3.00	2500	130	2	AB	1	Q2	CH
CH - 89	Borated water	4.00	2500	130	2	AB&TUN# 1	1	Q2	CH
CH - 90	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 91	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 92	Borated water	2.00	2500	130	2	AB&TUN# 1	1	Q1	CH
CH - 94	Borated water	2.00	2500	130	2	AB&TUN# 1	1	Q1	CH
CH - 96	Borated water	2.00	2500	130	2	AB&TUN# 1	1	Q1	CH
CH - 114	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 115	Borated water	0.75	2500	130	2	AB	1	Q2	CH
CH - 116	Borated water	0.75	2500	130	2	AB	1	Q2	CH
CH - 125	Borated water	2.00	280	115	2	AB	1	Q2	CH
CH - 161	Steam	2.00	15	250	2	AB	NS	-	CH
CH - 167	Borated water	0.75	2500	130	2	AB	1	Q2	CH
CH - 187	Borated water	0.75	2500	130	2	AB	1	Q2	CH
CH - 188	Borated water	0.75	2500	130	2	AB	1	Q2	CH
CH - 189	Borated water	0.75	2500	130	2	AB	1	Q2	CH
CH - 231	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 254	Borated water	0.75	2500	130	2	AB&TUN#1	1	Q2	CH
CH - 256	Borated water	0.75	2500	130	2	AB	1	Q2	CH
CH - 257	Borated water	0.75	2500	130	2	AB	1	Q2	CH
CH - 264	Borated water	2.00	335	283	1	AB&TUN#1	1	Q2	CH
CH - 266	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 267	Borated water	3.00	2500	130	2	AB&TUN#1	1	Q2	CH

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
CH - 299	Steam	1.00	15	250	2	AB	NS	-	CH
CH - 300	Steam	1.00	15	250	2	AB	NS	-	CH
CH - 310	Water	0.75	15	250	2	AB	NS	-	CH
CH - 318	Steam	1.00	15	250	2	AB	NS	-	CH
CH - 376	Borated water	3.00	2500	130	2	AB	1	Q2	CH
CH - 377	Borated water	3.00	2500	130	2	AB	1	Q2	CH
CH - 378	Borated water	3.00	2500	130	2	AB	1	Q2	CH
CH - 379	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 380	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 381	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 382	Borated water	2.00	280	115	2	AB	1	Q2	CH
CH - 383	Borated water	3.00	280	115	2	AB	1	Q2	CH
CH - 384	Borated water	1.00	2500	130	2	AB	1	Q2	CH
CH - 386	Borated water	1.00	2500	130	2	AB	1	Q2	CH
CH - 388	Borated water	1.00	2500	130	2	AB	1	Q2	CH
CH - 402	Borated water	3.00	2500	130	2	AB	1	Q2	CH
CH - 407	Borated water	2.00	280	115	2	AB&TUN#1	1	Q2	CH
CH - 411	Borated water	3.00	2500	130	2	AB&TUN#1	1	Q2	CH
CH - 412	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 413	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 420	Borated water	0.75	2500	130	2	AB	1	Q2	CH
CH - 422	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 437	Borated water	0.75	2235	138	2	AB	1	Q2	CH
CH - 438	Borated water	0.75	2235	544	2	AB	1	Q2	CH
CH - 469	Borated water	3.00	2500	130	2	AB	1	Q2	CH

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
CH - 470	Borated water	3.00	2500	130	2	AB	1	Q2	CH
CH - 471	Borated water	3.00	2500	130	2	AB	1	Q2	CH
CH - 474	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 475	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 476	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 477	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 478	Borated water	0.75	2500	130	2	AB	1	Q2	CH
CH - 479	Borated water	3.00	2500	130	2	AB&TUN#1	1	Q1	CH
CH - 480	Borated water	4.00	2500	130	2	AB&TUN#1	1	Q2	CH
CH - 481	Borated water	3.00	2500	130	2	AB	1	Q2	CH
CH - 489	Borated water	4.00	2500	130	2	AB&TUN#1	1	Q2	CH
CH - 490	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 491	Borated water	2.00	2500	130	2	AB&TUN#1	1	Q2	CH
CH - 492	Borated water	2.00	2500	130	2	AB&TUN#1	1	Q1	CH
CH - 494	Borated water	2.00	2500	130	2	AB&TUN#1	1	Q1	CH
CH - 496	Borated water	2.00	2500	130	2	AB&TUN#1	1	Q1	CH
CH - 514	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 515	Borated water	0.75	2500	130	2	AB	1	Q2	CH
CH - 516	Borated water	0.75	2500	130	2	AB	1	Q2	CH
CH - 523	Borated water	0.75	2235	544	2	AB	1	Q2	CH
CH - 525	Borated water	2.00	280	115	2	AB	1	Q2	CH
CH - 567	Borated water	0.75	2500	130	2	AB	1	Q2	CH
CH - 587	Borated water	0.75	2500	130	2	AB	1	Q2	CH
CH - 588	Borated water	0.75	2500	130	2	AB	1	Q2	CH
CH - 589	Borated water	0.75	2500	130	2	AB	1	Q2	CH

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
CH - 623	Borated water	0.75	2235	138	2	AB	1	Q2	CH
CH - 631	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 654	Borated water	0.75	2500	130	2	AB&TUN#1	1	Q2	CH
CH - 656	Borated water	0.75	2500	130	2	AB	1	Q2	CH
CH - 657	Borated water	0.75	2500	130	2	AB	1	Q2	CH
CH - 664	Borated water	2.00	335	283	1	AB&TUN#1	1	Q2	CH
CH - 666	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 667	Borated water	3.00	2500	130	2	AB&TUN#1	1	Q2	CH
CH - 777	Borated water	3.00	2500	130	2	AB	1	Q2	CH
CH - 778	Borated water	3.00	2500	130	2	AB	1	Q2	CH
CH - 779	Borated water	2.00	2500	130	2	AB	1	Q2	CH
CH - 783	Borated water	3.00	280	115	2	AB	1	Q2	CH
CH - 784	Borated water	1.00	2500	130	2	AB	1	Q2	CH
CH - 786	Borated water	1.00	2500	130	2	AB	1	Q2	CH
CH - 787	Borated water	1.00	2500	130	2	AB	1	Q1	CH
CH - 788	Borated water	1.00	2500	130	2	AB	1	Q2	CH
CH - 789	Borated water	1.00	2500	130	2	AB	1	Q1	CH
CH - 796	Borated water	1.50	2500	130	2	AB	1	Q1	CH
CH - 797	Borated water	1.50	2500	130	2	AB	1	Q1	CH
CH - 798	Borated water	1.50	2500	130	2	AB	1	Q1	CH
CH - 943	Borated water	2.00	335	283	1	AB	1	Q2	CH
LW - 50	Water	1.00	30	250	2	AB	NS	-	LW
LW - 69	Water	0.75	25	250	2	AB	NS	-	LW
LW - 73	Water	8.00	15	250	2	AB	NS	-	LW
LW - 74	Water	6.00	25	250	2	AB	NS	-	LW

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
LW - 75	Water	6.00	25	270	2	AB	NS	-	LW
LW - 76	Water	6.00	15	250	2	AB	NS	-	LW
LW - 77	Water	3.00	15	250	2	AB	NS	-	LW
LW - 78	Water	2.00	20	250	2	AB	NS	-	LW
LW - 79	Water	1.00	50	250	2	AB	NS	-	LW
LW - 80	Water	2.00	10	250	2	AB	NS	-	LW
LW - 90	Water	0.75	50	250	2	AB	NS	-	LW
LW - 96	Water	1.50	15	250	2	AB	NS	-	LW
LW - 102	Water	0.75	50	250	2	AB	NS	-	LW
LW - 149	Water	1.50	10	250	2	AB	NS	-	LW
LW - 161	Water	6.00	25	270	2	AB	NS	-	LW
LW - 162	Water	6.00	25	270	2	AB	NS	-	LW
LW - 163	Water	6.00	25	270	2	AB	NS	-	LW
LW - 273	Water	1.00	45	250	2	AB	NS	-	LW
LW - 274	Water	1.00	45	250	2	AB	NS	-	LW
LW - 275	Water	1.00	15	270	2	AB	NS	-	LW
LW - 276	Water	1.00	15	270	2	AB	NS	-	LW
LW - 285	Water	1.00	125	250	2	AB	NS	-	LW
LW - 286	Water	1.00	125	250	2	AB	NS	-	LW
SA - 1	Steam	12.00	150	365	2	TB&AB	NS	-	AS
SA - 2	Steam	4.00	150	365	2	TB	NS	-	AS
SA - 6	Steam	8.00	150	365	2	TB	NS	-	AS
SA - 7	Steam	20.00	10	240	2	TB	NS	-	AS
SA - 8	Steam	4.00	150	365	2	TB	NS	-	AS
SA - 9	Steam	3.00	150	365	2	TB	NS	-	AS

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
SA - 10	Steam	3.00	150	365	2	TB	NS	-	AS
SA - 11	Steam	16.00	10	240	2	TB	NS	-	AS
SA - 12	Steam	16.00	10	240	2	TB	NS	-	AS
SA - 13	Steam	8.00	150	365	2	AB	NS	-	AS
SA - 14	Steam	8.00	150	365	2	AB	NS	-	AS
SA - 19	Steam	6.00	150	365	2	TB	NS	-	AS
SA - 20	Steam	6.00	110	345	2	AB	NS	-	AS
SA - 21	Steam	4.00	110	345	2	AB	NS	-	AS
SA - 22	Steam	3.00	110	345	2	AB	NS	-	AS
SA - 23	Steam	6.00	110	345	2	AB	NS	-	AS
SA - 24	Steam	3.00	150	365	2	AB	NS	-	AS
SA - 25	Steam	6.00	150	365	2	AB	NS	-	AS
SA - 26	Steam	4.00	150	365	2	AB	NS	-	AS
SA - 27	Steam	4.00	150	365	2	AB	NS	-	AS
SA - 28	Steam	6.00	150	365	2	AB	NS	-	AS
SA - 29	Steam	4.00	150	365	2	AB	NS	-	AS
SA - 30	Steam	4.00	150	365	2	AB	NS	-	AS
SA - 31	Steam	1.00	150	365	2	AB	NS	-	AS
SA - 32	Steam	2.00	15	250	2	AB	NS	-	AS
SA - 33	Steam	3.00	150	365	2	AB	NS	-	AS
SA - 36	Steam	4.00	150	365	2	AB	NS	-	AS
SA - 38	Steam	2.00	150	365	2	AB	NS	-	AS
SA - 39	Steam	3.00	150	365	2	AB	NS	-	AS
SA - 41	Steam	2.00	150	365	2	AB	NS	-	AS
SA - 42	Steam	2.00	150	365	2	AB	NS	-	AS

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
SA - 43	Steam	6.00	0	212	2	AB	NS	-	AS
SA - 50	Steam	8.00	150	365	2	SB	NS	-	AS
SA - 51	Steam	8.00	150	365	2	SB	NS	-	AS
SA - 52	Steam	4.00	150	365	2	AB	NS	-	AS
SA - 53	Steam	12.00	150	365	2	AB	NS	-	AS
SA - 54	Steam	6.00	150	365	2	SB	NS	-	AS
SA - 55	Steam	6.00	150	365	2	SB	NS	-	AS
SA - 56	Steam	12.00	35	281	2	AB	NS	-	AS
SA - 57	Steam	12.00	150	365	2	TB	NS	-	AS
SA - 58	Steam	0.75	150	365	2	TB	NS	-	AS
SA - 401	Steam	12.00	150	365	2	TB	NS	-	AS
SA - 402	Steam	4.00	150	365	2	TB	NS	-	AS
SA - 406	Steam	8.00	150	365	2	TB	NS	-	AS
SA - 407	Steam	20.00	10	240	2	TB	NS	-	AS
SA - 408	Steam	4.00	150	365	2	TB	NS	-	AS
SA - 409	Steam	3.00	150	365	2	TB	NS	-	AS
SA - 410	Steam	3.00	150	365	2	TB	NS	-	AS
SA - 411	Steam	16.00	10	240	2	TB	NS	-	AS
SA - 412	Steam	16.00	10	240	2	TB	NS	-	AS
SA - 413	Steam	8.00	150	365	2	AB	NS	-	AS
SA - 419	Steam	6.00	150	265	2	TB	NS	-	AS
SA - 420	Steam	6.00	110	345	2	AB	NS	-	AS
SA - 421	Steam	4.00	110	345	2	AB	NS	-	AS
SA - 422	Steam	3.00	110	345	2	AB	NS	-	AS
SA - 423	Steam	6.00	110	345	2	AB	NS	-	AS

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
SA - 450	Steam	12.00	150	365	2	SB	NS	-	AS
SA - 457	Steam	12.00	150	365	2	TB	NS	-	AS
SAD - 1	Water	3.00	150	358	2	TB	NS	-	AS
SAD - 401	Water	3.00	150	358	2	TB	NS	-	AS
SBTV - 1	Steam	18.00	25	267	2	AB	NS	-	AS
SBTV - 401	Steam	18.00	25	267	2	AB	NS	-	AS
SDHV - 1	Steam	3.00	775	517	1	MSVH	1	Q2	MS
SDHV - 2	Steam	3.00	775	517	1	MSVH	1	Q2	MS
SDHV - 3	Steam	3.00	775	517	1	MSVH	1	Q2	MS
SDHV - 4	Steam	4.00	775	517	1	MSVH	1	Q2	MS
SDHV - 401	Steam	3.00	775	517	1	MSVH	1	Q2	MS
SDHV - 402	Steam	3.00	775	517	1	MSVH	1	Q2	MS
SDHV - 403	Steam	3.00	775	517	1	MSVH	1	Q2	MS
SDHV - 404	Steam	4.00	775	517	1	MSVH	1	Q2	MS
SDRV - 1	Steam	12.00	215	393	2	TB	NS	-	HPDV
SDRV - 2	Steam	12.00	215	393	2	TB	NS	-	HPDV
SDRV - 3	Steam	10.00	215	393	2	TB	NS	-	HPDV
SDRV - 4	Steam	10.00	215	393	2	TB	NS	-	HPDV
SDRV - 5	Steam	10.00	215	393	2	TB	NS	-	HPDV
SDRV - 6	Steam	10.00	215	393	2	TB	NS	-	HPDV
SDRV - 7	Steam	10.00	215	393	2	TB	NS	-	HPDV
SDRV - 401	Steam	12.00	215	393	2	TB	NS	-	HPDV
SDRV - 402	Steam	10.00	215	393	2	TB	NS	-	HPDV
SDRV - 403	Steam	10.00	215	393	2	TB	NS	-	HPDV
SDRV - 404	Steam	10.00	215	393	2	TB	NS	-	HPDV

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
SDRV - 405	Steam	10.00	215	393	2	TB	NS	-	HPDV
SDRV - 406	Steam	10.00	215	393	2	TB	NS	-	HPDV
SDRV - 407	Steam	10.00	215	393	2	TB	NS	-	HPDV
SGLO - 1	Steam	4.00	0	300	2	TB	NS	-	GS
SGLO - 2	Steam	6.00	0	300	2	TB	NS	-	GS
SGLO - 4	Steam	6.00	0	300	2	TB	NS	-	GS
SGLO - 5	Steam	6.00	0	300	2	TB	NS	-	GS
SGLO - 6	Steam	6.00	0	300	2	TB	NS	-	GS
SGLO - 8	Steam	10.00	0	300	2	TB	NS	-	GS
SGLO - 9	Steam	4.00	0	300	2	TB	NS	-	GS
SGLO - 10	Steam	4.00	0	300	2	TB	NS	-	GS
SGLO - 11	Steam	6.00	0	300	2	TB	NS	-	GS
SGLO - 12	Steam	4.00	0	300	2	TB	NS	-	GS
SGLO - 14	Steam	4.00	0	300	2	TB	NS	-	GS
SGLO - 15	Steam	8.00	0	300	2	TB	NS	-	GS
SGLO - 16	Steam	4.00	0	300	2	TB	NS	-	GS
SGLO - 17	Steam	4.00	0	300	2	TB	NS	-	GS
SGLO - 401	Steam	4.00	0	300	2	TB	NS	-	GS
SGLO - 402	Steam	6.00	0	300	2	TB	NS	-	GS
SGLO - 404	Steam	6.00	0	300	2	TB	NS	-	GS
SGLO - 405	Steam	6.00	0	300	2	TB	NS	-	GS
SGLO - 406	Steam	6.00	0	300	2	TB	NS	-	GS
SGLO - 408	Steam	10.00	0	300	2	TB	NS	-	GS
SGLO - 409	Steam	4.00	0	300	2	TB	NS	-	GS
SGLO - 410	Steam	4.00	0	300	2	TB	NS	-	GS

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
SGLO - 411	Steam	6.00	0	300	2	TB	NS	-	GS
SGLO - 412	Steam	4.00	0	300	2	TB	NS	-	GS
SGLO - 414	Steam	4.00	0	300	2	TB	NS	-	GS
SGLO - 415	Steam	8.00	0	300	2	TB	NS	-	GS
SGLO - 416	Steam	4.00	0	300	2	TB	NS	-	GS
SGLO - 417	Steam	4.00	0	300	2	TB	NS	-	GS
SGLO - 419	Steam	6.00	0	300	2	TB	NS	-	GS
SHP - 1	Steam	32.00	1005	545	1	MSVH	1	Q2	MS
SHP - 2	Steam	32.00	1005	545	1	MSVH	1	Q2	MS
SHP - 3	Steam	32.00	1005	545	1	MSVH	1	Q2	MS
SHP - 4	Steam	40.00	1005	545	1	TB	NS	-	MS
SHP - 5	Steam	28.00	1005	545	1	TB	NS	-	MS
SHP - 6	Steam	28.00	1005	545	1	TB	NS	-	MS
SHP - 7	Steam	28.00	1005	545	1	TB	NS	-	MS
SHP - 8	Steam	28.00	1005	545	1	TB	NS	-	MS
SHP - 9	Steam	18.00	1005	545	1	TB	NS	-	MS
SHP - 10	Steam	8.00	1005	545	1	TB	NS	-	MS
SHP - 11	Steam	8.00	1005	545	1	TB	NS	-	MS
SHP - 12	Steam	8.00	1005	545	1	TB	NS	-	MS
SHP - 13	Steam	8.00	1005	545	1	TB	NS	-	MS
SHP - 14	Steam	14.00	1005	545	1	TB	NS	-	MS
SHP - 15	Steam	18.00	1005	545	1	TB	NS	-	MS
SHP - 16	Steam	8.00	1005	545	1	TB	NS	-	MS
SHP - 17	Steam	8.00	1005	545	1	TB	NS	-	MS
SHP - 18	Steam	8.00	1005	545	1	TB	NS	-	MS

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
SHP - 19	Steam	8.00	1005	545	1	TB	NS	-	MS
SHP - 20	Steam	14.00	1005	545	1	TB	NS	-	MS
SHP - 21	Steam	6.00	1005	545	1	TB	NS	-	MS
SHP - 22	Steam	32.00	1005	545	1	MSVH	1	Q2	MS
SHP - 23	Steam	32.00	1005	545	1	MSVH	1	Q2	MS
SHP - 24	Steam	32.00	1005	545	1	MSVH	1	Q2	MS
SHP - 25	Steam	3.00	1005	545	1	MSVH	1	Q3	MS
SHP - 26	Steam	3.00	1005	545	1	MSVH	1	Q3	MS
SHP - 27	Steam	3.00	1005	545	1	MSVH	1	Q3	MS
SHP - 28	Steam	3.00	1005	545	1	MSVH	1	Q3	MS
SHP - 29	Steam	3.00	1005	545	1	MSVH	1	Q3	MS
SHP - 30	Steam	3.00	1005	545	1	MSVH	1	Q3	MS
SHP - 31	Steam	3.00	1005	545	1	MSVH	1	Q3	MS
SHP - 36	Steam	3.00	1005	545	1	MSVH	1	Q3	MS
SHP - 37	Steam	6.00	1005	545	1	MSVH	1	Q2	MS
SHP - 38	Steam	6.00	1005	545	1	MSVH	1	Q2	MS
SHP - 39	Steam	6.00	1005	545	1	MSVH	1	Q2	MS
SHP - 45	Steam	3.00	1005	545	1	MSVH	1	Q2	MS
SHP - 46	Steam	3.00	1005	545	1	MSVH	1	Q2	MS
SHP - 47	Steam	3.00	1005	545	1	MSVH	1	Q2	MS
SHP - 48	Steam	14.00	1005	545	1	TB	NS	-	MS
SHP - 49	Steam	8.00	1005	545	1	TB	NS	-	MS
SHP - 50	Steam	8.00	1005	545	1	TB	NS	-	MS
SHP - 51	Steam	14.00	1005	545	1	TB	NS	-	MS
SHP - 52	Steam	8.00	1005	545	1	TB	NS	-	MS

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
SHP - 53	Steam	8.00	1005	545	1	TB	NS	-	MS
SHP - 54	Steam	3.00	1005	545	1	TB	NS	-	MS
SHP - 57	Steam	32.00	1005	545	1	MSVH-SB-TB	NS	-	MS
SHP - 58	Steam	32.00	1005	545	1	MSVH-SB-TB	NS	-	MS
SHP - 59	Steam	32.00	1005	545	1	MSVH-SB-TB	NS	-	MS
SHP - 60	Steam	3.00	1005	545	1	MSVH	1	Q2	MS
SHP - 61	Steam	3.00	1005	545	1	MSVH	1	Q2	MS
SHP - 62	Steam	3.00	1005	545	1	MSVH	1	Q2	MS
SHP - 63	Steam	14.00	1005	545	1	TB	NS	-	MS
SHP - 64	Steam	3.00	1005	545	1	MSVH	1	Q2	MS
SHP - 65	Steam	3.00	1005	545	1	MSVH	1	Q2	MS
SHP - 66	Steam	3.00	1005	545	1	MSVH	1	Q2	MS
SHP - 67	Steam	1.00	1005	545	2	MSVH	1	Q3	MS
SHP - 68	Steam	14.00	1005	545	1	TB	NS	-	MS
SHP - 69	Steam	6.00	1005	545	1	TB	NS	-	MS
SHP - 401	Steam	32.00	1005	545	1	MSVH	1	Q2	MS
SHP - 402	Steam	32.00	1005	545	1	MSVH	1	Q2	MS
SHP - 403	Steam	32.00	1005	545	1	MSVH	1	Q2	MS
SHP - 404	Steam	40.00	1005	545	1	TB	NS	-	MS
SHP - 405	Steam	28.00	1005	545	1	TB	NS	-	MS
SHP - 406	Steam	28.00	1005	545	1	TB	NS	-	MS
SHP - 407	Steam	28.00	1005	545	1	TB	NS	-	MS
SHP - 408	Steam	28.00	1005	545	1	TB	NS	-	MS
SHP - 409	Steam	18.00	1005	545	1	TB	NS	-	MS
SHP - 410	Steam	8.00	1005	545	1	TB	NS	-	MS

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
SHP - 411	Steam	8.00	1005	545	1	TB	NS	-	MS
SHP - 412	Steam	8.00	1005	545	1	TB	NS	-	MS
SHP - 413	Steam	8.00	1005	545	1	TB	NS	-	MS
SHP - 414	Steam	14.00	1005	545	1	TB	NS	-	MS
SHP - 415	Steam	18.00	1005	545	1	TB	NS	-	MS
SHP - 416	Steam	8.00	1005	545	1	TB	NS	-	MS
SHP - 417	Steam	8.00	1005	545	1	TB	NS	-	MS
SHP - 418	Steam	8.00	1005	545	1	TB	NS	-	MS
SHP - 419	Steam	8.00	1005	545	1	TB	NS	-	MS
SHP - 420	Steam	14.00	1005	545	1	TB	NS	-	MS
SHP - 421	Steam	6.00	1005	545	1	TB	NS	-	MS
SHP - 422	Steam	32.00	1005	545	1	MSVH	1	Q2	MS
SHP - 423	Steam	32.00	1005	545	1	MSVH	1	Q2	MS
SHP - 424	Steam	32.00	1005	545	1	MSVH	1	Q2	MS
SHP - 425	Steam	4.00	1005	545	1	MSVH	1	Q3	MS
SHP - 426	Steam	4.00	1005	545	1	MSVH	1	Q3	MS
SHP - 427	Steam	4.00	1005	545	1	MSVH	1	Q3	MS
SHP - 428	Steam	3.00	1005	545	1	MSVH	1	Q3	MS
SHP - 429	Steam	3.00	1005	545	1	MSVH	1	Q3	MS
SHP - 430	Steam	3.00	1005	545	1	MSVH	1	Q3	MS
SHP - 431	Steam	3.00	1005	545	1	MSVH	1	Q3	MS
SHP - 436	Steam	3.00	1005	545	1	MSVH	1	Q3	MS
SHP - 437	Steam	6.00	1005	545	1	MSVH	1	Q2	MS
SHP - 438	Steam	6.00	1005	545	1	MSVH	1	Q2	MS
SHP - 439	Steam	6.00	1005	545	1	MSVH	1	Q2	MS

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
SHP - 445	Steam	3.00	1005	545	1	MSVH	1	Q2	MS
SHP - 446	Steam	3.00	1005	545	1	MSVH	1	Q2	MS
SHP - 447	Steam	3.00	1005	545	1	MSVH	1	Q2	MS
SHP - 448	Steam	14.00	1005	545	1	TB	NS	-	MS
SHP - 449	Steam	8.00	1005	545	1	TB	NS	-	MS
SHP - 450	Steam	8.00	1005	545	1	TB	NS	-	MS
SHP - 451	Steam	14.00	1005	545	1	TB	NS	-	MS
SHP - 452	Steam	8.00	1005	545	1	TB	NS	-	MS
SHP - 453	Steam	8.00	1005	545	1	TB	NS	-	MS
SHP - 454	Steam	3.00	1005	545	1	TB	NS	-	MS
SHP - 457	Steam	32.00	1005	545	1	MSVH&SB&TB	NS	-	MS
SHP - 458	Steam	32.00	1005	545	1	MSVH&SB&TB	NS	-	MS
SHP - 459	Steam	32.00	1005	545	1	MSVH&SB&TB	NS	-	MS
SHP - 460	Steam	3.00	1005	545	1	MSVH	1	Q2	MS
SHP - 461	Steam	3.00	1005	545	1	MSVH	1	Q2	MS
SHP - 462	Steam	3.00	1005	545	1	MSVH	1	Q2	MS
SHP - 463	Steam	14.00	1005	545	1	TB	NS	-	MS
SHP - 464	Steam	4.00	1005	545	1	MSVH	1	Q2	MS
SHP - 465	Steam	4.00	1005	545	1	MSVH	1	Q2	MS
SHP - 466	Steam	4.00	1005	545	1	MSVH	1	Q2	MS
SHP - 467	Steam	1.00	1005	545	2	MSVH	1	Q3	MS
SHP - 468	Steam	14.00	1005	545	1	TB	NS	-	MS
SHP - 469	Steam	6.00	1005	545	1	TB	NS	-	MS
SHPD - 1	Steam-water	1.50	1005	545	1	MSVH	1	Q3	MS
SHPD - 2	Steam-water	1.50	1005	545	1	MSVH	1	Q3	MS

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
SHPD - 3	Steam-water	1.50	1005	545	1	MSVH	1	Q3	MS
SHPD - 6	Steam-water	1.50	1005	545	1	MSVH	1	Q2	MS
SHPD - 7	Steam-water	1.50	1005	545	1	MSVH	1	Q2	MS
SHPD - 8	Steam-water	1.50	1005	545	1	MSVH	1	Q2	MS
SHPD - 16	Steam-water	2.00	1005	545	1	MSVH	1	Q3	MS
SHPD - 17	Steam-water	1.50	1005	545	1	MSVH	1	Q3	MS
SHPD - 18	Steam-water	1.50	1005	545	1	MSVH	1	Q3	MS
SHPD - 19	Steam-water	1.50	1005	545	1	MSVH	1	Q3	MS
SHPD - 21	Steam-water	1.00	1005	545	2	MSVH	1	Q3	MS
SHPD - 22	Steam-water	1.00	1005	545	2	MSVH	1	Q3	MS
SHPD - 23	Steam-water	1.00	1005	545	2	MSVH	1	Q3	MS
SHPD - 24	Steam-water	1.00	1005	545	2	MSVH	1	Q3	MS
SHPD - 25	Steam-water	1.00	1005	545	2	MSVH	1	Q3	MS
SHPD - 26	Steam-water	1.00	1005	545	2	MSVH	1	Q3	MS
SHPD - 27	Steam-water	1.00	1005	545	2	MSVH	1	Q3	MS
SHPD - 28	Steam-water	1.00	1005	545	2	MSVH	1	Q3	MS
SHPD - 29	Steam-water	1.00	1005	545	2	MSVH	1	Q3	MS
SHPD - 30	Steam	1.00	1005	545	2	MSVH	1	Q2	MS
SHPD - 37	Steam	1.00	1005	545	2	MSVH	1	Q3	MS
SHPD - 38	Steam	1.00	1005	545	2	MSVH	1	Q2	MS
SHPD - 39	Steam	1.00	1005	545	2	MSVH	1	Q2	MS
SHPD - 401	Steam	1.50	1005	545	1	MSVH	1	Q3	MS
SHPD - 402	Steam	1.50	1005	545	1	MSVH	1	Q3	MS
SHPD - 403	Steam	1.50	1005	545	1	MSVH	1	Q3	MS
SHPD - 406	Steam	1.50	1005	545	1	MSVH	1	Q2	MS

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
SHPD - 407	Steam	1.50	1005	545	1	MSVH	1	Q2	MS
SHPD - 408	Steam	1.50	1005	545	1	MSVH	1	Q2	MS
SHPD - 416	Steam	2.00	1005	545	1	MSVH	1	Q3	MS
SHPD - 417	Steam	1.50	1005	545	1	MSVH	1	Q3	MS
SHPD - 418	Steam	1.50	1005	545	1	MSVH	1	Q3	MS
SHPD - 419	Steam	1.50	1005	545	1	MSVH	1	Q3	MS
SHPD - 421	Steam	1.00	1005	545	2	MSVH	1	Q3	MS
SHPD - 422	Steam	1.00	1005	545	2	MSVH	1	Q3	MS
SHPD - 423	Steam	1.00	1005	545	2	MSVH	1	Q3	MS
SHPD - 424	Steam	1.00	1005	545	2	MSVH	1	Q3	MS
SHPD - 425	Steam	1.00	1005	545	2	MSVH	1	Q3	MS
SHPD - 426	Steam	1.00	1005	545	2	MSVH	1	Q3	MS
SHPD - 427	Steam	1.00	1005	545	2	MSVH	1	Q3	MS
SHPD - 428	Steam	1.00	1005	545	2	MSVH	1	Q3	MS
SHPD - 429	Steam	1.00	1005	545	2	MSVH	1	Q3	MS
SHPD - 430	Steam	2.00	1005	545	2	MSVH	1	Q2	MS
SHPD - 437	Steam	1.00	1005	545	2	MSVH	1	Q3	MS
SHPD - 438	Steam	1.00	1005	545	2	MSVH	1	Q2	MS
SHPD - 439	Steam	1.00	1005	545	2	MSVH	1	Q2	MS
SI - 6	Borated water	0.75	2235	160	2	AB TUN#1	1	Q2	SI
SI - 22	Borated water	4.00	2235	160	2	AB TUN#1	1	Q2	SI
SI - 23	Borated water	3.00	2235	160	2	AB TUN#1	1	Q2	SI
SI - 24	Borated water	3.00	2235	160	2	AB TUN#1	1	Q2	SI
SI - 26	Borated water	1.00	2235	160	2	AB TUN#1	1	Q2	SI
SI - 27	Borated water	1.00	2235	160	2	AB TUN#1	1	Q3	SI

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
SI - 28	Borated water	1.00	2235	160	2	AB TUN#1	1	Q2	SI
SI - 29	Borated water	1.00	2235	160	2	AB TUN#1	1	Q2	SI
SI - 30	Borated water	1.00	2235	160	2	AB TUN#1	1	Q2	SI
SI - 44	Borated water	0.75	600	105	2	AB	1	Q3	SI
SI - 50	Borated water	1.00	2235	160	2	AB TUN#1	1	Q1	SI
SI - 122	Borated water	1.00	2235	160	2	AB TUN#1	1	Q2	SI
SI - 137	Borated water	3.00	2235	180	2	AB TUN#1	1	Q2	SI
SI - 144	Borated water	0.75	660	120	2	AB TUN#1	1	Q2	SI
SI - 145	Borated water	0.75	660	120	2	AB TUN#1	1	Q3	SI
SI - 146	Borated water	1.50	660	120	2	AB TUN#1	1	Q3	SI
SI - 147	Borated water	0.75	660	120	2	AB TUN#1	1	Q3	SI
SI - 159	Borated water	4.00	2235	180	2	AB TUN#1	1	Q2	SI
SI - 160	Borated water	3.00	2235	180	2	AB TUN#1	1	Q2	SI
SI - 406	Borated water	0.75	2235	170	2	AB TUN#2	1	Q2	SI
SI - 422	Borated water	4.00	2235	160	2	AB TUN#2	1	Q2	SI
SI - 423	Borated water	3.00	2235	170	2	AB TUN#2	1	Q2	SI
SI - 424	Borated water	3.00	2235	170	2	AB TUN#2	1	Q2	SI
SI - 426	Borated water	1.00	2235	170	2	AB TUN#2	1	Q2	SI
SI - 427	Borated water	1.00	2235	170	2	AB TUN#2	1	Q2	SI
SI - 428	Borated water	1.00	2235	170	2	AB TUN#2	1	Q2	SI
SI - 429	Borated water	1.00	2235	170	2	AB TUN#2	1	Q2	SI
SI - 444	Borated water	1.00	600	105	2	AB	1	Q3	SI
SI - 450	Borated water	1.00	2235	170	2	AB TUN#2	1	Q1	SI
SI - 522	Borated water	1.00	2235	170	2	AB TUN#2	1	Q2	SI
SI - 537	Borated water	3.00	2235	180	2	AB TUN#2	1	Q2	SI

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
SI - 544	Borated water	0.75	660	120	2	AB TUN#2	1	Q2	SI
SI - 545	Borated water	0.75	660	120	2	AB TUN#2	1	Q3	SI
SI - 546	Borated water	1.50	660	120	2	AB TUN#2	1	Q3	SI
SI - 547	Borated water	0.75	660	120	2	AB TUN#2	1	Q3	SI
SI - 559	Borated water	4.00	2235	180	2	AB TUN#2	1	Q2	SI
SI - 560	Borated water	3.00	2235	180	2	AB TUN#2	1	Q2	SI
SLP - 1	Steam	14.00	250	406	2	TB	NS	-	MS
SLP - 2	Steam	14.00	250	406	2	TB	NS	-	MS
SLP - 3	Steam	14.00	250	406	2	TB	NS	-	MS
SLP - 4	Steam	14.00	250	406	2	TB	NS	-	MS
SLP - 6	Steam	14.00	250	406	2	TB	NS	-	MS
SLP - 7	Steam	14.00	250	406	2	TB	NS	-	MS
SLP - 8	Steam	14.00	250	406	2	TB	NS	-	MS
SLP - 9	Steam	14.00	250	406	2	TB	NS	-	MS
SLP - 401	Steam	14.00	250	406	2	TB	NS	-	MS
SLP - 402	Steam	14.00	250	406	2	TB	NS	-	MS
SLP - 403	Steam	14.00	250	406	2	TB	NS	-	MS
SLP - 404	Steam	14.00	250	406	2	TB	NS	-	MS
SLP - 406	Steam	14.00	250	406	2	TB	NS	-	MS
SLP - 407	Steam	14.00	250	406	2	TB	NS	-	MS
SLP - 408	Steam	14.00	250	406	2	TB	NS	-	MS
SLP - 409	Steam	14.00	250	406	2	TB	NS	-	MS
SLPD - 50	Condensate	4.00	100	330	2	AB	NS	-	AS
SLPD - 51	Condensate	3.00	100	330	2	AB	NS	-	AS
SLPD - 52	Condensate	2.00	100	330	2	AB	NS	-	AS

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
SLPD - 53	Condensate	3.00	100	330	2	AB	NS	-	AS
SLPD - 54	Condensate	3.00	100	330	2	AB	NS	-	AS
SLPD - 55	Condensate	2.00	100	330	2	AB	NS	-	AS
SLPD - 56	Condensate	1.00	15	215	2	AB	NS	-	AS
SLPD - 58	Condensate	1.00	0	212	2	AB	NS	-	AS
SLPD - 59	Condensate	2.00	100	330	2	AB	NS	-	AS
SLPD - 60	Condensate	3.00	100	212	2	AB	NS	-	AS
SLPD - 62	Condensate	3.00	100	212	2	AB	NS	-	AS
SLPD - 64	Condensate	1.50	100	330	2	TUN	NS	-	AS
SLPD - 65	Condensate	1.50	100	330	2	TUN	NS	-	AS
SLPD - 66	Condensate	1.00	0	212	2	AB	NS	-	AS
SLPD - 67	Condensate	2.00	100	330	2	AB	NS	-	AS
SLPD - 68	Condensate	2.00	75	212	2	AB	NS	-	AS
SLPD - 69	Condensate	2.00	75	212	2	AB	NS	-	AS
SLPD - 70	Condensate	6.00	100	330	2	AB	NS	-	AS
SLPD - 71	Condensate	1.50	100	330	2	AB	NS	-	AS
SLPD - 72	Condensate	2.00	100	330	2	AB	NS	-	AS
SLPD - 73	Condensate	2.00	100	330	2	AB	NS	-	AS
SLPD - 74	Condensate	1.50	100	330	2	AB	NS	-	AS
SLPD - 75	Condensate	1.50	100	330	2	TUN	NS	-	AS
SLPD - 76	Condensate	1.50	100	330	2	TUN	NS	-	AS
SLPD - 77	Condensate	1.50	100	330	2	TUN	NS	-	AS
SLPD - 78	Condensate	1.00	15	215	2	TUN	NS	-	AS
SLPD - 80	Condensate	1.50	100	330	2	TUN	NS	-	AS
SLPD - 81	Condensate	1.50	100	330	2	TUN	NS	-	AS

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
SLPD - 82	Condensate	1.50	100	330	2	TUN	NS	-	AS
SS - 53	Water	0.75	0	212	2	TB	NS	-	SS
SS - 154	Water	0.50	844	200	2	TB	NS	-	SS
SS - 155	Water	0.50	844	200	2	TB	NS	-	SS
SS - 156	Water	0.50	844	150	2	TB	NS	-	SS
SS - 157	Water	0.50	844	150	2	TB	NS	-	SS
SS - 200	Water	0.75	880	150	2	TB	NS	-	SS
SS - 201	Water	0.75	880	150	2	TB	NS	-	SS
SS - 205	Water	0.50	1085	335	2	TB	NS	-	SS
SS - 206	Water	0.50	1085	335	2	TB	NS	-	SS
SS - 207	Water	0.50	1085	335	2	TB	NS	-	SS
SS - 208	Water	0.50	1655	295	2	TB	NS	-	SS
SS - 209	Water	0.50	1085	375	2	TB	NS	-	SS
SS - 210	Water	0.50	1085	375	2	TB	NS	-	SS
SS - 211	Water	0.50	1085	375	2	TB	NS	-	SS
SS - 212	Water	0.50	2485	382	2	TB	NS	-	SS
SS - 213	Water	0.50	150	365	2	TB	NS	-	SS
SS - 214	Water	0.50	350	250	2	TB	NS	-	SS
SS - 215	Water	0.50	2235	395	2	TB	NS	-	SS
SS - 216	Water	0.50	2485	349	2	TB	NS	-	ES
SS - 233	Water	0.50	880	521	2	TB	NS	-	ES
S1E - 1	Steam	12.00	413	444	1	TB	NS	-	ES
S1E - 2	Steam	12.00	413	444	1	TB	NS	-	ES
S1E - 3	Steam	12.00	413	444	1	TB	NS	-	ES
S1E - 401	Steam	12.00	413	444	1	TB	NS	-	ES

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
S1E - 402	Steam	12.00	413	444	1	TB	NS	-	ES
S1E - 403	Steam	12.00	413	444	1	TB	NS	-	ES
S2E - 1	Steam	18.00	236	390	2	TB	NS	-	ES
S2E - 2	Steam	6.00	236	390	2	TB	NS	-	ES
S2E - 3	Steam	18.00	236	390	2	TB	NS	-	ES
S2E - 4	Steam	6.00	236	390	2	TB	NS	-	ES
S2E - 5	Steam	8.00	236	390	2	TB	NS	-	ES
S2E - 401	Steam	18.00	236	390	2	TB	NS	-	ES
S2E - 402	Steam	6.00	236	390	2	TB	NS	-	ES
S2E - 403	Steam	18.00	236	390	2	TB	NS	-	ES
S2E - 404	Steam	6.00	236	390	2	TB	NS	-	ES
S2E - 405	Steam	8.00	236	390	2	TB	NS	-	ES
S3E - 1	Steam	16.00	100	316	2	TB	NS	-	ES
S3E - 2	Steam	16.00	100	316	2	TB	NS	-	ES
S3E - 3	Steam	12.00	100	316	2	TB	NS	-	ES
S3E - 4	Steam	12.00	100	316	2	TB	NS	-	ES
S3E - 5	Steam	12.00	100	316	2	TB	NS	-	ES
S3E - 6	Steam	12.00	100	316	2	TB	NS	-	ES
S3E - 401	Steam	16.00	100	316	2	TB	NS	-	ES
S3E - 402	Steam	16.00	100	316	2	TB	NS	-	ES
S3E - 403	Steam	12.00	100	316	2	TB	NS	-	ES
S3E - 404	Steam	12.00	100	316	2	TB	NS	-	ES
S3E - 405	Steam	12.00	100	316	2	TB	NS	-	ES
S3E - 406	Steam	12.00	100	316	2	TB	NS	-	ES
S4E - 1	Steam	18.00	68	285	2	TB	NS	-	ES

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
S4E - 2	Steam	18.00	68	285	2	TB	NS	-	ES
S4E - 3	Steam	24.00	68	285	2	TB	NS	-	ES
S4E - 4	Steam	18.00	68	285	2	TB	NS	-	ES
S4E - 5	Steam	18.00	68	285	2	TB	NS	-	ES
S4E - 6	Steam	18.00	68	285	2	TB	NS	-	ES
S4E - 7	Steam	18.00	68	285	2	TB	NS	-	ES
S4E - 8	Steam	24.00	68	285	2	TB	NS	-	ES
S4E - 9	Steam	18.00	68	285	2	TB	NS	-	ES
S4E - 10	Steam	18.00	68	285	2	TB	NS	-	ES
S4E - 401	Steam	18.00	68	285	2	TB	NS	-	ES
S4E - 402	Steam	18.00	68	285	2	TB	NS	-	ES
S4E - 403	Steam	24.00	68	285	2	TB	NS	-	ES
S4E - 404	Steam	18.00	68	285	2	TB	NS	-	ES
S4E - 405	Steam	18.00	68	285	2	TB	NS	-	ES
S4E - 407	Steam	18.00	68	285	2	TB	NS	-	ES
S4E - 408	Steam	24.00	68	285	2	TB	NS	-	ES
S4E - 409	Steam	18.00	68	285	2	TB	NS	-	ES
S4E - 410	Steam	18.00	68	285	2	TB	NS	-	ES
WCMU - 23	Water	2.50	525	95	2	TB	NS	-	CN
WCMU - 423	Water	2.50	525	95	2	TB	NS	-	CN
WCPD - 1	Water	18.00	525	95	2	TB	NS	-	CN
WCPD - 2	Water	18.00	525	95	2	TB	NS	-	CN
WCPD - 3	Water	18.00	525	95	2	TB	NS	-	CN
WCPD - 4	Water	24.00	525	95	2	TB	NS	-	CN
WCPD - 5	Water	18.00	525	95	2	TB	NS	-	CN

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
WCPD - 6	Water	18.00	525	95	2	TB	NS	-	CN
WCPD - 7	Water	18.00	525	96	2	TB	NS	-	CN
WCPD - 8	Water	18.00	525	96	2	TB	NS	-	CN
WCPD - 9	Water	14.00	525	96	2	TB	NS	-	CN
WCPD - 10	Water	24.00	525	96	2	TB	NS	-	CN
WCPD - 11	Water	14.00	525	96	2	TB	NS	-	CN
WCPD - 12	Water	18.00	525	96	2	TB	NS	-	CN
WCPD - 13	Water	14.00	525	96	2	TB	NS	-	CN
WCPD - 14	Water	24.00	525	96	2	TB	NS	-	CN
WCPD - 15	Water	24.00	525	96	2	TB	NS	-	CN
WCPD - 16	Water	24.00	525	96	2	TB	NS	-	CN
WCPD - 17	Water	18.00	525	96	2	TB	NS	-	CN
WCPD - 18	Water	18.00	525	96	2	TB	NS	-	CN
WCPD - 19	Water	18.00	525	96	2	TB	NS	-	CN
WCPD - 20	Water	18.00	491	180	2	TB	NS	-	CN
WCPD - 21	Water	18.00	461	227	1	TB	NS	-	CN
WCPD - 22	Water	18.00	525	96	2	TB	NS	-	CN
WCPD - 23	Water	18.00	491	180	2	TB	NS	-	CN
WCPD - 24	Water	18.00	461	227	1	TB	NS	-	CN
WCPD - 25	Water	18.00	430	283	1	TB	NS	-	CN
WCPD - 26	Water	18.00	430	283	1	TB	NS	-	CN
WCPD - 27	Water	18.00	401	314	1	TB	NS	-	CN
WCPD - 28	Water	18.00	401	314	1	TB	NS	-	CN
WCPD - 29	Water	18.00	375	384	1	TB	NS	-	CN
WCPD - 30	Water	18.00	375	384	1	TB	NS	-	CN

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
WCPD - 31	Water	24.00	375	384	1	TB	NS	-	CN
WCPD - 32	Water	18.00	375	384	1	TB	NS	-	CN
WCPD - 33	Water	18.00	375	384	1	TB	NS	-	CN
WCPD - 34	Water	4.00	525	95	2	TB	NS	-	CN
WCPD - 35	Water	14.00	474	225	1	TB	NS	-	CN
WCPD - 36	Water	14.00	461	96	2	TB	NS	-	CN
WCPD - 37	Water	14.00	461	96	2	TB	NS	-	CN
WCPD - 38	Water	6.00	525	95	2	TB	NS	-	CN
WCPD - 39	Water	2.50	525	95	2	TB-AB	NS	-	CN
WCPD - 40	Water	14.00	525	96	2	TB	NS	-	CN
WCPD - 41	Water	2.50	525	95	2	TB	NS	-	CN
WCPD - 42	Water	18.00	375	384	1	TB	NS	-	CN
WCPD - 43	Water	24.00	525	96	2	TB	NS	-	CN
WCPD - 51	Water	2.00	525	95	2	AB	NS	-	CN
WCPD - 158	Water	4.00	544	244	2	TB	NS	-	CN
WCPD - 159	Water	6.00	550	105	2	TB	NS	-	CN
WCPD - 160	Water	6.00	540	210	2	TB	NS	-	CN
WCPD - 401	Condensate	18.00	525	95	2	TB	NS	-	CN
WCPD - 402	Condensate	18.00	525	95	2	TB	NS	-	CN
WCPD - 403	Condensate	18.00	525	95	2	TB	NS	-	CN
WCPD - 404	Condensate	24.00	525	95	2	TB	NS	-	CN
WCPD - 405	Condensate	18.00	525	95	2	TB	NS	-	CN
WCPD - 406	Condensate	18.00	525	95	2	TB	NS	-	CN
WCPD - 407	Condensate	18.00	525	95	2	TB	NS	-	CN
WCPD - 408	Condensate	18.00	525	95	2	TB	NS	-	CN

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
WCPD - 409	Condensate	14.00	525	95	2	TB	NS	-	CN
WCPD - 410	Condensate	24.00	525	95	2	TB	NS	-	CN
WCPD - 411	Condensate	14.00	525	95	2	TB	NS	-	CN
WCPD - 412	Condensate	18.00	525	95	2	TB	NS	-	CN
WCPD - 413	Condensate	14.00	525	95	2	TB	NS	-	CN
WCPD - 414	Condensate	24.00	525	95	2	TB	NS	-	CN
WCPD - 415	Condensate	24.00	525	95	2	TB	NS	-	CN
WCPD - 416	Condensate	18.00	525	95	2	TB	NS	-	CN
WCPD - 417	Condensate	18.00	525	95	2	TB	NS	-	CN
WCPD - 418	Condensate	18.00	525	95	2	TB	NS	-	CN
WCPD - 419	Condensate	18.00	525	95	2	TB	NS	-	CN
WCPD - 420	Condensate	18.00	525	180	2	TB	NS	-	CN
WCPD - 421	Condensate	18.00	525	227	1	TB	NS	-	CN
WCPD - 422	Condensate	18.00	525	96	2	TB	NS	-	CN
WCPD - 423	Condensate	18.00	491	180	2	TB	NS	-	CN
WCPD - 424	Condensate	18.00	461	227	1	TB	NS	-	CN
WCPD - 425	Condensate	18.00	430	283	1	TB	NS	-	CN
WCPD - 426	Condensate	18.00	430	283	1	TB	NS	-	CN
WCPD - 427	Condensate	18.00	401	314	1	TB	NS	-	CN
WCPD - 428	Condensate	18.00	401	314	1	TB	NS	-	CN
WCPD - 429	Condensate	18.00	375	384	1	TB	NS	-	CN
WCPD - 430	Condensate	18.00	375	384	1	TB	NS	-	CN
WCPD - 431	Condensate	24.00	375	375	1	TB	NS	-	CN
WCPD - 432	Condensate	18.00	375	384	1	TB	NS	-	CN
WCPD - 433	Condensate	18.00	375	384	1	TB	NS	-	CN

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
WCPD - 434	Condensate	4.00	525	95	2	TB	NS	-	CN
WCPD - 435	Condensate	14.00	474	225	1	TB	NS	-	CN
WCPD - 436	Condensate	14.00	461	96	2	TB	NS	-	CN
WCPD - 437	Condensate	14.00	461	96	2	TB	NS	-	CN
WCPD - 438	Condensate	6.00	525	95	2	TB	NS	-	CN
WCPD - 439	Condensate	2.50	525	95	2	TB-AB	NS	-	CN
WCPD - 440	Condensate	14.00	525	95	2	TB	NS	-	CN
WCPD - 441	Condensate	2.50	525	95	2	TB	NS	-	CN
WCPD - 442	Condensate	18.00	375	384	1	TB	NS	-	CN
WCPD - 443	Condensate	24.00	525	96	2	TB	NS	-	CN
WDRD - 1	Water	12.00	215	393	2	TB	NS	-	HPDV
WDRD - 2	Water	20.00	215	393	2	TB	NS	-	HPDV
WDRD - 3	Water	20.00	215	393	2	TB	NS	-	HPDV
WDRD - 4	Water	20.00	215	393	2	TB	NS	-	HPDV
WDRD - 5	Water	12.00	215	393	2	TB	NS	-	HPDV
WDRD - 6	Water	12.00	215	393	2	TB	NS	-	HPDV
WDRD - 7	Water	4.00	215	393	2	TB	NS	-	HPDV
WDRD - 8	Water	4.00	215	393	2	TB	NS	-	HPDV
WDRD - 9	Water	4.00	215	393	2	TB	NS	-	HPDV
WDRD - 401	Water	12.00	215	393	2	TB	NS	-	HPDV
WDRD - 402	Water	20.00	215	393	2	TB	NS	-	HPDV
WDRD - 403	Water	20.00	215	393	2	TB	NS	-	HPDV
WDRD - 404	Water	20.00	215	393	2	TB	NS	-	HPDV
WDRD - 405	Water	12.00	215	393	2	TB	NS	-	HPDV
WDRD - 406	Water	12.00	215	393	2	TB	NS	-	HPDV

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
WDRD - 407	Water	4.00	215	393	2	TB	NS	-	HPDV
WDRD - 408	Water	4.00	215	393	2	TB	NS	-	HPDV
WDRD - 409	Water	4.00	215	393	2	TB	NS	-	HPDV
WFPD - 1	Water	18.00	1170	395	1	TB	NS	-	FW
WFPD - 2	Water	18.00	1170	395	1	TB	NS	-	FW
WFPD - 3	Water	26.00	1170	395	1	TB	NS	-	FW
WFPD - 4	Water	18.00	1170	440	1	TB	NS	-	FW
WFPD - 5	Water	18.00	1170	440	1	TB	NS	-	FW
WFPD - 6	Water	26.00	1170	440	1	SB	NS	-	FW
WFPD - 7	Water	16.00	1170	440	1	SB	NS	-	FW
WFPD - 8	Water	16.00	1170	440	1	SB	NS	-	FW
WFPD - 9	Water	16.00	850	440	1	SB-MSVH	NS	-	FW
WFPD - 10	Water	6.00	1170	440	1	SB	NS	-	FW
WFPD - 11	Water	6.00	850	440	1	SB	NS	-	FW
WFPD - 12	Water	16.00	1170	440	1	TB	NS	-	FW
WFPD - 13	Water	16.00	850	440	1	SB-MSVH	NS	-	FW
WFPD - 14	Water	6.00	1170	440	1	SB	NS	-	FW
WFPD - 15	Water	6.00	850	440	1	SB	NS	-	FW
WFPD - 16	Water	18.00	1170	388	1	TB	NS	-	FW
WFPD - 17	Water	16.00	850	440	1	SB-MSVH	NS	-	FW
WFPD - 18	Water	6.00	1170	440	1	SB	NS	-	FW
WFPD - 19	Water	6.00	850	440	1	SB	NS	-	FW
WFPD - 20	Water	16.00	1170	440	1	TB	NS	-	FW
WFPD - 21	Water	16.00	1170	440	1	TB	NS	-	FW
WFPD - 22	Water	16.00	850	440	1	MSVH	1	Q2	FW

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
WFPD - 23	Water	16.00	850	440	1	MSVH	1	Q2	FW
WFPD - 24	Water	16.00	850	440	1	MSVH	1	Q2	FW
WFPD - 25	Water	18.00	850	440	1	MSVH	NS	-	FW
WFPD - 30	Water	18.00	1170	388	1	TB	NS	-	FW
WFPD - 31	Water	18.00	1170	388	1	TB	NS	-	FW
WFPD - 32	Water	18.00	1170	388	1	TB	NS	-	FW
WFPD - 401	Water	18.00	1170	388	1	TB	NS	-	FW
WFPD - 402	Water	18.00	1170	388	1	TB	NS	-	FW
WFPD - 403	Water	26.00	1170	388	1	SB	NS	-	FW
WFPD - 404	Water	18.00	1170	440	1	TB	NS	-	FW
WFPD - 405	Water	18.00	1170	440	1	TB	NS	-	FW
WFPD - 406	Water	26.00	1170	440	1	SB	NS	-	FW
WFPD - 407	Water	16.00	1170	440	1	SB	NS	-	FW
WFPD - 408	Water	16.00	1170	440	1	SB	NS	-	FW
WFPD - 409	Water	16.00	850	440	1	SB-MSVH	NS	-	FW
WFPD - 410	Water	6.00	1170	440	1	SB	NS	-	FW
WFPD - 411	Water	6.00	850	440	1	SB	NS	-	FW
WFPD - 412	Water	16.00	1170	440	1	TB	NS	-	FW
WFPD - 413	Water	16.00	850	440	1	SB-MSVH	NS	-	FW
WFPD - 414	Water	6.00	1170	440	1	SB	NS	-	FW
WFPD - 415	Water	6.00	850	440	1	SB	NS	-	FW
WFPD - 416	Water	18.00	1170	388	1	TB	NS	-	FW
WFPD - 417	Water	16.00	850	440	1	SB-MSVH	NS	-	FW
WFPD - 418	Water	6.00	1170	440	1	SB	NS	-	FW
WFPD - 419	Water	6.00	850	440	1	TB	NS	-	FW

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
WFPD - 420	Water	16.00	1170	440	1	TB	NS	-	FW
WFPD - 421	Water	16.00	1170	440	1	TB	NS	-	FW
WFPD - 422	Water	16.00	850	440	1	MSVH	1	Q2	FW
WFPD - 423	Water	16.00	850	440	1	MSVH	1	Q2	FW
WFPD - 424	Water	16.00	850	440	1	MSVH	1	Q2	FW
WFPD - 430	Water	18.00	1170	395	1	TB	NS	-	FW
WFPD - 431	Water	18.00	1170	395	1	TB	NS	-	FW
WFPD - 432	Water	18.00	1170	395	1	TB	NS	-	FW
WFPR - 1	Water	8.00	1170	395	1	TB	NS	-	FW
WFPR - 2	Water	8.00	1170	395	1	TB	NS	-	FW
WFPR - 3	Water	8.00	1170	395	1	TB	NS	-	FW
WFPR - 7	Water	12.00	1170	395	1	TB	NS	-	FW
WFPR - 14	Water	18.00	1170	395	1	TB	NS	-	FW
WFPR - 16	Water	12.00	1170	395	1	TB	NS	-	FW
WFPR - 17	Water	12.00	1170	395	1	TB	NS	-	FW
WFPR - 18	Water	12.00	1170	395	1	TB	NS	-	FW
WFPR - 25	Water	12.00	1170	395	1	TB	NS	-	FW
WFPR - 26	Water	12.00	1170	395	1	TB	NS	-	FW
WFPR - 27	Water	12.00	1170	395	1	TB	NS	-	FW
WFPR - 401	Water	8.00	1170	395	1	TB	NS	-	FW
WFPR - 402	Water	8.00	1170	395	1	TB	NS	-	FW
WFPR - 403	Water	8.00	1170	395	1	TB	NS	-	FW
WFPR - 404	Water	8.00	1170	395	1	TB	NS	-	FW
WFPR - 405	Water	8.00	1170	395	1	TB	NS	-	FW
WFPR - 406	Water	8.00	1170	395	1	TB	NS	-	FW

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
WFPR - 407	Water	12.00	1170	395	1	TB	NS	-	FW
WGCB - 108	Water	0.75	80	324	2	TB	NS	-	BD
WGCB - 109	Water	0.75	80	324	2	TB	NS	-	BD
WGCB - 110	Water	0.75	80	324	2	TB	NS	-	BD
WGCB - 111	Water	0.75	80	324	2	TB	NS	-	BD
WGCB - 1l2	Water	0.75	80	324	2	TB	NS	-	BD
WGCB - 94	Water	0.75	80	324	2	TB	NS	-	BD
WGCB - 98	Water	0.75	80	324	2	TB	NS	-	BD
WGCB - 61	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 62	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 63	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 64	Water	1.00	141	362	2	AB	NS	-	BD
WGCB - 65	Water	1.00	141	362	2	AB	NS	-	BD
WGCB - 66	Water	1.00	141	362	2	AB	NS	-	BD
WGCB - 70	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 71	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 72	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 73	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 74	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 75	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 80	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 81	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 82	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 83	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 84	Water	1.00	818	521	1	AB	NS	-	BD

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
WGCB - 85	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 86	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 87	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 88	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 99	Water	1.00	80	324	2	TB	NS	-	BD
WGCB - 115	Water	2.00	818	521	1	TB	NS	-	BD
WGCB - 116	Water	2.00	818	521	1	TB	NS	-	BD
WGCB - 117	Water	2.00	818	521	1	TB	NS	-	BD
WGCB - 48	Water	2.00	818	521	1	TB	NS	-	BD
WGCB - 49	Water	2.00	818	521	1	TB	NS	-	BD
WGCB - 50	Water	2.00	818	521	1	TB	NS	-	BD
WGCB - 51	Water	2.00	818	521	1	AB	NS	-	BD
WGCB - 52	Water	2.00	818	521	1	AB	NS	-	BD
WGCB - 53	Water	2.00	818	521	1	AB	NS	-	BD
WGCB - 54	Water	2.00	75	320	2	AB	NS	-	BD
WGCB - 55	Water	2.00	75	320	2	AB	NS	-	BD
WGCB - 56	Water	2.00	75	320	2	AB	NS	-	BD
WGCB - 67	Water	2.00	141	362	2	AB	NS	-	BD
WGCB - 68	Water	2.00	141	362	2	AB	NS	-	BD
WGCB - 69	Water	2.00	141	362	2	AB	NS	-	BD
WGCB - 89	Water	2.00	818	521	1	AB	NS	-	BD
WGCB - 90	Water	2.00	818	521	1	AB	NS	-	BD
WGCB - 91	Water	2.00	818	521	1	AB	NS	-	BD
WGCB - 100	Water	3.00	80	324	2	TB	NS	-	BD
WGCB - 100	Water	3.00	818	521	1	TB	NS	-	BD

Table 3C-2 (continued)

HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
WGCB - 106	Water	3.00	818	521	1	TB	NS	-	BD
WGCB - 107	Water	3.00	818	521	1	TB	NS	-	BD
WGCB - 14	Water	3.00	818	521	1	RC/AB	1	Q2	BD
WGCB - 15	Water	3.00	818	521	1	RC/AB	1	Q2	BD
WGCB - 16	Water	3.00	818	521	1	RC/AB	1	Q2	BD
WGCB - 20	Water	3.00	818	521	1	AB	NS	-	BD
WGCB - 21	Water	3.00	818	521	1	AB	NS	-	BD
WGCB - 22	Water	3.00	818	521	1	AB	NS	-	BD
WGCB - 23	Water	3.00	818	521	1	AB/TUN/TB	NS	-	BD
WGCB - 24	Water	3.00	818	521	1	TB	NS	-	BD
WGCB - 27	Water	3.00	818	521	1	AB/TUN/TB	NS	-	BD
WGCB - 28	Water	3.00	818	521	1	TB	NS	-	BD
WGCB - 30	Water	3.00	818	521	1	AB/TUN/TB	NS	-	BD
WGCB - 31	Water	3.00	818	521	1	TB	NS	-	BD
WGCB - 102	Water	4.00	80	324	2	TB	NS	-	BD
WGCB - l05	Water	6.00	80	324	2	TB	NS	-	BD
WGCB - 62	Water	6.00	80	324	2	TB	NS	-	BD
WGCB - 63	Water	6.00	80	324	2	TB	NS	-	BD
WGCB - 40	Water	8.00	80	324	2	TB	NS	-	BD
WGCB - 41	Water	8.00	80	324	2	TB	NS	-	BD
WGCB - 42	Water	8.00	80	324	2	TB	NS	-	BD
WGCB - 43	Water	8.00	80	324	2	TB	NS	-	BD
WGCB - 45	Water	8.00	80	324	2	TB	NS	-	BD
WGCB - 26	Water	10.00	80	324	2	TB	NS	-	BD
WGCB - 44	Water	14.00	80	324	2	TB	NS	-	BD

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
WGCB - 490	Water	0.75	80	324	2	TB	NS	-	BD
WGCB - 497	Water	0.75	80	324	2	TB	NS	-	BD
WGCB - 498	Water	0.75	80	324	2	TB	NS	-	BD
WGCB - 499	Water	0.75	80	324	2	TB	NS	-	BD
WGCB - 500	Water	0.75	80	324	2	TB	NS	-	BD
WGCB - 501	Water	0.75	80	324	2	TB	NS	-	BD
WGCB - 502	Water	0.75	80	324	2	TB	NS	-	BD
WGCB - 464	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 465	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 466	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 467	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 468	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 469	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 473	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 474	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 475	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 480	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 481	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 482	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 483	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 484	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 485	Water	1.00	818	521	1	AB	NS	-	BD
WGCB - 491	Water	1.00	80	324	2	TB	NS	-	BD
WGCB - 451	Water	2.00	818	521	1	AB	NS	-	BD
WGCB - 452	Water	2.00	818	521	1	AB	NS	-	BD

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
WGCB - 453	Water	2.00	818	521	1	AB	NS	-	BD
WGCB - 470	Water	2.00	141	362	2	AB	NS	-	BD
WGCB - 471	Water	2.00	141	362	2	AB	NS	-	BD
WGCB - 472	Water	2.00	141	362	2	AB	NS	-	BD
WGCB - 515	Water	2.00	818	521	1	TB	NS	-	BD
WGCB - 516	Water	2.00	818	521	1	TB	NS	-	BD
WGCB - 517	Water	2.00	818	521	1	TB	NS	-	BD
WGCB - 414	Water	3.00	818	521	1	RC/AB	1	Q2	BD
WGCB - 415	Water	3.00	818	521	1	RC/AB	1	Q2	BD
WGCB - 416	Water	3.00	818	521	1	RC/AB	1	Q2	BD
WGCB - 420	Water	3.00	818	521	1	AB	NS	-	BD
WGCB - 421	Water	3.00	818	521	1	AB	NS	-	BD
WGCB - 422	Water	3.00	818	521	1	AB	NS	-	BD
WGCB - 423	Water	3.00	818	521	1	AB/TUN/TB	NS	-	BD
WGCB - 424	Water	3.00	818	521	1	TB	NS	-	BD
WGCB - 427	Water	3.00	818	521	1	AB/TUN/TB	NS	-	BD
WGCB - 428	Water	3.00	818	521	1	TB	NS	-	BD
WGCB - 430	Water	3.00	818	521	1	AB/TUN/TB	NS	-	BD
WGCB - 431	Water	3.00	818	521	1	TB	NS	-	BD
WGCB - 489	Water	3.00	80	324	2	TB	NS	-	BD
WGCB - 413	Water	4.00	141	362	2	AB	NS	-	BD
WGCB - 486	Water	4.00	80	324	2	TB	NS	-	BD
WGCB - 434	Water	6.00	80	324	2	TB	NS	-	BD
WGCB - 440	Water	6.00	80	324	2	TB	NS	-	BD
WGCB - 462	Water	6.00	80	324	2	TB	NS	-	BD

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
WGCB - 463	Water	6.00	80	324	2	TB	NS	-	BD
WGCB - 441	Water	8.00	80	324	2	TB	NS	-	BD
WGCB - 442	Water	8.00	80	324	2	TB	NS	-	BD
WGCB - 443	Water	8.00	80	324	2	TB	NS	-	BD
WGCB - 445	Water	8.00	80	324	2	TB	NS	-	BD
WGCB - 426	Water	10.00	80	324	2	TB	NS	-	BD
WGCB - 444	Water	14.00	80	324	2	TB	NS	-	BD
WHPD - 1	Water	10.00	525	393	1	TB	NS	-	HPDV
WHPD - 2	Water	10.00	525	393	1	TB	NS	-	HPDV
WHPD - 3	Water	10.00	525	393	1	TB	NS	-	HPDV
WHPD - 401	Water	10.00	525	393	1	TB	NS	-	HPDV
WHPD - 402	Water	10.00	525	393	1	TB	NS	-	HPDV
WHPD - 403	Water	10.00	525	393	1	TB	NS	-	HPDV
WRD - 1	Water	8.00	800	521	1	TD	NS	-	HPDV
WRD - 2	Water	8.00	800	521	1	TD	NS	-	HPDV
WRD - 3	Water	8.00	800	521	1	TD	NS	-	HPDV
WRD - 4	Water	8.00	800	521	1	TD	NS	-	HPDV
WRD - 401	Water	8.00	800	521	1	TD	NS	-	HPDV
WRD - 402	Water	8.00	800	521	1	TD	NS	-	HPDV
WRD - 403	Water	8.00	800	521	1	TD	NS	-	HPDV
WRD - 404	Water	8.00	800	521	1	TD	NS	-	HPDV
WRRD - 1	Water	8.00	800	521	1	TB	NS	-	HPDV
WRRD - 2	Water	8.00	800	521	1	TB	NS	-	HPDV
WRRD - 3	Water	8.00	800	521	1	TB	NS	-	HPDV
WRRD - 4	Water	8.00	800	521	1	TB	NS	-	HPDV

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
WRRD - 5	Water	6.00	800	521	1	TB	NS	-	HPDV
WRRD - 6	Water	6.00	800	521	1	TB	NS	-	HPDV
WRRD - 7	Water	6.00	800	521	1	TB	NS	-	HPDV
WRRD - 8	Water	6.00	800	521	1	TB	NS	-	HPDV
WRRD - 9	Water	8.00	390	520	1	TB	NS	-	HPDV
WRRD - 10	Water	8.00	390	520	1	TB	NS	-	HPDV
WRRD - 11	Water	8.00	390	520	1	TB	NS	-	HPDV
WRRD - 12	Water	8.00	390	520	1	TB	NS	-	HPDV
WRRD - 13	Water	10.00	390	520	1	TB	NS	-	HPDV
WRRD - 15	Water	6.00	170	520	2	TB	NS	-	HPDV
WRRD - 16	Water	6.00	170	520	2	TB	NS	-	HPDV
WRRD - 17	Water	6.00	170	520	2	TB	NS	-	HPDV
WRRD - 18	Water	6.00	170	520	2	TB	NS	-	HPDV
WRRD - 19	Water	8.00	170	520	2	TB	NS	-	HPDV
WRRD - 20	Water	8.00	170	520	2	TB	NS	-	HPDV
WRRD - 401	Water	8.00	800	521	1	TB	NS	-	HPDV
WRRD - 402	Water	8.00	800	521	1	TB	NS	-	HPDV
WRRD - 403	Water	8.00	800	521	1	TB	NS	-	HPDV
WRRD - 404	Water	8.00	800	521	1	TB	NS	-	HPDV
WRRD - 405	Water	6.00	800	521	1	TB	NS	-	HPDV
WRRD - 406	Water	6.00	800	521	1	TB	NS	-	HPDV
WRRD - 407	Water	6.00	800	521	1	TB	NS	-	HPDV
WRRD - 408	Water	6.00	800	521	1	TB	NS	-	HPDV
WRRD - 409	Water	8.00	390	435	1	TB	NS	-	HPDV
WRRD - 410	Water	8.00	390	435	1	TB	NS	-	HPDV

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
WRRD - 411	Water	8.00	390	435	1	TB	NS	-	HPDV
WRRD - 412	Water	8.00	390	435	1	TB	NS	-	HPDV
WRRD - 413	Water	10.00	390	435	1	TB	NS	-	HPDV
WRRD - 415	Water	6.00	170	360	2	TB	NS	-	HPDV
WRRD - 416	Water	6.00	170	360	2	TB	NS	-	HPDV
WRRD - 417	Water	6.00	170	360	2	TB	NS	-	HPDV
WRRD - 418	Water	6.00	170	360	2	TB	NS	-	HPDV
WRRD - 419	Water	8.00	180	360	2	TB	NS	-	HPDV
WRRD - 420	Water	8.00	170	360	2	TB	NS	-	HPDV
WRV - 1	Steam	3.00	800	521	1	TB	NS	-	HPDV
WRV - 2	Steam	3.00	800	521	1	TB	NS	-	HPDV
WRV - 3	Steam	3.00	800	521	1	TB	NS	-	HPDV
WRV - 4	Steam	3.00	800	521	1	TB	NS	-	HPDV
WRV - 401	Steam	3.00	800	521	1	TB	NS	-	HPDV
WRV - 402	Steam	3.00	800	521	1	TB	NS	-	HPDV
WRV - 403	Steam	3.00	800	521	1	TB	NS	-	HPDV
WRV - 404	Steam	3.00	800	521	1	TB	NS	-	HPDV
WSD - 1	Water	10.00	221	396	2	TB	NS	-	HPDV
WSD - 2	Water	10.00	221	396	2	TB	NS	-	HPDV
WSD - 3	Water	10.00	221	396	2	TB	NS	-	HPDV
WSD - 4	Water	10.00	221	396	2	TB	NS	-	HPDV
WSD - 401	Water	10.00	221	396	2	TB	NS	-	HPDV
WSD - 402	Water	10.00	221	396	2	TB	NS	-	HPDV
WSD - 403	Water	10.00	221	396	2	TB	NS	-	HPDV
WSD - 404	Water	10.00	221	396	2	TB	NS	-	HPDV

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
W1D - 1	Water	12.00	385	445	1	TB	NS	-	HPDV
W1D - 2	Water	12.00	385	445	1	TB	NS	-	HPDV
W1D - 5	Water	12.00	214	402	2	TB	NS	-	HPDV
W1D - 6	Water	12.00	214	402	2	TB	NS	-	HPDV
W1D - 7	Water	12.00	385	402	1	TB	NS	-	HPDV
W1D - 8	Water	12.00	385	402	1	TB	NS	-	HPDV
W1D - 401	Water	12.00	385	445	1	TB	NS	-	HPDV
W1D - 402	Water	12.00	385	445	1	TB	NS	-	HPDV
W1D - 405	Water	12.00	214	402	2	TB	NS	-	HPDV
W1D - 406	Water	12.00	214	402	2	TB	NS	-	HPDV
W1D - 407	Water	12.00	385	445	1	TB	NS	-	HPDV
W1D - 408	Water	12.00	385	445	1	TB	NS	-	HPDV
W2D - 1	Water	16.00	215	393	2	TB	NS	-	HPDV
W2D - 2	Water	16.00	215	393	2	TB	NS	-	HPDV
W2D - 3	Water	12.00	215	393	2	TB	NS	-	HPDV
W2D - 4	Water	12.00	215	393	2	TB	NS	-	HPDV
W2D - 401	Water	16.00	215	393	2	TB	NS	-	HPDV
W2D - 402	Water	16.00	215	393	2	TB	NS	-	HPDV
W2D - 403	Water	12.00	215	393	2	TB	NS	-	HPDV
W2D - 404	Water	12.00	215	393	2	TB	NS	-	HPDV
W3D - 1	Water	6.00	73	293	2	TB	NS	-	LPDV
W3D - 2	Water	6.00	74	293	2	TB	NS	-	LPDV
W3D - 3	Water	6.00	73	293	2	TB	NS	-	LPDV
W3D - 4	Water	6.00	74	293	2	TB	NS	-	LPDV
W3D - 5	Water	8.00	43	293	2	TB	NS	-	LPDV

Table 3C-2 (continued)
HIGH-ENERGY LINES (OUTSIDE CONTAINMENT)

Line No.	Fluid	Line Size	Operating Pressure, psig	Operating Temp. °F	Type Pipe Break Eval. Req'd.	Location	Seismic Class	QA	System
W3D - 6	Water	8.00	43	293	2	TB	NS	-	LPDV
W3D - 7	Water	8.00	12	293	2	TB	NS	-	LPDV
W3D - 8	Water	8.00	12	293	2	TB	NS	-	LPDV
W3D - 401	Water	6.00	73	293	2	TB	NS	-	LPDV
W3D - 402	Water	6.00	73	293	2	TB	NS	-	LPDV
W3D - 403	Water	6.00	73	293	2	TB	NS	-	LPDV
W3D - 404	Water	6.00	73	293	2	TB	NS	-	LPDV
W3D - 405	Water	8.00	43	293	2	TB	NS	-	LPDV
W3D - 406	Water	8.00	43	293	2	TB	NS	-	LPDV
W3D - 407	Water	8.00	12	293	2	TB	NS	-	LPDV
W3D - 408	Water	8.00	12	293	2	TB	NS	-	LPDV
W4D - 1	Water	10.00	48	278	2	TB	NS	-	LPDV
W4D - 2	Water	10.00	48	278	2	TB	NS	-	LPDV
W4D - 3	Water	10.00	48	278	2	TB	NS	-	LPDV
W4D - 4	Water	10.00	48	278	2	TB	NS	-	LPDV
W4D - 5	Water	6.00	487	278	1	TB	NS	-	LPDV
W4D - 6	Water	6.00	487	278	1	TB	NS	-	LPDV
W4D - 401	Water	10.00	48	278	2	TB	NS	-	LPDV
W4D - 402	Water	10.00	48	278	2	TB	NS	-	LPDV
W4D - 403	Water	10.00	48	278	2	TB	NS	-	LPDV
W4D - 404	Water	10.00	48	278	2	TB	NS	-	LPDV
W4D - 405	Water	6.00	487	278	1	TB	NS	-	LPDV
W4D - 406	Water	6.00	487	278	1	TB	NS	-	LPDV

Withhold under 10 CFR 2.390 (d) (1)

[redacted]

Withhold under 10 CFR 2.390 (d) (1)

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Withhold under 10 CFR 2.390 (d) (1)

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Withhold under 10 CFR 2.390 (d) (1)

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Withhold under 10 CFR 2.390 (d) (1)

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Withhold under 10 CFR 2.390 (d) (1)

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Table 3C-4
BREAK LOCATIONS - MAIN STEAM

Line Descriptions	Break Points	Location	Augmented Inspection WMKS Drawing	Weld Number
32"-SHP-1	267	MSVH		
32"-SHP-57	336	SB	11715-WMKS-101A-4	SW-20
	343	TB	11715-WMKS-101A-4	SW-10
32"-SHP-2	40	MSVH		
32"-SHP-59	201	SB	11715-WMKS-101A-4	SW-24
	209	TB	11715-WMKS-101A-4	SW-11
32"-SHP-3	150	MSVH		
32"-SHP-58	105	SB	11715-WMKS-101A-4	SW-21
	116	TB	11715-WMKS-101A-4	SW-12
32"-SHP-22	268	MSVH		
	461B	MSVH		
32"-SHP-23	151	MSVH		
	461A	MSVH		
32"-SHP-24	41	MSVH		
	461C	MSVH		
28"-SHP-5	360	TB		
	370	TB		
	383	TB		
28"-SHP-6	220	TB		
	240	TB		
	253	TB		
28"-SHP-7	120	TB		
	131	TB		
	144	TB		
28"-SHP-8	1	TB		
	10	TB		
	25	TB		
32"-SHP-403	267	MSVH		
32"-SHP-459	336	SB	12050-WMKS-101A-4	SW-53
	343	TB	12050-WMKS-101A-4	SW-5
32"-SHP-402	40	MSVH		
32"-SHP-458	201	SB	12050-WMKS-101A-4	SW-55

Table 3C-4 (continued)
BREAK LOCATIONS - MAIN STEAM

Line Descriptions	Break Points	Location	Augmented Inspection WMKS Drawing	Weld Number
	209	TB	12050-WMKS-101A-4	SW-7
32"-SHP-401	150	MSVH		
32"-SHP-457	105	SB	12050-WMKS-101A-4	SW-55
	116	TB	12050-WMKS-101A-4	SW-8
32"-SHP-424	268	MSVH		
	461B	MSVH		
32"-SHP-423	151	MSVH		
	461A	MSVH		
32"-SHP-422	41	MSVH		
	461C	MSVH		
28"-SHP-405	360	TB		
	370	TB		
	383	TB		
28"-SHP-406	220	TB		
	240	TB		
	253	TB		
28"-SHP-407	120	TB		
	131	TB		
	144	TB		
28"-SHP-408	1	TB		
	10	TB		
	25	TB		

Table 3C-5
Jet Impingement Loads Main Steam Valve House Structures

Break Location	Target	Impingement Area, ft^2	Jet Pressure psig
461	North wall	125.0	39.7
461, 151	South wall	11.4	441.3
461, 151	East wall	19.6	251.6
461, 151	West wall	40.9	131.0
153	Floor	53.3	92.9
153	Roof	280.0	17.5

Table 3C-6
Jet Impingement Loads Main Steam Valve House Valves

Break Location	Target	Jet Pressure psig	At Impingement Area, in.	Incident Angle	Fv Normal Force
461	NRV-MS101A	111.6	4274	0	286
461	NRV-MS101B	71.0	5005	0	213
152	TV-MS101B	119.3	2432	10	168
153	SV-MS101B	34.0	783	66	2.6

Table 3C-7
BREAK LOCATION - FEEDWATER

Line Designation	Break Points	Location	Augmented Inspection WMKS Drawing	Weld Numbers
		Unit 1		
16"-WFPD-9	120	MSVH		
16"-WFPD-8	225	SB	11715-WMKS-102D	SW-40
				SW-41
16"-WFPD-13	110	MSVH		
16"-WFPD-12	325	SB	11715-WMKS-102D	SW-37
				SW-38
16"-WFPD-17	200	MSVH		
16"-WFPD-7	230	SB	11715-WMKS-102D	SW-43
				SW-44
6"-WFPD-18	582	SB	11715-WMKS-102D	SW-42
6"-WFPD-19	551	SB	11715-WMKS-102D	21
	473	SB	11715-WMKS-102D	SW-53
6"-WFPD-10	282	SB	11715-WMKS-102D	SW-43
6"-WFPD-11	251	SB	11715-WMKS-102D	14
	178	SB	11715-WMKS-102D	SW-61
6"-WFPD-14	882	SB	11715-WMKS-102D	SW-44
6"-WFPD-15	851	SB	11715-WMKS-102D	7
	763	SB	11715-WMKS-102D	SW-44

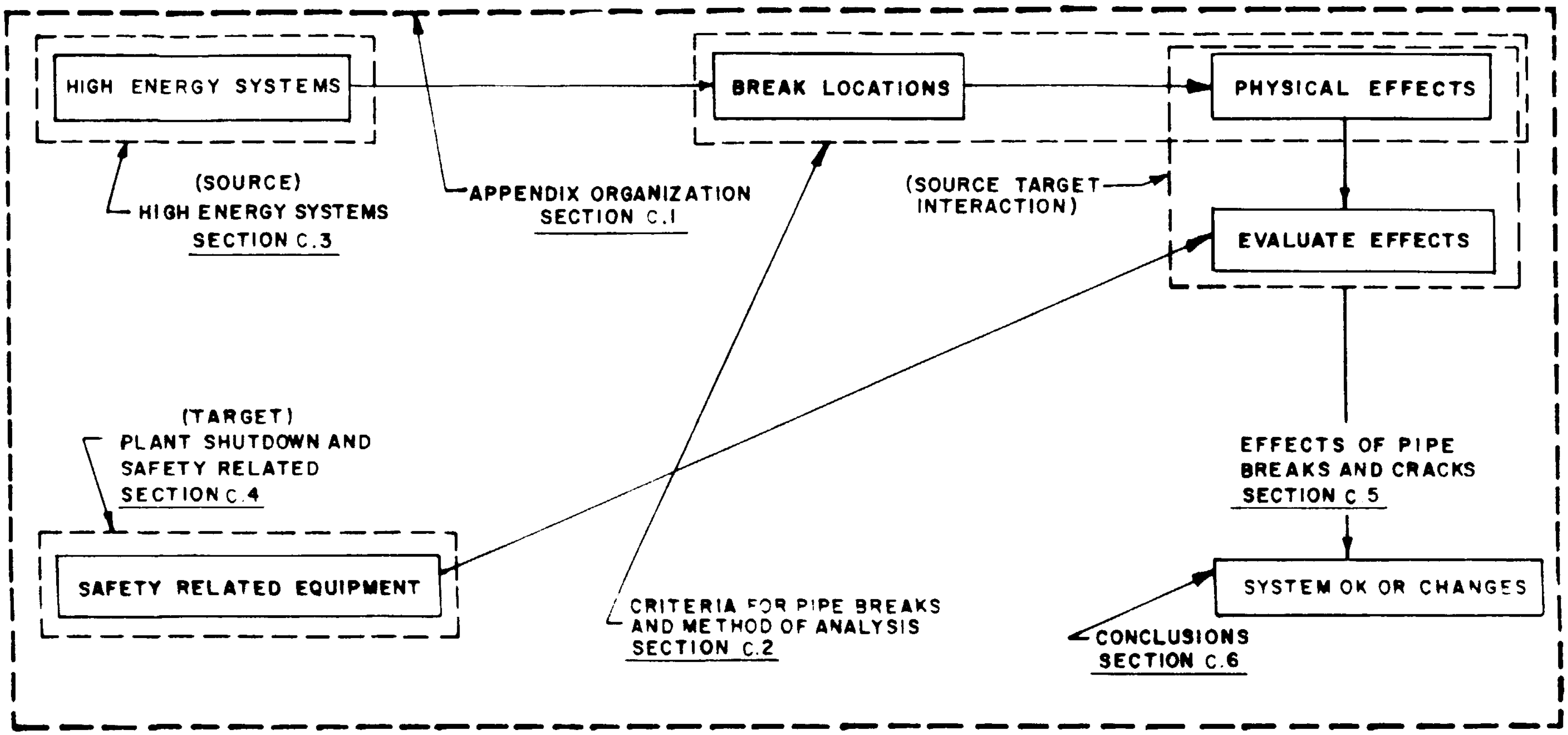
Table 3C-7 (continued)
BREAK LOCATION - FEEDWATER

Line Designation	Break Points	Location	Augmented Inspection WMKS Drawing	Weld Numbers
		Unit 2		
16"-WFPD-413	120	MSVH		
16"-WFPD-412	225	SB	12050-WMKS-102D	SW-131 SW-132
16"-WFPD-417	110	MSVH		
16"-WFPD-407	325	SB	12050-WMKS-102D	SW-129 SW-130
16"-WFPD-409	200	MSVH		
16"-WFPD-408	230	SB	12050-WMKS-102D	SW-133 SW-134
6"-WFPD-418	582	SB	12050-WMKS-102D	SW-127
6"-WFPD-419	551	SB	12050-WMKS-102D	27
	473	SB	12050-WMKS-102D	SW-60W
6"-WFPD-414	282	SB	12050-WMKS-102D	SW-128
6"-WFPD-415	251	SB	12050-WMKS-102D	16
	178	SB	12050-WMKS-102D	SW-19
6"-WFPD-410	882	SB	12050-WMKS-102D	SW-126
6"-WFPD-411	851	SB	12050-WMKS-102D	5
	763	SB	12050-WMKS-102D	SW-08

Table 3C-8
WHIP RESTRAINT FUNCTION

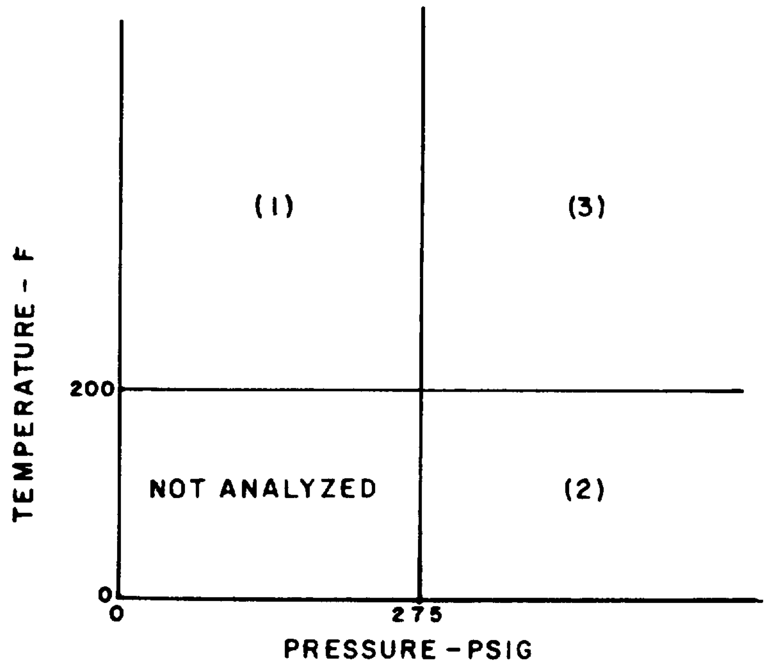
Restaint	Function	Targets
R1	Prevent whip of 2" -CH-6-601-Q2 to the east	MOV-1867C 1"-SI-30-1502-Q2
R2	Prevent whip of 3" -WGCB-14-601-Q2 toward the containment wall	3"-WS-42, 43, 44, 45-151-Q3
R3	Prevent whip of 3"-WGCB-15-601-Q2 toward the containment wall	3"-WS-42, 43, 44, 45-151-Q3
R4	Prevent whip of 2"-CH-406-601-Q2 to the west	MOV-2867C 1”-SI-430-1502-Q2
R5	Prevent whip of 3"-WGCB-414-601-Q2 toward the containment wall	3"-WS-442, 443, 444, 445-151-Q3
R6	Prevent whip of 3"-WGCB-415-601-Q2 toward the containment wall	3"-WS-442, 443, 444, 445-151-Q3

Figure 3C-1
APPENDIX ORGANIZATION EFFECTS OF HIGH ENERGY PIPING SYSTEM BREAK OUTSIDE CONTAINMENT



N03C0001

Figure 3C-2
ANALYSIS FOR HIGH ENERGY SYSTEMS PIPE BREAK EVALUATION REPORT



(1) ≥ 200 F, < 275 PSIG - ANALYZED FOR CRACKS, ENVIRONMENTAL CONCERN
(2) ≥ 275 PSIG, < 200 F - ANALYZED FOR CRACKS, ENVIRONMENTAL CONCERN
(3) ≥ 200 F, ≥ 275 PSIG - ANALYZED FOR BREAKS OR CRACKS; PIPE WHIP, JET IMPINGEMENT AND ENVIRONMENTAL CONCERN

N03C0002

Figure 3C-3
BREAK LOCATION POINTS AT BRANCH RUNS

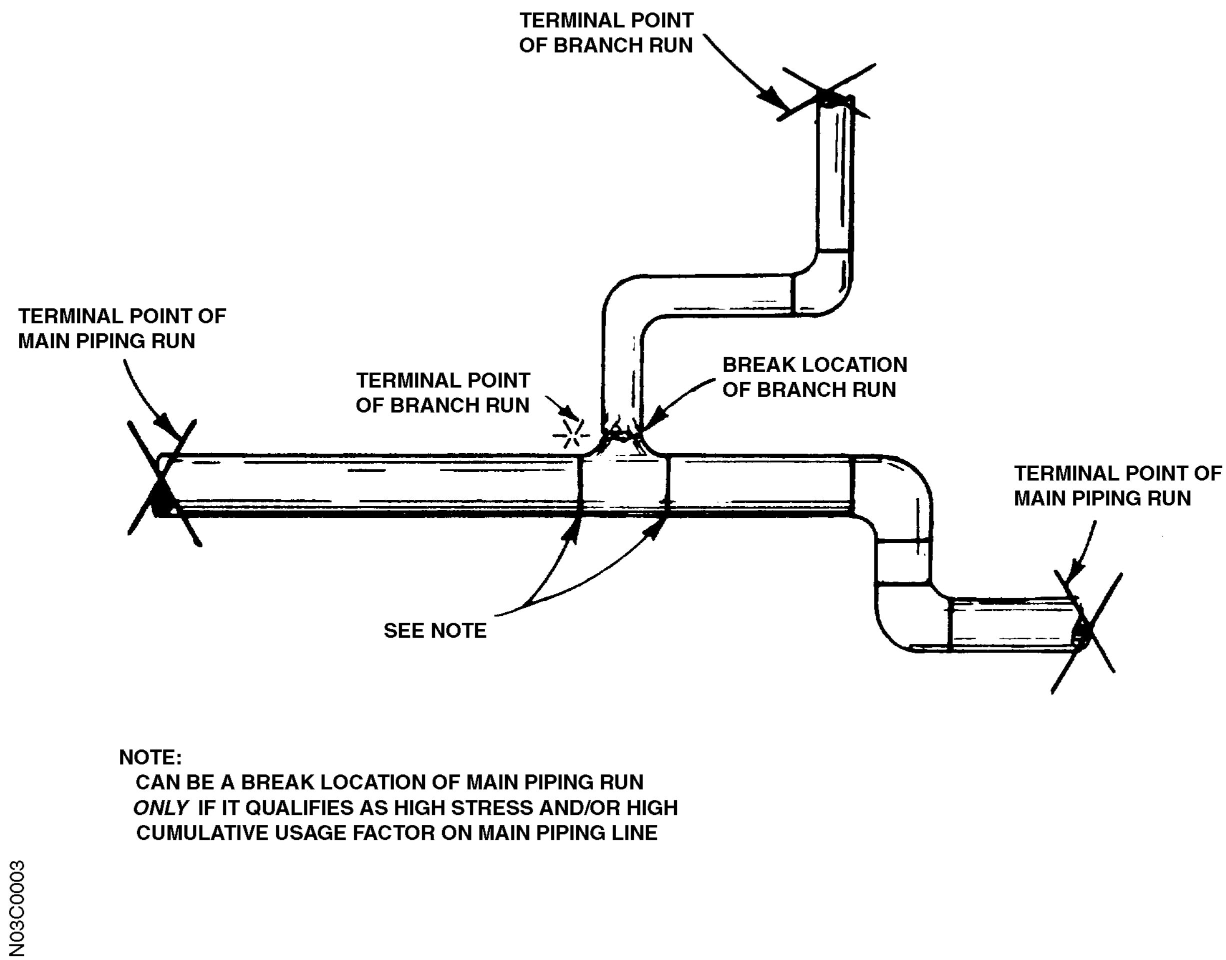
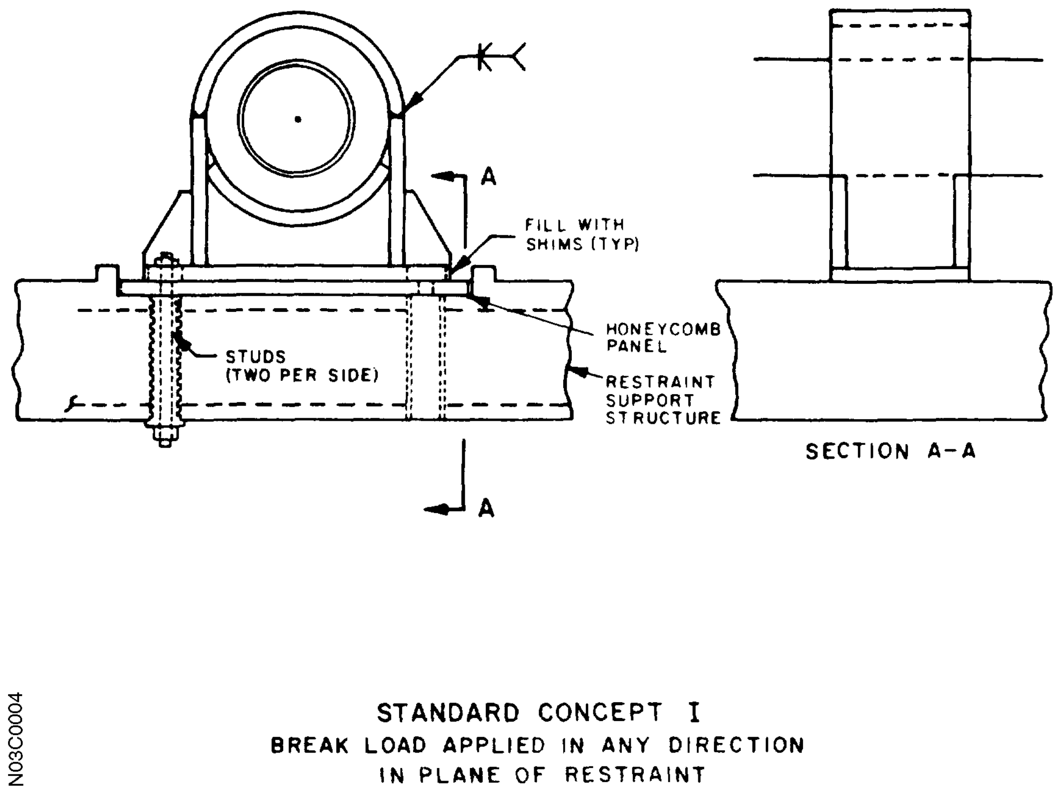


Figure 3C-4
PIPE RUPTURE GENERAL CONCEPT PIPE BREAK EVALUATION REPORT



STANDARD CONCEPT I
BREAK LOAD APPLIED IN ANY DIRECTION
IN PLANE OF RESTRAINT

Figure 3C-5
PIPE RUPTURE RESTRAINT GENERAL CONCEPT PIPE BREAK EVALUATION REPORT

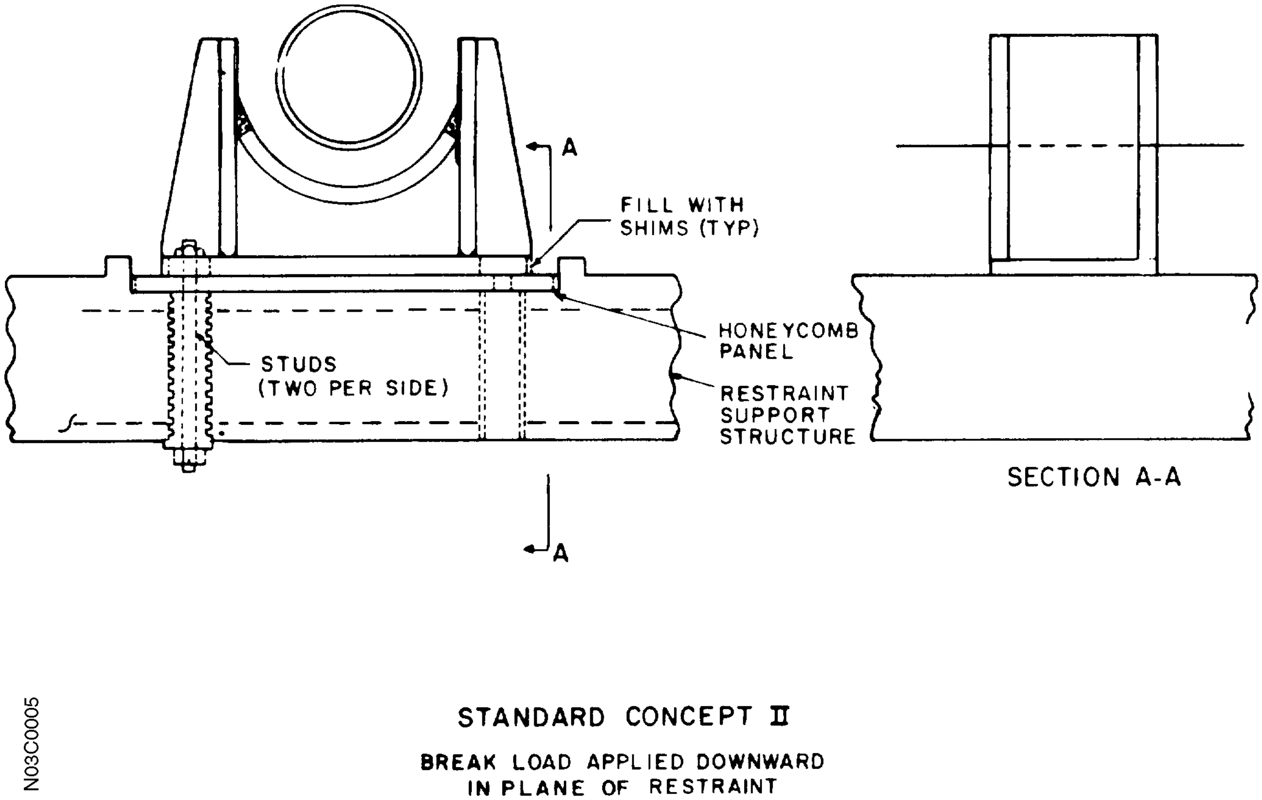


Figure 3C-6
MATHEMATICAL MODEL AND FORCING FUNCTIONS

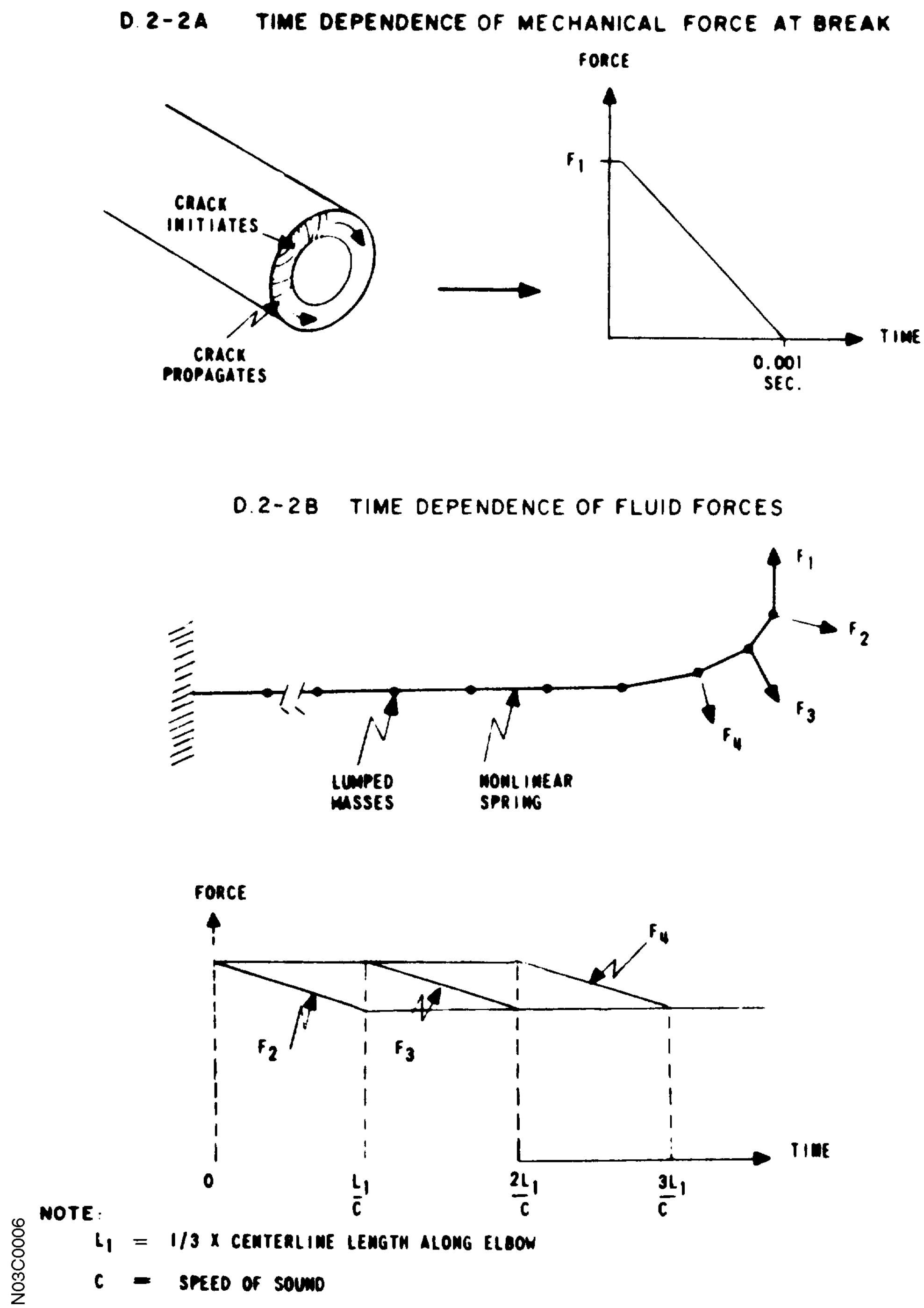
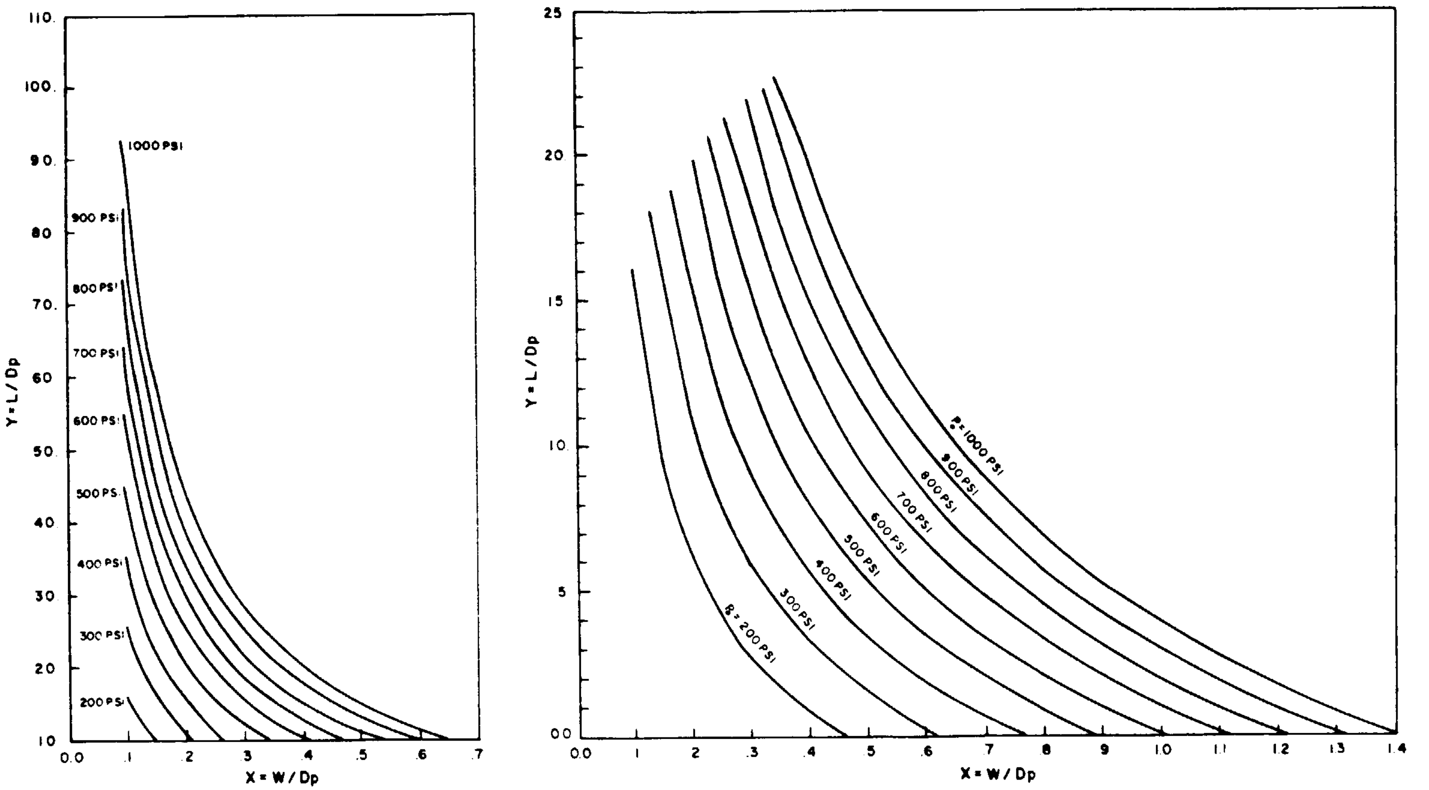


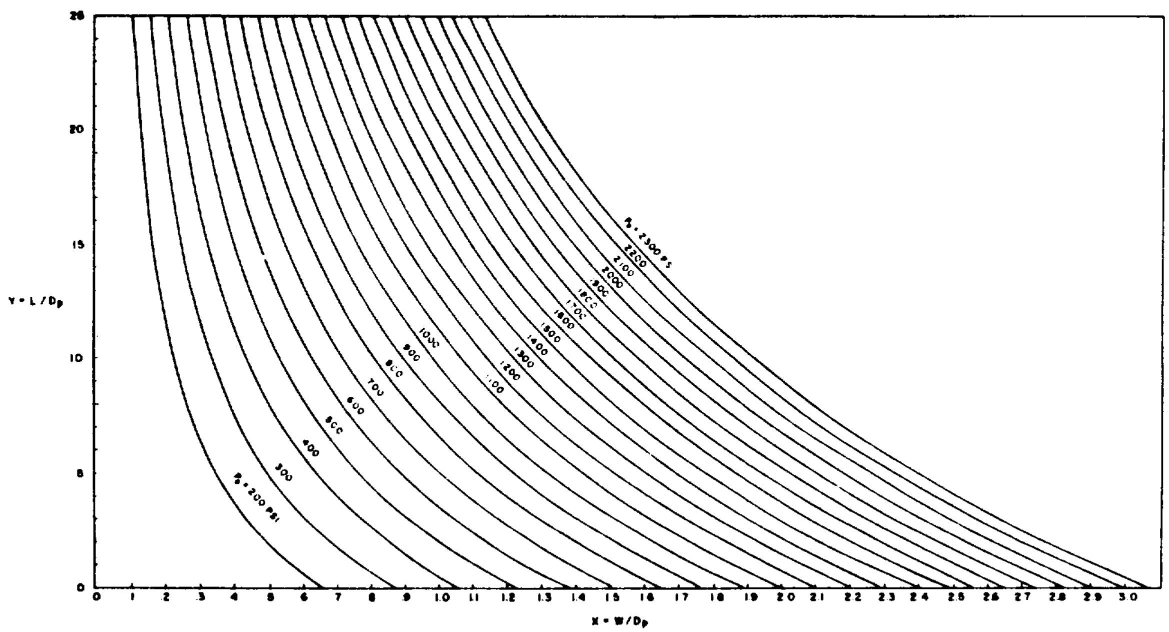
Figure 3C-7
PUNCH SHEAR OF REINFORCED CONCRETE WALL DUE
TO JET IMPINGEMENT FROM STEAM PIPE BREAK



LEGEND:
Dp = PIPE DIAMETER
W = WALL THICKNESS
L = DISTANCE BETWEEN WALL AND PIPE BREAK LOCATION
X = DIMENSIONLESS WALL THICKNESS
Y = DIMENSIONLESS DISTANCE

N03C0007

Figure 3C-8
PUNCH SHEAR OF REINFORCED CONCRETE WALL
DUE TO JET IMPINGEMENT FROM WATER PIPE BREAK



LEGEND

D_p = PIPE DIAMETER

W = WALL THICKNESS

L = DISTANCE BETWEEN WALL AND PIPE BREAK LOCATION

X = DIMENSIONLESS WALL THICKNESS

Y = DIMENSIONLESS DISTANCE

N03C0008

Figure 3C-8 (CONTINUED)
PUNCH SHEAR OF REINFORCED CONCRETE WALL
DUE TO JET IMPINGEMENT FROM WATER PIPE BREAK

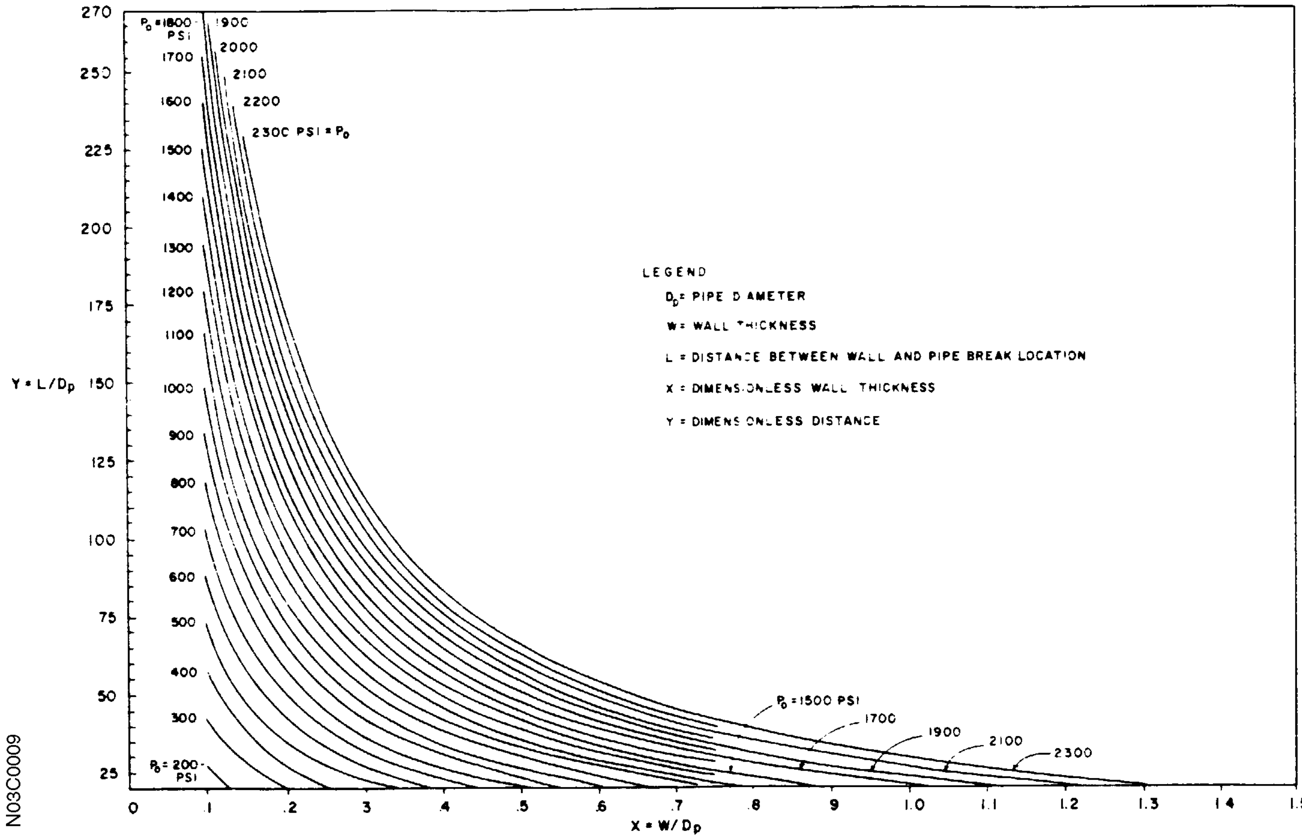


Figure 3C-9
CUPAT LOGIC DIAGRAM

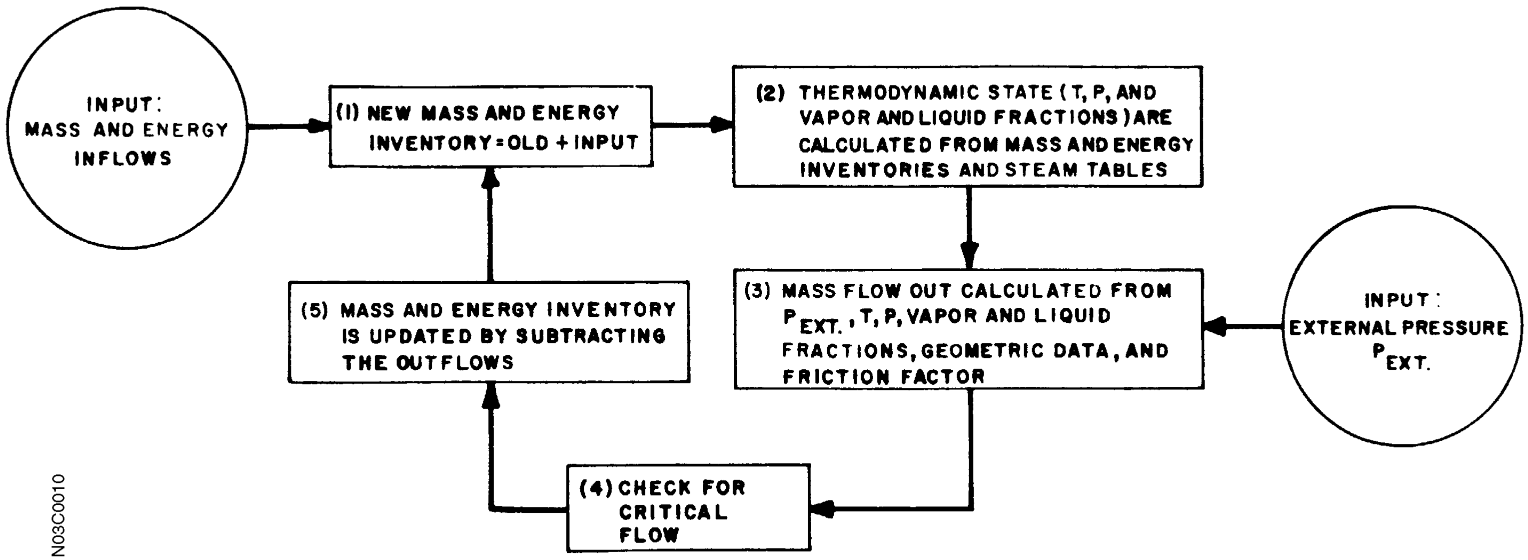


Figure 3C-10
CRACK AND FLAW GEOMETRIES

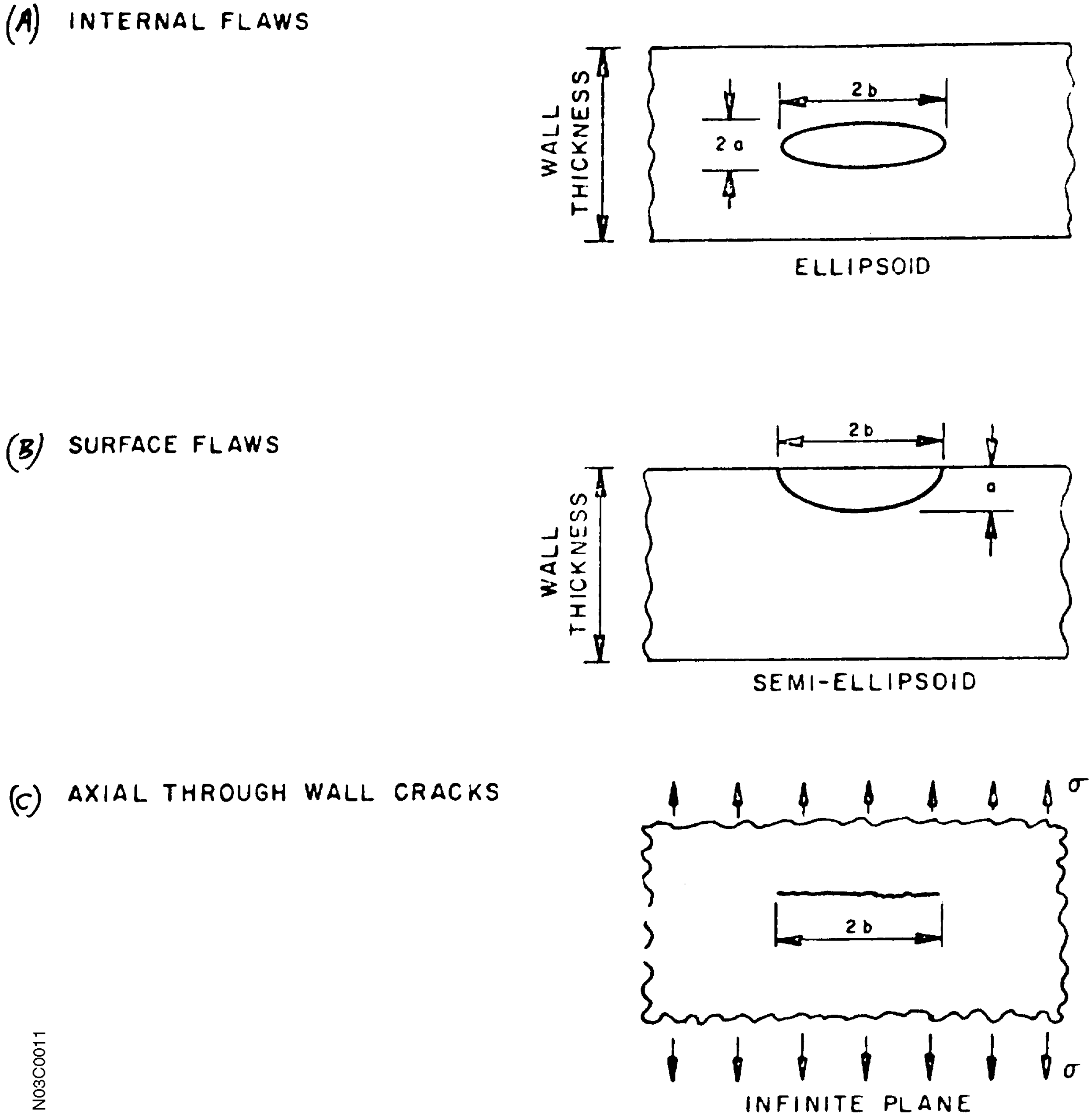


Figure 3C-11
MOISTURE DETECTION TAPE

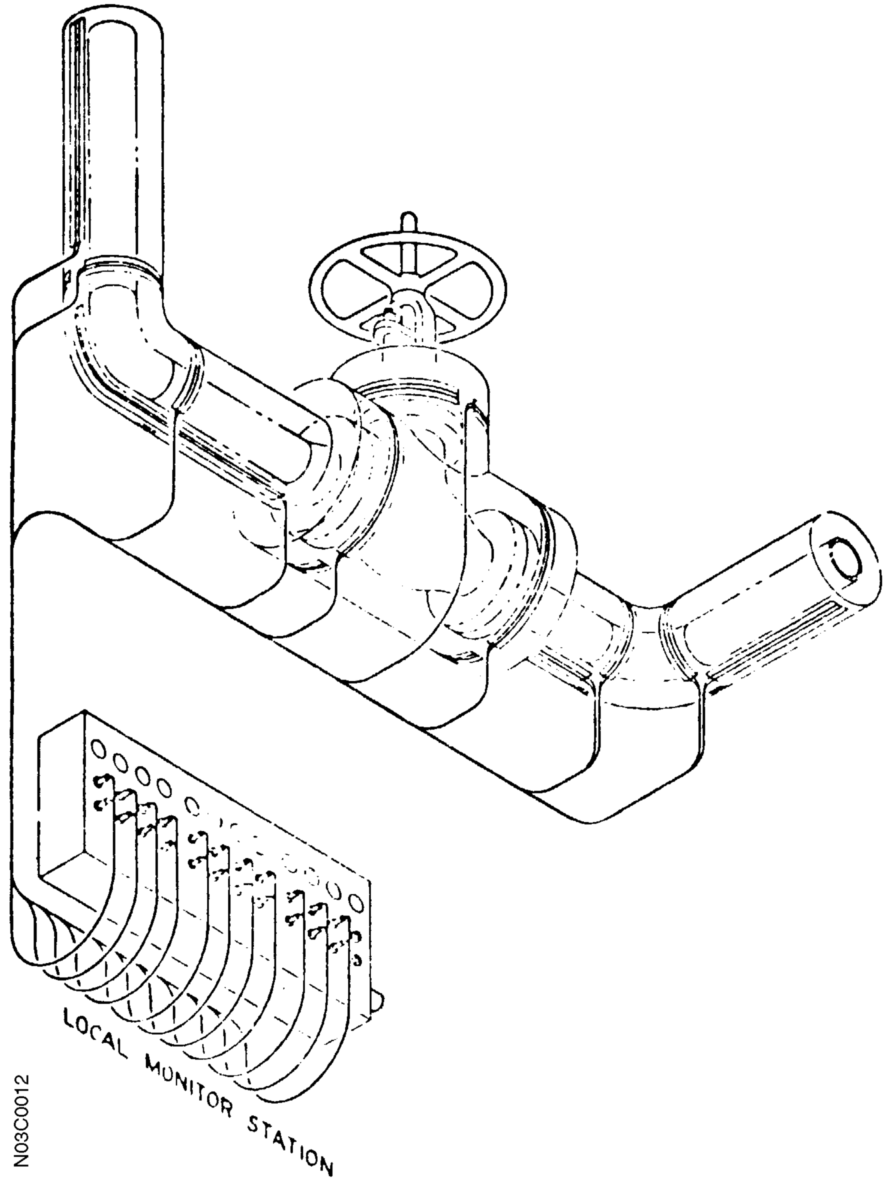


Figure 3C-12
RESTRAINT LOCATIONS MAIN STEAM VALVE HOUSING

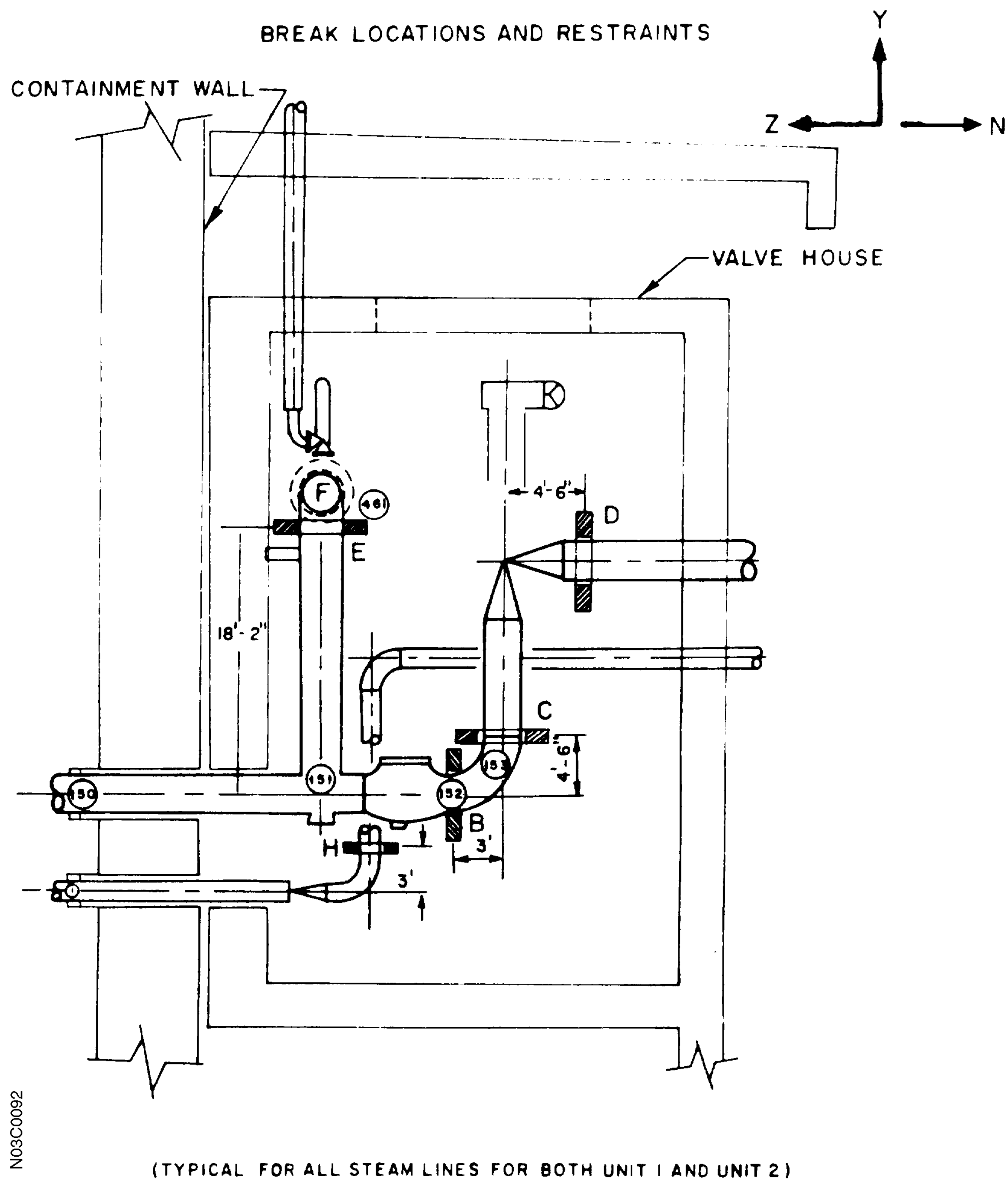
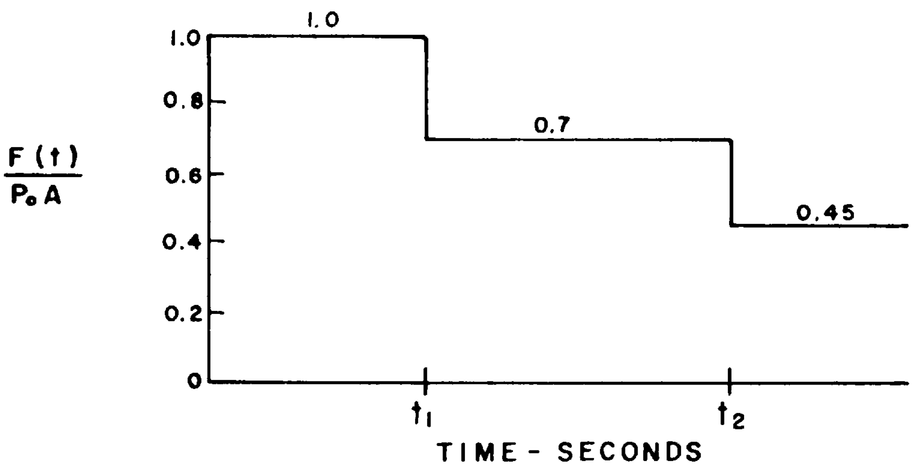


Figure 3C-13
TIME HISTORY OF JET FORCE F (1) MAIN STEAM LINE BREAKS
MAIN STEAM LINE VALVE HOUSE



BREAK LOCATION	UNIT 1 t1(SEC)	UNIT 1 t2(SEC)	UNIT 2 t1(SEC)	UNIT 2 t2(SEC)
150	.003	.092	.003	.102
61	.012	.124	.012	.134
152	.019	.108	.019	.119
153	.019	.108	019	.119

N03C0093

Figure 3C-14
MAIN STEAM IMPINGEMENT SHIELD

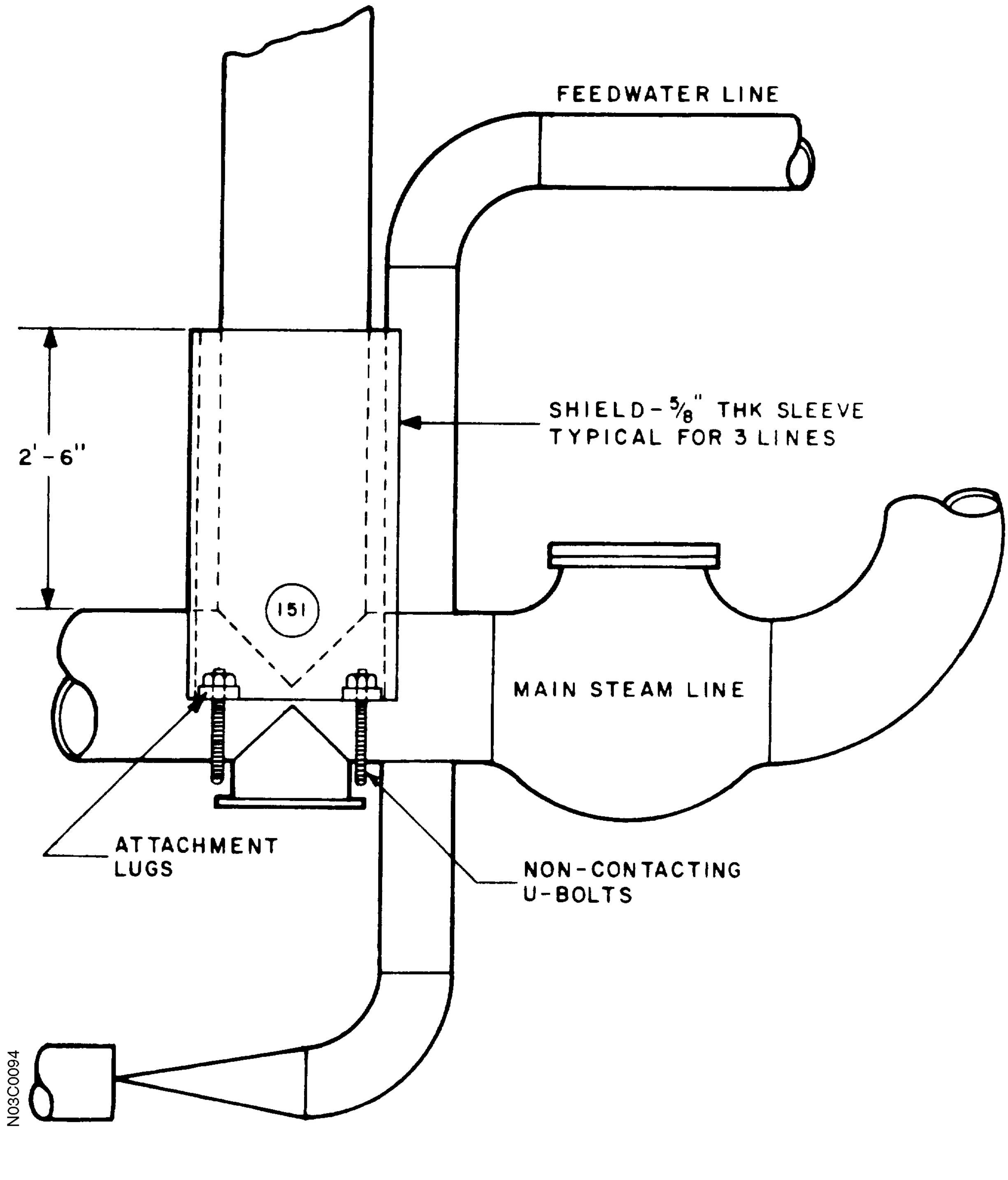


Figure 3C-15
PRESSURE DIFFERENCE ACROSS WALL OF MAIN STEAM VALVE HOUSE
DOUBLE ENDED RUPTURE FRICTIONLESS MOODY FLOW

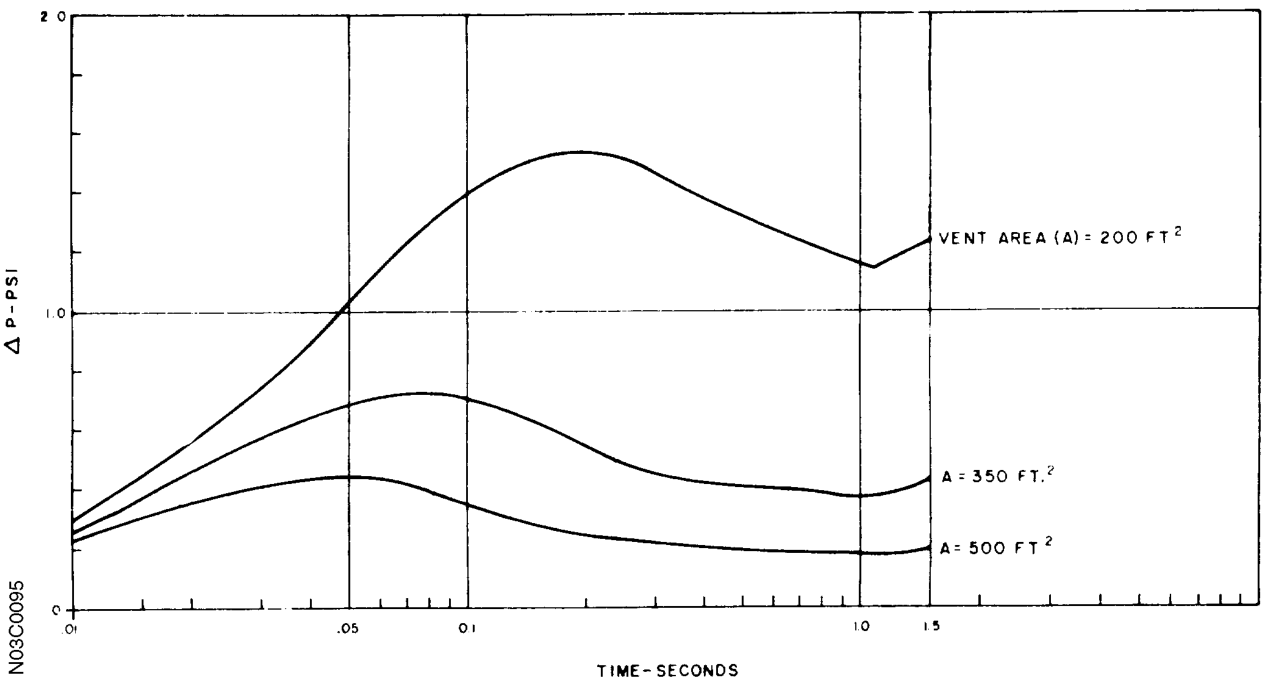


Figure 3C-16
PEAK PRESSURE DIFFERENCE ACROSS WALL OF MAIN STEAM VALVE HOUSE

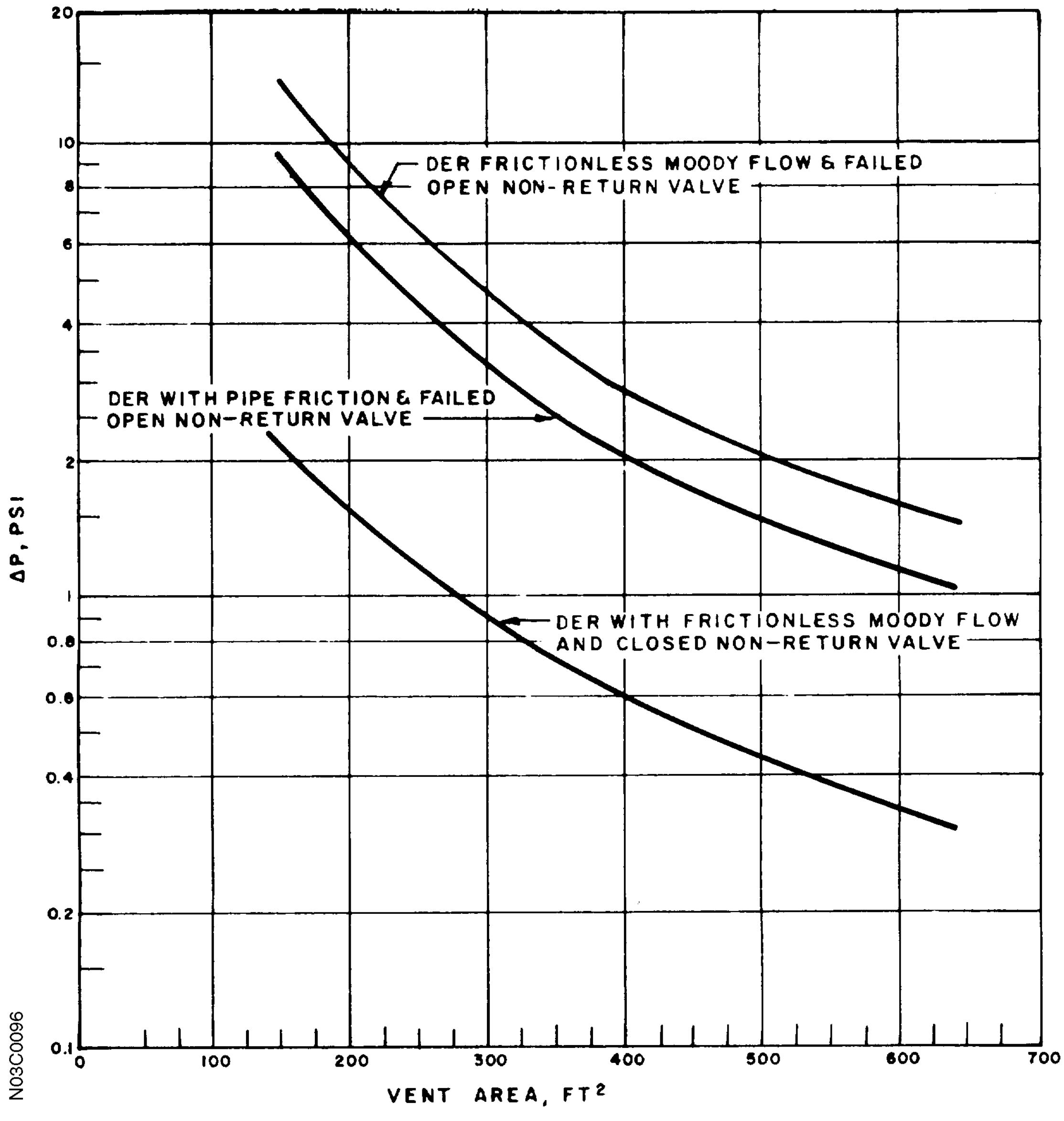


Figure 3C-17
PRESSURE DIFFERENCE ACROSS WALL OF MAIN STEAM VALVE HOUSE
DOUBLE ENDED RUPTURE - FLOW WITH PIPE FRICTION AND NON-RETURN
VALVE FAILED OPEN

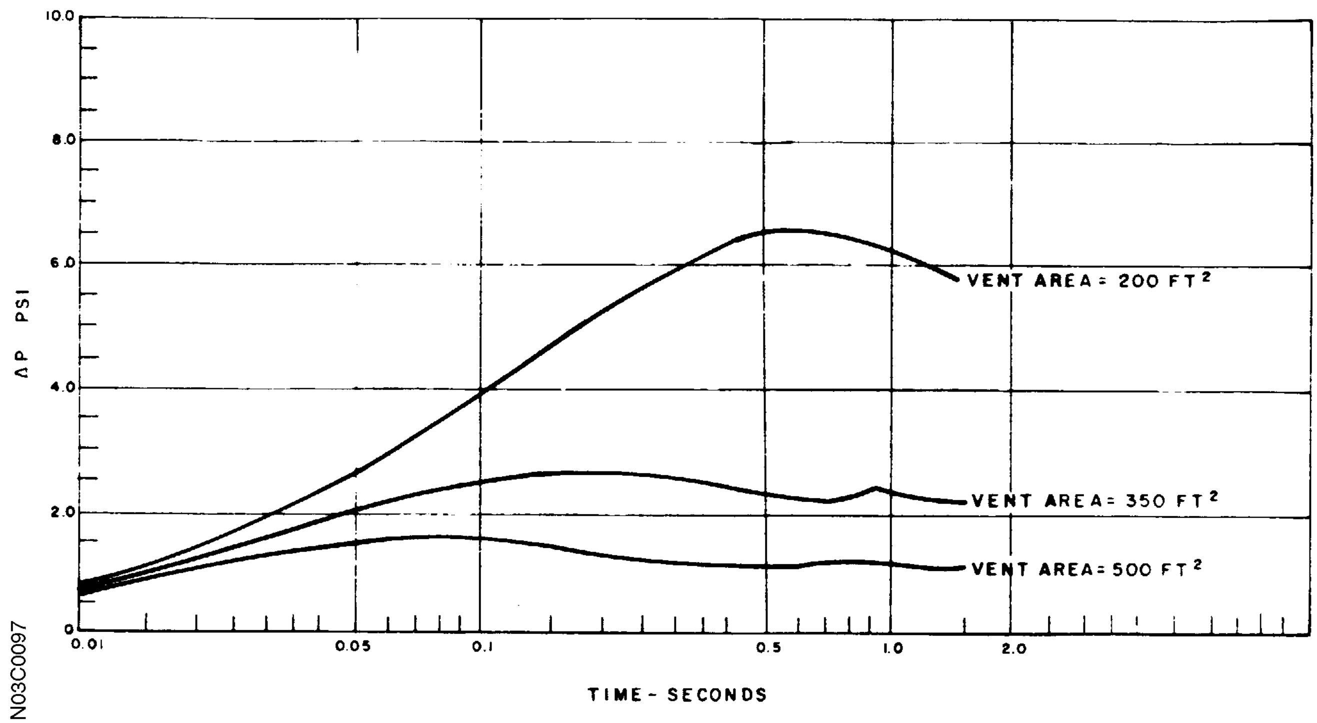


Figure 3C-18
PRESSURE DIFFERENCE ACROSS WALL OF MAIN STEAM VALVE HOUSE
DOUBLE ENDED RUPTURE - FRICTIONLESS MOODY FLOW AND NON-RETURN
VALVE FAILED OPEN

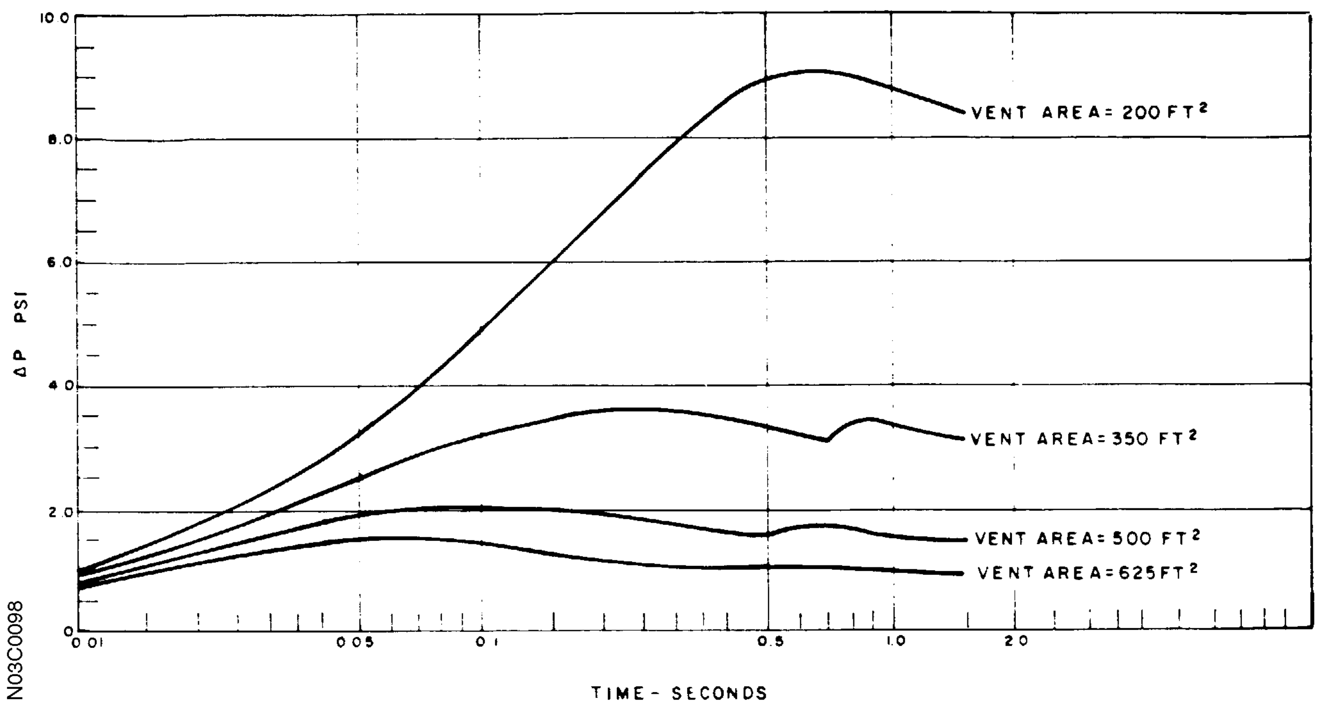


Figure 3C-19
TEMPERATURE TRANSIENT OF MAIN STEAM VALVE HOUSE ATMOSPHERE DOUBLE ENDED RUPTURE - FRICTIONLESS MOODY FLOW AND NON-RETURN VALVE FAILED OPEN

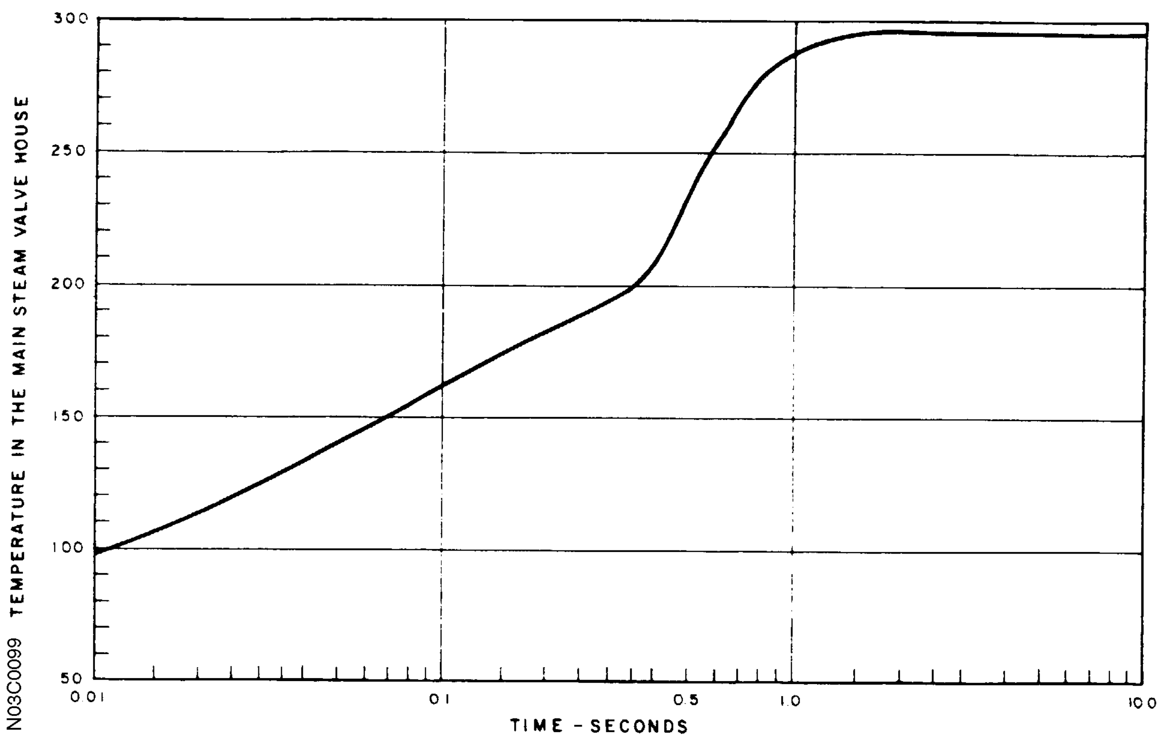
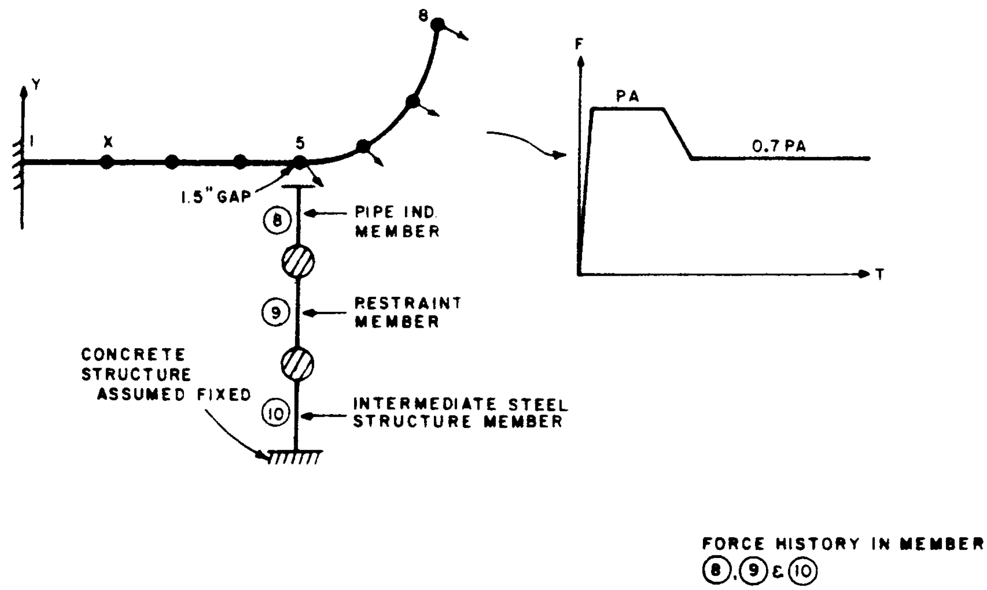


Figure 3C-20
TYPICAL DYNAMIC ANALYSIS OF MAIN STEAM PIPE WHIP RESISTANT SYSTEM



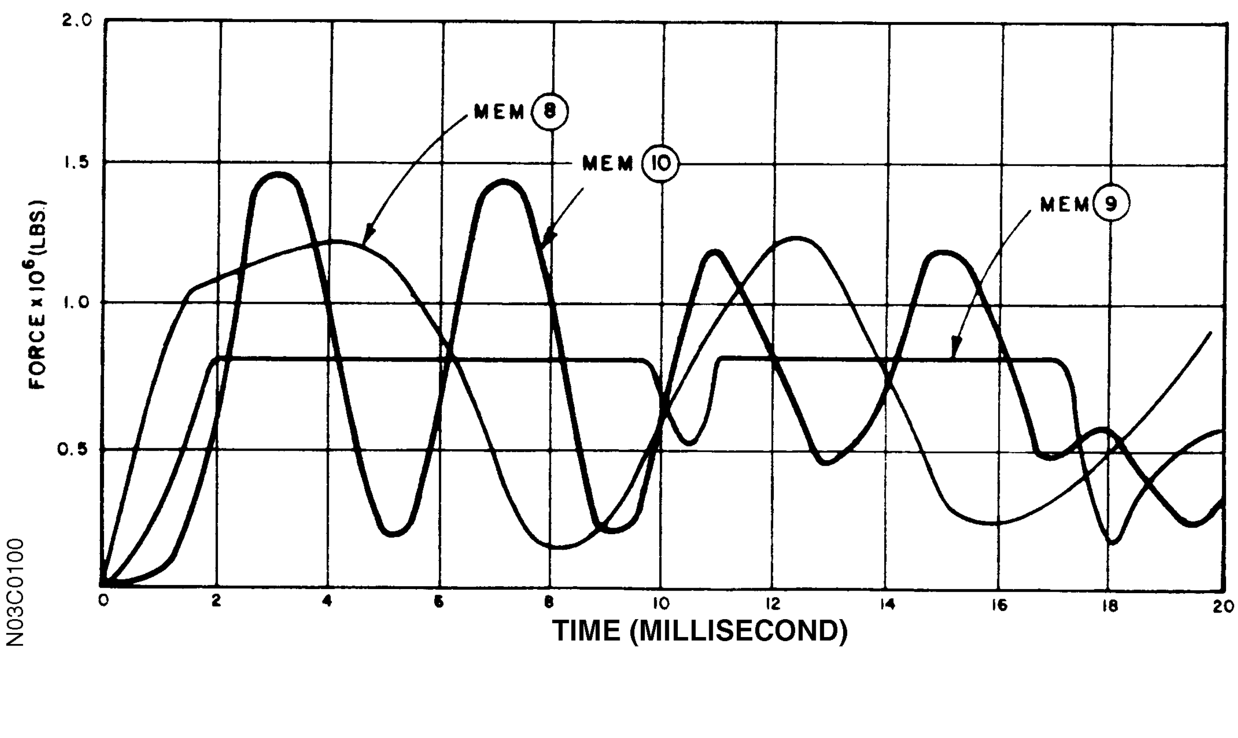
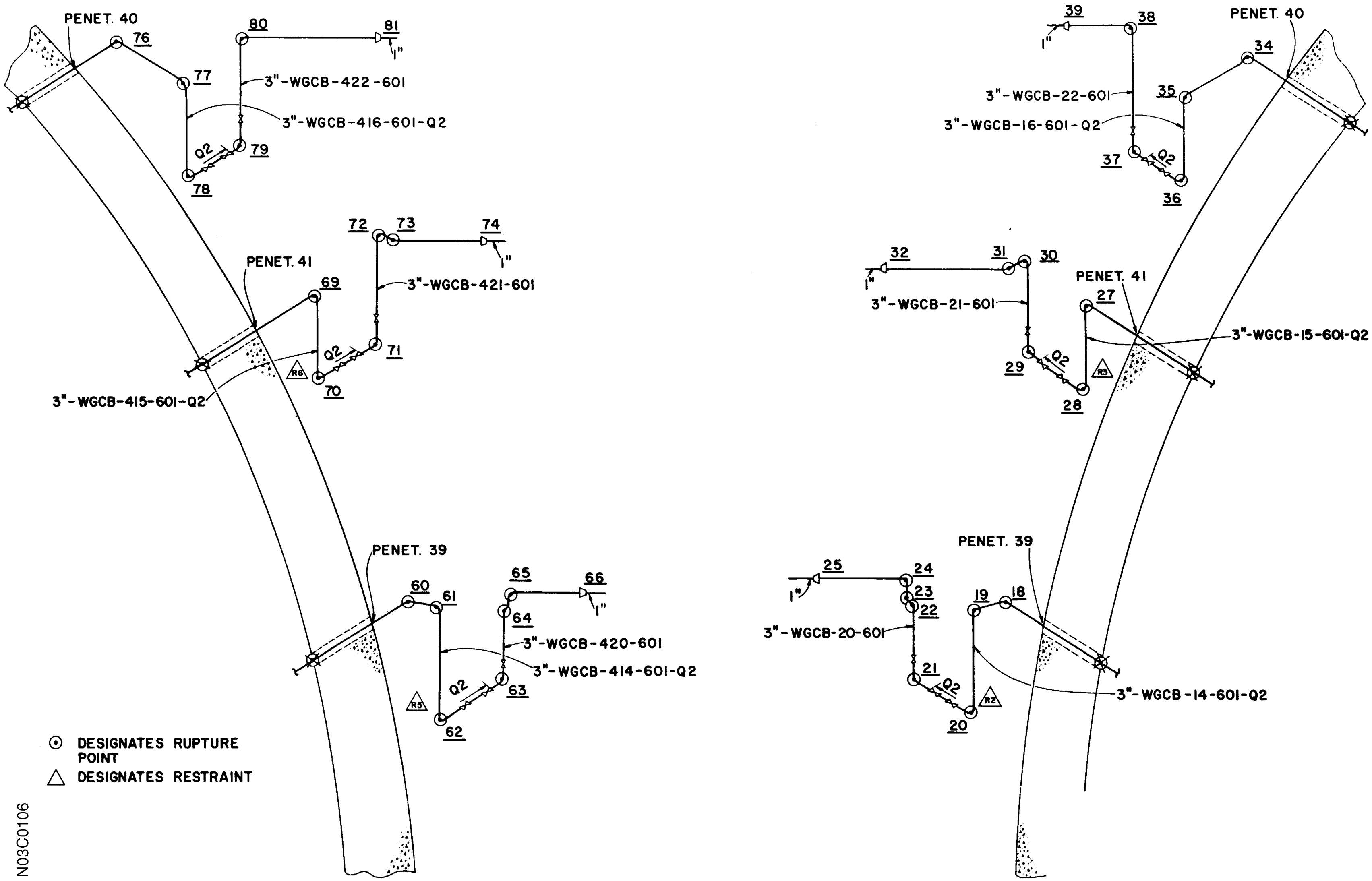
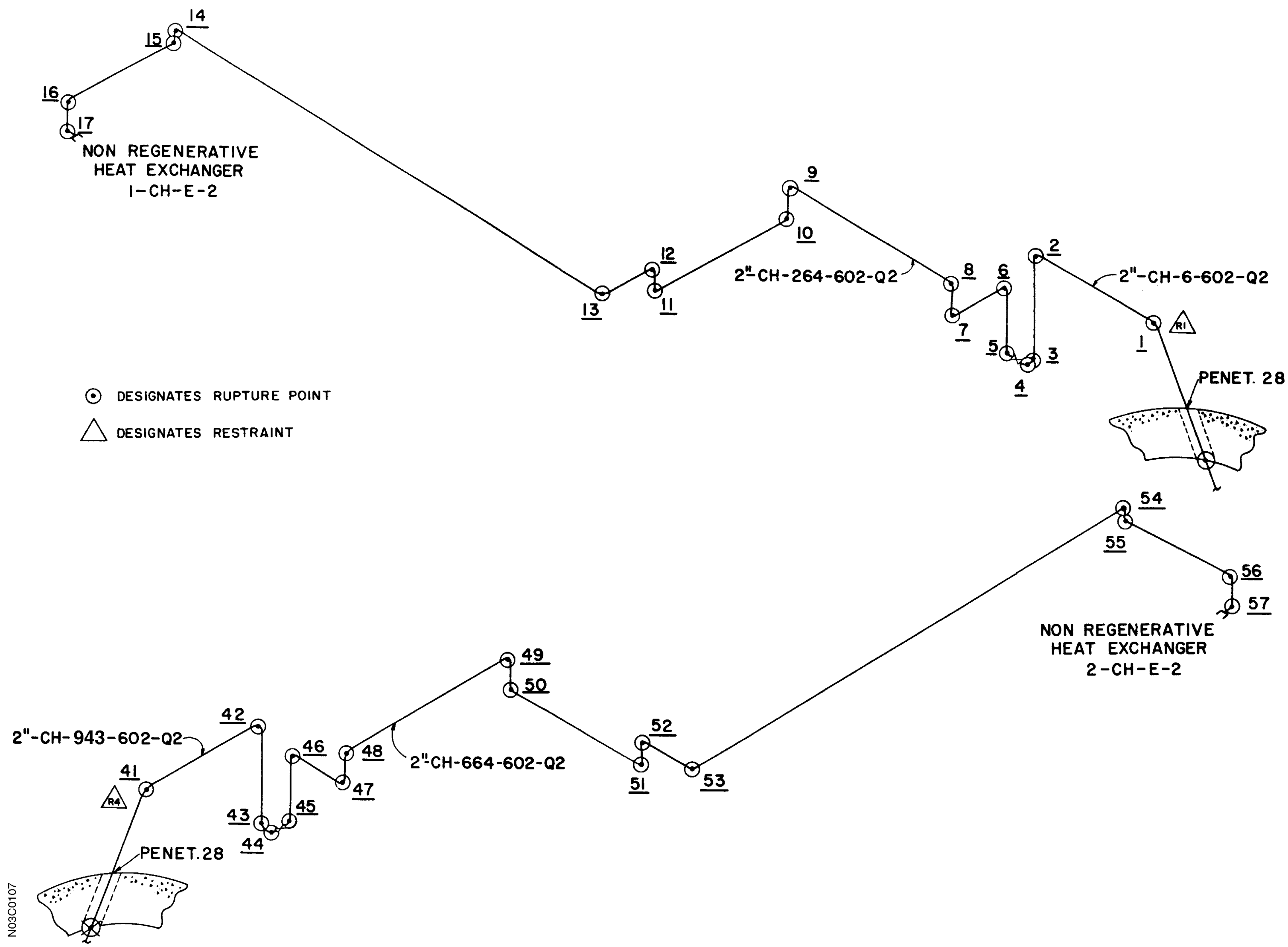


Figure 3C-21
STEAM GENERATOR BLOWDOWN BREAK LOCATIONS OUTSIDE CONTAINMENT



N03C0106

Figure 3C-22
LETDOWN LINE BREAK LOCATIONS OUTSIDE CONTAINMENT



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Technical

Final Report
F-C3486

Report

TESTING OF PROTECTIVE COATINGS
UNDER
DESIGN BASIS ACCIDENT ENVIRONMENT

Prepared for

Stone & Webster Engineering Corporation
Boston, Massachusetts

April 1973

THE FRANKLIN INSTITUTE RESEARCH LABORATORIES
THE BENJAMIN FRANKLIN PARKWAY · PHILADELPHIA PENNSYLVANIA 19103

INTEROFFICE MEMORANDUM
▲ 040.28

J.O. OR W.O. NO. 11715

SUBJECT TESTING OF PROTECTIVE COATINGS FOR DESIGN BASIS ACCIDENT ENVIRONMENT

DATE November 26, 1973

FROM GJBurroughs

TO Holders of Technical Report F-C3486, dated April 1973, subject as above, prepared by The Franklin Institute Research Laboratories (FIRL)

CC General Files
VEPCO (92 ea + encl)
GVSpires(1 ea + encl)
SHPopper (1 ea + encl)
RMBaumgarten(1 ea + encl)
JGDyckman(3 ea + encl):cc

ADDENDUM 1

The following documents are attached:

1. Laboratory Test Report dated October 2, 1973, from Carboline Research and Development Laboratory to G. V. Spires, Testing Project SR 36A.

2. Interoffice Memorandum dated October 10, 1973, from G. V. Spires to G. J. Burroughs, subject: Report On Basis for Resolution of N.A. 11715 N&D No. 1080. (Liner Primer Overthickness).

This memorandum and these documents constitute Addendum 1 to FIRL Technical Report F-C3486 and should be permanently attached on the inside of the cover.

On March 27, 1973, Nonconformity and Disposition Report 11715.00, No. 1080, was issued to document containment liner primer thickness in excess of the 2.0 to 5.0 mil range permitted by the Specification for Shop Fabrication and Field Erection of Reactor Containment Steel Plate Liner, NAS-41, revised June 8, 1970. Since the test program, conducted by FIRL to qualify the containment coating systems, had not included panels to determine the effect of liner primer overthickness, additional testing was performed. The results of these tests are included as Attachment 1. An evaluation of the various technical aspects of the overthickness problem, and the results of the additional testing, is included as Attachment 2. This evaluation provided the basis for the "accept as is" disposition which was assigned to N&D 11715.00, No. 1080, on November 26, 1973.

G J Burroughs

G. J. Burroughs
Project Engineer

Enclosures

ATTACHMENT 1

LABORATORY TEST REPORT

October 2, 1973

Testing Project: SR36A

Subject: Evaluation of performance of test coupons for Ston & Webster Engineering Corporation consisting of Carbo Zinc 11 at various dry film thicknesses, with and without 2 coats and 3 coats of DuPont Corlar Epoxy, after exposure to a specified time-temperature curve.

Reference: Testing Project: 01224; Mr. George V. Spires, Stone & Webster; Mr. James R. Lopata.

Purpose: To observe and record those surface defects and indications of loss of film integrity identified in the referenced failure modes upon exposing the test panels to the time-temperature curve specified in the referenced test exposure.

Conclusions: Please refer to Report #01224, and Report #SR36.

Procedure:

1) Test Coupon
2" x 4" x 3/8" steel panels cut from the liner plate.
SSPC-SP6-63 + modification sandblast profile.

2) Systems Tested

*Dry Film Thickness (DFT)
Please refer to "Results" for measurements of the film thickness

1) 1c Carbo Zinc 11, 5 mils
2) 1c Carbo Zinc 11, 7 mils
3) 1c Carbo Zinc 11, 9 mils
4) 1c Carbo Zinc 11, 11 mils
5) 1c Carbo Zinc 11, 5 mils
   2c Corlar Epoxy, 4 mils
6) 1c Carbo Zinc 11, 7 mils
   2c Corlar Epoxy, 4 mils
7) 1c Carbo Zinc 11, 9 mils
   2c Corlar Epoxy, 4 mils
8) 1c Carbo Zinc 11, 11 mils
   2c Corlar Epoxy, 4 mils
9) 1c Carbo Zinc 11, 5 mils
   3c Corlar Epoxy, 6 mils
10) 1c Carbo Zinc 11, 7 mils
   3c Corlar Epoxy, 6 mils

ATTACHMENT 1

LABORATORY TEST REPORT

October 2, 1973

2) Systems Tested (cont'd.)
   11) 1c Carbo Zinc 11, 9 mils
       3c Corlar Epoxy, 6 mils
   12) 1c Carbo Zinc 11, 11 mils
       3c Corlar Epoxy, 6 mils

*The source of these dry film thickness values was the detailed paper work provided with the project request.

3) Cure Schedule
All test coupons had the coatings applied and completely cured when received from Stone & Webster. Application was made in the field (jobsite) by Stone & Webster personnel.

4) Exposure

Test Solution: Demineralized water with 0.22 Molar Boric Acid and 0.037 Molar Sodium Hydroxide--adjusted to PH 8.0 $\pm$.

The test coupons were subjected to the following time-temperature profile:

Total Time Lapse	Temperature °F
Initial	105°F
10 seconds	280°F
2400 seconds (40 minutes)	280°F
3600 seconds (1 hour)	140°F
168 hours	140°F

All test coupons were partially immersed into the solution inside the test chamber and scribed down to the steel substrate before being exposed to the test criteria.

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Coating System	Reported (1) Dry Film Thickness Mils	Measured Dry Film Thickness Range Mils	Flaking	Delamination or Peeling	Blistering	Chalking
1) 1c Carbo Zinc 11	5	3-6	10	None	10	10
2) 1c Carbo Zinc 11	7	6-7	10	None	10	10
3) 1c Carbo Zinc 11	9	9-10	10	None	10	10
4) 1c Carbo Zinc 11	10+	10	10	None	10	10
5) 1c Carbo Zinc 11, 5 mils 2c DuPont Corlar	9	9	10	None	#8M over 25% of surface area, by scribe	10
6) 1c Carbo Zinc 11, 7 mils 2c DuPont Corlar	11	10	10	None	#4M over 20% of surface area, by scribe	10
7) 1c Carbo Zinc 11, 9 mils 2c DuPont Corlar	13	12	10	None	#6MD over 20% of surface area, by scribe; #8F on edge	10
8) 1c Carbo Zinc 11, 10 mils 2c DuPont Corlar	14	13-14	10	None	#6M over 10% of surface area, by scribe	10
9) 1c Carbo Zinc 11, 5 mils 3c DuPont Corlar	11	10-11	10	None	#2F over 15% of surface area, & #8M over 6% of surface area, by scribe	10
10) 1c Carbo Zinc 11, 7 mils 3c DuPont Corlar	13	10-12	10	None	#8M over 10% of surface area & 2F over 30% of surface area	10
11) 1c Carbo Zinc 11, 9 mils 3c DuPont Corlar	15	14-15	10	None	#4M over 50% of surface area	10
12) 1c Carbo Zinc 11, 11 mils 3c DuPont Corlar	17	15-16	10	None	#6M over 20% of surface area	10
Acceptable Performance N101.2-1972			10	None	4F	6

(1) These values for dry film thickness were obtained from the identification tags which were attached to each test coupon as received.

ATTACHMENT 1

ATTACHMENT 1

LABORATORY TEST REPORT

October 2, 1973

Discussion of Results:

An appropriate acceptance criteria with regard to blistering is established under ANSI N101.2-1972, Section 4.5 as "Size No. 4" with a concentration classification as "Few" as described under ASTM D714. Though certain of the topcoated panels did evidence intact blisters of size No. 4 or larger at a frequency greater than "few", the coating systems ability to remain intact under simulated DBA temperature and spray conditions were demonstrated. The area effected is identified by a percent value under the "Blistering" classification of the Results Table.

Blistering of a portion of a test coupon must be evaluated with regard to blister density for the affected area. Invalid results would be obtained if the density was reduced to take in the entire area of the sample coupon which is being evaluated.

Please refer to attached photographs of the test coupons after they were exposed to the test criteria.

Daniel R. Leritz
Testing Department

DRL/rg
485/124/044/054
OR: Testing Department
cc: G. Spires
Stone & Webster
xc: SLL/RRR/HDT/JFM/EWS/JDB/GHD/SLS/JRL/Lab Group Leaders/File

From the Carboline Research & Development Laboratory

ATTACHMENT 2

INTEROFFICE MEMORANDUM
▲ 040.20

SUBJECT	Report On Basis For Resolution of N.A. 11715 N&D NO. 1080 (Liner Primer Over Thickness)	J.O. OR W.O. NO.	11715
		DATE	October 10, 1973
		FROM	GVSpires:cmd
TO	G. J. Burroughs	CC	General Files DEEllis MPBerardi PJGill DAPiccione JGDyckmen WJLKennedy M.E.File (enc.)

In accordance with request of your IOM dated 8/23/73, the following information is submitted.

Some 250 dry film thickness (DFT) readings were taken on the zinc primer which had been shop applied to the inside surface of the Unit No. 1 containment subsequent to its erection. This was done in order to determine if or to what extent the maximum specified DFT of 5.0 had been exceeded. The average of the recorded readings was 4.7 mils and it was determined with a 99.9% confidence level, that the average primer thickness over the entire liner would lie between 4.4 and 5.0 mils. However, some 75 readings (30% of the total) were found to exceed the 5.0 mil maximum and 12 readings (5%) exceeded 7.0 mils.

It was apparent that the DFT of the liner primer had, to a significant extent, exceeded the maximum allowable and, accordingly, an N&D (No. 1080) was issued. Consequently, it was determined that a test simulating the steam/temperature/spray occurring in a LOCA should be run so that the affect of primer overthickness on the integrity of the specified primer/topcoat system might be evaluated. Such a test was conducted at the laboratories of the Carboline Company and their test report is attached. The specimens provided were cut from scrap pieces of the N.A. containment No. 1 liner plate itself and reflected various DFT's of from 5 to 11 mils. Topcoating was performed by field personnel at the site. Results of a previous sequential (not simultaneous) autoclave/wet irradiation test program performed by Franklin Institute (FIRL) for screening coating system for use at Surry No. 1 & 2 indicated that post-irradiation of the same coating system, i.e., Dupont Corlar on Carbo Zinc 11, had no effect other than discoloration. This observation was verified in another FIRL test when a pure epoxy coating system was tested for S&W. Based on these referenced demonstrations that post-irradiation will not significantly alter a coating system's performance, it was decided that the North Anna liner plate specimens would not be irradiated.

As indicated in the "Results" table of the Carboline Test Report, three of the coupons tested (No's. 6, 9, and 11) sustained intact blisters having a blister size or frequency greater than the "... few intact blisters, size No. 4..." acceptance criteria established under ANSI N101.2. However, this blister size and frequency was comparable to that observed for the coupon representing the liner plate which was tested as a part of the general test program conducted earlier this year by FIRL for North Anna (refer NAS-5275, dated 3/13/73). The results from this latter test were acceptable.

ATTACHMENT 2

As was noted on page 2 of the reference letter, in discussing the results of those tests and as is again applicable in the instance of the testing done by Carboline, while the ANSI blistering criteria was exceeded, there was no evidence of flaking, delamination or peeling. The Carbo Zinc 11/Corlar coating system's ability to remain intact under a simulated LOCA has been substantiated.

The foregoing summarizes the basis for the course of action we have indicated for resolving N&D 1080, as reflected in the disposition instruction statement: "Corrective action not required, accept as is". The N & D form with this disposition indicated, was previously returned to the project under an IOC dated 9/7/73.

G. V. Spires

G. V. Spires

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I. INTRODUCTION

Performance qualification tests were conducted to determine the integrity of protective coating systems subjected to a Design Basis Accident (DBA) environment specified by the Stone and Webster Engineering Corporation (SWEC). This included simultaneous exposure for seven days to gamma radiation, steam, and chemical spray in accordance with SWEC specification NAS 361, included here as Appendix A.1.

Fifty four samples, consisting of 16 concrete blocks, 37 steel panels, and 1 transite panel, were tested. The samples furnished were prepared by others in accordance with SWEC specification NAS 364, given here as Appendix A.2. The samples were evaluated for coating system performance in accordance with ASTM standards for evaluating exterior paints.

The test program was conducted by the Franklin Institute Research Laboratories (FIRL) in two runs commencing on November 13, 1972, and January 20, 1973, using the radiation facilities of a subcontractor.

II. SAMPLE DESCRIPTION

The samples were grouped into eight systems, each unique with respect to the surface coating. Appendixes A.2 and 3 describe the SWEC identification of samples, the coatings used, and the method of application.

The systems were designated as A, B, C, D, E, F, G and T, and are described below. Figures 1a through 1e are photographs of the test samples showing the front face of each and both faces of samples C1 to C8.

All samples were numbered and tagged by SWEC with 1-1/4-inch-diameter tags attached by 1/16-inch-diameter wire placed through holes in each piece. The wire was subsequently replaced with a threaded rod to facilitate mounting of the samples within the test chamber. Except for sample G9, one side of each metal panel was scribed by SWEC with a line that penetrated to the substrate. Samples C1 to C8 had an extra hole in the bottom of each sample.

It was noted that the concrete blocks of samples A1 to A8 and B1 to B8 had scratch marks on one end. Also, one face of each sample had a rougher texture than the other faces. Appendix B contains the visual inspection report of the samples.

The following is a brief description of the samples:

System A - Samples A1 to A8: Concrete blocks measuring 2 in. x 2 in. x 4 in. Side with tag arbitrarily chosen as side 1. Top selected as end closest to tag. Sides 2, 3 and 4 were numbered clockwise from side 1 when the block was viewed from the top.

System B - Samples B1 to B8: Same size and identification as samples A1 to A8.

System C - Samples Cl to C8: Steel panels measuring 4 in. x 4 in. x 3/8 in. with weld seam running horizontally through the center. Side 1 selected as that side which had a scribed line and white top coat. Side 2 was grey-coated.

System D - Samples Dl to D8: Steel panels measuring 2 in. x 4 in. x 3/8 in. Side 1 had a scribed line.

System E - Samples El to E4: Steel panels measuring 2 in. x 4 in. x 3/8 in. Side 1 had a scribed line and side 2 was uncoated.

System F - Samples Fl to F8: Steel panels measuring 2 in. x 4 in. x 3/8 in. Side 1 had a scribed line.

System G - Samples Gl to G8: Steel panels measuring 2 in. x 4 in. x 20 gage. Side 1 had a scribed line.

Sample G9: Galvanized steel panel measuring 2 in. x 4 in. x 20 gage with no other coating and no scribed line. Side 1 chosen as that side with the writing on the tag facing out when the tag is against the panel.

System T - Sample Tl: Transite panel measuring 2 in. x 4 in. x 3/8 in. and not coated or scribed. Side 1 chosen in same manner as G9.

Side 1 of the concrete blocks is also referred to as the front and side 3 as the back. Side 1 of all panels is referred to as the front and side 2 as the back.

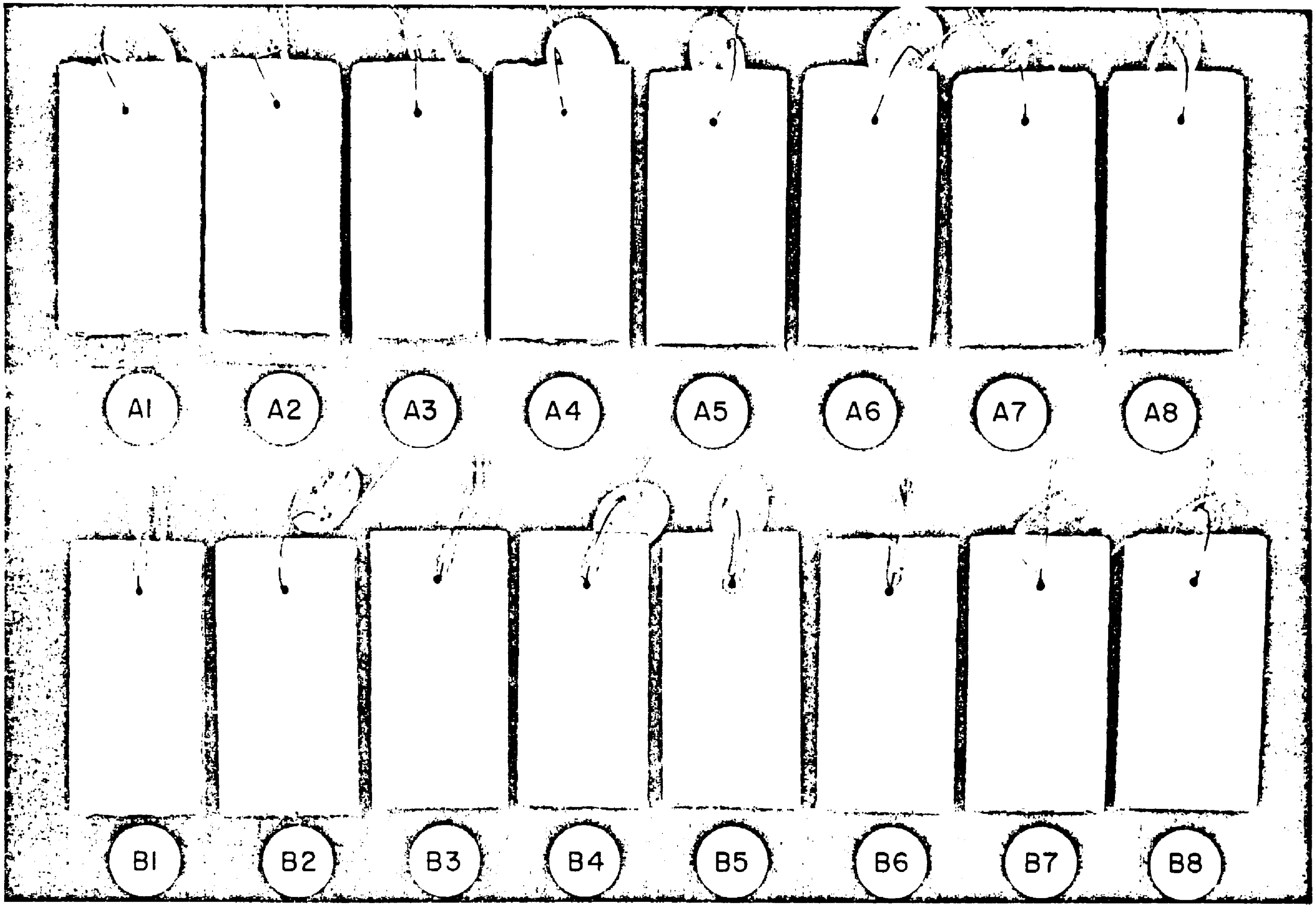

Figure 1a. Half-Size Photograph of Side 1 of Systems A and B Prior to Testing

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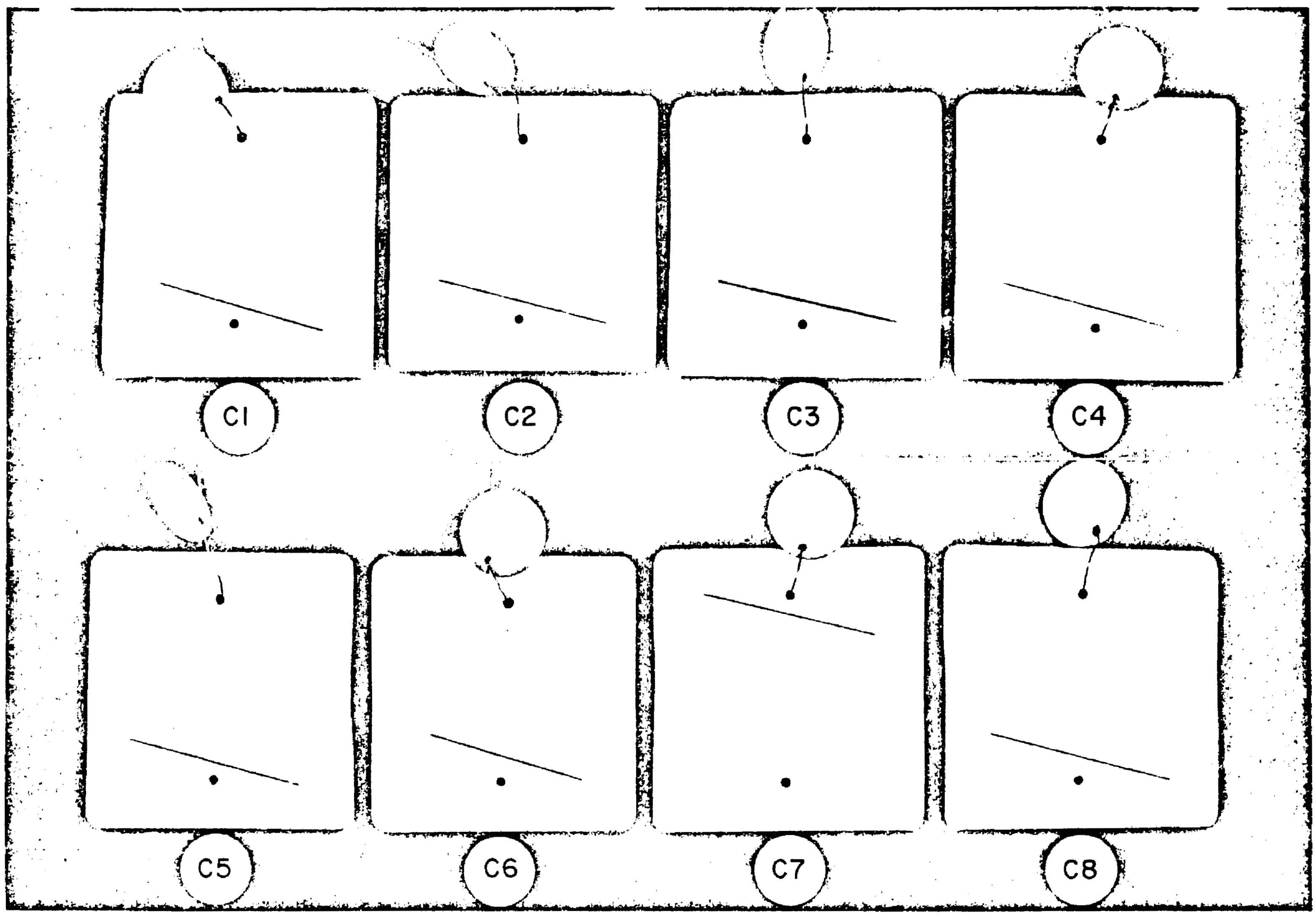

Figure 1b. Half-Size Photograph of Side 1 of System C Prior to Testing

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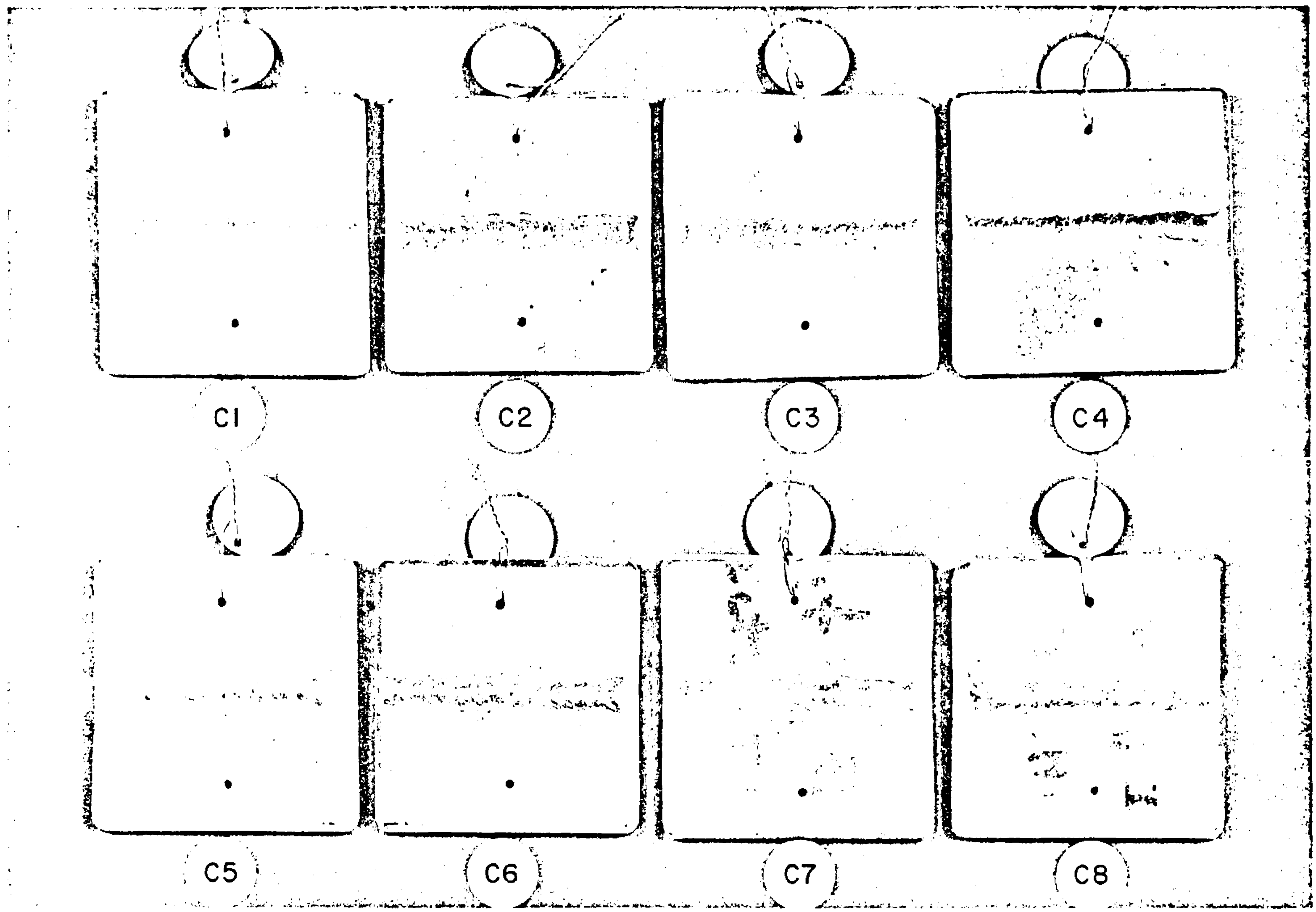

Figure 1c. Half-Size Photograph of Side 2 of System C Prior to Testing

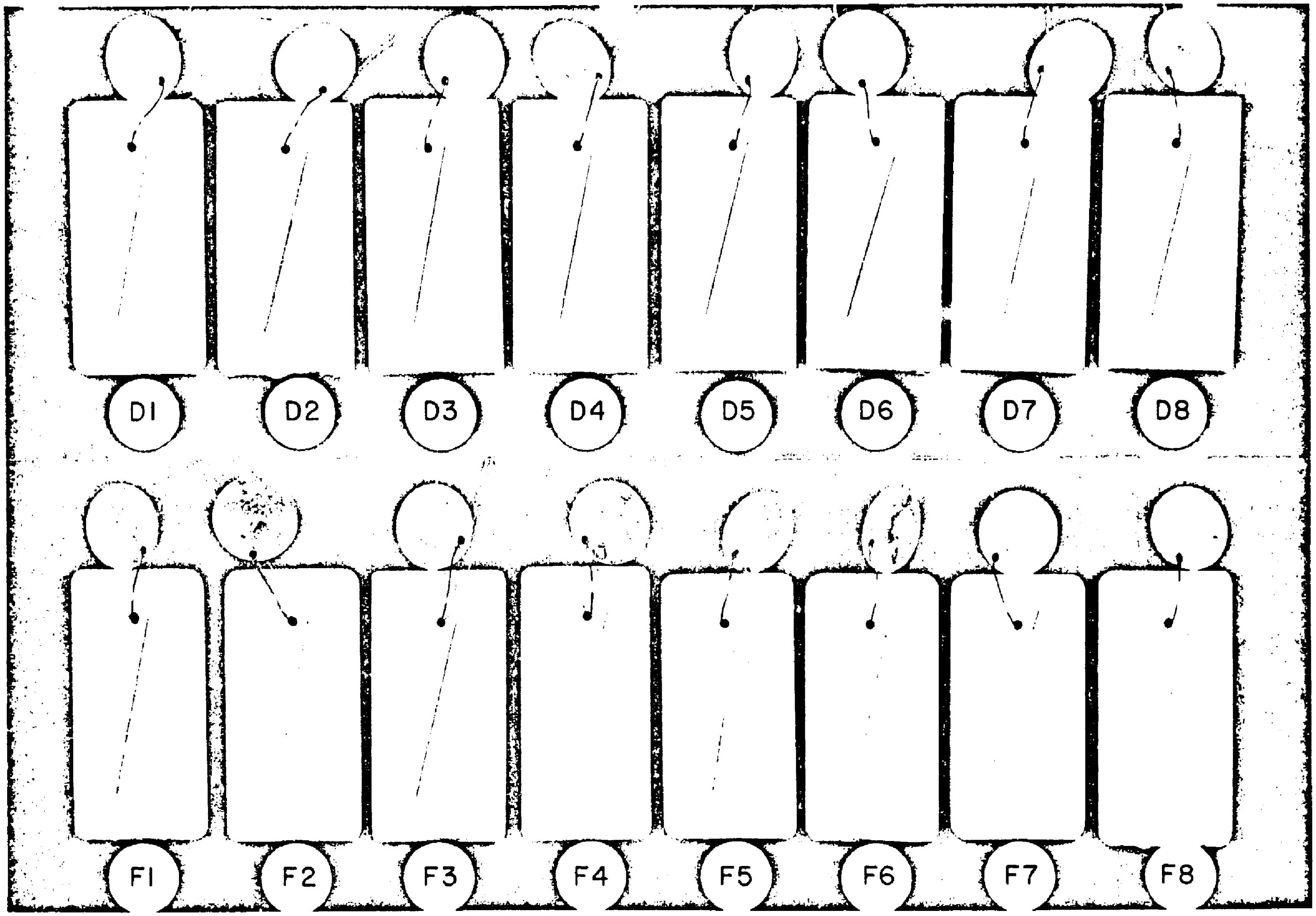

Figure 1d. Half-Size Photograph of Side 1 of Systems D and F Prior to Testing

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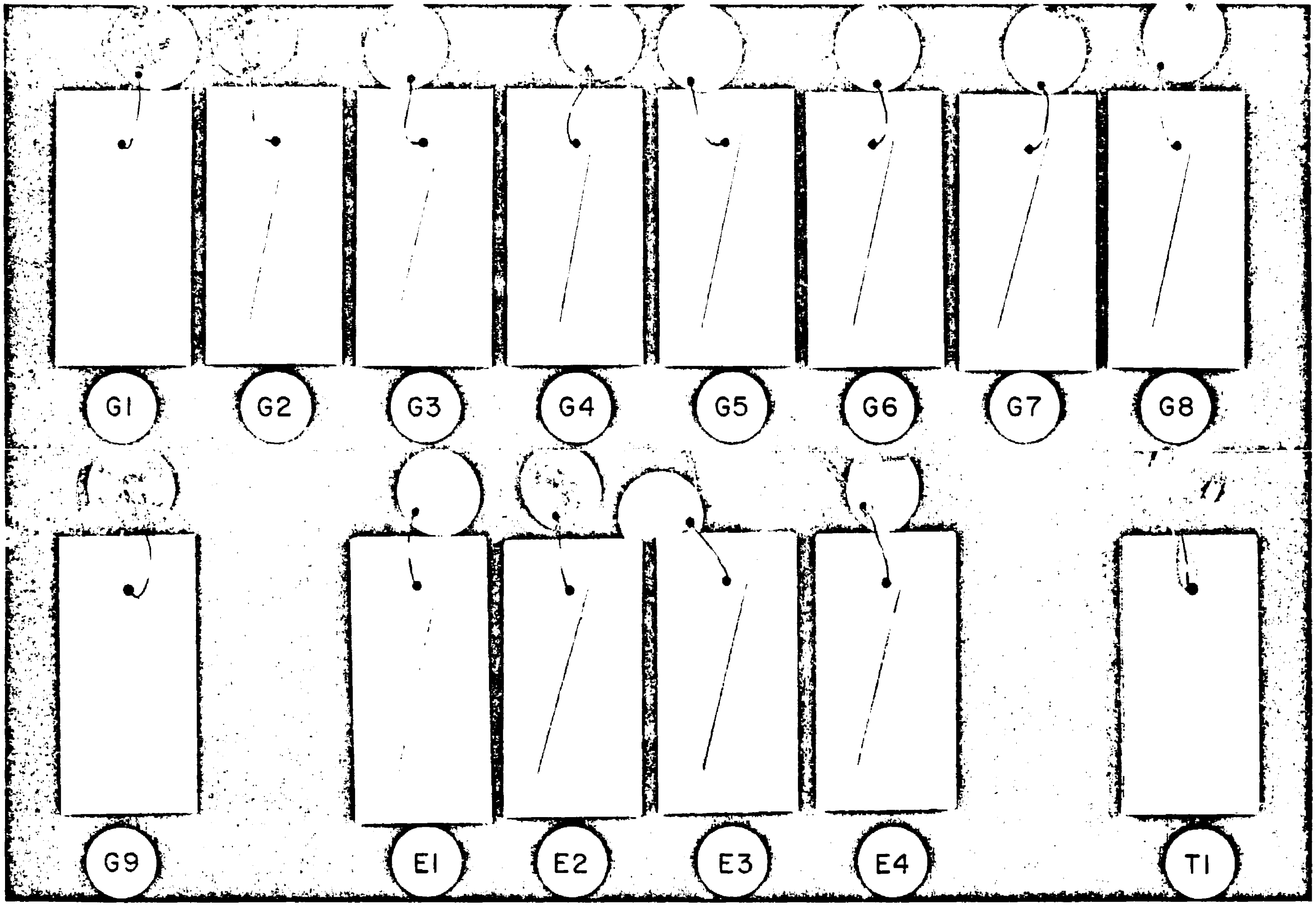

Figure 1e. Half-Size Photograph of Side 1 of Systems E, G and T Prior to Testing

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III. TEST SPECIFICATION

The DBA environment test consisted of simultaneous exposure to gamma radiation, steam, and chemical spray in accordance with the profile shown in Figure 2.

