SMUD

SACRAMENTO MUNICIPAL UTILITY DISTRICT

RANCHO SECO NUCLEAR GENERATING STATION
UNIT NO. 1

SUPPLEMENT NO. 2

PRELIMINARY SAFETY ANALYSIS REPORT

0002

DOCKET 50-312

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JULY 1969

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BEFORE THE UNITED STATES ATOMIC ENERGY COMMISSION

In the Matter of	)	Docket No. 50-312
	)	
SACRAMENTO MUNICIPAL UTILITY DISTRICT	)	
(Rancho Seco)	)	Supplement No. 2

Now comes SACRAMENTO MUNICIPAL UTILITY DISTRICT and amends its above numbered application by submitting herewith Supplement No. 2. This supplement reflects a change in the type of tendon used for the reactor containment building post-tensioning system, and in the type of cooling tower used for power conversion cycle heat rejection.

Subscribed in Sacramento, California, this 10th day of July, 1969.

Respectfully submitted,

SACRAMENTO MUNICIPAL UTILITY DISTRICT

By____________________________
Paul E. Shaad
General Manager and Chief Engineer

E. K. Davis
DAVID S. KAPLAN
Attorneys for Sacramento
Municipal Utility District

By____________________________
David S. Kaplan

Subscribed and sworn to before me this 10th day of July, 1969.

VIOLET PHELPS
NOTARY PUBLIC
SACRAMENTO CO., CALIF.
Commission Expires 7/11/69

____
Violet Phelps, Notary Public in and for the County of Sacramento, State of California.

My Commission expires July 11, 1969.

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Docket No. 50-312
July 15, 1969

SUPPLEMENT NO. 2

SACRAMENTO MUNICIPAL UTILITY DISTRICT

RANCHO SECO NUCLEAR GENERATING STATION

UNIT NO. 1

Supplement No. 2 to Sacramento Municipal Utility District's Preliminary Safety Analysis Report reflects three changes:

a) A change in the type of tendon system proposed for the prestressed reactor containment building. An updated Section 5 incorporating the VSL tendon system is included together with a description of the system and SMUD's analysis of it in Appendix 5K. This portion of the supplement answers questions raised in AEC's letter dated February 27, 1969, Item 7 as it pertains to the tendon system.

b) A change in containment liner plate material to ASTM A285. Opportunity has been taken to present additional data on containment liner anchorages as requested in item 13 of AEC's letter of February 27, 1969.

c) A change in the type of cooling tower used for heat rejection in the power conversion cycle from mechanical draft to two natural draft hyperbolic towers. These structures, each 425 ft. high and 310 feet base diameter, are shown on Figures 1.1-2 and 1.1-3 attached.

It is noted that some form of blowdown is normally associated with hyperbolic cooling towers, and such will be the case at Rancho Seco. However, note that SMUD has no present plan to introduce radioactive wastes into the effluent from this blowdown system. SMUD will maintain the water quality in this blowdown to meet the State of California requirements for Class II irrigation water.


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TO CLAY
SEE DWG C-153 FOR GRADING
NUCLEAR SERVICE SPRAY POND
HYPERBOLIC COOLING TOWERS
INTAKE STRUCTURE
REACTOR
ADMIN
BECHTEL TRAILER SITE
WAREHOUSE & SHOPS
SWITCHYARD
CONSTRUCTION OFFICE
FUTURE UNIT 2
DUE SOUTH 110'
BOUNDARY RADIO STATION LEASE
ACCESS ROAD TO CLAY EAST ROAD
EXISTING GRAVEL SURFACED 20' WIDE ROAD

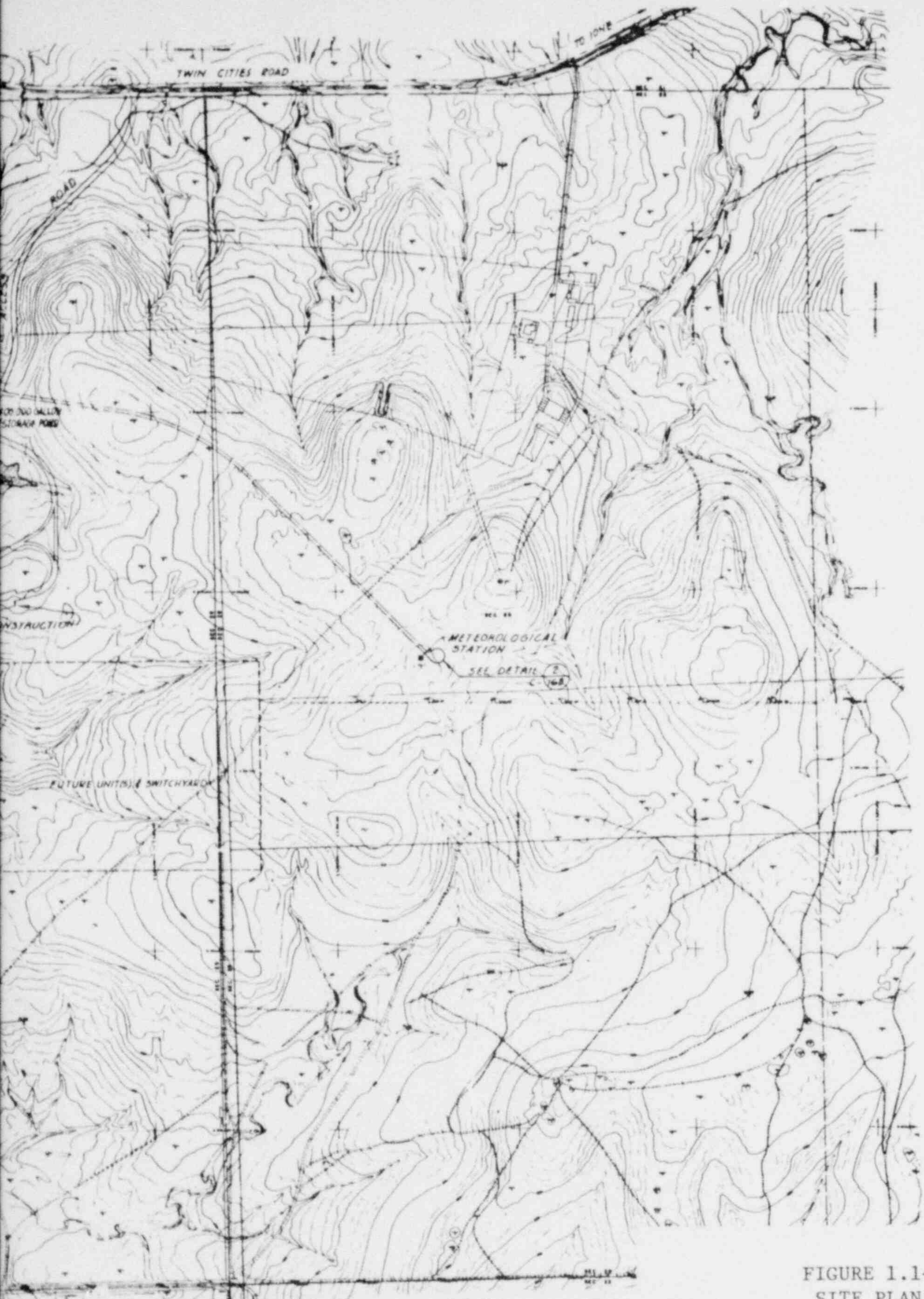

FIGURE 1.1-2
SITE PLAN

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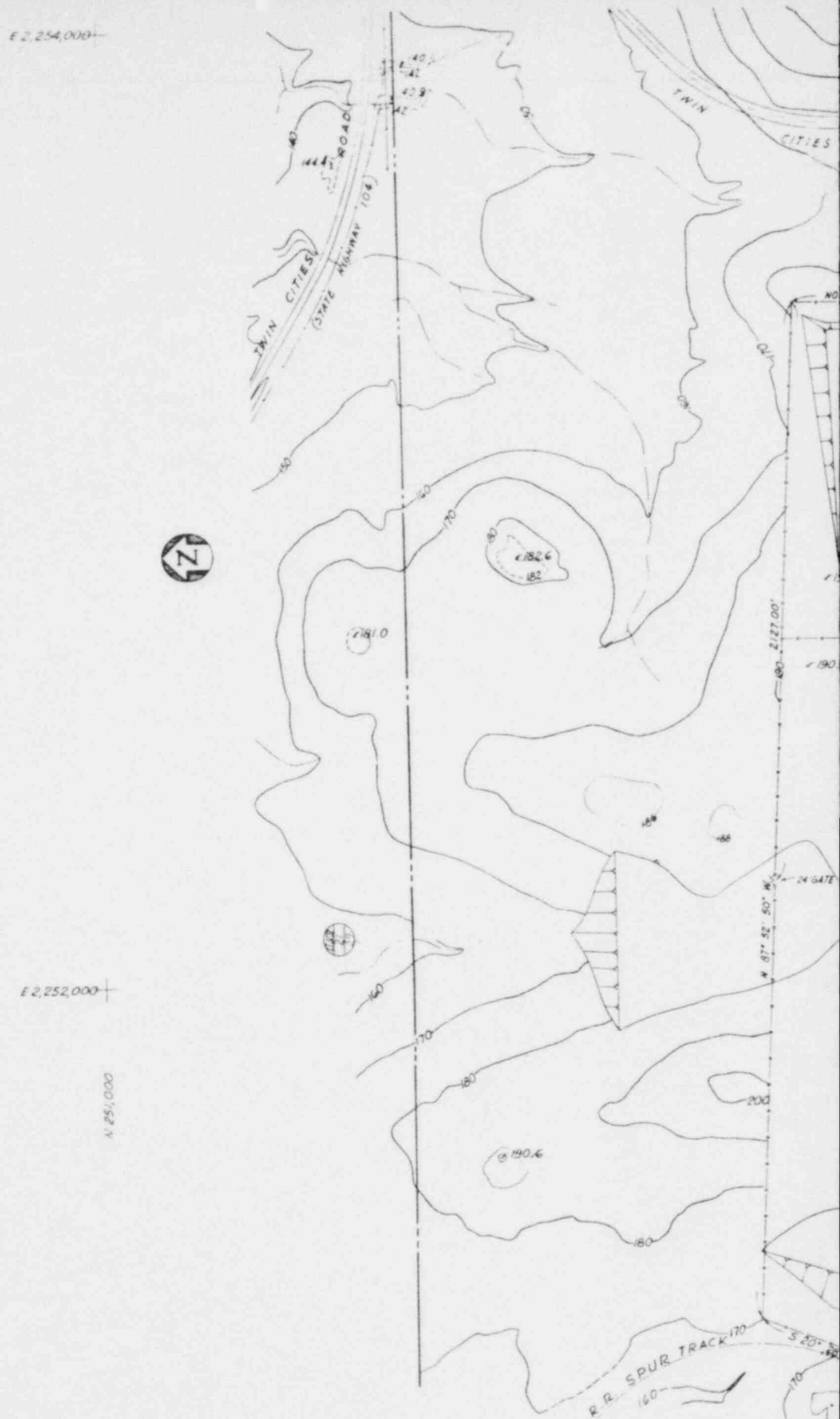
E 2,254,000
TWIN CITIES ROAD
STATE HIGHWAY 104
TWIN CITIES
E 2,252,000
N 251,000
R.R. SPUR TRACK
24' GATE
N 87° 52' 50" W
2127.00'

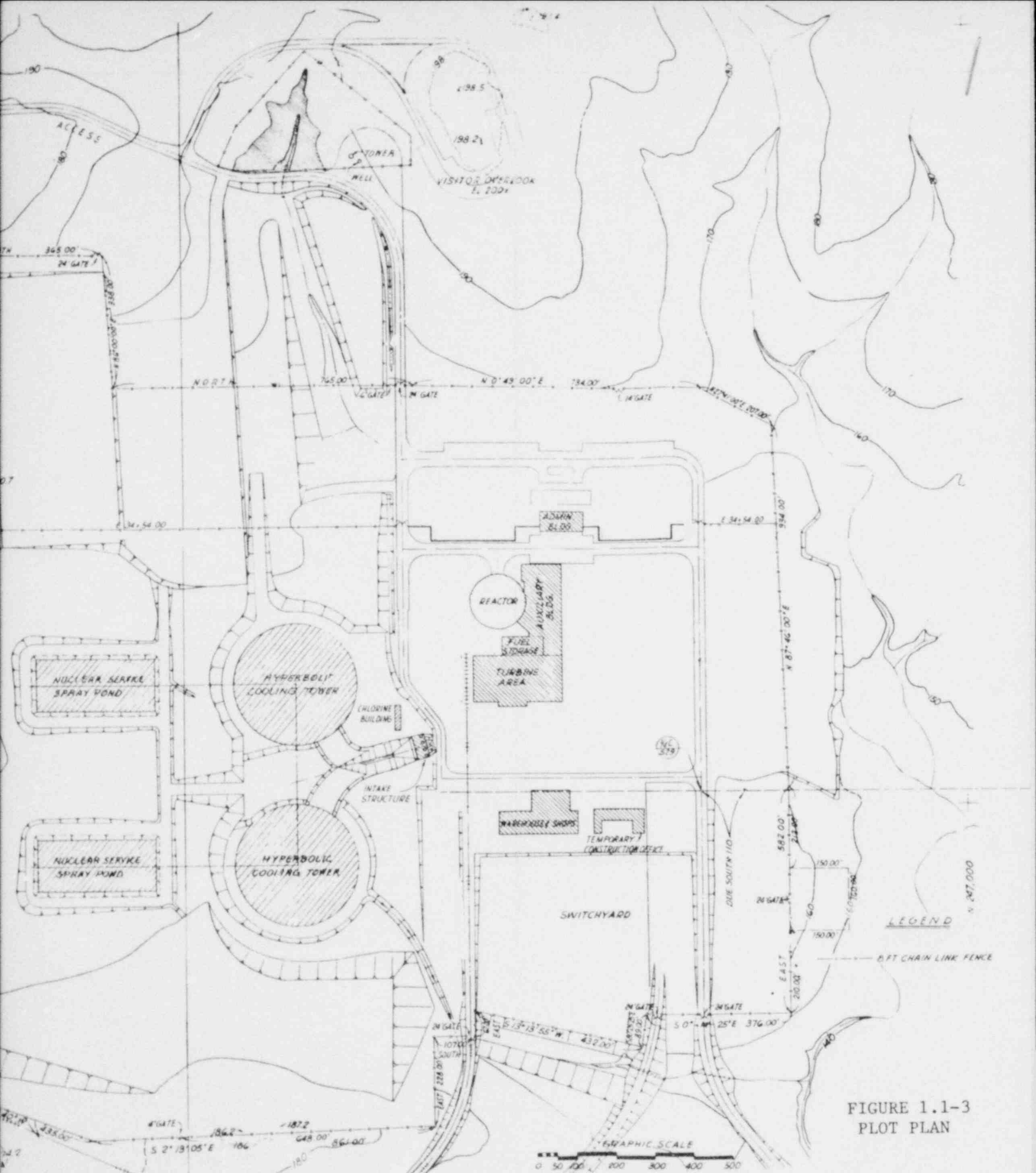

FIGURE 1.1-3
PLOT PLAN

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5. CONTAINMENT SYSTEM

5.1 STRUCTURAL DESIGN

5.1.1 GENERAL DESCRIPTION OF CONTAINMENT STRUCTURE

The reactor containment is a fully continuous reinforced concrete structure in the shape of a cylinder with a shallow domed roof and a flat foundation slab. The cylindrical portion is prestressed by a post-tensioning system consisting of horizontal and vertical tendons. The dome has a three-way post-tensioning system. Hoop tendons are placed in
240 degree systems using three buttresses as anchorages, with the tendons S1
staggered so that half of the tendons at each buttress terminate at that buttress. The foundation slab is reinforced with conventional reinforcing steel. A welded steel liner is attached to the inside face of the concrete shell to insure a high degree of leaktightness. The base liner is installed on top of the structural slab and will be covered with concrete. The structure will provide biological shielding for both normal and accident situations.

The reactor containment will completely enclose the entire reactor and reactor coolant system and ensure that an acceptable upper limit for leakage of radioactive materials to the environment would not be exceeded even if gross failure of the reactor coolant system were to occur. The approximate dimensions of the reactor containment are: inside diameter,
130 feet; inside height, 185 feet; vertical wall thickness, 3-3/4 feet; S1
dome thickness, 3-1/4 feet; and the foundation slab, 8 feet. The building encloses the pressurized water reactor, steam generators, reactor coolant loops and portions of the auxiliary and engineered safeguards systems.
The internal net free volume is 2,005,000 cubic feet. S1

Full advantage is being taken in the design of this reactor building of the experience gained in the review of similar designs with the AEC for the Florida Power and Light Company's Turkey Point Plant, Consumers Power Company's Palisades Plant, Wisconsin-Michigan Power Company's Point Beach Plant and Duke Power Company's Oconee Nuclear Station, as well as containment designs by others which meet the same functional requirements.

Representative details of the construction that will be used are shown in
Figures 5.1-1, 5.1-2, 5.1-3 and Table 5.1-1. 1

5.1.2 BASIS FOR DESIGN LOADS

The reactor containment will be designed for all credible conditions of loading, including normal loads, loads during maximum credible accident, test load, and loads due to adverse environmental conditions. The following loadings will be considered:

a. The loading caused by the pressure and temperature transients of the design base accident.

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b. Structure dead load

c. Live loads

d. Earthquake load

e. Wind loads

f. External pressure load

The two critical loading conditions are those caused by the design base accident resulting from failure of the reactor coolant system and those caused by an earthquake.

5.1.2.1 Maximum Credible Accident Load

The minimum design pressure and temperature of the containment will be equal to the peak pressure and temperature occurring as a result of the complete blowdown of the reactor coolant through any rupture of the reactor coolant system up to and including the hypothetical double-ended severance of a 36-inch ID reactor coolant pipe.

The supports for the reactor coolant system will be designed to withstand the blowdown forces associated with the sudden severance of the reactor coolant piping so that the coincidental rupture of the steam system is not considered credible.

Transients resulting from the design base accident and other, lesser, accidents are presented in Section 14 and serve as the basis for a containment design pressure of 59 psig.

The design pressure will not be exceeded during any subsequent long-term pressure transient caused by the combined effects of such heat sources as residual heat and metal-water reactions. These effects will be overcome by the combination of emergency-powered engineered safeguards and structural heat sinks.

5.1.2.2 Structure Dead Load

Dead load will consist of the weight of the concrete wall, dome, base slab, and any internal concrete. Weights used for dead load calculations will be as follows:

a. Concrete	148 lb/ft^3
b. Steel reinforcing	489 lb/ft^3 using nominal cross-sectional areas of reinforcing as defined in ASTM for bar sizes and nominal cross-sectional areas of prestressing
c. Steel lining	489 lb/ft^3, using nominal cross-sectional area of lining

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5.1.2.3 Live Loads

live loads will include snow and ice loads on the roof of the containment dome. The roof load will be 20 pounds per horizontal square foot.

Equipment loads will be those specified on the drawings supplied by the manufacturers of the various pieces of equipment.

Live loads will be assumed for the design of internal slabs consistent with the intended use of the slabs.

5.1.2.4 Earthquake Loads

Earthquake loading is predicated upon a design earthquake at the site having a horizontal ground acceleration of 0.13g. In addition, a
maximum hypothetical earthquake having a ground acceleration of 0.25g 3
will be used to check the design to ensure no loss of function.

Seismic response spectrum curves are given in Appendix 5A for both
horizontal ground motion and vertical ground motion. A dynamic analysis S1
will be used to arrive at equivalent static loads for design. Seismic loads will be combined as outlined in Appendix 5A.

5.1.2.5 Wind Loads 1

Wind loading for the containment structure is based on Figure 1 (b) of ASCE Paper 3269, "Wind Forces on Structures," using the fastest wind speed for a 100-year recurrence period. ASCE Paper 3629 will also be used to determine shape factors, gust factors, and variation of wind velocity with height. Based upon the site location and inland classi-
fication the design wind velocity is 90 MPH at a reference 30 feet 1
above ground level.

5.1.2.6 External Pressure Load

External pressure loading with a differential of approximately two pounds per square inch from outside to inside will be considered.

The external design pressure is equivalent to have a barometric pressure rise to 31 inches of mercury after the containment was sealed at 29 inches of mercury. Therefore, operation of purge valves will not be required due to barometric changes during normal operation.

The external design pressure is also adequate to permit the containment to be cooled to 60 F from an initial maximum operating condition of 120 F. Therefore, operation of purge valves will not be necessary during this condition. Vacuum breakers are not required.

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5.1.3 CONSTRUCTION MATERIALS

Basically four materials will be used for the foundation and the containment structure. These are:

a. Concrete

b. Reinforcing steel

c. _ el prestressing tendons

d. Steel liner plate

Detailed specifications and working drawings for these materials and their installation will be of such scope as to assure that the quality of work will be commensurate with the necessary integrity of the containment structure.

Basic specifications for these materials include the following.

5.1.3.1 Concrete

All concrete work will be in accordance with ACI 318-63 "Building Code Requirements for Reinforced Concrete" and to ACI-301 "Specifications for Structural Concrete for Buildings." Concrete will be a dense, durable mixture of sound coarse aggregate, fine aggregate, cement, and water. Admixtures will be added to improve the quality and workability of the fluid concrete during placement and to retard the set of the concrete. Maximum practical size aggregate, water reducing additives, and a low slump of two to three inches will be used to minimize shrinkage and creep. Aggregates will conform to "Standard Specifications for Concrete Aggregate" ASTM Designation C33. Fine aggregate will consist of sharp, hard, strong, and durable sand, free from adherent coatings, clay loam, alkali, organic material, or other deleterious substances.

Acceptability of aggregates will be based on the ASTM Tests as stated in Section 5.4.3.1.

Cement will be Type II as specified in "Standard Specifications for Portland Cement" ASTM Designation C150 and will be tested to comply with ASTM C-114.

Water for mixing concrete will be clean and free from any deleterious amounts of acid, alkali, salts, oil, sediment, or organic matter.

The water will be potable and will not contain impurities in amounts that will cause a change of more than 25 percent in setting time for the Portland Cement, nor a reduction in the compressive strength of mortar of more than 5 percent as compared with results obtained using distilled water.

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A water-reducing agent will be employed to reduce shrinkage and creep of concrete. Admixtures containing chlorides will not be used. The following types of agent will be tested with the concrete materials selected for the containment structure.

a. Pozzolith No. 8

b. Pozzolith 100 R

c. Plastiment

d. Placewell LS

The agent selected will be the one providing the smallest shrinkage as determined by ASTM C-494, "Specifications for Chemical Admixtures for Concrete."

Concrete mixes will be designed in accordance with ACI 613 using materials qualified and accepted for this work. Only mixes meeting the design requirements specified for containment structure concrete will be used.

Trial mixes will be tested in accordance with applicable ASTM Codes as indicated below:

Test	ASTM
Making and Curing Cylinder in Laboratory	C-192
Air Content	C-231
Slump	C-143
Bleeding	C-232
Compressive Strength Tests	C-39

Eight cylinders will be cast from each design mix for two tests on each of the following days: 3, 7, 28, and 90. The concrete will have a design compressive strength of 5000 psi at 28 days for the containment wall and dome and 4000 psi at 28 days for the containment base slab.

Test cylinders will be cast from the mix proportions selected for construction and the following concrete properties will be determined:

a. Uniaxial creep

b. Modulus of elasticity and Poisson's ratio

c. Autogenous shrinkage

d. Thermal diffusivity

e. Thermal coefficient of expansion

f. Compressive strength

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Concrete samples will be taken from the mix according to ASTM C-172, "Sampling Fresh Concrete." From these samples, cylinders for compression testing will be made. They will be stripped within 24 hours after casting and marked and stored in the curing room. These cylinders will be made in accordance with ASTM C-31, "Tentative Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Field."

Slump, air content, and temperature measurements will be taken when cylinders are cast. Slump tests will be performed in accordance with ASTM C-143, "Standard Method of Test for Slump of Portland Cement Concrete." Air content tests will be performed in accordance with ASTM C-231, "Standard Method of Test for Air Content of Freshly Mixed Concrete by the Pressure Method." Compressive strength tests will be made in accordance with ASTM C-39, "Method of Test for Compressive Strength of Molded Concrete Cylinders."

Evaluation of compression tests will be in accordance with ACI 214-65.

A full-time inspector, who has had experience in concrete work, will continuously check the concrete batching and placing operations.

5.1.3.2 Reinforcing Steel

Reinforcing steel for the containment structure will be deformed billet steel bars conforming to ASTM Designation A615-68 Grade 60. This steel has a minimum yield strength of 60,000 psi, a minimum tensile strength of 90,000 psi, and a minimum elongation of 7 percent in an 8 inch specimen.

Mill tests results will be obtained from the reinforcing steel supplier for each heat of steel to show proof that the reinforcing steel has the specified composition strength, and ductility. Splices in reinforcing bar
S 2 sizes No. 11 and smaller will be lapped in accordance with ACI 318-63, or joined by the Cadweld process and for bars larger than No. 11, Cadweld splices will be used exclusively.

Welding of Reinforcing steel, if required, will be performed by qualified welders in accordance with AWS D12.1, "Recommended Practice for Welding Reinforcing Steel, Metal Inserts, and Connections in Reinforced Concrete Construction," but tack welding will not be permitted.

5.1.3.3 Steel Prestressing Tendons

There are a number of post tensioning systems suited to containment vessels available in this country. The ultimate capacity of the wire or strand systems presently considered suitable for this containment
S 2 vary from 494 kips to 2270 kips. The design will permit the use of any system that meets the specified requirements

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The VSL System is presented as the basis for licensing of the Rancho Seco plant. VSL is a wedge anchor system using 55-0.5" seven-wire strands with a ultimate capacity of 2270 kips.

Strand systems have been used for a reactor vessel in England, and a containment structure in France. The system is widely used for bridge and building construction in the United States as well as Europe.

The steel strand will conform to Specifications for Uncoated Seven-Wire Stress-Relieved Strand for Prestressed Concrete ASTM A416 with a minimum ultimate strength of 270,000 psi. The minimum yield strength for all strands will not be less than 85 percent of the specified minimum breaking strength. S2

Anchorages will develop 100 percent of guaranteed minimum ultimate strength of tendons. The tendons will be housed in galvanized, semi-rigid, sheathing and will be greased but not grouted. The prestressing wire will be protected against atmospheric corrosion during its shipment and installation, and during the life of the structure. Prior to shipment the wire will be coated with a thin film of petrolatum containing rust inhibitors, such as Dearborn Chemical Company 500 R. The interior surface of the sheathing is also coated with the same material during manufacture to protect against rusting during shipment, storage, and prior to filling with a grease-like material. The sheathing filler material used for permanent corrosion protection is a modified, thixiotropic, refined petroleum oil base product such as Dearborn Chemical Company NO-Ox-Id CM Casing Filler. It has a proven history of serving as a casing filler for cased pipelines under railroads and highways. The material will be introduced into the sheathing after stressing by pumping at ambient temperature.

The tendon anchorages will develop the minimum guaranteed ultimate tensile strength of the prestressing steel without permanent deformation and without excessive slip. The unit compressive stress developed by the bearing plate under the anchorage will be in conformance with ACI Code 318-63.

Dynamic earthquake loading acceptance standards of the tendons and anchorages are based on 500 cycles of rapid loading from a stress level of 0.70 f's to a stress level of 0.75 f's and back again in cycles of 0.1 second.

The number of cycles where the peaks exceed one half of the maximum value falls in the range between 20 and 30 cycles. A highly conservative factor was applied to the number of observed cycles to provide a margin of safety comparable to the reliance placed on the anchorage system in developing the tendon.

Earthquake, wind, and accident loadings will not generate more than 100 cycles of maximum stress variations during the life of the plant. In addition, the stress level due to these loadings will be between 0.60 f's to 0.64 f's, which is on the safe side. Of this range of 0.04 f's only 10 percent is actually due to seismic loading.

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Anchorage performance requirements are now established by the Seismic Committee of the Prestressed Concrete Institute and published in their journal of June, 1966. These requirements are as follows and will be met by the tendon system:

"All anchors of unbonded tendons should develop at least 100 percent of the guaranteed ultimate strength of the tendon. The anchorage gripping shall function in such a way that no harmful notching effect would occur on the tendon. Any such anchorage system used in earthquake areas must be capable of maintaining the prestressing force under sustained and fluctuating load and under the effect of shock. Anchors should also possess adequate reserve strength to withstand any overstress to which they may be subjected during the most severe probable earthquake. Particular attention should be directed to accurate positioning and alignment of end anchorages."

The bearing plate is included as a part of the prestressing system and at its interface with the concrete there is one of the greater interactions with the structures. The average contact pressure between bearing plate and concrete is limited to those permissible by ACI 318-63. The maximum contact pressure exceeds the average at locations nearest where the end anchor contacts the bearing plate. This results from a bending of the bearing plate. It is possible that the bending stress near the end anchor will reach yield since concrete differential creep will increase the bending of the plate from its initially loaded condition,
4 and the largest bending stress in the bearing plate results from a yield moment for the plate. Although a difficult analytical problem, because of the inelastic nature of the materials and difficulty in defining boundary conditions, long experience and testing has shown that concrete reinforcing as used under column base plates and prestressing bearing plates, coupled with the bearing and base plate design approach, result in bearing and base plates that have not failed even though exposed to sub-zero temperatures. Since the bearing plates are designed and tested to proven standards; are not subjected to large cycling loads or repeated impact loads; and are used in a climate less extreme than those for which the standards have been proven, it appears that they can satisfy the performance requirements. The conclusion that is drawn from the above dis-
S2 cussion is that brittle fracture is not a problem for post-tensioning bearing plates.

Certified test results of engineering data for the selected post-tensioning system will be furnished vendor. These results will include tests of ultimate strength, yield strength, wire area reduction, jacking stress, initial prestress, effective prestress, stress-strain relations, and elongation at rupture, and dynamic fatigue characteristics of the anchorages.

In addition, a number of assemblies will be made up with tendons and anchorages as they would be for final installation. These sample tendons will be used in static tests to failure, as appropriate.