Specifications required that steam be admitted rapidly, raising the temperature from 105° to 280°F and the pressure from atmospheric to 45 psig within 10 seconds; these conditions (280°F/45 psig) were to be maintained for 40 minutes. The temperature and pressure were to be reduced over the next 20 minutes to 140°F and -1 psig and maintained for the balance of one week. The specification was subsequently altered to allow the minimum pressure to be between 0 and 5 psig instead of -1 psig after the first hour because an overpressure inside the test chamber was required to pump steam condensate and spray solution from the bottom of the radiation pool, where the test chamber was located, to the top of the pool, where the pump was located.

The chemical spray was to be turned on at the start of the test and remain on throughout the seven-day exposure period. Three different solutions were specified for use at different times during the exposure period to simulate actual changes in the spray chemistry expected to occur during an accident.

The solutions were composed of boric acid. Two were buffered with different amounts of sodium hydroxide to alter the alkalinity content. The first solution was acidic, having a pH of 4.9; the second and third solutions were alkaline, having a pH of 11.0 and 8.05, respectively.

The concurrent radiation exposure was to consist of 100 megarads total accumulated dose administered at the rate of 1.1 megarads during the first hour and 98.9 megarads over the next 167 hours.

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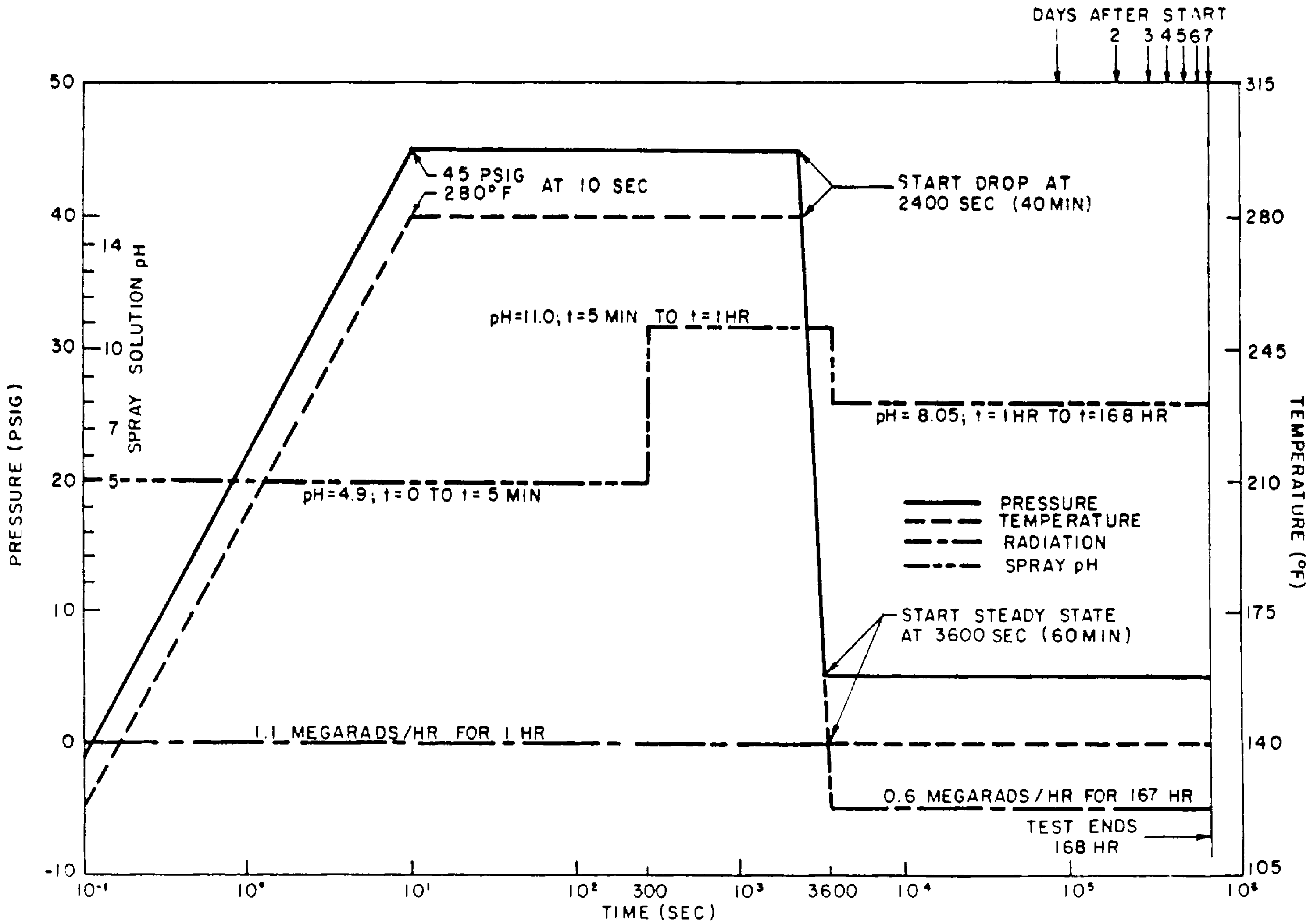

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Figure 2. Specified Test Profile

IV. TEST APPARATUS AND PROCEDURES

A. Apparatus

1. Test Vessel

The tests were conducted in a double-walled vessel immersed in a pool of water that shielded the operators from the Co-60 sources of gamma radiation. The inner chamber of the vessel (8 in. ID x 3 ft. long) contained the apparatus for holding the samples and provided the steam/chemical-spray environment. The outer chamber (12 in. ID x 4 ft long) was used to insulate the inner chamber and was connected to a pipe (6 in. OD x 20 ft long) through which all external connections were brought out of the pool. Figure 3 shows the sample tray, inner chamber (foreground), outer chamber, and extension pipe.

2. Sample Support System

The sample holding device, shown in Figure 4, consisted of four trays mounted on side rails with a flat ring above each tray to hold the samples. The samples were positioned so that side 1 faced the Co-60 source

The panels were held with the 4-inch dimension in the vertical direction and with the lower third of each panel immersed in the spray solution tray. This portion of each sample was referred to as the *liquid phase*; that area not immersed in spray solution was referred to as the *vapor phase*. Samples were arranged for each run as shown in Figure 5.

As shown in Figure 4, a threaded rod connected the samples to the horizontal flat ring above each pan. Since the wire supplied with the panels occupied most of the hole space and prevented the rod from passing through the panels, it was replaced by 1/32-inch-diameter stainless-steel wire. The rod was passed through the concrete blocks, a nut placed on each end of the rod and the thread upset to prevent removal. The remaining portion of the threaded rod was fastened to the flat ring. To avoid mixing the tags, one sample was changed at a time.

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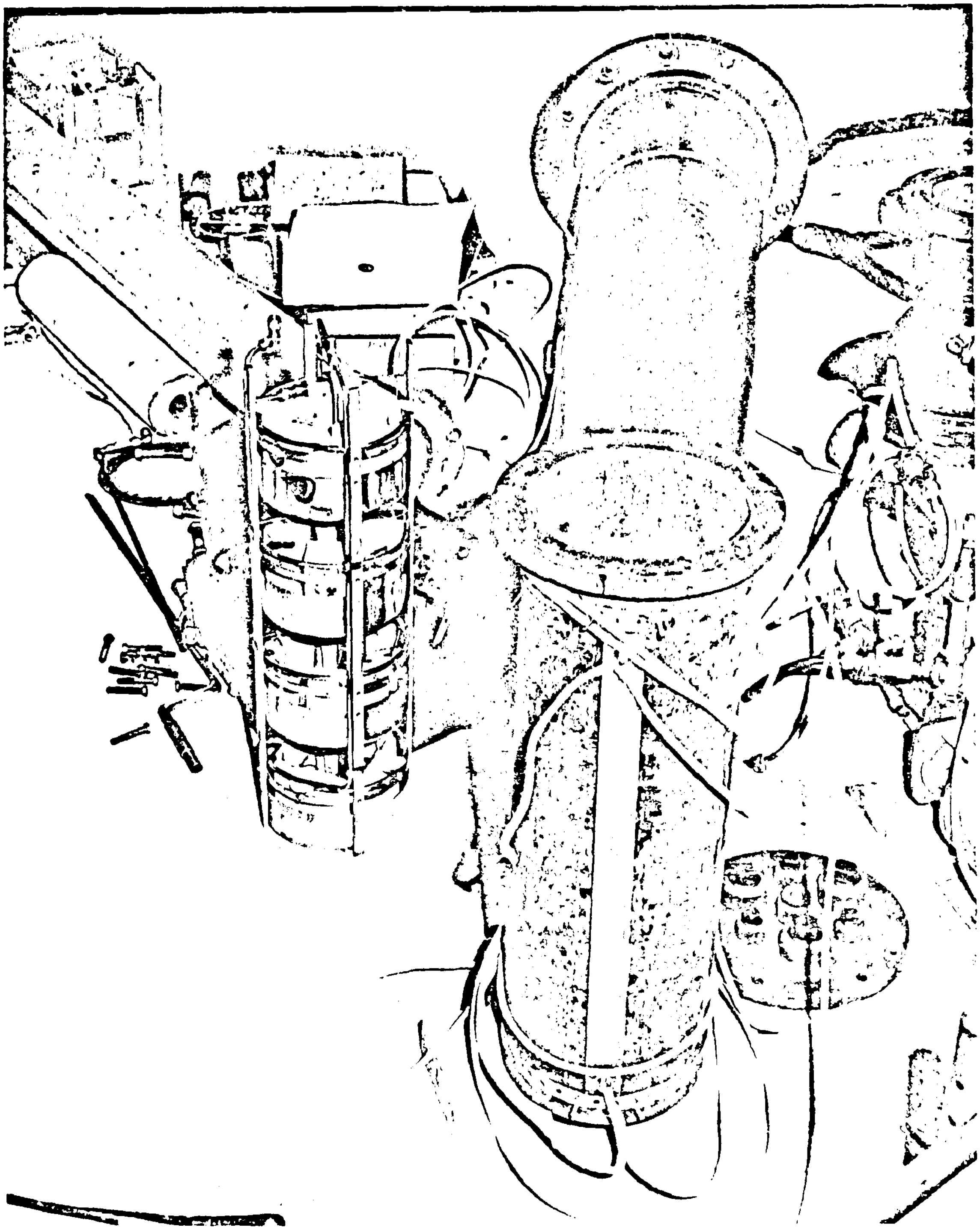

Figure 3. Test Vessel Components: Inner and Outer Vessel, Sample Support Trays and Extension Pipe

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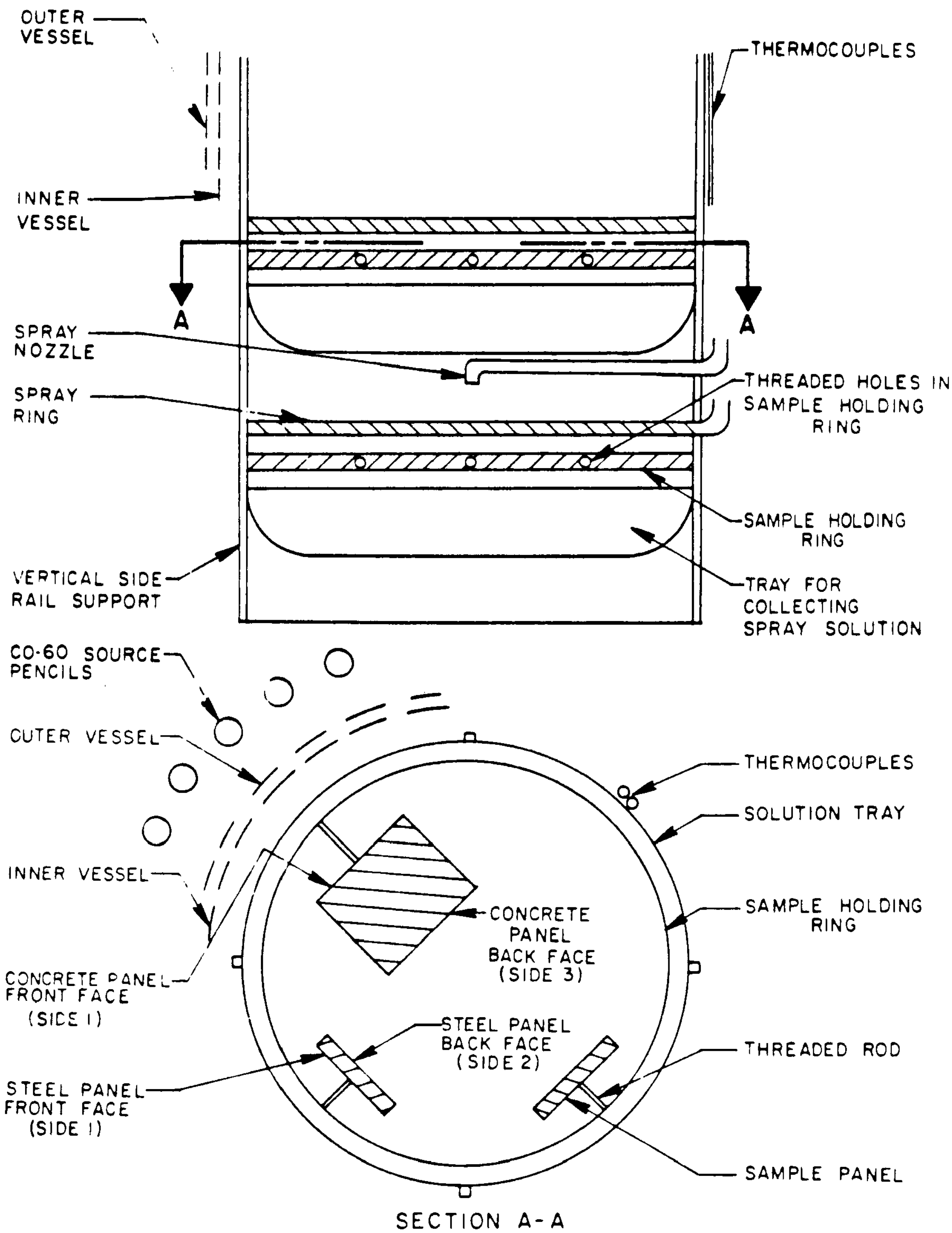

Figure 4. Sample Support System

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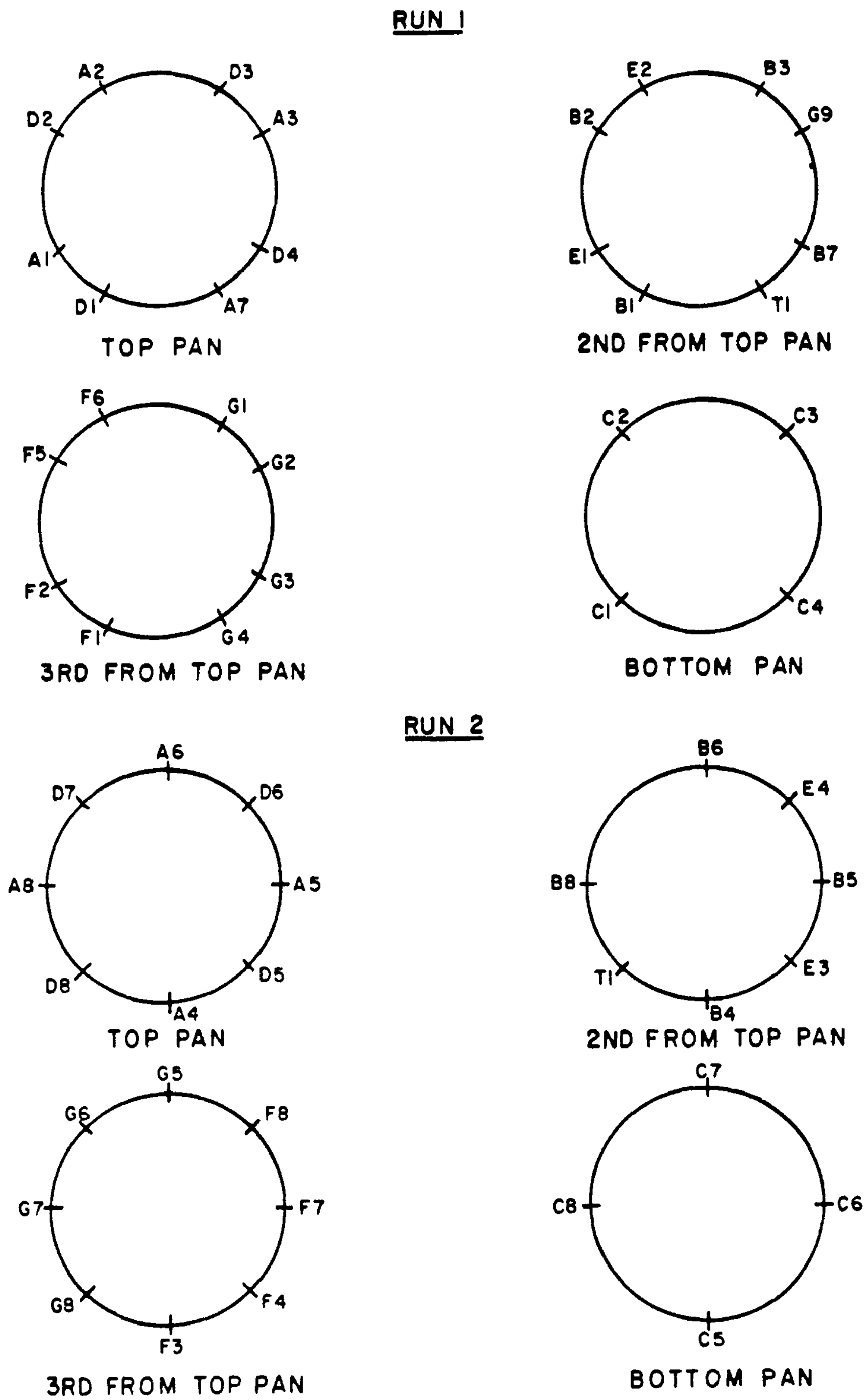

Figure 5. Sample Positions for Test Runs

3. Vessel Assembly

The sample support system was attached to the inner vessel flange. The flange had penetrations for steam inlet, spray solution inlet and return, and thermocouple leads. Two thermocouples were located between the second and third pans and vertically between two support struts as shown in Figure 4. As shown in Figure 6, a baffle was fixed to the underside of the flange to direct the steam away from the samples.

4. Spray Flow System

Two separate systems provided chemical spray to the samples: spray rings sprayed the fronts of the panels, and flow nozzles sprayed the backs.

Four spray rings were manifolded and mounted above the sample holding rings. The spray rings were fabricated from 1/4-inch stainless-steel tubing. Transverse saw cuts, made every half inch around the ring, produced a fan-shaped spray pattern.

The flow nozzles were also manifolded and were mounted under the pans to spray the next lower pan. These were commercial nozzles that produced a parasol spray pattern.

It was determined experimentally that a flow rate of 1-1/2 gpm through the spray rings and 1 gpm through the flow nozzles would provide a spray that adequately covered each panel. Spray solution collected in each pan to the overflow level, spilled into the bottom of the inner vessel, and was then pumped back to the surface level, thus completing the flow loop.

5. Radiation Source

The radiation source consisted of individual pencils (line source elements) of Co-60 arranged in two staggered rows around a circular holder that had an opening for the vessel assembly. The gamma radiation dose rate was 1.25 megarads per hour when all the source pencils were in position (full load); this was reduced to 0.6 megarad per hour by removing several pencils. These dose rates were determined by dosimetry measurements prior to the test, with the test vessel in place but without any samples in it. Each dose rate is the average of three readings made with potassium nitrate

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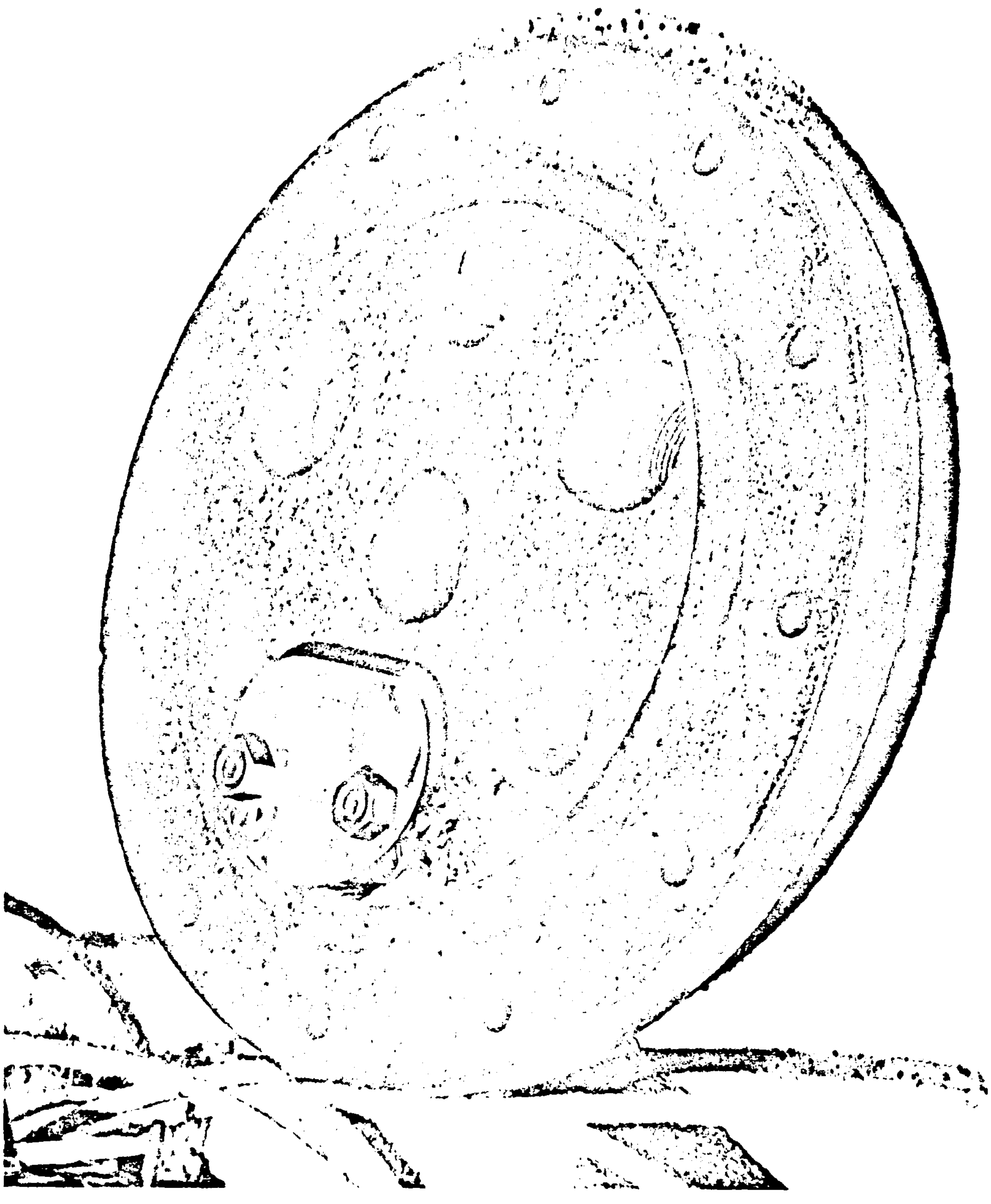

Figure 6. Baffle Plate on Underside of Inner Vessel Flange

dosimeters placed along the vessel centerline at heights of approximately one inch above the bottom of the top pan, one inch below the bottom of the second pan and two inches above the bottom of the bottom pan.

Prior to initiating each run the vessel was placed in the pool adjacent to the source ring, under full load, and was exposed at a dose rate of 0.1 megarad per hour for approximately four hours. This amount of radiation was considered negligible and was not added to the total dose received by the samples.

B. Procedures

1. Operating Procedure

The assembled unit was inserted into the pool adjacent to the Co-60 source ring.

For Runs 1 and 2 the inner vessel was preheated to 110°F by means of band heaters. In addition, for Run 2 the steam line was preheated to approximately 300°F up to the point where it entered the extension pipe, and the spray solution was preheated to 280°F at 80 psig by means of electric hot water heaters.

At the completion of preheating, the test assembly was placed within the Co-60 source ring and the test was begun. After the initial one-hour period of high-level radiation exposure, the vessel was raised and several source pencils were removed. Several lines to the vessel, including the spray system lines, were disconnected in order to raise the vessel. The spray was turned off for 17 minutes during Run 1 and 20 minutes during Run 2 while the source pencils were being removed. The reduced exposure at the low level was continued for the balance of the seven-day test period.

2. Performance Evaluation Procedure

Performance evaluations of the coating samples were conducted at the conclusion of the seven-day DBA exposure period, and then again 14 days after the initial evaluation. Samples were inspected immediately upon removal from the inner chamber to determine any gross effects due to the test environment. It took between two and three hours to remove all the samples and to prepare for the detailed inspection.

The evaluations were made to determine the amount of degradation caused by each of the following conditions in accordance with the criteria set forth in the ASTM documents noted.*

1. Flaking (ASTM D772)
2. Blistering (ASTM D714)
3. Chalking (ASTM D659)
4. Delamination, peeling or other changes in the coating system that could be determined by visual inspection.

Only the worst side of the panels coated with systems A, B, D, F, G and T were evaluated. Both sides of the panels coated with system C and only the coated face of system E panels were evaluated.

As required, the final evaluation was conducted without referring to the results of the initial evaluation; that is, the worst face was evaluated, whether or not it happened to be the face evaluated initially.

*The ASTM documents are reproduced in Appendix C along with standards for evaluating the degree of cracking and checking included as part of Item 4.

V. RADIATION DOSIMETRY

The dosimetry data supplied by Neutron Products, Inc., and contained in Appendix D were used to obtain dose levels received by each sample. The high-level dose rate, as a function of pan location, was taken from the values for dosimeters 7, 8 and 9 as shown on Figure D-1 and given in Table D-1 of Appendix D.1. Pan 1, the top pan, corresponds to dosimeter 7, pan 2 to dosimeter 8, pan 3 to the average of dosimeters 8 and 9, and pan 4 to dosimeter 9. These values are given in Table 1 under the column "Run 1 - High Level".

Run 2 high-level values were obtained by reducing Run 1 values by 2.4% because of the natural decay of the radiation source. This decay was taken as the difference between dose rate values of the two runs, as certified by the Neutron Products letter contained in Appendix D.2.

The low-level values were taken from dosimeters 11, 13, 15 and 17 of Figure D-1, corresponding to pans 1, 2, 3 and 4 for Run 1. The values for Run 2 were obtained by reducing the values for Run 1 in a manner similar to that for the high levels. These values are all presented in Table 1.

The dosimetry data of Appendix D.1 were further utilized in obtaining the reduction in dose rate through the sample materials. Dummy samples of the same material as the test specimens were arranged in the corresponding test position. The reduction in radiation through a sample was taken as the difference between the dose rate on the outside surface, facing the source, and that on the inside surface, away from the source, divided by the outside dose rate. The reduction through concrete, systems A and B, was based on readings from dosimeters 10 and 11 and was computed as 16%; that through 3/8-inch-thick steel, systems D, E, and F, was based on dosimeters 12 and 13 and computed as 3.5%; that through 3/8-inch-thick steel, system C, was based on dosimeters 16 and 17 and computed as 7%. No reduction was obtained for system G, 20-gage

Table 1. Radiation Levels as a Function of Pan Position (Megarads/Hour)

Pan Number (No. 1 at top)	Run 1		Run 2	
	High Level	Low Level	High Level	Low Level
1	1.17	0.56	1.14	0.55
2	1.30	0.58	1.27	0.57
3	1.28	0.68	1.25	0.66
4	1.26	0.43	1.23	0.42

steel, based on dosimeters 14 and 15. The reduction through transite, system T, was based on the density ratio of about 4 between transite and steel and a value of 1% was used. The difference between systems D, E and F, and system C, each 3/8-inch-thick steel, results from the unsymmetrical placement of source pencils relative to the panels, shadowing of radiation by different parts of the assembled vessel, and the nonlinear radiation flux field in the vertical direction.

Table 2 presents a summary of the accumulated total dose of radiation received by the samples. The column headed "Dose Rate - High Level" shows the dose rates with a full load of source pencils; the column headed "Dose Rate - Low Level" shows the dose with source pencils removed. The values in these columns were obtained from the results of Table 1 with the dose rate for the inside face, side 2 or 3, away from the source, computed by reducing the value for the outside face, side 1, by the appropriate reduction factor. The accumulated total dose (in megarads) for the fronts and backs of the samples was obtained by multiplying the high and low dose rates by the duration of each and summing. The radiation dose received on the sides of the concrete samples, sides 2 and 4, can be obtained by linear interpolation of the doses received by sides 1 and 3. The samples were exposed to the high level of radiation for 1 hour during Runs 1 and 2 and to low-level radiation for 168 hours during Run 1 and for 166 hours during Run 2.

Table 2. Summary of Accumulated Total Dose of Gamma Radiation Exposure Received by Test Specimens

Sample No.	Pan Loc.	Run No.	Reduction Factors (Percent)	Dose Rate (Mrad/hr) High Level Front	High Level Back	Low Level Front	Low Level Back	Accumulated Total Dose (Mrad) Front	Back
A-1	1	1	16	1.2	0.98	0.56	0.47	95	80
A-2		1							
A-3		1							
A-4		2		1.1	0.96	0.55	0.46	92	77
A-5		2							
A-6		2							
A-7		1		1.2	0.98	0.56	0.47	95	80
A-8		2		1.1	0.96	0.55	0.46	92	77
B-1	2	1	16	1.3	1.1	0.58	0.49	98	83
B-2		1							
B-3		1							
B-4		2		1.2		0.57	0.48	96	81
B-5		2							
B-6		2							
B-7		1		1.3		0.58	0.49	98	83
B-8		2		1.2		0.57	0.48	96	81
C-1	4	1	7	1.2	1.1	0.43	0.40	74	68
C-2									
C-3									
C-4									
C-5		2				0.42		71	
C-6									
C-7									
C-8									
D-1	1	1	3.5	1.2	1.1	0.56	0.54	95	92
D-2									
D-3									
D-4									
D-5		2				0.55	0.53	92	89
D-6									
D-7									
D-8									
E-1	2	1	3.5	1.3	1.2	0.58	0.56	98	95
E-2									
E-3		2		1.2		0.57	0.55	96	92
E-4		2							
F-1	3	1	3.5	1.2	1.2	0.68	0.66	115	112
F-2		1							
F-3		2				0.66	0.64	111	107
F-4		2							
F-5		1				0.68	0.66	115	112
F-6		1							
F-7		2				0.66	0.64	111	107
F-8		2							
G-1	3	1	0	1.2	1.2	0.68	0.68	115	115
G-2									
G-3									
G-4									
G-5		2				0.66	0.66	111	111
G-6									
G-7									
G-8									
G-9	2	1		1.3	1.3	0.58	0.58	98	98
T-1	2	1	1	1.3	1.3	0.58	0.57	98	97
T-1	2	2	1	1.2	1.2	0.57	0.56	96	94

VI. TEST DESCRIPTION

Although the test requirements of NAS 361 specified that all panels be subjected to the DBA environment at the same time, the limited size of the test vessel made it necessary to make two test runs to satisfy the most important test parameters: uniformity of irradiation (at least on one side of the panels) and dose rate profile. The samples tested in the two runs are listed below:

Run 1 (28 panels)	Run 2 (27 panels)
A-1, 2, 3 and 7	A-4, 5, 6 and 8
B-1, 2, 3 and 7	B-4, 5, 6 and 8
C-1, 2, 3 and 4	C-5, 6, 7 and 8
D-1, 2, 3 and 4	D-5, 6, 7 and 8
E-1 and 2	E-3 and 4
F-1, 2, 5 and 6	F-3, 4, 7 and 8
G-1, 2, 3, 4 and 9	G-5, 6, 7 and 8
T-1	T-1

A. Run 1

The test vessel was positioned in the Co-60 source ring, and the inner vessel was maintained at 104°F at atmospheric pressure for approximately two days.

To initiate the test, steam was admitted rapidly to the vessel causing an increase in pressure and temperature to 45 psig and 290°F within 50 seconds. Over the next 28 minutes, the vessel pressure was maintained at 45 $\pm$3 psig and the temperature at 300°F. The pressure and temperature were then decreased to 4 psig and 84°F over the next 25 minutes. The temperature was not maintained at the specified level of 140°F because of a short circuit on the heater connections. From this point until the end of the fourth day of testing the temperature remained at 75°F with occasional rises to 82°F, depending on the temperature of the water in the storage pool. At the end of the fourth day the heater circuit was repaired and the temperature was maintained at 105° ±2°F for the remaining three days. The pressure remained between 3 and 11 psig throughout the test after it had dropped to 4 psig at 53 minutes. Figures 7 and 8 show the temperature and pressure profiles, respectively.

The first spray solution was turned on at a rate of 2 gpm 50 seconds after steam injection and was run through the system once and not recirculated. At 5 minutes the first solution was purged and the second solution was introduced. The second solution was sprayed for 73 minutes at a rate of approximately 1-1/2 gpm, being pumped straight through for the first 43 minutes and then recirculated for 30 minutes. The third solution was sprayed at a rate of 1-1/2 gpm for the remainder of the test period, recirculation being started after the first 12 minutes of use. Figure 9 shows the periods during which the spray system operated.

The pumps were shut off at several intervals for a total of 36 hours during the test to reduce the inlet temperature to the impeller and eliminate cavitation.

B. Run 2

The test vessel was placed in the pool adjacent to the Co-60 source ring approximately four hours before the test started. The chamber was preheated at 110°F for two hours. The system was pressure-tested at 45 psig to check for leaks.

To initiate the test, steam was admitted rapidly to the chamber causing the temperature to increase to 280°F in 4.6 seconds and the pressure to 45 psig in 9.45 seconds. The spray rail system was turned on 12 seconds after the test began at a flow rate of 1-1/2 gpm. The temperature rise continued, peaked to 312°F after 22 seconds, was reduced to 236°F at 1.8 minutes, and brought up to 280°F at 1.9 minutes. The pressure peaked to 48 psig at 11 seconds, dropped to 34.5 psig at 14 seconds, then oscillated between 35 and 50 psig until the regulator took over control and maintained the pressure at 44 ±1 psig after 2 minutes.

Figures 10 and 11 show the temperature and pressure profiles, respectively. Figure 12 shows the periods during which the spray operated.

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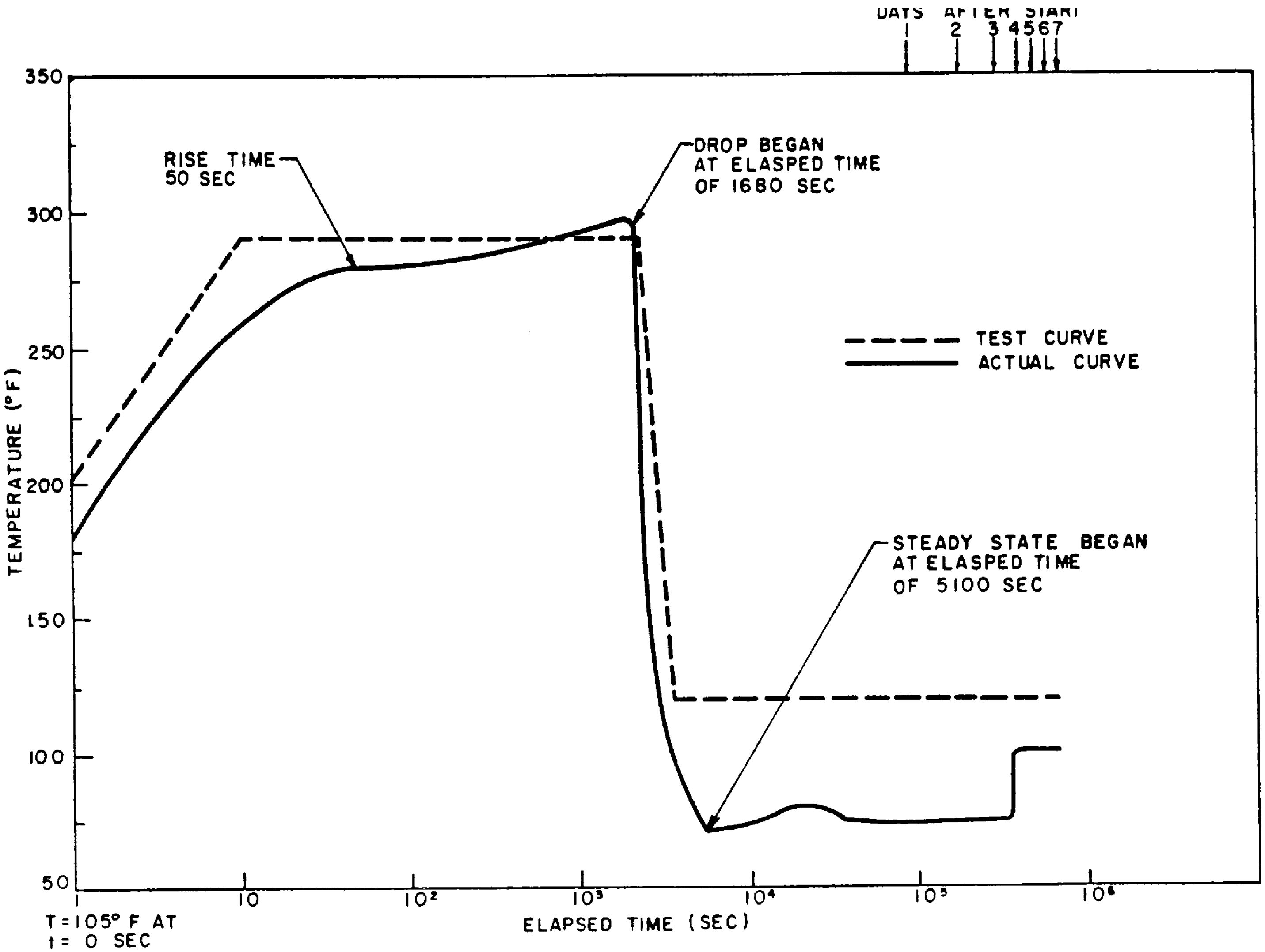

Figure 7. Temperature Profile for Run 1

F-C3486

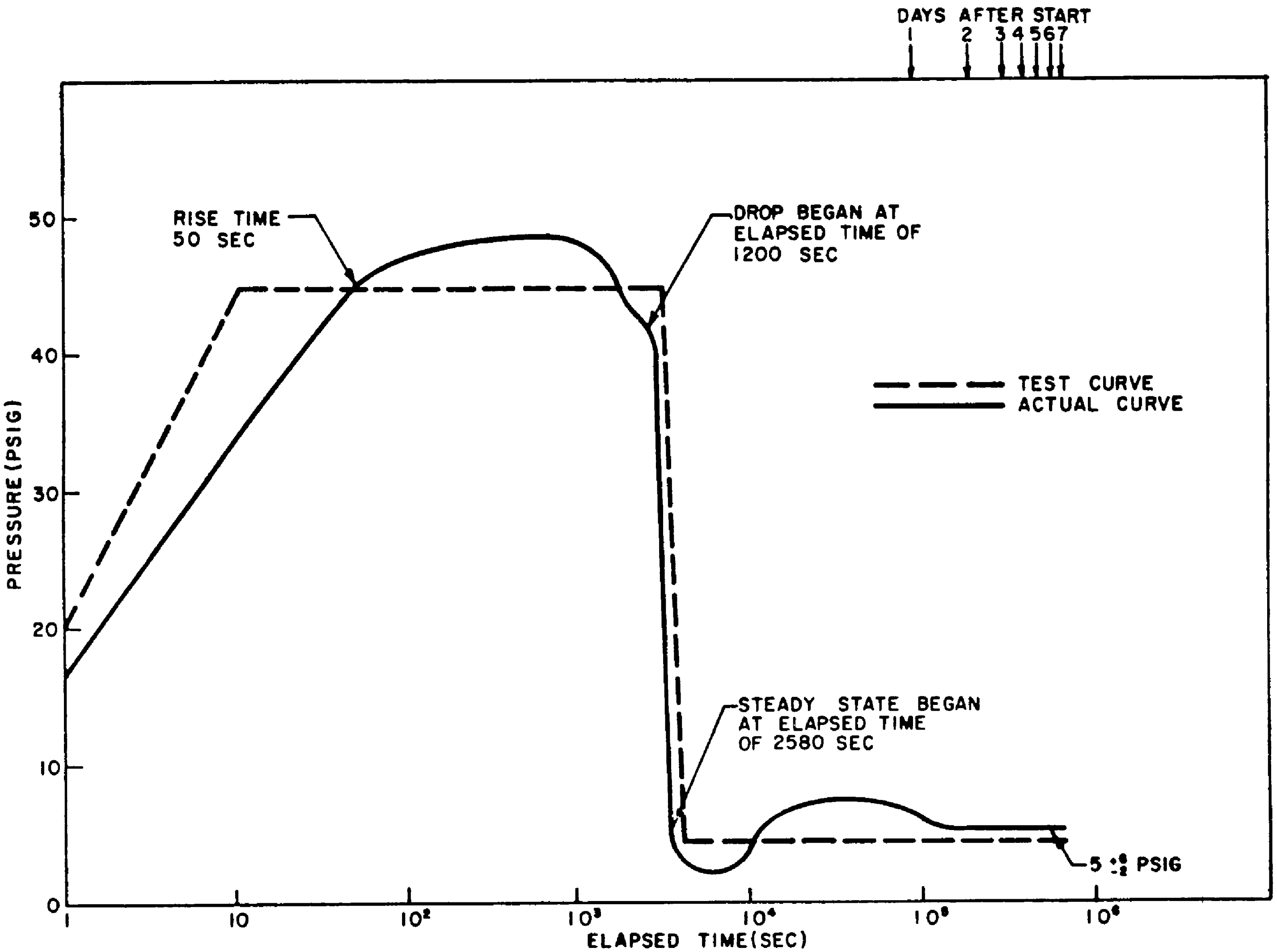

Figure 8. Pressure Profile for Run 1

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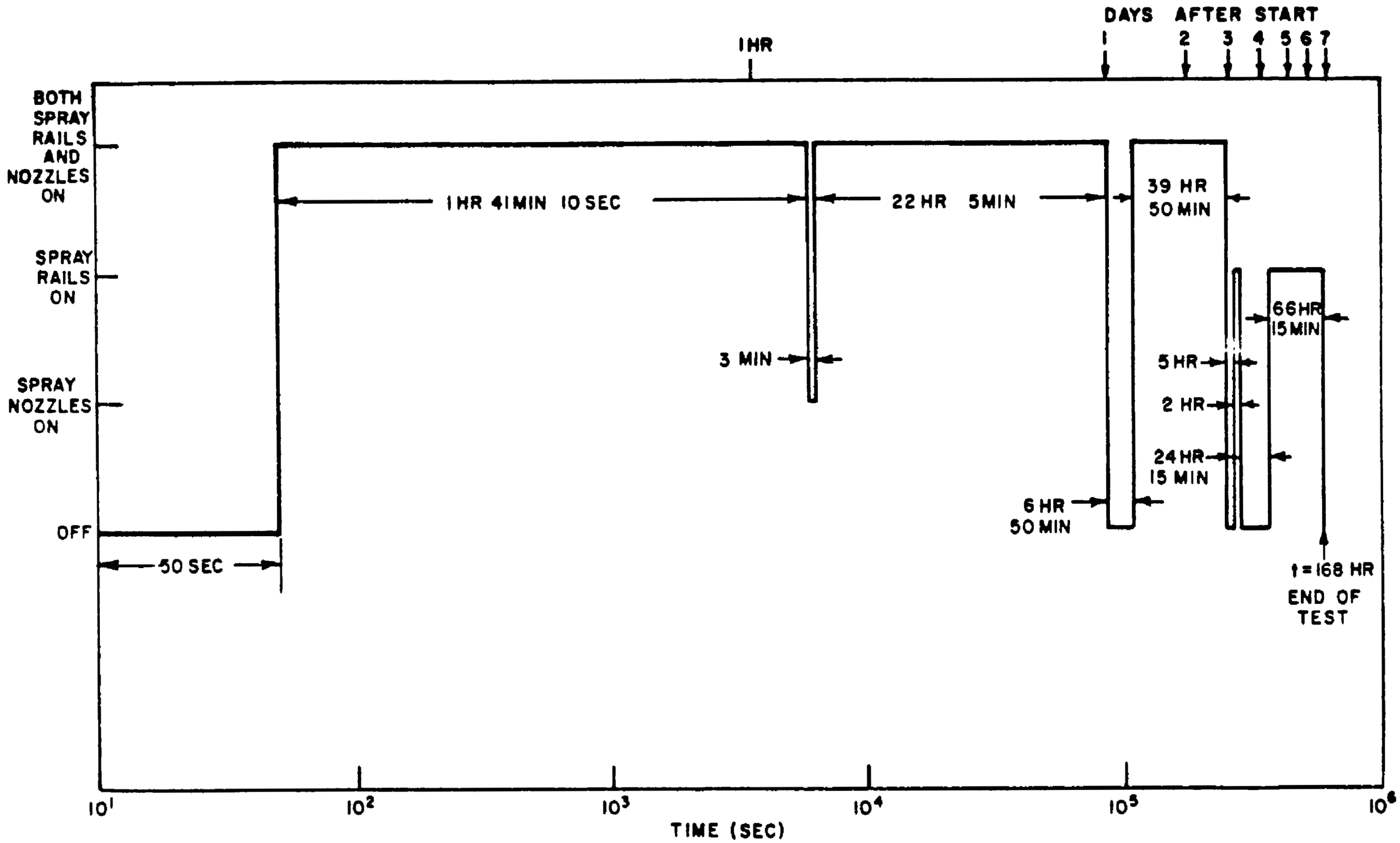

Figure 9. Operation Time of Chemical-Spray Solution During Run 1

F-C3486

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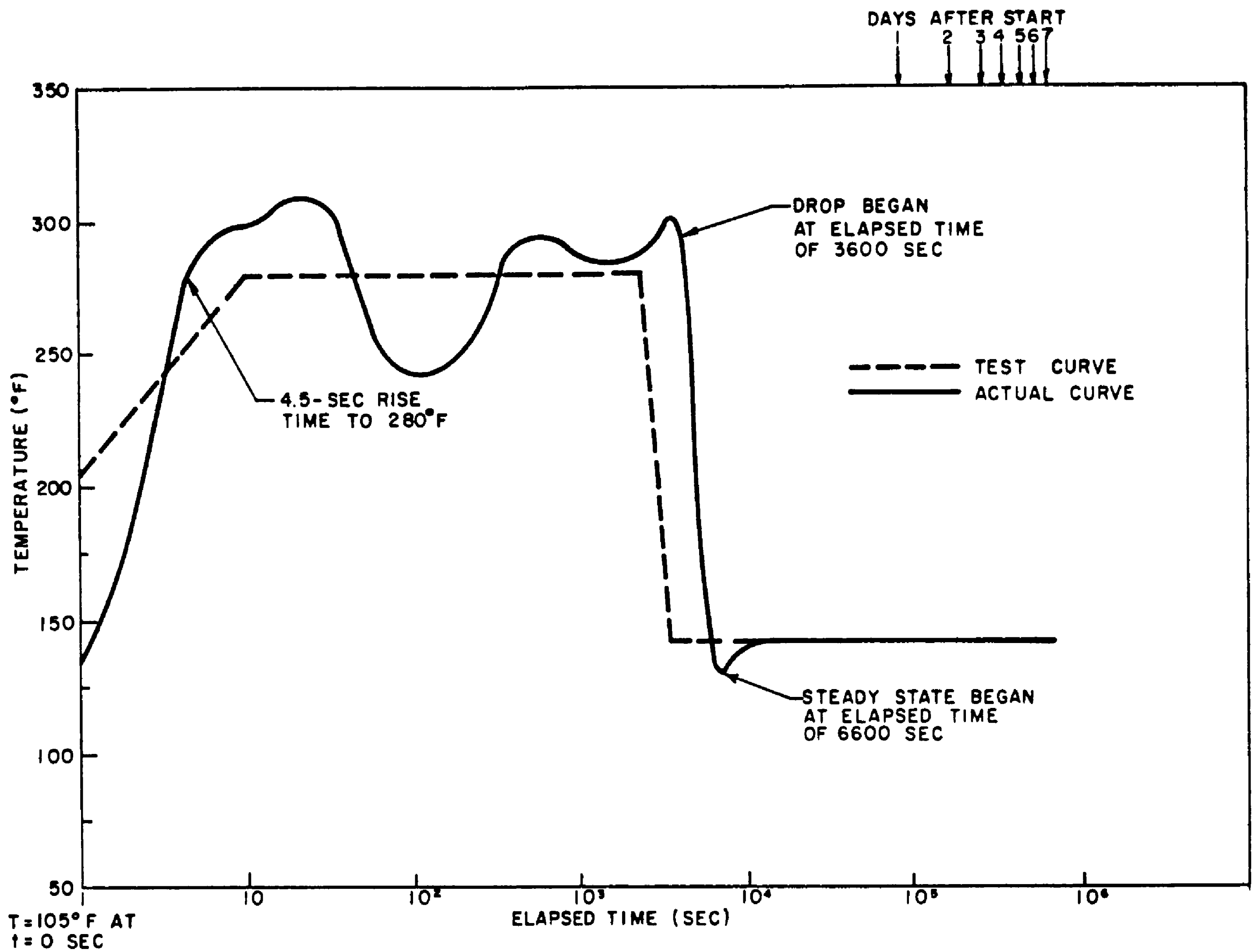
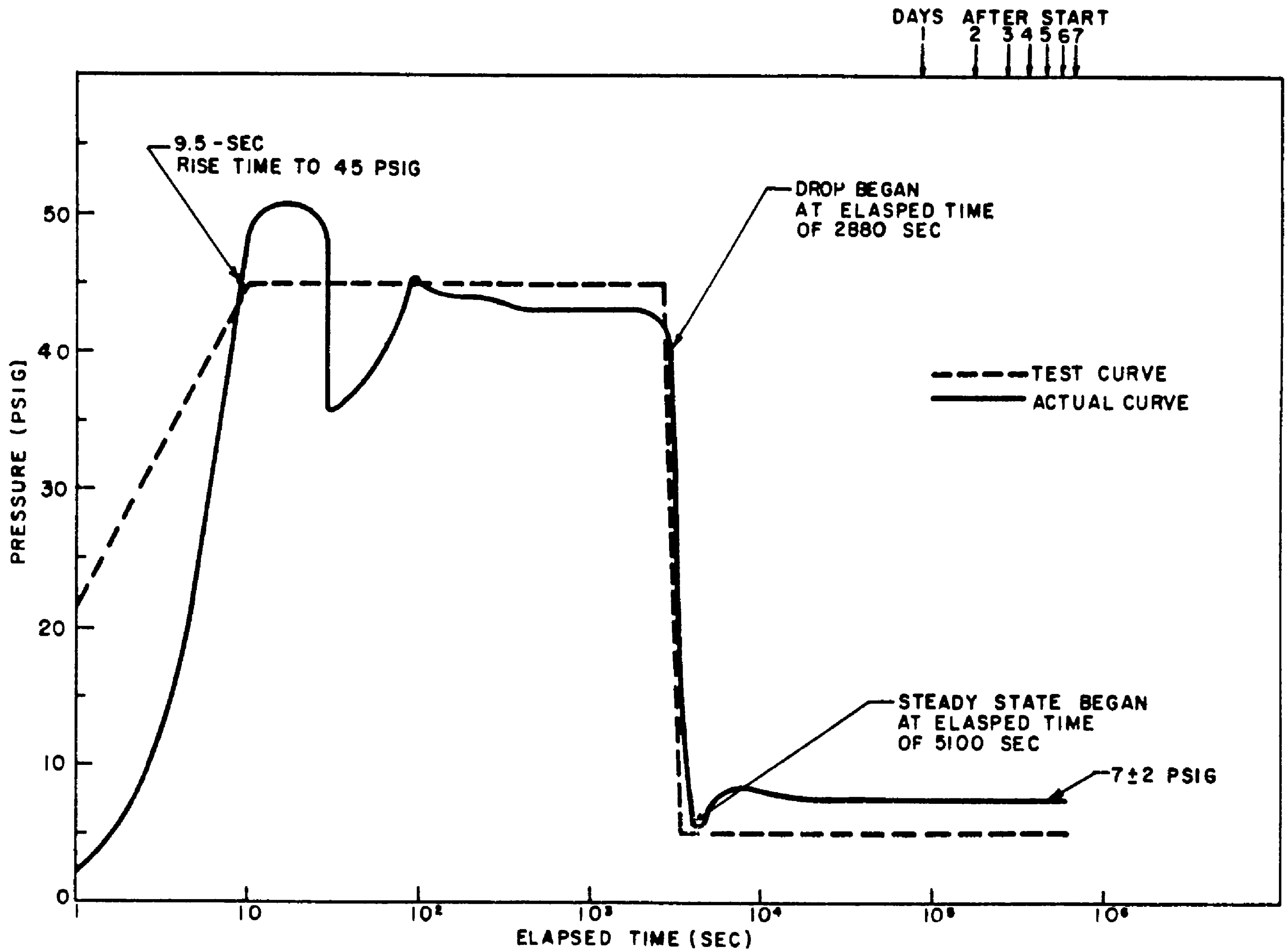


F-C3486

Figure 10. Temperature Profile for Run 2



F-C3486

Figure 11. Pressure Profile for Run 2

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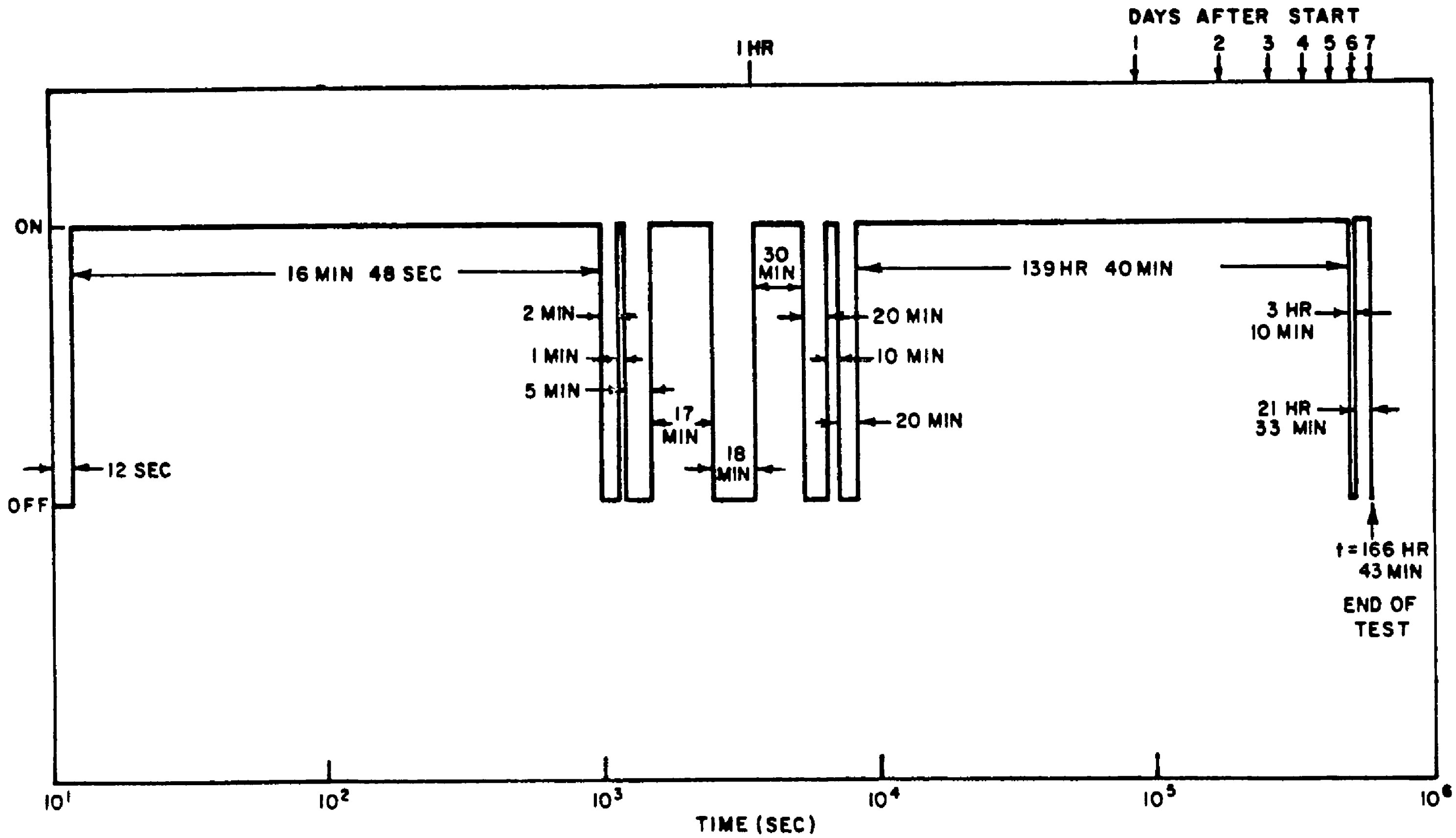


Figure 12. Operation Time of Chemical-Spray Solution During Run 2

F-C3486

The first solution of chemical spray was used during the first 5 minutes of the run without being recirculated. The second solution was used during the next 65 minutes, recirculation being initiated after the first 10 minutes of use. The third solution was used in the recirculation mode throughout the remainder of the test.

The drop in pressure and temperature to 5 psig/140°F began 40 minutes after the test began.

The vessel was taken out of the high radiation field 90 minutes after the test started. Twenty-one minutes were required to change the source field from the high to low level, during which time several lines to the vessel were disconnected, including those from the spray system. Thus, steady-state operation in the low source field was established 1 hour and 51 minutes after the test was begun.

After the change in the source field was made, the flow was maintained properly except for several intervals when the pump was shut off for a total of 4 hours and 15 minutes.

VII. PERFORMANCE EVALUATION

A. RUN 1

The vessel was removed from the pool and disassembled at the conclusion of the exposure period. The following general observations were made as the samples were removed from the pan support system.

1. Panels appeared in good condition and not substantially degraded.
2. The top coat was soft to the touch in the liquid phase only.
3. The C-system panels had changed in color from white to cream.
4. Sample B-3 had three blisters of 3/8-inch diameter on side 2.
5. Sample E-2 had a 1/4-inch-diameter blister in the liquid phase and delamination along the scribed line and near the tag hole. Delamination was observed on E-1, but to a lesser degree.
6. Samples G-2, 3 and 9 were blistered, but not seriously.

Figure 13 is a photograph of the samples at the time of these observations.

Table 3a summarizes the results of the initial evaluation which was conducted seven days after the start of the test. Table 3b summarizes the results for the final evaluation conducted 14 days after the initial evaluation. There were no significant differences between the results of the initial and final evaluations. The data sheets for each evaluation are included in Appendix B. Figures 14a through c are photographs of the samples after the initial evaluation was made, showing the side evaluated.

B. RUN 2

At the end of the seven-day exposure period, the vessel was removed from the pool and the samples inspected. An initial evaluation was conducted at that time and a final evaluation was conducted 14 days later.

Table 4a summarizes the results of the initial evaluation, and Table 4b the results of the final evaluation. Figures 15a through c are photographs of the samples after the final evaluation, showing the side evaluated. Appendix B contains the data sheets of the sample evaluations.

F-C3486

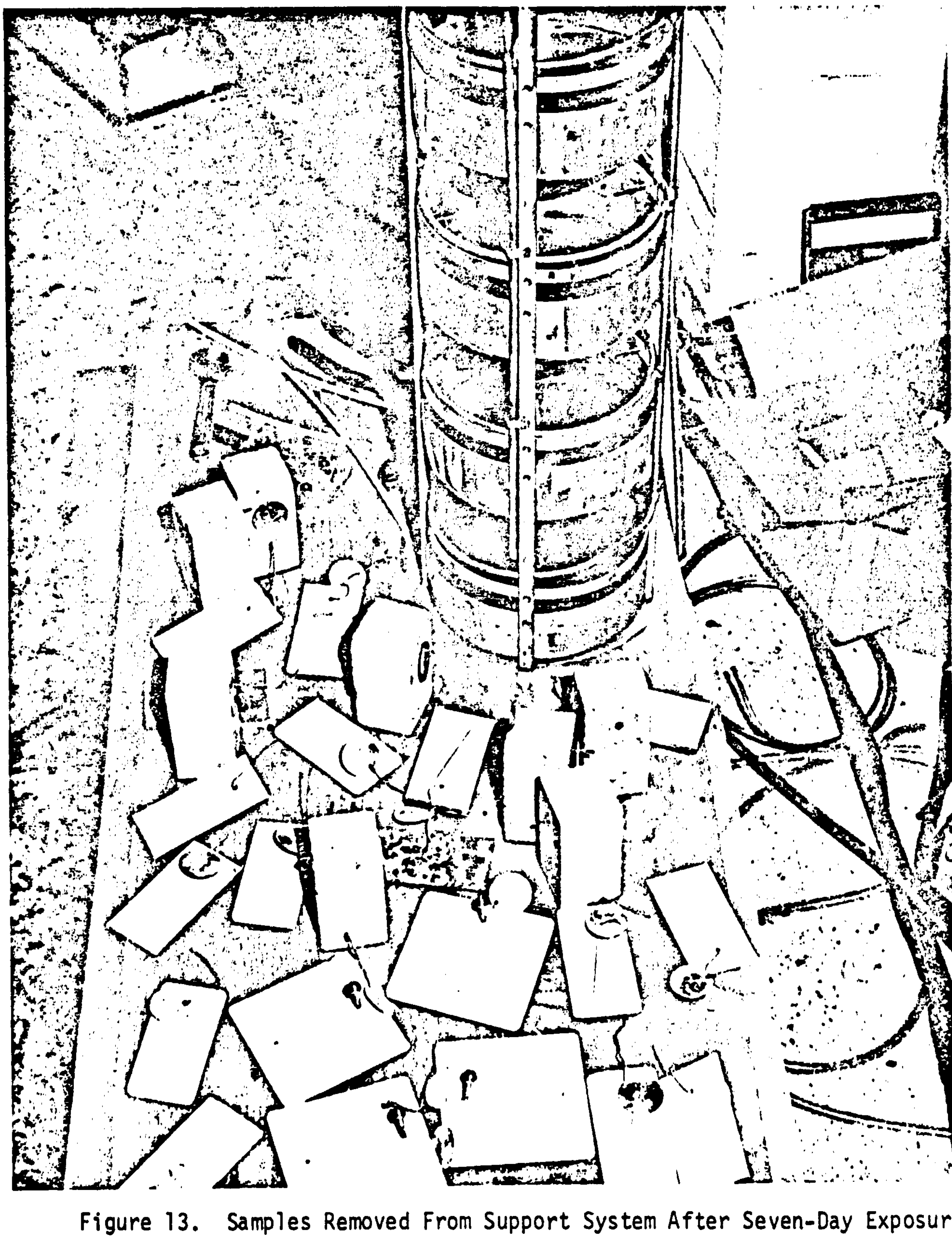


Figure 13. Samples Removed From Support System After Seven-Day Exposure

Best Copy Available

Table 3a. Summary of Initial Evaluation of Coating System Performance for Run 1

NOTE: N= NONE

Sample No.	Side	Chalking*	Blistering*	Flaking	Other†
A-1	2	N	8>F	N	N
A-2	1	9+V	8F-L	N	N
A-3	2	9	7F	N	N
A-7	1	9.5	one 1/16" dia two 1/32" dia	N	N
B-1	2	N	9M	N	N
B-2	1	N	9F-L	N	N
B-3	3	N	three 1/4" to 1/2" dia	N	N
B-7	3	10-	several 1/32" to 3/16" dia	N	N
C-1	1 2	10- 9+	N N	N N	N N
C-2	1 2	10- 9.5	8M N	N N	N N
C-3	1 2	10- 9	N N	N N	N N
C-4	1 2	N 9	N N	N N	N N
D-1	1	8	N	N	N
D-2	2	N	<8MD	N	N
D-3	2	9+	7M-V	N	N
D-4	1	9.5	7M	N	N
E-1	1	9.5	one 5/16" dia two 1/32" dia	N	Surface break around tag hole; surface raised along scribe
E-2	1	9.5	N	N	N
F-1	1	N	8MD	N	N
F-2	1	N	8MD	N	N
F-5	1	N	N	N	N
F-6	1	N	N	N	N
G-1	1	N	one 1/8" dia 8F-L	N	N
G-2	2	9.5	8M one 1/4" dia broken	N	N
	1		7 along scribe		Rust in scribe
G-3	1	9.5	5>MD one 1/4" dia broken	N	Peeling RH corner 1/16" x 1/2" area
G-4	2 1	9.5 -	8M-L -	N -	N White foreign substance in scribe; surface raised along scribe
G-9	1	-	-	-	Both sides corroded
T-1	1	7	N	N	N

*V=vapor phase; L=liquid phase.
†Refers to degradation of coating system determined by visual inspection; specifically, delamination, peeling, cracking and checking.

Table 3b. Summary of Final Evaluation of Coating System Performance for Run 1

NOTE: N= NONE

Sample No.	Side	Chalking	Blistering*	Flaking	Other†
A-1	2	9+	8F	N	N
A-2	1	9	8F	N	N
A-3	4	9+	6<F	N	N
A-7	1	9+	one 1/16" dia	N	N
B-1	2	N	8<M-V 8F-L		
B-2	2	N	N	N	N
B-3	3	N	three 1/4", 3/8"&1/2" dia	N	N
B-7	3	9+	one 1/8" & one 3/16" dia 8F	N	N
C-1	1	N	N	N	N
	2	9+	N	N	N
C-2	1	N	8<M	N	N
	2	9+	N	N	N
C-3	1	N	N	N	N
	2	9	N	N	N
C-4	1	N	N	N	N
	2	9+	N	N	N
D-1	1	9+	N	N	N
D-2	2	9	8MD	N	N
D-3	1	9+	8M	N	N
D-4	1	9	6<M	N	N
E-1	1	N	one 5/16" dia	N	N
E-2	1	N	N	N	N
F-1	1	N	7<M-V 8<M-L	N	N
F-2	1	9+	8M	N	N
F-5	1	N	N	N	N
F-6	1	N	N	N	N
G-1	1	N	8<F	N	N
G-2	2	9+	8<F	N	N
G-3	1	N	6MD & 4<M	Along top edge	N
G-4	2	N	8M	N	N
G-9	1	Corroded	N	N	N
T-1	1	8	N	N	N

*V=vapor phase; L=liquid phase.
†Refers to degradation of coating system determined by visual inspection; specifically, delamination, peeling, cracking or checking.

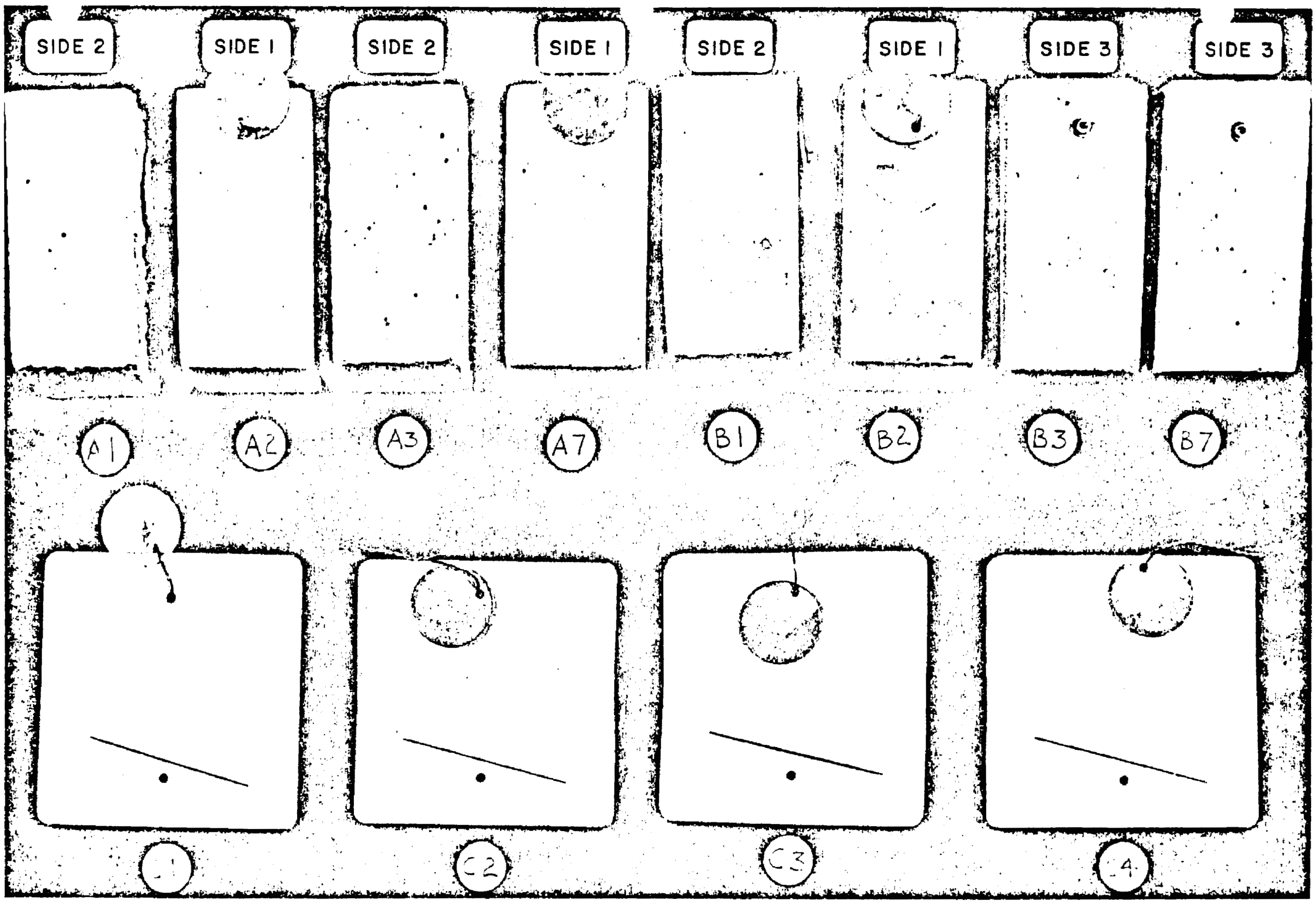
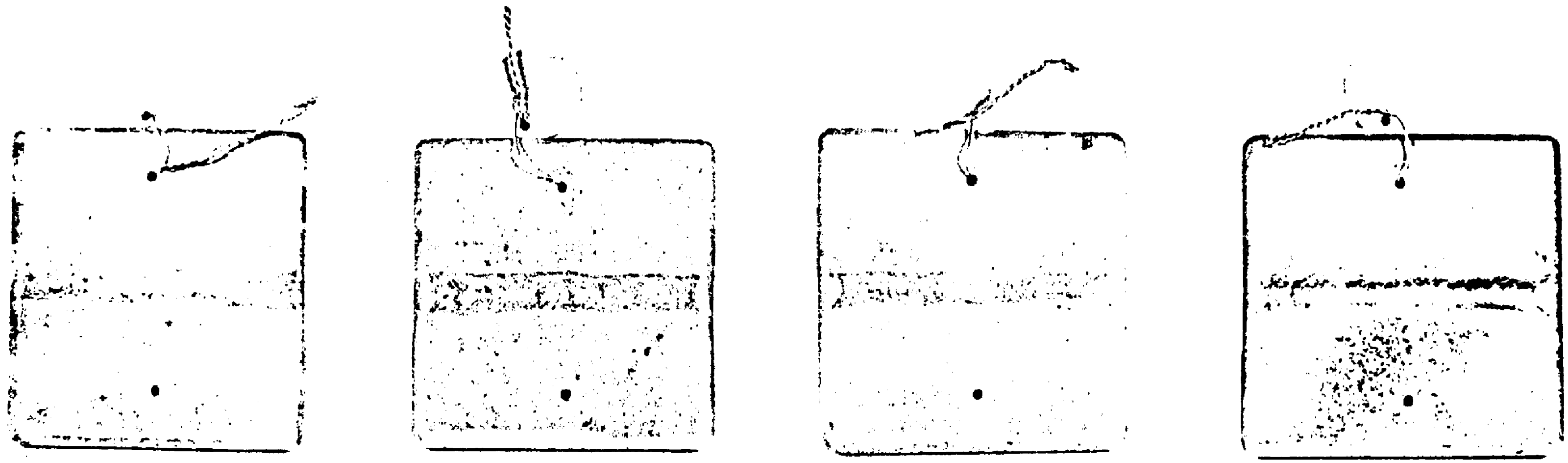


Figure 14a. Half-Size Photograph of Side 1 of System C and the Evaluated Side of Systems A and B, Taken After Initial Evaluation Following Run 1

F-C3486



C1 C2 C3 C4

Figure 14b. Half-Size Photograph of Side 2 of System C After the Initial Evaluation Following Run 1

F-C3486

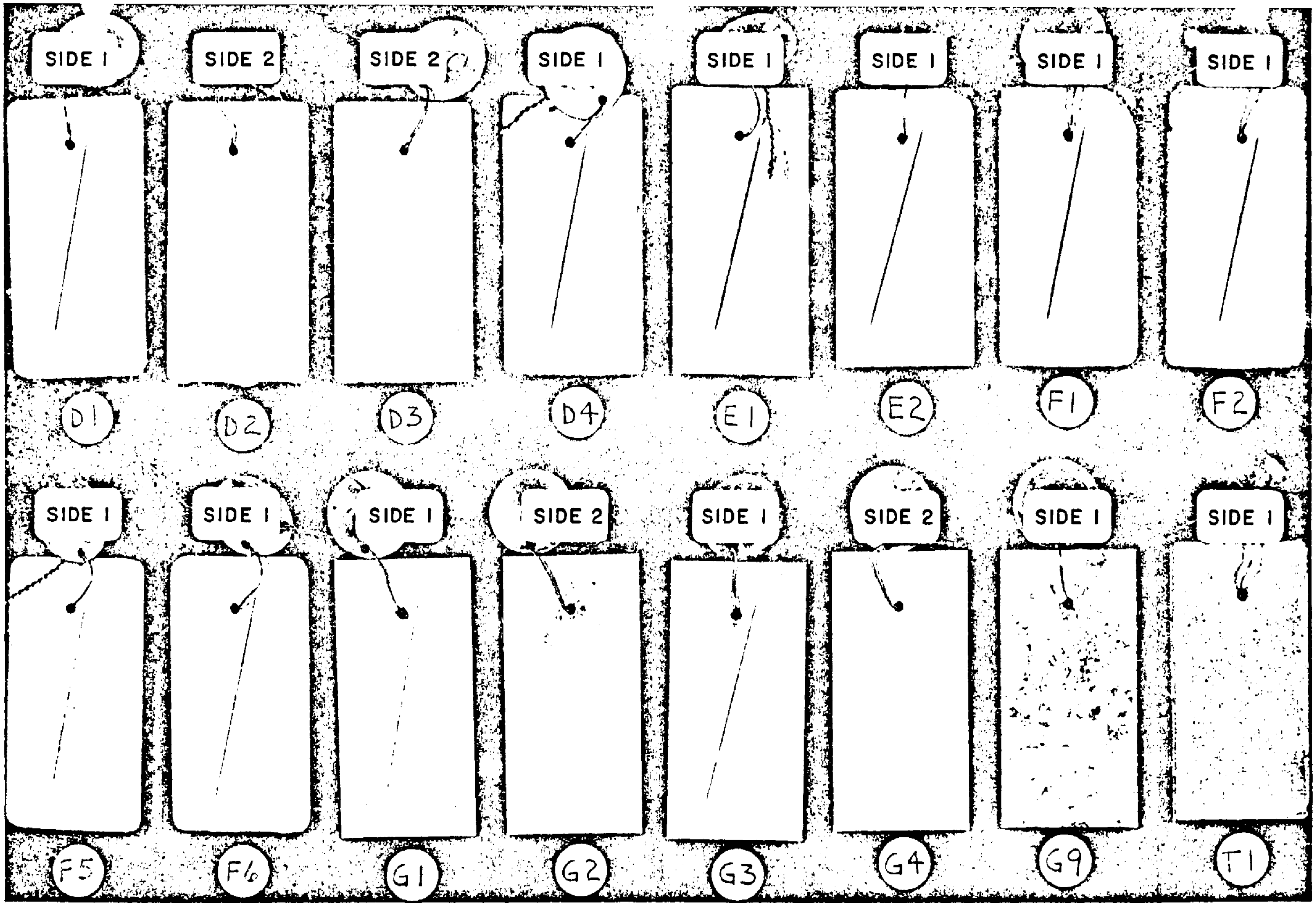


Figure 14c. Half-Size Photograph of Side Evaluated After the Initial Evaluation Following Run 1 for Systems D, E, F, G and T

F-C3486

Best Copy Available

Table 4a. Summary of Initial Evaluation of Coating System Performance for Run 2

Note: N = None

Sample No.	Side	Chalking*	Blistering*	Flaking	Other†
A-4	3	9	6D	N	N
A-5	1	9	7<MD	N	N
A-6	1	9	6M	N	N
A-8	1	9	N	N	N
B-4	2	N	6D	N	N
B-5	1	8	8>M	two areas	1/16"x1/8" and 1/8"x3/16" flaked
B-6	1	N	6F	N	1/2" dia area of top coat peeled off
B-8	4	9	one 1/16" dia	N	N
C-5	1	6	one 1/4" dia	N	N
	2	8-V	N	N	N
C-6	1	9	6MD-V 6F-L	N	N
	2	7	N	N	N
C-7	1	7	8M	N	1/2" dia area at weld blistered
	2	9	N	N	N
C-8	1	7	6M	N	N
	2	9	N	N	N
D-5	1	6	8F-V	N	N
D-6	1	6-L	8>F	N	N
D-7	2	N	6F	N	N
D-8	1	N	6M	N	N
E-3	1	6-L	2>F	N	N
E-4	1	8-L	2M	N	Delamination along scribe
F-3	1	N	3MD	N	N
F-4	1	N	5M	N	N
F-7	1	N	N	N	N
F-8	2	8-L	2>M-L	N	N
G-5	1	8-L	2M-L	N	N
G-6	2	8-L	6>F	N	N
G-7§	2	-	-	-	-
G-8	1	9	8MD	N	N
T-1	1	N	N	N	N

*V=vapor phase; L=liquid phase.
†Refers to degradation of coating system determined by visual inspection; specifically, delamination, peeling, cracking or checking.
§Practically all delaminated with one-third flaked off exposing substrate.

Table 4b. Summary of Final Evaluation of Coating System Performance for Run 2

Note: N = None

Sample No.	Side	Chalking	Blistering*	Flaking	Other+
A-4	3	8	7D	N	N
A-5	1	8	7<MD	N	N
A-6	1	8	6MD	N	N
A-8	1	9	N	N	N
B-4	2	9	5>MD	N	N
B-5	1	9	8MD	1/8x1/4"area	N
B-6	1	9	6M	N	3/4" sq. area peeled off
B-8	4	9	one 1/16"dia	N	N
C-5	1	8	N	N	N
	2	8	N	N	N
C-6	1	8	4MD-V 4F-L	N	N
	2	8	N	N	N
C-7	1	8	N	N	N
	2	8	N	N	N
C-8	1	8	6F-V 6M-L	N	N
	2	8	N	N	N
D-5	1	9	8F	N	N
D-6	2	9	8M	N	N
D-7	2	9	7F-L	N	N
D-8	1	9	6M	N	N
E-3	1	9	2>F	N	N
E-4	1	9	2>M	N	Delamination along scribe
F-3	1	N	2MD	N	N
F-4	1	9	4M&8F	N	N
F-7	1	N	N	N	Delamination along scribe
F-8	2	8	3M-L	N	N
G-5	1	9	2F-L	N	N
G-6	2	9	6F-V 8F-L	N	N
G-7§	2	-	-	-	-
G-8	1	9	8MD	N	N
T-1	1	N	N	N	N

*V=vapor phase; L=liquid phase.

+Refers to degradation of coating system determined by visual inspection; specifically, delamination, peeling, cracking or checking.

§Practically all delaminated with one-third flaked off exposing substrate.

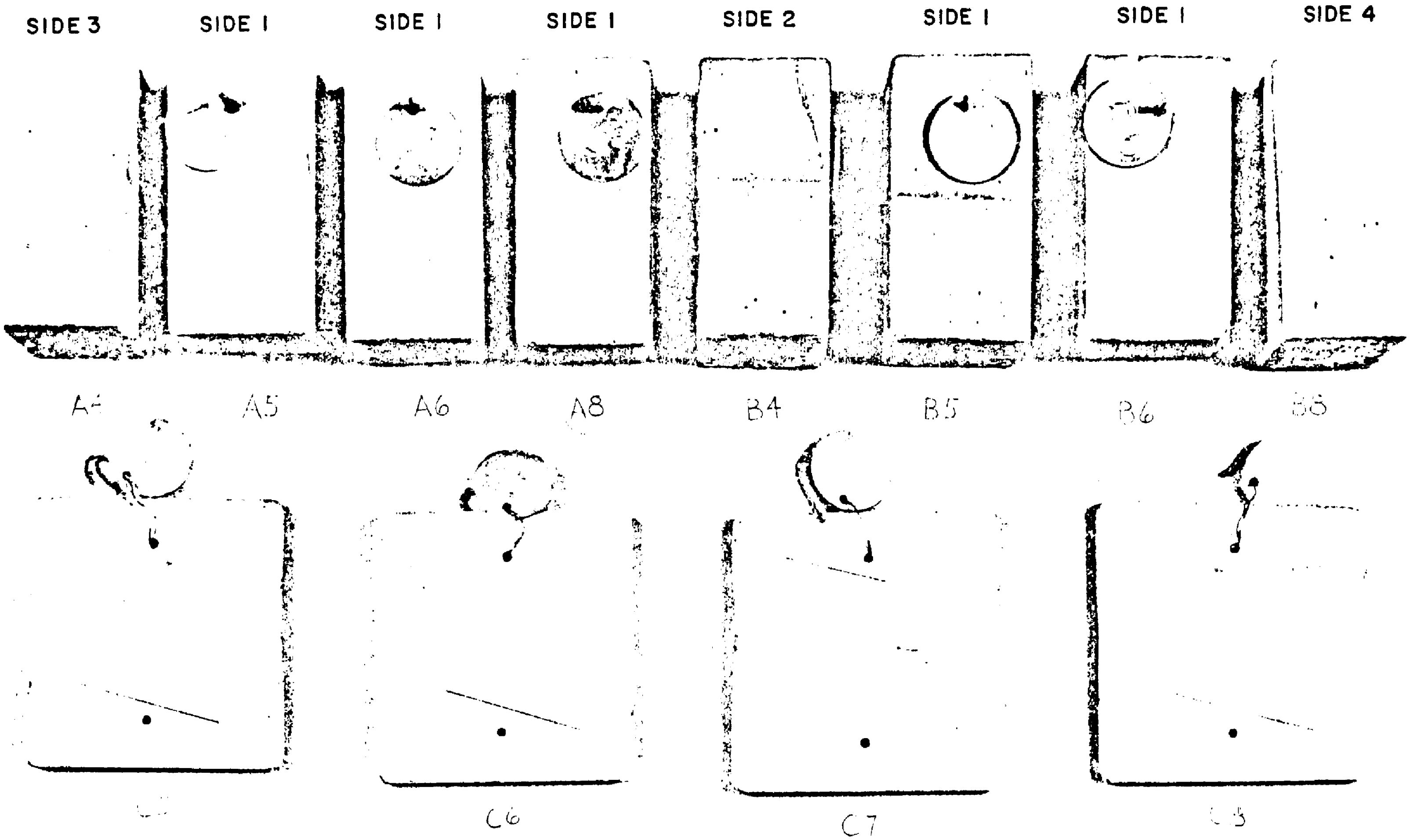


Figure 15a. Half-Size Photograph of Side 1 of System C and the Evaluated Side of Systems A and B, Taken After the Final Evaluation Following Run 2

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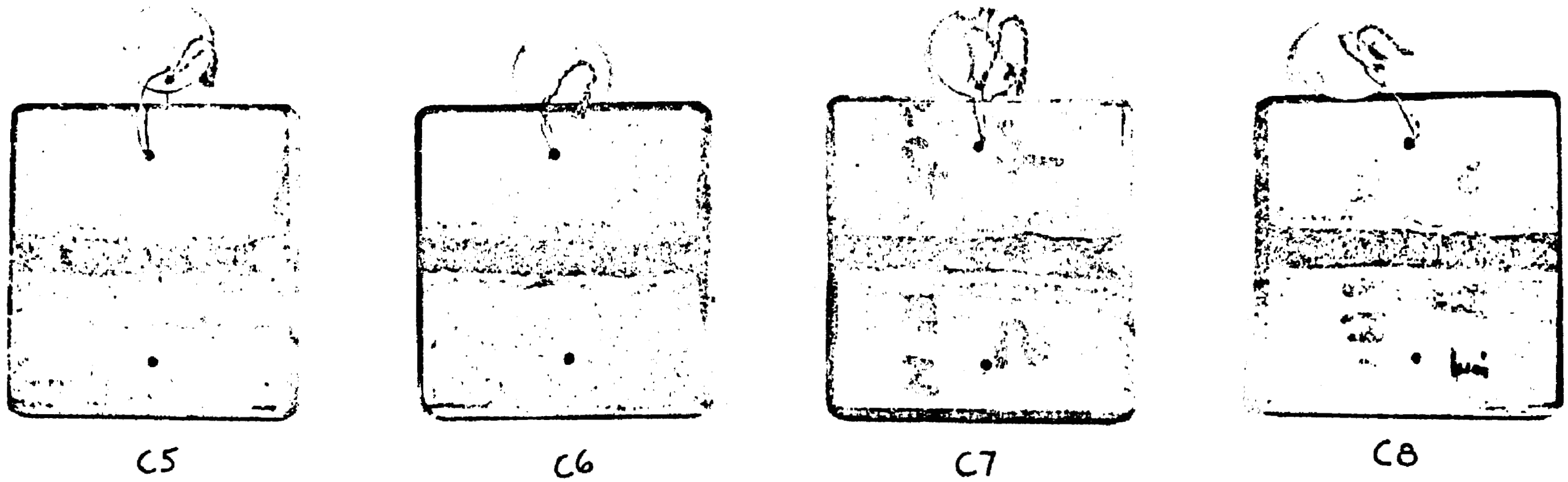

Figure 15b. Half-Size Photograph of Side 2 of System C After the Final Evaluation Following Run 2

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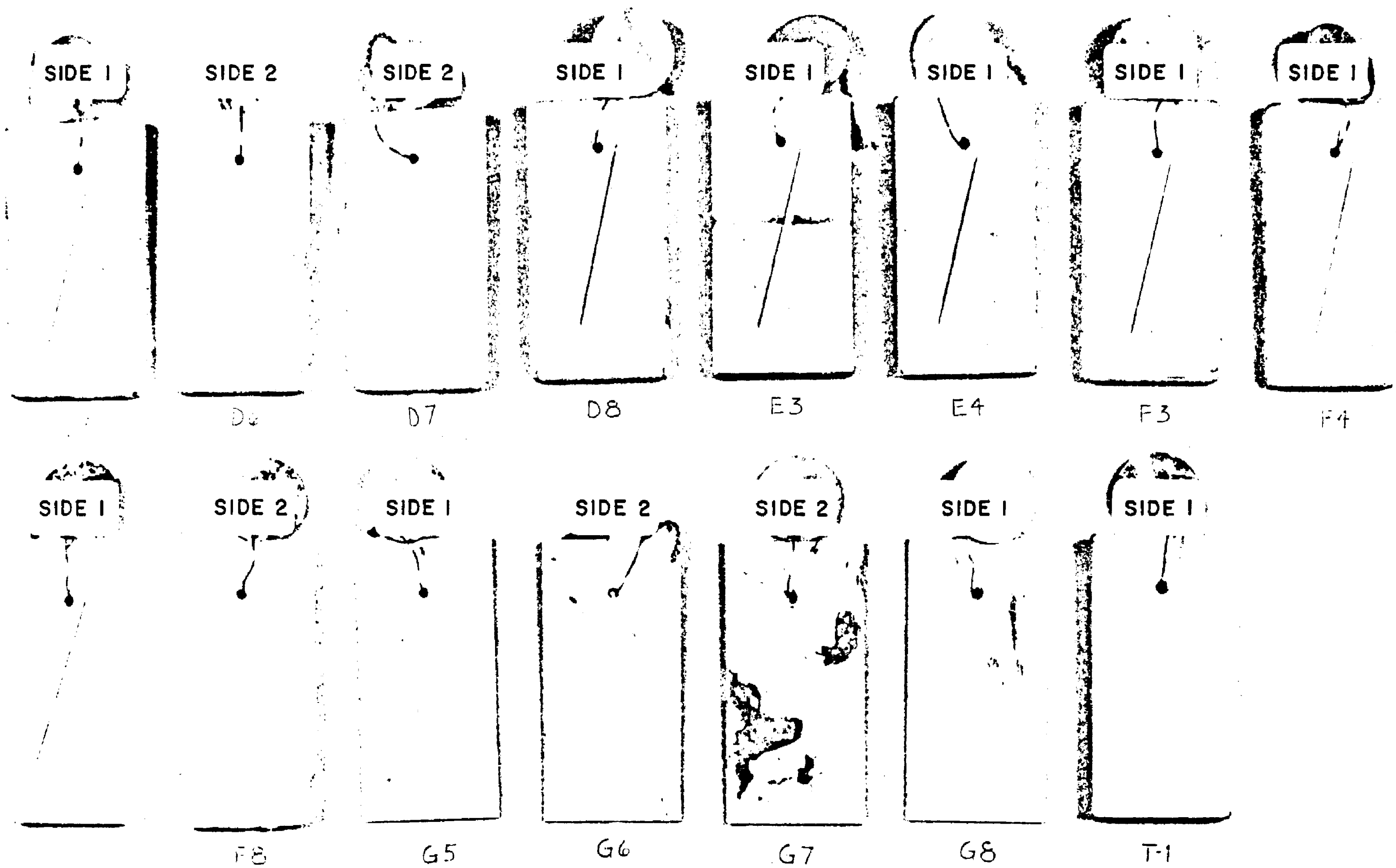


Figure 15c. Half-Size Photograph of Side Evaluated After the Final Evaluation Following Run 2 for Systems D, E, F, G and T

F-C3486

VIII. SUMMARY AND CONCLUSIONS

Samples of coating systems applied to concrete blocks and steel panels and 1 uncoated transite panel were submitted for qualification testing under environmental conditions designed to simulate a Design Basis Accident (DBA). Samples were exposed simultaneously to gamma radiation, steam, and chemical spray.

One-half of the samples were exposed during each of two runs. During the first run the initial rise time to high pressure and temperature took five times longer than the specified rise time, and subsequent steady-state conditions deviated substantially from the specified conditions.

The second run was successful in meeting the test requirements, and the samples tested were considered to have undergone the specified exposure, which encompassed the postulated accident conditions.

The coating systems were evaluated in accordance with ASTM standards for blistering, chalking, flaking, delamination and cracking. Determination of the acceptability of the coatings for nuclear application was not within the scope of this study.

IX. CERTIFICATION

The undersigned certify that this report presents a true account of the tests conducted and results obtained.

Leroy E. Witcher
Test Engineer

Nissen M. Burstein
Project Leader

Salvatore P. Carfagno
Chief
Qualification Testing Section

APPROVED:

Zenons Zudans, Director
Mechanical & Nuclear Engineering
Department

William H. Steigelmann
Manager
Energy Systems Laboratory

Appendix

A

SWEC SPECIFICATIONS AND DOCUMENTS

A.1 NAS 361 - Specification for Testing of Protective Coatings for Design Basis Accident Environment for North Anna Power Station 1975 Extension - North Anna Power Station, Virginia Electric and Power Company, Richmond, Virginia

A.2 NAS 364 - Specification for Test Panels for Design Basis Accident Environment Test for North Anna Power Station 1975 Extension - North Anna Power Station, Virginia Electric and Power Company, Richmond, Virginia

A.3 F.Q.C. Report Summary - SWEC Report of Applied Coating Film Thicknesses

Appendix A.1

NAS 361 - Specification for testing of Protective Coatings for Design Basis Accident Environment for North Anna Power Station 1975 Extension - North Anna Power Station, Virginia Electric and Power Company, Richmond, Virginia

J.O. Nos. 11715/12050
NAS-361
P.O. No. NA-319

March 13, 1972
Revised May 19, 1972
Revised August 14, 1972
Revised October 18, 1972

SPECIFICATION

FOR

TESTING OF PROTECTIVE COATINGS
FOR
DESIGN BASIS ACCIDENT ENVIRONMENT

FOR

NORTH ANNA POWER STATION
1975 EXTENSION-NORTH ANNA POWER STATION

VIRGINIA ELECTRIC AND POWER COMPANY

RICHMOND, VIRGINIA

-:-

EQUIPMENT CATEGORY NA   SELLER: THE FRANKLIN INSTITUTE RESEARCH LABORATORIES

ENGINEERING APPROVAL

REVISIONS	REV. 0	REV. 1	REV. 2	REV. 3
PREPARED BY / LEAD ENGINEER APPROVAL	[signature]	[signature]	[signature]	[signature]
EQUIPMENT SPECIALIST	[signature]	[signature]	[signature]	[signature]
PROJECT ENGINEER	RPW	[signature]	[signature]	[signature]

OTHER REVIEWS

QUALITY ASSURANCE COORDINATOR	PC [signature] 3/27/72	PC [signature] 5/25/72	[signature] 8/22/72	[signature] 10-16-72
CONSTRUCTION MANAGER	X	X	X	X
PSAR COMPLIANCE REVIEW	JRF	JRF	JRF	JRF

STONE & WEBSTER ENGINEERING CORPORATION

J.O.Nos. 11715/12050
NAS-361

SPECIFICATION

FOR

TESTING OF PROTECTIVE COATINGS

FOR

DESIGN BASIS ACCIDENT ENVIRONMENT

FOR

NORTH ANNA POWER STATION

1975 EXTENSION - NORTH ANNA POWER STATION

VIRGINIA ELECTRIC AND POWER COMPANY

-:-

Stone & Webster Eng. Corp., Engrs.

Boston, Mass.
March 13, 1972
Revised May 19, 1972
Revised August 14, 1972
Revised October 18, 1972

GENERAL

The purpose of the specification is to describe the requirements for a test program for protective coating systems proposed for use in the calculated Design Basis Accident environment. The coating systems covered by this specification may be used for coating surfaces within the containment structures of a nuclear power plant if found satisfactory.

DEFINITIONS

Coating System - refers to the substrate, its surface preparation prior to coating, and the topcoats.

DBA - The Design Basis Accident is a double ended rupture of the largest primary loop pipe of a pressurized water reactor which results in a sudden loss of coolant from the primary system.

DBA Environment - the particular set of conditions within the reactor containment structure during and after a DBA, characterized by the temperature and pressure versus time curves, chemical spray and irradiation levels described herein.

DFT - The Dry Film Thickness is the depth of a coating or coating system, when dry, expressed in mils (0.001 inch)

Finish Coat - refers to the topcoat or topcoats applied over a prime coat. Coating materials designed as finish coats may, under certain circumstances, be applied directly to substrates where service conditions do not require the use of prime coat.

Prime Coat - refers to the initial topcoat applied to a substrate. Coating materials designed as prime coats may not generally be used as finish coats.

PWR - a pressurized Water Reactor is a nuclear reactor that uses liquid water under high pressure as a moderator/coolant.

Engineers - Boston Office Structural Engineer,
The address as follows:

Stone & Webster Engineering Corporation
Attn: J. R. Finnimore
P. O. Box 2325
Boston, Mass. 02107

STANDARD SPECIFICATIONS

The following abbreviations refer to the organizations indicated:

ANSI - American National Standards Institute
1430 Broadway, New York, N.Y. 10018

ASTM - American Society for Testing and Materials
1916 Race St., Philadelphia, Pa. 19103

SSPC - Steel Structures Painting Council
4400 Fifth Ave., Pittsburgh, Pa. 15213

SCOPE OF WORK

DBA Environment Test

The testing laboratories shall furnish facilities, apparatus, and personnel to supervise and perform a DBA environment test on coated test panels in accordance with this specification.

DBA Environment Test Report

The testing laboratories shall furnish a written test report to document the test panel identification tag number and the test results, in accoradance with this specification.

WORK NOT INCLUDED 127

Test panels shall be coated, tagged, scribed, and 129
furnished by others in accordance with the Specification for Test
Panels for Design Basis Accident Environment Test, NAS-364. 130

REQUIREMENTS - DBA ENVIRONMENT TEST 134

General 136

The DBA Environment Test shall consist of simultaneous 138
Temperature-Pressure and Irradiation exposures. 139

The temperature-pressure test apparatus shall be as 142
recommended for use in American National Standard, Protective 143
Coatings for Light Water Nuclear Reactor Containment Facilities,
ANSI N101.2, currently in effect, modified as necessary to 144
uniformly irradiate all panels with the specified dose.

The test shall be run continously for seven days 146
(168 hr). All test panels shall be positioned with the 4 in. 147
dimension vertically: The approximate lower third shall be 148
immersed in the recirculation spray solution while the upper two 149
thirds, with the identification tag, shall be exposed to the
recirculation spray.

Tables I, through IV indicate the calculated set of 151
conditions which must be simulated for this test. 152

Test Panel Description 156

Detailed descriptions of test panels are contained in 159
Table I of Specification NAS-364. 160

I.D. No.	Substrate	Size	Specified Face for Photographs and Performance Evaluation	Remarks	
					165 166 167 168
A1-A8	Concrete	4"x2"x2"	Any 4"x2" face	All faces coated except one 2"x2" end	170 171 172
B1-B8	Concrete	4"x2"x2"	Any 4"x2" face	All faces coated except one 2"x2" end	175 176 177
C1-C8	Steel	4"x4"x3/8"	Each 4"x4" face	Front face epoxy coated, back face zinc coated	180 181 182
D1-D8	Steel	4"x2"x3/8"	Any 4"x2" face	Both faces coated	184
E1-E4	Steel	4"x2"x3/8"	Front 4"x2"face	Front face coated Back face un-coated	186 187 188 189

F1-F8	Steel	4"x2"x3/8"	Any 4"x2" face	Both faces coated	19
G1-G8	Steel	4"x2"x20ga.	Any 4"x2" face	Both faces coated	19
G9	Steel	4"x2"x20ga.	Any 4"x2" face	Both faces un-coated	19 19
T1	Transite	4"x2"x3/8"	Any 4"x2" face	Both faces un-coated	19 19

Test panel G-9 (galvanized steel) and T-1 (Transite) are 20
uncoated. Performance evaluations shall be modified as necessary 20
to document changes in the panel material associated with its 20
breakdown or disintegration.

Photographs of Test Panels 20

Photographs of test panels shall be black and white, one 21
half the actual panel size with the identification tag or other 21
similar lettering clearly visible and legible. Photographs shall 21
be taken once prior to the test exposure and once during
subsequent performance evaluations. If more than one face has 21
been specified under "Test Panel Description," photographs shall
show that face demonstrating the least satisfactory performance. 21
Test panel edges and ends shall not be photographed. 21

Performance Evaluation of Test Panels 22

Performance evaluation of the specified faces of test 22
panels shall be conducted at the conclusion of the DBA 22
Environment Test and again at fourteen days after the conclusion 22
of this test. The first evaluation shall be made as soon after 22
the termination of the test as practical, preferably within 22
15 min. During this fourteen day period, test panels will be 22
permitted to dry in air at room ambient conditions.

Performance evaluations shall be for the purpose of 23
defining the degree of:

1. Flaking by ASTM D772, Evaluating Degree of Resistance to 23
Flaking (Scaling) of Exterior Paints 23

2. Blistering by ASTM D714, Standard Method of Evaluating 23
Degree of Blistering of Paints. 23

3. Chalking by ASTM D659, Standard Method of Evaluating 23
Degree of Resistance to Chalking of Exterior Paints. 24

4. Delamination, peeling, or any other changes in coating 24
properties associated with the release of individual 24
coats or the coating system from the substrate, based on
visual inspection.

If more than one face has been specified under "Test 24
Panel Description," written performance evaluations shall pertain 24
to that face which demonstrates the least satisfactory 24

performance. Test panel edges and ends shall be excluded from this evaluation.

REQUIREMENTS FOR DBA ENVIRONMENT TEST REPORT

The DBA Environment Test Report shall contain, as a minimum, the following:

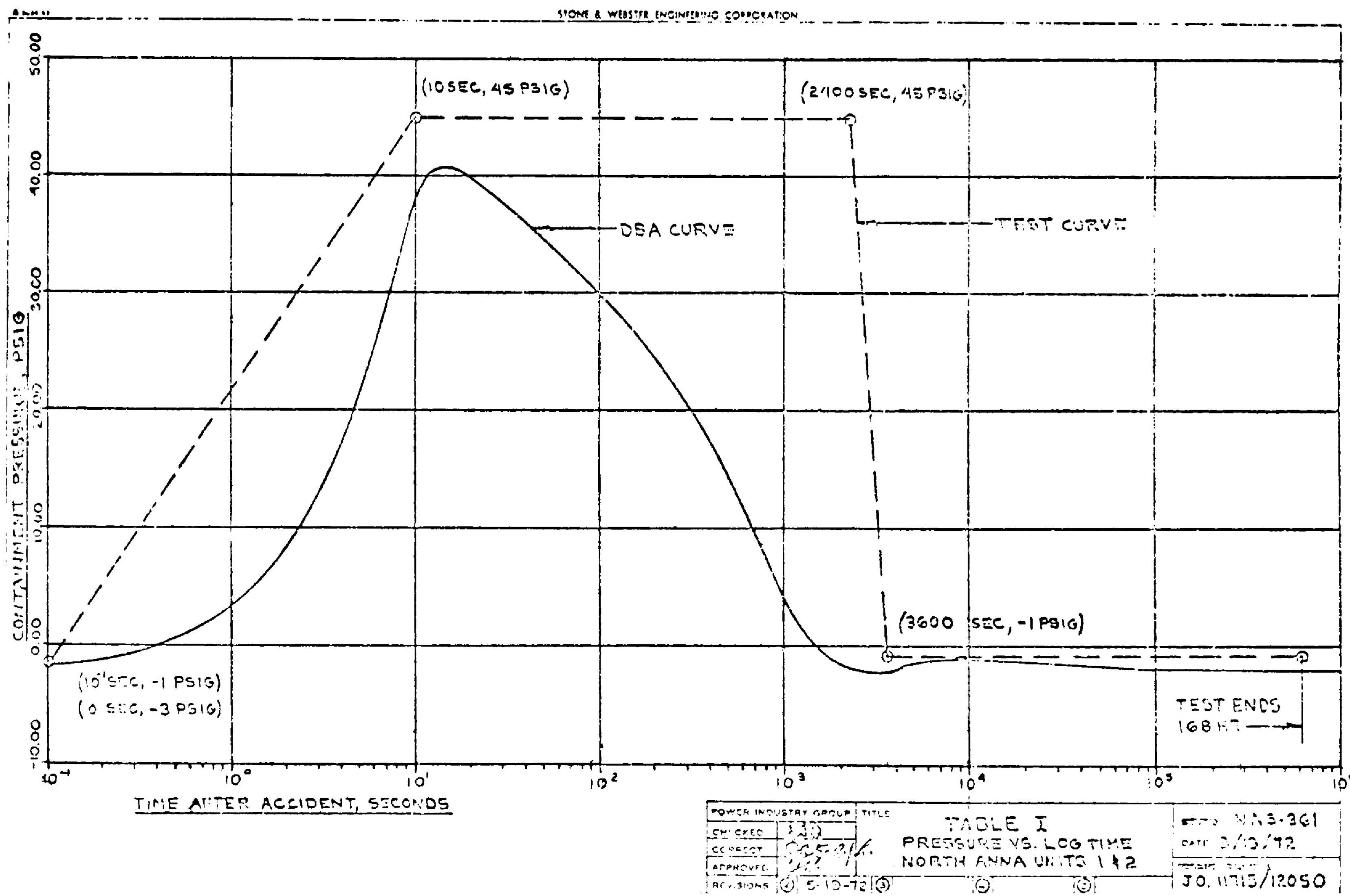
1. Description of test apparatus and procedures.

2. Tabulation of test panel identification tag numbers and performance evaluations for each.

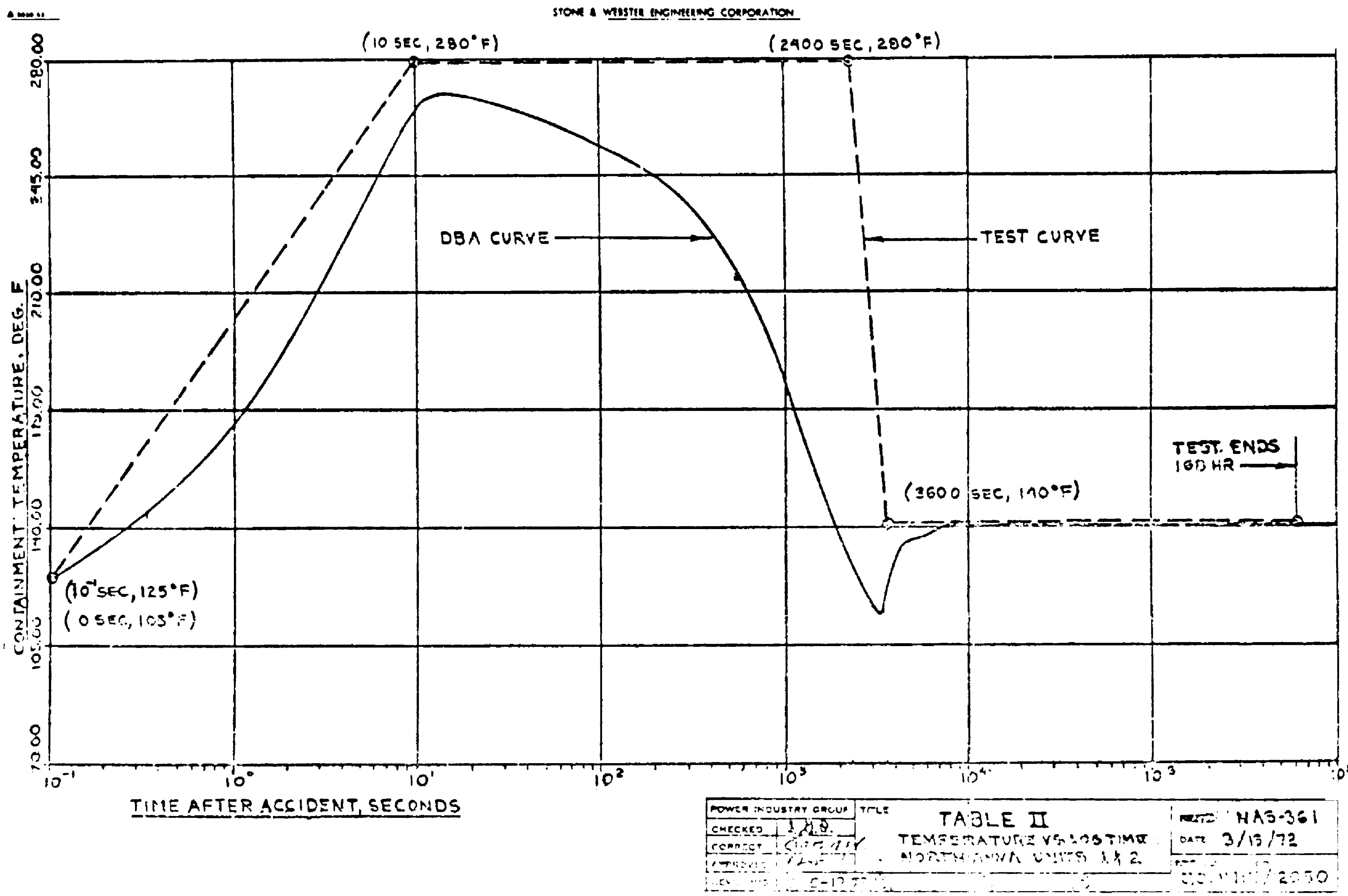
3. Photographs of test panels.

4. Appendices to include this specification, extracts of ASTM standards used for test panel performance evaluation, the Specification for Test Panels for Design Basis Accident Environment, NAS-364, including associated inspection reports, and testing personnel qualification and related experience summaries.

Test panels and this test report shall be shipped complete to the Engineers. Care shall be taken to assure the test panels are handled and packed in such a manner that they will not be damaged. 100 copies of this test report are required.


STONE & WEBSTER ENGINEERING CORPORATION
CONTAINMENT PRESSURE, PSIG
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
(10 SEC, 45 PSIG)
(2400 SEC, 45 PSIG)
DBA CURVE
TEST CURVE
(3600 SEC, -1 PSIG)
(10⁻¹SEC, -1 PSIG)
(0 SEC, -3 PSIG)
TEST ENDS
168 HR
TIME AFTER ACCIDENT, SECONDS
POWER INDUSTRY GROUP
CHECKED
CORRECT
APPROVED
REVISIONS
5-10-72
TITLE
TABLE I
PRESSURE VS. LOG TIME
NORTH ANNA UNITS 1 & 2
DATE 3/13/72
J.O. 11715/12050

Best Copy Available



RECIRCULATION SPRAY CHEMISTRY

TIME	pH	H_3BO_3	NaOH
0-5 min.	4.90	0.19 MOLAR	—
5-60 min.	11.00	0.19 MOLAR	0.184 MOLAR
1-168 hr.	8.05	0.22 MOLAR	0.037 MOLAR

NOTE: THE ABOVE SOLUTION SHALL BE PREPARED USING DEMINERALIZED WATER WITH A CONDUCTIVITY LESS THAN 2.0 μmhos/cm AT 25°C, pH 6.0 TO 8.0 AND A HALIDE CONTENT OF LESS THAN 0.10 ppm

POWER INDUSTRY GROUP		TITLE		
CHECKED	J.A.O.	TABLE III RECIRCULATION SPRAY NORTH ANNA UNITS 1 & 2		NAS-361
CORRECT	[illegible]		DATE:	3/13/72
APPROVED	[illegible]			J.O. 11715/12050
REVISIONS	② 5-19-72			

RADIATION EXPOSURE

TIME	DOSE
FIRST HR.	1.1×10^{6} ROENTGENS
AFTER FIRST HR.	98.9×10^{6} ROENTGENS
TOTAL DOSE	1.0×10^{8} ROENTGENS

POWER INDUSTRY GROUP		TITLE	
CHECKED		TABLE IV IRRADIATION NORTH ANNA UNITS 1&2	[redacted] NAS-361 DATE: 3/13/72
CORRECT			[redacted] J.O. 11715/12[illegible]
APPROVED			
REVISIONS	(2)	(3) (4) (5)	

Appendix A.2

NAS 364 - Specification for Test Panels for Design Basis Accident Environment Test for North Anna Power Station 1975 Extension - North Anna Power Station, Virginia Electric and Power Company, Richmond, Virginia

Appendix A.2

NAS 364 - Specification for Test Panels for Design Basis Accident Environment Test for North Anna Power Station 1975 Extension - North Anna Power Station, Virginia Electric and Power Company, Richmond, Virginia

Best Copy Available

J.O. Nos. 11715/12050
NAS-364

March 13, 1972
Revised May 19, 1972
Revised June 19, 1972
Revised August 14, 1972

SPECIFICATION

FOR

TEST PANELS
FOR
DESIGN BASIS ACCIDENT ENVIRONMENT TEST

FOR

NORTH ANNA POWER STATION
1975 EXTENSION - NORTH ANNA POWER STATION

VIRGINIA ELECTRIC AND POWER COMPANY

RICHMOND, VIRGINIA

-:-

EQUIPMENT CATEGORY NA

ENGINEERING APPROVAL

REVISIONS	REV. 0	REV. 1	REV. 2	REV. 3
PREPARED BY / LEAD ENGINEER APPROVAL	JJO / JRF	JJO / JRF	JJO / JRF	JJO / JRF
EQUIPMENT SPECIALIST	AVS	AVS	AVS	AVS
PROJECT ENGINEER	RPW	RPW	RPW	RPW

OTHER REVIEWS

QUALITY ASSURANCE COORDINATOR	[signature] 3/21/72	[signature] 6/7/72	[signature] 6/26/72	[signature] 8-15-72
CONSTRUCTION MANAGER	X	X	X	X
PSAR COMPLIANCE REVIEW	JRF	JRF	JRF	JRF

STONE & WEBSTER ENGINEERING CORPORATION

SPECIFICATION FOR TEST PANELS FOR DESIGN BASIS ACCIDENT ENVIRONMENT TEST FOR NORTH ANNA POWER STATION

1975 EXTENSION - NORTH ANNA POWER STATION
VIRGINIA ELECTRIC AND POWER COMPANY

Stone & Webster Eng. Corp., Engrs. Boston, Mass.

March 13, 1972
Revised May 19, 1972
Revised June 19, 1972
Revised August 14, 1972

GENERAL

The purpose of this specification is to describe the requirements for furnishing test panels to be used in a Design Basis Accident environment test. The coating systems covered by this specification may be used for coating surfaces within the containment structures of a nuclear power plant if found satisfactory.

DEFINITIONS

Coating System - Refers to the substrate, its surface preparation prior to coating, and the topcoats.

DBA - The Design Basis Accident is a double ended rupture of the largest primary loop pipe of a pressurized water reactor which results in a sudden loss of coolant from the primary system.

DBA Environment - The particular set of conditions within the reactor containment structure during and after a DBA, characterized by the temperature and pressure versus time curves, chemical spray, and irradiation levels described herein.

DFT - The Dry Film Thickness is the depth of a coating or coating system, when dry, expressed in mils (0.001 inch).

Finish Coat - Refers to the topcoat or topcoats applied over a prime coat. Coating materials designed as finish coats may, under certain circumstances, be applied directly to substrates where service conditions do not require the use of a prime coat.

Prime Coat - Refers to the initial topcoat applied to a substrate. Coating materials designed as prime coats may not generally be used as finish coats.

PWR - A Pressurized Water Reactor is a nuclear reactor that uses liquid under high pressure as a moderator/coolant.

STANDARD SPECIFICATIONS

The following abbreviations refer to the organizations indicated:

SSPC - Steel Structures Painting Council
4400 Fifth Avenue
Pittsburgh, Pa. 15213

ASTM - American Society for Testing of Materials
1916 Race Street
Philadelphia, Pa. 19103

AWS - American Welding Society
2501 N.W. Seventh Street
Miami, Fla. 33125

ANSI - American National Standards Institute
1430 Broadway
New York, New York 10018

SCOPE OF WORK

Fabricate, prepare, coat, and furnish, masonry and steel test panels in accordance with this specification, and with the coating systems contained in Table I. Furnish inspection reports in accordance with this specification.

WORK NOT INCLUDED

The DBA environment test shall be performed by others in accordance with the Specification for Testing of Protective Coatings for Design Basis Accident Environment, NAS-361.

Test panel material by others, as required by Table I, will be furnished, pickled on each face, and prime coated on one face only with Carbo Zinc 11. This steel plate conforms to the Specification for Shop Fabrication and Field Erection of Reactor Containment Steel Plate Liner, NAS—41.

Coating materials, product identity certification, and coating application procedures will be furnished by others.

TEST PANEL REQUIREMENTS

Fabrication

Masonry Panels

Masonry panels shall be made of concrete mixed in ratio to the following proportions:

Cement	658 lb	Lone Star Type II
Coarse Aggregate (Dry Basis)	1,465 lb	ASTM C-33, No. 7
Fine Aggregate (Dry Basis)	1,321 lb	ASTM C-33
M.B.V.R	3.2 oz	
Water	42 gal	

and shall be permitted to cure 28 days prior to coating. Form oil or curing compounds shall not be used.

Panel dimensions shall be approximately 4 in. x 2 in. x 2 in. Each panel shall be sleeved with stainless steel to provide a 1/8 in. diam hole, centered along a 2 in. width, 3/4 in. down from the top edge.

Steel Panels

Steel panels shall conform to the material specification and thickness requirements of Table I.

Panels shall be saw cut and ground smooth to dimensions of approximately 4 in. x 2 in. with rounded edges and corners. All panels shall be drilled to provide a 1/8 in. diam hole centered along a 2 in. width, 3/4 in. down from the top edge. Care shall be taken to assure the prime coat on material furnished by others is not damaged during panel fabrication.

Test panels used to simulate liner weld seams (see Table I) shall be fabricated as double panels, i.e. bevelled and double butt welded at adjacent 4 in. edges. Ends of welds should be rounded to the contour of the panel edge. Completed welds shall be checked for surface cracks with dye penetrant on the face to be topcoated only. Double panels showing evidence of surface cracking shall be rejected. Welding electrode shall be AWS, E70XX.

Test panels fabricated from material furnished by 174
others, and which require finish coating over the prime coat
applied by others, shall not be used if the prime coat DFT is
greater than 5.0 mils, as received. 175

Preparation 178

Masonry Panels 180

Surface preparation of panels used to simulate walls and 182
ceilings (see Table I) shall consist of a board form finish, 183
cleaned of laitance, effloresence, and any other loose or 184
otherwise deleterious material. Surface preparation of panels 186
used to simulate floors shall consist of the same requirements
for walls and ceilings and, additionally, assuring surfaces are 187
roughed to the texture of medium flint sandpaper to eliminate any 188
evidence of a board form finish.

Steel Panels 191

Surface preparation of test panel material requiring 193
blast cleaning shall be accomplished by dry abrasive blast in 194
accordance with the requirements of Table I. Visual evaluation 196
to corroborate the required degree of surface preparation shall
be accomplished by use of "pictorial standards," SSPC SP-VIS-1. 197

Surface preparation of test panels fabricated from 199
material furnished by others, and which require finish coating 200
over the prime coat applied by others, shall consist of removing
deleterious materials such as mud, dirt, grease, rust stain, and 201
loose zinc. Initially, the surface shall be scrubbed with a dry, 202
soft bristled brush to remove surface dirt. Loose zinc shall be 204
removed by sanding or rubbing with fine screening. Other loose 205
contaminants shall be removed by washing or hosing with water, 206
tight contaminants by wire brushing, and oil by wiping with
thinner. Additionally, for areas where the prime coat is less 207
than 2.0 mils, the coating shall be cleaned as described and 208
built up to a total minimum DFT of 2.0 mils using a mixture of up 209
to one quart of Carboline Thinner No. 33 to one gallon of Carbo 210
Zinc 11.

Identification 213

Masonry and steel test panels shall be identified with a 215
permanently attached metal disc wired to the 1/8 in. diameter 216
hole of the test panel. The disc shall be stainless steel 218
approximately 1 in. in diameter, stamped with approximately 219
1/2 in. high lettering. Lettering shall be in accordance with 220
the identification number of Table I and shall be affixed to the
test panels prior to surface preparation. Wire shall be of 222
stainless steel. Only one identification tag is required for 223
double panels.

Coating Application 226

Coating application shall be accomplished by the spray 228
method to assure a uniform coating. Application procedures, 231
including ambient conditions, will be furnished by the Boston
Engineers prior to the commencement of coating work. 232

Coating application shall be accomplished in three 234
phases: prime coating, finish coating, and maintenance coating. 235
DFT's for coatings shall be maintained within the specified 236
tolerances.

Single Coating	Deviation From Specified DFT		
			240
Zinc - prime	-0.5 mils	+2.5 mils	242
Epoxy - prime	-0.75 mils	+0.75 mils	243
Epoxy - finish	-0.5 mils	+1.0 mils	244
Epoxy - maintenance	-0.5 mils	+1.0 mils	245
Coating System	**Deviation From Specified DFT**		247
Zinc - Epoxy	-0.5 mils	+3.0 mils	249
All Epoxy	-0.5 mils	+2.0 mils	250

If required to control bubbling on surfaces to which 254
epoxy coatings are applied, the "mist coat" technique shall be 255
used. This technique consists of a fast pass of a thinned 256
topcoat followed almost immediately by a full wet coat. 257

Steel and masonry panels shall be coated only on those 259
faces which have been prepared as required by Table I.

Curing 262

Prime and finish coated test panels not requiring a 264
maintenance coat (see Table I) shall be cured in air for at least 265
two weeks at approximately 70 F.

Prime and finish coated test panels requiring a 268
maintenance coat shall be cured in air at least two weeks at 269
approximately 150 F prior to application of that coat. After 270
maintenance coating, these panels shall again be cured in air for
at least two weeks, but at approximately 70 F. 271

Scribing 274

All steel test panels shall be scribed to base metal, on 276
one coated side only, after initial curing at the specified 277
temperature, regardless of whether they will be maintenance
coated or not. Any suitable sharp pointed tool may be used for 279
this purpose. The scribe should be a single diagonal line, 280

approximately 3 in. long, extending no closer than 1/2 in. to any 281
edge or weld seam across the completed coating system.

Handling and Shipment 284

Test panels shall be shipped complete as directed by the 286
Boston office Structural Engineer. Care shall be taken to assure 289
the test panels are handled and packed in such a manner that the 290
coatings will not be damaged.

CHECKING REQUIREMENTS 293

Test panels shall be checked by the coating applicator 295
prior to coating application to assure proper fabrication, 296
identification and surface preparation.

Coating materials shall be checked prior to use for 299
product identity certification requirements contained in American 300
National Standard, Quality Assurance for Protective Coatings
Applied to Nuclear Facilities, ANSI N101.5.7-1972, Section 3.3.1. 301

Coating application shall be checked by the coating 303
applicator to assure correctness of the coating system and 304
compliance with the manufacturer's approved application
procedures. Each coating of each coating system, including 305
coating work performed by others, shall be checked by the coating 306
applicator to assure the DFT tolerances are maintained for
individual coatings and coating systems. Steel panels shall be 307
checked on coated faces for DFT with a properly calibrated
magnetic gage. Masonry panels shall be checked for DFT with a 308
scratch gage on the 2 in. square coated end.

Curing apparatus shall be checked by the coating 310
applicator to assure that it is capable of performing the 311
specified function.

Scribing of steel panels shall be checked by the coating 313
applicator to assure penetration to substrate. 314

INSPECTION 317

Field Quality Control personnel shall assure that all 319
requirements for checking by the coating applicator are performed 320
and documented as specified.

<u>INSPECTION REPORT</u> 323

An inspection report shall be prepared for each test panel to document the following: 325

1. Test panel number 327

2. Substrate type (concrete or carbon steel) 329

3. Dye penetrant check for welded panels 332

4. Surface preparation 335

    a. By coating applicator or by others 337

    b. If by coating applicator, what degree of surface preparation (also indicate mill profile and abrasive for sand blasted carbon steel panels) 340 341

5. Prime coat 344

    a. If by others indicate DFT 346

    b. If by coating applicator 348

        1. Date/time 350
        2. Coating material - name and batch number 352
        3. Relative humidity 354
        4. Temperature, ambient and surface 356
        5. Dew point 358
        6. DFT 360
        7. Name of applicator 362

6. Each finish and maintenance coat - Repeat 5.b. 365

7. Curing of completed coating systems 367

    a. Date/time entered curing apparatus 369

    b. Date/time removed from curing apparatus 371

    c. Average temperature maintained 373

8. Scribed to substrate - Yes/No (carbon steel panels only) 375

9. Signatures 377

    a. Coating applicator foreman 379

    b. Field Quality Control Inspector 381

10. Coating manufacturer's product identity certification 383

This report should be in tabular form with appropriate columns for each of the items indicated above.

Best Copy Available

;PECTION REPORT

40 49

INAL REPORT

RIP REPORT NO. ____

STONE & WEBSTER ENGINEERING CORPORATION

FIELD [redacted] QUALITY CONTROL

SHEET 1 OF 1

NT: rginia Electric and Power Company	J O NO: 11715/12050	MARK NO
ECT: rth Anna Power Station/1975 Extension	ORDER NO	ITEM NO
DOR: W Field Forces, Surry Power Station	SHOP/ORDER NO	
VENDOR	SHOP NO	
RIPTION: st panels in accordance with Specification NAS-364	VENDOR'S NO	
DOR'S DRAWING(S)	CODE	
REPORT	REPORT PERIOD FROM	TO

NSPECTION AND OCUMENT RECORD	ITEM REQ'D	RECORD REQ'D IN VENDOR FILE	COPIES REQ'D BY S&W	APPROVED	CHECKED	WITNESSED	BY	DATE	DATE RECORD SENT TO BOSTON	DATE RECORD SENT TO JOB BY BOSTON
brication: materials, dimensions, and dye										
enetrant check of welds	x				x					
eparation: attachment of identification										
ags and surface preparation	x					x				
ating material product identity										
ertification	x				x					
ating application procedures	x			x						
ating application: performed in accordance										
ith procedures, correct materials, and										
ithin DFT tolerances	x					x				
ring: adequate apparatus	x				x					
ribing: to base metal, steel panels only	x				x					
ndling and shipment: panels undamaged	x					x				

T ALL DEVIATIONS FROM SPECIFICATION OR DRAWINGS. NAME OF ENGINEER GIVING APPROVAL AND DATE

EMARKS:

Approved" means the inspector will assure the item is approved in accordance with the requirements of the specification.

Checked" means the inspector will assure the item has been checked by the coating applicator in accordance with the requirements of the specification.

itnessed" means the inspector will assure the item is accomplished in accordance with the requirements of the specification by witnessing the coating applicator's work.

FICE	REPORTED BY (SIGNED IF FINAL)	DATE

N03D0084

TABLE I

(SHEET 1 OF 2)

I.D. NO.	SURFACE	TYP. USE	REMARKS	SURFACE PREP.	COAT (NOTE 1) PRIME CODE	PRIME DFT	FIRST FINISH CODE	FIRST FINISH DFT	SECOND FINISH CODE	SECOND FINISH DFT	MAINTENANCE CODE	MAINTENANCE DFT	FINISH COLOR	TTL DFT
A1	CONC.	WALLS &	MAT'L BY FIELD	NOTE 2	HS	2.0	HR	2.0	NONE	—	NONE	—	WHITE	4.0
A2		CEILINGS	PREPARE AND COAT		N	3.0	LR	2.5		—		—		5.5
A3			FOUR FACES AND		ZS	2.0	ZS	2.0		—		—		4.0
A4			ONE END		HS	2.0	HR	2.0		—	HR	2.0		6.0
A5					N	3.0	LR	2.5		—	LR	2.5		8.0
A6					ZS	2.0	ZS	2.0		—	ZS	2.0		6.0
A7					CFM	4.0	NONE	—		—	NONE	—	TAN	4.0
A8					CFM	4.0	NONE	—		—	CFM	2.0	TAN	6.0
B1		FLOORS			HS	2.0	HR	2.0	HS	2.0	NONE	—	GRAY	6.0
B2					N	3.0	LS	2.5	NONE	—		—		5.5
B3					ZS	2.0	ZS	2.0	ZS	2.0		—		6.0
B4					HS	2.0	HR	2.0	HS	2.0	HS	2.0		8.0
B5					N	3.0	LS	2.5	NONE	—	LS	2.5		8.0
B6					ZS	2.0	ZS	2.0	ZS	2.0	ZS	2.0		8.0
B7					CFM	2.0	CFM	4.0	NONE	—	NONE	—	TAN	6.0
B8					CFM	2.0	CFM	4.0	NONE	—	CFM	2.0	TAN	8.0
C1	STEEL,	LINER WELD	MAT'L BY OTHERS	SP-6	Z	2.5	HS	2.0	HR	2.0	NONE	—	WHITE	6.5
C2	ASTM	SEAM	PREPARE AND COAT	SP-6	Z	2.5	ZR	4.0	NONE	—		—		6.5
C3	A-516,		PICKLED FACE ONLY	SP-10	Z	2.5	HS	2.0	HR	2.0		—		6.5
C4	3/8 in		SEE NOTE 3	SP-10	Z	2.5	ZR	4.0	NONE	—		—		6.5
C5				SP-6	Z	2.5	HS	2.0	HR	2.0	HR	2.0		8.5
C6				SP-6	Z	2.5	ZR	4.0	NONE	—	ZS	2.0		8.5
C7				SP-10	Z	2.5	HS	2.0	HR	2.0	HR	2.0		8.5
C8				SP-10	Z	2.5	ZR	4.0	NONE	—	ZS	2.0		8.5
D1	STEEL,	STRUC. STEEL	MAT'L BY FIELD	SP-6	N	3.0	LR	2.5	NONE	—	NONE	—		5.5
D2	ASTM	MOTORS, PUMPS	PREPARE AND COAT	SP-6	HR	2.0	HS	2.0	HR	2.0		—		6.0
D3	A-36,	UNITS, PIPE,	BOTH FACES AND	SP-10	N	3.0	LR	2.5	NONE	—		—		5.5
D4	3/8 IN	MISC. STEEL	ALL EDGES	SP-10	HR	2.0	HS	2.0	HR	2.0		—		6.0
D5				SP-6	N	3.0	LR	2.5	NONE	—	LR	2.5		8.0
D6				SP-6	HR	2.0	HS	2.0	HR	2.0	HR	2.0		8.0
D7				SP-10	N	3.0	LR	2.5	NONE	—	LR	2.5		8.0
D8				SP-10	HR	2.0	HS	2.0	HR	2.0	HR	2.0		8.0
E1	STEEL,	LINER	MAT'L BY OTHERS	BY OTHERS			HS	2.0	HR	2.0	NONE	—		6.5
E2	ASTM		PREPARE AND COAT				ZR	4.0	NONE	—	NONE	—		6.5
E3	A-516,		PRIMED FACE ONLY				HS	2.0	HR	2.0	HR	2.0		8.5
E4	3/8 in		SEE NOTE 3				ZR	4.0	NONE	—	ZS	2.0		8.5
F1	STEEL,	LINER	MAT'L BY FIELD	SP-6	CPRM	3.0	CFM	4.0	NONE	—	NONE	—	TAN	7.0
F2	ASTM		PREPARE AND COAT	SP-10	CPRM	3.0	CFM	4.0		—	NONE	—		7.0
F3	A-36		BOTH FACES AND	SP-6	CPRM	3.0	CFM	4.0		—	CFM	2.0		9.0
F4	3/8 IN		ALL EDGES	SP-10	CPRM	3.0	CFM	4.0		—	CFM	2.0		9.0
F5				SP-6	HZ	3.0	HS	2.0	HR	2.0	NONE	—	WHITE	7.0
F6				SP-10	HZ	3.0	HS	2.0	HR	2.0	NONE	—		7.0
F7				SP-6	HZ	3.0	HS	2.0	HR	2.0	HR	2.0		9.0
F8				SP-10	HZ	3.0	HS	2.0	HR	2.0	HR	2.0		9.0

NOTES

1. COATING MATERIAL CODE

HR*	E.I. duPONT de NEMOURS	CORLAR WHITE	823-8022
HS*	" "	CORLAR HORIZON GRAY	823-8021
HZ	" "	GANICIN (INORGANIC)	347-931
N	KEELER & LONG	EPOXY WHITE PRIMER	7107
LR	" "	EPOXY WHITE ENAMEL	7475
LS	" "	EPOXY HORZ. GRAY ENAML	8392
Z	CARBOLINE	CARBO ZINC 11, GREEN	
ZR	"	CARBOLINE 190 HBW	
ZS		CARBOLINE 193 FINISH	
CPRM	MOBIL CHEMICAL	MOBIL ZINC 7	
CFM	" "	MOBIL 89 HI-BUILD EPOXY LIGHT BUFF (TAN)	

* USE GLOSS ACTIVATOR YG 8339

2. SEE THIS SPEC., PREPARATION-MASONRY PANELS
3. PRIME COATED LINER MATERIAL BY OTHERS HAS BEEN PICKLED ON EACH FACE AND PRIME COATED ON ONE FACE ONLY WITH CARBO ZINC 11, 2.5 MILLS DFT, IN ACCORDANCE WITH SPEC. NAS-41. SEE THIS SPEC., PREPARATION-STEEL PANELS
4. ACID ETCH IN ACCORDANCE WITH MFGR'S INSTRUCTIONS USING GALVAPREP 45, PORTER COATING DIV., LOUISVILLE, KY. OR AMERCOAT NO. 59 ETCHANT, AMERON, BREA, CALIF., OR APPROVED EQUAL.
5. FLAT TRANSITE, MFG JOHNS-MANVILLE, 4" x 2" x 3/8" THICK BY OTHERS.

TEST PANEL COATING SYSTEMS
NORTH ANNA UNITS 1 & 2
VIRGINIA ELECTRIC & POWER CO

7	6	5	4	3	2	
			8-14-72 J.D.	6-19-72 J.D.	5-19-72 REDRAWN J.D.	3-13-72 JGD

STONE & WEBSTER ENGINEERING CORPORATION
J.O. NOS. 11715/12050 [redacted] AS-354

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TABLE I

(SHEET 2OF2)

ID NO.	SURFACE	TYP. USE	REMARKS	SURFACE PREP.	COAT: PRIME CODE	PRIME DFT	FIRST FINISH CODE	FIRST FINISH DFT	SECOND FINISH CODE	SECOND FINISH DFT	MAINTENANCE CODE	MAINTENANCE DFT	FINISH COLOR	TTL DFT
G1	STEEL,	GALVANIZED	MAT'L BY FIELD	SP-1	HR	2.0	NONE	—	NONE	—	NONE	—	WHITE	2.0
G2	ASTM	VENT DUCT	PREPARE AND COAT	SP-1	CFM	2.0	NONE	—	↓	—	↓	—	TAN	2.0
G3	A-527	↓	BOTH FACES AND	SP-1	ZR	2.0	NONE	—	↓	—	↓	—	WHITE	2.0
G4	20GA.,	↓	ALL EDGES	SP-1	N	3.0	LR	2.5	↓	—	↓	—	WHITE	5.5
G5	COATING	↓	↓	NOTE 4	HR	2.0	NONE	—	↓	—	↓	—	WHITE	2.0
G6	CLASS125	↓	↓	↓	CFM	2.0	NONE	—	↓	—	↓	—	TAN	2.0
G7	COMMERCIAL	↓	↓	↓	ZR	2.0	NONE	—	↓	—	↓	—	WHITE	2.0
G8	↓	↓	↓	↓	N	3.0	LR	2.5	↓	—	↓	—	WHITE	5.5
G9	↓	↓	UNCOATED	←					NA					→
T1	TRANSITE	SIDING	UNCOATED, SEE NOTE 5	←					NA					→

7	6	5	4	3	2	8-14-72	1	6-19-72

TEST PANEL COATING SYSTEMS
NORTH ANNA UNITS 1 & 2
VIRGINIA ELECTRIC & POWER CO.

STONE & WEBSTER ENGINEERING CORPORATION

[illegible] NGS [illegible] 5/ 2350 [redacted] [illegible]

Appendix A.3

F.Q.C. Report Summary - SWEC Report of Applied Coating Film Thicknesses

Best Copy Available

STONE & WEBSTER ENGINEERING CORPORATION

FIELD QUALITY CONTROL REPORT SUMMARY

APPLIED COATING FILM THICKNESSES

I.D. NO.	COAT: PRIME CODE	PRIME DFT	FIRST FINISH CODE	FIRST FINISH DFT	SECOND FINISH CODE	SECOND FINISH DFT	MAINTENANCE CODE	MAINTENANCE DFT	FINISH COLOR	TTL DFT	
A 1	HS	*	HR	*	none	—	none	—	White	4.1	
A 2	N	2.5	LR	3.5	↓	—	none	—	↓	6.0	
A 3	ZS	*	ZS	*	↓	—	none	—	↓	5.5	
A 4	HS	2.0	HR	2.5	↓	—	HR	1.8	↓	6.3	
A 5	N	3.0	LR	3.0	↓	—	LR	2.5	↓	8.5	
A 6	ZS	2.6	ZS	2.9	↓	—	ZS	2.4	↓	7.9	
A 7	CFM	6.0	none	—	↓	—	none	—	Tan	6.0	
A 8	CFM	6.0	none	—	↓	—	CFM	1.5	Tan	7.5	
B 1	HS	2.3	HR	2.5	HS	2.2	none	—	Gray	7.0	
B 2	N	3.0	LS	3.0	none	—	none	—	↓	6.0	
B 3	ZS	2.2	ZS	2.8	ZS	3.0	none	—	↓	8.0	
B 4	HS	2.4	HR	2.6	HS	2.0	HS	3.0	↓	10.0	
B 5	N	2.5	LS	3.5	none	—	LS	3.0	↓	5.0	
B 6	ZS	2.7	ZS	2.5	ZS	2.6	ZS	2.1	↓	9.9	
B 7	CFM	2.8	CFM	5.2	none	—	none	—	Tan	8.0	
B 8	CFM	2.8	CFM	6.2	none	—	CFM	1.0	Tan	10.0	
C 1	Z	3.0	HS	2.5	HR	1.6	none	—	White	7.1	FRONT SIDE
C 2	Z	2.8	ZR	3.9	none	—	none	—	↓	6.7	FRONT SIDE
C 3	Z	2.6	HS	2.9	HR	2.5	none	—	↓	8.0	FRONT SIDE
C 4	Z	3.2	ZR	4.0	none	—	none	—	↓	7.2	FRONT SIDE
C 5	Z	2.6	HS	2.3	HR	2.1	HR	2.0	↓	9.0	FRONT SIDE
C 6	Z	3.4	ZR	4.0	none	—	ZS	3.5	↓	10.9	FRONT SIDE
C 7	Z	2.5	HS	3.3	HR	1.9	HR	1.8	↓	9.5	FRONT SIDE
C 8	Z	3.0	ZR	3.5	none	—	ZS	3.0	↓	9.5	FRONT SIDE
C 1	Z	3.5	none	—	none	—	none	—	Gray	3.5	BACK SIDE
C 2	Z	2.3	↓	—	↓	—	↓	—	↓	2.3	BACK SIDE
C 3	Z	3.8	↓	—	↓	—	↓	—	↓	3.8	BACK SIDE
C 4	Z	3.5	↓	—	↓	—	↓	—	↓	3.5	BACK SIDE
C 5	Z	2.5	↓	—	↓	—	↓	—	↓	2.5	BACK SIDE
C 6	Z	2.5	↓	—	↓	—	↓	—	↓	2.5	BACK SIDE
C 7	Z	3.0	↓	—	↓	—	↓	—	↓	3.0	BACK SIDE
C 8	Z	3.5	↓	—	↓	—	↓	—	↓	3.5	BACK SIDE
D 1	N	2.5	LR	3.5	none	—	none	—	White	6.0	
D 2	HR	2.6	HS	2.0	HR	1.9	none	—	↓	6.5	
D 3	N	3.2	LR	2.4	none	—	none	—	↓	5.6	
D 4	HR	2.3	HS	2.4	HR	1.4	none	—	↓	6.1	

I.D. NO.	COAT: PRIME CODE	PRIME DFT	FIRST FINISH CODE	FIRST FINISH DFT	SECOND FINISH CODE	SECOND FINISH DFT	MAINTENANCE CODE	MAINTENANCE DFT	FINISH COLOR	TTL DFT
D 5	N	2.5	LR	3.7	none	—	LR	3.0	White	9.2
D 6	HR	2.4	HS	2.4	HR	1.6	HR	1.6	↓	8.0
D 7	N	3.1	LR	2.7	none	—	LR	2.6	↓	8.4
D 8	HR	1.8	HS	2.7	HR	2.0	HR	1.6	↓	8.1
E 1	Z	4.3	HS	0.9	HR	2.4	none	--	White	7.6
E 2	Z	3.7	ZR	3.8	none	—	none	—	↓	7.5
E 3	Z	4.1	HS	1.8	HR	2.1	HR	2.2	↓	10.2
E 4	Z	4.3	ZR	3.7	none	—	ZS	2.0	↓	10.0
F 1	CPRM	4.3	CFM	4.9	none	—	none	—	Tan	9.2
F 2	CPRM	3.7	CFM	5.0	none	—	none	—	↓	8.7
F 3	CPRM	3.6	CFM	6.9	none	—	CFM	2.0	↓	12.5
F 4	CPRM	3.6	CFM	4.1	none	—	CFM	1.5	↓	9.2
F 5	HZ	2.0	HS	1.0	HR	2.4	none		White	7.0
F 6	HZ	3.8	HS	1.7	HR	2.8	none	—	↓	8.3
F 7	HZ	3.5	HS	2.3	HR	2.7	HR	1.5	↓	10.0
F 8	HZ	3.3	HS	3.0	HR	2.1	HR	2.0	↓	10.4
G 1	HR	1.9	none	—	none	—	none	—	White	1.9
G 2	CFM	3.0	none	—	↓	—	↓	—	Tan	3.0
G 3	ZR	2.7	none	—	↓	—	↓	—	White	2.7
G 4	N	3.4	LR	3.9	↓	—	↓	--	White	7.3
G 5	HR	2.1	none	—	↓	—	↓	—	White	2.1
G 6	CFM	3.2	none	—	↓	—	↓	—	Tan	3.2
G 7	ZR	2.8	none	—	↓	—	↓	—	White	2.8
G 8	N	3.0	LR	3.7	↓	—	↓	—	White	6.7
G 9	← UNCOATED →									
T 1	← UNCOATED →									

NOTES

1. INFORMATION SHOWN TAKEN FROM "F.Q.C. REPORT FOR SPEC. NAS-364, TEST PANELS FOR DBA ENVIRONMENT TEST", 8-16-72.
2. SEE SPEC. NAS-364 FOR COATING MATERIAL CODE
3. DFT IN MILS (.001 INCH)

POWER INDUSTRY GROUP	TITLE	
CHECKED: JJO.	F.Q.C. REPORT SUMMARY	SCALE: None
CORRECT: MJ		DATE: 9-25-72
APPROVED: JRF		SKETCH NUMBER: None
REVISIONS: ② ③ ④ ⑤		

Appendix

B

COATING SYSTEM PERFORMANCE EVALUATION DATA SHEETS

B.1 Visual Inspection of Samples Upon Receipt

B.2 Run 1 Initial Evaluation

B.3 Run 1 Final Evaluation

B.4 Run 2 Initial Evaluation

B.5 Run 2 Final Evaluation

Appendix B.1

Visual Inspection of Samples Upon Receipt

COMPUTED BY	DATE	THE FRANKLIN INSTITUTE RESEARCH LABORATORIES PHILADELPHIA, PA. 19103	PAGE
A.H.B.	5/72		1 of 6
CHECKED BY	DATE		PROJECT No. 18-C3456-01

TITLE VISUAL INSPECTION REPORT

SPONSOR: [illegible]

Item	Comments	OBS.	Date
A1.	All [illegible] holes on all surfaces of [illegible] — Pinhole size up to 1/8" dia. 4 scribe lines on top surface	[illegible]	9-17-[illegible]
A2	As above except 3 scribe lines on top [illegible]		
A3	As in A1 except holes are generally larger — [illegible] up to 3/16 [illegible]. Also area around hole where wire comes out has irregular cavities up to 1/2 in length & 1/8" in width. One scratch on top		
A4	Few pin holes on all surfaces. Three scribbles on top.		
A5	As A4		
A6	As A3 except cavities [illegible] up to [illegible] 1/4 [illegible]		
A7	As A4 except one scratch on top. Also scrape mark on top 1/8 x 1/4 [illegible]		
A8	As A4		
B1	As A1 except [illegible] has more [illegible] pin holes. One scratch mark on top [illegible]		
B2	As A1 except 2 scratch marks on top		
B3	As B2		

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N.M.B.	5/72	THE FRANKLIN INSTITUTE RESEARCH LABORATORIES PHILADELPHIA, PA. 19103	2 of 2
CHECKED BY	DATE		PROJECT No. 185-C3480-01

TITLE VISUAL INSPECTION REPORT

SPONSOR: Stone & Webster

Item	Comments	OBS.	Date
B4	Some pin holes & up to 1/16 dia. on all surfaces. Two scratch marks on top. One face has paint which ran & dried ≈ 1/4 from bottom.	[illegible]	[illegible]
B5	One scratch mark on top & many gas holes on surfaces.		
B6	Some pin holes on all surfaces. Two scratch marks on top.		
B7	Many gas holes on all surfaces. Four scratch marks on top.		
B8	As B7 except scratch marks on top number ≈ 10.		
C1	Few blister like # 8 marks on [illegible]		
C2	Crater marks similar to # 8 blisters in [illegible] on right side of panel. Density - few		
C3	1/32 dia. [illegible] imperfections mainly along welded seam.		
C4	Top coat missing in small area right side of panel 1/2 from bottom & 1 1/4 from bottom.		
C5	Several blister like marks ≈ 1/32 dia. scattered. 1 - 1/16 " " " 1 1/8 from left edge & 5/8 from bottom.		
C6	< 1/64 dia blister like marks MD in density	↓	↓

Best Copy Available

A.O.I.B.	5/72	THE FRANKLIN INSTITUTE RESEARCH LABORATORIES PHILADELPHIA, PA. 19103	2 of 2
CHECKED BY	DATE		PROJECT No. 18I-C3492-01

TITLE: VISUAL INSPECTION REPORT

SPONSOR: STONE & WEBSTER

Item	Comments	OBS.	Date
C7.	3 - 1/32" dia. blister like marks near upper hole		
C8	Scattered 1/32" dia. blister like marks ≈ 10 in number, mainly in upper half of panel. < 1/64" dia. MD blister like marks covering all of panel.		
D1	1 - 1/32" blister like mark 1/2" from top & 1/4" from right edge		
D2	A few scattered < 1/32" dia. blister like imperfections on side [illegible]		
D3	Side 1 (1 - 1/64) blister on right edge 1 1/2" from top Side 2 1 - 1/32 dia mark raised 1/4" from right edge ≈ 1" from bottom		
D4	Side 1 - Scattered few 1/64 blister like marks " 2 - OK		
D5	Side 1 - 2 - 1/64 blister like marks 1 1/2" from bottom center Side 2 - 2 as on side 1 top left size		
D6	Side 1 - 1/32 imperfection bottom edge right side " 2 - OK		
D7	Side 1 - 3 irregular shaped marks along bottom edge Side 2 - A few scattered 1/64 blister like marks		
D8	Side 1 - 1/64 to 1/32 marks dark in color similar to collapsed blisters. Scattered a few in [illegible] Side 2 - A few scattered blister like marks < 1/32 in dia.		

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K.M.B.	5/72	THE FRANKLIN INSTITUTE RESEARCH LABORATORIES PHILADELPHIA, PA. 19103	4 of 6
CHECKED BY	DATE		PROJECT No. 18I-C3486-01

TITLE VISUAL INSPECTION REPORT

SPONSOR: STONE & WEBSTER

Item	Comments	OBS.	Date
E1.	Scribe line appears to have lifted paint along right side, back ≈ 1/16	[illegible]	7/1/72
E2	1-1/32 blister like mark near center of panel, pack mark or collapsed blister like marks medium in density.		
E3	Coating seems to be raised slightly along right side of scribe line, back ≈ 1/..		
E4	Two 1/64 & 1/32 blister like marks, top [illegible] <#8 (Fin) MD " all over surface		
F1	Side 1 - Crater marks or collapsed blister like marks ≈ 8M Side 2 - As side 1 only < size 8		
F2	As F1		
F3	Side 1 - As in F2 side 2 above only 8F plus 3 craters up to 1/16" dia top left side Side 2 8F craters		
F4	Side 1 - As in F1 side 1 mainly in upper half of panel Side 2 - As in F1 side 1		
F5	Side 1 - Scratch mark 1/4 long along scribe line. A couple of scattered #8 blister like marks. Side 2 - Dippled surface		
F6	Side 1 - Paint runs left side 1/4" from top Side 2 - Gouge mark top [illegible] 3/.. long.	↓	↓

B.1-4

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A.M.B. 5/72 CHECKED BY DATE	THE FRANKLIN INSTITUTE RESEARCH LABORATORIES PHILADELPHIA, PA. 19103	5 of 6 PROJECT No. 18I-C3486-0	

TITLE VISUAL INSPECTION REPORT

SPONSOR: STONE & WEBSTER

Item	Comments	OBS.	Date
F7	Side 1 Very fine cracks over hole, center, [illegible]. Side 2 - Two imperfections 1/16" [illegible] top left side & 3/4" from left side, 1 3/8" from bottom.		
F8	Side 1 - Numerous pin holes scattered & dark in color. Paint also sagged in spots. Side 2 - 1/8 [illegible] surface imperfection left side, center.		
G1	Side 1 - 1/16" blister like mark 3/4 from right side & 1 3/8 from bottom. Paint very wavy in appearance. Side 2 - Paint sag top left side.		
G2	Side 1 - Paint coating appears to be very thin, scarcely covering @ bottom & around hole. Side 2 - As side 1		
G3	Side 1 - A few blister like marks up to 1/16 dia. Tracking along bottom edge where there is an absence of paint. Side 2 - OK except for an absence of paint in 4 small areas near bottom.		
G4	Side 1 - ok but paint has slight ripple & bottom edge has paint sag. Side 2 - as side 1		
G5	Side 1 - Paint has ripple. Side 2 - " " ", Also 2 runs near hole.		
G6	Side 1 - Absence of paint where tracking is 3/4" from bottom. Side 2 - As side 1, also few blisters [illegible] ≈ 1/64 dia		

Form 207 10M 12-66 OGILVIE PRESS DIVISION GRAPHIC CONTROLS CORP., BROOKLYN, N. Y. 11217 STOCK NO. 450

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K.M.B.	5/72	THE FRANKLIN INSTITUTE RESEARCH LABORATORIES PHILADELPHIA, PA. 19103	6 of 6
CHECKED BY	DATE		PROJECT No. I8I-C3482-01

TITLE VISUAL INSPECTION REPORT

SPONSOR: [illegible]

Item	Comments	OBS.	Date
G7	Side 1 Paint chipped along right [illegible] scribe line up to 1/16 [illegible] of paint where tracking near bottom. Side 2: Tracking marks near bottom	[illegible]	[illegible]
G8	Side 1 - 1/2 dia dimple marks all over panel. Side 2 - Upper 1/8 dia marks [illegible] side 1 located in upper 1/3 of panel. Surface rippled [illegible] [illegible] near hole.		
G9	[illegible] galling [illegible] marks on [illegible]		
T1	[illegible] smooth, other [illegible] pattern	V	V

Appendix B.2

Run 1 Initial Evaluation

PAINT SAMPLE EVALUATION **PROJ. NO. C3486**

DATE: [illegible]
RUN NO. 1
BY: [illegible] + [illegible]
*SAMPLE NO. A-1

Side 2

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	8 > F	
FLAKING (ASTM D772)	N	
DELAMINATION / PEELING / CRACKING / CHECKING	N	

COMMENTS: [illegible] pinhole to 1/16 in [illegible]
other 3 faces same
black is over white

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION **PROJ. NO. C3486**

DATE: 11/20/72 [illegible]

BY: [illegible]

RUN NO. 1

*SAMPLE NO. A-2

Side 1

CHALKING (ASTM D659)	[illegible] in vapor phase [illegible]	
BLISTERING (ASTM D714)	8F in liquid phase	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: [illegible] holes from pin to 1/32 [illegible]

[illegible] White color

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 11/20/82

RUN NO. 1

BY: [illegible]

*SAMPLE NO. A-3

Side 2

CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	7F mostly in lower right corner liquid [illegible]	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: 1 - 1/8 dia [illegible] on side 4
Numerous holes & cavities ranging up to 1/8" on side 2
[illegible]

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 11/20/72

RUN NO. 1

BY: N.T.B. & G.J.V.

*SAMPLE NO. A-7

Side 1

CHALKING (ASTM D659)	7.5	
BLISTERING (ASTM D714)	1- 1/16 in. & 2- 1/32 dia. lower right corner liquid phase	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Some pinholes Tan colored

*EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: [illegible]
RUN NO. 1
BY: [illegible]
*SAMPLE NO. B-1

Side [illegible]

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	9M	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: All [illegible] sides ≃ same
Gray colored all sides

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 11/20/72 RUN NO. 1

BY: [illegible] *SAMPLE NO. B-2

Side 1

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	9F in liquid phase	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Some [illegible] up to [illegible]
Black to gray

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 11/20/72 RUN NO. 1

BY: N.M.E. &
G.J. L. *SAMPLE NO. B-3

Side 3

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	3 large blisters from 1/4" to 1/2" dia.	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Few pin holes
Gray Colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

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PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 11/20/72

BY: N. M. B. &

G. J. V.

RUN NO. 1

*SAMPLE NO. B-7

Side 3

CHALKING (ASTM D659)	10-	
BLISTERING (ASTM D714)	Several blisters from 1/32 dia up to 3/16 dia. right edge	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Few pin holes
Tan colored

*EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION **PROJ. NO. C3486**

DATE: 11/20/72 RUN NO. 1

BY: [illegible] & [illegible] *SAMPLE NO. C-1

	Front	Back
CHALKING (ASTM D659)	10-	9+
BLISTERING (ASTM D714)	N	N
FLAKING (ASTM D772)	N	N
DELAMINATION PEELING CRACKING CHECKING	N	N

COMMENTS: Paint slightly [illegible] line
Cream colored | Slight rust [illegible] along [illegible]

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION **PROJ. NO. C3486**

DATE: 11/20/72 RUN NO. 1

BY: N.M.B. & G.J.V. *SAMPLE NO. C-2

	Front	Back
CHALKING (ASTM D659)	10-	7.5
BLISTERING (ASTM D714)	#8 Medium collapsed along right edge	N
FLAKING (ASTM D772)	N	N
DELAMINATION, PEELING, CRACKING, CHECKING	N	N
COMMENTS:	Slight rusting in scribe. Cream colored	Discoloration along weld with rust colored spots.

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 11/20/72 RUN NO. 1

BY: N.M.B. [illegible] *SAMPLE NO. C-3

G.W.V.

	Front	Back
CHALKING (ASTM D659)	10-	9
BLISTERING (ASTM D714)	N	N
FLAKING (ASTM D772)	N	N
DELAMINATION, PEELING, CRACKING, CHECKING	N	N

COMMENTS: Some small surface imperfections projecting above surface. Slight raise in paint along scribe. Cream colored.

Slight [illegible] colored spots [illegible]

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION — PROJ. NO. C3486

DATE: 11/20/72 — RUN NO. 1

BY: N.M.R. & G.J.V. — *SAMPLE NO. C-4

	Front	Back
CHALKING (ASTM D659)	N	9
BLISTERING (ASTM D714)	N	N
FLAKING (ASTM D772)	N	N
DELAMINATION / PEELING / CRACKING / CHECKING	N	N

COMMENTS:

Cream in color

Bare interrupted streak along right edge ≈ 1 inch long

Dense pinhole size pock marks in liquid phase

Rust colored in scribe line

White foreign substance in liquid phase.

Rust spots along weld

Semi circle of paint outline around tag hole

*EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 11/20/72 RUN NO. 1

BY: N.M.B. & G.J.V. *SAMPLE NO. D-1

Side 1

CHALKING (ASTM D659)	8	
BLISTERING (ASTM D714)	N	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Rust colored in scribe
cream colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 11/20/72 RUN NO. 1

BY: N. M. B. & G. J. V *SAMPLE NO. D-2

Side 2

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	<8 MD	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Rust colored in scribe - liquid phase side 1
Cream colored

*EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 11/20/72 RUN NO. 1

BY: N. M. B. & G. J. V. *SAMPLE NO. D-3

Side 2

CHALKING (ASTM D659)	9+	
BLISTERING (ASTM D714)	7M – Vapor phase	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: 8M - left side liquid phase
Side 1
Cream colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 11/20/72 RUN NO. 1

BY: N.M.B. + G.J.V. *SAMPLE NO. D-4

Side 1

CHALKING (ASTM D659)	9.5	
BLISTERING (ASTM D714)	7M in center of panel.	
FLAKING (ASTM D772)	N	
DELAMINATION, PEELING, CRACKING, CHECKING	N	

COMMENTS: Rust colored in scribe liquid phase
Cream colored

*EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 11/20/77

BY: M.H.B. & G.S.V.

RUN NO. 1

*SAMPLE NO. E-1

Front

CHALKING (ASTM D659)	9.5	
BLISTERING (ASTM D714)	1 - 5/16" blister on bottom edge 2 - 1/32' dia - vapor phase	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	Surface break around tag hole ≈ 1/4" long.	

COMMENTS: Surface raised along scribe line

Cream colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 11/20/72

RUN NO. 1

BY: N.M.C. & G.J.I

*SAMPLE NO. E-2

	Front	
CHALKING (ASTM D659)	9.5	
BLISTERING (ASTM D714)	N	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Dense pinhole size pink marks
Cream colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 11/20/72 RUN NO. 1

BY: [illegible] & [illegible] *SAMPLE NO. F-1

	Side 1	
CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	8MD collapsed	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Other side ≈ same
Tan colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 11/20/72
BY: N.M.B. & G.J.V.

RUN NO. 1
*SAMPLE NO. F-2

Side 1

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	8MD collapsed	
FLAKING (ASTM D772)	N	
DELAMINATION, PEELING, CRACKING, CHECKING	N	

COMMENTS: Other side ≈ same.
Tan colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 11/20/72 RUN NO. 1

BY: N.M.B & G.J.V. *SAMPLE NO. F-5

Side 1

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	N	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Cream colored
Slight raising of paint at scribe line.
Rust spots in scribe

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 11/20/72 RUN NO. 1

BY: N.M.B. + G.J.V *SAMPLE NO. F-6

Side 1

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	N	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Paint raised along scribe
Dark spots in scribe line
2 - 1/8 surface protrusions
Cream colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 11/2-/72
BY: H. M. S. &
G. J. ✓

RUN NO. 1
*SAMPLE NO. G-1

	Side 1	
CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	1 - ½ dia at tag hole Few # [illegible] in liquid [illegible]	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Surface raised along scribe
Rust colored spots in scribe
Cream colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION — **PROJ. NO. C3486**

DATE: 11/20/72 — RUN NO. 1

BY: [illegible] — *SAMPLE NO. G-2

G [illegible]

Side 2

CHALKING (ASTM D659)	1.5	
BLISTERING (ASTM D714)	8M 1 - ½ in. in upper right corner, broken through to substrate	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Tan colored

Side 1 – { Some rust spots in [illegible]
7 [illegible] along [illegible] }

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 11/20/72 RUN NO. 1

BY: [illegible] *SAMPLE NO. G-3

Side 1

CHALKING (ASTM D659)	7.5	
BLISTERING (ASTM D714)	5 > MD 1-1/2" 1 inch from top on right edge, broken with	substrate visible
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	Upper right corner 1/16 x 1/2 area	

COMMENTS: White [illegible] substance in scribe
dust spots in scribe
Other side generally same
Cream colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 11/30/72 RUN NO. 1

BY: [illegible] *SAMPLE NO. G-4

G. [illegible]

Side 2

CHALKING (ASTM D659)	9.5	
BLISTERING (ASTM D714)	S N in lower portion or [illegible] plate.	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Side 1 { white [illegible] substance in scribe / Surface is raised along the " . }

[illegible] colored

*EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION — PROJ. NO. C3486

DATE: 11/20/72 — RUN NO. 1

BY: N. M. B. & G. J. V — *SAMPLE NO. G-9

	Side 1	
CHALKING (ASTM D659)	See comments below	
BLISTERING (ASTM D714)	N	
FLAKING (ASTM D772)	N	
DELAMINATION / PEELING / CRACKING / CHECKING	N	

COMMENTS: Severely corroded on both sides.
Both sides coated with white foreign substance.
Galvanized surface appears very dark colored along bottom edge of both sides

*EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 11/20/72 RUN NO. 1

BY: N.M.B. & G.J.V *SAMPLE NO. T-1

Side 1

CHALKING (ASTM D659)	7	
BLISTERING (ASTM D714)	N	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Panel feels damp and has water mark along edge.

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Appendix B.3

Run 1 Final Evaluation

PAINT SAMPLE EVALUATION Time - 1830 hours **PROJ. NO. C3486**

DATE: 12/4/72 RUN NO. 1

BY: [signature] *SAMPLE NO. A-1

Side 2

CHALKING (ASTM D659)	9+	
BLISTERING (ASTM D714)	8F	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Cream colored
Hair like mark about center of block
Numerous pinholes & holes up to 1/16 dia

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 12/4/72 RUN NO. 1

BY: G.V. *SAMPLE NO. A-2

	Side 1	
CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	8F along bottom	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Numerous pin holes up to 1/32 dia
" " " " " " on side 2 also
Cream colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION **PROJ. NO. C3486**

DATE: 12/4/72 RUN NO. 1

BY: G. V. *SAMPLE NO. A-3

Side 4

CHALKING (ASTM D659)	9+	
BLISTERING (ASTM D714)	1- 1/8 dia center, 1 inch from top. 6 < F	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Cream colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 12/4/72 RUN NO. 1

BY: G.V. *SAMPLE NO. A-7

Side 1

CHALKING (ASTM D659)	9+	
BLISTERING (ASTM D714)	1 - 1/16 dia near bottom center of panel	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Tan colored
Few pinholes

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 12/4/72

RUN NO. 1

BY: G. V.

*SAMPLE NO. B-1

Side 2

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	8 <M vapor phase 8 F liquid phase	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Gray colored
Numerous cavities up to 3/16 inch

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 12/4/72 RUN NO. 1

BY: G V. *SAMPLE NO. B-2

Side 2

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	N	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Pin holes up to 1/16 dia
Other sides ≈ same.
Gray colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 12/4/72 RUN NO. 1

BY: G.V. *SAMPLE NO. B-3

Side 3

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	3 large blisters 1/4, 3/8 & 1/2 inch dias. located about center of block	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Surface roughness
Gray colored
Few pinholes

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION **PROJ. NO. C3486**

DATE: 12/4/72 RUN NO. 1

BY: G. V. *SAMPLE NO. B-7

	Side 3	
CHALKING (ASTM D659)	9+	
BLISTERING (ASTM D714)	1- 1/8 dia & 1- 3/16 dia along right edge Few #8 broken in center of block	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Tan colored
Numerous pinholes up to ≈ 1/16 dia

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 12/4/72 RUN NO. 1

BY: G. V. *SAMPLE NO. C-1

	Front	Back
CHALKING (ASTM D659)	N	9+
BLISTERING (ASTM D714)	N	N
FLAKING (ASTM D772)	N	N
DELAMINATION PEELING CRACKING CHECKING	N	N

COMMENTS: Cream colored. Surface raised slightly at scribe | Rusting along seam edges & slightly o[n] head.

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 12/4/72 RUN NO. 1

BY: G.V. *SAMPLE NO. C-2

	Front	Back
CHALKING (ASTM D659)	N	9+
BLISTERING (ASTM D714)	8 < M broken along right edge	N
FLAKING (ASTM D772)	N	N
DELAMINATION, PEELING, CRACKING, CHECKING	N	N
COMMENTS:	Rust colored spots in scribe	Slight rusting along edge of weld and on bead!

*EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 12/4/72 RUN NO. 1

BY: G. V. *SAMPLE NO. C-3

	Front	Back
CHALKING (ASTM D659)	N	9
BLISTERING (ASTM D714)	N	N
FLAKING (ASTM D772)	N	N
DELAMINATION, PEELING, CRACKING, CHECKING	N	N
COMMENTS:	Surface raised along scribe upper edge. Few 1/32 surface imperfections	Few rust spots along weld edges. Dark spots in scribe

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 12/4/72 RUN NO. 1

BY: G.V. *SAMPLE NO. C-4

	Front	Back
CHALKING (ASTM D659)	N	9+
BLISTERING (ASTM D714)	N	N
FLAKING (ASTM D772)	N	N
DELAMINATION PEELING CRACKING CHECKING	N	N
COMMENTS:	Very small pock marks all over surface, barely discernible Cream colored	Rust spots along weld edges white colored area left side @ seam.

*EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 12/4/72

RUN NO. 1

BY: G. V.

*SAMPLE NO. D-1

	Side 1	
CHALKING (ASTM D659)	9+	
BLISTERING (ASTM D714)	N	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Cream Colored & discolored
Rust colored spots in scribe

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 12/4/72 RUN NO. 1

BY: G. V. *SAMPLE NO. D-2

Side 2

CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	8 MD only at top left corner and center left area	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Cream colored with discoloration. Other side rust colored spots in scribe

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 12/4/72

RUN NO. 1

BY: G. V.

*SAMPLE NO. D-3

Side 1

CHALKING (ASTM D659)	9+	
BLISTERING (ASTM D714)	8M only on area ≈ 1/2" x 1/2 left side @ boundry line	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Cream colored with discoloration
Rust colored in scribe liquid phase
Other side 6M only upper right corner

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 12/4/72 RUN NO. 1

BY: G.V. *SAMPLE NO. D-4

Side 1

CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	6 < M mainly along boundary line ≈ 1" wide	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Cream colored with brown discoloration dark in scribe

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 12/4/72

BY: G.V.

RUN NO. 1

*SAMPLE NO. E-1

	Front	
CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	1 - 5/16 Dia @ bot right corner	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Cream colored
Surface Raised along scribe line
Cracked ≈ 1/4 in length @ tag hole

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 12/4/72 RUN NO. 1

BY: G. V. *SAMPLE NO. E-2

Front

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	N	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Dark spots in scribe
Cream colored
Slightly raised surface along scribe

* EVALUATE WORST FACE OF SYSTEMS A, B, D, F, G, TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 12/4/72

RUN NO. 1

BY: G. V.

*SAMPLE NO. F-1

Side 1

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	7 < M broken - vapor 8 < M " - liquid	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Tan colored
Dark spots in scribe
Other side 8 < M blisters

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 12/4/72 RUN NO. 1

BY: G V. *SAMPLE NO. F-2

	Side 1	
CHALKING (ASTM D659)	9+	
BLISTERING (ASTM D714)	8 M with collapse	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: other side ≈ same
Tan colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 12/4/72

RUN NO. 1

BY: G.V.

*SAMPLE NO. F-5

	Side 1	
CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	N	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Slightly raised surface along some of scribe line.

Cream colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION | **PROJ. NO. C3486**

DATE: 12/4/72 | RUN NO. 1
BY: G. V. | *SAMPLE NO. F-6

Side 1

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	N	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Slightly raised along scribe
Dark spots in Scribe
2 - 1/8" raised areas in vapor phase resembling paint runs
Cream colored

*EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 12/4/72 RUN NO. 1

BY: G. V. *SAMPLE NO. G-1

	Side 1	
CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	8 < F Also large ≈ 3/16' @ tag hole	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Surface raised slightly along scribe
Dark spots in scribe
Cream colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 12/4/72 RUN NO. 1

BY: G.V. *SAMPLE NO. G-2

Side 2

CHALKING (ASTM D659)	9+	
BLISTERING (ASTM D714)	8 < F 1/16 blisters along scribe	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Rust colored spots in scribe
Tan colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION — PROJ. NO. C3486

DATE: 12/4/72 — RUN NO. 1

BY: G. V. — *SAMPLE NO. G-3

Side 1		
CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	6 MD with 4< M superimposed. Also 1-1/4" dia broken @ top right edge.	
FLAKING (ASTM D772)	Along edge @ top right.	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Cream colored
Other side ≈ same condition except less dense in liquid phase

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION PROJ. NO. C3496

DATE: 12/4/72 RUN NO. 1

BY: G.V *SAMPLE NO. G-4

Side 2

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	8 M along bottom edge	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Cream colored
other side slightly raised @ scribe

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 12/4/72 RUN NO. 1

BY: G VACCA *SAMPLE NO. G-9

Side 1

CHALKING (ASTM D659)	See comments	
BLISTERING (ASTM D714)	N	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Severely corroded on both sides with white encrustments. Dark area along bottom edge on both sides. Rust colored in 3 small areas on chemical buildup

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

Time 2050 hours

DATE: 12/4/72

RUN NO. 1

BY: G.V.

*SAMPLE NO. T-1

	Side 1	
CHALKING (ASTM D659)	8	
BLISTERING (ASTM D714)	N	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS:

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Appendix B.4

Run 2 Initial Evaluation

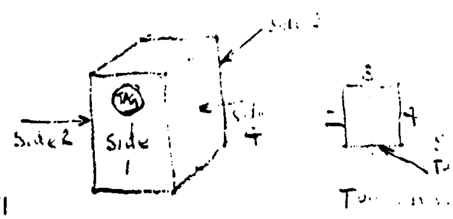
PAINT SAMPLE EVALUATION — **PROJ. NO. C3486**

DATE: 2/2/73 — RUN NO. 2

BY: LEW/GJV — *SAMPLE NO. A-4

	Side 3	
CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	6D	
FLAKING (ASTM D772)	N	
DELAMINATION, PEELING, CRACKING, CHECKING	N	

COMMENTS: Some pin holes
off white in color



* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/2/73 RUN NO. 2

BY: GJU /KEW *SAMPLE NO. A-5

	Side 1	
CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	7 < MD	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: off white color

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/2/73

RUN NO. 2

BY: GJV & LEW

*SAMPLE NO. A-6

Side 1

CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	6M mainly around edges.	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: off white color

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/2/73

RUN NO. 2

BY: LEW + GWV

*SAMPLE NO. A-8

	Side 1	
CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	N	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: ligh tan color

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/2/73

RUN NO. 2

BY: LEW & GJ.V.

*SAMPLE NO. B-4

Side 2

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	6D	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: gray colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/[illegible]/73 RUN NO. 2

BY: [illegible] *SAMPLE NO. B-5

Side 1

CHALKING (ASTM D659)	8	
BLISTERING (ASTM D714)	8 > M some of which are collapsed & broken	
FLAKING (ASTM D772)	2 small areas ≈ 1/16 × 1/8 & 1/8 × 3/16 near top	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: [illegible] in spots on all 4 faces, especially [illegible] on side 1.

gray colored

*EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/2/73 RUN NO. 2

BY: Lew & GJV *SAMPLE NO. B-6

	Side 1	
CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	6 F near bottom edge	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	Area ≈ 1/2" in dia. top coat only peeled off.	

COMMENTS: gray colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/2/73

BY: LEW & GJV

RUN NO. 2

*SAMPLE NO. B-8

Side 4

CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	1 - 1/16 blister ½ from right side center	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: light tan colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/2/73

BY: Lew & Guy

RUN NO. 2

*SAMPLE NO. C-5

	Front	Back
CHALKING (ASTM D659)	6	8 in vapor phase only
BLISTERING (ASTM D714)	1 - 1/4" dia 1/2 inch from bottom & 1" from left side	N
FLAKING (ASTM D772)	N	N
DELAMINATION, PEELING, CRACKING, CHECKING	N	N

COMMENTS: More Discoloration of vapor phase than liquid phase. off white colored. rusting around edges in vapor phase only. Vapor phase discolored more than liquid phase.

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/2/73 RUN NO. 2

BY: LEW & GJV *SAMPLE NO. C-6

	Front	Back
CHALKING (ASTM D659)	9	7
BLISTERING (ASTM D714)	6 MD Vapor phase Few #6 liquid phase	N
FLAKING (ASTM D772)	N	N
DELAMINATION PEELING CRACKING CHECKING	N	N

COMMENTS: off white colored

[illegible] Some rusting along weld & edges of panel

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/2/73 RUN NO. 2

BY: LEW & [illegible] *SAMPLE NO. C-7

	Front	Back
CHALKING (ASTM D659)	7	9
BLISTERING (ASTM D714)	1/2 inch dia area @ center of weld with 8M blistering. Also small area below scribe	N
FLAKING (ASTM D772)	N	N
DELAMINATION PEELING CRACKING CHECKING	N	N

COMMENTS: off white colored — gray. Some rusting along weld & edges

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/2/73
RUN NO. 2
BY: Lew & Guy
*SAMPLE NO. C-8

	Front	Back
CHALKING (ASTM D659)	7	9
BLISTERING (ASTM D714)	6M	N
FLAKING (ASTM D772)	N	N
DELAMINATION / PEELING / CRACKING / CHECKING	N	N
COMMENTS:	off white some discoloration	Gray colored discoloration Some rusting along weld & edges

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/2/73 RUN NO. 2

BY: LEW & GJ.V. *SAMPLE NO. D-5

Side 1

CHALKING (ASTM D659)	6	
BLISTERING (ASTM D714)	8F in Vapor phase only	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: off white color

*EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/2/73 RUN NO. 2

BY: Low & G.J.V. *SAMPLE NO. D-6

Side 1

CHALKING (ASTM D659)	6 liquid plane only.	
BLISTERING (ASTM D714)	8 > F	> · > F
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: off white

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2-2-73 RUN NO. 2

BY: Lew & GJV *SAMPLE NO. D-7

Side 2

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	6 F @ center right side & bottom edge.	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: off white

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 3/2/73

RUN NO. 2

BY: [illegible]

*SAMPLE NO. D-8

	Side 1	
CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	[illegible]	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: off white color

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/7/73 RUN NO. 2

BY: LEW & GJ.V *SAMPLE NO. E-3

	Front	
CHALKING (ASTM D659)	6 only in liquid phase	
BLISTERING (ASTM D714)	2 > F crows feet type	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: off white

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/2/73 RUN NO. 2

BY: [illegible] *SAMPLE NO. F-3

Side 1

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	3 MD	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Vapor phase lighter in color than liquid phase. Light tan colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/2/73 RUN NO. 2

BY: LEW & GJV *SAMPLE NO. F-4

Side 1		
CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	5 M with some smaller collapsed blisters	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: As in F-3

*EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/2/73 RUN NO. 2

BY: LEW & GUV *SAMPLE NO. F-7

	Side 1	
CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	N	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: OFF white colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/2/73 RUN NO. 2

BY: [illegible] *SAMPLE NO. F-8

Side 2

CHALKING (ASTM D659)	8 in liquid phase only.	
BLISTERING (ASTM D714)	2 > M crows feet type only on left side liquid phase	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: off white color

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/3/73

RUN NO. 2

BY: [illegible]

*SAMPLE NO. G-5

Site 1

CHALKING (ASTM D659)	8 in liquid phase only	
BLISTERING (ASTM D714)	2 M crows feet type in liquid phase only. 1 - broken top center of panel ≈ 1/4 inch - metal visible	
FLAKING (ASTM D772)	N	
DELAMINATION, PEELING, CRACKING, CHECKING	N	

COMMENTS: off white

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/ /73 RUN NO. 2

BY: [illegible] *SAMPLE NO. G-6

Side 2

CHALKING (ASTM D659)	8 in liquid phase only	
BLISTERING (ASTM D714)	6 > F mainly top vapor phase	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Light tan colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION **PROJ. NO. C3486**

DATE: 2/2/73 RUN NO. 2

BY: Lew & Gun *SAMPLE NO. G-7

Site 2

CHALKING (ASTM D659)	—	
BLISTERING (ASTM D714)	See Delam. below	
FLAKING (ASTM D772)	See below	
DELAMINATION PEELING CRACKING CHECKING	Almost complete delamination from very large blisters. Metal showing where blisters flaked off	

COMMENTS: off white in color

*EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/2/73 RUN NO. 2

BY: LEW & GJV *SAMPLE NO. G-8

Site 1

CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	8 MD with collapse	
FLAKING (ASTM D772)	N	
DELAMINATION / PEELING / CRACKING / CHECKING	N	

COMMENTS: Surface roughness
off white color

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/2/73 RUN NO. 2

BY: L.E. Witcher & G.J. Vacca *SAMPLE NO. T1

End of evaluation 1820 hours

Side 1

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	N	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS:

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Appendix B.5

Run 2 Final Evaluation

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/23/82

BY: [illegible]

RUN NO. 2

*SAMPLE NO. A-4

Start 1400 hrs

Side 3

CHALKING (ASTM D659)	8	
BLISTERING (ASTM D714)	7D with some collapse	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Few pinholes
off white color

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/23/73 RUN NO. 2

BY: [illegible] *SAMPLE NO. A-5

Side 1

CHALKING (ASTM D659)	8	
BLISTERING (ASTM D714)	7 < MD with some collapse	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: off white color

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/23/73 RUN NO. 2

BY: G.J.V. *SAMPLE NO. A-6

	Side 1	
CHALKING (ASTM D659)	8	
BLISTERING (ASTM D714)	6 MD only along edges	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: off white color
few pinholes

*EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/23/77 RUN NO. 2

BY: G.J. *SAMPLE NO. A-B

Side 1

CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	N	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Few pinholes
Tan colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/22/73 RUN NO. 2

BY: GJV *SAMPLE NO. B-4

Side 2

CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	5 > MD with some collapse	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Some pinholes up to 1/32" dia. gray colored
Rust mark - upper right corner

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/23/73 RUN NO. 2

BY: GJV *SAMPLE NO. B-5

Side 1

CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	8 MD with some collapsed and some broken exposing white paint.	
FLAKING (ASTM D772)	2 small areas in upper right corner. Area exposed ≈ 1/8 × 1/4"	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Gray colored with a blue tint mainly in upper right corner.
Some pinholes

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/23/73

BY: GJV

RUN NO. 2

*SAMPLE NO. B-6

Side 1

CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	6M lower edge only	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	3/4 inch irregularly shaped area at top of block peeled off.	

COMMENTS: Gray in color
Few pinholes up to 1/32 dia.

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/23/73 RUN NO. 2

BY: GJV *SAMPLE NO. B-8

Side 4

CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	1 - 1/16 dia blister - 1/2 inch from right edge and center of block.	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Few pinholes
Tan colored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/23/73
BY: G.J.V.

RUN NO. 2
*SAMPLE NO. C-5

	Front	Back
CHALKING (ASTM D659)	8	8
BLISTERING (ASTM D714)	N	N
FLAKING (ASTM D772)	N	N
DELAMINATION PEELING CRACKING CHECKING	N	N
COMMENTS:	off white Vapor phase appears darker in color. (stained more)	Gray with heavy discoloration Slight rusting along weld.

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/23/73 RUN NO. 2

BY: G.J.V *SAMPLE NO. C-6

	Front	Back
CHALKING (ASTM D659)	8	8
BLISTERING (ASTM D714)	4 MD with some collapse in vapor phase 4 F in liquid phase	N
FLAKING (ASTM D772)	N	N
DELAMINATION PEELING CRACKING CHECKING	N	N
COMMENTS:	off white color	As in C-5

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/23/73

BY: G.J.V.

RUN NO. 2

*SAMPLE NO. C-7

	Front	Back
CHALKING (ASTM D659)	8	8
BLISTERING (ASTM D714)	N	N
FLAKING (ASTM D772)	N	N
DELAMINATION PEELING CRACKING CHECKING	N	N

COMMENTS:

Front: Paint surface raised along one side of scribe line extending back ≈ 1/16" off white vapor phase discolored

Back: Gray colored with some discoloration. Weld rusted slightly.

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/22/82

BY: [illegible]

RUN NO. 2

*SAMPLE NO. C-8

	Front	Back
CHALKING (ASTM D659)	8	8
BLISTERING (ASTM D714)	6F - vapor phase 6M - liquid "	N
FLAKING (ASTM D772)	N	N
DELAMINATION PEELING CRACKING CHECKING	N	N

COMMENTS: off white color with heavy discoloration in vapor phase — As in C-5

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/23/73

BY: G.J.V.

RUN NO. 2

*SAMPLE NO. D-5

Side 1

CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	8F with some collapse mainly in vapor phase	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: off white

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/23/73 RUN NO. 2

BY: GJ.V. *SAMPLE NO. D-6

Side 2

CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	8M	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: off white

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/23/73 RUN NO. 2

BY: G.J.V. *SAMPLE NO. D-7

Side 2

CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	7F - liquid phase only.	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: OFF white color

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/23/73 RUN NO. 2

BY: G.J.V. *SAMPLE NO. D-8

	Side 1	
CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	6M mainly in liquid phase	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: off white color.

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/23/73

RUN NO. 2

BY: G.J.V.

*SAMPLE NO. E-3

	Front	
CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	2 >F crow's feet type blisters	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: off white color

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/23/73

BY: G.J.V.

RUN NO. 2

*SAMPLE NO. E-4

Front

CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	2 >M irregularly shaped blisters with collapse	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	Both sides of scribe line delaminated back from 0 to 1/8 inch	

COMMENTS: off white

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/23/73

RUN NO. 2

BY: G.J.V.

*SAMPLE NO. F-3

Side 1

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	2 MD	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Tan colored with vapor phase discoloration

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/23/73

RUN NO. 2

BY: G.J.V

*SAMPLE NO. F-4

Side 1

CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	4M with 8F collapsed in center of panel	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Tan colored with vapor phase discolored

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/23/73

BY: G.J.V.

RUN NO. 2

*SAMPLE NO. F-7

Side 1

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	N	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	slight lifting of surface along 30% of scribe line	

COMMENTS: OFF white color

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/23/73 RUN NO. 2

BY: G. J. V. *SAMPLE NO. F-8

Side 2

CHALKING (ASTM D659)	8	
BLISTERING (ASTM D714)	3M crow's feet type blisters only in liquid phase- left side	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: OFF white color.

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/23/73

BY: G.J.V.

RUN NO. 2

*SAMPLE NO. G-5

Side 1

CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	2F crow's feet type only in liquid phase.	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Chipped 1/8 x 1/4 inch area @ top edge of panel.
off white color

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/23/73

RUN NO. 2

BY: G J V

*SAMPLE NO. G-6

	side 2	
CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	6F - vapor phase 8F - liquid phase	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: Tan color liquid phase
off white " vapor "

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/23/73 RUN NO. 2

BY: G.J.V. *SAMPLE NO. G-7

Side 2

CHALKING (ASTM D659)	No attempt made	
BLISTERING (ASTM D714)	—	
FLAKING (ASTM D772)	—	
DELAMINATION PEELING CRACKING CHECKING	Practically all delaminated with 30% flaked off, exposing galvanized substrate.	

COMMENTS: other side similarly damaged
OFF white color.

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION PROJ. NO. C3486

DATE: 2/23/73 RUN NO. 2

BY: G.J.V. *SAMPLE NO. G-8

Side 1

CHALKING (ASTM D659)	9	
BLISTERING (ASTM D714)	8MD with collapse and broken blisters. White showing thru broken blisters	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS: OFF white & discolored
Surface roughness.

*EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Best Copy Available

PAINT SAMPLE EVALUATION

PROJ. NO. C3486

DATE: 2/23/73

RUN NO. 2

BY: G.J.V.

*SAMPLE NO. T-1

Completed eval. 1645 hours.

Side 1

CHALKING (ASTM D659)	N	
BLISTERING (ASTM D714)	N	
FLAKING (ASTM D772)	N	
DELAMINATION PEELING CRACKING CHECKING	N	

COMMENTS:

* EVALUATE WORST FACE OF SYSTEMS A,B,D,F,G,TI
EVALUATE FRONT FACE OF SYSTEMS E
EVALUATE BOTH FACES OF SYSTEM C
PHOTOGRAPH FACE THAT HAS BEEN EVALUATED
NOTE ANY SOFTENING OF TOPCOAT

Appendix

APPENDIX C

STANDARDS OF EVALUATION

C.1 Evaluating Degree of Resistance to Chalking of Exterior Paints (ASTM D659)

C.2 Evaluating Degree of Blistering of Paints (ASTM D714)

C.3 Evaluating Degree of Flaking (Scaling) of Exterior Paints (ASTM D772)

C.4 Evaluating Degree of Resistance to Checking of Exterior Paints (ASTM D660)

C.5 Evaluating Degree of Resistance to Cracking of Exterior Paints (ASTM D661)

Best Copy Available

AMERICAN SOCIETY FOR TESTING AND MATERIALS

1916 Race St., Philadelphia, Pa., 19103

FEDERATION OF SOCIETIES FOR
PAINT TECHNOLOGY STANDARD NO. Ld-2-58

Standard Method of

EVALUATING DEGREE OF CHALKING OF EXTERIOR PAINTS[1]

ASTM Designation: D 659 – 44 (Reapproved 1970)

This Standard of the American Society for Testing and Materials is issued under the fixed designation D 659; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 The photographic reference standards included in this method are representative of degrees of resistance to chalking of exterior paint films. These standards are primarily intended for comparative evaluation.

2. Definition

2.1 Chalking is that phenomenon manifested in paint films by the presence of loose removable powder, evolved from the film itself, at or just beneath the surface. Chalking may be detected by rubbing the film with the fingertip or other means.

3. Type of Chalking

3.1 Only one type of chalking is recognized, as defined in Section 2.

4. Procedure

4.1 Use a black or dark blue, pure wool felt for white and lightly tinted paints and a white, pure wool felt for darker colored paints. Wrap the felt around the index finger, then apply the felt with medium pressure to the film under observation. Rotate the finger through an angle of 180 deg, holding the felt so it also rotates. Remove the felt and compare the spot of chalk on the felt with the photographic standard.

5. Use of Photographic Reference Standards

5.1 The use of the photographic reference standards[2] shown in Fig. 1 requires the following precautions:

5.1.1 It must be realized that the degree of failure will vary over any given area. Therefore, an average portion of the film should be used for comparison.

NOTE—On large surfaces it is recommended ratings be made of several locations ano the mean and range reported.

5.1.2 It is verydifficult to make read-

[1] Under the standardization procedure of the Society this method is under the jurisdiction of the ASTM Committee D-1 on Paint, Varnish, Lacquer, and Related Products. A list of members may be found in the ASTM Year Book.

Current edition accepted Sept. 15, 1944. Originally issued 1942. Replaces D 659 – 42 T.

[2] Copies of the Exposure Standards Manual prepared by the Federation of Societies for Paint Technology, giving actual photographs of various types of failures of exterior paints, may be obtained from the Secretary of the Federation, 121 South Broad St., Philadelphia, Pa. 19107.