5.1.3.4 Steel Liner Plate

The containment structure will be lined with welded steel plate conforming to the requirement of ASTM A285, "Low and Intermediate Tensile Strength Carbon Steel Plates of Flange and Firebox Qualities for Pressure Vessels" Grade A, firebox quality, to ensure low leakage. This steel has a minimum yield strength of 24,000 psi and a minimum elongation in an 8 inch specimen of 27 percent. The A-285 material was chosen on the basis that it has sufficient strength as well as ductility to resist the expected stresses from design criteria loading and at the same time preserve the required leak tightness of the containment. It is readily weldable by all of the commercially available arc and gas welding processes. Structural shapes will conform to the requirements of ASTM A36. S2 S2

The design, construction, inspection and testing of the liner plate, which acts as a leak tight membrane and is not a pressure vessel, is not covered by any recognized code or specification.

All components of the liner which must resist the full design pressure, such as penetrations, are selected to meet the requirements of Paragraph N-1211 of Section III, Nuclear Vessels, of the ASME Code. ASTM A-516 Grade 60 or 70 made to ASTM A-300 is typical of a steel which meets these requirements and will be used as a plate material for penetrations. This material has excellent weldability characteristics and as much ductility as is obtainable in any commercially available pressure vessel quality steel.

In accordance with ASME Code Case 1347, allowable stresses for A-516 Grade 60 and 70 are the same as those permitted for A-201 Grade B and A-212 Grade B, respectively.

The liner plate is designed to function only as a leak tight membrane. It is not designed to resist the tension stresses from internal applied pressure which may result from any credible accident conditions. The structural integrity of the containment is maintained by the prestressed, post-tensioned concrete. Since the principal applied stress to the liner plate membrane, from shrinkage and creep of the concrete, will be in compression and no significant applied tension stresses are expected from internal pressure loading, there is no need to apply special nil ductility transition temperature criteria to the liner plate material. On the other hand, all material for containment parts which must resist applied internal pressure stresses, such as penetrations, shall be impact tested in accordance with the requirements of Paragraph N-1211 of Section III, Nuclear Vessels, of the ASME Code.

A fundamental requirement for fabrication and erection of the liner plate is that all welding procedures and welding operators be qualified by tests as specified in Section IX of the ASME Code. This Code requires testing of welded transverse root and face bend samples in order to verify adequate weld metal ductility. Specifically, Section IX of the Code requires that transverse root and face bend samples be capable of being bent cold 180 degrees to an inside radius equal to twice the thickness of the test sample. Satisfactory completion of these bend tests is accepted as adequate evidence of required weld metal and plate material compatibility.

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Mill test results will be obtained for the liner plate material. The plate will be visually checked for thickness, possible laminations and pitting.

The surfaces of the liner plate not to be embedded in concrete will be protected by an initial surface cleaning and prime coat of paint applied at the fabrication plant to protect it until installation. A suitable finish paint will be applied to the exposed surface after the plate is
1 installed.

5.1.4 CONTAINMENT STRUCTURE DESIGN CRITERIA

Safety of the structure under extraordinary circumstances and performance of the containment structure at various loading stages are the main considerations in establishing the structural design criteria.

The two basic criteria are:

a. The integrity of the liner plate shall be guaranteed under all loading conditions.

b. The structure shall have a low-strain elastic response such that its behavior will be predictable under all design loadings.

The strength of the containment structure at working stress and over-all yielding will be compared to various loading combinations to ensure safety. The containment structure will be examined with respect to strength, the nature and the amount of cracking, the magnitude of deformation, and the extent of corrosion to ensure proper performance. The structure will be designed to meet the performance and strength requirements under the following conditions:

a. Prior to prestressing

b. At transfer of prestress

c. Under sustained prestress

d. At design loads

e. At factored loads

S2 Minor deviations in allowable stresses for the design loading conditions in the working stress method will be permitted if the factored load capacity criteria are fully satisfied. All design will be in accordance with the ACI Code 318-63 unless otherwise stated herein.

No special design bases are required for the design and checking of the base slab. It will act primarily in bending rather than membrane stress. This condition is covered by the ACI Code 318-63. The loads and stresses in the cylinder and dome will be determined as described below.

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5.1.4.1 Design Method

The structure will be analyzed using a finite element computer program for individual and various combinations of loading cases of dead load, live load, prestress, temperature and pressure. The computer output will include direct stresses, shear stresses, principal stresses, and displacements of each nodal point. 4

Stress plots which show the total stresses from appropriate combinations of loading cases will be made and areas of high stress will be identified. The modulus of elasticity will be corrected to account for the nonliner stress-strain relationship at high compression, if necessary. Stresses then will be recomputed if these are sufficient areas which require attention. 4

In order to consider creep deformations, the modulus of elasticity of concrete under sustained loads such as dead load and prestress will be differentiated from the modulus of elasticity of concrete under instantaneous loads such as internal pressure and earthquake loads. S1

The forces and shears will be added over the cross-section and the total moment, axial force, and shear will be determined. From these values, the straight-line elastic stresses will be computed and compared to the allowable values. The ACI 318-63 design methods and allowable stresses will be used for concrete and prestressed and non-prestressed reinforcing steel except as noted in these criteria. 4

5.1.4.2 Loads Prior to Prestressing

Under this condition the structure will be designed as a conventionally reinforced concrete structure. It will be designed for dead load, live loads (including construction loads), and a reduced wind load. Allowable stresses will be according to ACI 318-63 Code.

5.1.4.3 Loads at Transfer of Prestress

The containment structure will be checked for prestress loads and the stresses compared with those allowed by the ACI 318-63 Code with the following exceptions: ACI 318-63, Section 26, allows concrete stress of 0.60 f'_{ci} at initial transfer. In order to limit creep deformations, the membrane compression stress will be limited to 0.30 f'_{ci} whereas in combination with flexural compression the maximum allowable stress will be limited to 0.60 f'_{ci} per the ACI Code. 4

For local stress concentrations with non linear stress distribution as predicted by the finite element analysis, 0.75 f'_{ci} will be permitted when local reinforcing is included to distribute and control these localized strains. These high local stresses are present in every structure but they 4

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are seldom identified because of simplifications made in design analysis. These high stresses are allowed because they occur in a very small percentage of the cross-section, are confined by material at lower stress and would have to be considerably greater than the values allowed before significant
4 local plastic yielding would result. Bonded reinforcing will be added to distribute and control these local strains.

Membrane tension and flexural tension will be permitted provided they do not jeopardize the integrity of liner plate. Membrane tension will be permitted to occur during the post-tensioning sequence but will be limited to $1.0 \sqrt{f'_c}$.
S1 The stress in the liner plate due to combined membrane tension and flexural tension will be limited to 0.5 fy. When there is flexural tension, but no membrane tension, the section will be designed in accordance with section 2605 (a) of the ACI Code.

Shear criteria will be in accordance with the ACI 318-63 Code, Chapter 26 as modified by the equations shown in paragraph 5.1.4.6, using a load factor of 1.5 for shear loads.

5.1.4.4 Loads Under Sustained Prestress

The conditions for design and the allowable stresses for this case will be the same as above except that the allowable tensile stress in non-prestressed reinforcing will be limited to 0.5 fy. ACI 318-63 limits the concrete com-
4 pression to $0.45\ f'_c$ for sustained prestress load. Values of $0.30\ f'_c$ and $0.60\ f'_c$ will be used as described above, which bracket the ACI allowable value. However, with these same limits for concrete stress at transfer of prestress, the stresses under sustained load will be reduced due to creep.

5.1.4.5 At Design Loads

This loading case is the basic "working stress" design. The containment structure will be designed for the following loading cases:

(a) $D+F+L+T_O$

(b) $D+F+L+P+T_A$

4 Where:

D = Dead Load

L = Appropriate Live Load

F = Appropriate Prestressing Load

P = Pressure Load (varies with time from design pressure to no pressure)

S1 T_O= Thermal Loads due to Operating Temperature

T_A= Thermal Loads Based on a Temperature Corresponding to a Pressure P

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Sufficient prestressing will be provided in the cylindrical and dome portions of the vessel to eliminate membrane tensile stress (tensile stress across the entire wall thickness) under design loads. Flexural tensile cracking will be permitted but will be controlled by bonded unprestressed reinforcing steel. The control of cracking under operating condition denoted by equation (a) above will be in accordance with the provision of ACI 318-63.

Under the design loads the same performance limits stated in 5.1.4.3 will apply with the following exception:

(a) If the net membrane compression is below 100 psi it will be neglected and a cracked section will be assumed in the computation of flexural bonded reinforcing steel. The allowable tensile stresse in bonded reinforcing will be 0.5 fy. S1

(b) When the maximum flexural stress does not exceed $6\sqrt{f'_c}$ and the extent of the tension zone is no more than 1/3 the depth of the section, bonded reinforcing steel will be provided to carry the entire tension in the tension block. Otherwise, the bonded reinforcing steel will be designed assuming a cracked section. When the bending moment tension is additive to the thermal tension, the allowable tensile stress in the bonded reinforcing steel will be 0.5 fy minus the stress in bonded reinforcing due to the thermal gradient as determined in accordance with the method of ACI-505.

(c) The problem of shear and diagonal tension in a prestressed concrete structure should be considered in two parts: membrane principal tension and flexural principal tension. Since sufficient prestressing is used to eliminate membrane tensile stress, membrane principal tension is not critical at design loads. Membrane principal tension due to combined membrane tension and membrane shear is considered under 5.1.4.6.

Flexural principal tension is the tension associated with bending in planes perpendicular to the surface of the shell and shear stress normal to the shell (radial shear stress). S1

The present ACI 318-63 provisions of chapter 26 for shear are adequate for the design purposes with proper modifications as discussed under 5.1.4.6, using a load factor of 1.5 for shear loads. S1

Crack control in the concrete will be accomplished by adhering to the ACI-ASCE Code Committee standards for the use of reinforcing steel. These criteria are based upon a recommendation of the Prestressed Concrete Institute, and are as follows:

0021 ~~00292~~

0.25 percent reinforcing shall be provided at the tension face for small members

4 0.20 percent for medium size members

0.15 percent for large members

S1 A minimum of 0.25 percent bonded steel reinforcing will be provided in two perpendicular directions on the exterior faces of the wall and dome for proper crack control.

4 The liner plate is attached on the inside faces of the wall and dome. Since, in general, there is no tensile stress due to temperature on the inside faces, bonded reinforcing steel is not necessary at the inside faces.

S1 5.1.4.6 Factored Loads

4 The structure will be checked for the factored loads and load combinations given below.

The load factors are the ratio by which loads will be multiplied for design purposes to assure that the load/deformation behavior of the structure is one of elastic, low strain behavior. The load factor approach is being used in this design as a means of making a rational evaluation of the isolated factors which must be considered in assuring an adequate safety margin for the structure. This approach permits the designer to place the greatest conservatism on those loads most subject to variation and which most directly control the overall safety of the structure. It also places minimum emphasis on the fixed gravity loads and maximum emphasis on accident and earthquake or wind loads.

4 The final design of the containment structure will satisfy the following load combinations and factors:

(a) $C = 1/\emptyset \ (1.05D+1.5P+1.0T_A+1.0F)$

S1 (b) $C = 1/\emptyset \ (1.05D+1.25P+1.0T_A+1.25H+1.25E+1.0F)$

4 (c) $C = 1/\emptyset \ (1.05D+1.25H+1.0R+1.0F+1.25E+1.0T_o)$

(d) $C = 1/\emptyset \ (1.0D+1.0P+1.0T_A+1.0H+1.0E'+1.0F)$

S1 (e) $C = 1/\emptyset \ (1.0D+1.0H+1.0R+1.0E'+1.0F+1.0T_o)$

4 (Wind, W, replaces earthquake, E, where wind stresses control)

0022

Where: C = required capacity of the structure to resist factored loads. S1

Ø = capacity reduction factor (defined in Section 5.1.4.7)

D = dead loads of structures and equipment plus any other permanent loading contributing stress, such as hydrostatic or soil. In addition, a portion of live load is added when it includes items such as piping, cable and trays suspended from floors. An allowance is made for future additional permanent loads.

P = design accident pressure load

F = effective prestress loads

R = force or pressure on structure due to rupture of any one pipe

H = force on structure due to thermal expansion of pipes due to design conditions

T_O = thermal loads due to the temperature gradient through wall during operating conditions

T_A = thermal loads due to the temperature gradient through the wall and expansion of the liner. It is based on a temperature corresponding to the factored design accident pressure.

E = design earthquake load

E' = maximum earthquake load

W = wind load

Equation (a) assures that the containment will have the capacity to withstand pressure loadings at least 50 percent greater than those calculated for the postulated loss-of-coolant accident alone.

Equation (b) assures that the containment will have the capacity to withstand loadings at least 25 percent greater than those calculated for the postulated loss-of-coolant accident with a coincident design earthquake or wind.

Equation (c) assures that the containment will have the capacity to withstand earthquake loadings 25 percent greater than those calculated for the design earthquake coincident with rupture of any attached piping.

Equation (d) and (e) assure that the containment will have the capacity to withstand either the postulated loss-of-coolant accident or the rupture of any attached piping coincident with the maximum hypothetical earthquake. 4

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The stress in prestressing steel and bonded reinforcing steel will be limited to fy, where fy is the guaranteed minimum yield stress given in the appropriate ASTM specifications. The membrane compressive stress in concrete will
S1 be limited to 0.85 f'_c. The flexural compressive stress in concrete will be allowed to go up to f'_c (28 day ultimate compressive stress). The ultimate strength assumptions of the ACI code for concrete beams in flexure will be allowed. The peak strain in the concrete due to secondary moments, membrane loads and thermal loads will be limited to 0.003 inch/inch.

S1 The peak strain in the liner plate considering peak strain in the concrete and flexural strain in the liner will be limited to 0.005 inch/inch.

The following criteria will be used for the design of membrane shear.

Principal membrane tension in the concrete due to combined membrane tension and membrane shear, excluding flexural tension due to bending moments or thermal gradients, will be calculated.

When the value of principal membrane tension exceeds $3\sqrt{f'_c}$, the combination of reinforcing steel and prestressing steel will resist the calculated value
S1 of principal membrane tension without exceeding the above mentioned stress limitation.

When the value of principal membrane tension does not exceed $3\sqrt{f'_c}$ and when the principal concrete tension due to combined membrane tension, membrane shear and flexural tension due to bending moments or thermal gradients will exceed $6\sqrt{f'_c}$, bonded reinforcing steel will be provided in the following manner:

(a.) Thermal Flexural tension - Bonded reinforcing steel will be provided in accordance with the methods of ACI-505. The
S1 minimum area of steel provided will be 0.25 percent in each direction.

(b.) Bending moment Tension - Sufficient bonded reinforcingsteel will be provided to resist the moment on the basis of cracked section theory using the yield stresses stated above with the following exception:

When the bending moment tension is additive to the thermal tension, the allowable tensile stress in the reinforcing steel will be fy minus the stress in reinforcing due to the thermal gradient as determined in accordance with the methods of ACI-505.

0024

Shear stress limits and shear reinforcing for radial shear will be in accordance with chapter 26 of ACI 318-63 with the following exceptions: 4

a. Formula 26-12 of the code shall be replaced by

$$V_{ci} = K\, b'd\, \sqrt{f'_c} + M_{cr}\left(\frac{V}{M'}\right) + V_i \qquad (1)$$

3

where

$$K = \left[1.75 - \frac{0.036}{np'} + 4.0\, np'\right]$$

but not less than 0.6 for $p' \geqq 0.003$. 4

For $p' < 0.003$, the value of K shall be zero.

$$M_{cr} = \frac{I}{Y}\left[6\sqrt{f'_c} + f_{pe} + f_n + f_i\right]$$

f_{pe} = Compressive stress in concrete due to prestress applied normal to the cross-section after all losses, (including the stress due to any secondary moment) at the extreme fibre of the section at which tension stresses are caused by live loads.

f_n = Stress due to axial applied loads, (f_n shall be negative for tension stress and positive for compression stress).

f_i = Stress due to initial loads, at the extreme fibre of a section at which tension stresses are caused by applied loads, (including the stress due to any secondary moment. f_i shall be negative for tension stress and positive for compression stress.) 3

$$n = \frac{505}{\sqrt{f_c'}}$$

$$p' = \frac{As'}{bd}$$

V = Shear at the section under consideration due to the applied loads.

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M' = Moment at a distance d/2 from the section under consideration, measured in the direction of decreasing moment, due to applied loads.

V_i = Shear due to initial loads (positive when initial shear is in the same direction as the shear due to applied loads.)

Lower limit placed by ACI-318-63 on V_{ci} as 1.7 $b'd\sqrt{fc'}$ will not be applied.

b. Formula 26-13 of the code shall be replaced by

3

$$V_{cw} = 3.5\ b'd\sqrt{fc'}\left(\sqrt{1 + \frac{f_{pc} + f_n}{3.5\sqrt{f_c'}}}\right) \qquad (2)$$

The term f_n is as defined above. All other notations are in accordance with chapter 26, ACI-318-63.

(1) This formula is based on the recent tests and work done by Dr. A. H. Mattock of the University of Washington.

(2) This formula is based on the commentary for Proposed Redraft of section 2610-ACI-318 by Dr. A. H. Mattock, dated December, 1962.

When the above mentioned equations show that allowable shear in concrete
4 is zero, radial horizontal shear ties will be provided to resist all the calculated shear.

5.1.4.7 <u>Yield Capacity Reduction Factors</u>

The yield capacity of all load carrying structural elements will be reduced by a yield capacity reduction factor (Ø) as given below. The justification for these numerical values is given in Appendix 5-E. This factor will provide for "the possibility that small adverse variations in material strengths, workmanship, dimensions, control, and degree of supervision while individually within required tolerance and the limits of good practice, occasionally may combine to result in undercapacity" (refer to footnote on page 66 of ACI 318-63 Code).

Yield Capacity Reduction Factors:

Ø = 0.90 for concrete in flexure

Ø = 0.85 for tension shear bond and anchorage in concrete

Ø = 0.75 for spirally reinforced concrete compression members

Ø = 0.70 for tied compression members

Ø = 0.90 for fabricated structural steel

Ø = 0.90 for reinforcing steel in direct tension

Ø = 0.90 for welded or mechanical splices of reinforcing steel 4

Ø = 0.85 for lap splices of reinforcing steel

Ø = 0.95 for prestressed tendons in direct tension

5.1.4.8 Prestress Losses

In accordance with the ACI Code 318-63, the design will provide for prestress losses caused by the following effects:

a. Seating of anchorage

b. Elastic shortening of concrete

c. Creep of concrete

d. Shrinkage of concrete

e. Relaxation of prestressing steel stress 4

f. Frictional loss due to intended or unintended curvature in the tendons.

All of the above losses can be predicted with a reasonable degree of accuracy.

The environment of the prestress system and concrete is not appreciably different, in this case, from that found in numerous bridge and building applications. Considerable research has been done to evaluate the above items and is available to designers in assigning the allowances. Building code authorities consider it acceptable practice to develop permanent designs based on these allowances.

5.1.4.9 Liner Plate Criteria

The design criteria which will be applied to the containment liner to meet the specified leak rate under accident conditions are as follows:

a. That the liner be protected against damage by missiles. (See 5.1.4.10)

b. That the liner plate strains be limited to allowable values that have been shown to result in leak tight vessels or pressure piping.

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c. That the liner plate be prevented from developing significant distortion.

d. That all discontinuities and openings be well anchored to accommodate the forces exerted by the restrained liner plate, and that careful attention be paid to details of corners and connections to minimize the effects of discontinuities.

Pressure vessels, pressure piping, high pressure hydraulic tubing, and similar containers are made by cold forming, drawing, and dishing operations where strains may approach the elongation capacity of the material. (For
S1 mild steel at failure, this elongation varies from 15 percent to 30 percent.) These forming operations result in high strains both in tension and compression. Vessels and piping components manufactured by these methods have a history of high leak tight integrity proving that subjecting the steel material to high strain does not affect its leak tight integrity.

The best basis for establishing allowable liner plate strains is considered to be that portion of the ASME Boiler and Pressure Vessel Code, Section III, Nuclear Vessels, Article 4. Specifically, the following sections have been adopted as guides in establishing allowable strain limits:

a.	Para. N-412 (m)	Thermal Stress (2)
b.	Para. N-414.5	Peak Stress Intensity Table N-413 Fig. N-414, N-415 (A)
c.	Para. N-412 (n)	
d.	Para. N-415.1	

Implementation of the ASME design criteria requires that the liner material be prevented from experiencing significant distortion due to the thermal load and that the stresses be considered from a fatigue standpoint. (Para. N-412 (m) (2).)

The following fatigue loads will be considered in the design of the liner plate.

a. Thermal cycling due to annual outdoor temperature variations. Daily temperature variations will not penetrate a significant distance into the concrete shell to appreciably change the average temperature of the shell relative to the liner plate. The number of cycles for this loading will be 40 cycles for the plant life of 40 years.

b. Thermal cycling due to containment interior temperature varying during the startup and shutdown of the reactor system. The number of cycles for this loading will be assumed to be 500 cycles.

c. Thermal cycling due to the MCA will be assumed to be one cycle. Thermal load cycles in the piping systems are somewhat isolated from the liner plate penetrations by the concentric sleeves betwe n the pipe and the liner plate. The attachment sleeve will be designed in accordance with ASME Section III fatigue considerations. All penetrations will be reviewed for a conservative number of cycles to be expected during the plant life.

The thermal stresses in the liner plate fall into the categories considered in Article 4, Section III, Nuclear Vessels of the ASME Boiler and Pressure Vessel Code. The allowable stress in Figure N-415 (A) are for alternating stress intensity for carbon steels and temperatures not exceeding 700 F. In addition, the ASME Code further requires that significant distortion of the material be prevented.

In accordance with ASME Code Paragraph 412 (M) 2, the liner plate is retrained against significant distortion by continuous angle anchors and never exceeds the temperature limitation of 700 F and also satisfies the criteria for limiting strains on the basis of fatigue consideration.

Paragraph 412 (N) Figure N-415 (A) of the ASME Code has been developed as a result of research, industry experience, and the proven performance of code vessels. Because of the conservative factors it contains on both stress intensity and stress cycles, and its being a part of a recognized design code, Figure N-415 (A) and its appropriate limitations have been used as a basis for establishing allowable liner plate strains. Since the graph in Figure N-415 (A) does not extend below 10 cycles, 10 cycles is being used for an MCA instead of one cycle.

Establishing an allowable strain based on the one significant thermal cycle of the accident condition would permit an allowable strain (from Fig. N-415A) of approximately 2 percent. The strain in the liner plate at proportional limit will be approximately 0.1 percent. The liner plate will be allowed to go beyond proportional limit strains during the accident condition. Maximum allowable tensile or compressive strain has been conservatively set at 0.5 percent (compared to 2 percent shown above). The maximum predicted membrane strain in the liner plate during accident conditions has been found to be 0.25 percent. The maximum combined membrane and flexural strain is predicted to be 0.40 percent. S1

At the design accident pressure condition, there will be no tensile stress anywhere in the liner plate membrane. This is true both at the time of initial pressure release and under any later pressure temperature condition. The purpose of specifying an NDT temperature requirement is to provide protection against a brittle fracture or cleavage mode of failure. However, this type of failure is precluded by the absence of tensile stresses.

No allowable compressive strain value has been set for the test condition because the value will be less than that experienced under the accident conditions. The maximum predicted compressive membrane strain will be approximately 0.07 percent. S1

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The maximum allowable tensile strain will be 0.2 percent under test conditions. The predicted value will be very nearly zero.

The stability of the liner plate will be ensured by the stiffening and anchoring of the plate to the prestressed concrete structure.

3 (Deleted)

S1 The maximum compressive membrane strains are caused by accident pressure, thermal loading, prestress, shrinkage and creep. The maximum strains will not exceed .0025 in./in. and the liner plate will always remain in a stable condition.

The conservative design approach of the stiffening system used in the liner plate to prevent significant distortions at accident conditions, and stringent welding and weld inspection requirements will ensure that the leak tightness of the liner plate at accident conditions will not change from that at the test conditions.

In isolated areas the liner plate may have initial inward curvature due to construction. The anchors will be designed to resist the forces and moments induced when a section of the liner plate between anchors has initial inward curvature.

The anchor and welds will be designed to accommodate the differential force or displacements caused by the partially restrained panel. The liner plate will be anchored at all discontinuities to eliminate excessive strains at the discontinuities. The forces in the liner plate at the discontinuities will be evaluated by use of the finite element
S1 computer program and the anchors will be designed to resist these forces.

At all penetrations the liner plate will be thickened to reduce stress concentrations in accordance with the ASME Boiler and Pressure Vessel Code 1965, Section III, Nuclear Vessels. The thickened portion of the liner plate will then be anchored to the concrete by use of anchor studs completely around the penetrations. For details of the penetrations see Figure 5.1-2. The sleeves, pipe cap, and all welds associated with the penetrations will be designed to resist all loads previously mentioned and also the prestress forces and internal design pressure.

(Deleted)
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5.1.4.10 Missile Protection Criteria

High pressure reactor coolant system equipment which could be the source of missiles is suitably screened either by the concrete shield wall enclosing the reactor coolant loops, by the concrete operating floor or by special missile shields to block any passage of missiles to the containment walls. Potential missile sources are oriented so that the missile will be intercepted by the shields and structures provided. A structure is provided over the control rod drive mechanism to block any missiles generated from fracture of the mechanisms.

Missile protection will be provided to comply with the following criteria.

a. The containment and liner will be protected from loss of function due to damage by such missiles as might be generated in a loss-of-coolant accident for break sizes up to and including the double-ended severance of a main coolant pipe.

b. The engineered safeguards systems and components required to maintain containment integrity will be protected against loss of function due to damage by the missiles defined below.

During the detailed plant design, the missile protection necessary to meet the above criteria will be developed and implemented using the following methods:

a. Components of the reactor coolant system will be examined to identify and to classify missiles according to size, shape and kinetic energy for purposes of analyzing their effects.

b. Missile velocities will be calculated considering both fluid and mechanical driving forces which can act during missile generation.

c. The reactor coolant system will be surrounded by reinforced concrete and steel structures designed to withstand the forces associated with double-ended rupture of a main coolant pipe and designed to stop the missiles.

d. The structural design of the missile shielding will take into account both static and impact loads and will be based upon the state of the art of missile penetration data.

The types of missiles for which missile protection will be provided are:

a. Valve stems

b. Valve bonnets

c. Instrument thimbles

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d. Various types and sizes of nuts and bolts

S1 e. External missiles originating from loading conditions outlined in 5.1.2.5.

(Deleted)

Protection is not provided for certain types of missiles for which postulated accidents are considered incredible because of the material characteristics, inspections, quality control during fabrication, and conservative design as applied to the particular component. Included in this category are missiles caused by massive, rapid failure of the reactor vessel, steam generator, pressurizer and main coolant pump casings.

5.1.4.11 Main Steam Turbine Missiles

The turbine-generator supplier* has made a study of potential missiles resulting from the failure of turbine-generator rotating elements operating at design (115% of normal operating) speed or, due to failure of components that control admission of steam to the turbine, operating at excessive overspeed. Historical reliability plus continued improvements in design indicate that excessive overspeed is the only envisaged cause of turbine-generator failure. An overspeed condition is very unlikely because of the redundancy and reliability of the turbine control and protection system and of the steam system. Nevertheless, the consequences of a turbine-generator runaway caused by all the steam admission valves stuck fully open upon a full load rejection have been analyzed.

On the low pressure turbine, an analysis was made of the bursting speed of each disc based upon an ultimate tensile strength 20 percent greater than the minimum guaranteed tensile strength. Each alloy steel disc is accurately machined and shrunk on to an alloy steel rotor. After shrinking on all the discs, the blading is installed, and the finished assembly is balanced to close tolerances. The completed rotor is tested at operating temperature and overspeed. Based upon experience and tests, it is concluded that the mode of failure of a disc, should it occur, is a rupture in two or four parts. The maximum speed at which the unit might run with no disc failure is 175 percent of nominal speed. At this speed the first discs will rupture. Immediately following the rupture of the first discs, the steam flow between the blades of the remaining discs would be significantly reduced, the turbine-generator would slow down, and further disc failures would not be anticipated. A disc rupture in the low pressure turbine would result in a missile which would strike and deeply deform the inner cylinder 1 causing some deformation of the inner cylinder 2 and of the outer cylinder but will be contained within the unit. Therefore, no outside missile is anticipated to be generated from the low pressure turbine.

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*Westinghouse Electric Corporation

On the high pressure turbine the maximum theoretical speed at which the unit may run, based on the admission steam thermodynamic properties and blade geometry, is 205 percent of normal speed. As shown here before, the maximum speed at which the unit may run, based upon the stress analysis of the low pressure unit, is 175 percent of nominal speed. The minimum bursting speed of the spindle, based on the minimum guaranteed mechanical properties of the spindle material, is 270 percent of nominal speed. Therefore, it is concluded that no missiles should be generated by the high pressure turbine due to a unit runaway.

A more complete description of the results of the analysis of potential turbine missiles is contained in a report titled Consideration of the Consequences of a Turbine Generator Failure in Which Missiles are Generated, included as Appendix 5-D.

5.1.5 STRUCTURAL DESIGN ANALYSIS

The containment structure will be analyzed by a finite element computer program for individual loading cases of dead load, live load, temperature, and pressure as described in 5.1.4.1.

The ACI-318-63 code design methods and allowable stresses will be used for concrete and prestressed and non-prestressed reinforcing steel except as noted herein.

5.1.5.1. Critical Design Areas

Based on a recent design study of prestressed concrete containment structures, it has been substantiated that the main areas for design analysis are:

a. The restraints at the top and bottom of the cylinder

b. The restraints at the edge of the spherical sector dome

c. The stresses around the large penetrations

d. The behavior of the base slab relative to an elastic foundation

e. The stresses due to transient temperature gradients in the liner plate and concrete

f. Stresses within the ring girder

g. Penetrations and concentrated loads

h. Seismic or wind loads

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5.1.5.2 Analytical Techniques

The containment structure analysis will be performed by the finite element method developed by E. L. Wilson, under sponsorship of National Science Foundation Research Grant G18986. This program has been further developed to apply to axisymmetric structures. Such a method of analysis is normally used only for thick-walled structures where conventional shell analysis yields inaccurate results. Good correlation has been demonstrated between the finite element analysis method and the test results for thick wall model vessels.

The design analysis for items a - f is done using the finite computer program because all of the conditions are axisymmetric. Items g and h are non-axisymmetric and are handled by techniques described in 5.1.5.5. 5.1.5.6 and 5.1.5.7. Effect of the non-axisymmetric loads will be combined with those obtained from the finite element technique.