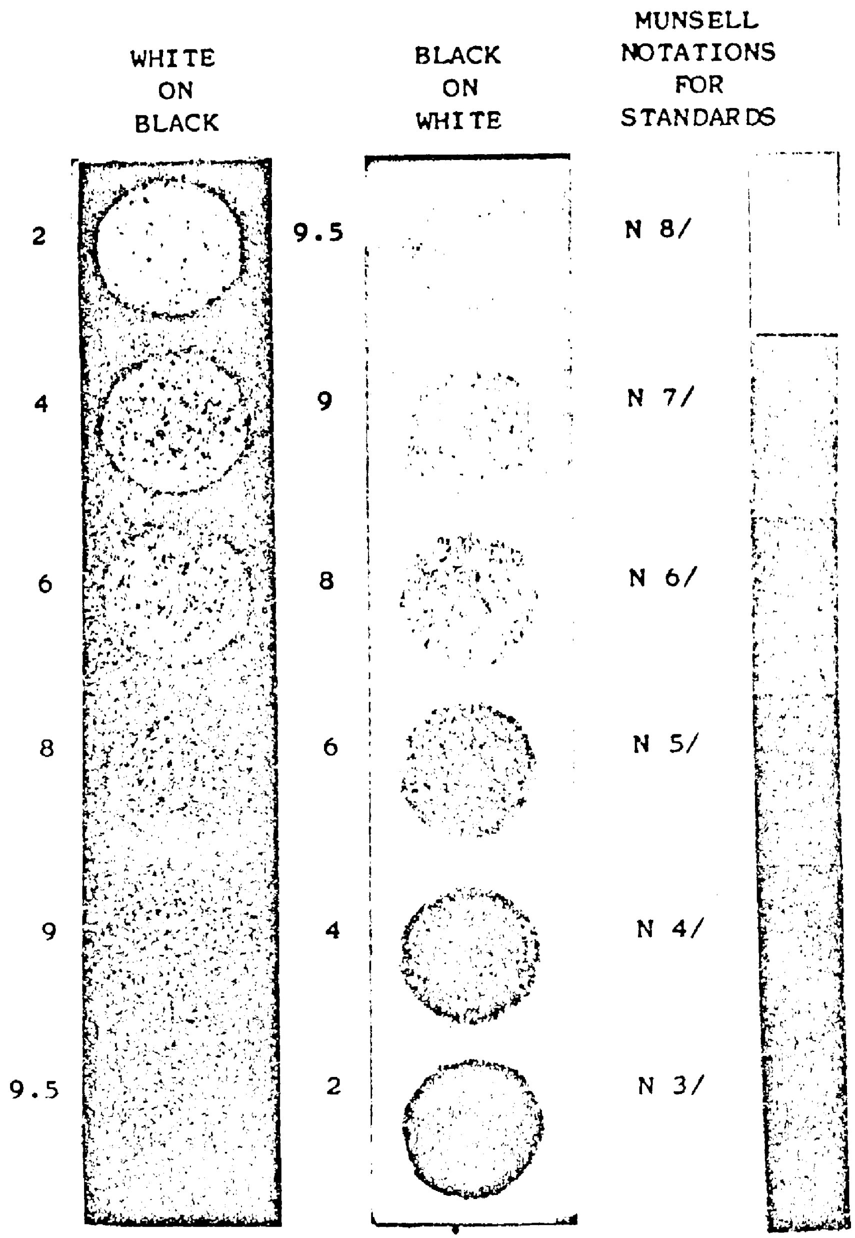


FIG. 1.—Degrees of Chalking—Rating of Ten as Perfect.

ings on a windy day and making readings at such a time should be avoided. It should also be noted that rain or snow will remove chalk, so that readings should be made after a period of clear weather and when the surface is dry.

5.1.3 It should be remembered that chalking and erosion[3] are closely related and that erosion is a result of chalking failure. However, the rate of chalking, as measured by this method, and the rate of erosion may not be comparable, because some pigment combinations tend to retain chalk on the surface while other pigment combinations exert a self-cleaning action by natural means.

5.1.4 For convenience in recording the data obtained, the records may be kept on forms such as the Single and Multi-Panel Forms for Recording Results of Exposure Tests of Paints (ASTM Designation: D 1150).[4,5]

[3] For evaluation of erosion, see the Standard Method of Evaluating Degree of Resistance to Erosion of Exterior Paints (ASTM Designation: D 662), which appears in this publication.

[4] *Annual Book of ASTM Standards*, Part 21.

[5] These record sheets may be obtained from the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103, and from the Federation of Societies for Paint Technology, 121 S. Broad St., Philadelphia, Pa. 19107

C.2

FEDERATION OF SOCIETIES FOR
PAINT TECHNOLOGY STANDARD NO. [illegible]

Standard Method of

EVALUATING DEGREE OF BLISTERING OF PAINTS[1]

ASTM Designation: D 714 - 56 (Reapproved 1970)

This Standard of the American Society for Testing and Materials is issued under the fixed designation D 714; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

Scope

1. This method employs photographic reference standards to evaluate the degree of blistering that may develop when paint systems are subjected to conditions which will cause blistering. While primarily intended for use on metal and other nonporous surfaces, this method may be used to evaluate blisters on porous surfaces, such as wood, if the size of blisters falls within the scope of these reference standards. When the reference standards are used as a specification of performance, the permissible degree of blistering of the paint system shall be agreed upon by the purchaser and the seller.

Reference Standards

2. (*a*) The photographic reference standards[2] shown in Figs. 1 to 4 represent two characteristics of blistering: size and frequency. The size is described on an arbitrary numerical scale, and the frequency is described qualitatively. The photographs have been selected to show random distribution over the entire surface (Note 1).

(*b*) *Size*.—Reference standards have been selected for four steps as to size on a numerical scale from 10 to 0, in which No. 10 represents no blistering. Blistering standard No. 8 represents the smallest size blister easily seen by the unaided eye. Blistering standards Nos. 6, 4, and 2 represent progressively larger sizes.

(*c*) *Frequency*.—Reference standards have been selected for four steps in frequency at each step in size, designated as follows:

Dense, *D*,
Medium dense, *MD*,
Medium, *M*, and
Few, *F*.

NOTE 1.—A quantitative physical description of blistering would include the following characteristics determined by actual count:

Size distribution in terms of mensuration units,
Frequency of occurrence per unit area,
Pattern of distribution over the surface, and
Shape of blister.

For the usual tests, an actual count is more elaborate than is necessary.

[1] Under the standardisation procedure of the Society, this method is under the jurisdiction of the ASTM Committee D-1 on Paint, Varnish, Lacquer and Related Products.

Current edition accepted Sept. 10, 1956. Originally issued 1943. Replaces D 714 - 51 T.

[2] Glossy prints of the photographic reference standards showing types of blistering are available at a nominal charge from ASTM Headquarters, 1916 Race St., Philadelphia, Pa. 19103.

Procedure

3. Subject the paint film to the test conditions agreed upon by the purchaser and the seller. Then evaluate the paint film for the degree of blistering by comparison with the photographic reference standards in Figs. 1 to 4.

Reporting

4. (*a*) Report blistering as a number (Note 2) designating the size of the blisters and a qualitative term or symb indicating the frequency.

(*b*) Intermediate steps in size or fr quency of blisters may be judged b interpolation.

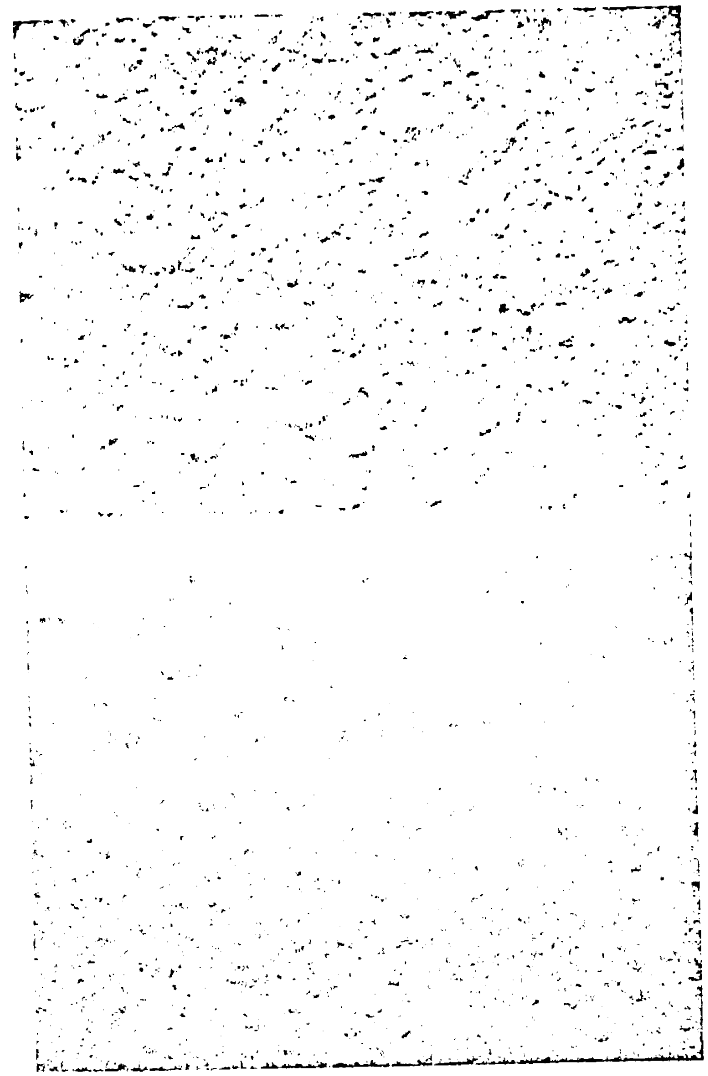
(*c*) When the distribution of bliste over the area has a nonuniform patter use an additional phrase to describe th distribution, such as "small clusters," "large patches."

NOTE 2.—The number refers to the large size blister that is numerous enough to be repr sentative of the specimen. For example, phot graphic standard No. 4, "Dense," has bliste ranging in size from about No. 7 to No. 4, i clusive.

(See Figs. 1–4 following)

Medium

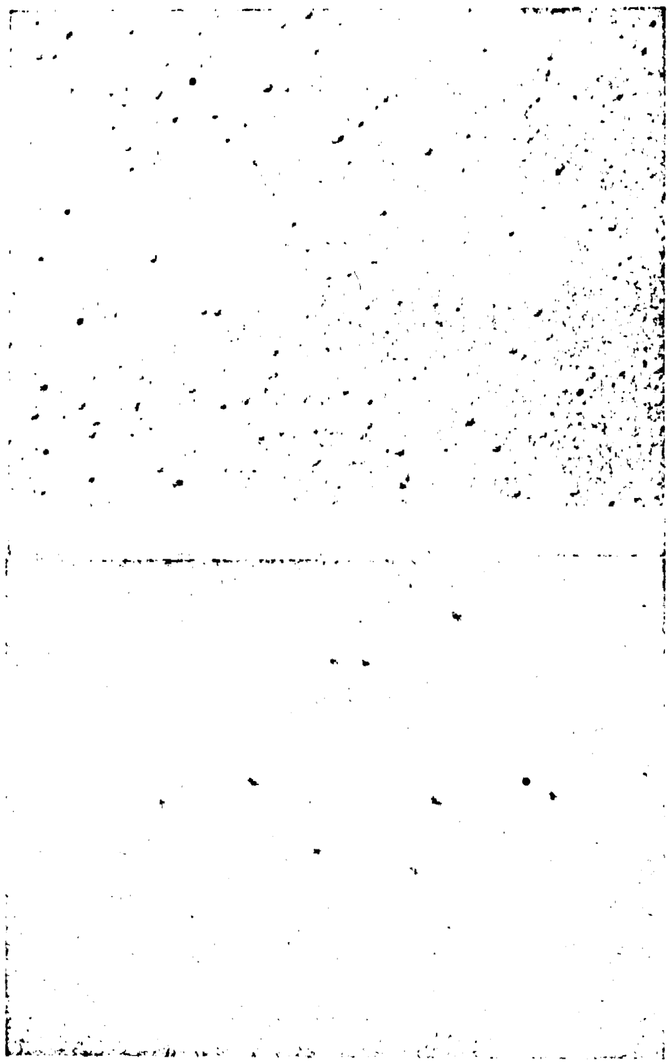
Few



Dense

Medium Dense

Fig. 1. Blister Size No. 2



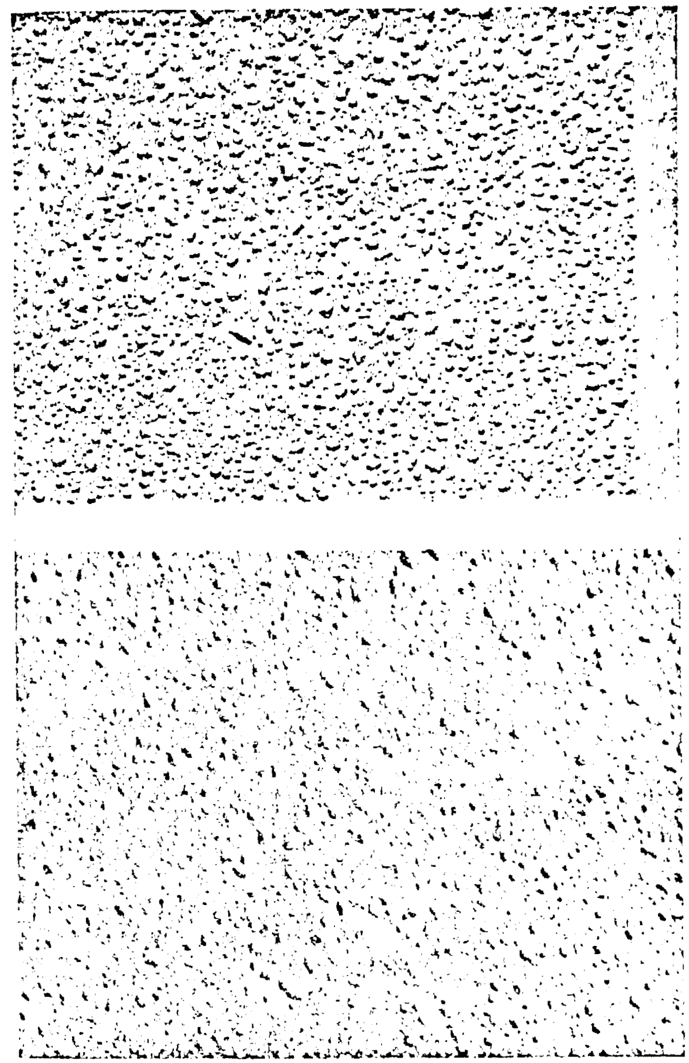
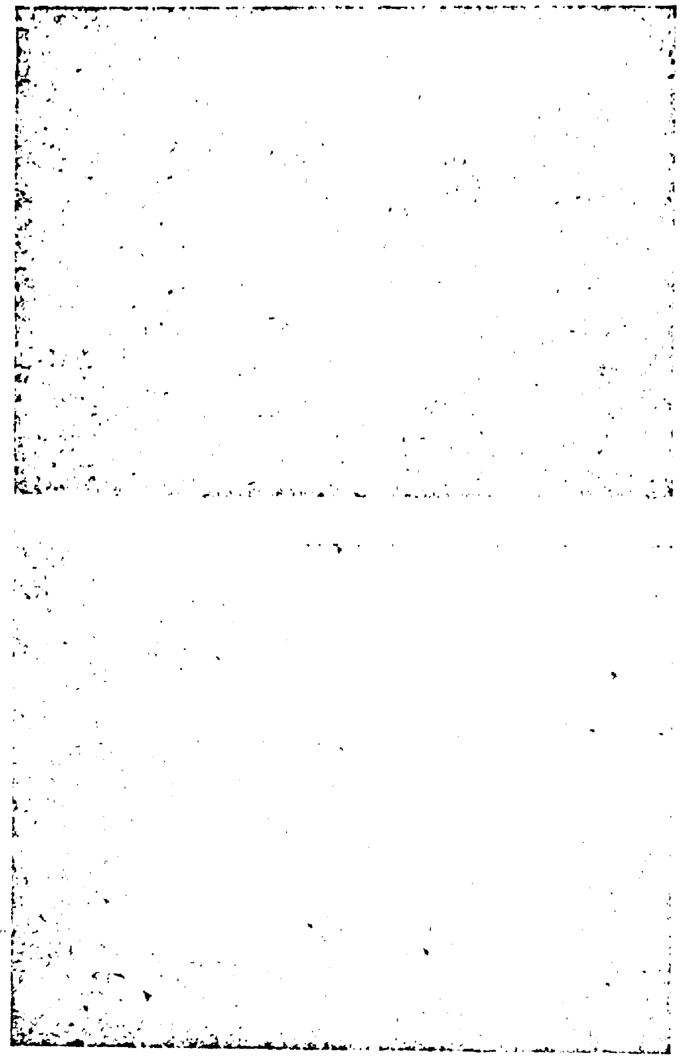


FIG. 2.—Blister Size No. 4.



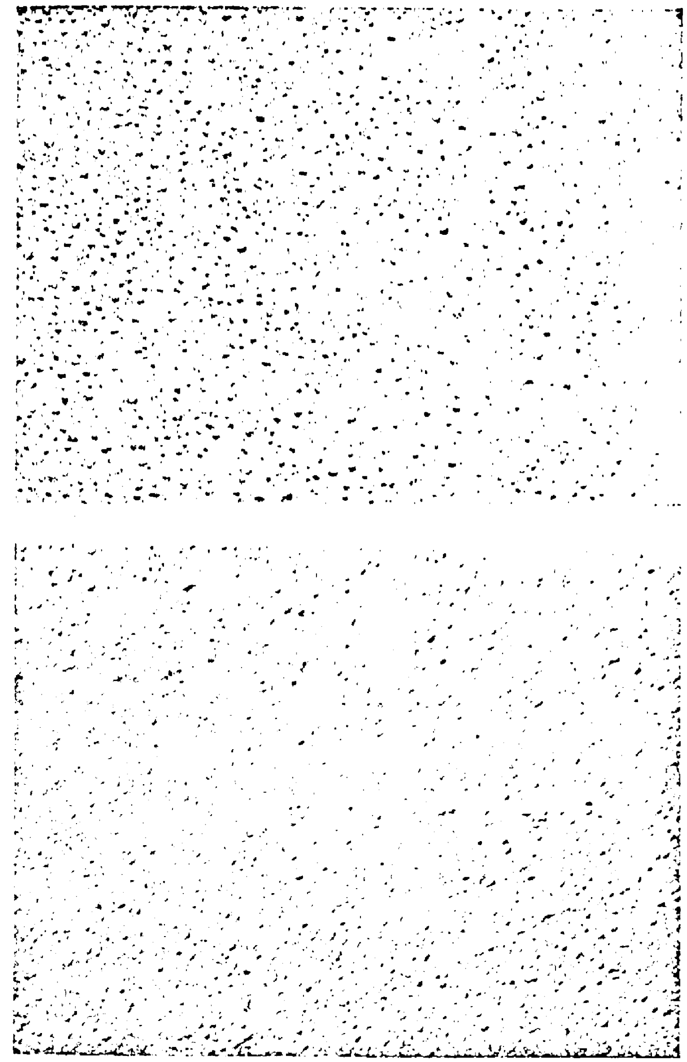
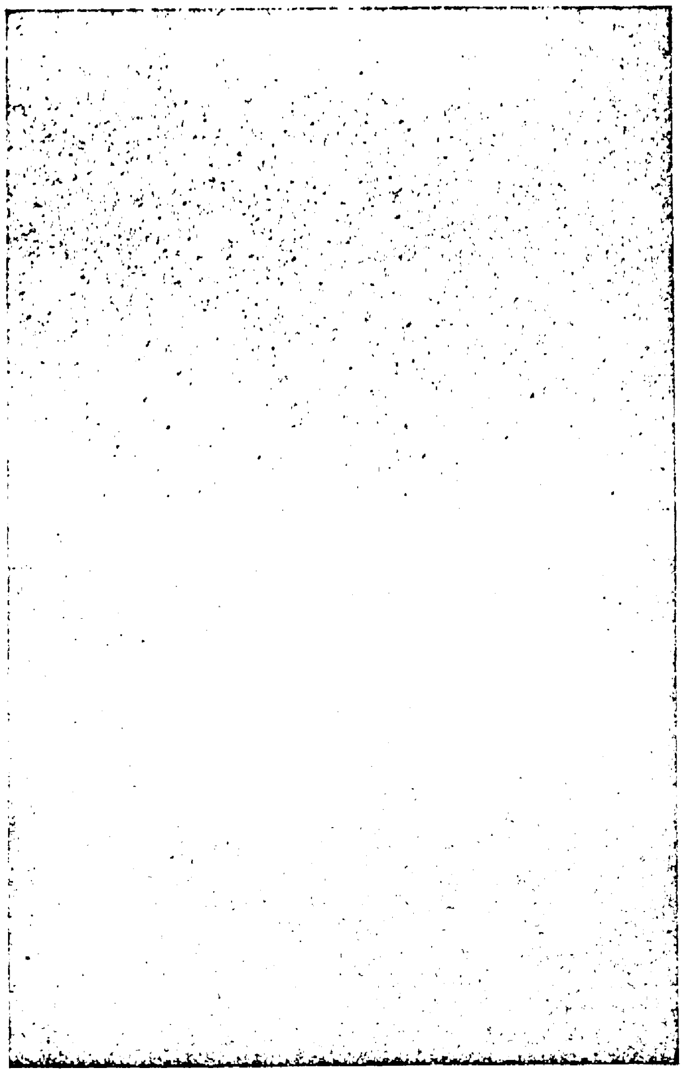


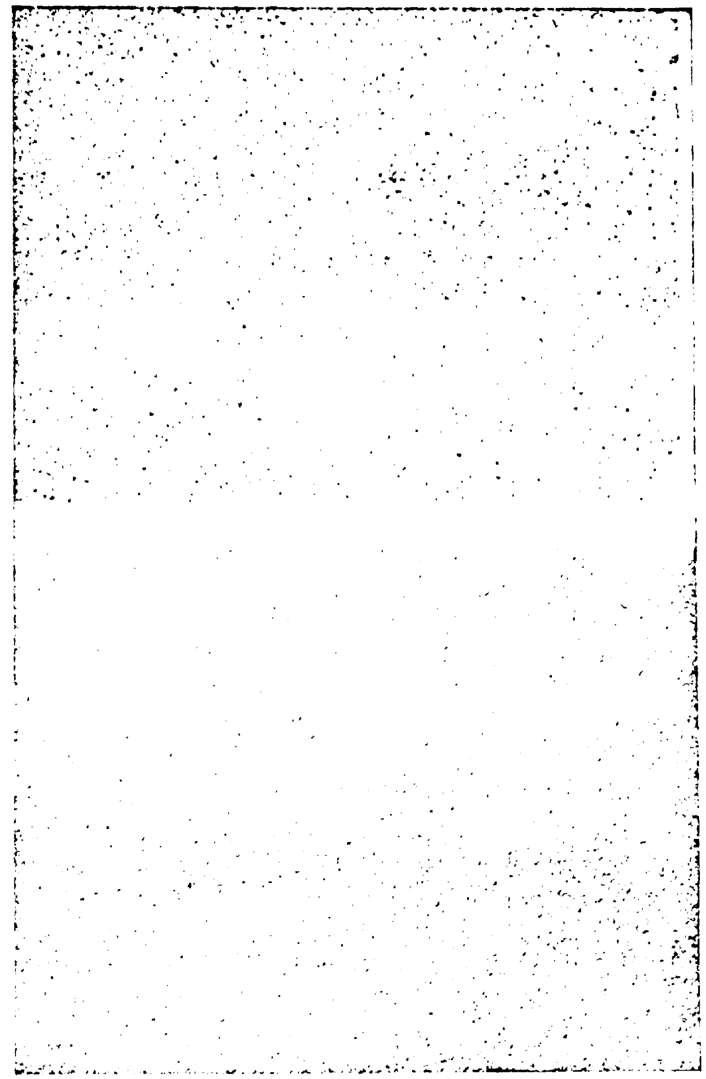
FIG. 3.—Blister Size No. 6.

Best Copy Available



Medium

Few



Den

Medium Dense

FIG. 4.—Blister Size No. 8

C.3

AMERICAN SOCIETY FOR TESTING AND MATERIALS
1916 Race St., Philadelphia, Pa., 19103
Reprinted from the Annual Book of ASTM Standards, Copyright ASTM

FEDERATION OF SOCIETIES FOR PAINT TECHNOLOGY STANDARD NO. Ld-6-58

Standard Method of

EVALUATING DEGREE OF FLAKING (SCALING) OF EXTERIOR PAINTS[1]

ASTM Designation: D 772 – 47 (Reapproved 1970)

This Standard of the American Society for Testing and Materials is issued under the fixed designation D 772; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 The photographic reference standards included in this method are representative of degrees of flaking (scaling) of exterior paint films. These standards are primarily intended for comparative evaluation.

2. Definition

2.1 Flaking (scaling) is that phenomenon manifested in paint films by the actual detachment of pieces of the film itself either from its substrate or from paint previously applied. Flaking (scaling) is generally preceded by cracking or checking or blistering, and is the result of loss of adhesion, usually due to stress-strain factors coming into play.

3. Type of Flaking (Scaling)

3.1 Only one type of flaking (scaling) is recognized, as defined in Section 2.

[1] Under the standardization procedure of the Society, this method is under the jurisdiction of the ASTM Committee D-1 on Paint, Varnish, Lacquer, and Related Products. A list of members may be found in the ASTM Year Book.
Current edition accepted Oct. 15, 1947. Originally issued 1944. Replaces D 772 – 44 T.

4. Use of Photographic Reference Standards

4.1 The use of the photographic reference standards[2] shown in Fig. 1 requires the following precautions:

4.1.1 Care must be taken not to confuse various types of failure that may be present on the same surface.

4.1.2 It must be realized that degree of failure will vary over any given area. Therefore, an average portion of the film should be used for comparison.

4.1.3 In technical literature, a distinction is sometimes made between flaking and scaling. In most cases, however, flaking and scaling refer to the same phenomenon. In some instances, the term flaking is used to describe the detachment of pieces of film less than ⅛ in. in size, and scaling, the detachment of

[2] Copies of the Exposure Standards Manual prepared by the Federation of Societies for Paint Technology, giving actual photographs of various types of failures of exterior paints, may be obtained from the Secretary of the Federation, 121 South Broad St., Philadelphia, Pa. 19107.

pieces over ⅛ in. in size. In other instances, the term flaking is used to describe the detachment of pieces of film from the immediate undercoat (intercoat failure) and scaling the detachment of pieces from the base (complete failure). It should be kept in mind that the flakes may vary widely in size and shape from those illustrated by the reference standards in Fig. 1, varying from a fraction of an inch to several inches in size.

4.1.4 Peeling is frequently due to a moisture condition and when this is evident it should be taken into consideration in any evaluation.

4.1.5 For convenience in recording the data obtained, the records may be kept on forms such as the Single and Multi-Panel Forms for Recording Results of Exposure Tests of Paints (ASTM Designation: D 1150).[3,4]

[3] *Annual Book of ASTM Standards*, Part 21.
[4] These record sheets may be obtained from the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103 and from the Federation of Societies for Paint Technology, 121 S. Broad St., Philadelphia, Pa. 19107.

19-11 x

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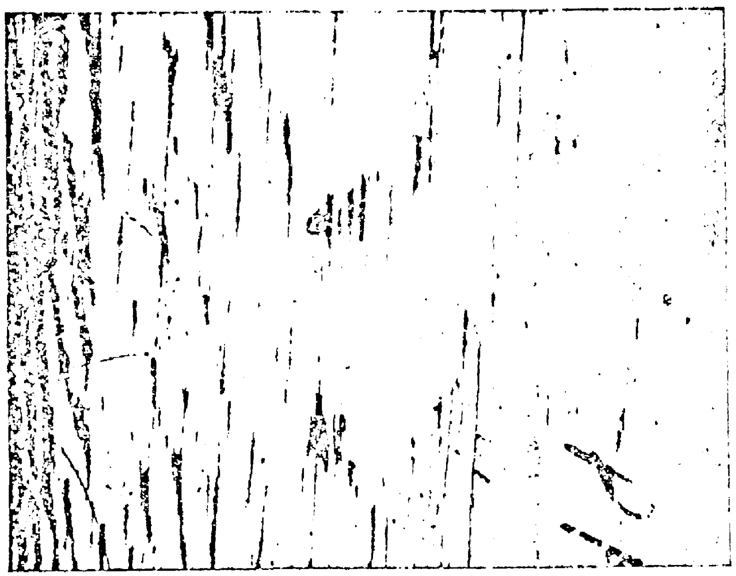
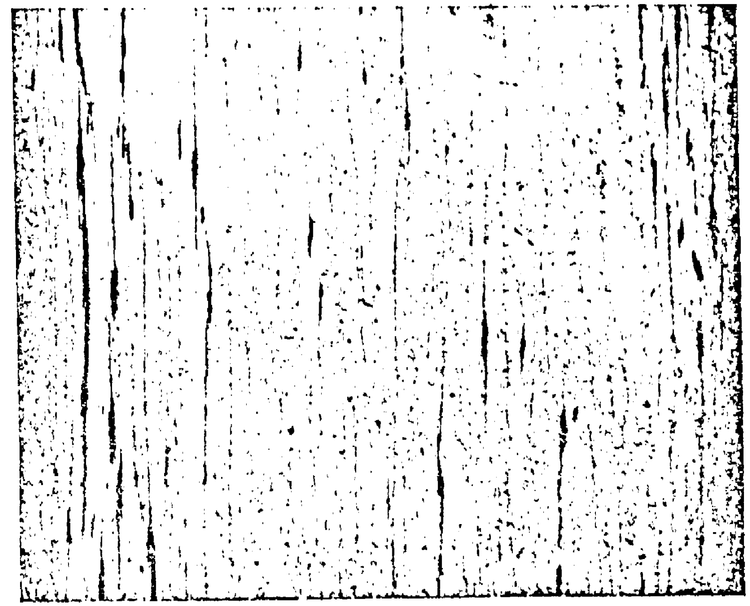
No. 2

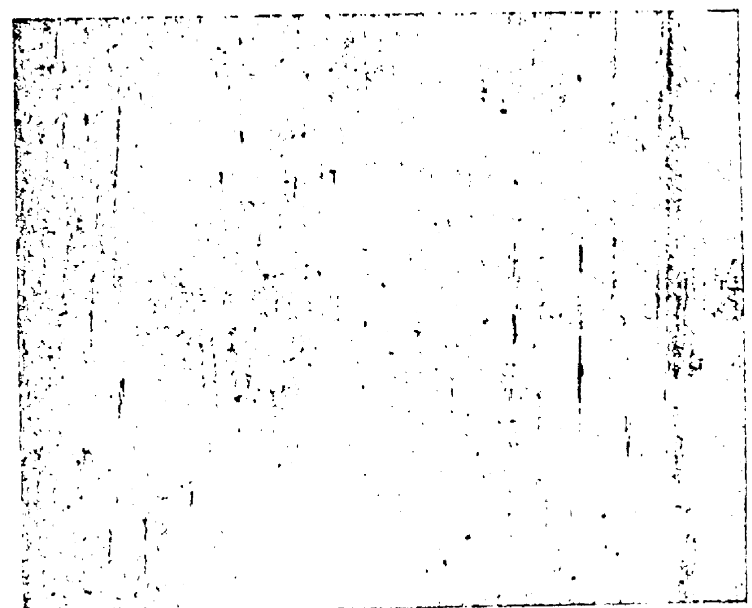


No. 4

FIG. 1.—Degrees of Flaking (Scaling).



No. 6



No. 8

FIG. 1.—Degrees of Flaking (Scaling) (*Concluded*).

AMERICAN SOCIETY FOR TESTING AND MATERIALS

1916 Race St., Philadelphia, Pa. 19103

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FEDERATION OF SOCIETIES FOR PAINT TECHNOLOGY STANDARD NO. Ld-3-38

Standard Method of

EVALUATING DEGREE OF RESISTANCE TO CHECKING OF EXTERIOR PAINTS[1]

ASTM Designation: D 660 - 44 (Reapproved 1965)

This Standard of the American Society for Testing and Materials is issued under the fixed designation D 660; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

NOTE.—Editorial changes in Section 4(*g*) were made in January, 1955. The title, and Sections 1 and 4(*d*) were editorially revised in June, 1961.

Scope

1. The photographic reference standards included in this method are representative of degrees of resistance to checking of exterior paint films. These standards are primarily intended for comparative evaluation.

Definition

2. Checking is that phenomenon manifested in paint films by slight breaks in the film that do not penetrate to the underlying surface. The break should be called a crack[2] if the underlying surface is visible. Where precision is necessary in evaluating a paint film, checking may be described as visible (as seen with the naked eye) or as microscopic (as observed under a magnification of 10 diameters).

Types of Checking

3. Three types of checking are recognized:

Irregular Pattern Type.—Checking in which the breaks develop in the surface of the film in no definite pattern.

Line Type.—Checking in which the breaks in the surface of the film are generally arranged in parallel lines, usually either horizontally or vertically, over the surface of the film. These breaks often follow the line of brush marks.

Crowfoot Type.—Checking in which the breaks in the surface of the film form in a definite three-prong pattern with th breaks running from a center and forming an angle of about 120 deg between the prongs.

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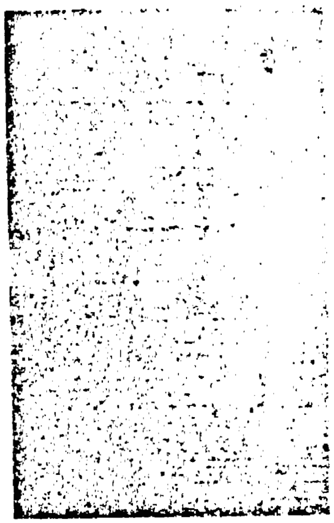
[1] Under the standardization procedure of the Society, this method is under the jurisdiction of the ASTM Committee D-1 on Paint, Varnish, Lacquer, and Related Products. A list of members may be found in the ASTM Year Book.

Current edition accepted Sept. 15, 1944. Originally issued 1942. Replaces D 660 - 44 T.

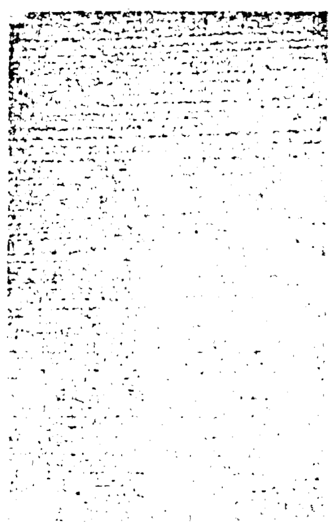
[2] For evaluation of cracking, see the Standard Method of Evaluating Degree of Resistance to Cracking of Exterior Paints (ASTM Designation: D 661), which appears in this publication.

No. 8



No. 6

No. 4



No. 2

Use of Photographic Reference Standards

4. The use of the photographic reference standards[3] shown in Fig. 1 requires the following precautions:

(*a*) The accompanying photographic reference standards show line-type checking only. Crowfoot and irregular-type checking may also be interpreted from the photographs.

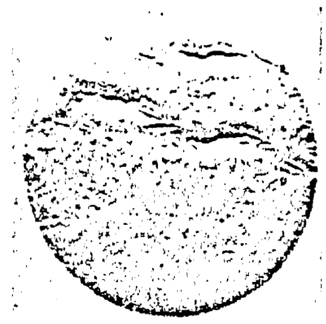


FIG. 2.—No. 8 Checking Magnified 10 Diameters.

(*b*) Care must be taken not to confuse various types of failure that may be present on the same surface.

(*c*) It must be realized that the degree of failure will vary over any given area. Therefore, an average portion of the film should be used for comparison.

(*d*) Paint films may collect excessive quantities of dirt, which may mask the type and degree of failure. If necessary dirt should be removed by careful and gentle brushing with a moderately soft brush.

(*e*) The use of a microscope is recommended to detect and evaluate incipient checking.

(*f*) The No. 8 standard must be examined closely under adequate lighting conditions to distinguish the failure present. For the sake of clarity, a 10-diameter magnification of No. 8 checking is shown in Fig. 2, as well as the unmagnified view shown in Fig. 1.

(*g*) For convenience in recording the data obtained, the records may be kept on forms such as the Single and Multi-Panel Forms for Recording Results of Exposure Tests of Paints (ASTM Designation D 1150).[4,5]

[3] Copies of the Exposure Standards Manual prepared by the Federation of Societies for Paint Technology, giving actual photographs of various types of failures of exterior paints, may be obtained from the Secretary of the Federation, 12[illegible] South Broad St., Philadelphia 7, Pa.

[4] Appears in this publication.

[5] These record sheets may be obtained from the American Society for Testing and Materials, 1916 Race St., Philadelphia 3, Pa., and from the Federation of Societies for Paint Technology, 121 S. Broad St., Philadelphia 7, Pa.

FEDERATION OF SOCIETIES FOR
PAINT TECHNOLOGY STANDARD NO. L4-4-58

Standard Method of

EVALUATING DEGREE OF RESISTANCE TO CRACKING OF EXTERIOR PAINTS[1]

ASTM Designation: D 661 – 44 (Reapproved 1970)

This Standard of the American Society for Testing and Materials is issued under the fixed designation D 661; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

Scope

1. The photographic reference standards included in this method are representative of degrees of resistance to cracking of exterior paint films. These standards are primarily intended for comparative evaluation.

Definition

2. Cracking is that phenomenon manifested in paint films by a break extending through to the surface painted. Where this is difficult to determine, the break should be called a crack only if the underlying surface is visible. The use of a magnification of 10 diameters is recommended in cases where it is difficult to differentiate between cracking and checking.[2]

Types of Cracking

3. Three types of cracking are recognized:

Irregular Pattern Type.—Cracking in which the breaks in the film are in no definite pattern.

Line Type.—Cracking in which the breaks in the film are generally arranged in parallel lines, usually either horizontally or vertically, over the surface of the film. These breaks often follow the line of brush marks.

Sigmoid Type.—Cracking in which the breaks in the film form a pattern consisting of curves meeting and intersecting, usually on a relatively large scale.

Use of Photographic Reference Standards

4. The use of the photographic reference standards[3] shown in Fig. 1 requires the following precautions:

[1] Under the standardization procedure of the Society, this method is under the jurisdiction of the ASTM Committee D-1 on Paint, Varnish, Lacquer, and Related Products.

Current edition accepted Sept. 15, 1944. Originally issued 1942. Replaces D 661 – 42 T.

[2] For evaluation of checking, see the Method of Evaluating Degree of Resistance to Checking of Exterior Paints (ASTM Designation: D 660), which appears in this publication.

[3] Copies of the Exposure Standards Manual prepared by the Federation of Societies for Paint Technology giving actual photographs of various types of failures of exterior paints, may be obtained from the Secretary of the Federation, 121 South Broad St., Philadelphia, Pa. 19107.

(*a*) The accompanying photographic reference standards show line-type cracking only. Irregular and sigmoid-type cracking may also be interpreted from these photographs.

(*b*) Care must be taken not to confuse various types of failure that may be present on the same surface. This is particularly true in observing cracking and checking. Cracking may very often be an advanced stage of checking and is very often in evidence along with checking and other failures.

(*c*) It must be realized that the degree of failure will vary over any given area. Therefore, an average portion of the film should be used for comparison.

(*d*) Paint films may collect excessive quantities of dirt, which may mask the type and degree of failure. If necessary, dirt should be removed by careful and gentle brushing with a moderately soft brush.

(*e*) In examining wood panels for cracking failure, the possibility of wood failure should be recognized. This takes the form of a cracking or splitting of the wood itself with a resultant rupture of the paint film. Also, some panels will develop "resin spewing" which will cause early failure by cracking. These points should be taken into consideration in any evaluations.

(*f*) For convenience in recording the data obtained, the records may be kept on forms such as the Single and Multi-Panel Forms for Recording Results of Exposure Tests of Paints (ASTM Designation: D 1150.[4,5]

[4] Appears in this publication.

[5] These record sheets may be obtained from the American Society for Testing and Materials 1916 Race St., Philadelphia, Pa., 19103 and from the Federation of Societies for Paint Technology, 121 S. Broad St., Philadelphia, Pa. 19107

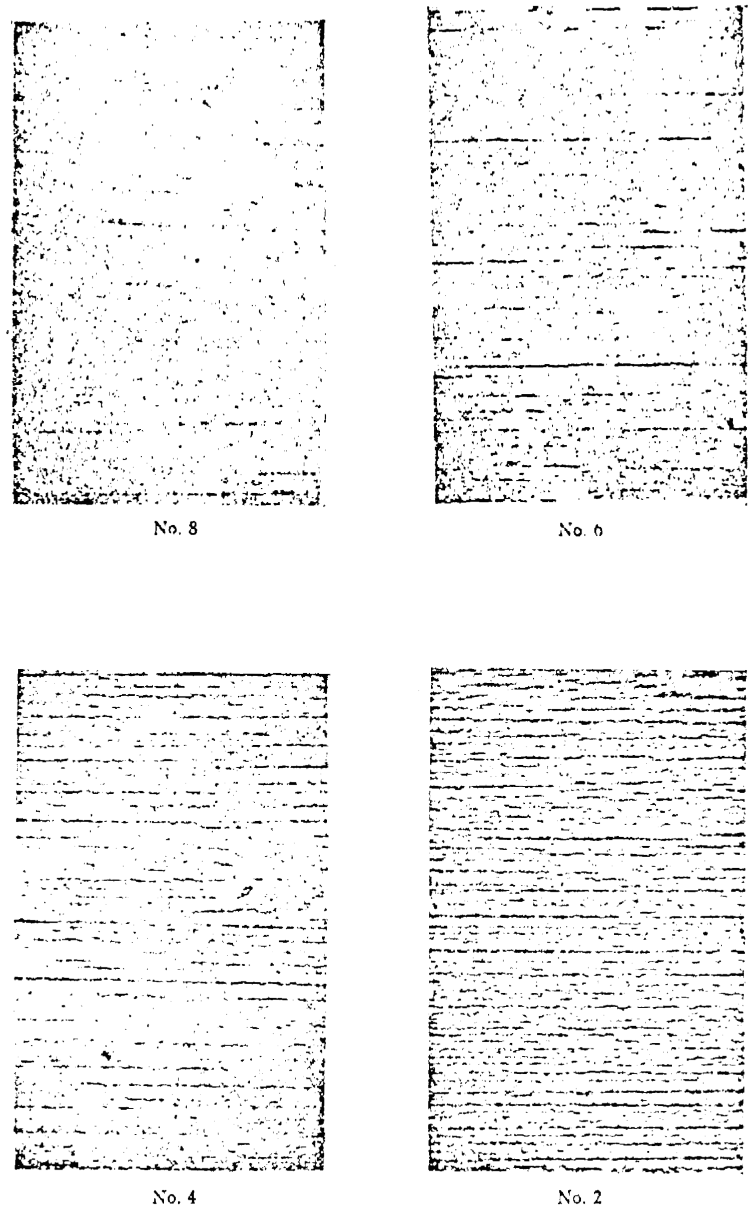


FIG. 1.—Degrees of Cracking.

Appendix

APPENDIX D

CERTIFICATION OF RADIATION EXPOSURE

D.1 Summary Report of Dosimetry Tests Conducted by Neutron Products, Inc.

D.2 Certification of Irradiation Performed at Neutron Products, Inc.

Appendix D.1

Summary Report of Dosimetry Tests Conducted by
Neutron Products, Inc.

NEUTRON PRODUCTS inc

Dickerson Maryland 2075[illegible]

301 349-5001 TWX 710-828-[illegible]

March 20, 1973

Mr. Nissen Burstein
The Franklin Institute
Twentieth and Parkway
Philadelphia, Pennsylvania 19103

Dear Nissen:

Attached is a summary of dosimetry performed on the Neutron Products 12" in-pool research irradiator which was used in the Stone and Webster tests in November of 1972. Please refer to the attached drawing for the location of the dosimeters relative to your test volume.

Dosimeters 1 through 3 were placed on the centerline of the inner steel pressure vessel which was positioned inside the steel outer vessel. These represent the centerline dose rate at the lower dose rate cobalt-60 loading unattenuated by the Stone and Webster samples, and average 0.68 megarads/hour.

Dosimeters 4 through 6 are similarly placed on the centerline but at the higher cobalt-60 loading, again with no samples present, and show a dose rate of 1.25 megarads/hour. Dosimeters 7 through 9, located on the circumference of the inner vessel, were exposed at the same time as 4 through 6 and averaged 1.24 megarads/hour.

Dosimeters 10 through 17 were located in the inner vessel which had been loaded with dummy samples to gain some indication of the attenuated dose rate. In the top level which contained concrete samples, the dosimeter (#11) on the outside of one of these showed the dose rate to be 0.57 megarads per hour and the dosimeter (#10) positioned on the inner surface of the same block indicated 0.47 megarads per hour. The second level contained 4 concrete, one 3/8" transite, two 3/8" steel, and one 20 gauge steel samples. The dosimeters placed on the inner (#12) and the outer (#13) surfaces of the 3/8" steel sample read 0.56 megarads per hour and 0.58 megarads per hour respectively. The third level contained four 3/8" steel samples and four 20 gauge steel samples. The dosimeters (#14 and #15) on one of the 20 gauge samples indicated that both the inner and outer surface dose rates were 0.68 megarads per hour. The bottom layer contained all 3/8" steel and had a dose rate of 0.4 megarads per hour on the inner surface (#16) and 0.43 megarads per hour on the outer (#17).

Dosimeters 18 through 22 had been placed 5" apart on the centerline of our aluminum vessel (not shown in drawing) prior to this test, and indicate the dose distribution. These show a dose rate of 1.24 ± 0.1 megarads/hour over 16" vertical distance near the middle of the vessel in the irradiator with the identical cobalt-60 loading as the low dose part of the Stone and Webster test.

If I may be of further assistance please contact me.

Sincerely,

NEUTRON PRODUCTS, INC.

Dudley

Dudley G. Woodard, Manager
Service Irradiations

DGW/cbl

Enclosure

NEUTRON PRODUCTS inc

Table D-1

NPI 12" In-Pool Irradiator

Dosimeter (See Figure for Location)	Cobalt-60 Loading	Nov. 1972 Dose Rate (M/hr) In Attenuating Vessels	S & W Samples	Dosimeter Type
1	Low	0.60 in S & W test vessels	No	KNO_3
2	Low	0.78 in S & W test vessels	No	KNO_3
3	Low	0.65 in S & W test vessels	No	KNO_3
4	High	1.20 in S & W test vessels	No	KNO_3
5	High	1.29 in S & W test vessels	No	KNO_3
6	High	1.28 in S & W test vessels	No	KNO_3
7	High	1.17 in S & W test vessels	No	KNO_3
8	High	1.30 in S & W test vessels	No	KNO_3
9	High	1.26 in S & W test vessels	No	KNO_3
10	Low	0.47 in S & W test vessels	Yes	KNO_3
11	Low	0.56 in S & W test vessels	Yes	KNO_3
12	Low	0.56 in S & W test vessels	Yes	KNO_3
13	Low	0.58 in S & W test vessels	Yes	KNO_3
14	Low	0.68 in S & W test vessels	Yes	KNO_3
15	Low	0.68 in S & W test vessels	Yes	KNO_3
16	Low	0.40 in S & W test vessels	Yes	KNO_3
17	Low	0.43 in S & W test vessels	Yes	KNO_3
18	Low	0.81 in NPI aluminum vessel	No	Fricke
19	Low	1.23 in NPI aluminum vessel	No	Fricke
20	Low	1.33 in NPI aluminum vessel	No	Fricke
21	Low	1.32 in NPI aluminum vessel	No	Fricke
22	Low	1.01 in NPI aluminum vessel	No	Fricke

Best Copy Available

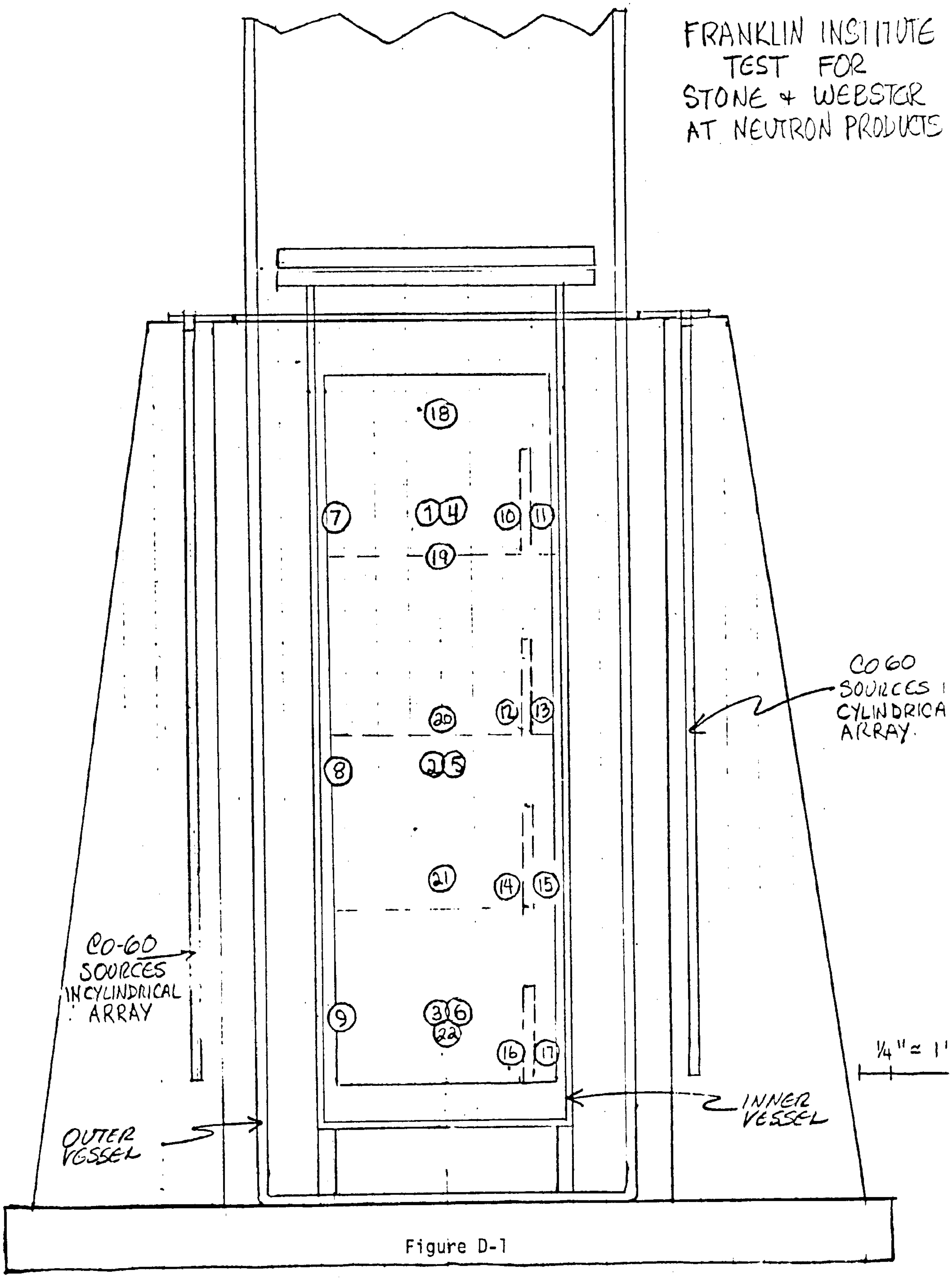


Figure D-1

Appendix D.2

Certification of Irradiation Performed at
Neutron Products, Inc.

DATE: February 20, 1973

CERTIFICATION OF IRRADIATION

LOT NO. Stone and Webster Paint Test

CUSTOMER Franklin Institute
Research Laboratories
Twentieth and Parkway
Philadelphia, Pa. 19103

PURCHASE ORDER NO. OR
ORDER REFERENCE

Project Number C3486

SAMPLE CONTAINER DESCRIPTION
AND IDENTIFICATION

Samples of Painted Concrete and Metal Substrates

IRRADIATION DOSE In Container Without Samples

	Part	Exposure Time	Dose Rate	Dose
Test 1. (November 1972)	A	1 hour	1.25 Mrad/hr	1.25 Mrad
	B	168 hours	0.676 Mrad/hr	1.14×10^2 Mrad
Test 2. (January 1973)	A	1 hour	1.22 Mrad/hr	1.22 Mrad
	B	166 hours	0.661 Mrad/hr	1.10×10^2 Mrad

[ ] EXPOSED DOSE CALCULATED FROM FRICKE

[ ] MINIMUM DOSE CORRECTED FOR ___% ATTENUATION

[X] MEASURED DOSE USING Potasium Nitrate DOSIMETERS In Pressure Vessel

COMMENTS

APPROVED BY: [signature]

NEUTRON PRODUCTS inc

The Franklin Institute Research Laboratories (FIRL) was established in 1946 as the research division of The Franklin Institute, which was founded in 1824.

As a not-for-profit organization, independent of commercial and academic interests, FIRL undertakes research, development, and engineering projects for both government agencies and private industry in the United States and abroad.

The Research Laboratories has a technical staff of approximately 300. It is organized into 17 Laboratories, grouped into six operating Departments: Materials Science and Engineering, Mechanical and Nuclear Engineering, Chemistry, Electrical Engineering, Systems Science, and Science Information Services. The Laboratories also maintains a full Support Services Department which includes a publications group, photographic Laboratory, instrument repair and calibration shop, and a large machine shop.

DATE: February 20, 1973

CERTIFICATION OF IRRADIATION

LOT NO. Stone and Webster Paint Test

CUSTOMER Franklin Institute
Research Laboratories
Twentieth and Parkway
Philadelphia, Pa. 19103

PURCHASE ORDER NO. OR
ORDER REFERENCE

Project Number C3486

SAMPLE CONTAINER DESCRIPTION
AND IDENTIFICATION

Samples of Painted Concrete and Metal Substrates

IRRADIATION DOSE In Container Without Samples

		Part	Exposure Time	Dose Rate	Dose
Test 1.	(November 1972)	A	1 hour	1.25 Mrad/hr	1.25 Mrad
		B	168 hours	0.676 Mrad/hr	1.14×10^2 Mrad
Test 2.	(January 1973)	A	1 hour	1.22 Mrad/hr	1.22 Mrad
		B	166 hours	0.661 Mrad/hr	1.10×10^2 Mrad

[ ] EXPOSED DOSE CALCULATED FROM FRICKE

[ ] MINIMUM DOSE CORRECTED FOR ____% ATTENUATION

[X] MEASURED DOSE USING Potasium Nitrate DOSIMETERS In Pressure Vessel

COMMENTS

____

____

APPROVED BY: ____________________

NEUTRON PRODUCTS inc

N03D0231

The Franklin Institute Research Laboratories (FIRL) was established in 1946 as the research division of The Franklin Institute, which was founded in 1824.

As a not-for-profit organization, independent of commercial and academic interests, FIRL undertakes research, development, and engineering projects for both government agencies and private industry in the United States and abroad.

The Research Laboratories has a technical staff of approximately 300. It is organized into 17 Laboratories, grouped into six operating Departments: Materials Science and Engineering, Mechanical and Nuclear Engineering, Chemistry, Electrical Engineering, Systems Science, and Science Information Services. The Laboratories also maintains a full Support Services Department which includes a publications group, photographic Laboratory, instrument repair and calibration shop, and a large machine shop.

Appendix 3E[1]
Geotechnical Investigations and Soil Sample Testing for the Service Water Reservoir

This appendix discusses geotechnical investigations in the vicinity of the North Anna service water reservoir. It is comprised of correspondence and technical reports that were prepared to address NRC concerns, raised during plant licensing, about service water reservoir and pump house settlement. This information has been preserved as originally submitted and is not intended or expected to be updated for the life of the plant.

1. Appendix 3E was submitted as Appendix E in the original FSAR. (see also page 3E-1)

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APPENDIX 3E GEOTECHNICAL INVESTIGATIONS AND SOIL SAMPLE TESTING FOR THE SERVICE WATER RESERVOIR

This appendix discusses geotechnical investigations in the vicinity of the North Anna service water reservoir. It is comprised of correspondence and technical reports that were prepared to address NRC concerns, raised during plant licensing, about service water reservoir and pump house settlement. This information has been preserved as originally submitted and is not intended or expected to be updated for the life of the plant. As such, Appendix 3E has not been updated to reflect current plant conditions and analyses. An updated discussion of the service water reservoir and pump house can be found in Section 3.8.4. This appendix was originally submitted, as part of Amendment 44 to the license application, as Appendix E. The attachments were added as follows:

1. Attachment 1, dated December 5, 1975, was initially submitted as part of Amendment 44.
2. Attachment 2, dated December 31, 1975, was initially submitted as part of Amendment 49, identified as Appendix F.
3. Attachment 3, dated June 21, 1976, was initially submitted as part of Amendment 54, identified as Appendix L.
4. Attachment 4 was excerpted from the response to NRC comment P3.8.
5. Attachment 5 was excerpted from the response to NRC comment P3.8.

3E.1 INTRODUCTION

This Appendix completes the response required by Mr. A. Schwencer's letter of July 24, 1975, and its attached document, *P3.6, Settlement of Service Water Pumphouse and Dikes*. The results of additional borings and laboratory tests are included, together with discussion, interpretation, and application of new data to analyses of pump house settlement, dike stability, seepage, and liquefaction.

3E.2 DIKE AND FOUNDATION CONDITIONS

3E.2.1 Description of Reservoir and Purpose of Investigation

The Service Water Reservoir consists of a spray pond, approximately 9.1 acres in size, which was sized to supply service water to Units 1, 2, 3, and 4. The reservoir is formed by an earth-rock dike with a 2-foot-thick clay lining. The maximum height of the dike is 33 feet and maximum design water depth is 10 feet. Service water is circulated from the reservoir by means of two pump houses located in the inner dike slope. Service water lines run from the pump houses to the station.

Construction of the dike and Service Water Reservoir lining, including the pump house for Units 1 and 2, was completed in July 1973. The pump house for Units 3 and 4 is currently under construction above the reservoir level. The pump house for Units 1 and 2 has experienced settlement since construction with a maximum settlement of 0.56 feet at the northwest corner. A separation of the east wing wall and some minor cracking of the west wing wall has also occurred.

An additional boring and testing program was carried out during the fall of 1975 for the purpose of documenting in more detail the foundation conditions and dike fill characteristics influencing pump house movement, particularly those at the maximum dike sections at the pump house for Units 1 and 2, and at a section on the southeast side of the reservoir.

Specific objectives of the investigation were:

1. Determination of sound bedrock elevations beneath the dike.
2. Laboratory evaluation of consolidation parameters for foundation materials.
3. Determination of ground-water elevations at the pump house for Units 1 and 2 and southeast dike sections.
4. Evaluation of the cyclic shear strength of foundation soils.
5. Evaluation of the static shear strength parameters for the dike and foundation soils.

3E.2.2 Borings and Instrumentation

Seven exploratory borings and nine instrumentation installation borings were made during the period August 27, 1975, through September 18, 1975. The location, depth of borings, and materials encountered are shown by the boring logs, plan, and profiles in Sections 3E.2.5 and 3E.2.6.

Exploratory holes were 4-inch-diameter wash borings advanced by roller bit. These holes were uncased except near the surface, where rockfill material was encountered. Drilling mud was used in some instances to prevent caving. Completed holes were backfilled with cement grout.

Instrumentation borings consisted of three 8-inch-diameter holes for slope indicators, three 4-inch-diameter holes for piezometers, and three 4-inch-diameter holes for reference monuments. Drilling mud was used in slope indicator and reference monument borings, and clean water was used for piezometer borings.

Except for SWR-7, 8, and 9, exploratory and slope indicator borings were advanced to sound rock, defined as the depth at which penetration by the roller bit was less than 1 inch per 2 minutes by prior agreement with the NRC. Borings SWR-7, 8, and 9, located along the south side of the reservoir, were carried to depths sufficient for correlation of materials.

Exploratory borings and borings for piezometers and slope indicators were logged and sampled. Standard penetration tests were made at approximately 5-foot intervals. Forty four 3-inch-diameter undisturbed tube samples and 178 split-spoon samples of dike and foundation material were recovered. Of the undisturbed samples, 43 were obtained by fixed piston Shelby tube sampler, and one was obtained using a 3-inch Dennison sampler. Undisturbed samples were handled in accordance with Specification NAS-445 (Specification for Instrumentation Borings and Subsurface Sampling) and ASTM D1587-67. They were transported to the Stone & Webster Boston soils laboratory in vehicles driven by Stone & Webster personnel involved in the field investigations.

Piezometers of the pneumatic diaphragm type and slope indicators were manufactured by Slope Indicator Company of Seattle, Washington. Two reference monuments consist of grouted 4-inch flush joint casing carried to sound rock. In the third reference monument, the casing stopped 38 feet above sound rock. A 50-foot-long No. 6 rebar was placed in the center of the monument to connect the cased portion with the uncased portion.

3E.2.3 Soils Testing Program

Laboratory tests reports and data are included in Section 3E.2.7.

Field classifications and descriptions of all samples were checked by the Stone & Webster Boston geotechnical laboratory. A series of grain size analyses and Atterburg Limit tests were performed on dike and foundation materials.

In-place density and natural water content were determined for 22 undisturbed samples of foundation material and for five undisturbed embankment samples. Additional data on embankment density were obtained from construction test records.

Fifteen one-dimensional consolidation tests were performed on undisturbed samples. Tests were run at both constant rate of strain and by loading in increments. Specimens were trimmed to 2.5 inches in diameter where possible; nonplastic samples were tested in sections cut from Shelby tubes.

Cyclic triaxial tests on foundation samples were performed by Geotechnical Engineers, Inc., (GEI) of Winchester, Massachusetts. Reports on the results of these tests are presented as Attachments 1, 2, and 3.

Consolidated undrained triaxial compression tests with pore pressure measurements were performed on two embankment samples and on five foundation samples. Two direct shear tests were run on foundation samples.

3E.2.4 Presentation of Data

3E.2.4.1 **Foundation Conditions**

All borings encountered fill, residual soil, and saprolite grading to sound rock, with depths to firm rock varying from 64.0 feet to 104.8 feet along the dike centerline. The materials are silts of low to moderate plasticity near the surface (ML or MH), grading to coarser grained material, classified as SM, SP, and SP-SM at greater depths. The saprolite retains the foliation of the parent rock and exhibits cementation of particles. The residual soil overlying the saprolite is shallow (less than 10 feet) or nonexistent in some locations. Mica is present in most samples.

Blow counts are erratic, indicating the presence of hard inclusions less severely weathered than the surrounding material, or the effect of mica, which may reduce blow counts by as much as 50%. In general, however, blow counts increase with depth, from values less than 20 near the original ground surface, to well over 100 near the sound rock surface.

The approximate elevations of sound rock along the centerline of the dike and on sections through the dike are shown on the subsurface profiles and sections in Section 3E.2.6. For the purpose of engineering calculations, the lower boundary of compressible material would be somewhat higher in a zone where standard penetration test values exceed 100 blows for 6 inches.

Except for one Shelby tube sample from SWR-6, laboratory measurements of in-place density ranged from 83.3 to 112.5 pcf, with an average of 94 pcf. The sample from SWR-6 (ST-4) had measured densities of 72.3 and 66.4 pcf but was disturbed during sampling.

The highest measured ground-water level in the service water reservoir area is Elevation 291 (Dames & Moore boring 46 in the center of the water storage area). At the southeast dike section, recent readings from piezometer P-10 indicate a ground-water level at Elevation 274. At the section near the pump house for Units 1 and 2, piezometer P-11 (near the centerline of the dike) reads Elevation 281, and P-12 (downstream toe) reads Elevation 277. These elevations place the ground-water table approximately 10 feet below the original ground surface at the dike centerline at both sections. When the phreatic surface is fully developed under operating conditions, the water surface is expected to be approximately at Elevation 287-290 under the dike at both sections (Section 3E.4), an increase of less than 10 feet.

Triaxial tests on two foundation samples indicated effective friction angles of 30.5 and 31.1 degrees, while direct shear tests on two samples gave values of 32.4 and 37 degrees, which would represent foundation strength in stability analyses of sections defined by a circular failure surface. Triaxial tests on foundation material where failure occurred along foliation planes gave effective friction angles of 17.3, 18.8, and 23.3 degrees.

Consolidation test data are shown in Section 3E.2.7 and discussed in detail in Section 3E.3.

Permeability of foundation materials determined from consolidation test data ranged from 2×10^{-7} to 4×10^{-5} cm/sec.

Samples for cyclic triaxial testing were selected after examination of material classifications and standard penetration test results, and consideration of liquefaction potential using the Seed and Idriss simplified procedure. The samples selected represented the only questionable zones. Analysis of test results is discussed in Section 3E.6.

3E.2.4.2 **Service Water Reservoir Embankment**

Zonation and materials used in the constructed dike sections are shown in Section 3E.2.6. Select fill material is a highly plastic, sandy clay or silt (CH or MH), and random fill is similar material that may be somewhat less plastic and that in some cases is classified as SM material. Both zones were placed at or above 95% of maximum standard Proctor density. Specifications for select fill required a plasticity index of 15 or above. Laboratory tests on samples of fill material from borings P-11, SI-1, SWR-6, SWR-3, SWR-5, SWR-7, and SWR-8 showed PIs in all cases greater than 8, ranging upward to 38.

In-place densities from tests in the general area of the maximum sections at the pump house for Units 1 and 2 and the southeast dike section were extracted from construction test records. Locations and test values are shown by Figures 3E-1 through 3E-3. The average of all tests in these critical areas is 93.3 pcf, slightly but not significantly lower than the average of 95 pcf for all field tests made.

Five laboratory measurements on undisturbed samples of fill material taken from borings SWR-6, P-11, and P-12 gave values of in-place dry density of 90.9, 93.9, 103.0, 92.5, and 82.0.

A one-dimensional consolidation test on an undisturbed sample from boring P-11 (Section 3E.2.7) showed a unit strain potential of 0.0375 ft/ft under a load of 4040 psf, approximately equivalent to the maximum loading on embankment material at the base of the maximum section.

Two consolidated-undrained triaxial shear tests were made on undisturbed samples of compacted fill from boring SWR-6 (southeast dike section). Effective friction angles of 34.7 and 35.1 degrees were obtained. A similar test on a sample taken from beneath the toe of the dike at the pump house for Units 1 and 2 gave an effective friction angle of 31.1 degrees.

3E.2.5 Boring Logs

Boring logs are presented in Figure 3E-4. Descriptions of materials are from field records, modified where appropriate by laboratory examination of samples.

3E.2.6 Boring Locations, Profiles, and Sections

Locations of borings are shown by Figures 3E-5 and 3E-6. Profiles along the centerline of the dike are shown by Figure 3E-7.

Sections through the dike at the southeast section, pump house for Units 1 and 2, and in the north-south direction through the reservoir are shown by Figures 3E-8 through 3E-10.

3E.2.7 Laboratory Test Results

3E.2.7.1 **General**

Descriptions of all the undisturbed samples taken in the course of the current investigation are given in Table 3E-1. These descriptions are based on soil classifications in accordance with the Unified Soil Classification System, as described in ASTM D 2487, and contain terms defined in ASTM D 2488. The bases for these descriptions are not entirely applicable to the residual soil and saprolite underlying the service water reservoir. The descriptions do not clearly indicate the relict structure and foliation in these materials or that certain size fractions and types of minerals occur in layers or zones. The words "fine sand" must be interpreted to mean "particles of hard material having the same size range as fine sand (that is, between the No. 40 and the No. 200 sieves)."

The order in which data are presented in Table 3E-1 (and in Table 3E-2) is in accordance with the following locations of the borings:

1. Pump house for Units 1 and 2

   Borings P-11
   SI-1
   P-12
   SI-2

2. Maximum dike section (at southeast corner of reservoir)

   Borings SWR-6
   SI-3
   P-10

3. Spaced around crest of dike

   Borings SWR-3
   SWR-4
   SWR-5
   SWR-7
   SWR-8
   SWR-9

Table 3E-2 presents the densities, water contents, and classification indexes that were determined and indicates, by code letters in the right-hand column, the tests that were performed on the undisturbed samples. Results of the indicated tests are presented in the subsequent tables and figures, with the following two exceptions. First, the gradation curves have not been included due to their bulk. However, the percentages of fines given in Table 3E-2 and the descriptions of the samples given in Table 3E-1 are taken from these gradation curves. Second, the results of the cyclic triaxial tests are given in Attachment 1.

3E.2.7.2 **Consolidation Tests**

The 15 consolidation tests are summarized in Table 3E-3, which also indicates the test number assigned to each test. The plots of vertical strain versus log of stress for all the tests have been collected in Figure 3E-11, with each curve identified by the test number given in Table 3E-3. Plots of vertical strain versus log of stress and change in height versus log of elapsed time for the individual tests are given in Figure 3E-12 in the same order as the test numbers.

3E.2.7.3 **Strength Tests**

The eight consolidated-undrained triaxial compression tests are summarized in Table 3E-4, which also indicates the test number assigned to each test and the type of material (dike fill versus foundation) that was tested. Mohr effective stress circles are shown in Figures 3E-13 and 3E-14 for the tests performed on the dike fill and foundation materials, respectively. Each stress circle in these figures is identified by the test number given in Table 3E-4. Plots of stress versus strain for the individual triaxial tests are given in Figure 3E-15 in the same order as the test numbers.

Plots of stress versus displacement for the two drained direct shear tests of foundation material are given in Figure 3E-16.

3E.3 SETTLEMENT OF PUMP HOUSE FOR UNITS 1 AND 2

3E.3.1 Settlement History

The SWR pump house for Units 1 and 2 is a rigid concrete structure founded at Elevation 297 on a bedding layer of compacted select fill below the original ground surface. Upon completion of the structure on August 25, 1972 (the starting time for settlement plots), the random fill of the dike was placed around and against the structure to Elevation 318. This fill placement was completed on October 16, 1972 (after an elapsed time of 52 days). Settlement measurements of points at the corners of the pump house operating floor (at Elevation 328) taken on December 4, 1972 (after an elapsed time of 101 days), revealed that the pump house was tilting toward the northwest and had already undergone an average settlement of 0.12 foot. This magnitude of average settlement was equal to the total settlement initially estimated in 1970.

The initial settlement estimate can be rationally substantiated. If a recompression index, C_r, of 0.010 vertical strain per log cycle of stress change were assumed for the foundation material, the total settlement under the center of the pump house would be calculated as 0.12 to 0.14 foot. A value of C_r equal to 0.010 would have been a reasonable assumption for a saprolite, agrees with values empirically correlated with the water contents, and corresponds to values measured in some consolidation tests performed by Dames & Moore before the prediction was made.

As shown in Figure 3E-17, settlement continued under this loading at a low rate (about 0.0013 vertical strain per log cycle of elapsed time) until mid-1973, when the average total settlement of the pump house had reached about 0.15 foot. On June 11, 1973, excavation was started in the slope north of the pump house for the service water lines. Fill placement in the excavated area and on the dike began July 10, 1973 (after an elapsed time of 319 days), and was completed on May 10, 1974 (after an elapsed time of 623 days), with the crest of the dike at Elevation 327.5. During the period of fill placement, the rate of settlement increased (to about 0.00041 vertical strain per log cycle of elapsed time) and the average total settlement of the pump house had become about 0.20 foot by the time the dike in front of the pump house had been brought to its final elevation.

In March 1974, the settlement prediction for the pump house was reevaluated on the basis of the record of measured settlement. The average rate of settlement prior to that point in time was determined to be 0.0024 vertical strain per log cycle of elapsed time. Considering the settlement to have become entirely due to secondary compression, this rate was assumed equal to the coefficient of secondary compression, C_α, and was used to predict a future settlement due to secondary compression of 0.156 foot over the next 40 years. In addition, the settlement of the pump house due to impounding a 10-foot depth of water in the reservoir was calculated to be 0.098 foot. These two components of future settlement, when added to the existing average settlement of 0.195 foot, indicated a total average settlement of 0.449 foot over the life of the plant. Because of the conservative nature of the assumptions and calculations made to arrive at that number, the FSAR was amended to reflect a figure of 0.40 foot.

Following a completion of the dike in May 1974, the rate of settlement increased to about 0.019 vertical strain per log cycle of elapsed time, through this rate decreased to about 0.006 by July 1974 (after an elapsed time of about 680 days). By early December 1974 (after an elapsed time of about 830 days), the average total settlement of the pump house had reached about 0.30 foot.

During December 1974 and January 1975, the pump house settled at a rate of about 0.064 vertical strain per log cycle of elapsed time, possibly in association with heavy rainfalls during the first half of December. On February 19, 1975 (after an elapsed time of 908 days), the average total settlement was about 0.38 foot.

At the request of the NRC staff, a second reevaluation of the pump house settlement was made in July 1975, which indicated an average rate of settlement prior to that point in time between 0.0026 and 0.0028, confirming the results of the March 1974 calculation.

From February 19, 1975, through November 24, 1975 (to an elapsed time of 1186 days), there has been virtually no settlement of the pump house.

3E.3.2 Consolidation Test Data

As a part of the current investigation of the service water reservoir, a total of 15 consolidation tests were performed, though two of these were on samples taken from the compacted random fill of the dike. Five of the tests were continuously loaded and then unloaded at a constant rate of strain. The other 10 tests were loaded in stress increments, though seven were loaded in only two increments for the purpose of determining coefficients of secondary compression. The results of these tests are presented in Section 3E.2.7, Figures 3E-11 and 3E-12, and summarized in Table 3E-3.

The plots of vertical strain versus log of stress, collected in Figure 3E-11, show a strongly and continuously curving downward relationship from the initial loading until the straight virgin consolidation line is reached. There is no tendency for linearity in the range of initial compression and no clear break, or “knee,” in the relationship to define the preconsolidation pressure. The curvature during initial compression results from the elastic rebound and swelling and specimen preparation. Considerable swelling of this highly micaceous and foliated saprolite is apparent when extruding the material from the sampling tubes. The behavior of the material in situ, undergoing a change in stress, would not follow the strongly curving relationship but would rebound and recompress along much flatter and more linear curves.

Although no cycles of rebound followed by recompression were included in any of the consolidation tests performed under the current investigation, several were included in earlier tests performed by Dames & Moore on similar foundation materials at this site. Comparison of the plots of vertical strain versus log of stress from the current tests to those determined by Dames & Moore shows close agreement in the shape of the strongly curved relationship during initial loading. Furthermore, the slopes of the rebound curves from the current tests are approximately equal to those from the Dames & Moore tests. Because of these similarities, the recompression indexes determined in the Dames & Moore tests should be applicable to the pump house foundation materials.

In the range of stress change associated with constructing the pump house and dike (about 1.0 to 10 kips/ft^2), the slopes of the recompression curves from the Dames & Moore tests indicate values of C_r varying from slightly less than 0.010 vertical strain per log cycle of stress change to a number of values about 0.015, with a few values as high as 0.035.

Plots are presented in Section 3E.2.7 of the change in specimen height versus log of elapsed time from incrementally loaded consolidation tests. These plots show that, in almost every case, any change in height that might be considered as primary consolidation occurred before the first reading was taken at an elapsed time of 15 seconds. Therefore, these straight-line relationships define the secondary compression of the material. In the range of stress change associated with constructing the pump house and dike, the slopes of the plots give values of C_α varying from 0.00025 vertical strain per log cycle of elapsed time to 0.00144, with one unusual value (from a specimen with a very high void ratio loaded in a very large stress increment) of 0.00442. The average coefficient of secondary compression is about 0.0007 to 0.0008 vertical strain per log cycle of elapsed time.

3E.3.3 Settlement Analysis

Conventional analysis of the stresses induced in the 50-foot thickness of compressible foundation material by constructing the pump house and dike, indicate the pump house settlement to be as follows:

Average settlement at south side = 10.2 C_r

Average settlement at north side = 19.2 C_r

If a value of C_r equal to 0.025 were used with these factors and if secondary compression were ignored, the following total settlements of the pump house would be calculated:

Average settlement at south side = 0.25 ft

Average settlement at north side = 0.48 ft

The average of these two values (giving the total settlement under the center of the pump house) is 0.37 foot, while the ratio of the smaller value to the larger is 0.53.

The measured settlement of the pump house on May 19, 1975 (after an elapsed time of 997 days), was 0.27 foot at the south side and 0.48 at the north side. The average of these two values is 0.38 foot and the ratio between them is 0.57.

Therefore, in hindsight, it is possible to calculate the settlement of the pump house by selecting a suitable value of C_r. As noted above, a value of C_r equal to 0.010 gives an average total settlement of only 0.12 foot. Despite the problem of applying judgment in selecting a value of C_r, the analysis does predict the correct ratio of settlements at the south and north sides that result in the tilting of the pump house.

If secondary compression were included in the analysis, a value of C_r lower than 0.025 would provide agreement with the measured settlement. For example, a C_r equal to 0.015 would give an average settlement of 0.22 foot, while a value of C_α equal to 0.0008 vertical strain per log cycle of elapsed time (after an elapsed time of 997 days, or three log cycles) would add an average settlement of 0.12 foot The sum of the primary and secondary components is 0.34 foot, as compared to the measured average settlement of 0.38 foot.

Although analyses can give rational bases for the total settlement experienced by the pump house, they cannot explain the time-rate of settlement shown in Figure 3E-17. The measured vertical movements of the pump house are believed to have resulted from the complex pattern of loading, unloading, and reloading, together with variations in ground-water level due to local excavations and a number of intensive rainfalls. Regardless of the uncertainty in the past rate of settlement, there is no question that all primary consolidation under the current loads has been completed. This is apparent from the settlement record and is substantiated by the almost instantaneous completion of primary consolidation in the laboratory tests.

Any future settlement would result only from an increase in loading or as secondary compression.

3E.3.4 Future Settlement

Since February 19, 1975, under a constant loading, there has been no further settlement of the pump house, despite the occurrence of several heavy rainfalls. However, additional settlement may be anticipated when water is impounded in the reservoir and consideration should be given to secondary compression.

The calculation made in March 1974 indicated the pump house would settle an additional 0.10 foot due to impounding of 10 foot depth of water in the reservoir. This prediction was based on a value of C_r equal to 0.015, which is reasonable. In view of the large settlement experienced to date by the pump house, this predicted settlement is considered to be a maximum value. Also, the distribution of the added load is not likely to cause further tilting of the pump house toward the northwest, and it may reduce the tilting.

An allowance for secondary compression may be based on a value of C_α equal to 0.0008 vertical strain per log cycle of elapsed time. The elapsed time to a point 40 years in the future would be approximately 15,600 days or 1.2 additional log cycles of elapsed time from the present. Therefore, the possible further settlement of the pump house due to secondary compression would be no more than 0.05 foot.

The further average settlement of the pump house due to these two influences over the life of the plant should not exceed 0.15 foot. A projection of additional settlement for an extended license period of 20 years was not performed since settlement of the pumphouse is monitored as required by the Technical Requirements Manual.

3E.3.5 Conclusions

Previous predictions of pump house settlement have had rational bases, though the selection of appropriate consolidation parameters has been a problem.

Conventional settlement analyses can yield calculated values of the amount of settlement corresponding to the measured values, including the differential settlement causing the tilting of the pump house.

The time-rate of settlement is a complex function of the changing ground-water level and conditions of loading caused by construction operations, and is not amenable to theoretical analysis.

Primary consolidation of the pump house foundation material under the current loading has been completed, resulting in an average total settlement of 0.38 foot. Future additional settlement, resulting from impounding water in the reservoir and secondary compression, should be less than 0.15 foot, giving a maximum average settlement of 0.53 foot over the life of the plant.

Connections of service water lines to the pump house have been redesigned to eliminate any possibility of overstressing these lines due to pump house settlement. Construction of these connections will cause no change in load and, therefore, will not affect settlement.

Constant monitoring of pump house settlement in the future will provide a basis for corrective measures, if required, in the event of any additional movement.

3E.4 SEEPAGE MONITORING

3E.4.1 Introduction

Twelve piezometers of the pneumatic diaphragm type, manufactured by the Slope Indicator Company, have been installed in the service water reservoir dike and adjacent areas to measure pore water pressures within the dike, its foundation, and in the immediate vicinity of the reservoir.

Five wiers have been installed in the service water reservoir area for the purpose of monitoring and evaluating ground-water seepage.

3E.4.2 Steady-State Seepage Prediction

To study the future development of the phreatic surface through the service water dike and its foundation, a series of six FEDAR runs was performed. FEDAR is a general-purpose finite element program to analyze seepage problems.

The finite element mesh used is shown in Figure 3E-18.

Because the boundary conditions cannot be known accurately, a parametric study, consisting of five FEDAR runs, was initiated. The elevation of the ground-water table was varied at Node 3 (boundary 110 feet downstream from toe of dike) between 267 feet and 275 feet, and at Node 224 (boundary 270 feet inboard from the inboard toe of the dike) between 289 feet and 303 feet. Because the inboard boundary of the mesh was chosen to be at a point inside the service water reservoir where the flow of ground water diverges either toward the northeast or toward the southeast, a “no flow” boundary condition was also investigated.

It has been postulated by the NRC staff that the rupture of one of the pipes inside the service water reservoir could erode the clay liner at the bottom of the reservoir and consequently increase the amount of seepage from the service water reservoir. The NRC staff had questioned the adequacy of the piezometers to detect such an increase. A sixth analysis was therefore made (Run 6) in which a 15-foot-wide crack, 50 feet inboard from the toe of the dike, was modeled.

The six FEDAR analyses performed are summarized in Table 3E-5. The corresponding results are presented in Figures 3E-19 through 3E-24. These figures show lines of equal total head and lines of equal fluid pressure. Although the figures resemble flow rates, they are not because the nearly horizontal lines of equal fluid pressure are not flow lines.

3E.4.3 Comments and Conclusions

While performing the FEDAR analyses it became evident that the very low permeability of the clay liner almost entirely dissipates all the hydrostatic head, and that the foundation soil between the bottom of the clay liner and the natural ground-water surface will stay in an unsaturated state. This can also be stated as follows: the amount of water able to seep through the impermeable clay liner will not be sufficient to saturate the saprolite just below the bottom of the service water reservoir. Along the inboard face of the dike this creates a “roof effect”; the water seeping through the liner trickles down to the steady-state phreatic surface existing some distance below.

Because of this effect, the analyses are independent of the service water reservoir embankment cross section, and the results are applicable to any section of the dike. Table 3E-6 gives the range of anticipated phreatic levels at the locations of the 12 piezometers.

The phreatic lines for all runs are plotted in composite Figure 3E-25. This figure, along with Table 3E-6, shows that the assumptions made for boundary conditions have very little effect on the piezometric conditions. However, when a crack is introduced in Run 6, there is a significant rise in the elevation of the phreatic surface, and this is reflected directly in the fluid pressures at the piezometers. Thus, the formation of a crack would be detected by the measurements in the piezometers.

3E.5 STABILITY ANALYSIS

A purpose of the investigation was to check soil properties and strength parameters used in stability analyses. Methods of analysis are discussed fully in Section 3.8.4.4. All analyses showed adequate factors of safety under static and dynamic loadings, using conservative input parameters. Factors of safety are summarized in Table 3.8-14.

Table 3E-7 shows material properties and strength parameters determined during the recent investigation, compared to values used in the stability analyses. The saturated densities and angles of internal friction for fill and foundation material are in good agreement with those used for the analyses.

Substitution in the stability analyses of a higher saturated density for fill and lower saturated density for foundation material would increase the driving forces on a circular or wedge-shaped failure block, but only in approximate proportion to the change in density values (120 vs. 116 pcf and 121 vs. 125 pcf). However, substitution of the higher angles of internal friction in the analysis would increase computed shear resistance by an amount approximately proportional to the increase in tan Ø', or by a factor of 1.06 for fill (tan 33.6 degrees divided by tan 32 degrees), and 1.12 for foundation material (tan 32.8 degrees divided by tan 30 degrees). This increased shear resistance would more than offset the increased driving force and would result in a higher calculated factor of safety. Therefore, the input parameters used in the stability analyses result in conservative safety factors, and further computations are not warranted.

3E.6 LIQUEFACTION POTENTIAL OF FOUNDATION MATERIALS

3E.6.1 Introduction

The liquefaction potential of the founding materials of the service water reservoir dikes was evaluated based on laboratory testing of undisturbed samples. The selection of silty sand samples, located below the service water reservoir dikes that might be susceptible to liquefaction, was based on blow counts, the Gibbs & Holtz relationship, and the criteria determined by Ohsaki. A total of seven silty sand samples were subsequently chosen for testing.

Analyses were conducted to determine the actual in situ stress conditions that existed in the field. Original overburden stresses were calculated based on the calculated value of K_o and the tested total unit weight of the soil. The additional stresses induced by the construction of the embankment were then calculated for the plane strain condition $((\bar{\sigma}_2 \neq \bar{\sigma}_3)$. Results from finite element analyses of flow were then used to determine the water pressure levels and the seepage forces that would be experienced during the life of the plant. The results were then combined to calculate the in situ octahedral state of stress and the consolidation stress ratio $(CSR \neq \bar{\sigma}_1 / \bar{\sigma}_3)$.

Cyclic triaxial testing was then conducted by Geotechnical Engineers, Inc. (GEI). To more closely duplicate in the laboratory the in situ soil conditions, the samples were tested at five different anisotropic confining stresses $(\bar{\sigma}_{1c} \neq \bar{\sigma}_{3c})$ and three different CSRs. Two of the samples were tested at $\bar{\sigma}_{oct}$ of 1.33 kg/cm^2 with CSR of 2.0, one sample was tested at $\bar{\sigma}_{oct}$ of 0.67 kg/cm^2 with CSR of 3.0, one sample was tested at $\bar{\sigma}_{oct}$ of 0.93 kg/cm^2 with CSR of 2.0, two samples were tested at $\bar{\sigma}_{oct}$ of 1.75 kg/cm^2 with CSR of 1.50, and one sample was tested at $\bar{\sigma}_{oct}$ of 1.17 kg/cm^2 with CSR of 1.5.

3E.6.2 Method of Analysis

The factor of safety against liquefaction was calculated based on the comparison between the change in the octahedral shear stress required to cause liquefaction in the laboratory during cyclic loading and the change in the octahedral shear stress occurring in the field during the safe shutdown earthquake. The comparison was made on the basis of the ratio between the octahedral shear stress and the octahedral normal effective consolidation stress. Such a procedure is necessary because the field conditions are different from the usually assumed horizontal layering with vertical loads, and the laboratory conditions include initial shear stresses.

In the laboratory, this relationship, defined by the initial octahedral stress in the chamber, is:

$$\sigma_{OL} = \frac{1}{3}(\bar{\sigma}_1 + \sigma_2 + \bar{\sigma}_3)$$

The octahedral shear component of the cyclic load is:

$$\Delta\tau = \frac{1}{3}[(\bar{\sigma}_1 - \bar{\sigma}_3)^2 cy + (\bar{\sigma}_2 - \bar{\sigma}_3)^2 cy + (\bar{\sigma}_1 - \bar{\sigma}_2)^2 cy]^{\frac{1}{2}}$$

and the cyclic deviator stress is:

$$(\bar{\sigma}_1 - \bar{\sigma}_3)cy = (\bar{\sigma}_1 - \bar{\sigma}_2)cy \text{ and } (\bar{\sigma}_2 - \bar{\sigma}_3)cy = 0$$

The stress ratio is defined by:

$$SR_L = \Delta\tau/\bar{\sigma}_{OL}$$

The SR_L was calculated for each tested sample at a double amplitude (DA) strain level of 5% and plotted on semi-log paper vs. number of cycles. Tests were conducted at three predetermined CSRs. These results are presented in Figure 3E-26. The relationship between SR_L and CSR for a safe shutdown earthquake with 10 cycles of duration and 5% DA strain is shown in Figure 3E-27. This curve indicates that for an increase in the CSR there is also an increase in the value of the SR_L.

In the field, the initial octahedral stress state is:

$$\bar{\sigma}_{OF} = \frac{1}{3}(\bar{\sigma}_1 + \bar{\sigma}_2 + \bar{\sigma}_3)$$

and the induced shear stress due to the earthquake is:

$$\tau_F = 0.65(Amax)\sigma_v\ rd$$

where:

Amax = 0.18

σ_v = total vertical stress

rd = stress reduction coefficient
(average value based on the actual depth of embedment)

During the earthquake, the octahedral component or the change in shear stress is:

$$\Delta\tau = \frac{1}{3}[(\Delta\bar{\sigma}_1 - \Delta\bar{\sigma}_3)^2 + (\Delta\bar{\sigma}_2 - \Delta\bar{\sigma}_3)^2 + (\Delta\bar{\sigma}_1 - \Delta\bar{\sigma}_2)^2]^{\frac{1}{2}}$$

and is defined by the principal stresses where:

$$\Delta\bar{\sigma}_1 = -\Delta\bar{\sigma}_3 = \tau_F \text{ and } \Delta\bar{\sigma}_2 = 0$$

By substitution, the octahedral component of the change in shear stress is:

$$\Delta\tau = 0.816\tau_F$$

Therefore, the change in the stress ratio is:

$$SR_F = \Delta\tau/\bar{\sigma}_{OF}$$

The factor of safety for any sample is then simply defined by:

$$FS = SR_L/SR_F$$

and by substitution:

$$FS = SR_L(\bar{\sigma}_{OF})/0.816\tau_F$$

The factor of safety is then simply defined by the SR_L for any given soil element, as determined by the value of the CSR, the initial in situ octahedral stress state, and the induced principal shear stress that occurs during the safe shutdown earthquake.

3E.6.3 Conclusions

The $\bar{\sigma}_{OF}$ and CSRs for the seven samples were then calculated as outlined in Section 3E.6.1. The value of SR_L was then obtained by entering Figure 3E-27 with the corresponding value CSR.

τ_F for each sample was based on σ_V and rd. The rds and σ_V were calculated based on the actual depth of sample embedment. The corresponding factors of safety were then calculated directly by combining the SR_L, τ_F, and $\bar{\sigma}_{OF}$ as outlined in Section 3E.6.2.

Table 3E-8 presents the various sample parameters and the calculated factors of safety for the seven samples obtained from the dike area.

The calculated factors of safety for these samples range from 2.52 to 3.31 with the average value being 3.00. To take into account the effects of two-dimensional shaking, Seed suggests that 90% of the factor of safety be used. If this is done, the above values range from 2.77 to 2.98, with an average value of 2.70.

The conclusion, based on the high values of the factor of safety and the conservative nature of the analysis, is that no liquefaction problems exist in the founding materials of the service water reservoir dike.

Table 3E-1
DESCRIPTIONS OF UNDISTURBED SAMPLES

Boring Number	Sample Number	Depth, ft	Group Symbol	Description
P-11	1	17.0-18.3	SM-MH	Silty sand, widely graded, 6% gravel to 0.3 in. max, mostly fine sand, 47% highly plastic fines, brownish red, micaceous, few large roots, some mica partings, fill.
	2	23.0-24.2	ML-SM	Sandy silt, moderately to highly plastic, 46% medium to fine sand, reddish brown mottled with light brown and yellow micaceous, 1.8 in. particle gravel, fill.
	3	37.0-38.2	SM	Silty sand, medium to fine, mostly fine, 29% nonplastic fines, light gray, micaceous.
	4	42.0-43.2	SM	Silty sand, medium to fine, 24% nonplastic fines, light yellowish gray, micaceous.
	5	48.0-49.0	SM	Silty sand, medium to fine, 24% nonplastic fines, brownish gray, micaceous.
SI-1	1	17.0-18.3	MH-SM	Sandy silt, highly plastic, 47% medium to fine sand, reddish brown, micaceous, fill.
	2	27.0-27.9	CH-SC	Sandy clay, highly plastic, 37% medium to fine sand, reddish brown, micaceous, few particles gravel, 10 1.5 in. max, fill.
	3	40.0-41.2	SM	Silty sand, medium to fine, mostly fine, 30% nonplastic fines, brownish gray, very micaceous, 1.2 in. particle gravel, pocket greenish gray sandy silt.
	4	47.0-48.3	SM	Silty sand, medium to fine, 19% nonplastic fines, light yellowish gray, very micaceous.
	5	52.0-53.0	SM	Silty sand, medium to fine, 15% nonplastic fines, light yellowish gray, some mica.
	6	62.0-63.5	SM	Silty sand, medium to fine, mostly fine, 31% nonplastic fines, yellowish green, mostly mica.

Table 3E-1 (continued)
DESCRIPTIONS OF UNDISTURBED SAMPLES

Boring Number	Sample Number	Depth, ft	Group Symbol	Description
P-12	1	7.0-8.8	CH-SC and SM	Sandy clay, highly plastic, 43% medium to fine sand, yellowish brown mottled with reddish brown, micaceous, few particles gravel to 0.3 in. max, fill, at bottom changes to silty sand, widely graded, 10-15% gravel to 0.3 in. max, mostly medium to fine sand, 10-15% nonplastic fines, greenish gray.
	2	17.0-18.4	SM	Silty sand, medium to fine, 25% nonplastic fines, yellowish gray, micaceous, few particles gravel to 0.3 in. max.
SI-2	1	12.0-13.6	SM	Silty sand, medium to fine, mostly fine, 18% nonplastic fines, light gray, micaceous.
SWR-6	1	12.0-13.6	CH-SC and SM-MH	Sandy clay, highly plastic, 32% medium to fine sand, yellowish brown, few particles gravel to 0.3 in. max, at bottom changes to sandy silt, highly plastic, 48% medium to fine sand, very stiff undisturbed, becomes stiff when remolded, reddish brown, very micaceous, few pockets highly plastic clay, fill.
	2	22.5-24.1	MH-SM	Sandy silt, highly plastic, 40% medium to fine sand, very stiff undisturbed, becomes stiff when remolded, reddish brown, micaceous, few particles gravel to 0.3 in. max, few pockets highly plastic clay, fill.
	3	42.0-44.0	SM	Silty sand, medium to fine, mostly fine, slightly to moderately plastic fines, yellowish gray.
	4	57.0-58.9	SM	Silty sand, medium to fine, mostly fine, 33% highly plastic fines, yellowish gray, very micaceous, some pockets black organic material.
SI-3	1	42.0-42.3	SM	Silty sand, medium to fine, mostly fine, 10-20% nonplastic fines, brownish green, large pockets light brown silty sand (sample disturbed by lump of hard material entering tube).
P-10	1	5.0-7.0	SC	Clayey sand, medium to fine, 26% moderately plastic fines, yellowish gray, very micaceous.
	2	22.0-23.4	SM	Silty sand, coarse to fine, mostly medium to fine, 18% nonplastic fines, greenish gray, mostly mica.

Table 3E-1 (continued)
DESCRIPTIONS OF UNDISTURBED SAMPLES

Boring Number	Sample Number	Depth, ft	Group Symbol	Description
SWR-3	1	7.5-9.0	SM	Silty sand, widely graded, 5% gravel to 0.6% in. max, mostly fine sand, 32% nonplastic fines, yellowish brown, very micaceous, some thin lenses black silt, fill.
	2	12.0-13.8	MH-SM	Silty-sand, gap-graded, 11% gravel to 0.4 in. max, mostly coarse and fine sand, 14% nonplastic fines, reddish brown, very micaceous, at bottom becomes sandy silt, highly plastic, 35% fine sand, reddish brown, micaceous, fill.
	3	42.5-44.4	SM	Silty-sand, medium to fine, 27% nonplastic fines, yellowish brown.
	4	62.0-63.1	SM	Silty sand, coarse to fine, mostly medium to fine, 23% nonplastic fines, yellowish brown and white.
SWR-4	1	12.0-13.5	ML-SM	Sandy silt, moderately to highly plastic, 43% medium to fine sand, light yellowish gray and dark yellowish brown, very micaceous, foliation planes inclined about 30 degrees from horizontal.
	2	27.0-28.8	SM	Silty sand, medium to fine, mostly fine, 36% nonplastic fines, yellowish brown, micaceous.
	3	42.0-43.3	SP-SM and SM	Sand, uniform, medium to fine, 3-8% nonplastic fines, brownish gray, micaceous, becomes silty sand, medium to fine, 25% nonplastic fines, brownish gray, micaceous, at bottom becomes sand, uniform, medium to fine, 10-15% nonplastic fines, brownish gray layered with white, micaceous.
	4	52.0-53.7	SM	Silty sand, medium to fine, 16% nonplastic fines, brownish gray, micaceous.
	5	62.0-63.8	SP-SM and SM-ML	Sand, uniform, medium to fine, 3-8% nonplastic fines, brownish gray, micaceous, at bottom becomes silty sand, medium to fine, 48% moderately plastic fines, light yellow.
	6	77.0-77.7	SM	Silty sand, medium to fine, 34% slightly plastic fines, yellowish brown, at bottom becomes mostly medium sand, 21% nonplastic fines.

Table 3E-1 (continued)
DESCRIPTIONS OF UNDISTURBED SAMPLES

Boring Number	Sample Number	Depth, ft	Group Symbol	Description
SWR-5	1	12.0-13.0	CH-SC	Sandy clay, highly plastic, 40% medium to fine sand, brownish red, micaceous, 1.0 in. particle gravel, fill.
	2	22.0-24.0	ML-SM and SM-ML	Sandy silt, mostly fine, brownish yellow, micaceous, 1.2 in. particle gravel, at bottom becomes silty sand, coarse to fine, mostly fine, 46% moderately plastic fines, reddish brown, micaceous, fill.
	3	32.0-33.2	SM-ML	Silty sand, medium to fine, mostly fine, 30-35% nonplastic fines, greenish gray, very micaceous, at bottom becomes 48% slightly plastic fines, micaceous, brownish yellow.
	4	42.0-43.4	SM	Silty sand, medium to fine, mostly medium, 35% nonplastic fines, dark green layered with light gray and white, micaceous, at bottom becomes 15-20% nonplastic fines, yellowish brown.
	5	57.0-59.0	SM	Silty sand, medium to fine, mostly fine, 22% nonplastic fines, grayish green, very micaceous.
	6	85.0-86.2	SM	Silty sand, medium to fine, 17% nonplastic fines, brownish yellow at top, becomes grayish green at bottom, micaceous.
SWR-7	1	12.0-13.5	CH-SC	Sandy clay, highlt plastic, 45% medium to fine sand, reddish brown mottled with yellowish brown, some mica, fill.
	4	32.0-33.9	SC-CH	Clayey sand, medium to fine, 35% moderately plastic fines, light reddish brown mottled with light yellowish brown, few particles gravel to 0.8 in. max, at bottom becomes medium to fine, mostly fine, 45% moderately plastic fines, light yellowish gray streaked with light reddish brown, trace mica, fill.
	5	42.0-43.2	SM	Silty sand, medium to fine, mostly fine, 30% nonplastic fines, light brown, some mica.
	6	47.0-48.2	SM-ML	Silty sand, medium to fine, 36% moderately plastic fines, dark yellowish and reddish brown, very micaceous, some particles fractured gravel to 1.0 in. max, at bottom becomes 46% nonplastic fines, dark yellowish brown.

Table 3E-1 (continued)
DESCRIPTIONS OF UNDISTURBED SAMPLES

Boring Number	Sample Number	Depth, ft	Group Symbol	Description
	7	52.0-53.3	ML-SM and SM-ML	Sandy silt, slightly to moderately plastic, 35-40% medium to fine sand, dark yellowish brown, micaceous, at bottom becomes silty sand, medium to fine, mostly fine, 38% nonplastic fines, yellowish brown, micaceous.
SWR-8	1	7.0-8.7	MH-SM	Sandy silt, highly plastic, 35-45% medium to fine sand, reddish brown, very micaceous, fill.
	2	27.0-27.9	MH-SM	Sandy silt, highly plastic, 47% medium to fine sand, brown, very micaceous, some thin lenses and small pockets black organic material.
SWR-9	1	17.0-18.6	SM	Silty sand, uniform, fine, 30% slightly plastic fines, light brown, very micaceous, few pockets light yellow silt and black organic material.
	2	22.0-23.2	SM	Silty sand, uniform, fine, 27% nonplastic fines, dark yellowish brown mottled with light gray, very micaceous, few pockets light yellow silt and black organic material.

Table 3E-2

LABORATORY TESTS OF UNDISTURBED SAMPLES

Boring Number	Sample Number	Depth, ft	Dry Unit Weight, pcf	Water Content,%	Atterberg Limits			Percent Fines	Group Symbol	Tests Performed[a]
					LL	PL	PI			
P-11	1	17.0-18.3	-	25.5	51.7	31.5	20.2	47	SM-MH	G
	2	23.0-24.2	90.9	25.8	48.9	35.2	13.7	54	ML-SM	IC, G
	3	37.0-37.9	98.5	20.2	Nonplastic			-	SM	CT
		37.9-38.2	95.6	21.8	Nonplastic			23	SM	CRSC, G
	4	42.0-43.2	94.3	23.2	Nonplastic			24	SM	DS, G
	5	48.0-49.0	95.8	21.9	Nonplastic			23	SM	IC, G
SI-1	1	17.0-18.3	-	26.4	52.3	31.0	21.3	53	MH-SM	G
	2	27.0-27.9	-	31.3	71.4	33.2	38.2	63	CH-SC	G
	3	40.0-41.2	86.4	27.2	Nonplastic			30	SM	CRSC, G
	4	47.0-48.3	-	17.0	Nonplastic			19	SM	G
	5	52.0-52.7	94.8	17.6	Nonplastic			-	SM	DS
		52.7-53.0	104.2	15.7	Nonplastic			19	SM	IC, G
	6	62.0-63.5	90.3	31.0	Nonplastic			31	SM	IC, G
P-12	1	7.0-8.3	93.9	24.6	-	-	-	52	CH-SC	CIU
		8.3-8.7	103.0	21.2	57.3	23.2	34.1	57	CH-SC	CRSC, G
		8.7-8.8	-	9.5		Nonplastic		10-15	SM	-
	2	17.0-18.1	105.9	18.4	Nonplastic			-	SM	CT
		18.1-18.4	98.8	14.6	Nonplastic			25	SM	IC, G
SI-2	1	12.0-12.7	89.7	14.1	Nonplastic			23	SM	CIU
		12.7-13.6	99.2	11.1	Nonplastic			18	SM	IC, G
SWR-6	1	12.0-13.6	-	34.6	83.3	30.2	53.1	68	CH-SC	-
			92.5	24.8	51.4	31.1	20.3	48	SM-MH	CIU
SWR-6	2	22.5-24.1	82.0	34.1	55.1	40.9	14.2	49	MH-SM	CIU, G
	3	42.0-43.6	83.3	39.8	-	-	-	20-30	SM	CIU
		43.6-44.0	90.8	22.3	-	-	-	31	SM	G

a. See key at end of table.

Table 3E-2 (continued)
LABORATORY TESTS OF UNDISTURBED SAMPLES

Boring Number	Sample Number	Depth, ft	Dry Unit Weight, pcf	Water Content,%	Atterberg Limits			Percent Fines	Group Symbol	Tests Performed[a]
					LL	PL	PI			
	4	57.0-58.5	72.3	36.2	Nonplastic			24	SM	CIU
		58.5-58.9	66.4	46.3	Nonplastic			33	SM	IC, G
SI-3	1	42.0-42.3	-	-	Nonplastic			10-20	SM	-
P-10	1	5.0-7.0	-	18.6	-	-	-	26	SC	G
	2	22.0-23.4	112.5	21.1	Nonplastic			18	SM	IC, G
SWR-3	1	7.5-9.0	-	26.3	Nonplastic			32	SM	G
	2	12.0-12.1	-	16.7		Nonplastic		14	SM	G
		12.1-13.8	-	41.8	51.8	43.0	8.8	65	MH-SM	G
	3	42.5-44.4	-	17.7	Nonplastic			27	SM	G
	4	62.0-63.1	-	15.4	Nonplastic			23	SM	G
SWR-4	1	12.0-13.5	85.6	28.9	48.1	37.6	10.5	57	ML-SM	CIU, G
	2	27.0-28.8	92.5	23.5	Nonplastic			36	SM	CRSC, G
	3	42.0-42.9	95.5	23.5	Nonplastic			3-8	SP-SM	CIU
		42.9-43.2	93.2	20.9	Nonplastic			25	SM	IC, G
		43.2-43.3	-	9.5	Nonplastic			10-15	SP-SM	-
	4	52.0-53.7	-	19.1	Nonplastic			16	SM	G
	5	62.0-62.1	-	21.0		Nonplastic		3-8	SP-SM	-
		62.1-63.8	91.9	22.3	36.6	31.8	4.8	48	SM-ML	CRSC, G
SWR-4	6	77.0-77.2	-	23.3	Nonplastic			34	SM	G
		77.2-77.7	96.8	19.9	Nonplastic			22	SM	G
SWR-5	1	12.0-13.0	-	23.7	55.5	25.0	30.5	60	CH-SC	G
	2	22.0-22.1	-	32.6	-	-	-	57	ML-SM	G
		22.1-24.0	-	24.5	44.0	31.1	12.9	46	SM-ML	-
	3	32.0-32.2	-	29.3		Nonplastic		30-35	SM-ML	-
		32.2-33.2	-	25.9	-	-	-	48	ML-SM	G

a. See key at end of table.

Table 3E-2 (continued)

LABORATORY TESTS OF UNDISTURBED SAMPLES

Boring Number	Sample Number	Depth, ft	Dry Unit Weight, pcf	Water Content,%	Atterberg Limits			Percent Fines	Group Symbol	Tests Performed[a]
					LL	PL	PI			
	4	42.0-42.1	-	25.8	Nonplastic			35	SM	G
		42.1-43.4	-	26.5	Nonplastic			15-20	SM	-
	5	57.0-59.0	-	26.2	Nonplastic			22	SM	G
	6	85.0-86.2	-	28.2	Nonplastic			17	SM	G
SWR-7	1	12.0-13.5	-	23.1	58.9	27.0	31.9	55	CH-SC	G
	4	32.0-32.1	-	17.0	-	-	-	35	SC-CH	G
		32.1-33.8	-	22.8	40.9	21.3	19.6	45	SC-CH	G
	5	42.0-43.2	94.4	26.1	Nonplastic			30	SM	CT, G
	6	47.0-47.2	-	20.9	-	-	-	36	SM-ML	G
		47.2-48.2	-	21.9		Nonplastic		46	SM-ML	G
	7	52.0-52.1	-	40.5	-	-	-	60-65	ML-SM	-
		52.1-53.2	-	22.9		Nonplastic		38	SM-ML	G
SWR-8	1	7.0-8.7	-	27.2	51.3	31.3	20.0	55-65	MH-SM	-
	2	27.0-27.9	-	43.5	-	-	-	53	MH-SM	G
SWR-9	1	17.0-18.6	-	31.6	-	-	-	30	SM	G
SWR-9	2	22.0-23.2	89.4	23.7		Nonplastic		27	SM	CT, G

Key:

CRSC - Consolidation test performed by continuously loading at a constant rate of strain with measurement of pore pressure.

IC - Consolidation test on specimen contained within original section of sampling tube and performed by loading in increments.

CIU - Consolidated - undrained triaxial compression test with measurement of pore pressure.

CT - Cyclic-loaded consolidated - undrained triaxial test.

DS - Drained direct shear test.

G - Gradation analysis.

a. See key at end of table.

Table 3E-3
RESULTS OF CONSOLIDATION TESTS

Test Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Boring number	P-11	P-11	P-11	SI-1	SI-1	SI-1	P-12	P-12	SI-2	SWR-6	P-10	SWR-4	SWR-4	SWR-4	SWR-4
Sample number	2F	3F	5F	3B	5F	6E	1F	2F	1F	4G	2B	2D	3E	5D	6
Depth, ft	24.0	37.9	48.8	40.1	52.7	63.0	8.5	18.1	13.3	58.5	22.1	28.3	39.9	63.2	77.5
Group symbol	ML-SM	SM	SM	SM	SM	SM	CH-SC	SM	SM	SM	SM	SM	SM	SM-ML	SM
Percent fines	54	29	24	30	15	31	57	25	18	33	18	36	25	48	34
Initial w_o,%	28.4	21.8	21.9	27.2	15.7	31.0	21.2	14.6	11.1	46.3	22.1	23.5	24.4	22.3	19.9
Initial d_o, pcf	90.9	95.6	95.8	86.4	104.2	90.3	103.0	98.8	99.2	66.4	112.5	92.5	93.2	91.9	96.8
Initial e_o	0.869	0.776	0.771	0.965	0.625	0.879	0.648	0.719	0.712	1.561	0.507	0.808	0.823	0.828	0.755
Type of loading	I	CRS	I	CRS	I	I	CRS	I	I	I	I	CRS	I	CRS	I
Rate of loading[a]	1000	0.079	1	0.096	1000	1000	0.090	1000	I	1000	1000	0.070	1000	0.096	1000
Maximum $\bar{\sigma}_v$, ksf	58.6	51.9	39.9	59.4	3.2	3.2	38.5	3.2	44.6	8.1	3.2	42.4	3.2	43.0	3.2
C_c	0.306	0.237	0.225	0.375	-	-	0.280	-	0.123	-	-	0.279	-	0.234	-
C_s, 10^{-2}	-	1.55	-	3.25	-	-	1.80	-	-	-	-	2.20	-	2.22	-
C, x 10^{-4}	7.05	-	-	-	8.83	5.67	-	2.51	-	42.2	14.4	-	7.32	-	7.07

a. For incrementally loaded tests (I), elapsed time in min for load increments; for constant rate of strain tests (CRS), rate of vertical strain in percent strain per min.

Table 3E-4

RESULTS OF CONSOLIDATED-UNDRAINED TRIAXIAL COMPRESSION TESTS

Type of Material	Dike Fill			Foundation		Foundation with Foliation		
Test Number	1	2	3	4	5	6	7	8
Boring number	P-12	SWR-6	SWR-6	SI-2	SWR-4	SWR-6	SWR-6	SWR-4
Sample number	1D	1D	2E	1D	3D	3D	4F	1F
Depth, ft	7.9	12.7	23.6	12.1	42.2	43.1	57.2	12.9
Group symbol	CH-SC	SM-MH	MH-SM	SM	SM	SM	SM	ML-SM
Percent fines	57	48	58	18	25	31	33	57
Initial w_o,%	24.6	24.8	34.1	14.3	23.5	39.8	36.2	28.9
Initial $\sqrt{d_o}$, pcf	93.9	92.5	82.0	89.7	95.5	83.3	72.3	85.6
Initial e_o	0.783	0.808	1.042	0.865	0.752	1.135	1.314	0.954
Consolidated w_c,%	22.3	23.5	30.8	9.4	21.0	33.7	27.6	27.1
Consolidated $\sqrt{d_c}$ 1, pcf	97.2	94.3	85.7	93.1	99.2	80.5	79.5	87.8
Consolidated e_c	0.722	0.774	0.952	0.797	0.686	1.079	1.104	0.906
ν_o, kips/ft^2	6.5	8.6	9.4	23.1	14.4	8.6	9.4	7.9
$\bar{\sigma}_c$, kips/ft^2	3.00	2.00	4.00	5.00	4.50	5.00	8.00	2.50
At $(\bar{\sigma}_1/\bar{\sigma}_3)$ max								
$\bar{\sigma}_3$, ksf	1.60	1.22	2.23	2.65	3.01	3.69	3.27	1.75
$\bar{\sigma}_1 - \bar{\sigma}_3$, ksf	3.40	3.31	5.85	5.66	6.19	3.14	4.29	1.66
$\bar{\sigma}_1/\bar{\sigma}_3$	3.13	3.71	3.63	3.14	3.06	1.85	2.31	1.95
$(\nu - \nu_0)/(\sigma_1 - \sigma_3)$	0.41	0.24	0.30	0.42	0.24	0.42	1.10	0.45
θ, %	4.8	2.8	3.3	9.9	5.7	1.6	7.8	1.2
ϕ', degrees[a]	31.1	35.1	34.7	31.1	30.5	17.3	23.3	18.8

a. $\phi' = \arcsin\frac{(\bar{\sigma}_1/\bar{\sigma}_3) - 1}{(\bar{\sigma}_1/\bar{\sigma}_3) + 1}$

Table 3E-5
FEDAR SEAPAGE SUMMARY

Run No.	Main Features of Run - Boundary Conditions	Materials[a] Permeabilities ft/min
1	Ground-water table at node 224 (Elevation 289) and at node 3 at Elevation 267	$k_1 = 2 \times 10^{-7}$ $k_2 = 2 \times 10^{-5}$ $k_3 = 2 \times 10^{-4}$
2	Ground-water table at node 226 (Elevation 303) and at node 3 at Elevation 267	Same as above
3	Ground-water table at node 226 (Elevation 303) and at node 3 at Elevation 267 with a positive inflow specified at nodes 68, 74, and 80	Same as above
4	Ground-water table at node 3 (Elevation 267). No flow boundary condition on right side of mesh	Same as above
5	Same as above except node 3 at Elevation 275	Same as above
6	Same as above but a 15-ft-wide crack modeled at 50 feet of dike toe	Same as above

a. Material 1 - clay liner, Permeability is k_1
Material 2 - compacted dike. Permeability is $k._2$.
Material 3 - saprolitic foundation. Permeability is k_3.

Table 3E-6
PHREATIC SURFACES

Piezometer No.	Location	Tip Elevation	Anticipated Piezometric Level, ft[a] Run No. 1	2	3	4	5	6
P-1	10' US CL	286.7	0	291.2	291.2	289.9	292.0	299.8
P-2	20' DS CL	283.5	284.3	288.3	288.3	287.1	290.0	296.4
P-3	48' DS CL	273.7	282.4	286.0	286.0	285.2	288.0	293.3
P-4	10' US CL	290.9	(b)	291.5	291.5	(b)	292.0	299.8
P-5	14' DS CL	288.4	(b)	289.0	289.0	(b)	290.3	297.0
P-6	40' DS CL	279.7	283.4	287.0	287.0	286.1	288.2	294.2
P-7	10' US CL	300.1	(b)	(b)	(b)	(b)	(b)	298.4
P-8	20' DS CL	298.6	(b)	(b)	(b)	(b)	(b)	295.1
P-9	50' DS CL	290.8	(b)	(b)	(b)	(b)	(b)	291.5
P-10	110' DS CL	258.7	277.0	279.5	279.5	278.7	282.7	285.0
P-11	10' DS CL	275.4	284.3	288.5	288.5	287.0	289.8	296.2
P-12	75' DS CL	268.2	279.4	282.2	282.0	282.0	285.0	288.5

a. Piezometric levels were obtained from FEDAR pressure contour plots performed on September 26-30, 1975.
b. Calculated piezometric level is below piezometer tip.

Key: US= upstream
DS= downstream
CL= centerline

Table 3E-7
SOIL PHYSICAL PROPERTIES

	Saturated Density, S (pcf)		Dry Density, d (pcf)		Effective Stress Parameters			
					ϕ' (degree)		C' (psf)	
	Used in Analyses	Section 3E.2	Used in Analyses	Section 3E.2	Used in Analyses	Section 3E.2	Used in Analyses	Section 3E.2
Compacted impervious core and select lining	116	120	95	92.5[a] 93.3[b]	32	33.6	0	0
Transition filters	130	-	115	-	38	-	0	-
Compacted rock shell	140	-	120	-	43	-	0	-
Foundation saprolite	125	121	105	94	30	32.8 (av)	0	0
Foundation relic joint	-	-	-	-	12	(c)	0	-

a. Average of five measurements on undisturbed samples.
b. Average of field density tests in vicinity of pump house for Units 1 and 2 and southeast dike sections.
c. No relic joints encountered. Three foundation samples failing on foliation planes had friction angles of 17.3, 18.8, and 23.3 degrees.

Table 3E-8
LIQUEFACTION ANALYSES SUMMARY OF SAMPLE PARAMETERS
AND FACTOR OF SAFETY

Boring	No.	GWL	σ_v	r_d	CSR	SR_L	$\bar{\sigma}_{OF}$	$\Delta\tau_f$	FS
P-12	ST-2	283.9	1.15	0.96	1.29	0.29	1.02	0.129	2.81
SWR-9	ST-2	298.2	1.33	0.95	1.56	0.35	1.04	0.141	3.02
SWR-9	ST-1	303.6	0.98	0.96	1.56	0.35	0.76	0.110	2.96
P-11	ST-3	288.3	2.21	0.86	1.59	0.36	1.64	0.222	3.26
SWR-3	ST-3	287.2	2.43	0.82	1.74	0.39	1.52	0.233	3.12
SWR-7	ST-5	289.4	2.45	0.82	1.74	0.39	1.53	0.235	3.11
SWR-5	ST-5	289.4	3.12	0.72	1.91	0.43	1.65	0.263	3.31
							Average value		3.07

Legend

GWL = Groundwater level (feet)

σ_v = Total vertical stress (kg/cm^2)

r_d = Stress reduction coefficient

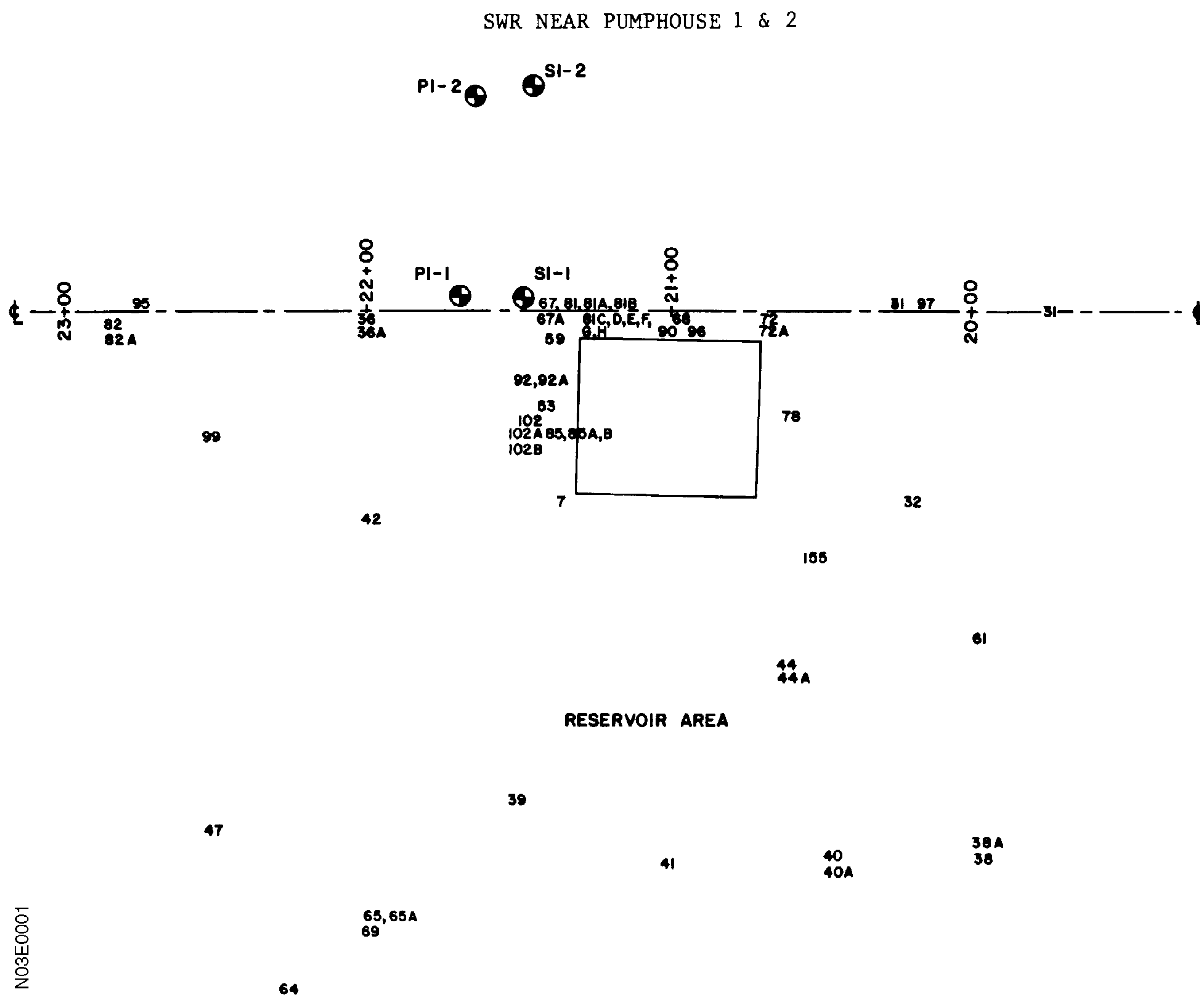
CSR = Consolidation stress ratio

$\bar{\sigma}_{OF}$ = Effective octahedral normal stress in situ (kg/cm^2)

$\Delta\tau_f$ = Octahedral shear stress due to seismic event (kg/cm^2)

FS = Factor of safety against liquefaction

Figure 3E-1
LOCATION OF FIELD DENSITY TESTS NEAR PUMPHOUSE, SOUTHWEST SECTION



N03E0001

Figure 3E-2
LOCATION OF FIELD DENSITY TESTS

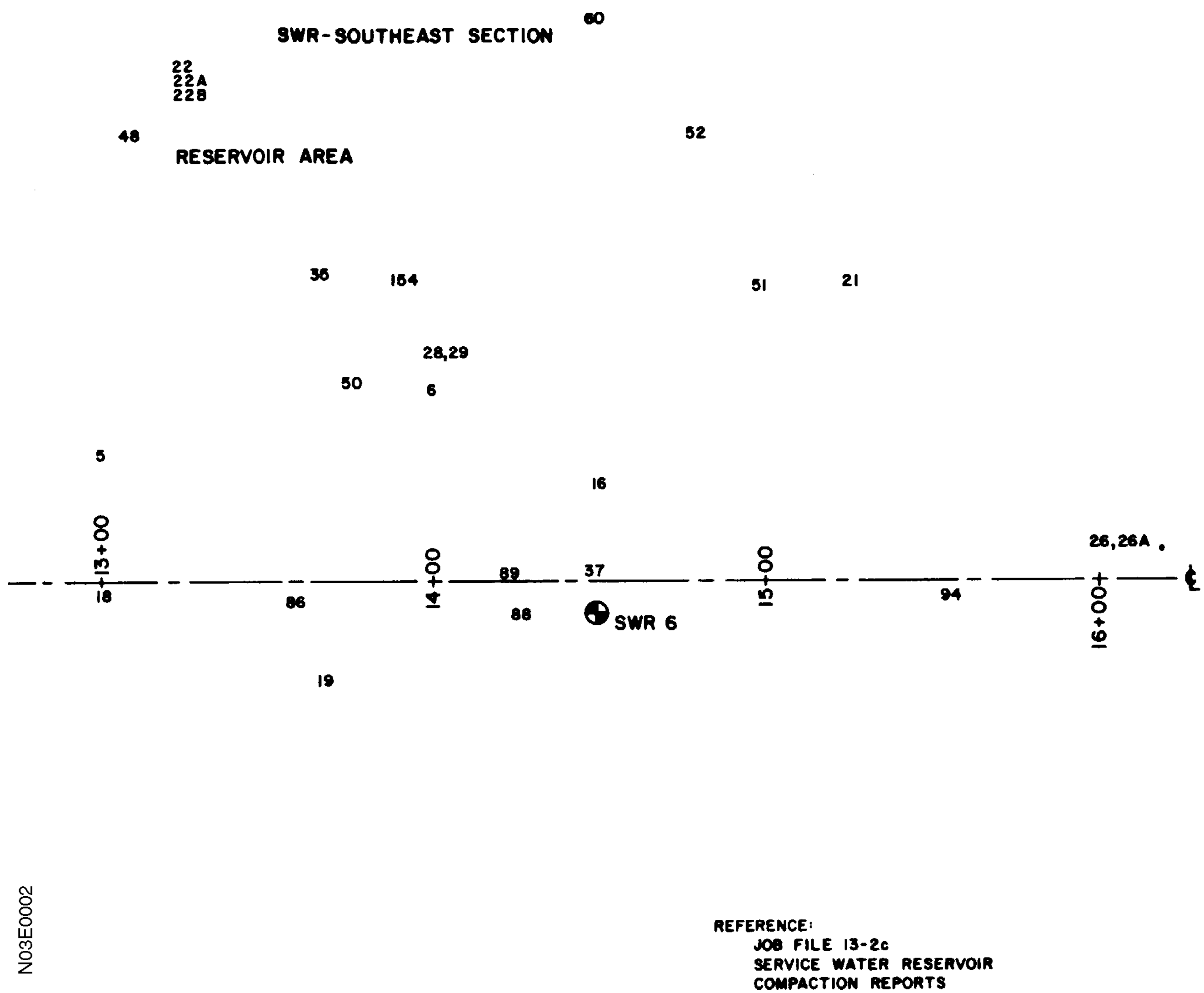


Figure 3E-3 (SHEET 1 OF 2)
SERVICE WATER RESERVOIR: FIELD DENSITY TESTS SHEET 1

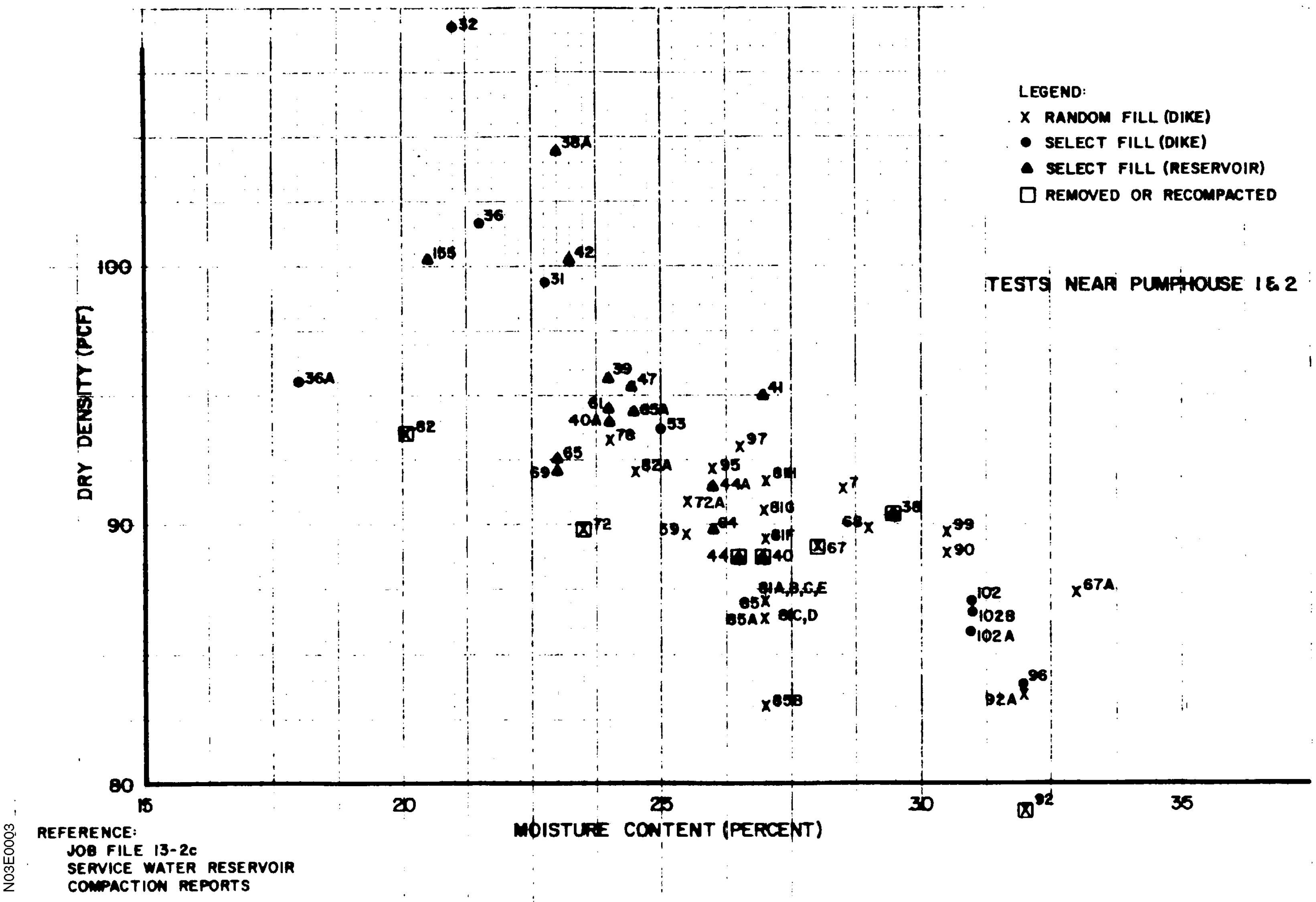


Figure 3E-3 (SHEET 2 OF 2)
SERVICE WATER RESERVOIR: FIELD DENSITY TESTS SHEET 1

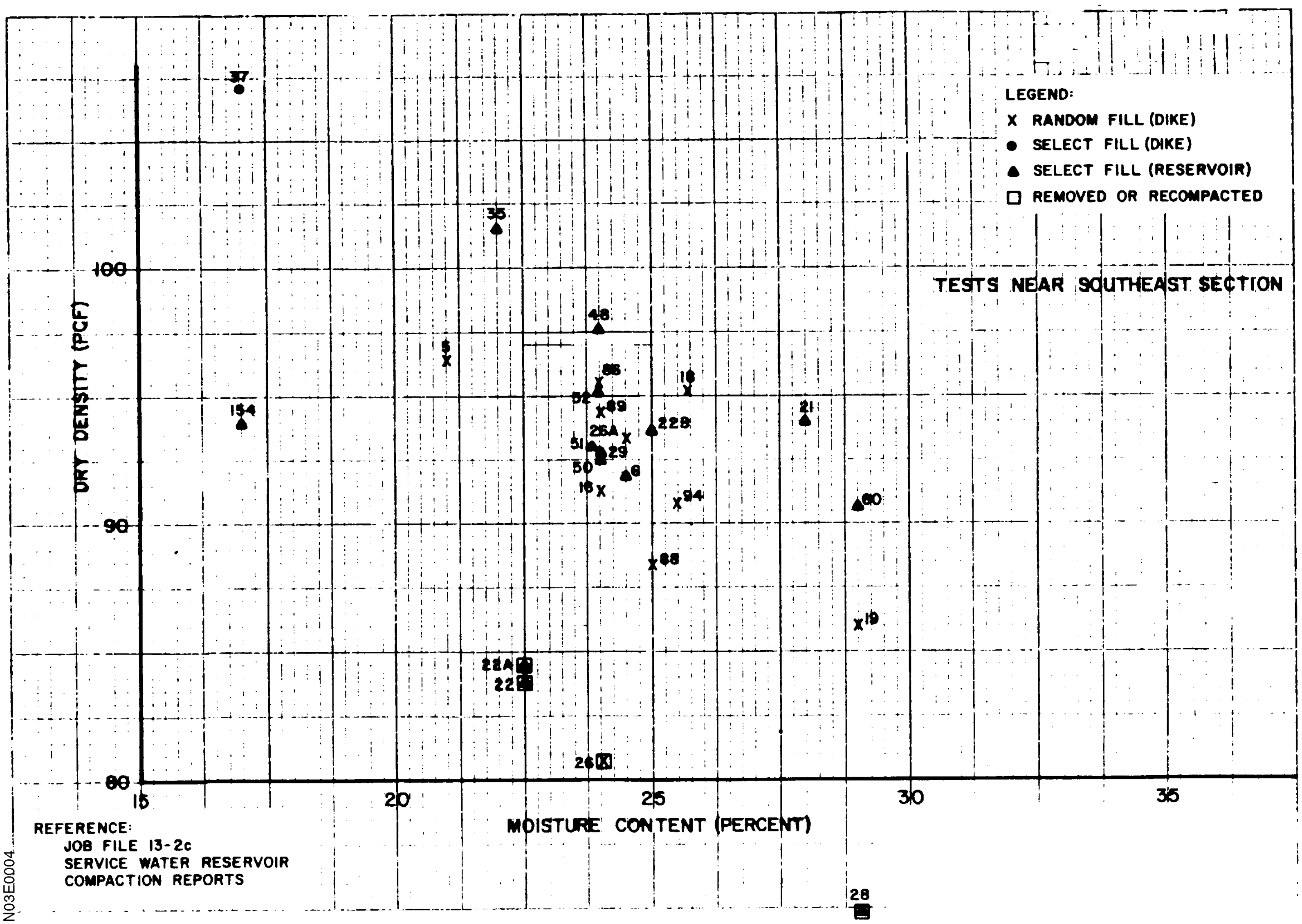
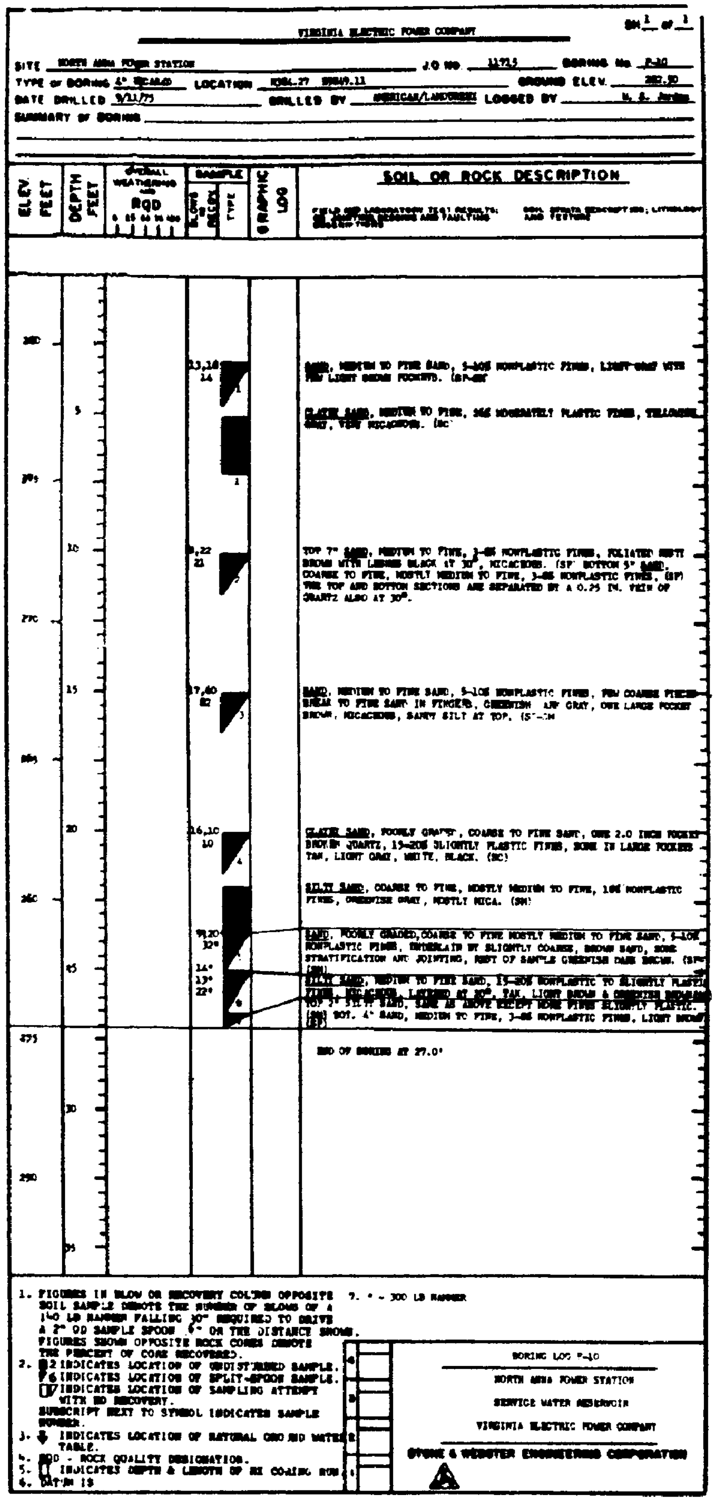
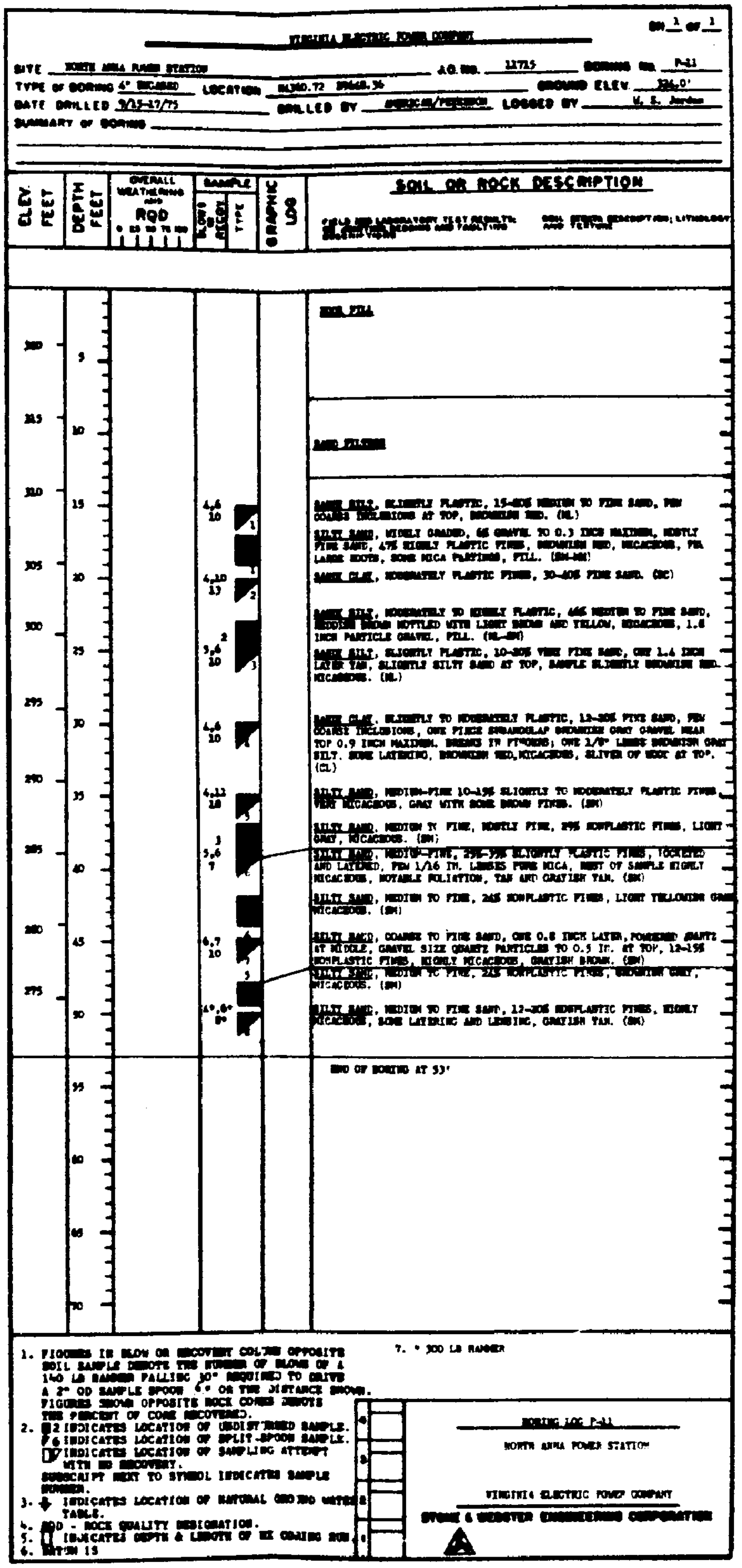


Figure 3E-4 (SHEET 1 OF 26)
BORING LOGS



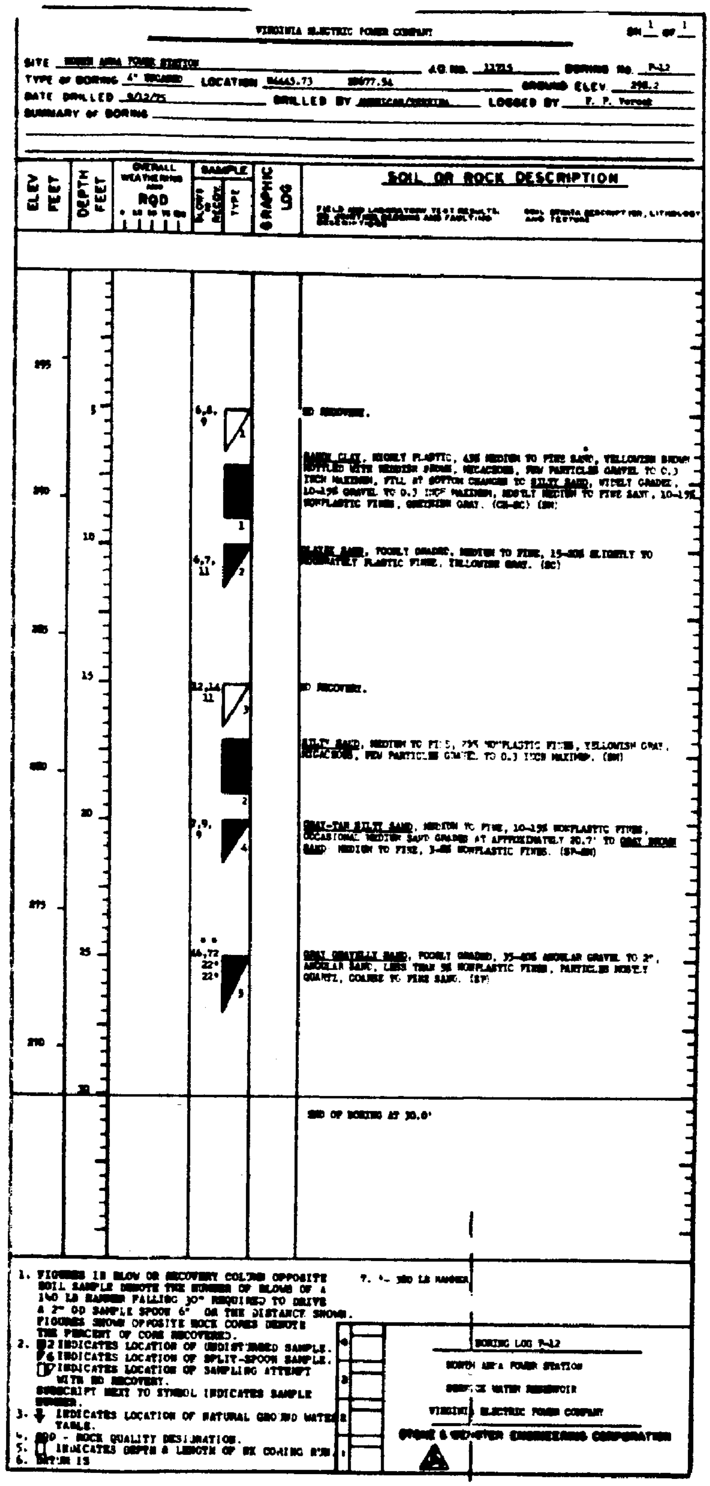
N03E0005

Figure 3E-4 (SHEET 2 OF 26)
BORING LOGS



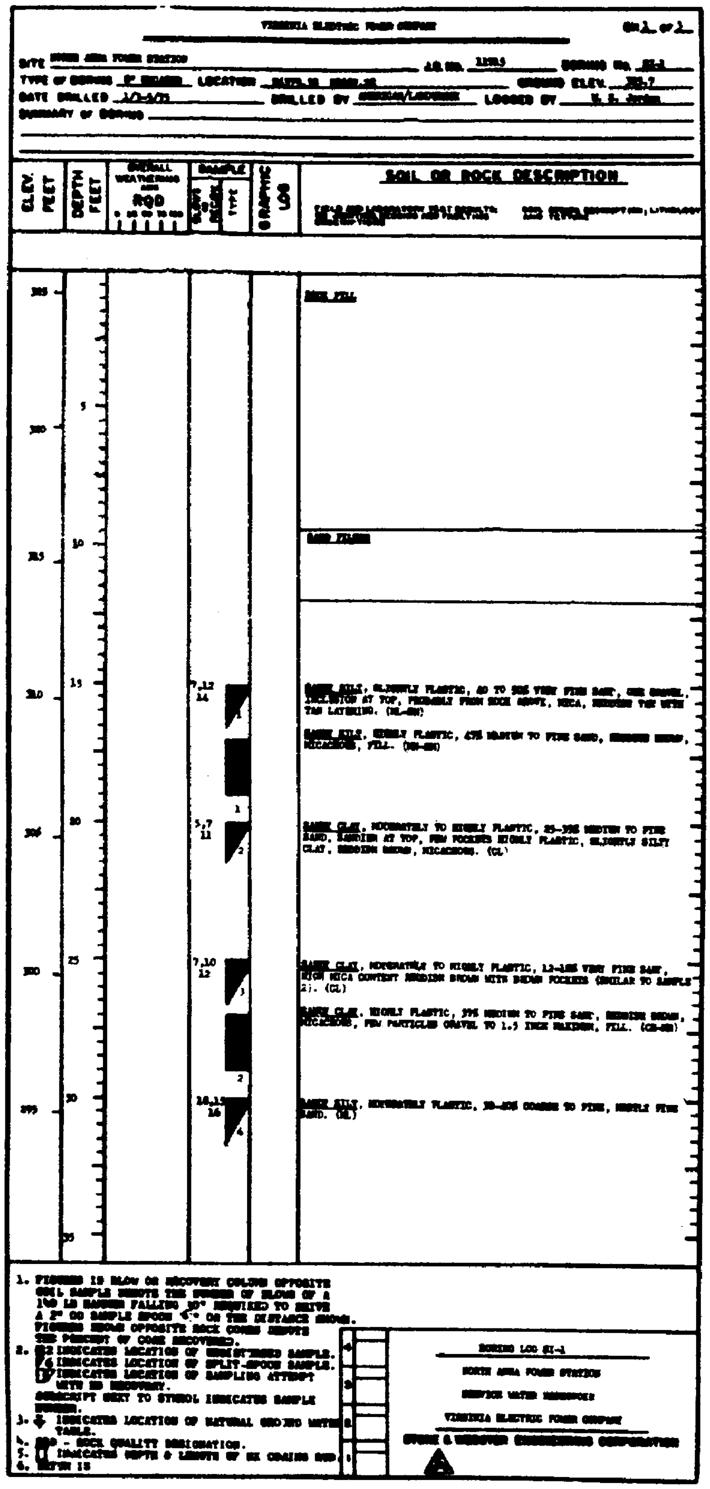
N03E0073

Figure 3E-4 (SHEET 3 OF 26)
BORING LOGS



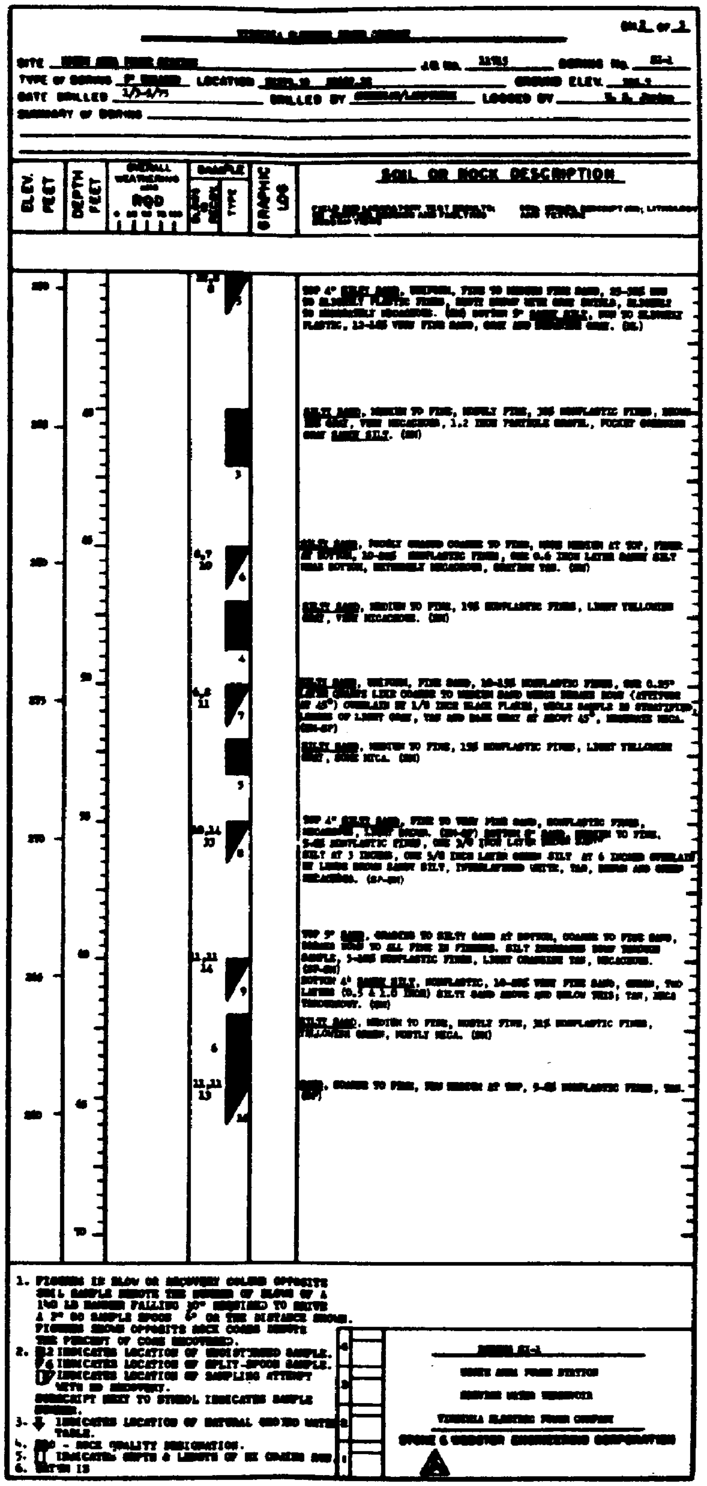
N03E0074

Figure 3E-4 (SHEET 4 OF 26)
BORING LOGS



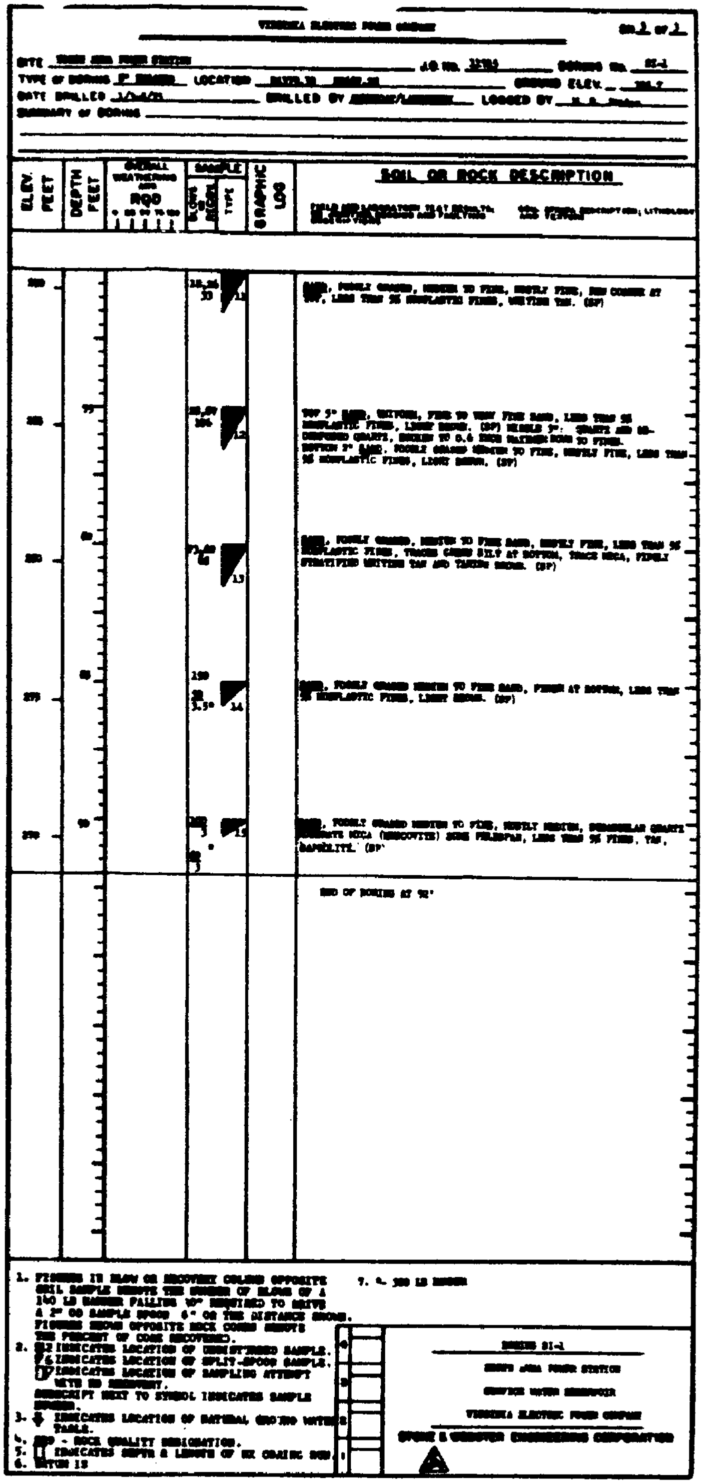
N03E0006

Figure 3E-4 (SHEET 5 OF 26)
BORING LOGS



N03E0075

Figure 3E-4 (SHEET 6 OF 26)
BORING LOGS



N03E0076

Figure 3E-4 (SHEET 7 OF 26)
BORING LOGS

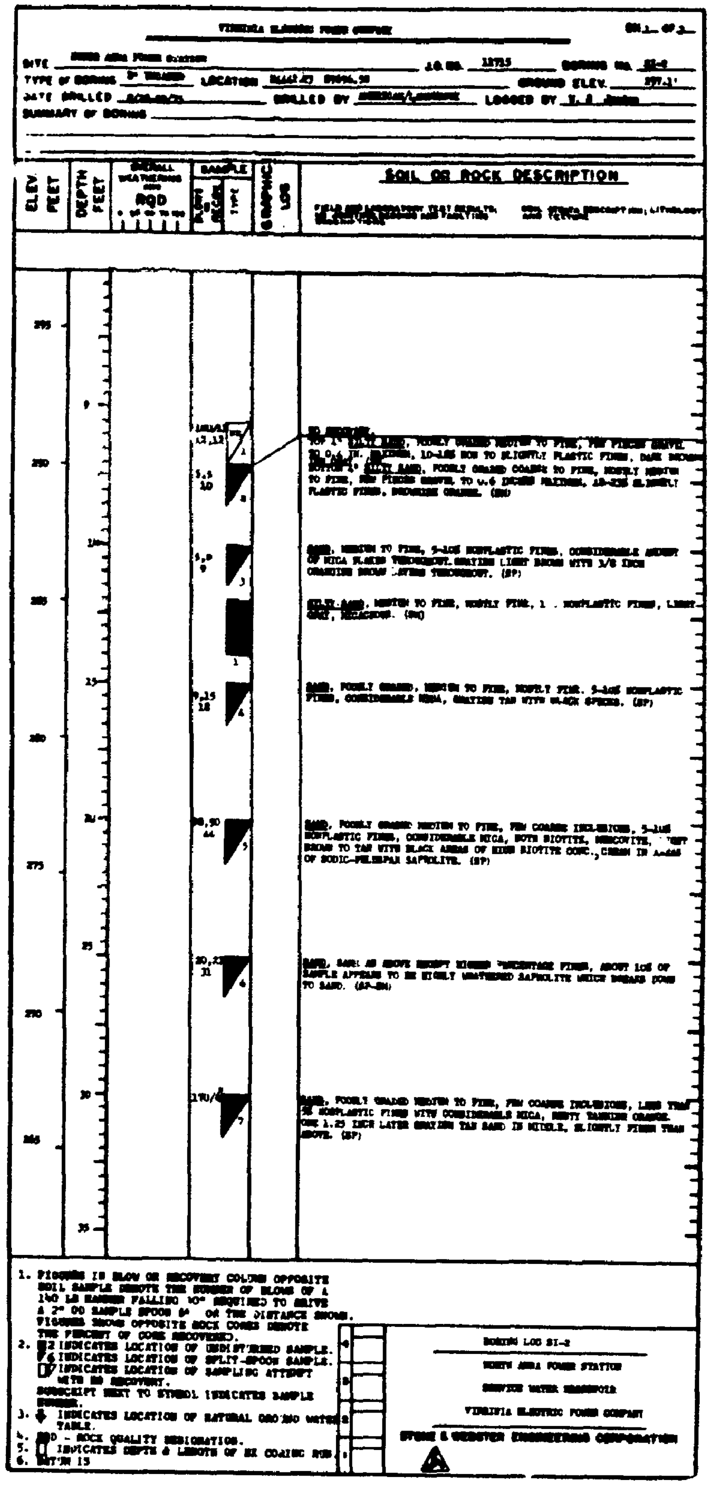


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Figure 3E-4 (SHEET 8 OF 26)
BORING LOGS

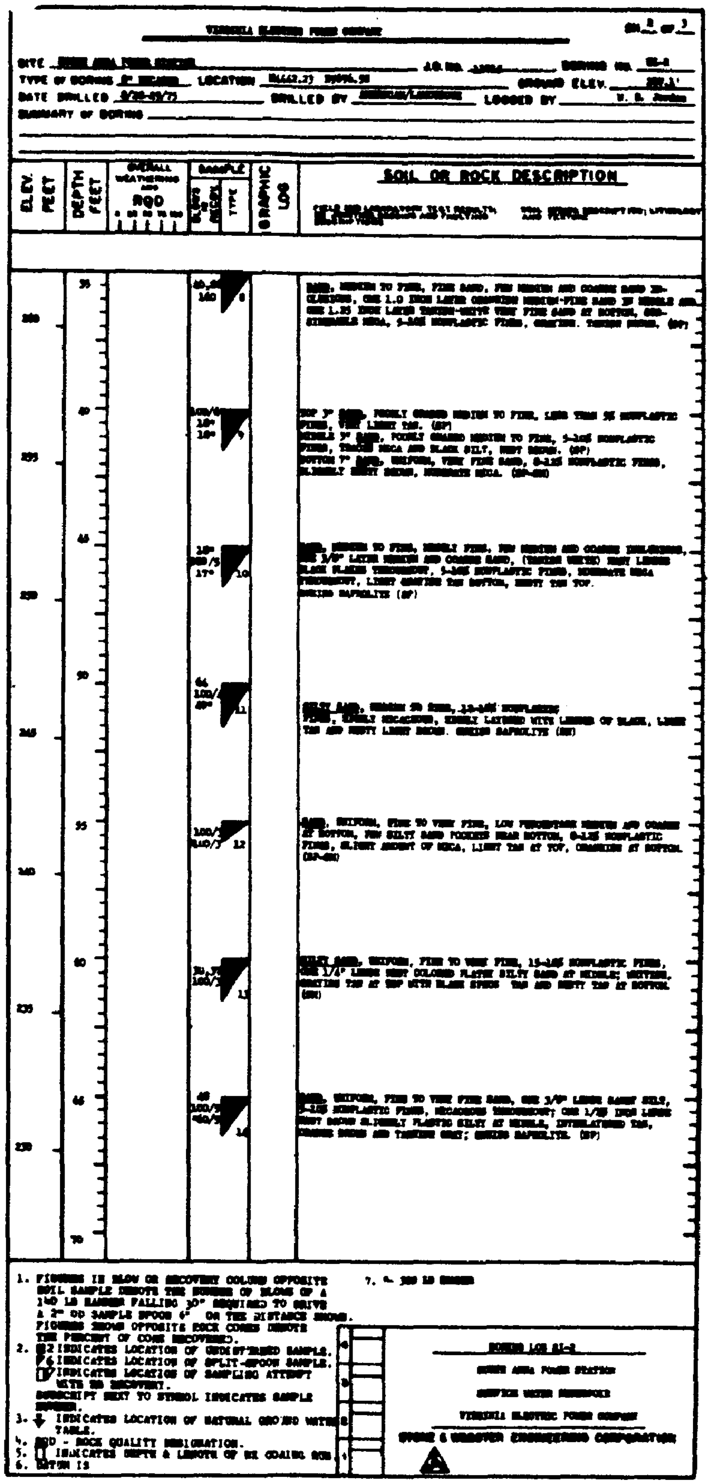

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Figure 3E-4 (SHEET 9 OF 26)
BORING LOGS

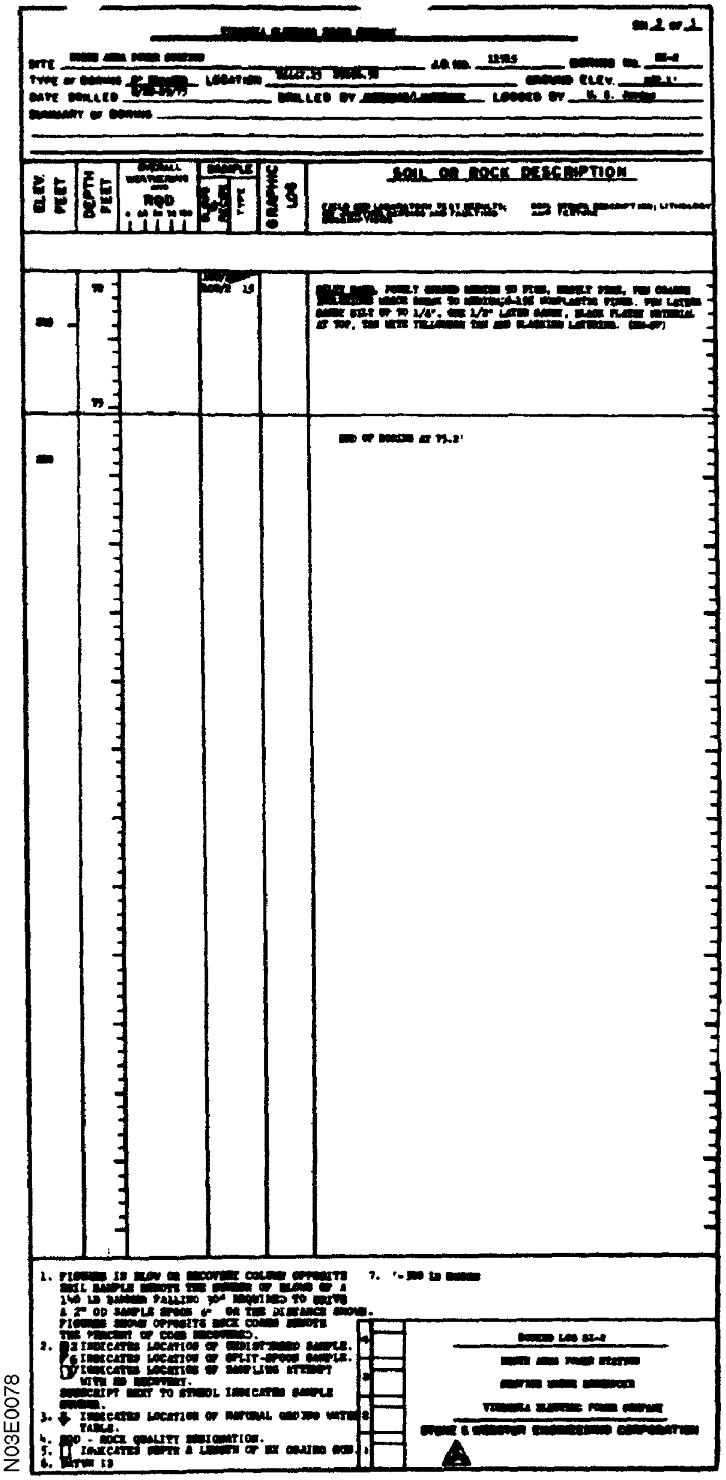

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Figure 3E-4 (SHEET 10 OF 26)
BORING LOGS

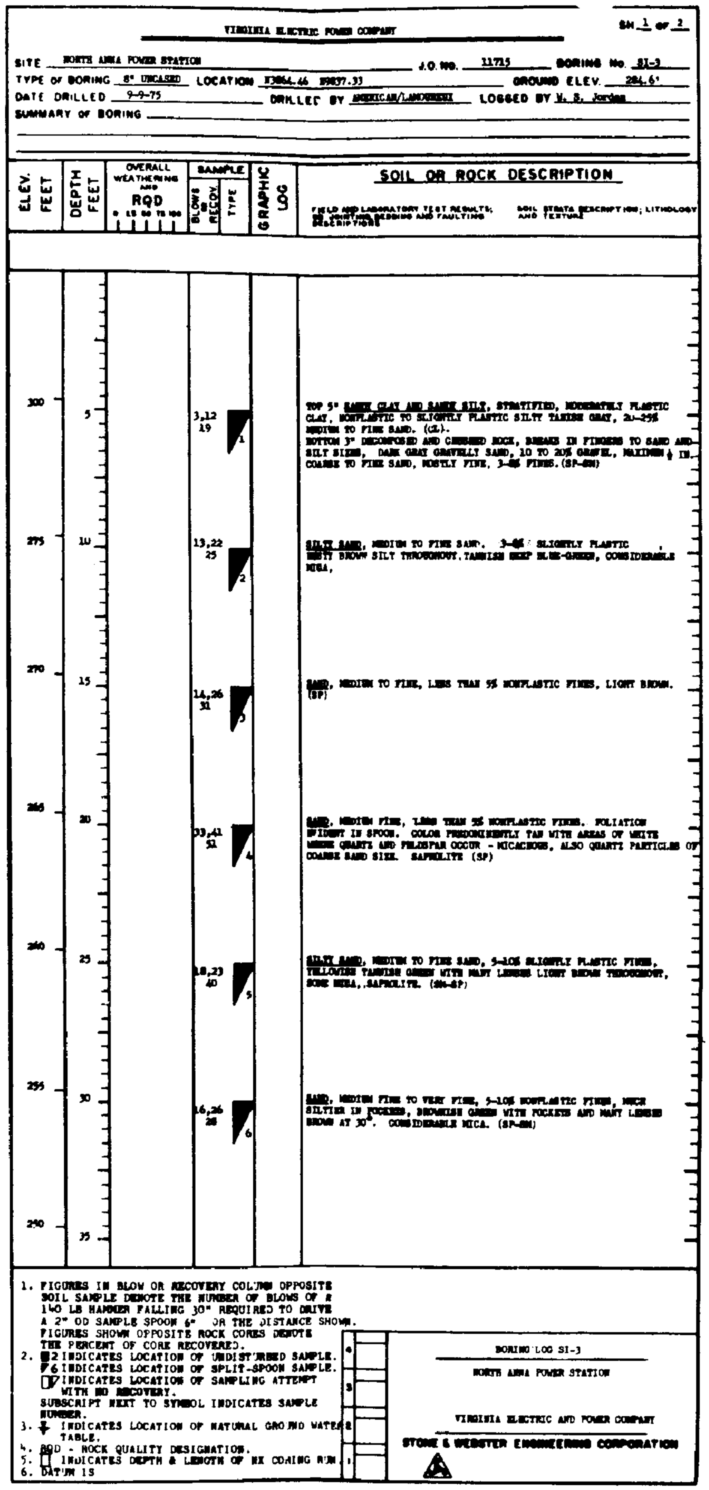

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Figure 3E-4 (SHEET 11 OF 26)
BORING LOGS

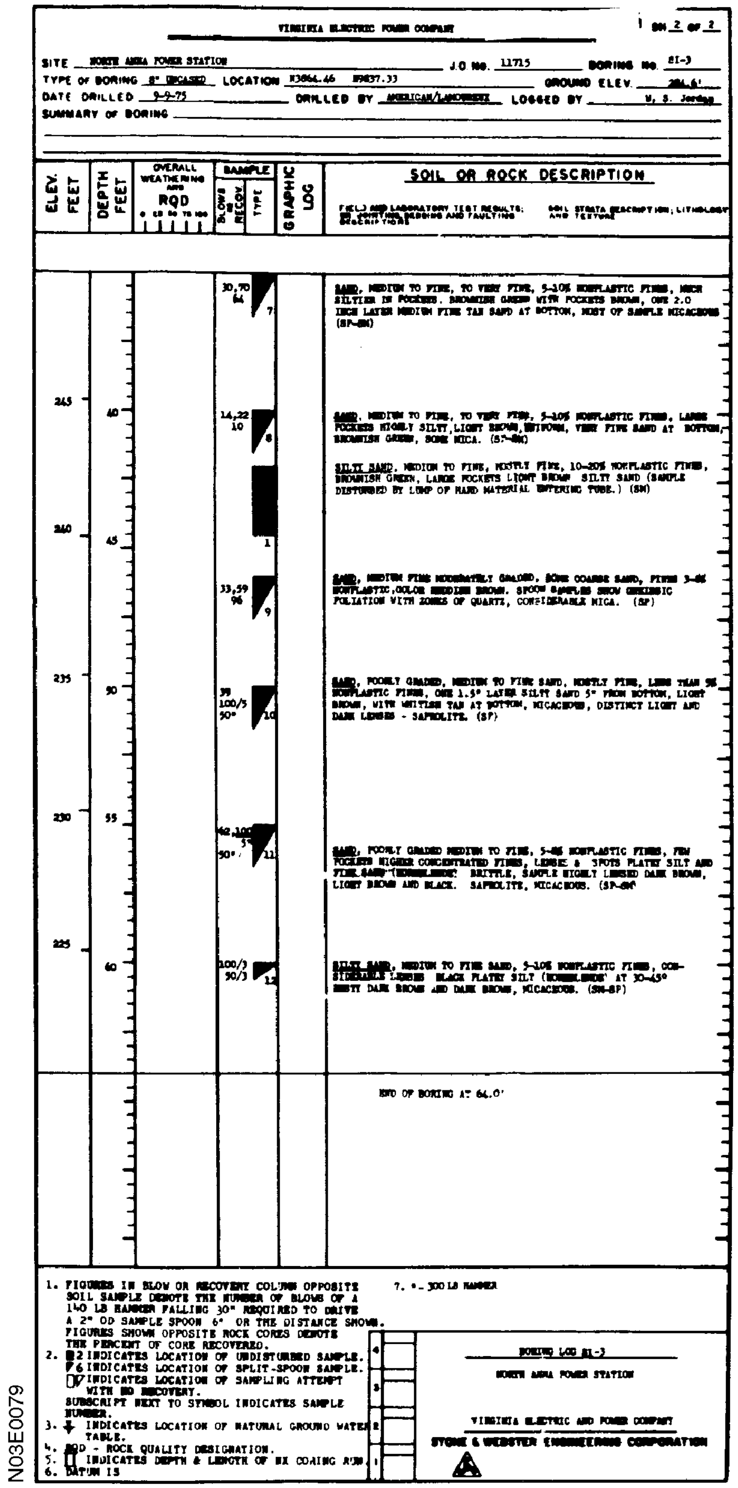

Figure 3E-4 (SHEET 12 OF 26)
BORING LOGS

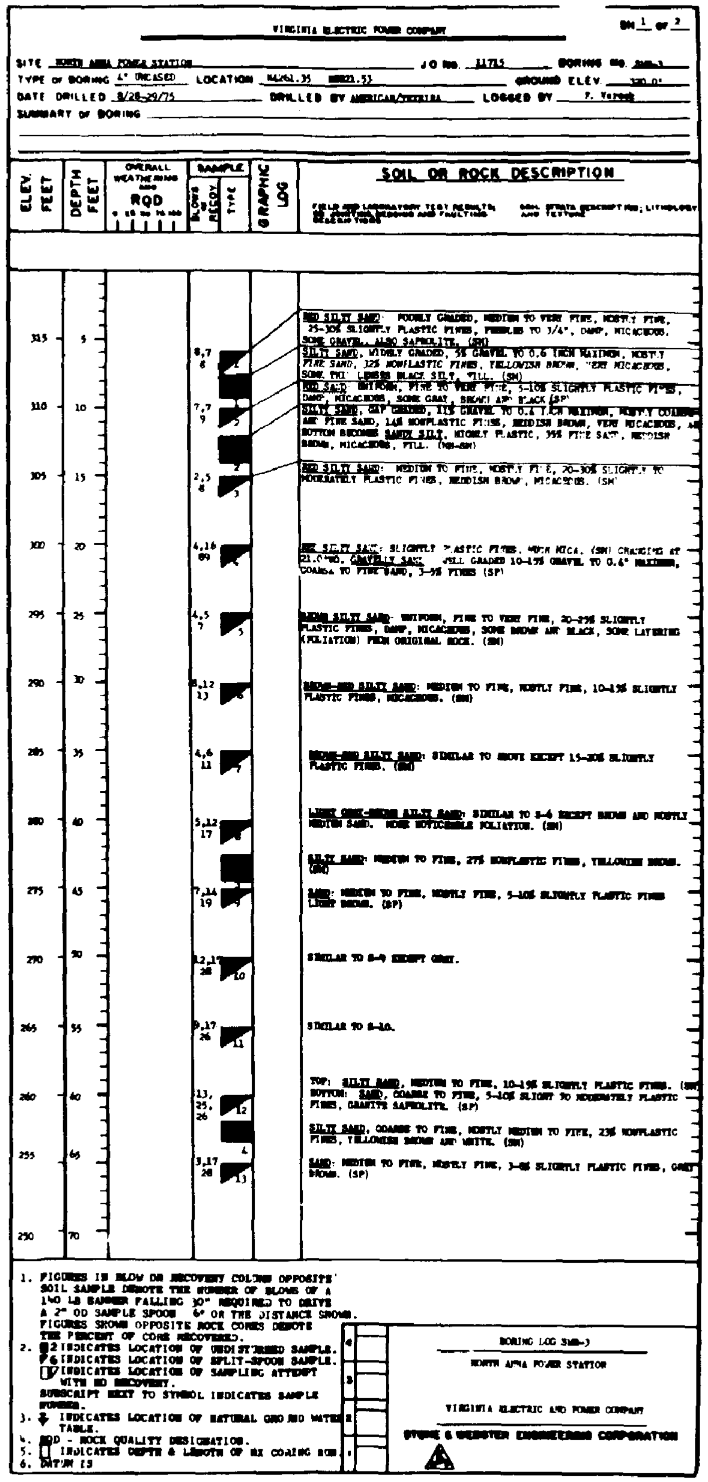

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Figure 3E-4 (SHEET 13 OF 26)
BORING LOGS

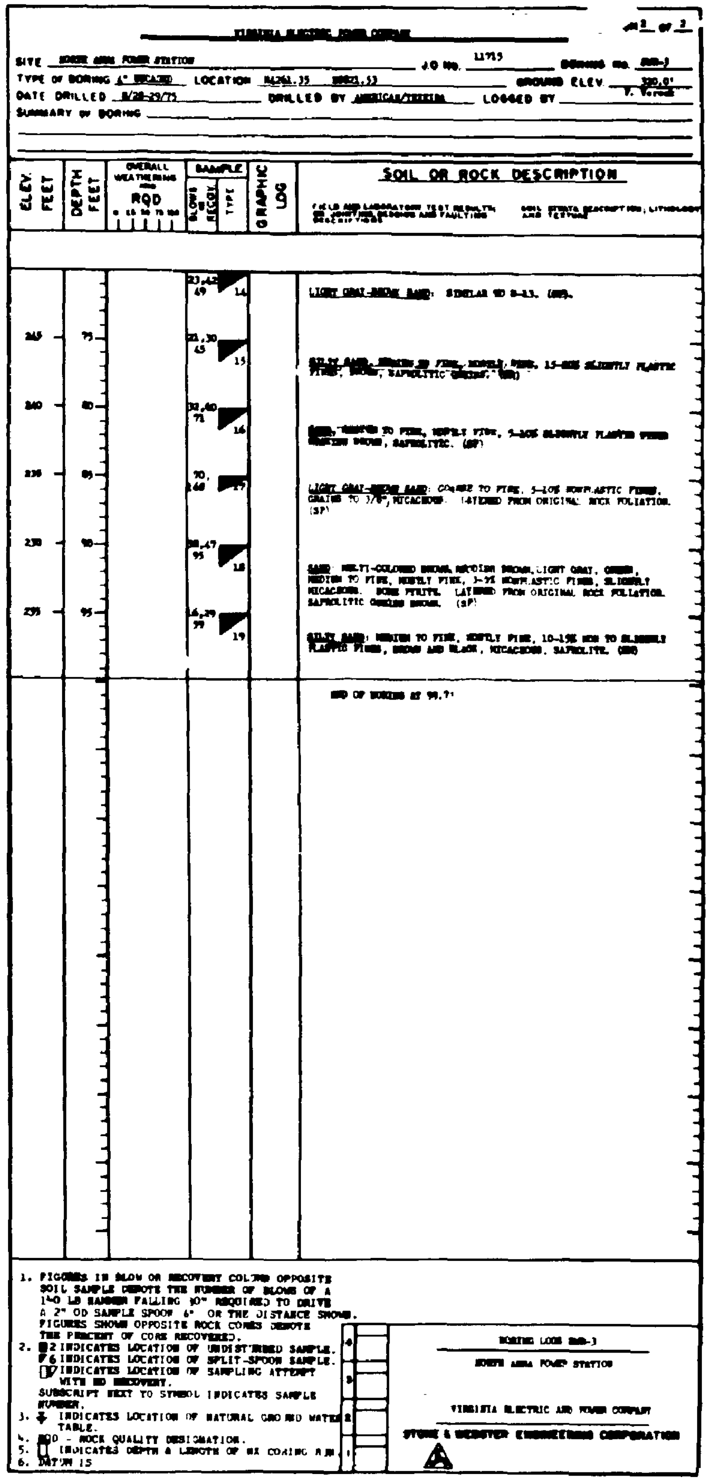

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Figure 3E-4 (SHEET 14 OF 26)
BORING LOGS

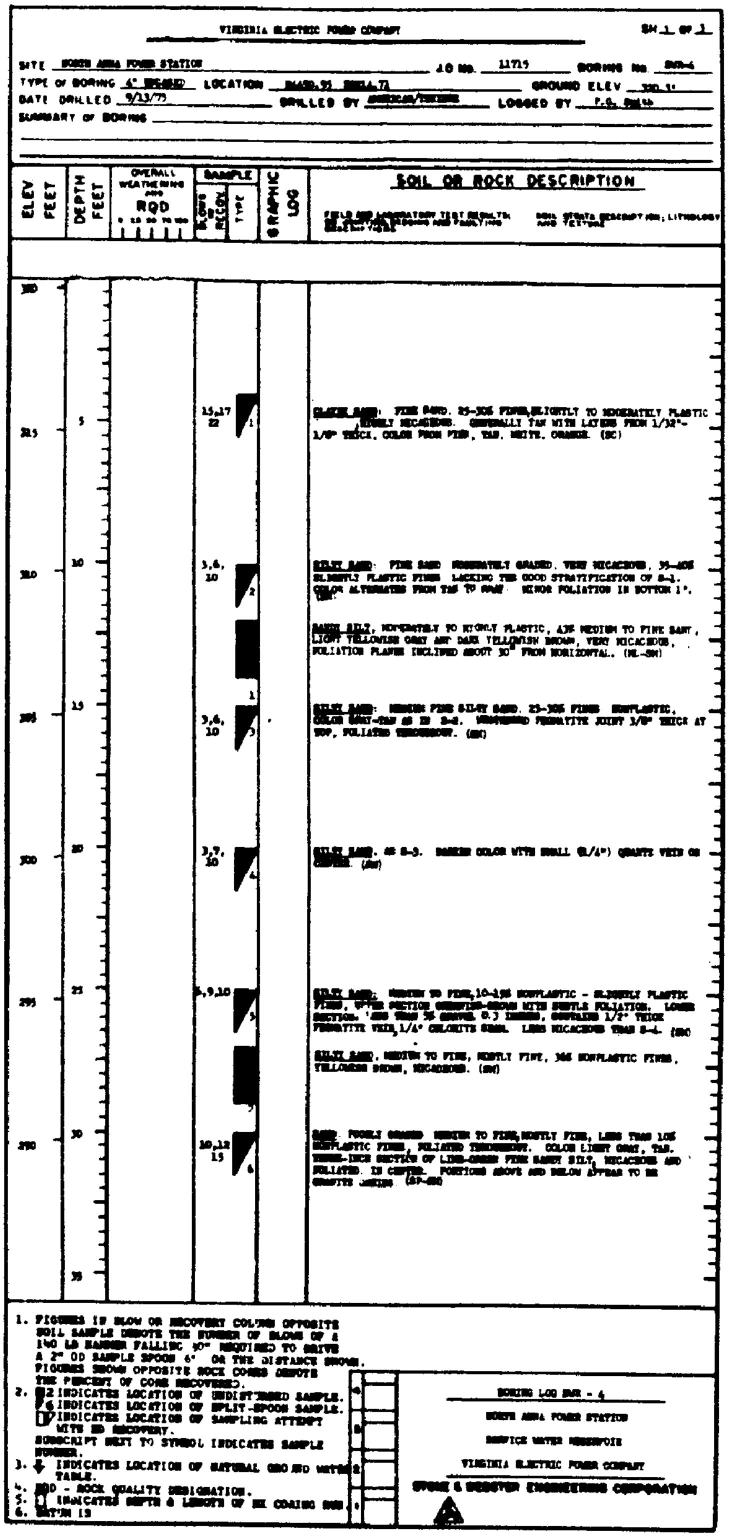

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Figure 3E-4 (SHEET 15 OF 26)
BORING LOGS

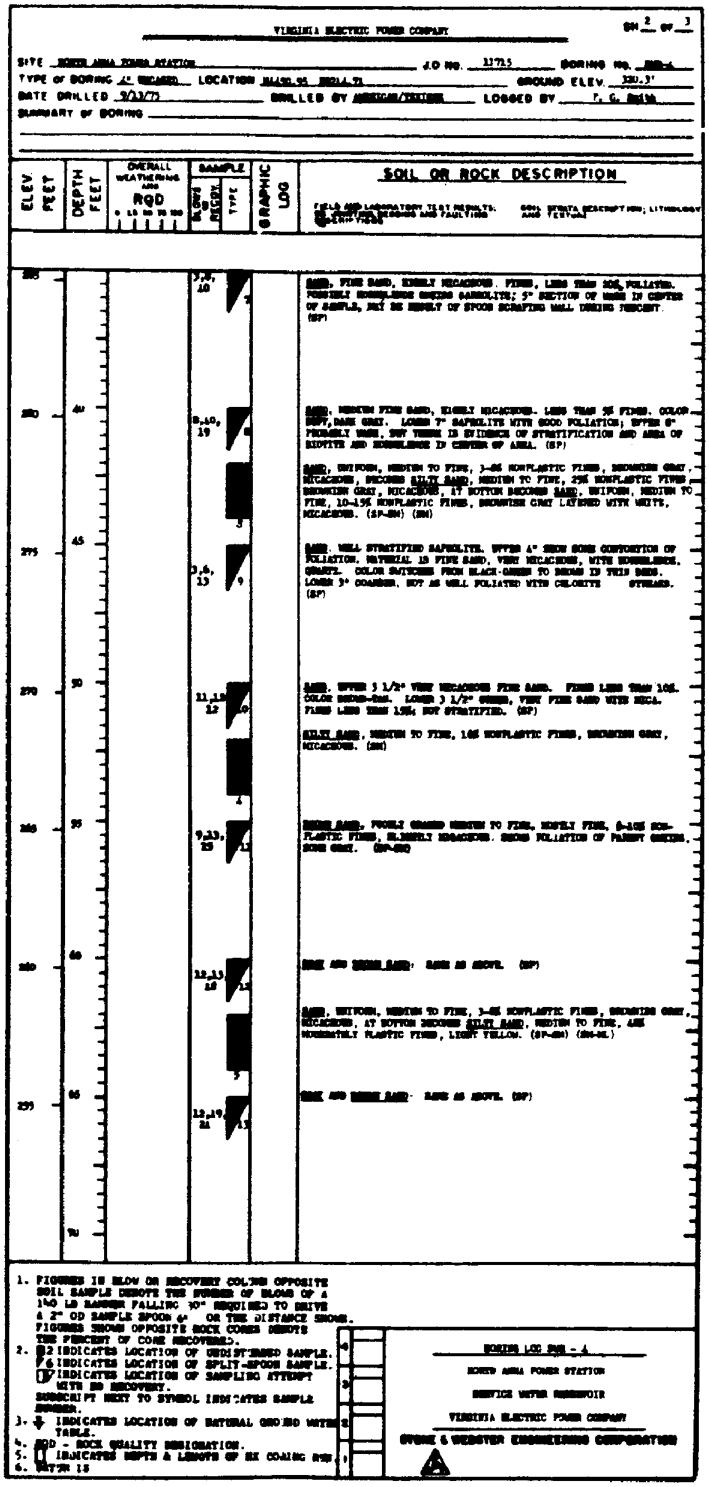

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Figure 3E-4 (SHEET 16 OF 26)
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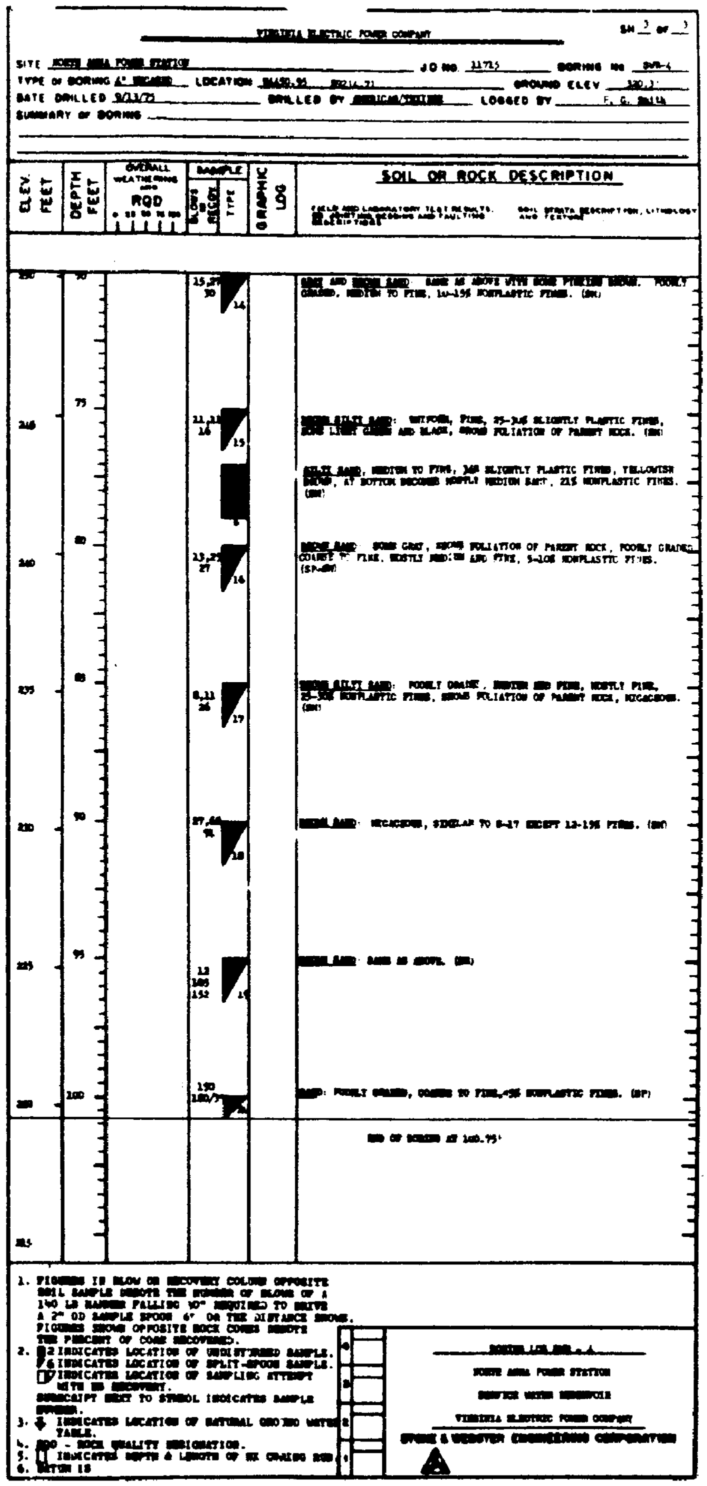

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Figure 3E-4 (SHEET 17 OF 26)
BORING LOGS

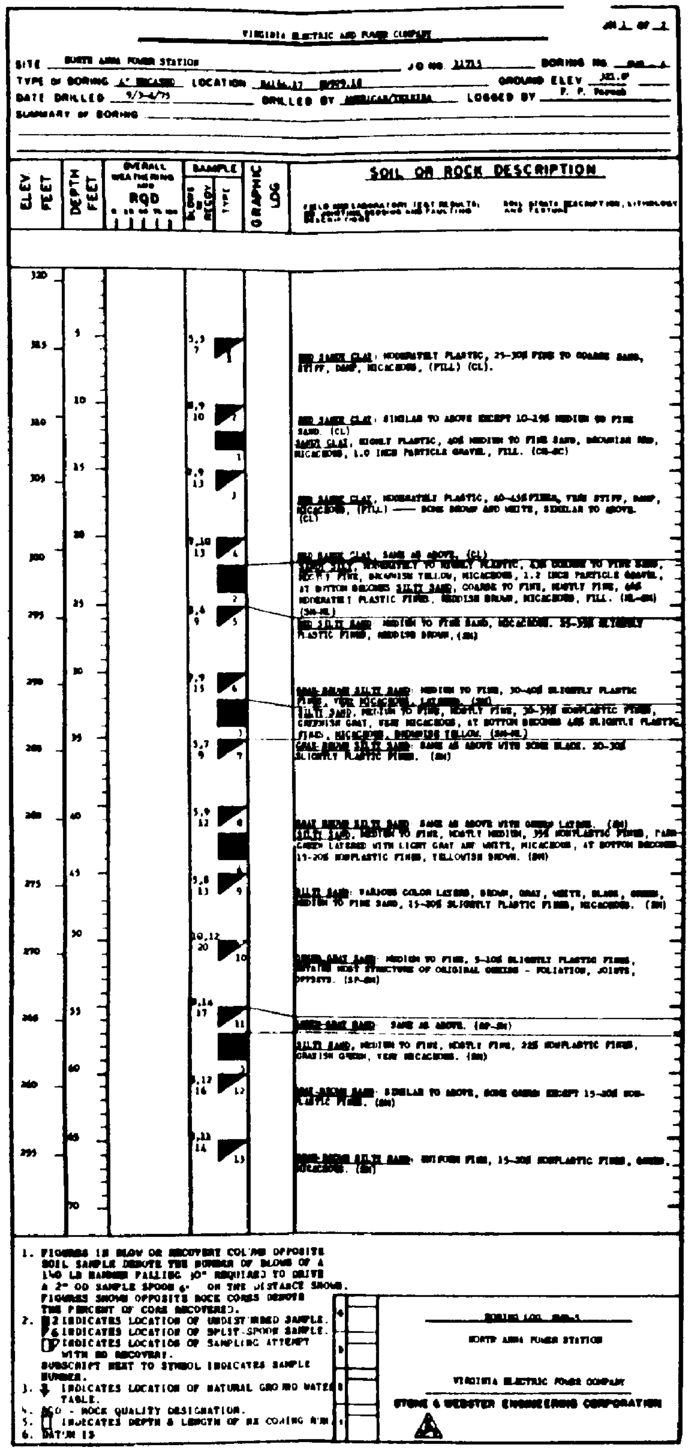

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Figure 3E-4 (SHEET 18 OF 26)
BORING LOGS

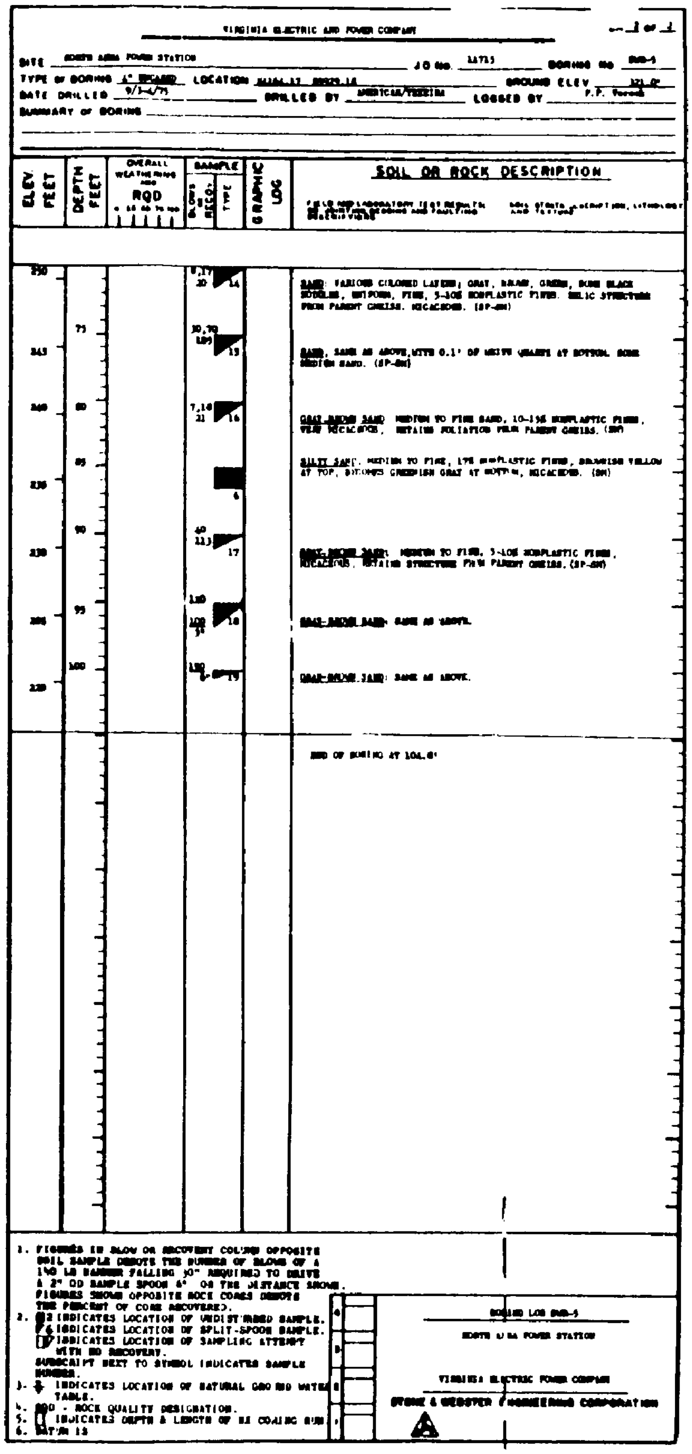

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Figure 3E-4 (SHEET 19 OF 26)
BORING LOGS

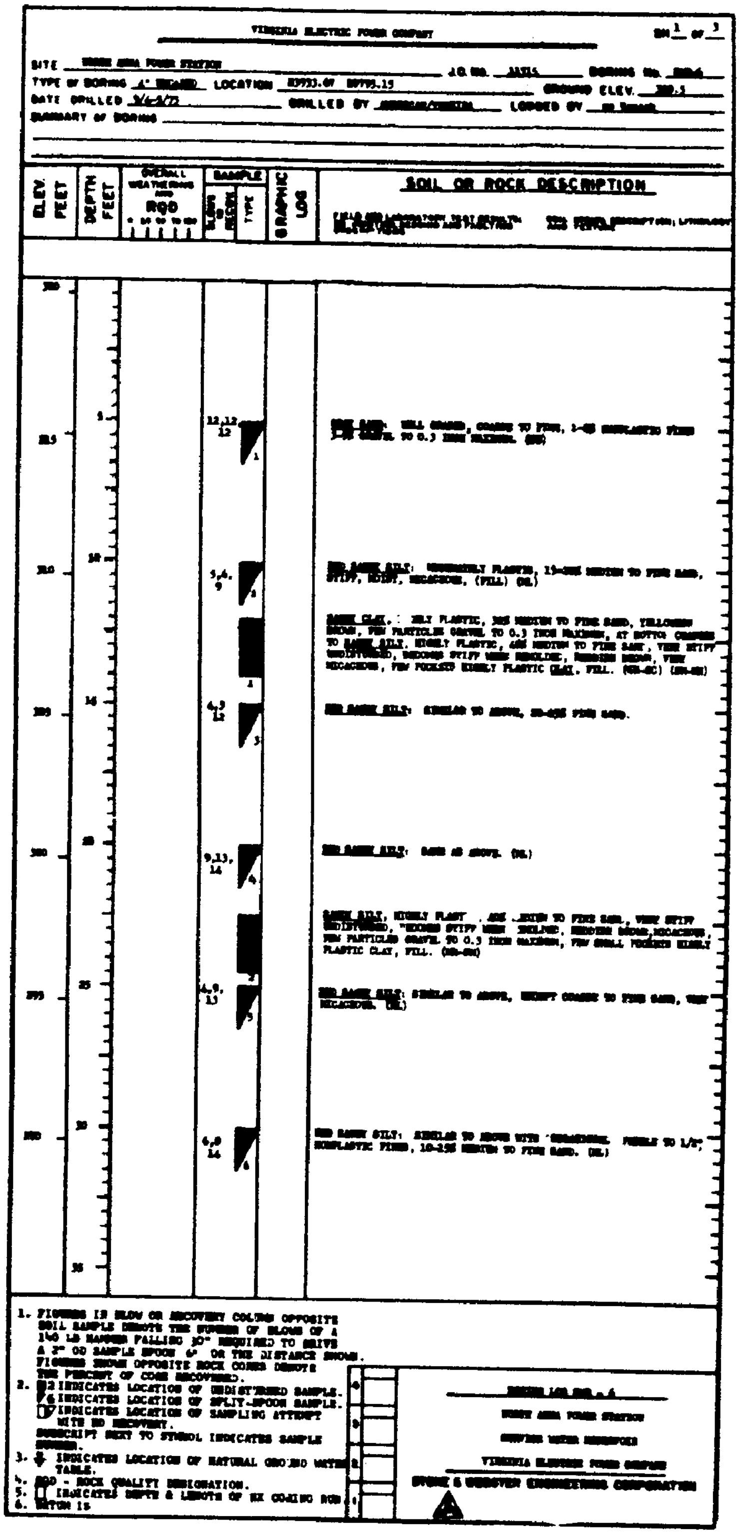

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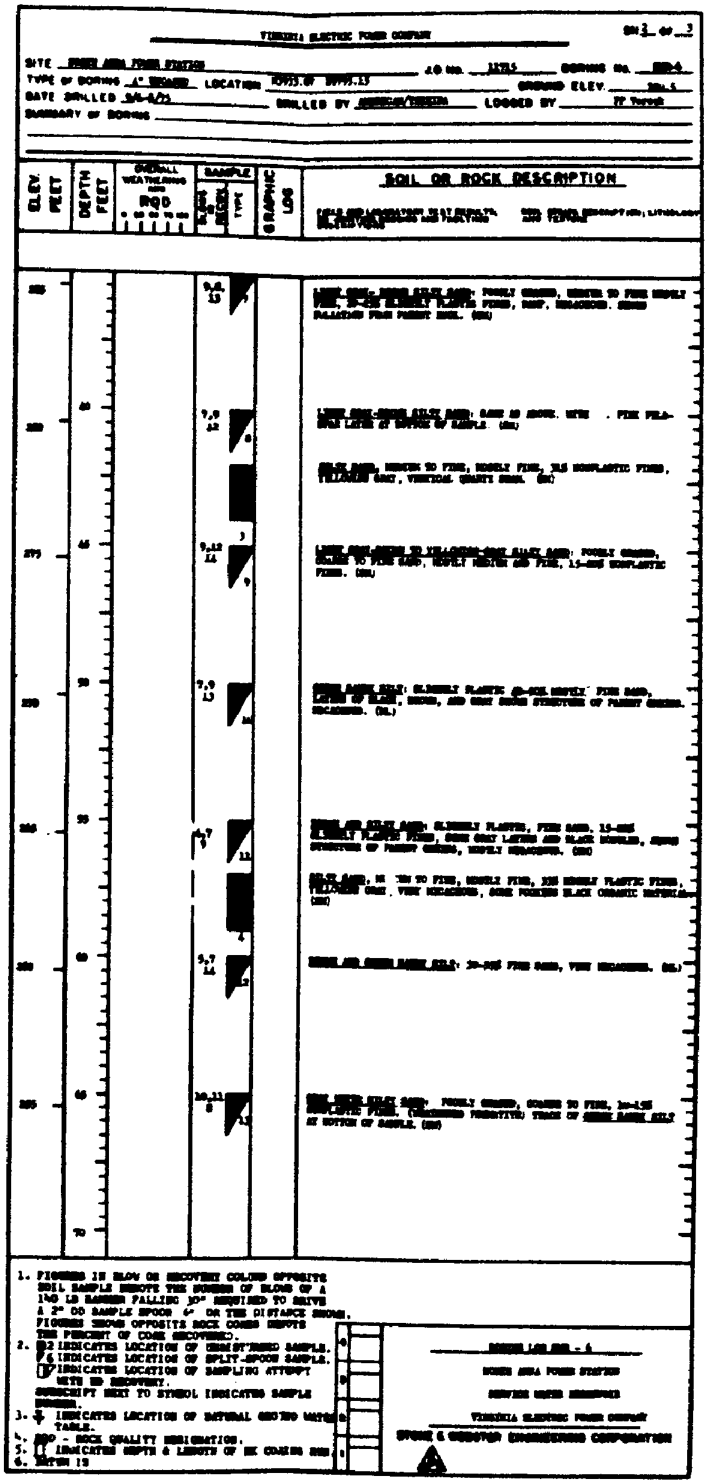
Figure 3E-4 (SHEET 20 OF 26)
BORING LOGS



N03E0089

Figure 3E-4 (SHEET 21 OF 26)
BORING LOGS

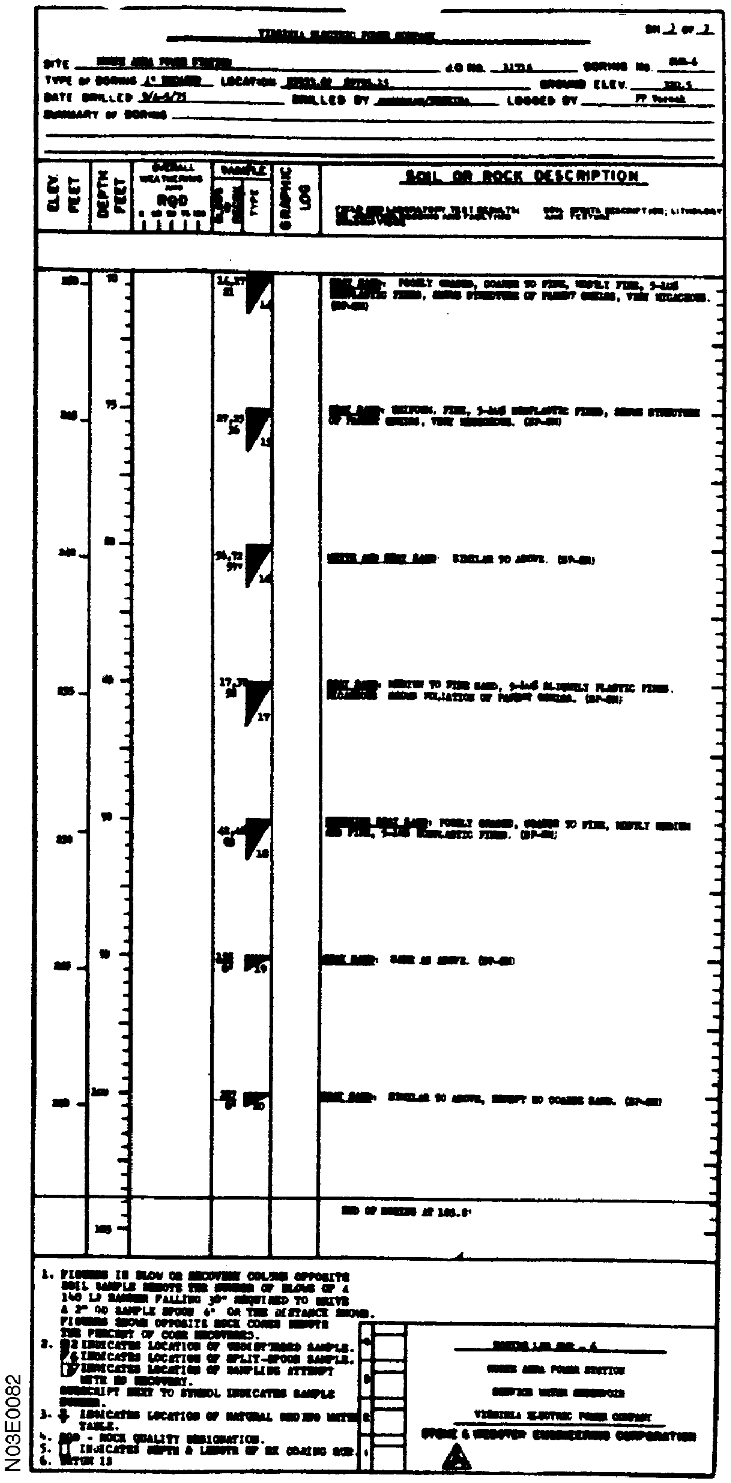
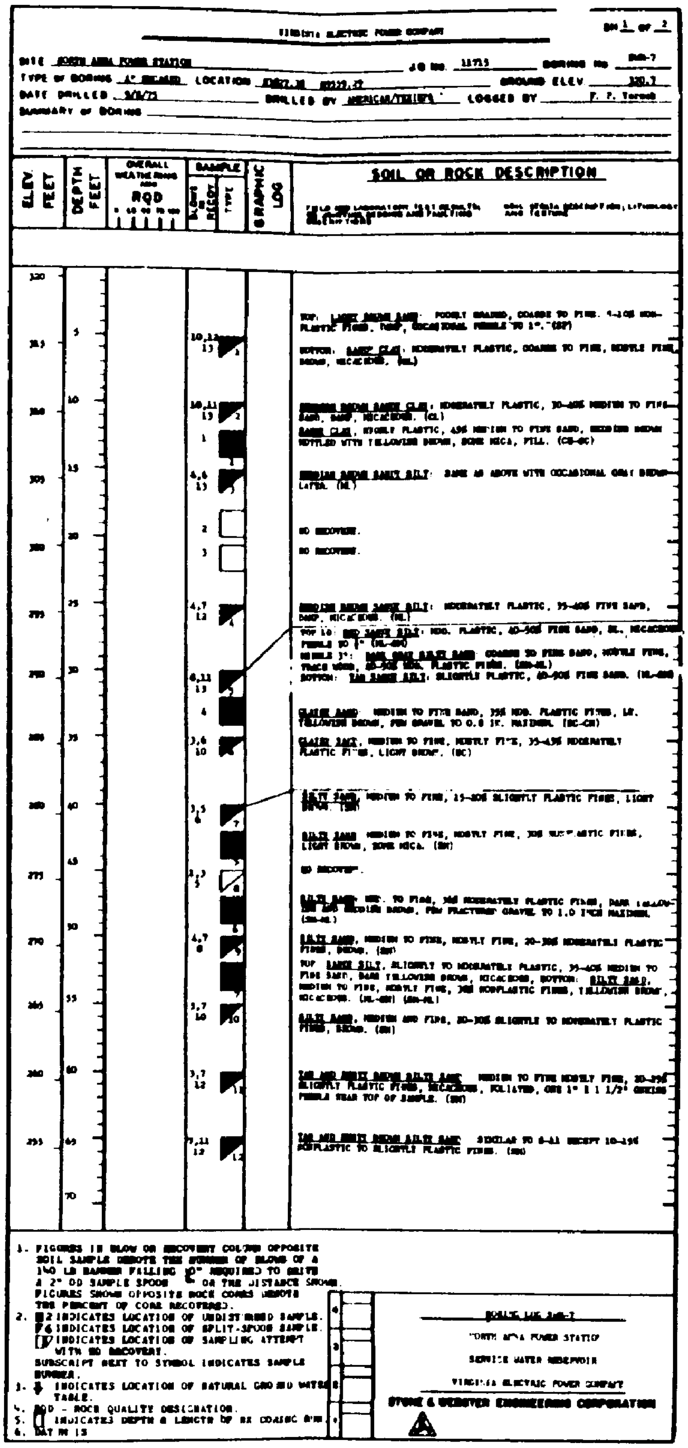


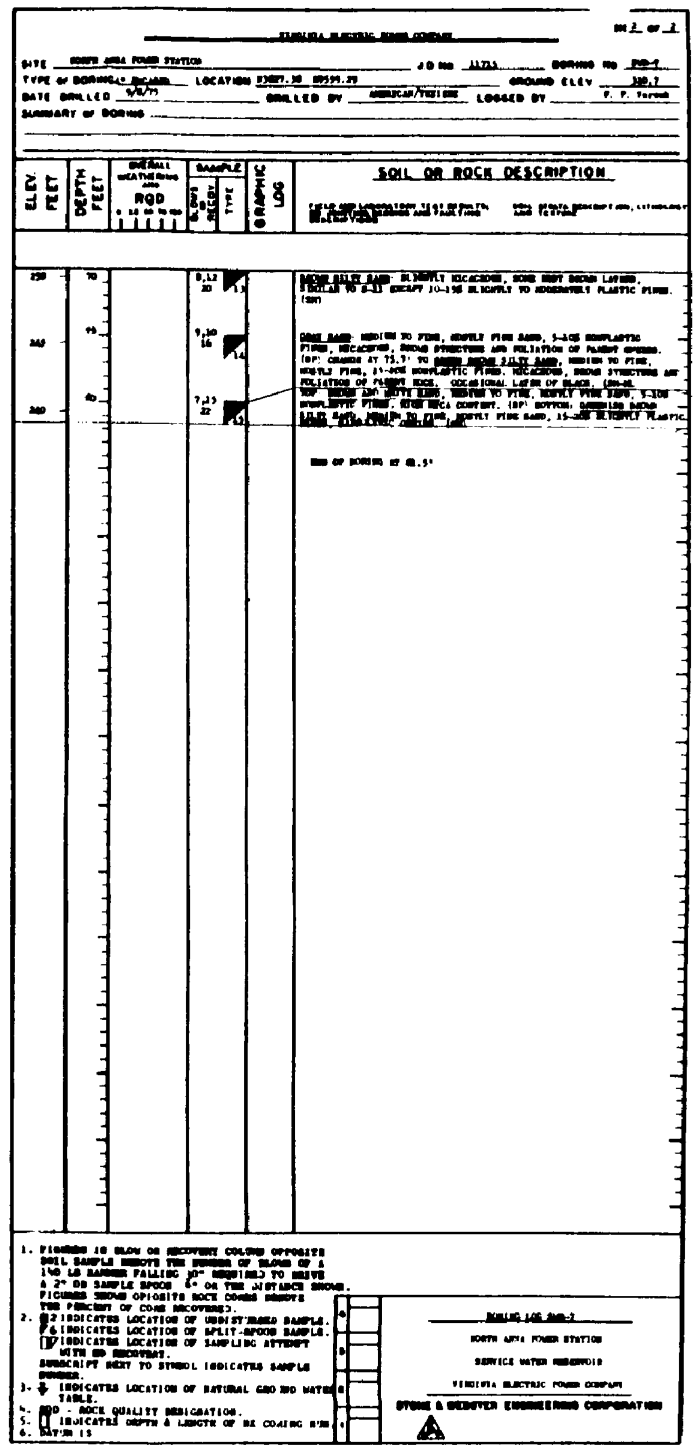
Figure 3E-4 (SHEET 22 OF 26)
BORING LOGS



N03E0013

a

Figure 3E-4 (SHEET 23 OF 26)
BORING LOGS



N03E0086

Figure 3E-4 (SHEET 24 OF 26)
BORING LOGS

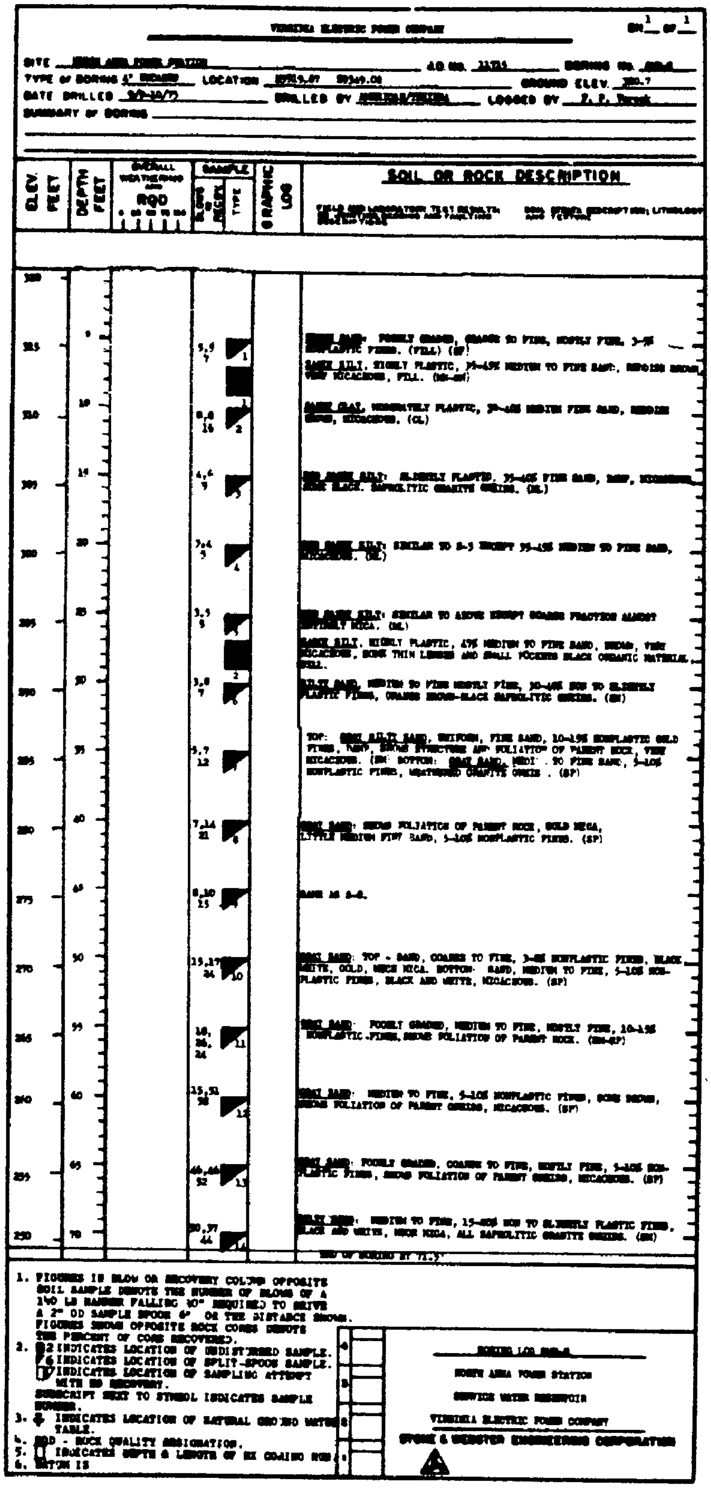


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Figure 3E-4 (SHEET 25 OF 26)
BORING LOGS

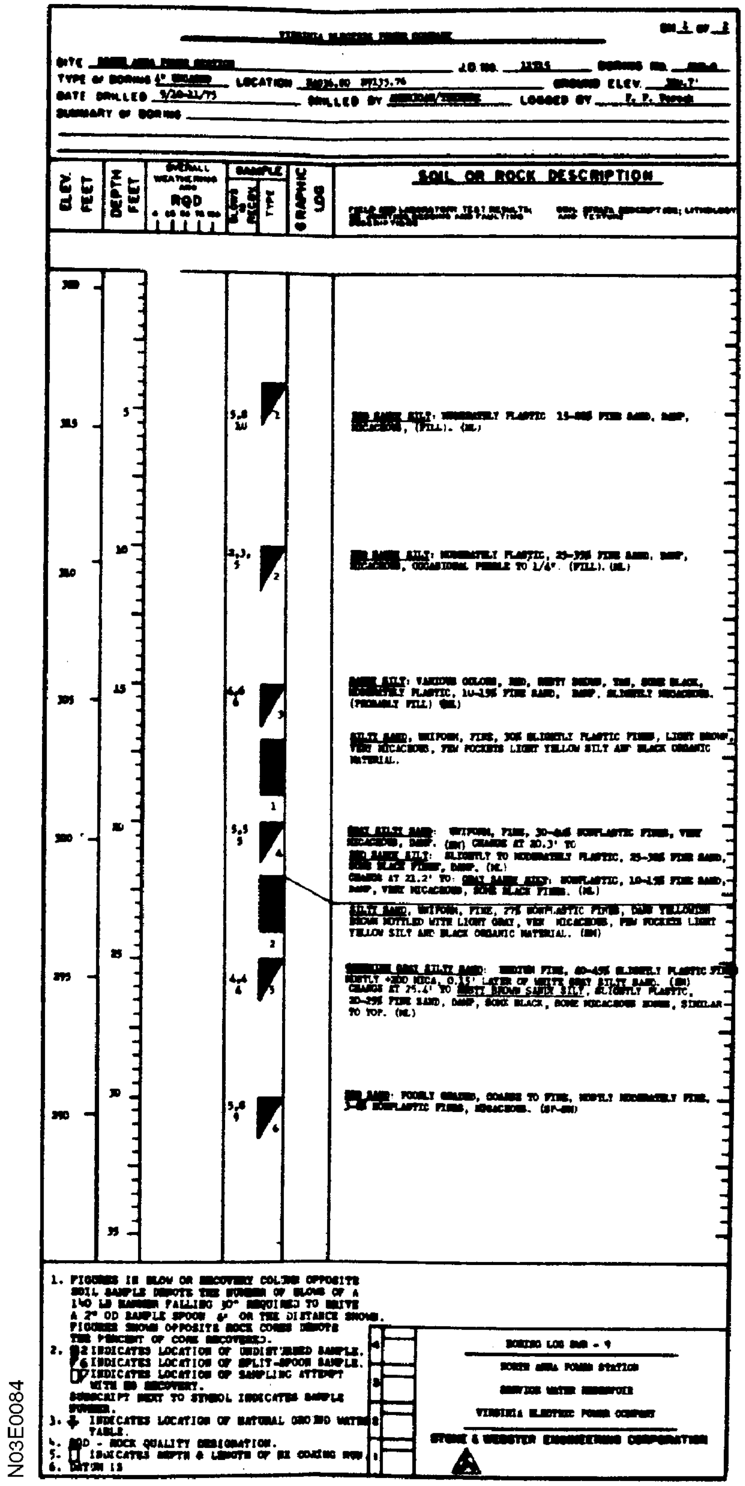
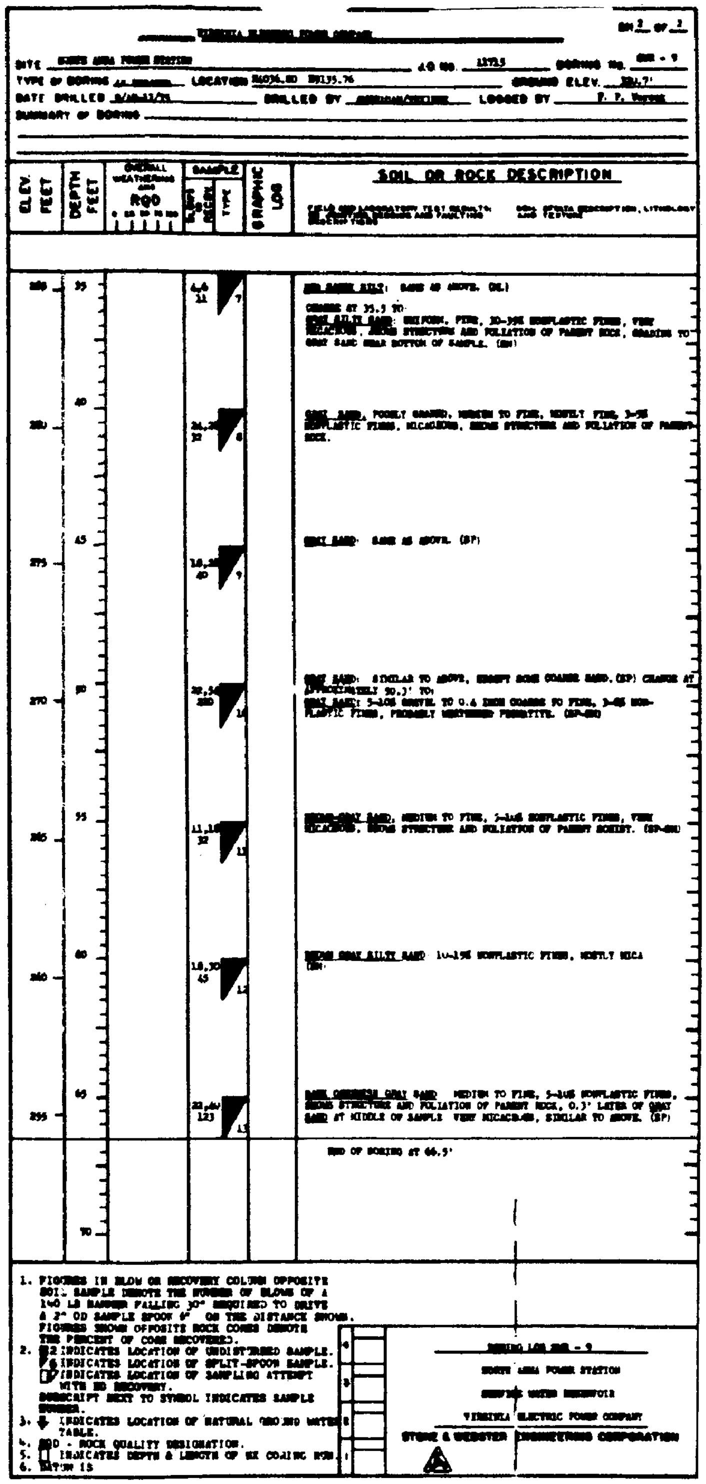
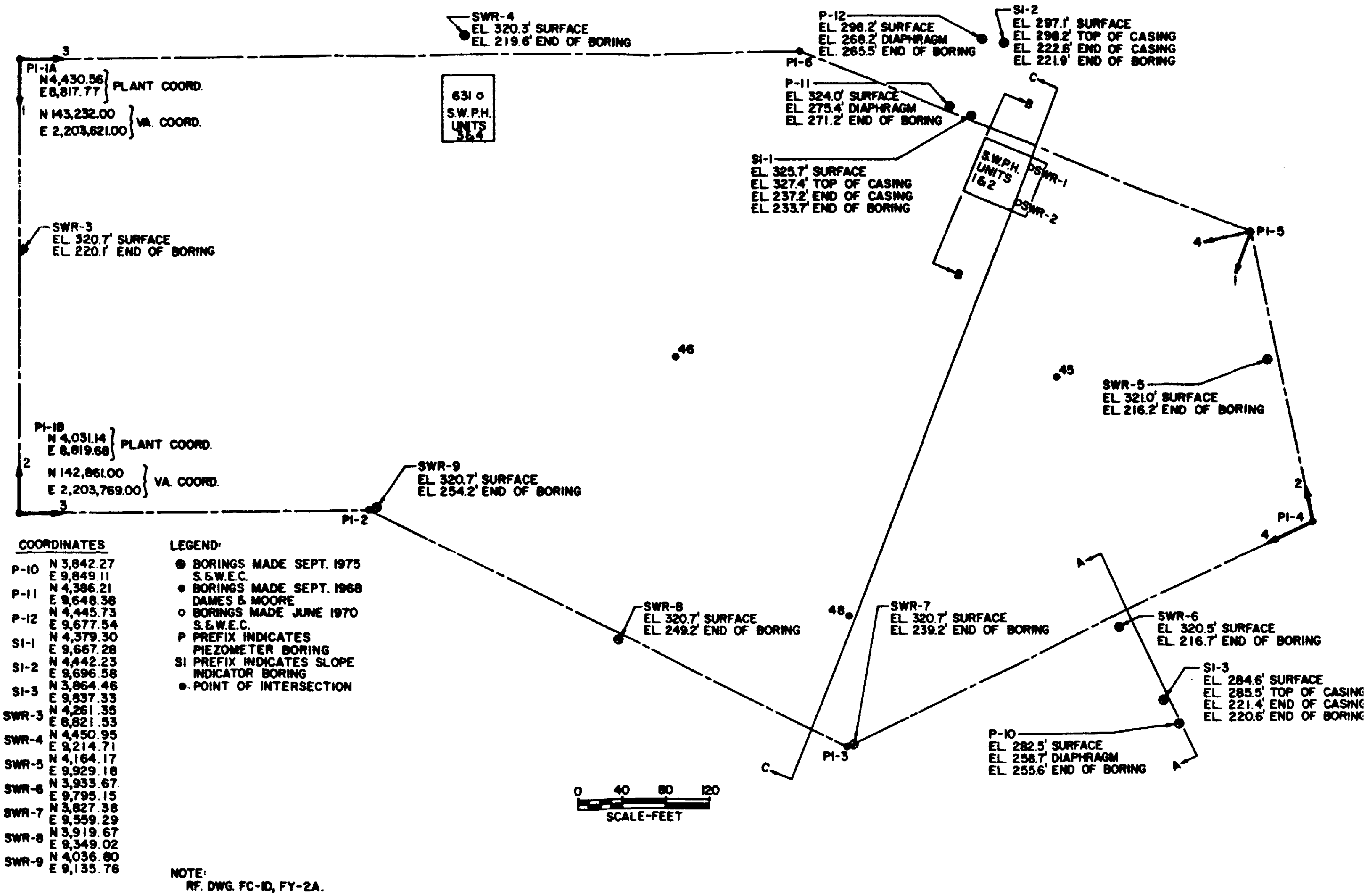


Figure 3E-4 (SHEET 26 OF 26)
BORING LOGS



N03E0085

Figure 3E-5
SERVICE WATER RESERVOIR: BORING LOCATION PLAN



N03E0015

Figure 3E-6
SERVICE WATER RESERVOIR LEGEND - SUBSURFACE PROFILES AND SECTIONS

LABORATORY TESTS:

CRSC - CONSOLIDATION TEST PEFORMED BY CONTINUOUS LOADING AT A CONSTANT RATE OF STRAIN.

IC - CONSOLIDATION TEST ON SPECIMEN CONTAINED WITHIN ORIGINAL SAMPLING TUBE AND PERFORMED BY LOADING IN INCREMENTS.

CT - CYCLIC LOADED CONSOLIDATED - UNDRAINED TRIAXIAL TEST

R - CONSOLIDATED - UNDRAINED TRIAXIAL TEST

DS - DIRECT SHEAR TEST

G_s - SPECIFIC GRAVITY TEST

BORING AND SAMPLING:

SWR 1 - EXPLORATORY BORING

SI-1 - SLOPE INDICATOR BORING

P-11 - PIEZOMETER BORING

ST 3 - UNDISTURBED SAMPLE No. 3

yel - YELLOW

br - BROWN

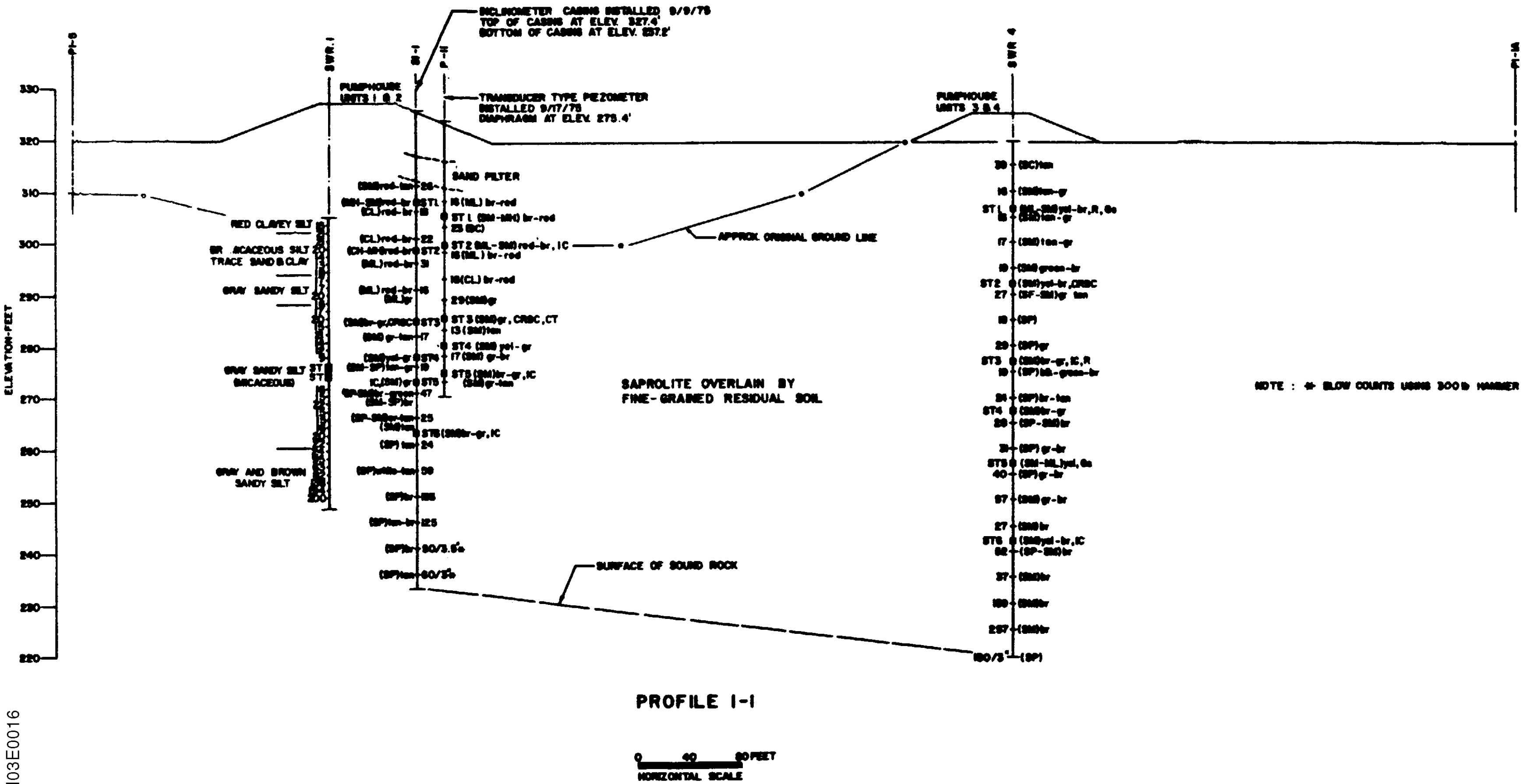
gr - GRAY

blk - BLACK

wh - WHITE

N03E0090

Figure 3E-7 (SHEET 1 OF 3)
SERVICE WATER RESERVOIR SUBSURFACE PROFILE ALONG CENTERLINE OF DIKE



N03E0016

Figure 3E-7 (SHEET 2 OF 3)
SERVICE WATER RESERVOIR SUBSURFACE PROFILE ALONG CENTERLINE OF DIKE

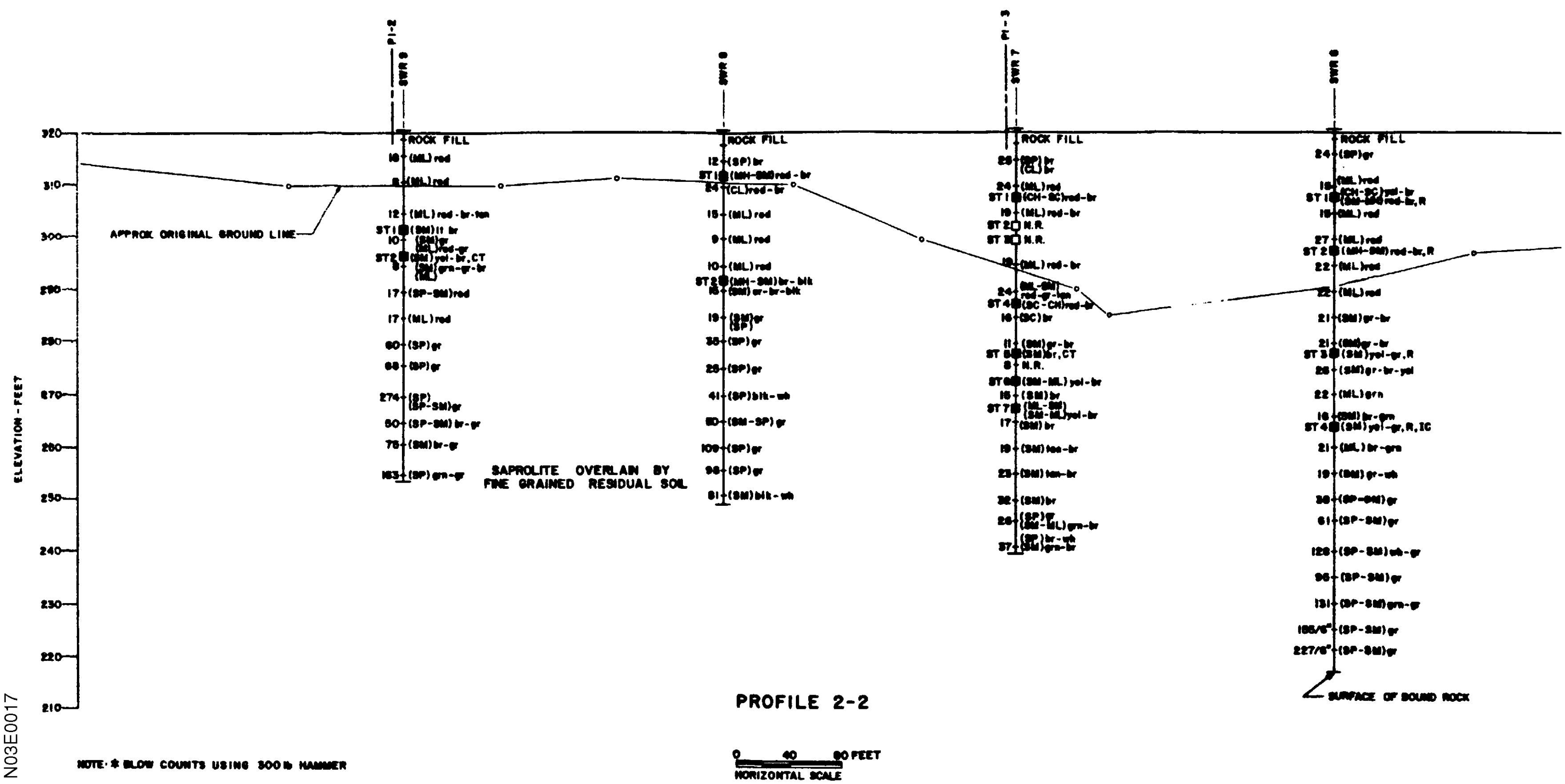
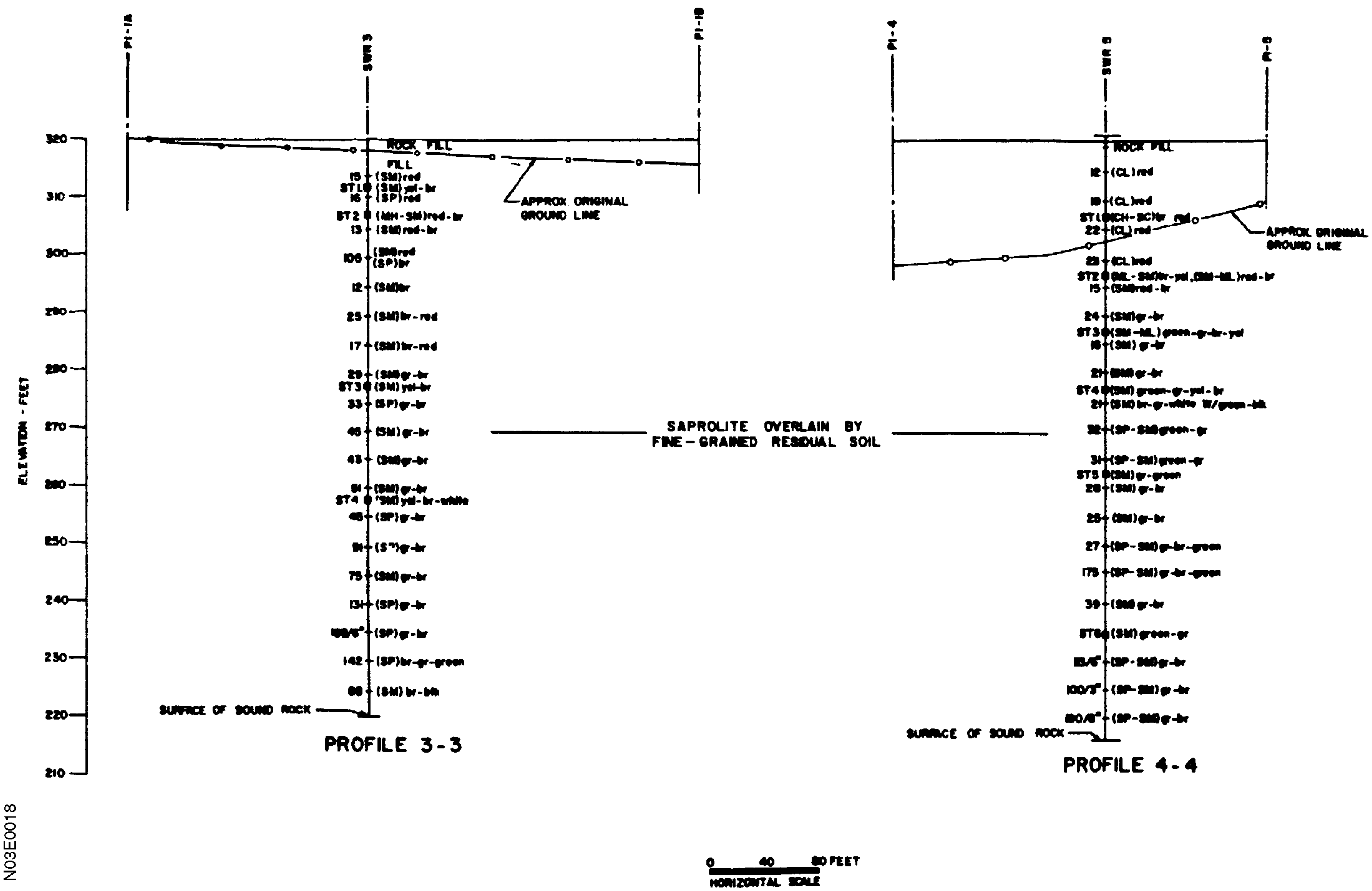
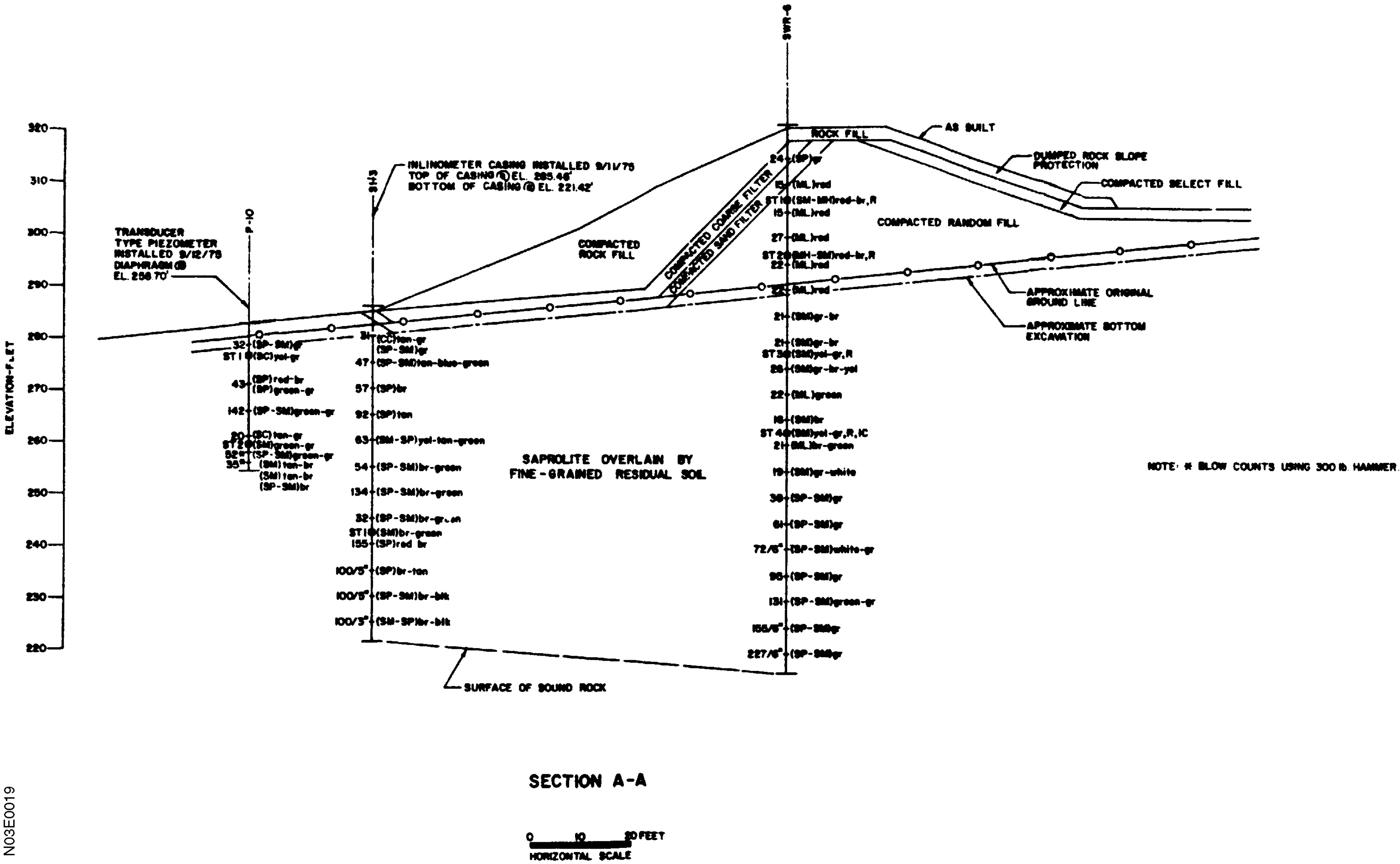


Figure 3E-7 (SHEET 3 OF 3)
SERVICE WATER RESERVOIR SUBSURFACE PROFILE ALONG CENTERLINE OF DIKE



N03E0018

Figure 3E-8
SERVICE WATER RESERVOIR SUBSURFACE SECTION THROUGH DIKE



N03E0019

Figure 3E-9
SERVICE WATER RESERVOIR SUBSURFACE SECTION THROUGH DIKE
AT 1 & 2 PUMPHOUSE

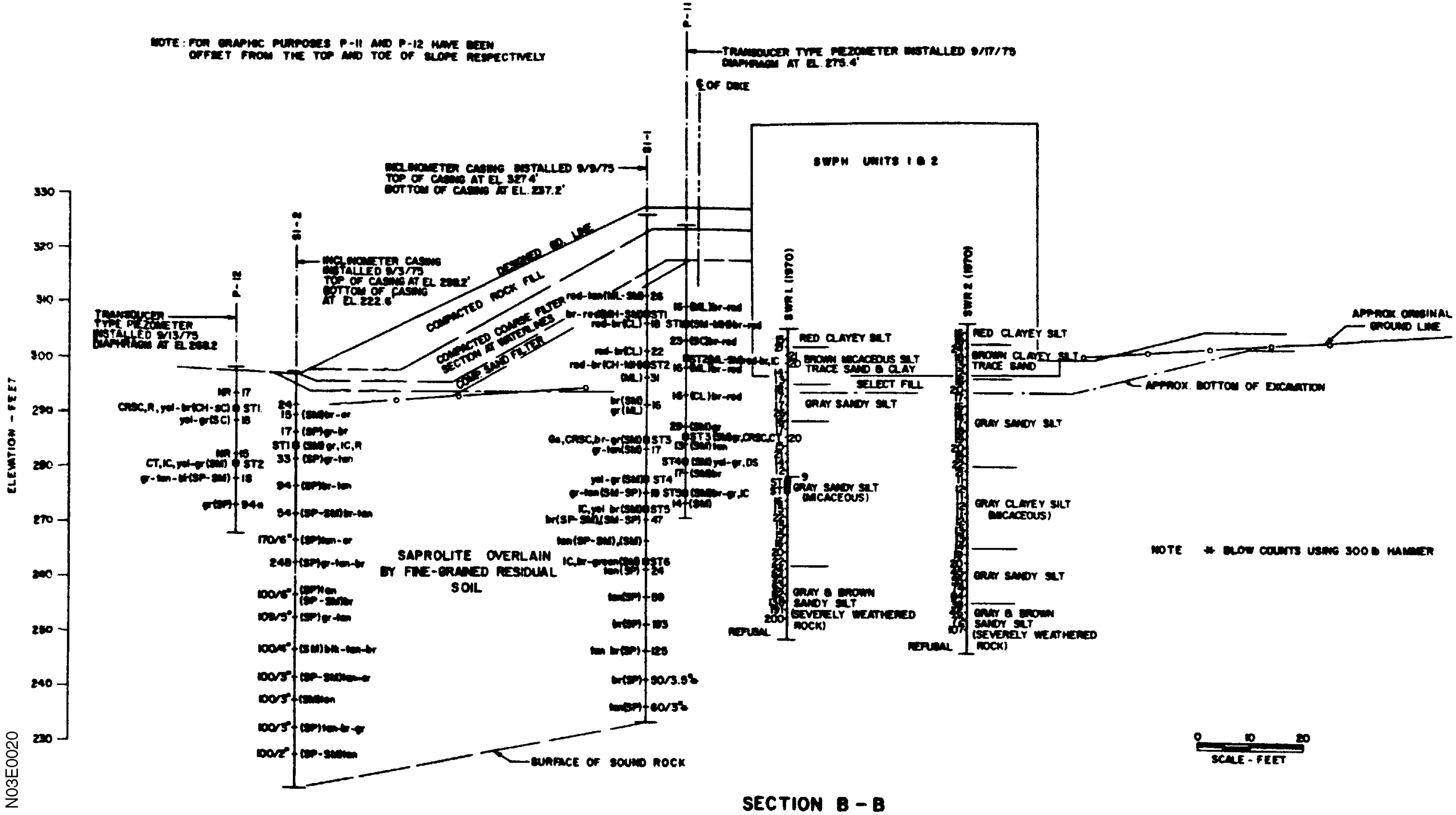
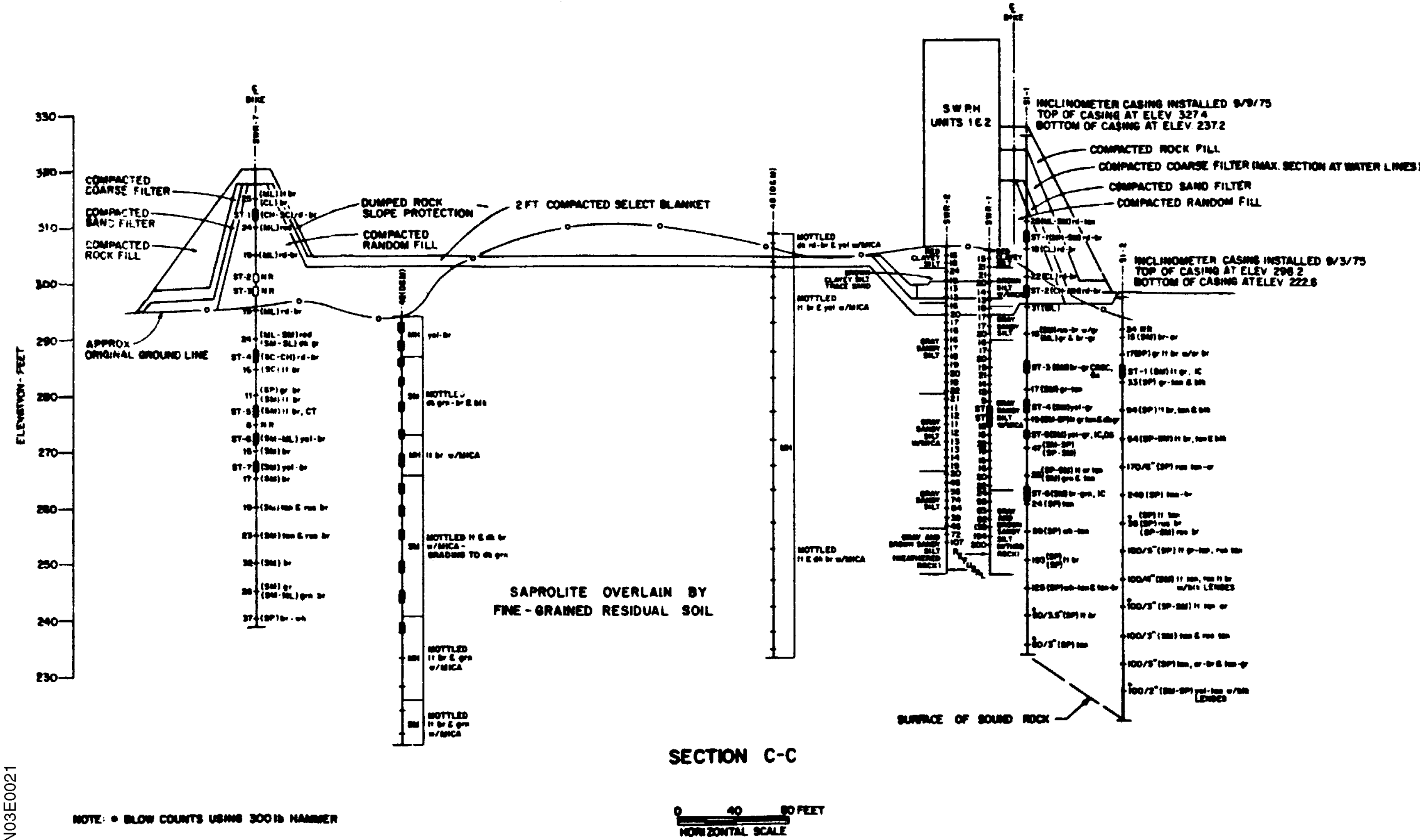


Figure 3E-10
SERVICE WATER RESERVOIR N-S SECTION THROUGH RESERVOIR



N03E0021

Figure 3E-11
VERTICAL STRAIN VERSUS STRESS RELATIONSHIPS CONSOLIDATION TESTS

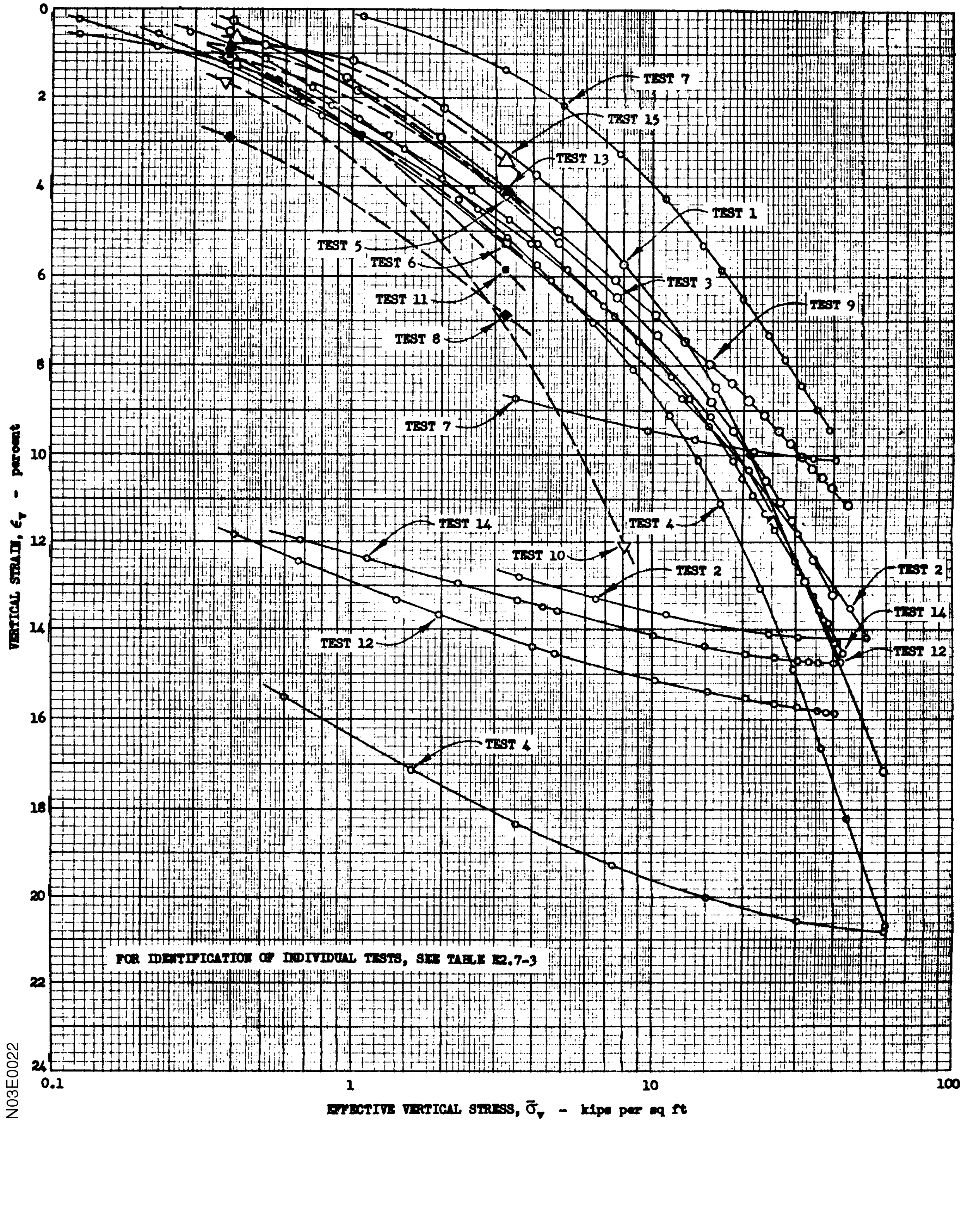


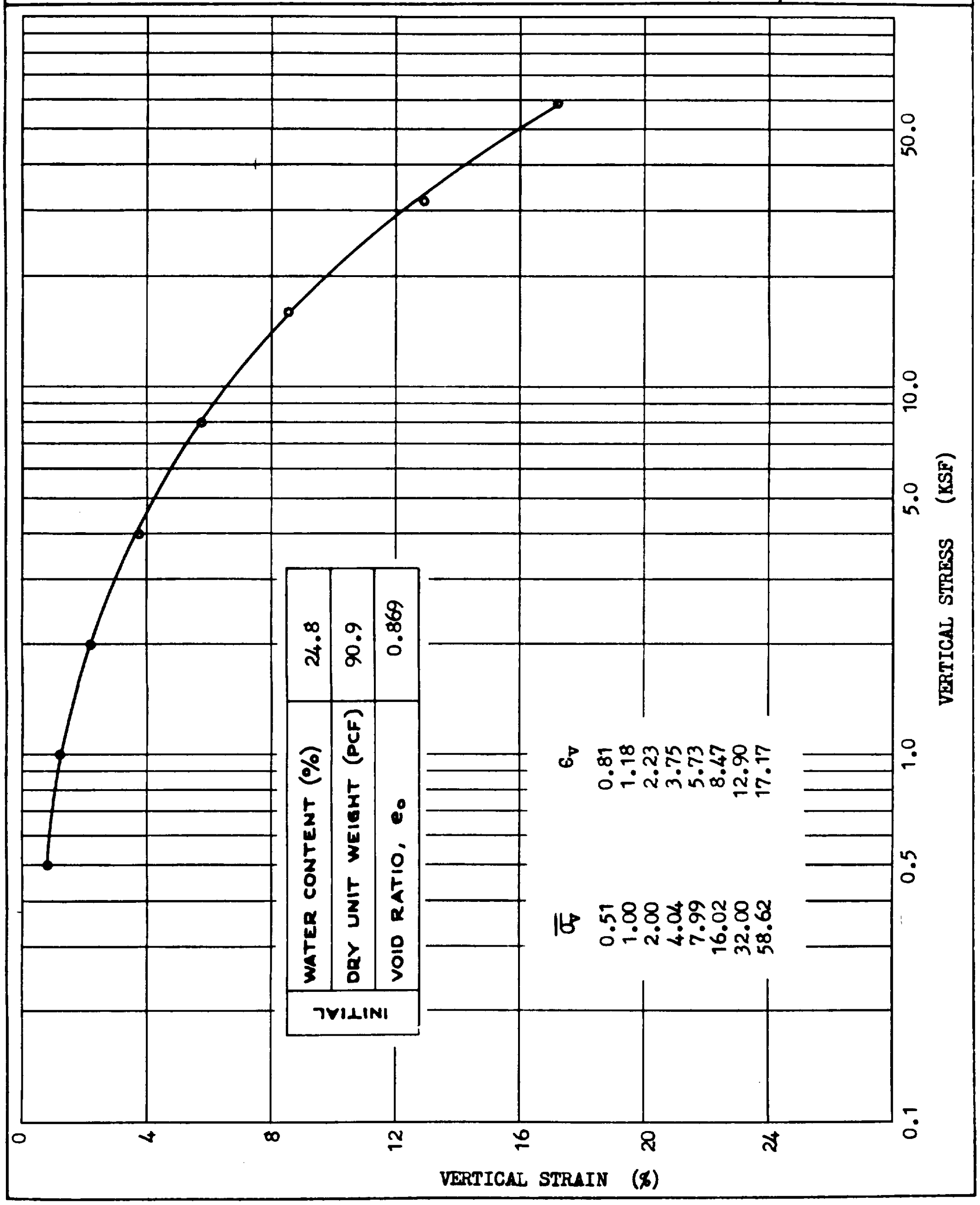
Figure 3E-12 (SHEET 1 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

CONSOLIDATION TEST REPORT

Sheet 1

CLIENT	J.O. NUMBER	BORING NUMBER
VIRGINIA ELECTRIC POWER COMPANY	11715	P-11
SITE: NORTH ANNA 1 & 2	DATE: 27 OCT 75	SAMPLE NUMBER: 2F
VERTICAL STRAIN vs. LOG STRESS		DEPTH: 24.0



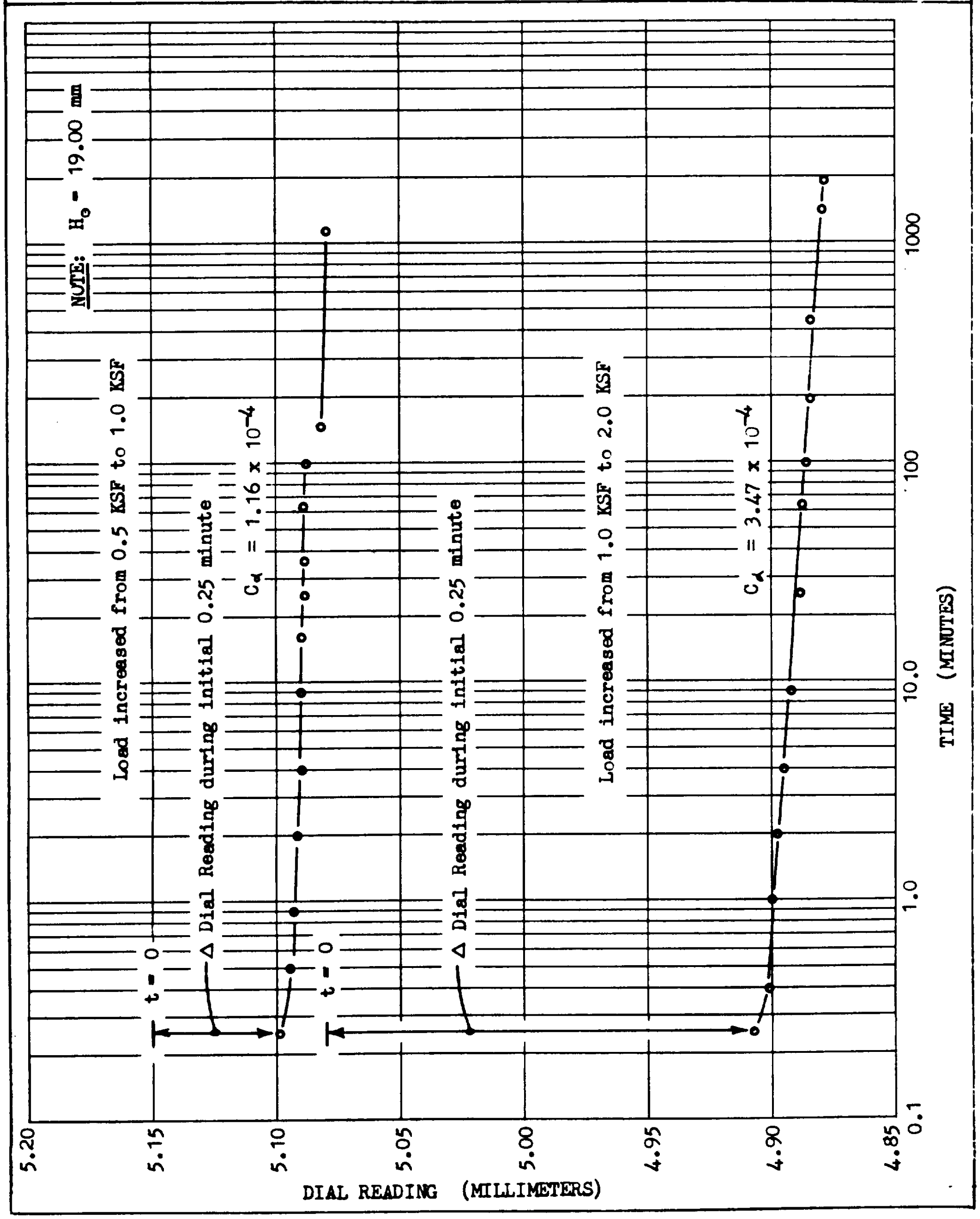
N03E0023

Figure 3E-12 (SHEET 2 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

CONSOLIDATION TEST REPORT
Sheet 2

CLIENT	J.O. NUMBER	BORING NUMBER
VIRGINIA ELECTRIC POWER COMPANY	11715	P-11
SITE	**DATE**	**SAMPLE NUMBER**
NORTH ANNA 1 & 2	27 OCT 75	2F
		DEPTH
DISPLACEMENT vs. LOG TIME PLOTS		24.0



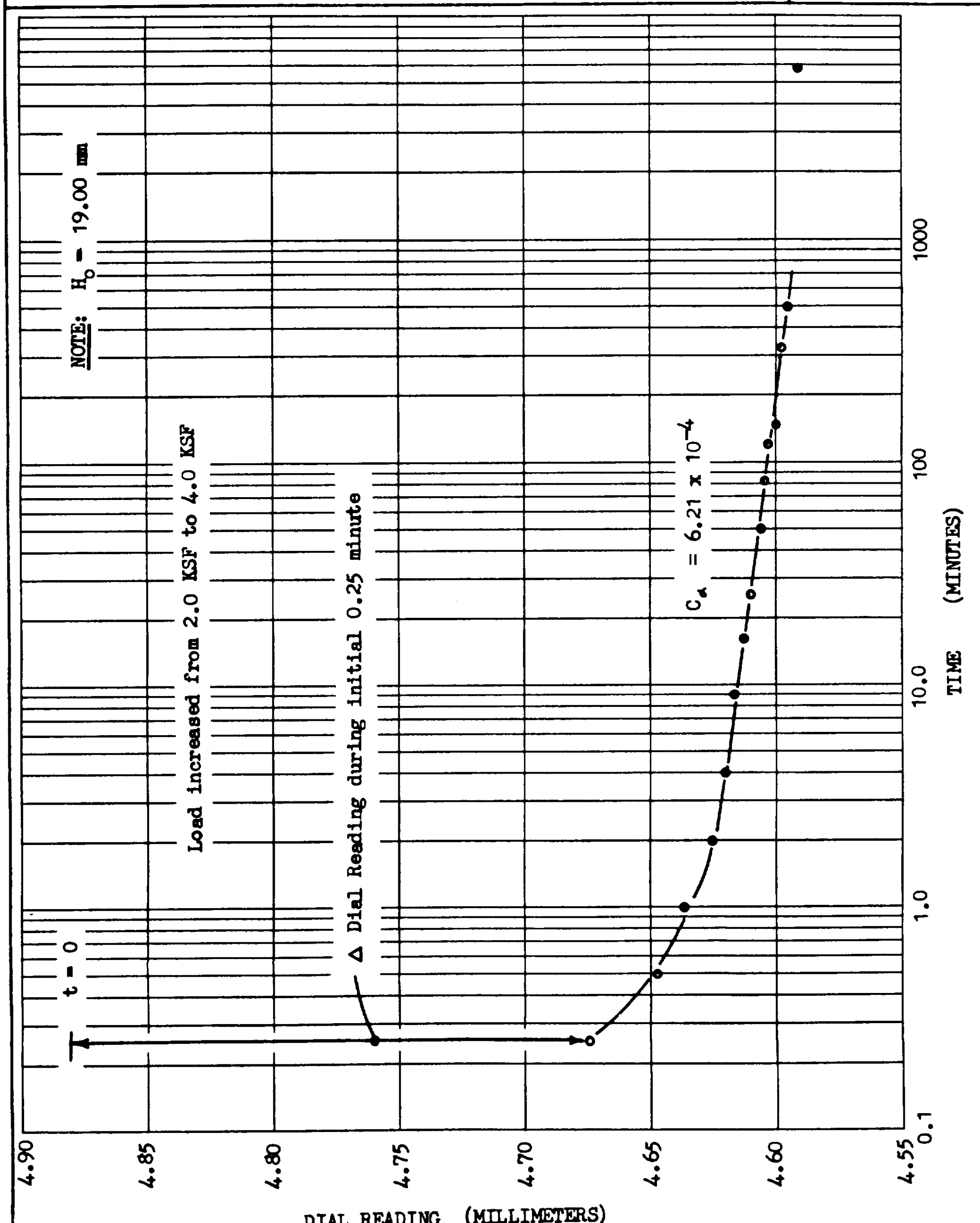
N03E0024

Figure 3E-12 (SHEET 3 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

CONSOLIDATION TEST REPORT
Sheet 3

CLIENT	J.O. NUMBER	BORING NUMBER
VIRGINIA ELECTRIC POWER COMPANY	11715	P-11
SITE	DATE	SAMPLE NUMBER
NORTH ANNA 1 & 2	27 OCT 75	2F
DISPLACEMENT vs. LOG TIME PLOTS		DEPTH 24.0



N03E0025

Figure 3E-12 (SHEET 4 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

CONSOLIDATION TEST REPORT
Sheet 4

CLIENT	J.O. NUMBER	BORING NUMBER
VIRGINIA ELECTRIC POWER COMPANY	11715	P-11
SITE	**DATE**	**SAMPLE NUMBER**
NORTH ANNA 1 & 2	27 OCT 75	2F
DISPLACEMENT vs. LOG TIME PLOTS		**DEPTH** 24.0

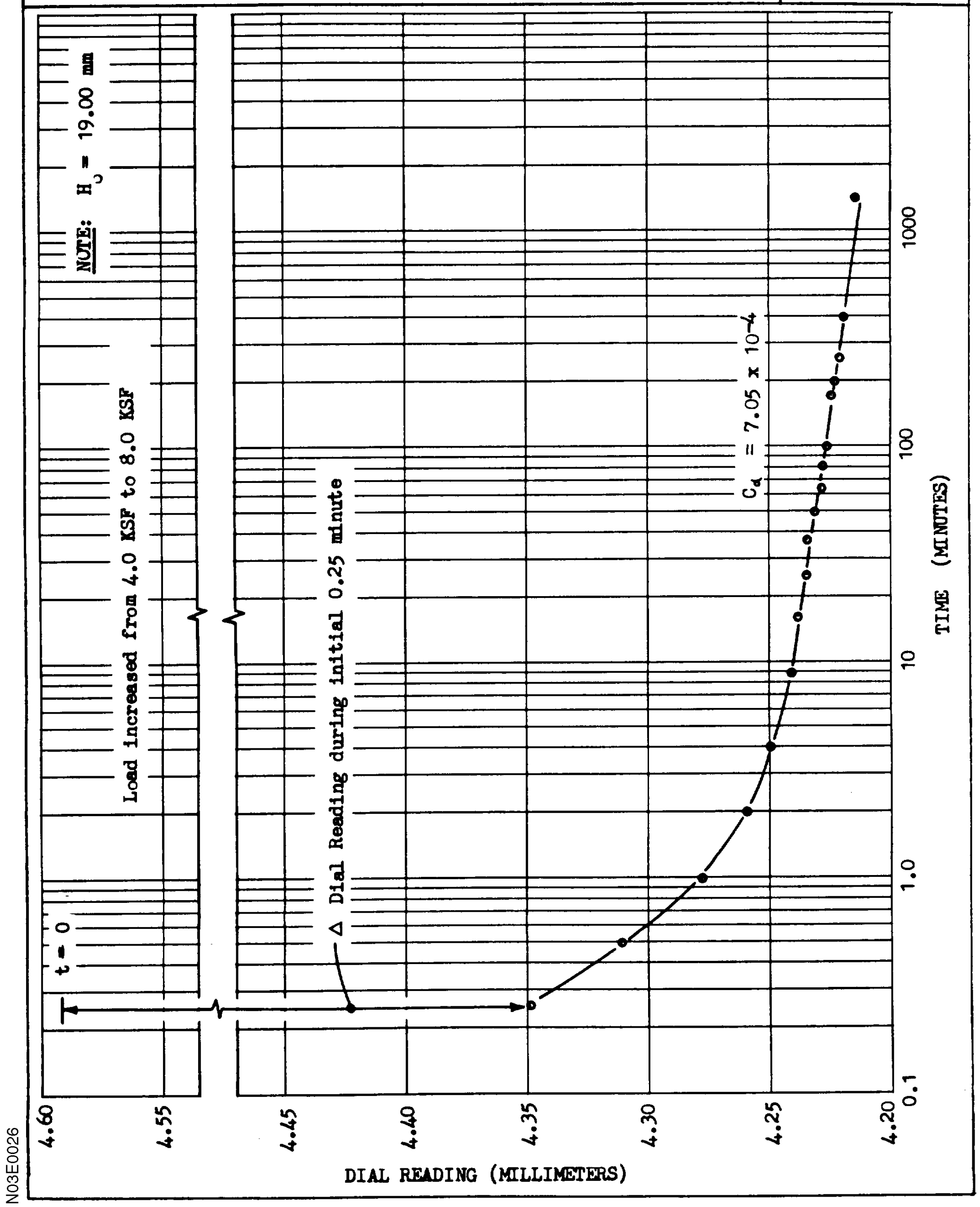
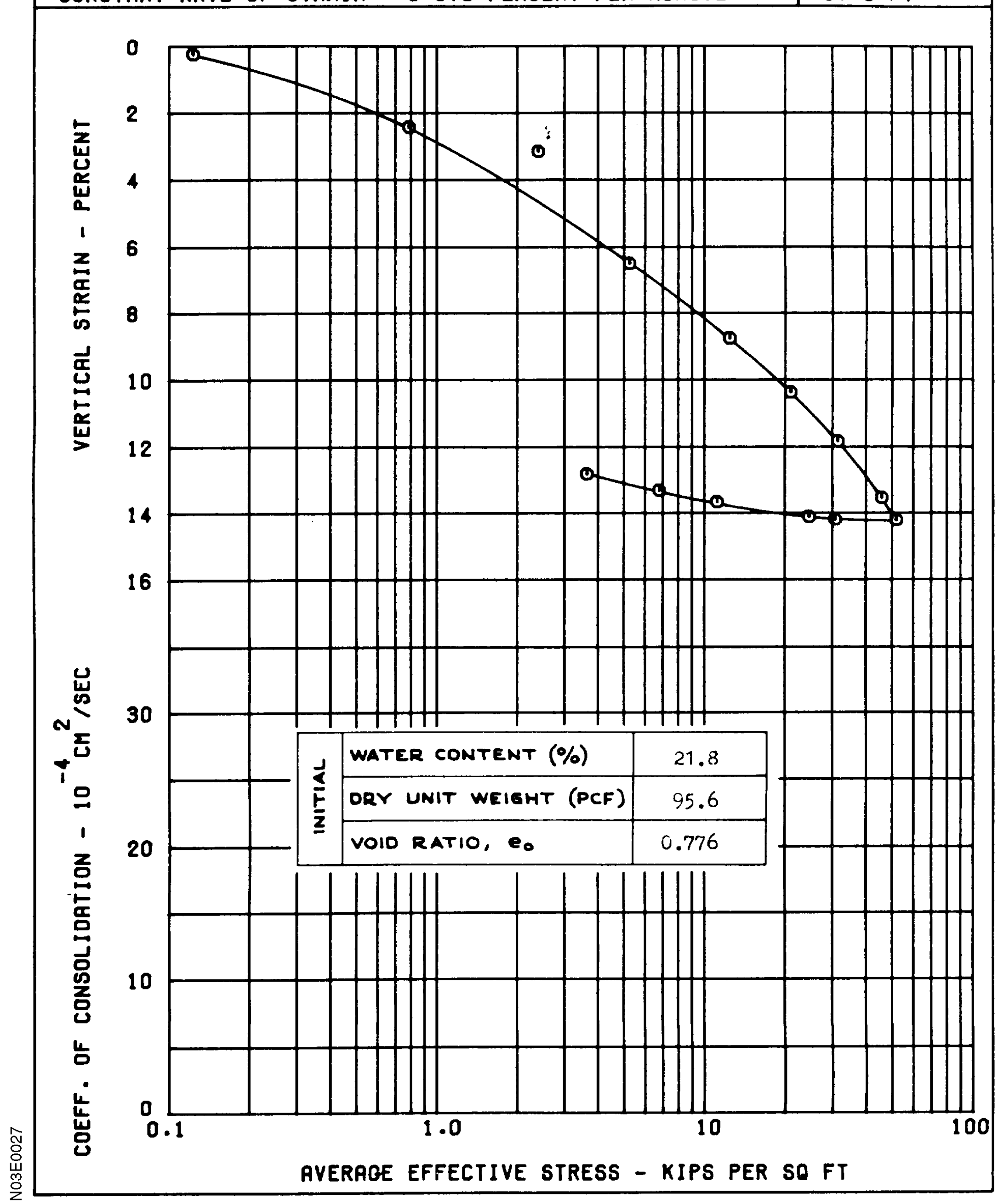


Figure 3E-12 (SHEET 5 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION CONSOLIDATION TEST REPORT

Sheet 5

CLIENT VIRGINIA ELECTRIC POWER COMPANY	J.O. NUMBER 11715	BORING NUMBER P-11
SITE NORTH ANNA 1 & 2	DATE 20 OCT 75	SAMPLE NUMBER 3F
CONSTANT RATE OF STRAIN - 0.079 PERCENT PER MINUTE		DEPTH 37.9 FT



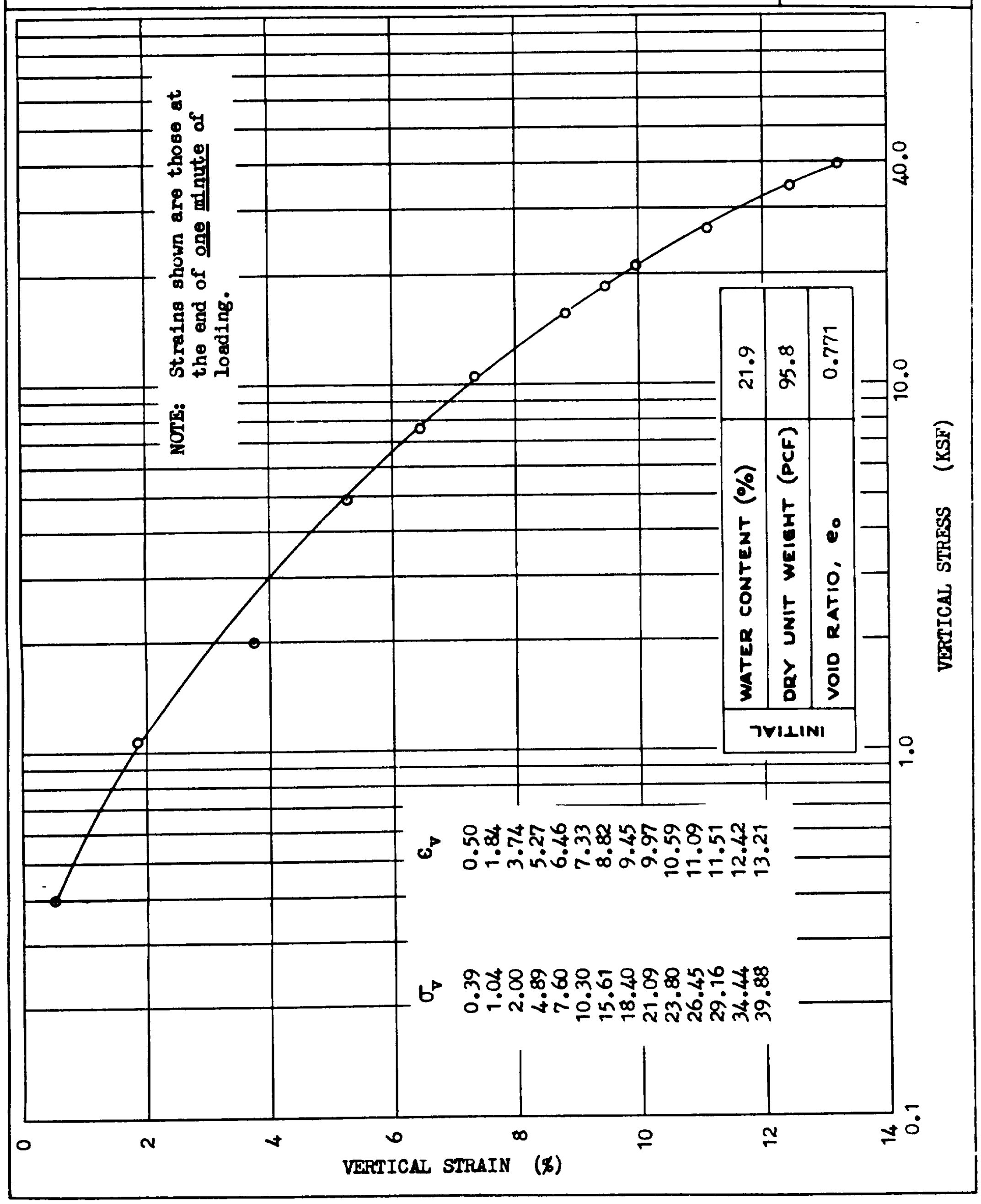
INITIAL		
	WATER CONTENT (%)	21.8
	DRY UNIT WEIGHT (PCF)	95.6
	VOID RATIO, e_o	0.776

Figure 3E-12 (SHEET 6 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

CONSOLIDATION TEST REPORT
Sheet 6

CLIENT VIRGINIA ELECTRIC POWER COMPANY	J.O. NUMBER 11715	BORING NUMBER P-11
SITE NORTH ANNA 1 & 2	DATE 7 NOV 75	SAMPLE NUMBER 5F
VERTICAL STRAIN vs. LOG STRESS		DEPTH 48.8



σ_v	ε_v
0.39	0.50
1.04	1.84
2.00	3.74
4.89	5.27
7.60	6.46
10.30	7.33
15.61	8.82
18.40	9.45
21.09	9.97
23.80	10.59
26.45	11.09
29.16	11.51
34.44	12.42
39.88	13.21

N03E0028

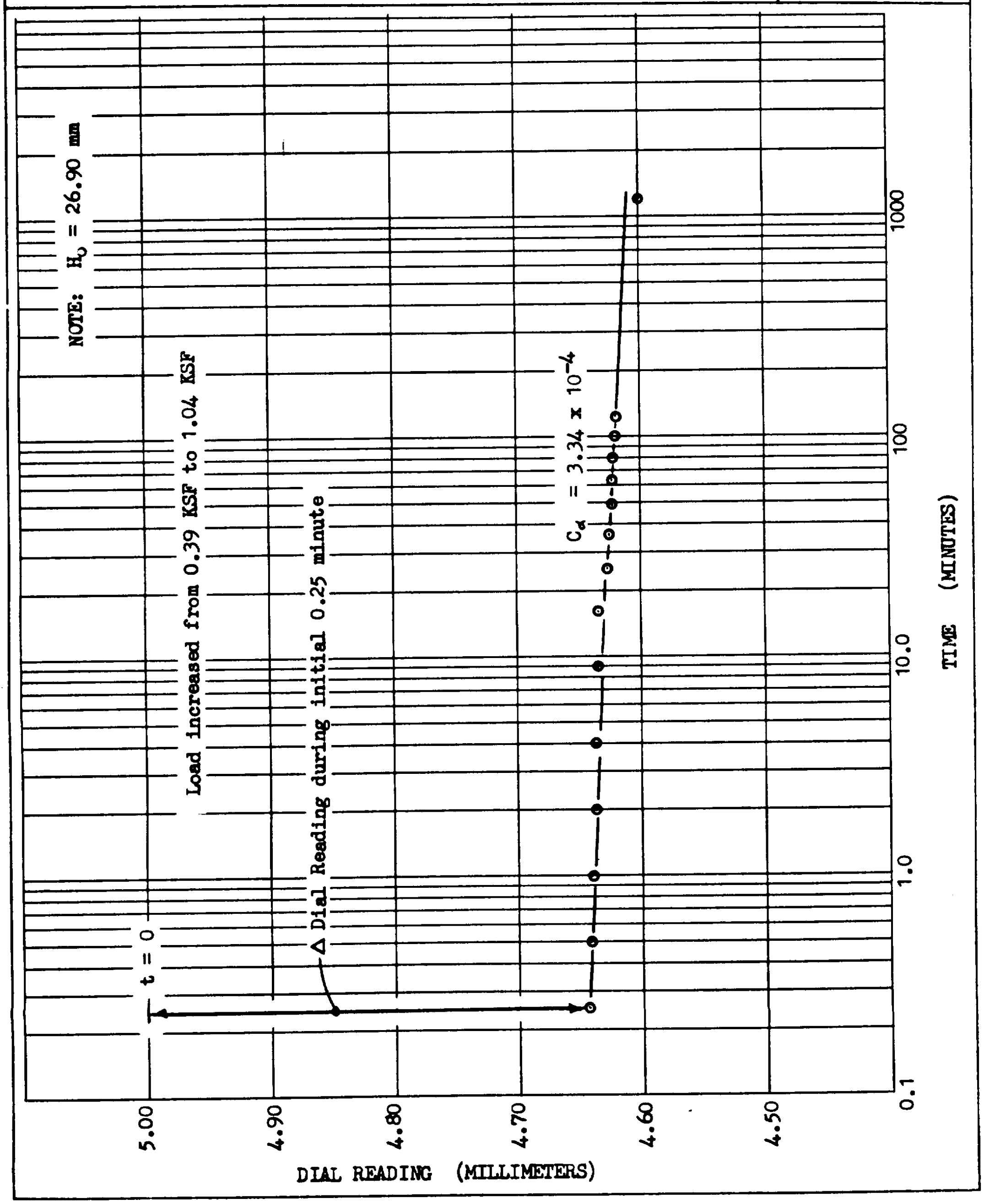
Figure 3E-12 (SHEET 7 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

CONSOLIDATION TEST REPORT

Sheet 7

CLIENT	J.O. NUMBER	BORING NUMBER
VIRGINIA ELECTRIC POWER COMPANY	11715	P-11
SITE	DATE	SAMPLE NUMBER
NORTH ANNA 1 & 2	7 NOV 75	5F
		DEPTH
DISPLACEMENT vs. LOG TIME PLOTS		48.8



N03E0029

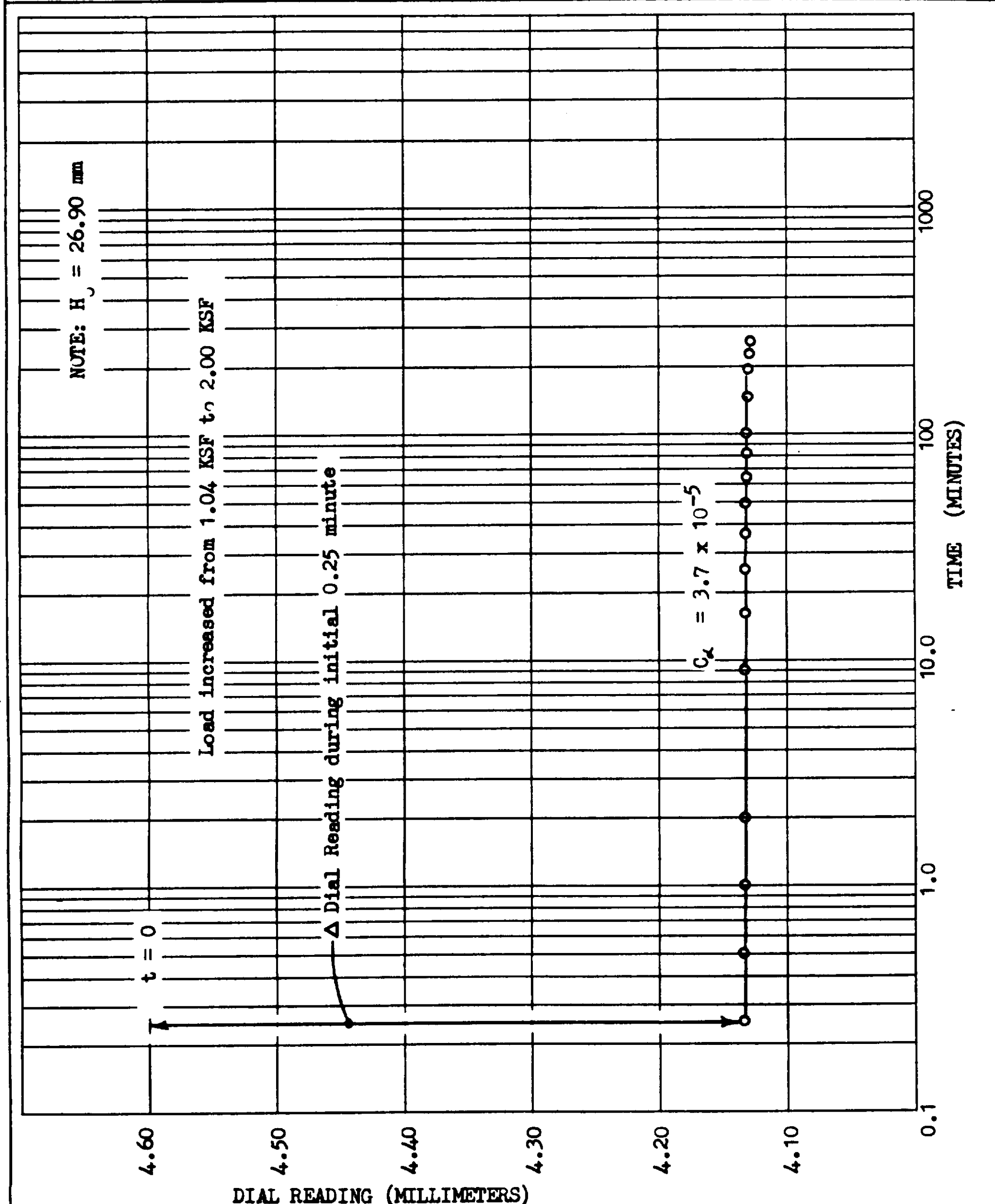
Figure 3E-12 (SHEET 8 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

CONSOLIDATION TEST REPORT

Sheet 8

CLIENT VIRGINIA ELECTRIC POWER COMPANY	J.O. NUMBER 11715	BORING NUMBER P-11
SITE NORTH ANNA 1 & 2	DATE 7 NOV 75	SAMPLE NUMBER 5F
DISPLACEMENT vs. LOG TIME PLOTS		DEPTH 48.8



N03E0030

Figure 3E-12 (SHEET 9 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

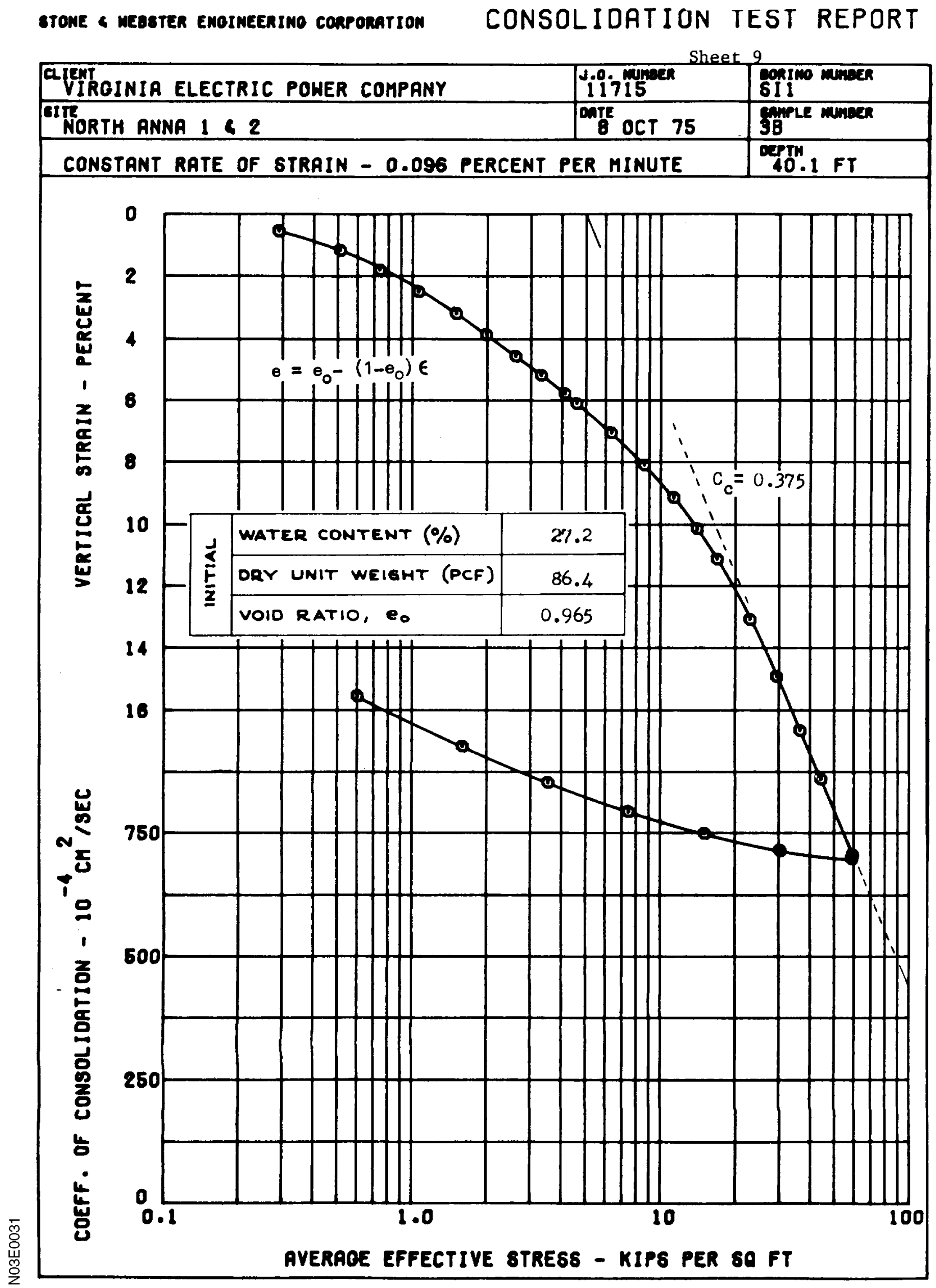
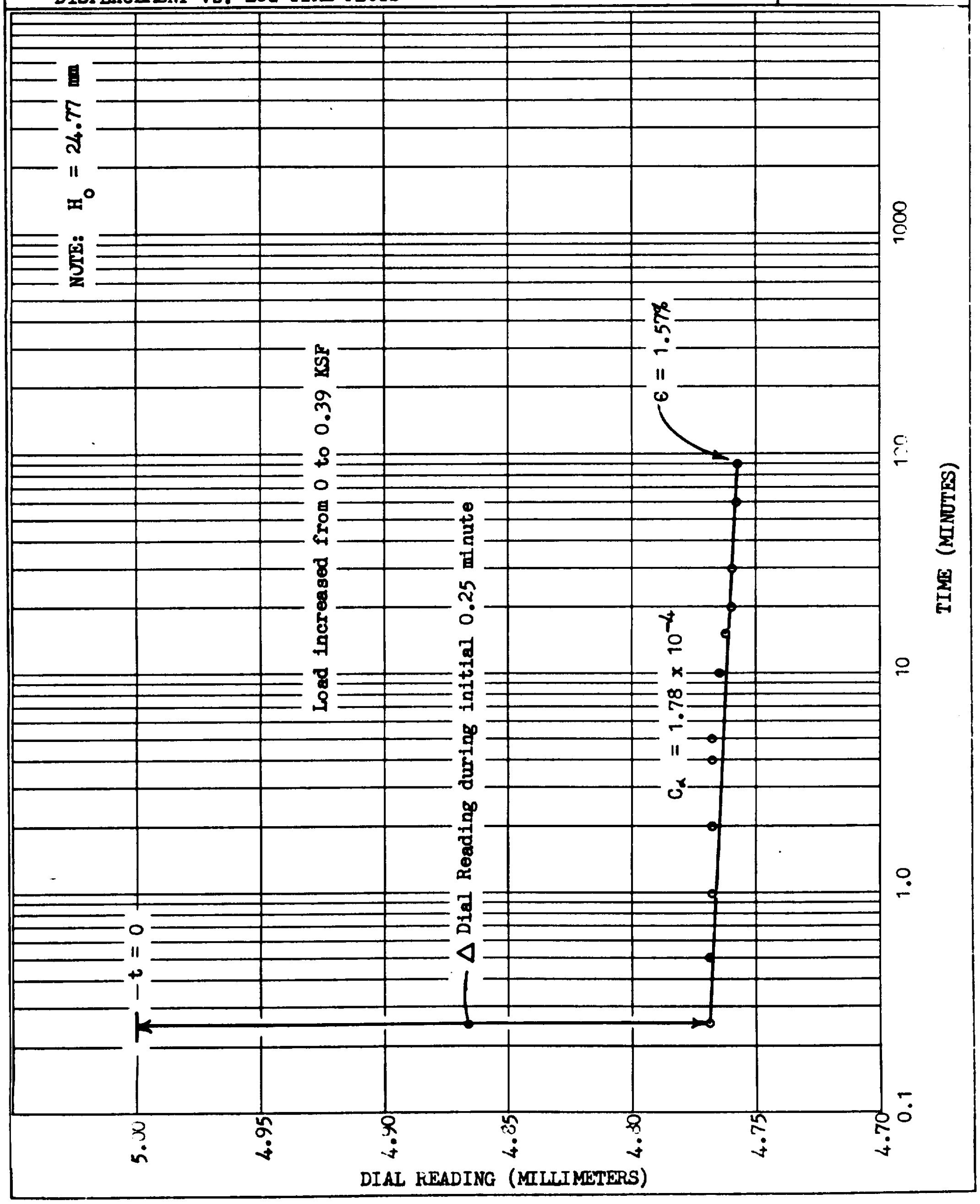


Figure 3E-12 (SHEET 10 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

CONSOLIDATION TEST REPORT
Sheet 10

CLIENT	J.O. NUMBER	BORING NUMBER
VIRGINIA ELECTRIC AND POWER COMPANY	11715	SI-1
SITE	DATE	SAMPLE NUMBER
NORTH ANNA 1 & 2	7 NOV 75	5F
		DEPTH
DISPLACEMENT vs. LOG TIME PLOTS		52.7



N03E0032

Figure 3E-12 (SHEET 11 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

CONSOLIDATION TEST REPORT

Sheet 11

CLIENT	J.O. NUMBER	BORING NUMBER
VIRGINIA ELECTRIC AND POWER COMPANY	11715	SI-1
SITE	DATE	SAMPLE NUMBER
NORTH ANNA 1 & 2	7 NOV 75	5F
DISPLACEMENT vs. LOG TIME PLOTS		DEPTH 52.7

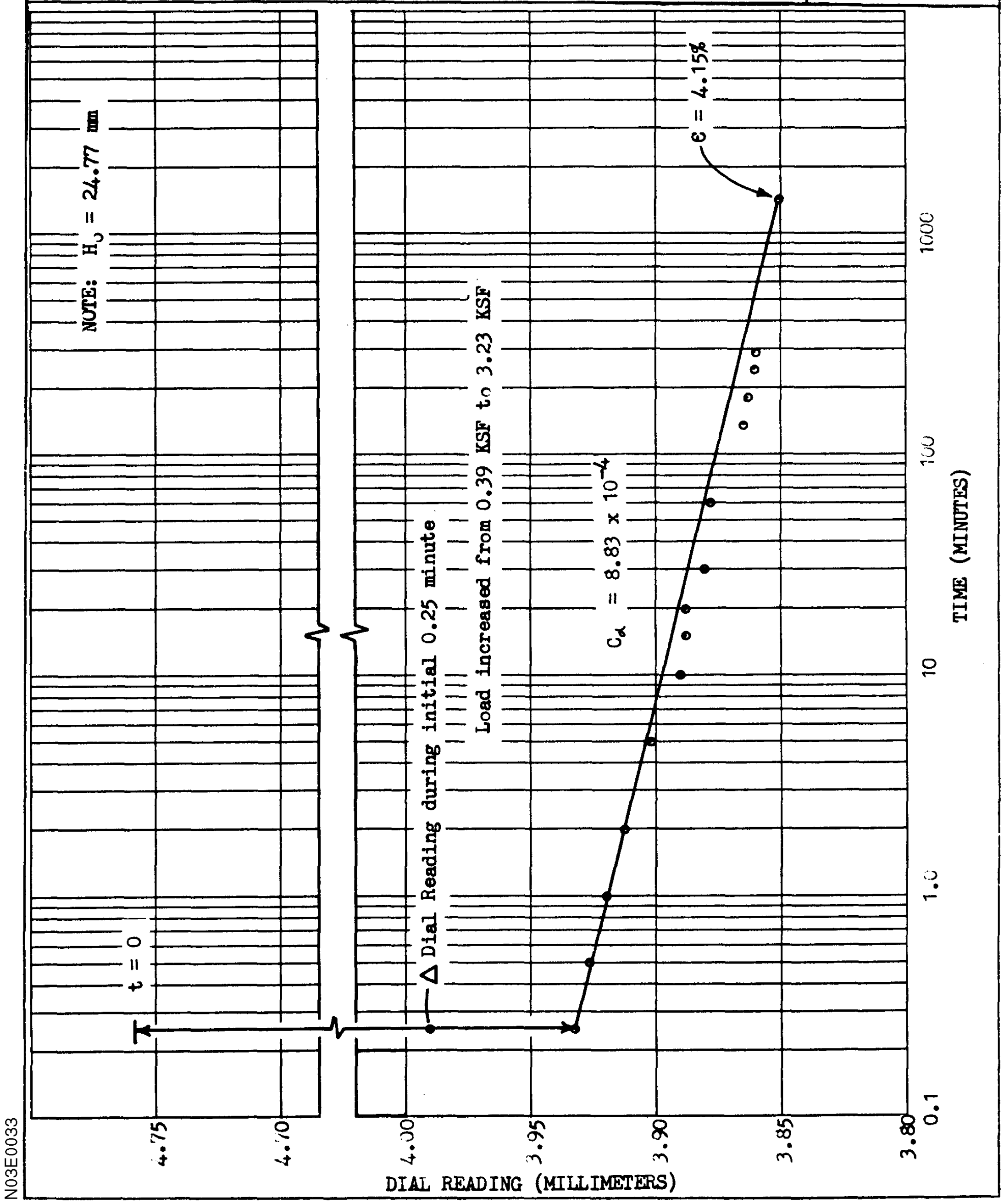


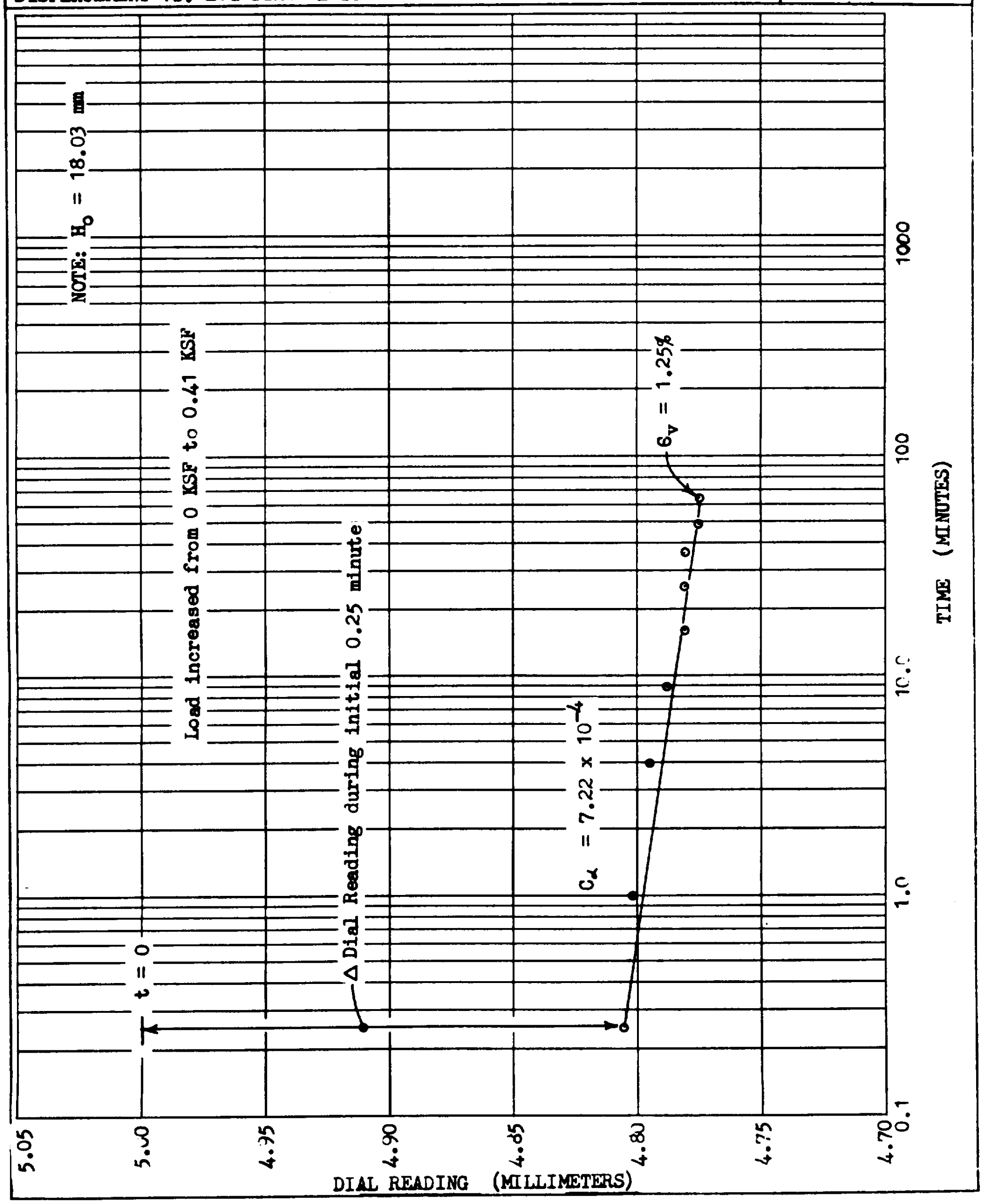
Figure 3E-12 (SHEET 12 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

CONSOLIDATION TEST REPORT

Sheet 12

CLIENT	J.O. NUMBER	BORING NUMBER
VIRGINIA ELECTRIC POWER COMPANY	11715	SI-1
SITE	DATE	SAMPLE NUMBER
NORTH ANNA 1 & 2	30 OCT 75	6E
DISPLACEMENT vs. LOG TIME PLOTS		DEPTH 63.0



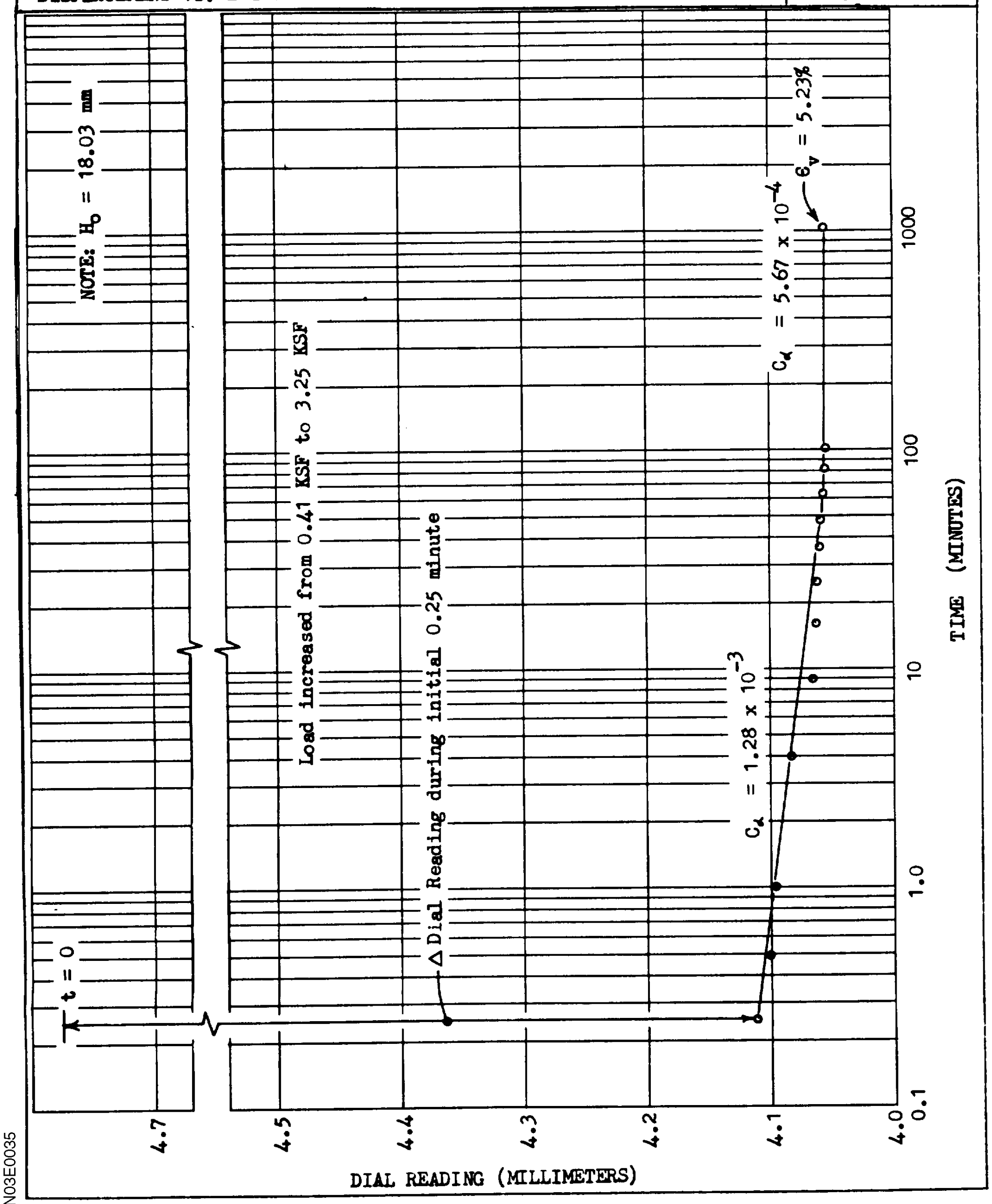
N03E0034

Figure 3E-12 (SHEET 13 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION **CONSOLIDATION TEST REPORT**

Sheet 13

CLIENT	J.O. NUMBER	BORING NUMBER
VIRGINIA ELECTRIC POWER COMPANY	11715	SI-1
SITE	DATE	SAMPLE NUMBER
NORTH ANNA 1 & 2	30 OCT 75	6E
		DEPTH
DISPLACEMENT vs. LOG TIME PLOTS		63.0



N03E0035

Figure 3E-12 (SHEET 14 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

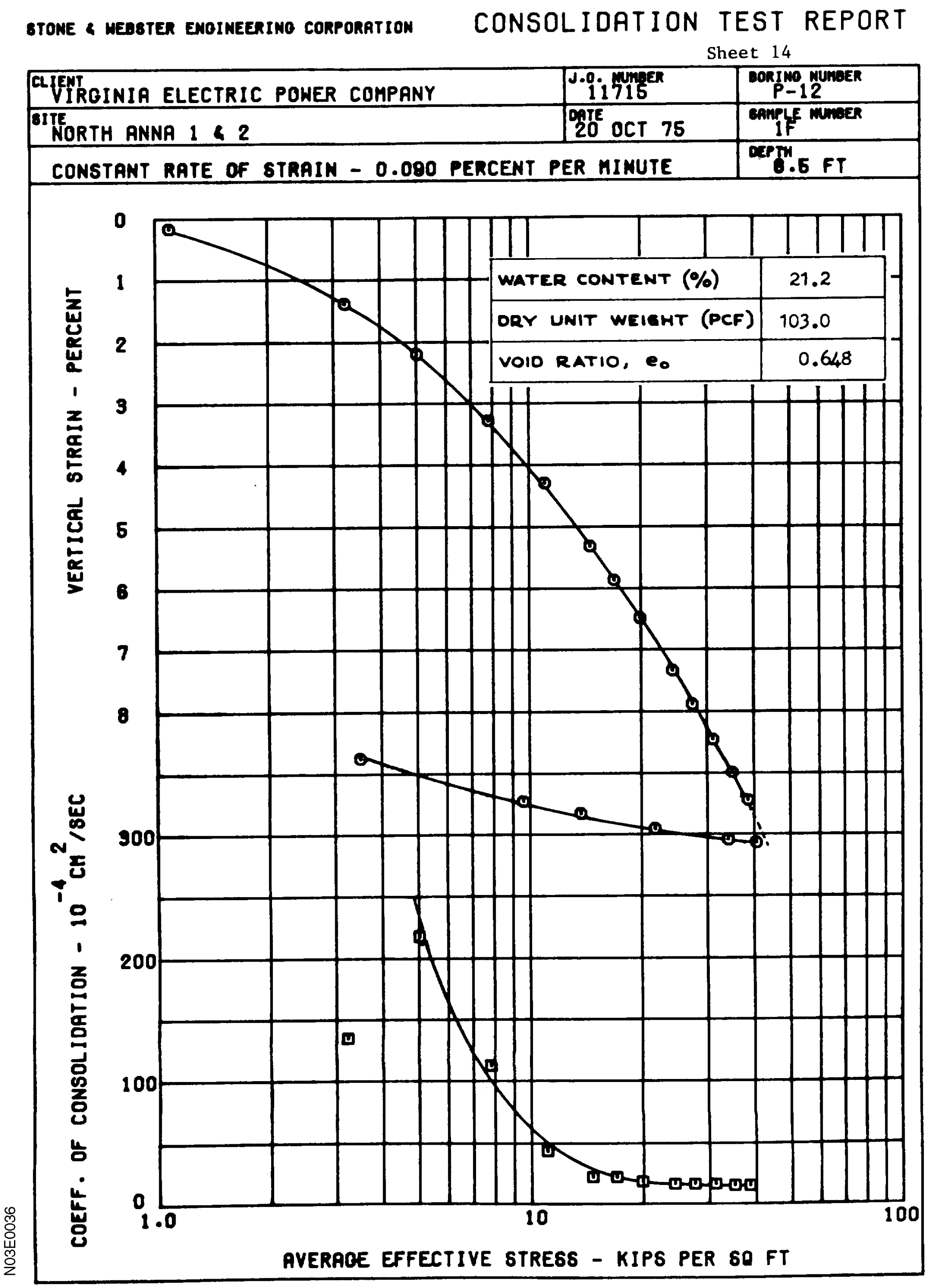


Figure 3E-12 (SHEET 15 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

CONSOLIDATION TEST REPORT

Sheet 15

CLIENT	J.O. NUMBER	BORING NUMBER
VIRGINIA ELECTRIC POWER COMPANY	11715	P-12
SITE	DATE	SAMPLE NUMBER
NORTH ANNA 1 & 2	12 NOV 75	2F
DISPLACEMENT vs. LOG TIME PLOTS		DEPTH 18.1

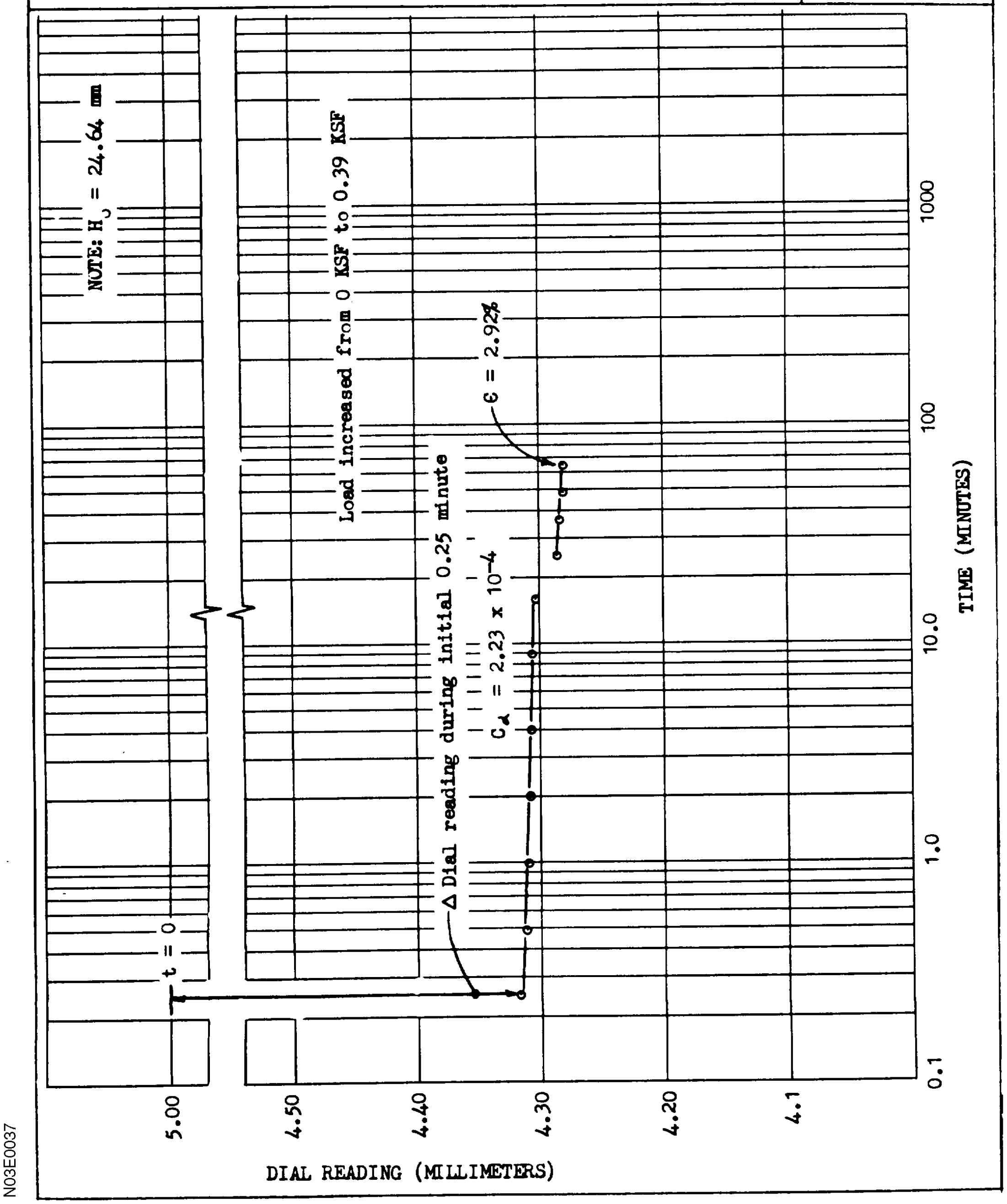
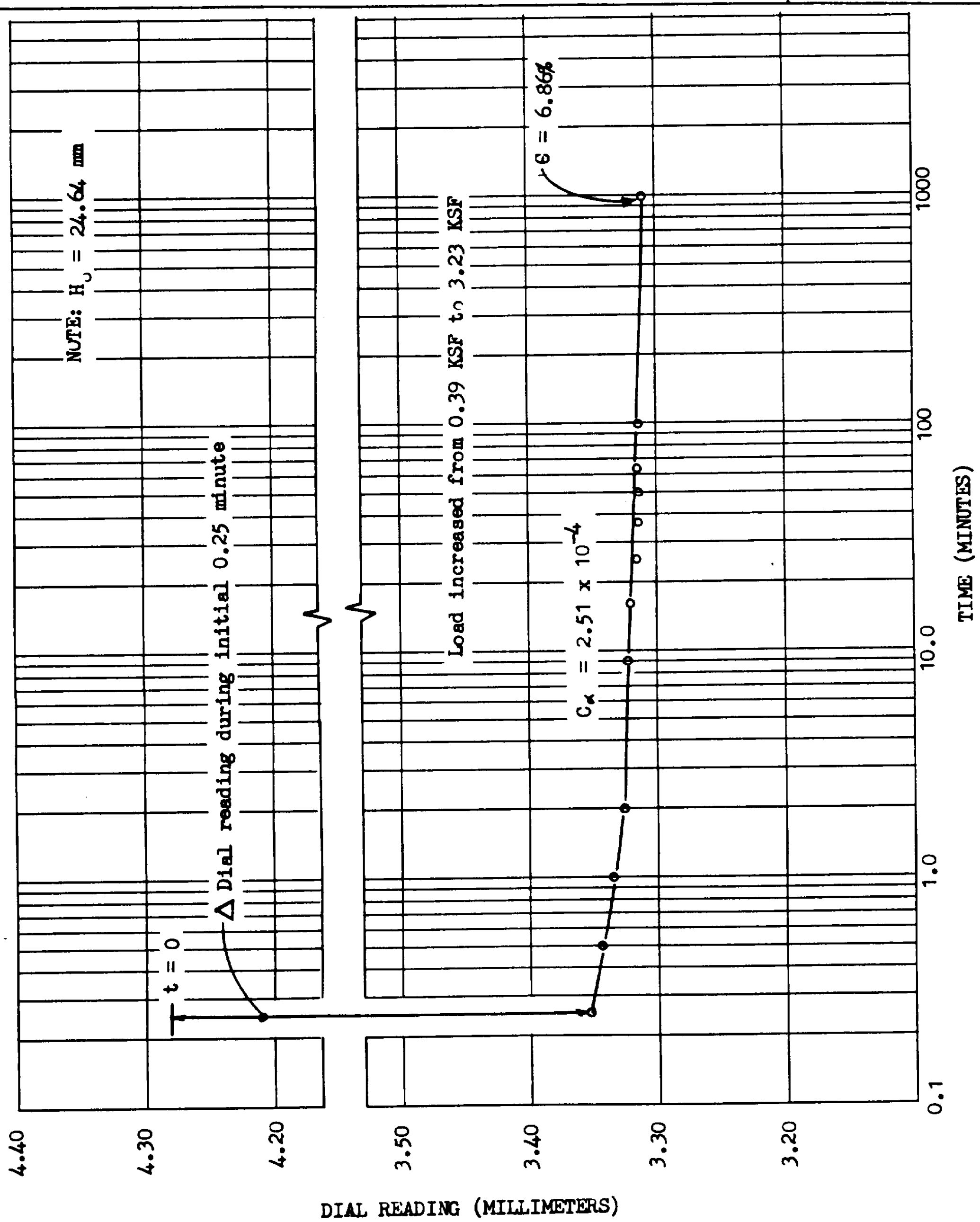


Figure 3E-12 (SHEET 16 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

CONSOLIDATION TEST REPORT
Sheet 16

CLIENT: VIRGINIA ELECTRIC POWER COMPANY	J.O. NUMBER: 11715	BORING NUMBER: P-12
SITE: NORTH ANNA 1 & 2	DATE: 12 NOV 75	SAMPLE NUMBER: 2F
DISPLACEMENT vs. LOG TIME PLOT		DEPTH: 18.1



N03E0038

Figure 3E-12 (SHEET 17 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

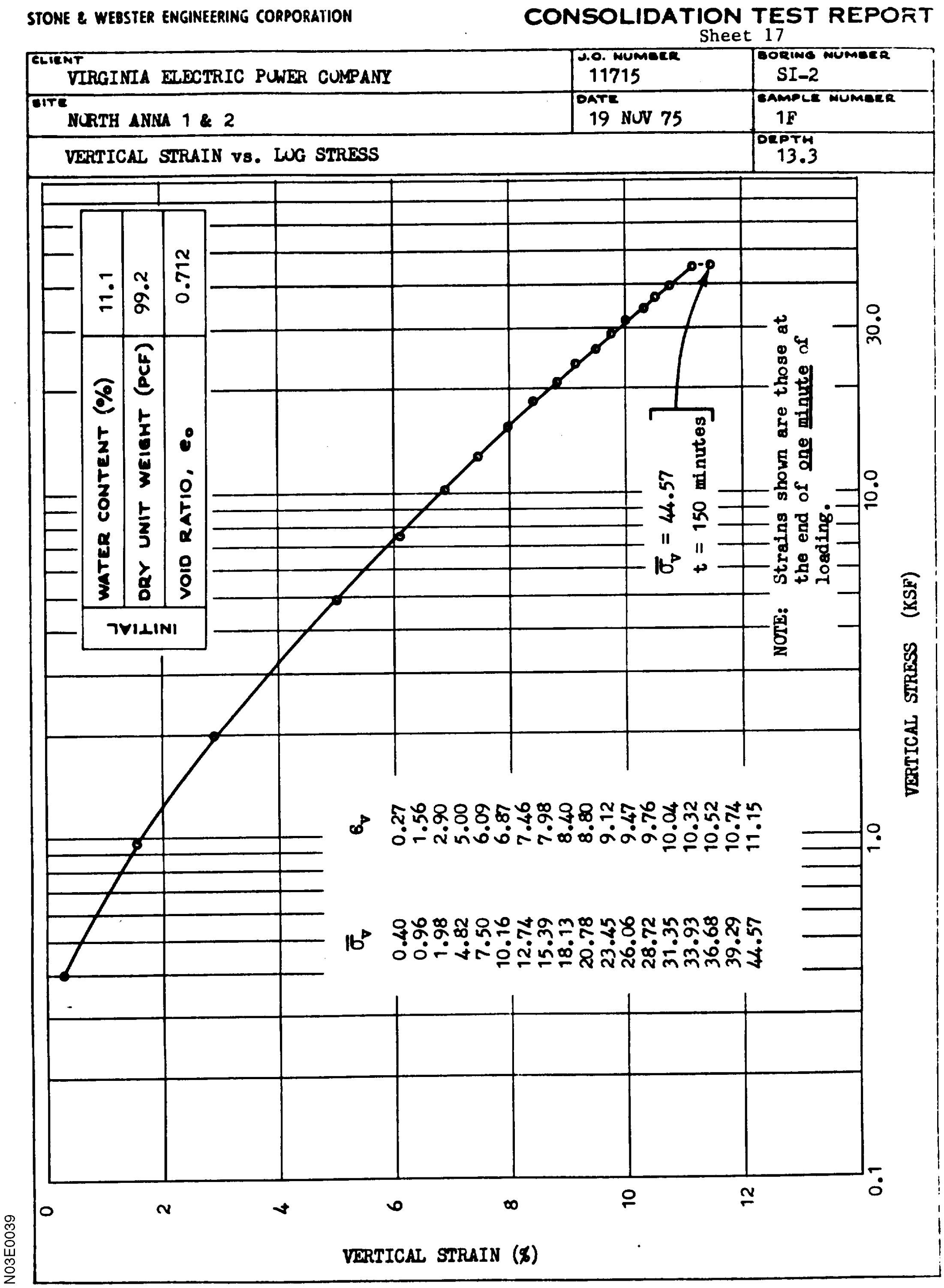


Figure 3E-12 (SHEET 18 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

CONSOLIDATION TEST REPORT

Sheet 18

CLIENT	J.O. NUMBER	BORING NUMBER
VIRGINIA ELECTRIC POWER COMPANY	11715	SWR-6
SITE: NORTH ANNA 1 & 2	DATE: 11 NOV 75	SAMPLE NUMBER: 4G
DISPLACEMENT vs. LOG TIME PLOTS		DEPTH: 58.5

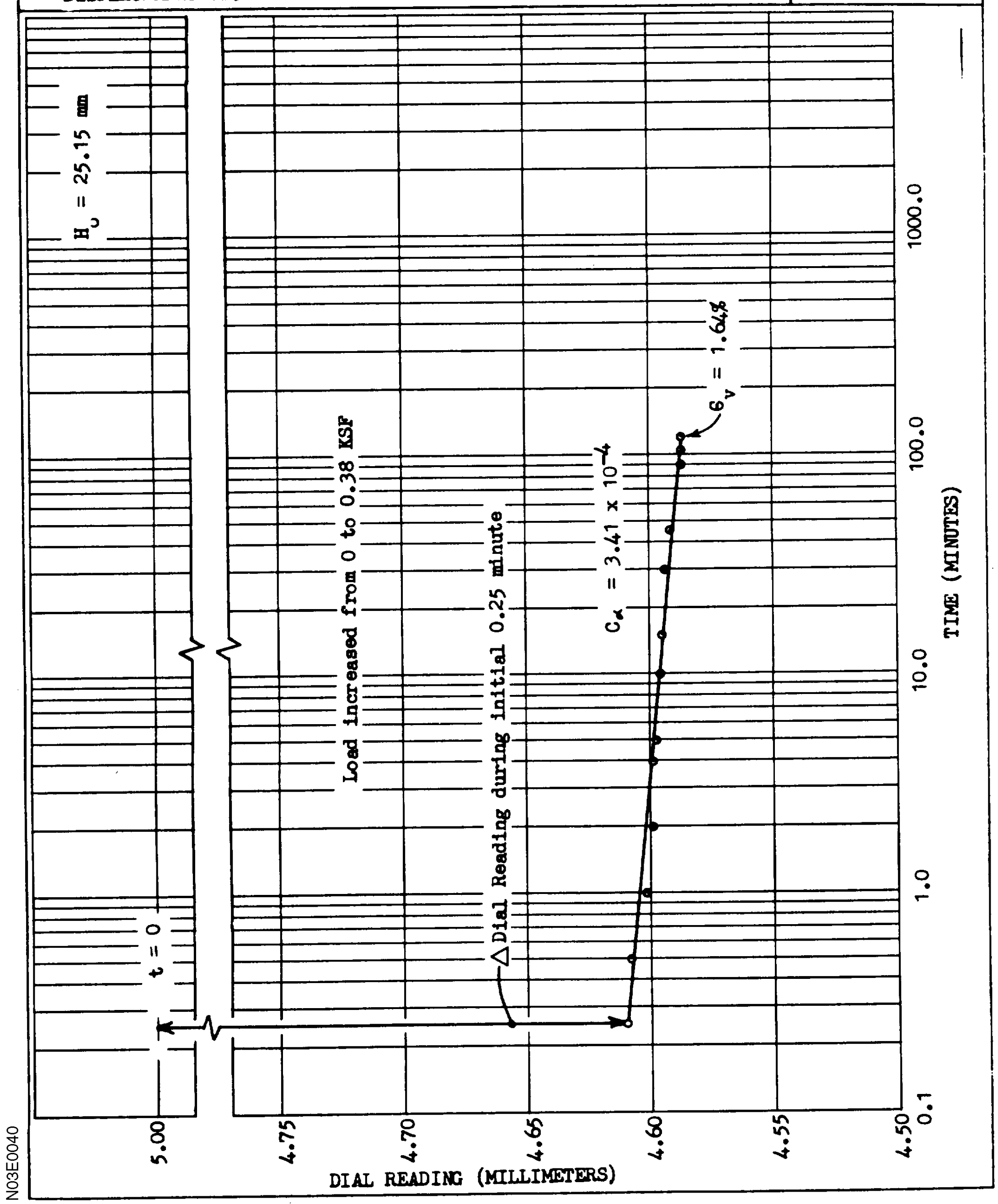


Figure 3E-12 (SHEET 19 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

CONSOLIDATION TEST REPORT
Sheet 19

CLIENT: VIRGINIA ELECTRIC POWER COMPANY	J.O. NUMBER: 11715	BORING NUMBER: SWR-6
SITE: NORTH ANNA 1 & 2	DATE: 11 NOV 75	SAMPLE NUMBER: 4G
DISPLACEMENT vs. LOG TIME PLOTS		DEPTH: 58.5

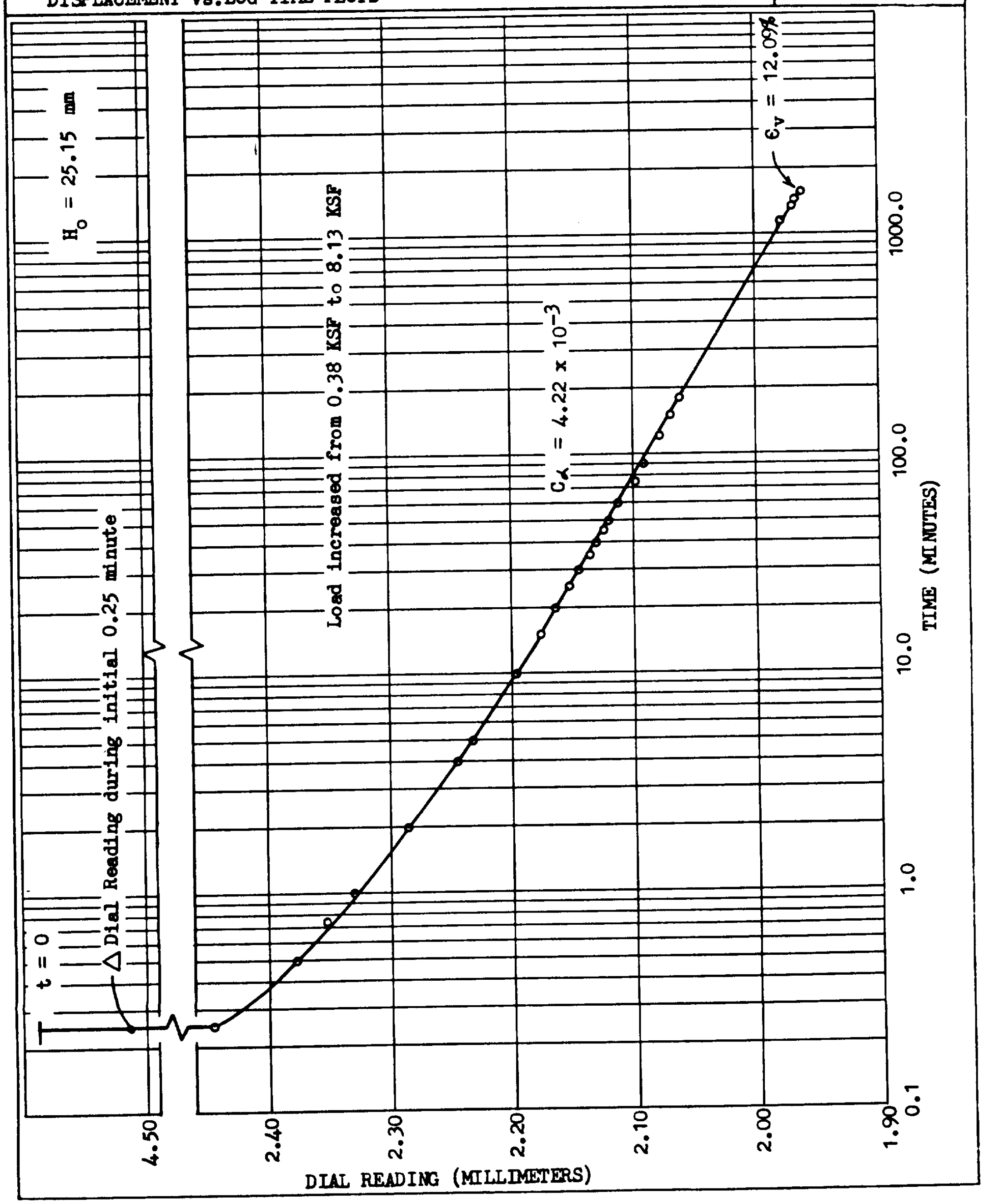


Figure 3E-12 (SHEET 20 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION **CONSOLIDATION TEST REPORT**

Sheet 20

CLIENT	J.O. NUMBER	BORING NUMBER
VIRGINIA ELECTRIC POWER COMPANY	11715	P-10
SITE: NORTH ANNA 1 & 2	DATE: 3 NOV 75	SAMPLE NUMBER: 2B
DISPLACEMENT vs. LOG TIME PLOTS		DEPTH: 22.1

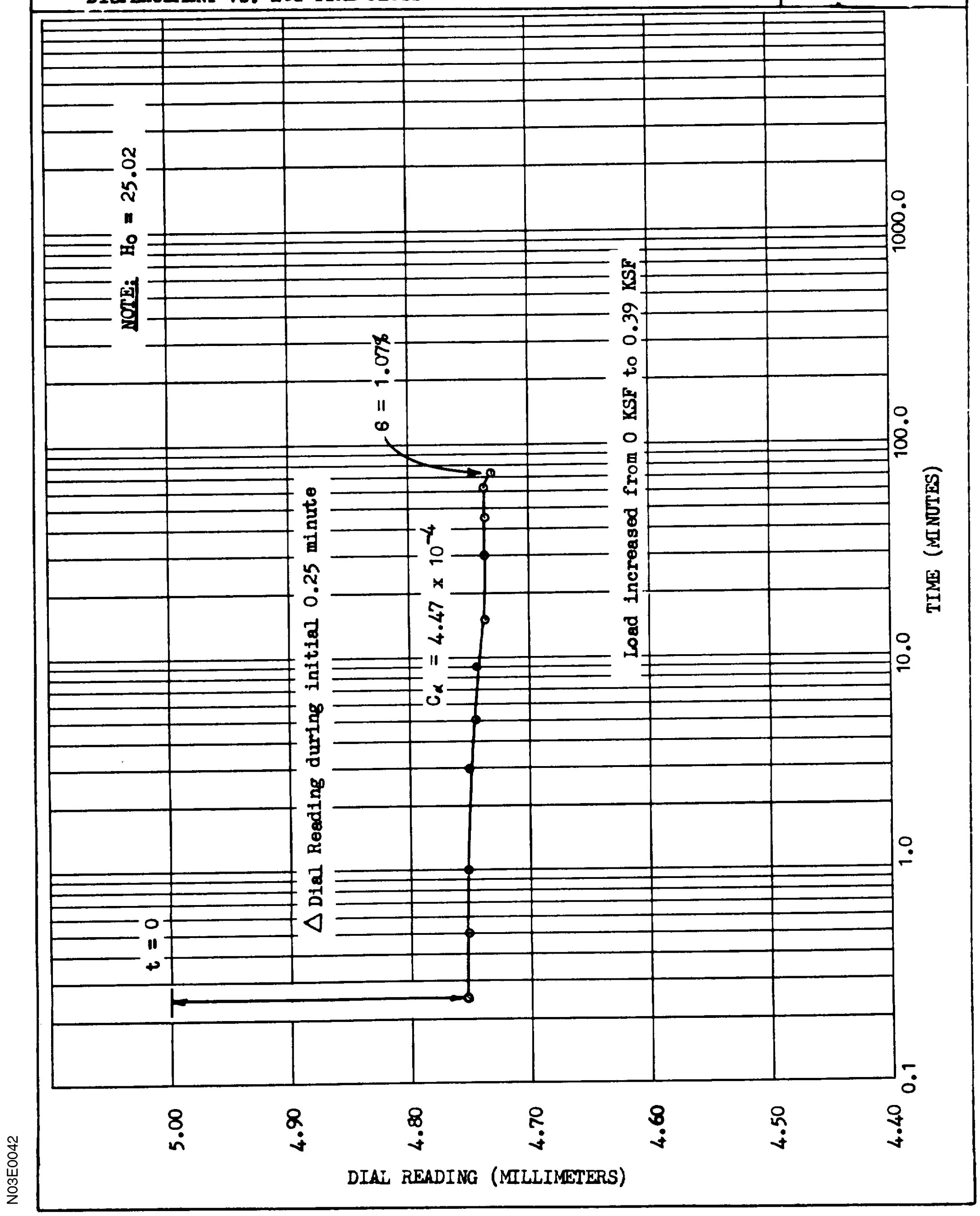


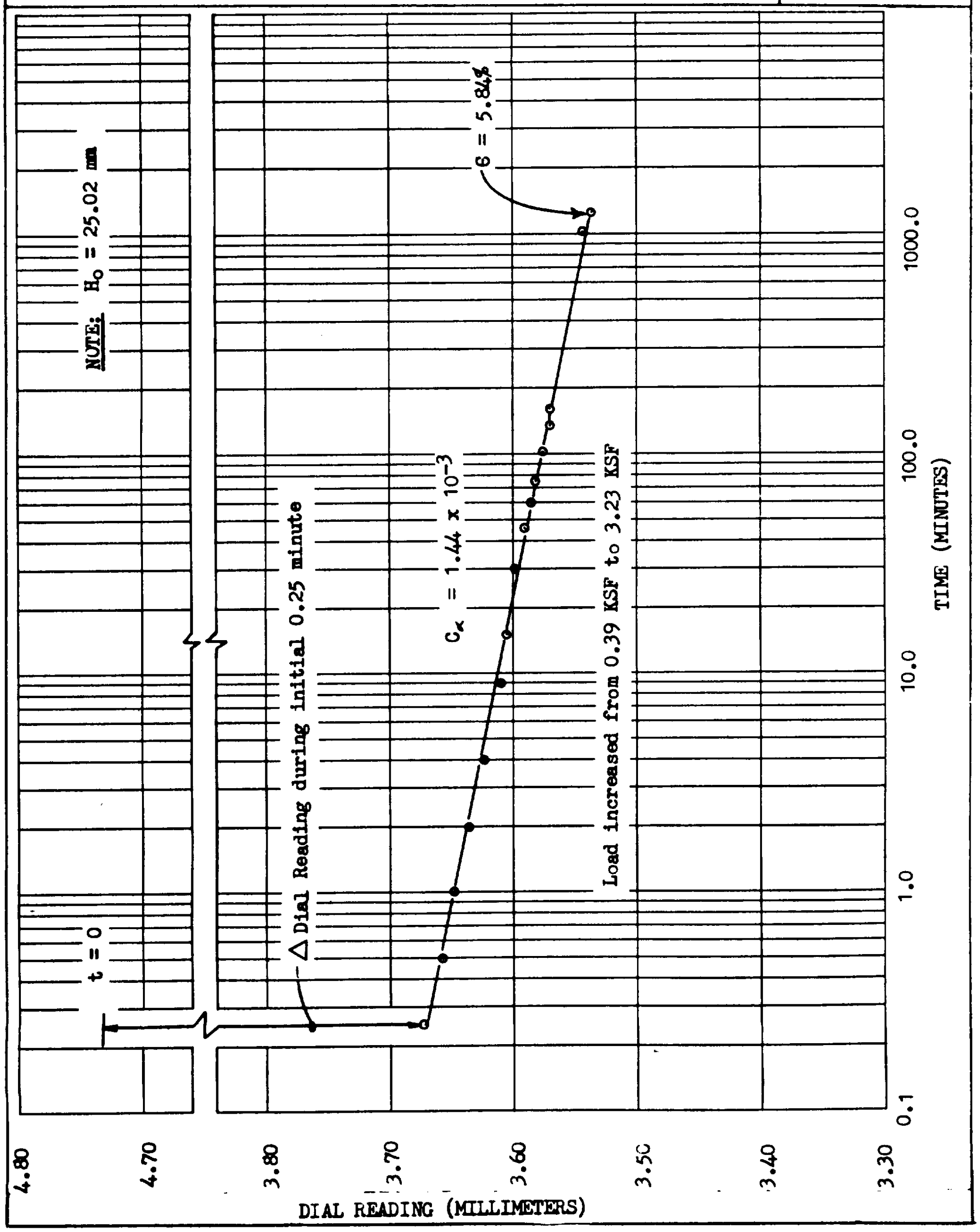
Figure 3E-12 (SHEET 21 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

CONSOLIDATION TEST REPORT

Sheet 21

CLIENT	J.O. NUMBER	BORING NUMBER
VIRGINIA ELECTRIC POWER COMPANY	11715	P-10
SITE	DATE	SAMPLE NUMBER
NORTH ANNA 1 & 2	3 NOV. 75	2B
DISPLACEMENT vs. LOG TIME PLOTS		DEPTH 22.1



N03E0043

Figure 3E-12 (SHEET 22 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

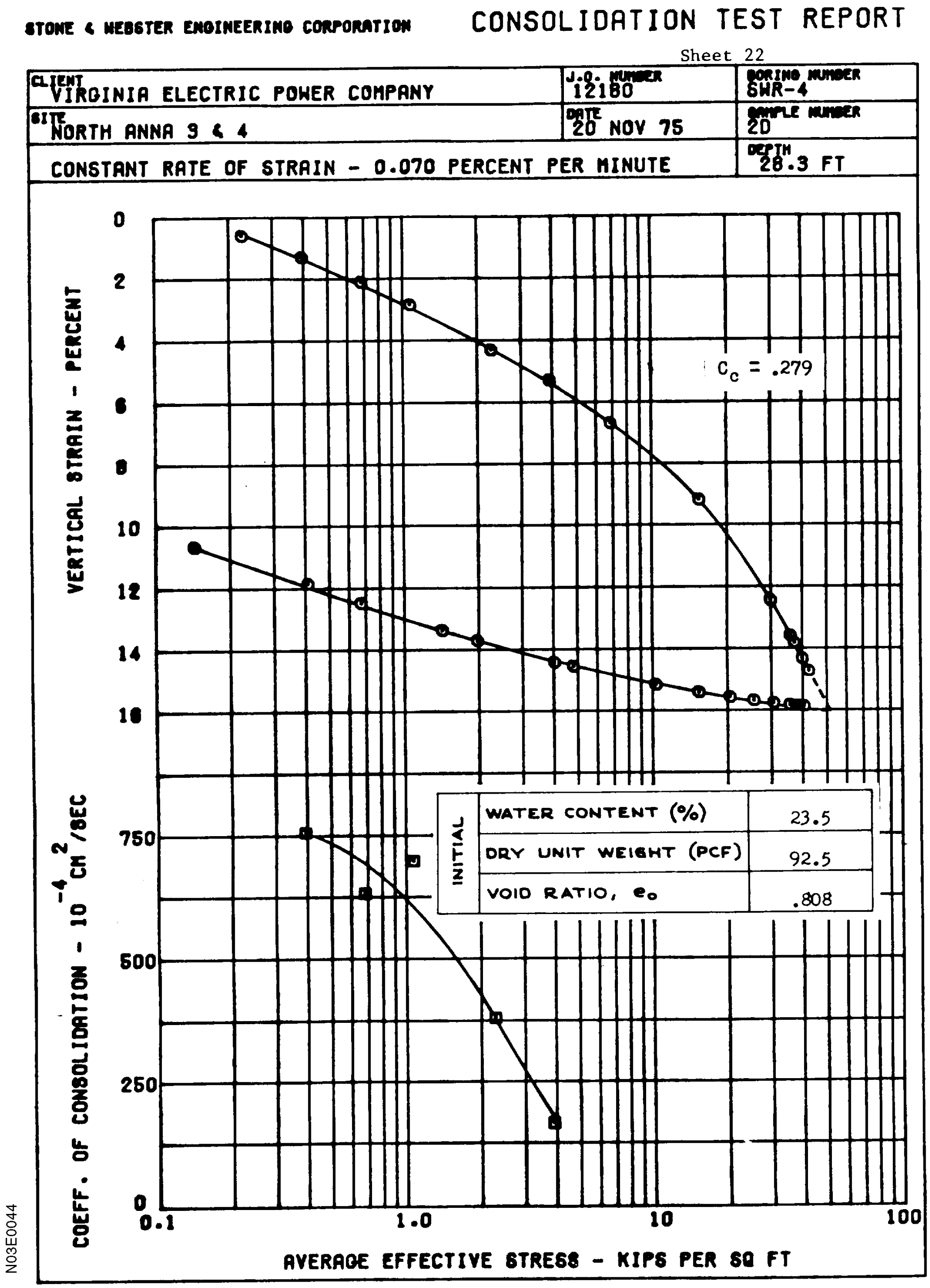
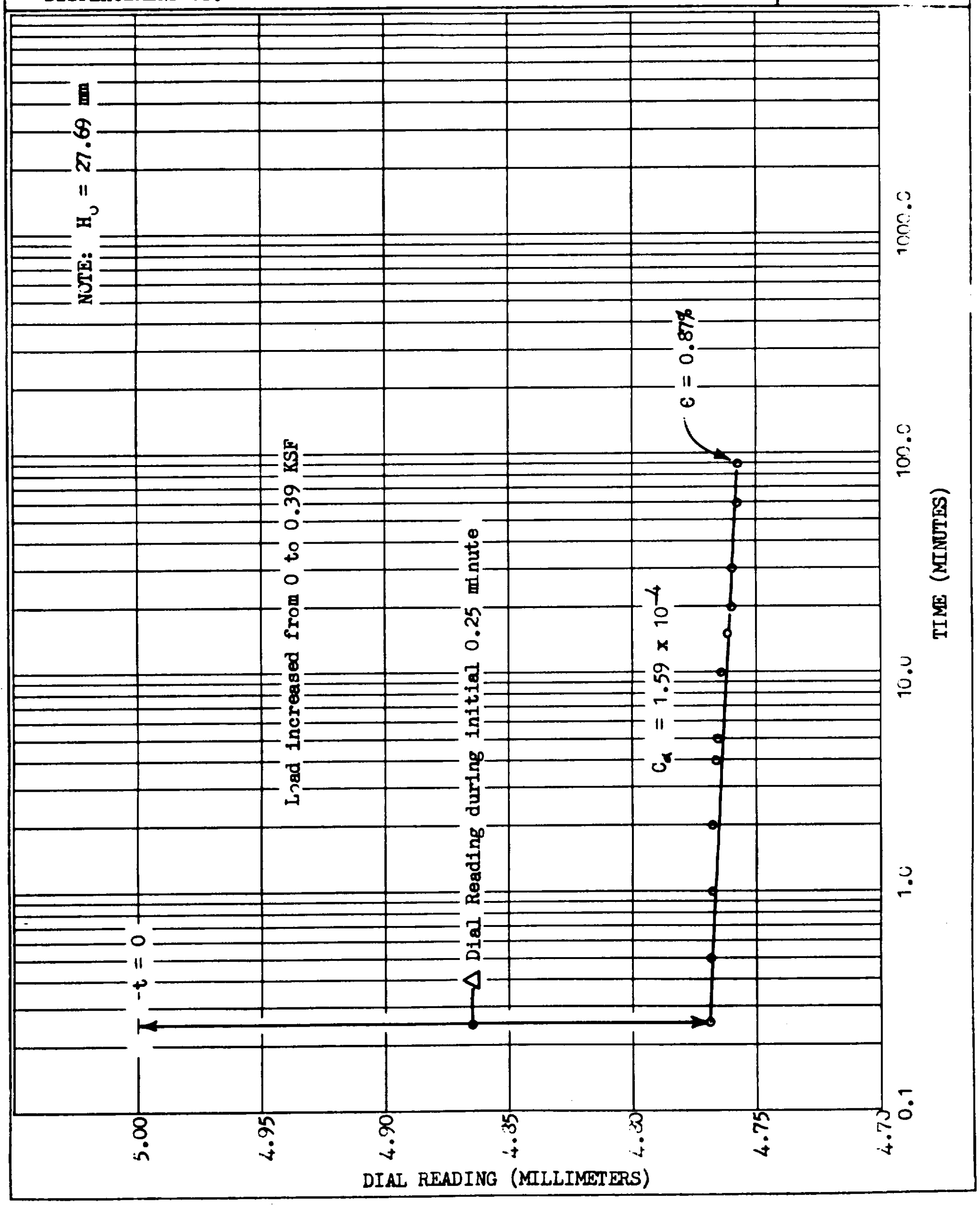


Figure 3E-12 (SHEET 23 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

CONSOLIDATION TEST REPORT
SHEET 23

CLIENT VIRGINIA ELECTRIC AND POWER COMPANY	J.O. NUMBER 11715	BORING NUMBER SWR-4
SITE NORTH ANNA 1 & 2	DATE 6 NOV 75	SAMPLE NUMBER 3E
DISPLACEMENT vs. LOG TIME PLOTS		DEPTH 39.9



N03E0045

Figure 3E-12 (SHEET 24 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

CONSOLIDATION TEST REPORT
SHEET 24

CLIENT	J.O. NUMBER	BORING NUMBER
VIRGINIA ELECTRIC AND POWER COMPANY	11715	SWR-4
SITE	**DATE**	**SAMPLE NUMBER**
NORTH ANNA 1 & 2	6 NOV 75	3E
DISPLACEMENT vs. LOG TIME PLOTS		DEPTH 39.9

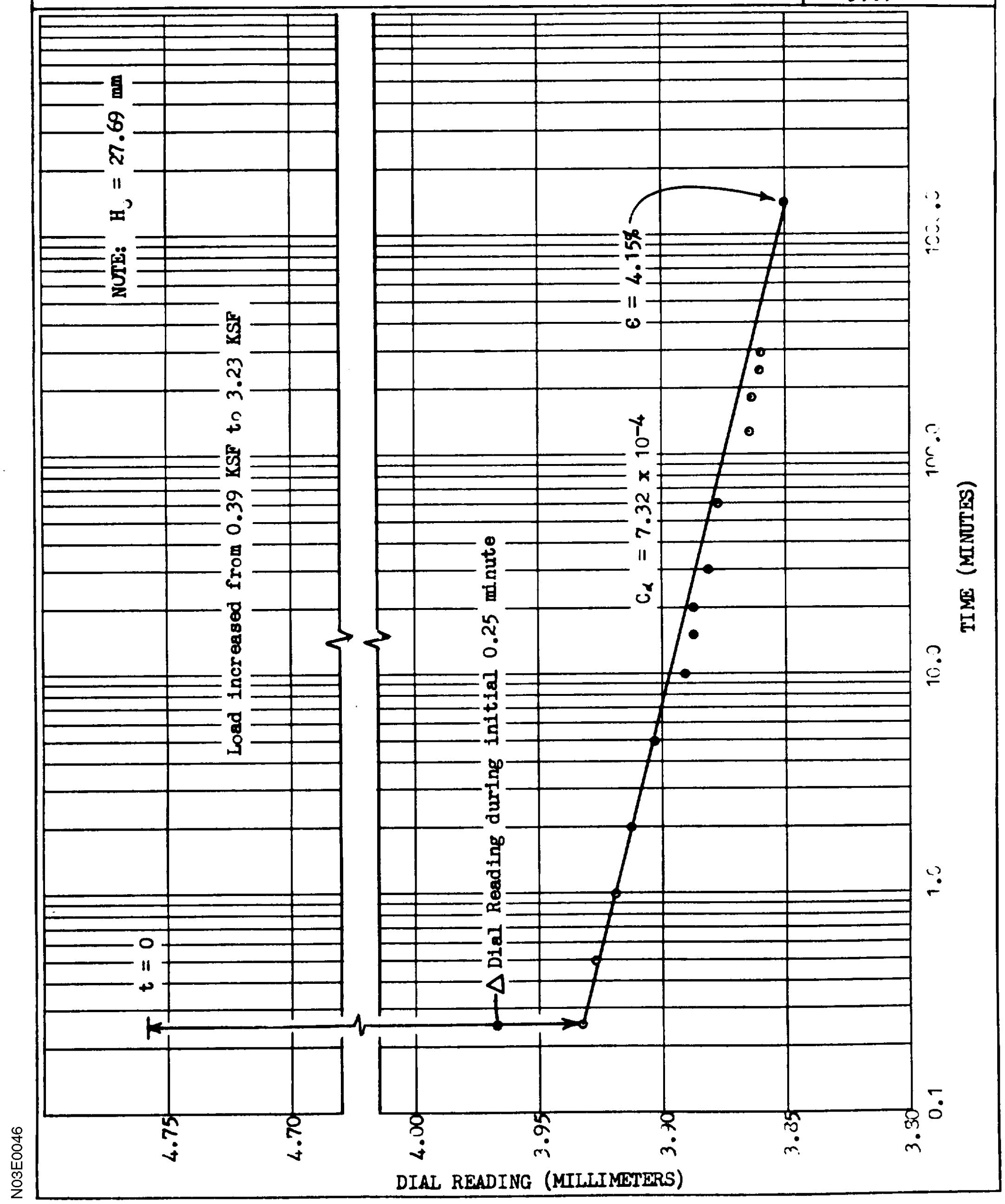


Figure 3E-12 (SHEET 25 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

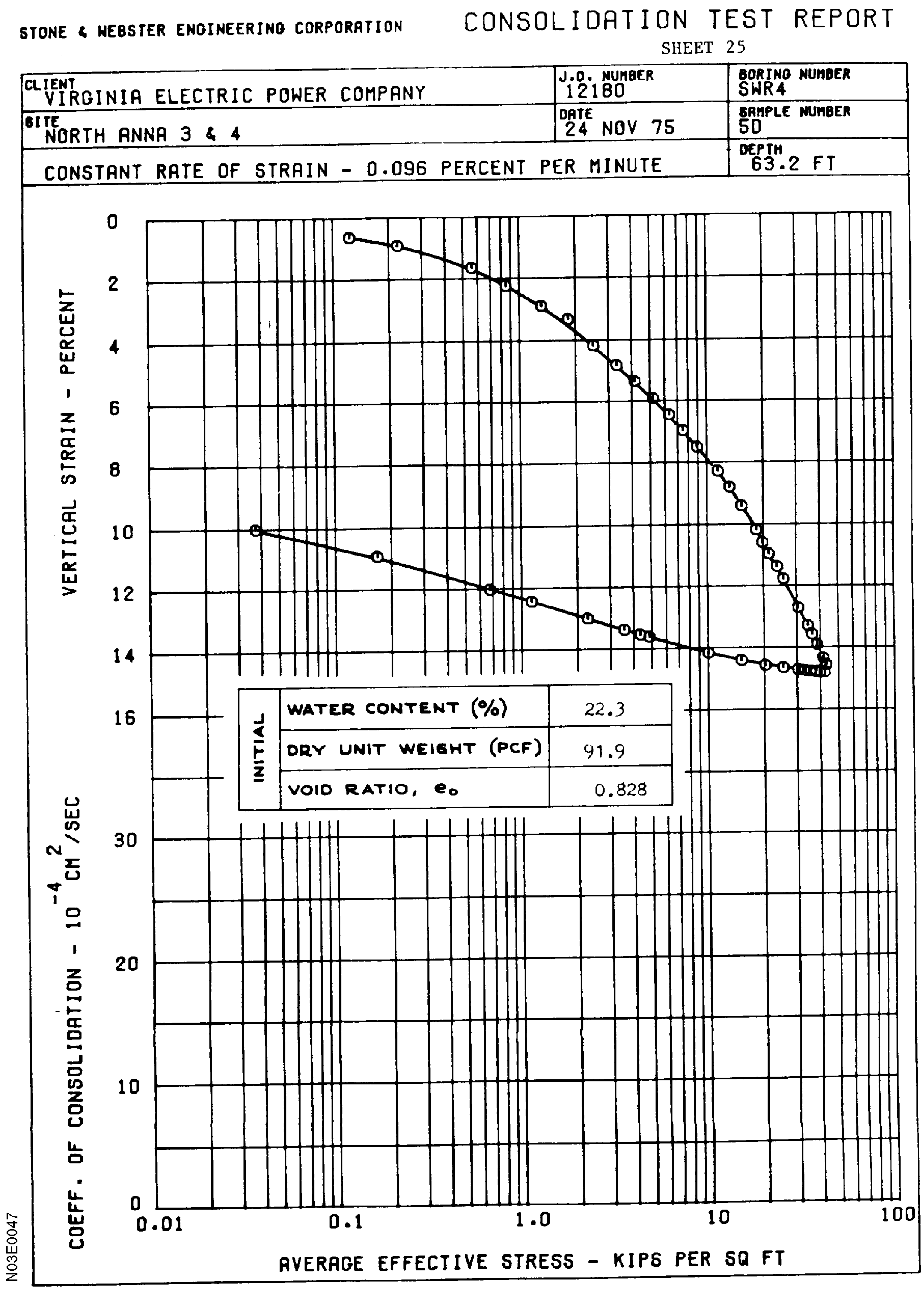


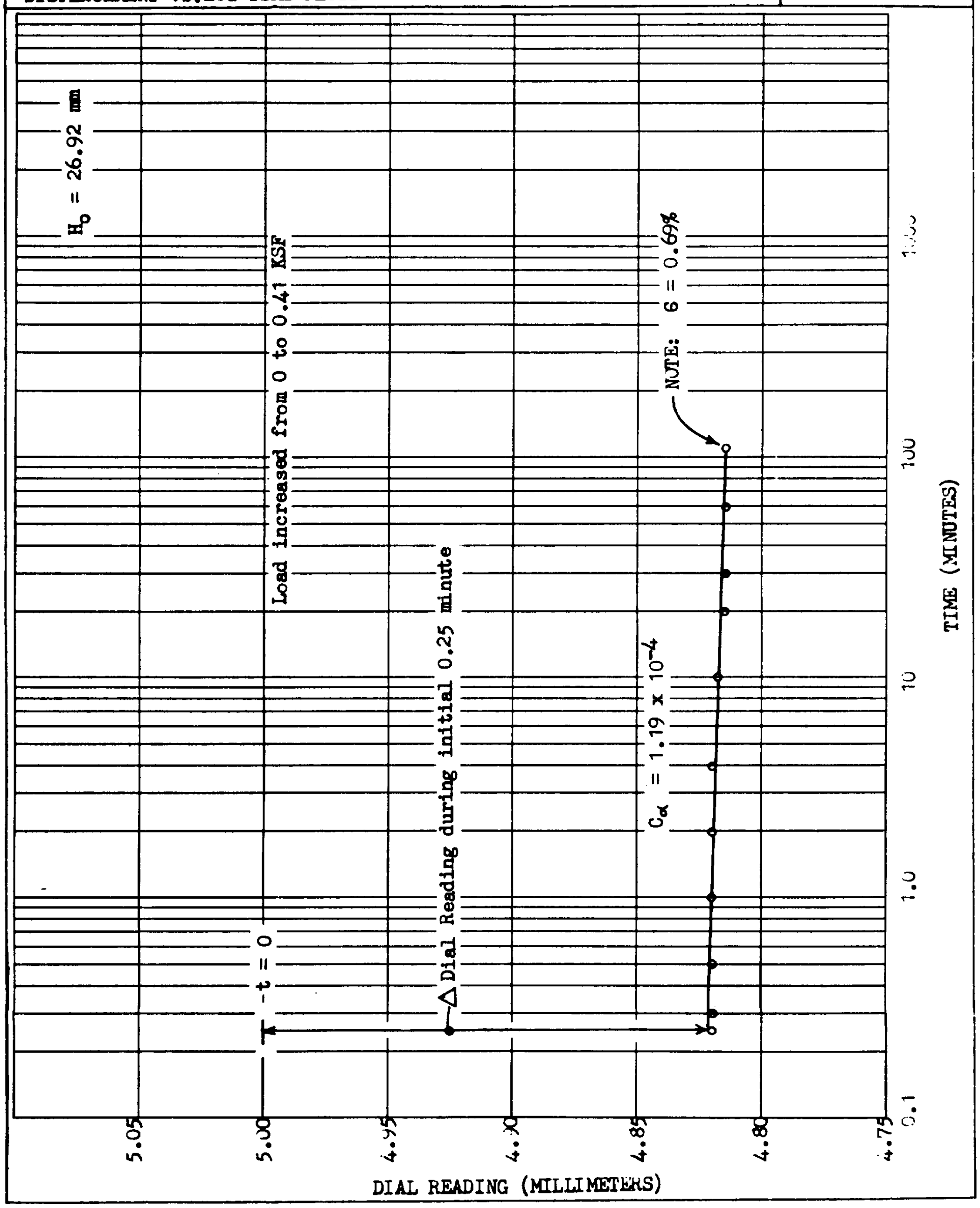
Figure 3E-12 (SHEET 26 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

CONSOLIDATION TEST REPORT

SHEET 26

CLIENT	J.O. NUMBER	BORING NUMBER
VIRGINIA ELECTRIC AND POWER COMPANY	11715	SWR-4
SITE: NORTH ANNA 1 & 2	DATE: 4 NOV 75	SAMPLE NUMBER: 6C
DISPLACEMENT vs. LOG TIME PLOTS		DEPTH: 77.5



N03E0048

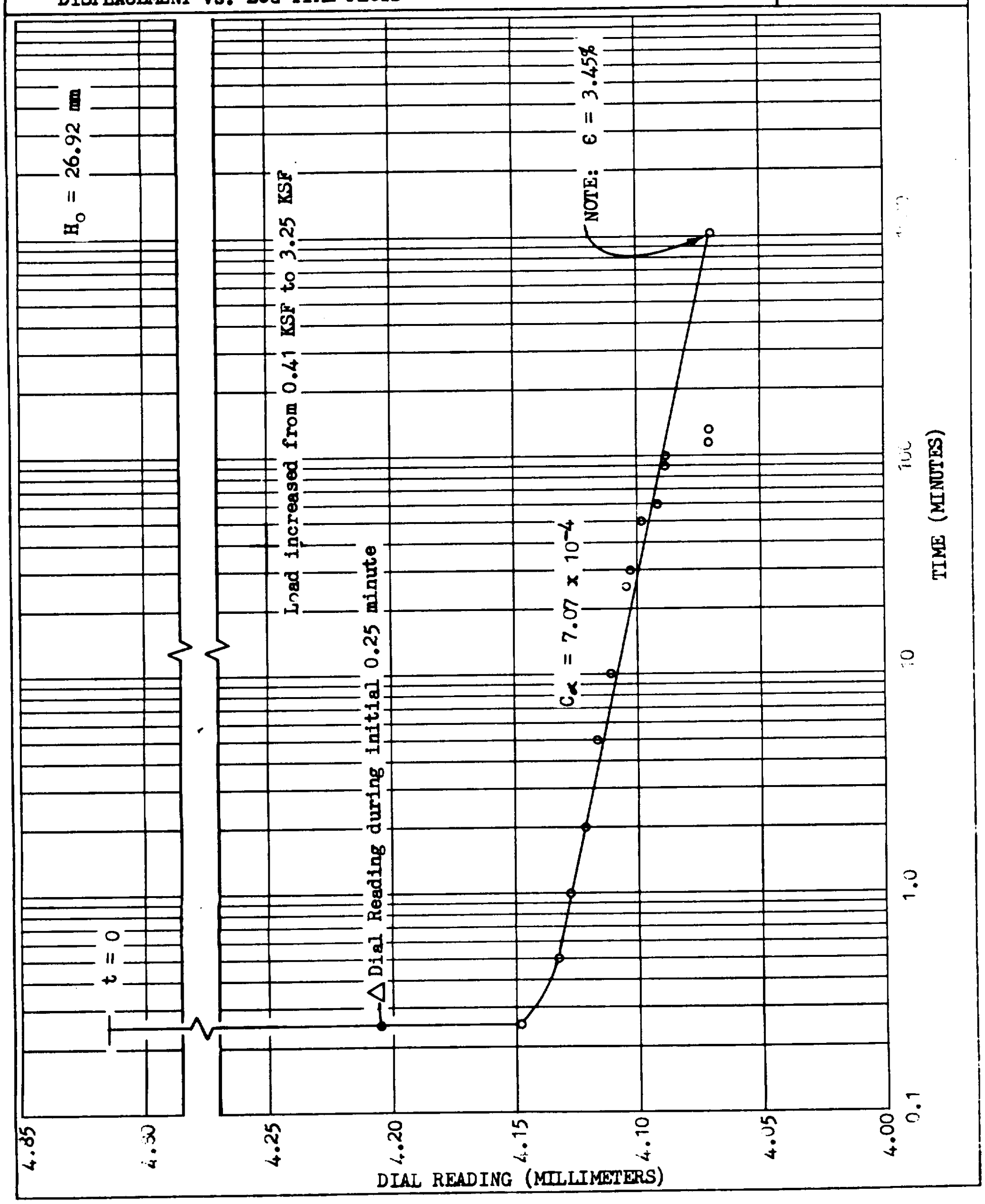
Figure 3E-12 (SHEET 27 OF 27)
CONSOLIDATION TEST REPORT
STONE AND WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

CONSOLIDATION TEST REPORT

SHEET 27

CLIENT	J.O. NUMBER	BORING NUMBER
VIRGINIA ELECTRIC AND POWER COMPANY	11715	SWR-4
SITE	DATE	SAMPLE NUMBER
NORTH ANNA 1&2	4 NOV 75	6C
		DEPTH
DISPLACEMENT vs. LOG TIME PLOTS		77.5



N03E0049

Figure 3E-13
EFFECTIVE STRESS CIRCLES CONSOLIDATED-UNDRAINED
TRIAXIAL TESTS: DIKE FILL MATERIAL

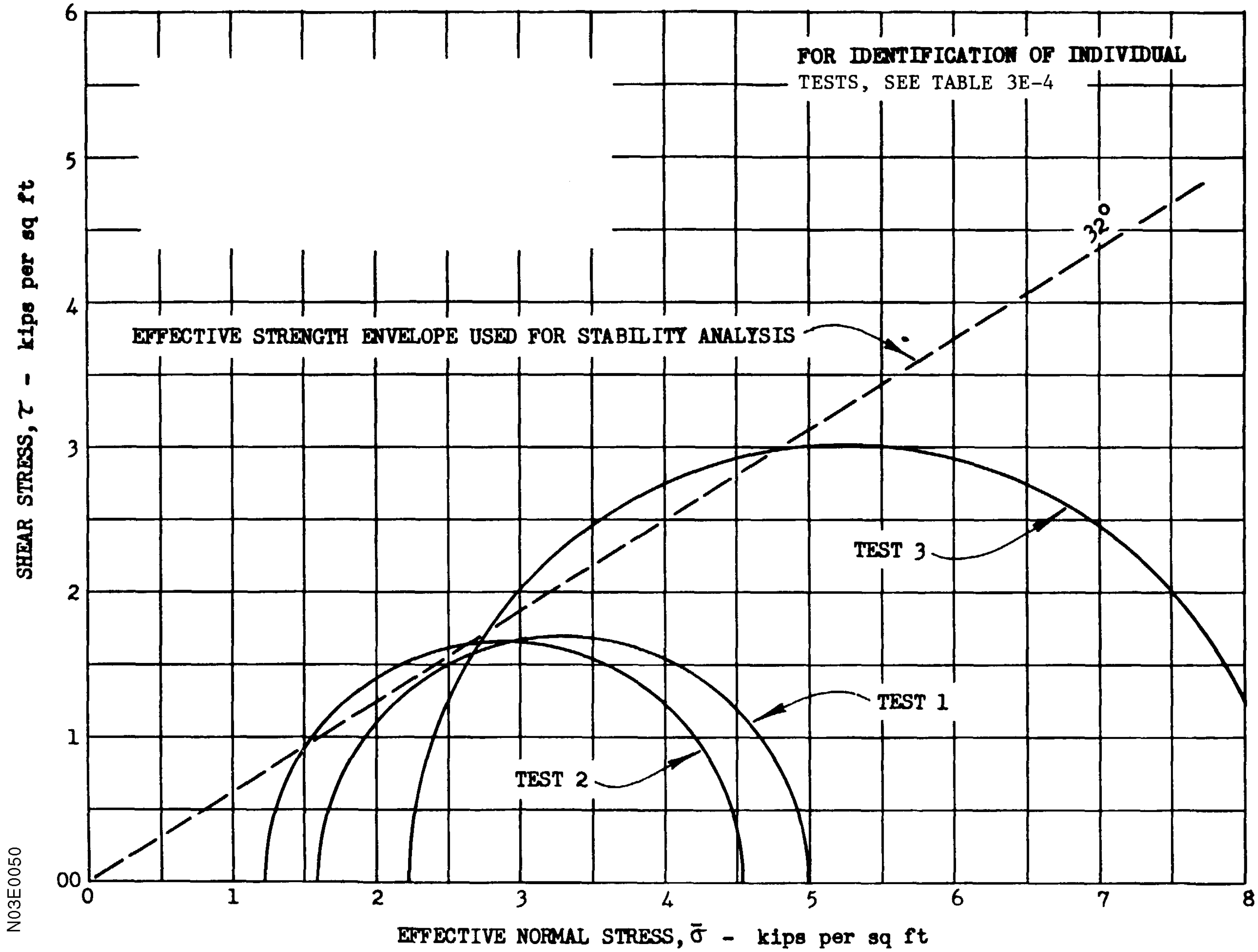


Figure 3E-14
EFFECTIVE STRESS CIRCLES CONSOLIDATED-UNDRAINED
TRIAXIAL TESTS: FOUNDATION MATERIAL

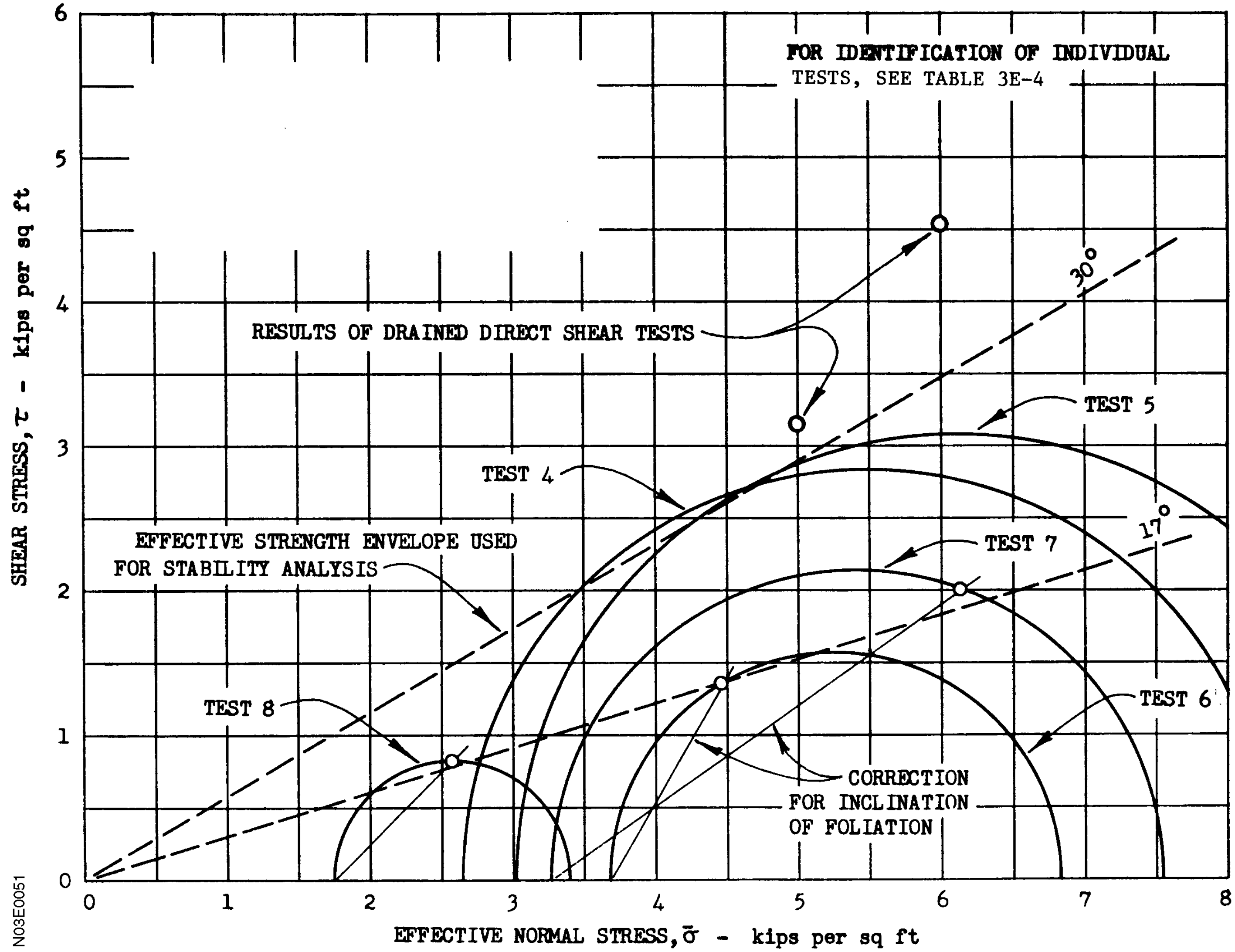


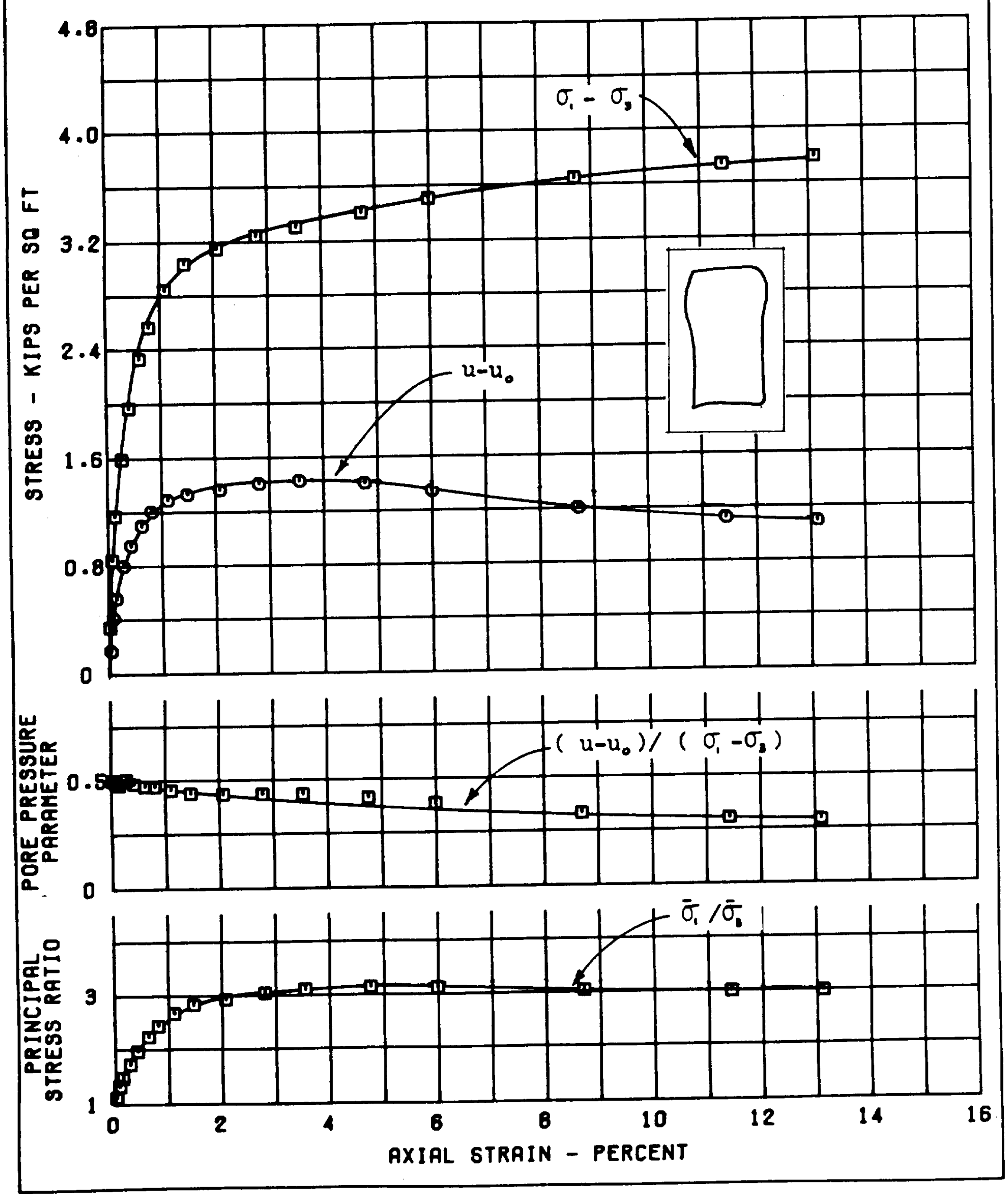
Figure 3E-15 (SHEET 1 OF 8)
TRIAXIAL TEST REPORT STONE & WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

TRIAXIAL TEST REPORT

SHEET 1

CLIENT VIRGINIA ELECTRIC POWER COMPANY	J.O. NUMBER 11715	BORING NUMBER P12
SITE NORTH ANNA 1 & 2	DATE 4 NOV 75	SAMPLE NUMBER 1D
EFFECTIVE CONSOLIDATION PRESSURE: 3.00 KIPS PER SQ FT		DEPTH 7.9 FT



N03E0052

Figure 3E-15 (SHEET 2 OF 8)
TRIAXIAL TEST REPORT STONE & WEBSTER ENGINEERING CORPORATION

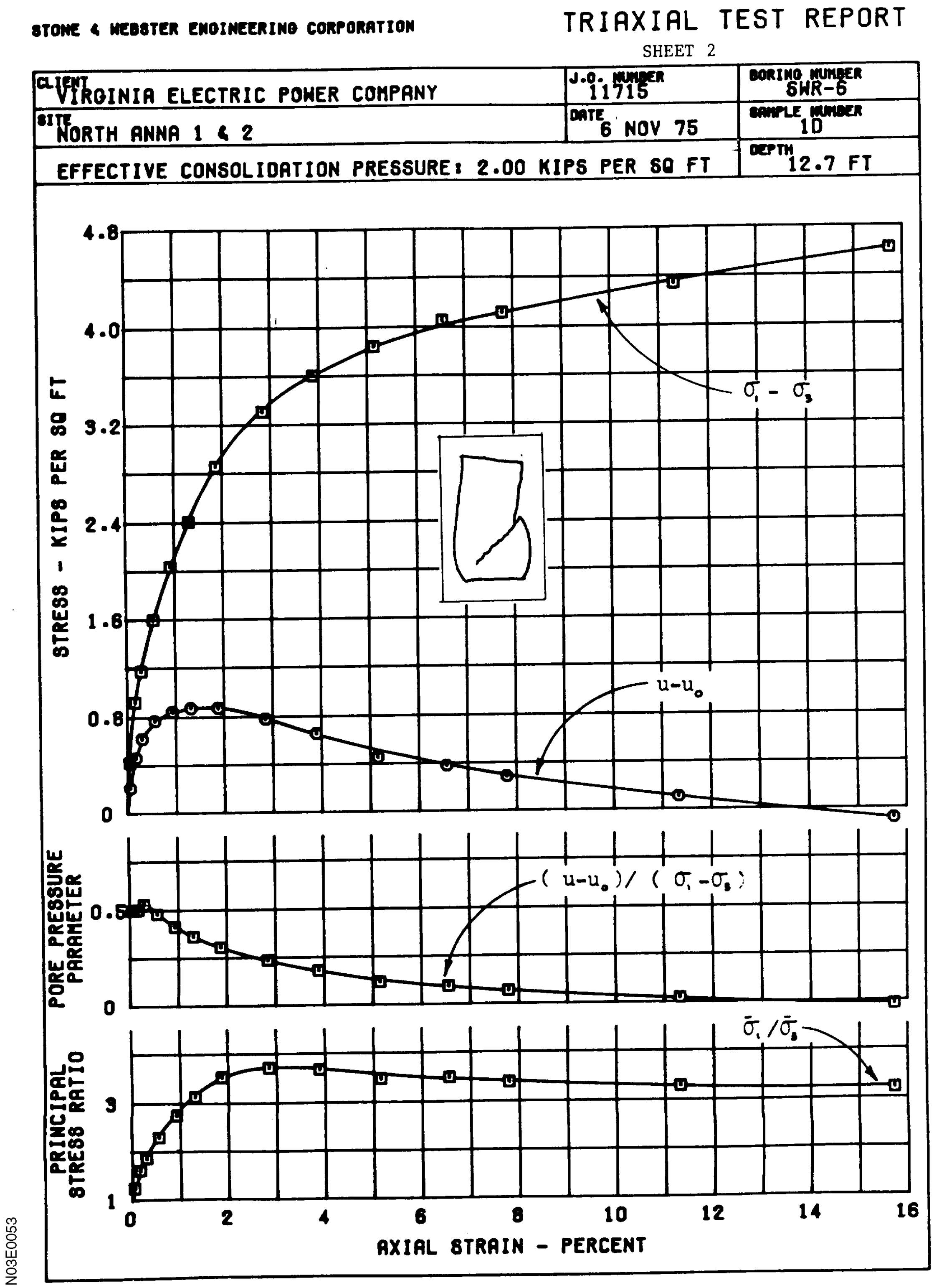


Figure 3E-15 (SHEET 3 OF 8)
TRIAXIAL TEST REPORT STONE & WEBSTER ENGINEERING CORPORATION

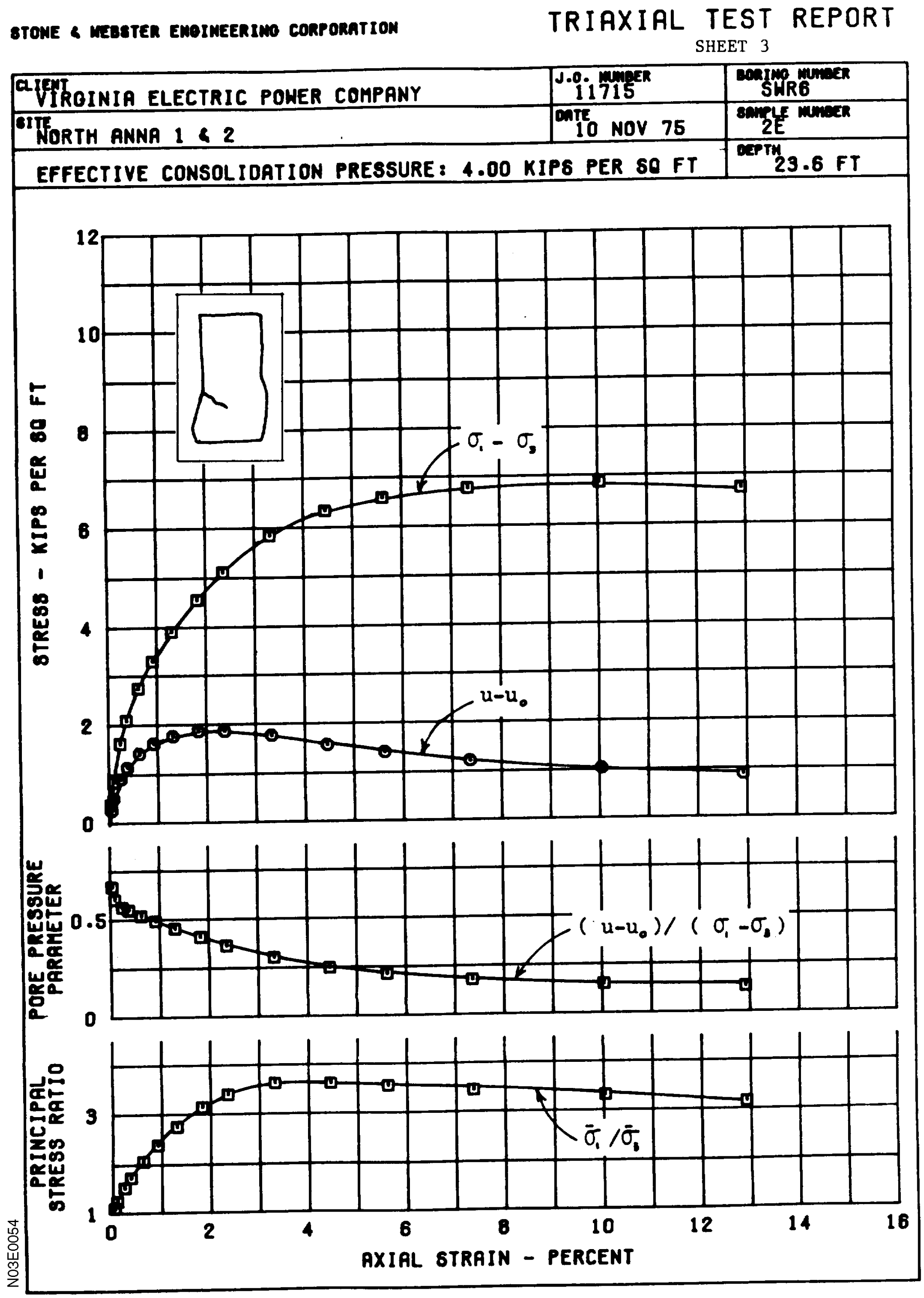


Figure 3E-15 (SHEET4 OF 8)
TRIAXIAL TEST REPORT STONE & WEBSTER ENGINEERING CORPORATION

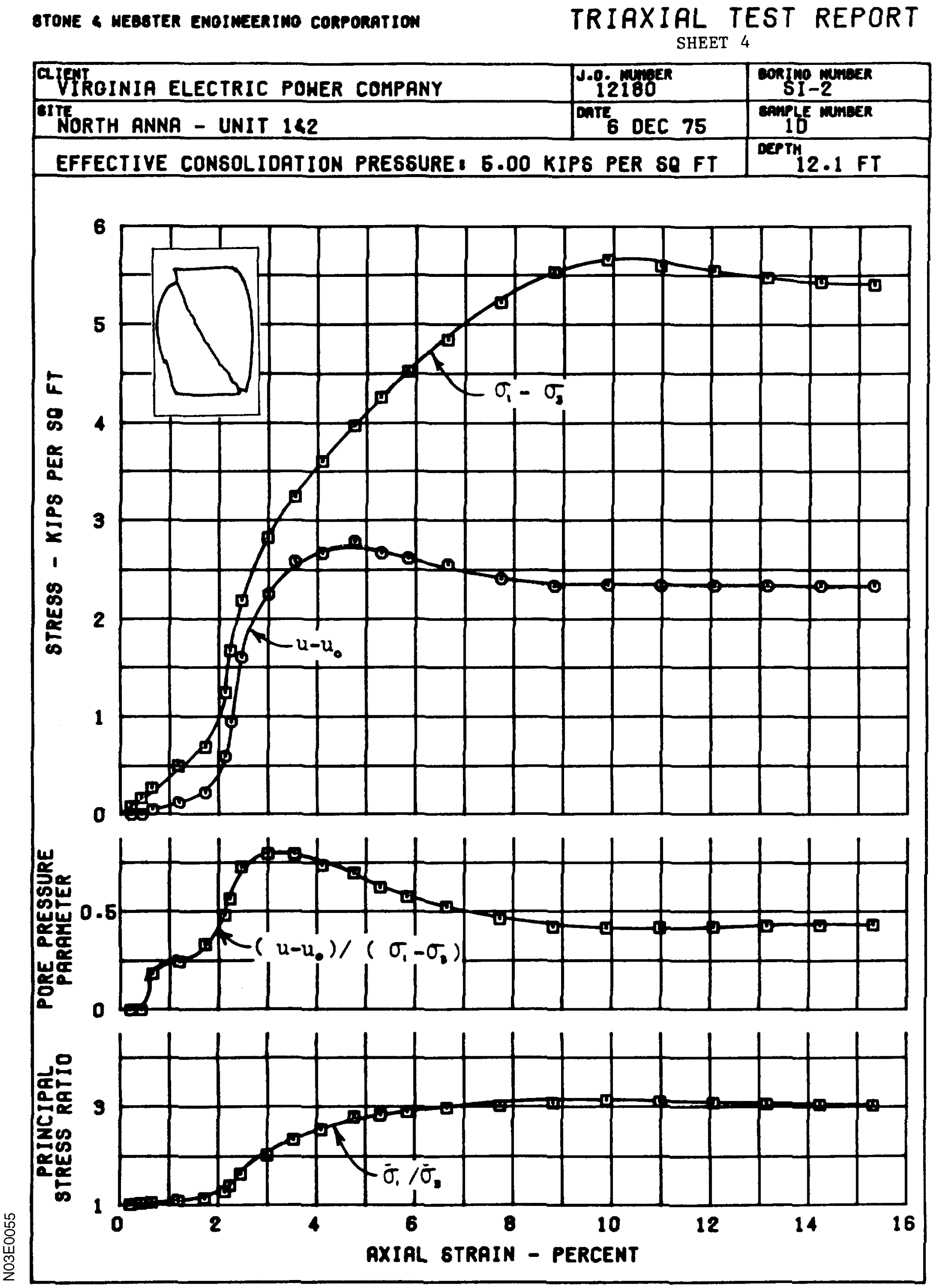


Figure 3E-15 (SHEET 5 OF 8)
TRIAXIAL TEST REPORT STONE & WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

TRIAXIAL TEST REPORT

SHEET 5

CLIENT VIRGINIA ELECTRIC POWER COMPANY	J.O. NUMBER 11716	BORING NUMBER SWR4
SITE NORTH ANNA 1 & 2	DATE 3 DEC 75	SAMPLE NUMBER 3D
EFFECTIVE CONSOLIDATION PRESSURE: 4.50 KIPS PER SQ FT		DEPTH 42.2 FT

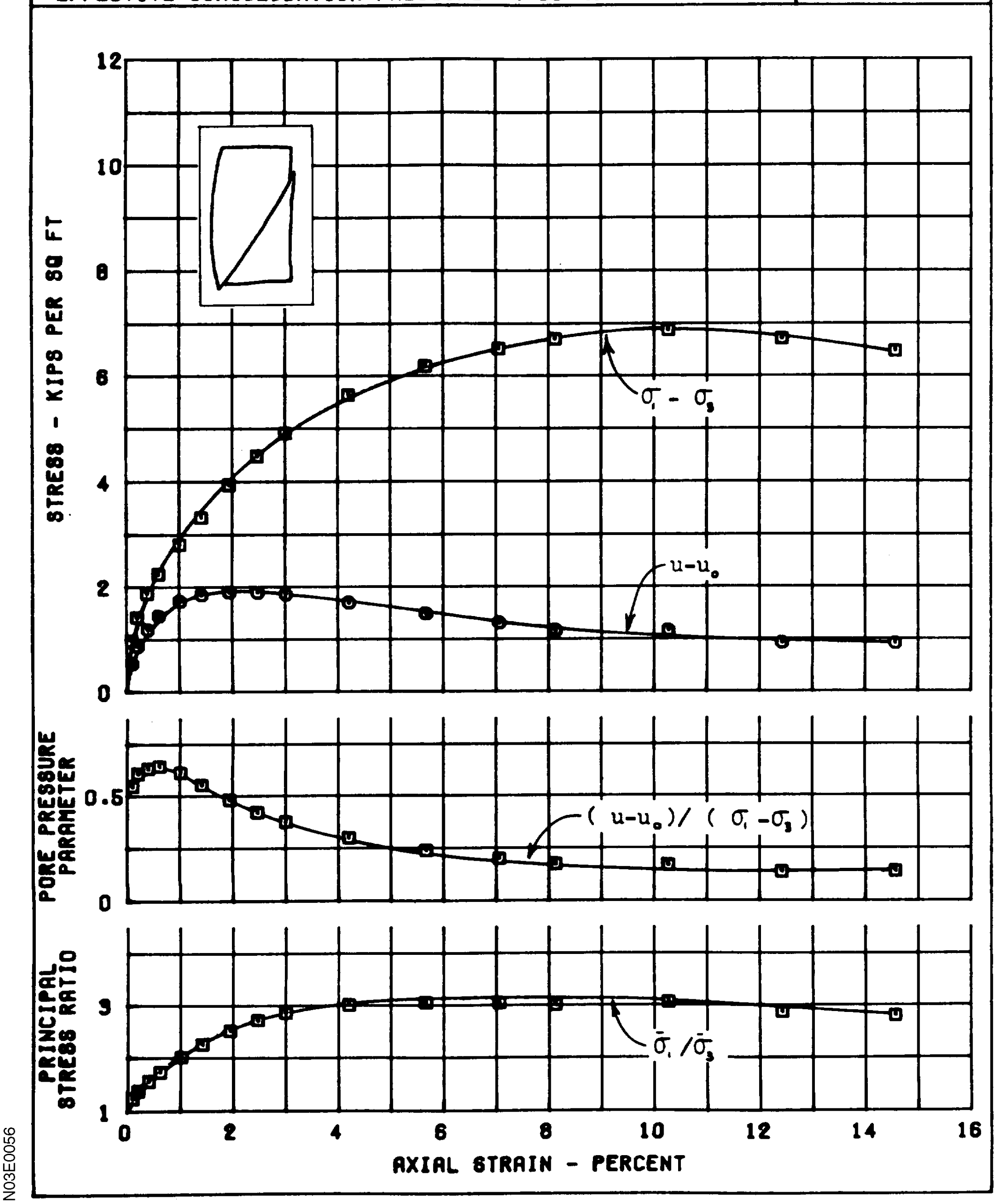


Figure 3E-15 (SHEET 6 OF 8)
TRIAXIAL TEST REPORT STONE & WEBSTER ENGINEERING CORPORATION

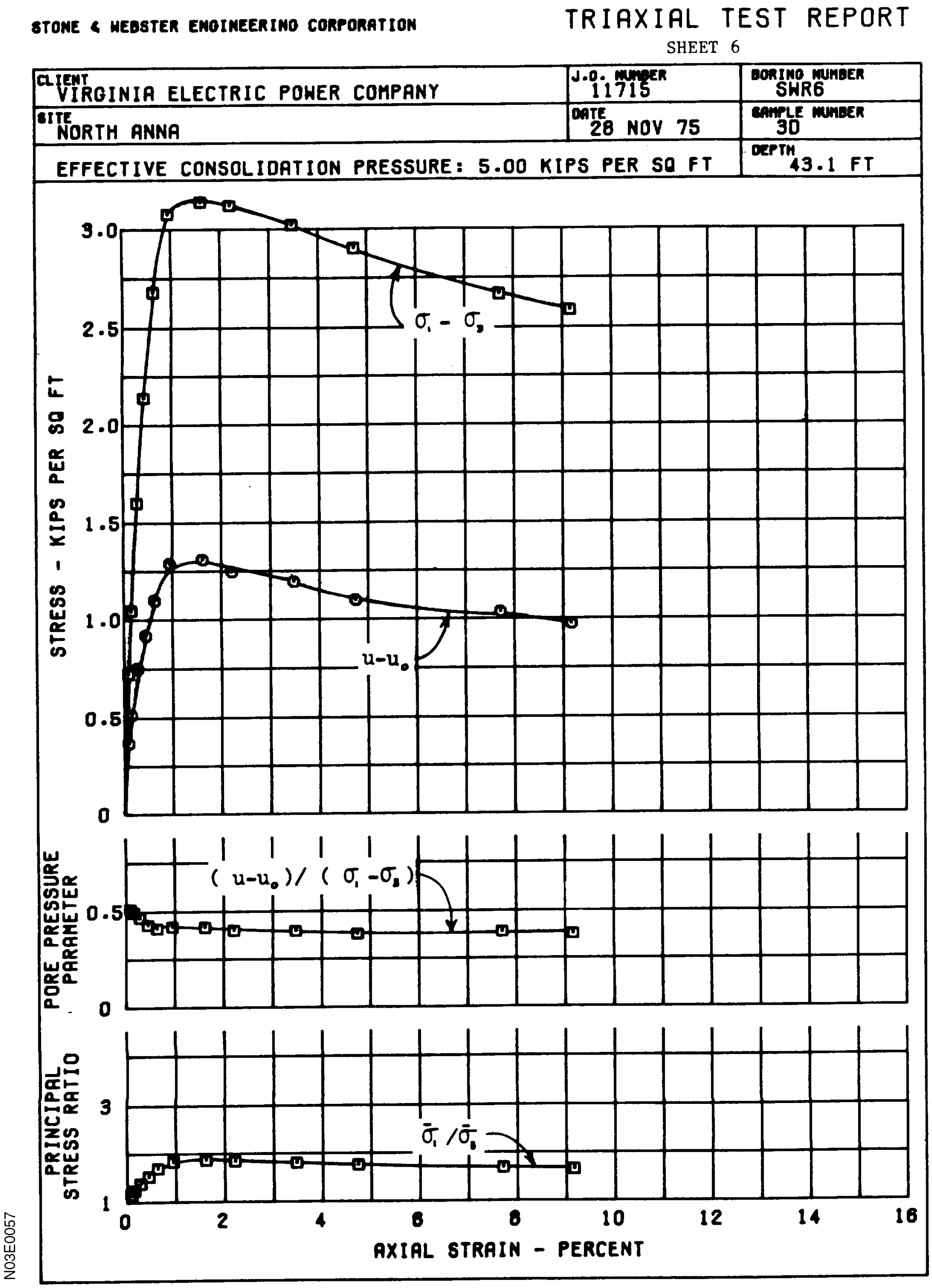


Figure 3E-15 (SHEET 7 OF 8)
TRIAXIAL TEST REPORT STONE & WEBSTER ENGINEERING CORPORATION

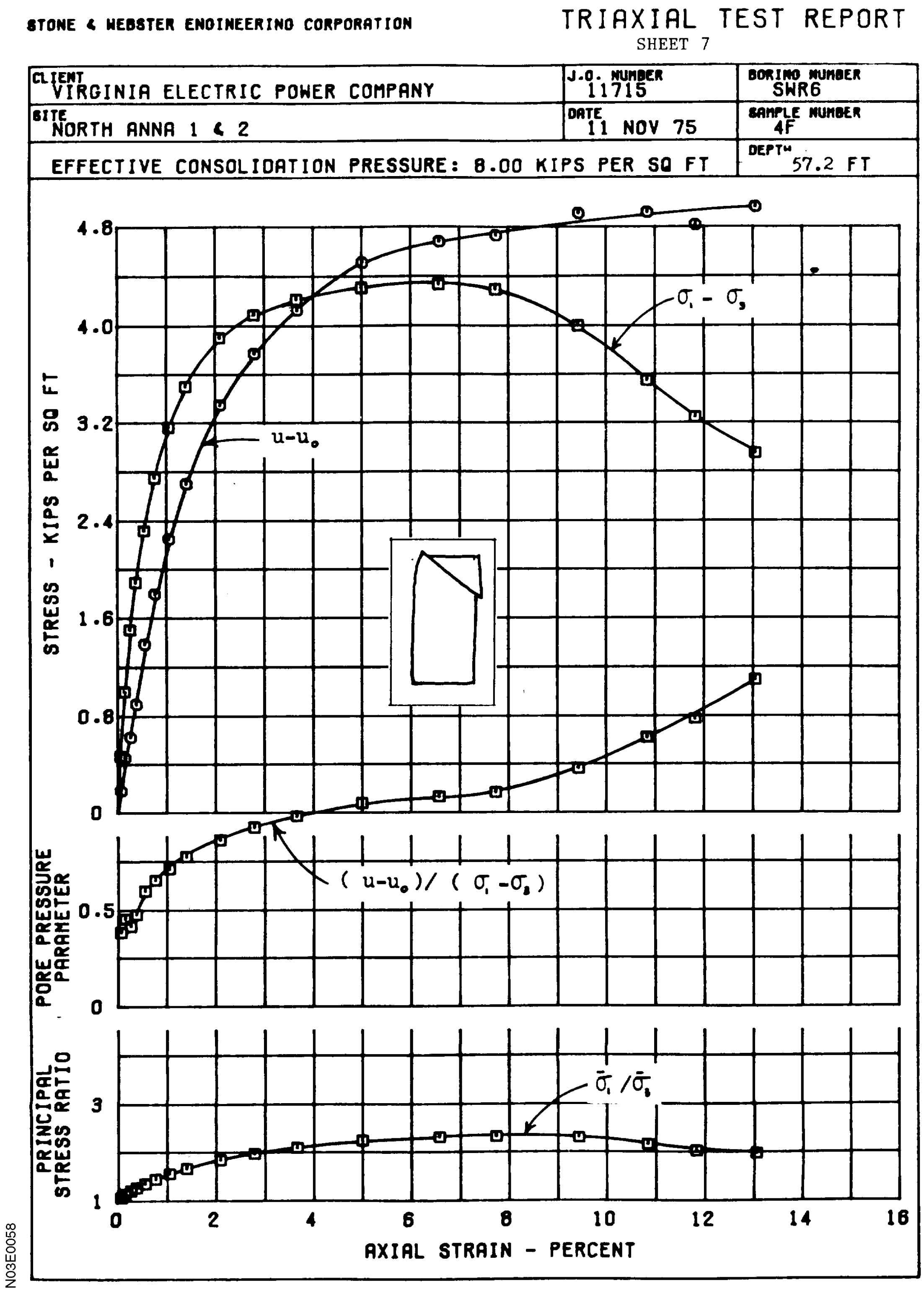


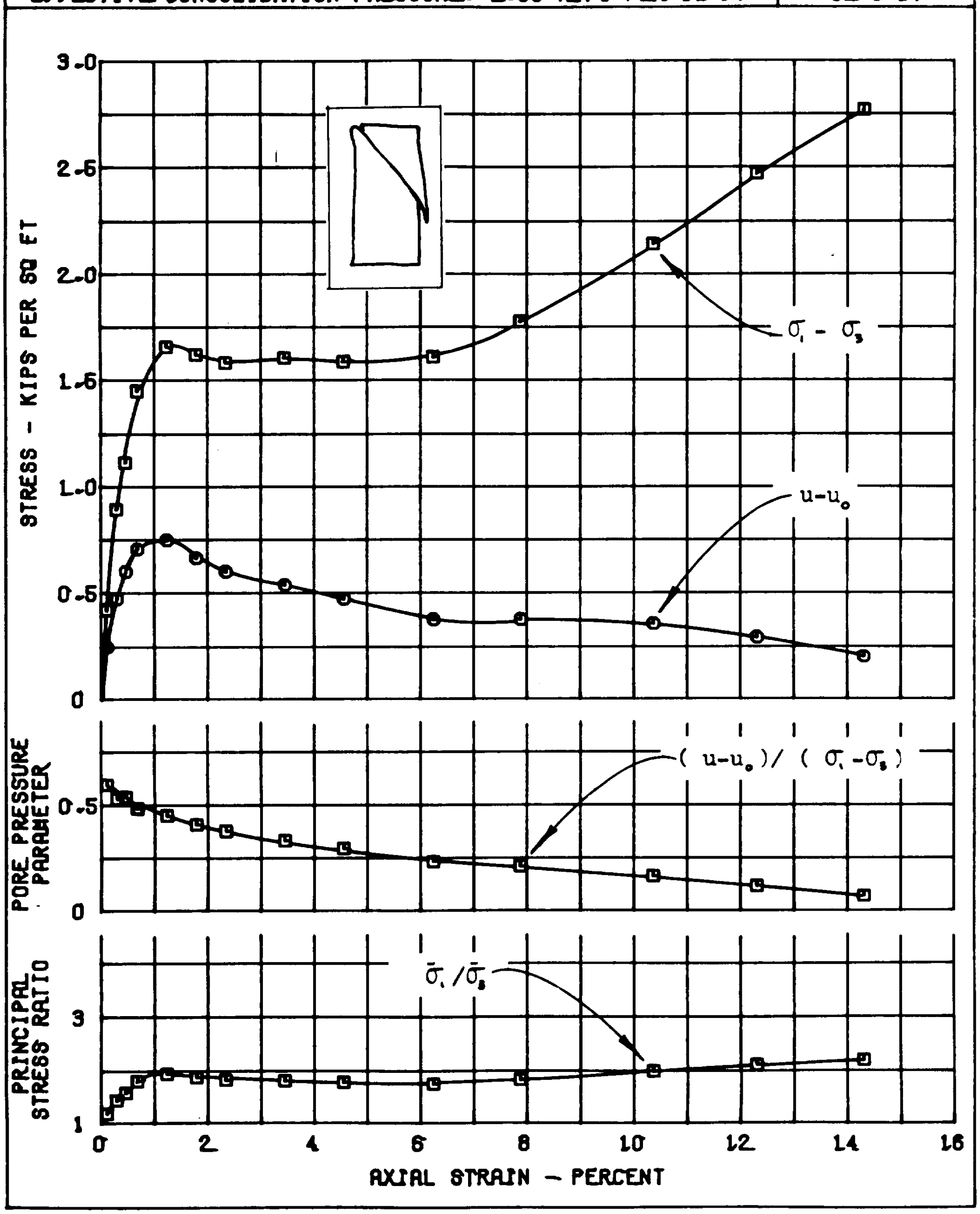
Figure 3E-15 (SHEET 8 OF 8)
TRIAXIAL TEST REPORT STONE & WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

TRIAXIAL TEST REPORT

SHEET 8

CLIENT VIRGINIA ELECTRIC POWER COMPANY	J.O. NUMBER 11715	BORING NUMBER SWR4
SITE NORTH ANNA 1 & 2	DATE 13 NOV 75	SAMPLE NUMBER 1F
EFFECTIVE CONSOLIDATION PRESSURE: 2.50 KIPS PER SQ FT		DEPTH 12.9 FT



N03E0059

Figure 3E-16 (SHEET 1 OF 2)
DIRECT SHEAR TEST REPORT STONE & WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION

DIRECT SHEAR TEST REPORT
SHEET 1

CLIENT	J.O. NUMBER	EXPLORATION TYPE AND NUMBER
VIRGINIA ELECTRIC POWER COMPANY	11715	BORING P-11
SITE	DATE	SAMPLE NUMBERS
NORTH ANNA 1 & 2	5 DEC 75	4

EFFECTIVE NORMAL STRESS: 5.0 KIPS PER SQ. FT.