The finite element technique is a general method of structural analysis in which the continuous structure is replaced by a system of elements (members) connected at a finite number of nodal points (joints). Conventional analysis of frames and trusses can be considered to be examples of the finite element method.

In the application of the method to an axisymmetric solid (e.g.,) a concrete containment structure, the continuous structure is replaced by a system of rings of triangular cross-section which are interconnected along circumferential joints. Based on energy principles, work equilibrium equations are formed in which the radial and axial displacements at the circumferential joints are unknowns of the system. A solution of this set of equations is inherent in the solution of the finite element system.

The finite element grid of the structure base slab will be extended down into the foundation material to take into consideration the elastic nature of the foundation material and its effect upon the behavior of the base slab.

The use of a finite element analysis will permit an accurate determination of the stress pattern at any location on the structure. The analysis method has been demonstrated on the following types of structures:

a. Arch dams (including a portion of the foundation)

b. Thick-walled prestressed concrete vessels

c. Spacecraft heat shields

d. Rocket nozzles

The computer program used in the analysis will handle the following inputs:

a. Seven different materials

b. Non-linear stress-strain curves for each material

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c. Any shape transient temperature curves

d. Any shape axisymmetric loading

The program outputs will be:

a. The direct stress and shear stress for each element

b. The principal stresses and their directions for each element

c. The deflections for each nodal point

An auxiliary computer program will plot stress curves based on the above analysis program outputs.

Additional information regarding this technique, the computer program employed, and a comparison of the results with other analytical methods is contained in Appendix 5-G.

5.1.5.3 Thermal Loads

The thermal loads are a result of the temperature differential within the structure. The design temperature gradients for this structure are shown on Figure 5.1-4. The finite element analysis was prepared so that when temperatures are given at every nodal point, stresses are calculated at the center of each element. This way the liner plate was handled as an integral part of the structure, having different material properties, and not as a mechanism which would act as an outside source to produce loading on the concrete portion of the structure.

The liner plate is designed to have plastic deformation as a result of prestressing and high thermal stresses.

The finite element method includes this analysis too, by successive approximations, changing the modulus of elasticity of those elements which are subject to stresses higher than the proportional limit.

The output of the computer analysis shows the effect of the thermal loads on liner plate and concrete. The liner plate and the inside of the concrete are subject to compressive stress and the outside of the concrete section is subject to tension. These tension stresses balance the compressive stresses so that, except close to any discontinuity, there is no resultant membrane force. That is, all the compressive forces in the liner plate are carried by the prestressed concrete and reinforcement near the outside surface of the structure.

The compressive stresses in the liner plate exceed the proportional limit in the case of the design basis accident. An increased temperature would keep the liner plate in plastic condition, but only a negligible additional stress could develop, and thermal stresses would stay unchanged.

5.1.5.4 Tendon Failure Analysis

S2 S1 There will be approximately 126 vertical tendons and 117 hoop tendons. The hoop tendons will be placed in three 240° sections around the cylinder using three buttresses as anchorages. Therefore, failure of a hoop tendon or a series of adjoining tendons or spaced hoop tendons is limited between 240° segments of the containment vessel.

It is well known that all prestressed tendons are subject to the most critical stress during initial tensioning. There will be a loss of prestress on the order of 15 percent due to elastic and plastic losses, which will reduce the stress level. Even at the factored yield loads, the stress in the tendons will not be as high as during initial tensioning. Each of the tendons has been pre-tested at the time of initial jacking and the stress in the tendons under accident loading is only 80 percent of this jacking stress. This means that the possibility of tendon failure under design accident loading is quite remote.

Although it is felt that there is ample reserve capacity in the tendon and structure, the complex nature of the structural behavior makes it difficult to predict the effect of a hypothetical series of tendon failures until the final design is complete.

It is estimated that if two or three of the tendons fail during accident conditions, and if they are side by side or close together, it will not affect the integrity of the structure or the liner because the thick concrete walls will be sufficient to transmit the force from the adjoining tendons without resulting in any serious local stresses.

5.1.5.5 Stresses Near Equipment Openings

Analytical solutions for the determination of state of stress in the vicinity of equipment openings are obtained from reference to the following articles.

a. "State of Stress in a Circular Cylindrical Shell with a Circular Hole," by A. C. Eringen, A. K. Naghdi, and C. C. Thiel - Welding Research Council Bulletin No. 102, January, 1965.

b. Samuel Levy, A. E. McPherson and F. C. Smith, "Reinforcement of a Small Circular Hole in a Plane Sheet Under Tension," Journal of Applied Mechanics, June, 1948.

The analysis of the containment structure as a whole is first carried out without considering the openings in it. This analysis has been done by using the finite element program.

The containment structure with the opening in it is then analyzed in the following steps.

a. Formulation of differential equations for the shell in complex variable form with the center of the hole as the origin (See reference a above)

b. Solution of the differential equations (See reference a above)

c. Evaluation of parameters in the solution (See reference a above)

d. Formulation of the boundary conditions based on the stresses obtained from the vessel analysis above without the hole

e. Calculation of membrane forces, moments, and shears around and at the edge of the opening

f. The wall thickness around the opening will then be increased and reinforced to carry the higher forces, moment, and shears. The affect of the thickening on the stress concentration factors will be considered using reference b above.

g. Evaluation of some of the effects of prestressing that are not handled in reference a above

h. Finally, the design will be checked to ensure that the strength of the reinforcement provided replaces the strength removed by the opening. This check is to maintain a good degree of compatibility between the general vessel shell and the area around the opening.

Details of the reinforcing and deflected strand pattern around the equipment hatch opening are shown on Figure 5.1-3.

The pattern of membrane stresses at design accident loading is not expected to be significantly different from the pattern of membrane stresses during the proof test, since the membrane stresses due to pressure are far more significant than those due to dead load or seismic load.

The deflection of the tendons does not significantly affect the stress concentrations. This is a plane stress analysis, and did not include the effect of the curvature of the shell; however, it gives an assurance of the correctness of the assumed membrane stress pattern caused by the prestressing around the opening.

The seismic load creates vertical membrane stress in the structure based on a cantilevered circular beam subjected to base accelerations. The membrane stresses at the opening are modified by appropriate stress concentration factors.

The temperature variation through the concrete wall creates a stress condition like one caused by a moment, constant in all directions on the continuous cylindrical or spherical surface. However, at any discontinuity, such as an opening, stress concentrations occur.

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Using the center of the opening as the reference point to relate the directions of moments, the radial moment is zero at the edge of the opening, there being no resistance against radial rotation. The hoop moment is highly increased, the outside fiber being forced to take the shape of a larger circle, while the inside fiber takes the shape of a smaller circle.

Away from the edge of the opening both moments gradually reach the constant value on the undisturbed portion of the cylinder.

In the case of 1.5P (prestress fully neutralized) + 1.0T (accident temperature) the cracked concrete with highly strained tension reinforcement constitutes a shell with stiffness decreased but still constant in all directions. In order to control the increased hoop moment around the opening, the hoop reinforcement should produce strength about twice that of the radial one.

In the case of accident temperature combined with low internal pressure, very small or no tension develops on the outside, so the thermal strains will be built up without the relieving effect of the cracks. However, as has already been stated elsewhere, the liner plate will reach its yield stress, and so will the concrete at the inside corner of the penetration, thereby relieving once again the very high stresses, but still carrying the high moment in the state of redistributed stresses.

For the analysis of the thermal stresses around the opening the same method was used as for the other loadings.

At the edge of the opening a uniformly distributed moment equal but opposite to the moment existing on the rest of the shell was applied, and evaluated using the methods of the preceding reference and the effects were superimposed on the stresses calculated by the computer using the finite element method for axisymmetric solids.

5.1.5.6 Seismic Analysis

The loads on the containment structure caused by earthquake will be determined as a result of a dynamic analysis of the structure. The dynamic analysis will be made on an idealized structure of lumped masses and weightless elastic columns acting as spring restraints. The analysis will be performed in two stages; the determination of the natural frequencies of the structure and its mode shapes, and the modal response of these modes to the earthquake by the spectrum response method. Appendix 5-A contains more details on the seismic design basis for this plant.

The natural frequencies and mode shapes are computed from the equations of motion of the lumped masses established in a stiffness of displacement method and are solved by iteration techniques by a fully tested digital computer program. The form of the equations is:

$$(K) \quad (\Delta) \quad = \quad \omega^2 \quad (M) \quad (\Delta)$$

(K) = Matrix of stiffness coefficients including the combined effects of shear and flexure

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(M) = Matrix of concentrated masses

(Δ) = Matrix of mode shape

ω = Angular frequency of vibration

The results of this computation are the several values of ω_n and mode shapes $(\Delta)_n$ for n = 1, 2, 3 --- m where m is the number of degrees of freedom (i.e., lumped masses) assumed in the idealized structure.

The response of each mode of vibration to the design earthquake is then computed by the response spectrum technique, as follows:

a. The base shear contribution of the n^{th} mode

$$V_n = W_n S_{an} (W_n \gamma)$$

Where:

W_n = Effective weight of the structure in the n^{th} mode computed from:

$$Wn = \frac{(\Sigma_x \Delta_{xn} W_x)^2}{\Sigma_x (\Delta_{xn})^2 W_x}$$ where the

subscript x refers to levels throughout the height of the structure.

ω_n = Angular frequency of the n^{th} mode

$S_{an} (\omega_n, \gamma)$ = Spectral acceleration of a single degree of freedom system with a damping coefficient of γ, obtained from the response spectrum.

b. The horizontal load distribution for the n^{th} mode is then computed as:

$$F_x = V_n \left(\frac{\Delta_{xn} W_x}{\Sigma_x \Delta_{xn} W_x} \right)$$

The several mode contributions are then combined to give the final response of the structure to the design earthquake.

c. Additional Considerations:

The number of modes to be considered in th analysis will be determined at the time of final design to adequately represent the structure being analyzed. Since the spectral response technique yields the maximum value of response for each mode, and these maxima do not occur at the same time, the response of the modes of vibration will be combined on a root-mean-square basis to obtain the most probable value of maximum response.

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The mathemetical model to be used in the earthquake analysis of the containment structure will be established with due consideration given to the rotational and translational stiffness of the surrounding soil.

The following values of damping and ground acceleration will be used in the analysis together with the natural periods to obtain spectral accelerations:

3

Type of Motion	Design Earthquake % Damping	Maximum Hypothetical Earthquake % Damping
Structural	2%	5%
Translation	30%	30%
Rocking	5%	9%

5.1.5.7 Wind Analysis

The loads caused by the incident design wind on the containment structure are a function of the kinetic energy per unit volume of the moving air mass. The product of one-half of the air density and the square of the resultant design velocity results in the dynamic pressure of the design wind.

The dynamic pressure (PSF) for standard air at 0.07651 pcf corresponding to 15°C at 760 mm of mercury in terms of the velocity at the appropriate height zone is given by:

$$q = 0.002558\ V^2$$

Similarly, the design pressure to be mutliplied by the projected elevation
1 area to obtain the total force on the structure includes the effect of the
shape coefficient (C_d) and is given by:

$$p = q \times C_d = 0.002558V^2C_d$$

The shape coefficient includes the effect of drag, lift, shape, aspect ratio, and surface smoothness. The containment structure has an aspect ratio (h/d) of 1.48 and surface smoothness (t/d) of 1.57 percent. The shape coefficient is found to be:

$$C_d = 0.70$$

Where

h = Containment height above ground
t = Projection of buttresses
d = Maximum outside diameter of the containment structure

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The final design pressure including the variation of design wind velocity with height are as follows:

Height Above Ground (H)	Fastest Wind (V)	Design Pressure ($p = 0.002558V^2C_d$)
0-50 ft.	90 MPH	14.5 PSF
50-150 ft.	105 MPH	19.8 PSF
150-400 ft.	125 MPH	28.0 PSF

The variation of design pressure in the horizontal direction follows the ASCE recommendations of Table 4(f). Maximum positive and negative pressures in terms of the incident pressure at the appropriate height level are 1.0 p and -1.7 p respectively.

A gust factor of 1.1 will be taken in accordance with the report recommendations.

The final wind pressures will be applied to the structure as equivalent static loads.

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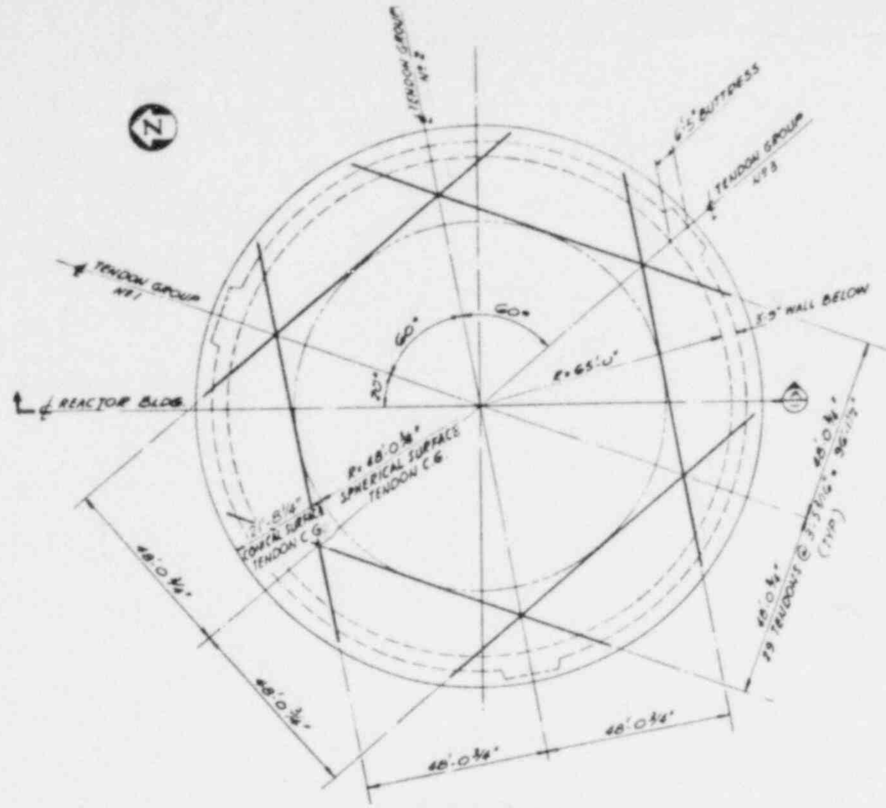
TABLE 5.1-1

CONCRETE PROTECTION FOR REINFORCEMENT AND PRESTRESSING TENDONS

LOCATION	TYPE OF STEEL	COVERAGE TO BE USED	ACI 318-63	
			INTERIOR	EXTERIOR
Dome	Reinforcing	18 & 14S 2-1/4 IN. Others 2-1/4 IN.	2-1/4 & 1-3/4 IN. 1-1/2 IN.	2-1/4 & 2 IN. 2 IN.
	Prestressing	6 IN.	1-1/2 IN.	2 IN.
Cylinder	Reinforcing	18 & 14S 2-1/4 IN. Others 2-1/4 IN.	2-1/4 & 1-3/4 IN. 1-1/2 IN.	2-1/4 & 2 IN. 2 IN.
	Prestressing	6 IN.	1-1/2 IN.	2 IN.
Base Mat	Bottom Reinforcing & Unformed Surfaces	18 & 14S 3 IN. Others 3 IN.		3 IN. 3 IN.
	Top Reinforcing	18 & 14S-2-1/4 IN. Others -2-1/4 IN.	2-1/4 & 1/3-4 IN. 1-1/2 IN.	2-1/4 & 2 IN. 2 IN.



ROOF PLAN

0 10' 20' 30' 40'

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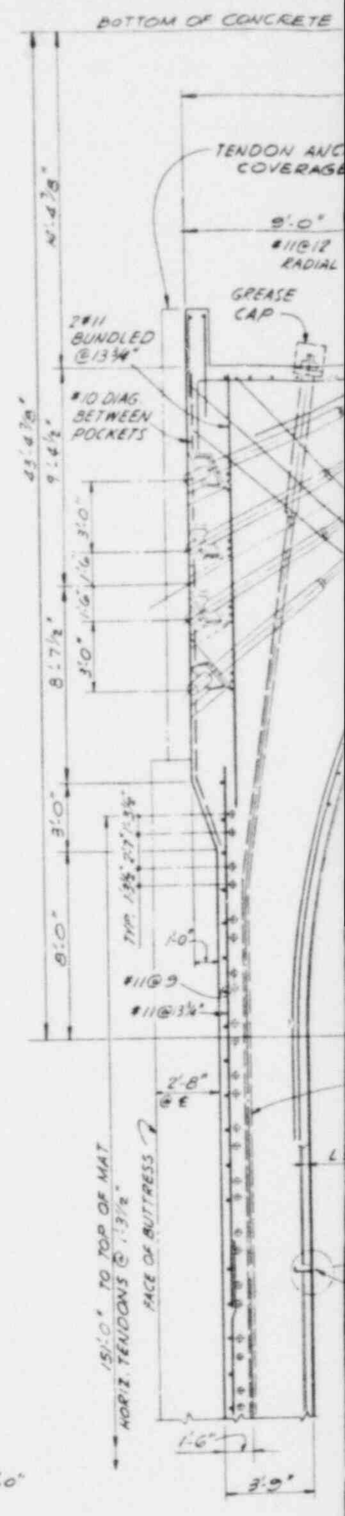
SECTION (A)

0 10' 20' 30' 40'



TYPICAL SEC
THROUGH D

0 1 2 4 6

0032

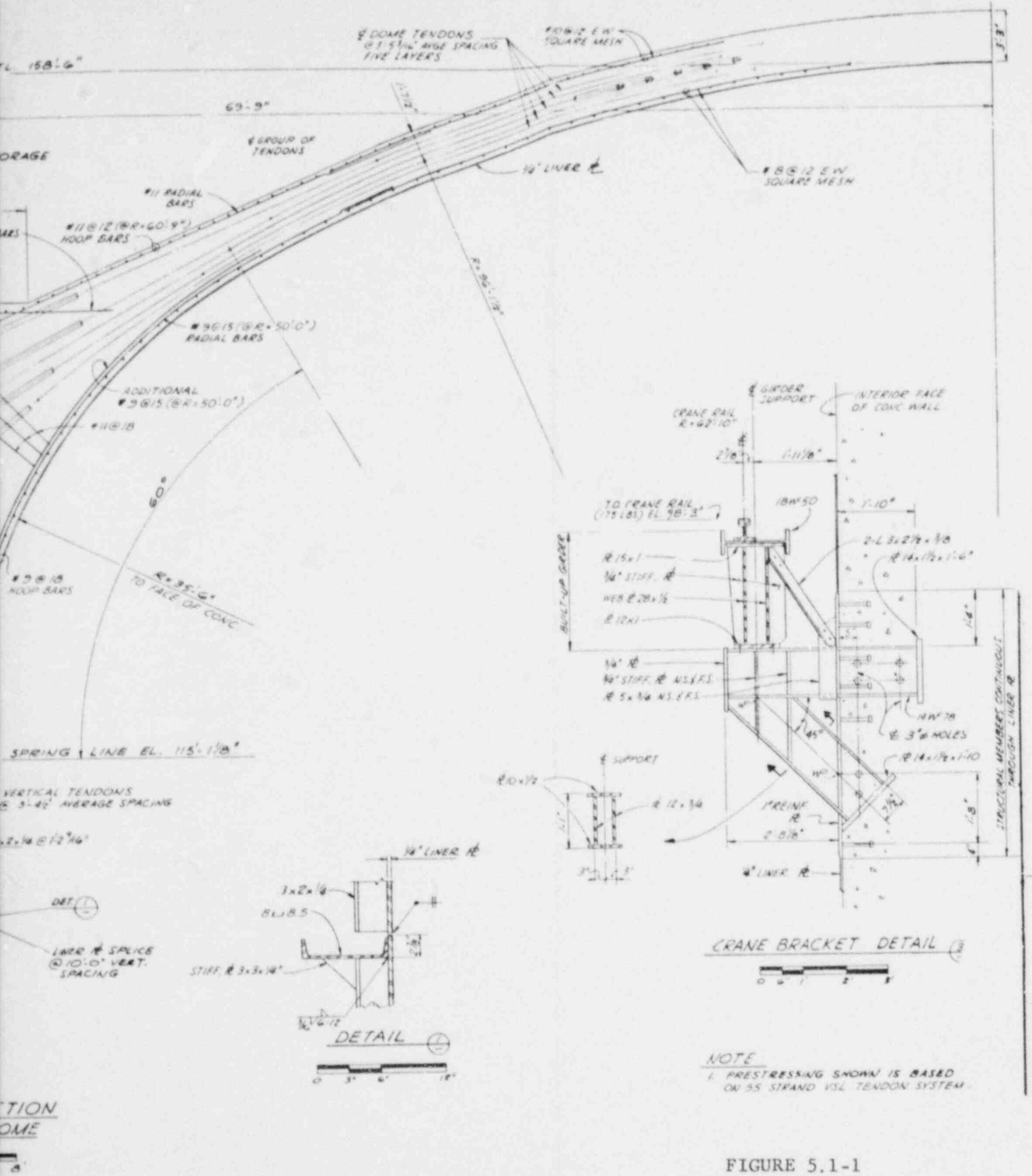


FIGURE 5.1-1
REACTOR BUILDING
TYPICAL DETAILS
SHEET 1

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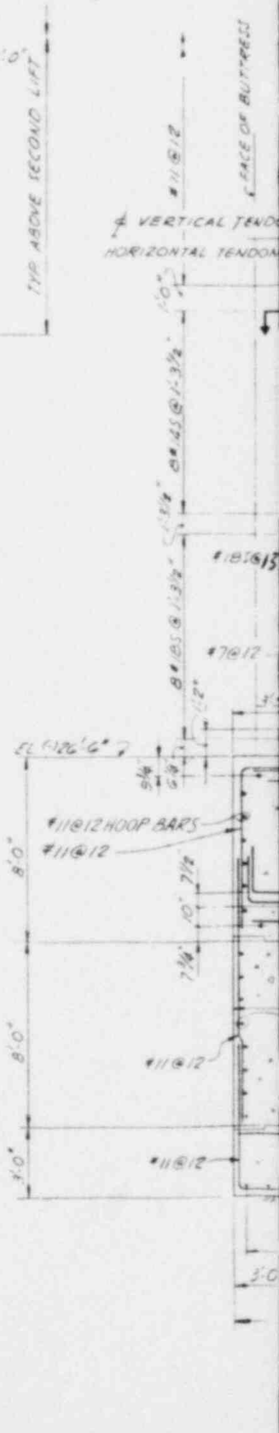
BUTTRESS DETAILS

0 6" 1' 2' 3' 4'



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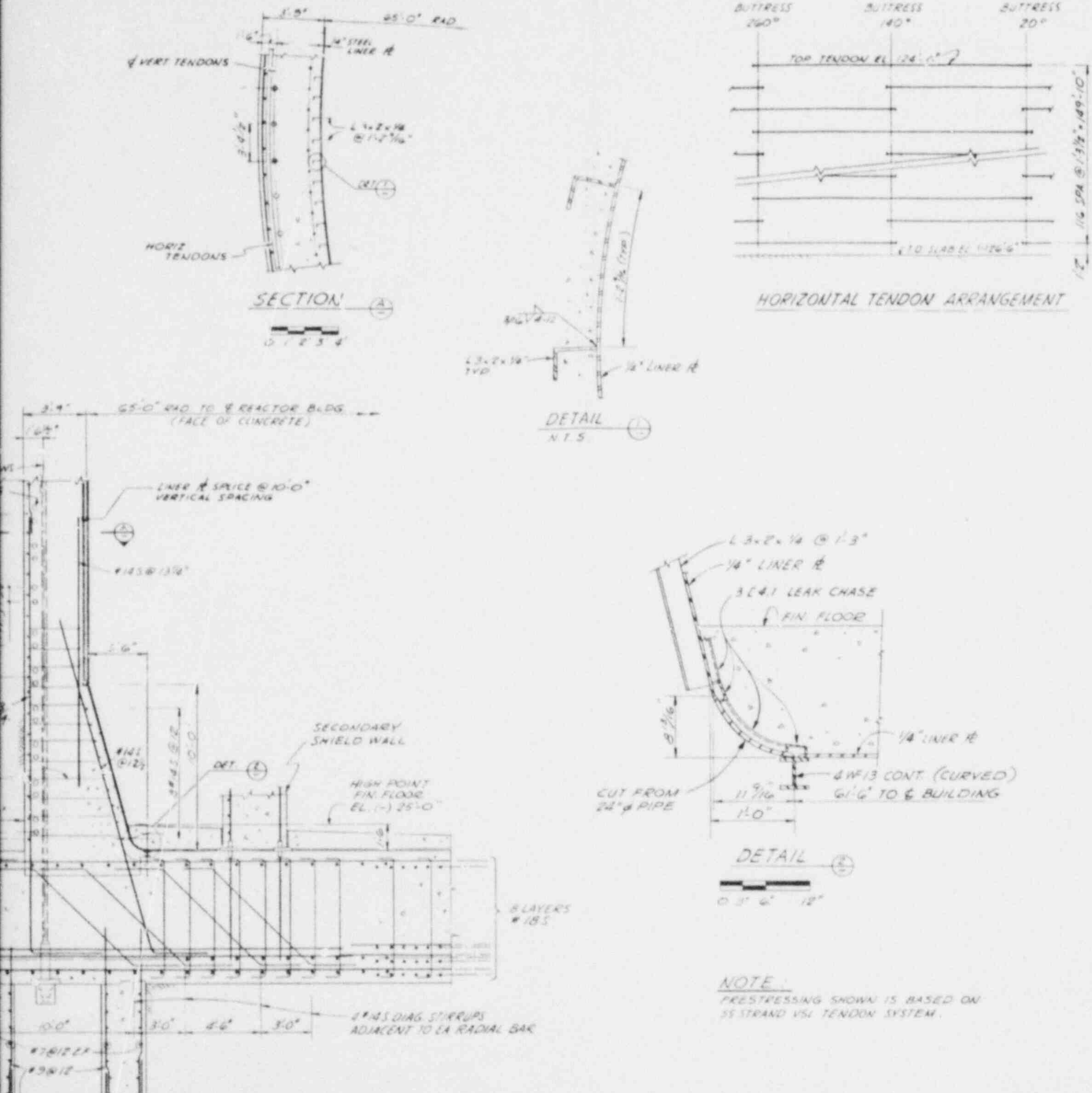

FIGURE 5.1-1
REACTOR BUILDING
TYPICAL DETAILS
SHEET 2

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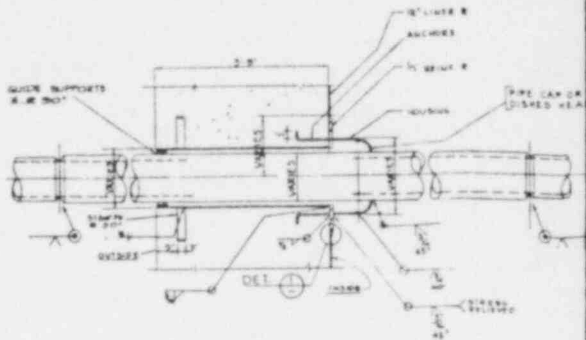
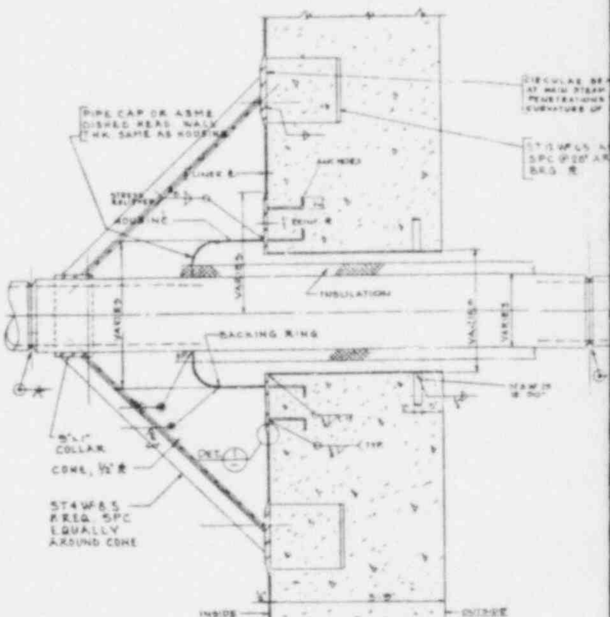
SACRAMENTO MUNICIPAL UTILITY DISTRICT

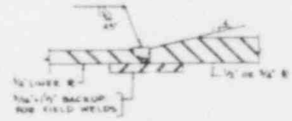
SUPPLEMENT 2



TYPE - I
TYP. COLD PIPE PENETRATION
LESS THAN 150° F.
NO SCALE



TYPE - II
TYP. HOT PIPE PENETRATION
GREATER THAN 150° F.
NO SCALE



DET. 1

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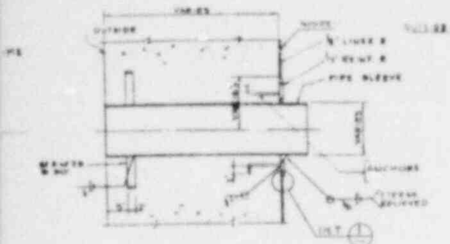
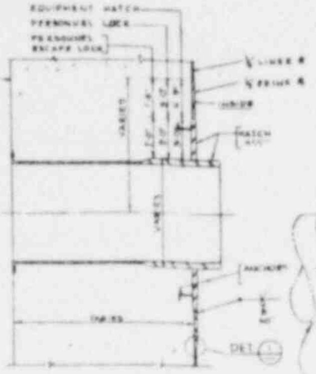
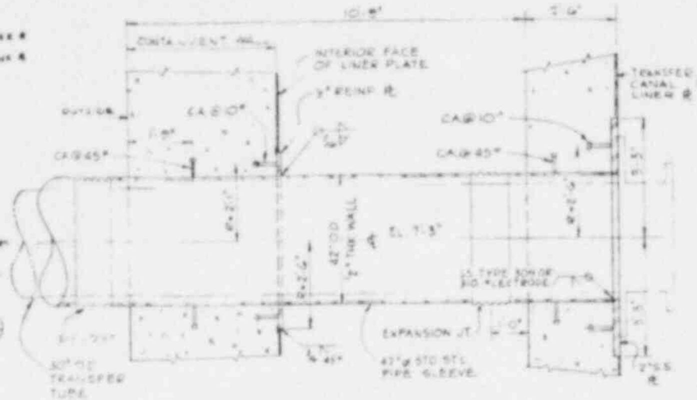