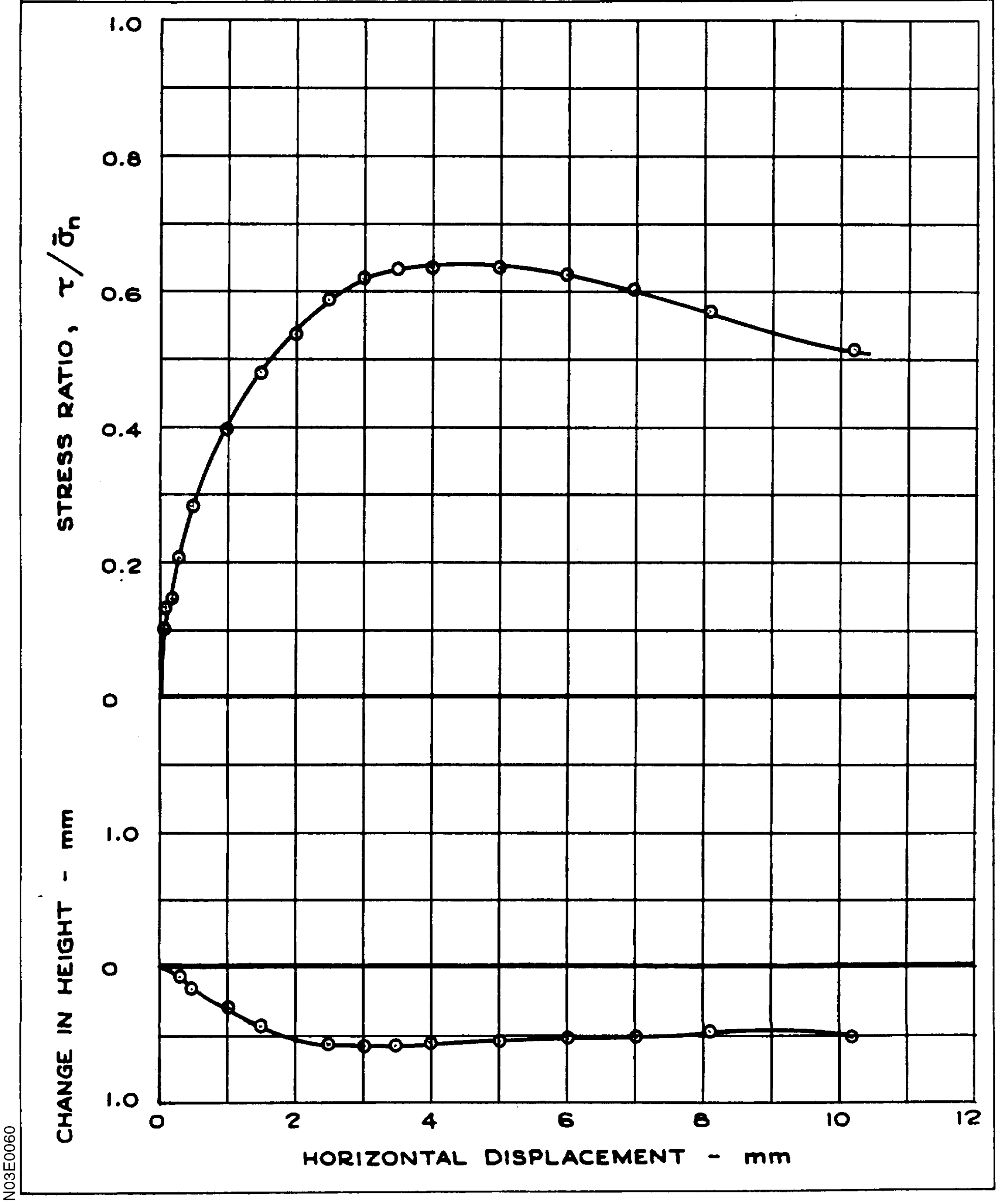


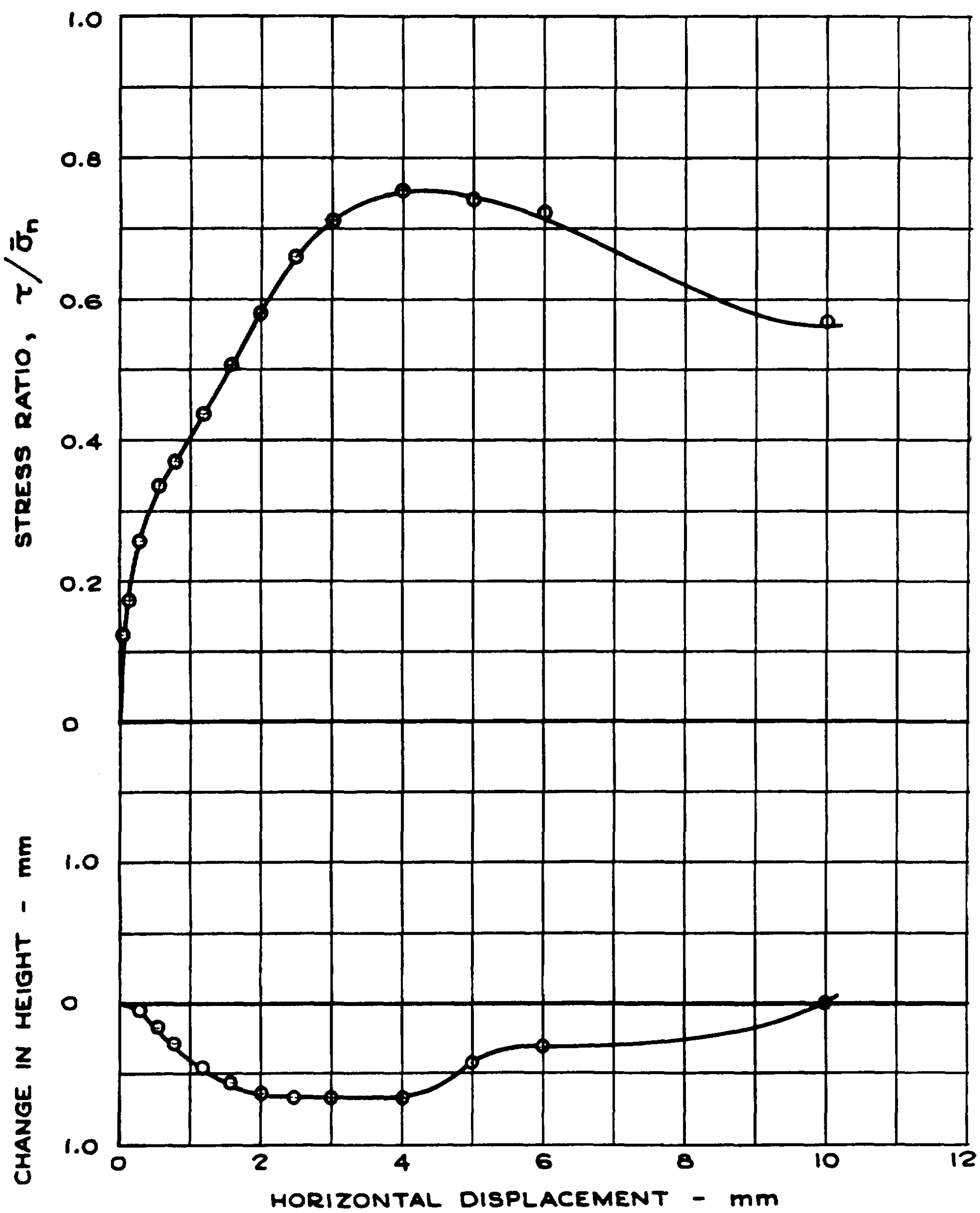
Figure 3E-16 (SHEET 2 OF 2)
DIRECT SHEAR TEST REPORT STONE & WEBSTER ENGINEERING CORPORATION

STONE & WEBSTER ENGINEERING CORPORATION **DIRECT SHEAR TEST REPORT**

SHEET 2

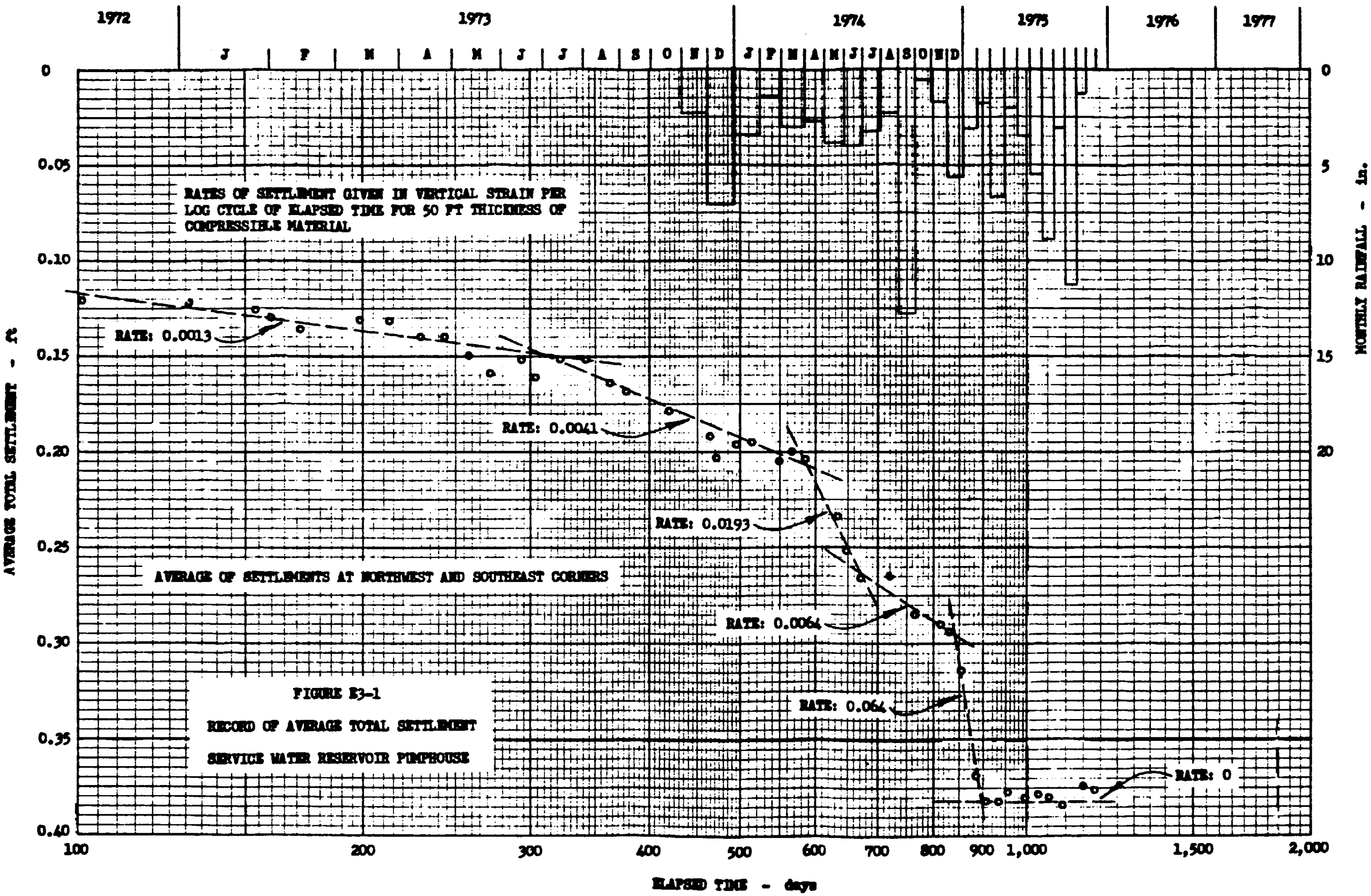
CLIENT	J.O. NUMBER	EXPLORATION TYPE AND NUMBER
VIRGINIA ELECTRIC POWER COMPANY	11715	BORING SI-1
SITE	DATE	SAMPLE NUMBERS
NORTH ANNA 1 & 2	4 DEC 75	5E

EFFECTIVE NORMAL STRESS: 6.0 KIPS PER SQ. FT.



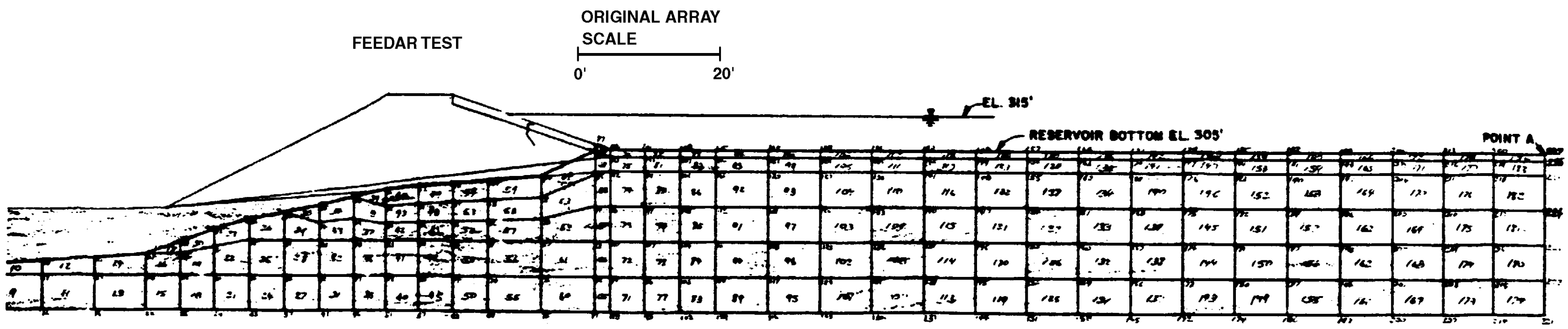
N03E0061

Figure 3E-17
RECORD OF AVERAGE TOTAL SETTLEMENT; SERVICE WATER RESERVOIR PUMPHOUSE



N03E0062

Figure 3E-18
SERVICE WATER RESERVOIR FINITE ELEMENT SEEPAGE MESH



N03E0063

Figure 3E-19
SERVICE WATER RESERVOIR RUN NO. 1 PRESSURE PLOTS

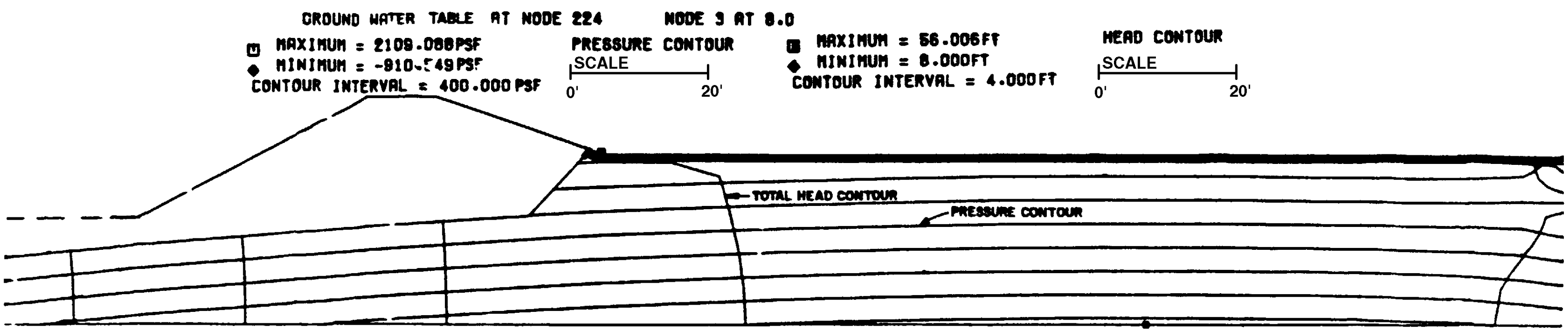


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Figure 3E-20
SERVICE WATER RESERVOIR RUN NO. 2 PRESSURE PLOTS

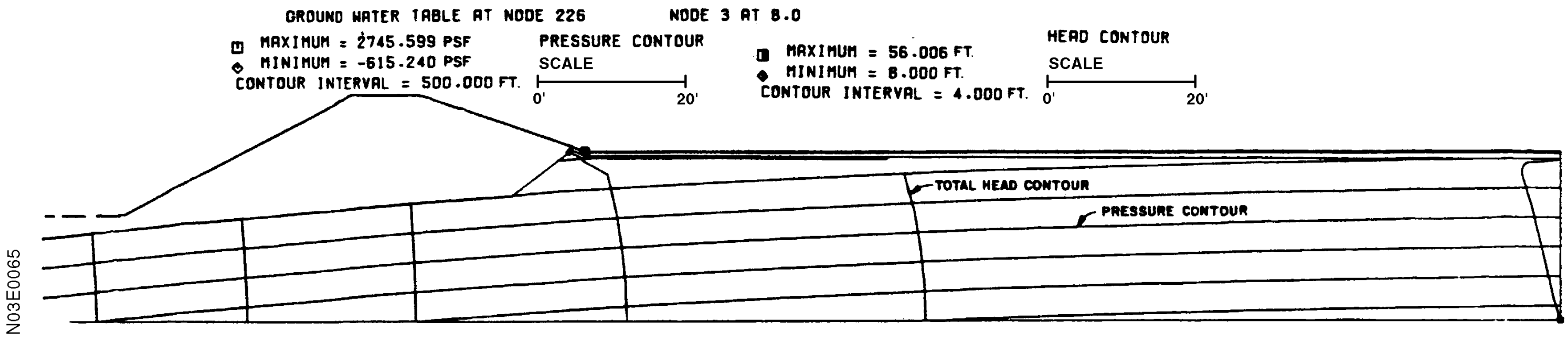


Figure 3E-21
SERVICE WATER RESERVOIR RUN NO. 3 PRESSURE PLOTS

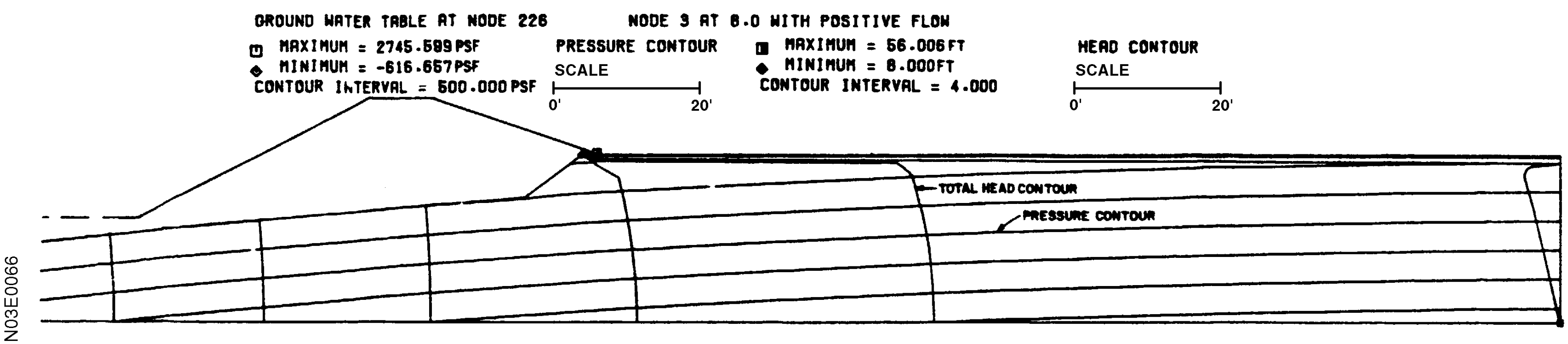


Figure 3E-22
SERVICE WATER RESERVOIR RUN NO. 4 PRESSURE PLOTS

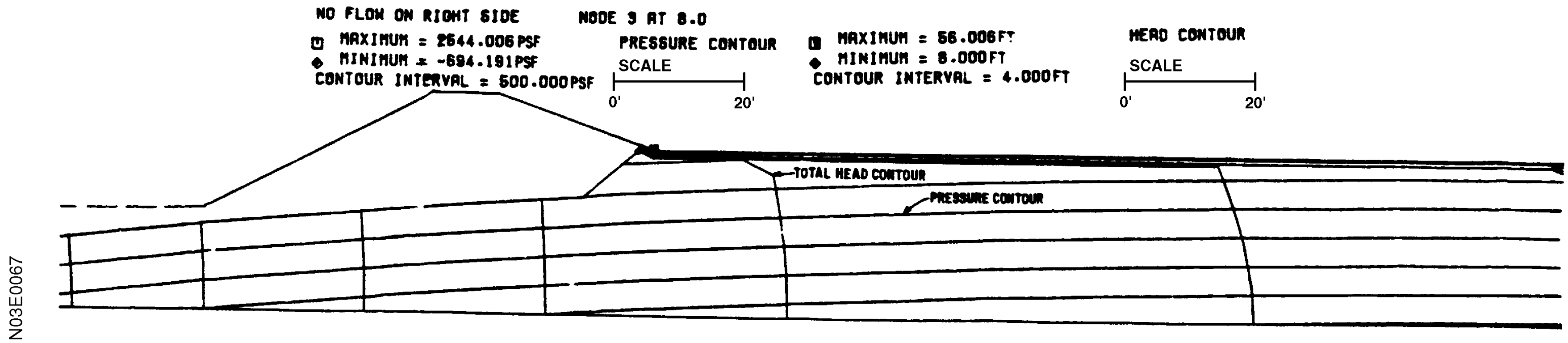


Figure 3E-23
SERVICE WATER RESERVOIR RUN NO. 5 PRESSURE PLOTS

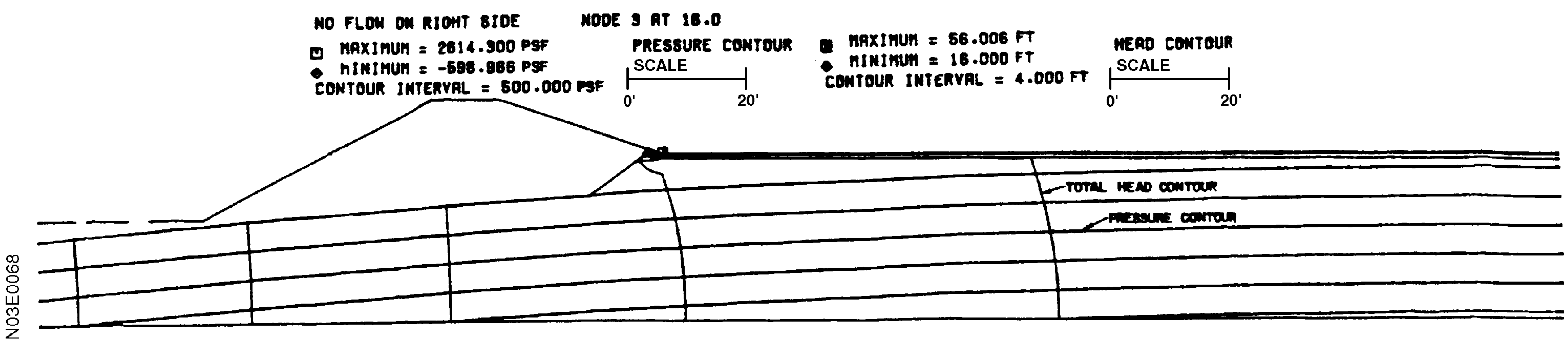


Figure 3E-24
SERVICE WATER RESERVOIR RUN NO. 6 PRESSURE PLOTS

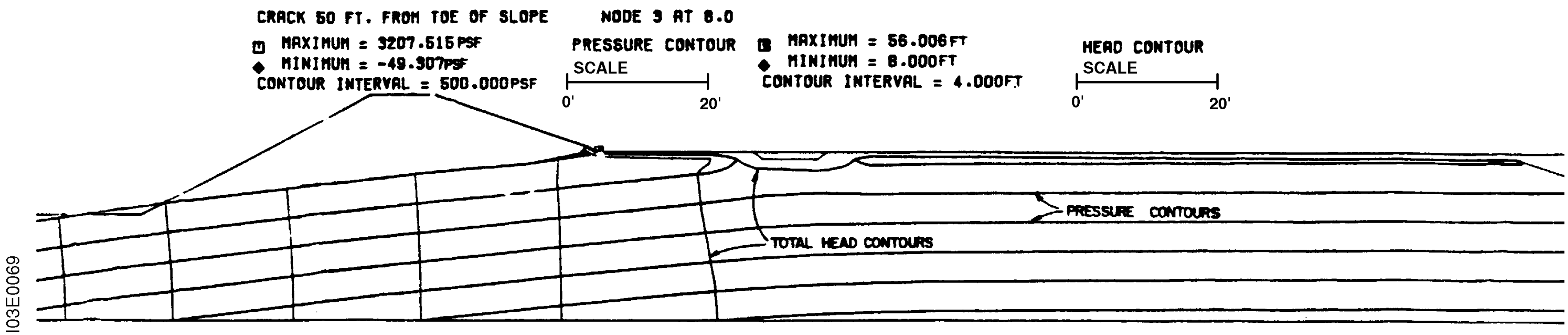


Figure 3E-25
SERVICE WATER RESERVOIR PHREATIC SURFACE—ALL RUNS

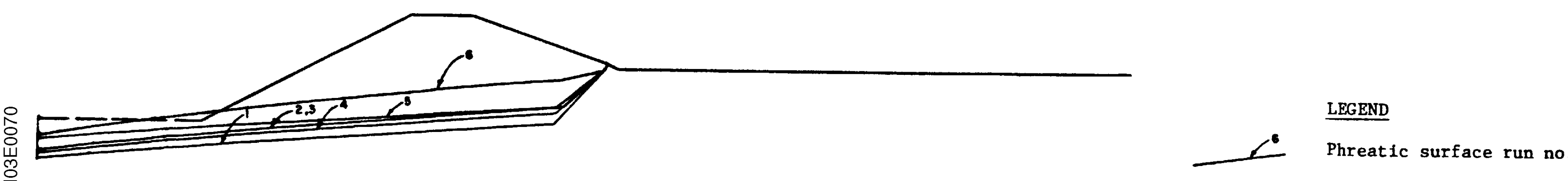


Figure 3E-26
STRESS RATIO VS. NUMBER OF CYCLES

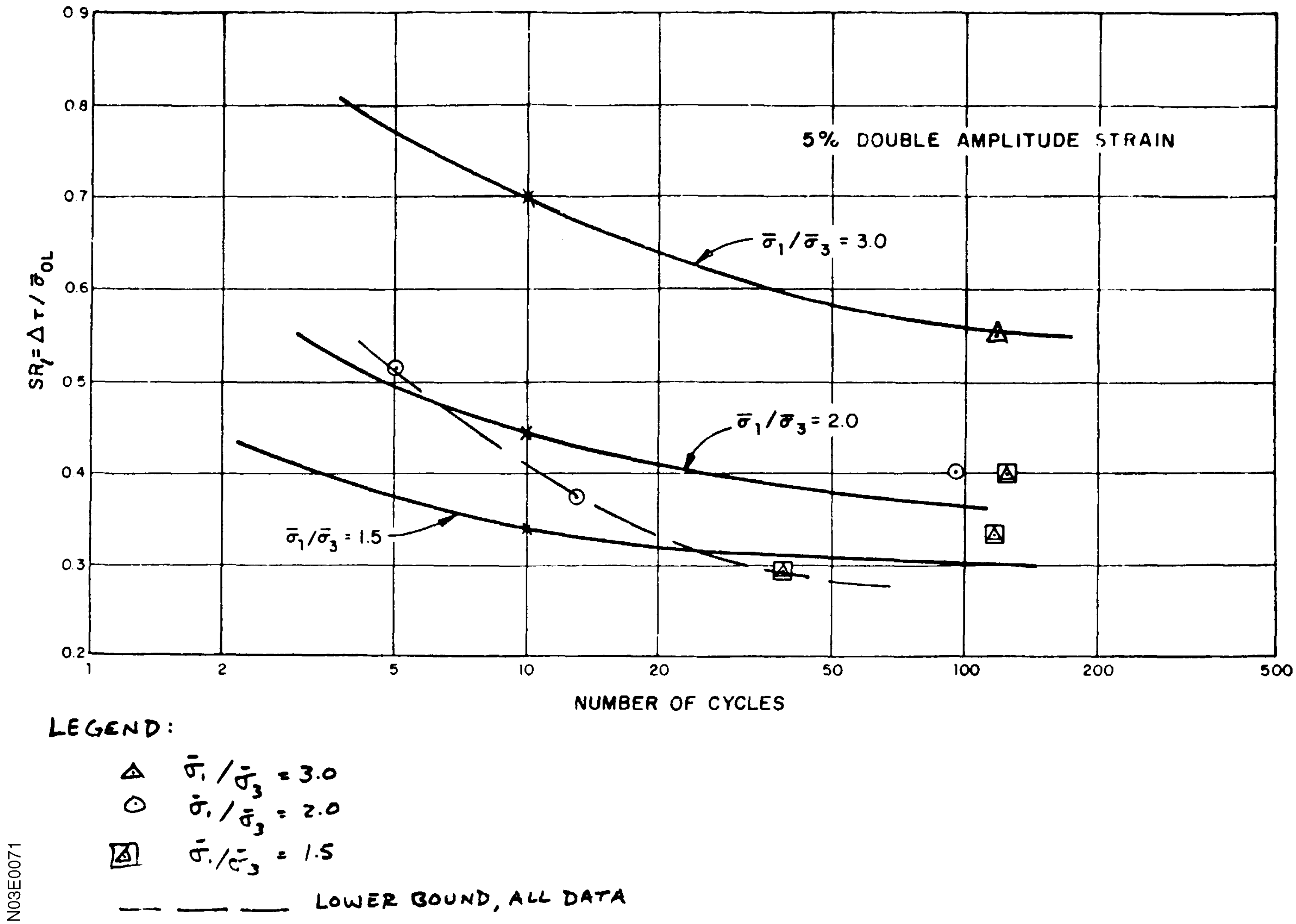
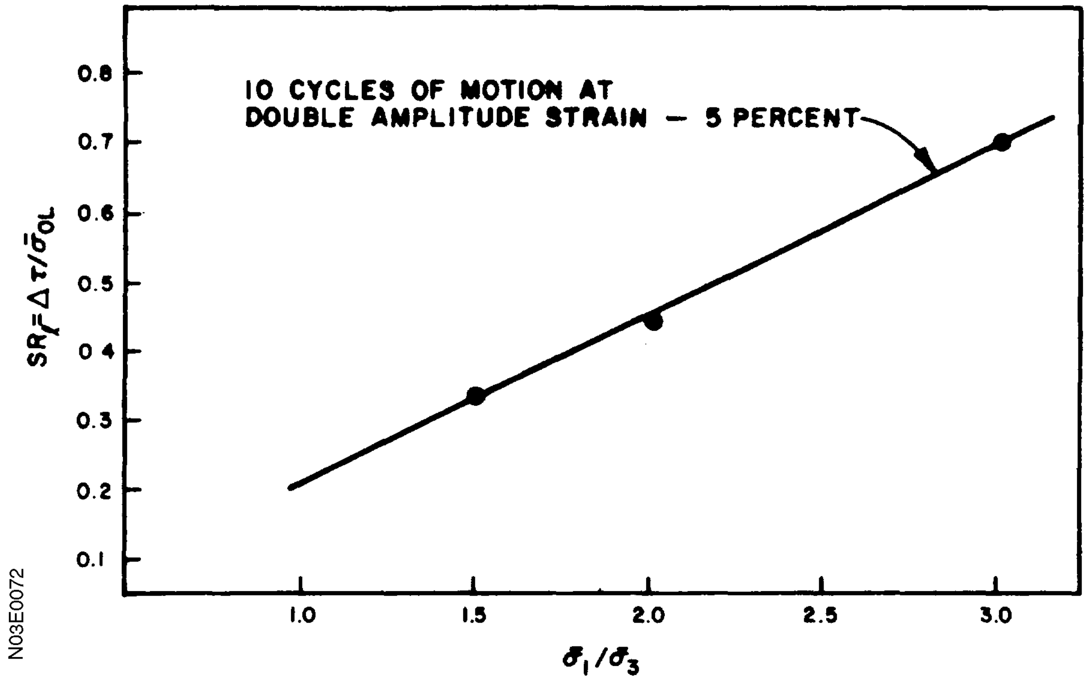


Figure 3E-27
STRESS RATIO VS. CONSOLIDATION STRESS RATIO



Appendix 3E
Attachment 1

Report on Cyclic Triaxial Tests on Soil Samples
Service Water Reservoir North Anna Power Station
Submitted to Stone & Webster Engineering Corp.
Boston, Massachusetts by Geotechnical Engineers Inc.
1017 Main Street Winchester, Massachusetts 01890 Project 75260
December 5, 1975

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1. INTRODUCTION

1.1. Purpose

The purpose of this report is to present the results of cyclic triaxial tests performed on undisturbed specimens of residual soil taken from the site of the Service Water Reservoir of the North Anna Power Station.

1.2. Scope

A total of four tube samples, each about 1 ft long, were delivered to Geotechnical Engineers Inc. The scope of work consisted of four cyclic triaxial tests on anisotropically consolidated specimens and four grain size analyses.

1.3. Authorization

This work was authorized by Mr. Jean Audibert of Stone & Webster under Purchase Order No. E-17115 dated November 4, 1975.

2. OUTLINE OF TESTING PROCEDURE

A section of tube about 7 in. long was cut by means of a tube cutter while maintaining the tube in its upright position. The pressure applied to the tube cutter was kept at a minimum to avoid deforming the tube. The bottom 7 in. of each tube sample was used for testing. The top and bottom of the sample were trimmed flat and its length and weight were determined while in the tube. The specimen was then extruded into a membrane, weighed and placed in the cell. Any material which remained in the tube after extrusion was oven dried and weighed.

The length and diameter of each specimen was determined again prior to assembling the triaxial cell. In all cases, it was noticed that the volume of the specimens expanded during extrusion, probably due to the micaceous character of the soil.

After completion of the cyclic triaxial test, the specimen was sliced longitudinally, described and photographed. The specimen was oven dried and its initial water content and dry unit weight before and after extrusion were determined. These are listed in the table at the end of this report.

Grain size distributions were determined for each of the four specimens tested and are presented in Figs. 1 to 4.

3. SAMPLE DESCRIPTIONS

Detailed descriptions of each specimen are given in the Appendix. Photographs of each specimen are shown on Fig. 11.

In general, the specimens are residual soils consisting of micaceous silty medium to fine sand. They are generally tan in color but contain black and white minerals. In some specimens the banding of the minerals which occurred in the parent rock was noticeable. Three of the four samples have 29 to 44% fines (finer than #200 mesh sieve). The fourth sample, Boring SWR9, Sample ST2 had only 16% fines.

As was noted previously, the high content of mica caused the specimens to swell after extrusion from the tube, reducing their dry unit weights from 1 to 3 pcf. However, the original unit weight was generally exceeded after consolidation.

4. CYCLIC CONSOLIDATED-UNDRAINED TRIAXIAL ($C\overline{R}$) TESTS

4.1. Procedure

A 7-in.-long tube section was cut and extruded as described in Section 2. After the cell was assembled, the 0.4 to 0. 5 kg/cm^2. Initial saturation was achieved by circulating water up through the bottom of the specimen under a head of about 0.1 kg/cm^2.

At this point the specimen was anisotropically consolidated to the desired effective consolidation stresses as listed in the table. A back pressure ranging from 7.6 to 10.0 kg/cm^2 was applied to ensure saturation. The measured B value for each test was in the range between 0.87 and 0.94.

The drainage valves were then closed, a symmetrical cyclic deviator stress was applied to the specimen, and a continuous record was obtained of axial load, pore pressure and deformation by means of a strip chart recorder.

4.2. Results

The results of the individual tests are presented in Figs. 5 to 8. Each figure shows a plot of the following:

Peak Cyclic Deviator Stress in Compression and Extension versus Cycle Number

Peak Axial Strain in Compression and Extension and Double Amplitude versus Cycle Number

Maximum Induced Pore Pressure during Each Cycle versus Cycle Number.

The table summarizes the $C\overline{R}$ test results. Two summary plots were prepared which show the relationship between the applied cyclic deviator stress and the number of cycles to reach a maximum compressive strain of 5 and 10%, Figs. 9 and 10, respectively.

4.3. Comments

For the four anisotropically consolidated cyclic triaxial tests performed, the measured effective confining pressure did not reach zero at any stage of the test. The minimum effective confining pressure ranged from 6 to 26% of the initial effective confining pressure.

All of the tests failed in compression by developing shear planes accompanied by some bulging. The maximum compressive strain was chosen as the strain criteria since the specimens developed higher compressive strains than double amplitude strains. In the first cycle of the test, the double amplitude strain was greater than the maximum compressive strain. However, the peak compressive strain quickly exceeded the double amplitude strain. In two tests, $C\overline{R}$-1 and $C\overline{R}$-2, the specimen developed 2.5% double amplitude strain one cycle before it reached 2.5% maximum compressive strain. In all four tests, a maximum compressive strain of 5% was reached at the same time or earlier than 5% double amplitude strain.

In terms of the cyclic deviator stress ratio the sample consolidated under a principal stress ratio of 3 was almost twice as strong under cyclic loading as the samples consolidated under a principal stress ratio of 2, see Figs. 9 and 10.

TABLE 1 - CYCLIC CONSOLIDATED-UNDRAINED (C$\bar{R}$) TRIAXIAL TESTS NORTH ANNA SERVICE WATER RESERVOIR

Test No.	Boring No.	Sample No.	Depth (ft)	Initial Water Content (%)	Dry Unit Weights(1): In the Tube γ_d (pcf)	Dry Unit Weights(1): Triaxial Specimen, Initial γ_{di} (pcf)	Dry Unit Weights(1): Triaxial Specimen, After Consolidation γ_{dc} (pcf)	Effective Confining Pressure $\bar{\sigma}_{3c}$ (kg/cm^2)	Consolidation Stress Ratio K_c $\bar{\sigma}_{1c}/\bar{\sigma}_{3c}$	Cyclic Deviator Stress $(\sigma_1 - \sigma_3)_{cy}$	Cyclic Stress Ratio $\frac{(\sigma_1 - \sigma_3)_{cy}}{2\bar{\sigma}_{3c}}$	Number of Cycles to Reach: $\bar{\sigma}_{3c} = 0$ (2)	Number of Cycles to Reach: Maximum Compressive Strain Equal to 2.5%	5%	10%
C$\bar{R}$-1	SWR7	ST5	42.5-43.1	26.1	94	93	95	1.0	2.0	1.47	0.74	-	2(3)	5	8
C$\bar{R}$-2	SWR9	ST2	22.5-23.1	23.7	89	88	91	0.7	2.0	0.76	0.54	-	5(3)	13	30
C$\bar{R}$-3	P11	ST3	37.3-37.9	20.2	99	96	100	1.0	2.0	1.14	0.57	-	32	95	152
C$\bar{R}$-4	P12	ST2	17.5-18.1	18.4	106	103	105	0.4	3.0	0.80	1.00	-	41	119	213

NOTES: (1) Due to the high mica content, the specimens swelled after extrusion from the tube and therefore, the initial dry unit weights of the triaxial specimen are lower than the dry unit weights in the tube.

(2) At no point during any test did the effective confining pressure reach zero.

(3) In test C$\bar{R}$-1 and C$\bar{R}$-2, the specimens reached a double amplitude strain of 2.5% in the cycle preceding the one listed. In all other cases, the maximum compressive strain of 2.5%, 5% and 10% occurred before the double amplitude strain of 2.5%, 5% and 10%, respectively.

Geotechnical Engineers Inc.

Project 75260
December 3, 1975

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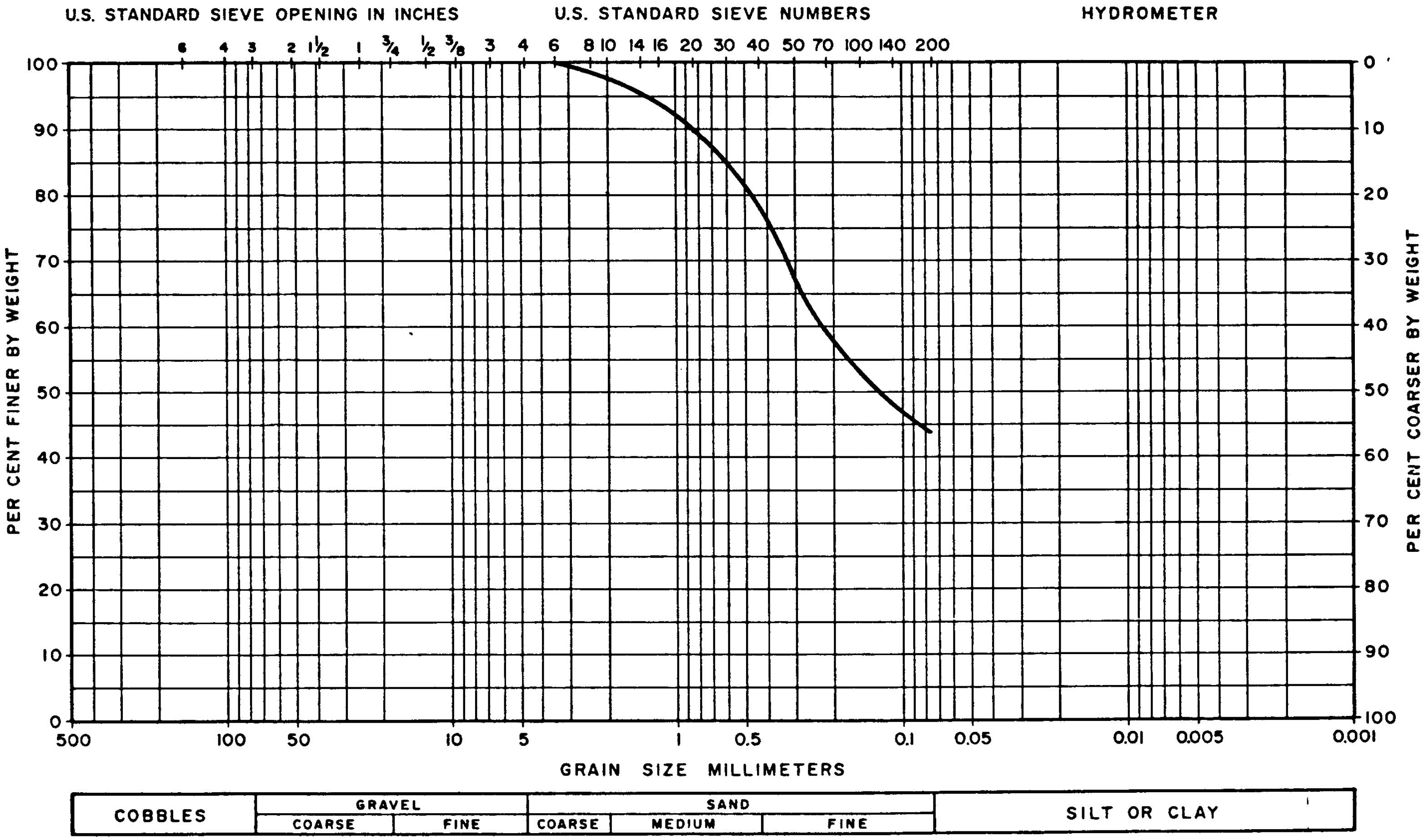

Stone & Webster Boston, Massachusetts	North Anna Power Station	GRAIN SIZE CURVE Boring SWR7 Sample ST5
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	December 3, 1975 Fig. 1

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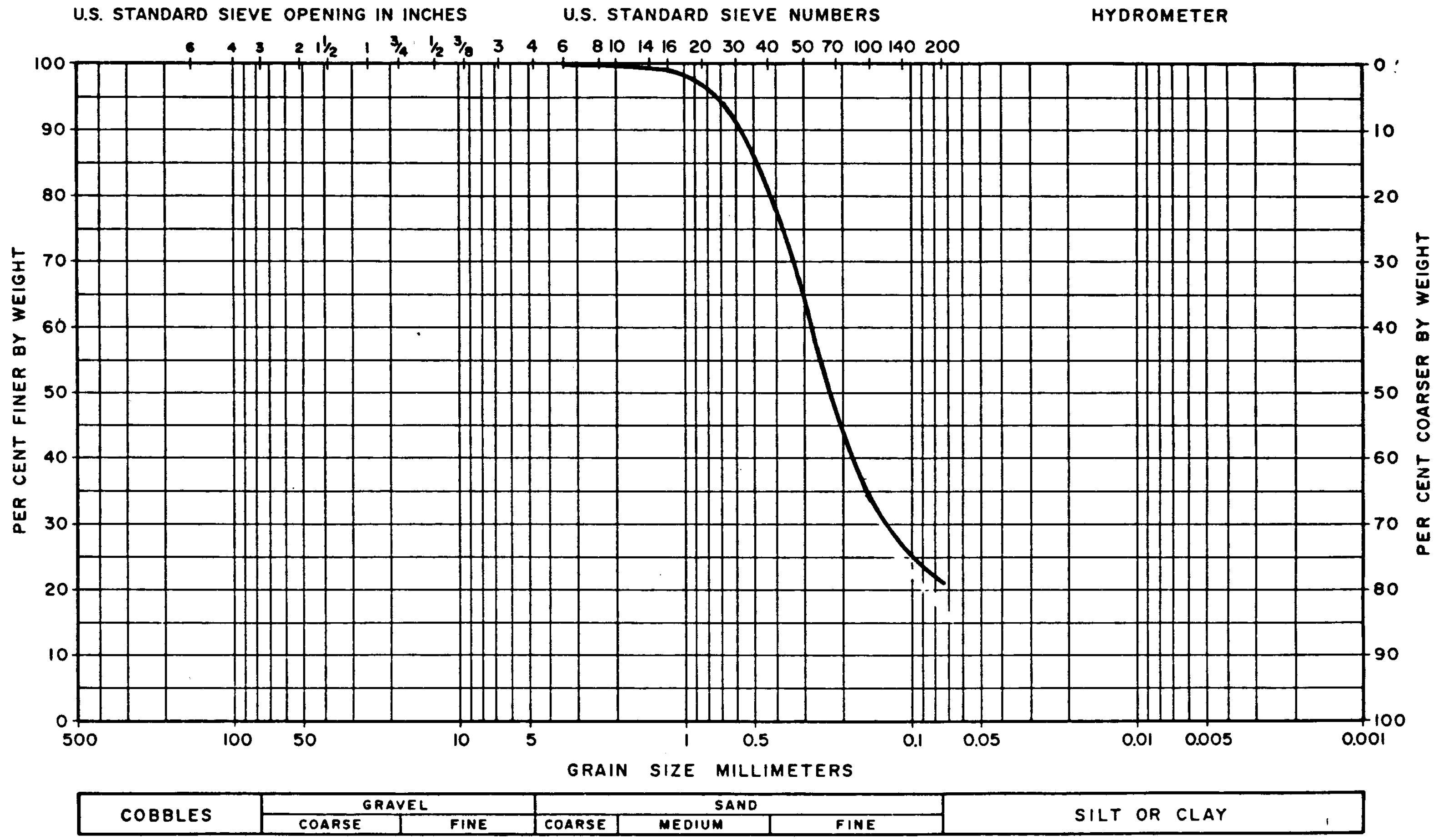

Stone & Webster Boston, Massachusetts	North Anna Power Station	GRAIN SIZE CURVE Boring SWR9 Sample ST2
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	December 3, 1975 Fig. 2

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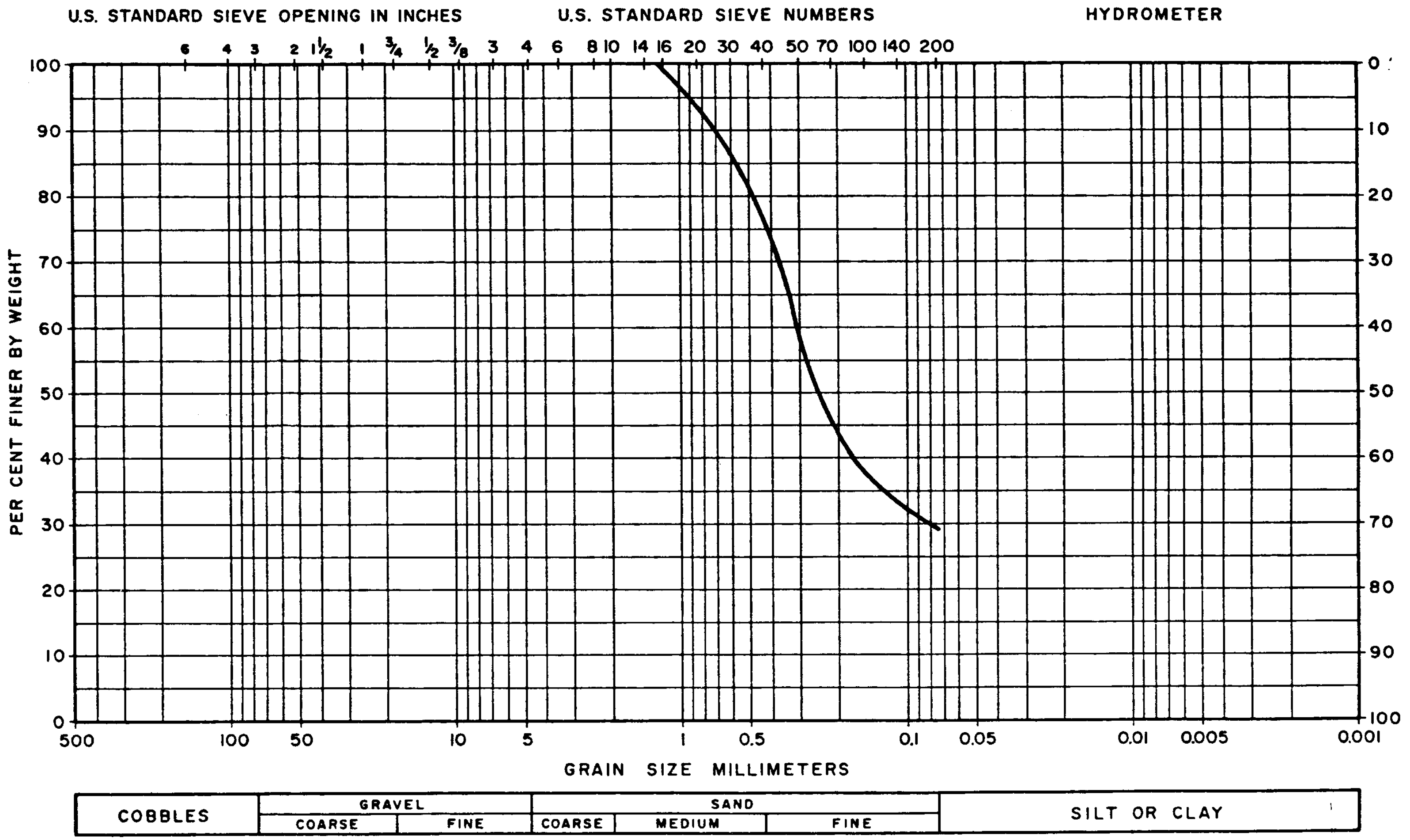
Lab. 4-3 rev. 0 28 May 74



Stone & Webster Boston, Massachusetts	North Anna Power Station	GRAIN SIZE CURVE Boring P11 Sample ST3
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	December 3, 1975 Fig. 3

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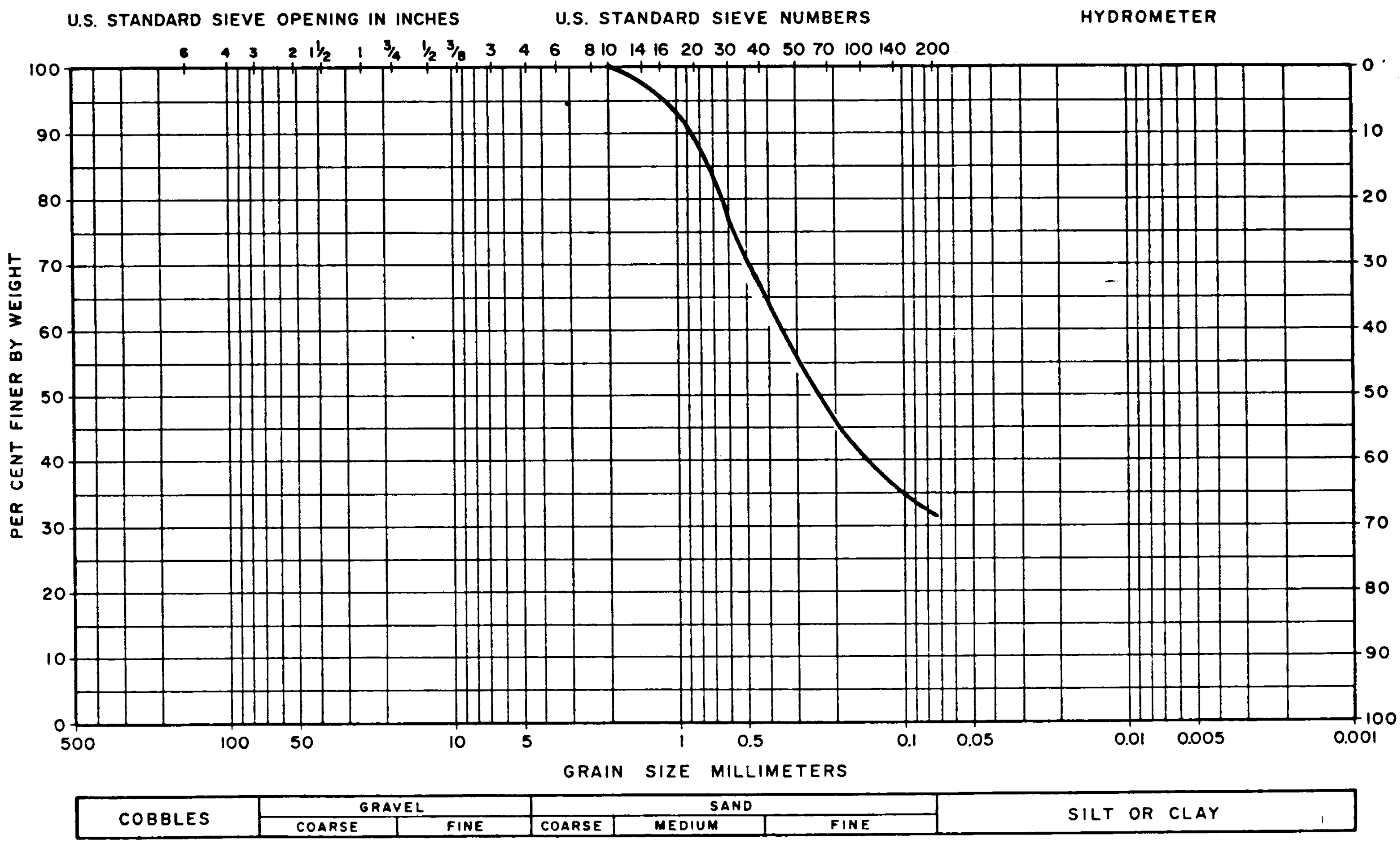
Lab. 4-3 rev. 0 28 May 74



Stone & Webster Boston, Massachusetts	North Anna Power Station	GRAIN SIZE CURVE Boring P12 Sample ST2
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	December 3, 1975 Fig. 4

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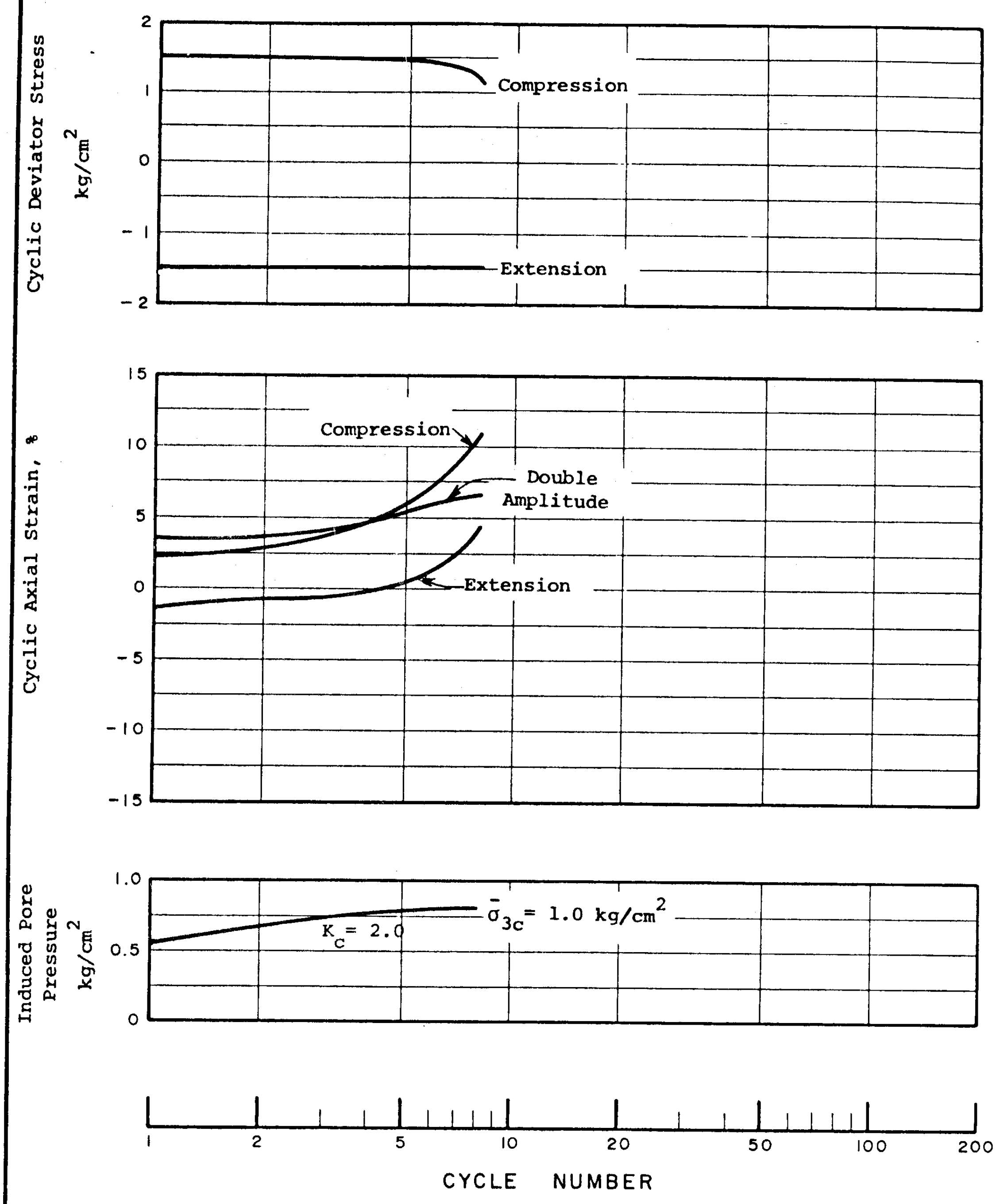
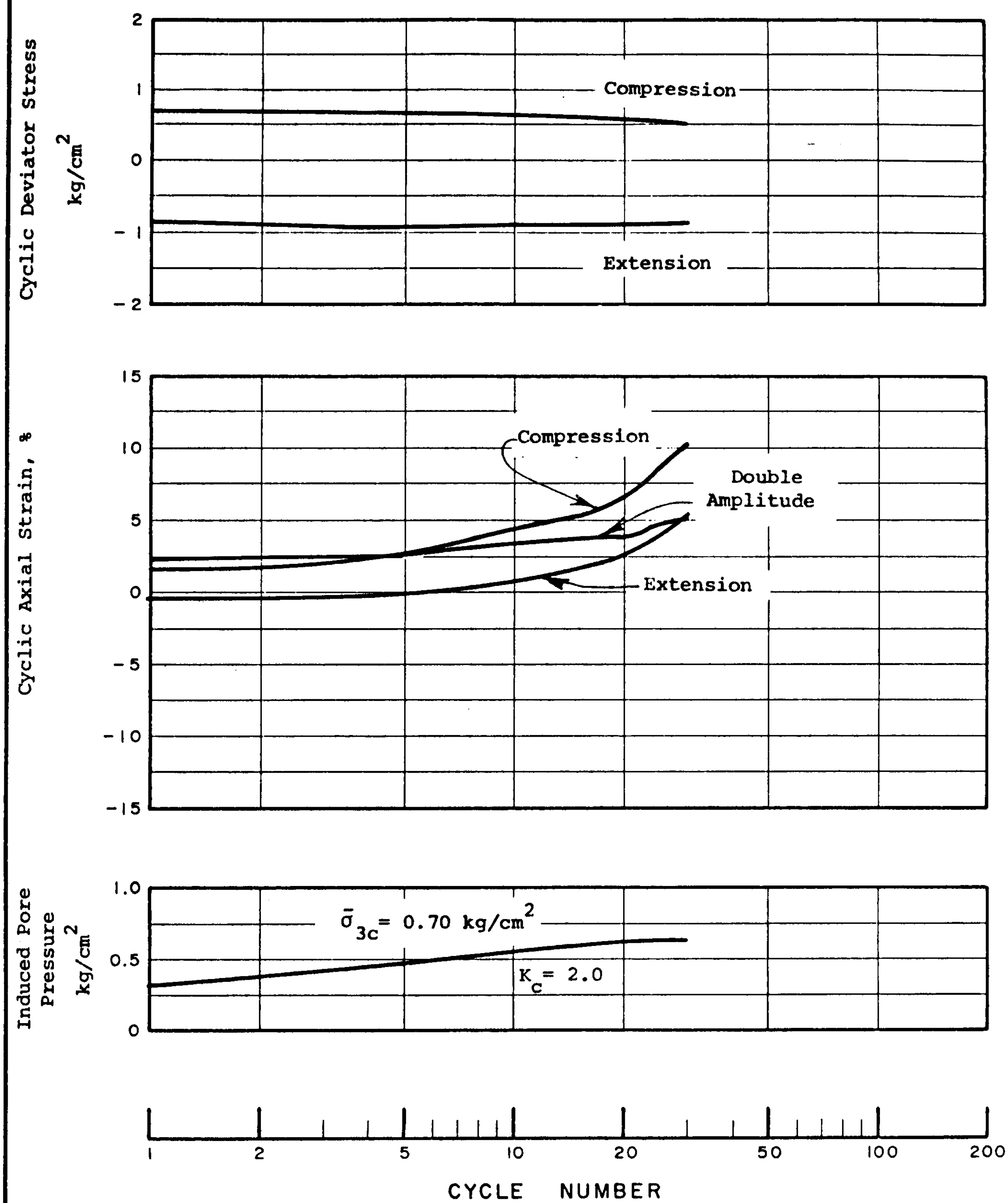
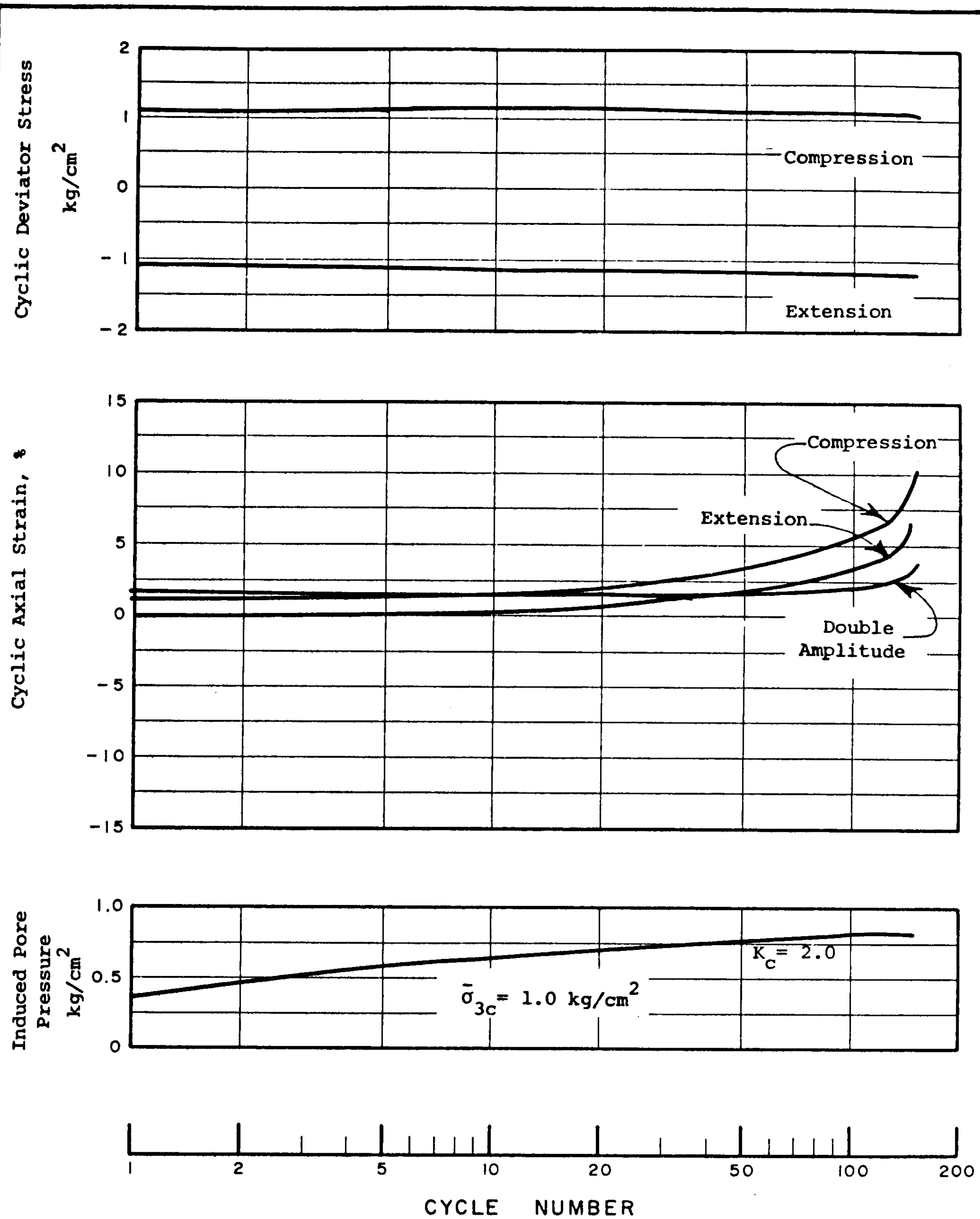


Stone & Webster Boston, Massachusetts	North Anna Power Station	CYCLIC LOAD TEST C$\bar{R}$-1 Boring SWR7 Sample ST5
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	December 3, 1975 Fig. 5



Stone & Webster Boston, Massachusetts	North Anna Power Station	CYCLIC LOAD TEST CR̄-2 Boring SWR9 Sample ST2
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	December 3, 1975 Fig. 6



Stone & Webster Boston, Massachusetts	North Anna Power Station	CYCLIC LOAD TEST CR-3 Boring P11 Sample ST3
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	December 3, 1975 Fig. 7

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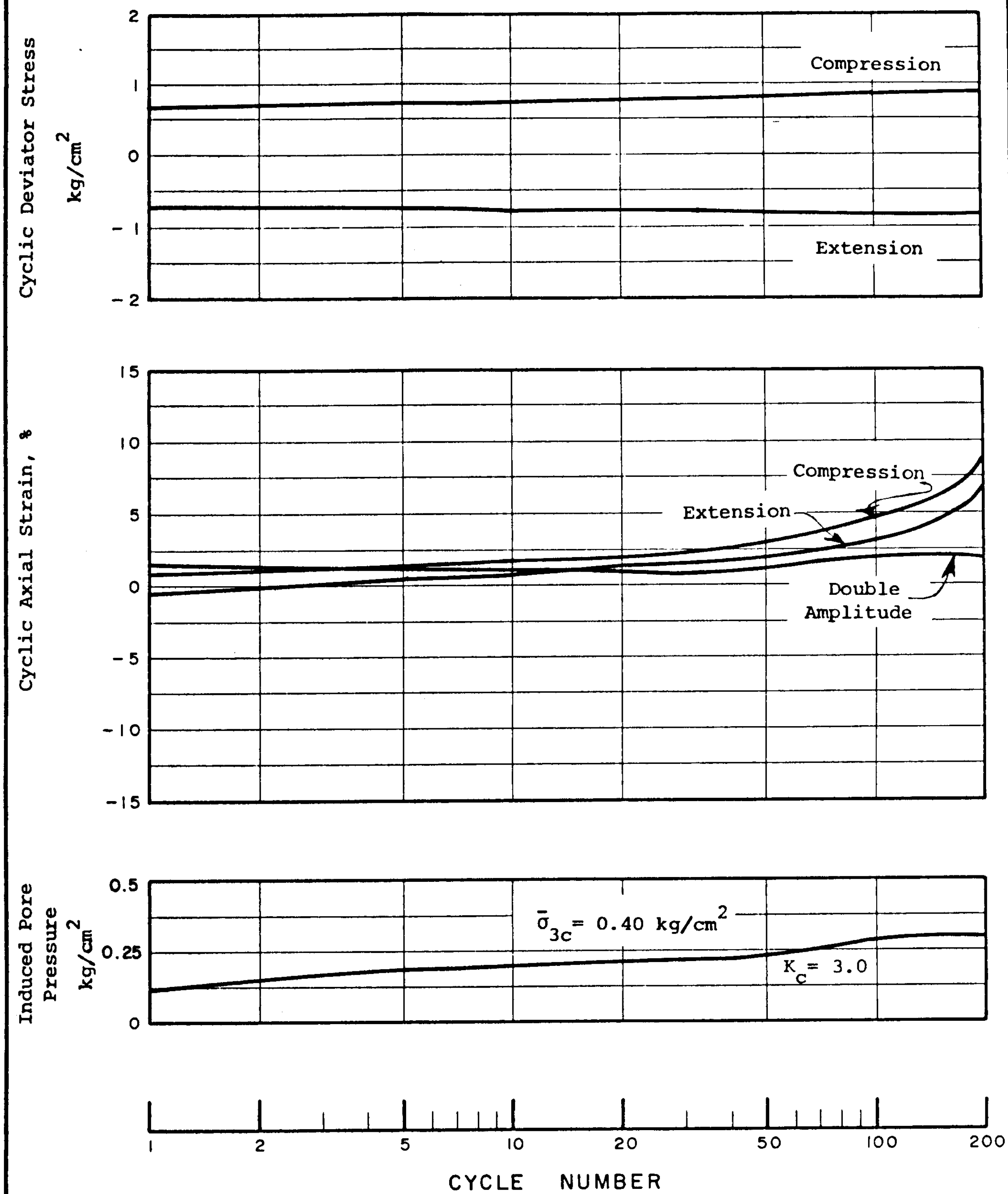

Stone & Webster Boston, Massachusetts	North Anna Power Station	CYCLIC LOAD TEST CR-4 Boring P12 Sample ST2
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	December 3, 1975 Fig. 8

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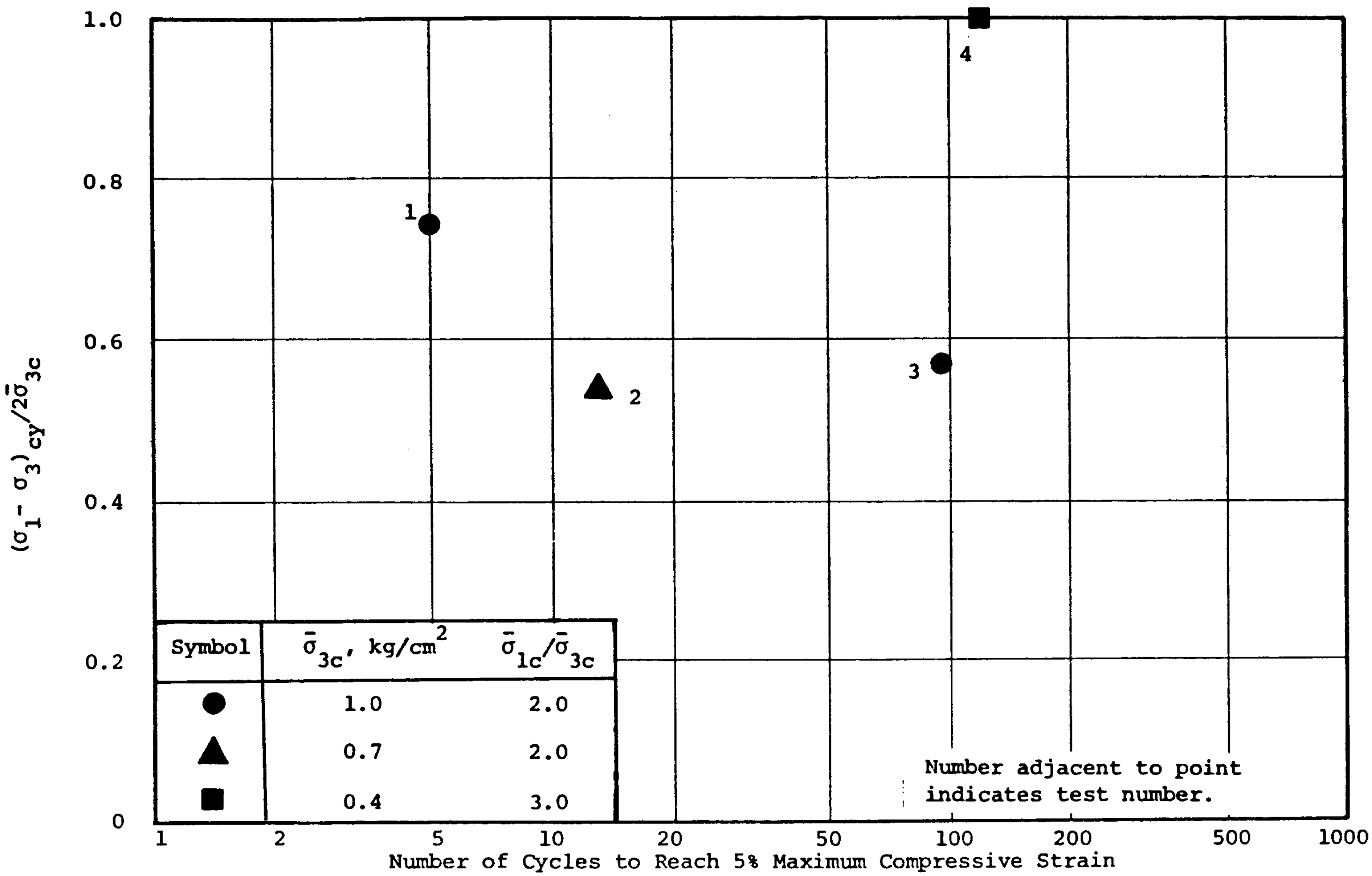

Stone & Webster Boston, Massachusetts	North Anna Power Station	SUMMARY PLOT $C\bar{R}$ Tests
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	December 4, 1975 Fig. 9

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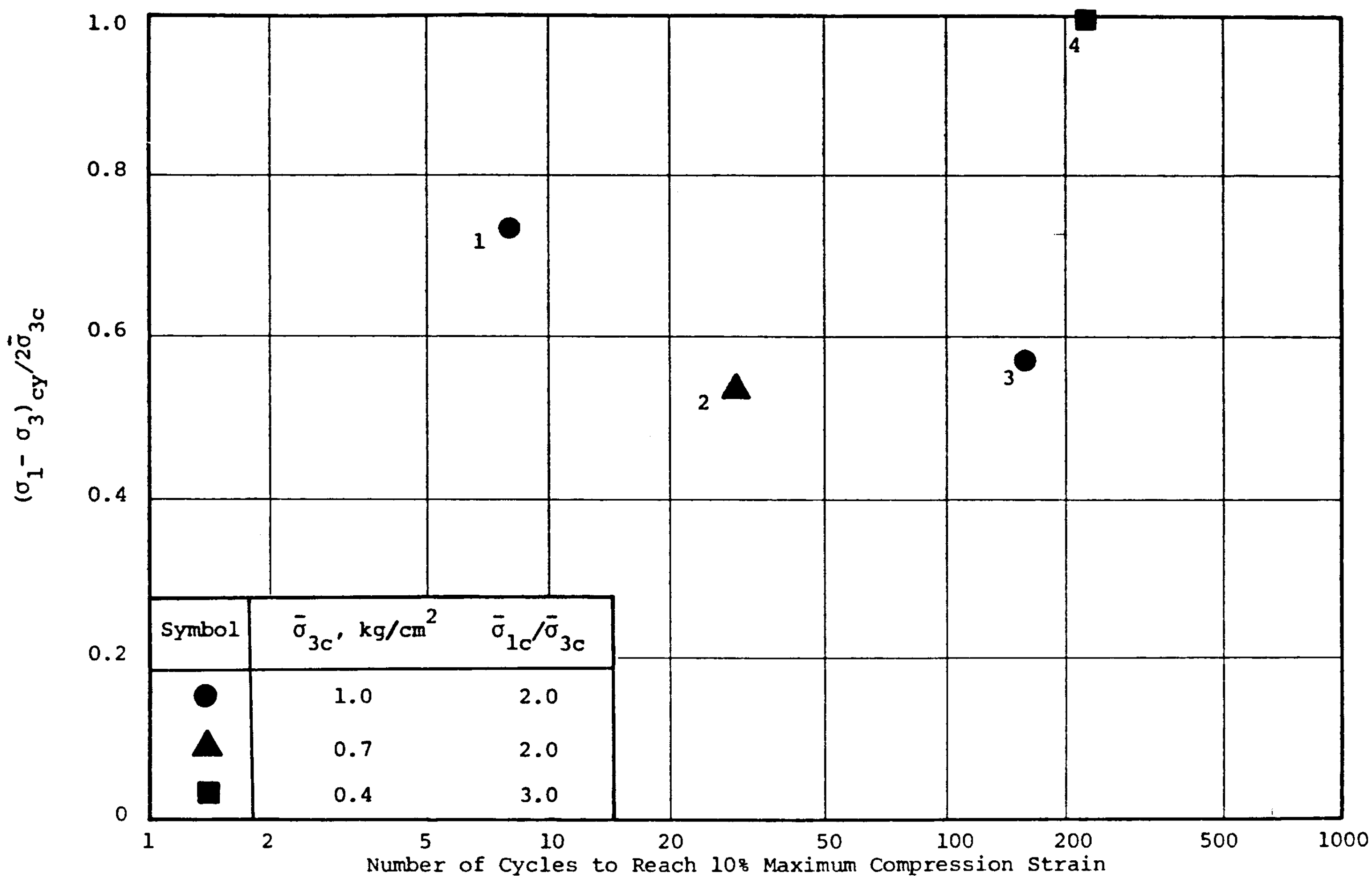
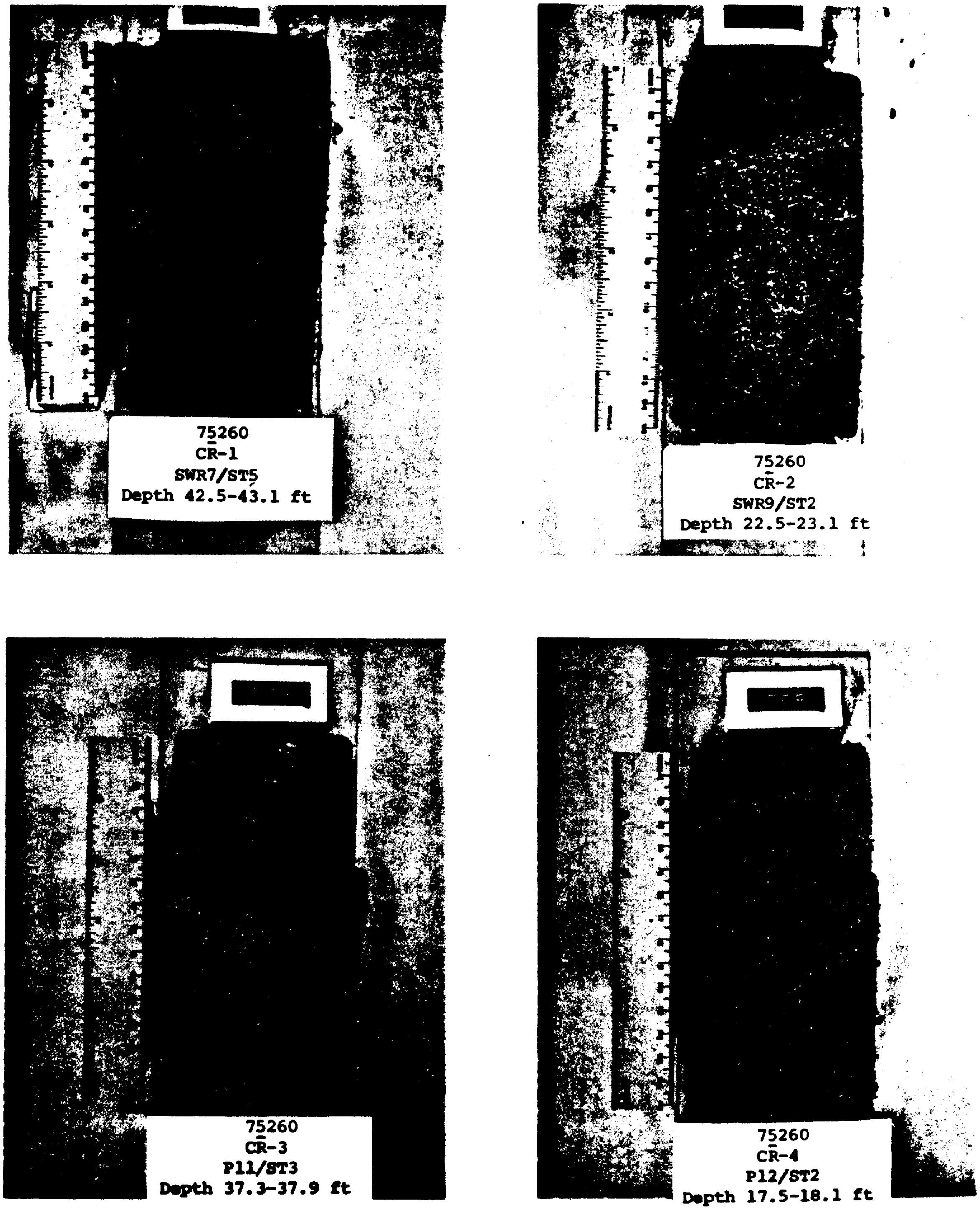


Stone & Webster Boston, Massachusetts	North Anna Power Station	SUMMARY PLOT C$\bar{R}$ Tests
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	December 4, 1975 Fig. 10



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GEOTECHNICAL ENGINEERS INC.

Fig. 11

DESCRIPTION OF UNDISTURBED SAMPLES
BORING NO. SWR7

Project North Anna Power Station

Project No. 75260
Page 1 of 1

Sample No. and Depth ft.	Section No.	Length of Section in.	Description
ST5 42.5- 43.1	-	7.0	Tan micaceous very silty medium to fine sand. Minerals vary from black to white and appear in spots and streaks throughout the specimen. Fines are non-plastic. (Residual Soil) Specimen swelled after extrusion from the tube due to the large mica content. Failure occurred in compression by developing 2 shear planes in the top half of the specimen.

DESCRIPTION OF UNDISTURBED SAMPLES
BORING NO. SWR9

Project North Anna Power Station

Project No. 75260
Page 1 of 1

Sample No. and Depth ft.	Section No.	Length of Section in.	Description
ST22 22.5- 23.1	-	7.0	Mottled gray, tan, rust orange and black micaceous silty fine sand. Coloring occurs in streaks, pockets and zones throughout the specimen showing structure of parent rock. (Residual Soil) Specimen swelled after extrusion from the tube due to the large mica content. Failure occurred in compression primarily by bulging and shearing in the top half of specimen.

DESCRIPTION OF UNDISTURBED SAMPLES
BORING NO. P11

Project North Anna Power Station

Project No. 75260
Page 1 of 1

Sample No. and Depth ft.	Section No.	Length of Section in.	Description
ST3	-	6.9	Multicolored micaceous silty medium to fine sand. Minerals are rust orange, brown, black, white and green in color. Some banding o f light and dark minerals at about 30° from horizontal. Fines non-plastic. (Residual Soil) Specimen swelled after extrusion from the tube due to the large mica content. Failure occurred in compression by developing a shear plane at about 45° in the lower half of the specimen.

DESCRIPTION OF UNDISTURBED SAMPLES
BORING NO. P12

Project North Anna Power Station

Project No. 75260
Page 1 of 1

Sample No. and Depth ft.	Section No.	Length of Section in.	Description
ST2 17.5- 18.1	-	7.0	Tan to black brown micaceous silty medium to fine sand. Minerals occur in bands and streaks at approximately 45°. Grains are subangular. Top half of specimen is predominantly dark minerals. Bottom half is predominantly tan-white minerals. (Residual Soil) Specimen swelled after extrusion from the tube due to the large mica content. Failure occurred in compression in bottom half of specimen by developing a shear plane at approximately 45°, parallel to banding of minerals.

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Appendix 3E
Attachment 2[1]

Cyclic Triaxial Tests on Soil Samples From the Service Water Reservoir North Anna Power Station

1. Attachment 2 to Appendix 3E was submitted as Appendix F in the original FSAR (see also page 3E-1).

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Attachment 2 to Appendix 3E
Cyclic Triaxial Tests on Soil Water Samples
From the Service Water Reservoir

The report entitled *Cyclic Triaxial Tests on Soil Samples from the Service Water Reservoir, North Anna Power Station*, dated December 31, 1975 and prepared by Geotechnical Engineers Inc., was incorporated into the license application and submitted to the Nuclear Regulatory Commission as a separate document in Amendment No. 49. The report, however, was not given general distribution to all holders of the FSAR. Copies of the Report are available for review in the Commission's Public Document Room.

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GEOTECHNICAL ENGINEERS INC.
WINCHESTER, MASSACHUSETTS HOUSTON TEXAS
1017 MAIN STREET · WINCHESTER · MASSACHUSETTS 01890 (617) 729-1625

PRINCIPALS
RONALD C. HIRSCHFELD
STEVE J. POULOS
DANIEL P. LA GATTA
RICHARD F. MURDOCK
GONZALO CASTRO

SENIOR ASSOCIATE
N. LEE WORTH
ASSOCIATE
CHARLES E. OSGOOD

December 31, 1975
Project 75260

Mr. David Campbell
Stone & Webster Engineering Corp.
P.O. Box 2325
Boston, Massachusetts

Subject: Cyclic Triaxial Tests on Soil Samples from the Service Water Reservoir, North Anna Power Station

Dear Mr. Campbell:

INTRODUCTION

The purpose of this letter report is to present the results of three cyclic triaxial tests ($C\overline{R}$-5 to $C\overline{R}$-7) performed subsequent to our report of December 5, 1975 titled “Report on Cyclic Triaxial Tests - Soil Samples - Service Water Reservoir - North Anna Power Station.

SOIL DESCRIPTIONS

A description of each of the soil samples tested is included at the end of this letter. A photograph showing a longitudinal slice of each test specimen is given in Fig. 11. Grain size distributions for each specimen are presented in Figs. 1 to 3.

In general, the specimens are residual soils, consisting of micaceous silty medium to fine sand. The specimen used for test $C\overline{R}$-7 was a very micaceous silty fine sand.

CYCLIC TRIAXIAL TESTS

The test procedure used for the cyclic triaxial tests is discussed in our report of December 5. The specimens were consolidated anisotropically to a value of σ_{1c}/σ_{3c} of 1.5 prior to applying a symmetrical cyclic deviator stress. The individual test results are given in Figs. 4 through 6.

A summary of these three tests is presented together with the four tests performed for our December 5 report in Table 1.

Summary plots were prepared which include all seven tests and show the relationship between the applied cyclic deviator stress, $(\sigma_1 - \sigma_3)_{cy}/2\sigma_{3c}$, and the number of cycles to reach a maximum compressive strain of 5 and 10%, Figs. 7 and 8, respectively.

Similar plots were prepared which show the relationship between $T_{oct\ (Dynamic)}/\sigma_{oct\ (Static)}$ and the number of cycles to reach a maximum compressive strain of 5 and 10%, Figs. 9 and 10, respectively

In this case,

$$\tau_{oct\ (Dynamic)} = 1/3 \left[(\sigma_1 - \sigma_2)^2_{cy} + (\sigma_2 - \sigma_3)^2_{cy} + (\sigma_3 - \sigma_1)^2_{cy} \right]^{1/2}$$

where $(\sigma_1 - \sigma_2)_{cy}$ refers to cyclic stresses, and

$$\bar{\sigma}_{oct\ (Static)} = 1/3\ (\bar{\sigma}_{1c} + \bar{\sigma}_{2c} + \bar{\sigma}_{3c})$$

where $\bar{\sigma}_{1c}$ refers to consolidation stresses.

COMMENTS

The scatter of the data is primarily due to the different dry unit weights, percent finer than #200 sieve and mica content of the specimens tested.

In particular, Test C$\overline{\text{R}}$-7 does not appear to be consistent with the other two tests (C$\overline{\text{R}}$-5 and 6) performed at a consolidation stress ratio of 1.5. In addition to the difference in grain size distribution between these three specimens, the specimen for Test C$\overline{\text{R}}$-7 appeared to contain a significantly larger percentage of mica. The lower dry unit weight of this specimen may be indicative of the mica content.

If you have any questions, please call me.

Very truly yours,

GEOTECHNICAL ENGINEERS INC.

Gonzalo Castro

Principal

GC: kmb

Enclosures

TABLE 1 - CYCLIC CONSOLIDATED-UNDRAINED (C$\bar{R}$) TRIAXIAL TESTS
NORTH ANNA SERVICE WATER RESERVOIR

Test No.	Boring No.	Sample No.	Depth (ft)	Initial Water Content (%)	Dry Unit Weights[1]: In the Tube γ_d (pcf)	Dry Unit Weights[1]: Triaxial Specimen: Initial γ_{di} (pcf)	Dry Unit Weights[1]: Triaxial Specimen: After Consolidation γ_{dc} (pcf)	Effective Confining Pressure $\bar{\sigma}_{3c}$ (kg/cm^2)	Consolidation Stress Ratio K_c $\bar{\sigma}_{1c}/\bar{\sigma}_{3c}$	Cyclic Deviator Stress $(\sigma_1 - \sigma_3)_{cy}$	Cyclic Stress Ratio $\frac{(\sigma_1 - \sigma_3)_{cy}}{2\bar{\sigma}_{3c}}$	Number of Cycles to Reach: $\bar{\sigma}_{3c} = 0$[2]	Number of Cycles to Reach: Maximum Compressive Strain Equal to[5]: 2.5%	5%	10%	Percent Finer Than # 200 Sieve (%)
C$\bar{R}$-1	SWR7	ST5	42.5-43.1	26.1	94	93	95	1.0	2.0	1.47	0.74	-	2[3]	5	8	44
C$\bar{R}$-2	SWR9	ST2	22.5-23.1	23.7	89	88	91	0.7	2.0	0.76	0.54	-	5[3]	13	30	31
C$\bar{R}$-3	P11	ST3	37.3-37.9	20.2	99	96	100	1.0	2.0	1.14	0.57	-	32	95	182	29
C$\bar{R}$-4	P12	ST2	17.5-18.1	18.4	106	103	105	0.4	3.0	0.80	1.00	-	41	119	213	32
C$\bar{R}$-5	SWR3	ST3	42.6-44.2	18.7	108	105	108	1.5	1.5	1.03	0.35	-	24	39	65	22
C$\bar{R}$-6	SWR6	ST5	57.2-58.9	27.1	94	90	94	1.5	1.5	1.24	0.41	-	73	120	122	23
C$\bar{R}$-7	SWR9	ST1	17.1-19.5	32.6	83	80	83	1.0	1.5	1.01	0.50	-	34[4]	126	194	31

GEOTECHNICAL ENGINEERS INC.

NOTES: (1) Due to high mica content, the specimens swelled after extrusion from the tube and therefore, the initial dry unit weights of the triaxial specimen are lower than the dry unit weights in the tube.

(2) At no point during any test did the effective confining pressure reach zero.

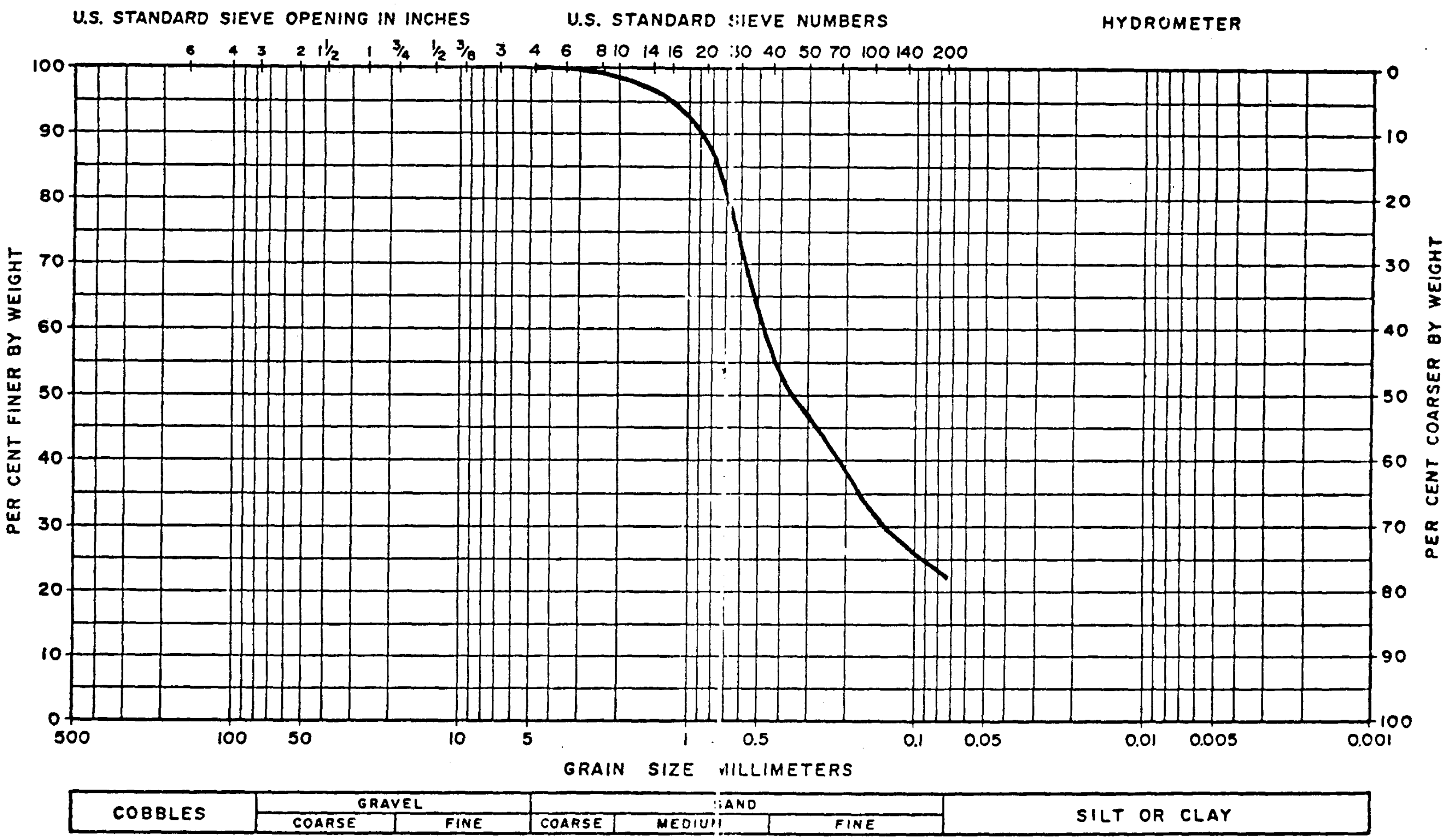
(3) In test C$\bar{R}$-1 and C$\bar{R}$-2, the specimens reached a double amplitude strain of 2.5% in the cycle preceding the one listed.

(4) In test C$\bar{R}$-7, the specimen reached a double amplitude strain of 2.5% in 17 cycles.

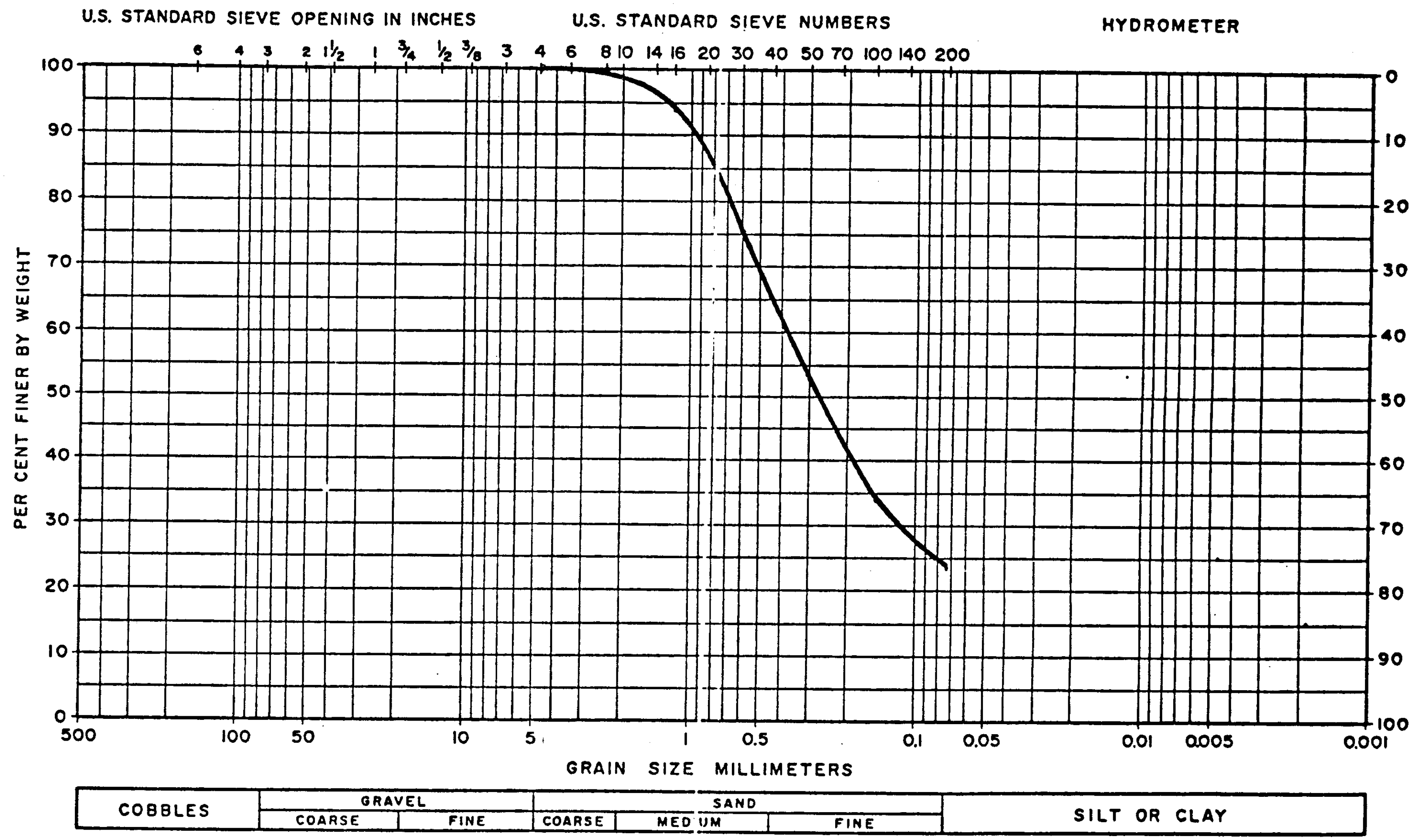
(5) In all tests except those noted, the maximum compressive strain of 2.5%, 5% and 10% occurred at the same time or earlier than the double amplitude strain of 2.5%, 5% and 10% respectively.

Project 75260
December 31, 1975
Revised March 28, 1978

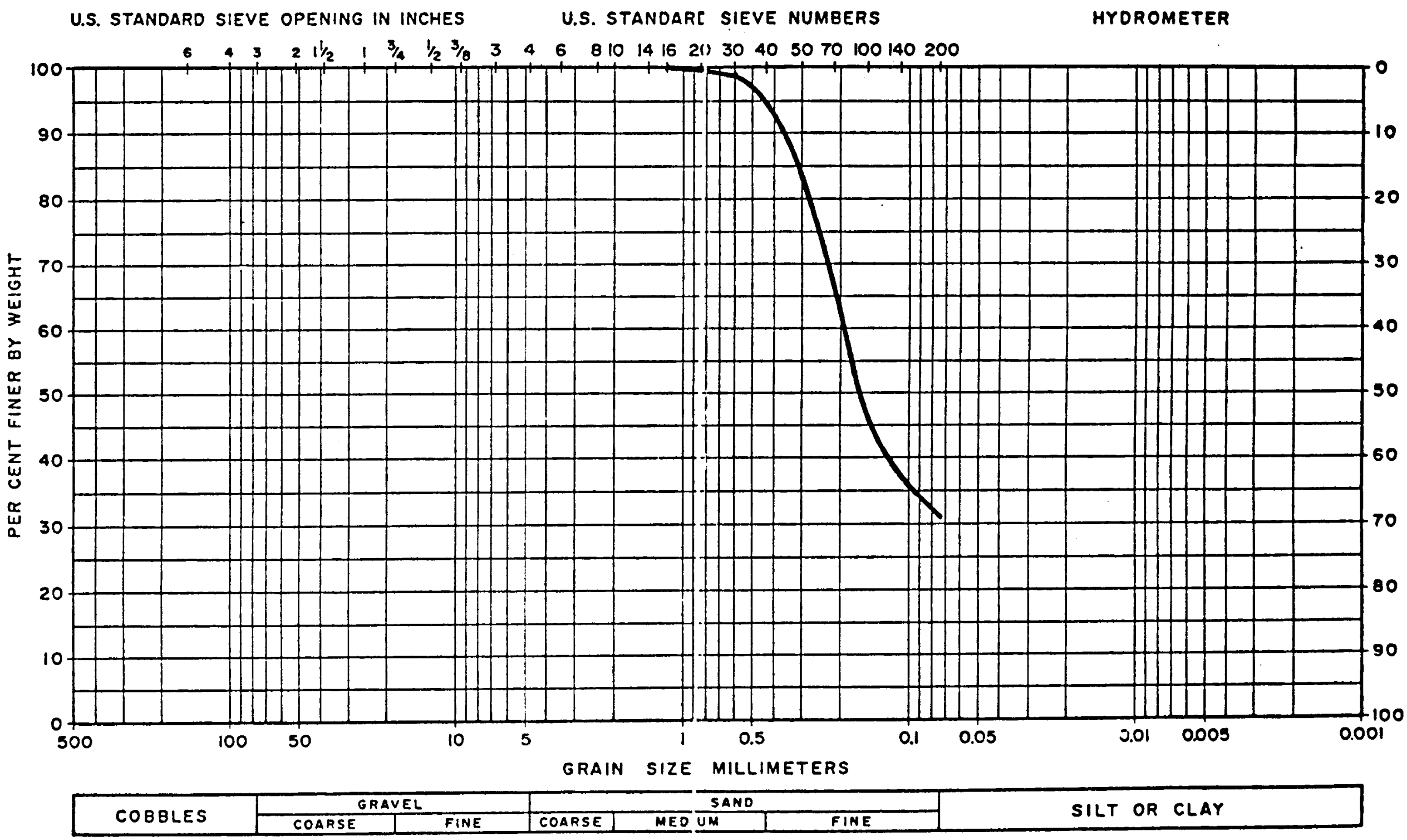
N03EA204



Stone & Webster Boston, Massachusetts	North Anna Power Station	GRAIN SIZE CURVE Boring SWR3 Sample ST3
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	December 30, 1975 Fig. 1

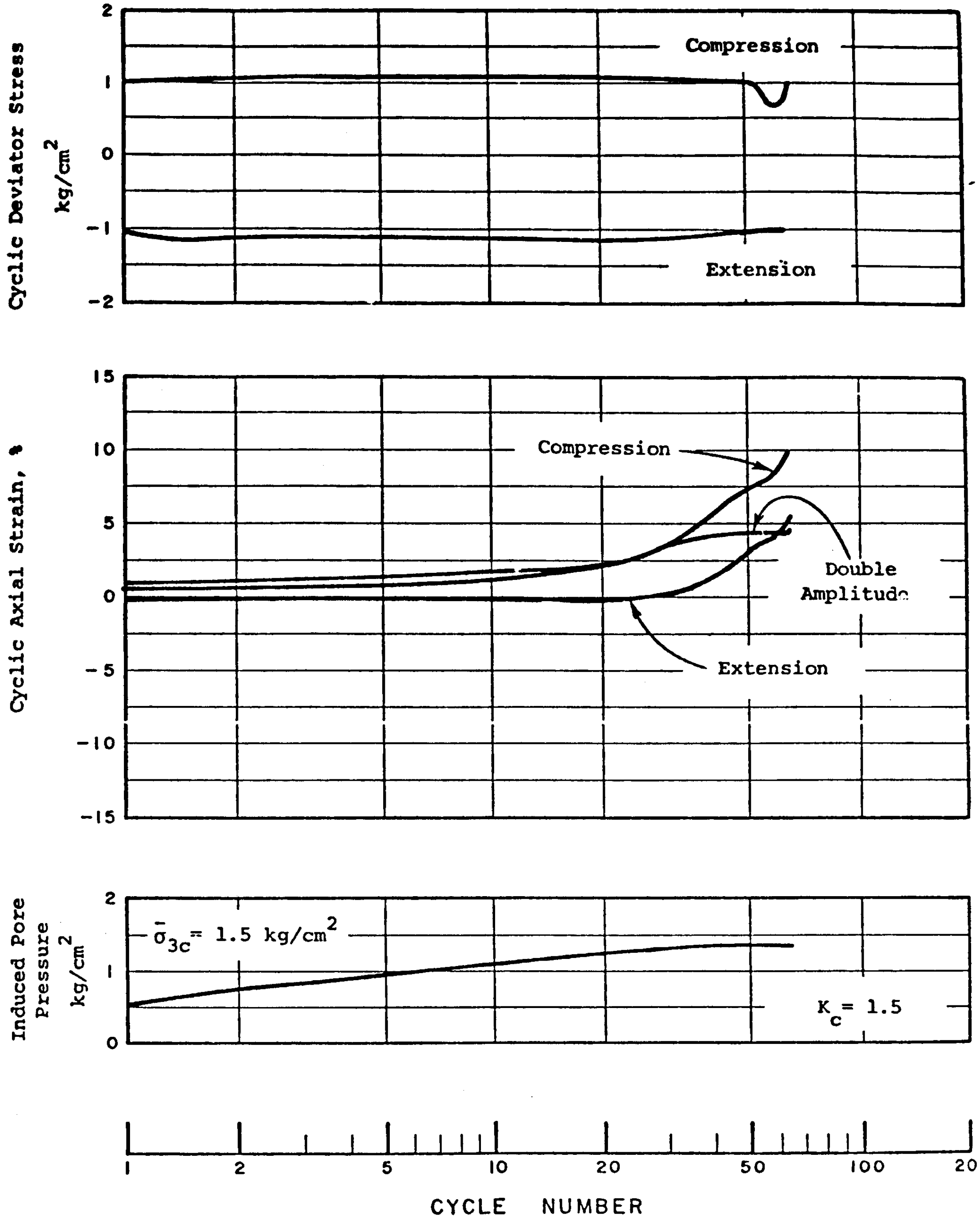


Stone & Webster Boston, Massachusetts	North Anna Power Station	GRAIN SIZE CURVE Boring SWR5 Sample ST5
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	December 30, 1975 Fig. 2



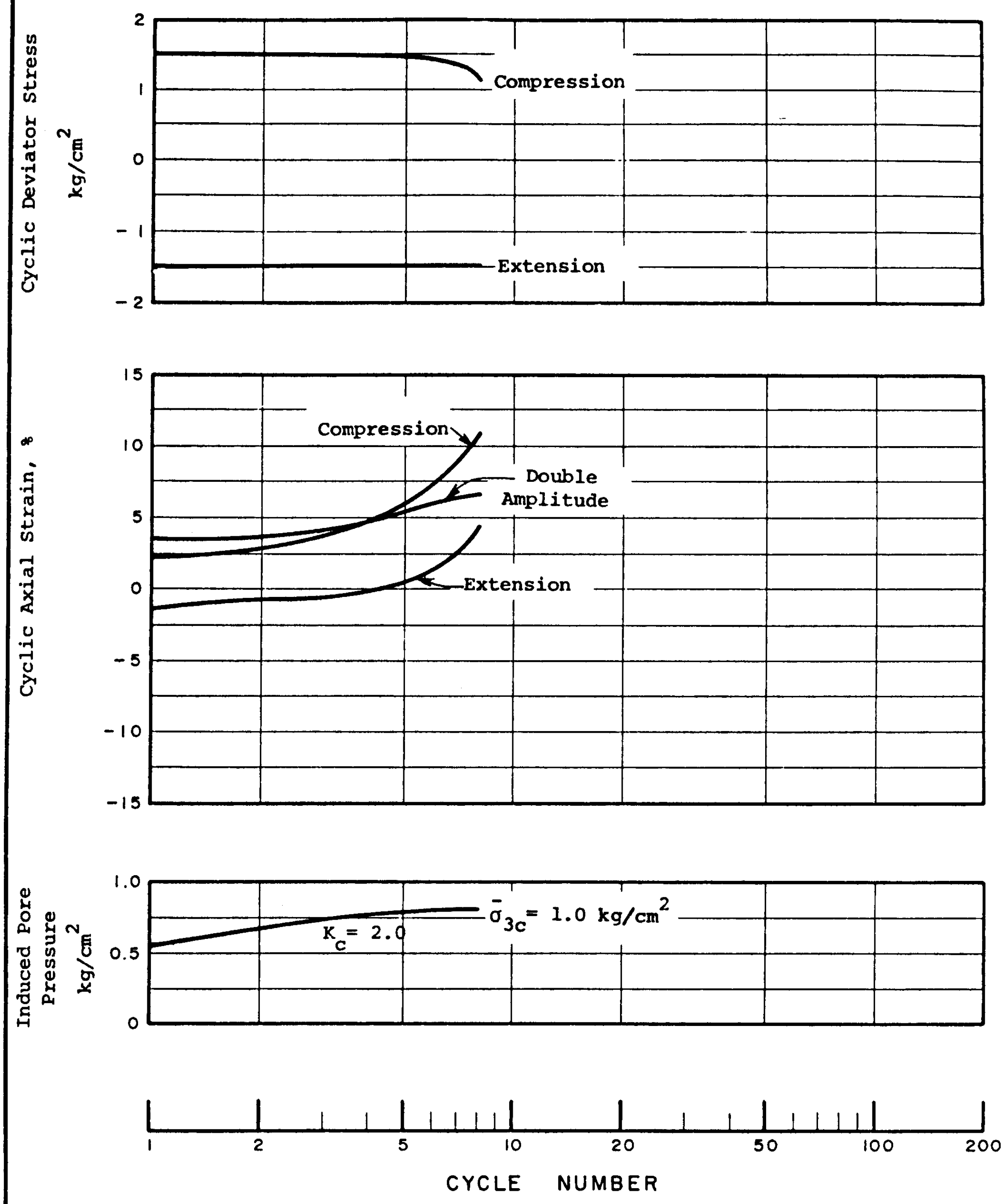
Stone & Webster Boston, Massachusetts	North Anna Power Station	GRAIN SIZE CURVE Boring SWR9 Sample ST1
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	December 30, 1975 Fig. 3

N03EA207



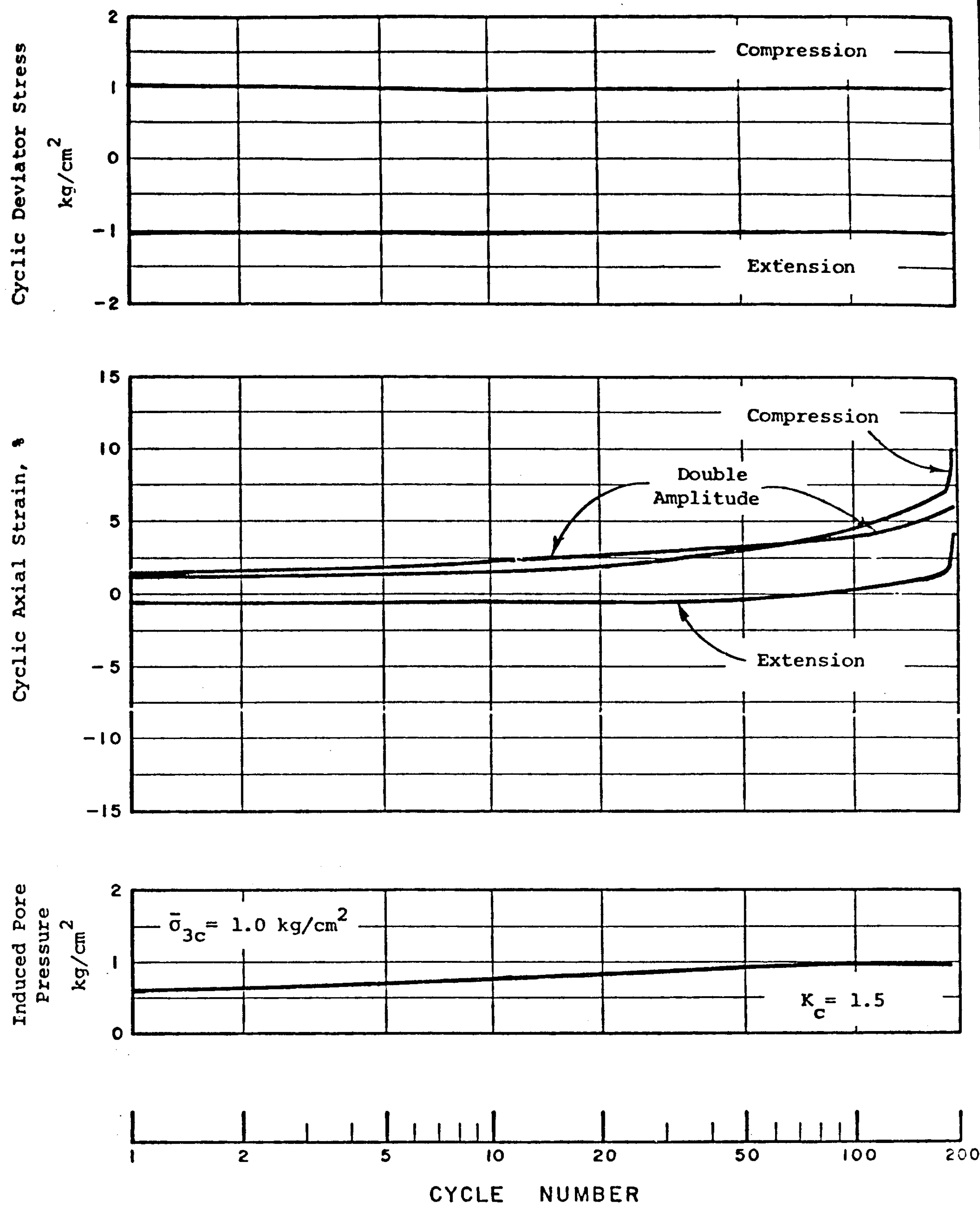
Stone & Webster Boston, Massachusetts	North Anna Power Station	CYCLIC LOAD TEST CR-5 Boring SWR3 Sample ST3
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	December 30, 1975 Fig. 4

N03EA208

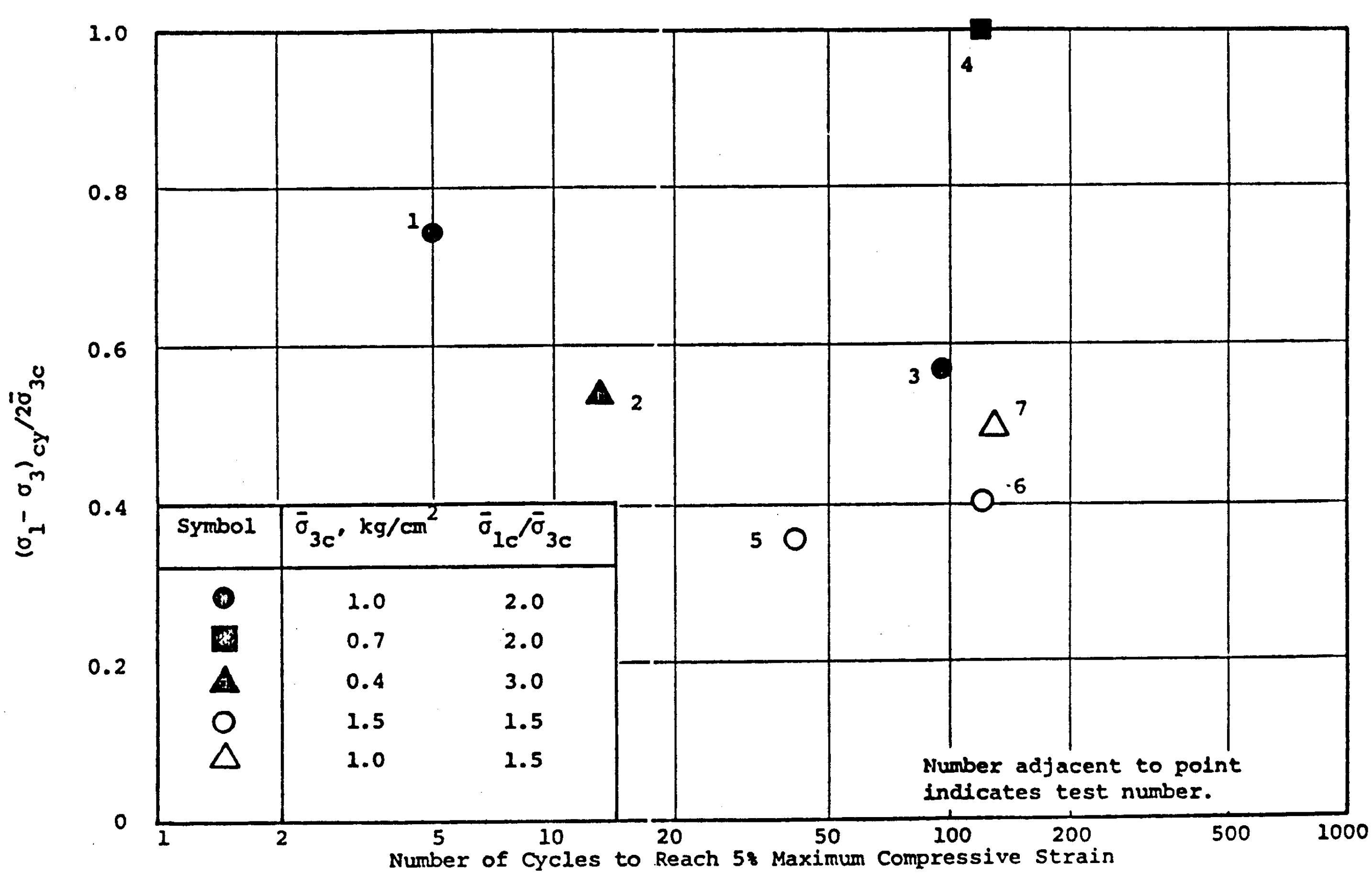


Stone & Webster Boston, Massachusetts	North Anna Power Station	CYCLIC LOAD TEST CR-1 Boring SWR7 Sample ST5
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	December 3, 1975 Fig. 5

N03EA209

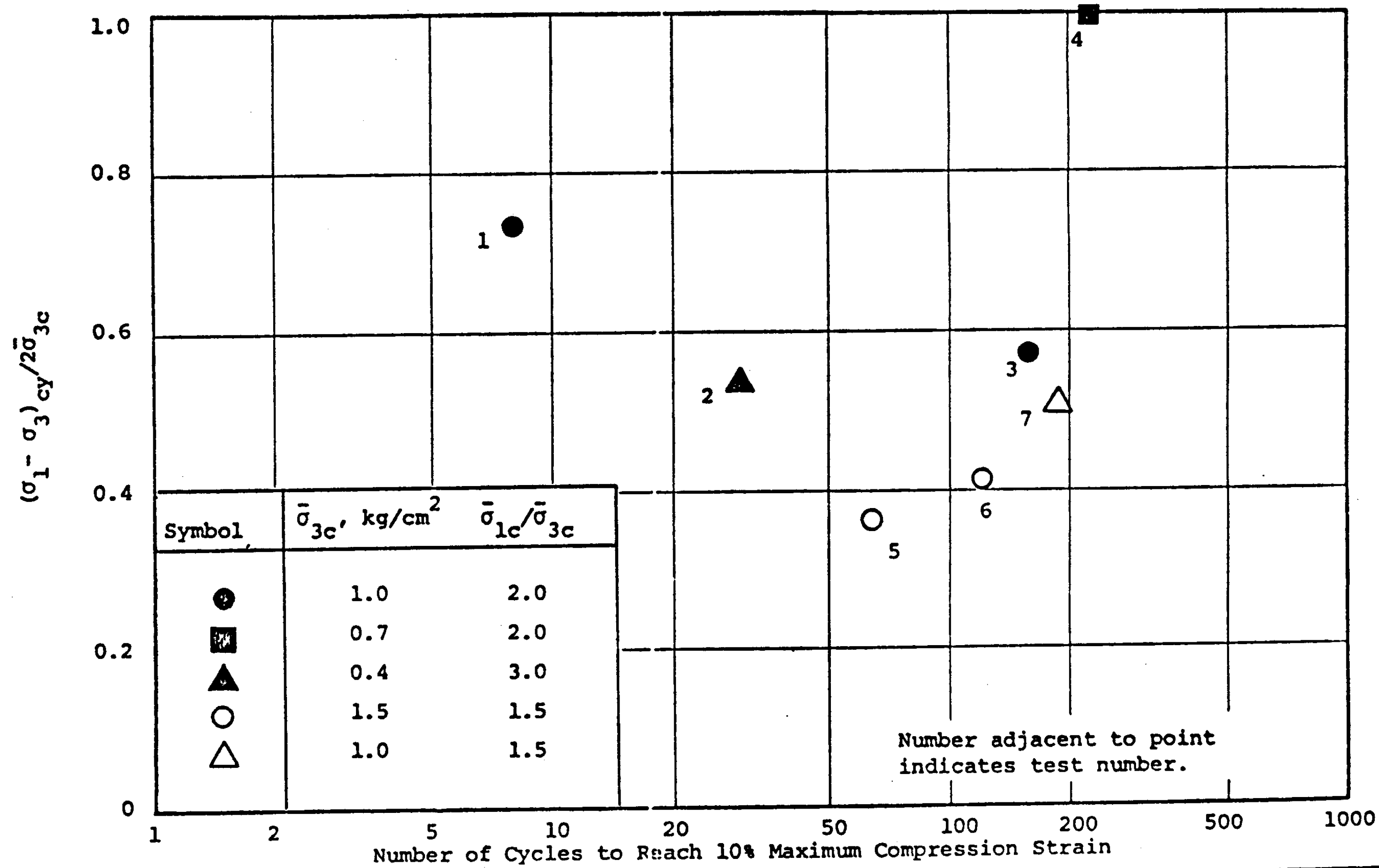


Stone & Webster Boston, Massachusetts	North Anna Power Station	CYCLIC LOAD TEST CR-7 Boring SWR9 Sample ST1
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	December 30, 1975 Fig. 6



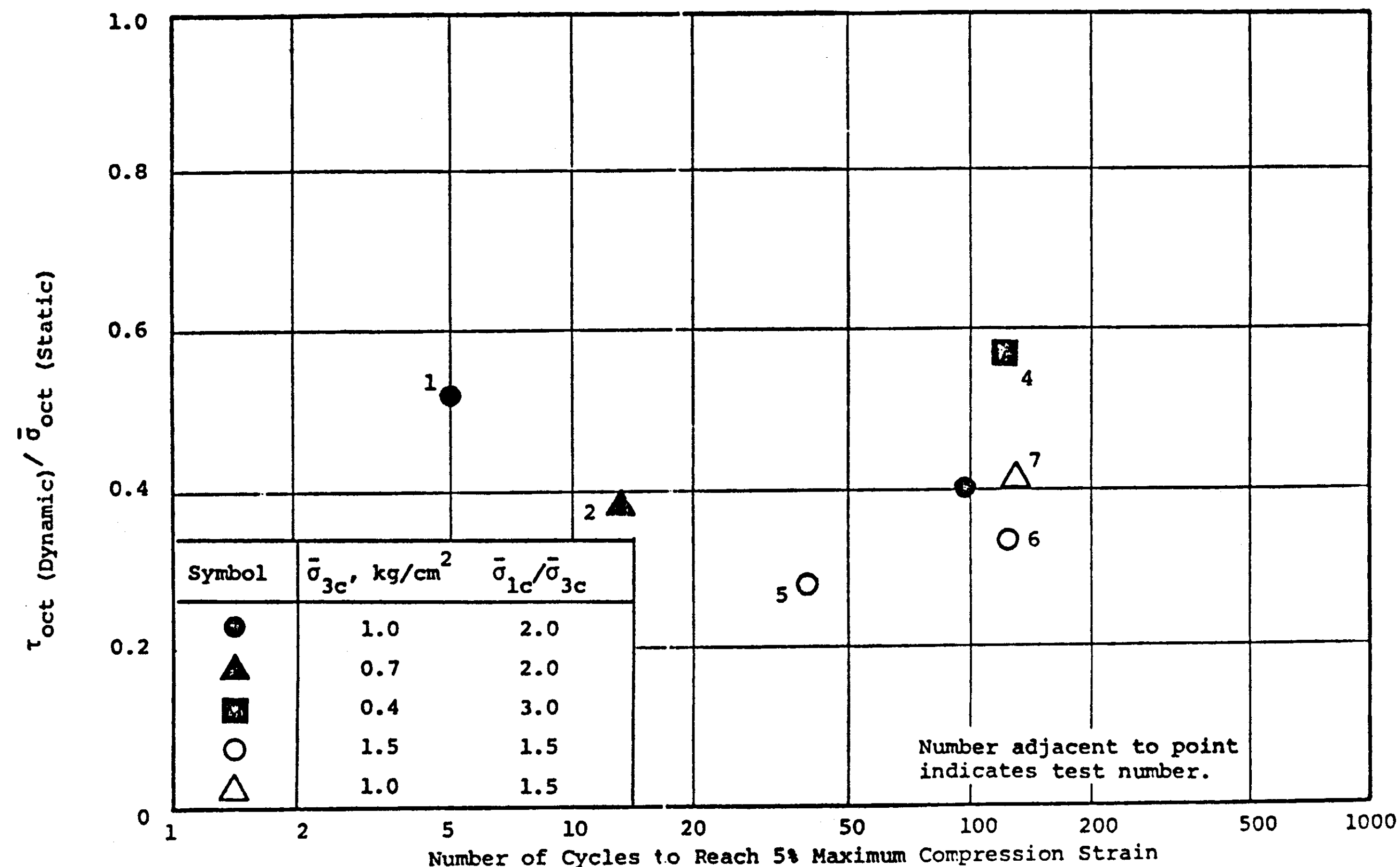
Stone & Webster Boston, Massachusetts	North Anna Power Station	SUMMARY PLOT $C\bar{R}$ Tests
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	December 29, 1975 Fig. 7

N03EA211



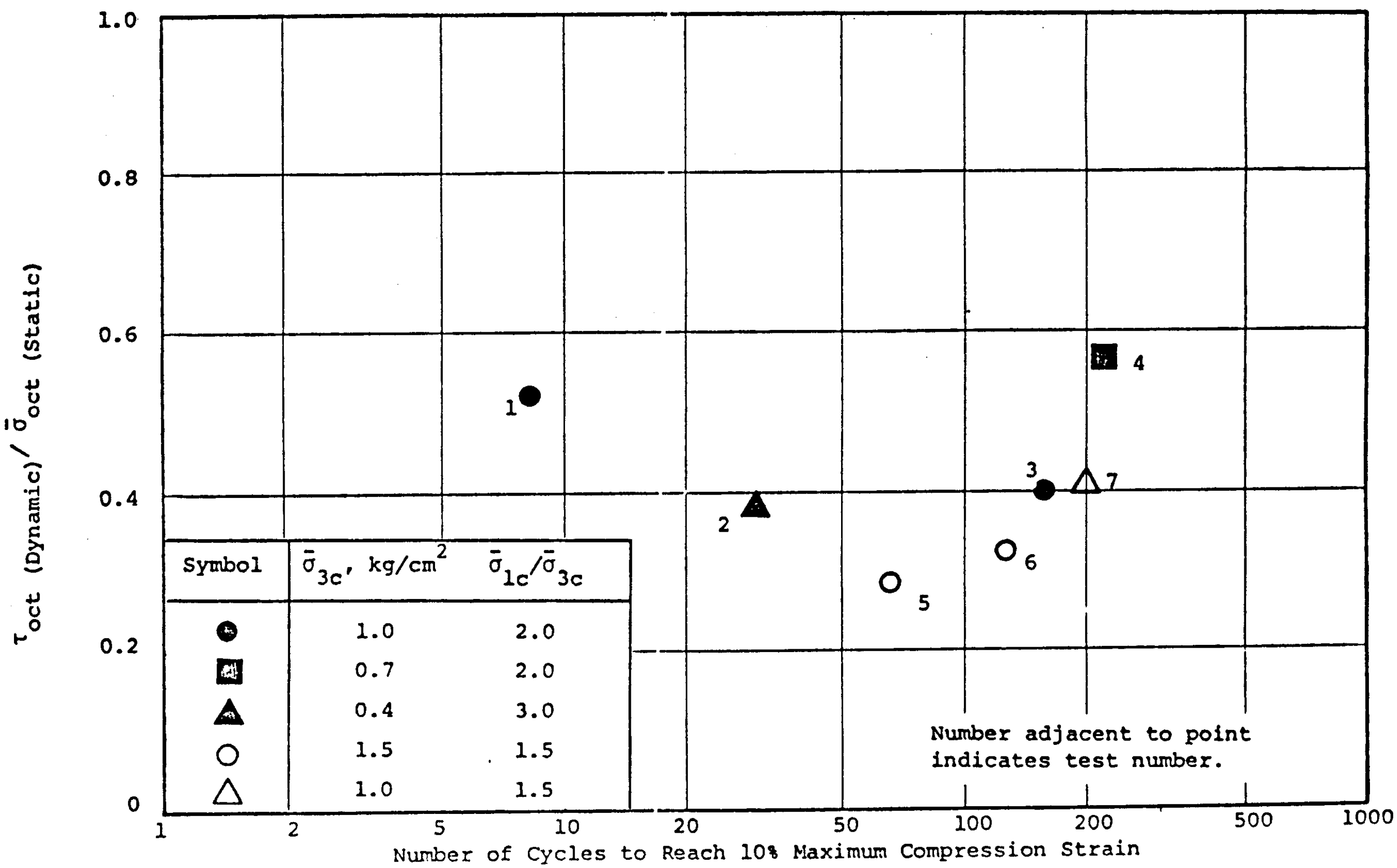
Stone & Webster Boston, Massachusetts	North Anna Power Station	SUMMARY PLOT $C\bar{R}$ Tests
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	December 29, 1975 Fig. 8

N03EA212



Stone & Webster Boston, Massachusetts	North Anna Power Station	SUMMARY PLOT CR Tests
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	December 29, 1975 Fig. 9

N03EA213



Stone & Webster Boston, Massachusetts	North Anna Power Station	SUMMARY PLOT C$\bar{R}$ Tests
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	December 30, 1975 Fig. 10

N03EA214

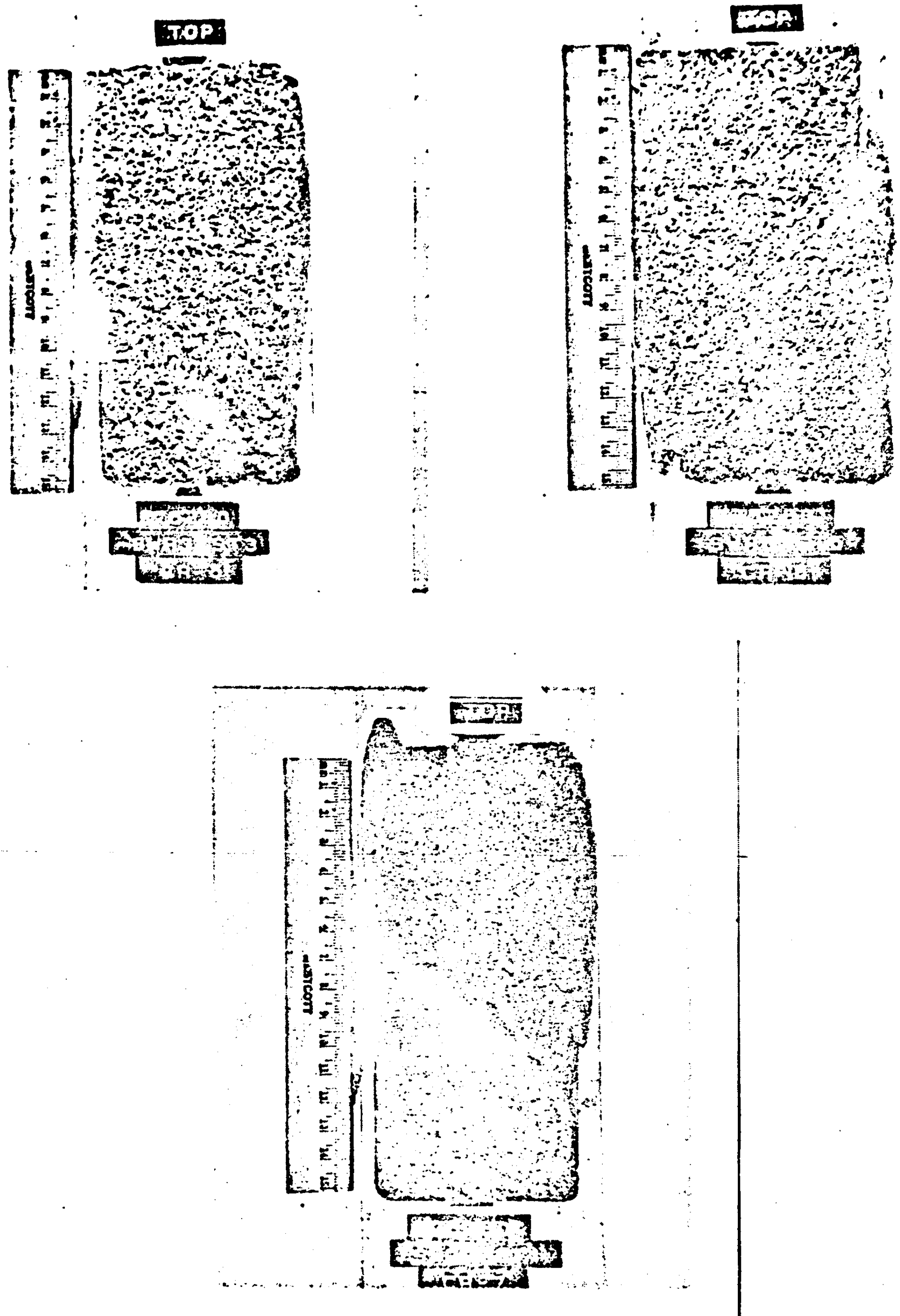


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Fig. 11

DESCRIPTION OF UNDISTURBED SAMPLES
BORING NO. SWR3

Project North Anna Power Station

Project No. 75260
Page 1 of 1

Sample No. and Depth ft.	Section No.	Length of Section in.	Description
ST3	-	7.2	Tan slightly micaceous silty medium to fine sand. Minerals vary from black to white and are banded at approximately 40° from the vertical. One very prominent band of intact quartz crystals up t o 16 mm wide is located in the bottom half of the speci-men (Residual Soil). The specimen swelled after extrusion from the tube due to the mica content of the soil. Failure occurred in compression by develop-ing 2 shear planes in the top half of the specimen.

DESCRIPTION OF UNDISTURBED SAMPLES
BORING NO. SWR5

Project North Anna Power Station

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Sample No. and Depth ft.	Section No.	Length of Section in.	Description
ST5	-	7.2	Multicolored silty micaceous medium to fine sand. Colors range from black to white and green to brown. Minerals are banded at approximately 45°. (Residual Soil) The specimen swelled after extrusion from the tube due to the mica content of the soil. Failure occurred in compression by developing one well defined shear plane parallel to foliation of minerals.

DESCRIPTION OF UNDISTURBED SAMPLES
BORING NO. SWR9

Project North Anna Power Station

Project No. 75260
Page 1 of 1

Sample No. and Depth ft.	Section No.	Length of Section in.	Description
ST1	-	7.0	Mottled tan, light brown and black very micaceous silty fine sand. Coloring of minerals occurs in spots and streaks and generally trend 45° from vertical. Bottom half of specimen contains one streak of black silty fine sand up to 10 mm wide and 45° from vertical. (Residual Soil) The specimen swelled after extrusion from the tube due to the mica content of the soi1. Failure occurred in compression by developing a shear plane in the top 2/3 of the specimen parallel to banding of minerals.

Appendix 3E
Attachment 3[1]

Report on Laboratory Soil Testing Service Water Reservoir Virginia Electric and Power Company

1. Attachment 3 to Appendix 3E was submitted as Appendix L in the original FSAR.

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Attachment 3 to Appendix 3E
Report on Laboratory Soil Testing
North Anna Power Station
Service Water Reservoir
Virginia Electric and Power Company

The report *Report on Laboratory Soil Testing, North Anna Power Station, Service Water Reservoir, Virginia Electric and Power Company* prepared by Geotechnical Engineers Inc. and dated June 21, 1976, was incorporated into the license application and submitted to the Nuclear Regulatory Commission as a separately bound document (20 copies) in Amendment 54. The report, however, was not given general distribution to all holders of the FSAR. A copy of the report, if not included in this FSAR, is available for review in the Nuclear Regulatory Commission's Public Document Reading Room.

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REPORT ON
LABORATORY SOIL TESTING
NORTH ANNA POWER STATION
SERVICE WATER RESERVOIR
VIRGINIA ELECTRIC AND POWER COMPANY

Submitted to

STONE AND WEBSTER ENGINEERING CORP.
Boston, Massachusetts

GEOTECHNICAL ENGINEERS INC.
1017 Main Street
Winchester, Massachusetts 01890

Project 75260
June 21, 1976

Donald D. Hunt

Ronald C. Hirschfeld for Gonzalo Castro

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4. CONSOLIDATED-UNDRAINED ($\bar{R}$) TRIAXIAL TESTS

1. INTRODUCTION

1.1 Purpose

The purpose of this report is to present the results of a laboratory testing program carried out on undisturbed specimens of residual soil obtained from the site of the Service Water Reservoir of the North Anna Power Station.

1.2 Scope

The scope of work included the following:

11 Sieve Analyses
4 Combined Sieve and Hydrometer Analyses
11 Cyclic Consolidated-Undrained ($C\bar{R}$) Triaxial Tests
2 Consolidated-Undrained Triaxial Test

1.3 Authorization

The work described in this report was authorized by Mr. J. H. Bryant of Stone & Webster Engineering Corporation under Purchase Order No. E17115 on May 27, 1976.

2. SAMPLE DESCRIPTIONS

Detailed descriptions of each specimen are given in Appendix A and photographs of longitudinal slices are given in Appendix B.

In general, the specimens were residual soils consisting of silty medium to fine sands. The percentage of soil by weight passing the No. 200 sieve ranged from approximately 20% to 65%. Specimens from borings P15 and SWR11 contained micaceous banding. The bands of minerals which occurred in the parent rock were still noticeable and dipped at angles ranging from about 30° to 60° from the horizontal.

3. OUTLINE OF TRIAXIAL TESTING PROCEDURE

A section of tube about 8 in. (20 cm) long was cut using a tube cutter while maintaining the tube in its upright position. The pressure applied to the tube during the cutting operation was kept to a minimum to avoid deforming the tube. The test specimen was trimmed to the desired length and weighed while still in the cut section of tube. It was then extruded into a rubber membrane, weighed again and placed in the triaxial cell. Any material which remained in the tube after extrusion of the specimen was collected, oven-dried and weighed to permit the determination of the specimen dry unit weight in the tube. No vacuum was applied to the specimen at any time during setup.

The specimen dimensions were determined prior to performing the test and before consolidation, they measured about 17 cm in height and 7.3 cm in diameter. When compared to the in-tube measurements, the specimens expanded upon extrusion with only one exception, namely Sample ST7, Boring P16. The in-tube dimensions of this sample were considered invalid due to the existence of a slight annular space (less than 0.3 mm) between the sample and the inside wall of the tube.

After completion of the triaxial test, the specimen was sliced longitudinally, described and photographed. It was then oven-dried and its initial water content and dry unit weights before and after extrusion and after consolidation were determined. Table 1 is a summary of the calculated dry unit weights. The dry unit weight in the tube was determined using both the inside diameter of the cutting edge and the inside diameter of the tube which measured 7.2 cm and 7.3 cm, respectively. It can be seen that although the specimens expanded upon extrusion, after consolidation the dry unit weights generally exceeded the dry unit weights in the tube as calculated from the cutting edge diameter of the tube.

Grain size analyses were performed on each specimen and are presented in Figs. 1 through 13.

4. CYCLIC CONSOLIDATED-UNDRAINED ($C\bar{R}$) TRIAXIAL TESTS

4.1 Procedure

An 8-in.-long tube section was cut and prepared as described in Section 3. After the cell was assembled, the specimen was subjected to an initial confining pressure of 0.5 kg/cm^2, the valves were opened, and the sample was consolidated isotropically to $\bar{\sigma}_{3c}$ = 0.5 kg/cm^2. To improve the saturation, water was then circulated upwards through the specimen under a head of water equal to about 8 to 10 inches.

At this point the specimens were anisotropically consolidated to the required K_c ($\bar{\sigma}_{1c}/\bar{\sigma}_{3c}$) with $\bar{\sigma}_{3c}$ = 0.5 kg/cm^2. A back pressure ranging from 3 to 10 kg/cm^2 was applied to ensure saturation. The measured B values ranged from 0.91 to 0.98. After saturation, the consolidation was continued to the desired effective consolidation stresses as listed in Summary Table 2.

The drainage values were then closed and a cyclic deviator stress was applied to the specimen at a frequency of 0.5 cycles per second. A continuous record of axial load, pore pressure, and deformation was obtained using a strip chart recorder.

4.2 Results

The results of the individual tests are presented in Figs. 14 to 21, and are summarized in Table 2. Each figure shows a plot of the following:

Peak Cyclic Deviator Stress in Compression and Extension versus Cycle Number

Peak Axial Strain in Compression and Extension and Double Amplitude Strain versus Cycle Number

Maximum Induced Pore Pressure During Each Cycle versus Cycle Number

Summary plots are shown in Figs. 22, 24 and 25 which show the relationship between the cyclic stress ratio, $(\sigma_1 - \sigma_3)_{cy}/2\bar{\sigma}_c$, and the number of cycles to reach a specified cyclic axial strain.

Similar plots, shown in Figures 23, 26 and 27, show the relationship between $\tau_{oct}(\text{dynamic})/\bar{\sigma}_{oct}(\text{static})$ and the number of cycles to reach a specified cyclic axial strain.

The octahedral stresses were computed as follows:

$$\tau_{oct(Dynamic)} = \frac{1}{3}\left[(\sigma_1 - \sigma_2)^2_{cy} + (\sigma_2 - \sigma_3)^2_{cy} + (\sigma_3 - \sigma_1)^2_{cy}\right]^{\frac{1}{2}}$$

$$= \frac{\sqrt{2}}{3}(\sigma_1 - \sigma_3)_{cy}$$

where the subscript cy refers to cyclic stresses.

$$\bar{\sigma}_{oct(Static)} = \frac{1}{3}(\bar{\sigma}_{1c} + \bar{\sigma}_{2c} + \bar{\sigma}_{3c})$$

$$= \frac{1}{3}(2 + K_c)\bar{\sigma}_{3c}$$

where the subscript c refers to consolidation stresses and $K_c = \bar{\sigma}_{1c}/\bar{\sigma}_{3c}$

The results of two C$\bar{R}$ tests conducted at $K_c = 1.5$ and $\bar{\sigma}_{3c} = 1.5$ kg/cm^2 presented in the previous letter report dated December 31, 1975 are listed in Table 3 for convenience and are plotted in the appropriate summary figures. (Figs. 24-27).

4.3 Comments

In none of the tests performed did the measured effective confining pressure reach zero during the test. The pore pressure was measured at the end of the specimens. Thus, the pore pressure in the zone of large deformations could have been different, since the pore pressure probably did not equalize along the length of the specimen due to the fast rate of loading.

For the three anisotropically consolidated tests the maximum compressive strain was chosen as the strain criterion since the specimens developed higher strains in compression than extension. The mode of deformation was bulging; failure planes were not apparent.

Two tests, C$\bar{R}$17 and C$\bar{R}$18 gave results which seemed consistent with each other but not with the other three anisotropically consolidated tests in that a lower cyclic stress ratio was needed to obtain a given strain in the same number of cycles. A reason for the difference may be the significantly lower unit weight and higher contents of fines for the lower strength specimens (74 pcf) as compared to the stronger specimens (94 to 108 pcf).

For the isotropically consolidated tests, the double amplitude strain was chosen as the strain criterion. In all cases, the strain in extension was greater than in compression and, in several cases, as evidenced in the photographs, failure planes developed.

The results in Figs. 22 and 23 indicate that as the effective confining pressure is increased the cyclic stress ratio required to cause a given percent double amplitude strain in a given number of cycles is decreased. This result is in agreement with test results on other soils.

5. CONSOLIDATED-UNDRAINED ($\bar{R}$) TRIAXIAL TESTS

5.1 Procedure

One $\bar{R}$-test was performed on sample ST10B from Boring P15. The specimen preparation up to beginning the test is as previously described in Sections 3 and 4. The specimen was consolidated to an effective confining pressure of 1.9 kg/cm^2 which was approximately equal to the vertical effective stress in-situ.

To ensure equalization of pore pressure, the rate of strain used was 0.3 mm/min.

5.2 Results

The test results are given in Fig. 28 and summarized in Table 4.

The specimen tested consisted of a faintly banded, orange brown, micaceous, silty, medium to fine sand. The banding dipped approximately 30^o from the horizontal. Near the top of the specimen was a 5 mm band of angular, coarse sand-size quartz particles. During the test the specimen developed two failure planes, parallel to the banding, one of which was along the coarse sand band.

The maximum $(\sigma_1 - \sigma_3)$ reached was 3.5 kg/cm^2 and $\bar{\phi}$ was about 36^o.

TABLE 1 - SUMMARY OF SPECIMEN DRY UNIT WEIGHTS

Test No.	Boring No.	Sample Section	Depth	Dry Unit Weights			
				In the Tube		Triaxial Specimen	
				γ_{d_t} (1)	γ_{d_t} (2)	Initial γ_{di}	After Consolidation γ_{dc}
			ft	pcf	pcf	pcf	pcf
$\overline{CR}$-8	P-15	ST24B	66-68	105.8	102.4	101.1	-
$\overline{CR}$-9	P-16	ST7A	37.5-39.5	(3) -	-	104.1	107.2
$\overline{CR}$-10	P-15	ST24A	66-68	110.4	107.3	106.4	111.1
$\overline{CR}$-11	P-17	ST9B	47.5-49.5	89.8	87.6	86.3	90.9
$\overline{CR}$-12	P-16	ST7B	37.5-39.5	(3) -	-	92.1	95.3
$\overline{CR}$-13	P-17	ST9A	47.5-49.5	95.8	93.7	92.8	97.6
$\overline{CR}$-14	SWR-11	ST1C	19.5-21.5	97.0	94.4	93.2	96.9
$\overline{CR}$-15	P-15	ST10A	31-33	96.7	94.1	93.3	96.2
$\overline{CR}$-16	SWR-11	ST1B	19.5-21.5	91.8	89.3	88.5	92.1
$\overline{CR}$-17	SWR-13	ST9B	47.5-49.5	75.9	74.2	73.3	75.9
$\overline{CR}$-18	SWR-13	ST9A	47.5-49.5	75.3	73.7	73.5	76.0
$\overline{R}$-1	SWR-11	ST1A	19.5-21.5	95.2	92.3	92.1	95.4
$\overline{R}$-2	P-15	ST10B	31-33	103.0	100.0	97.2	99.9

NOTES: (1) Calculated using measured cutting edge inside diameter.

(2) Calculated using measured tube inside diameter.

(3) Annular space of about 0.03 mm., unit weight not valid.

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TABLE 2 - CYCLIC CONSOLIDATED-UNDRAINED ($C\bar{R}$) TRIAXIAL TESTS
NORTH ANNA POWER STATION / SERVICE WATER RESERVOIR

Test No. $C\bar{R}$-	Boring No.	Sample and Section	Depth	Initial Water Content	Dry Unit Weights: Triaxial Initial γ_{di}	Dry Unit Weights: Specimen After Consolidation γ_{dc}	Effective Confining Pressure $\bar{\sigma}_{3c}$	Consolidation Ratio k_c $\bar{\sigma}_{1c}/\bar{\sigma}_{3c}$	Cyclic Deviator Stress $(\sigma_1 - \sigma_3)_{cy}$	Cyclic Stress Ratio $\frac{(\sigma_1 - \sigma_3)_{cy}}{2\bar{\sigma}_c}$	$\frac{\tau_{oct}\ (dynamic)}{\sigma_{oct}\ (static)}$	Number of Cycles to Reach: $\bar{\sigma}_3 = 0$	Double Amplitude Strain (4): 2.5%	5%	10%	Grain Size: Fig. No.	Passing No. 200 Sieve
			ft	%	pcf	pcf	kg/cm^2		kg/cm^2								%
8 (1)	P-15	ST24B	66-68	24.2	101.1	-	-	-	-	-	-	-	-	-	-	4	23
9 (2)	P-16	ST7A	37.5-39.5	17.8	104.1	107.2	2.5	1.0	-	-	-	-	-	-	-	5	24
10	P-15	ST24A	66-68	21.7	106.4	111.1	2.5	1.0	1.94	0.39	0.36	-	1	3	5	3	26
11	P-17	ST9B	47.5-49.5	33.9	86.3	90.9	2.5	1.0	1.51	0.30	0.28	-	2	7	16	8	56
12 (3)	P-16	ST7B	37.5-39.5	21.2	92.1	95.3	2.5	1.0	-	-	-	-	-	-	-	6	32
13	P-17	ST9A	47.5-49.5	28.0	92.8	97.6	2.5	1.0	1.20	0.24	0.23	-	14	23	37	7	25-40
14	SWR-11	ST1C	19.5-21.5	29.4	93.2	96.9	1.0	1.0	0.79	0.40	0.37	-	3	74	171	11	20
15	P-15	ST10A	31-33	19.5	93.3	96.2	1.5	1.5	1.69	0.56	0.46	-	1	1	2	1	28
16	SWR-11	ST1B	19.5-21.5	32.3	88.5	92.1	1.0	1.0	0.94	0.47	0.44	-	1	4	19	10	25
17	SWR-13	ST9B	47.5-49.5	36.9	73.3	75.9	1.5	1.5	1.30	0.43	0.35	-	1	1	2	13	65
18	SWR-13	ST9A	47.5-49.5	33.3	73.5	76.0	1.5	1.5	0.85	0.28	0.23	-	6	6	13	12	64

NOTES: (1) Test aborted - membrane leakage.
(2) Test aborted - cell malfunction.
(3) Test result not reported - error during load application.
(4) For the Anisotropic consolidated samples, the number cycles listed are those needed to reach compressive strains of 2.5, 5 and 10%.

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June 17, 1976

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TABLE 3 - CYCLIC CONSOLIDATED-UNDRAINED ($C\bar{R}$) TRIAXIAL TESTS
NORTH ANNA SERVICE WATER RESERVOIR

Test No.	Boring No.	Sample No.	Depth	Initial Water Content	Dry Unit Weights (1)			Effective Confining Pressure $\bar{\sigma}_{3c}$	Consolidation Stress Ratio K_c $\bar{\sigma}_{1c}/\bar{\sigma}_{3c}$	Cyclic Deviator Stress $(\sigma_1 - \sigma_3)_{cy}$	Cyclic Stress Ratio $\frac{(\sigma_1 - \sigma_3)_{cy}}{2\bar{\sigma}_{3c}}$	Number of Cycles to Reach				Percent Finer Than • 200 Sieve
					In the Tube γ_d	Triaxial Specimen Initial γ_{di}	Triaxial Specimen After Consolidation γ_{dc}					$\bar{\sigma}_{3c}$ 0 (2)	Maximum Compressive Strain Equal to (5) 2.5%	5%	10%	
			ft	%	pcf	pcf	pcf	kg/cm²								%
$C\bar{R}$-1	SWR7	ST5	42.5-43.1	26.1	94	93	95	1.0	2.0	1.47	0.74	-	2 (3)	5	8	44
$C\bar{R}$-2	SWR9	ST2	22.5-23.1	23.7	89	89	91	0.7	2.0	0.76	0.54	-	5 (3)	13	30	21
$C\bar{R}$-3	P11	ST3	37.3-37.9	20.2	99	96	100	1.0	2.0	1.14	0.57	-	32	95	152	29
$C\bar{R}$-4	P12	ST2	17.5-18.1	18.4	106	103	105	0.4	3.0	0.80	1.00	-	41	119	213	32
$C\bar{R}$-5	SWR3	ST3	42.6-44.2	18.7	108	105	108	1.5	1.5	1.05	0.35	-	24	39	65	22
$C\bar{R}$-6	SWR5	ST5	57.2-58.9	27.1	94	90	94	1.5	1.5	1.24	0.41	-	73	120	122	23
$C\bar{R}$-7	SWR9	ST1	17.1-18.5	32.6	83	80	83	1.0	1.5	1.01	0.50	-	34 (4)	126	194	31

NOTES: (1) Due to high mica content, the specimens swelled after extrusion from the tube and therefore, the initial dry unit weights of the triaxial specimen are lower than the dry unit weights in the tube.

(2) At no point during any test did the effective confining pressure reach zero.

(3) In test $C\bar{R}$-1 and $C\bar{R}$-2, the specimens reached a double amplitude strain of 2.5% in the cycle preceding the one listed.

(4) In test $C\bar{R}$-7, the specimen reached a double amplitude strain of 2.5% in 17 cycles.

(5) In all tests except those noted, the maximum compressive strain of 2.5%, 5% and 10% occurred at the same time or earlier than the double amplitude strain of 2.5%, 5% and 10% respectively.

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TABLE 4 - CONSOLIDATED UNDRAINED TRIAXIAL ($\bar{R}$) TESTS
NORTH ANNA POWER STATION / SERVICE WATER RESERVOIR

Test No.	Boring No.	Sample and Section	Depth	Initial Water Content	Dry Unit Weight Triaxial Specimen: Initial γ_{di}	Dry Unit Weight Triaxial Specimen: After Consolidation γ_{dc}	Effective Confining Pressure $\bar{\sigma}_c$	Back Pressure u_o	Maximum Deviator Stress $(\sigma_1 - \sigma_3)_{max}$	Induced Pore Pressure $(\sigma_1 - \sigma_3)_{max}$	Maximum Obliquity $\bar{\sigma}_1/\bar{\sigma}_{3\,max}$	Grain Size: Fig. No.	Grain Size: Passing No. 200 Sieve
			ft	%	pcf	pcf	kg/cm^2	kg/cm^2	kg/cm^2	kg/cm^2			%
$\bar{R}$-1	SWR-11	ST1A	19.5-21.5	31.1	92.1	95.4	1.0	8.0	(1) -	-	-	9	32
$\bar{R}$-2	P-15	ST10B	31-33	17.3	97.2	99.9	1.9	10.0	3.49	0.58	3.87	2	42

NOTE: (1) Test aborted, equipment failure.