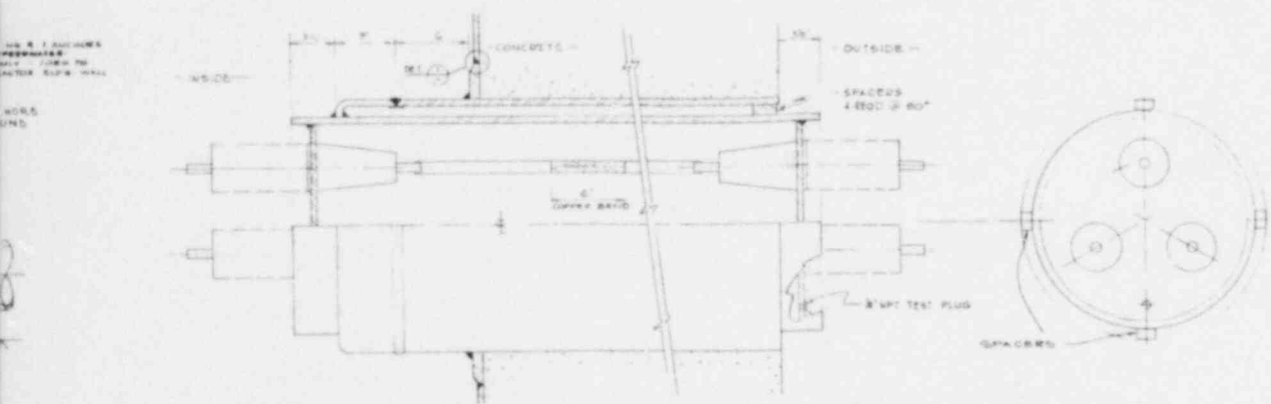
TYPE - III
TYP ELECTRICAL PENETRATION
NO SCALE



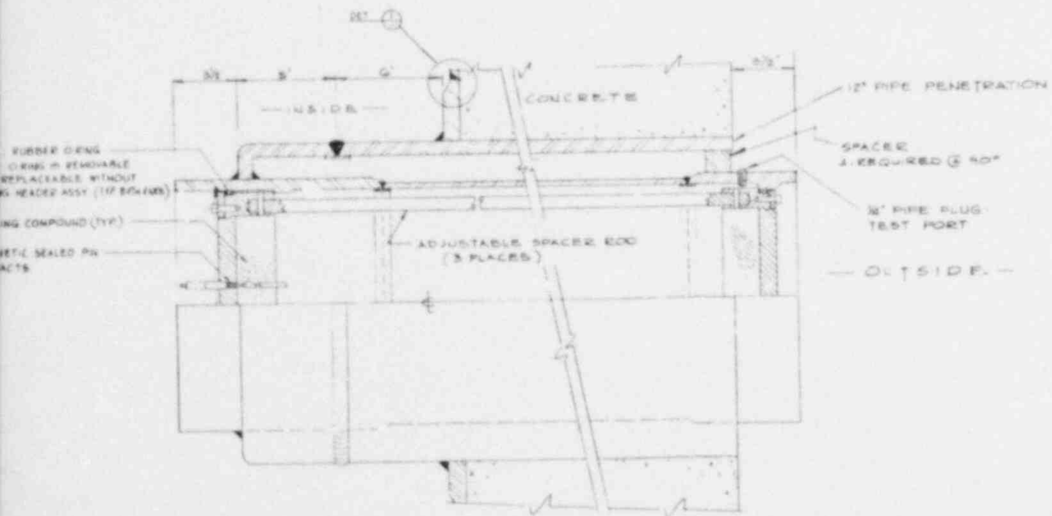
TYPE IV
HATCH PENETRATION
NO SCALE



FUEL TRANSFER TUBE PENETRATION



TYPICAL 4.16 AND 6.9 KV ELECTRICAL PENETRATION
NOT TO SCALE



TYPICAL LOW VOLTAGE POWER, CONTROL & INSTRUMENTATION PENETRATION
NO SCALE

FIGURE 5.1-2
YPICAL ELECTRICAL AND
PIPING PENETRATIONS

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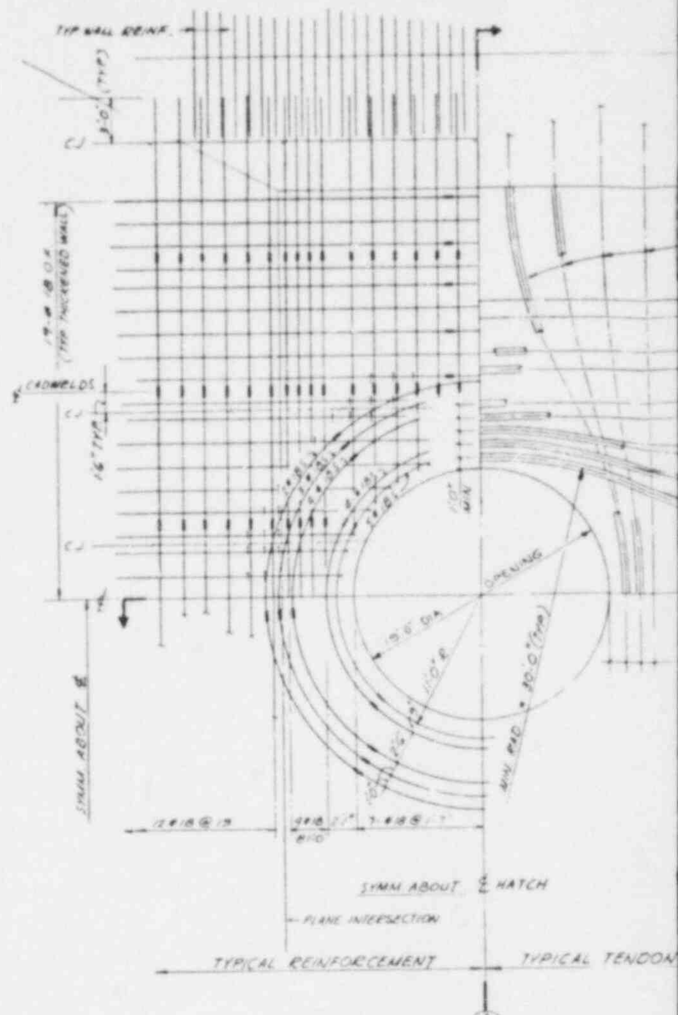
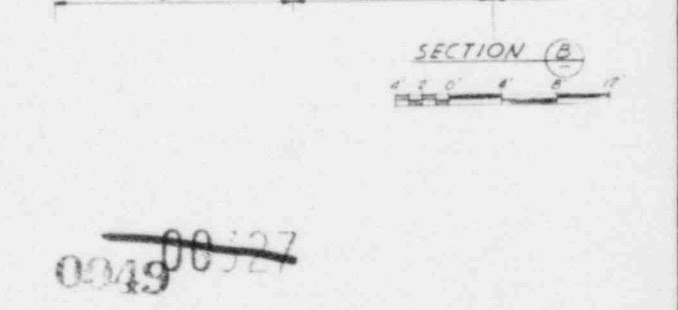
Supplement 2



ELEVATION - EQUIPMENT HATC



SECTION (B)

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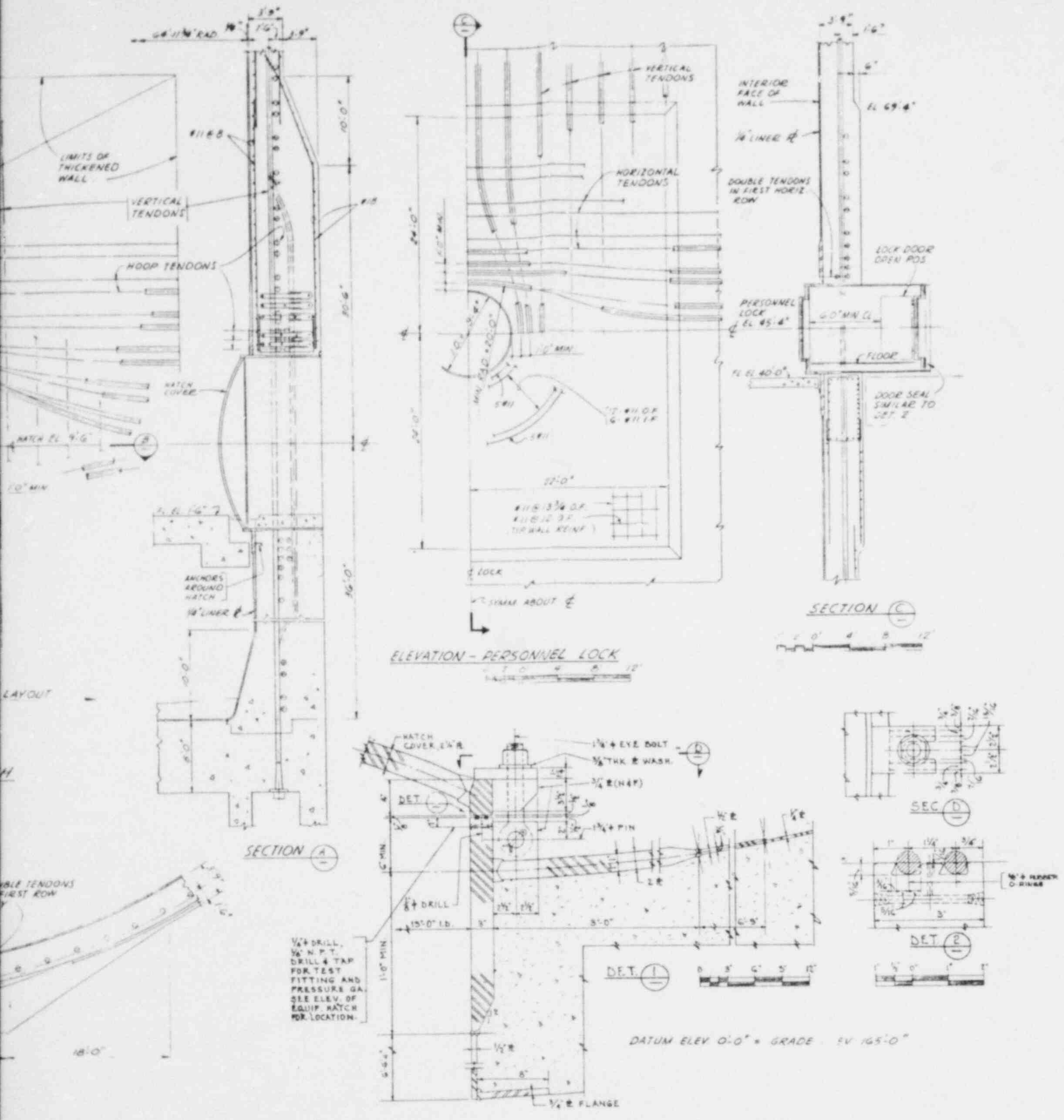

FIGURE 5.1-3
TYPICAL EQUIPMENT AND
PERSONNEL OPENINGS

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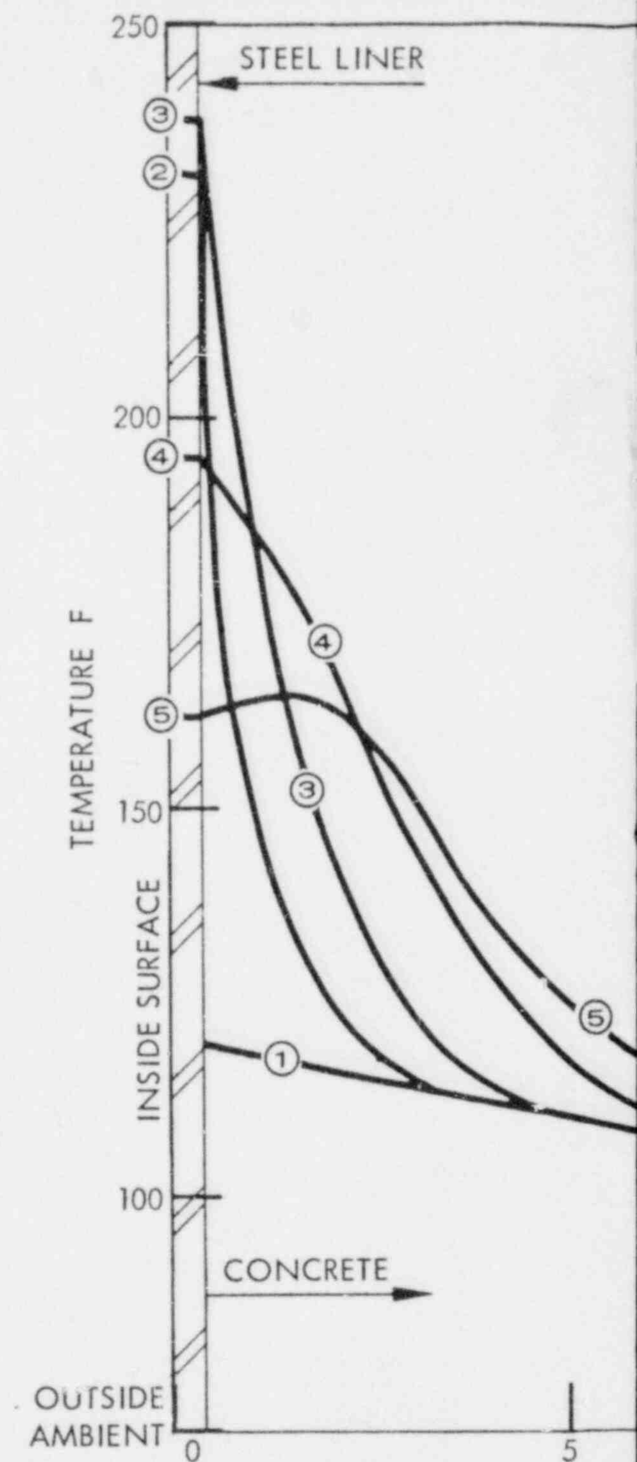
SACRAMENTO MUNICIPAL UTILITY DISTRICT