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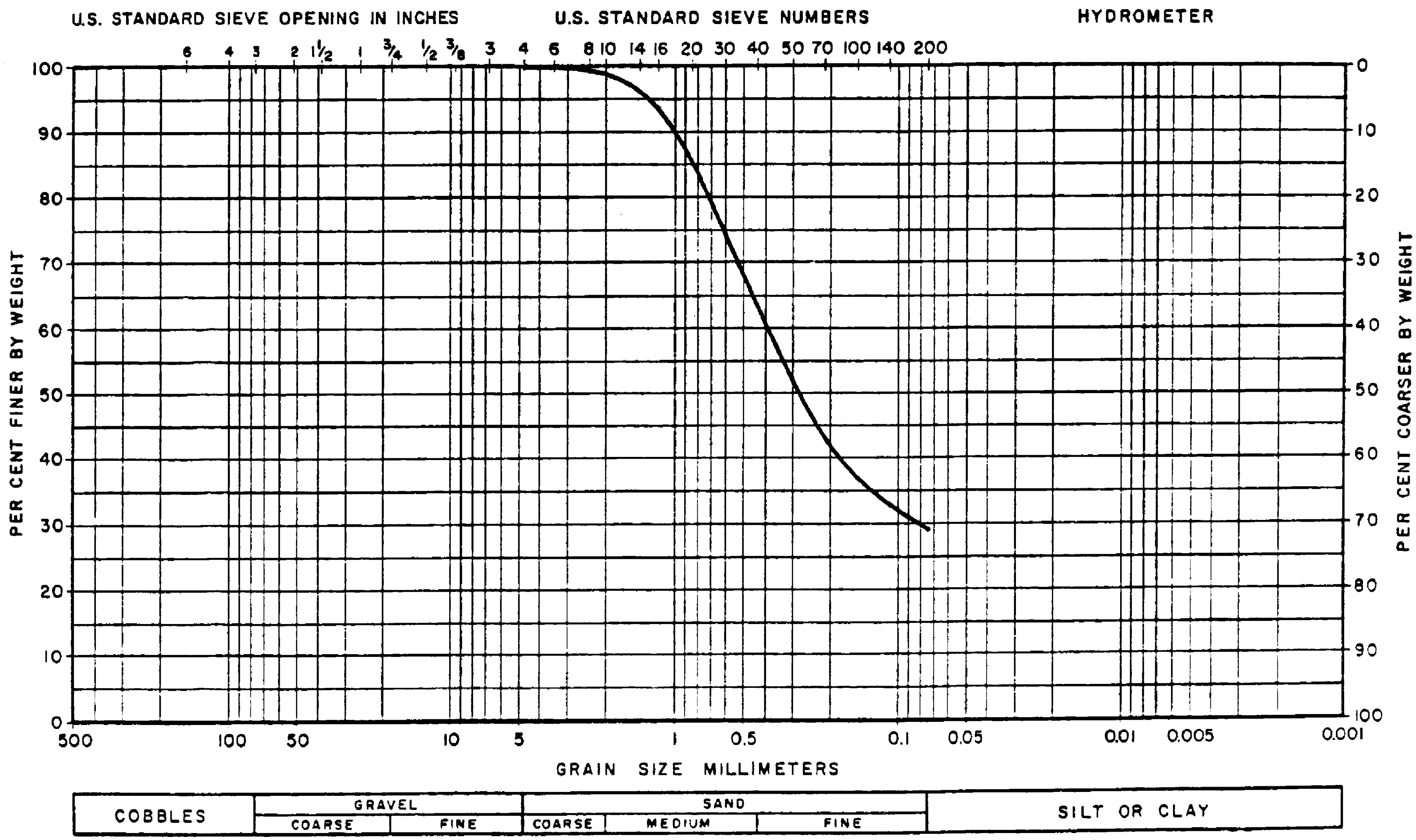

Test No. CR̄-15

Stone & Webster Eng. Corp. Boston, Massachusetts	North Anna Power Station	GRAIN SIZE CURVE Boring P-15 Sample ST10A
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 1

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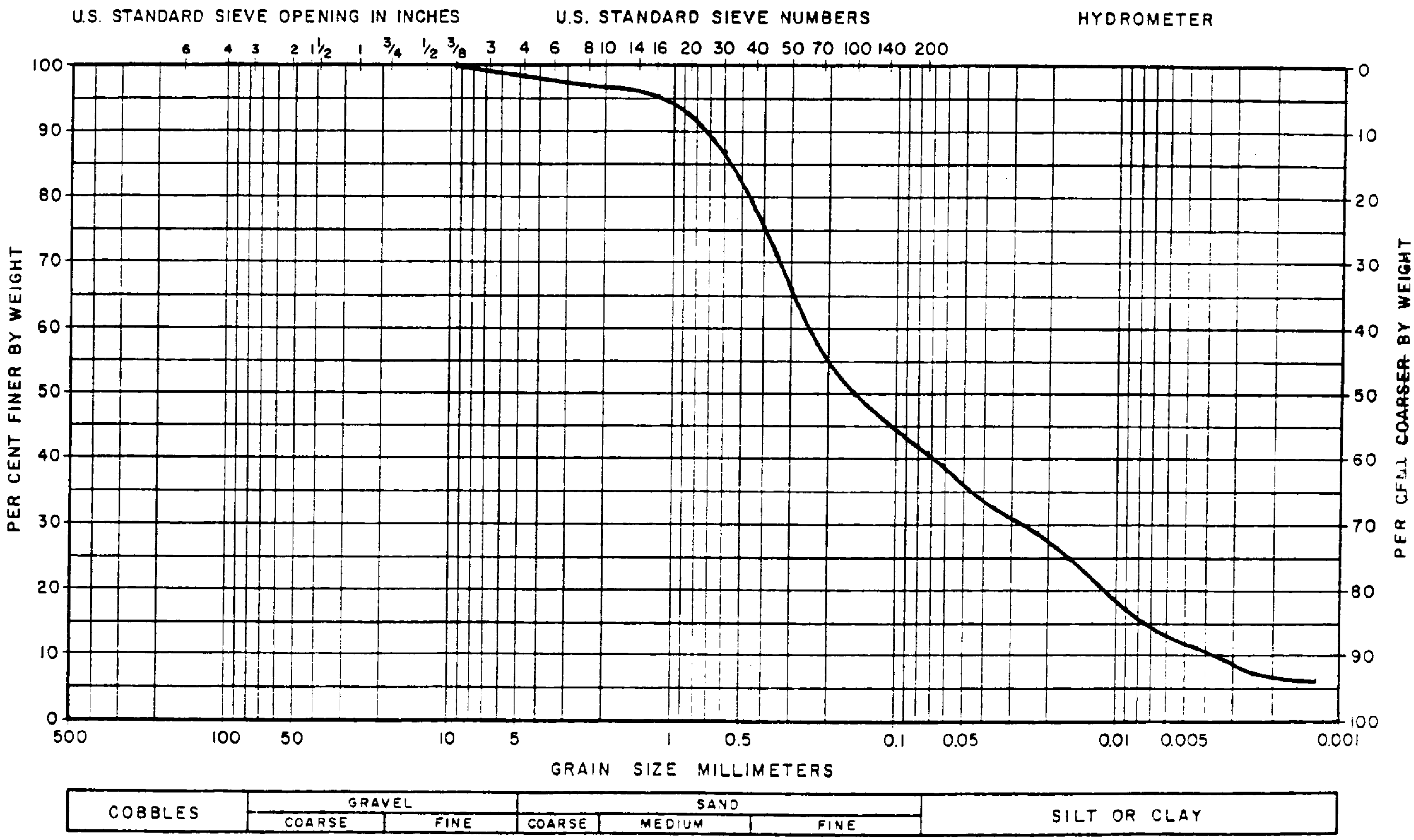

From Test No. $\bar{R}$-2

Stone & Webster Eng. Corp. Boston, Massachusetts	North Anna Power Station	GRAIN SIZE CURVE Boring P-15 Sample ST10B
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 2

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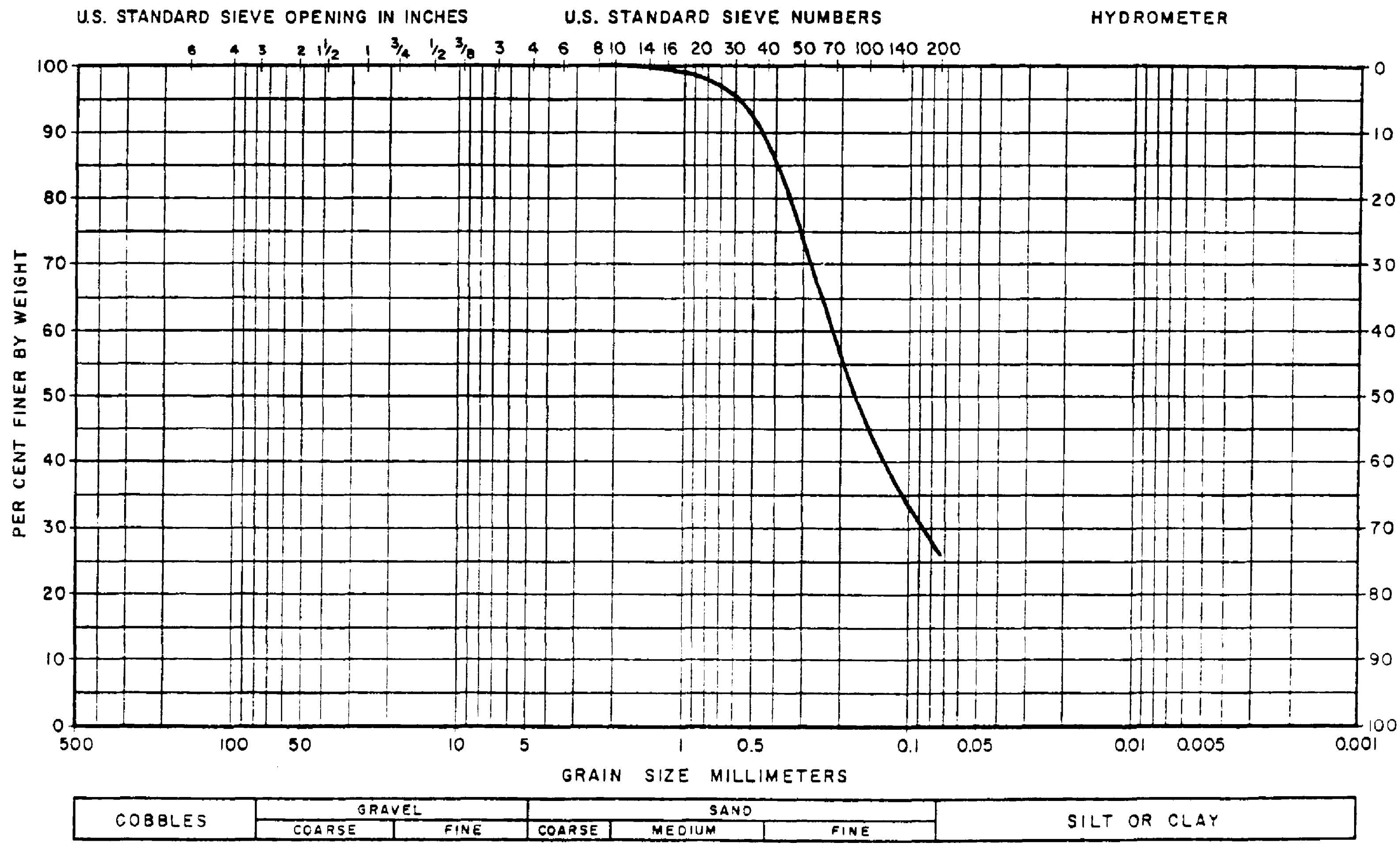

From Test No. CR-10

Stone & Webster Eng. Corp. Boston, Massachusetts	North Anna Power Station	GRAIN SIZE CURVE Boring P-15 Sample ST24A
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 3

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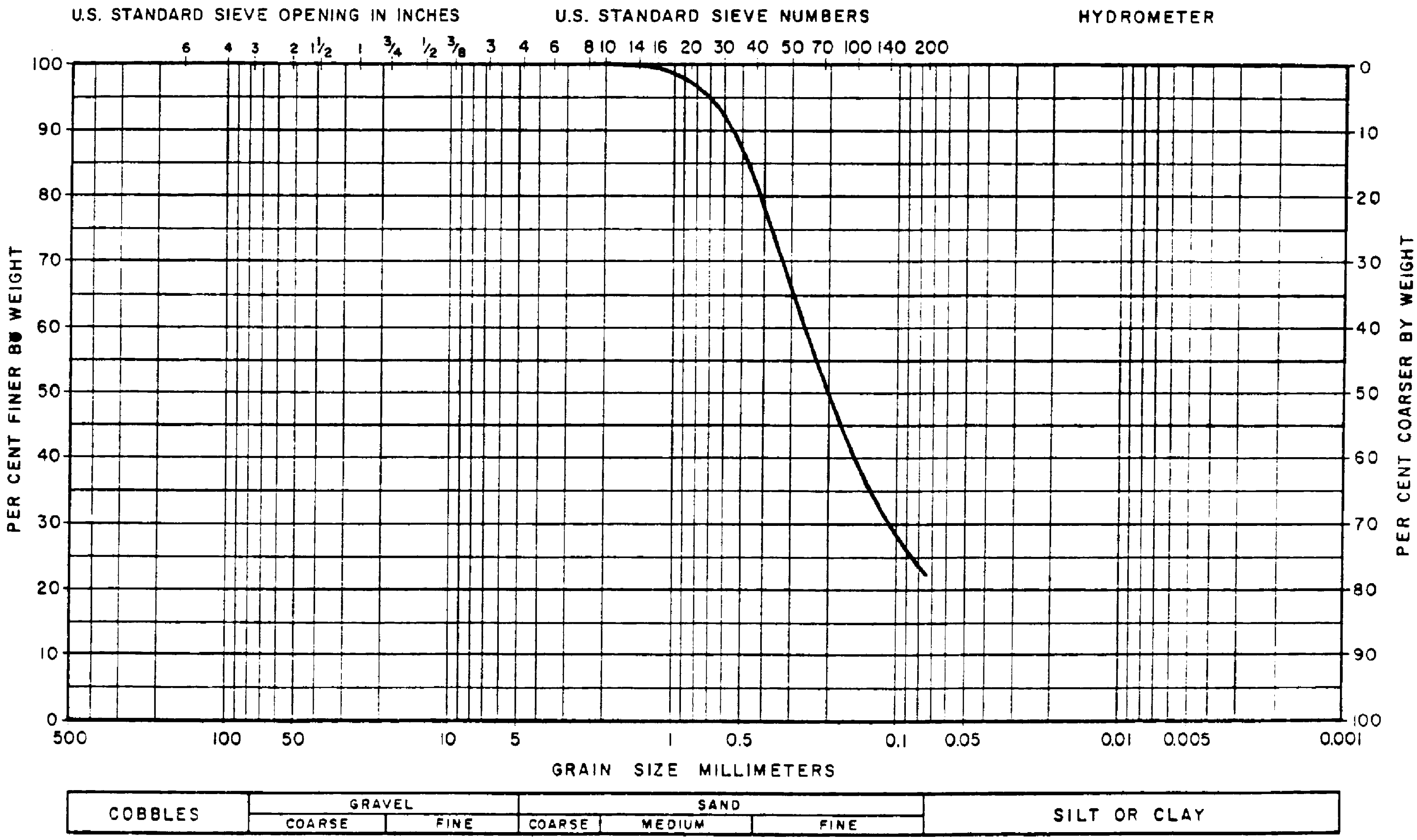

From Test No. CR-8

Stone & Webster Eng. Corp. Boston, Massachusetts	North Anna Power Station	GRAIN SIZE CURVE Boring P-15 Sample ST24B
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 4

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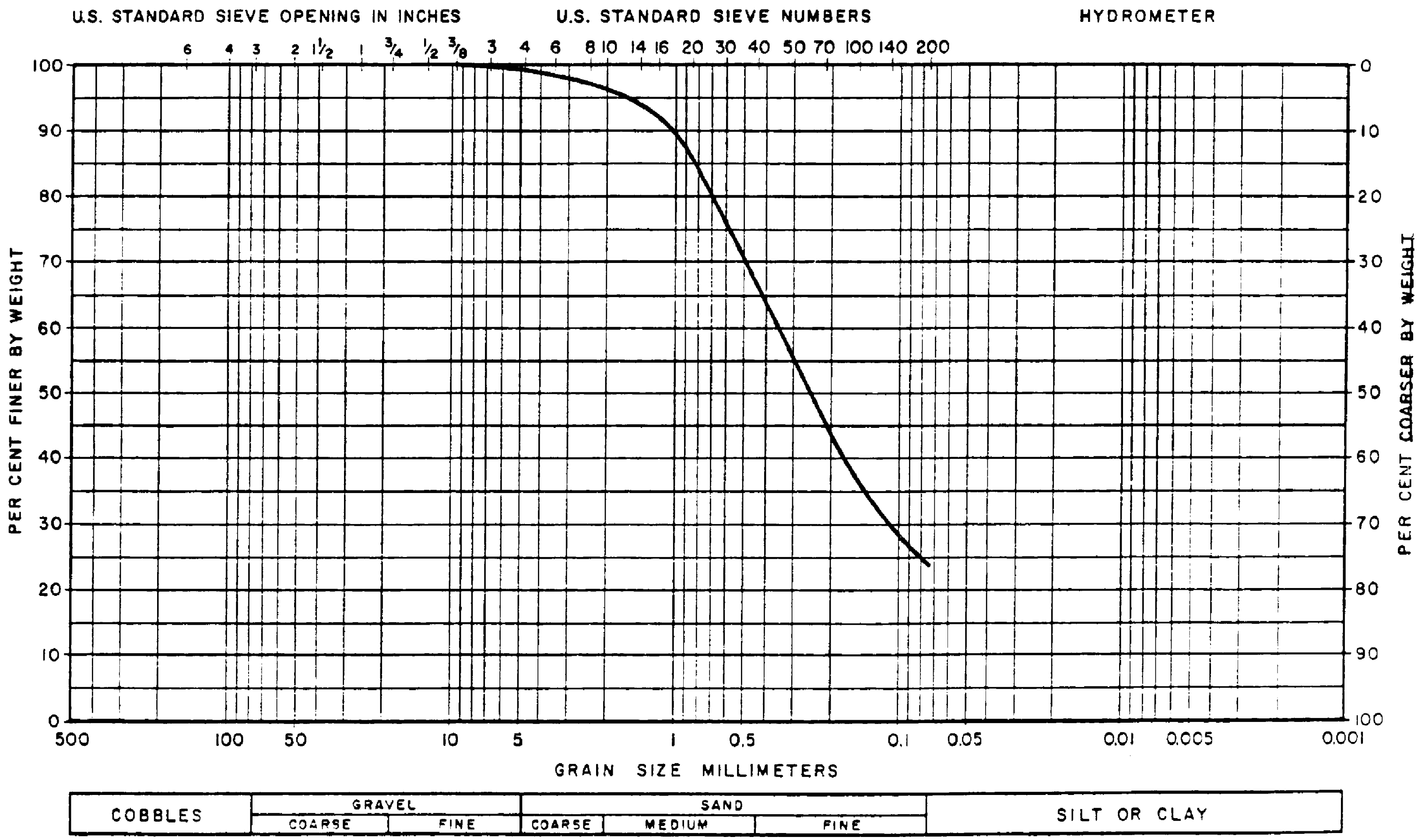

From Test No. CR̄-9

Stone & Webster Eng. Corp. Boston, Massachusetts	North Anna Power Station	GRAIN SIZE CURVE Boring P-16 Sample ST7A
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 5

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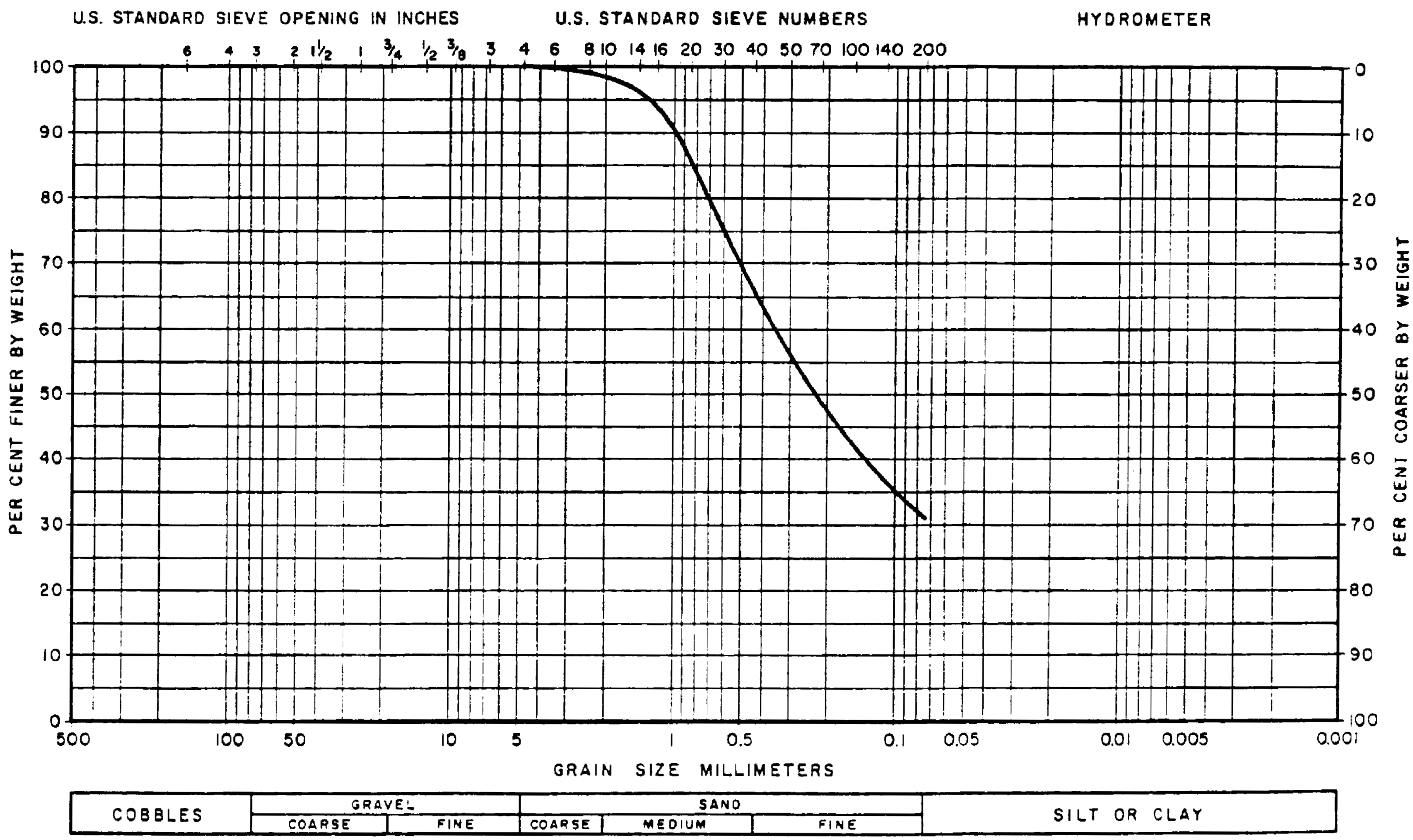

From Test No. CR-12

Stone & Webster Eng. Corp. Boston, Massachusetts	North Anna Power Station	GRAIN SIZE CURVE Boring P-16 Sample ST7B
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 6

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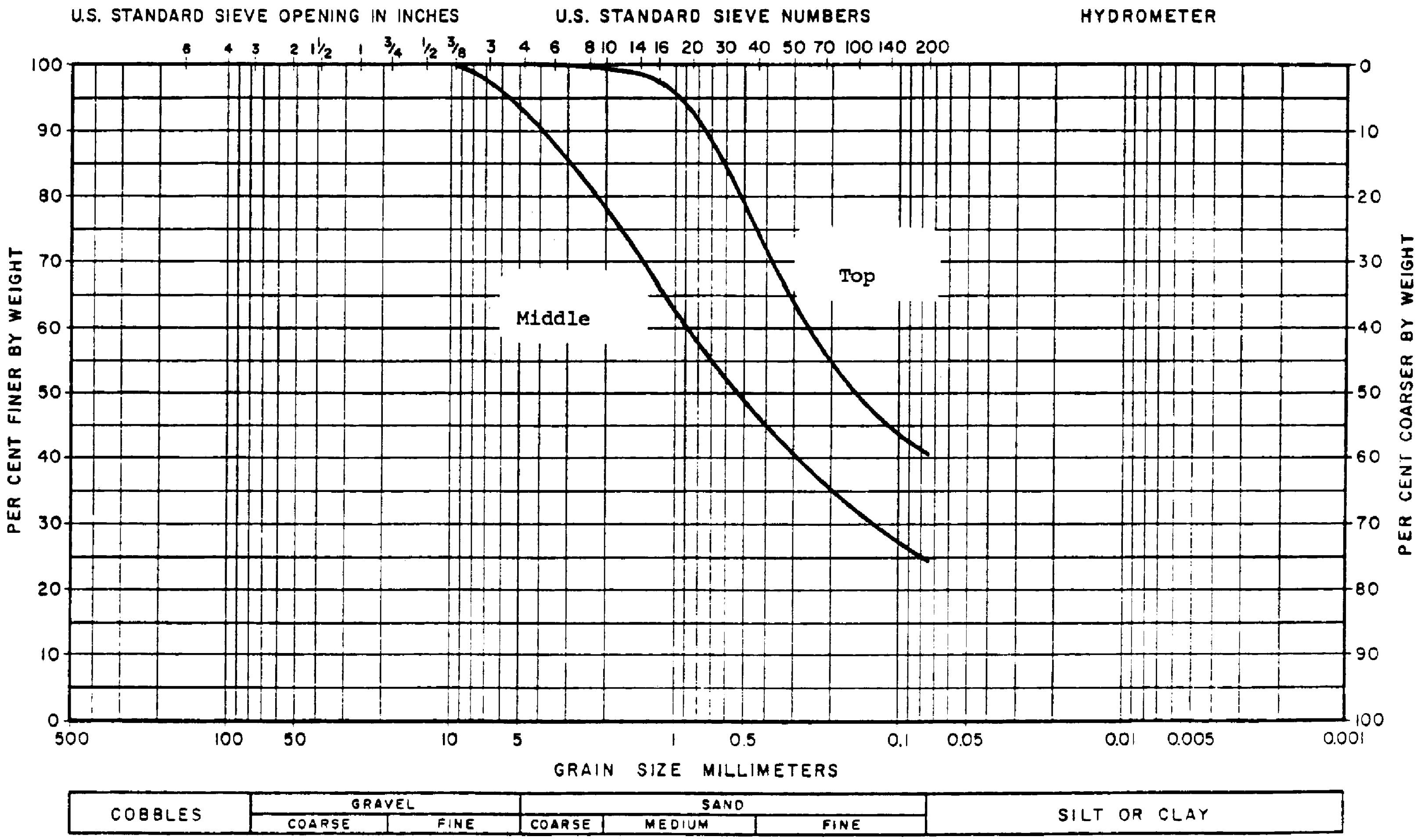

From Test No. CR̄-13

Stone & Webster Eng. Corp. Boston, Massachusetts	North Anna Power Station	GRAIN SIZE CURVE Boring P-17 Sample ST9A
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 7

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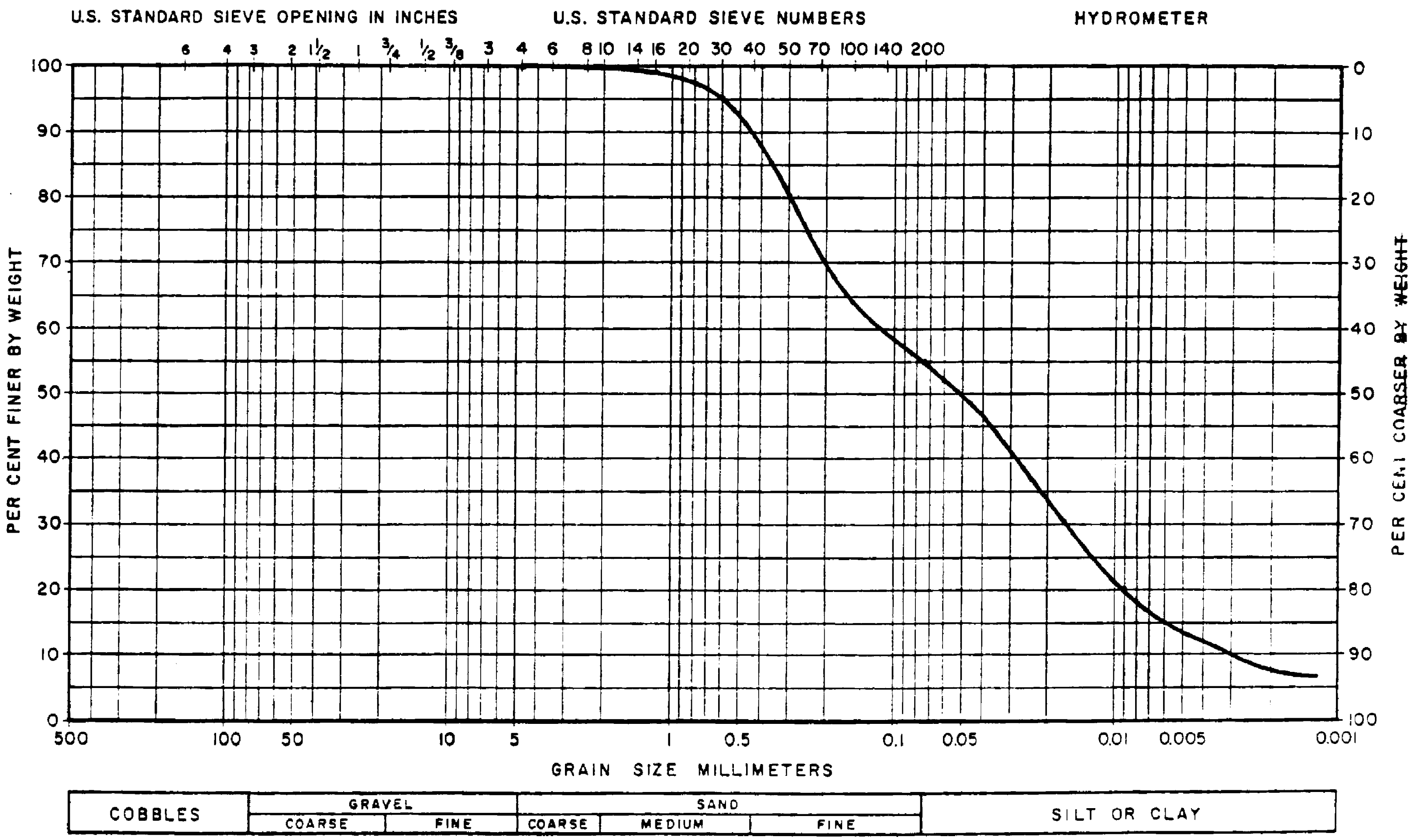

From Test No. CR-11

Stone & Webster Eng. Corp. Boston, Massachusetts	North Anna Power Station	GRAIN SIZE CURVE Boring P-17 Sample ST9B
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 8

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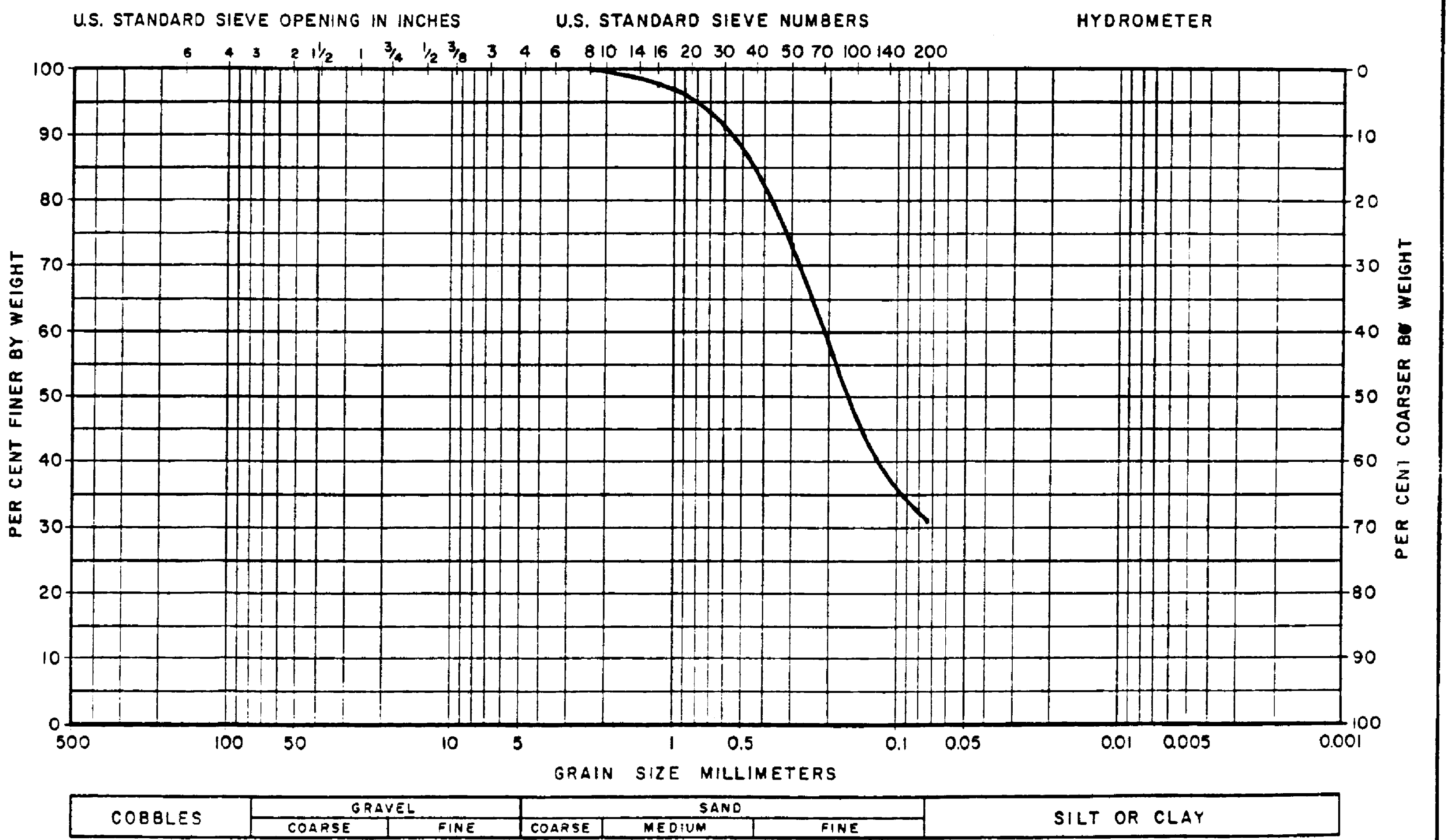

From Test No. R̄-1

Stone & Webster Eng. Corp. Boston, Massachusetts	North Anna Power Station	GRAIN SIZE CURVE Boring SWR-11 Sample ST1A
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 9

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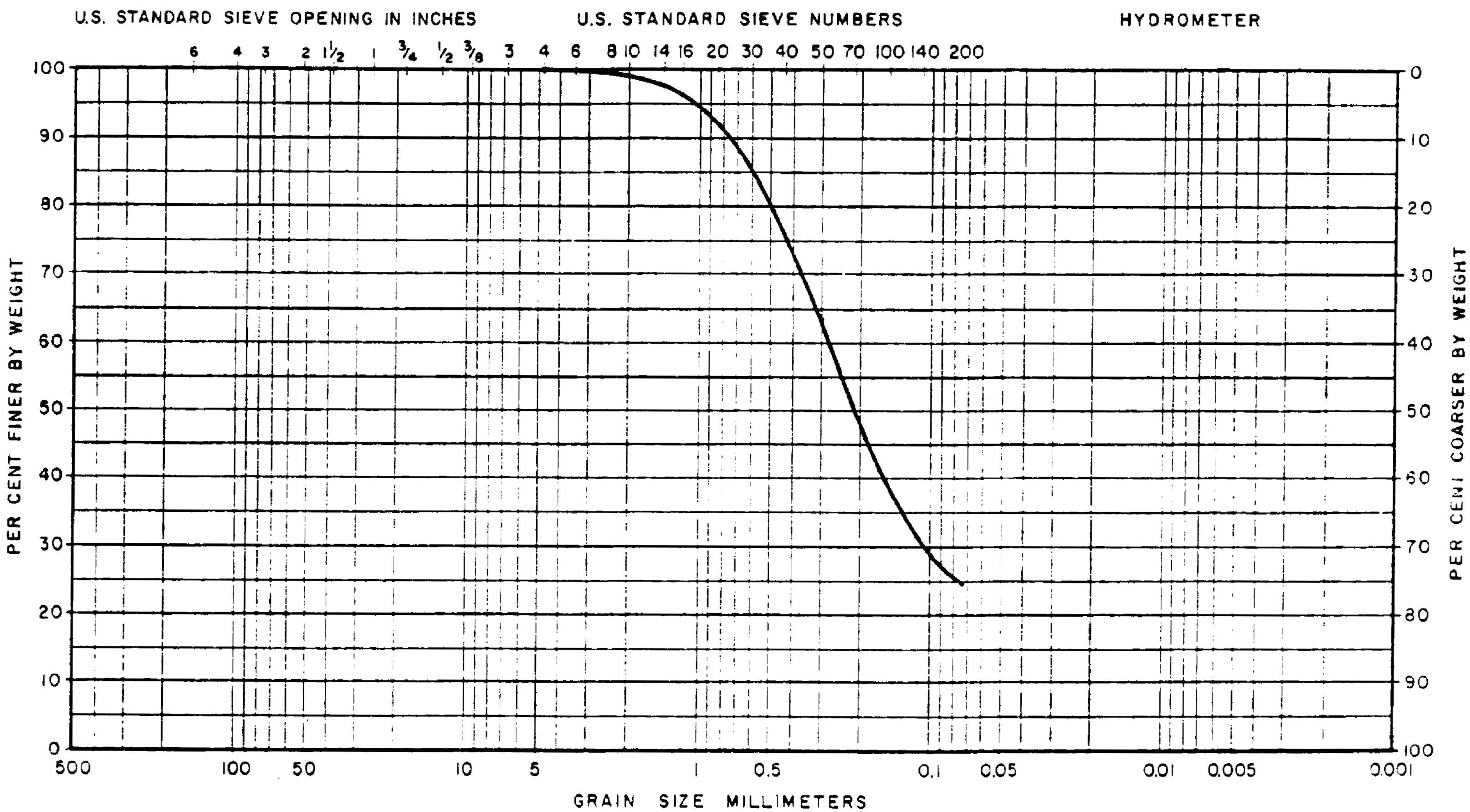

COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

From Test No. CR̄-16

Stone & Webster Eng. Corp. Boston, Massachusetts	North Anna Power Station	GRAIN SIZE CURVE Boring SWR-11 Sample ST1B
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 10

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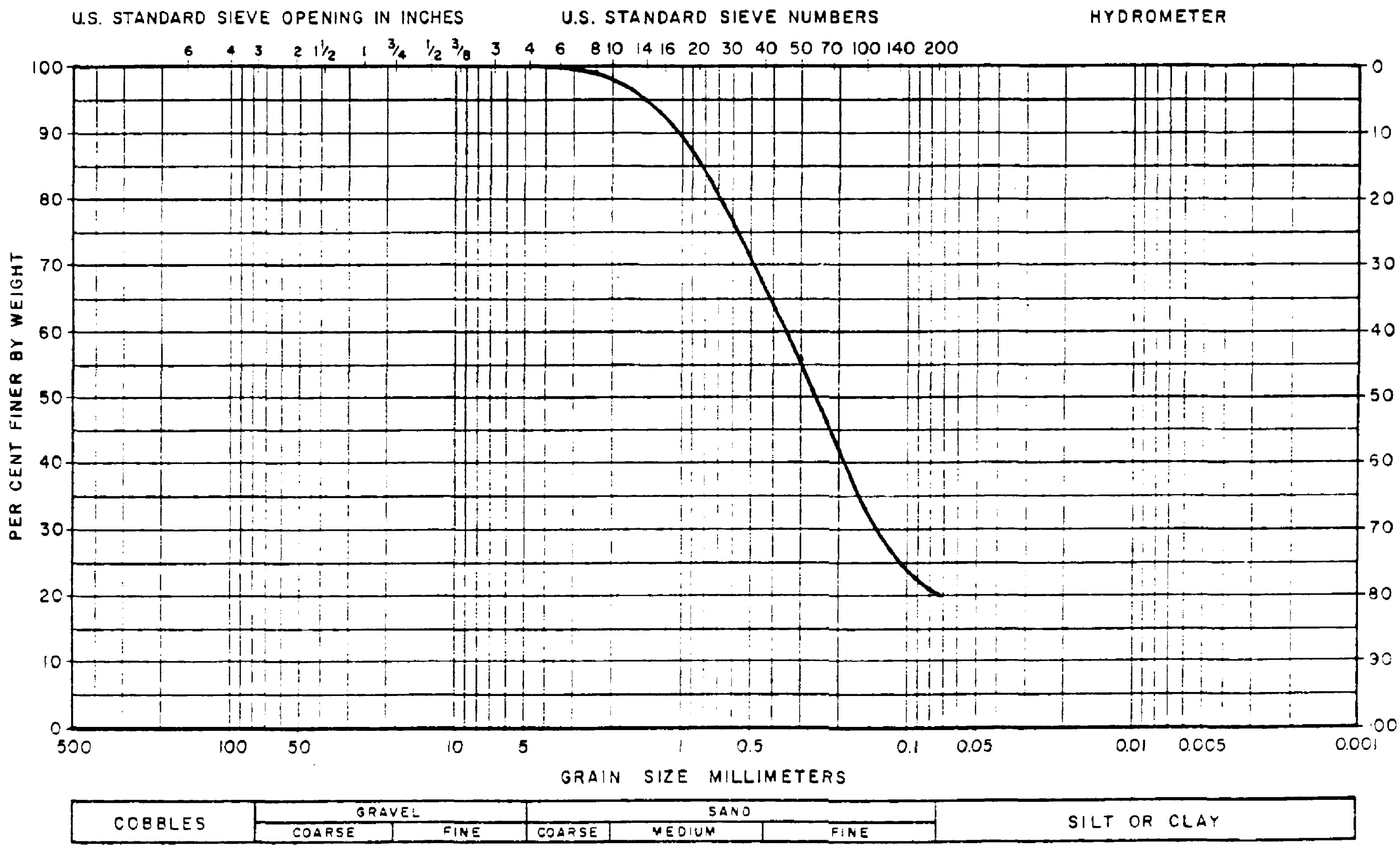

From Test No. CR-14

Stone & Webster Eng. Corp. Boston, Massachusetts	North Anna Power Station	GRAIN SIZE CURVE Boring SWR-11 Sample ST1C
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 11

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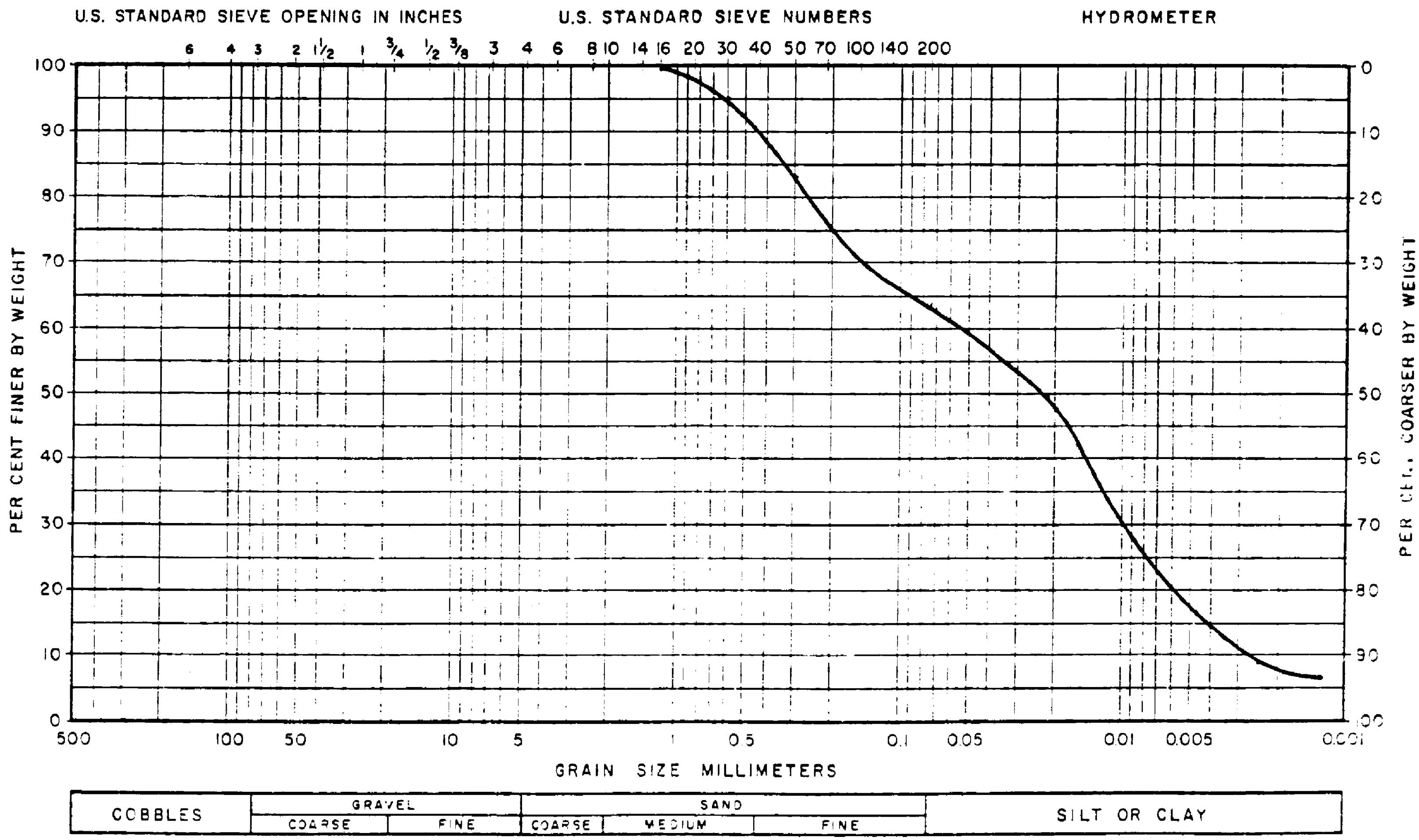

From Test No. CR-18

Stone & Webster Eng. Corp. Boston, Massachusetts	North Anna Power Station	GRAIN SIZE CURVE Boring SWR-13 Sample ST9A
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 12

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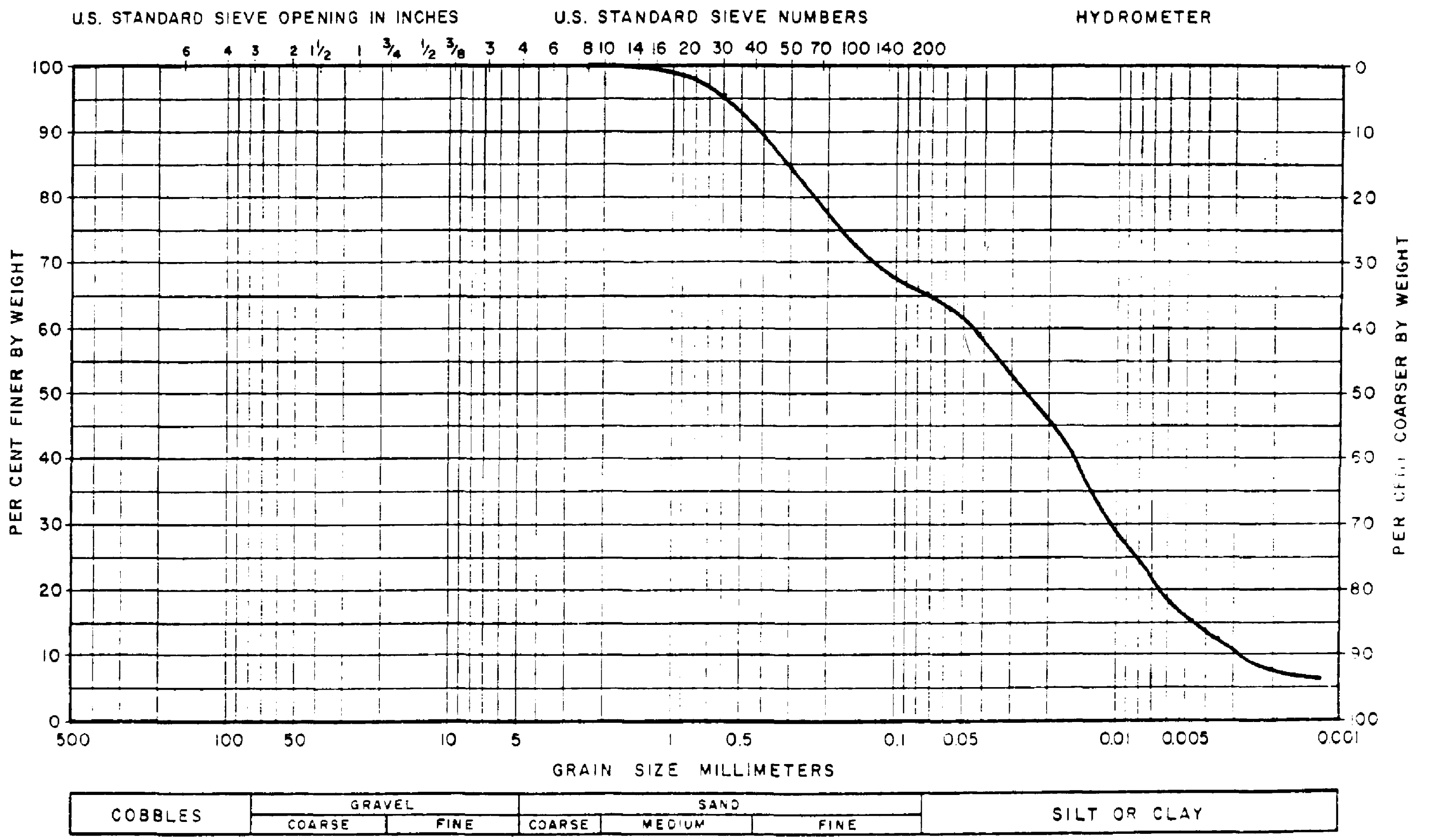

From Test No. CR-17

Stone & Webster Eng. Corp. Boston, Massachusetts	North Anna Power Station	GRAIN SIZE CURVE Boring SWR-13 Sample ST?B
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 13

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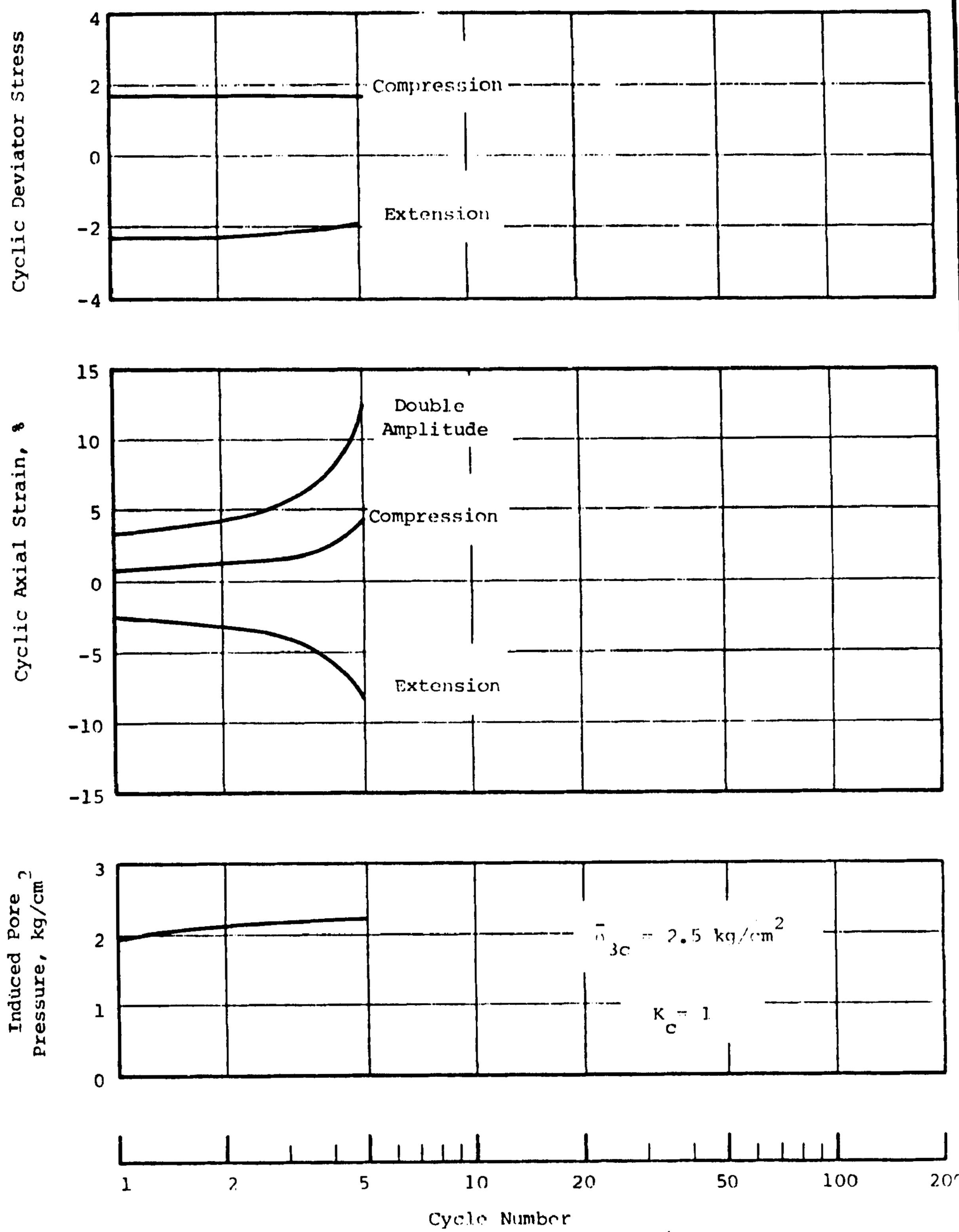

(ISOTROPIC CONSOLIDATION)

Stone & Webster Engineering Boston, Massachusetts	North Anna Power Station	CYCLIC LOAD TEST CR-10 BORING P-15 SAMPLE ST24A
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 14

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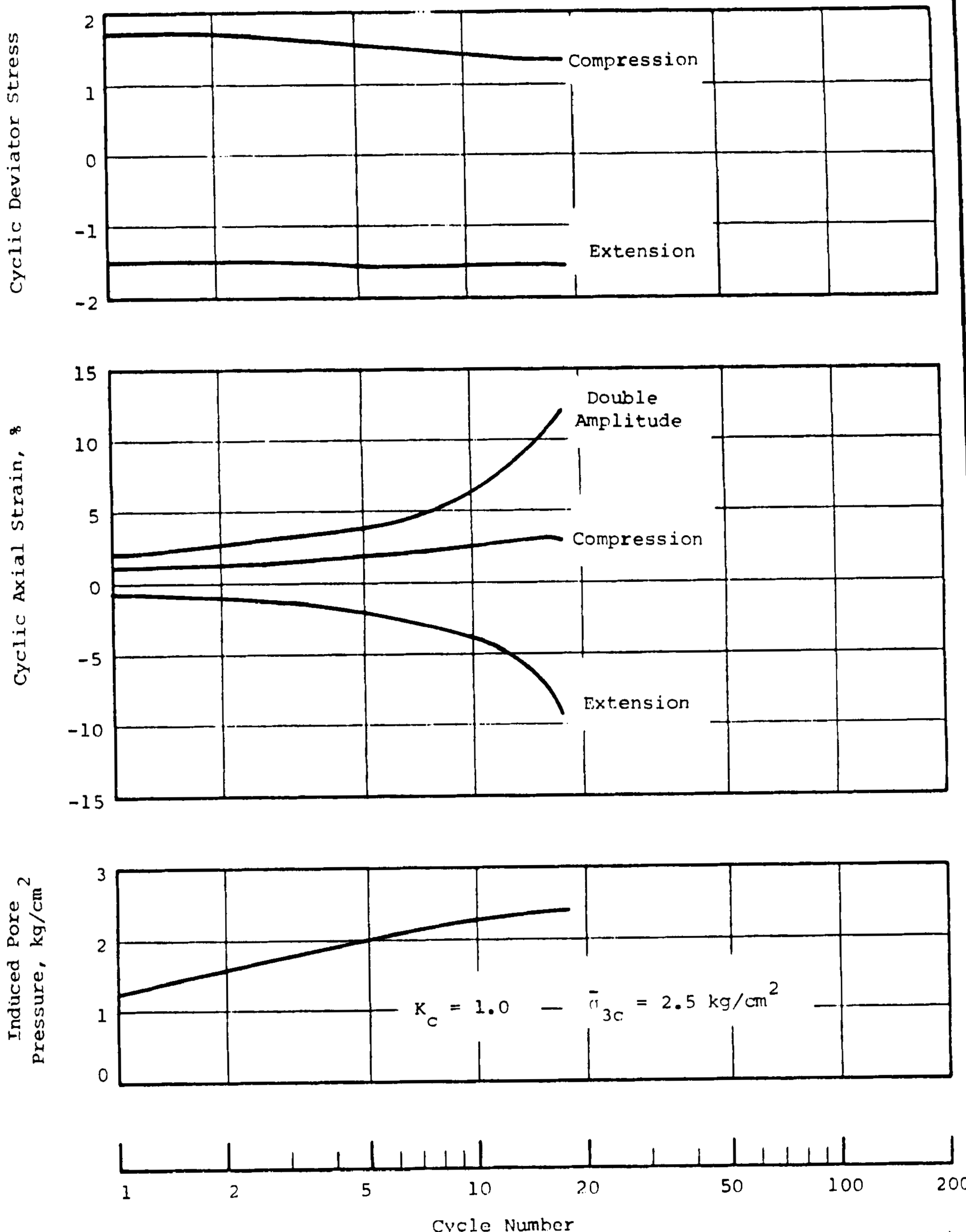

(ISOTROPIC CONSOLIDATION)

Stone & Webster Engineering Boston, Massachusetts	North Anna Power Station	CYCLIC LOAD TEST CR-11 BORING P-17 SAMPLE ST9B
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 15

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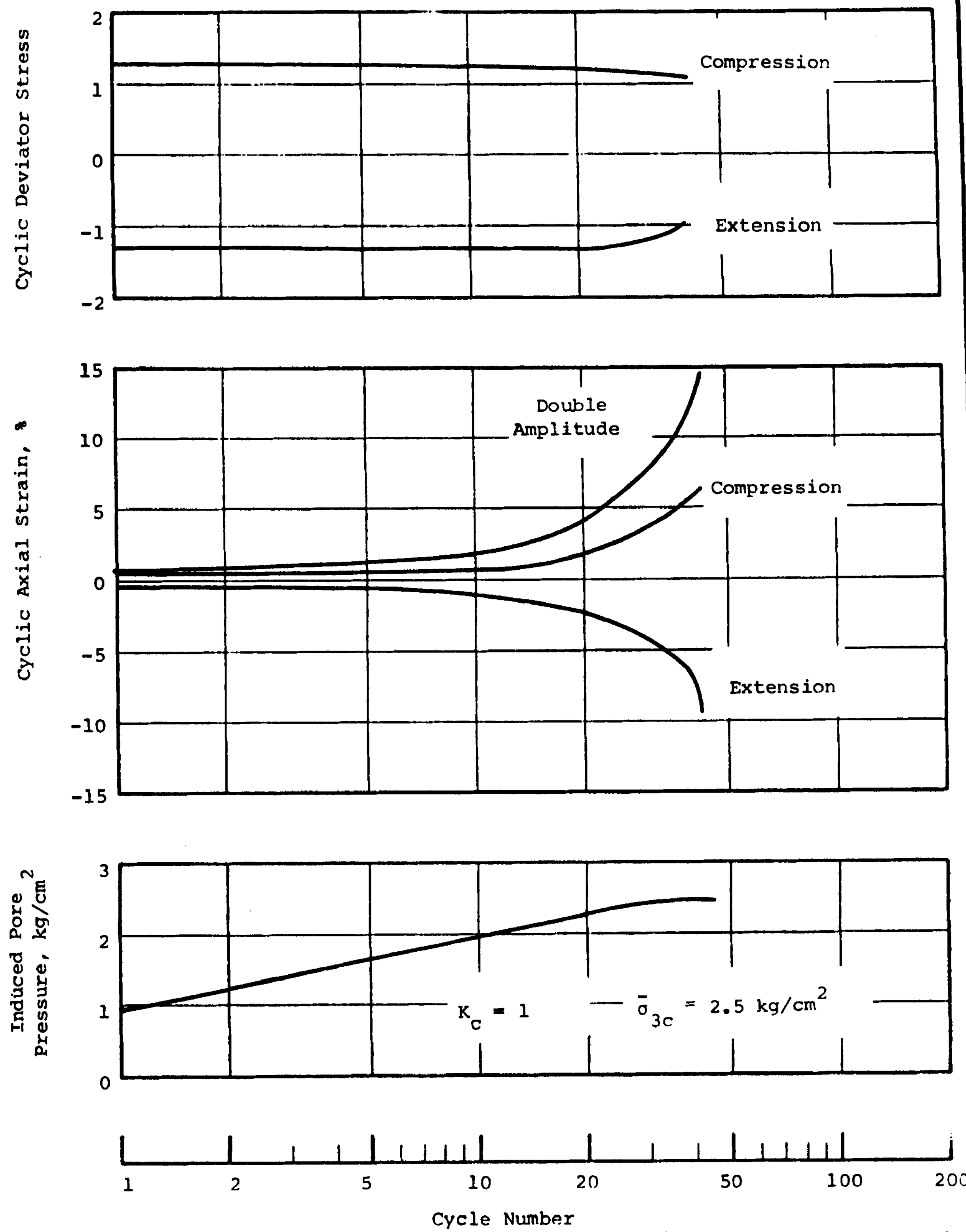

(ISOTROPIC CONSOLIDATION)

Stone & Webster Engineering Boston, Massachusetts	North Anna Power Station	CYCLIC LOAD TEST CR-13 BORING P-17 SAMPLE ST9A
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 16

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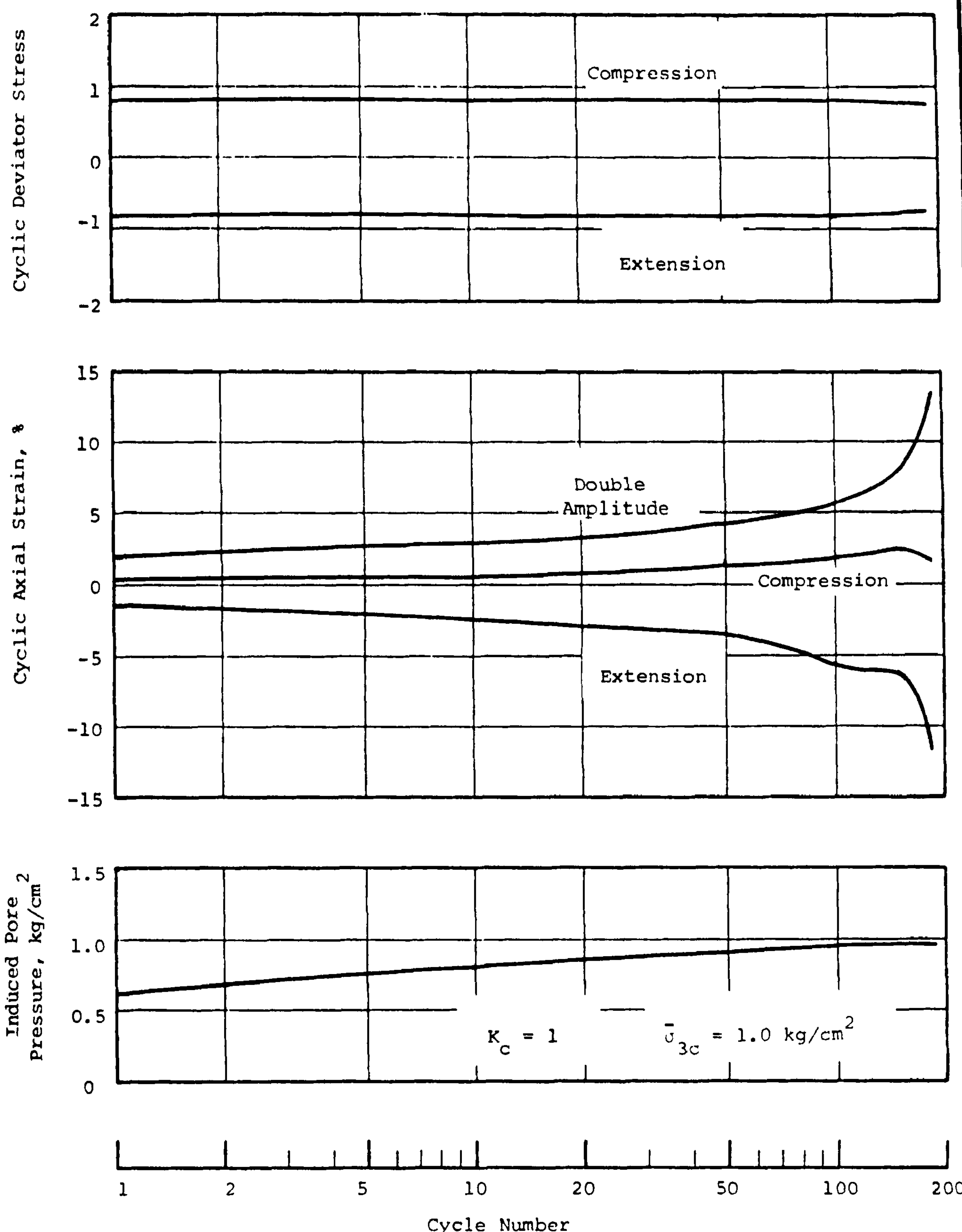

(ISOTROPIC CONSOLIDATION)

Stone & Webster Engineering Boston, Massachusetts	North Anna Power Station	CYCLIC LOAD TEST CR̄-14 BORING SWR-11 SAMPLE ST1C
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 17

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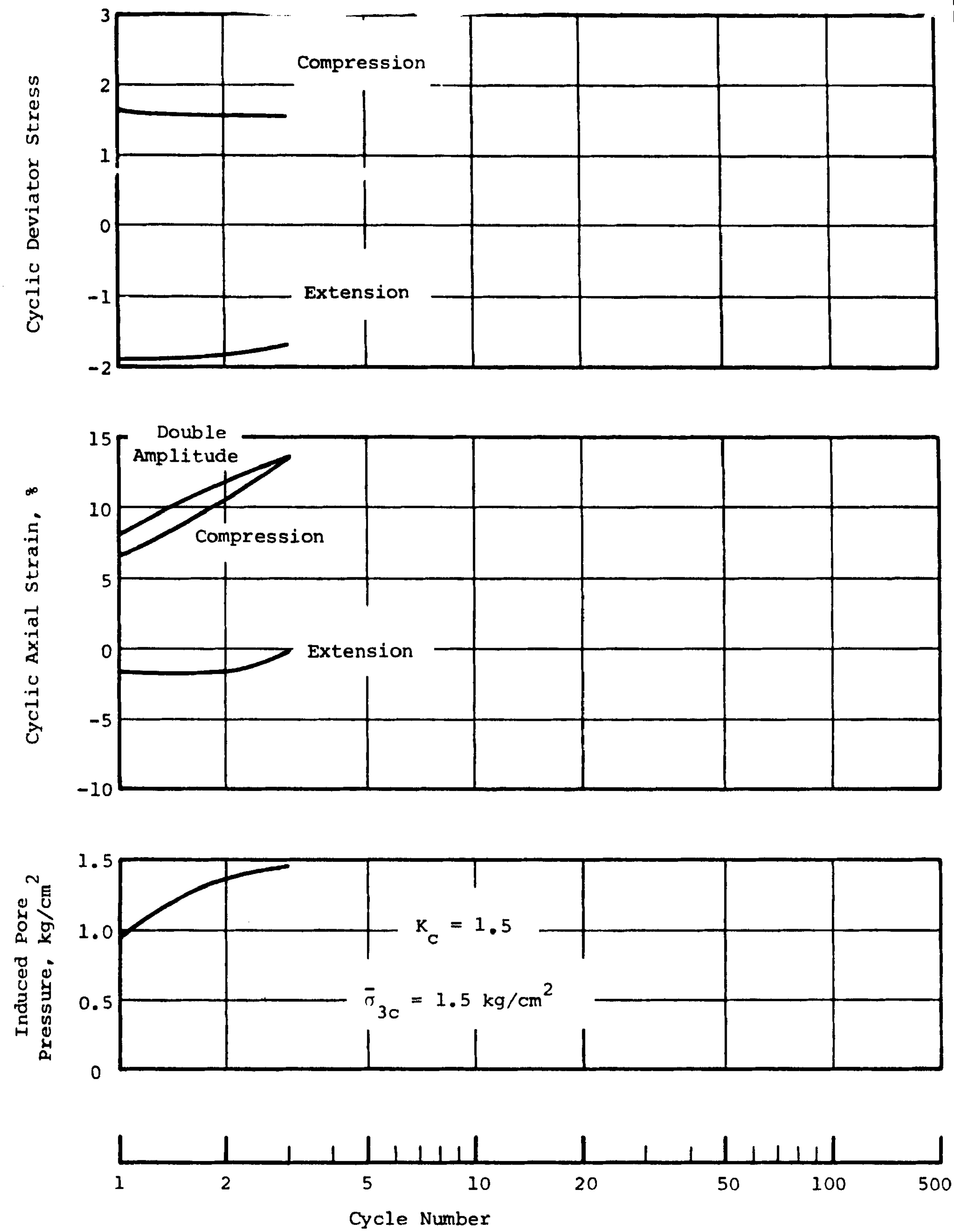

(ANISOTROPIC CONSOLIDATION)

Stone & Webster Engineering Boston, Massachusetts	North Anna Power Station	CYCLIC LOAD TEST C$\bar{R}$-15 BORING P-15 SAMPLE ST10A
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. [illegible]

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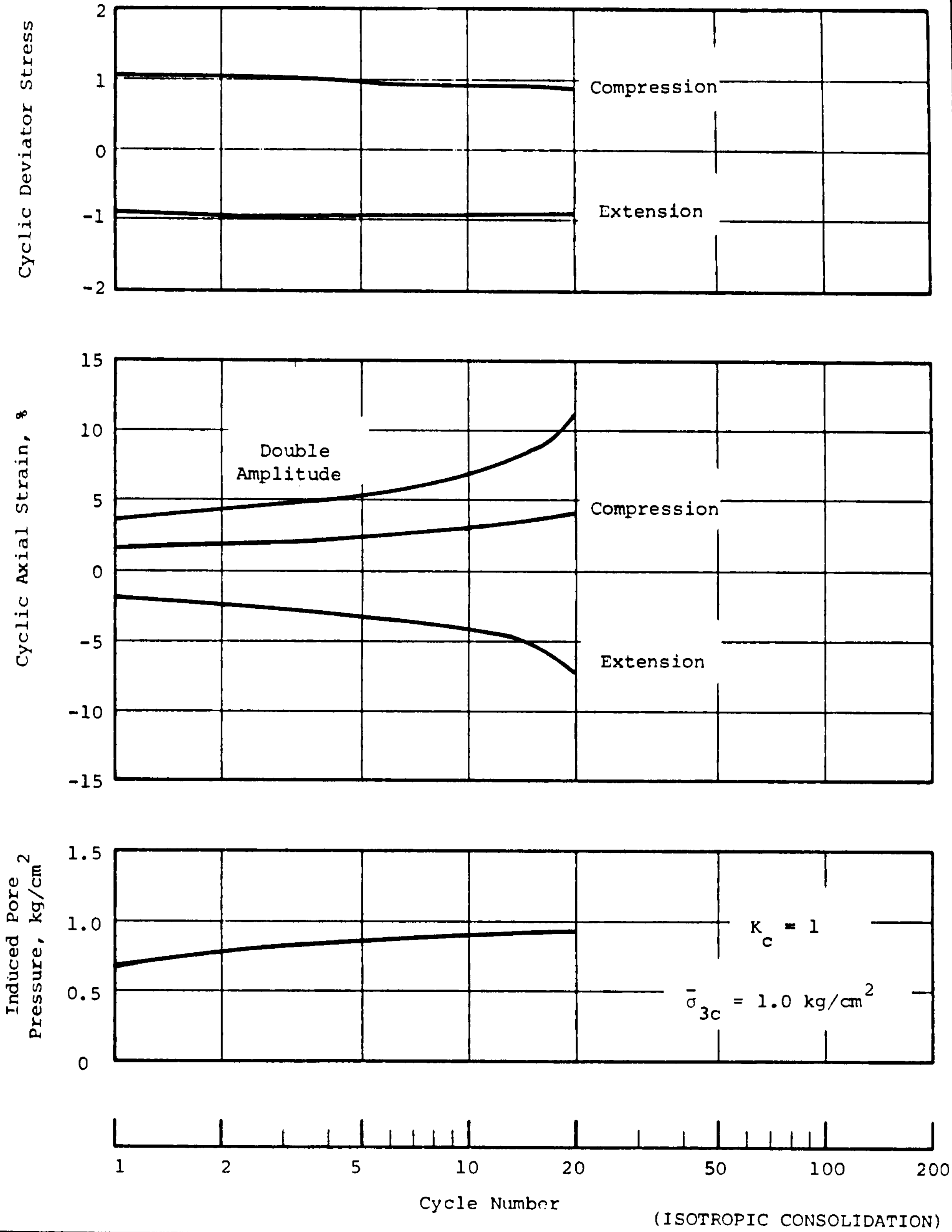

Stone & Webster Engineering Boston, Massachusetts	North Anna Power Station	CYCLIC LOAD TEST CR-16 BORING SWR-11 SAMPLE ST1B
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 19

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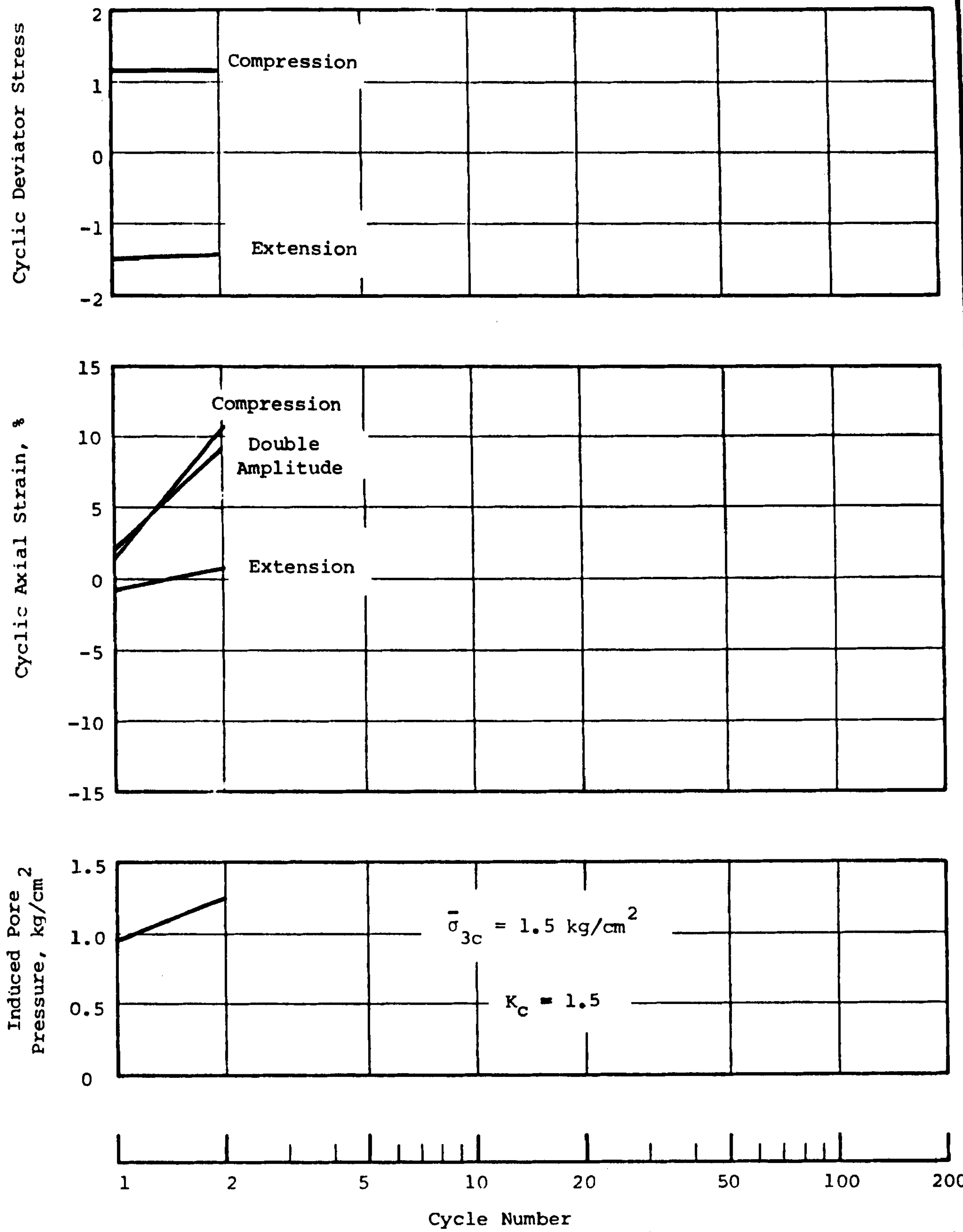

(ANISOTROPIC CONSOLIDATION)

Stone & Webster Engineering Boston, Massachusetts	North Anna Power Station	CYCLIC LOAD TEST $C\bar{R}$-17 BORING SWR-13 SAMPLE ST9B
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 20

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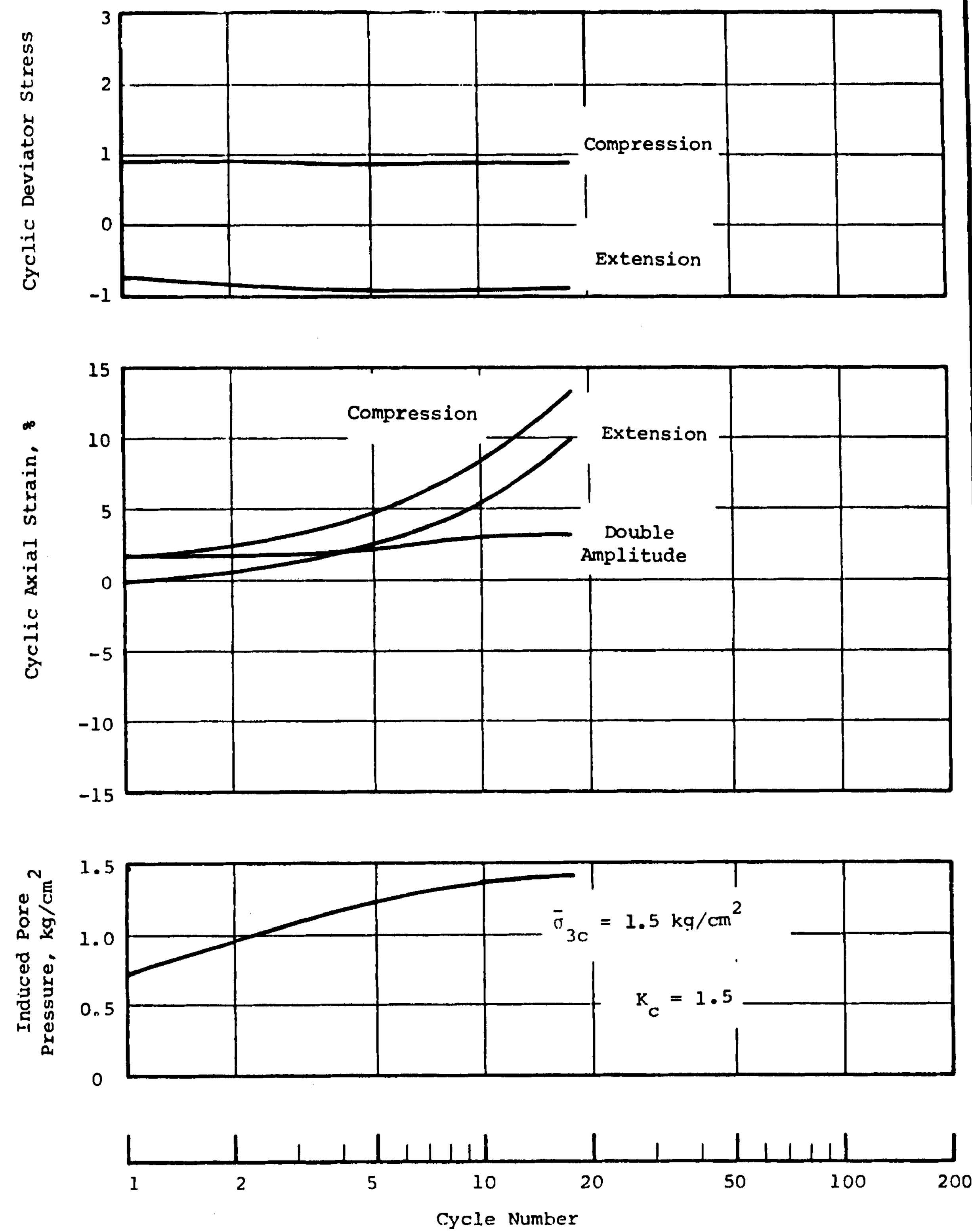

(ANISOTROPIC CONSOLIDATION)

Stone & Webster Engineering Boston, Massachusetts	North Anna Power Station	CYCLIC LOAD TEST CR-18 BORING SWR-13 SAMPLE ST9A
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 21

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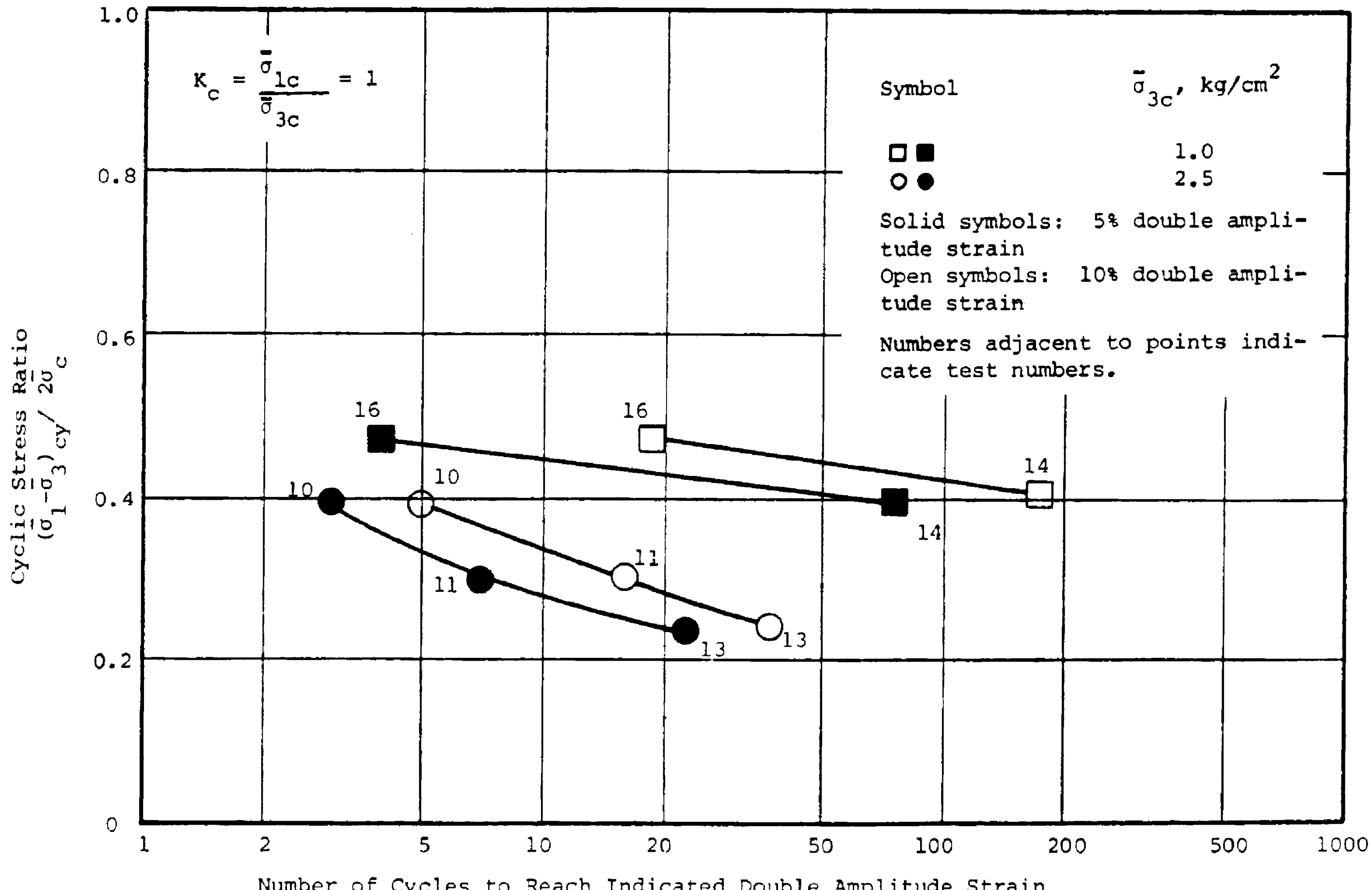

Stone & Webster Engineering Boston, Massachusetts	North Anna Power Station	SUMMARY PLOT CR TESTS
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 22

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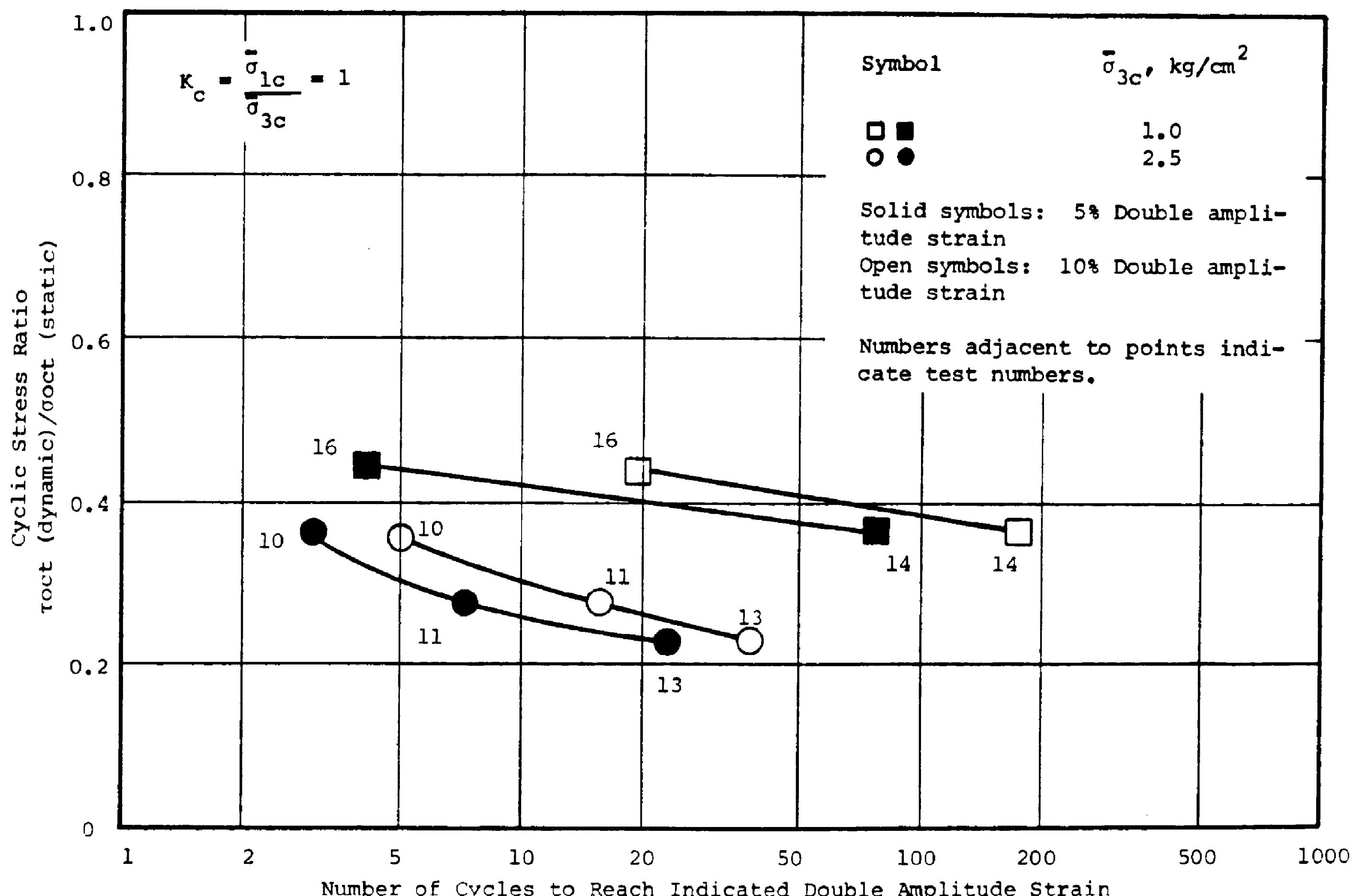

Stone & Webster Engineering Boston, Massachusetts	North Anna Power Station	SUMMARY PLOT $\bar{CR}$ TESTS
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 23

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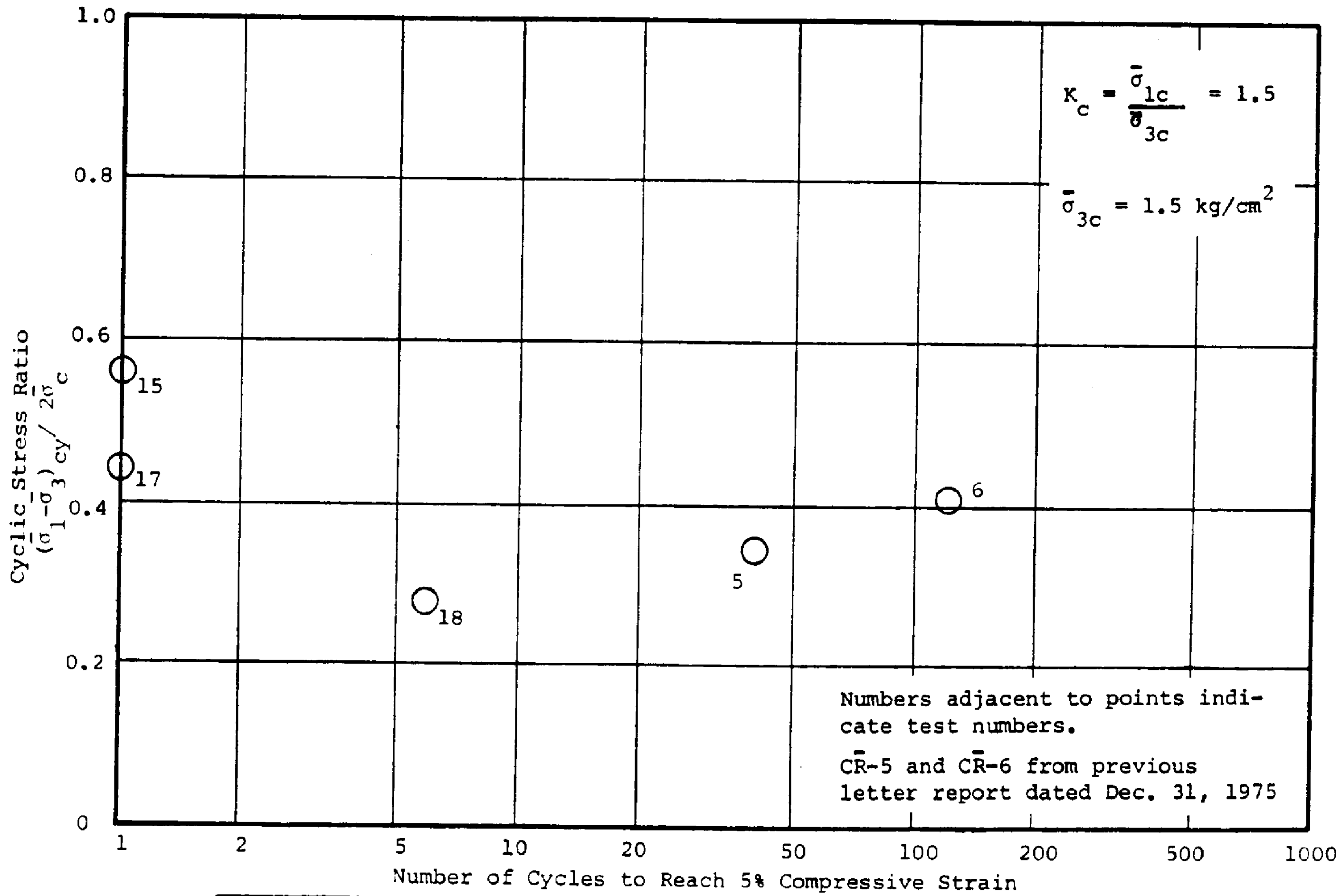

Stone & Webster Engineering Boston, Massachusetts	North Anna Power Station	SUMMARY PLOT C$\bar{R}$ TESTS
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 24

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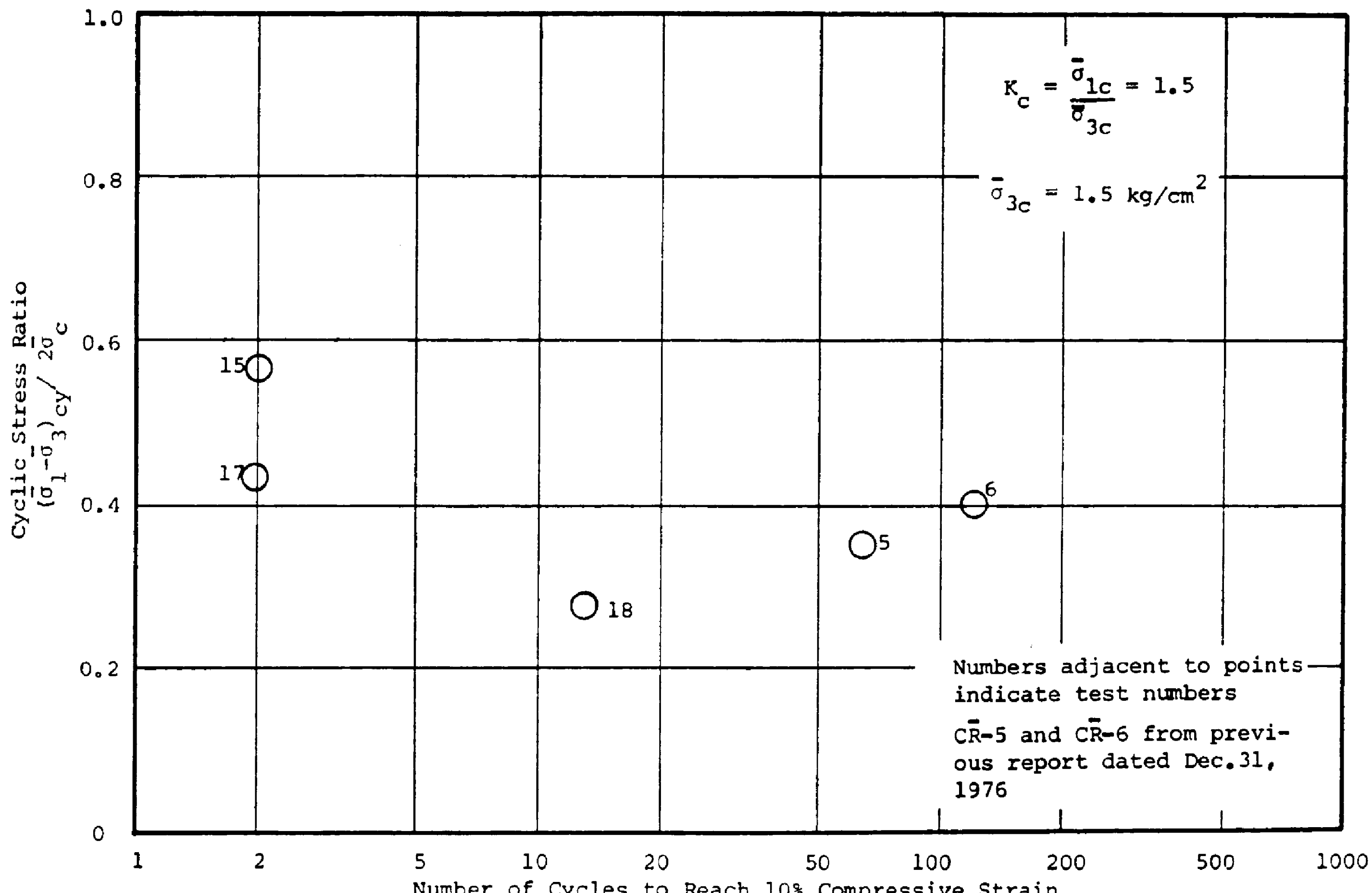
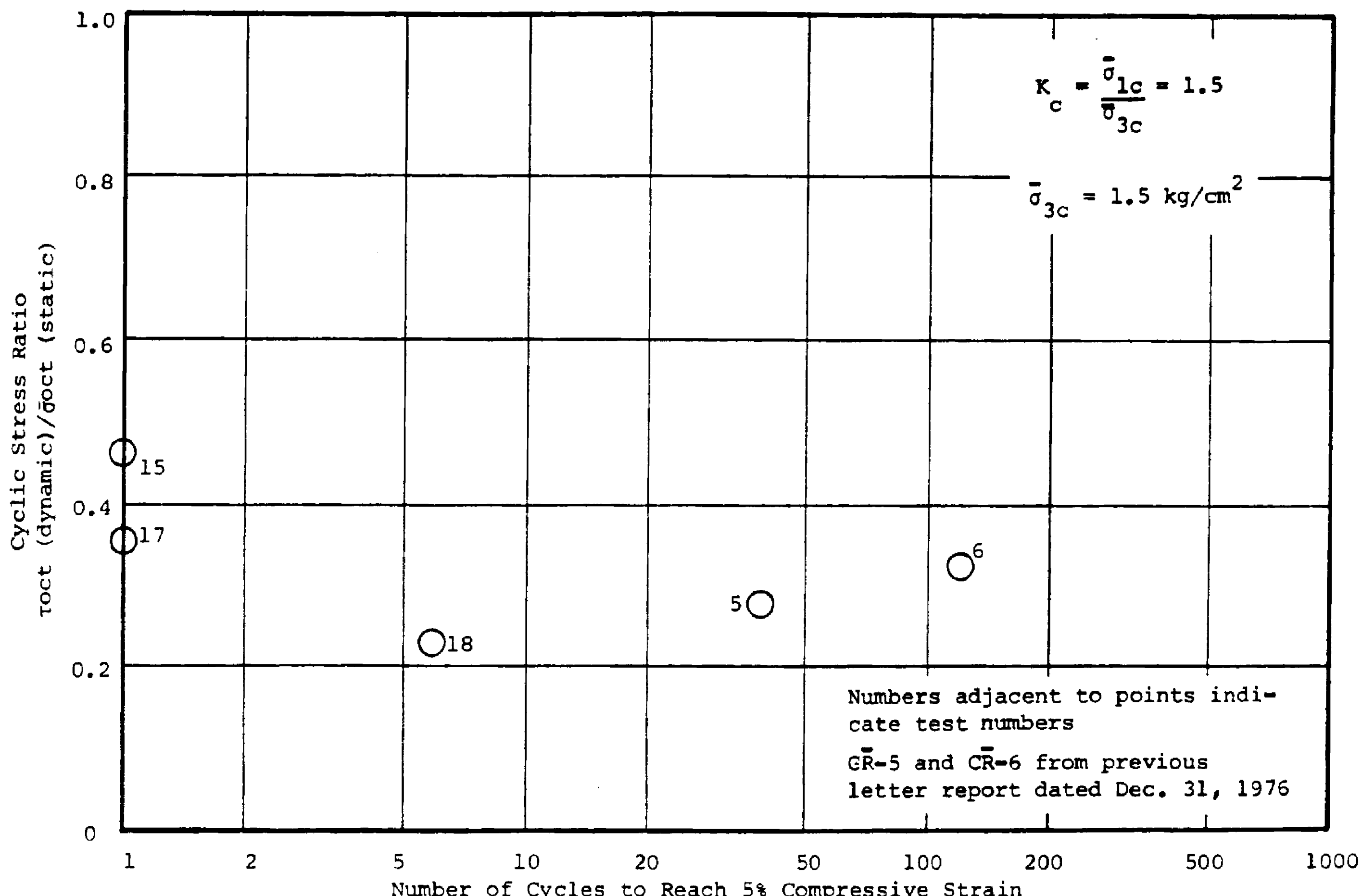
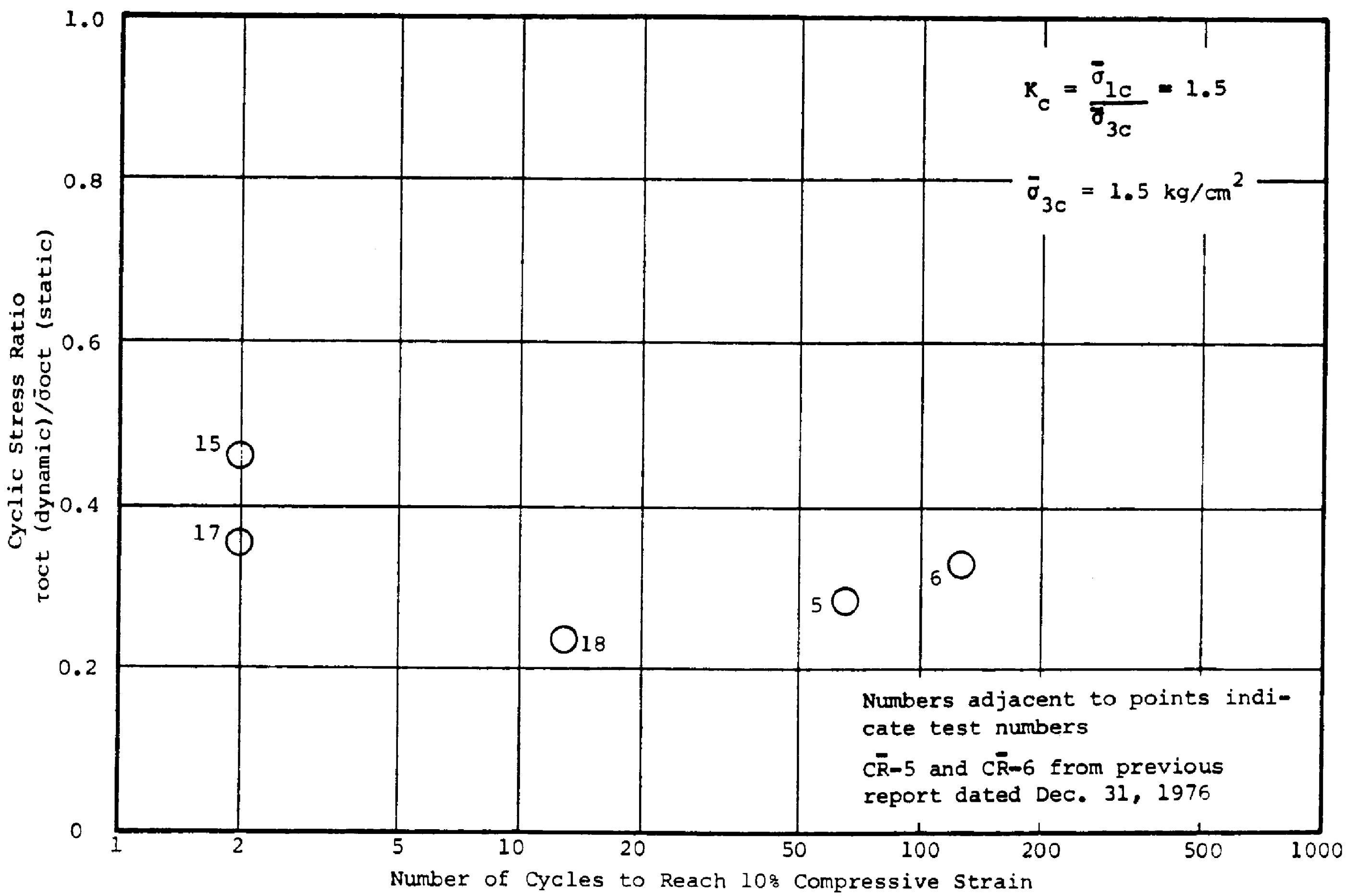


Stone & Webster Engineering Boston, Massachusetts	North Anna Power Station	SUMMARY PLOT CR̄ TESTS
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 25



Stone & Webster Engineering Boston, Massachusetts	North Anna Power Station	SUMMARY PLOT C̄R TESTS
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 26



Stone & Webster Engineering Boston, Massachusetts	North Anna Power Station	SUMMARY PLOT C$\bar{R}$ TESTS
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 27

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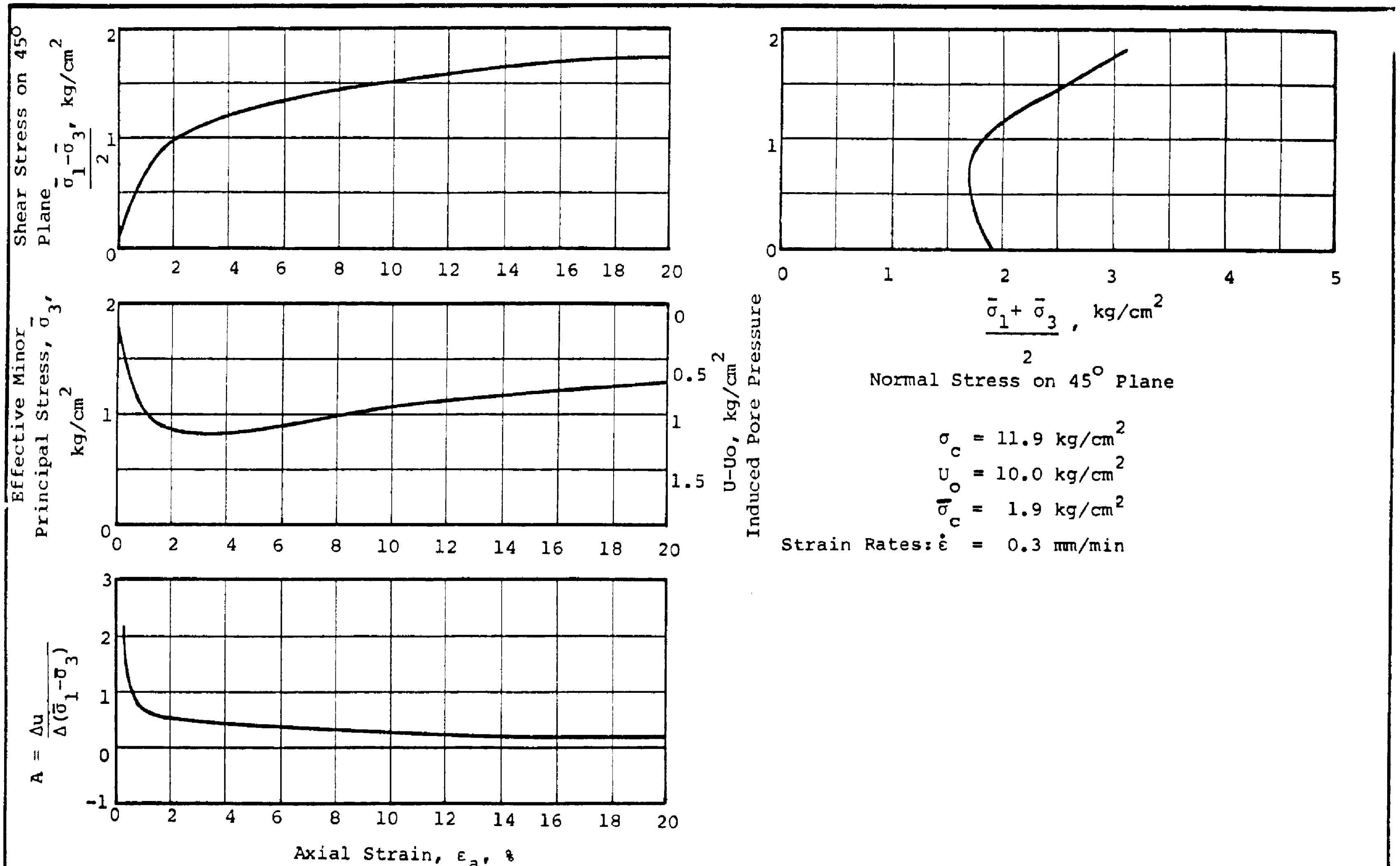

Stone & Webster Engineering Boston, Massachusetts	North Anna Power Station	$\bar{R}$ TEST 2 BORING P-15 SAMPLE ST10B
Geotechnical Engineers Inc. Winchester, Massachusetts	Project 75260	June 1976 Fig. 28

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Appendix A

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DESCRIPTION OF UNDISTURBED SAMPLES

BORING NO. P-15

Project North Anna Power Station

Project No. 75260

Sample No. and Depth ft.	Section No.	Length of Section in.	Description
ST-10 31.0 to 33.0	A	6.7	Faintly banded, orange brown silty medium to fine sand. Approximately 30% passing No. 200 sieve. Contains micaceous bands and an occasional angular quartz particle up to 5-mm in diameter. Bands dip approximately 45° from horizontal. (Saprolite) (C$\bar{R}$-15)
	B	6.7	Faintly banded, orange brown silty, medium to fine sand. Approximately 40% passing No. 200 sieve. Contains micaceous bands and a 5-mm band of angular, coarse-sand-size quartz particles at top of sample along which failure plane developed. Bands dip approximately 30° from horizontal. (Saprolite) ($\bar{R}$-2)
ST-24 66 to 68	A	6.7	Strongly banded gray white silty fine sand. Micaceous bands. Contains approximately 30% passing No. 200 sieve. Top of specimen contains several 2-3mm bands of white clayey material; possibly weathered feldspar. Relic structure of parent rock still very visible and dips at approximately 56°. (Saprolite) Developed failure plane in upper 1/3 of specimen. (Saprolite) (C$\bar{R}$-10)
	B	6.7	Slightly banded gray white silty fine sand. Micaceous bands; contains approximately 20% passing No. 200 sieve. Near bottom of sample are two orthogonal bands about 3 mm wide which contain soft, white clayey material. Relic

DESCRIPTION OF UNDISTURBED SAMPLES

BORING NO. P-15

Project North Anna Power Station

Project No. 75260

Sample No. and Depth ft.	Section No.	Length of Section in.	Description
			structure of parent rock visible and dips at about 45°. (Saprolite) (C$\bar{R}$-8)

DESCRIPTION OF UNDISTURBED SAMPLES

BORING NO. P-16

Project North Anna Power Station

Project No. 75260
Page 1 of 1

Sample No. and Depth ft.	Section No.	Length of Section in.	Description
ST-7 37.5 to 39.5	A	6.6	Banded, orange and white, silty medium to fine sand. Contains about 20% passing the No. 200 sieve. Bands dip 58° from horizontal. (Saprolite) (C$\bar{R}$-9)
	B	6.7	Top 2 cm: Grayish white, clayey fine and medium sand. Middle 4.5 cm: White, fine sandy clay. Medium plastic. Bottom: Orange white, clayey, medium to fine sand. Becoming less clayey toward bottom. (Saprolite) (C$\bar{R}$-12)

DESCRIPTION OF UNDISTURBED SAMPLES

BORING NO. P-17

Project **North Anna Power Station**

Project No. 75260
Page 1 of 1

Sample No. and Depth ft.	Section No.	Length of Section in.	Description
ST-9 47.5 to 49.5	A	6.7	Top: Orange brown silty medium to fine sand. Approximately 40% passing No. 200 sieve. Contains one blackish band about 2 mm wide. Faint failure zone at top 1/3 of layer inclined at 35° from horizontal. Middle: Orange white clayey coarse to fine sand. Approximately 25% passing No. 200 sieve. Bottom: Similar to top layer. Banding dips at about 56°. (Saprolite) (C$\bar{R}$-13)
	B	6.7	Banded brown silty fine sand-fine sandy silt. Contains 40% to 60% passing No. 200 sieve. Contains 3 mm wide band of medium sand size quartz particles which extends from top of sample for a length of 2 inches. Relic structure dips approximately 45° for top 1/4 of specimen and then bends around and dips 60° in the opposite direction for the remainder of the sample. (Saprolite) (C$\bar{R}$-11)

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DESCRIPTION OF UNDISTURBED SAMPLES

BORING NO. SWR-11

Project **North Anna Power Station**

Project No. 75260
Page 1 of 1

Sample No. and Depth ft.	Section No.	Length of Section in.	Description
ST-1 19.5 to 21.5	A	5.9	Faintly banded, yellow green silty fine sand. Micaceous bands; contains about 30% passing No. 200 sieve. Contained 1-4 mm layer in upper 1/3 of sample of white clayey medium to fine sand. During failure, developed 3 mm wide failure zone inclined at approximately 35° from horizontal. Mica flakes oriented parallel to failure surface. (Saprolite) ($\bar{R}$-1)
	B	6.5	Mottled yellow green silty fine sand. Micaceous bands; contains about 25% passing No. 200 sieve. Developed wedge shaped failure surface. Top surface and bottom surface inclined at 46° and 24° respectively from the horizontal. (Saprolite) (C$\bar{R}$-16)
ST-1 19.5 to 21.5	C	6.6	Slightly banded, yellow green, silty medium to fine sand. Micaceous, bands. Contains approximately 20% passing No. 200 sieve. Relic structure dips at 34: Color changes to brownish green in lower 5 cm. Less stratification visible. (Saprolite) Failure place developed in upper 1/3 of specimen. Along failure place was noted whitish-green, slightly plastic fines. (C$\bar{R}$-14)

DESCRIPTION OF UNDISTURBED SAMPLES

BORING NO. SWR-13

Project North Anna Power Station

Project No. 75260

Sample No. and Depth ft.	Section No.	Length of Section in.	Description
ST-9 47.5 to 49.5	A	6.8	Slightly banded orange-pink fine sandy silt. Contains approximately 65% passing No. 200 sieve. Banding dips at about 53°. (Saprolite) (C$\bar{R}$-18)
	B	6.6	Slightly banded, mottled orange brown and pink silty fine sand or fine sandy silt. Contains about 40% passing No. 200 sieve. Banding dips at approximately 43°. (Saprolite) (C$\bar{R}$-17)

APPENDIX B

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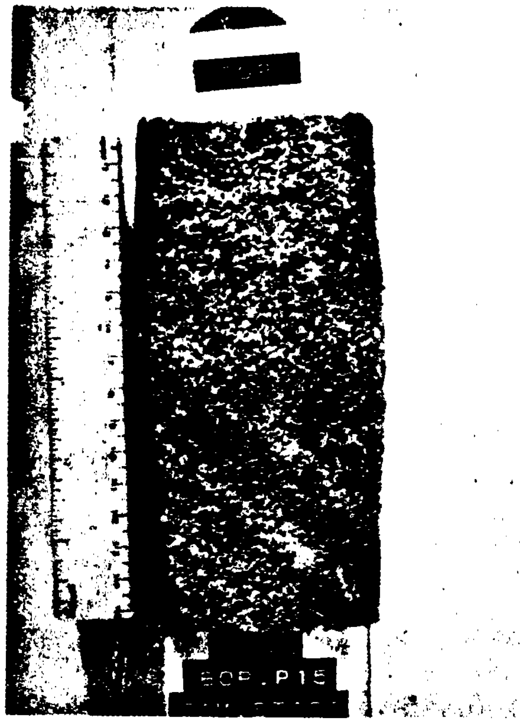

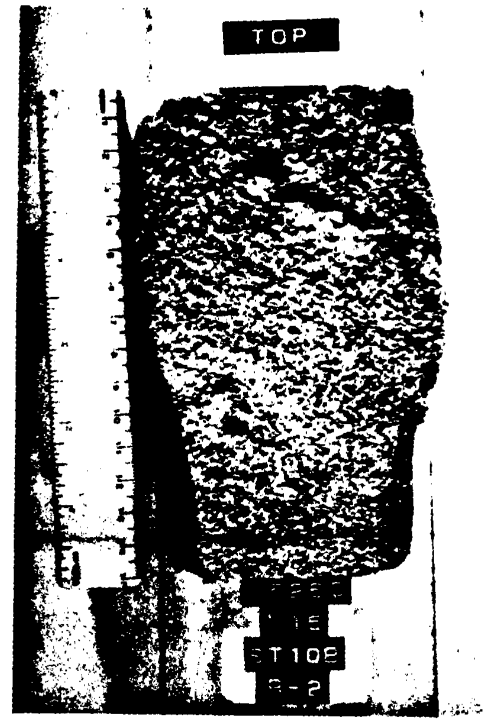

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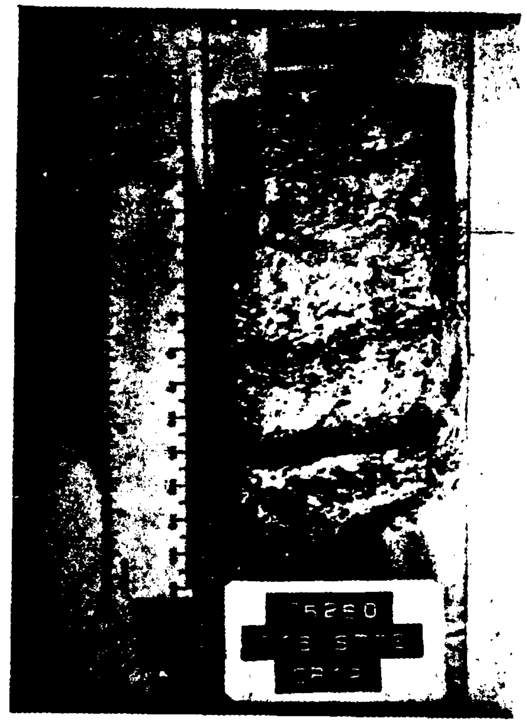

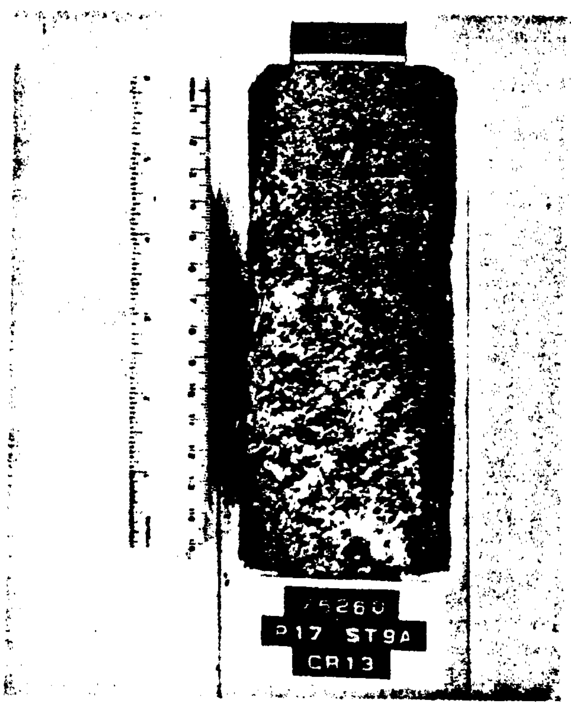

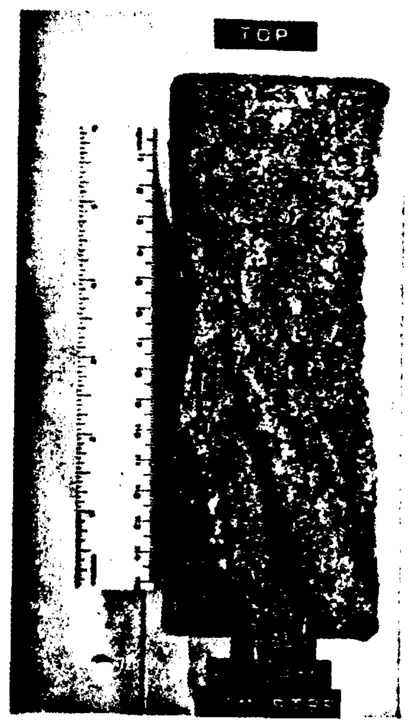

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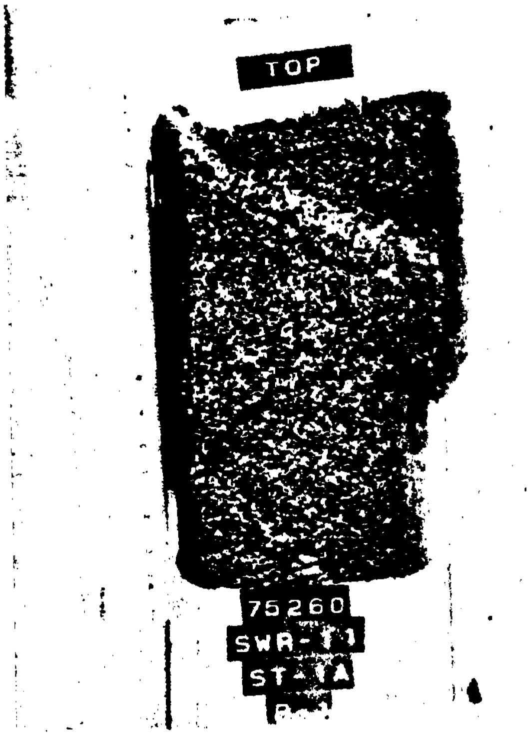

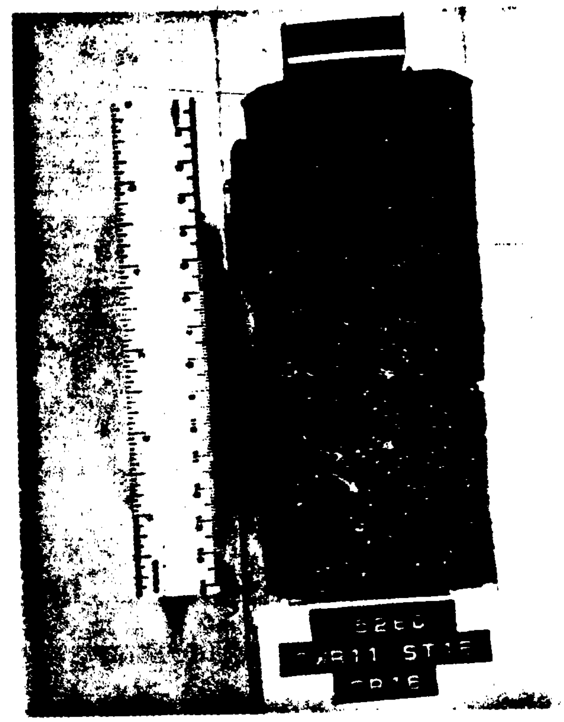

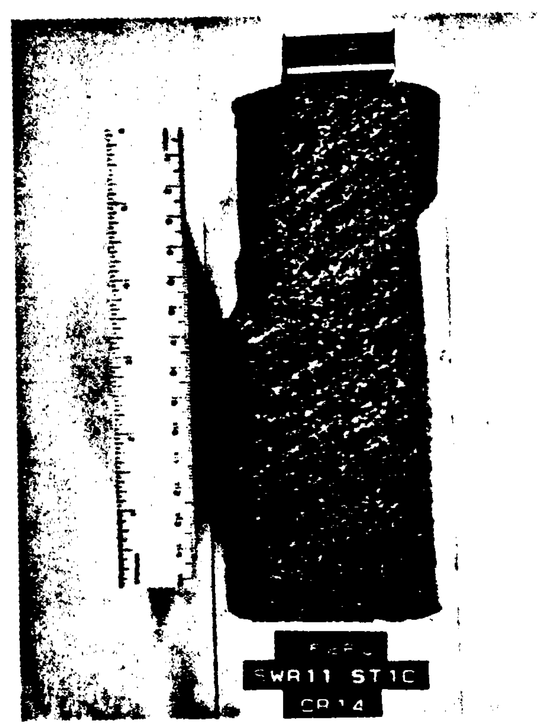

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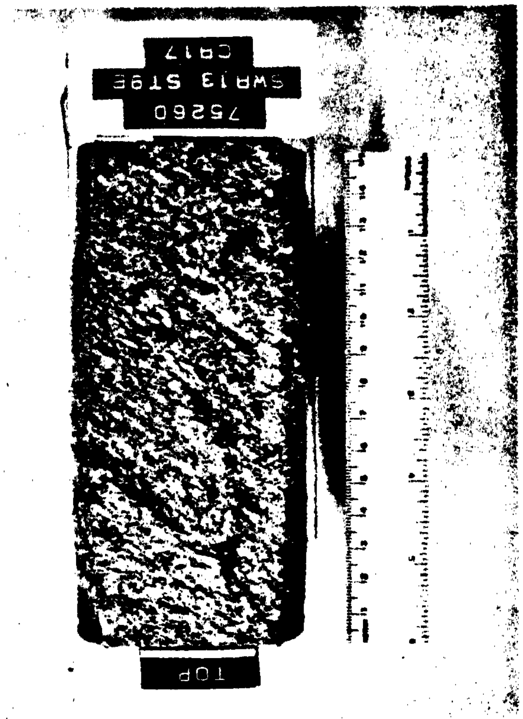

Appendix 3E
Attachment 4

Investigations of Loose Saprolite

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Attachment 4 to Appendix 3E
INVESTIGATIONS OF LOOSE SAPROLITE

1. Field Investigations

Additional borings were undertaken in the area of the southeast section of the service water reservoir dike. Borings SWR-10, 11, 12, and 13, and P-15, 16, and 17 (Figure 1-7) were completed during May 1976.

The boring program has been designed to identify and delineate “loose” foundation zones per Regulatory Position 3.8. A subsequent NRC request required that undisturbed samples of material be obtained for determination of in situ strength under unconsolidated undrained (U-U) conditions. (Results of strength tests and stability analyses are reported later in this attachment.) The program, therefore, has concentrated on determination of standard penetration test (SPT) values and in situ density measurements of both dike and foundation material along the highest section of dike, and at specific locations where previous borings indicated the possible existence of “loose” zones. The locations of additional borings are shown by the boring location plan, Figures 8 and 9. Borings with “P” suffix indicate new piezometer installations.

Total or dry unit weights, water contents, and SPT values determined at locations along the dike centerline are shown by Figure 10.

Borings SWR-10 and P-15 were located near SWR-6, primarily to check repeatability of previously measured low densities of 82.0, 83.3, 72.3, and 66.4 pcf. As shown on Figure 10, these low densities were not confirmed, and in fact, densities measured in 16 undisturbed samples of foundation material averaged over 100 pcf. Boring SWR-10, however, found lower SPT values, with blow counts equal to 14 to 20, than previously measured in the 15-ft.-thick zone immediately beneath the fill-foundation contact.

Where previous measurements in SWR-7 gave blow counts of 8, 11, and 16 in foundation material near the fill-foundation contact, the additional adjacent boring P-17 measured SPT values of 17 and greater in this zone.

The additional borings and measurements indicate that measured densities of foundation materials in the sampling tubes as low as 75 pcf are not anomalous. However, extreme variations in density can occur within one 30-inch tube. For example, P-17, ST-11, densities recorded for two separate sections of the tube were 95.6 and 77.5 pcf, respectively. Similarly, relatively large variations in blow counts occur within very small areas of the foundation. The occurrence of both high and low measured densities and SPT values is generally random throughout the foundation; that is, low densities occur in spots rather than in zones of a size that would be significant with respect to foundation performance.

Boring SWR-12 was angled in an attempt to obtain undisturbed samples for U-U tests having axes perpendicular to the foliation of the saprolite. Density measurements indicate a zone approximately 15 feet thick beneath the rock toe with lower densities and higher water contents than encountered beneath the centerline of dike. These conditions are probably associated with a greater depth of weathering near the natural drainage course. However, laboratory test data indicate severe disturbance for many samples from this boring. The rock toe will provide positive ground-water control, and stability analyses described separately account for the possibility of low toe foundation strengths. For these reasons, the conditions measured by boring SWR-12 are not considered critical to foundation performance. Foundation conditions at the dike toe to the northeast of boring SWR-12 improve, as shown by borings SWR-11, P-10, and SI-3, where high blow counts were measured at relatively shallow depths.

Evaluation of the results of investigations have considered the following factors:

a. New investigations into the structure and composition of the saprolites have been undertaken (Parts 2, 3 and 4 of this response) which indicate that relatively low in situ densities are not necessarily indicative of low strength or susceptibility to liquefaction.

b. It is apparent that measured (and reported) densities are lower than those actually existing, due to the presence of halloysite. There is also a probability that the in situ material swells just prior to sampling, in addition to the swelling observed when the material is extruded from the sampling tube. Although the method of sampling (fixed-piston with 3-inch. Shelby tubes) has been found to be the most effective means available, inclusions of quartz often nick or bend the sample tubes, leading to an indeterminate reduction in average density measured in the array of samples.

In view of these factors, measured in-place densities of less than 80 pcf are of less significance than previously thought.

The additional field investigations indicate the embankment dry densities to be somewhat higher than previously reported. The average of tests on a set of 18 tube samples was slightly over 100 pcf, compared to 95 pcf previously reported.

Density measurements of undisturbed foundation samples from SWR-13 showed lower values than measured in other borings. For this reason, two additional borings were made located approximately 70 feet to either side of SWR-13 on the dike centerline. Boring SWR-14, 70 feet northwest of SWR-13, has been completed, and the remaining boring is in progress. Upon evaluation of data from these borings, including additional in-place density measurements, sufficient information will be available to approximate the extent, if indicated, of an area having densities generally lower than those measured at other locations. This finding would result in installation of a permanent dewatering system in the area defined to control ground water at present levels, as indicated previously, the maximum extent of which would include an area of foundation along the dike centerline between borings SWR-6 and SWR-5.

2. Laboratory Testing of Undisturbed Samples

General

Testing of the 80 3.0-inch-diameter, thin-wall tube samples began in a soil laboratory at the site where sections were cut from approximately half the samples for density determinations. These sections were all cut from the top of the samples in order to leave intact the wax plug and seal at the bottom for later transportation to Boston. First, about 2 inches of the sample was cut from the top to ensure that the section of tube below it contained intact material (this topmost section was always designated “A”). If the “A” section appeared disturbed, another 3 inches or more would be removed before making a density determination. For each density determination at the site, a 4-inch section (typically the “B” section, though sometimes the “C”) was cut for weighing and measuring. The top of the remainder of each tube was then capped and sealed with tape for transporting to Boston.

Samples were cut into sections by clamping each tube between the circular faces of two aligned pairs of hardwood blocks, one pair of blocks on either side of the point being cut. (The all-around rigidity of the clamping blocks prevents any flexing of the tube out-of-round during cutting.) Each steel sampling tube was cut through by the slow revolution of a thin-wheeled tube cutter.

The material within the tube was then cut by a taut, thin (0.15-inch) steel wire. The inside edge of the cut rim of the tube was always deburred before extruding the contents of the tube past the rim.

At the soils laboratory in Boston, sections for density and strength determinations were cut from each sample starting at the bottom. First, 2 to 3 inches (always called the “G” section) were cut from the bottom to ensure that the section of tube above it contained undisturbed material and to permit a thorough examination of the sampling tube cutting edge. Succeeding sections above the “G” section of each tube were cut into 6- to 7-inch lengths (designated, in turn, “F,” “E,” etc.).

The results of all measurements and tests on the undisturbed samples are summarized in Tables 1 through 6 and are discussed in the following paragraphs.

In Situ Density Determinations

Procedure

Both the embankment and the foundation materials, containing relatively high percentages of mica, expand significantly upon being extruded from the confinement of a sampling tube. The expansion results in a decrease of the computed unit weight by as much as 10 pcf. During this investigation, the unit weight of essentially every section cut from the samples was determined both while the material was still in the tube and after it had been extruded from the tube. The sample diameter for computing the unit weight before extruding the material was taken from the inside diameter of the cutting edge of the sampling tube. This dimension is preferable for a fixed-piston sampler (where the sample cannot increase in length) to correct for the expansion of a material to completely fill the area of the tube. (These particular materials certainly expanded in the tubes, as shown by the wall friction that prevented axial expansion until extrusion from the tubes.) The cutting edges of sampling tubes being used by the driller during this investigation were examined and measured to determine an average inside diameter to be applied to all computations of unit weights. These inside diameters, as well as those of the cylindrical bodies of the tubes, were found to be within very close tolerances, and an average value of 7.22 cm was taken for the inside diameter of the cutting edge and an average value of 7.29 cm was taken for the inside diameter of the cutting edge and an average value of 7.29 cm was taken for the inside diameter of the tube itself (used for computing unit weights for comparison purposes).

After each section (excluding the “A” and “G” sections) had been cut from a sample, the ends of the material were dressed with a straightedge to the same length as the tube, and each end was covered with a rigid plate. The tube, plates, and material were then weighed together. After the material had been extruded, the section of tubing and the two plates were thoroughly cleaned and weighed to permit computation of the weight of the wet material. Measurement of the length of the tube then permitted computation of the wet unit weight of the material before being extruded.

The length, diameter, and weight of the extruded section were determined to permit computation of the wet unit weight of the material after being extruded.

Either the entire section of material was used to determine the water content needed for computing the dry unit weight or else the water content was taken from the records of the undrained compression test performed on that section.

When a compression test specimen was trimmed to a diameter smaller than that of the extruded section, the dimensions and weight of the test specimen were used to compute an additional unit weight of the material.

The four possible bases for computing the dry unit weight of the material are indicated in Tables 1 through 6 as follows:

a. Before being extruded, based on inside diameter of cutting edge.

b. Before being extruded, based on inside diameter of sampling tube.

c. After being extruded.

d. After trimming of test specimen.

To further show the effect of the expansion of these materials on the computed properties of the samples, Tables 1 through 6 also show values of void ratio, e, and degree of saturation, S, based on the dry unit weight and water content, which were computed by standard relationships, where the specific gravity of the solids, G, was assumed to be 2.68, based on determinations made during the investigation in late 1975. Only two bases for computing these properties were considered, as follows:

a. Before being extruded, based on inside diameter of cutting edge; that is, the closest approximation of the in situ property.

b. Either after being extruded (basis “C”) or, if a test specimen were trimmed, after trimming the specimen (basis “D”); that is, the property of the test specimen.

Embankment

From a total of 24 determinations, the dry unit weight of in-place embankment material was found to vary from a low of 86.9 pcf to a high of 109.8 pcf, with an average of 100.7 pcf. These values, however, may include results from samples that had been disturbed during sampling; gravel-size particles in the fill caused heavy damage to the cutting edge in several instances leading to a reduction in measured density.

Samples taken within the top 1 foot showed lower than average unit weights. Two samples (sample 6 from boring P-16 and sample 4 from boring SWR-13) intersected the interface between the embankment and the foundation. The dry unit weight of the embankment material immediately above this interface was found to be 86.9 and 97.6 pcf, respectively, in these two samples.

Foundation

A total of 86 determinations were made of the in-place dry unit weight of the foundation material. Values varied from as low as 69.4 pcf (sample 6 from boring SWR-12) to as high as 119.2 pcf (samples 22 and 23 from boring P-15). It should be noted that accurate representation of actual foundation conditions involves a spatial display of density values at the points in the foundation at which each value was measured; a simple averaging of density values is not an appropriate means of describing conditions. Average density is, of course, appropriately used in evaluating the overall performance of these foundation zones. The possibility of sample disturbance must also be kept in mind when examining these unit weights, though, in general, no damage to cutting edges can be related to the lower unit weights determined.

The shape of the stress-strain curves for undrained compression tests performed on samples from boring SWR-12 (Figure 11 Sheets 1-5) shows clearly that these samples were disturbed, and all of the unit weights determined in this angle boring must be considered to be lower than their actual weights. Similarly, two samples (12F and 12E) from boring SWR-13 gave stress-strain curves (Figure 11 Sheet 5) showing possible disturbance that might be related to the low dry unit weights (80.8 and 75.5 pcf, respectively) of these samples. On the other hand, other samples for boring SWR-13 (6, 8, and 10) with equally low dry unit weights (71.9, 84.1, and 75.7 pcf, respectively) gave stress-strain curves (Figure 11 Sheets 6-7) showing a relative freedom from disturbance.

3. Composition of Saprolite

Thin sections of samples from borings SWR-3, SWR-4, SWR-5, SWR-7, and P-10 (Table 7) were examined in order to determine in a qualitative manner the fabric, texture, and mineralogy of the saprolite beneath the service water reservoir dike (see boring location plan, Figure 12).

The analysis was undertaken to clarify some of the results of soil classification and laboratory analyses, and to clarify the engineering behavior of the saprolite. Twenty-seven thin sections were examined under plane and polarized light at various magnifications up to 400x.

Sections were cut at various angles to the visible banding in undisturbed samples. Part a of Figure 13 shows a section cut perpendicular to the plane of foliation. Other sections were cut parallel to the foliation in both felsic (quartz- and feldspar-rich) layers and mafic (biotite-rich) layers to see if any minerals were oriented in the plane of foliation. Large sections (1.75-inch x 2-inch) were cut horizontally across six of the samples, and small sections (1-inch x 1.75-inch) were cut vertically at the ends of the large sections. A wide range of orientations of section to foliation resulted from the procedure.

Percentage of minerals present in the thin sections was estimated by scanning the sections under low magnification or by projection of the thin section onto a screen using a slide projector. Size of grains was estimated by using a micrometer eyepiece in the polarizing microscope. Major minerals were identified by standard optical petrographic techniques; accessory and trace minerals were ignored for this analysis.

Fabric

The fabric of the saprolite is shown in Part a of Figure 13. The fabric is that of the parent rock, a biotitic granite gneiss. The saprolite consists of irregular planar bands of light-colored minerals in interlocking grains and irregular bands of dark-colored minerals in elongate grains. The strong foliation evident in the saprolite dips at angles of about 50 degrees from the horizontal. Some elongation of feldspar and quartz in the plane of the foliation occurs in one section, but no elongation is apparent in the direction perpendicular to the strike. Within the gneissic bands, the felsic grains are well interlocked and not strongly oriented. The biotite grains are strongly oriented with basal planes parallel to the plane of foliation. There is no apparent preferred alignment or elongation of the biotite within the plane of foliation. The biotite layers appear to be planes along which slippage could take place more readily than along the intervening well-interlocked felsic layers.

The fabric of the saprolite contrasts strongly with that of a sand (Part b of Figure 13). The sand shows no foliation and no interlocking of grains, even though the grains are quite angular.

The sand thin section also shows a well-developed void network unlike that of the saprolite. The fabric of saprolite is therefore not one of a transported soil but one of the parent rock material. The fabric is anisotropic; that is, it has strongly directional properties.

Texture

The textural relationships of the North Anna saprolite are shown in Parts a and c of Figure 13. Visual estimates of grain size in the thin sections yields a range of 0.05 to 10 mm. However, most of the grains fall in a much narrower range of about 0.1 to 2 mm. These size ranges are for discrete mineral grains observable under the microscope. Many “grains” with very sharp boundaries are composed of minute particles of clay minerals. The size of the individual clay minerals is too small to ascertain under the magnification available, but is smaller than 0.010 mm in most cases.

Therefore, although the grain size of the clay mineral aggregations or parent “grains” are similar to surrounding minerals in the interlocked fabric, the size of the clay within the “grains” is much smaller.

The most striking textural feature of the saprolite is the angularity and interlocking nature of the grains. There is no indication that individual grains are arranged so as to be able to reorient. On the contrary, any change in orientation of one grain would affect the surrounding grains because they are so completely locked geometrically in the overall fabric. The interlocking nature of the grains is shown in Part c of Figure 13.

The textural relationship of void space to grains is difficult to ascertain in the thin sections studied. There is no apparent volumetrically identifiable void network extensive enough to allow reorientation of grains (compare Parts a and b of Figure 13). Void space must occur along grain interfaces and within clay mineral aggregates as well as irregular joints and partially filled fractures. Many of the grains are fractured, but it is not known how much of the fracturing is due to the thin sectioning process. Clearly, some of the fractures are geologic because they are stained by weathering products.

The geometric interlocking of the grains and the lack of a void network that would allow reorientation of grains indicates that the saprolite could not liquefy.

Mineralogy

The mineralogy of the saprolite reflects to a large degree the mineralogy of the parent gneiss. The parent rock is composed mostly of quartz, microcline (potassium feldspar), and plagioclase (sodium-calcium feldspar), with minor to moderate amounts of biotite (brown to black mica). Other constituents are of minor importance and were ignored for the purposes of this investigation.

The mineralogy of the saprolite in thin section is seen to consist of quartz, microcline, clay minerals (unidentified as to type), and biotite. Much of the biotite is bleached and shows low birefringence. This is no doubt due to weathering and incipient hydration of the biotite. Quartz and microcline are clear and unaltered in thin section. There has been no significant corrosion of the grain boundaries. Plagioclase was identified only in one section, SWR-4 sample 6A2 from a depth of 77 feet (see Table 7). This grain is shown in Part c of Figure 13. Even at a depth of 77 feet, the plagioclase is nearly 50% altered to clay minerals. Clay aggregations in other thin sections retain the polygonal form of plagioclase grains and are therefore interpreted to be alteration products of plagioclase. The mineralogy of the clay aggregates are discussed in another section of this report.

The mineralogy of the saprolite therefore reflects a weathering process in which plagioclase feldspar has been converted to clay minerals, biotite has been bleached and partially hydrated, and quartz and microcline have remained unaffected. The weathering and change in mineral composition has not disrupted the relic fabric or significantly increased visible void space.

Visual estimates of mineral percentages yield the following:

Quartz	30% - 40%
Microcline	20% - 30%
Clay minerals	25% - 40%
Biotite	5% - 20%

Depth Relationships

Section P-10 sample 1 taken from a depth of 3 feet is not saprolite. No relic rock fabric is preserved. Each grain is an individual in a matrix of biotite and clay minerals with no apparent preferred orientation. The mineralogy is similar to that of the saprolite but the original fabric has been destroyed. This sample is interpreted to have been disturbed by near surface activity, either climatic or man-induced.

The saprolite from the greatest depth (77 feet) is somewhat less altered than that from samples above. Plagioclase is still recognizable and biotite is relatively fresh. Little iron oxide staining occurs at this depth. As depth decreases, the only apparent change is that plagioclase is entirely altered to clay, biotite becomes progressively more bleached, and straining is more abundant and pervasive. No significant change in fabric or texture occurs with decreasing depth until near the surface.

Clay Mineralogy

Dr. R. Torrence Martin has studied the clay mineralogy of samples taken just above those used for thin sectioning in the borings listed in Table 7. Previously he had also reported on the clay mineralogy of a sample from boring P-11. In conjuction with X-ray diffraction (XRD) analysis, Dr. Martin photographed some of the clay particles using a scanning electron microscope. The XRD analysis and photomicrography were undertaken to ascertain the size, shape, and mineralogy of clay within the North Anna saprolite and to establish the kind and quantity of clay minerals over the site of the service water reservoir dike.

The major clay mineral in all samples was halloysite with lesser amounts of illite and smectite (montmorillonite). Hallysite is a hydrated form of kaolinite. Halloysite occurs as aggregates of plates and hollow tubes with large amounts of void space within the aggregates (Figure 13). Much of the clay mineral is larger than the 2μm equivalent spherical diameter. Estimates of clay mineral content range from 20% to 75% and, in general, indicate that large amounts of the samples consist of clay minerals.

The general conclusions resulting from the clay mineral analysis are the following:

a. Most of the clay in the saprolite is halloysite, a mineral difficult to orient and one that contains much water.

b. Much of the halloysite is in the form of aggregates that are larger than 2μm and therefore would be classified as silt.

c. The clay mineral content is significantly higher than indicated by the soil classification indices. The clay aggregations are too strongly interbonded to be dispersed by the normal methods used in soil classification tests.

d. The halloysite content may account in part for the low relative densities obtained for the saprolite.

4. Liquefaction Study of Service Water Reservoir Foundation Materials

Part 3 of this attachment describes the composition of the saprolite foundation material. It is quite evident that the material, which has formed in place, and basically is comprised of interlocking particles with intersticial clays, would not tend to rearrange under seismic loading, with subsequent transfer of stress to pore water. Examination of the material in these terms leads to the conclusion that the saprolite is not susceptible to liquefaction.

Previous reports submitted in December 1975 (Section 3E.2) and March 1976 (FSAR Amendment 49 response to P 3.8) have discussed the susceptibility of the service water reservoir (SWR) foundation soils to liquefaction. In this attachment, this earlier material is reviewed, along with some recently developed laboratory data. The general character of the foundation soils with respect to their liquefaction potential is discussed, and the factor of safety against liquefaction for a cross section taken through the service water reservoir embankment is evaluated.

The foundation material beneath the service water reservoir embankment is saprolite, i.e., an "earth material that has been derived by disintegration and decomposition in place and has not been transported." (Reference 1) The most significant characteristic of this material is its spatial variability. This characteristic is exhibited in both the visual descriptions of material and measured sample dry unit weights and water content. Some of these data are presented in the boring logs shown in Figure 1-7.

Between November 1975 and June 1976, Geotechnical Engineers, Inc. (GEI) carried out 18 consolidated-undrained cyclic triaxial tests. Three of these 18 tests were aborted due to testing equipment failures (leaking membrane, faulty triaxial cell). Table 8 presents the significant details of the 18 tests. Some of these data have been presented in previous reports. Table 9 gives preliminary descriptions of the samples tested. The final report, Report on Laboratory Soil Testing, North Anna Power Station, Service Water Reservoir, dated June 21, 1976, is included as Attachment 3 to Appendix 3E.

VEPCO based its selection of undisturbed samples for the cyclic triaxial tests on four criteria:

a. Sample classification of the material near the ends of the undisturbed sampling tubes and the classification of adjacent disturbed standard penetration test (SPT) samples.

b. Proximity of undisturbed samples to low SPT blow counts.

c. Inclusion of samples selected over the entire soil foundation depth range, from the bottom of compacted fill to the top of hard foundation material.

d. Measured sample densities of undisturbed specimens taken from the ends of the undisturbed sampling tubes. Low sample density was the principal basis for sample selection.

Because of the spatial variability of the saprolite, the four criteria were unable to pinpoint the optimum locations for test specimen selection. GEI laboratory personnel made the final, precise selection of cyclic triaxial test specimens based on close examination of the entire undisturbed sample following extrusion from the tubes.

The visual sample descriptions of the test specimens may be examined in Table 9. Table 8 lists the dry unit weights and water contents of the test specimens. The spatial variability of the saprolite is most vividly demonstrated by comparing data on different specimens derived from a single undisturbed sampling tube, such as for tests 8 and 20, tests 9 and 12, tests 11 and 13, tests 14 and 16, and tests 17 and 18. The maximum difference in unit weight for these five pairs of samples, each from the same sampling tube, is 12%; the maximum difference in water content is 19%. An examination of the sample visual descriptions also shows large variability.

Table 8 reports results of the cyclic triaxial tests in terms of cyclic deviator stress, (σ1 - σ3)cy, and the ratio of the cyclic deviator stress to the minimum principal effective consolidation stress or the cyclic stress ratio. In keeping with earlier discussions of liquefaction of the SWR foundation materials, the liquefaction potential of these soils is analyzed in terms of the octahedral shear stress:

$$T_{oct} = \frac{1}{3}\sqrt{(\sigma_1 - \sigma_3)^2 + (\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2}$$

and the octahedral normal stress:

$$\sigma_{oct} = \frac{1}{3}(\sigma_1 + \sigma_2 + \sigma_3)$$

where σ_1, σ_2, and σ_3 represent the principal normal stress components. The test result data of Table 8 are plotted in Figure 14 in terms of the applied laboratory octahedral shear stress ratio versus the number of loading cycles required to reach 5% maximum compressive strain.

The most consistent segment of the cyclic triaxial test data is the three tests performed at a CSR = $\bar{\sigma}_1 / \bar{\sigma}_3$ = 1.0 and at an effective confining stress of 2.5 kg/cm^2 (tests 10, 11, and 13). A least-squares fit of a log-linear relation was drawn through these data points to produce the correlation line for σ_1 / σ_2 = 1.0 shown in Figure 14. For conservatism, the data from tests 14 and 16 were not used to produce this correlation.

In order to produce the correlations for the larger values of CSR, log-linear relations were drawn at the same slope as the CSR = 1.0 line. These correlations pass through the centroid of the data points for each of the CSR values greater than 1.0 and are parallel to the trend of the most consistent segment of the cyclic triaxial test data.

In order to evaluate the level of cyclic octahedral shear stress necessary to cause liquefaction, the data of Figure 14 must be evaluated for a particular number of equivalent earthquake cycles. Based on the recommendations given by Seed et al. (1975) (Reference 2) and on data presented in Section 2.5.2.6, 10 equivalent cycles have been used. The data for Figure 14, a plot of octahedral cyclic shear stress ratio versus consolidation stress ratio, were derived by evaluating the correlation curves of Figure 14 at an abscissa of 10 cycles. Figure 14 was used as the basis for evaluation of cyclic shear strength in the SWR foundation.

To calculate the range of liquefaction potential that exists under the SWR embankment, five profiles were selected along the embankment cross section shown in Figure 15. This cross section is identical to the section that was most critical in the calculations of slope stability.

Evaluation of the cyclic shear stress necessary to cause liquefaction (5% compression strain at 10 cycles) requires the following data along each profile:

a. Vertical and horizontal total stresses, σ_V and σ_H.

b. Pore pressure, u.

c. Octahedral normal effective stress, $\bar{\sigma}_{oct}$ = (σ_V + σ_H) (1 + υ) - U where υ is the Poisson's ratio.

d. Consolidation stress ratio, $\bar{\sigma}_1 / \bar{\sigma}_3$

From these data, the shear strength relation shown in Figure 14 was used to calculate the allowable octahedral cyclic shear strength. To calculate the values of the total stress components beneath the embankment, a finite element analysis was used. In this calculation, the modulus of all the material in the cross section was assumed to be uniform, homogeneous, isotropic, and linearly elastic.

In order to assess the level of octahedral shear stress caused by a potential earthquake, a modified relation proposed by Seed et al. (1975) (Reference 2) was adopted:

$$\Delta T_{oct_f} = 0.65 \frac{a_{max}}{g} \times \sigma_V \times (d \times F_{oct})$$

where F_{oct} converts the original expression for the shear stress on horizontal planes into octahedral shear stress. For the plane strain conditions appropriate for this long embankment section, F_{oct} = 0.816.

Table 10 lists the stress values and strength magnitudes calculated by the procedure just described. From these data were developed the shear stress profiles shown in Figure 15. This figure illustrates that there is no point along the profiles analyzed where the earthquake-developed octahedral shear stress exceeds the octahedral cyclic shear strength.

A factor of safety against liquefaction has been defined as the ratio of the cyclic octahedral shear strength to the cyclic octahedral earthquake shear stress, $\Delta T_{oct_l} / \Delta T_{oct_f}$. Figure 16 shows the distribution of factor of safety against liquefaction versus depth for the five profiles analyzed. The factor-of-safety values plotted range from a low of 1.51 to a high of 6. Seed et al. (1975) (Reference 2) have suggested that the values of cyclic shear stress necessary to cause initial liquefaction with combined two-dimensional horizontal shaking may be 10% less than the one-dimensional shear stresses applied in the laboratory tests. Incorporating this factor into the calculated data shown in Table 10, Figures 15 and 16 will reduce the cyclic shear strength and the factors of safety by 10%. The factors of safety for two-dimensional shaking range from 1.36 to about 5.4.

The liquefaction analyses given in previous reports, the additional laboratory cyclic testing results, and the reanalysis reported above all show that liquefaction of the foundation soils beneath the service water reservoir embankment will not occur during the safe-shutdown earthquake (SSE). For the case analyzed where the ground-water level is at its most likely position, as shown in Figure 15, the minimum factor of safety against liquefaction is 1.36, including the effects of two-dimensional shaking.

In a previous report, VEPCO investigated the effect of an elevated water table at a level of 303 feet. Incorporating this condition into the present analysis will influence the results only for profiles D and E, which used ground-water levels below Elevation 303 feet. The ground surface elevation at these two locations is 287 feet and 283 feet, respectively. If it is assumed that the ground-water level at Sections D and E is at the ground surface, the calculated effective octahedral normal stresses, the calculated cyclic shear strengths, and the factors of safety will be smaller than the values shown in the table and figures. Including the effect of the elevated water table, as well as two-dimensional shaking, the minimum factor of safety along Sections D and E is 1.6. Thus, it has been shown that even for the most conservative location of the ground-water surface elevation, the foundation of the service water reservoir embankment will not liquefy during the safe-shutdown earthquake.

ATTACHMENT 4 TO APPENDIX 3E REFERENCES

1. W. L. Stokes and D. J. Varnes, Glossary of Selected Geologic Terms, Proceedings, Colorado Scientific Society, 1955, p. 128.
2. H. B. Seed, I. Arango, and C. K. Chang, Evaluation of Soil Liquefaction Potential During Earthquakes, EERC Report 75-28, University of California, Berkley, 1975.

Table 1
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING P-15

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt%)	Dry Unit Weight γ_d A (pcf)	B (pcf)	C (pcf)	D (pcf)	Void Ratio e A	E	Saturation S A (%)	E (%)	Unconsolidated-Undrained Compression Test Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-1A	7.4	312.6	CH-SC	60	26.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Bent deeply inward
ST-1B	7.6	312.4	SC-CH	48	25.4	98.8	97.0	96.1	—	0.693	0.740	98.3	92.0	—	—	—	—	—	—	
ST-1F	8.0	312.0	Preserved in tube																	
ST-1G	8.5	311.5	SM-ML	34	24.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-2A	10.0	310.0	SC-CH	47	28.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good
ST-2B	10.2	309.8	Preserved in tube																	
ST-2E	10.4	309.6	CH-SC	55-65	28.4	96.2	94.3	93.8	93.0	0.738	0.798	103.1	95.4	2.54	1.35	4.13	8.9	2.06	Shearing	
ST-2F	10.9	309.1	CH-SC	59	28.0	97.7	95.9	91.7	—	0.712	0.824	105.4	91.1	2.89	1.35	5.65	10.2	2.78	Shearing	
ST-2G	11.3	308.7	CH-SC	54	22.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-3A	13.0	307.0	CH-SC	61	26.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Many small dents
ST-3D	13.2	306.8	Preserved in tube																	
ST-3E	13.7	306.3	CH-SC	65-75	22.9	104.5	102.4	—	100.4	0.600	0.666	102.3	92.2	2.57	1.73	8.51	11.0	4.06	Shearing	
ST-3F	14.2	305.8	CH-SC	55-65	22.8	104.4	102.4	101.3	—	0.602	0.651	101.5	93.9	2.88	1.73	4.89	7.8	2.44	Shearing	
ST-3G	14.8	305.2	CH-SC	61	35.7	—	—	—	—	—	—	—	—	—	—	—	—	—		
ST-4A	15.5	304.5	CH SC	64	30.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good
ST-4D	15.7	304.3	Preserved in tube																	
ST-4E	15.8	304.2	CH-SC	57	22.5	104.7	102.8	101.2	100.8	0.597	0.659	101.0	91.5	2.54	1.98	8.34	6.1	4.22	Shearing and bulging	
ST-4F	16.3	303.7	SC-CH	48	22.9	103.7	101.7	94.5	—	0.613	0.770	100.1	79.7	2.88	1.98	6.89	10.4	3.26	Shearing	
ST-4G	16.9	303.1	CH-SC	52	19.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-5A	18.0	302.0	CH-SC	58	22.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	One deep inward dent
ST-5B	18.2	301.8	CH-SC	52	19.9	109.8	107.8	104.8	—	0.523	—	102.0	—	—	—	—	—	—	—	
ST-5F	18.7	301.3	Preserved in tube																	
ST-5G	19.2	300.8	SM	26	12.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-6A	21.0	299.0	SC-CH	45	27.5															Bent deeply inward
ST-6B	21.2	298.8	SC-CH	44	30.1															
ST-6F	21.7	298.3	Discarded																	
ST-6G	22.4	297.6	CH-SC	51	35.9															
ST-7A	23.5	296.5	SC-CH	47	28.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Two large dents
ST-7E	23.8	296.2	CH-SC	53	24.1	100.2	98.3	95.8	95.3	0.669	0.755	96.5	85.5	2.49	2.90	5.80	9.2	2.87	Shearing	
ST-7F	24.3	295.7	CH-SC	50	22.7	104.6	102.6	102.8	—	0.599	0.627	101.6	97.0	2.85	2.90	7.25	15	3.43	Shearing	
ST-7G	24.8	295.2	CH-SC	52	27.8	—	—	—	—	—	—	—	—	—	—	—	—	—		

Table 1 (continued)
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING P-15

						Dry Unit Weight γ_d				Void Ratio e		Saturation S		Unconsolidated-Undrained Compression Test						
Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt%)	A (pcf)	B (pcf)	C (pcf)	D (pcf)	A	E	A (%)	E (%)	Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-8A	26.0	294.0	ML	85-90	31.3															—
Interface between embankment and foundation at about elevation 292.5																				
ST-9A	28. 5	291.5	SC-CL	48	19.7	—	—	—	—	—	—	—	—	—	—	—	—	—		Good
ST-9E	28.6	291.4	Preserved in tube																	
ST-9F	29.7	290.3	SM	30-40	17.3	98.5	96.6	93.1	—	0.698	0.796	66.4	58.2	2.87	3.54	6.94	11.5	3.28	With foliation at 50°	
ST-9G	30.3	289.7	SM	33	16.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-10A	31.0	289.0	SM	10-15	23.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Not
ST-10B	31.1	288.9	SM	30	22.8	93.8	92.0	91.1	—	0.783	0.836	78.0	73.1	—	—	—	—	—	—	viewed
ST-10D	31.5	288.5	Provided to Geotechnical Engineers, Inc., for cyclic triaxial testing																	
ST-11A	33.5	286.5	SM	30	20.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good
ST-11E	33.7	286.3	Preserved in tube																	
S-11F	34.6	285.4	SM	20-25	14.9	102.6	100.7	96.4	—	0.630	0.735	63.4	54.3	2.88	4.15	7.74	12.9	3.68	Shear across foliation	
ST-11G	35.2	284.8	SM	23	13.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-12A	36.0	284.0	SM	10-15	17.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	One
ST-12B	36.1	283.9	SM	10-15	17.0	100.1	98.2	97.2	—	0.671	0.720	67.9	63.3	—	—	—	—	—	—	very
ST-12E	36.4	283.6	Preserved in tube																	small
ST-12F	36.9	283.1	SM	20-25	16.1	107.2	105.1	97.6	—	0.560	0.713	77.0	60.5	2.89	4.45	8.00	>15	3.86	With foliation at 45°	dent
ST-12G	37.4	282.6	SM	21	15.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-13A	38.5	281.5	SM	26	18.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair
ST-13E	38.7	281.3	Preserved in tube																	
ST-13F	39.6	280.4	SM	15-25	13.3	106.0	104.0	95.5	—	0.578	0.751	61.7	47.5	2.89	4.78	9.51	10.4	4.52	Shear across foliation	
ST-13G	40.2	279.8	SM	22	13.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-14A	41.0	279.0	SM	10-20	16.7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very
ST-14B	41.1	278.9	SM	10-20	15.9	101.7	99.8	97.4	—	0.644	0.717	66.2	59.4	—	—	—	—	—	—	good
ST-14E	41.4	278.6	Preserved in tube																	
ST-14F	42.0	278.0	SM	20-25	15.4	108.2	106.1	99.4	—	0.546	0.682	75.6	60.5	2.89	5.08	8.77	9.4	4.35	Slip along clay seam	
ST-14G	42.5	277.5	SM	23	13.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-15A	43.5	276.5	SP	4	13.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good
ST-15E	43.6	276.4	Preserved in tube																	

Table 1 (continued)
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING P-15

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt%)	Dry Unit Weight γ_d A (pcf)	B (pcf)	C (pcf)	D (pcf)	Void Ratio e A	E	Saturation S A (%)	E (%)	Unconsolidated-Undrained Compression Test Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-15F	44.5	275.5	SM	20-25	17.1	110.7	108.5	99.3	—	0.511	0.684	89.7	67.0	2.88	5.39	8.85	>15	3.84	With foliation at 45°	
ST-15G	45.0	275.0	SM	23	15.7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-16A	46.0	274.0	SM	10-20	17.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair, but out-
ST-16B	46.2	273.8	SM	10-20	19.7	100.9	99.0	97.3	—	0.657	0.719	80.4	73.4	—	—	—	—	—	—	of-round
ST-16E	46.5	273.5	Preserved in tube																	
ST-16F	47.0	273.0	SM	19	13.9	117.0	114.8	108.3	—	0.429	0.544	86.8	68.5	2.89	5.70	10.17	7.6	5.06	With foliation at 55°	
ST-16G	47.6	272.4	SM	10-20	15.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-17A	48.5	271.5	SM	10-20	18.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very
ST-17D	48.7	271.3	Preserved in tube																	good
ST-17E	49.1	270.9	SM	15-20	16.5	112.2	110.0	103.5	—	0.490	0.616	90.2	71.8	2.88	5.96	9.34	>15	3.60	With foliation at 40°	
ST-17F	49.7	270.3	SM	15-20	15.3	116.0	113.7	106.6	—	0.442	0.569	92.8	72.1	2.89	6.04	4.99	3.4	2.56	Slip along clay joint	
ST-17G	50.2	269.8	SM	18	16.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-18A	51.0	269.0	SM	10-20	16.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very
ST-18B	51.2	268.8	SM	10-20	17.0	109.6	107.5	103.4	—	0.526	0.617	86.6	73.8	—	—	—	—	—	—	good
ST-18E	51.5	268.5	Preserved in tube																	
ST-18F	52.2	267.8	SM	30-35	21.1	107.3	105.3	99.2	—	0.599	0.686	101.2	82.4	2.88	6.35	3.40	8.2	1.69	With foliation 50°	
ST-18G	52.7	267.3	SM	39	37.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-19A	53.5	266.5	SM	35-45	41.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	One
ST-19D	53.7	266.3	SM	15-20	17.8	108.9	106.9	105,2	—	0.536	0.590	89.0	80.9	2.88	6.56	6.95	>15	2.72	With foliation at 45°	deep
ST-19E	54.1	265.9	SM	18	17.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-19F	54.2	265.8	SM	15-20	18.8	110.4	108.3	103.9	—	0.515	0.610	97.8	82.6	2.89	6.61	2.24	13.6	1.10	In clean sand layer	Inward
ST-19G	54.7	265.3	SM	30	17.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	dent
ST-20A	56.0	264.0	SM	25-35	23.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair
ST-20B	56.2	263.8	SM	25-35	28.0	98.4	96.5	94.9	—	0.699	0.762	67.4	98.5	—	—	—	—	—	—	
ST-20E	56.5	263.5	Preserved in tube																	
ST-20F	57.2	262.8	SM	26	20.0	109.8	107.8	101.3	—	0.523	0.651	102.5	82.3	2.87	6.96	4.08	3.8	1.35	With foliation at 50°	
ST-20G	57.7	262.3	SM	31	25.0		—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-21A	58.5	261.5	SM	21	21.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-21D	58.7	261.3	Preserved in tube																	
ST-21E	59.3	260.7	SM	15-20	20.1	109.6	107.6	102.0	—	0.526	0.640	102.4	84.2	2.89	7.24	4.25	9.3	2.00	With foliation at 40°	
ST-21F	59.8	260.2	SM	15-20	21.1	108.9	106.9	102.7	—	0.536	0.628	105.5	90.0	2.89	7.31	5.64	8.2	1.80	With foliation at 55°	

Table 1 (continued)
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING P-15

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt%)	Dry Unit Weight γ_d A (pcf)	B (pcf)	C (pcf)	D (pcf)	Void Ratio e A	E	Saturation S A (%)	E (%)	Unconsolidated-Undrained Compression Test: Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-21G	60.3	259.7	SM	17	22.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-22A	61.0	259.0	SM	20-30	20.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good
ST-22B	61.2	258.8	SM	20-30	22.0	107.1	105.1	101.6	—	0.561	0.646	105.1	91.3	—	—	—	—	—	—	
ST-22D	61.5	258.5	Preserved in tube																	Good
ST-22E	61.7	258.3	SP-SM	5-10	19.4	113.3	111.1	104.7	—	0.476	0.597	109.2	87.1	2.90	7.54	3.55	8.1	1.76	Shearing	
ST-22F	62.2	257.8	SM	17	18.2	119.2	116.9	115.7	—	0.403	0.445	121.0	109.6	2.87	7.59	6.54	5.0	2.90	Shear across foliation	
ST-22G	62.7	257.3	SM	31	29.7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-23A	63.5	256.5	SP-SM	8-12	23.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good, one small dent
ST-23B	63.7	256.3	Preserved in tube																	
ST-23D	64.3	255.7	SP-SM	8-12	27.1	—	—	—	91.3	—	0.832	—	87.3	Constant-volume direct shear test						
ST-23E	64.5	255.5	Preserved in tube																	
ST-23F	64.7	255.3	SM	18	18.9	119.2	116.9	114.8	—	0.403	0.457	125.7	110.8	2.87	7.92	2.77	3.2	1.40	With foliation at 60°	
ST-23G	65.8	254.2	SP-SM	8-12	21.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-24A	66.0	254.0	SM	15-25	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Not viewed
ST-24B	66.2	253.8	SM	24	37.9	92.5	90.7	89.9	—	0.808	0.860	125.7	118.1	—	—	—	—	—	—	
ST-24D	66.5	253.5	Provided to Geotechnical Engineers, Inc., for cyclic triaxial testing																	
ST-25A	69.5	250.5	SM	10-15	23.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair
ST-25D	69.7	250.3	Preserved in tube																	
ST-25E	70.2	249.8	SM	10-15	27.0	98.3	96.5	91.4	—	0.701	0.830	103.2	87.2	2.88	8.60	4.37	7.6	2.18	Shearing and bulging	
ST-25F	70.8	249.2	SM	31	25.6	104.2	102.2	95.1	—	0.605	0.758	113.4	90.5	2.87	8.67	2.48	>15	0.82	Along thin clay layer	
ST-25G	71.4	248.6	SM	25-30	14.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Table 2
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING P-16

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt%)	Dry Unit Weight γ_d A (pcf)	Dry Unit Weight γ_d B (pcf)	Dry Unit Weight γ_d C (pcf)	Dry Unit Weight γ_d D (pcf)	Void Ratio e A	Void Ratio e E	Saturation S A (%)	Saturation S E (%)	Unconsolidated-Undrained Compression Test: Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-1A	7.5	312.5	Empty																	Good
ST-1B	7.5	312.5	CH-SC	65-75	24.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-1C	7.7	312.3	CH-SC	65-75	25.5	97.3	95.4	—	—	0.719	—	95.0	—	—	—	—	—	—	—	
ST-1F	8.0	312.0	Preserved in tube																	
ST-1G	9.0	311.0	CH-SC	78	37.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-2A	12.5	307.5	CH-SC	56	25.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair
ST-2E	12.6	307.4	Preserved in tube																	
ST-2F	13.5	306.5	CH-SC	55-60	20.6	109.0	107.0	103.3	—	0.534	0.619	103.4	89.2	2.87	1.66	6.59	14.8	3.00	Bulging and shearing	
ST-2G	14.0	306.0	CH-SC	52	19.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-3A	17.5	302.5	ML-SM	55-65	20.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-3B	17.6	302.4	ML-SM	55-65	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-3C	17.7	302.3	ML-SM	55-65	25.7	101.1	99.1	98.9	—	0.654	0.691	105.3	99.7	—	—	—	—	—	—	
ST-3F	18.1	301.9	Preserved in tube																	
ST-3G	19.1	300.9	SM	27	21.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-4A	22.5	297.5	ML-SM	54	29.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good
ST-4E	22.7	297.3	Preserved in tube																	
ST-4F	23.7	296.3	ML-SM	50-55	23.7	99.2	97.3	95.6	—	0.686	0.749	92.6	84.8	2.87	2.82	6.12	9.9	3.00	Shearing	
ST-4G	24.3	295.7	ML-SM	50	25.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-5A	27.5	292.5	ML-SM	65-75	32.7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair
ST-5B	27.7	292.3	ML-SM	65-75	31.5	87.9	86.2	84.6	—3	0.90	0.977	93.5	86.4	—	—	—	—	—	—	
ST-5E	28.0	292.0	Preserved in tube																	
ST-5F	28.7	291.3	ML-SM	55-65	23.0	102.6	100.6	98.6	—	0.630	0.696	97.8	88.6	2.87	3.41	7.85	14.4	3.71	Shearing	
ST-5G	29.2	290.8	ML-SM	61	23.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-6A	32.5	287.5	ML-SM	55-60	18.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good
ST-6E	32.7	287.3	Preserved in tube																	
ST-6F	33.7	286.3	ML-SM	70-80	31.0	86.9	85.2	84.8	—	0.924	0.972	89.9	85.5	2.87	4.00	6.19	12.0	2.98	Shearing	
ST-6G	34.4	285.6	SM	10-15	19.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Interface between embankment and foundation at exactly elevation 285.9 (near bottom of test specimen)																				
ST-7A	37.5	282.5	SM	10-20	34.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Not viewed
ST-7B	37.7	282.3	SM	10-20	31.2	88.2	86.4	86.1	—	0.896	0.942	93.3	88.8	—	—	—	—	—	—	
ST-7C	38.0	282.0	Provided to Geotechnical Engineers, Inc., for cyclic triaxial testing																	

Table 2 (continued)
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING P-16

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt%)	Dry Unit Weight γ_d A (pcf)	Dry Unit Weight γ_d B (pcf)	Dry Unit Weight γ_d C (pcf)	Dry Unit Weight γ_d D (pcf)	Void Ratio e A	Void Ratio e E	Saturation S A (%)	Saturation S E (%)	Unconsolidated-Undrained Compression Test: Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-8	42.5	277.5	Provided to USAE Waterways Experiment Station for cyclic triaxial testing																	Not viewed
ST-9A	47.5	272.5	SM	10-20	33.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair
ST-9B	47.7	272.3	SM	10-20	30.8	91.2	89.4	89.2	—	0.834	0.875	99.0	94.3	—	—	—	—	—	—	
ST-9D	48.0	272.0	Provided to USAE Waterways Experiment Station																	
ST-9E	48.4	271.6	SM	10-20	31.0	92.9	91.2	88.5	—	0.800	0.890	103.8	93.3	—	—	—	—	—	—	
ST-9F	48.9	271.1	SM	10-20	29.8	93.7	91.9	88.6	—	0.785	0.887	101.7	90.0	—	—	—	—	—	—	
ST-9G	49.3	270.7	SM	20	30.7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-10	52.5	267.5	Provided to USAE Waterways Experiment Station for cyclic triaxial testing																	Not viewed
ST-11A	57.5	262.5	SM	10-15	22.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Bent deeply inward
ST-11B	57.7	262.3	SM	10-15	20.4	106.8	104.7	104.4	—	0.566	0.602	96.6	90.8	—	—	—	—	—	—	
ST-11E	58.0	262.0	SM	10-15	22.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-11F	58.4	261.6	SP-SM	8-12	21.0	107.2	105.1	101.7	—	0.560	0.644	100.5	87.4	2.87	7.09	5.67	13.5	1.91	Bulging	
ST-11G	59.0	261.0	SM	21	23.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-12A	62.5	257.5	SM	17	23.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Large inward dent
ST-12E	62.6	257.4	SM	15-20	23.4	104.0	101.9	98.9	—	0.608	0.691	103.1	90.8	—	—	—	—	—	—	
ST-12F	63.1	256.9	SM	15-20	19.1	109.5	107.4	—	—	0.527	—	97.1	—	—	—	—	—	—	—	
ST-12G	63.9	256.1	SM	15	15.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-13A	67.5	252.5	SM	20-30	20.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-13B	67.8	252.2	SM	20-30	20.8	108.9	106.6	106.0	—	0.536	0.578	104.0	96.4	—	—	—	—	—	—	
ST-13E	68.1	251.9	Preserved in tube																	
ST-13F	68.4	251.6	SM	25-30	20.2	109.5	107.3	101.1	—	0.527	0.654	102.7	82.8	2.88	8.34	2.35	6.8	1.17	Shearing	
ST-13G	69.0	251.0	SM	26	22.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Table 3
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING P-17

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt%)	Dry Unit Weight γ_d A (pcf)	B (pcf)	C (pcf)	D (pcf)	Void Ratio e A	E	Saturation S A (%)	E (%)	Unconsolidated-Undrained Compression Test Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-1A	7.5	312.5	CH-SC	55-60	18.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Not viewed
ST-1B	7.8	312.2	CH-SC	55-60	26.2	97.4	95.6	—	—	0.717	—	97.9	—	—	—	—	—	—	—	
ST-1F	8.1	311.9	Preserved in tube																	
ST-1G	—																			
ST-2A	12.5	307.5	CH-SC	66	33.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Bent deeply inward
ST-2F	12.6	307.4	Preserved in tube																	
ST-2G	13.9	306.1	SC-CH	44	22.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-3A	17.5	302.5	MH	70-80	30.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good
ST-3B	17.8	302.2	MH-SM	55-65	22.2	105.6	103.5	104.2	—	0.584	0.605	101.9	98.3	—	—	—	—	—	—	
ST-3F	18.1	301.9	Preserved in tube																	
ST-3G	19.3	300.7	CH-SC	54	16.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-4A	22.5	297.5	Preserved in tube																	
ST-4F	23.8	296.2	SM-ML	40-50	23.9	100.7	99.8	96.0	—	0.661	0.742	105.8	94.3	—	—	—	—	—	—	Very good
ST-4G	24.2	295.8	SM-ML	45	26.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-5A	27.5	292.5	MH-SM	55-60	24.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Deeply dented
ST-5F	27.6	292.4	Preserved in tube																	
ST-5G	28.1	291.9	ML-SM	55	24.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Interface between embankment and foundation at about elev. 288.0																				
ST-6A	32.5	287.5	SC-CH	40-48	17.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-6E	32.7	287.3	Preserved in tube																	
ST-6F	33.6	286.4	SC-CH	35-40	13.9	114.4	112.2	110.6	—	0.462	0.512	80.6	72.8	2.88	3.99	11.19	9.0	5.50	Shearing	
ST-6G	34.1	285.9	SC-CH	38	15.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-7A	37.5	282.5	SM-ML	40-48	29.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-7B	37.8	282.2	SM-ML	40-48	34.0	88.1	86.4	86.6	—	0.898	0.931	101.5	97.9	—	—	—	—	—	—	
ST-7E	38.2	281.8	Preserved in tube																	
ST-7F	38.7	281.3	SM-ML	35-45	31.9	86.1	84.5	83.4	—	0.942	1.005	90.8	85.1	2.87	4.63	3.40	14.6	1.59	Shearing	
ST-7G	39.2	280.8	SM-ML	44	36.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-8	42.5	277.5	Provided to USAE Waterways Experiment Station for cyclic triaxial testing																	
ST-9A	47.5	272.5	SM-ML	30-45	45.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Not viewed
ST-9B	47.8	272.2	SM-ML	30-40	38.4	86.3	84.6	82.9	—	0.938	1.017	109.7	101.2	—	—	—	—	—	—	
ST-9C	48.1	271.9	Provided to Goetechnical Engineers, Inc., for cyclic triaxial testing																	

Table 3 (continued)
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING P-17

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt%)	Dry Unit Weight γ_d A (pcf)	Dry Unit Weight γ_d B (pcf)	Dry Unit Weight γ_d C (pcf)	Dry Unit Weight γ_d D (pcf)	Void Ratio e A	Void Ratio e E	Saturation S A (%)	Saturation S E (%)	Unconsolidated-Undrained Compression Test Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-10	52.5	267.5	Provided to USAE Waterways Experiment Station for cyclic triaxial testing																	
ST-11A	57.5	262.5	SM	12-22	27.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-11B	57.8	262.2	SM	12-22	38.8	95.6	93.7	93.0	—	0.749	0.798	110.2	103.4	—	—	—	—	—	—	
ST-11E	58.1	261.9	SM-ML	40	40.2	83.5	81.8	81.4	—	1.043	1.054	107.4	102.2	2.87	7.07	2.28	10.7	1.09	With foliation at 60°	
ST-11F	58.7	261.3	SM-ML	40-45	46.5	77.5	76.0	74.6	—	1.158	1.242	107.6	100.3	2.87	7.13	2.41	10.5	1.18	Shearing	
ST-11G	59.2	260.8	SM-ML	44	49.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-12A	62.5	257.5	GP	3-8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	One small dent
ST-12B	62.6	257.4	SM	20-30	27.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-12D	62.7	257.3	Preserved in tube																	
ST-12E	62.9	257.1	SM	25-35	21.9	105.0	130.0	97.9	—	0.593	0.708	99.0	82.9	2.88	7.65	8.07	14.5	3.24	Bulging	
ST-12F	63.5	256.5	SM	10-20	31.1	93.6	91.8	87.3	—	0.787	0.916	105.9	91.0	2.90	7.74	4.51	12.1	2.04	Shearing	
ST-12G	64.0	256.0	SM	28	31.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-13A	67.5	252.5	SM	15-20	22.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	One deep inward dent
ST-13B	67.8	252.2	SM	15-20	20.6	110.4	108.4	105.7	—	0.515	0.582	107.2	94.9	—	—	—	—	—	—	
ST-13F	68.1	251.9	SM	15-20	23.3	106.0	104.0	101.5	—	0.578	0.648	108.0	96.4	2.88	8.31	3.19	7.2	1.54	With foliation at 55°	
ST-134G	68.6	251.4	EMPTY																	
ST-14A	72.5	247.5	SM	15-25	26.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Badly dented
ST-14F	72.6	247.4	SM	—	—	Sample disturbed: void in center due to separation on horizontal plane														
ST-14G	73.6	246.4	SM	18	26.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Table 4
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING SWR-11

						Dry Unit Weight γ_d				Void Ratio e		Saturation S		Unconsolidated-Undrained Compression Test						
Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt%)	A (pcf)	B (pcf)	C (pcf)	D (pcf)	A	E	A (%)	E (%)	Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-1	19.5	276.5	Provided to Geotechnical Engineers, Inc., for cyclic triaxial testing																	Not viewed
ST-2A	25.0	271.0	SM	25-35	42.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very
ST-2B	25.2	270.8	SM	25-35	43.7	79.9	78.4	78.6	—	1.093	1.128	107.2	103.8	—	—	—	—	—	—	good
ST-2E	25.7	270.3	Preserved in tube																	
ST-2F	26.1	269.9	SM	20-30	32.8	93.6	1.8	90.7	—	0.787	0.844	111.7	104.2	2.89	3.41	1.40	>15	0.51	In clay seam at 65°	
ST-2G	26.8	269.2	SM	20-30	25.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-3A	30.5	265.5	SM	15-20	37.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very
ST-3B	30.7	265.3	SM	15-20	33.1	101.0	99.0	96.5	—	0.656	0.733	135.2	121.0							good
ST-3G	31.0	265.0	SM	29	24.2															

Table 5
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING SWR-12

						Dry Unit Weight γ_d				Void Ratio e		Saturation S		Unconsolidated-Undrained Compression Test						
Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt%)	A (pcf)	B (pcf)	C (pcf)	D (pcf)	A	E	A (%)	E (%)	Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-1A	7.5	312.5	ML-SM	55-65	24.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good
ST-1B	7.9	312.1	ML-SM	55-65	27.8		94.1	94.2	—	0.744	0.775	100.1	96.1	—	—	—	—	—	—	
ST-1E	8.2	311.8	Preserved in tube																	
ST-1F	9.0	311.0	SM	29	19.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-1G	9.2	310.8	CH-SC		29.7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-2A	12.5	307.5	ML-SM	60-70	26.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair
ST-2E	12.6	307.4	Preserved in tube																	
ST-2F	13.5	306.5	SM-ML	45-50	20.4			103.8	—	0.533	0.611	102.6	89.5	—	—	—	—	—	—	
ST-2G	14.0	306.0	SM-ML	48	20.3	—	—	—	—											
ST-3A	17.5	302.5	ML	70-80	25.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Not viewed
ST-3B	17.8	302.2	ML	70-80	24.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-3C	18.1	301.9	SM-ML	20-30	23.9	102.0	100.1	100.1	—	0.640	0.671	100.1	95.5	—	—	—	—	—	—	
ST-3F	18.4	301.6	Preserved in tube																	
ST-3G																				
ST-4A	22.5	297.5	SM-ML	49	25.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair
ST-4E	22.7	297.3	Preserved in tube																	
ST-4F	23.8	296.2	SM-ML	40-45	26.0	97.6	95.8	92.1	—	0.713	0.816	97.7	85.4	2.87	2.84	4.90	6.6	2.31	Shearing	
ST-4G	24.3	295.7	CH-SC	62	28.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Interface between embankment and foundation at exactly elevation 295.8 (near bottom of test specimen)																				
ST-5A	27.5	292.5	SM-ML	30-40	21.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Few small dents
ST-5B	27.8	292.2	SM-ML	30-40	31.2	77.3	75.8	74.9	—	1.163	1.233	71.9	67.8	—	—	—	—	—	—	
ST-5E	28.2	291.8	Consumed for visual-manual examination																	
ST-5F	29.0	291.0	SM-ML	30-40	34.3	71.0	68.7	—	—	1.355	—	67.8	—	—	—	—	—	—	—	
ST-5G	29.3	290.7	SM-ML	30-40	35.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-6A	32.5	287.5	SM	20-30	19.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-6D	32.7	287.3	SM	31	23.5	89.3	87.5	84.9	—	0.873	0.970	72.1	64.9	2.87	3.92	5.17	6.0	1.92	With foliation at 50°	
ST-6E	33.3	286.7	ML-SM	53	33.3	71.9	70.5	—	—	1.326	—	67.3	—	—	—	—	—	—	—	
ST-6F	33.8	286.2	CH	90-95		73.6	70.8	—	—	1.323	—	78.8	—	—	—	—	—	—	—	
ST-6G	34.3	285.7	ML	70-80	36.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Table 5 (continued)
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING SWR-12

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt%)	Dry Unit Weight γ_d A (pcf)	B (pcf)	C (pcf)	D (pcf)	Void Ratio e A	E	Saturation S A (%)	E (%)	Unconsolidated-Undrained Compression Test Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-7A	37.5	282.5	SM	10-15	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Few
ST-7B	37.7	282.3	SM	10-15	29.0	79.4	77.9	—	—	1.106	—	70.3	—	—	—	—	—	—	—	small
ST-7E	38.0	282.0	Preserved in tube																	dents
ST-7F	38.9	281.1	SM	10-15	16.5	85.8	84.2	75.3	—	0.949	1.221	46.6	36.2	—	—	—	—	—	—	
ST-7G	39.3	280.7	SM	10-15	18.0	—	—	—	—	—	—	—	—	—	—	—	—	—		
ST-8A	42.5	266.5	SM	33	23.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good
ST-8E	42.6	277.4	Preserved in tube																	
ST-8F	43.6	276.4	SM	30-35	23.5	84.1	82.5	80.8	—	0.988	1.070	63.7	58.9	2.88	5.30	6.04	15.0	2.65	Shear across foliation	
ST-8G	44.2	275.8	SM	34	22.7	—	—	—	—	—	—	—	—	—	—	—	—	—		
ST-9A	30.3	258.7	Empty																	Very
ST-9B	30.6	258.4	SM	10-20	24.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	good
ST-9C	30.9	258.1	SM	10-20	23.5	108.1	101.1	99.9	—	0.622	0.674	101.3	98.6	—	—	—	—	—	—	
ST-9F	31.2	257.8	SM	10-15	22.0	100.2	104.2	101.0	—	0.575	0.656	102.5	89.9	2.88	4.06	4.29	>15	1.43	Bulging	
ST-9G	31.6	257.4	SM	10-15	21.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-10A	32.4	256.6	SM	24	30.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very
ST-10D	32.5	256.5	Preserved in tube																	
ST-10E	32.7	256.3	SM	20-25	22.4	105.4	103.2	101.5	—	0.587	0.648	104.6	94.7	2.88	4.25	2.20	15.0	0.90	With foliation at 50°	
ST-10F	33.2	255.8	SM	15-20	24.0	104.0	102.0	97.8	96.1	0.608	0.740	105.8	86.9	1.42	4.31	4.40	11.3	1.91	Bulging	
ST-10G	33.5	255.5	SM-ML	43	34.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-11A	34.8	254.2	SM	15-25	26.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-11B	35.0	254.0	SM	15-25	26.1	98.5	96.6	96.7	—	0.698	0.729	102.9	98.5	—	—	—	—	—	—	
ST-11E	35.2	253.8																		
ST-11F																				
ST-11G																				
ST-12A	36.5	252.5	Preserved in tube																	Bent
ST-12E	36.7	252.3	SM	25-35	31.5	94.2	92.4	91.3	—	0.775	0.832	108.9	101.5	2.87	4.75	1.54	11.3	0.74	With foliation at 45°	deeply inward
ST-12F	37.2	251.8	SM	29	31.8	94.2	92.3	90.3	86.6	0.775	0.931	110.0	91.5	1.43	4.80	2.18	>15	0.96	Shearing	
ST-12G	37.5	251.5	SM	15-20	29.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Table 6
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING SWR-13

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt%)	Dry Unit Weight γ_d A (pcf)	Dry Unit Weight γ_d B (pcf)	Dry Unit Weight γ_d C (pcf)	Dry Unit Weight γ_d D (pcf)	Void Ratio e A	Void Ratio e E	Saturation S A (%)	Saturation S E (%)	Unconsolidated-Undrained Compression Test: Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-1A	13.9	275.1	SM	10-15	41.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair
ST-1B	14.1	274.9	SM	10-15	27.7	90.2	89.0	90.1	—	0.842	0.856	88.2	86.7	—	—	—	—	—	—	
ST-1E	14.3	274.7	Preserved in tube																	
ST-1F	14.9	274.1	SM	10-15	40.3	82.8	81.3	80.5	—	1.020	1.077	105.9	100.3	—	—	—	—	—	—	
ST-1G	15.3	273.7	SM	10-15	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-2A	16.0	273.0	Preserved in tube																	Very good
ST-2F	16.6	272.4	SM	20-25	48.5	77.2	75.8	—	70.0	1.166	1.389	111.5	93.6	1.43	2.24	1.19	12.7	0.55	Bulging and shearing	
ST-2G	17.0	272.0	SM	19	40.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
ST-3A	18.0	271.0	Empty																	Very good
ST-3B	18.0	271.0	SM	15-25	38.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-3C	18.4	270.6	SM	15-25	45.4	79.2	77.8	76.8	—	1.111	1.177	109.5	103.4	—	—	—	—	—	—	
ST-3F	18.6	270.4	SM	15	41.9	81.5	79.9	78.9	—	1.052	1.120	106.7	100.3	2.88	2.50	1.36	>15	0.55	With foliation at 50°	
ST-3G	19.1	269.9	SM	15	42.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-4A	20.1	268.9	Preserved in tube																	Very good
ST-4F	21.1	267.9	SM	15-20	42.4	81.3	79.6	78.2	74.9	1.057	1.233	107.5	92.2	1.44	2.80	1.39	>15	0.57	Bulging in weak zone	
ST-4G	21.3	267.7	SM	17	42.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-5A	22.1	266.9	Empty																	Good
ST-5B	22.3	266.7	SM	10-20	40.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-5C	22.6	266.4	SM	10-20	43.7	80.0	78.4	79.0	—	1.090	1.117	107.4	104.8	—	—	—	—	—	—	
ST-5F	22.8	266.2	SM	30	49.2	74.9	73.5	71.3	—	1.233	1.345	106.9	98.0	2.89	3.01	1.38	7.3	0.66	With foliation at 50°	
ST-5G	23.3	265.7	SM	25-30	36.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-6A	24.2	264.8	SM	15-20	55.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-6B	24.4	264.6	SM	15-20	57.3	69.4	68.1	—	—	1.410	1.456	108.9	105.5	—	—	—	—	—	—	
ST-6E	24.6	264.4	Preserved in tube																	
ST-6F	25.2	263.8	SM	18	39.0.	86.0	84.3	81.3	—	0.945	1.057	110.6	98.9	2.89	3.31	1.32	12.4	0.59	In clean sand layer	
ST-6G	25.6	264.4	SM	15-20	40.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-7A	26.2	262.8	SM	10-15	37.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-7B	26.4	262.6	SM	10-15	47.5	76.3	74.8	—	—	1.192	—	106.8	—	—	—	—	—	—	—	
ST-7E	26.7	262.3	Preserved in tube																	
ST-7F	27.2	261.8	SM	29	40.6	83.7	82.1	79.7	—	0.998	1.098	109.0	99.1	2.89	3.55	1.32	12.7	0.63	With foliation at 40°	
ST-7G	27.6	261.4	SM	25-30	38.7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Table 6 (continued)
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING SWR-13

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt%)	Dry Unit Weight γ_d				Void Ratio e		Saturation S		Unconsolidated-Undrained Compression Test						Condition of Tube Cutting Edge
						A (pcf)	B (pcf)	C (pcf)	D (pcf)	A	E	A (%)	E (%)	Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	
ST-8A	28.3	260.7	SM	15-20	30.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very
ST-8D	28.4	260.6	Preserved in tube																	good
ST-8E	28.8	260.2	SM	15-20	23.9	91.1	89.3	87.6	—	0.836	0.909	105.5	97.0	2.89	3.76	1.32	12.0	0.58	With foliation at 60°	
ST-8F	29.2	259.8	SM	15-20	30.2	94.4	92.8	90.8	—	0.772	0.842	104.8	96.1	—	—	—	—	—	—	
ST-8G	29.5	259.5	SM	20	27.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
ST-9A	47.5	272.5	SM-ML	35-45	36.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Not
ST-9B	47.8	272.2	SM-ML	35-45	35.6	76.9	75.4	74.6	—	1.175	1.242	81.2	76.8	—	—	—	—	—	—	viewed
ST-9C	48.1	271.1	Provided to Geotechnical Engineers, Inc., for cyclic triaxial testing																	
ST-10A	52.2	267.5	Empty																	Good
ST-10D	52.6	267.4	Preserved in tube																	
ST-10E	53.2	266.8	SM-ML	40-45	39.9	77.0	75.5	74.4	—	1.172	1.248	91.2	85.7	2.87	6.48	3.79	10.9	1.88	Slip on weak seam	
ST10F	53.7	266.3	SM-ML	40-45	39.2	75.7	74.3	73.4	—	1.209	1.278	86.9	82.2	2.87	6.54	5.43	5.7	2.68	Bulging	
ST-10G	54.2	265.8	SM-ML	46	42.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-11A	57.5	262.5	SM	30-40	32.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Few
ST-11B	57.8	262.2	SM	30-40	32.0	90.8	89.1	86.9	—	0.842	0.924	101.9	92.8	—	—	—	—	—	—	small
ST-11D	58.1	261.9	Preserved in tube																	dents
ST-11E	58.4	261.6	SM	10-15	15.4	113.7	111.5	108.7	—	0.471	0.538	70.6	76.7	2.88	7.14	5.84	4.6	2.54	Shear in quartz vein	
ST-11F	59.0	261.0	SM	30-40	28.8	93.2	90.9	88.9	—	0.794	0.881	97.2	87.6	—	—	—	—	—	—	
ST-11G	59.3	260.7	SM	30-40	24.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-12A	62.5	257.5	SM	20-30	23.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair
ST-12C	62.6	257.4	Preserved in tube																	
ST-12D	63.3	256.7	SM-ML	45	37.3	—	—	—	79.4	—	1.106	—	90.4	Constant-volume direct shear test						
ST-12E	63.5	256.5	Preserved in tube																	
ST-12F	63.8	256.2	SM	35-40	41.3	80.8	79.3	76.9	—	1.070	1.175	103.4	94.2	2.87	7.81	2.51	12.0	1.19	With foliation at 60°	
ST-12G	64.4	255.6	SM	40	42.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-13A	67.5	252.5	SM-ML	40-45	47.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	One
ST-13B	67.7	252.3	SM-ML	43	37.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	small
ST-13C	68.0	252.0	SM-ML	40-45	42.0	82.3	80.7	—	—	1.032	—	109.1	—	—	—	—	—	—	—	dent
ST-13D	68.3	251.7	SM-ML	40-45		—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-13E	68.4	251.6	SM-ML	40-45	36.6	86.1	84.4	82.2	—	0.942	1.034	104.1	94.9	2.87	8.39	2.27	13.8	1.00	With foliation at 60°	
ST-13F	69.0	251.0	SM-ML	50	47.4	75.5	74.1	72.2	—	1.215	1.316	104.6	96.5	—	—	—	—	—	—	
ST-13G	69.4	250.6	SM-ML	40-45	36.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Table 7
DATA FOR SAMPLES THIN SECTIONED

Boring Number	Sample Number	Depth Below Original Ground, ft	Percent Fines	Percent Water Content
P-10	1E	3	26	19
SWR-5	4B[a]	26	35	26
SWR-7	7B	26	38	23
SWR-4	2A1[a]	27	36	24
SWR-3	4E	60	23	15
SWR-4	6A2[a]	77	34	20

a. Oriented sections obtained.

Table 8
SUMMARY OF CYCLIC TRIAXIAL TESTS

Test No.	Boring No.	Sample No.	Depth ft.	Initial Water Content %	Dry Unit Weight (s)			Eff. Confining Press.	Consol. Stress Ration	Cyclic Deviator Stress	Cyclic Stress Ratio	Octahedral Shear Stress Ratio	Number of Cycle to Reach Maximum Compressive Strain equal to (s)				% Finer than #200 Sieve %
					In the Tube (6) γ d pcf	Triaxial Specimen: Initial γ di pct	Triaxial Specimen: After Consol. γ dc pct										
CR-1	SWR7	ST5	42.5-43.1	26.1	94	93	95	1.0	2.0	1.47	0.74	0.52	-	2(3)	5	8	44
CR-2	SWR9	ST2	22.5-23.1	23.7	89	88	91	0.7	2.0	0.76	0.54	0.39	-	5(3)	13	30	21
CR-3	P11	ST3	37.3-37.9	20.2	99	96	100	1.0	2.0	1.14	0.57	0.40	-	32	95	152	29
CR-4	P12	ST2	17.5-18.1	18.4	106	103	105	0.4	3.0	0.80	1.00	0.56	-	41	119	213	32
CR-5	SWR3	ST3	42.6-44.2	18.7	108	105	108	1.5	1.5	1.05	0.35	0.28	-	24	39	65	22
CR-6	SWR5	ST5	57.2-58.9	27.1	94	90	94	1.5	1.5	1.24	0.41	0.33	-	73	120	122	23
CR-7	SWR9	ST1	17.1-18.5	32.6	83	80	83	1.0	1.5	1.01	0.50	0.41	-	34(4)	126	194	31
CR-8	P15	ST24	66.0-68.0	24.2	102.4	101.1	-	-	-	-(9)	-	-	-	-	-	-	-
CR-9	P16	ST7	37.5-39.5	17.8	(7)	104.1	107.2	2.5	-	-(10)	-	-	-	-	-	-	-
CR-10	P15	ST24	66.0-68.0	21.7	107.3	106.4	111.1	2.5	1.0	1.94	0.39	0.37	-	1	1	5	(11)
CR-11	P17	ST9	47.5-49.5	33.9	87.6	86.3	90.9	2.5	1.0	1.46	0.29	0.28	-	2	7	16	(11)
CR-12	P16	ST7	37.5-39.5	21.2	(7)	92.1	95.3	2.5	1.0	-(8)	-	-	-	-	-	-	-
CR-13	P17	ST9	47.5-49.5	28.0	93.7	92.8	97.6	2.5	1.0	1.20	0.24	0.23	-	14	23	37	(11)
CR-14	SWR11	ST1	19.5-21.5	29.4	94.4	93.2	96.9	1.0	1.0	0.79	0.40	0.37	-	3	74	171	(11)
CR-15	P15	ST10	31.0-33.0	19.5	94.1	93.3	96.2	1.5	1.5	1.69	0.56	0.46	-	1	1	2	(11)
CR-16	SWR11	ST1	19.5-21.5	32.3	89.3	88.5	92.1	1.0	1.0	0.94	0.47	0.44	-	1	4	19	(11)
CR-17	SWR13	ST9	47.5-49.5	36.9	74.2	73.3	75.9	1.5	1.5	1.30	0.43	0.35	-	1	1	2	(11)

Table 8 (continued)
SUMMARY OF CYCLIC TRIAXIAL TESTS

Test No.	Boring No.	Sample No.	Depth ft.	Initial Water Content %	Dry Unit Weight (s): In the Tube (6) γ d pcf	Dry Unit Weight (s): Triaxial Specimen: Initial γ di pct	Dry Unit Weight (s): Triaxial Specimen: After Consol. γ dc pct	Eff. Confining Press.	Consol. Stress Ration	Cyclic Deviator Stress	Cyclic Stress Ratio	Octahedral Shear Stress Ratio	Number of Cycle to Reach Maximum Compressive Strain equal to (s)				% Finer than #200 Sieve %
CR-18	SWR13	ST9	47.5-49.5	33.3	73.7	73.5	76.0	1.5	1.5	0.85	0.28	0.23	-	6	6	13	(11)

Notes:

Due to high mica content, the specimens swelled after extrusion from the tube and therefore, the initial dry unit weights of the triaxial specimen are lower than the dry unit weights in the tube.

At no point during any test did the effective confining pressure reach zero.

In test CR-1 and CR-2, the specimens reached a double amplitude stain of 2.5% in the cycle preceding the one listed.

In test CR-7, the specimen reached a double amplitude stain of 2.5% in 17 cycles.

In all tests except those noted, the maximum compressive strain of 2.5%, 5%, and 10% occurred at the same time or earlier than the double amplitude strain of 2.5%, 5%, and 10% respectively.

Calculated from tube inside diameter.

Annular space of approximately 0.03 mm unit weight not valid.

Test not reported error during load application.

Test aborted - Membrane leakage.

Test aborted - cell malfunction.

Sieve analyses incomplete as of June 11, 1976.

Table 9
PRELIMINARY VISUAL DESCRIPTIONS OF CYCLIC TRIAXIAL TEST SAMPLES[a]

Test Number[b]	Description
CR-10	Grey/white saprolite breaks down to fine sand with silt, fine mica flakes throughout, top 3.5 cm, layered black and white, white layers clayey, foliation dips at 56°.
CR-11	Brown saprolite, fine silty sand, contains 3mm wide layer of med. sand size quartz particles, folation dips at 45° for top 1/4 of sample, then bends around to dip 60° in opposite direction.
CR-13	Orange-brown saprolite, silty fine to medium sand, band of orange-white clayey med. to coarse sound, foliation dips at 60°, possible failure plane at 35° in top 1/3 of sample.
CR-14	Yellowish-green saprolite, fine to med. sand, 2 to 3 mm layers of very fine mica flakes, foliation dips at 34°.
CR-15	Orange-brown saprolite, silty fine to med. sand, micaceous, contains occasional angular quartz particles to 5 mm, contains zones that are slightly plastic, foliation dips at 45°.
CR-16	Mottled yellow-green saprolite mostly fine to med. sand, slightly silty, fine to med. mica flakes.
CR-17	Mottled orange-brown saprolite, silty fine to med. sand, foliation dips at 43°.
CR-18	Mottled orange-pink saprolite silty sand, foliation at 53°.

a. Sample descriptions are preliminary pending completion of laboratory classification tests.
b. Descriptions for aborted tests are not included.

Table 10
SUMMARY OF LIQUEFACTION ANALYSES

Elevation Feet	Depth Feet	$\bar{\sigma}_{oct}$ PSF (2)	CSR(2)	SSR	$\Delta T\ oct_l$ PSF	σ_V PSF(3)	r_d	$\Delta T\ oct_f$ PSF	FS
Section A									
300	5	227	1.73	0.406	92	623	0.99	59	1.56
290	15	706	1.53	0.367	259	1862	0.97	172	1.51
280	25	1197	1.49	0.359	430	3117	0.94	280	1.53
270	35	1697	1.37	0.335	569	4392	0.90	377	1.51
260	45	2189	1.39	0.339	743	5675	0.80	433	1.71
250	55	2670	1.42	0.345	922	6967	0.72	479	1.92
240	65	3141	1.45	0.351	1103	8268	0.64	505	2.18
Section B									
300	5	219	4.77	0.500[1]	109	701	0.99	66	1.65
290	15	866	1.80	0.420	364	2113	0.97	196	1.86
280	25	1411	1.69	0.399	562	3457	0.94	310	1.81
270	35	1947	1.65	0.391	761	4794	0.90	412	1.85
260	45	2463	1.63	0.387	953	6103	0.80	466	2.04
250	55	2968	1.62	0.385	1142	7391	0.72	508	2.25
240	65	3462	1.61	0.383	1325	8666	0.64	530	2.50
Section C									
280	39.5	1938	3.34	0.500 [1]	969	4678	0.85	380	2.55
270	49.5	2263	2.81	0.500 [1]	1182	5850	0.77	430	2.75
260	59.5	2843	2.37	0.500 [1]	1421	7021	0.67	449	3.16
250	69.5	3378	2.01	0.462	1561	8186	0.60	469	3.33
240	79.5	3970	1.71	0.403	1598	9330	0.55	490	3.26
Section D									
280.8	5.9	1084	1.75	0.410	445	899	0.99	85	5.23
270	16.7	1874	1.50	0.361	677	2410	0.97	223	3.03

Table 10 (continued)
SUMMARY OF LIQUEFACTION ANALYSES

Elevation Feet	Depth Feet	$\bar{\sigma}_{oct}$ PSF (2)	CSR(2)	SSR	$\Delta T\ oct_l$ PSF	σ_V PSF(3)	r_d	$\Delta T\ oct_f$ PSF	FS
260	26.7	2393	1.56	0.373	892	3785	0.94	340	2.62
250	36.7	2869	1.69	0.399	1144	5140	0.89	437	2.62
240	46.0	3303	1.88	0.436	1441	6492	0.80	496	2.91
Section E									
278.8	3.9	658	1.85	0.430	283	498	0.99	47	6.02
270	12.7	1433	1.25	0.312	446	1635	0.98	153	2.92
260	22.7	1895	1.35	0.331	628	2931	0.98	263	2.39
250	32.7	2353	1.48	0.357	840	4240	0.91	368	2.28
240	42.7	2805	1.60	0.381	1068	5560	0.83	441	2.42

Notes:

1. Since cyclic strength data for CSR greater than 2.0 is limited, an upperbound of 0.50 has been set for the SSR.
2. Pore pressures for calculation of effective stresses were determined using the phreatic surface given in Figure 16.
3. For sections A and B free standing water was ignored in circulating the vertical total stress.

Legend:

$\bar{\sigma}_{oct}$ = Effective Octahedral Normal Stress

CSR = Consolidation Stress Ratio

$\bar{\sigma}_1$ = Major Principal Effective Stress

$\bar{\sigma}_3$ = Minor Principal Effective Stress

SSR = Octahedral Shear Stress Ratio for Maximum Compressive Strain of 5% in 10 Cycles

ΔT_{oct_l} = Octahedral Shear Stress for Maximum Compressive Strain of 5% in 10 Cycles

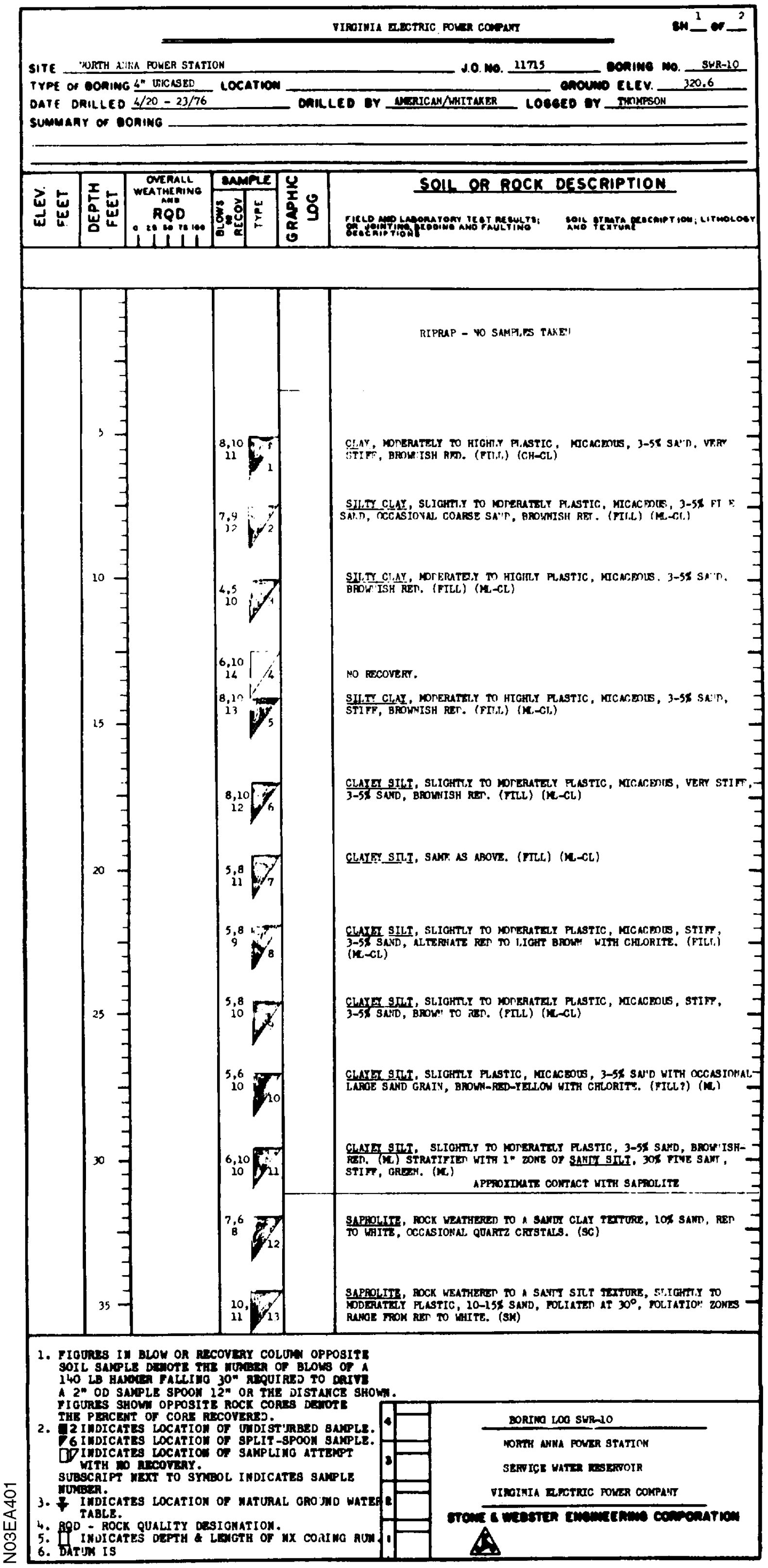
$\bar{\sigma}_V$ = Vertical Total Stress

r_d = Stress Reduction Coefficient

ΔT_{oct_f} = Octahedral Shear Stress caused by SSE = 0.18???

FS = Factor of Safety

Figure 1 (SHEET 1 OF 2)
BORING LOG SWR-10 SERVICE WATER RESERVOIR



VIRGINIA ELECTRIC POWER COMPANY SH 1 OF 2

SITE NORTH ANNA POWER STATION J.O. NO. 11715 BORING NO. SWR-10
TYPE OF BORING 4" UNCASED LOCATION GROUND ELEV. 320.6
DATE DRILLED 4/20 - 23/76 DRILLED BY AMERICAN/WHITAKER LOGGED BY THOMPSON
SUMMARY OF BORING

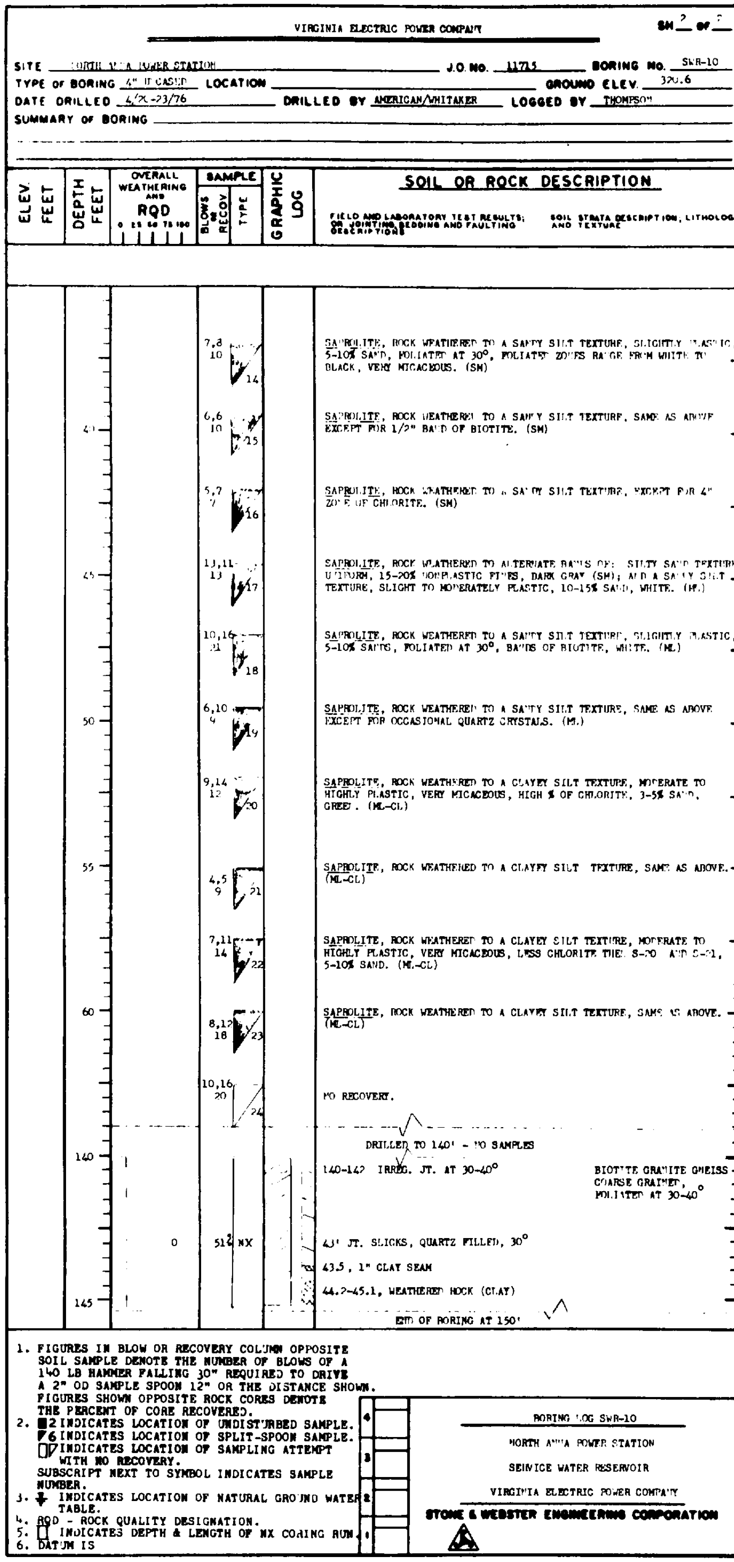
ELEV. FEET	DEPTH FEET	OVERALL WEATHERING AND RQD (0 25 50 75 100)	SAMPLE BLOWS OR RECOV	SAMPLE TYPE	GRAPHIC LOG	SOIL OR ROCK DESCRIPTION (FIELD AND LABORATORY TEST RESULTS; OR JOINTING, BEDDING AND FAULTING DESCRIPTIONS / SOIL STRATA DESCRIPTION; LITHOLOGY AND TEXTURE)
						RIPRAP - NO SAMPLES TAKEN
	5		8,10 11	1		CLAY, MODERATELY TO HIGHLY PLASTIC, MICACEOUS, 3-5% SAND, VERY STIFF, BROWNISH RED. (FILL) (CH-CL)
			7,9 12	2		SILTY CLAY, SLIGHTLY TO MODERATELY PLASTIC, MICACEOUS, 3-5% FINE SAND, OCCASIONAL COARSE SAND, BROWNISH RED. (FILL) (ML-CL)
	10		4,5 10	3		SILTY CLAY, MODERATELY TO HIGHLY PLASTIC, MICACEOUS, 3-5% SAND, BROWNISH RED. (FILL) (ML-CL)
			6,10 14	4		NO RECOVERY.
	15		8,10 13	5		SILTY CLAY, MODERATELY TO HIGHLY PLASTIC, MICACEOUS, 3-5% SAND, STIFF, BROWNISH RED. (FILL) (ML-CL)
			8,10 12	6		CLAYEY SILT, SLIGHTLY TO MODERATELY PLASTIC, MICACEOUS, VERY STIFF, 3-5% SAND, BROWNISH RED. (FILL) (ML-CL)
	20		5,8 11	7		CLAYEY SILT, SAME AS ABOVE. (FILL) (ML-CL)
			5,8 9	8		CLAYEY SILT, SLIGHTLY TO MODERATELY PLASTIC, MICACEOUS, STIFF, 3-5% SAND, ALTERNATE RED TO LIGHT BROWN WITH CHLORITE. (FILL) (ML-CL)
	25		5,8 10	9		CLAYEY SILT, SLIGHTLY TO MODERATELY PLASTIC, MICACEOUS, STIFF, 3-5% SAND, BROWN TO RED. (FILL) (ML-CL)
			5,6 10	10		CLAYEY SILT, SLIGHTLY PLASTIC, MICACEOUS, 3-5% SAND WITH OCCASIONAL LARGE SAND GRAIN, BROWN-RED-YELLOW WITH CHLORITE. (FILL?) (ML)
	30		6,10 10	11		CLAYEY SILT, SLIGHTLY TO MODERATELY PLASTIC, 3-5% SAND, BROWNISH-RED. (ML) STRATIFIED WITH 1" ZONE OF SANDY SILT, 30% FINE SAND, STIFF, GREEN. (ML) APPROXIMATE CONTACT WITH SAPROLITE
			7,6 8	12		SAPROLITE, ROCK WEATHERED TO A SANDY CLAY TEXTURE, 10% SAND, RED TO WHITE, OCCASIONAL QUARTZ CRYSTALS. (SC)
	35		10, 11	13		SAPROLITE, ROCK WEATHERED TO A SANDY SILT TEXTURE, SLIGHTLY TO MODERATELY PLASTIC, 10-15% SAND, FOLIATED AT 30°, FOLIATION ZONES RANGE FROM RED TO WHITE. (SM)

1. FIGURES IN BLOW OR RECOVERY COLUMN OPPOSITE SOIL SAMPLE DENOTE THE NUMBER OF BLOWS OF A 140 LB HAMMER FALLING 30" REQUIRED TO DRIVE A 2" OD SAMPLE SPOON 12" OR THE DISTANCE SHOWN. FIGURES SHOWN OPPOSITE ROCK CORES DENOTE THE PERCENT OF CORE RECOVERED.
2. ■2 INDICATES LOCATION OF UNDISTURBED SAMPLE. ◤6 INDICATES LOCATION OF SPLIT-SPOON SAMPLE. ◸7 INDICATES LOCATION OF SAMPLING ATTEMPT WITH NO RECOVERY. SUBSCRIPT NEXT TO SYMBOL INDICATES SAMPLE NUMBER.
3. INDICATES LOCATION OF NATURAL GROUND WATER TABLE.
4. RQD - ROCK QUALITY DESIGNATION.
5. INDICATES DEPTH & LENGTH OF NX CORING RUN.
6. DATUM IS

BORING LOG SWR-10
NORTH ANNA POWER STATION
SERVICE WATER RESERVOIR
VIRGINIA ELECTRIC POWER COMPANY
STONE & WEBSTER ENGINEERING CORPORATION

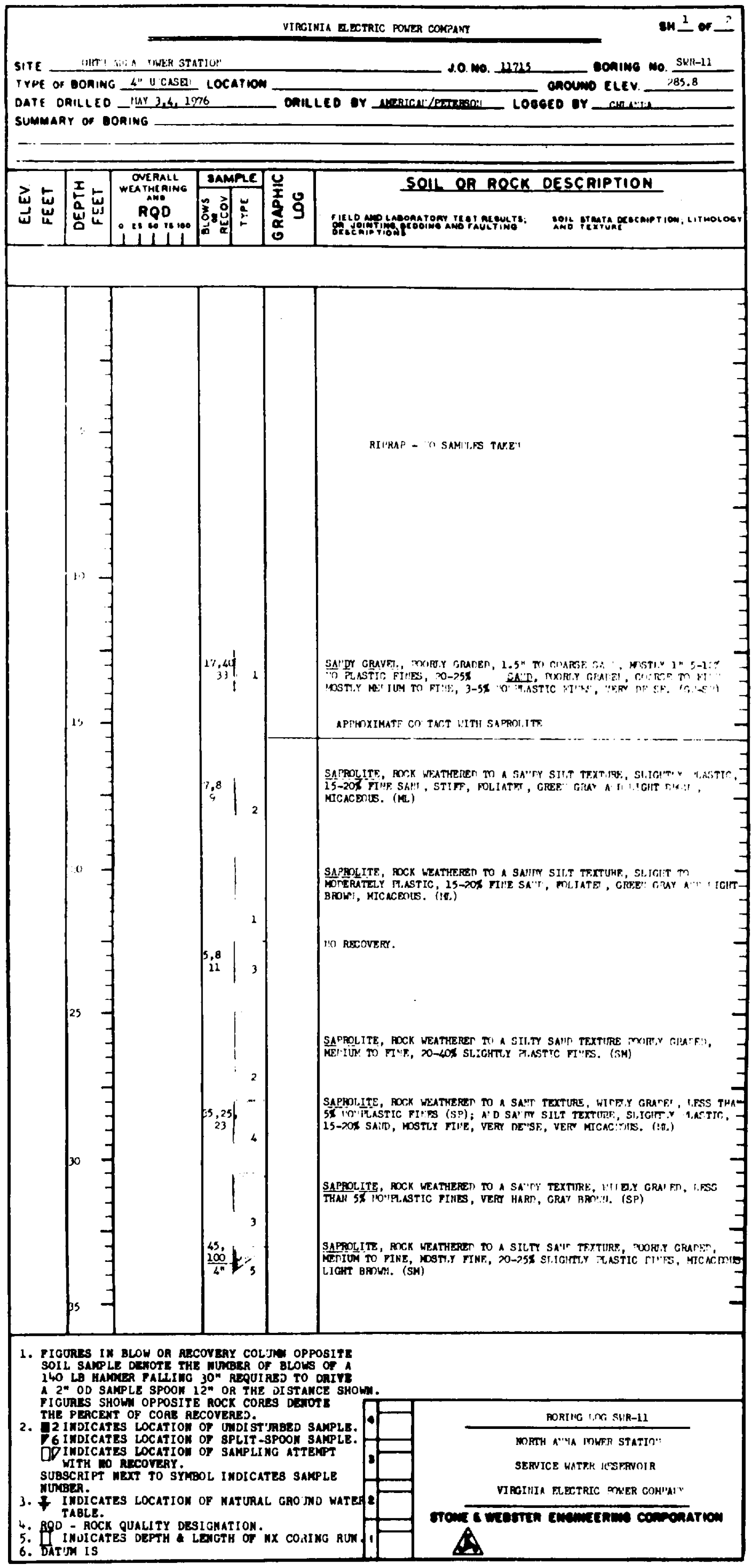
N03EA401

Figure 1 (SHEET 2 OF 2)
BORING LOG SWR-10 SERVICE WATER RESERVOIR



N03EA402

Figure 2 (SHEET 1 OF 2)
BORING LOG SWR-11 SERVICE WATER RESERVOIR



N03EA403

Figure 2 (SHEET 2 OF 2)
BORING LOG SWR-11 SERVICE WATER RESERVOIR

VIRGINIA ELECTRIC POWER COMPANY

SH 2 OF 2

SITE NORTH ANNA POWER STATION J.O. NO. 11715 BORING NO. SWR 11
TYPE OF BORING 4" UNCASED LOCATION GROUND ELEV. 285.0
DATE DRILLED MAY 3,4, 1976 DRILLED BY AMERICAN/PETERSON LOGGED BY CHLAPLA
SUMMARY OF BORING

ELEV. FEET	DEPTH FEET	OVERALL WEATHERING AND RQD 0 25 50 75 100	SAMPLE BLOWS OR RECOV.	SAMPLE TYPE	GRAPHIC LOG	SOIL OR ROCK DESCRIPTION (FIELD AND LABORATORY TEST RESULTS; OR JOINTING, BEDDING AND FAULTING DESCRIPTIONS / SOIL STRATA DESCRIPTION; LITHOLOGY AND TEXTURE)
			100 60 2"	6		SAPROLITE, SILTY SAND TEXTURE, POORLY GRADED, MEDIUM TO FINE, MOSTLY FINE, 15-20% SLIGHTLY PLASTIC FINES, MICACEOUS, VERY HARD, LIGHT BROWN. (SM)
			20,70 50/2"	7		SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, POORLY GRADED, MOSTLY FINE, 20-30% SLIGHTLY PLASTIC FINES, LIGHT BROWN, VERY HARD. (SM)
						END OF BORING AT 38.2'
	40					
	45					
	50					

1. FIGURES IN BLOW OR RECOVERY COLUMN OPPOSITE SOIL SAMPLE DENOTE THE NUMBER OF BLOWS OF A 140 LB HAMMER FALLING 30" REQUIRED TO DRIVE A 2" OD SAMPLE SPOON 12" OR THE DISTANCE SHOWN. FIGURES SHOWN OPPOSITE ROCK CORES DENOTE THE PERCENT OF CORE RECOVERED.
2. ■2 INDICATES LOCATION OF UNDISTURBED SAMPLE. ◤6 INDICATES LOCATION OF SPLIT-SPOON SAMPLE. □◸ INDICATES LOCATION OF SAMPLING ATTEMPT WITH NO RECOVERY. SUBSCRIPT NEXT TO SYMBOL INDICATES SAMPLE NUMBER.
3. ⯆ INDICATES LOCATION OF NATURAL GROUND WATER TABLE.
4. RQD - ROCK QUALITY DESIGNATION.
5. □ INDICATES DEPTH & LENGTH OF NX CORING RUN.
6. DATUM IS

4	
3	
2	
1	

BORING LOG SWR-11
NORTH ANNA POWER STATION
SERVICE WATER RESERVOIR
VIRGINIA ELECTRIC POWER COMPANY
STONE & WEBSTER ENGINEERING CORPORATION

N03EA404

Figure 3 (SHEET 1 OF 2)
BORING LOG SWR-12 SERVICE WATER RESERVOIR

VIRGINIA ELECTRIC POWER COMPANY SH 1 OF 2

SITE NORTH ANNA POWER COMPANY J.O. NO. 11715 BORING NO. SWR-12
TYPE OF BORING HX CASED LOCATION GROUND ELEV. 289.3
DATE DRILLED MAY 5-10, 1976 DRILLED BY AMERICAN/PETERSON LOGGED BY CHLAULA
SUMMARY OF BORING DRILLED AT 35° FROM VERTICAL ALIGNED AT S 35 E

ELEV. FEET	DEPTH FEET	OVERALL WEATHERING AND RQD (0 25 50 75 100)	SAMPLE: BLOWS OR RECOV	SAMPLE: TYPE	GRAPHIC LOG	SOIL OR ROCK DESCRIPTION (FIELD AND LABORATORY TEST RESULTS; OR JOINTING, BEDDING AND FAULTING DESCRIPTIONS / SOIL STRATA DESCRIPTION, LITHOLOGY AND TEXTURE)
	5					RIPRAP NO SAMPLE TAKEN
	10					
	15					APPROXIMATE CONTACT WITH SAPROLITE
						SAPROLITE, ROCK WEATHERED TO A SANDY SILT TEXTURE, SLIGHTLY PLASTIC, 15-20% FINE SAND, HIGHLY MICACEOUS, RED BROWN. (ML)
	20			1		SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, UNIFORM, FINE, 30-40% NONPLASTIC FINES, VERY MICACEOUS, YELLOWISH BROWN. (SM)
				2		SAPROLITE, ROCK WEATHERED TO SILTY SAND TEXTURE, UNIFORM FINE, 30-40% NONPLASTIC FINES, YELLOW BROWN, VERY MICACEOUS. (SM)
	25			3		SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, MEDIUM TO FINE, 25-35% NONPLASTIC FINES, YELLOW BROWN, MICACEOUS. (SM)
				4		ROCK, WEATHERED TO A CLAYEY SILT, TEXTURE SLIGHTLY PLASTIC, 10-[illegible]0% FINE SAND, ORANGE BROWN, MICACEOUS. (CL-ML)
	30			5		SAPROLITE, ROCK WEATHERED TO SILTY SAND TEXTURE, MEDIUM TO FINE, MOSTLY FINE, 20-30% NONPLASTIC FINES YELLOW BROWN, MICACEOUS. (SM)
				6		SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, MEDIUM TO FINE, MOSTLY FINE, 20-30% NONPLASTIC FINES, YELLOW BROWN, HIGHLY MICACEOUS. (SM)
	35			7		

1. FIGURES IN BLOW OR RECOVERY COLUMN OPPOSITE SOIL SAMPLE DENOTE THE NUMBER OF BLOWS OF A 140 LB HAMMER FALLING 30" REQUIRED TO DRIVE A 2" OD SAMPLE SPOON 12" OR THE DISTANCE SHOWN. FIGURES SHOWN OPPOSITE ROCK CORES DENOTE THE PERCENT OF CORE RECOVERED.
2. ■2 INDICATES LOCATION OF UNDISTURBED SAMPLE. ◤6 INDICATES LOCATION OF SPLIT-SPOON SAMPLE. ▯◸ INDICATES LOCATION OF SAMPLING ATTEMPT WITH NO RECOVERY. SUBSCRIPT NEXT TO SYMBOL INDICATES SAMPLE NUMBER.
3. ⯆ INDICATES LOCATION OF NATURAL GROUND WATER TABLE.
4. RQD - ROCK QUALITY DESIGNATION.
5. ▯ INDICATES DEPTH & LENGTH OF NX CORING RUN.
6. DATUM IS

4	
3	
2	
1	

BORING LOG SWR-12
NORTH ANNA POWER STATION
SERVICE WATER RESERVOIR
VIRGINIA ELECTRIC POWER COMPANY
STONE & WEBSTER ENGINEERING CORPORATION

N03EA405

Figure 3 (SHEET 2 OF 2)
BORING LOG SWR-12 SERVICE WATER RESERVOIR

VIRGINIA ELECTRIC POWER COMPANY SH __ OF __

SITE [illegible]RTH [illegible] POWER STATION J.O. No. 11715 BORING No. [illegible]-12
TYPE OF BORING HW CASED LOCATION GROUND ELEV. [illegible]
DATE DRILLED MAY 5-10, 1976 DRILLED BY AMERICAN/PETERSON LOGGED BY [illegible]
SUMMARY OF BORING DRILLED AT 35° FROM VERTICAL ALIGNED AT S 35 E

ELEV. FEET	DEPTH FEET	OVERALL WEATHERING AND RQD (0 25 50 75 100)	SAMPLE: BLOWS or RECOV	SAMPLE: TYPE	GRAPHIC LOG	SOIL OR ROCK DESCRIPTION (FIELD AND LABORATORY TEST RESULTS; OR JOINTING, BEDDING AND FAULTING DESCRIPTIONS / SOIL STRATA DESCRIPTION, LITHOLOGY AND TEXTURE)
	35					SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, [illegible], 25-35% NONPLASTIC FINES. (SM)
				8		SAPROLITE, SAME AS ABOVE EXCEPT 30-40% [illegible] FINES, [illegible] MICACEOUS. (SM-ML)
				9		SAPROLITE, ROCK WEATHERED TO A CLAYEY SILT TEXTURE, [illegible] PLASTIC, 5-10% FINE SAND, CHLORITIC GRAY [illegible]
	40			10		SAPROLITE, ROCK WEATHERED TO A SILTY CLAY TEXTURE, 5-[illegible]% FINE SAND, STIFF, GREENISH BROWN, MODERATELY PLASTIC. [illegible]
	45			11		SAPROLITE, SIMILAR TO ABOVE, EXCEPT 10-15% [illegible]
				12		NO RECOVERY - TUBE CRUSHED.
				13		END OF BORING AT 49'
	50					
	55					
	60					
	65					

1. FIGURES IN BLOW OR RECOVERY COLUMN OPPOSITE SOIL SAMPLE DENOTE THE NUMBER OF BLOWS OF A 140 LB HAMMER FALLING 30" REQUIRED TO DRIVE A 2" OD SAMPLE SPOON 12" OR THE DISTANCE SHOWN. FIGURES SHOWN OPPOSITE ROCK CORES DENOTE THE PERCENT OF CORE RECOVERED.
2. ■2 INDICATES LOCATION OF UNDISTURBED SAMPLE.
   ▼6 INDICATES LOCATION OF SPLIT-SPOON SAMPLE.
   □7 INDICATES LOCATION OF SAMPLING ATTEMPT WITH NO RECOVERY.
   SUBSCRIPT NEXT TO SYMBOL INDICATES SAMPLE NUMBER.
3. ▼ INDICATES LOCATION OF NATURAL GROUND WATER TABLE.
4. RQD - ROCK QUALITY DESIGNATION.
5. [] INDICATES DEPTH & LENGTH OF NX CORING RUN.
6. DATUM IS

BORING LOG SWR-12
NORTH ANNA POWER STATION
SERVICE WATER RESERVOIR
VIRGINIA ELECTRIC POWER COMPANY
STONE & WEBSTER ENGINEERING CORPORATION

N03EA406

Figure 4 (SHEET 1 OF 3)
BORING LOG SWR-13 SERVICE WATER RESERVOIR

VIRGINIA ELECTRIC POWER COMPANY SH 1 OF 3

SITE: NORTH ANNA POWER STATION J.O. NO. 11715 BORING NO. SWR-13
TYPE OF BORING: 4" UNCASED LOCATION: GROUND ELEV. 320.6
DATE DRILLED: 5/12-14/76 DRILLED BY: AMERICAN/AMITAKER LOGGED BY: THOMPSON/CHLADTA
SUMMARY OF BORING:

ELEV. FEET	DEPTH FEET	OVERALL WEATHERING AND RQD (0 25 50 75 100)	SAMPLE BLOWS OR RECOV.	SAMPLE TYPE	GRAPHIC LOG	SOIL OR ROCK DESCRIPTION (FIELD AND LABORATORY TEST RESULTS; OR JOINTING, BEDDING AND FAULTING DESCRIPTIONS / SOIL STRATA DESCRIPTION, LITHOLOGY AND TEXTURE)
						RIPRAP-NO SAMPLES TAKEN
	5		3,7 11			SILTY CLAY, MODERATE TO HIGHLY PLASTIC, 3-5% SAND, OCCASIONAL PEBBLE, RED. (FILL) (ML-CL)
						SILTY CLAY, MODERATELY PLASTIC, 10-15% SAND, VERY STIFF, RED. (FILL) (ML-CL)
	10		6,8 11			CLAYEY SILT, SLIGHTLY TO MODERATELY PLASTIC, 10-15% SAND, VERY STIFF, RED. (FILL) (ML)
						CLAYEY SILT, SAME AS ABOVE. (FILL) (ML)
	15		10,9 14			SILTY CLAY, MODERATELY PLASTIC, 5-10% SAND, VERY STIFF, RED. (FILL) (ML-CL)
						SILTY CLAY, MODERATELY PLASTIC, 5-10% SAND, OCCASIONAL QUARTZ, CRYSTAL UP TO 1/4" STIFF, RED. (FILL) (ML-CL)
	20		9,10 12			SILTY CLAY, MODERATELY PLASTIC, 5-10% SAND, STIFF, RED. (FILL) (ML-CL)
						SILTY CLAY, SAME AS ABOVE. (ML-CL)
	25		8,9 14			CLAYEY SILT, SLIGHTLY TO MODERATELY PLASTIC, 5-10% SAND, VERY STIFF, RED. (FILL) (ML)
						APPROXIMATE CONTACT WITH SAPROLITE
						SAPROLITE, ROCK WEATHERED TO A SILTY CLAY TEXTURE, MODERATE TO HIGHLY PLASTIC, VERY MICACEOUS, 3-5% SAND, GREEN BROWN. (MH-CH)
	30		9,11 11			SAPROLITE, ROCK WEATHERED TO A SILTY CLAY TEXTURE, MODERATE TO HIGHLY PLASTIC, 3-5% SAND, MICACEOUS, GREEN TO WHITE. (ML-CL)
						SAPROLITE, ROCK WEATHERED TO A CLAYEY SILT TEXTURE, MODERATE TO HIGHLY PLASTIC, 3-5% SAND, MICACEOUS, RED TO BLACK. (ML)
	35			6		

1. FIGURES IN BLOW OR RECOVERY COLUMN OPPOSITE SOIL SAMPLE DENOTE THE NUMBER OF BLOWS OF A 140 LB HAMMER FALLING 30" REQUIRED TO DRIVE A 2" OD SAMPLE SPOON 12" OR THE DISTANCE SHOWN. FIGURES SHOWN OPPOSITE ROCK CORES DENOTE THE PERCENT OF CORE RECOVERED.
2. ■2 INDICATES LOCATION OF UNDISTURBED SAMPLE.
   ◤6 INDICATES LOCATION OF SPLIT-SPOON SAMPLE.
   □▽ INDICATES LOCATION OF SAMPLING ATTEMPT WITH NO RECOVERY.
   SUBSCRIPT NEXT TO SYMBOL INDICATES SAMPLE NUMBER.
3. ⊥ INDICATES LOCATION OF NATURAL GROUND WATER TABLE.
4. RQD - ROCK QUALITY DESIGNATION.
5. □ INDICATES DEPTH & LENGTH OF NX CORING RUN.
6. DATUM IS

BORING SWR-13
NORTH ANNA POWER STATION
SERVICE WATER RESERVOIR
VIRGINIA ELECTRIC POWER COMPANY
STONE & WEBSTER ENGINEERING CORPORATION

N03EA407

Figure 4 (SHEET 2 OF 3)
BORING LOG SWR-13 SERVICE WATER RESERVOIR

VIRGINIA ELECTRIC POWER COMPANY

SH 2 OF 3

SITE: NORTH ANNA POWER STATION
J.O. NO.: 11715
BORING NO.: SWR-13
TYPE OF BORING: 4" UNCASED
LOCATION:
GROUND ELEV: [illegible]0.6
DATE DRILLED: 5/12-14/76
DRILLED BY: AMERICAN/WHITAKER
LOGGED BY: THOMISON/CHEATHA[illegible]
SUMMARY OF BORING:

ELEV FEET	DEPTH FEET	OVERALL WEATHERING AND RQD (< 25 50 75 100)	SAMPLE: BLOWS OR RECOV	SAMPLE: TYPE	GRAPHIC LOG	SOIL OR ROCK DESCRIPTION (FIELD AND LABORATORY TEST RESULTS; OR JOINTING BEDDING AND FAULTING DESCRIPTIONS / SOIL STRATA DESCRIPTION, LITHOLOGY AND TEXTURE)
			6,7 12	7		SAPROLITE, ROCK WEATHERED TO A CLAYEY SILT TEXTURE, MODERATELY TO HIGHLY PLASTIC, 5-10% SAND, MICACEOUS, FOLIATED 20°, RED BROWN. (ML)
						SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, 10-15% NON-PLASTIC FINES, POORLY GRADED, WHITE TO BLACK. (SM)
	40		15,12 9	8		SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, 10-20% NON-PLASTIC FINES, GRADED FROM FINE TO GRAVEL SIZE QUARTZ [illegible], MORE THAN 1/8", RED TO BROWN. (SP-SM)
						SAPROLITE, ROCK WEATHERED TO A SANDY SILT TEXTURE, MODERATELY PLASTIC, 15-20% SAND, MICACEOUS, TAN TO BROWN. (ML)
	45		8,10 15	9		SAPROLITE, ROCK WEATHERED TO A SILTY CLAY TEXTURE, MODERATE TO HIGHLY PLASTIC, 3-5% SAND, FOLIATED AT 20°, RED. (ML-CL)
						SAPROLITE, ROCK WEATHERED TO A SILTY CLAY TEXTURE, SAME AS ABOVE. (ML-CL)
	50		2,5 9	10		SAPROLITE, ROCK WEATHERED TO A CLAY TEXTURE, HIGHLY PLASTIC, 3-5% SAND, FOLIATED AT 20°, VERY MICACEOUS, HIGH CHLORITE, GREEN. (CL-CH)
						SAPROLITE, ROCK WEATHERED TO A SILTY CLAY TEXTURE, HIGHLY PLASTIC, 3-5% SAND, VERY MICACEOUS, GREEN TO WHITE. (ML-CH)
	55		5,5 8	11		SAPROLITE, ROCK WEATHERED TO A SILTY CLAY TEXTURE, HIGHLY PLASTIC, 3-5% SAND, VERY MICACEOUS, GREEN TO WHITE. (ML-CH)
						SAPROLITE, ROCK WEATHERED TO A SANDY SILT TEXTURE, SLIGHTLY PLASTIC, 10-20% SAND, RED BROWN. (ML)
	60		8,11 13	12		SAPROLITE, ROCK WEATHERED TO A SANDY SILT TEXTURE, SLIGHTLY PLASTIC, 10-20% FINE SAND, STIFF, GREEN TO BROWN, MICACEOUS. (ML)
						SAPROLITE, ROCK WEATHERED TO A SANDY SILT TEXTURE, SLIGHTLY PLASTIC, 10-20% FINE SAND, STIFF, LIGHT BROWN TO GREEN, MICACEOUS. (ML)
	65		10,14 17	13		SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, POORLY GRADED, MEDIUM TO FINE, MOSTLY FINE, 30-40% NONPLASTIC FINES, RED BROWN, (SM) ALTERNATING WITH CLAYEY SILT TEXTURE, SLIGHTLY PLASTIC, 10-20% SAND, GRAY GREEN, HIGHLY MICACEOUS. (CL-ML)
						SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, POORLY GRADED MEDIUM TO FINE, MOSTLY FINE, 10-20% NONPLASTIC FINES, GREEN BROWN. (SM)
	70			13		

1. FIGURES IN BLOW OR RECOVERY COLUMN OPPOSITE SOIL SAMPLE DENOTE THE NUMBER OF BLOWS OF A 140 LB HAMMER FALLING 30" REQUIRED TO DRIVE A 2" OD SAMPLE SPOON 12" OR THE DISTANCE SHOWN. FIGURES SHOWN OPPOSITE ROCK CORES DENOTE THE PERCENT OF CORE RECOVERED.
2. ■2 INDICATES LOCATION OF UNDISTURBED SAMPLE.
   ◤6 INDICATES LOCATION OF SPLIT-SPOON SAMPLE.
   □◸ INDICATES LOCATION OF SAMPLING ATTEMPT WITH NO RECOVERY.
   SUBSCRIPT NEXT TO SYMBOL INDICATES SAMPLE NUMBER.
3. ↓ INDICATES LOCATION OF NATURAL GROUND WATER TABLE.
4. RQD - ROCK QUALITY DESIGNATION.
5. □ INDICATES DEPTH & LENGTH OF NX CORING RUN.
6. DATUM IS

4	
3	
2	
1	

BORING SWR-13
NORTH ANNA POWER STATION
SERVICE WATER RESERVOIR
VIRGINIA ELECTRIC POWER COMPANY
STONE & WEBSTER ENGINEERING CORPORATION

N03EA408

Figure 4 (SHEET 3 OF 3)
BORING LOG SWR-13 SERVICE WATER RESERVOIR

VIRGINIA ELECTRIC POWER COMPANY SH 3 OF 3

SITE NORTH ANNA POWER STATION J.O. NO. 11715 BORING NO SWR-13
TYPE OF BORING 4" UNCASED LOCATION GROUND ELEV. 320.6
DATE DRILLED 5/12-14/76 DRILLED BY AMERICAN/WHITAKER LOGGED BY THOMPSON/CHIALTA
SUMMARY OF BORING

ELEV. FEET	DEPTH FEET	OVERALL WEATHERING AND RQD (0 25 50 75 100)	SAMPLE: BLOWS OR RECOV.	SAMPLE: TYPE	GRAPHIC LOG	SOIL OR ROCK DESCRIPTION (FIELD AND LABORATORY TEST RESULTS; OR JOINTING, BEDDING AND FAULTING DESCRIPTIONS / SOIL STRATA DESCRIPTION; LITHOLOGY AND TEXTURE)
	70		10,24 38	14		SAPROLITE, ROCK WEATHERED TO A SANDY SILT TEXTURE, 10-20% FINE SAND, VERY STIFF, COLOR RANGES FROM BROWN, GREEN, RED-BROWN, MICACEOUS, FOLIATED 30° (ML); ALTERNATES WITH LAYERS OF CLAYEY SILT TEXTURE, SLIGHTLY TO MODERATELY PLASTIC, GRAY BROWN, HIGHLY MICACEOUS. (CL-ML)
						END OF BORING AT 71.5'
	75					

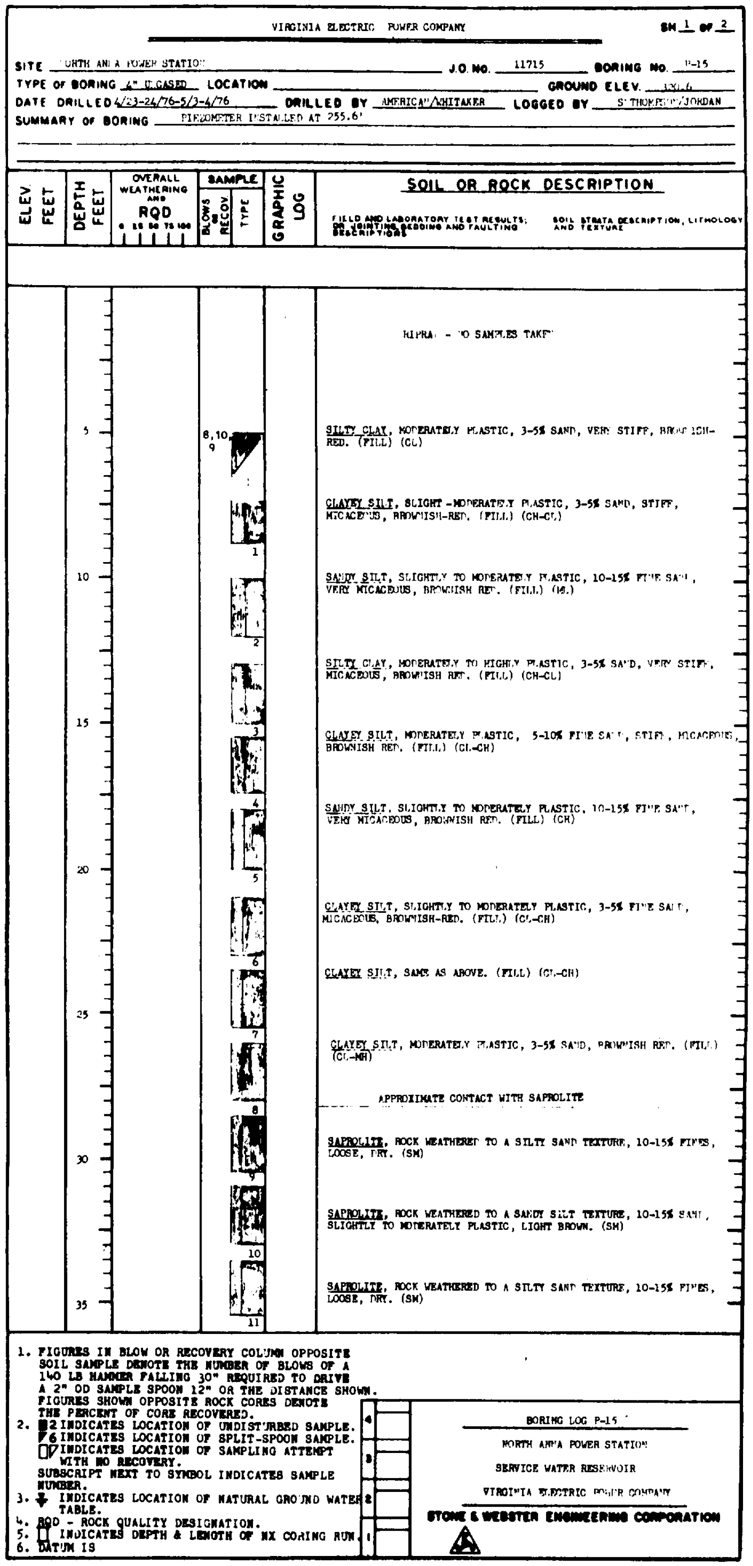
1. FIGURES IN BLOW OR RECOVERY COLUMN OPPOSITE SOIL SAMPLE DENOTE THE NUMBER OF BLOWS OF A 140 LB HAMMER FALLING 30" REQUIRED TO DRIVE A 2" OD SAMPLE SPOON 12" OR THE DISTANCE SHOWN. FIGURES SHOWN OPPOSITE ROCK CORES DENOTE THE PERCENT OF CORE RECOVERED.
2. ■2 INDICATES LOCATION OF UNDISTURBED SAMPLE.
◤6 INDICATES LOCATION OF SPLIT-SPOON SAMPLE.
□◸ INDICATES LOCATION OF SAMPLING ATTEMPT WITH NO RECOVERY.
SUBSCRIPT NEXT TO SYMBOL INDICATES SAMPLE NUMBER.
3. ⊻ INDICATES LOCATION OF NATURAL GROUND WATER TABLE.
4. RQD - ROCK QUALITY DESIGNATION.
5. ▯ INDICATES DEPTH & LENGTH OF NX CORING RUN.
6. DATUM IS

4	
3	
2	
1	

BORING SWR-13
NORTH ANNA POWER STATION
SERVICE WATER RESERVOIR
VIRGINIA ELECTRIC POWER COMPANY
STONE & WEBSTER ENGINEERING CORPORATION

N03EA409

Figure 5 (SHEET 1 OF 2)
BORING LOG SWR-15 SERVICE WATER RESERVOIR



N03EA410

Figure 5 (SHEET 2 OF 2)
BORING LOG SWR-15 SERVICE WATER RESERVOIR

VIRGINIA ELECTRIC POWER COMPANY SH 2 OF 2

SITE NORTH ANNA POWER STATION J.O. No. 11715 BORING No. P-15
TYPE OF BORING 4" UNCASED LOCATION GROUND ELEV. 320.6
DATE DRILLED 4/23-24/76 - 5/3-4/76 DRILLED BY AMERICAN/WHITAKER LOGGED BY THOMPSON JORDAN
SUMMARY OF BORING PIEZOMETER INSTALLED AT 255.6'

ELEV. FEET	DEPTH FEET	OVERALL WEATHERING AND RQD (0 25 50 75 100)	SAMPLE: BLOWS or RECOV.	SAMPLE: TYPE	GRAPHIC LOG	SOIL OR ROCK DESCRIPTION (FIELD AND LABORATORY TEST RESULTS; OR JOINTING, BEDDING AND FAULTING DESCRIPTIONS / SOIL STRATA DESCRIPTION; LITHOLOGY AND TEXTURE)
				12		SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, 20% FINES, UNIFORM, QUARTZ CRYSTALS 1/4-1/2", WHITE TO BROWN. (SM)
	40			13		SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, 10% FINES, POORLY GRADED, WHITE TO BROWN. (SM)
				14		SAPROLITE, ROCK WEATHERED TO A SANDY SILT TEXTURE, SLIGHTLY PLASTIC, 10-15% SAND, LIGHT BROWN. (ML)
	45			15		SAPROLITE, ROCK WEATHERS TO A SANDY SILT TEXTURE - SAME AS ABOVE. (ML)
				16		SAPROLITE, ROCK WEATHERED TO A SANDY SILT TEXTURE, SAME AS ABOVE. (ML)
	50			17		SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, POORLY GRADED 10-15% FINES, VERY MICACEOUS. (SM)
				18		SAPROLITE, ROCK WEATHERED TO A SILTY CLAY TEXTURE, HIGHLY PLASTIC, VERY MICACEOUS, 3-5% SAND, SOFT, WHITE TO BROWN. (MH-CH)
	55			19		SAPROLITE, ROCK WEATHERED TO A SANDY SILT TEXTURE, SLIGHTLY TO MODERATELY PLASTIC, 20% SAND, WHITE TO BROWN. (ML)
				20		SAPROLITE, ROCK WEATHERED TO A CLAYEY SILT TEXTURE, MODERATELY PLASTIC, 5-10% SAND, VERY MICACEOUS, WHITE-GREEN-BROWN. (MH)
	60			21		SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, 8-12% NONPLASTIC FINES, UNIFORM, MEDIUM TO FINE SAND, VERY MICACEOUS, GRAY. (SM-SP)
				22		SAPROLITE, ROCK WEATHERED TO SILTY SAND TEXTURE, 40% NON TO SLIGHTLY PLASTIC CHLORITE (ALTERED) FINES, UNIFORM, VERY FINE SAND, GREEN TO LIGHT BROWN, VERY MICACEOUS. (SM)
	65			23		SAPROLITE, ROCK WEATHERED TO SILTY SAND TEXTURE, 5-10% NONPLASTIC FINES, UNIFORM, VERY FINE SAND, GRAY. (SP-SM)
				24		SAPROLITE, ROCK WEATHERED TO SILTY SAND TEXTURE, 15-20% NONPLASTIC FINES, GRAYISH WHITE. (SM)
	70			24		SAPROLITE, ROCK WEATHERED TO SILTY SAND, 20% NON TO SLIGHTLY PLASTIC FINES, COARSE TO FINE SAND, FEW GRAVEL TO 1" MAXIMUM (BROKEN QUARTZ IN 1/2" QUARTZ LENSE) RUSTY, DARK GRAY AND BROWN. (SM)
						END OF BORING AT 71.5'

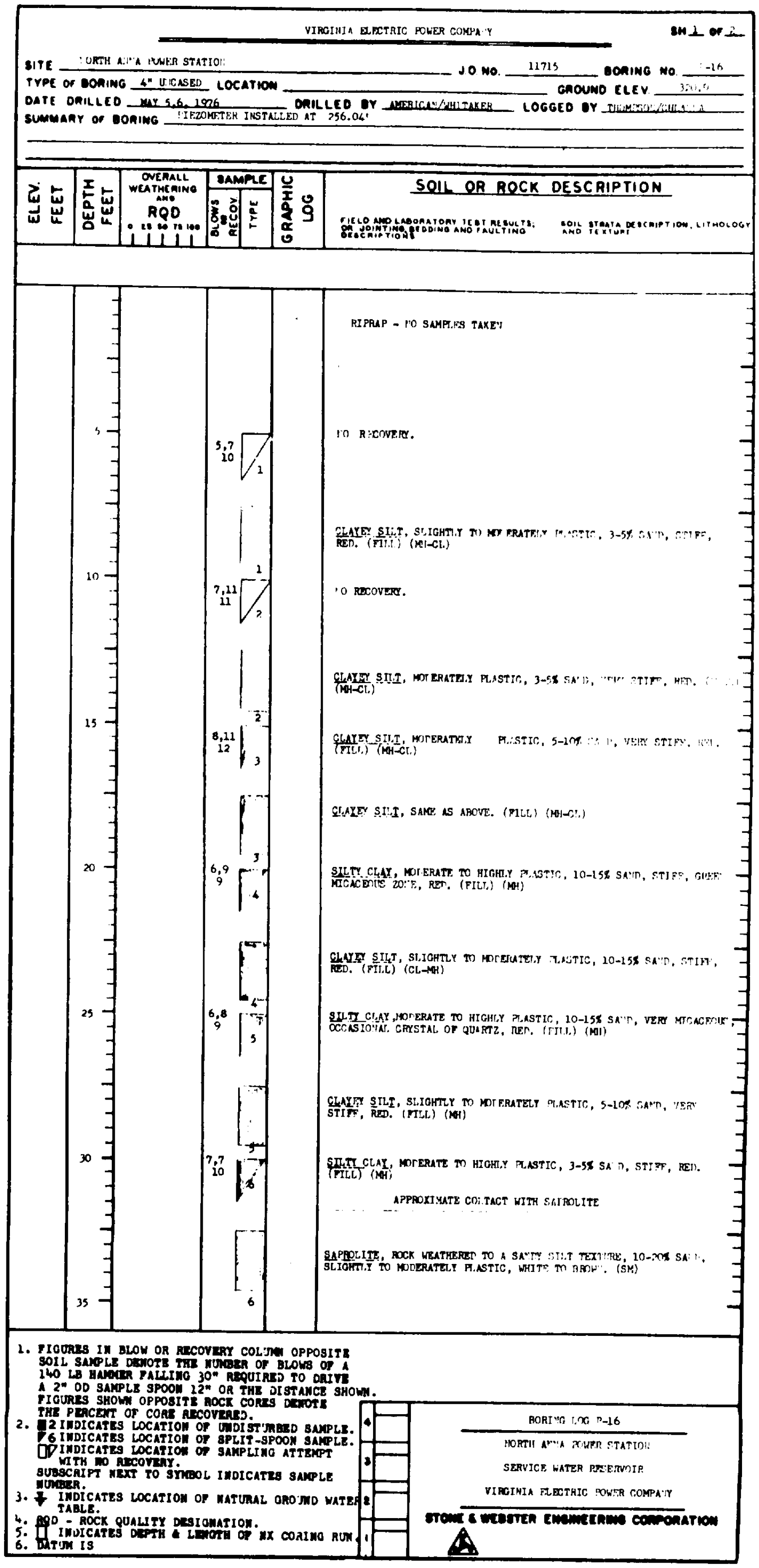
1. FIGURES IN BLOW OR RECOVERY COLUMN OPPOSITE SOIL SAMPLE DENOTE THE NUMBER OF BLOWS OF A 140 LB HAMMER FALLING 30" REQUIRED TO DRIVE A 2" OD SAMPLE SPOON 12" OR THE DISTANCE SHOWN. FIGURES SHOWN OPPOSITE ROCK CORES DENOTE THE PERCENT OF CORE RECOVERED.
2. ■2 INDICATES LOCATION OF UNDISTURBED SAMPLE.
◤6 INDICATES LOCATION OF SPLIT-SPOON SAMPLE.
□◸ INDICATES LOCATION OF SAMPLING ATTEMPT WITH NO RECOVERY.
SUBSCRIPT NEXT TO SYMBOL INDICATES SAMPLE NUMBER.
3. ↓ INDICATES LOCATION OF NATURAL GROUND WATER TABLE.
4. RQD - ROCK QUALITY DESIGNATION.
5. □ INDICATES DEPTH & LENGTH OF NX CORING RUN.
6. DATUM IS

4	
3	
2	
1	

BORING LOG P-15
NORTH ANNA POWER STATION
SERVICE WATER RESERVOIR
VIRGINIA ELECTRIC POWER COMPANY
STONE & WEBSTER ENGINEERING CORPORATION

N03EA411

Figure 6 (SHEET 1 OF 2)
BORING LOG SWR-16 SERVICE WATER RESERVOIR



N03EA412

Figure 6 (SHEET 2 OF 2)
BORING LOG SWR-16 SERVICE WATER RESERVOIR

VIRGINIA ELECTRIC POWER COMPANY SH 2 OF 2

SITE NORTH ANNA POWER STATION J.O. No. 11715 BORING No. P-16
TYPE OF BORING 4" UNCASED LOCATION GROUND ELEV. 320.9
DATE DRILLED JULY 5-6, 1976 DRILLED BY AMERICAN/WHITAKER LOGGED BY THOMPSON/CHLANDA
SUMMARY OF BORING PIEZOMETER INSTALLED AT 256.04'

ELEV FEET	DEPTH FEET	OVERALL WEATHERING AND RQD (0 25 50 75 100)	SAMPLE: BLOWS OR RECOV	SAMPLE: TYPE	GRAPHIC LOG	SOIL OR ROCK DESCRIPTION (FIELD AND LABORATORY TEST RESULTS; OR JOINTING, BEDDING AND FAULTING DESCRIPTIONS / SOIL STRATA DESCRIPTION; LITHOLOGY AND TEXTURE)
			7,8 10	7		SAPROLITE, ROCK WEATHERED TO A SANDY SILT TEXTURE, 10-20% SAND, MODERATELY PLASTIC, FOLIATED AT 30-40°, WHITE. (ML)
						SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, 10-15% FINES, POORLY GRADED, WHITE. (SM)
	40		6,8 11	7, 8		SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, 10-20% FINES, POORLY GRADED, FOLIATED WITH BIOTITE, BROWN TO BLACK. (SM)
						SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, SAME AS ABOVE EXCEPT WHITE TO BROWN COLOR. (SM)
	45		4,8 11	8, 9		SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, 10-15% FINES, POORLY GRADED, FOLIATED, TAN TO BROWN. (SM)
						SAPROLITE, SAME AS ABOVE. (SM)
	50		10,13 15	9, 10		SAPROLITE, SAME AS ABOVE, EXCEPT VERY MICACEOUS. (SM)
						SAPROLITE, SAME AS ABOVE. (SM)
	55		11,14 25	10, 11		SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, 10-15% FINES, POORLY GRADED, FOLIATED AT 30°, WHITE TO BROWN, VERY MICACEOUS. (SM)
						SAPROLITE, SAME AS ABOVE. (SM)
	60		27,40 67	11, 12		SAPROLITE, ROCK WEATHERED TO A SAND TEXTURE, 0-5% FINES, MEDIUM GRAIN QUARTZ. (SP) AND A SILTY SAND TEXTURE, 10-15% FINES, OCCASIONAL QUARTZ CRYSTALS, 1/8", WHITE. (SM)
						SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, 25% FINES, WHITE TO BROWN. (SM)
	65		28,30 32	12, 13		SAPROLITE, SAME AS ABOVE, FOLIATED AT 30°. (SM)
						SAPROLITE, ROCK WEATHERED TO A SILTY SANDY TEXTURE, 30-40% NONPLASTIC FINES, LIGHT BROWN. (SM)
	70			13		END OF BORING AT 70.2'

1. FIGURES IN BLOW OR RECOVERY COLUMN OPPOSITE SOIL SAMPLE DENOTE THE NUMBER OF BLOWS OF A 140 LB HAMMER FALLING 30" REQUIRED TO DRIVE A 2" OD SAMPLE SPOON 12" OR THE DISTANCE SHOWN. FIGURES SHOWN OPPOSITE ROCK CORES DENOTE THE PERCENT OF CORE RECOVERED.
2. ▇2 INDICATES LOCATION OF UNDISTURBED SAMPLE. ▼6 INDICATES LOCATION OF SPLIT-SPOON SAMPLE. ▯7 INDICATES LOCATION OF SAMPLING ATTEMPT WITH NO RECOVERY. SUBSCRIPT NEXT TO SYMBOL INDICATES SAMPLE NUMBER.
3. ⊥ INDICATES LOCATION OF NATURAL GROUND WATER TABLE.
4. RQD - ROCK QUALITY DESIGNATION.
5. ▯ INDICATES DEPTH & LENGTH OF NX CORING RUN.
6. DATUM IS

4	
3	
2	
1	

BORING LOG P-16
NORTH ANNA POWER STATION
SERVICE WATER RESERVOIR
VIRGINIA ELECTRIC POWER COMPANY
STONE & WEBSTER ENGINEERING CORPORATION

N03EA413

Figure 7 (SHEET 1 OF 3)
BORING LOG SWR-17 SERVICE WATER RESERVOIR

VIRGINIA ELECTRIC POWER COMPANY SH 1 OF 3

SITE NORTH ANNA POWER STATION J.O. NO. 11715 BORING NO. P-17
TYPE OF BORING 4" UNCASED LOCATION GROUND ELEV. 320.6
DATE DRILLED MAY 10, 11, 1976 DRILLED BY AMERICAN/WHITAKER LOGGED BY S.H. THOMPSON
SUMMARY OF BORING PIEZOMETER INSTALLED AT EL. 256.0'

ELEV FEET	DEPTH FEET	OVERALL WEATHERING AND RQD (0 25 50 75 100)	SAMPLE BLOWS OR RECOV	SAMPLE TYPE	GRAPHIC LOG	SOIL OR ROCK DESCRIPTION (FIELD AND LABORATORY TEST RESULTS, OR JOINTING, BEDDING AND FAULTING DESCRIPTIONS; SOIL STRATA DESCRIPTION, LITHOLOGY AND TEXTURE)
						RIPRAP-NO SAMPLES TAKEN
	5		5, 6, 11	1		SANDY CLAY, MODERATE TO HIGHLY PLASTIC, 10% SAND, RED, (FILL) (SC)
						SANDY SILT, SLIGHTLY PLASTIC, 15-20% SAND, BROWN TO RED, (FILL) (ML)
	10		7, 7, 10	1, 2		SILTY CLAY, SLIGHT - MODERATELY PLASTIC, 5-10% SAND, STIFF, (FILL) (MH)
						SILTY CLAY, MODERATE - HIGHLY PLASTIC, 3-5% SAND, STIFF, VERY MICACEOUS, RED TO BROWN, (FILL) (MH)
	15		8, 13, 15	2, 3		SILTY CLAY, SAME AS ABOVE, (FILL) (MH)
						CLAYEY SILT, SLIGHTLY - MODERATELY PLASTIC, 3-5% SAND, STIFF, BROWN, (FILL) (ML)
	20		7, 10, 11	3, 4		CLAYEY SILT, SLIGHT - MODERATELY PLASTIC, 5-10% SAND, STIFF, RED TO BROWN, (FILL) (ML)
						CLAYEY SILT, SAME AS ABOVE, (FILL) (ML)
	25		6, 7, 11	4, 5		SILTY CLAY, MODERATELY PLASTIC, 3-5% SAND, STIFF, VERY MICACEOUS, RED, (FILL) (MH)
						SILTY CLAY, MODERATELY PLASTIC, WITH QUARTZ CRYSTALS UP TO 1", 3-5% SAND, RED, (FILL) (MH)
	30		6, 12, 12	5, 6		SILTY CLAY, MODERATE TO HIGHLY PLASTIC, 3-5% SAND, RED, (FILL) (MH)
						APPROXIMATE CONTACT WITH SAPROLITE
						SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, UNIFORM, POORLY GRADED, 10-15% FINES, WHITE TO GRAY. (SM)
	35			6		

1. FIGURES IN BLOW OR RECOVERY COLUMN OPPOSITE SOIL SAMPLE DENOTE THE NUMBER OF BLOWS OF A 140 LB HAMMER FALLING 30" REQUIRED TO DRIVE A 2" OD SAMPLE SPOON 12" OR THE DISTANCE SHOWN. FIGURES SHOWN OPPOSITE ROCK CORES DENOTE THE PERCENT OF CORE RECOVERED.
2. ■2 INDICATES LOCATION OF UNDISTURBED SAMPLE. ▼6 INDICATES LOCATION OF SPLIT-SPOON SAMPLE. ▯▽ INDICATES LOCATION OF SAMPLING ATTEMPT WITH NO RECOVERY. SUBSCRIPT NEXT TO SYMBOL INDICATES SAMPLE NUMBER.
3. ▼ INDICATES LOCATION OF NATURAL GROUND WATER TABLE.
4. RQD - ROCK QUALITY DESIGNATION.
5. ▯ INDICATES DEPTH & LENGTH OF NX CORING RUN.
6. DATUM IS

BORING P-17
NORTH ANNA POWER STATION
SERVICE WATER RESERVOIR

VIRGINIA ELECTRIC POWER COMPANY
STONE & WEBSTER ENGINEERING CORPORATION

N03EA414

Figure 7 (SHEET 2 OF 3)
BORING LOG SWR-17 SERVICE WATER RESERVOIR

VIRGINIA ELECTRIC POWER COMPANY — SH 2 OF 3

SITE: NORTH ANNA POWER STATION — J.O. No. 11715 — BORING No. P-17
TYPE OF BORING: 4" UNCASED — LOCATION: — GROUND ELEV. 3[illegible]0.6
DATE DRILLED: MAY 10, 11, 1976 — DRILLED BY: AMERICAN/WHITAKER — LOGGED BY: S.N. THOMPSON
SUMMARY OF BORING: PIEZOMETER INSTALLED AT EL. 256.0'

ELEV. FEET	DEPTH FEET	OVERALL WEATHERING AND RQD (0 25 50 75 100)	SAMPLE BLOWS OR RECOV.	SAMPLE TYPE	GRAPHIC LOG	SOIL OR ROCK DESCRIPTION (FIELD AND LABORATORY TEST RESULTS; OR JOINTING, BEDDING AND FAULTING DESCRIPTIONS / SOIL STRATA DESCRIPTION; LITHOLOGY AND TEXTURE)
			6,7, 11	7		SAPROLITE, ROCK WEATHERED TO A CLAYEY SILT TEXTURE, MODERATELY PLASTIC, 3-5% SAND, VERY MICACEOUS, GRAY. (ML)
						SAPROLITE, ROCK WEATHERED TO A CLAYEY SILT TEXTURE, HIGHLY PLASTIC, 3-5% SAND, GRAY. (CH)
	40		7,7, 10	7 / 8		SAPROLITE, ROCK WEATHERED TO SILTY CLAY TEXTURE, HIGHLY PLASTIC, 3-5% SAND, ZONE OF WEATHERED BIOTITE, GRAY TO BLACK. (CH)
						SAPROLITE, SAME AS ABOVE, EXCEPT WHITE TO GREEN. (CH)
	45		5,7, 10	8 / 9		SAPROLITE, ROCK WEATHERED TO A SILTY CLAY TEXTURE, HIGHLY PLASTIC, 3-5% SAND, VERY MICACEOUS, GREEN TO BLACK, FOLIATED AT 60°. (CH)
						SAPROLITE, ROCK WEATHERED TO A SILTY CLAY TEXTURE, HIGHLY PLASTIC, 3-5% SAND, BROWN, LOOSE. (CH)
	50		5,9, 8	9 / 10		SAPROLITE, ROCK WEATHERED TO A SILTY CLAY TEXTURE, HIGHLY PLASTIC, 3-5% SAND, BROWN. (CH)
						SAPROLITE, ROCK WEATHERED TO A SANDY SILT TEXTURE, MODERATELY PLASTIC, 10-15% SAND, VERY MICACEOUS, BROWN. (ML)
	55		6,8, 14	10 / 11		SAPROLITE, ROCK WEATHERED TO A SANDY SILT TEXTURE, MODERATELY PLASTIC, 10-15% SAND, VERY MICACEOUS. (ML)
						SAPROLITE, ROCK WEATHERED TO A CLAYEY SILT TEXTURE, SLIGHT - MODERATELY PLASTIC, 3-5% SAND, MICACEOUS. (ML-MH)
	60		7,11, 12	11 / 12		SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, UNIFORM, POORLY GRADED 15-20% FINES, VERY MICACEOUS, BROWN. (SM)
						SAPROLITE, ROCK WEATHERED TO A SANDY SILT TEXTURE, SLIGHTLY PLASTIC, 10-15% SAND, VERY MICACEOUS, DARK BROWN. (ML)
	65		15,21, 24	12 / 13		SAPROLITE, ROCK WEATHERED TO A SILTY SAND TEXTURE, UNIFORM, POORLY GRADED, FINE, 15-20% FINES, FOLIATED AT 30°. (SM)
				13		SAPROLITE, SAME AS ABOVE, GRANITE MATRIX VERY DISTINCT, WHITE TO BLACK. (SM)
	70					

1. FIGURES IN BLOW OR RECOVERY COLUMN OPPOSITE SOIL SAMPLE DENOTE THE NUMBER OF BLOWS OF A 140 LB HAMMER FALLING 30" REQUIRED TO DRIVE A 2" OD SAMPLE SPOON 12" OR THE DISTANCE SHOWN. FIGURES SHOWN OPPOSITE ROCK CORES DENOTE THE PERCENT OF CORE RECOVERED.
2. ■2 INDICATES LOCATION OF UNDISTURBED SAMPLE.
▼6 INDICATES LOCATION OF SPLIT-SPOON SAMPLE.
□▽ INDICATES LOCATION OF SAMPLING ATTEMPT WITH NO RECOVERY.
SUBSCRIPT NEXT TO SYMBOL INDICATES SAMPLE NUMBER.
3. ↓ INDICATES LOCATION OF NATURAL GROUND WATER TABLE.
4. RQD - ROCK QUALITY DESIGNATION.
5. □ INDICATES DEPTH & LENGTH OF NX CORING RUN.
6. DATUM IS

4	
3	
2	
1	

BORING P-17
NORTH ANNA POWER STATION
SERVICE WATER RESERVOIR

VIRGINIA ELECTRIC POWER COMPANY
STONE & WEBSTER ENGINEERING CORPORATION

N03EA415

Figure 7 (SHEET 3 OF 3)
BORING LOG SWR-17 SERVICE WATER RESERVOIR

VIRGINIA ELECTRIC POWER COMPANY SH 3 OF 3

SITE NORTH ANNA POWER STATION J.O. NO. 11715 BORING NO. P-17
TYPE OF BORING 4" UNCASED LOCATION GROUND ELEV. 320.6
DATE DRILLED MAY 10, 11, 1976 DRILLED BY AMERICAN/WHITAKER LOGGED BY S.H. THOMPSON
SUMMARY OF BORING PIEZOMETER INSTALLED AT EL. 256.0'

ELEV. FEET	DEPTH FEET	OVERALL WEATHERING AND RQD (0 25 50 75 100)	SAMPLE: BLOWS OR RECOV.	SAMPLE: TYPE	GRAPHIC LOG	SOIL OR ROCK DESCRIPTION (FIELD AND LABORATORY TEST RESULTS; OR JOINTING, BEDDING AND FAULTING DESCRIPTIONS / SOIL STRATA DESCRIPTION; LITHOLOGY AND TEXTURE)
			19, 22 49	14		SAPROLITE, SAME AS ABOVE, FOLIATED AT 10°. (SM)
				14		SAPROLITE, SAME AS ABOVE. (SH)
	75		29, 64, 73	15		SAPROLITE, SAME AS ABOVE. (SM) END OF BORING 76.5'

1. FIGURES IN BLOW OR RECOVERY COLUMN OPPOSITE SOIL SAMPLE DENOTE THE NUMBER OF BLOWS OF A 140 LB HAMMER FALLING 30" REQUIRED TO DRIVE A 2" OD SAMPLE SPOON 12" OR THE DISTANCE SHOWN. FIGURES SHOWN OPPOSITE ROCK CORES DENOTE THE PERCENT OF CORE RECOVERED.
2. ■2 INDICATES LOCATION OF UNDISTURBED SAMPLE.
   ▼6 INDICATES LOCATION OF SPLIT-SPOON SAMPLE.
   □▽ INDICATES LOCATION OF SAMPLING ATTEMPT WITH NO RECOVERY.
   SUBSCRIPT NEXT TO SYMBOL INDICATES SAMPLE NUMBER.
3. ⯆ INDICATES LOCATION OF NATURAL GROUND WATER TABLE.
4. RQD - ROCK QUALITY DESIGNATION.
5. ▯ INDICATES DEPTH & LENGTH OF NX CORING RUN.
6. DATUM IS

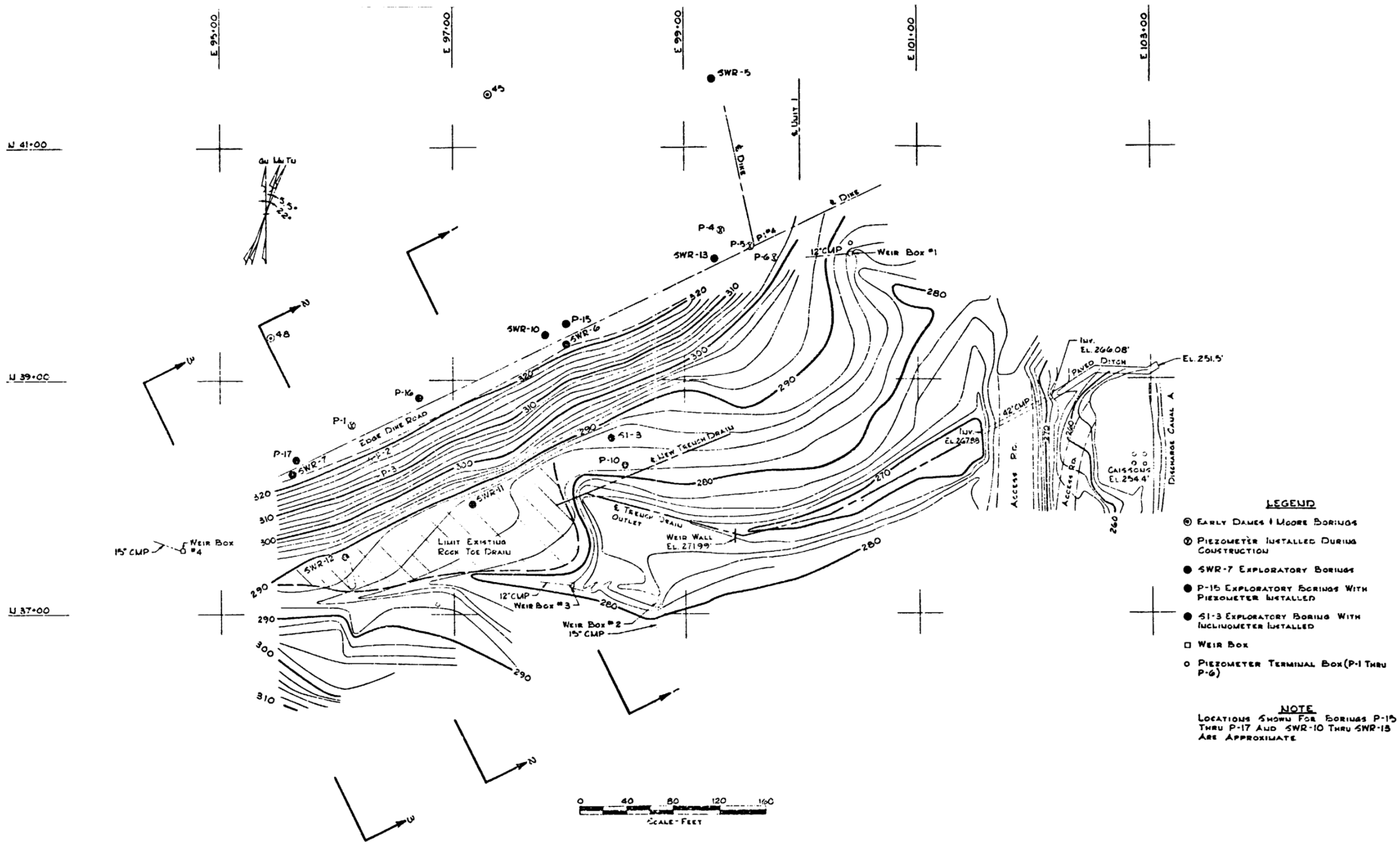
4
3
2
1

BORING P-17
NORTH ANNA POWER STATION
SERVICE WATER RESERVOIR

VIRGINIA ELECTRIC POWER COMPANY
STONE & WEBSTER ENGINEERING CORPORATION

N03EA416

Figure 8
SERVICE WATER RESERVOIR PLAN BORINGS S.E. DIKE SECTION



N03EA417

Figure 9 (SHEET 1 OF 3)
SERVICE WATER RESERVOIR BORING SECTION - S.E. DIKE

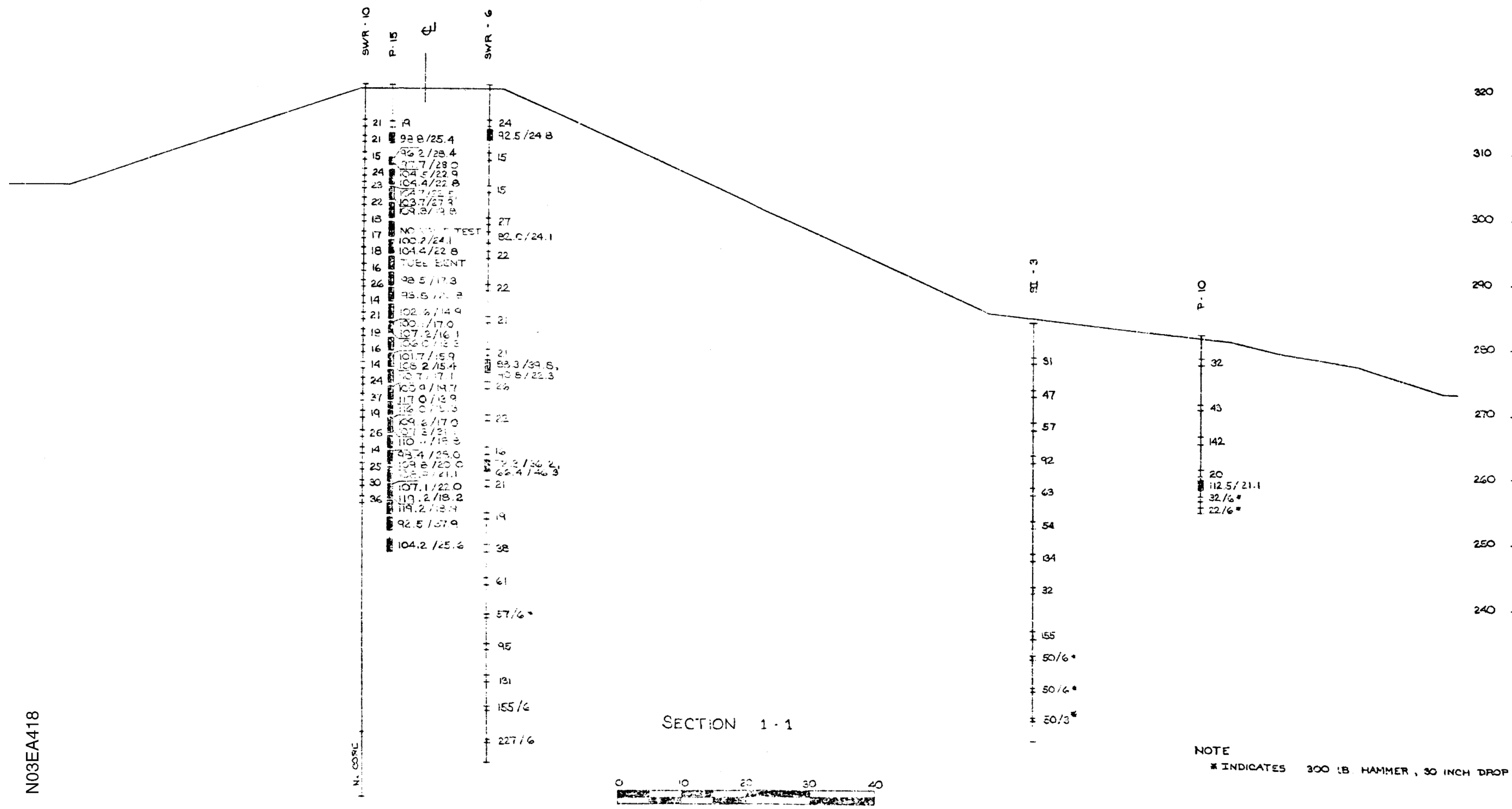
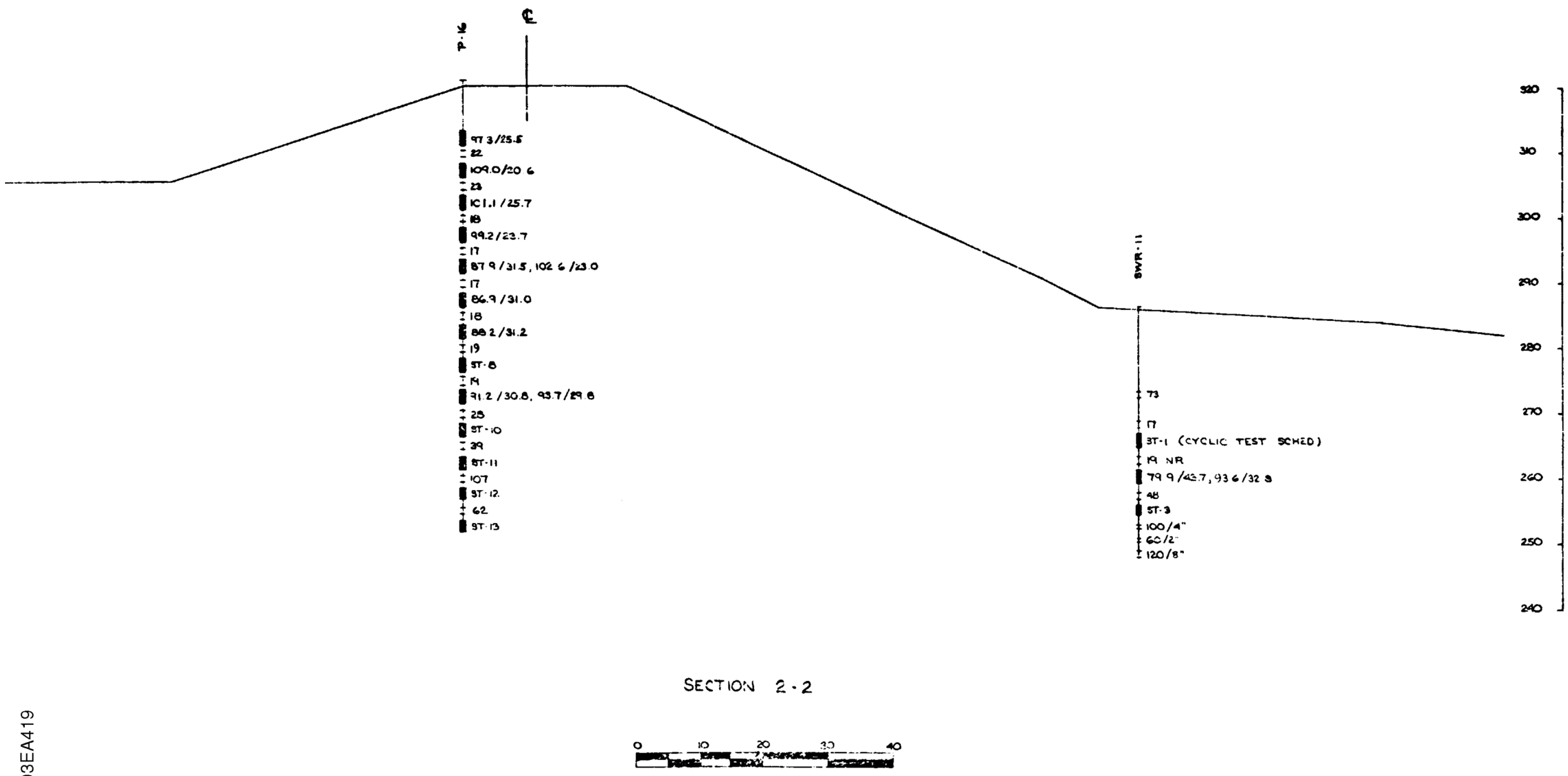
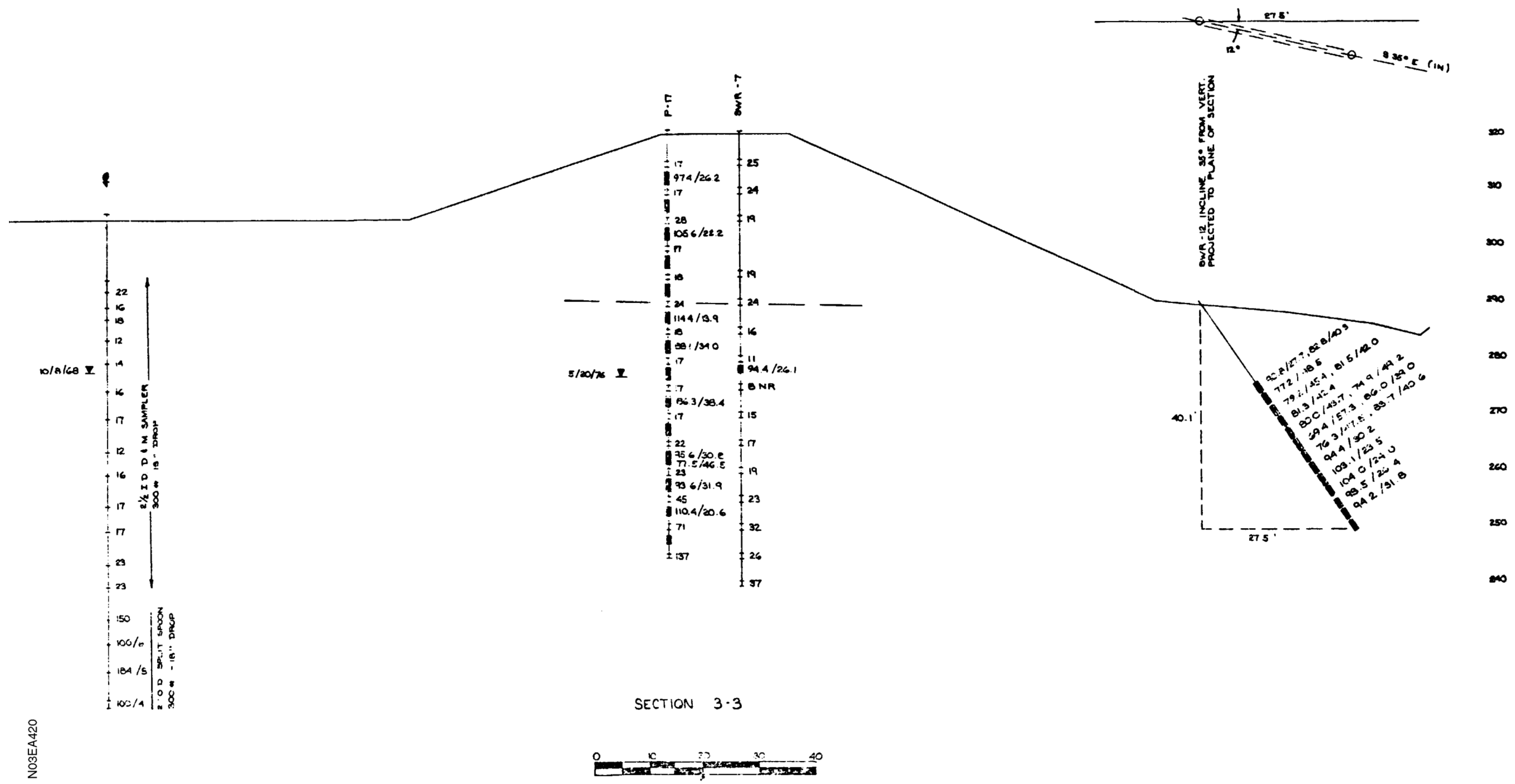


Figure 9 (SHEET 2 OF 3)
SERVICE WATER RESERVOIR BORING SECTION - S.E. DIKE



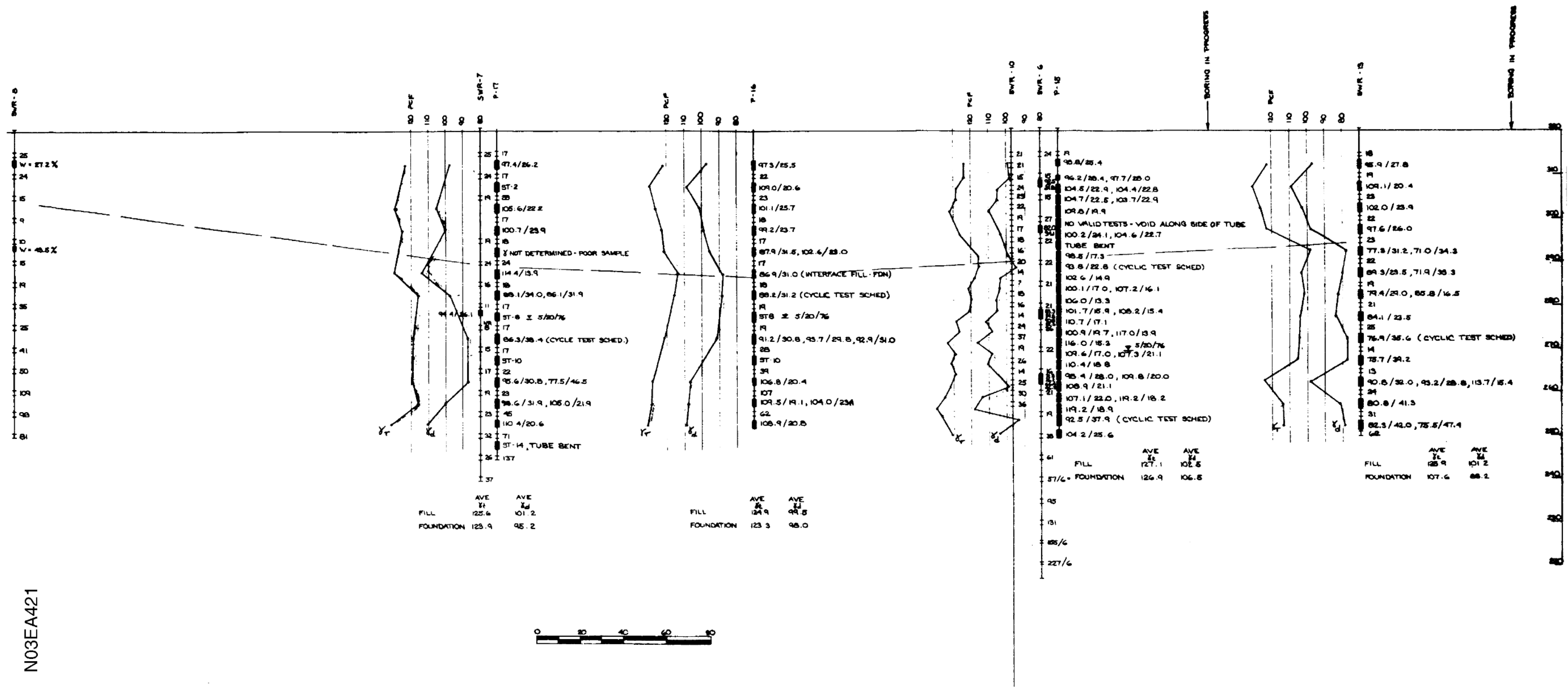
N03EA419

Figure 9 (SHEET 3 OF 3)
SERVICE WATER RESERVOIR BORING SECTION - S.E. DIKE



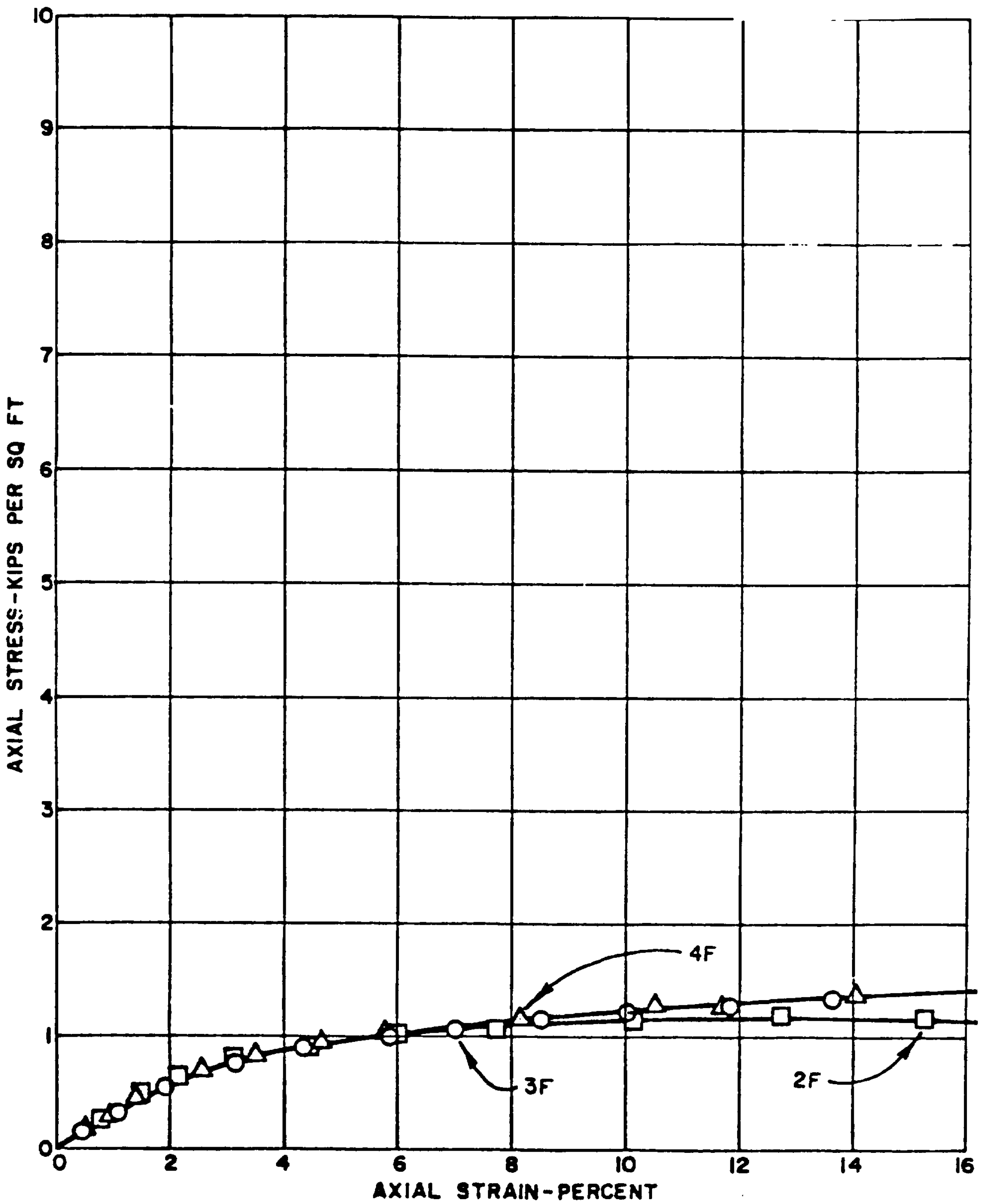
N03EA420

Figure 10
BORING PROFILE ALONG CENTERLINE DIKE SERVICE WATER RESERVOIR



N03EA421

Figure 11 (SHEET 1 OF 7)
UNDRAINED COMPRESSION TANKS SERVICE WATER RESERVOIR



N03EA422

BORING 3WR - 12
FOUNDATION

Figure 11 (SHEET 2 OF 7)
UNDRAINED COMPRESSION TANKS SERVICE WATER RESERVOIR

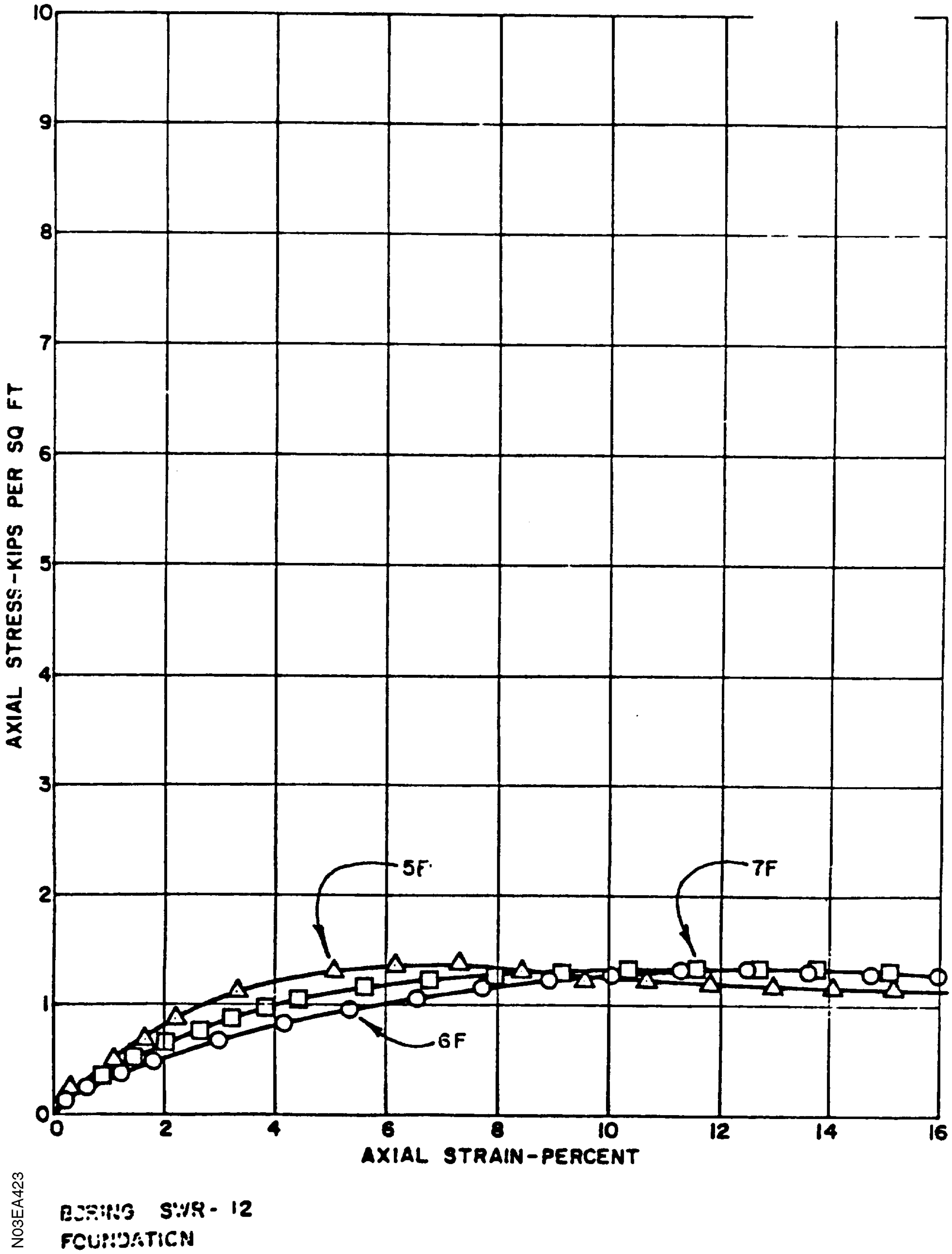
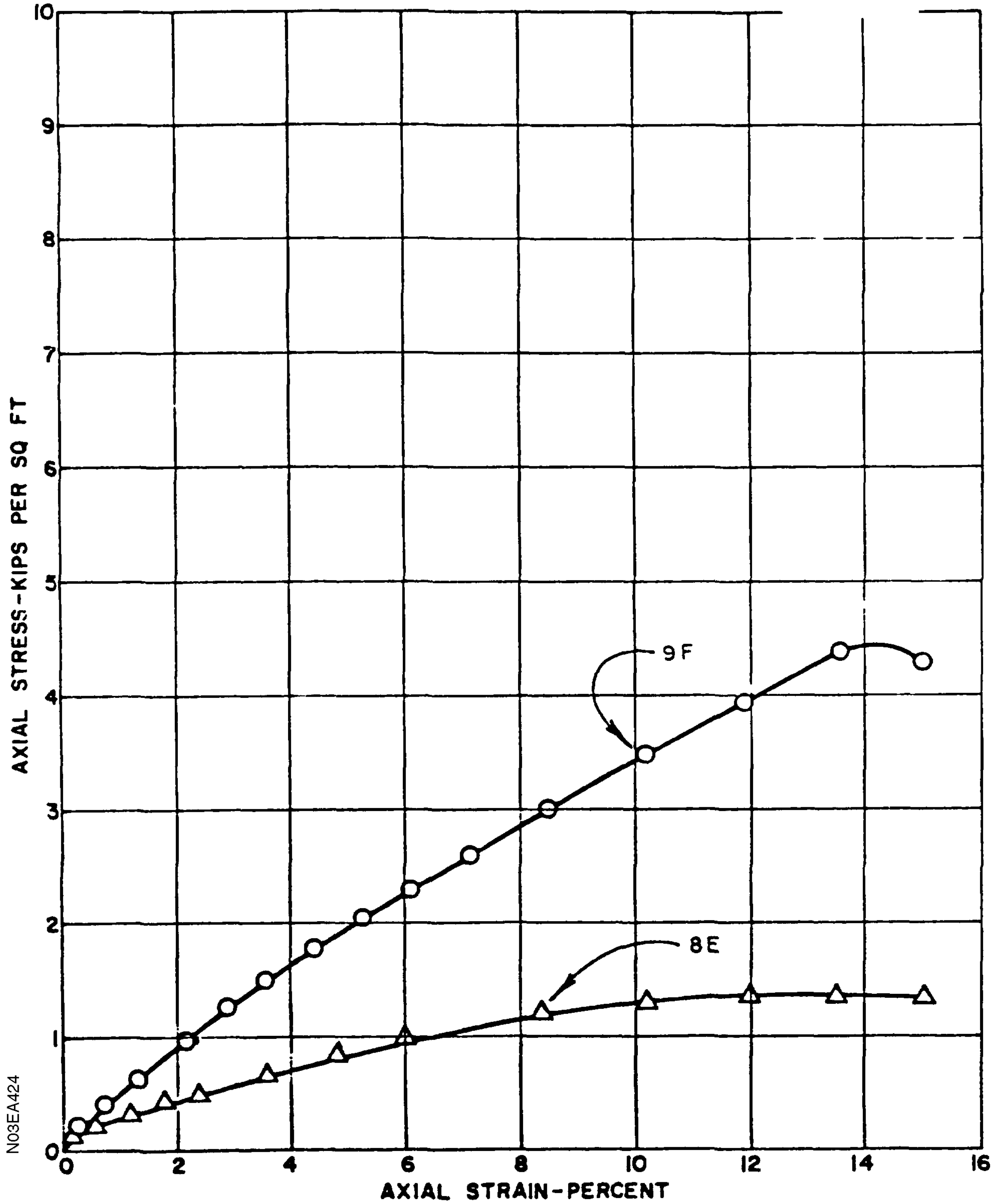
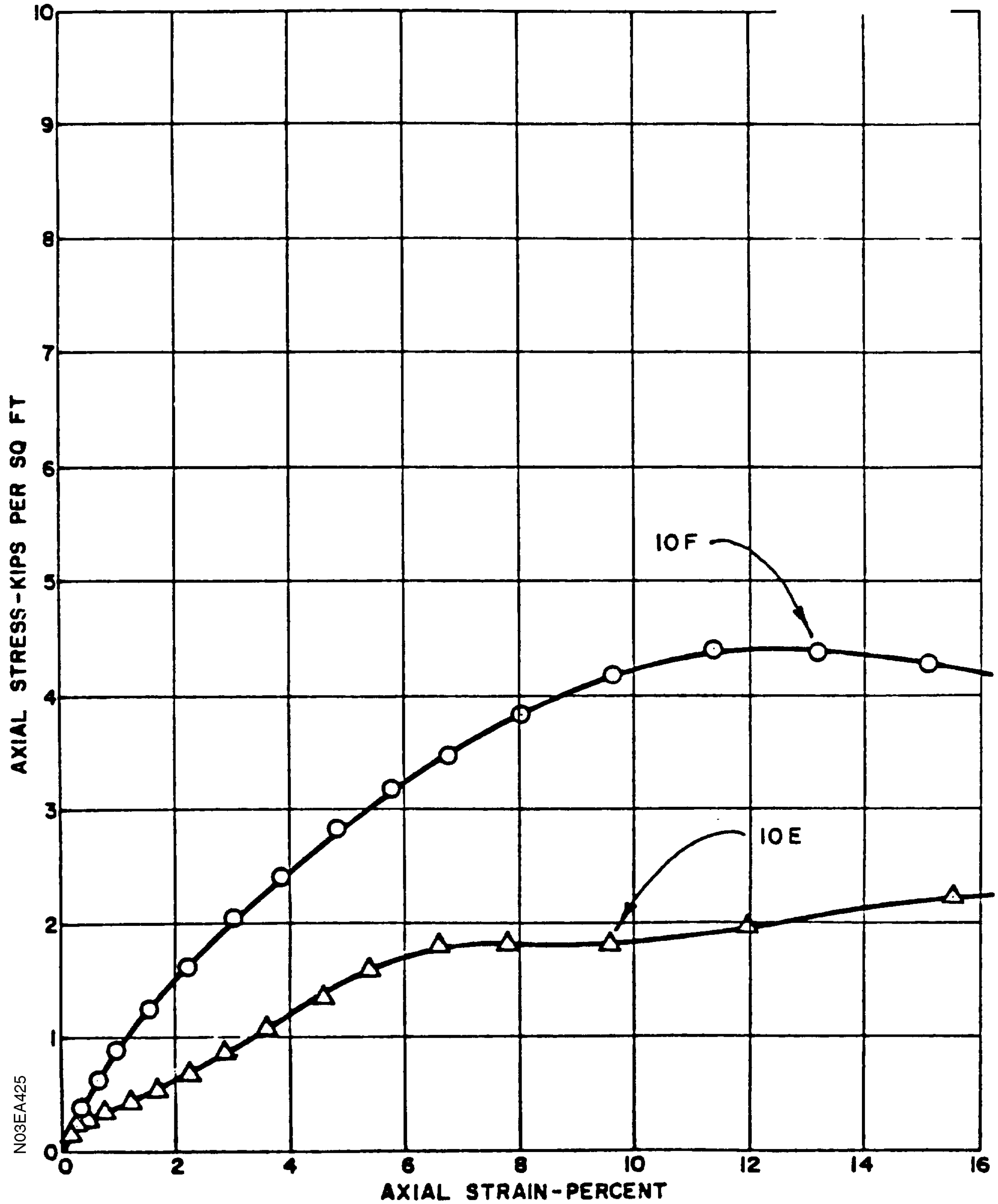


Figure 11 (SHEET 3 OF 7)
UNDRAINED COMPRESSION TANKS SERVICE WATER RESERVOIR



BORING SWR - 12
FOUNDATION

Figure 11 (SHEET 4 OF 7)
UNDRAINED COMPRESSION TANKS SERVICE WATER RESERVOIR



BORING SWR- 12
FOUNDATION

Figure 11 (SHEET 5 OF 7)
UNDRAINED COMPRESSION TANKS SERVICE WATER RESERVOIR

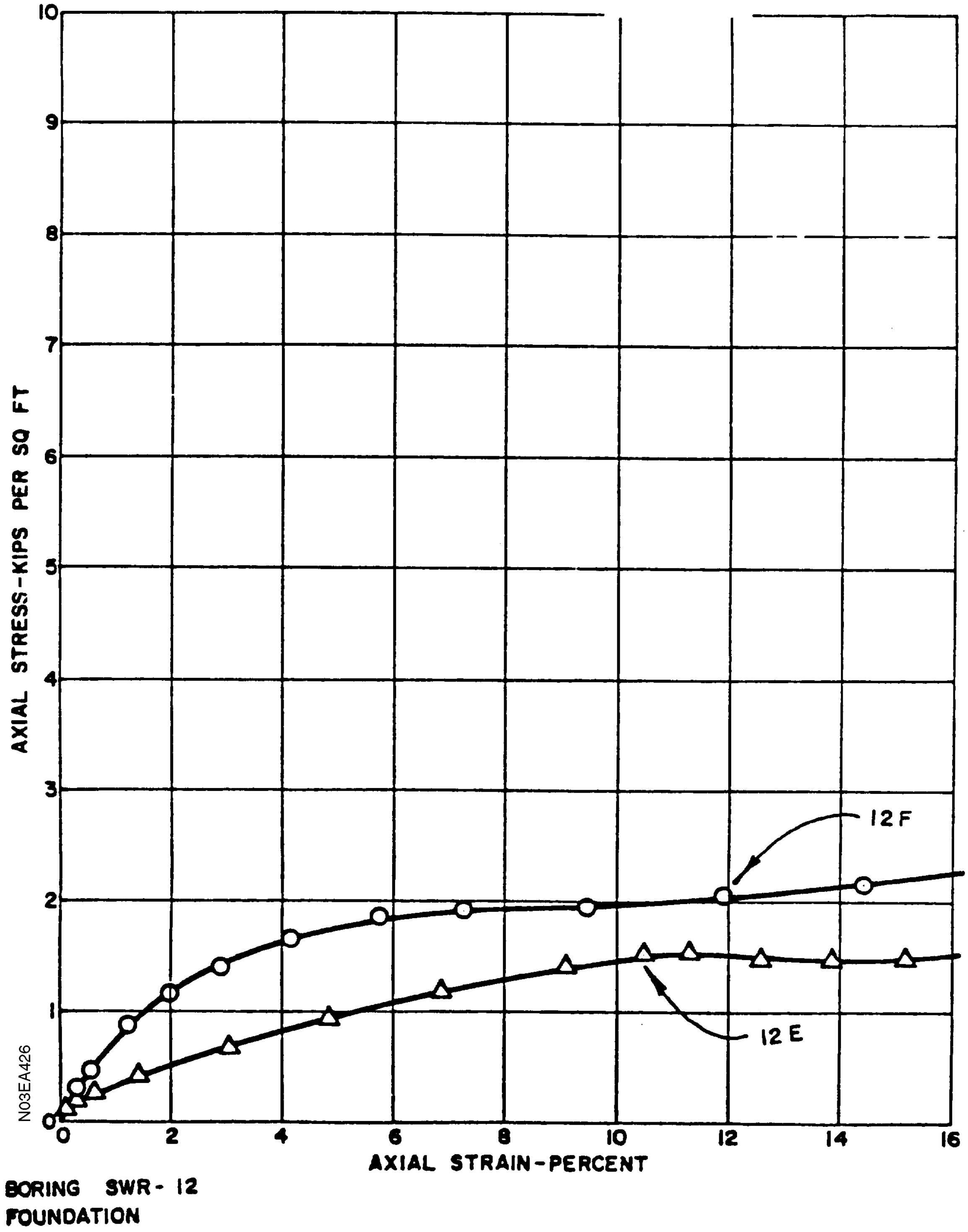


Figure 11 (SHEET 6 OF 7)
UNDRAINED COMPRESSION TANKS SERVICE WATER RESERVOIR

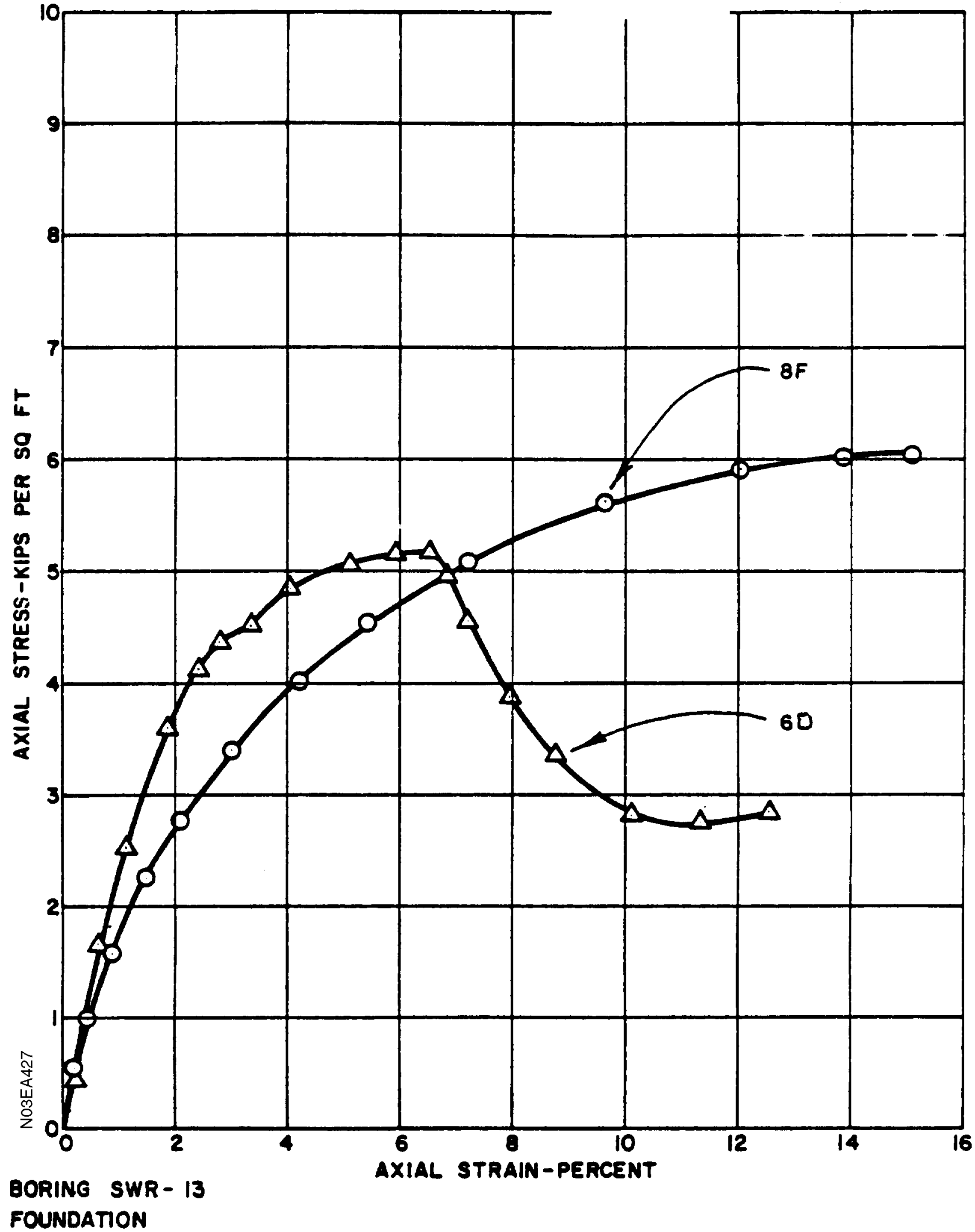
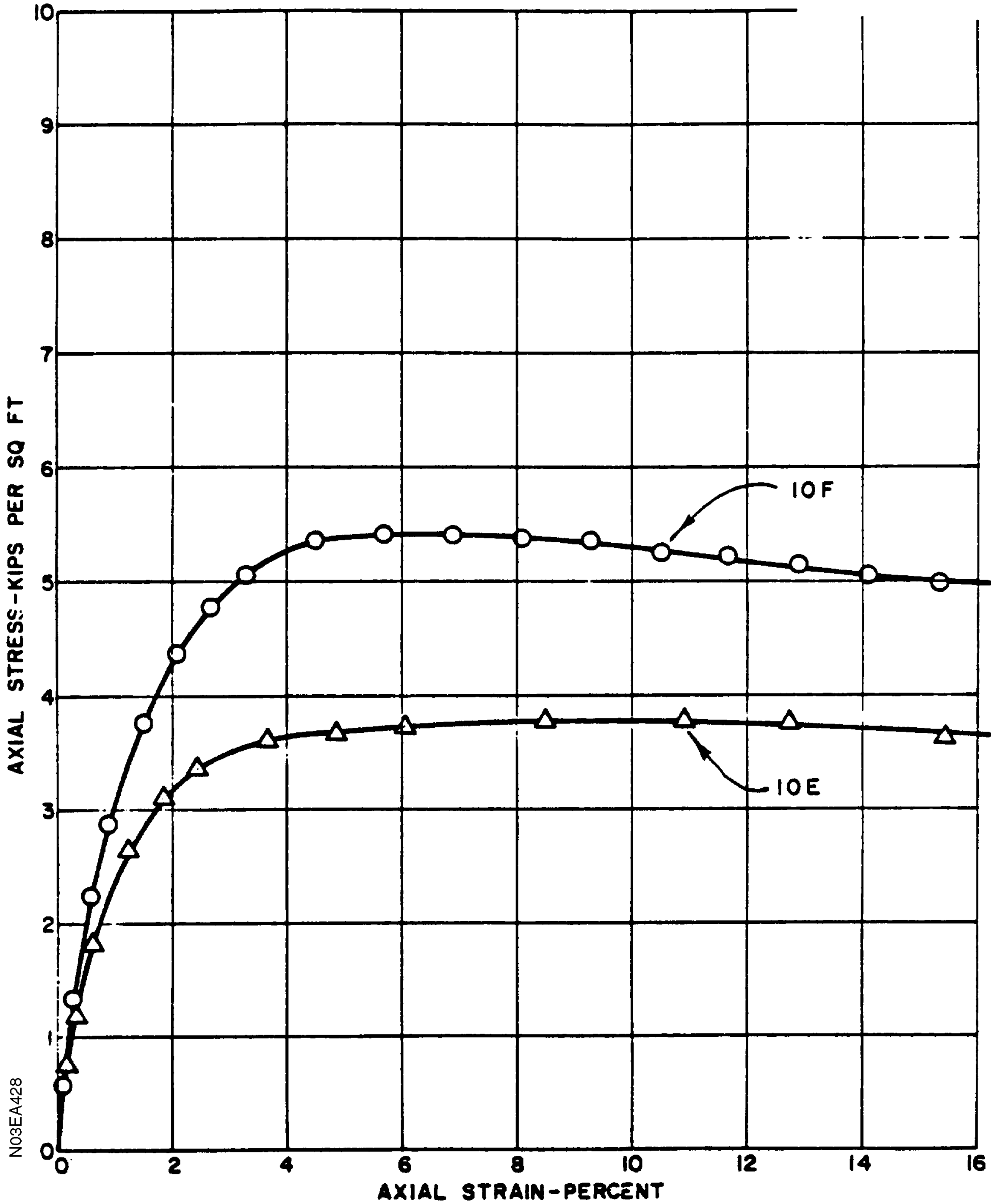


Figure 11 (SHEET 7 OF 7)
UNDRAINED COMPRESSION TANKS SERVICE WATER RESERVOIR



BORING SWR- 13
FOUNDATION

Figure 12
SUPPLEMENTAL BORINGS SERVICE WATER RESERVOIR; BORING LOCATION PLAN

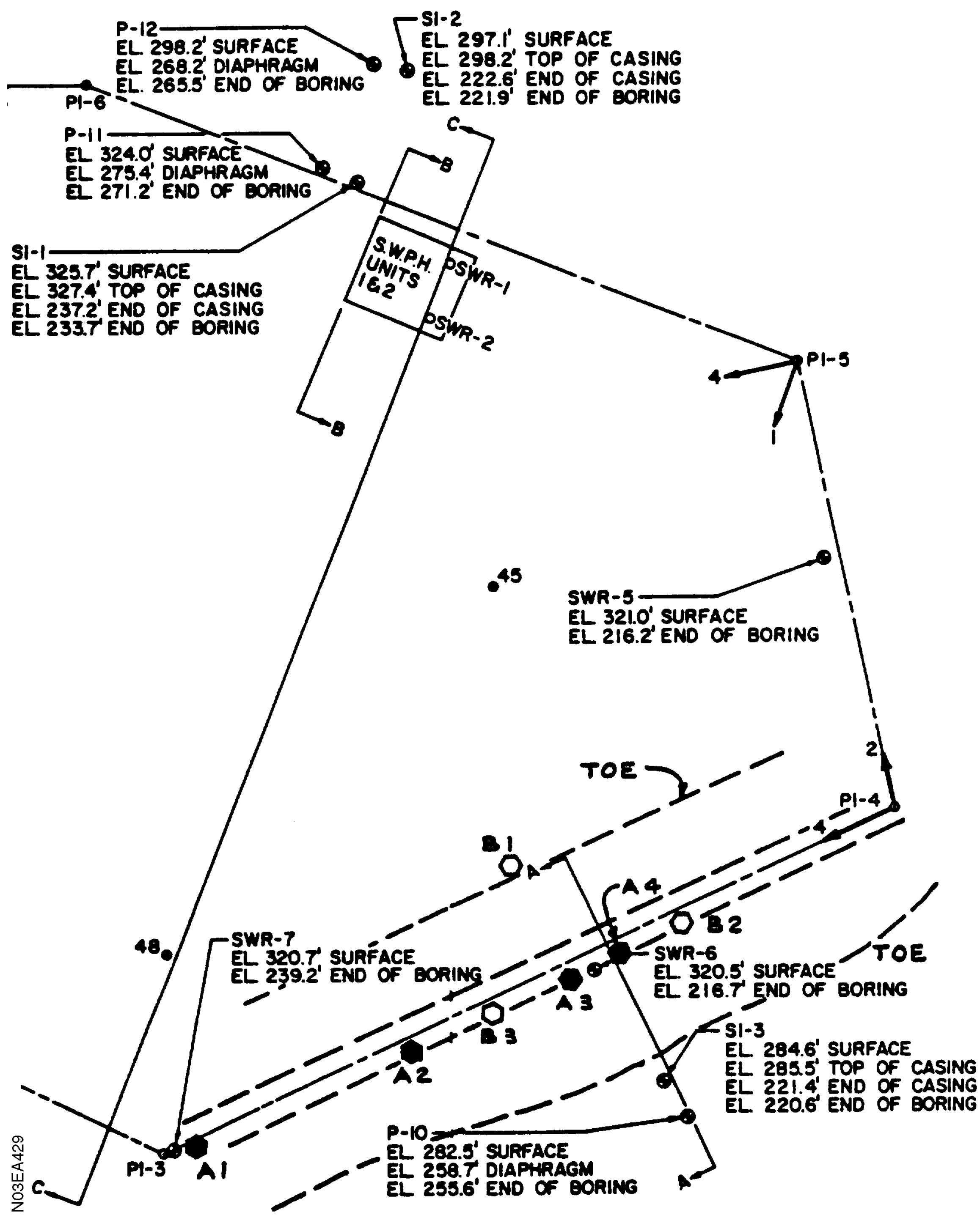


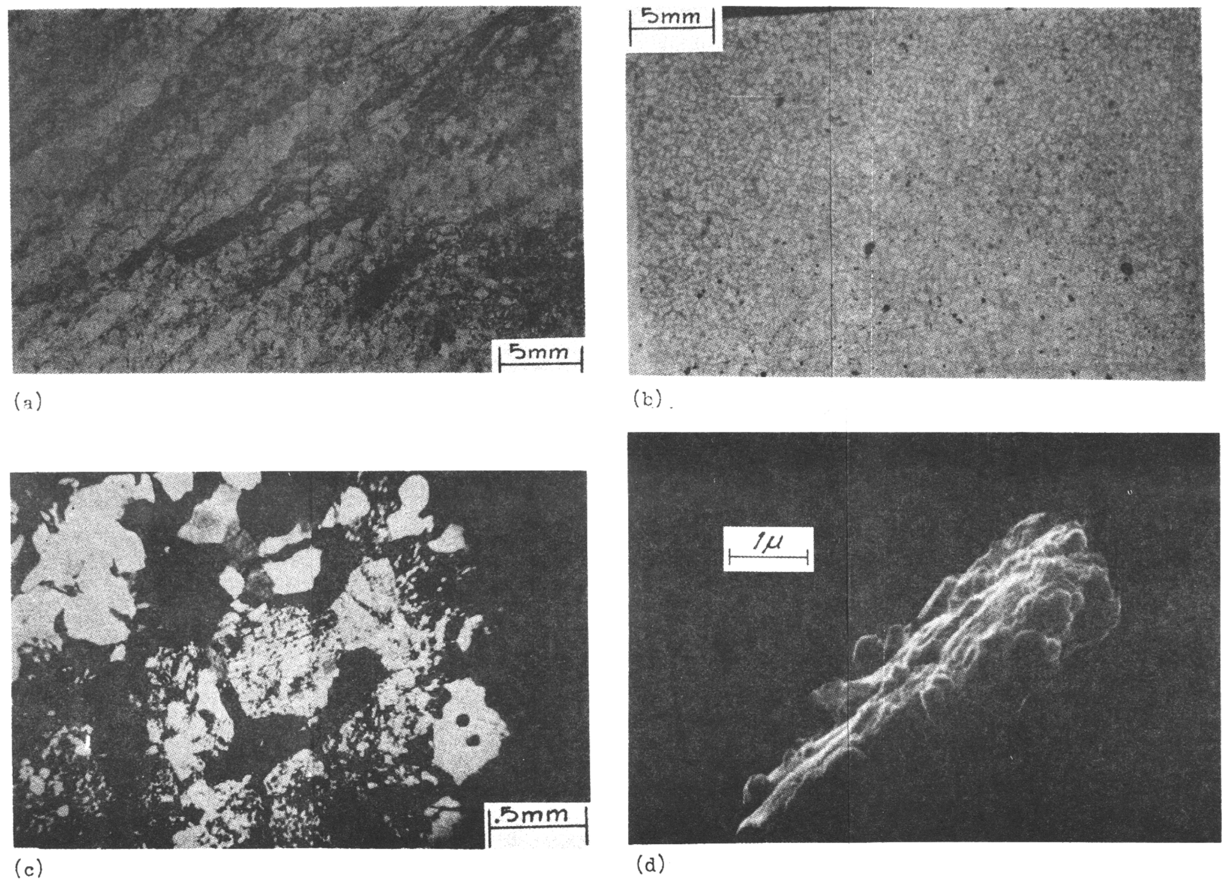
Figure 13
MICROPHOTOGRAPHS OF SOIL SAMPLES

a. Saprolite thin section cut perpendicular to relict foliation (SWR-4-6A2). Light bands composed of quartz, feldspar and clay minerals. Dark bands are biotite. Fabric and texture identical to parent rock. (plane light)

b. Thin section of sand. Grains are separate and void space is readily apparent. Dark grains are opaque minerals, gray is epoxy cement (void space) and white grains are mostly quartz with some fledspar. (plane light)

c. Photomicrograph of saprolite (SWR4-6A2) showing interlocking grains of quartz, microcline, plaqioclase and clay after plaqioclase. The grain with the striped appearance is plaqioclase feldspar. The very fine grained white material is clay. Light and dark grains not mottled with clay specks are quartz and microcline. Note retention of polygonal outline of grains which have been altered to clay. (Polarized light)

d. Photomicrograph of halloysite (SWR-3-4F) under scanning electron microscope. Note small plates and tube arrangement of particles. Void space within the aggregate of clay particles is large. Size corresponds to fine silt range. (plane light)



N03EA430

Figure 14
SERVICE WATER RESERVOIR

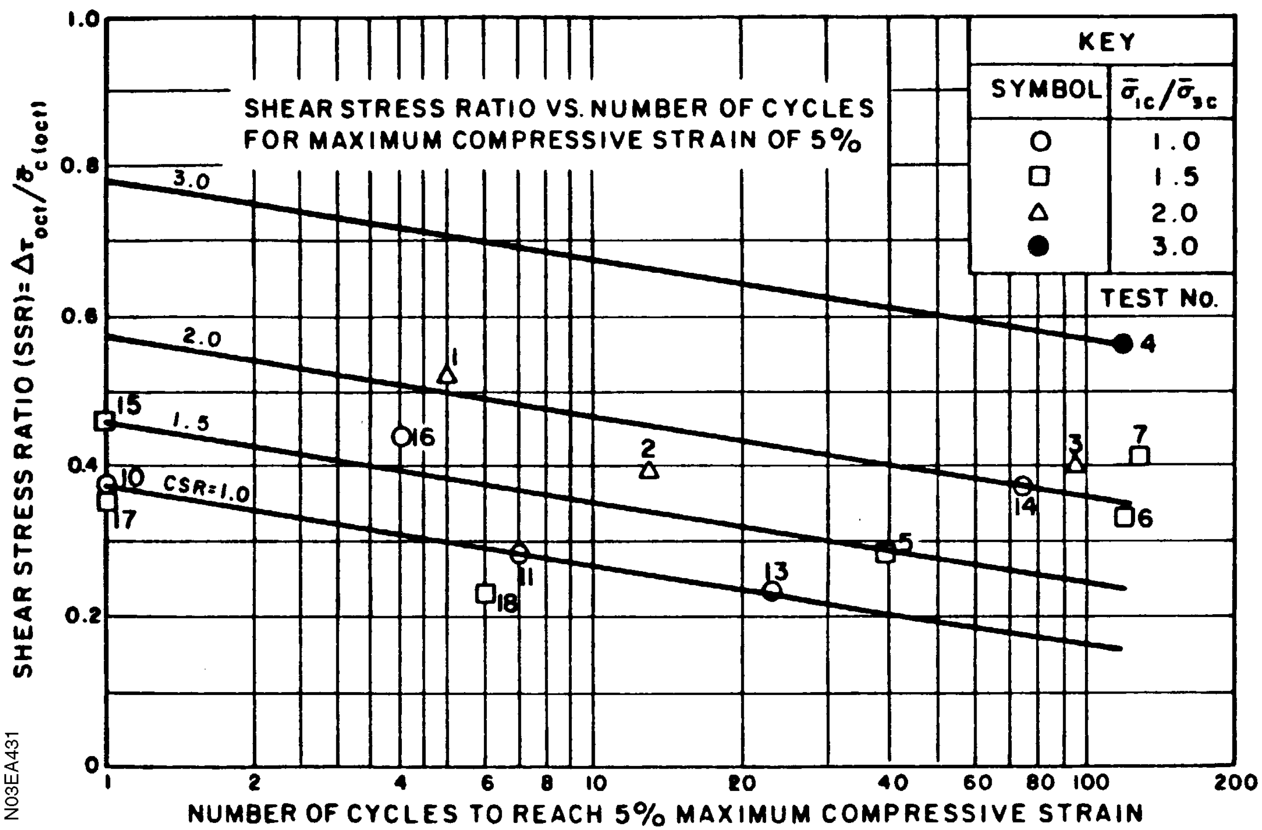


Figure 14 (CONTINUED)
SERVICE WATER RESERVOIR

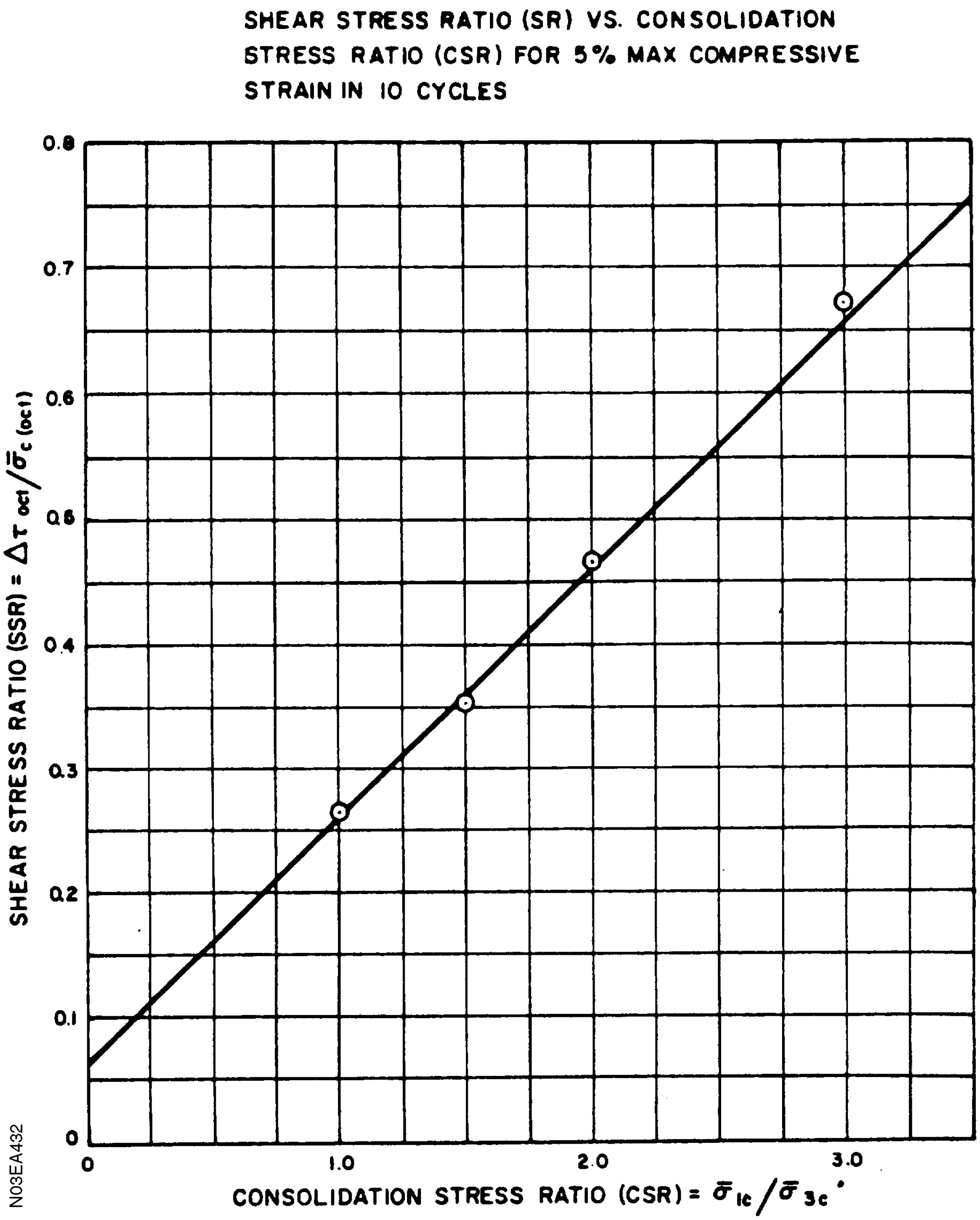


Figure 15
SEISMIC SHEAR STRESSES SERVICE WATER RESERVOIR

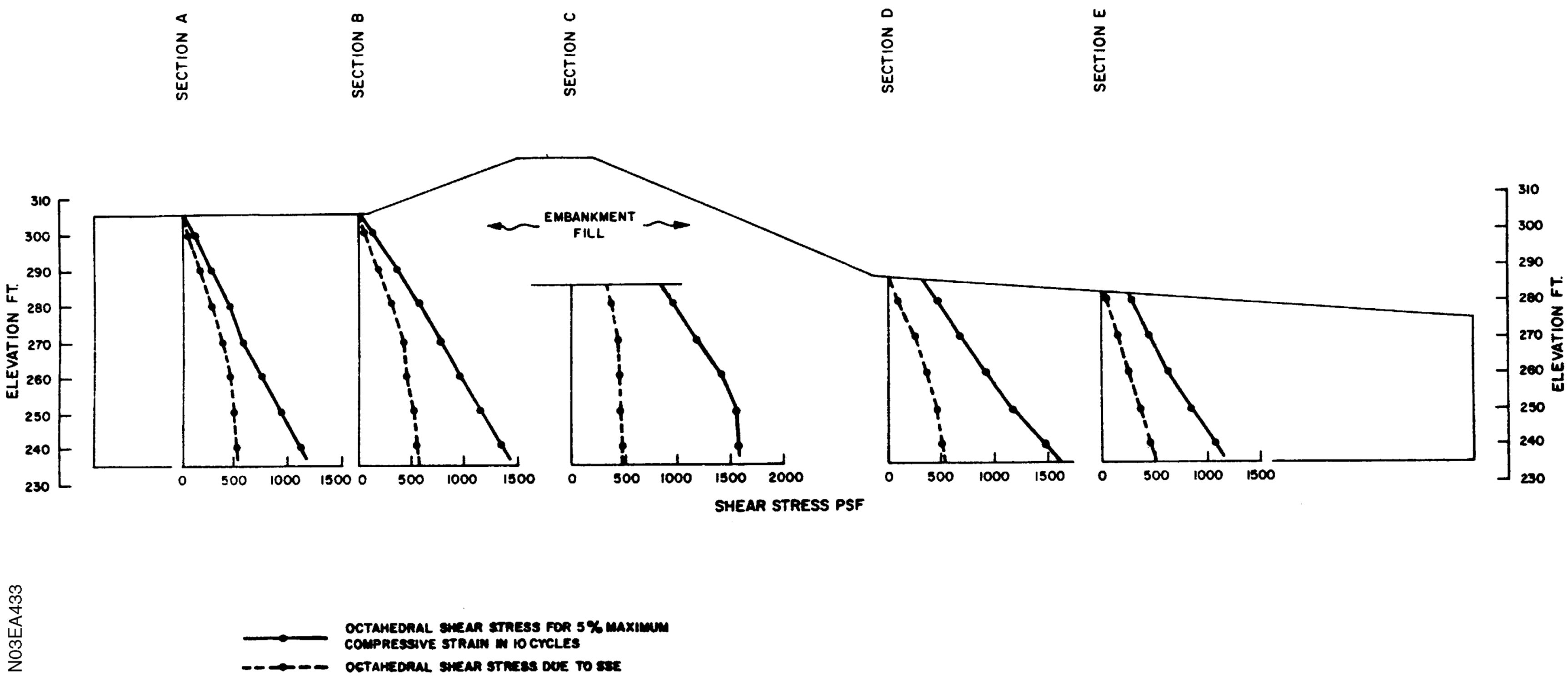
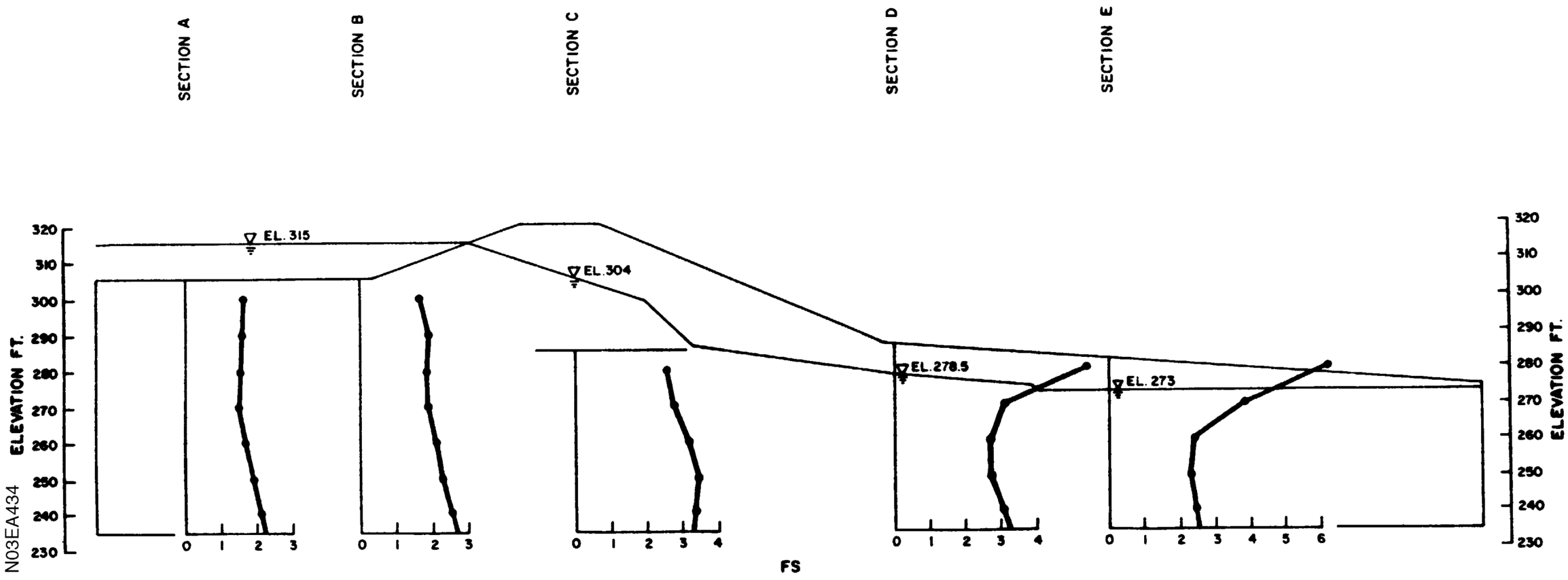


Figure 16
FACTOR OF SAFETY AGAINST LIQUEFACTION SERVICE WATER RESERVOIR



Appendix 3E
Attachment 5
Stability of the Service Water Reservoir Embankment

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Attachment 5 to Appendix 3E

STABILITY OF THE SERVICE WATER RESERVOIR EMBANKMENT

1. **Introduction**

Supplemental field and laboratory studies were undertaken to answer several questions with regard to stability of the service water reservoir embankment. The analyses discussed in response to NRC concerns are as follows:

1. Review of embankment and foundation properties affecting stability.
2. Determination of in situ strength under unconsolidated undrained (UU) test conditions.
3. Reanalysis of undrained stability using strain compatible UU strengths for the embankment and foundation.

2. **General**

Reanalysis of seismic stability of the service water reservoir embankment was made utilizing strain compatible, undrained strengths obtained from laboratory UU tests on undisturbed embankment and foundation samples. Analyses were made for the section of maximum height and most critical foundation geometry. This section is located in the southeast embankment area 50 feet east of Section 1-1 (Figure 1).

A parametric study of the effects of seismic input, material weight and strength, and the existence of foliation on stability of the embankment at this section has been made to illustrate the relative significance of changes in these inputs on the computed factor of safety (FS).

Seismic coefficients were input into the analysis in the horizontal and vertical directions most adverse to embankment stability. Reported factors of safety are for circular failure surfaces analyzed using the simplified Bishop method. For each of several trial centers, numerous circles of various radii were analyzed to determine the critical failure surface and the corresponding minimum factor of safety.

Analyses of stability for failure of the downstream slope have been reported, since this represents the operating condition of most critical potential stability under seismic loading.[1] Shallow failures through granular materials of the rock shell in the downstream slope were not considered, since the minimum factor of safety for this case has been previously established for the existing material density, strength, and slope geometry (see Table 3.8-14).

3. **Embankment/Foundation Geometry**

Embankment and foundation geometry was taken at the section of maximum height and the most unfavorable downstream topography of the reservoir area (Figure 2). The phreatic surface

1. A check of upstream seismic stability under full reservoir conditions was made utilizing the additional strength data confirming the previously reported factors of safety.

was assumed to vary from Elevation 315 ft. at the upstream face to Elevation 273 ft. beyond the downstream toe. This represents a somewhat more conservative phreatic surface than that expected under operating conditions. Embankment details were taken from construction as-built drawings. The base elevation of circular arcs was taken to be Elevation 240 ft., corresponding to the average upper boundary of severely to moderately weathered rock (SPT values of approximately 100 blows/ft). It should be noted that due to the nature of weathering of the parent gneiss, this surface is, in reality, extremely irregular.

4. **Material Anisotropy and Strength**

A detailed discussion and presentation of laboratory results is included in Attachment 4 of Appendix 3E. A brief discussion of the results of this work is included below.

Undrained strengths obtained from undisturbed samples of the compacted embankment core indicate strengths ($S_U$emb) varying with depth from 2.06 to 4.22 ksf at an axial strain of 8% and a degree of saturation of about 100%. For the foundation material, the undrained strength across foliation or through massive saprolite (S_U) is greater than the undrained strength along foliation (S_{fol}). The strength data available for saprolite samples unaffected by foliation indicate strengths varying from 2.00 to 3.24 ksf at an axial strain of 8% and 100% saturation. For samples influenced by foliation, the undrained strength varies from 1.00 to 1.80 ksf at comparable strains and level of saturation. Laboratory unit weights determined for samples obtained in the most recent investigations do not differ significantly from the saturated unit weights used in previous analyses; i.e., a saturated unit weight of 120 pcf for the embankment core and a saturated unit weight of 121 pcf for the foundation saprolite. One boring, SWR-13, had measured saturated unit weights in a zone near the embankment foundation contact of approximately 100 pcf. Material properties used in the stability analysis are summarized in Figure 2.

5. **Analysis**

Due to the orientation of foliation (N55-70E, 45-60NW) (Reference 1), potential downstream failure arcs through the foundation must pass normal or at a high angle to foliation for the majority of the arc length at this section. Excluding, for the present, that portion of the circular arc that might exit subparallel to foliation at the passive toe, the saprolite strength across foliation is applicable to the stability of this section.[1]

A graphical summary of the effect of ground acceleration on stability of the downstream slope under undrained conditions is shown in Figure 3. For the purposes of analysis, the undrained strength of the embankment core (S_{emb}) has been conservatively assumed to equal 2.0 ksf.

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1. For the northwest side of the reservoir the opposite geometric sense of foliation orientation relative to the failure arc applies, but failure along foliation is nonmechanistic. Further, failure of a wedge along postulated relic joint surfaces has been previously analyzed and found to have an acceptable factor of safety.

The minimum factor of safety for the embankment has been calculated for a varying undrained shear strength of the foundation (S_U) under the following seismic inputs: (1) static case, (2) a horizontal acceleration of 0.18g, and (3) for the safe shutdown earthquake maximum ground acceleration of 0.12g vertical and 0.18g horizontal, with orientations in the most adverse directions. Note that for seismic input less than the safe shutdown earthquake, the factor of safety for undrained conditions is significantly increased for any given value of S_U.

A conservative undrained strength for the foundation (S_U) is 2.0 ksf. Using this value, failure arcs for the static case are shown in Figure 4 and for the SSE maximum ground acceleration in Figure 5. The critical failure arc (Figure 5) has a minimum factor of safety of 1.32 and is of relatively large radius and depth. This is due to the fact that the horizontal driving force increases with depth, proportional to the slice height multiplied by a constant horizontal seismic coefficient, while the resisting strengths are constant with depth. Shallower potential failure surfaces have a correspondingly higher factor of safety.

In light of the anisotrophic strength characteristics of the saprolite, i.e., strength across foliation greater than strength along foliation, the stability computations were modified to approximate a weak passive toe where the circular arc might exit subparallel to, or along, foliation. Foliation was conservatively postulated to strike parallel to the axis of the embankment at this section and to dip to the north at 45 degrees. Where the secant of the arc made an angle greater than or equal to 30 degrees to the horizontal, the strength along the arc length was reduced to equal the saprolite's strength parallel to foliation. Figure 6 is a schematic of the arc length used to approximate exit of the circular arc along foliation planes of undrained strength (S_{fol}). Figure 7 shows the results of this analysis. The minimum factor of safety for the embankment has been calculated for the safe shut-down earthquake maximum ground acceleration and for various ratios of the saprolite's undrained strength across foliation (S_U) to its undrained strength along foliation (S_{fol}). For S_U = 2.0 ksf and S_{fol} = 1.0 ksf (S_u/S_{fol} = 2.0), the minimum factor of safety for the critical circle shown in Figure 5 is 1.20. Note that for large decreases in strength along foliation (S_u/S_{fol} = 10), the factor of safety of the embankment decreases only slightly.

In order to check the effect of a foundation of variable low density (measured in a portion of SWR-13), a low-density zone hypothetically located in the most critical portion of the embankment/foundation geometry was analyzed.

The minimum factor of safety has been calculated for the safe shutdown earthquake maximum ground acceleration, for S_U = 2.0 ksf, and for two values of S_U/S_{fol}. When this ratio is 1.0, the factor of safety is 1.32 or 1.29 for densities of 121 and 100 pcf, respectively; when the ratio is taken as 2.0, the corresponding factors of safety are 1.20 and 1.15. The results of this analysis illustrate that stability of the embankment is not significantly altered by the assumed lower unit weight.

6. Conclusions

For the material properties and most critical embankment geometry, presented in Figure 2, with (1) an undrained strength for the embankment of 2.0 ksf, (2) an undrained strength for the foundation saprolite which fails across foliation of 2.0 ksf, and (3) an undrained strength for saprolite failing along foliation of 1.0 ksf, the minimum FS under the SSE maximum ground acceleration is 1.20. The use of avarious hypothetical combinations of saprolite weight or strength across and along foliation does not significantly alter the results of this analysis or this minimum factor of safety.

7. Undrained Shear Strength Measurements

Procedure

Measurements of the undrained shear strength of the embankment and foundation materials were made almost entirely by means of unconsolidated-undrained triaxial compression tests. See Figure 8 for graphical summaries. In these tests, each specimen was confined under the total vertical overburden stress and axially loaded at a rate of strain less than 0.5% per minute and with an elapsed time to maximum axial stress in excess of 10 minutes.

Comparative tests were performed at the start of the work on samples of embankment material to determine whether trimming test specimens to a diameter smaller than that of the extruded section would give different results from those obtained by testing the untrimmed extruded sections. The results of four comparisons (Table 1 and Figure 9, Sheets 1-4) were inconclusive; the proximity of the trimmed specimens to the top of the samples and the variability of the material within some samples may have caused the conflicting comparisons. As a result, all subsequent compression tests (except where specimens were trimmed at an angle to the axis of the sample) were performed on the untrimmed extruded sections.

After a review of the results of all tests, the undrained shear strengths of both embankment and foundation materials were taken as one-half the undrained compressive stresses at an axial strain of 8%.

Embankment

A total of 13 undrained compression tests on the embankment material gave values of undrained shear strength varying from a low of 2.06 kips/ft^2 to a high of 4.22 kips/ft^2, with an average of 3.09 kips/ft^2. These values contain no consideration of the possibility of sample disturbance.

There may be a tendency for the strength to increase with depth in the embankment, but this is not clear. The two samples (sample 6F (Figure 9 Sheet 5) from boring P-16 and sample 4F (Figure 9 Sheet 6) from boring SWR-13) taken immediately above the interface with the foundation gave undrained shear strengths of 2.98 and 2.31 kips/ft^2, respectively, both below the average value.

As shown in Tables 1 through 6, the embankment material is completely saturated, with the possible exception of material within a very few feet of the surface.

Because of the adequacy of these measured shear strengths and the relatively high densities found in the embankment, no further strength testing was considered necessary.

Foundation

A total of 50 undrained compression tests were performed on samples of the foundation material. However, very few of these can be considered to provide valid measurements of the undrained shear strength of the foundation as applicable to the analysis of the dike stability. In the southeastern section of the service water reservoir, where the dike has maximum height, the foliation or banding in the saprolitic foundation material dips steeply from the downstream side toward the upstream side. Any potential surface of sliding through the foundation must cut through the planes of foliation, across both strong and weak layers, over most of its length; only beyond the downstream toe of the dike would the upward curving surface of sliding approach the inclination of the foliation and tend to follow a low-friction layer. It is extremely difficult to measure the mass strength of the foundation material by means of compression tests. Since the steeply inclined foliation (averaging about 50 degrees from the horizontal) is similarly inclined in the samples from vertical borings, sliding along the low-friction foliation planes controls the results of the compression tests. One boring (SWR-12) was oriented with a drip of 65 degrees toward the southeast in an attempt to have the axis of the boring intersect the foliation at a right angle. The attempt was not successful since (1) the foliation was found inclined to the axis of each sample due to an unusually high dip of the foliation at this point or a local variation in the strike of the foliation, and (2) the samples recovered from the angle boring were disturbed by this procedure. Several 1.4-inch-diameter specimens were trimmed from samples taken in boring SWR-12 at an angle to the axis of the sample in an attempt to improve the specimen orientation with respect to the foliation; this work was discontinued once the disturbed character of these samples had been established.

Many compression tests of the foundation material showed very high strengths, some between 3 and 5 kips/ft^2. High shear strengths were measured even when failure occurred by sliding along planes of foliation. A study of the sample properties given in Tables 1 through 6 reveals the reason for these high strengths. Above the ground-water table, the saprolite has a remarkably low degree of saturation, sometimes less than 70% under the completely saturated embankment. None of these strengths of the partially saturated material are valid for a stability analysis if it is conservatively assumed that the subsequent filling of the service water reservoir will result in essentially complete saturation of this material.

To verify the adequacy of the undrained shear strength of the partially saturated material once it becomes saturated, a single consolidated-undrained triaxial compression test was performed by Geotechnical Engineers, Inc., on sample 10B from boring P-15. The specimen was consolidated under the effective vertical overburden stress and completely saturated by backpressure. As shown in Figure 10, the undrained shear strength corresponding to 8% axial strain was 5.91 kips/ft^2. None of the strength tests of samples taken from boring SWR-12 can be considered valid due to the very low deformation moduli of the stress-strain curves shown in Figure 9, Sheets 8-12. These are all disturbed samples.

Of the remaining samples of completely saturated material, few were not affected by the adversely inclined foliation. These include samples 21E, 22F, and 25E (Figure 9, Sheets 13-15) from boring P-15 and samples 12E and 12F (Figure 9, Sheet 7) from boring P-17. The undrained shear strengths of these five samples varied from 2.00 to 3.24 kips/ft^2, with an average of 2.47 kips/ft^2.

To verify that the mass shear strength of the saturated material is in excess of 2.0 kips/ft^2, two constant-volume (that is, consolidated-undrained) direct shear tests were performed. In this test, a 2.5-inch-diameter by 1.0-inch high direct shear specimen is consolidated under a normal stress equal to the effective vertical overburden stress and then sheared without further drainage by varying the applied normal stress to maintain a constant specimen height. Since the axes of the specimens are coincident with the axes of the samples, shearing is horizontal, thus cutting across the steeply inclined foliation. The tests on sample 23D (Figure 11) from boring P-15 and sample 12D (Figure 12) from boring SWR-13 gave undrained shear strengths of 2.86 and 2.17 kips/ft^2, respectively, as shown in Figures 11 and 12. Sections from these two samples had been previously tested in compression and both had failed by sliding on the steeply inclined foliation.

Study of the results of compression tests on completely saturated foundation material where failure was controlled by the foliation shows that the undrained shear strength in these cases (without any correction for the inclination of the foliation) varied in 10 samples from 1.00 to 1.80 kips/ft^2, with an average of 1.40 kips/ft^2. These results indicate that an undrained shear strength of at least 1.0 kips/ft^2 could be used in a stability analysis along that portion of the potential surface of sliding beyond the downstream toe that approaches the inclination of the foliation.

ATTACHMENT 5 TO APPENDIX 3E REFERENCES

1. Stone & Webster Engineering Corporation, *Geotechnical Report on Excavation, Reinforcement, and Final Conditions of Foundation Rock*, 1975.

Table 1
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING P-15

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt %)	Dry Unit Weight γ_d A (pcf)	B (pcf)	C (pcf)	D (pcf)	Void Ratio e A	E	Saturation S A (%)	E (%)	Unconsolidated-Undrained Compression Test: Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-1A	7.4	312.6	CH-SC	60	26.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Bent deeply inward
ST-1B	7.6	312.4	SC-CH	48	25.4	98.8	97.0	96.1	—	0.693	0.740	98.3	92.0	—	—	—	—	—	—	
ST-1F	8.0	312.0	Preserved in tube																	
ST-1G	8.5	311.5	SM-ML	34	24.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-2A	10.0	310.0	SC-CH	47	28.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good
ST-2B	10.2	309.8	Preserved in tube																	
ST-2E	10.4	309.6	CH-SC	55-65	28.4	96.2	94.3	93.8	93.0	0.738	0.798	103.1	95.4	2.54	1.35	4.13	8.9	2.06	Shearing	
ST-2F	10.9	309.1	CH-SC	59	28.0	97.7	95.9	91.7	—	0.712	0.824	105.4	91.1	2.89	1.35	5.65	10.2	2.78	Shearing	
ST-2G	11.3	308.7	CH-SH	54	22.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-3A	13.0	307.0	CH-SH	61	26.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Many small dents
ST-3D	13.2	306.8	Preserved in tube																	
ST-3E	13.7	306.3	CH-SC	65-75	22.9	104.5	102.4	—	100.4	0.600	0.666	102.3	92.2	2.57	1.73	8.51	11.0	4.06	Shearing	
ST-3F	14.2	305.8	CH-SC	55-65	22.8	104.4	102.4	101.3	—	0.602	0.651	101.5	93.9	2.88	1.73	4.89	7.8	2.44	Shearing	
ST-3G	14.8	305.2	CH-SC	61	35.7	—	—	—	—	—	—	—	—	—	—	—	—	—		
ST-4A	15.5	304.5	CH SC	64	30.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good
ST-4D	15.7	304.3	Preserved in tube																	
ST-4E	15.8	304.2	CH-SC	57	22.5	104.7	102.8	101.2	100.8	0.597	0.659	101.0	91.5	2.54	1.98	8.34	6.1	4.22	Shearing and bulging	
ST-4F	16.3	303.7	SC-CH	48	22.9	103.7	101.7	94.5	—	0.613	0.770	100.1	79.7	2.88	1.98	6.89	10.4	3.26	Shearing	
ST-4G	16.9	303.1	CH-SC	52	19.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-5A	18.0	302.0	CH-SC	58	22.5	—	—	—	—	—	—	—-	—	—	—	—	—	—	—	One deep inward dent
ST-5B	18.2	301.8	CH-SC	52	19.9	109.8	107.8	104.8	—	0.523	—	102.0	—	—	—	—	—	—	—	
ST-5F	18.7	301.3	Preserved in tube																	
ST-5G	19.2	300.8	SM	26	12.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Table 1 (continued)
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING P-15

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt %)	Dry Unit Weight γ_d				Void Ratio e		Saturation S		Unconsolidated-Undrained Compression Test						Condition of Tube Cutting Edge
						A (pcf)	B (pcf)	C (pcf)	D (pcf)	A	E	A (%)	E (%)	Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	
ST-6A	21.0	299.0	SC-CH	45	27.5															Bent deeply inward
ST-6B	21.2	298.8	SC-CH	44	30.1															
ST-6F	21.7	298.3	Discarded																	
ST-6G	22.4	297.6	CH-SC	51	35.9															
ST-7A	23.5	296.5	SC-CH	47	28.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Two large dents
ST-7E	23.8	296.2	CH-SC	53	24.1	100.2	98.3	95.8	95.3	0.669	0.755	96.5	85.5	2.49	2.90	5.80	9.2	2.87	Shearing	
ST-7F	24.3	295.7	CH-SC	50	22.7	104.6	102.6	102.8	—	0.599	0.627	101.6	97.0	2.85	2.90	7.25	15	3.43	Shearing	
ST-7G	24.8	295.2	CH-SC	52	27.8	—	—	—	—	—	—	—	—	—	—	—	—	—		
ST-8A	26.0	294.0	ML	85-90	31.3															—
Interface between embankment and foundation at about elevation 292.5																				
ST-9A	28. 5	291.5	SC-CL	48	19.7	—	—	—	—	—	—	—	—	—	—	—	—	—		Good
ST-9E	28.6	291.4	Preserved in tube																	
ST-9F	29.7	290.3	SM	30-40	17.3	98.5	96.6	93.1	—	0.698	0.796	66.4	58.2	2.87	3.54	6.94	11.5	3.28	With foliation at 50°	
ST-9G	30.3	289.7	SM	33	16.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-10A	31.0	289.0	SM	10-15	23.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Not viewed
ST-10B	31.1	288.9	SM	30	22.8	93.8	92.0	91.1	—	0.783	0.836	78.0	73.1	—	—	—	—	—	—	
ST-10D	31.5	288.5	Provided to Geotechnical Engineers, Inc., for cyclic triaxial testing																	
ST-11A	33.5	286.5	SM	30	20.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good
ST-11E	33.7	286.3	Preserved in tube																	
S-11F	34.6	285.4	SM	20-25	14.9	102.6	100.7	96.4	—	0.630	0.735	63.4	54.3	2.88	4.15	7.74	12.9	3.68	Shear across foliation	
ST-11G	35.2	284.8	SM	23	13.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Table 1 (continued)
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING P-15

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt %)	Dry Unit Weight γ_d				Void Ratio e		Saturation S		Unconsolidated-Undrained Compression Test						Condition of Tube Cutting Edge
						A (pcf)	B (pcf)	C (pcf)	D (pcf)	A	E	A (%)	E (%)	Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	
ST-12A	36.0	284.0	SM	10-15	17.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	One very small dent
ST-12B	36.1	283.9	SM	10-15	17.0	100.1	98.2	97.2	—	0.671	0.720	67.9	63.3	—	—	—	—	—	—	
ST-12E	36.4	283.6	Preserved in tube																	
ST-12F	36.9	283.1	SM	20-25	16.1	107.2	105.1	97.6	—	0.560	0.713	77.0	60.5	2.89	4.45	8.00	>15	3.86	With foliation at 45°	
ST-12G	37.4	282.6	SM	21	15.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-13A	38.5	281.5	SM	26	18.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair
ST-13E	38.7	281.3	Preserved in tube																	
ST-13F	39.6	280.4	SM	15-25	13.3	106.0	104.0	95.5	—	0.578	0.751	61.7	47.5	2.89	4.78	9.51	10.4	4.52	Shear across foliation	
ST-13G	40.2	279.8	SM	22	13.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-14A	41.0	279.0	SM	10-20	16.7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-14B	41.1	278.9	SM	10-20	15.9	101.7	99.8	97.4	—	0.644	0.717	66.2	59.4	—	—	—	—	—	—	
ST-14E	41.4	278.6	Preserved in tube																	
ST-14F	42.0	278.0	SM	20-25	15.4	108.2	106.1	99.4	—	0.546	0.682	75.6	60.5	2.89	5.08	8.77	9.4	4.35	Slip along clay seam	
ST-14G	42.5	277.5	SM	23	13.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-15A	43.5	276.5	SP	4	13.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good
ST-15E	43.6	276.4	Preserved in tube																	
ST-15F	44.5	275.5	SM	20-25	17.1	110.7	108.5	99.3	—	0.511	0.684	89.7	67.0	2.88	5.39	8.85	>15	3.84	With foliation at 45°	
ST-15G	45.0	275.0	SM	23	15.7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-16A	46.0	274.0	SM	10-20	17.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair, but out-of-round
ST-16B	46.2	273.8	SM	10-20	19.7	100.9	99.0	97.3	—	0.657	0.719	80.4	73.4	—	—	—	—	—	—	
ST-16E	46.5	273.5	Preserved in tube																	

Table 1 (continued)
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING P-15

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt %)	Dry Unit Weight γ_d A (pcf)	B (pcf)	C (pcf)	D (pcf)	Void Ratio e A	E	Saturation S A (%)	E (%)	Unconsolidated-Undrained Compression Test Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-16F	47.0	273.0	SM	19	13.9	117.0	114.8	108.3	—	0.429	0.544	86.8	68.5	2.89	5.70	10.17	7.6	5.06	With foliation at 55°	
ST-16G	47.6	272.4	SM	10-20	15.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-17A	48.5	271.5	SM	10-20	18.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-17D	48.7	271.3	Preserved in tube																	
ST-17E	49.1	270.9	SM	15-20	16.5	112.2	110.0	103.5	—	0.490	0.616	90.2	71.8	2.88	5.96	9.34	>15	3.60	With foliation at 40°	
ST-17F	49.7	270.3	SM	15-20	15.3	116.0	113.7	106.6	—	0.442	0.569	92.8	72.1	2.89	6.04	4.99	3.4	2.56	Slip along clay joint	
ST-17G	50.2	269.8	SM	18	16.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-18A	51.0	269.0	SM	10-20	16.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-18B	51.2	268.8	SM	10-20	17.0	109.6	107.5	103.4	—	0.526	0.617	86.6	73.8	—	—	—	—	—	—	
ST-18E	51.5	268.5	Preserved in tube																	
ST-18F	52.2	267.8	SM	30-35	21.1	107.3	105.3	99.2	—	0.599	0.686	101.2	82.4	2.88	6.35	3.40	8.2	1.69	With foliation 50°	
ST-18G	52.7	267.3	SM	39	37.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-19A	53.5	266.5	SM	35-45	41.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	One deep
ST-19D	53.7	266.3	SM	15-20	17.8	108.9	106.9	105.2	—	0.536	0.590	89.0	80.9	2.88	6.56	6.95	>15	2.72	With foliation at 45°	
ST-19E	54.1	265.9	SM	18	17.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-19F	54.2	265.8	SM	15-20	18.8	110.4	108.3	103.9	—	0.515	0.610	97.8	82.6	2.89	6.61	2.24	13.6	1.10	In clean sand layer	Inward dent
ST-19G	54.7	265.3	SM	30	17.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-20A	56.0	264.0	SM	25-35	23.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair
ST-20B	56.2	263.8	SM	25-35	28.0	98.4	96.5	94.9	—	0.699	0.762	67.4	98.5	—	—	—	—	—	—	

Table 1 (continued)
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING P-15

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt %)	Dry Unit Weight γ_d				Void Ratio e		Saturation S		Unconsolidated-Undrained Compression Test						Condition of Tube Cutting Edge
						A (pcf)	B (pcf)	C (pcf)	D (pcf)	A	E	A (%)	E (%)	Specimen Diameter (in.)	σ_c (ksf)	q_u (max) (ksf)	ε_f (%)	s_u At 8% (ksf)	Mode of Failure Specimen	
ST-20E	56.5	263.5	Preserved in tube																	
ST-20F	57.2	262.8	SM	26	20.0	109.8	107.8	101.3	—	0.523	0.651	102.5	82.3	2.87	6.96	4.08	3.8	1.35	With foliation at 50°	
ST-20G	57.7	262.3	SM	31	25.0		—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-21A	58.5	261.5	SM	21	21.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-21D	58.7	261.3	Preserved in tube																	
ST-21E	59.3	260.7	SM	15-20	20.1	109.6	107.6	102.0	—	0.526	0.640	102.4	84.2	2.89	7.24	4.25	9.3	2.00	With foliation at 40°	
ST-21F	59.8	260.2	SM	15-20	21.1	108.9	106.9	102.7	—	0.536	0.628	105.5	90.0	2.89	7.31	5.64	8.2	11.80	With foliation at 55°	
ST-21G	60.3	259.7	SM	17	22.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-22A	61.0	259.0	SM	20-30	20.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good
ST-22B	61.2	258.8	SM	20-30	22.0	107.1	105.1	101.6	—	0.561	0.646	105.1	91.3	—	—	—	—	—	—	
ST-22D	61.5	258.5	Preserved in tube																	Good
ST-22E	61.7	258.3	SP-SM	5-10	19.4	113.3	111.1	104.7	—	0.476	0.597	109.2	87.1	2.90	7.54	3.55	8.1	1.76	Shearing	
ST-22F	62.2	257.8	SM	17	18.2	119.2	116.9	115.7	—	0.403	0.445	121.0	109.6	2.87	7.59	6.54	5.0	2.90	Shear across foliation	
ST-22G	62.7	257.3	SM	31	29.7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-23A	63.5	256.5	SP-SM	8-12	23.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good, one small dent
ST-23B	63.7	256.3	Preserved in tube																	
ST-23D	64.3	255.7	SP-SM	8-12	27.1	—	—	—	91.3	—	0.832	—	87.3	Constant-volume direct shear test						
ST-23E	64.5	255.5	Preserved in tube																	
ST-23F	64.7	255.3	SM	18	18.9	119.2	116.9	114.8	—	0.403	0.457	125.7	110.8	2.87	7.92	2.77	3.2	1.40	With foliation at 60°	
ST-23G	65.8	254.2	SP-SM	8-12	21.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Table 1 (continued)
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING P-15

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt %)	Dry Unit Weight γ_d A (pcf)	B (pcf)	C (pcf)	D (pcf)	Void Ratio e A	E	Saturation S A (%)	E (%)	Unconsolidated-Undrained Compression Test: Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-24A	66.0	254.0	SM	15-25	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Not viewed
ST-24B	66.2	253.8	SM	24	37.9	92.5	90.7	89.9	—	0.808	0.860	125.7	118.1	—	—	—	—	—	—	
ST-24D	66.5	253.5	Provided to Geotechnical Engineers, Inc., for cyclic triaxial testing																	
ST-25A	69.5	250.5	SM	10-15	23.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair
ST-25D	69.7	250.3	Preserved in tube																	
ST-25E	70.2	249.8	SM	10-15	27.0	98.3	96.5	91.4	—	0.701	0.830	103.2	87.2	2.88	8.60	4.37	7.6	2.18	Shearing and bulging	
ST-25F	70.8	249.2	SM	31	25.6	104.2	102.2	95.1	—	0.605	0.758	113.4	90.5	2.87	8.67	2.48	>15	0.82	Along thin clay layer	
ST-25G	71.4	248.6	SM	25-30	14.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Table 2
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING P-16

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt %)	Dry Unit Weight γ_d				Void Ratio e		Saturation S		Unconsolidated-Undrained Compression Test						Condition of Tube Cutting Edge
						A (pcf)	B (pcf)	C (pcf)	D (pcf)	A	E	A (%)	E (%)	Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	
ST-1A	7.5	312.5	Empty																	Good
ST-1B	7.5	312.5	CH-SC	65-75	24.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-1C	7.7	312.3	CH-SC	65-75	25.5	97.3	95.4	—	—	0.719	—	95.0	—	—	—	—	—	—	—	
ST-1F	8.0	312.0	Preserved in tube																	
ST-1G	9.0	311.0	CH-SC	78	37.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-2A	12.5	307.5	CH-SC	56	25.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair
ST-2E	12.6	307.4	Preserved in tube																	
ST-2F	13.5	306.5	CH-SC	55-60	20.6	109.0	107.0	103.3	—	0.534	0.619	103.4	89.2	2.87	1.66	6.59	14.8	3.00	Bulging and shearing	
ST-2G	14.0	306.0	CH-SC	52	19.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-3A	17.5	302.5	ML-SM	55-65	20.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-3B	17.6	302.4	ML-SM	55-65	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-3C	17.7	302.3	ML-SM	55-65	25.7	101.1	99.1	98.9	—	0.654	0.691	105.3	99.7	—	—	—	—	—	—	
ST-3F	18.1	301.9	Preserved in tube																	
ST-3G	19.1	300.9	SM	27	21.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-4A	22.5	297.5	ML-SM	54	29.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good
ST-4E	22.7	297.3	Preserved in tube																	
ST-4F	23.7	296.3	ML-SM	50-55	23.7	99.2	97.3	95.6	—	0.686	0.749	92.6	84.8	2.87	2.82	6.12	9.9	3.00	Shearing	
ST-4G	24.3	295.7	ML-SM	50	25.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-5A	27.5	292.5	ML-SM	65-75	32.7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair
ST-5B	27.7	292.3	ML-SM	65-75	31.5	87.9	86.2	84.6	—	0.903	0.977	93.5	86.4	—	—	—	—	—	—	
ST-5E	28.0	292.0	Preserved in tube																	
ST-5F	28.7	291.3	ML-SM	55-65	23.0	102.6	100.6	98.6	—	0.630	0.696	97.8	88.6	2.87	3.41	7.85	14.4	3.71	Shearing	
ST-5G	29.2	290.8	ML-SM	61	23.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-6A	32.5	287.5	ML-SM	55-60	18.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good
ST-6E	32.7	287.3	Preserved in tube																	

Table 2 (continued)
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING P-16

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt %)	Dry Unit Weight γ_d				Void Ratio e		Saturation S		Unconsolidated-Undrained Compression Test						Condition of Tube Cutting Edge
						A (pcf)	B (pcf)	C (pcf)	D (pcf)	A	E	A (%)	E (%)	Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	
ST-6F	33.7	286.3	ML-SM	70-80	31.0	86.9	85.2	84.8	—	0.924	0.972	89.9	85.5	2.87	4.00	6.19	12.0	2.98	Shearing	
ST-6G	34.4	285.6	SM	10-15	19.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Interface between embankment and foundation at exactly elevation 285.9 (near bottom of test specimen)																				
ST-7A	37.5	282.5	SM	10-20	34.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Not viewed
ST-7B	37.7	282.3	SM	10-20	31.2	88.2	86.4	86.1	—	0.896	0.942	93.3	88.8	—	—	—	—	—	—	
ST-7C	38.0	282.0	Provided to Geotechnical Engineers, Inc., for cyclic triaxial testing																	
ST-8	42.5	277.5	Provided to USAE Waterways Experiment Station for cyclic triaxial testing																	Not viewed
ST-9A	47.5	272.5	SM	10-20	33.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair
ST-9B	47.7	272.3	SM	10-20	30.8	91.2	89.4	89.2	—	0.834	0.875	99.0	94.3	—	—	—	—	—	—	
ST-9D	48.0	272.0	Provided to USAE Waterways Experiment Station																	
ST-9E	48.4	271.6	SM	10-20	31.0	92.9	91.2	88.5	—	0.800	0.890	103.8	93.3	—	—	—	—	—	—	
ST-9F	48.9	271.1	SM	10-20	29.8	93.7	91.9	88.6	—	0.785	0.887	101.7	90.0	—	—	—	—	—	—	
ST-9G	49.3	270.7	SM	20	30.7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-10	52.5	267.5	Provided to USAE Waterways Experiment Station for cyclic triaxial testing																	Not viewed
ST-11A	57.5	262.5	SM	10-15	22.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Bent deeply inward
ST-11B	57.7	262.3	SM	10-15	20.4	106.8	104.7	104.4	—	0.566	0.602	96.6	90.8	—	—	—	—	—	—	
ST-11E	58.0	262.0	SM	10-15	22.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-11F	58.4	261.6	SP-SM	8-12	21.0	107.2	105.1	101.7	—	0.560	0.644	100.5	87.4	2.87	7.09	5.67	13.5	1.91	Bulging	
ST-11G	59.0	261.0	SM	21	23.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-12A	62.5	257.5	SM	17	23.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Large inward dent
ST-12E	62.6	257.4	SM	15-20	23.4	104.0	101.9	98.9	—	0.608	0.691	103.1	90.8	—	—	—	—	—	—	
ST-12F	63.1	256.9	SM	15-20	19.1	109.5	107.4	—	—	0.527	—	97.1	—	—	—	—	—	—	—	
ST-12G	63.9	256.1	SM	15	15.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Table 2 (continued)
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING P-16

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt %)	Dry Unit Weight γ_d A (pcf)	B (pcf)	C (pcf)	D (pcf)	Void Ratio e A	E	Saturation S A (%)	E (%)	Unconsolidated-Undrained Compression Test Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-13A	67.5	252.5	SM	20-30	20.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-13B	67.8	252.2	SM	20-30	20.8	108.9	106.6	106.0	—	0.536	0.578	104.0	96.4	—	—	—	—	—	—	
ST-13E	68.1	251.9	Preserved in tube																	
ST-13F	68.4	251.6	SM	25-30	20.2	109.5	107.3	101.1	—	0.527	0.654	102.7	82.8	2.88	8.34	2.35	6.8	1.17	Shearing	
ST-13G	69.0	251.0	SM	26	22.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Table 3
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING P-17

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt %)	Dry Unit Weight γ_d A (pcf)	Dry Unit Weight γ_d B (pcf)	Dry Unit Weight γ_d C (pcf)	Dry Unit Weight γ_d D (pcf)	Void Ratio e A	Void Ratio e E	Saturation S A (%)	Saturation S E (%)	Unconsolidated-Undrained Compression Test: Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-1A	7.5	312.5	CH-SC	55-60	18.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Not viewed
ST-1B	7.8	312.2	CH-SC	55-60	26.2	97.4	95.6	—	—	0.717	—	97.9	—	—	—	—	—	—	—	
ST-1F	8.1	311.9	Preserved in tube																	
ST-1G	—																			
ST-2A	12.5	307.5	CH-SC	66	33.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Bent deeply inward
ST-2F	12.6	307.4	Preserved in tube																	
ST-2G	13.9	306.1	SC-CH	44	22.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-3A	17.5	302.5	MH	70-80	30.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good
ST-3B	17.8	302.2	MH-SM	55-65	22.2	105.6	103.5	104.2	—	0.584	0.605	101.9	98.3	—	—	—	—	—	—	
ST-3F	18.1	301.9	Preserved in tube																	
ST-3G	19.3	300.7	CH-SC	54	16.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-4A	22.5	297.5	Preserved in tube																	
ST-4F	23.8	296.2	SM-ML	40-50	23.9	100.7	99.8	96.0	—	0.661	0.742	105.8	94.3	—	—	—	—	—	—	Very good
ST-4G	24.2	295.8	SM-ML	45	26.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-5A	27.5	292.5	MH-SM	55-60	24.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Deeply dented
ST-5F	27.6	292.4	Preserved in tube																	
ST-5G	28.1	291.9	ML-SM	55	24.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Interface between embankment and foundation at about elev. 288.0																				
ST-6A	32.5	287.5	SC-CH	40-48	17.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-6E	32.7	287.3	Preserved in tube																	
ST-6F	33.6	286.4	SC-CH	35-40	13.9	114.4	112.2	110.6	—	0.462	0.512	80.6	72.8	2.88	3.99	11.19	9.0	5.50	Shearing	
ST-6G	34.1	285.9	SC-CH	38	15.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Table 3 (continued)
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING P-17

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt %)	Dry Unit Weight γ_d				Void Ratio e		Saturation S		Unconsolidated-Undrained Compression Test						Condition of Tube Cutting Edge
						A (pcf)	B (pcf)	C (pcf)	D (pcf)	A	E	A (%)	E (%)	Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	
ST-7A	37.5	282.5	SM-ML	40-48	29.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-7B	37.8	282.2	SM-ML	40-48	34.0	88.1	86.4	86.6	—	0.898	0.931	101.5	97.9	—	—	—	—	—	—	
ST-7E	38.2	281.8	Preserved in tube																	
ST-7F	38.7	281.3	SM-ML	35-45	31.9	86.1	84.5	83.4	—	0.942	1.005	90.8	85.1	2.87	4.63	3.40	14.6	1.59	Shearing	
ST-7G	39.2	280.8	SM-ML	44	36.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-8	42.5	277.5	Provided to USAE Waterways Experiment Station for cyclic triaxial testing																	
ST-9A	47.5	272.5	SM-ML	30-45	45.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Not viewed
ST-9B	47.8	272.2	SM-ML	30-40	38.4	86.3	84.6	82.9	—	0.938	1.017	109.7	101.2	—	—	—	—	—	—	
ST-9C	48.1	271.9	Provided to Goetechnical Engineers, Inc., for cyclic triaxial testing																	
ST-10	52.5	267.5	Provided to USAE Waterways Experiment Station for cyclic triaxial testing																	
ST-11A	57.5	262.5	SM	12-22	27.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-11B	57.8	262.2	SM	12-22	38.8	95.6	93.7	93.0	—	0.749	0.798	110.2	103.4	—	—	—	—	—	—	
ST-11E	58.1	261.9	SM-ML	40	40.2	83.5	81.8	81.4	—	1.043	1.054	107.4	102.2	2.87	7.07	2.28	10.7	1.09	With foliation at 60°	
ST-11F	58.7	261.3	SM-ML	40-45	46.5	77.5	76.0	74.6	—	1.158	1.242	107.6	100.3	2.87	7.13	2.41	10.5	1.18	Shearing	
ST-11G	59.2	260.8	SM-ML	44	49.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-12A	62.5	257.5	GP	3-8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	One small dent
ST-12B	62.6	257.4	SM	20-30	27.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-12D	62.7	257.3	Preserved in tube																	
ST-12E	62.9	257.1	SM	25-35	21.9	105.0	130.0	97.9	—	0.593	0.708	99.0	82.9	2.88	7.65	8.07	14.5	3.24	Bulging	
ST-12F	63.5	256.5	SM	10-20	31.1	93.6	91.8	87.3	—	0.787	0.916	105.9	91.0	2.90	7.74	4.51	12.1	2.04	Shearing	
ST-12G	64.0	256.0	SM	28	31.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Table 3 (continued)
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING P-17

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt %)	Dry Unit Weight γ_d				Void Ratio e		Saturation S		Unconsolidated-Undrained Compression Test						Condition of Tube Cutting Edge
						A (pcf)	B (pcf)	C (pcf)	D (pcf)	A	E	A (%)	E (%)	Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	
ST-13A	67.5	252.5	SM	15-20	22.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	One deep inward dent
ST-13B	67.8	252.2	SM	15-20	20.6	110.4	108.4	105.7	—	0.515	0.582	107.2	94.9	—	—	—	—	—	—	
ST-13F	68.1	251.9	SM	15-20	23.3	106.0	104.0	101.5	—	0.578	0.648	108.0	96.4	2.88	8.31	3.19	7.2	1.54	With foliation at 55°	
ST-13G	68.6	251.4	EMPTY																	
ST-14A	72.5	247.5	SM	15-25	26.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Badly dented
ST-14F	72.6	247.4	SM	—	—	Sample disturbed: void in center due to separation on horizontal plane														
ST-14G	73.6	246.4	SM	18	26.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Table 4
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING SWR-11

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt %)	Dry Unit Weight γ_d A (pcf)	B (pcf)	C (pcf)	D (pcf)	Void Ratio e A	E	Saturation S A (%)	E (%)	Unconsolidated-Undrained Compression Test Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-1	19.5	276.5	Provided to Geotechnical Engineers, Inc., for cyclic triaxial testing																	Not viewed
ST-2A	25.0	271.0	SM	25-35	42.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-2B	25.2	270.8	SM	25-35	43.7	79.9	78.4	78.6	—	1.093	1.128	107.2	103.8	—	—	—	—	—	—	
ST-2E	25.7	270.3	Preserved in tube																	
ST-2F	26.1	269.9	SM	20-30	32.8	93.6	1.8	90.7	—	0.787	0.844	111.7	104.2	2.89	3.41	1.40	>15	0.51	In clay seam at 65°	
ST-2G	26.8	269.2	SM	20-30	25.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-3A	30.5	265.5	SM	15-20	37.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-3B	30.7	265.3	SM	15-20	33.1	101.0	99.0	96.5	—	0.656	0.733	135.2	121.0							
ST-3G	31.0	265.0	SM	29	24.2															

Table 5
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING SWR-12

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt %)	Dry Unit Weight γ_d A (pcf)	Dry Unit Weight γ_d B (pcf)	Dry Unit Weight γ_d C (pcf)	Dry Unit Weight γ_d D (pcf)	Void Ratio e A	Void Ratio e E	Saturation S A (%)	Saturation S E (%)	Unconsolidated-Undrained Compression Test: Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-1A	7.5	312.5	ML-SM	55-65	24.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good
ST-1B	7.9	312.1	ML-SM	55-65	27.8		94.1	94.2	—	0.744	0.775	100.1	96.1	—	—	—	—	—	—	
ST-1E	8.2	311.8	Preserved in tube			—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-1F	9.0	311.0	SM	29	19.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-1G	9.2	310.8	CH-SC		29.7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-2A	12.5	307.5	ML-SM	60-70	26.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair
ST-2E	12.6	307.4	Preserved in tube																	
ST-2F	13.5	306.5	SM-ML	45-50	20.4			103.8	—	0.533	0.611	102.6	89.5	—	—	—	—	—	—	
ST-2G	14.0	306.0	SM-ML	48	20.3	—	—	—	—											
ST-3A	17.5	302.5	ML	70-80	25.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Not viewed
ST-3B	17.8	302.2	ML	70-80	24.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-3C	18.1	301.9	SM-ML	20-30	23.9	102.0	100.1	100.1	—	0.640	0.671	100.1	95.5	—	—	—	—	—	—	
ST-3F	18.4	301.6	Preserved in tube																	
ST-3G																				
ST-4A	22.5	297.5	SM-ML	49	25.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair
ST-4E	22.7	297.3	Preserved in tube																	
ST-4F	23.8	296.2	SM-ML	40-45	26.0	97.6	95.8	92.1	—	0.713	0.816	97.7	85.4	2.87	2.84	4.90	6.6	2.31	Shearing	
ST-4G	24.3	295.7	CH-SC	62	28.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Interface between embankment and foundation at exactly elevation 295.8 (near bottom of test specimen)																				
ST-5A	27.5	292.5	SM-ML	30-40	21.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Few small dents
ST-5B	27.8	292.2	SM-ML	30-40	31.2	77.3	75.8	74.9	—	1.163	1.233	71.9	67.8	—	—	—	—	—	—	
ST-5E	28.2	291.8	Consumed for visual-manual examination																	
ST-5F	29.0	291.0	SM-ML	30-40	34.3	71.0	68.7	—	—	1.355	—	67.8	—	—	—	—	—	—	—	
ST-5G	29.3	290.7	SM-ML	30-40	35.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Table 5 (continued)
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING SWR-12

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt %)	Dry Unit Weight γ_d A (pcf)	B (pcf)	C (pcf)	D (pcf)	Void Ratio e A	E	Saturation S A (%)	E (%)	Unconsolidated-Undrained Compression Test: Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-6A	32.5	287.5	SM	20-30	19.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-6D	32.7	287.3	SM	31	23.5	89.3	87.5	84.9	—	0.873	0.970	72.1	64.9	2.87	3.92	5.17	6.0	1.92	With foliation at 50°	
ST-6E	33.3	286.7	ML-SM	53	33.3	71.9	70.5	—	—	1.326	—	67.3	—	—	—	—	—	—	—	
ST-6F	33.8	286.2	CH	90-95		73.6	70.8	—	—	1.323	—	78.8	—	—	—	—	—	—	—	
ST-6G	34.3	285.7	ML	70-80	36.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-7A	37.5	282.5	SM	10-15	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Few small dents
ST-7B	37.7	282.3	SM	10-15	29.0	79.4	77.9	—	—	1.106	—	70.3	—	—	—	—	—	—	—	
ST-7E	38.0	282.0	Preserved in tube																	
ST-7F	38.9	281.1	SM	10-15	16.5	85.8	84.2	75.3	—	0.949	1.221	46.6	36.2	—	—	—	—	—	—	
ST-7G	39.3	280.7	SM	10-15	18.0	—	—	—	—	—	—	—	—	—	—	—	—	—		
ST-8A	42.5	266.5	SM	33	23.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Good
ST-8E	42.6	277.4	Preserved in tube																	
ST-8F	43.6	276.4	SM	30-35	23.5	84.1	82.5	80.8	—	0.988	1.070	63.7	58.9	2.88	5.30	6.04	15.0	2.65	Shear across foliation	
ST-8G	44.2	275.8	SM	34	22.7	—	—	—	—	—	—	—	—	—	—	—	—	—		
ST-9A	30.3	258.7	Empty																	Very good
ST-9B	30.6	258.4	SM	10-20	24.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-9C	30.9	258.1	SM	10-20	23.5	108.1	101.1	99.9	—	0.622	0.674	101.3	98.6	—	—	—	—	—	—	
ST-9F	31.2	257.8	SM	10-15	22.0	100.2	104.2	101.0	—	0.575	0.656	102.5	89.9	2.88	4.06	4.29	>15	1.43	Bulging	
ST-9G	31.6	257.4	SM	10-15	21.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-10A	32.4	256.6	SM	24	30.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very
ST-10D	32.5	256.5	Preserved in tube																	
ST-10E	32.7	256.3	SM	20-25	22.4	105.4	103.2	101.5	—	0.587	0.648	104.6	94.7	2.88	4.25	2.20	15.0	0.90	With foliation at 50°	
ST-10F	33.2	255.8	SM	15-20	24.0	104.0	102.0	97.8	96.1	0.608	0.740	105.8	86.9	1.42	4.31	4.40	11.3	1.91	Bulging	

Table 5 (continued)
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING SWR-12

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt %)	Dry Unit Weight γ_d				Void Ratio e		Saturation S		Unconsolidated-Undrained Compression Test						Condition of Tube Cutting Edge
						A (pcf)	B (pcf)	C (pcf)	D (pcf)	A	E	A (%)	E (%)	Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	
ST-10G	33.5	255.5	SM-ML	43	34.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-11A	34.8	254.2	SM	15-25	26.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-11B	35.0	254.0	SM	15-25	26.1	98.5	96.6	96.7	—	0.698	0.729	102.9	98.5	—	—	—	—	—	—	
ST-11E	35.2	253.8																		
ST-11F																				
ST-11G																				
ST-12A	36.5	252.5	Preserved in tube																	Bent deeply inward
ST-12E	36.7	252.3	SM	25-35	31.5	94.2	92.4	91.3	—	0.775	0.832	108.9	101.5	2.87	4.75	1.54	11.3	0.74	With foliation at 45°	
ST-12F	37.2	251.8	SM	29	31.8	94.2	92.3	90.3	86.6	0.775	0.931	110.0	91.5	1.43	4.80	2.18	>15	0.96	Shearing	
ST-12G	37.5	251.5	SM	15-20	29.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Table 6
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING SWR-13

						Dry Unit Weight γ_d				Void Ratio e		Saturation S		Unconsolidated-Undrained Compression Test						
Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt %)	A (pcf)	B (pcf)	C (pcf)	D (pcf)	A	E	A (%)	E (%)	Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-1A	13.9	275.1	SM	10-15	41.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair
ST-1B	14.1	274.9	SM	10-15	27.7	90.2	89.0	90.1	—	0.842	0.856	88.2	86.7	—	—	—	—	—	—	
ST-1E	14.3	274.7	Preserved in tube																	
ST-1F	14.9	274.1	SM	10-15	40.3	82.8	81.3	80.5	—	1.020	1.077	105.9	100.3	—	—	—	—	—	—	
ST-1G	15.3	273.7	SM	10-15	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-2A	16.0	273.0	Preserved in tube																	Very good
ST-2F	16.6	272.4	SM	20-25	48.5	77.2	75.8	—	70.0	1.166	1.389	111.5	93.6	1.43	2.24	1.19	12.7	0.55	Bulging and shearing	
ST-2G	17.0	272.0	SM	19	40.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
ST-3A	18.0	271.0	Empty																	Very good
ST-3B	18.0	271.0	SM	15-25	38.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-3C	18.4	270.6	SM	15-25	45.4	79.2	77.8	76.8	—	1.111	1.177	109.5	103.4	—	—	—	—	—	—	
ST-3F	18.6	270.4	SM	15	41.9	81.5	79.9	78.9	—	1.052	1.120	106.7	100.3	2.88	2.50	1.36	>15	0.55	With foliation at 50°	
ST-3G	19.1	269.9	SM	15	42.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-4A	20.1	268.9	Preserved in tube																	Very good
ST-4F	21.1	267.9	SM	15-20	42.4	81.3	79.6	78.2	74.9	1.057	1.233	107.5	92.2	1.44	2.80	1.39	>15	0.57	Bulging in weak zone	
ST-4G	21.3	267.7	SM	17	42.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-5A	22.1	266.9	Empty																	Good
ST-5B	22.3	266.7	SM	10-20	40.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-5C	22.6	266.4	SM	10-20	43.7	80.0	78.4	79.0	—	1.090	1.117	107.4	104.8	—	—	—	—	—	—	
ST-5F	22.8	266.2	SM	30	49.2	74.9	73.5	71.3	—	1.233	1.345	106.9	98.0	2.89	3.01	1.38	7.3	0.66	With foliation at 50°	
ST-5G	23.3	265.7	SM	25-30	36.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-6A	24.2	264.8	SM	15-20	55.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-6B	24.4	264.6	SM	15-20	57.3	69.4	68.1	68.1	—	1.410	1.456	108.9	105.5	—	—	—	—	—	—	
ST-6E	24.6	264.4	Preserved in tube																	
ST-6F	25.2	263.8	SM	18	39.0.	86.0	84.3	81.3	—	0.945	1.057	110.6	98.9	2.89	3.31	1.32	12.4	0.59	In clean sand layer	

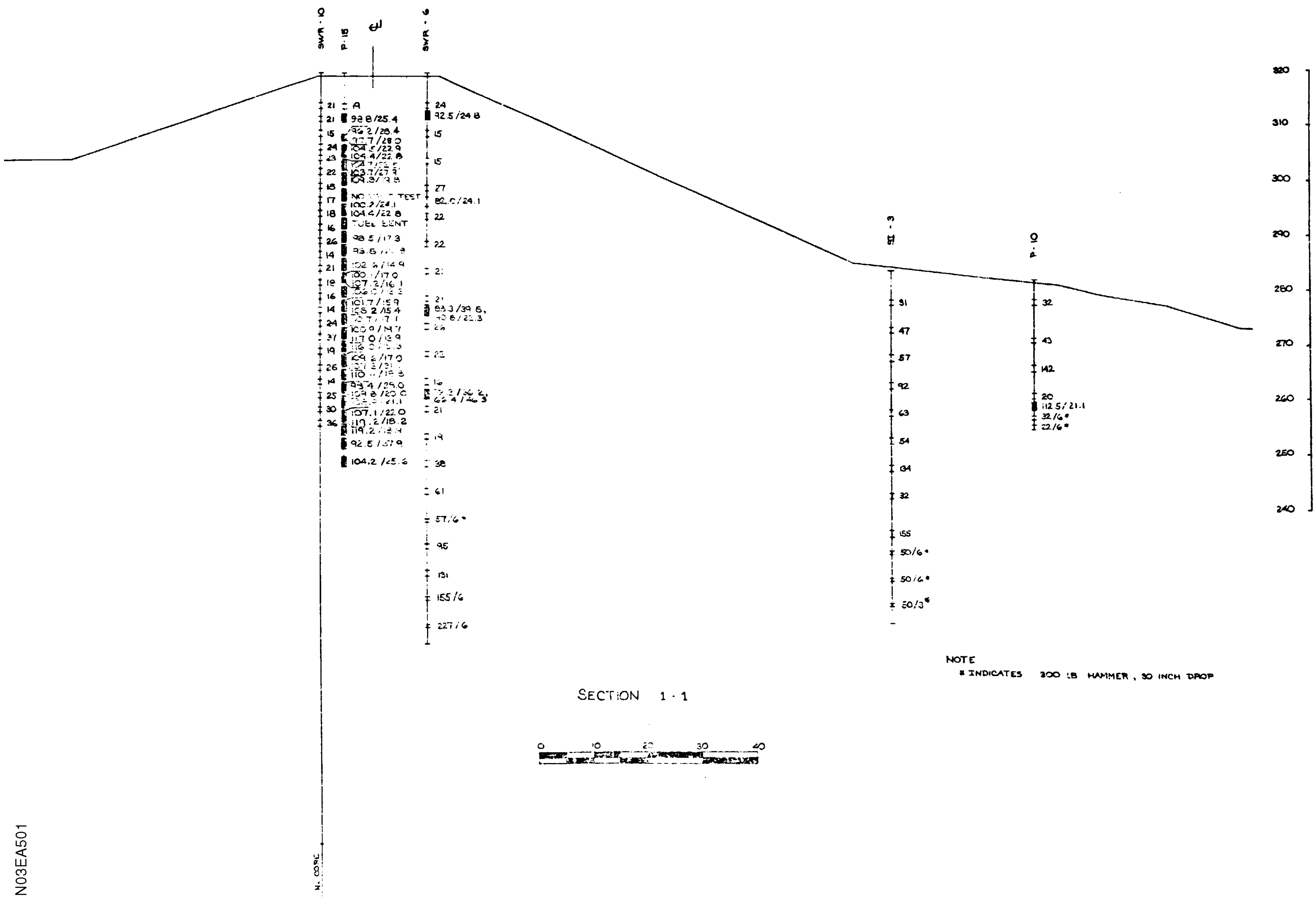
Table 6 (continued)
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING SWR-13

						Dry Unit Weight γ_d				Void Ratio e		Saturation S		Unconsolidated-Undrained Compression Test						
Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt %)	A (pcf)	B (pcf)	C (pcf)	D (pcf)	A	E	A (%)	E (%)	Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-6G	25.6	264.4	SM	15-20	40.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-7A	26.2	262.8	SM	10-15	37.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-7B	26.4	262.6	SM	10-15	47.5	76.3	74.8	—	—	1.192	—	106.8	—	—	—	—	—	—	—	
ST-7E	26.7	262.3	Preserved in tube																	
ST-7F	27.2	261.8	SM	29	40.6	83.7	82.1	79.7	—	0.998	1.098	109.0	99.1	2.89	3.55	1.32	12.7	0.63	With foliation at 40°	
ST-7G	27.6	261.4	SM	25-30	38.7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-8A	28.3	260.7	SM	15-20	30.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Very good
ST-8D	28.4	260.6	Preserved in tube																	
ST-8E	28.8	260.2	SM	15-20	23.9	91.1	89.3	87.6	—	0.836	0.909	105.5	97.0	2.89	3.76	1.32	12.0	0.58	With foliation at 60°	
ST-8F	29.2	259.8	SM	15-20	30.2	94.4	92.8	90.8	—	0.772	0.842	104.8	96.1	—	—	—	—	—	—	
ST-8G	29.5	259.5	SM	20	27.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
ST-9A	47.5	272.5	SM-ML	35-45	36.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Not viewed
ST-9B	47.8	272.2	SM-ML	35-45	35.6	76.9	75.4	74.6	—	1.175	1.242	81.2	76.8	—	—	—	—	—	—	
ST-9C	48.1	271.1	Provided to Geotechnical Engineers, Inc., for cyclic triaxial testing																	
ST-10A	52.5	267.5	Empty																	Good
ST-10D	52.6	267.4	Preserved in tube																	
ST-10E	53.2	266.8	SM-ML	40-45	39.9	77.0	75.5	74.4	—	1.172	1.248	91.2	85.7	2.87	6.48	3.79	10.9	1.88	Slip on weak seam	
ST-10F	53.7	266.3	SM-ML	40-45	39.2	75.7	74.3	73.4	—	1.209	1.278	86.9	82.2	2.87	6.54	5.43	5.7	2.68	Bulging	
ST-10G	54.2	265.8	SM-ML	46	42.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-11A	57.5	262.5	SM	30-40	32.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Few small dents
ST-11B	57.8	262.2	SM	30-40	32.0	90.8	89.1	86.9	—	0.842	0.924	101.9	92.8	—	—	—	—	—	—	
ST-11D	58.1	261.9	Preserved in tube																	
ST-11E	58.4	261.6	SM	10-15	15.4	113.7	111.5	108.7	—	0.471	0.538	70.6	76.7	2.88	7.14	5.84	4.6	2.54	Shear in quartz vein	
ST-11F	59.0	261.0	SM	30-40	28.8	93.2	90.9	88.9	—	0.794	0.881	97.2	87.6	—	—	—	—	—	—	
ST-11G	59.3	260.7	SM	30-40	24.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Table 6 (continued)
SUMMARY OF LABORATORY TESTING OF UNDISTURBED SAMPLES FROM BORING SWR-13

Sample Number	Depth (ft)	Elevation (ft)	USCS Group Symbol	Fines (%)	Water Content (wt %)	Dry Unit Weight γ_d A (pcf)	Dry Unit Weight γ_d B (pcf)	Dry Unit Weight γ_d C (pcf)	Dry Unit Weight γ_d D (pcf)	Void Ratio e A	Void Ratio e E	Saturation S A (%)	Saturation S E (%)	Unconsolidated-Undrained Compression Test: Specimen Diameter (in.)	σ_c (kef)	q_u (max) (kef)	ε_f (%)	s_u At 8% (kef)	Mode of Failure Specimen	Condition of Tube Cutting Edge
ST-12A	62.5	257.5	SM	20-30	23.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Fair
ST-12C	62.6	257.4	Preserved in tube																	
ST-12D	63.3	256.7	SM-ML	45	37.3	—	—	—	79.4	—	1.106	—	90.4	Constant-volume direct shear test						
ST-12E	63.5	256.5	Preserved in tube																	
ST-12F	63.8	256.2	SM	35-40	41.3	80.8	79.3	76.9	—	1.070	1.175	103.4	94.2	2.87	7.81	2.51	12.0	1.19	With foliation at 60°	
ST-12G	64.4	255.6	SM	40	42.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-13A	67.5	252.5	SM-ML	40-45	47.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	One small dent
ST-13B	67.7	252.3	SM-ML	43	37.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-13C	68.0	252.0	SM-ML	40-45	42.0	82.3	80.7	—	—	1.032	—	109.1	—	—	—	—	—	—	—	
ST-13D	68.3	251.7	SM-ML	40-45		—	—	—	—	—	—	—	—	—	—	—	—	—	—	
ST-13E	68.4	251.6	SM-ML	40-45	36.6	86.1	84.4	82.2	—	0.942	1.034	104.1	94.9	2.87	8.39	2.27	13.8	1.00	With foliation at 60°	
ST-13F	69.0	251.0	SM-ML	50	47.4	75.5	74.1	72.2	—	1.215	1.316	104.6	96.5	—	—	—	—	—	—	
ST-13G	69.4	250.6	SM-ML	40-45	36.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Figure 1
SERVICE WATER RESERVOIR BORING SECTION - SE DIKE



N03EA501

Figure 2
MATERIAL PROPERTIES SEISMIC STABILITY ANALYSIS SERVICE WATER RESERVOIR

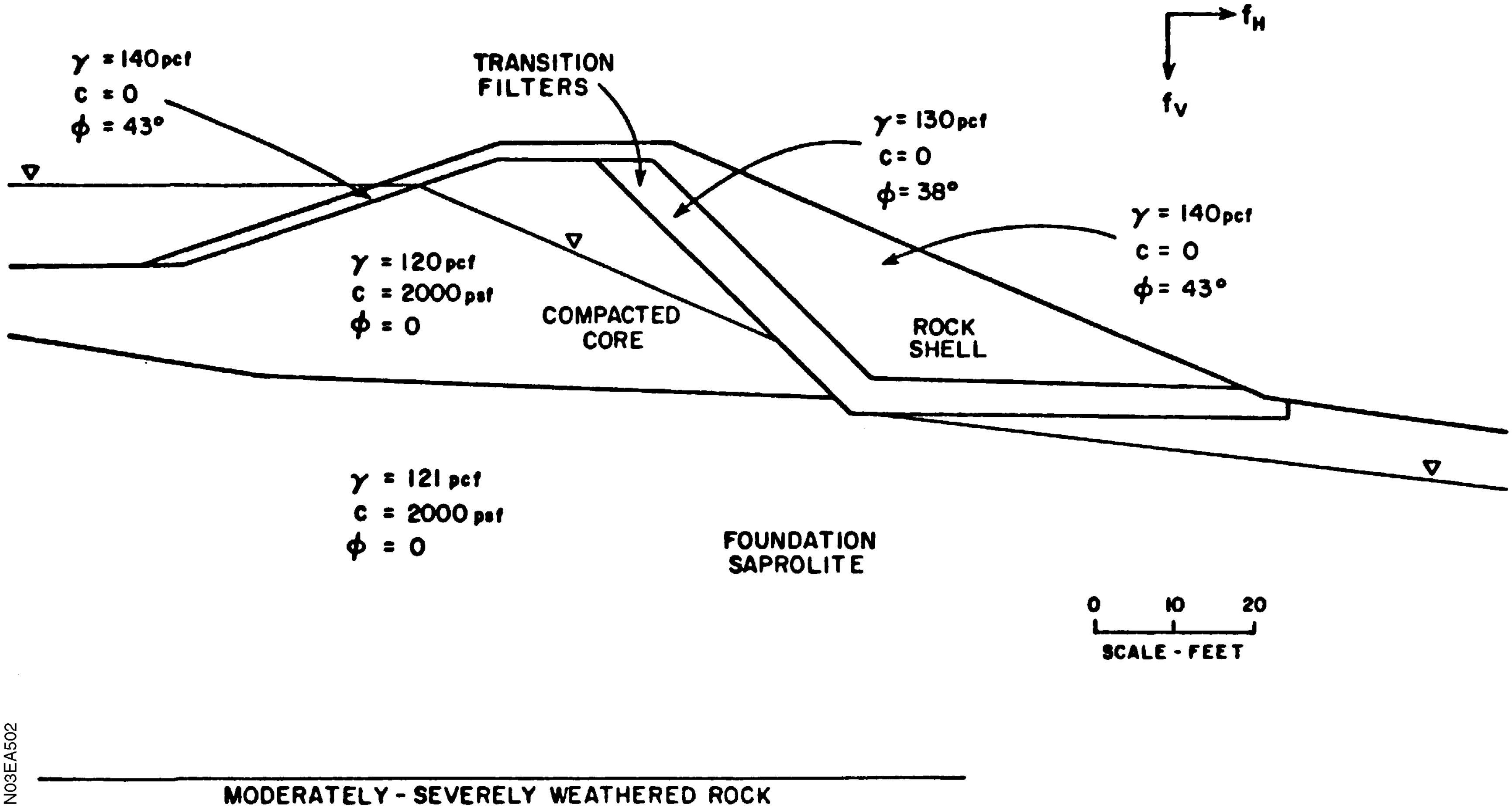
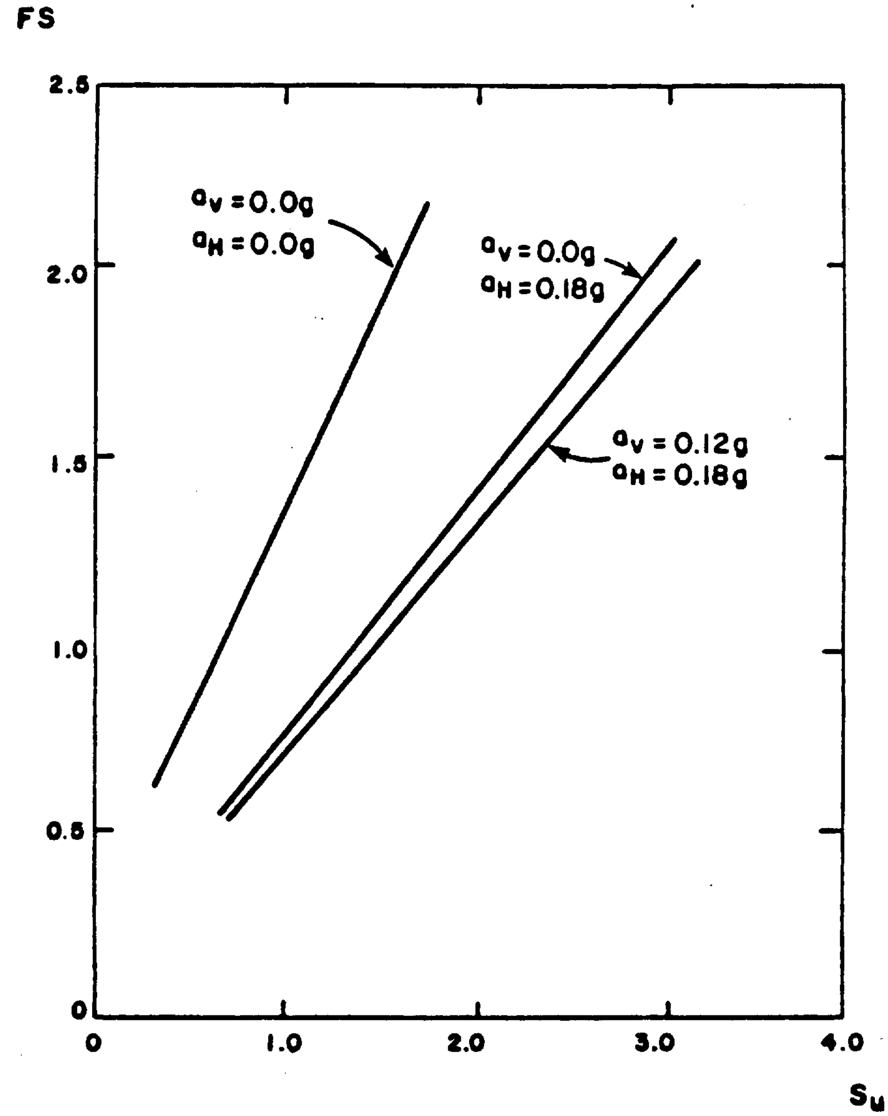


Figure 3
a_g VS. FACTOR OF SAFETY SEISMIC STABILITY ANALYSIS
SERVICE WATER RESERVOIR



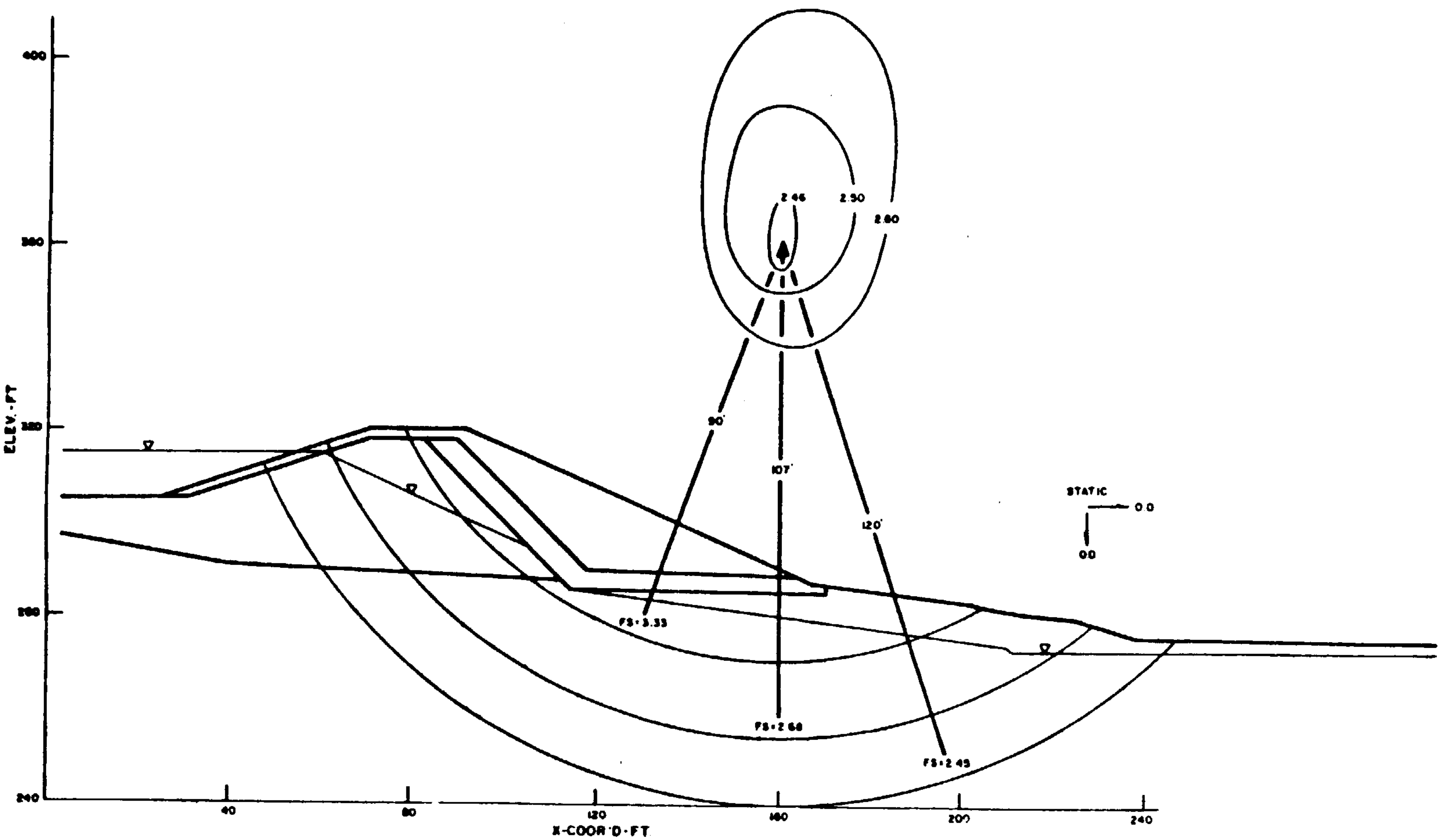
N03EA503

NOTE:

a_V = ACCELERATION IN THE VERTICAL DIRECTION

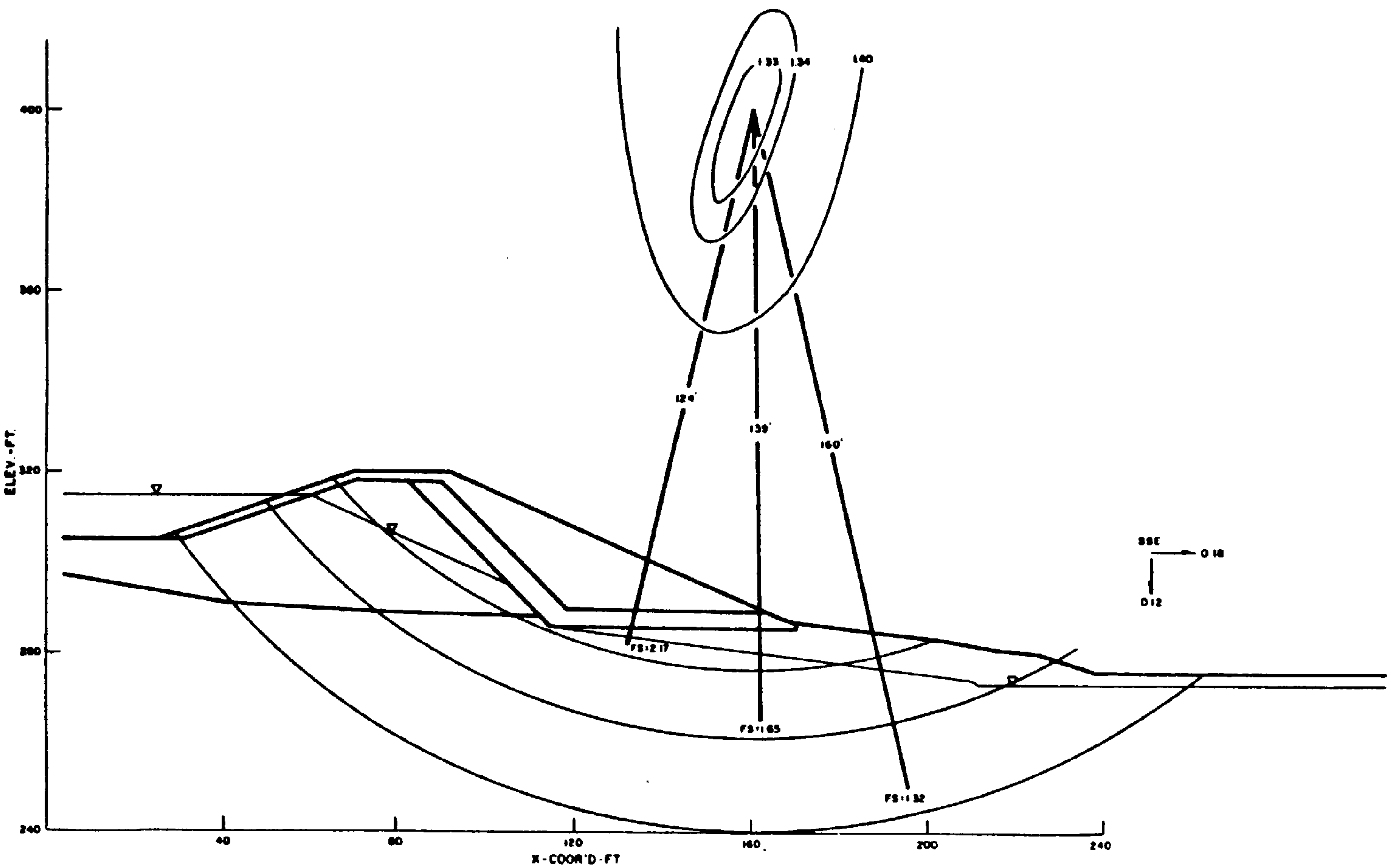
a_H = ACCELERATION IN THE HORIZONTAL DIRECTION

Figure 4
GRAPHICAL SUMMARY STATIC CASE SEISMIC STABILITY ANALYSIS SERVICE WATER RESERVOIR



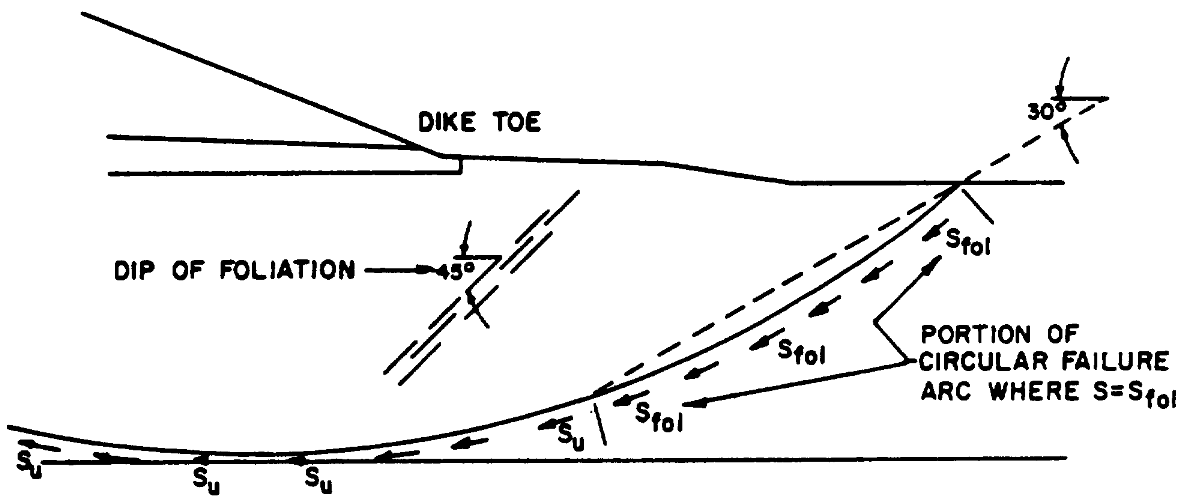
N03EA504

Figure 5
GRAPHICAL SUMMARY SSE SEISMIC CASE SEISMIC STABILITY ANALYSIS SERVICE WATER RESERVOIR



N03EA505

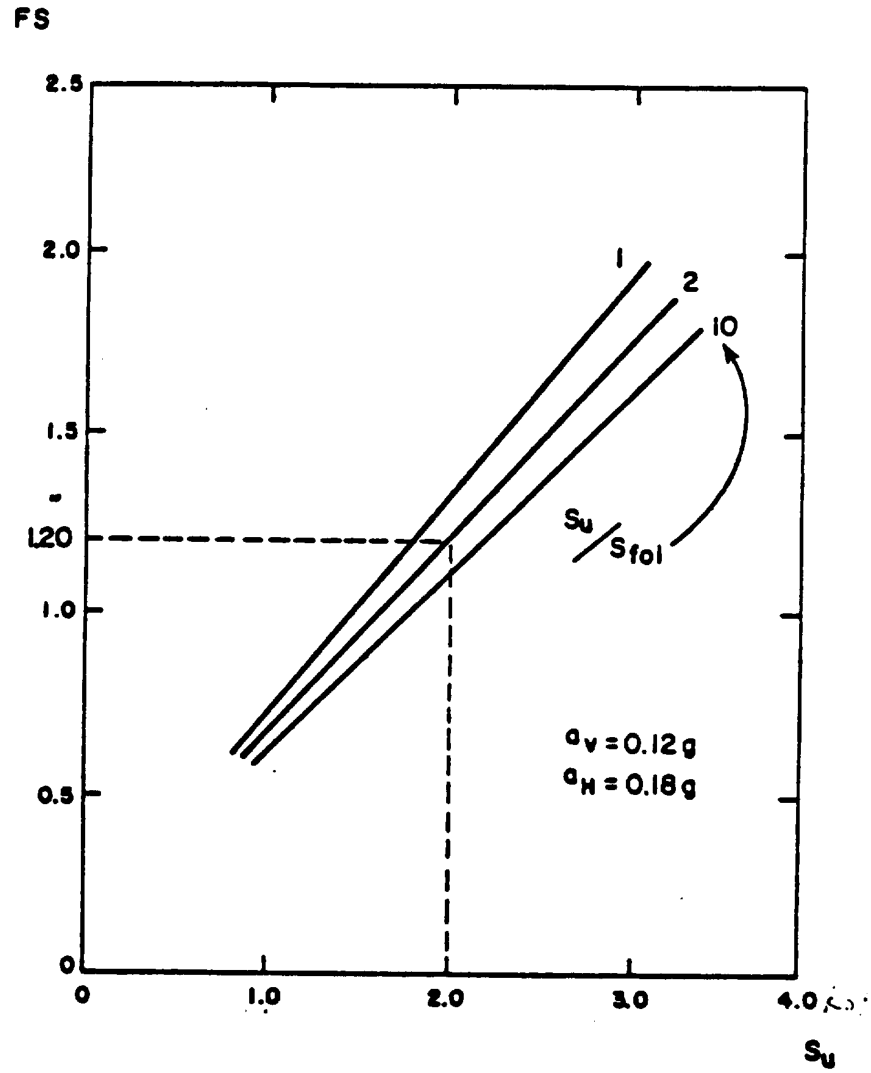
Figure 6
SCHEMATIC OF POSTULATED WEAK PASSIVE TOE SEISMIC STABILITY ANALYSIS SERVICE WATER RESERVOIR



NOTE:
S_u = UNDRAINED SHEAR STRENGTH OF SAPROLITE ACROSS FOLIATION.
S_{fol} = UNDRAINED SHEAR STRENGTH OF SAPROLITE ALONG FOLIATION.

N03EA506

Figure 7
S_U VS. FACTOR OF SAFETY SEISMIC STABILITY ANALYSIS
SERVICE WATER RESERVOIR



N03EA507

NOTE:

S_u = UNDRAINED SHEAR STRENGTH OF SAPROLITE ACROSS FOLIATION

S_{fol} = UNDRAINED SHEAR STRENGTH OF SAPROLITE ALONG FOLIATION

Figure 8 (SHEET 1 OF 2)
UNDRAINED SHEAR STRENGTH VS. ELEVATION SERVICE WATER RESERVOIR

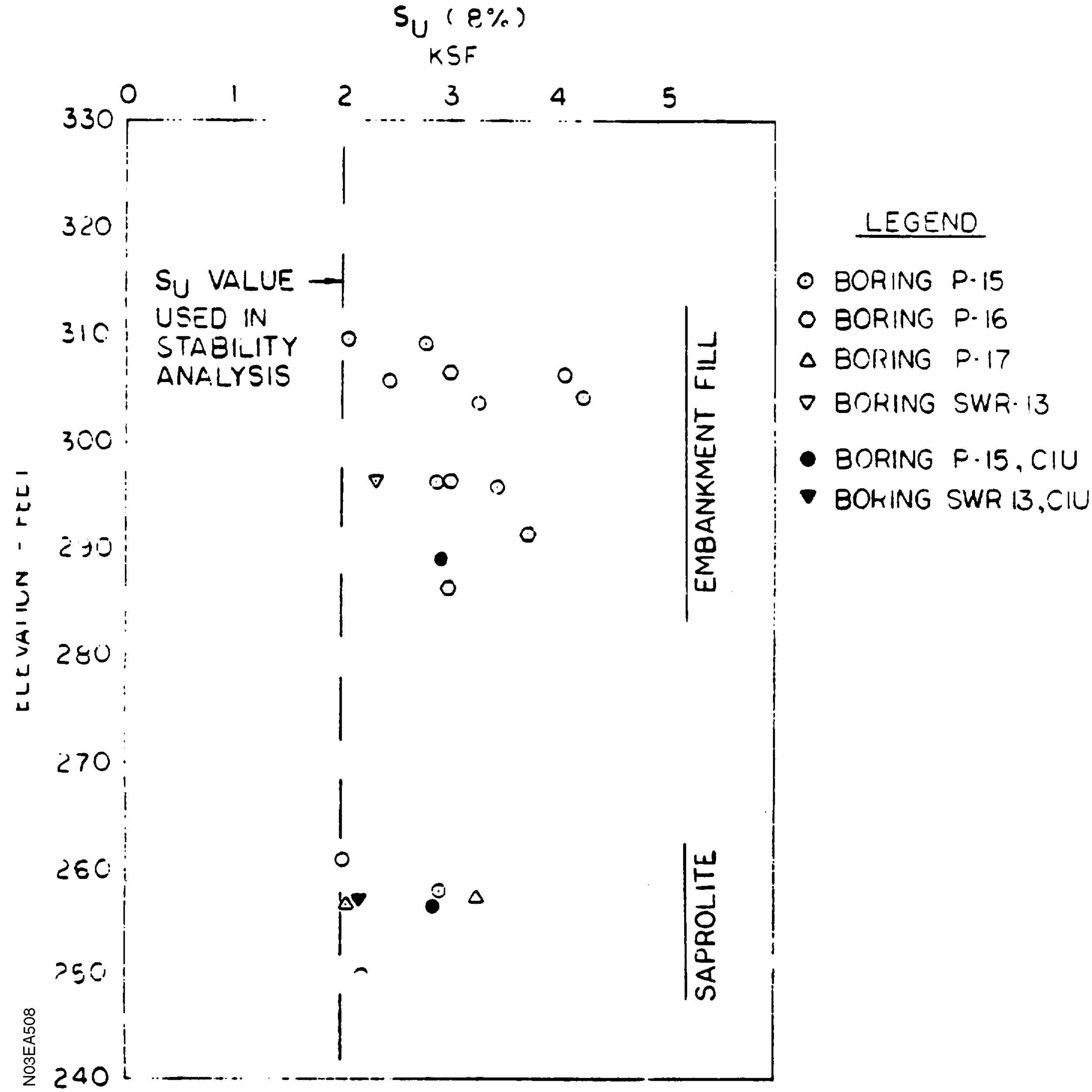


Figure 8 (SHEET 2 OF 2)
UNDRAINED SHEAR STRENGTH VS. ELEVATION
SERVICE WATER RESERVOIR

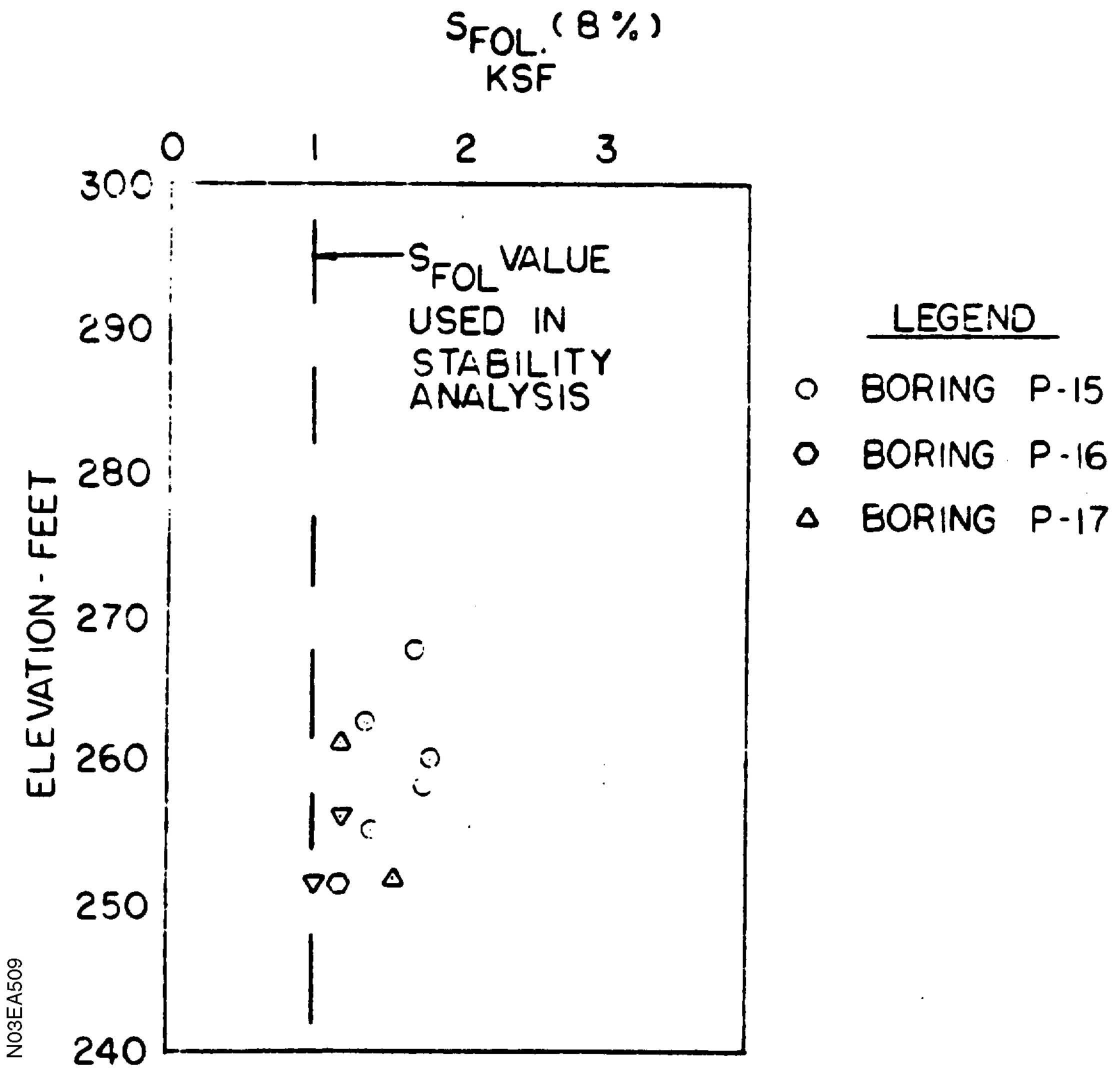
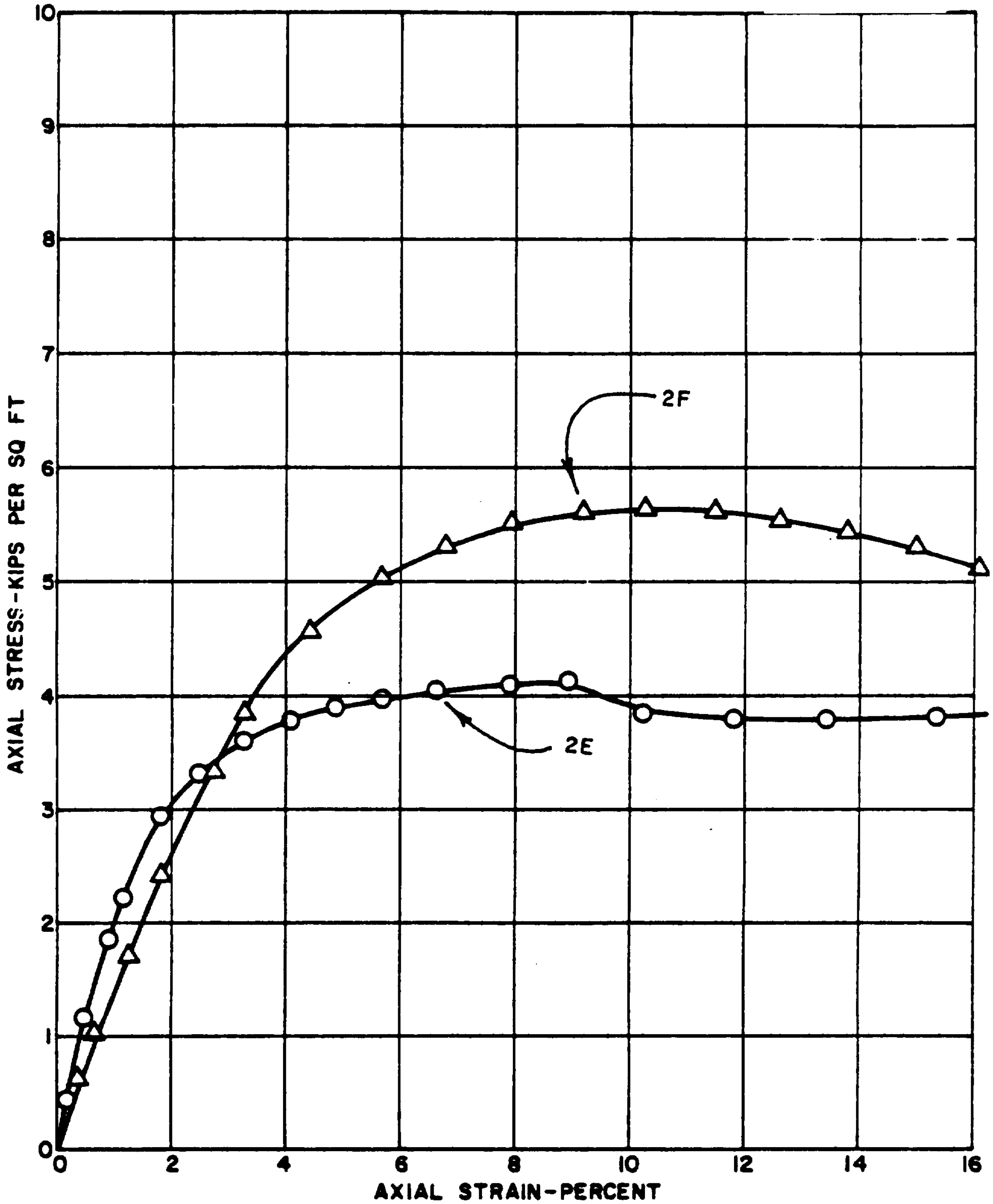


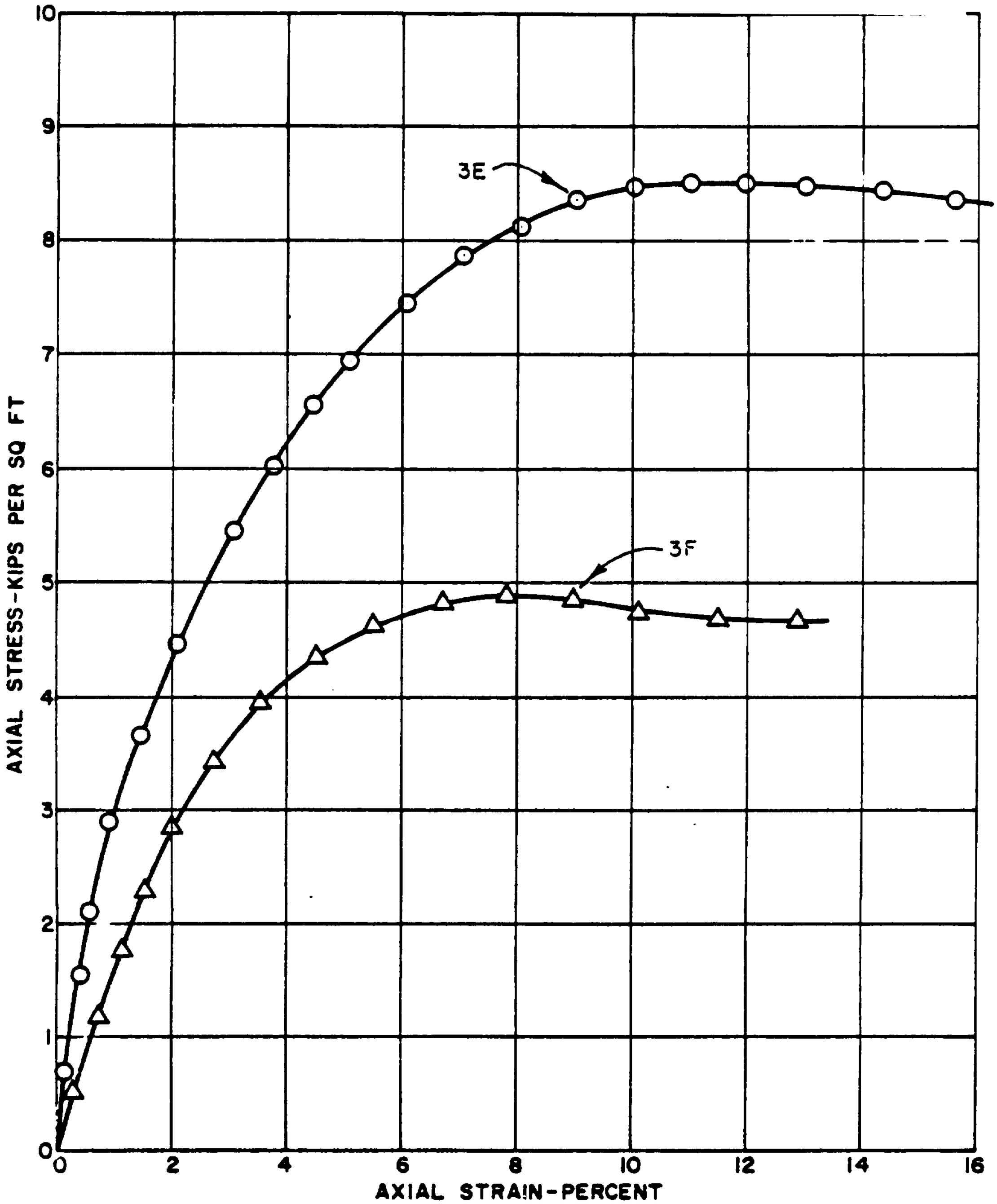
Figure 9 (SHEET 1 OF 15)
UNDRAINED COMPRESSION TESTS SERVICE WATER RESERVOIR



N03EA510

BORING P-15
EMBANKMENT

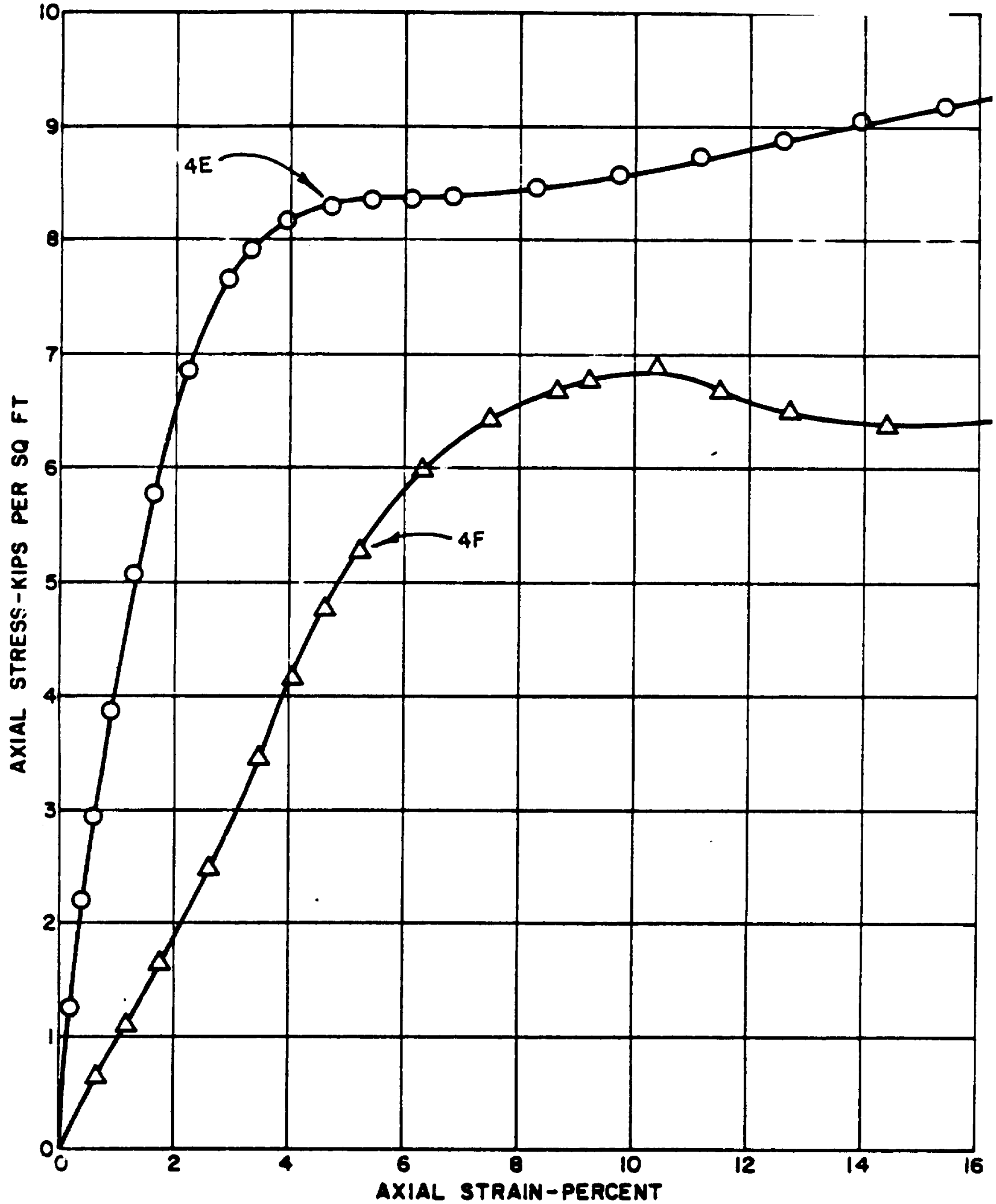
Figure 9 (SHEET 2 OF 15)
UNDRAINED COMPRESSION TESTS SERVICE WATER RESERVOIR



N03EA511

BORING P-15
EMBANKMENT

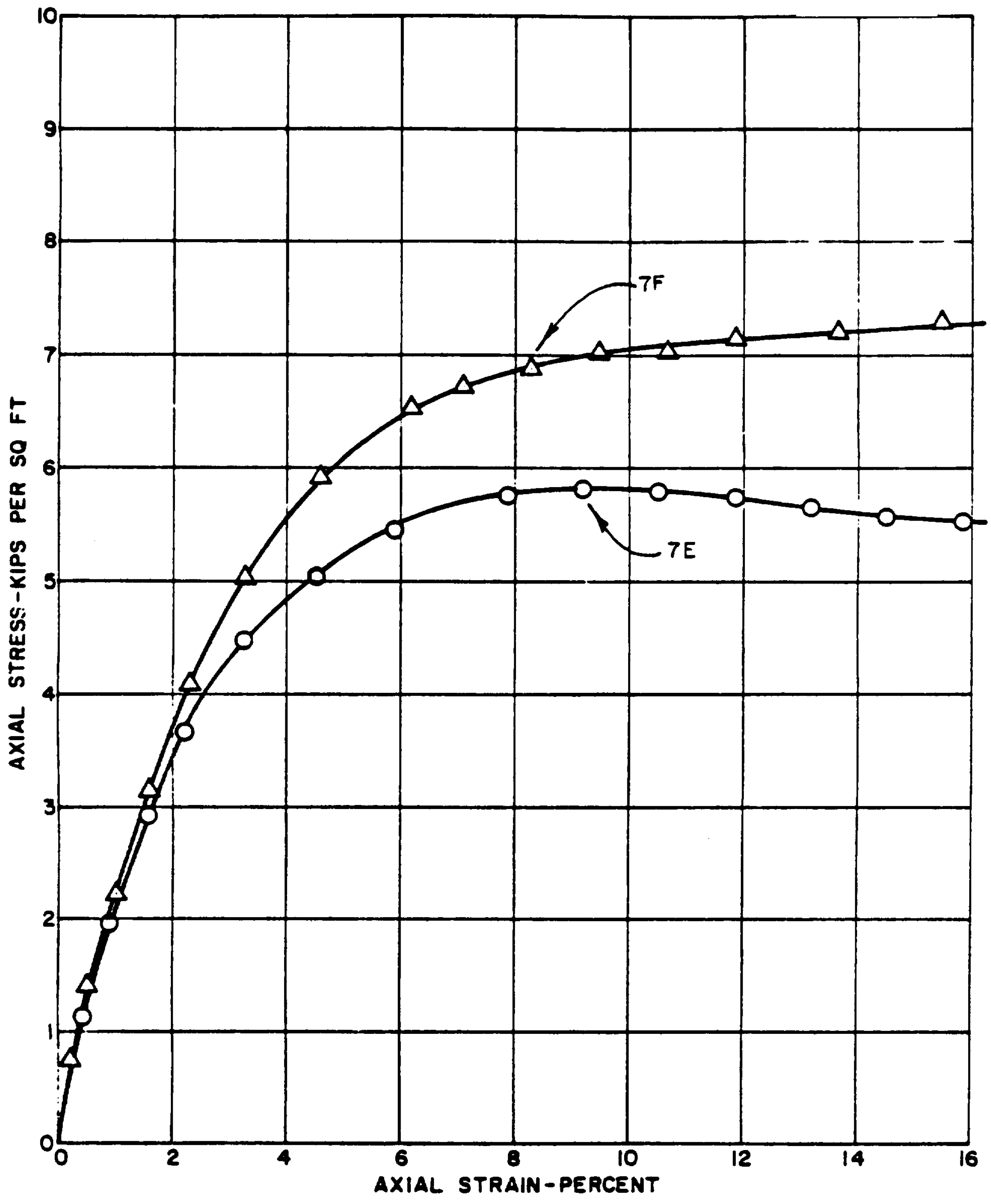
Figure 9 (SHEET 3 OF 15)
UNDRAINED COMPRESSION TESTS SERVICE WATER RESERVOIR



N03EA512

BORING P-15
EMBANKMENT

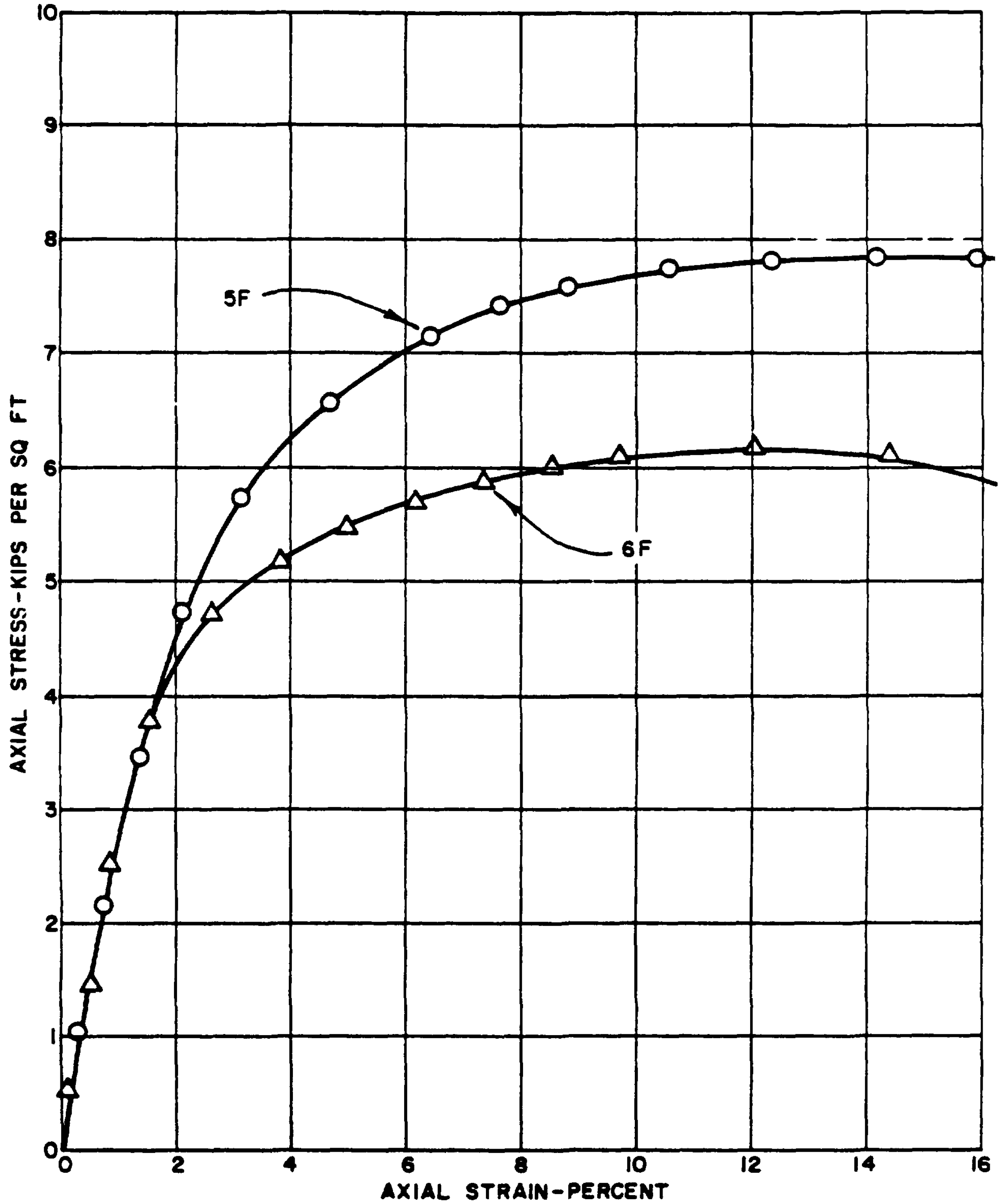
Figure 9 (SHEET 4 OF 15)
UNDRAINED COMPRESSION TESTS SERVICE WATER RESERVOIR



N03EA513

BORING P-15
EMBANKMENT

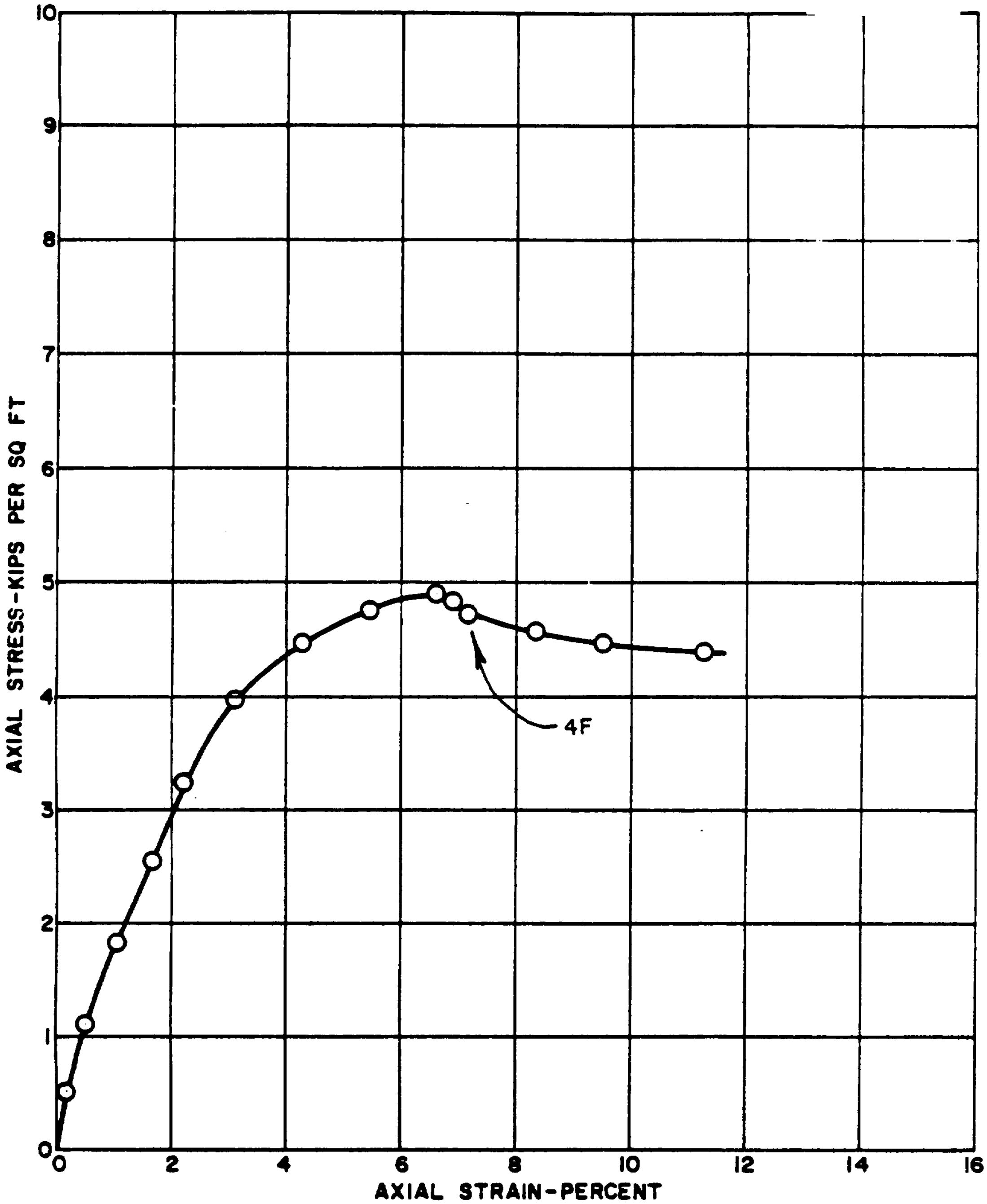
Figure 9 (SHEET 5 OF 15)
UNDRAINED COMPRESSION TESTS SERVICE WATER RESERVOIR



N03EA514

BORING P-16
EMBANKMENT

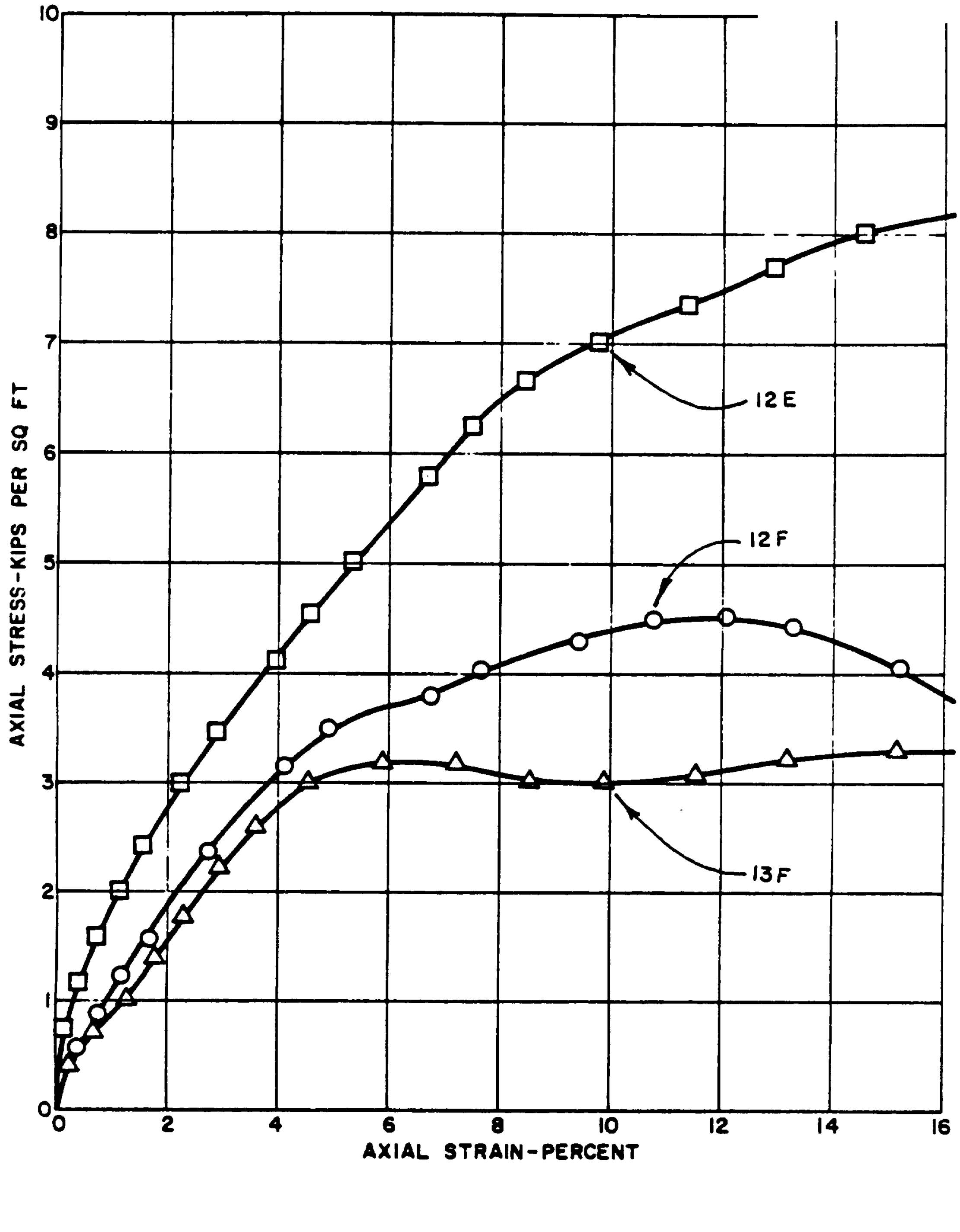
Figure 9 (SHEET 6 OF 15)
UNDRAINED COMPRESSION TESTS SERVICE WATER RESERVOIR



N03EA515

BORING SWR- 13
EMBANKMENT

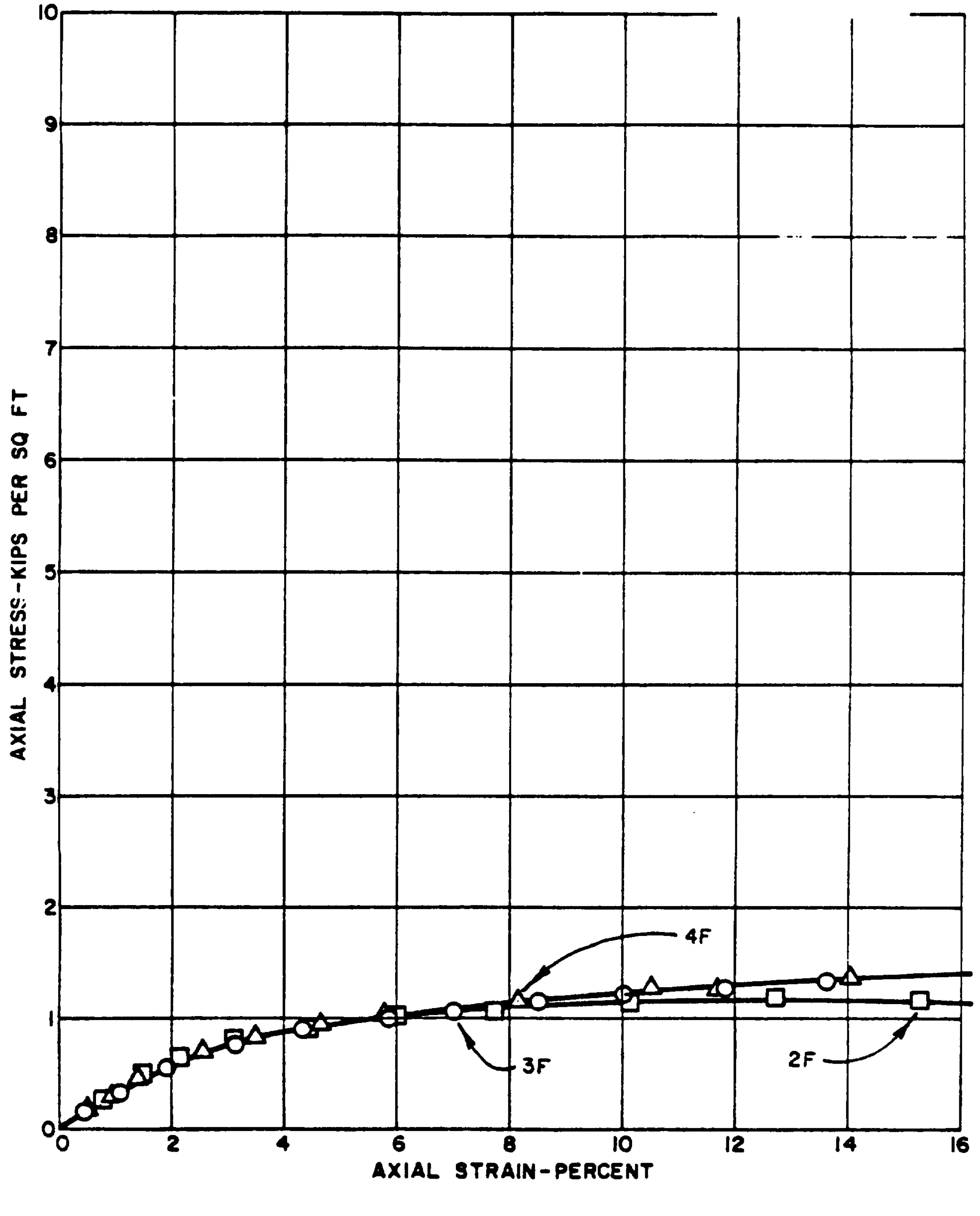
Figure 9 (SHEET 7 OF 15)
UNDRAINED COMPRESSION TESTS SERVICE WATER RESERVOIR



N03EA525

BORING P-17
FOUNDATION

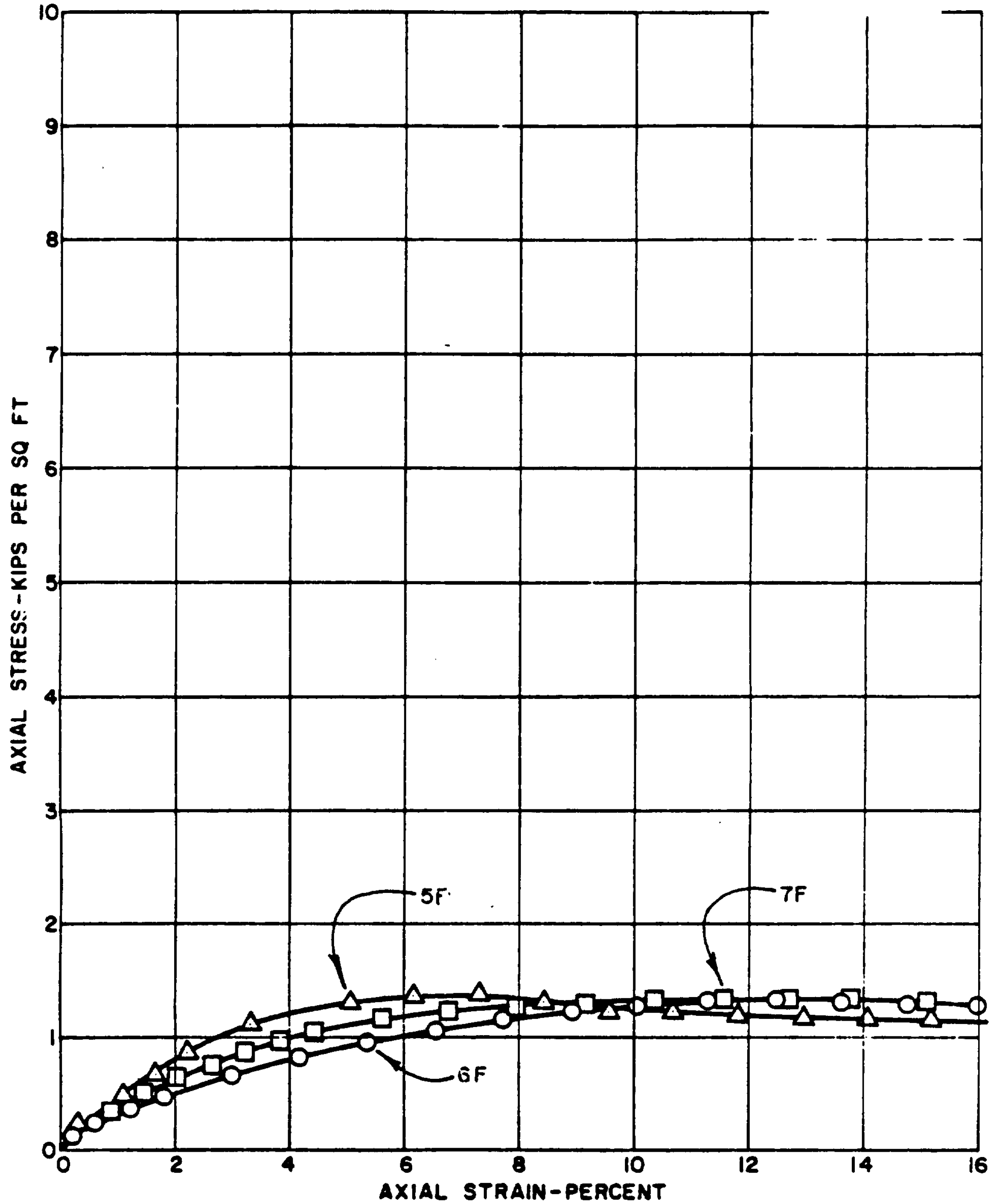
Figure 9 (SHEET 8 OF 15)
UNDRAINED COMPRESSION TESTS SERVICE WATER RESERVOIR



BORING SWR-12
FOUNDATION

N03EA517

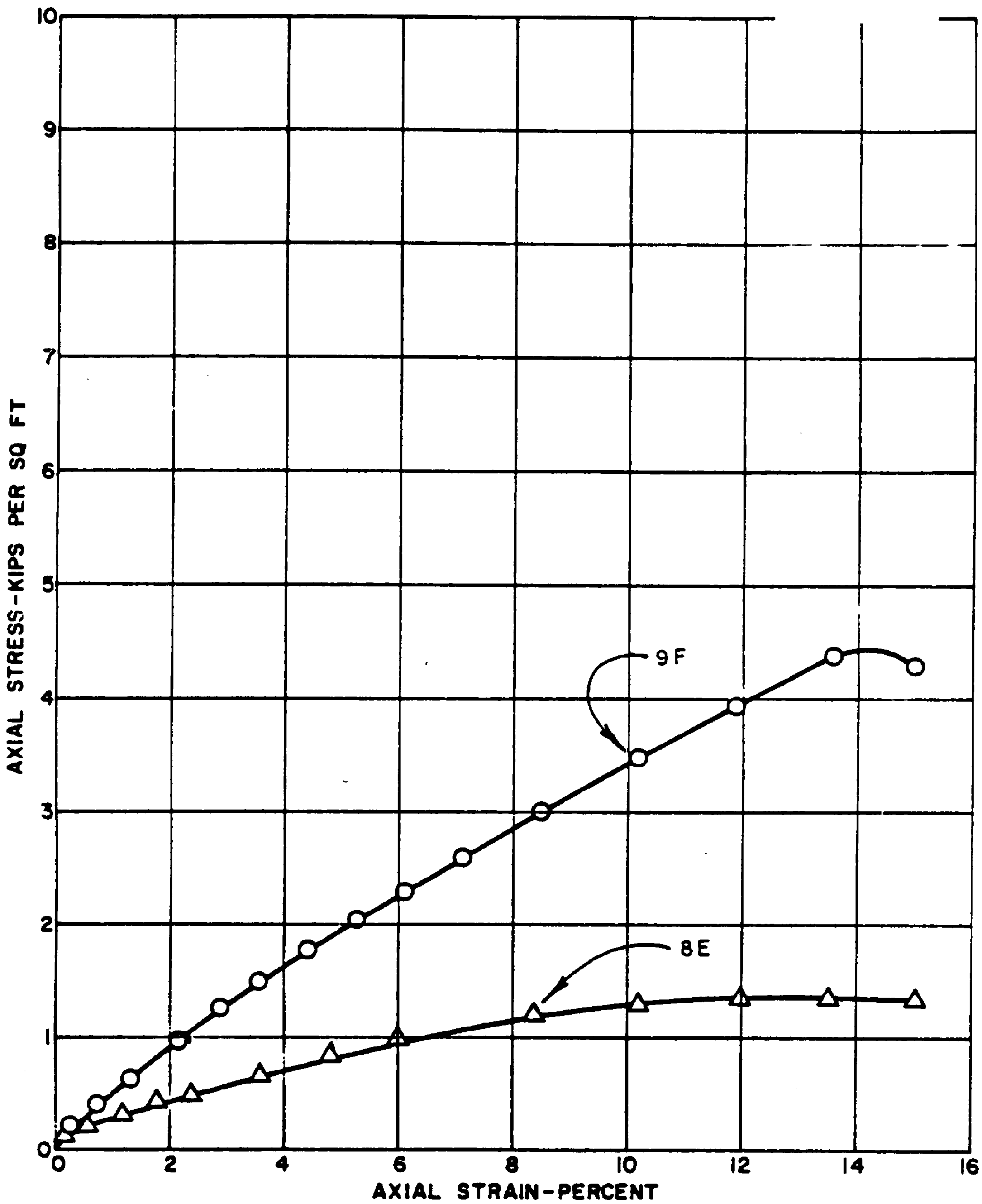
Figure 9 (SHEET 9 OF 15)
UNDRAINED COMPRESSION TESTS SERVICE WATER RESERVOIR



N03EA518

BORING SWR - 12
FOUNDATION

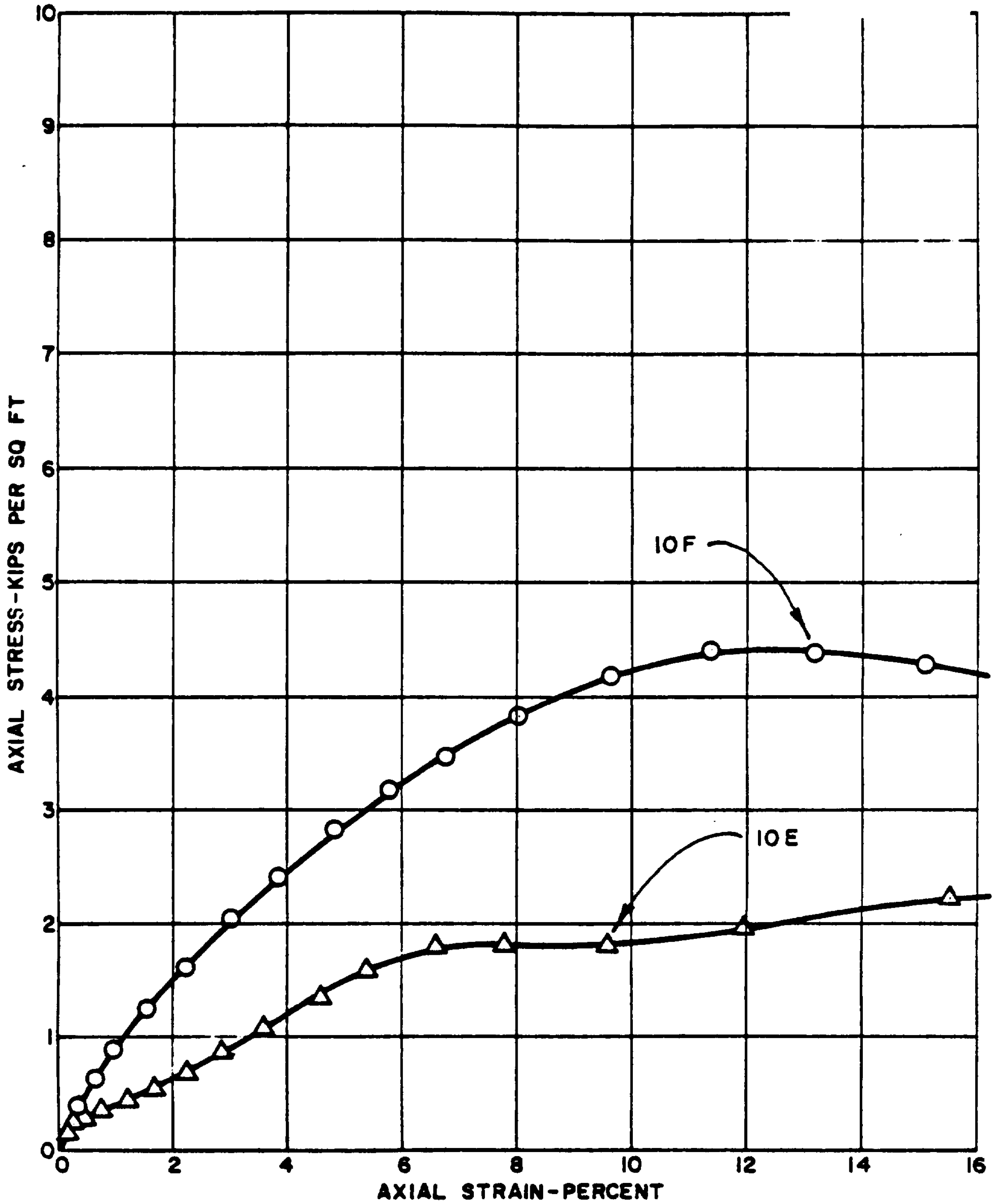
Figure 9 (SHEET 10 OF 15)
UNDRAINED COMPRESSION TESTS SERVICE WATER RESERVOIR



N03EA519

BORING SWR - 12
FOUNDATION

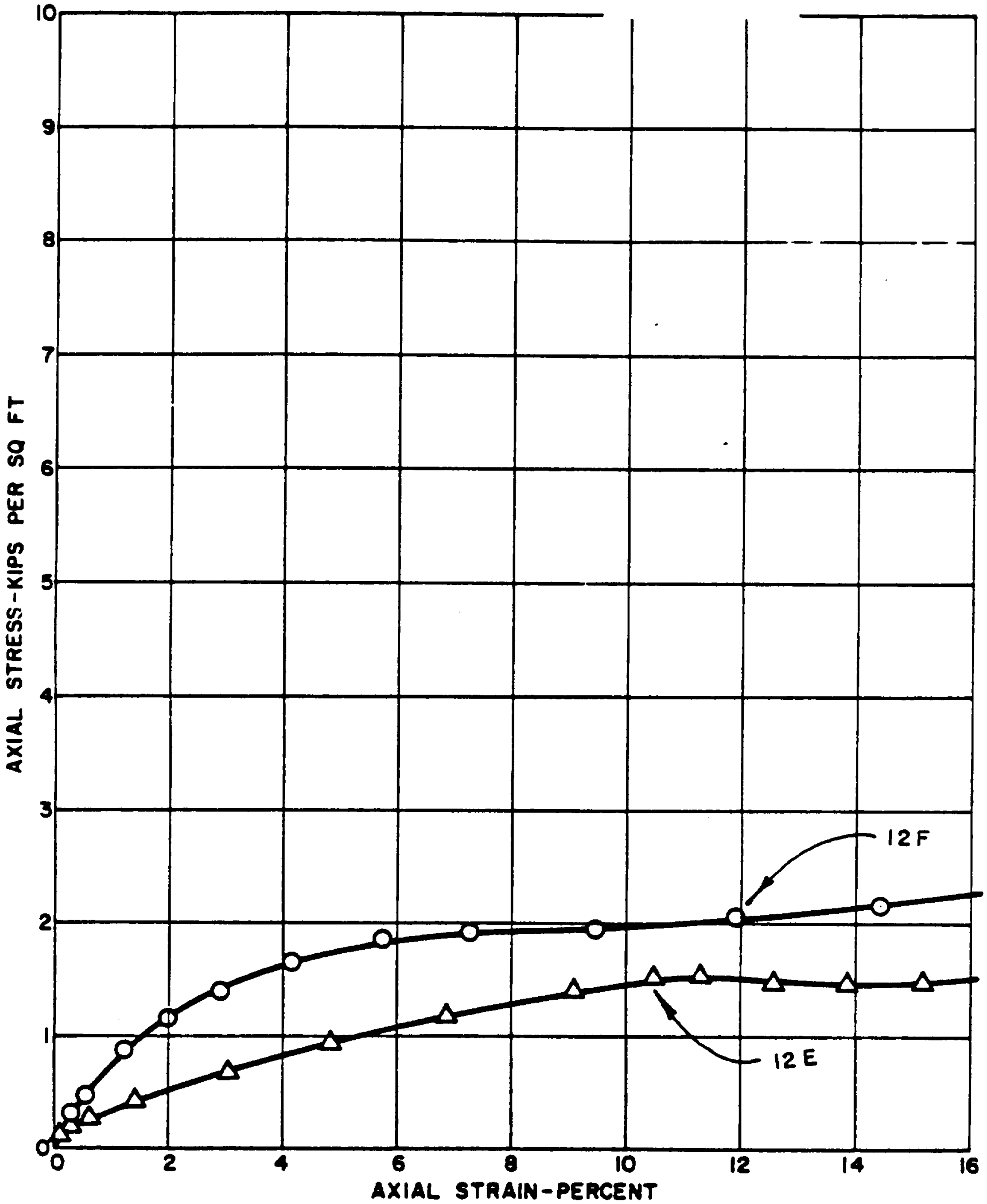
Figure 9 (SHEET 11 OF 15)
UNDRAINED COMPRESSION TESTS SERVICE WATER RESERVOIR



N03EA520

BORING SWR- 12
FOUNDATION

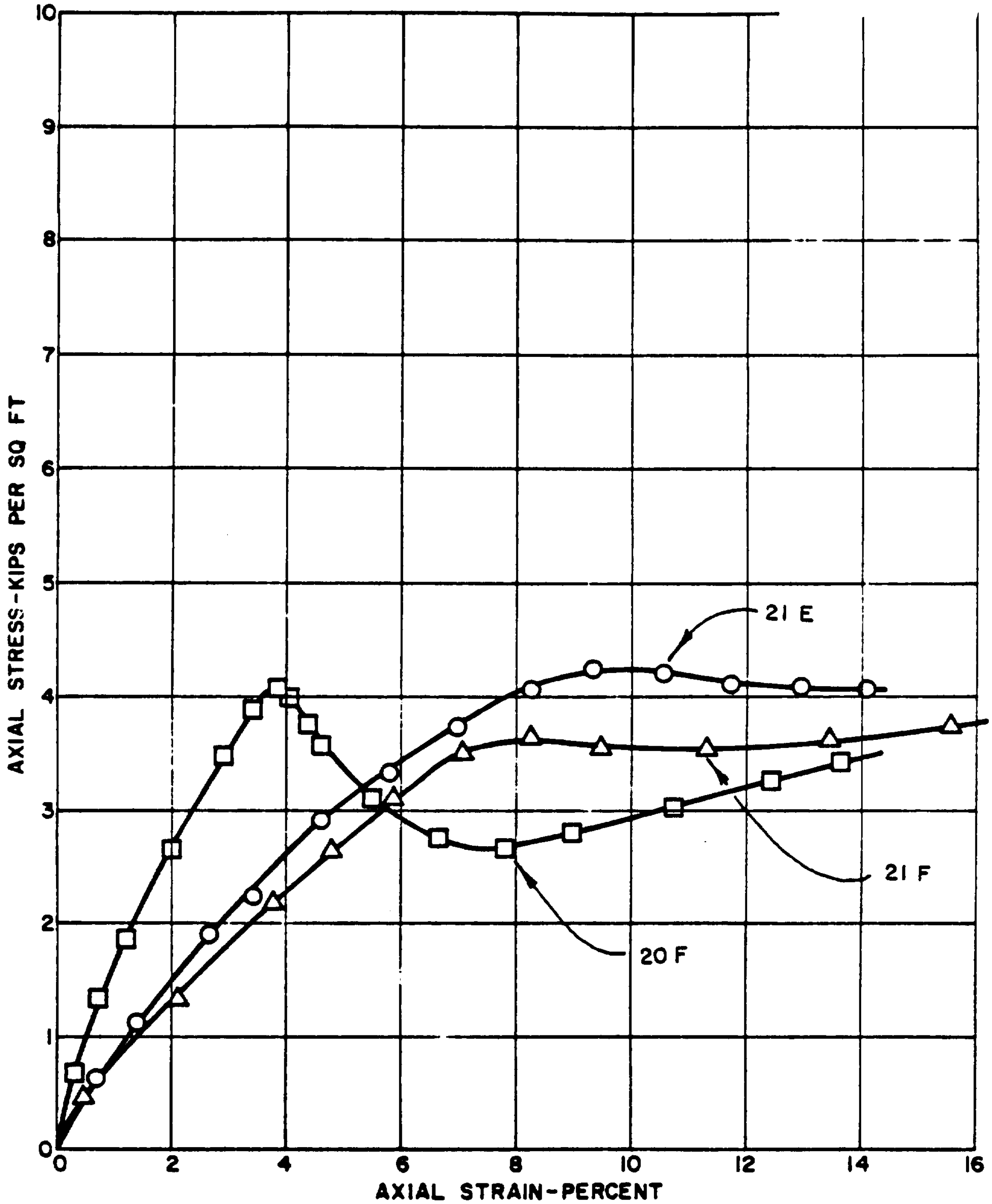
Figure 9 (SHEET 12 OF 15)
UNDRAINED COMPRESSION TESTS SERVICE WATER RESERVOIR



N03EA521

BORING SWR- 12
FOUNDATION

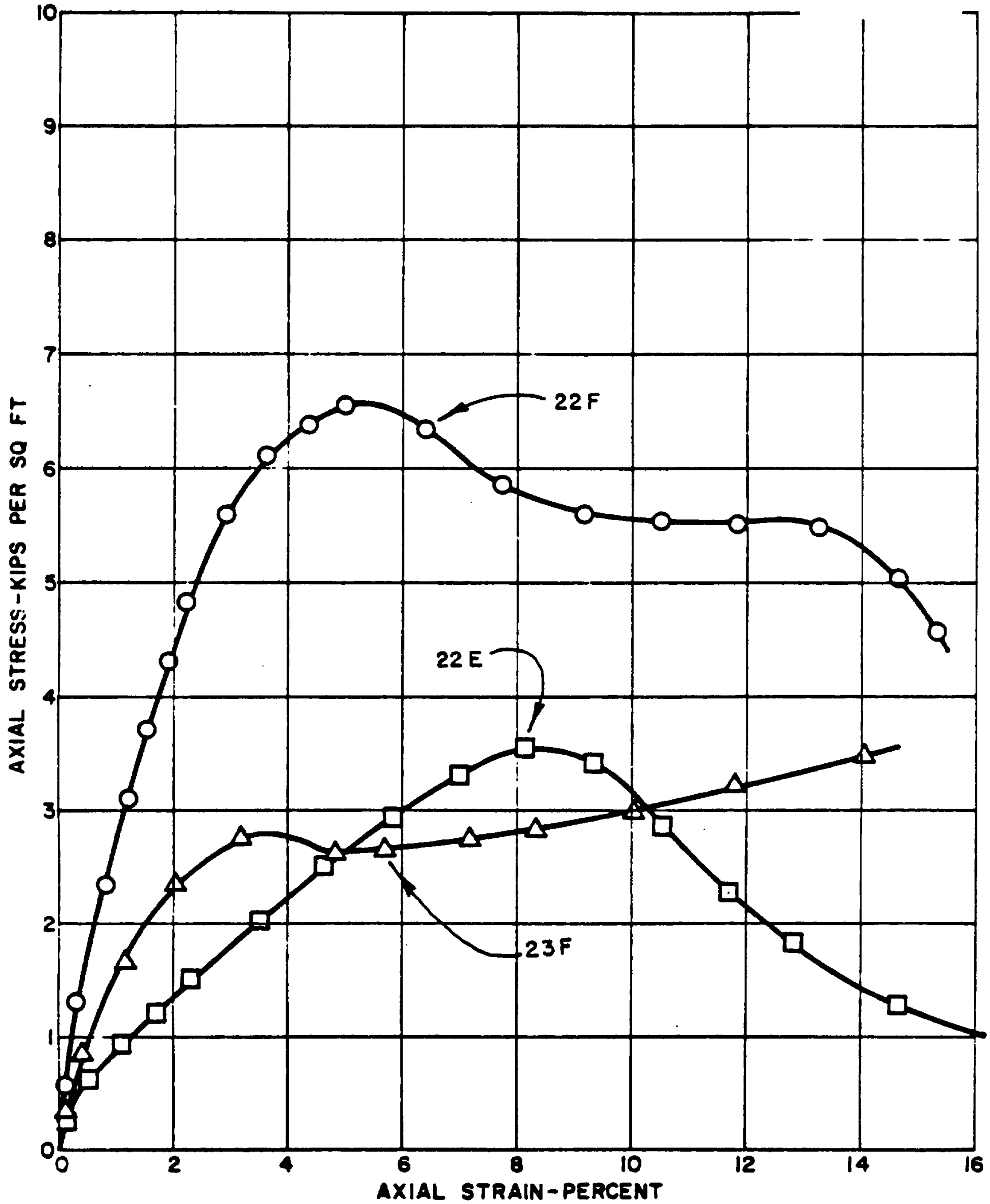
Figure 9 (SHEET 13 OF 15)
UNDRAINED COMPRESSION TESTS SERVICE WATER RESERVOIR



N03EA522

BORING P-15
FOUNDATION

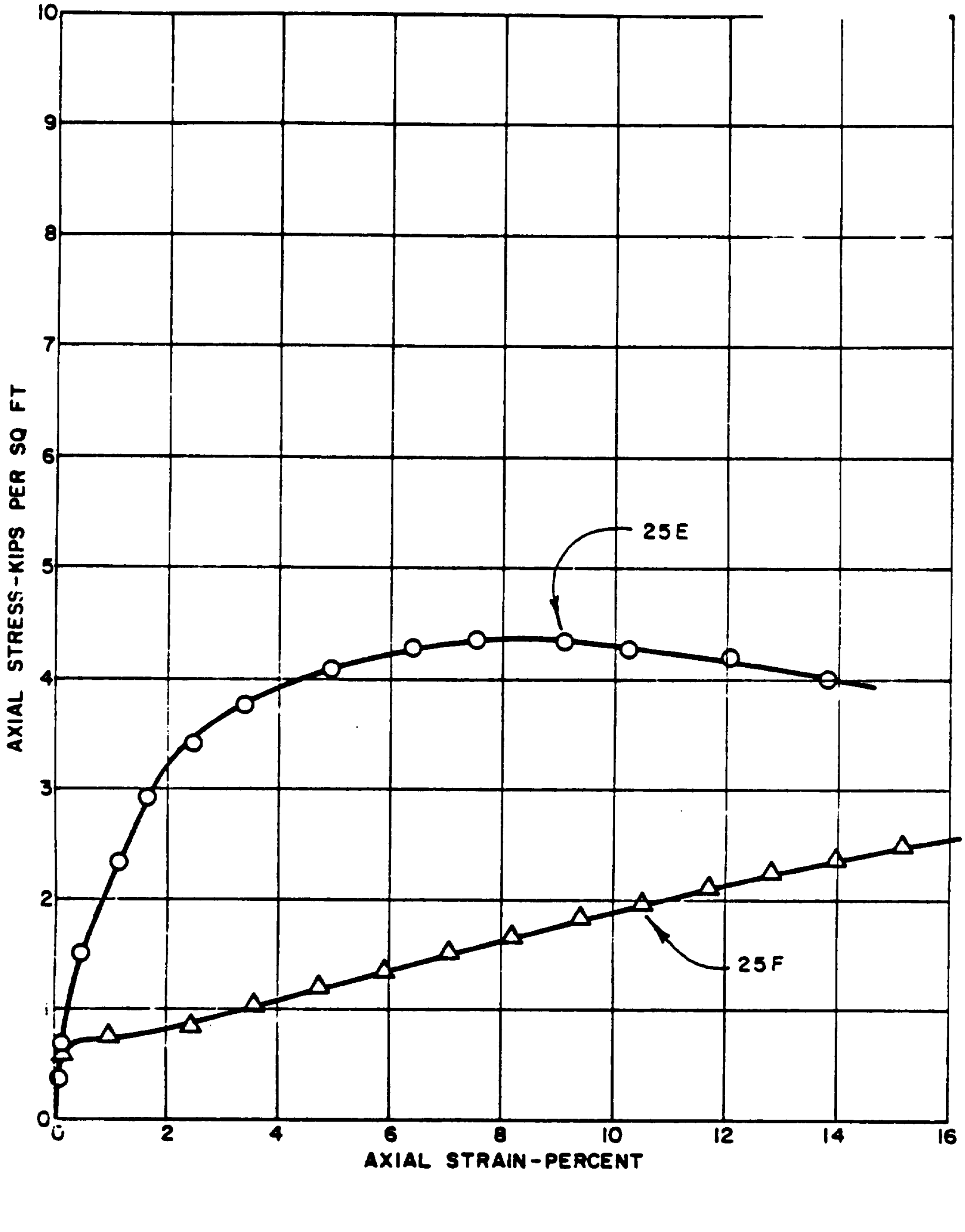
Figure 9 (SHEET 14 OF 15)
UNDRAINED COMPRESSION TESTS SERVICE WATER RESERVOIR



N03EA523

BORING P-15
FOUNDATION

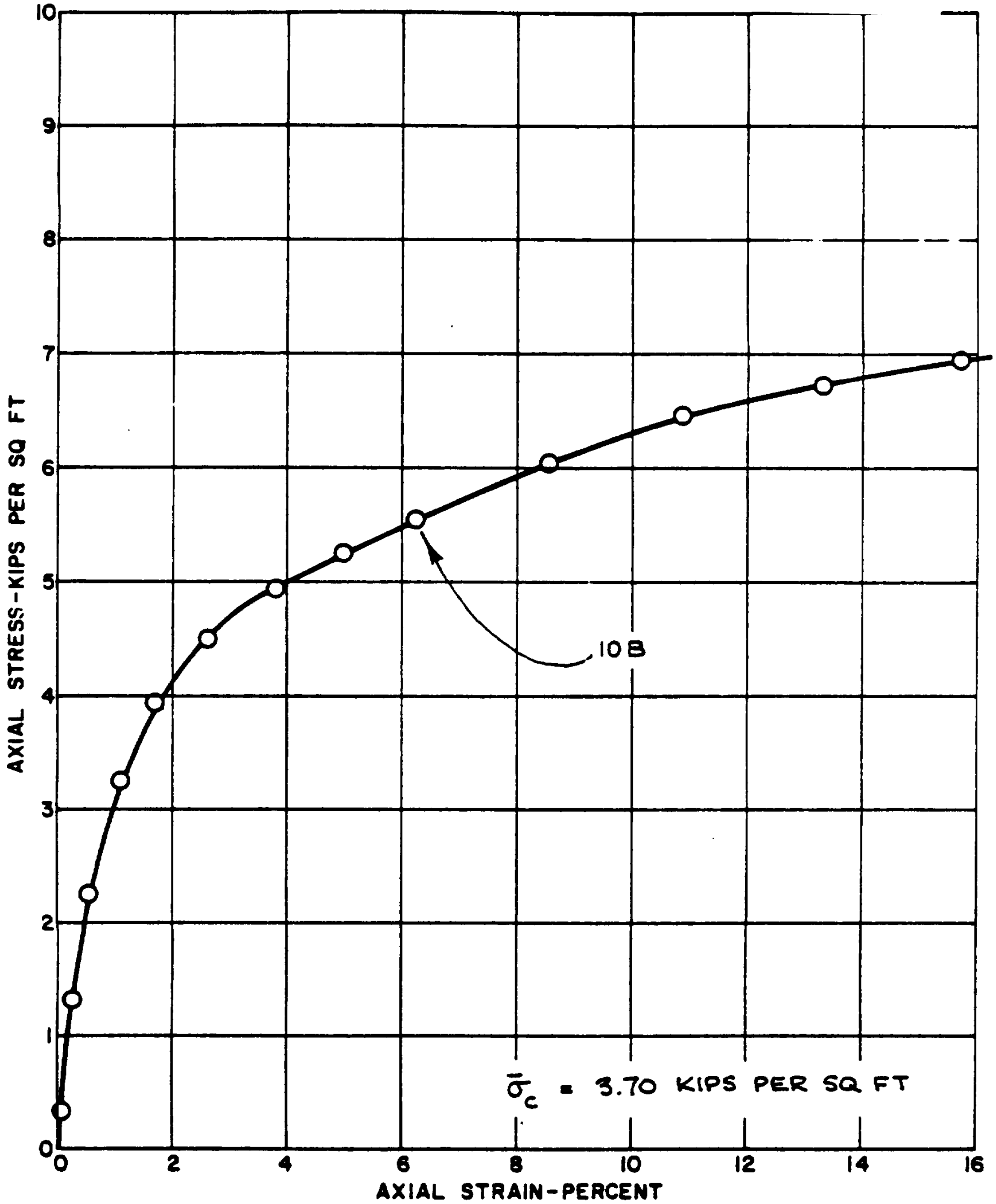
Figure 9 (SHEET 15 OF 15)
UNDRAINED COMPRESSION TESTS SERVICE WATER RESERVOIR



N03EA524

BORING P-15
FOUNDATION

Figure 10
CONSOLIDATED -UNDRAINED COMPRESSION TEST
SERVICE WATER RESERVOIR



N03EA516

BORING P-15
FOUNDATION

Figure 11
CONSTANT - VOLUME DIRECT SHEAR TEST

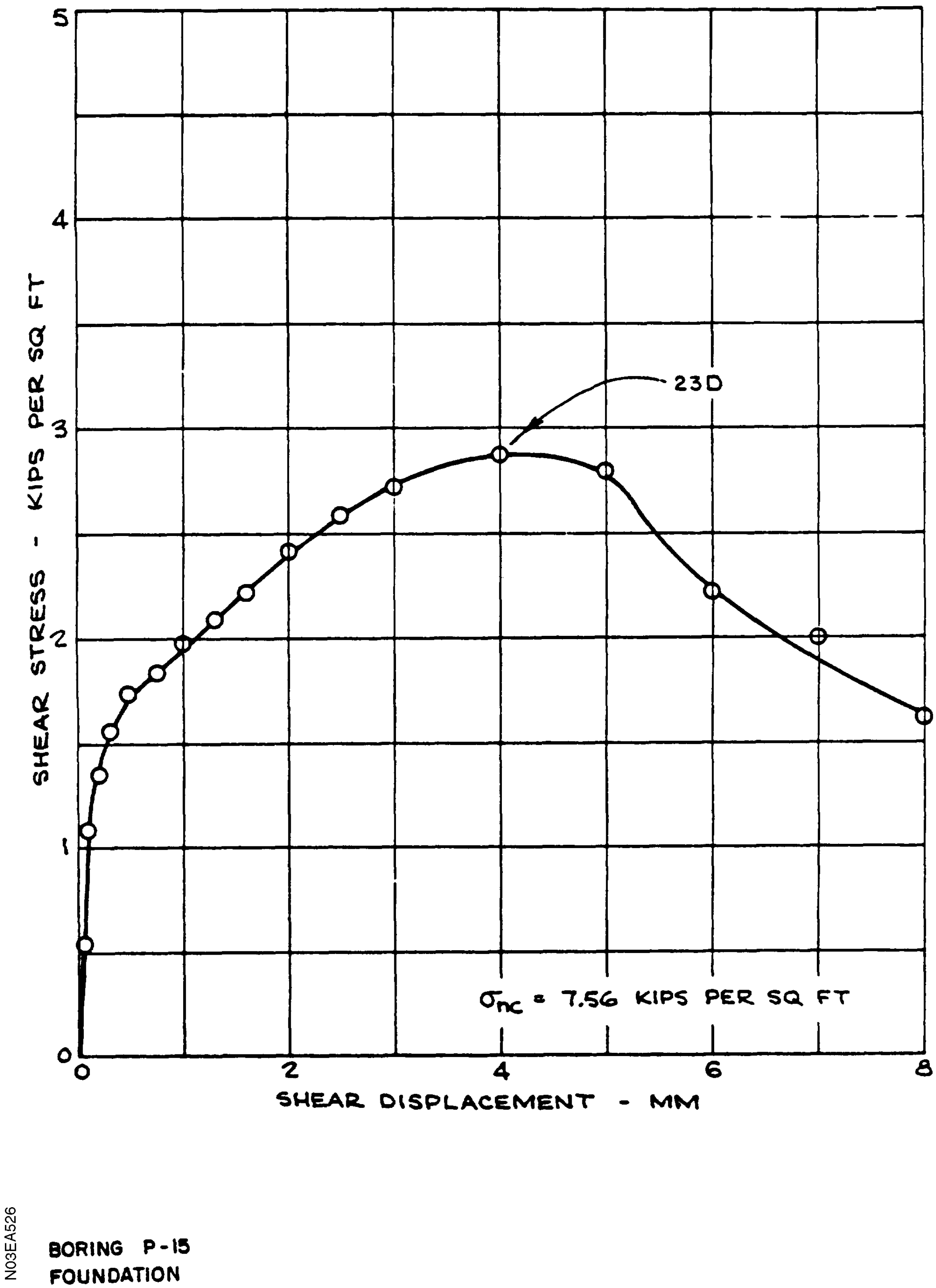
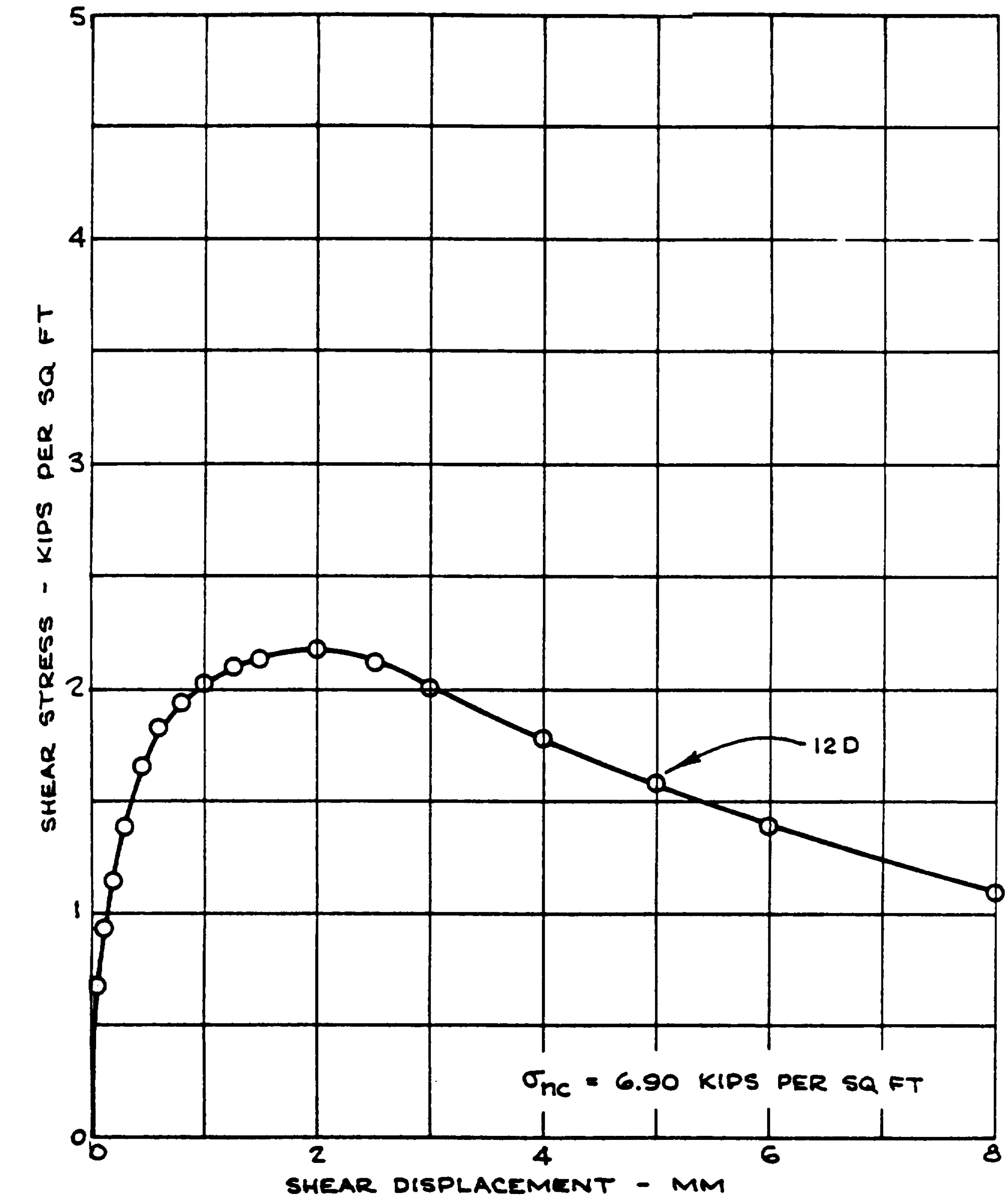


Figure 12
CONSTANT - VOLUME DIRECT SHEAR TEST



BORING SWR - 13
FOUNDATION

Appendix 3F[1]
Safety-Related Equipment Temperature Transients During the Limiting Main Steam Line Break

1. Appendix 3F was submitted as Appendix 3C in the original FSAR.

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APPENDIX 3F SAFETY-RELATED EQUIPMENT TEMPERATURE TRANSIENTS DURING THE LIMITING MAIN STEAM LINE BREAK

(See next page)

3F.1 INTRODUCTION

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

The main steam line break assumed for this analysis is a double-ended rupture of a 30-inch i.d. main steam pipe (4.9 ft^2) inside the containment, upstream of the 16-inch i.d. flow constrictor (1.4 ft^2) with the reactor at 0% power (6.3 ft^2 total break area). Failure of the nonreturn valve in the broken main steam line is the single active failure.

The safety-related equipment temperature transients during the limiting main steam line break have been reanalyzed using forced convection heat transfer coefficients as appropriate. The forced convection coefficients used are based on a correlation of the form:

$$Nu = C(Re)^n$$

where:

Nu = Nusselt number

Re = Reynolds number

C, n = empirical constants dependent on geometry

A conservative evaluation was ensured by making the following assumptions:

1. The maximum containment atmosphere velocity of 30 fps measured in the Carolinas Virginia Tube Reactor simulated steam-line break tests (Reference 1) was used.
2. Low estimates of the diameters of the equipment yield increased calculated heat transfer coefficients.
3. The equipment shape was modeled so that the correlation used tended to increase the value of the coefficient, e.g., the pressure transmitters were considered as spheres instead of cylinders.
4. Thermal properties evaluated at a low mean film temperature increased the coefficient because of the decrease in kinematic viscosity.
5. Containment atmosphere was considered to be 100% air since its thermal conductivity exceeds that of steam.

Additional conservative assumptions are: no moisture carryover in the blowdown, and revaporization of condensate into the highly superheated containment atmosphere.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

The effect of ignoring moisture carryover in the blowdown is to increase the maximum containment temperature by 66°F. The combined effect of ignoring both the moisture carryover in the blowdown and partial revaporization of condensate is to increase the maximum containment temperature by 106°F. Thus, proper consideration of both effects yields a maximum containment temperature of 336°F.

Table 3.F-1 presents the values of the heat transfer coefficient used in the analysis. Hilpert's correlation (Reference 4) was used to describe forced flow over cylinders. A correlation for spheres recommended by McAdams (Reference 4) was used for flow over irregular shapes, e.g., the Rosemount transmitters.

The empirical constants, C and n, are presented in Table 3.F-2 for the various correlations. Note in Table 3.F-1 that the heat transfer coefficients for the Rosemount transmitters are greater, and thus conservative, when their shapes are considered spherical rather than cylindrical.

The electrical cable containment penetrations were considered to experience natural convection heat transfer only. The penetrations are housed in a nozzle assembly (see Figure 3.8-13) that is sealed at its outside end (outside containment end). The only way the electrical cable penetration could be exposed to the atmosphere would be for the atmosphere topass through the small annular gap between the penetration support plate and the nozzle. For forced flow to be achieved, the flow would have to enter and exit through the same gap and the nozzle. In addition, the electrical penetrations are located so that they could not realize direct impingement from a broken main steam line. The following correlation for single horizontal wires or pipes in free convection, as recommended by McAdams (Reference 4), was therefore used for the electrical cable penetrations:

$$h = 0.53\ k/D\ (Gr\ Pr)_f^{1/4}$$

where:

h = natural convection heat transfer coefficient, Btu/hr-°F

Gr = Grashof number evaluated at the mean film temperature and a constant surface-to-atmosphere temperature difference of 300°F

Pr = Prandtl number at the mean film temperature

k = thermal conductivity at the mean film temperature, Btu/hr-ft-°F

D = diameter of cylinder, ft

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

The forcing functions for the equipment temperature transient, i.e., the containment dry bulb and dewpoint transients, are obtained from the run shown in Figures and . The dry bulb temperature rises to 400°F in 13 seconds and remains above 400°F until the quench spray becomes effective at 65 seconds. The quench spray rapidly removes the superheat and brings the atmosphere to a saturated condition at 85 seconds. Containment temperature at 85 seconds is 251°F. Subsequently, the atmosphere remains saturated and decreases in temperature.

Portions of the main steam line break analysis were reperformed with the assumption of no moisture entrainment in the steam released from the ruptured steam generator. The resulting reanalysis was based on a bubble rise velocity in the steam generator of 25 fps instead of 9 fps. The revised peak temperature was calculated to be 430°F, which was greater than the temperature calculated using 9 fps bubble rise as shown in Figures and . The revised peak temperature is used in the containment environmental zone descriptions. Additional analysis has been performed which used smaller pipe break sizes and allowed water mixing with steam exiting the break. The resulting calculated peak containment temperature is lower than the value used for the high energy line break analysis and is described in Section 6.2.1.3.1.2.

The information in Appendix 3F is historical and references the original main steam line break (MSLB) analysis. Current MSLB bounding analysis is presented in Chapter 6. For North Anna’s Environmental Qualification of Safety Related Equipment, the historical information presented in Appendix 3F remains a valid reference in accordance with the Plant Qualification Evaluations (PQEs).

The peak air temperature calculated for the limiting main steam line break exceeds the containment atmosphere design temperature as described in Section 6.2.1.3.1.2. However, the temperatures of equipment in the containment will not rise this high, because as long as the surface temperature is less than the dewpoint, condensate will cover the surface. Thus, the surface temperature will be limited to the temperature of the condensate, which has a maximum temperature equal to the dewpoint. The only way the surface temperature could exceed the dewpoint would be by revaporization of the entire condensate layer; however, revaporization of the entire layer is inconsistent with the zero revaporization assumption imposed by the NRC on the limiting main steam line break analysis.

In fact, the results of the Westinghouse Environmental Qualification Testing Program (Reference 5) demonstrate this very fact, namely, that the dewpoint rather than the dry bulb temperature governs the equipment temperature transients. This behavior was observed for periods of superheat as long as 10 minutes. (Figure 1, Reference 5). The temperature of the inner surface of the casing remained less than the dewpoint. In addition, it was observed that the measured casing temperature was relatively insensitive to the amount of superheat (Figure 3, Reference 5). The superheated transients varied from 5 to 60°F superheat (Figure 2, Reference 5). Even though the test chamber temperature transients did not reach the peak value calculated for the main steam line break, the time at superheated temperature greatly exceeds 2 minutes.

Despite the fact that dewpoint temperature governs the equipment temperature transient, as demonstrated by Westinghouse, a heat transfer analysis is provided similar to one the NRC approved on another application (Docket No. 50-528). The analysis shows that the small pieces of equipment in the containment, which are required for postaccident monitoring, do not attain temperatures exceeding those for which they have been qualified.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

3F.2 CALCULATIONAL MODEL

Condensing and convection heat transfer is modeled as a parallel process, i.e., both processes occur simultaneously on the same surface area. Condensing heat transfer is based on the temperature difference between the containment atmosphere dewpoint and the equipment surface. In addition, convective heat transfer is assumed, and is based on the temperature difference between the containment atmosphere dry bulb and the equipment surface. The dry bulb and dewpoint temperature transients are obtained from the limiting main steam line break containment analysis. The condensing coefficient is conservatively held constant at 500 Btu/hr-ft^3-°F (four times the maximum Uchida value from the limiting main steam line break containment analysis). The convective coefficients were taken from Table 3.F-2. Table 3.F-3 presents the thermal properties of the materials.

The transient and spatial calculation of the temperature of the safety-related equipment is based on the LOCTIC heat transfer model. LOCTIC uses the general numerical method of Dusinberre.

The technique used to conservatively calculate the temperature response of the equipment is, first, to thermally model the equipment interior to maximize the surface temperature, and then to consider the surface temperature to be representative of the entire equipment. Thus, conservatism is ensured because the most temperature-sensitive components are located within the interior, but the internal temperatures are less than the surface values since the transfer is directed inwards.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

3F.3 SAFETY-RELATED EQUIPMENT

Table 3.F-4 lists all the equipment required for a main steam line break, the manufacturer of the equipment, and a bibliography of the qualification information. Tables and include equipment analyzed during the initial analysis and equipment added since the original analysis. The equipment added refers to the appropriate qualification documents.

Table 3.F-5 presents a representative list of safety-related equipment inside containment required for a main steam line break. The table also references the drawings that describe the safety-related equipment, and the figures that indicate the modeling arrangement for the heat transfer analysis.

It should be noted that the 4/c #16 BIW instrumentation cable, not the 2/c #16 BIW cable, now represents the most limiting instrumentation cable. This is a consequence of a slightly smaller neoprene jacket and a slightly larger convection heat transfer coefficient. Figures 3.F-1 and 3.F-2 present the cross-sectional drawing and the slab model, respectively, of the 2/c #16 BIW cable.

The surface temperature transients of the safety-related equipment are presented in Figure 3.F-3. The containment atmosphere dry bulb (T_{DB}) and dewpoint (T_{DP}) temperature transients are also presented. The surface temperatures represent the maximum temperature of the equipment. Internal temperatures are less in every case, and much less for those cases that have an air gap within the interior.

All transients except the electrical cable transients indicate that the dewpoint temperature governs the equipment temperature transient (the condensing heat transfer process dominates). The surface temperature increases rapidly while experiencing condensing heat transfer, i.e., when less than T_{DP}. As the difference between the dewpoint and surface temperature diminishes, condensing heat transfer diminishes, and the surface temperature approaches the dewpoint temperature more slowly.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

3F.3 SAFETY-RELATED EQUIPMENT

When the surface temperature exceeds the dewpoint (only the check valve surface temperature does not rise above the dewpoint) because of the assumed convection heat transfer and the decreasing dewpoint temperature, condensation heat transfer is discontinued. After this time, the convective heat transfer is attenuated because the dry bulb temperature is decreasing, and the remaining time at superheated conditions is short.

The electrical cables respond rapidly to the superheated atmosphere and achieve their peak surface temperature at the time of spray initiation. The cables are more sensitive to the superheated atmosphere because of their insulator properties (small heat capacity and thermal conductivity), smaller size, and larger convective heat transfer coefficients. References 7 through 15, 24, and 25 demonstrate that the electrical cables are qualified for temperatures postulated for a main steam line break.

Table 3.F-6 lists the maximum calculated surface temperature of the safety-related equipment determined during the initial evaluation. Subsequent evaluations are reflected by the Plant Qualification Evaluations (PQEs) and environmental zone descriptions based on analysis and direct temperature monitoring data.

Neither the equipment identified in Reference 5 as being available to provide a “defense in depth” for the limiting main steam line break and for monitoring after the postulated accident, nor the remainder of the equipment listed in Table 3.F-5, are directly impinged upon by jets emanating from the breaks in the main steam line.

This conclusion is the result of a detailed analysis that included an inspection of the “as-built” locations of all components necessary for a particular function. The location of qualified instrumentation and equipment is maintained by the Equipment Qualification Master List (EQML).

A review of the constituents of the containment atmosphere after a postulated main steam line break and after a LOCA indicates no constituent that would affect the heat transfer analysis.

The remainder of Appendix 3F is HISTORICAL and is not intended or expected to be updated for the life of the plant.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

3F.4 RESULTS

The figures indicate that the dewpoint temperature governs the equipment temperature transient (the condensing heat transfer process dominated). The surface temperature increases rapidly while experiencing condensing heat transfer, i.e., when less than T_{DP}. As the dewpoint surface temperature difference diminishes, condensing heat transfer diminishes, and the surface temperature approaches the dewpoint temperature more slowly.

All equipment listed in Table 3.F-6 and detailed in Table 3.F-4 have been qualified by environmental test, with analysis as appropriate.

In the case of the positive closure check valves, the only material contained in the check valves that is temperature-sensitive is the ethylene propylene seat material. Manufacturers' test reports (Reference 16) performed in accordance with the applicable ASTM specifications indicate no degradation of this material at temperatures as high as 350°F in continuous oil quench testing.

As a result of the environmental tests performed, it has been established that the equipment tested will perform in the containment environment after a main steam line break incident. These tests are very conservative, for two reasons:

1. The calculated main steam line break transient temperatures and pressures derived are very conservative.
2. The equipment that was qualified in conjunction with the calculated peak surface temperatures determined by the methods described above was held at those peak calculated temperatures for time periods more than sufficient to ensure that temperatures were seen throughout the equipment, as indicated in the references tabulated in Table . The tested equipment functioned after the test or, in some cases, examination of the equipment in detail showed no degradation or damage that would impair the function of the equipment during or after the main steam line break transient.

Table 3.F-8 lists Class 1E balance of plant (BOP) equipment, provides a comparison of room and equipment rating temperatures, and outlines plans for temperature monitoring in certain areas.

Table 3.F-6 lists the maximum calculated surface temperature of the safety-related equipment determined during the initial evaluation. References to Qualification Documentation Reviews (QDR) reflect subsequent evaluations.

3F REFERENCES

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

1. R. C. Schmitt, *ETAL Simulated Design Basis Accident Tests of the Carolinas Virginia Tube Reactor Containment*, Final Report IN 1403, December 1970.
2. F. Keith, *Principles of Heat Transfer*, International Textbook Company, Scranton, Pennsylvania, 1965.
3. R. C. Schmitt, *ETAL Simulated Design Basis Accident Tests of the Carolinas Virginia Tube Reactor Containment*, Final Report IN 1403, December 1970.
4. F. Keith, *Principles of Heat Transfer*, International Textbook Company, Scranton, Pennsylvania, 1965.
5. Letter to Mr. B. C. Rusche, Director, Office of Nuclear Reactor Regulation, USNRC, from Mr. C. M. Stallings, Vice President, Power Supply and Production Operations, Virginia Electric and Power Company (with attachment, *Environmental Qualification of*
6. *Westinghouse NSSS Scope Safety-Related Instrumentation for North Anna Units 1 and 2)*, Serial No. 249, dated September 20, 1976.
7. QDR-N-6.1, Boston Insulated Wire & Cable Company 300V Instrument.
8. QDR-N-6.2, The Rockbestos (Cerro) Company Cable (XLPE).
9. QDR-N-6.3, High Temperature Silicone Rubber Insulated Cable - The Rockbestos (Cerro) Company.
10. QDR-N-6.5, Power Cable, General Cable Company.
11. QDR-N-6.7, The Okonite Company, 600V Power Cable.
12. QDR-N-6.8, The Okonite Company, 600V Cable.
13. QDR-N-6.10, Anaconda-Ericsson, 300V & 600V Cable.
14. QDR-N-6.11, Raychem Corporation Cable, 300V Instrument.
15. QDR-N-6.13, Brand Rex Company, 300V & 600V Cable.
16. *Seal Material for Nuclear Reactors*, November 26, 1975. Submitted to the NRC in VEPCO letter, Serial No. 100A/020177, April 25, 1977.
17. The Chemical Rubber Company, *Handbook of Chemistry and Physics*, 44th Edition, 1962.
18. QDR-N-15.1, Conax Corporation, Electrical Penetrations.
19. QDR-N-15.4, Conax Corporation, Electrical Penetrations.
20. QDR-N-8.5, Rosemount Transmitters, 1153D.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

21. QDR-N-4.4, General Electric Inside Recirculation Spray Pump Motor.
22. QDR-N-8.24, Weed Instrument Company, Resistance Temperature Detectors.
23. QDR-N-8.26, Rosemount Transmitter, 1153H.
24. QDR-N-6.17, General Electric - Vulkene XLPE 600V Wire.
25. QDR-N-6.19, Rockbestos - Radiation Resistant Silicone 600V Cable.
26. QDR-N-6.16, Core Exit Thermocouple System.
27. QDR-N-8.9, Minco RTD.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.F-1

HEAT TRANSFER COEFFICIENTS

Item	Outside Diameter (ft)	Heat Transfer Coefficient (Btu/hr-ft^2-°F)	Correlation
Rosemount pressure transmitter	0.375	6.4	Cylinder
	0.375	11.3	Sphere
Containment recirculation pump motor	2.25	4.7	Cylinder
Containment isolation check valve	0.792	5.8	Cylinder
Electrical power cable	0.111	10.3	Cylinder
Electrical instrumentation cable	0.0286	17.7	Cylinder

Item	Slab Thickness (in)	Heat Transfer Coefficient (Btu/hr-ft2-°F)	Correlation
Containment electrical penetrations	0.0625	2.0	Natural

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.F-2

FORCED CONVECTION HEAT TRANSFER COEFFICIENT CORRELATIONS

Shape	C	n	Re	Reference
Cylinder[a]	0.891	0.330	0.4 — 4	Ref. 2, p. 411
	0.821	0.385	4 — 40	
	0.615	0.466	40 — 4000	
	0.174	0.618	4000 — 4×10^4	
	0.0239	0.805	4×10^4 — 4×10^5	
Sphere[b]	0.37	0.6	25 — 10^5	Ref. 2, p. 414

a. Re based on mean film temperature.

b. Re based on dynamic viscosity at mean film temperature, density at containment atmosphere temperature.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.F-3

MATERIAL THERMAL PROPERTIES

	Thermal Properties [a]		
Material	Thermal Conductivity (Btu/hr-ft^2-°F)	Specific Heat (Btu/lbm-°F)	Density (lbm/ft^3)
SS-304	9.4	0.11	488.
Polysulfone (penetration seal)	0.1	0.24	77.4
Cast iron	28.3	0.10	455.
Mica [b] (winding insulation)	0.087	0.25	36.
Copper	218.	0.0914	558.
Fiberglass [b] (circuit board)	0.087	0.25	36.
Ethylene propylene (valve seat)	0.14	0.35	53.7
Asbestos	0.087	0.25	36.
Cross-linked polyethylene	0.144	1.0	62.4
Neoprene	0.116	0.4	75.
Silicone [b]	0.087	0.25	36.

a. Thermal properties obtained from vendor data and References 4 and 17.
b. Conservatively assumed thermal properties of asbestos for maximum surface temperature.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.F-4

QUALIFICATION REFERENCES FOR EQUIPMENT (INSIDE CONTAINMENT) REQUIRED DURING OR SUBSEQUENT TO A MAIN STEAM LINE BREAK

Equipment	Manufacturer	Qualification References
Pressurizer level transmitter	Rosemount 1153D	Reference 20
Pressurizer pressure transmitter	Rosemount 1153H	Reference 23
Steam flow transmitter[a]	Rosemount 1153D	Reference 20
Steam generator narrow range transmitter	Rosemount 1153D	Reference 20
Reactor coolant loop temperature detector	Weed	Reference 22
Recirculation spray pump meter	General Electric	Reference
Electrical penetrations	Conax	References 18 & 19
Electrical power cable (250 MCM triplex)	Rockbestos Cable	Reference 9
Electrical instrument cable	BIW, Brand Rex, Rockbestos, Anaconda-Ericsson, Raychem,	References 7, 8, 13, 14, 15
	General Electric	References 24 & 25
Containment isolation check valves	Atwood & Morrell Schute & Koerting	VEPCO letter, Serial No. 350, November 30, 1976, Reference 16
Reactor coolant system (RCS) wide range pressure transmitter	Rosemount 1153D	Reference 20
Core exit thermocouples	Westinghouse	Reference 26

a. In the event of a steam-line break inside the containment, the primary protection signal would be provided by the steam-line differential pressure function. Transmitters for this function are located outside the containment. Additional protection is provided by the containment pressure function, which is also generated by transmitter outside of the containment.

b. The electrical penetrations modules that extend into the containment consist of the copper conductors surrounded by two 50% overlapped layers of Kapton, followed by the Polysulfone insulation and sealer, and finally the stainless steel tubing. The Kapton insulation used consists of two layers of the Type HF construction described in Reference 18, except that on larger diameter conductors, the Kapton thickness is increased to 2 mils.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.F-4

QUALIFICATION REFERENCES FOR EQUIPMENT (INSIDE CONTAINMENT) REQUIRED DURING OR SUBSEQUENT TO A MAIN STEAM LINE BREAK

Equipment	Manufacturer	Qualification References
Reactor vessel level instrumentation system	Westinghouse	Reference 27

a. In the event of a steam-line break inside the containment, the primary protection signal would be provided by the steam-line differential pressure function. Transmitters for this function are located outside the containment. Additional protection is provided by the containment pressure function, which is also generated by transmitter outside of the containment.

b. The electrical penetrations modules that extend into the containment consist of the copper conductors surrounded by two 50% overlapped layers of Kapton, followed by the Polysulfone insulation and sealer, and finally the stainless steel tubing. The Kapton insulation used consists of two layers of the Type HF construction described in Reference 18, except that on larger diameter conductors, the Kapton thickness is increased to 2 mils.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3F-4 (continued)

BIBLIOGRAPHY OF QUALIFICATION INFORMATION SUBMITTED TO THE NRC FOR EQUIPMENT (INSIDE CONTAINMENT) REQUIRED DURING OR SUBSEQUENT TO A MAIN STEAM LINE BREAK

Equipment	Manufacturer	References for Qualification Information Submitted to the NRC
RCS wide-range pressure transmitter	Rosemount	VEPCO letter, Serial No. 085B, March 9, 1983
Recirculation spray pump motors	General Electric	VEPCO letter, Serial No. 03773, July 17, 1973, under Docket Nos. 50-280 and 50-281 VEPCO letter, Serial No. 350, November 30, 1976
Electrical penetrations[b]	Conax	VEPCO letter, Serial No. 350, November 30, 1976 VEPCO letter, Serial No. 251, June 21, 1977 References 15, 18, and 19
Containment isolation check valves	Atwood & Morrell Schute & Koerting	VEPCO letter, Serial 350, November 30, 1976 Reference 16
Electrical power cable (250 MCM triplex)	Cerro Cable	VEPCO letter, Serial No. 350, November 30, 1976 VEPCO letter, Serial No. 223, June 6, 1977 References 7 through 14 for electrical and power cable
Electrical instrument cable (No. 16 shielded)	Boston Insulated Wire and Cerro Cable	Same as above

References 18 and 19 were forwarded to the NRC in VEPCO letter, Serial No. 251, dated June 21, 1977. References 15, 18, and 19 demonstrate that containment penetrations, including the module that extends into the containment, can withstand temperatures postulated for a main steam line break.

a. In the event of a steam-line break inside the containment, the primary protection signal would be provided by the steam-line differential pressure function. Transmitters for this function are located outside the containment. Additional protection is provided by the containment pressure function, which is also generated by transmitter outside of the containment.

b. The electrical penetrations modules that extend into the containment consist of the copper conductors surrounded by two 50% overlapped layers of Kapton, followed by the Polysulfone insulation and sealer, and finally the stainless steel tubing. The Kapton insulation used consists of two layers of the Type HF construction described in Reference 18, except that on larger diameter conductors, the Kapton thickness is increased to 2 mils.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.F-5

SAFETY-RELATED EQUIPMENT INSIDE CONTAINMENT REQUIRED FOR A MAIN STEAM LINE BREAK

Item	Drawing	Model
Rosemount pressure transmitter	See Figure 3.F-5	See Figure
Containment recirculation pump motor	See Figure 3.F-7	See Figure
Containment isolation check valve	8" - 150 # Atwood & Morrell Co.	See Figure
Electrical power cable	See Figure	See Figure
Electrical instrumentation cable	See Figure 3.F-1	See Figure 3.F-2
Electrical containment penetration	See Figure 3.8-13	See Figure

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.F-6

COMPARISON OF THE MAXIMUM CALCULATED SURFACE TEMPERATURES OF THE SAFETY-RELATED EQUIPMENT WITH THEIR RESPECTIVE QUALIFICATION TEMPERATURES

Item	Max. Calc.Surface Temp. (°F)	Qualification Temperature[a] (°F)
Rosemount pressure transmitter [b]	264	See QDR-N-8.5
Containment recirculation pump motor	261	See QDR-N-4.4
Containment isolation check valve	236	280
Electrical power cable	335	See QDR-N-6.3
Electrical instrumentation cable	343	See QDR-N-6.1
Containment electrical penetrations	275	See QDR-N-15.1 & N-15.4
Core exit thermocouples	See QDR-N-6.16	See QDR-N-6.16
Reactor vessel level indication system	See QDR-N-8.9	See QDR-N-8.9

a. The maximum calculated surface temperature of the safety-related equipment was determined during the initial evaluation. References to Qualification Documentation Reviews (QDR) reflect subsequent evaluations.

b. The maximum calculated surface and qualification temperatures also apply to the Rosemount steam flow and steam generator narrow range level transmitters.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.F-7
(SHEET 1 OF 2)
LOCATION OF QUALIFIED EQUIPMENT

Component	Location Figure No.	Location Identification No.[a]
Pressurizer pressure transmitter		
Channel 1	3.F-4	1
Channel 2	3.F-4	2
Channel 3	3.F-4	3
Pressurizer level transmitter		
Channel 1	3.F-4	1
Channel 2	3.F-4	2
Channel 3	3.F-4	3
Steam flow transmitter		
Channel 1	3.F-4	4
Channel 2	3.F-4	5
RCS temperature detector		
Loop A	3.F-4	6
Loop B	3.F-4	7
Loop C	3.F-4	8
Steam generator level		
Loop A, Channel 1	3.F-4	11
Channel 2	3.F-4	12
Channel 3	3.F-4	13
Loop B, Channel 1	3.F-4	14
Channel 2	3.F-4	15
Channel 3	3.F-4	16
Loop C, Channel 1	3.F-4	17
Channel 2	3.F-4	18
Channel 3	3.F-4	19

a. Number shown on Figure 3.F-4.
b. The RVLIS RTDs are located in multiple locations throughout the containment and therefore are not shown on the figures.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.F-7
(SHEET 2 OF 2)
LOCATION OF QUALIFIED EQUIPMENT

	Location	
Component	Figure No.	Identification No.[a]
RCS pressure transmitter		
Channel 1	3.F-4	20
Channel 2	3.F-4	22
Recirculation spray pump		
motors	3.F-4	21
Electrical penetrations	3.F-4	23
Containment isolation check valve	3.F-4	24
Core exit thermocouples	3.F-4	25
RVLIS RTDs	3.F-4	b

a. Number shown on Figure 3.F-4.
b. The RVLIS RTDs are located in multiple locations throughout the containment and therefore are not shown on the figures.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3.F-8

ENVIRONMENTAL TEMPERATURE EVALUATIONS FOR CLASS 1E BOP EQUIPMENT

			Temperature[b,c] Extremes (°F)		Equipment Rating (°F)			
Equipment Identification	Location	Ventilation Systems[a]	Min.	Max.	Min.	Max	Proposed[d] Temperature Monitoring	Reference Standard/Comments
Aux. control and relay panels	Main control room	A	70	80	-	104	No	ANSI C19.3 1973 Section 3-2.3
	Emergency swgr. rm.	A	70	85	-	104	No	
	Instr. rack room	A	70	85	-	104	No	
Elec. penetrations	Cable tunnel	C	70	120	50	280	No	IEEE-317 (1971)[e]
Pressurizer heater control	Rod drive room	B	70	120	32	120	No	NEMA ICS (1974) Section 1-108.01
4-KV switchgear	Emer. swgr. room	A	70	85	-22	104	No	ANSI C37.20 (1974) Section 31 w/htrs.
480V switchgear	Emer. swgr. room	A	70	85	-22	104	No	ANSI C37.20 (1974) Section 3.1
	Rod drive room	B	70	120	–22	133[h]	No	
4-KV motors	Aux. feedwater pump house	B	50	104	50	104	Yes	NEMA MG-2 (1973) Section 3.07 w/htrs.
	Aux. bldg.	B	50	120	50	122	No	
Motor control centers	Emer. swgr. room	A	70	85	32	104	No	NEMA ICS (1974) Section 1-108.01
	Cable tunnel	C	70	120	32	120	No	
	Emer. diesel rooms	C	70	120	32	120	No	
	SWPH	B	70	120	32	120	No	
Emer. diesel generator	Emer. diesel room	C	70	120	32	120	No	(f)

Note: See last page of Table for footnotes.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant. (continued)

Table 3.F-8

ENVIRONMENTAL TEMPERATURE EVALUATIONS FOR CLASS 1E BOP EQUIPMENT

Equipment Identification	Location	Ventilation Systems[a]	Temperature[b,c] Extremes (°F) Min.	Temperature[b,c] Extremes (°F) Max.	Equipment Rating (°F) Min.	Equipment Rating (°F) Max	Proposed[d] Temperature Monitoring	Reference Standard/Comments
Main control board	Main control room	A	70	80	-	104	No	ANSI C19.3 (1973) Section 3-2.3
Batteries	Emer. swgr. room	D[g]	70	85	60	85	No	Manufacturer's rating
	Cable spreading room	D[g]	70	85	60	85	No	
Battery charger	Emer. swgr. room	A	70	85	32	113	No	Manufacturer's rating
125V dc distr. panel	Emer. swgr. room	A	70	85	32	104	No	NEMA AB-1 (1975)
	Main control room	A	70	80	32	104	No	Section 2.04
GE relays	Main control room	A	70	80	-4	131	No	C37.90 (1971)
	Emer. swgr room	A	70	85	-4	131	No	Section 6.1.1
Westinghouse relays	Main control room	A	70	80	-4	131	No	C37.90 (1971)
	Emer. swgr. room	A	70	85	-4	131	No	Section 6.1.1
Inverters	Emer. swgr. room	A	70	85	32	125	No	Manufacturer's rating No apparent standard
Ac distr. panels	Main control room	A	70	80	32	104	No	NEMA AB-1 (1975)
	rod drive room	B	70	120	32	140	No	Section 2.04
Service water pumps	SWPH	B	70	120	32	158	No	Manufacturer's rating NEMA MG-2 Section 3.07

Note: See last page of Table for footnotes.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant. (continued)

Table 3.F-8

ENVIRONMENTAL TEMPERATURE EVALUATIONS FOR CLASS 1E BOP EQUIPMENT

Equipment Identification	Location	Ventilation Systems[a]	Temperature[b,c] Extremes (°F) Min.	Max.	Equipment Rating (°F) Min.	Max	Proposed[d] Temperature Monitoring	Reference Standard/Comments
Traveling water screens	SWPH	B	70	120	32	104	Yes	Manufacturer's rating NEMA MG-2 Section 3.07
Service water ventilation	SWPH	B	70	120	32	120	No	Manufacturer's rating NEMA MG-2 Section 3.07
Outside recir. spray	Safeguards area	B	70	120	50	158	No	Manufacturer's rating NEMA MG-2 3.07 w/htrs.
Instr. air compressors	Aux. bldg.	B	50	120	32	122	No	NEMA MG-2 3.07
Quench spray	Quench spray house	C	70	120	32	122	No	Manufacturer's rating NEMA MG-2 3.07
Refrigeration equipment	Chiller rooms	D	70	104	32	104	No	NEMA MG-2 (1973) Section 3.07
Control room vent.	Control and ac rooms	A	70	80	32	104	No	NEMA MG-2 (1973) Section 3.07
Heat tracing control	Aux. bldg.	C	50	120	40	120	No	Manufacturer's rating
Aux. bldg. centralex fans	Aux. bldg.	B	50	120	-	149	No	Manufacturer's rating
Post-DBA recombiner	Recombiner vault	B	15	120	-	194	No	Manufacturer's rating

Note: See last page of Table for footnotes.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant. (continued)

Table 3.F-8

ENVIRONMENTAL TEMPERATURE EVALUATIONS FOR CLASS 1E BOP EQUIPMENT

Equipment Identification	Location	Ventilation Systems[a]	Temperature[b,c] Extremes (°F) Min.	Temperature[b,c] Extremes (°F) Max.	Equipment Rating (°F) Min.	Equipment Rating (°F) Max	Proposed[d] Temperature Monitoring	Reference Standard/Comments
Diesel exhaust fan	Emer. diesel room	C	70	104	32	120	No	NEMA MG-2 3.07
Emer. diesel fuel-oil transfer pump	Fuel-oil pump house	C	15	104	32	167	No	NEMA MG-2 3.07
Safeguards area exhaust	Aux. bldg.	B	50	120	32	122	No	NEMA MG-2 3.07 (1973)
Spent-fuel cooling pumps	Fuel building	C	70	120	32	122	No	Manufacturer's rating
Emer. swgr. ac	Ac equip. room	A	70	85	32	104	No	NEMA MG-2 Section 3.07 (1973)
Chiller room sump pump	Chiller room	D	70	104	32	104	No	NEMA MG-2 Section 3.07 (1973)
Battery room fans	Emer. swgr. room	A	70	85	32	104	No	NEMA MG-2 Section 3.07 (1973)
Radiation monitors	Main steam valve house	C	40	120	32	120	No	Manufacturer's rating
SW motor operators	SWPH	B	70	120	32	122	No	Manufacturer's rating
	Intake structure	B	70	120	32	122	No	Qualified to IEEE 382-1972

Note: See last page of Table for footnotes.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant. (continued)

Table 3.F-8

ENVIRONMENTAL TEMPERATURE EVALUATIONS FOR CLASS 1E BOP EQUIPMENT

			Temperature[b,c] Extremes (°F)		Equipment Rating (°F)			
Equipment Identification	Location	Ventilation Systems[a]	Min. /	Max.	Min. /	Max	Proposed[d] Temperature Monitoring	Reference Standard/Comments
	Aux. bldg.	C	50	120	32	122	No	
	Main steam valve house	C	40	120	32	122	No	

Note: See last page of Table for footnotes.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table 3F-8 (continued)

ENVIRONMENTAL TEMPERATURE EVALUATIONS FOR CLASS 1E BOP EQUIPMENT

a. Air conditioning and ventilation systems:
   A. Class 1E redundant air conditioning systems.
   B. Class 1E redundant ventilation systems.
   C. Normally powered single train ventilation system.
   D. Class 1E powered single train ventilation system.

b. The maximum and minimum temperatures for a given area of the plant were based on the following assumptions:
   1. Those areas served by redundant Class 1E powered air conditioning systems continue to operate at the normal control temperatures for the air conditioning system.
   2. Those areas served by Class 1E redundant ventilation systems assume the loss of one train of ventilation and the design climatic conditions for the site.
   3. Those areas served by normally powered single train ventilation systems or Class 1E powered single train ventilation systems assume a loss of powered ventilation in those areas.
   4. All calculations for maximum temperatures assume normal running machinery and the associated heat load from that machinery during the ventilation failure.
   5. Site design climatic conditions were obtained from ASHRAE, Handbook of Fundamentals, 1972 Edition, Table of Climatic Conditions for the United States and Canada (Richmond, Virginia data).

c. All heating systems are considered nonseismic, non-safety-related single train systems and, for all temperature extremes listed in the table, the heating system is considered to fail; however, ventilation systems equipped with minimum temperature thermostatic controls were assumed to operate, and the minimum temperatures listed have been calculated considering normal heat loss from the area and heat generated by the equipment. In those cases where normally running equipment is not found in a given area, e.g., hydrogen recombiner vault, the minimum temperatures listed by ASHRAE have been used.

d. The proposed area ambient temperature monitors in the locations identified in the table will alarm to inform the operator when an abnormal temperature is occurring in the given area. Operator action will include an investigation as to the cause of the high temperature condition and the initiation of portable emergency ventilation or, in the case where running machinery in a given space is not required, shutdown of nonessential machinery to reduce ambient air temperature. See Section 7.1.3.2.4 for additional information.

e. Electrical penetrations are rated and tested for all possible environmental conditions, including LOCA. Each installation is thus unique, and there are no “standard” conditions.

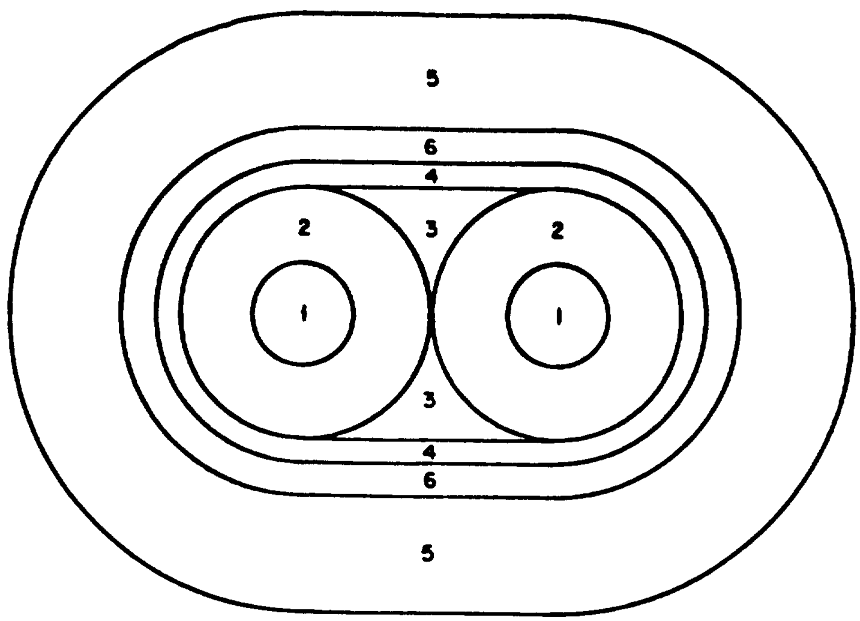
f. Diesel generator:
   1. Controls are rated for 32°F to 120°F. Reference Engineering Transmittal N-06-0043, *Evaluation of Emergency Diesel Generator Ambient Room Temperatures.*
   2. The diesel generator has keep-warm heaters for lube oil and jacket water to guarantee starting in the 15° to 120°F ambient temperature range. (There are no industry standard requirements for ambient environmental conditions.)

g. Battery room fans take suction from the emergency switchgear or main control rooms, which have Type A (see Note a) air conditioning systems.

h. The switchgear can tolerate an ambient temperature of 133°F if they are not loaded over 87%.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.F-1
CROSS SECTION - 300V INSTRUMENT CABLE



TYPE OF CABLE:

2/C #16 OVERALL SHIELD 25 MILS XLPE INSULATION.
45 MILS OVERALL NEOPRENE JACKET .38" OVERALL DIAMETER.

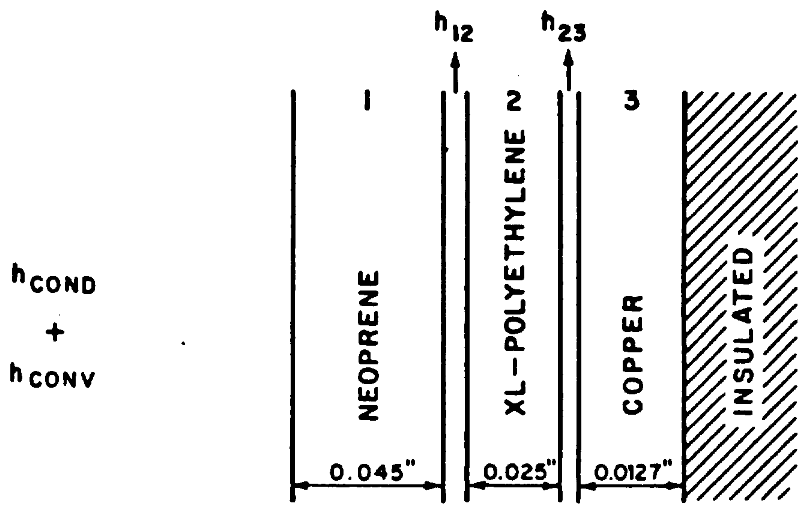
REGION:

1) NO. 16 AWG. COPPER CONDUCTOR.
2) 25 MILS (.025") XLPE INSULATION.
3) AIR SPACE DIMENSION ASSUMED SMALL.
4) OVERALL ALUMINUM FOIL SHIELD - 2 MILS (.0020") THICK.
5) OVERALL NEOPRENE JACKET - 65 MILS (.045") THICK.
6) ASBESTOS BINDING TAPE 6 MILS (.006").

N03F0001

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.F-2
ELECTRICAL INSTRUMENTATION CABLE MODEL



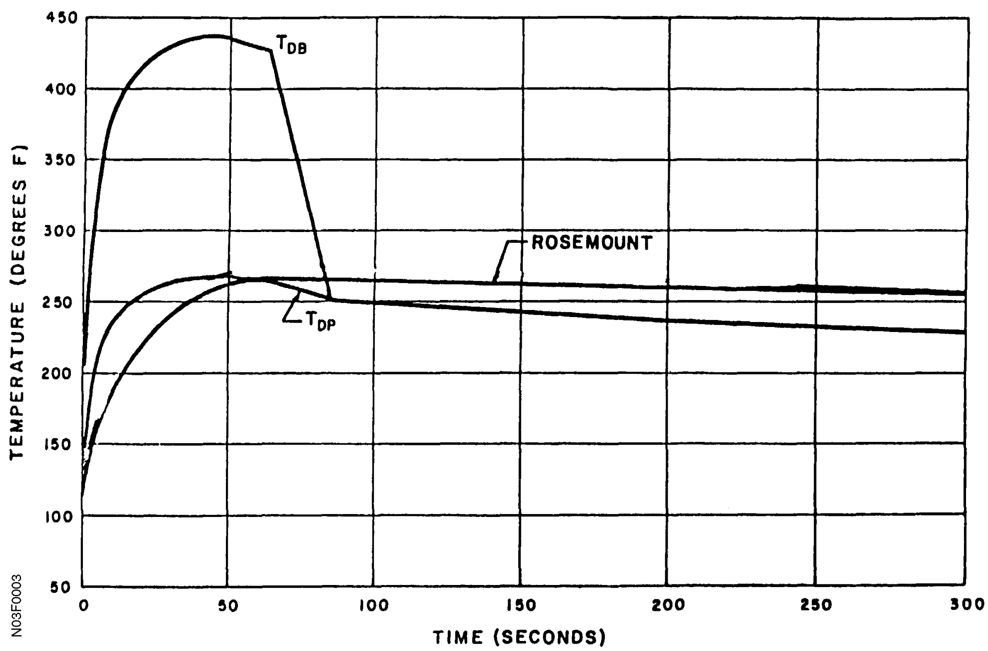
NOTES:

1) NO SURFACE PAINT.
2) h_{12} = 174 BTU/HR-FT^2-F BASED ON 6 MILS OF ASBESTOS BINDING TAPE.
3) h_{23} = 1000 BTU/HR-FT^2-F BASED ON AN ASSUMED GAP OF 0.1 MIL (INCREASES SURFACE TEMPERATURE). ACTUAL DESIGN CALLS FOR INTIMATE CONTACT.
4) INITIAL TEMPERATURE = 194 F.

N03F0002

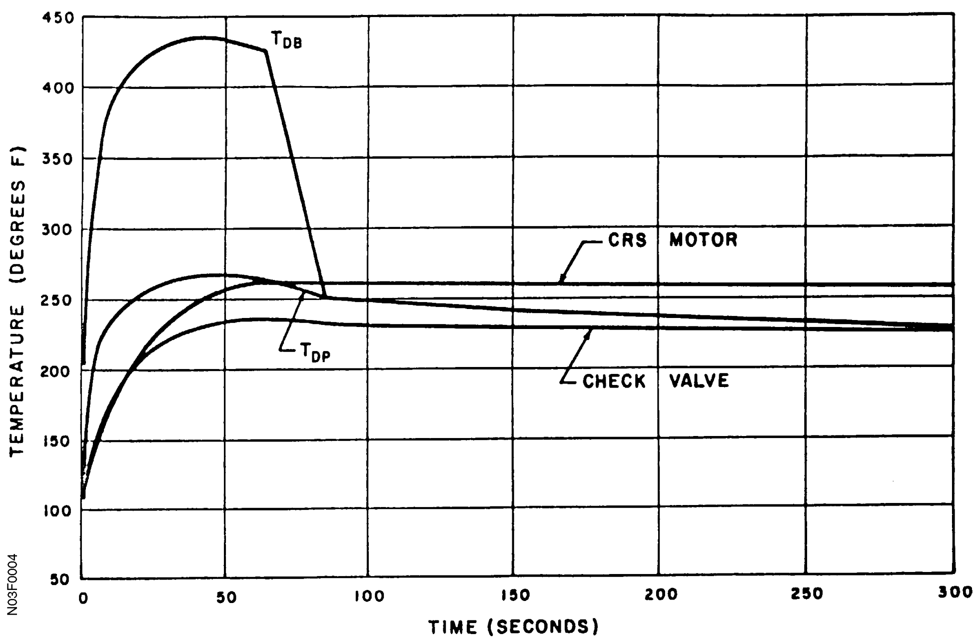
The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.F-3
(SHEET 1 OF 4)
SAFETY RELATED EQUIPMENT SURFACE TEMPERATURE TRANSIENTS, LIMITING MAIN STEAM LINE BREAK



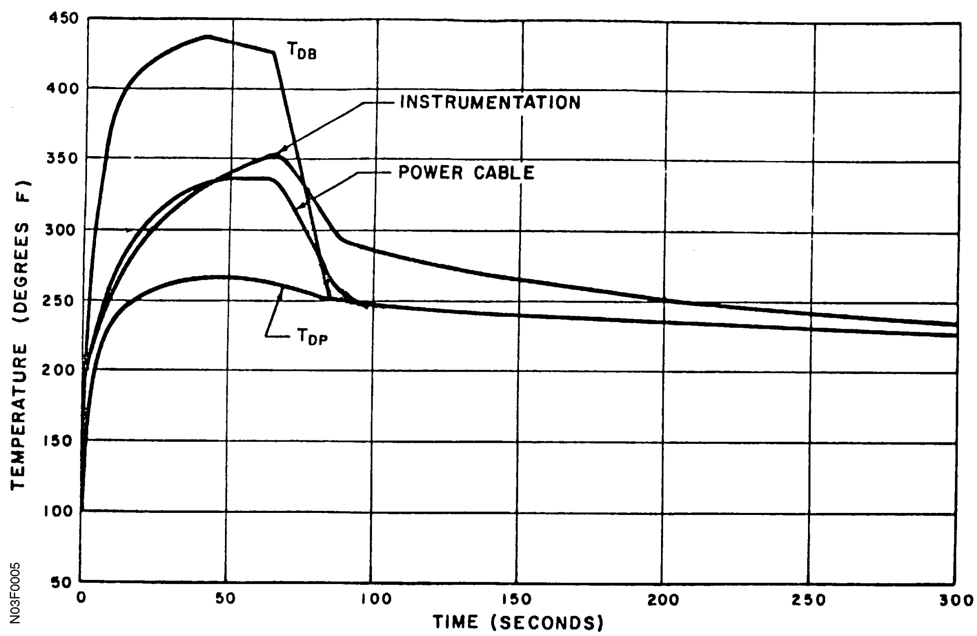
The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3F-3
(SHEET 2 OF 4)
SAFETY RELATED EQUIPMENT SURFACE TEMPERATURE TRANSIENTS,
LIMITING MAIN STEAM LINE BREAK



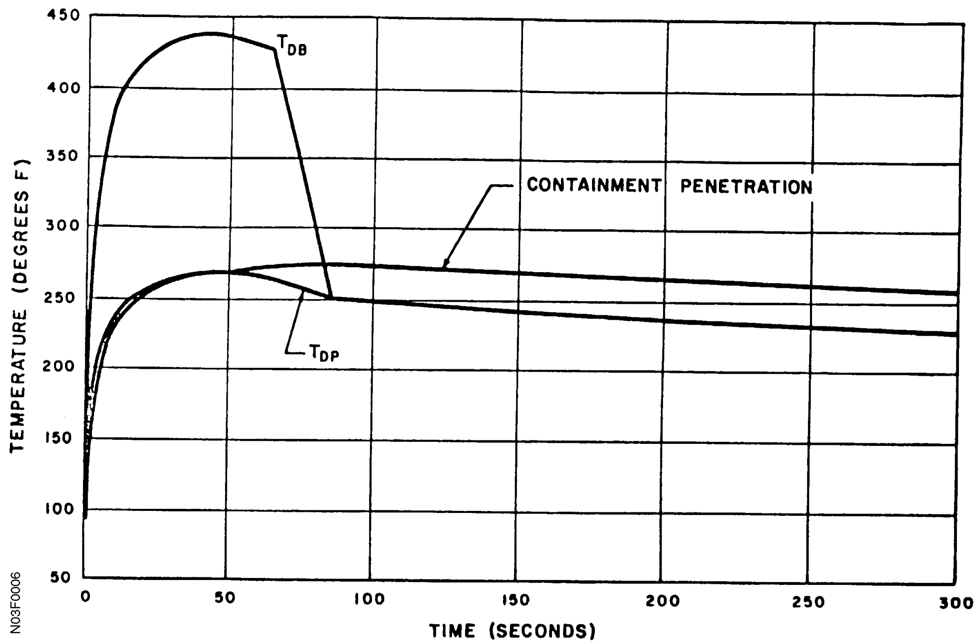
The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3F-3
(SHEET 3 OF 4)
SAFETY RELATED EQUIPMENT SURFACE TEMPERATURE TRANSIENTS, LIMITING MAIN STEAM LINE BREAK



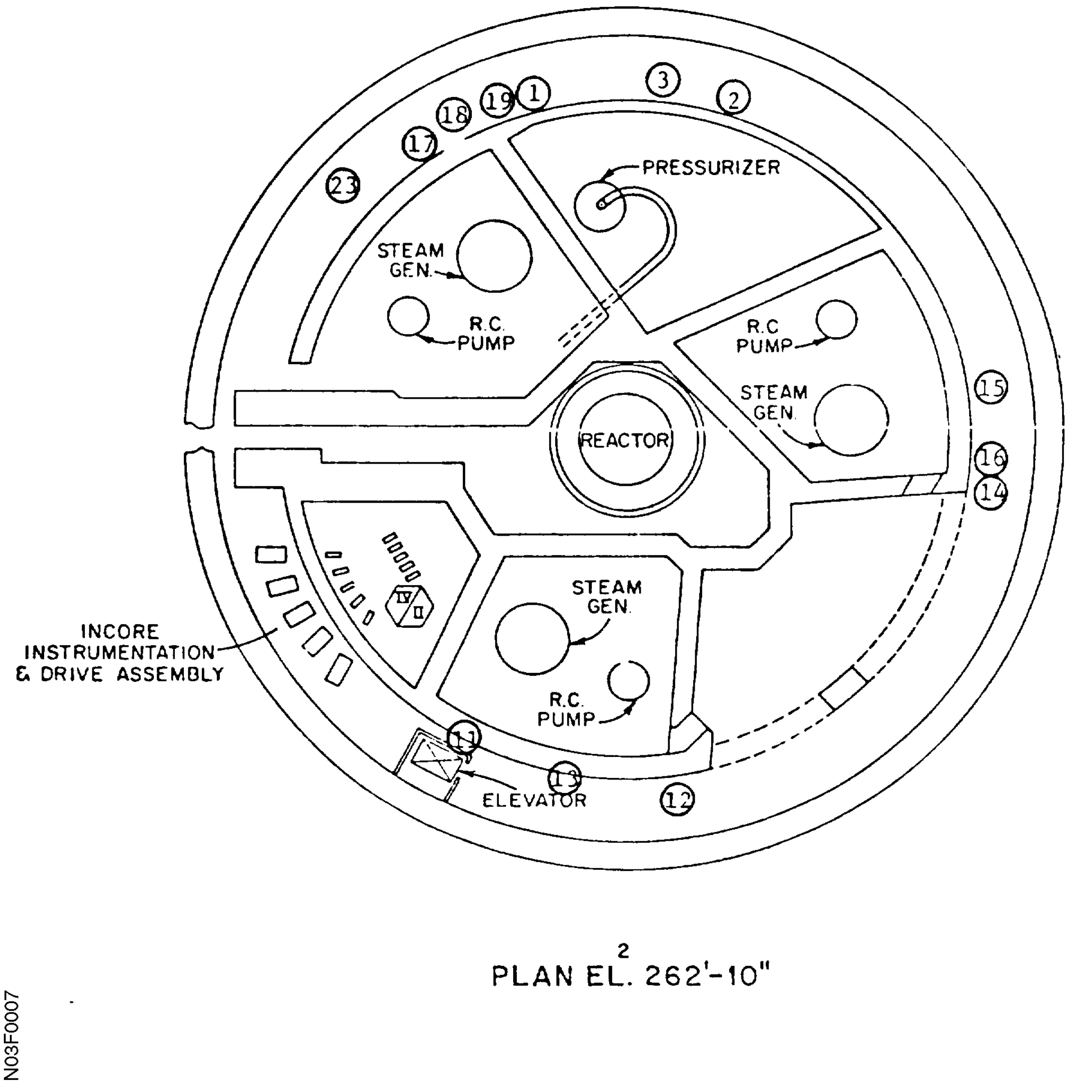
The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3F-3
(SHEET 4 OF 4)
SAFETY RELATED EQUIPMENT SURFACE TEMPERATURE TRANSIENTS, LIMITING MAIN STEAM LINE BREAK



The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

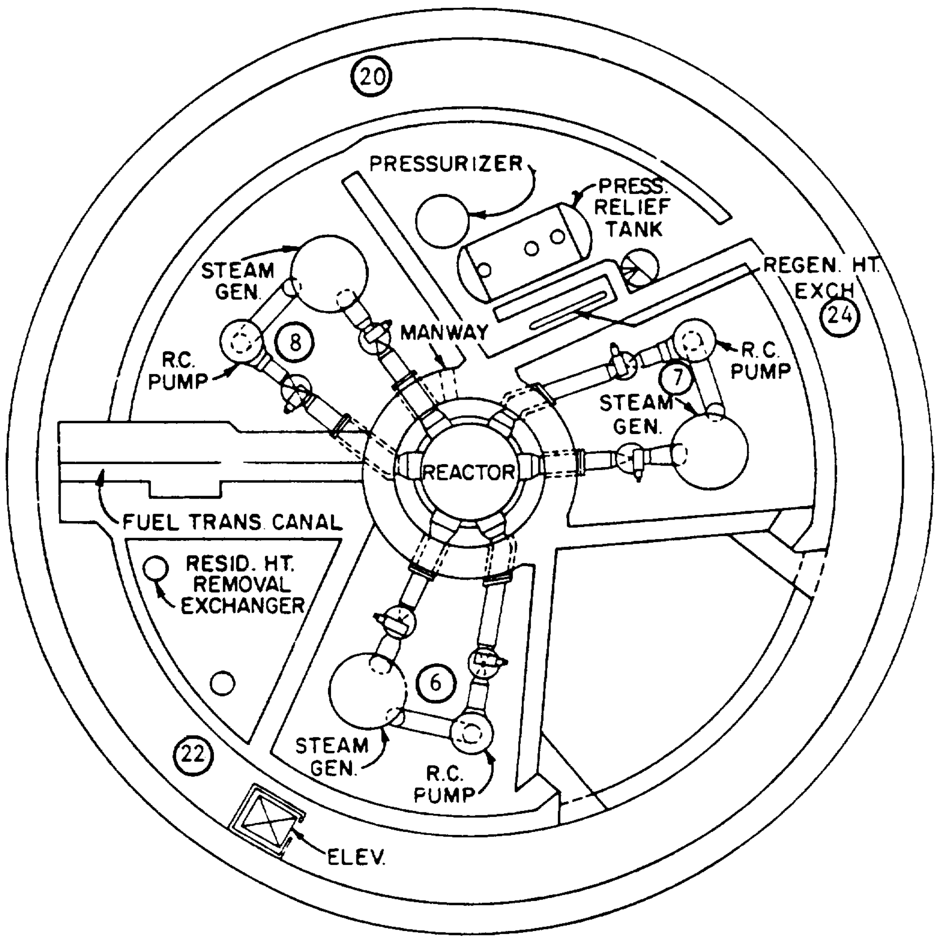
Figure 3.F-4 (SHEET 1 OF 4) 3CONTAINMENT STRUCTURE



Note: See Table 3F-7 for identification of the instrumentation associated with the numbers encircled.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3F-4 (SHEET 2 OF 4) CONTAINMENT STRUCTURE



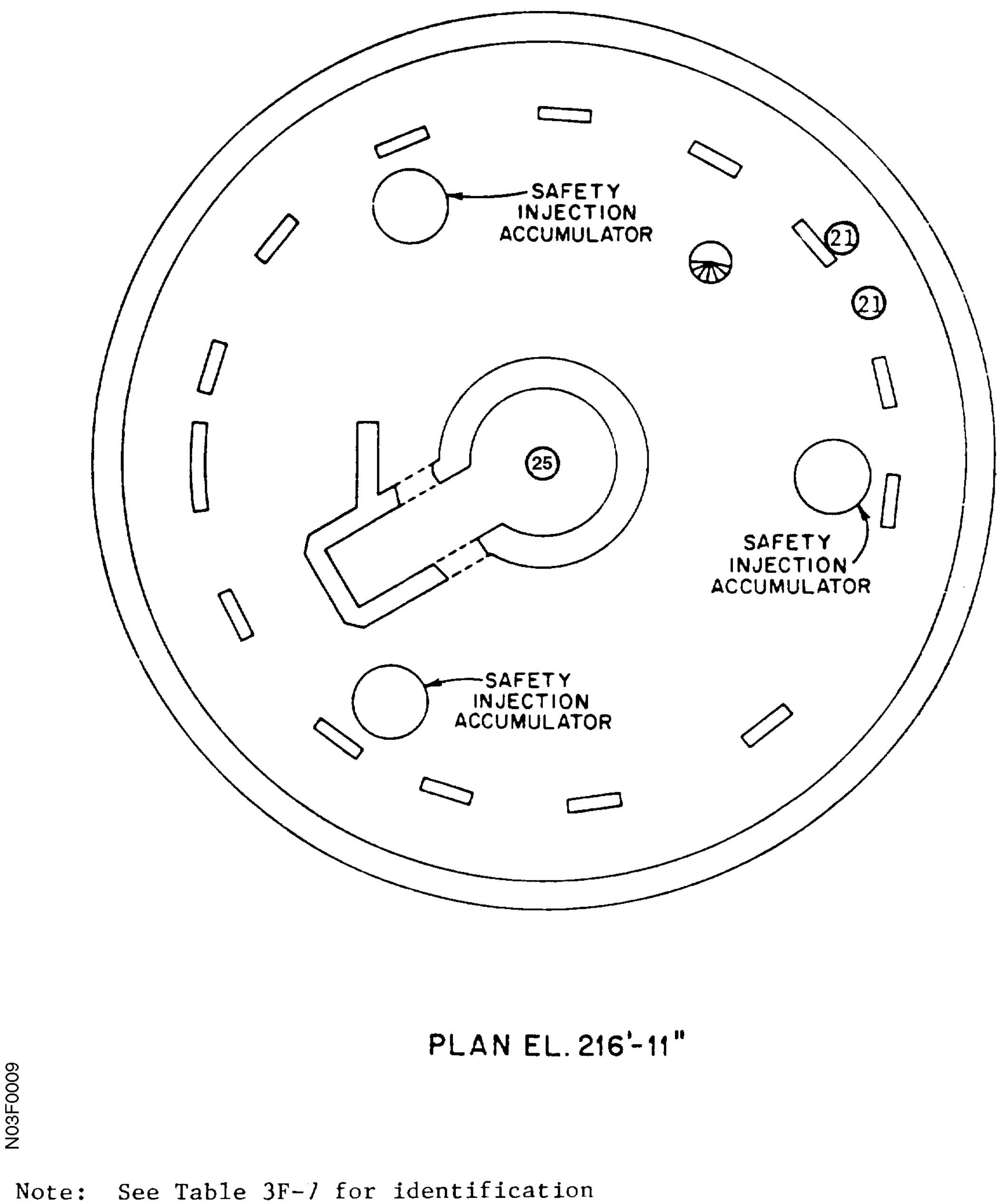
PLAN EL. 241'-0"

N03F0008

Note: See Table 3F-7 for identification of the instrumentation associated with the numbers encircled.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

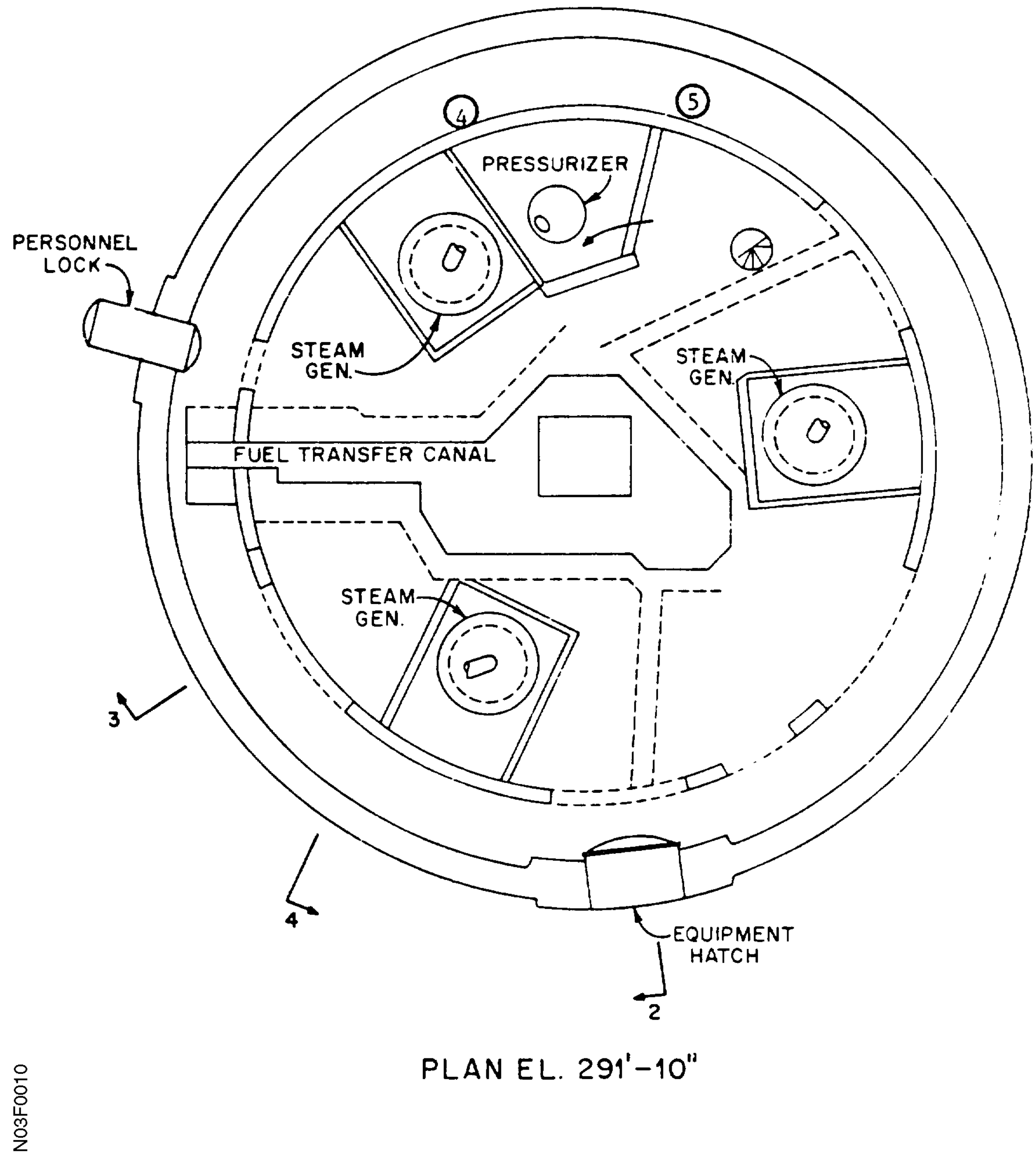
Figure 3F-4
(SHEET 3 OF 4) CONTAINMENT STRUCTURE



Note: See Table 3F-7 for identification of the instrumentation associated with the numbers encircled.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

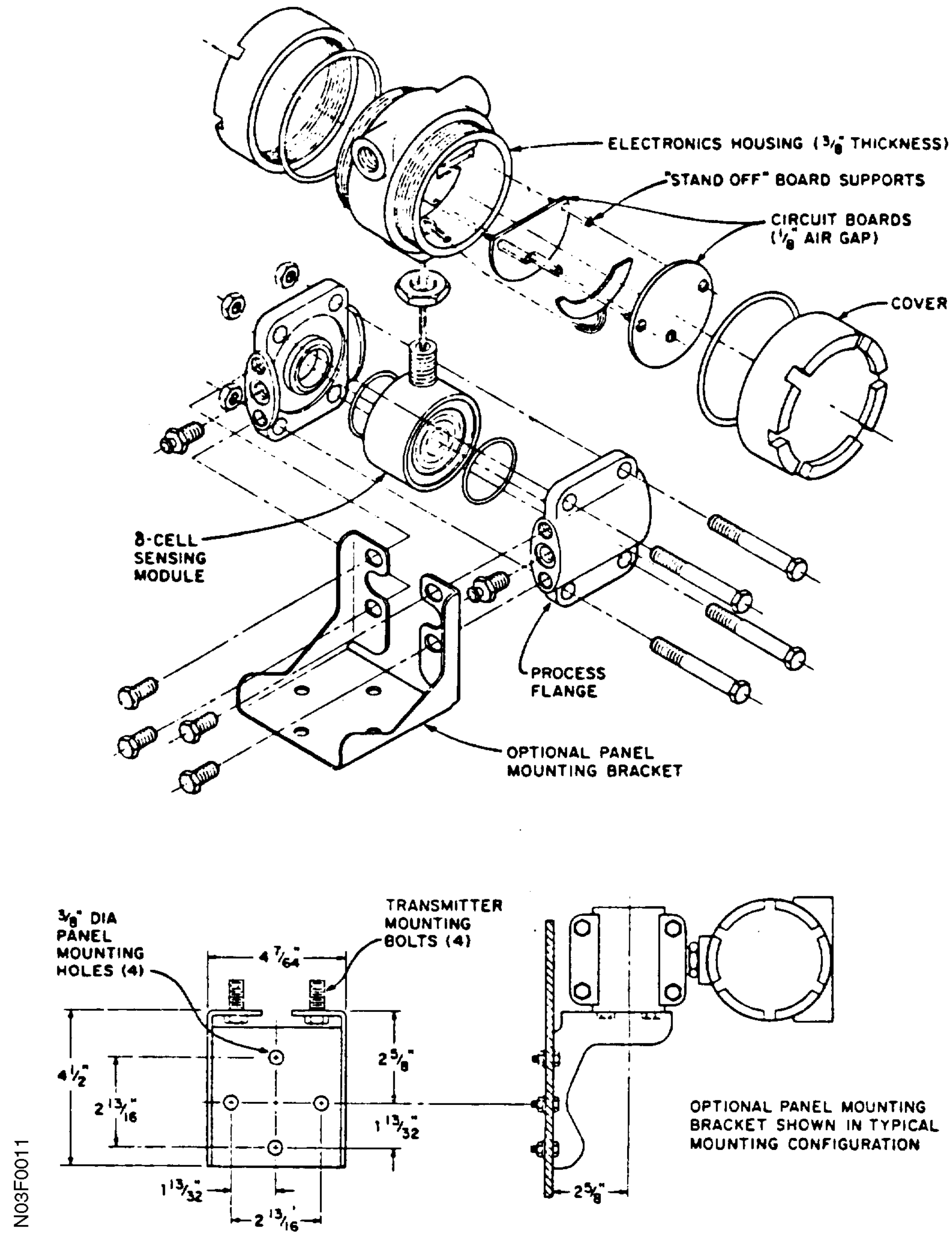
Figure 3F-4
(SHEET 4 OF 4) CONTAINMENT STRUCTURE



Note: See Table for identification of the instrumentation associated with the numbers circled.

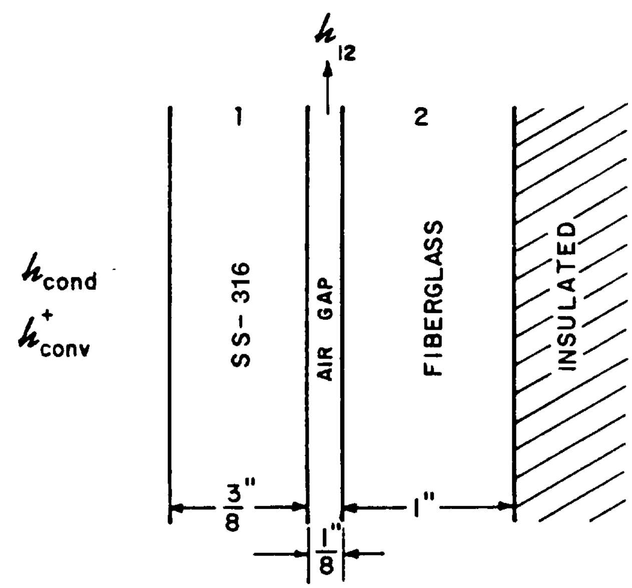
The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.F-5
PT-403-SYSTEM WIDE RANGE PRESSURE TRANSMITTER



The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.F-6
ROSEMOUNT PRESSURE TRANSDUCER MODEL

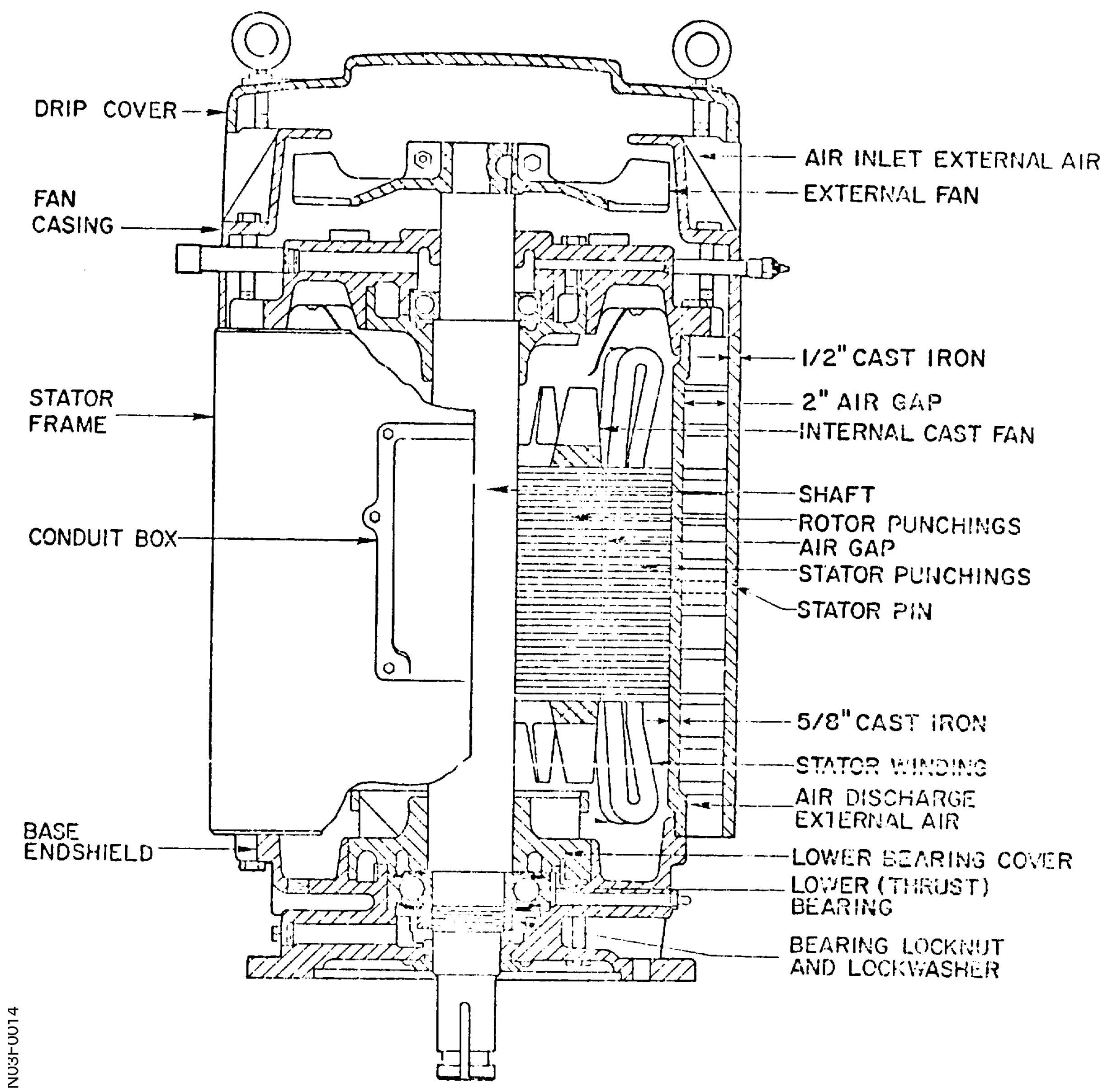


NOTE:
1. NO SURFACE PAINT
2. h_{12} = 0.05 BTU/HR.- FT^2 -F BASED ON A 3.7 INCH GAP BUT USING 0.05 BTU/HR.- FT^2- F MAXIMIZES SURFACE TEMPERATURE.
3. INITIAL UNIFORM TEMPERATURE = 105 F.

N03F0012

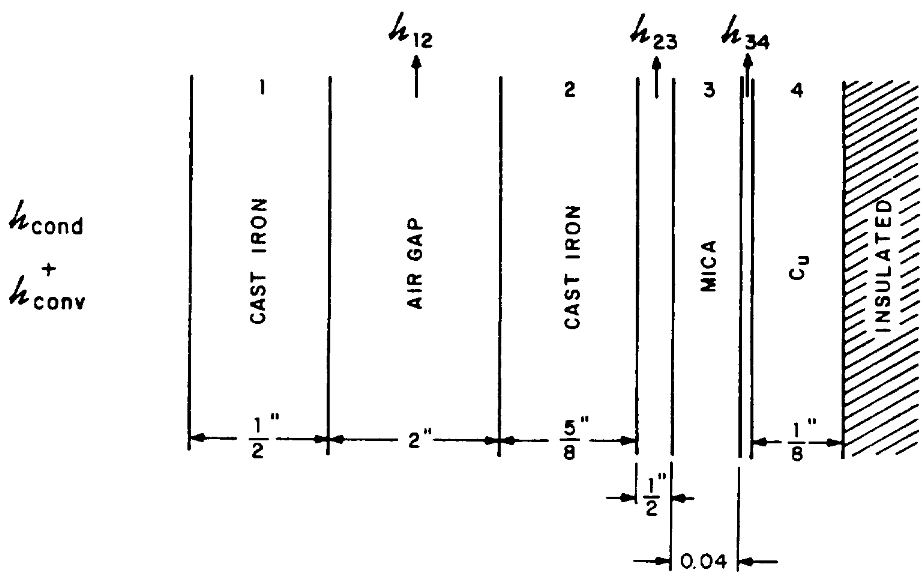
The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.F-7
INSIDE RECIRCULATION SPRAY PUMP MOTOR



The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.F-8
CONTAINMENT RECIRCULATION PUMP MOTOR MODEL



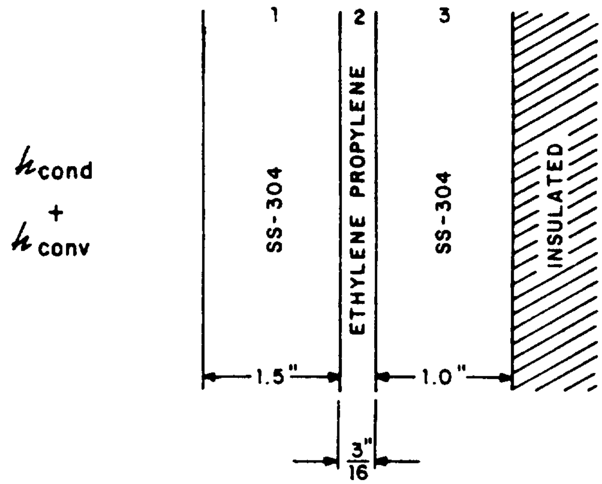
NOTE:

1. NO SURFACE PAINT. ACTUAL DESIGN CALLS FOR PAINT BUT ASSUMING NONE MAXIMIZE CAST IRON SURFACE TEMPERATURE.
2. h_{12} = 0.0924 BTU/HR-FT^2-F
3. h_{23} = 0.37 BTU/HR-FT^2-F. NEGLECTS CONDUCTION THROUGH STATOR PUNCHINGS, BUT MAXIMIZES SURFACE TEMPERATURE.
4. h_{34} = 1000. BTU/HR-FT^2-F. BASED ON AN ASSUMED GAP OF 0.1 MIL/S. ACTUAL DESIGN CALLS FOR INTIMATE CONTACT.
5. INITIAL UNIFORM TEMPERATURE = 105 F.

N03F0015

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

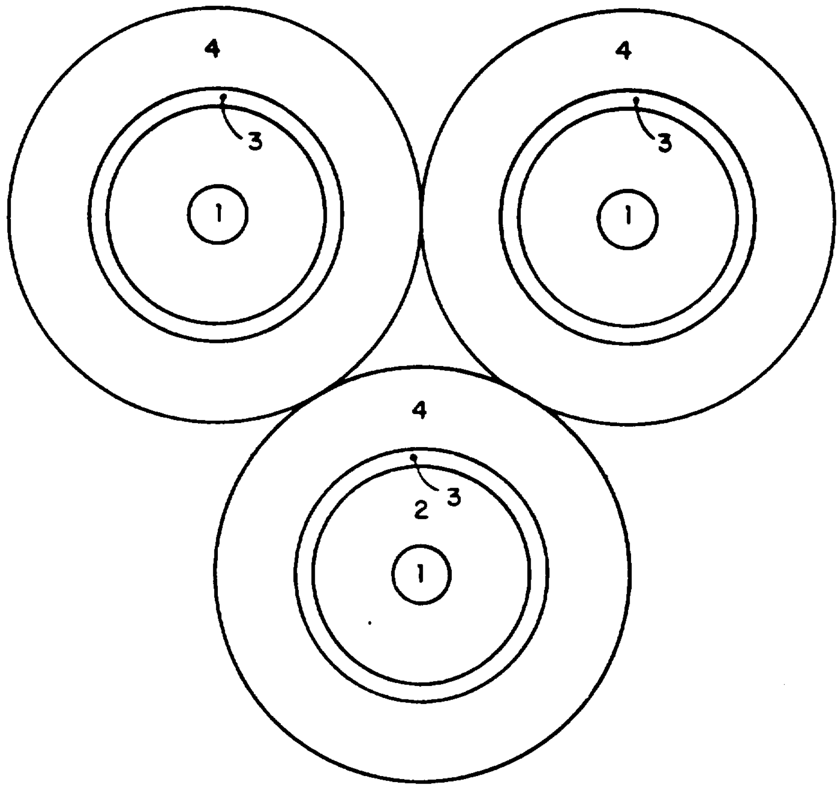
Figure 3.F-9
CONTAINMENT ISOLATION CHECK VALVE MODEL



NOTE:
1. NO SURFACE PAINT
2. SLABS ARE IN INTIMATE CONTACT.
3. INITIAL UNIFORM TEMPERATURE = 105 F.

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.F-10
CROSS SECTION - POWER CABLE



TYPE OF CABLE:

TRIPLEX 250 MCM, 95 MILS SILICONE INSULATED,
40 MILS ASBESTOS RUBBER

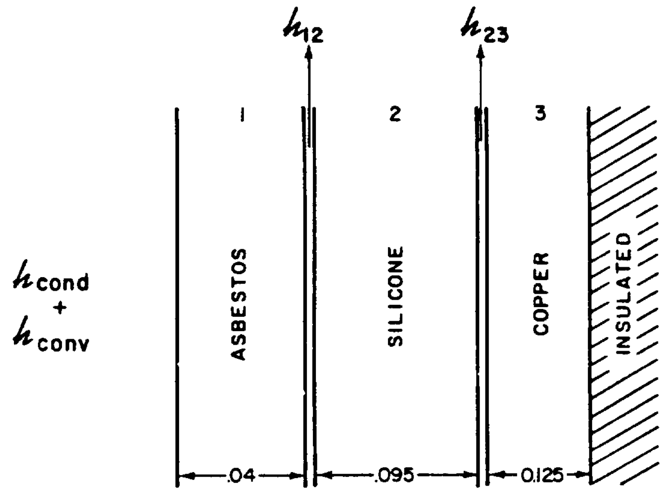
REGION:

1) 250 M.C.M. COPPER CONDUCTORS
2) 95 MILS SILICONE INSULATION
3) SILICONE COATED GLASS CLOTH TAPE (DIMENSION SMALL)
4) 40 MILS (.040") ASBESTOS JACKET

N03F0017

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.F-11
ELECTRICAL POWER CABLE MODEL



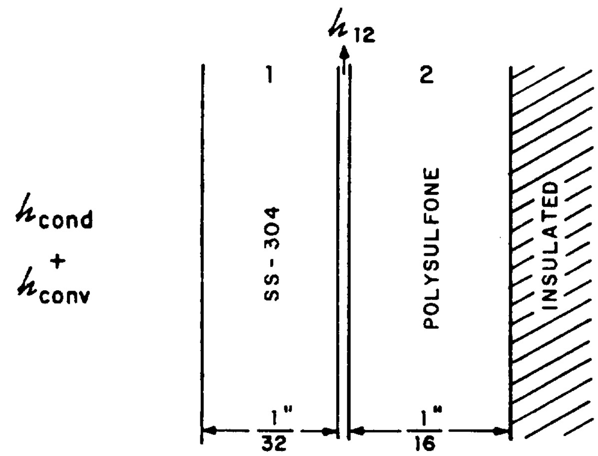
NOTE:

1. NO SURFACE PAINT
2. $h_{12} = h_{23}$ = 1000. BTU/HR-FT^2-F BASED ON AN ASSUMED GAP OF 0.1 MIL (INCREASES SURFACE TEMPERATURE). ACTUAL DESIGN CALLS FOR INTIMATE CONTACT.
3. INITIAL UNIFORM TEMPERATURE = 194 F.

N03F0018

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.F-12
CONTAINMENT PENETRATION MODEL



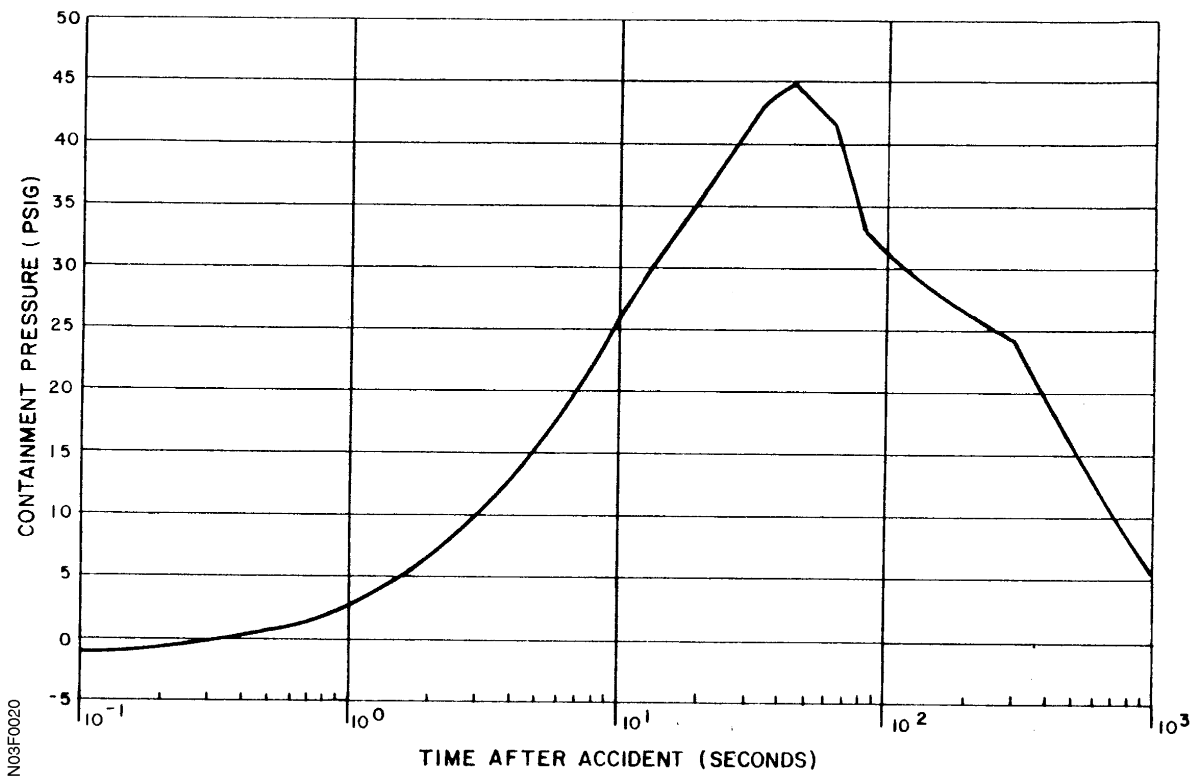
NOTE:

1. NO SURFACE PAINT
2. h_{12} = 100. BTU/HR.-FT^2-F BASED ON AN ASSUMED GAP OF 2 MILS. ACTUAL DESIGN CALLS FOR INTIMATE CONTACT BECAUSE POLYSULFONE IS THE SEAL
3. INITIAL UNIFORM TEMPERATURE = 105 F.

N03F0019

The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.F-13
CONTAINMENT ATMOSPHERE PRESSURE, 4.9 SQ FT. STEAM LINE BREAK UPSTREAM OF FLOW RESTRICTOR, 0 PERCENT POWER, MAXIMUM PRESSURE, 9 FPS BUBBLE RISE VELOCITY



The following information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure 3.F-14
CONTAINMENT ATMOSPHERE TEMPERATURE, 4.9 SQ FT. STEAM LINE BREAK UPSTREAM OF FLOW RESTRICTOR, 0 PERCENT POWER, MAXIMUM PRESSURE, 9 FPS BUBBLE RISE VELOCITY