250
STEEL LINER
③
②
200
④
TEMPERATURE F
④
⑤
③
150
INSIDE SURFACE
⑤
①
100
CONCRETE
OUTSIDE
AMBIENT
0
5

00529

0051

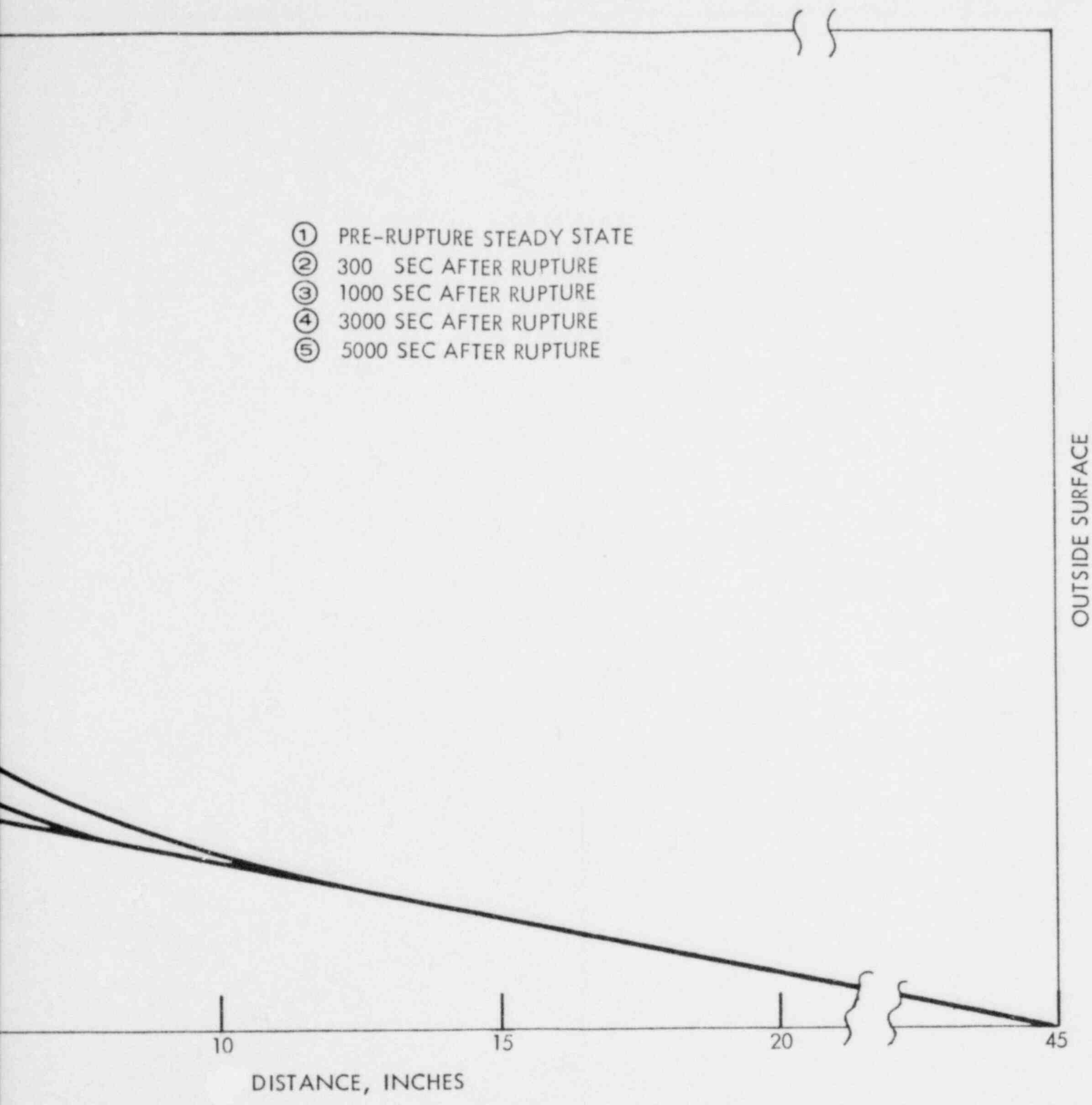


FIGURE 5.1-4
THERMAL GRADIENT ACROSS
CONTAINMENT WALL

APPENDIX 5K

VSL POST-TENSIONING SYSTEM

1.0 GENERAL

This appendix covers the pertinent specification requirements, engineering properties and test results on the VSL Post-Tensioning System. The selection of the VSL system was based on open competitive bidding to the District's specification, excerpts from which are in attachment 1 to this appendix.

2.0 PROCUREMENT SPECIFICATION

The District's Specification C12.1A was written to include both wire and strand systems, as the District felt both systems were acceptable provided they were designed, manufactured, tested and inspected in accordance with this specification.

It is not the intent of this appendix to compare various post-tensioning systems, only to present the VSL system as proposed for the Rancho Seco Project.

3.0 MATERIALS

All materials will be manufactured and fabricated in the United States.

3.1 BEARING PLATES AND TRUMPETS

The bearing plate material will conform to VSL specification E5-55 for bearing plates. A description of the material is on page 6 of attachment 2 to this appendix. The material will conform to all the requirements of ASTM 537 Grade A Normalized modified to 3-1/2-inch thickness. The trumpet material will conform to ASTM A569 and is compatible with the bearing plate material for welding.

3.2 ANCHOR HEAD AND WEDGES

The anchor head material will conform to VSL Specification E5-55 for anchor heads. The chemical composition will conform to AISI 10L50. The anchor head will be fabricated from a forged round and normalized before machining. The material will have a minimum yield strength of 50,000 psi at mid-radius. The ultimate strength of the material is approximately twice the yield strength.

The wedge material will conform to VSL Specification for post-tensioning wedge steel. The chemical composition will conform to AISI 86L20. The wedges will be fabricated from 1-3/64-inch diameter cold rolled bar and case hardened after machining of the wedge by a carbo-nitriding process.

3.3 STRAND

The strand will conform to ASTM A416 Grade 270, weldless grade, modified to include low-relaxation stabilized strand. The strand will be manufactured in the United States under the process patented by G.K.N.-Somerset Wire Limited of Great Britain.

3.4 SHEATHING

The sheathing will be made from material conforming to ASTM A366, and will be 6-inch O.D., 24 gauge.

3.5 FILLER MATERIAL

The filler material will conform to Paragraph 7.06 of Attachment 1 to this appendix.

4.0 DESIGN CONSIDERATIONS

4.1 LOADING CONDITIONS

The loading conditions for the containment are outlined in Section 5 of the PSAR. Paragraph 7.07 B of Attachment 1 to this appendix specifies the limits of temporary and effective stresses in the tendons. As in all prestressing the maximum load on strand and anchorages occurs at the time of stressing.

Section 4.5 of this appendix discusses the anchorage zone analysis of the concrete. The effects of seismic loading on the strand and wedges have been investigated from the standpoint of possible vibration of the strand and/or loosening of the wedges. It was concluded that the possible stress increase in the strand is well with the design limits. The conditions required to unseat the wedges do not exist. Please refer to page 4 of Attachment 2 of this appendix.

4.2 RELAXATION VALUES

The relaxation value used in design is 4 percent. This is based on a 40 year plant life. Manufactures test indicate the actual relaxation will be in the order of 2 percent at 0.7 f's. Test results have been published by both the patent holder and his licensee and are available as catalog data.

4.3 FRICTION FACTORS

Friction loss calculations for curvature and wobble are based on coefficients of u = 0.140 and k = 0.0003. The tendon suppliers test indicate these values are conservative. Please refer to pages 47 thru 49 of Attachment 2 of this appendix.

4.4 EFFICIENCY AS A FUNCTION OF CURVATURE

Two items are given prime consideration when curved tendons are used. One is the reduction, if any, in ultimate load capability and the other is friction loss.

The friction factors as presented in the ACI Code are not a function of the radius of curvature but of angle change and length. This has been verified by testing. Please refer to pages 47 through 49 of Attachment 2 to this appendix. In considering a possible reduction in ultimate strength the radius of curvature, length of curve, sheathing size and differences in individual strand stresses are considered. The normal horizontal and dome tendons both have a large radius of curvature and while the tendons around the large penetrations have a relatively short radius of curvature, this is accompanied by a small total angle change resulting in relatively minor transverse stresses. The sheathing size used is approximately 70 percent larger than required by the ACI Code which minimizes the number of strands stacked one upon the other. The length of an individual strand from bearing plate to bearing plate is determined by its position in the sheathing and will vary in length.

Each strand will be elongated the same amount and any differential stress between strands will be a function of the differential in total strand length. This value amounts ± 0.3 percent maximum. Therefore no overall reduction in tendon efficiency specifically for curved tendons is considered in the design.

4.5 ANCHORAGE ZONE ANALYSIS

The area of anchorage zone is one which is given prime consideration in the design of the containment and is considered Class I. The design is in accordance with the criteria in Section 5 of the PSAR as well as the ACI Code. The methods used in analysis of the concrete in this area are described in Section 5.1.3.3, Appendix 5G and the answers to questions 5J.7.5, 5J.7.33 and 5J.7.34. The allowable average concrete bearing stress is set by ACI Code 318, and accounts for uneven distribution of stress directly under the bearing plate.

The main consideration in the design is directed toward the prediction of the transverse tensile forces in the area of the anchorage as these forces will for the most part determine the amount of bonded reinforcement required in this area. The problem is complex when the interaction of all the forces which could exist on the structure are considered. The loading combinations presented in Section 5 of the PSAR consider the most severe combinations of loadings on the structure. In addition, transient thermal gradients are considered where they would produce higher stresses and/or strains than the steady state or accident gradients. These load combinations are considered along with the effect of the end anchor force.

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The basic approach followed is to provide reinforcement for those areas where predicted tensions could result in anchorage failure. There are uncertainties in any one method of analysis, therefore several methods, as previously outlined, are used and the design is prepared so that reinforcement is provided for the predictions of the various methods.

These methods reduce the three dimensional stress condition into a two dimensional one, however the three dimensional effect is also considered, especially near the base slab and ring girder.

Predicted stresses not originated by the anchorage forces are small compared to localized stresses immediately under the anchorage. Next to the bearing plate the concrete is predicted to be in compression in all three dimensions. Tensile cracks cannot penetrate this region. Further away from this highly compressed zone, in the so-called bursting zone, compressive stresses parallel to the tendons and tensile stresses in the hoop (relative to the tendon centerline) direction, will exist. Reinforcement is provided for the adverse conditions as predicted by the various methods of analysis. This most probably results in more reinforcement than would actually be needed, however it is provided as a design conservatism. Where tensile reinforcing cannot be arranged to follow the direction of principal tensile stresses, the relevant shear forces or stresses are considered in the detailing of the reinforcing.

The allowable stresses used for the bonded reinforcement to retain the bursting forces are the same as the allowable stresses for the other portions of the containment.

The highest stresses in the anchor zone will occur at the time of jacking and long term effects will tend to reduce the loads in the anchorage zone and therefore delayed rupture is not considered a possibility.

4.6 BRITTLE FRACTURE CHARACTERISTICS

Brittle fracture of the tendon anchorages and bearing plates is not considered a serious problem as stated in Section 5 of the PSAR, however, low temperature tests were required from the tendon manufacture on the anchorages and bearing plates. Please refer to Paragraph 7.04 of Attachment 1 and page 46 of Attachment 2 to this appendix.

4.7 WIRE REDUNDANCY PER TENDON

There are no specific requirements for wire redundancy in the form of additional wires per tendon in the design. The ultimate load tests indicate approximately 2 percent of the wires can be broken before any significant load reduction occurs.

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5.0 ULTIMATE STRENGTH CAPABILITY OF TENDON SYSTEM AND COMPONENTS

5.1 COMPLETE SYSTEM

The completed 55 strand system is capable of developing 100 percent of the guaranteed minimum ultimate strength of the strand. The complete system has been designed to develop the ultimate strength of the strand and all test results indicate considerable reserve strength in the other components. Please refer to Paragraph 7.03 and 7.04 of Attachment 1 and pages 1 thru 3 of Attachment 2 to this appendix.

5.2 BEARING PLATES

The bearing plates are designed and tested to develop 100 percent of guaranteed minimum ultimate strength of the strand and distribute the load in a uniform manner to the concrete. Please refer to Paragraph 7.04 of Attachment 1 and pages 6 thru 45 of Attachment 2 to this appendix.

5.3 ANCHORAGES

The anchor head and wedges are designed and tested to develop the guaranteed minimum ultimate strength of the strand with no harmful notching of the strand under dynamic load conditions. Please refer to Paragraph 7.04 of Attachment 1 and pages 4 thru 5 of Attachment 2 to this appendix.

5.4 STRAND

The strand has a guaranteed minimum ultimate strength of 270 ksi and this is used as the basis for design. The actual ultimate strength obtainable is somewhat dependent on the method of testing. Testing is conducted in accordance with ASTM A370. An approved method is one using a wedge grip similar to the one used by VSL. In effect the guaranteed ultimate strength of the strand has been established by and is predicated on the use of this type of anchorage. Please refer to pages 1 and 2 of Attachment 2 to this appendix.

6.0 FABRICATION METHODS AND QUALITY CONTROL PROCEDURES

Following is a description of the methods of fabrication and quality control for the various components of the Post Tensioning System as well as the control employed to assure a high quality installation.

6.1 TENDONS

6.1.1 Fabrication Method

The tendons which are a major element of the post tensioning system are each comprised of 55 strands, each strand consisting of 7 wires. The supplier of the tensioning system will purchase reels of strand in accordance with ASTM 416. The reels of strand will be staged on a 55 reel dispensing facility in an environmentally controlled area of his plant and processed into completed tendons.

6.1.2 Quality Control

a. Each tendon will be individually identified and traceable to the heat numbers of the wire utilized in its buildup. All chemical and physical test reports supporting the integrity of each heat of material will be reviewed as a condition of acceptance.

b. Specimens will be cut from each reel of strand and tension tested to assure compliance to specifications.

c. Strands will be examined for workmanship and quality prior to fabrication of the tendon.

6.2 BEARING PLATES

6.2.1 Fabrication Method

Bearing plate raw material will be procured in accordance with the applicable specifications. Center holes in the bearing plate are flame cut and the hole edge ground to a 125 finish. Trumpets will be welded to the bearing plate at the edge of the center hole by a 1/8 inch butt weld. The sheathing filler tube will be welded to the edge of the bearing plate and will connect to the trumpet several inches beyond the bearing plate.

6.2.2 Quality Control

a. The bearing plate material will comply with that specified on the drawings as evidenced by mill test reports traceable to the heat number by serial numbers permanently marked on each bearing plate.

b. Charpy V-notch tests will be conducted to provide assurance that the bearing plates are not susceptible to brittle fracture.

c. All plates will be examined for workmanship and quality. Cracks, burrs, corrosion and other defects are not acceptable.

6.3 ANCHOR HEADS

6.3.1 Method of Manufacture

Material for anchorages will be procured in accordance with the applicable specifications. The anchor heads will be machined by tape controlled machines. Parts will be sprayed with preservative prior to shipment to site.

6.3.2 Quality Control

a. All raw material will be accompanied by mill certificates and subjected to receiving inspection.

b. After Blanchard grinding, a first article inspection will be conducted to check proper surface finish.

c. After drilling of tapered holes a first article inspection will be made and on each 51st piece thereafter.

d. After forming 0.12 inch radius at bottom of strand holes, a first article dimensional inspection will be made, followed by a check of every 100th piece.

e. Parts will be coated with a preservative prior to shipment.

6.4 WEDGES

6.4.1 Method of Manufacture

Materials are purchased in accordance with applicable specifications. To insure a uniform product, the wedges will be made only on an automatic screw machine or an automatic multiple spindle chucking machine.

6.4.2 Quality Control

Wedges will be controlled by lot. Each lot will be identified by heat number so as to retain traceability. All raw material will be inspected upon receipt. In process inspection will consist of a first article inspection after the screw machine operation consisting of a check of the seven degree angle, concentricity, four degree taper and .080 inch length on 15 degree angle.

A first article inspection will be conducted on the thread of the first piece through the tapping operation and on every subsequent 200th piece thereafter.

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A first article inspection will be performed to check surface condition after the grinding and polishing operations and on every 200th piece thereafter.

The cutting operations will be subjected to a first article and on every 200th piece thereafter.

After case hardening, hardness tests will be conducted on 2 percent of each heat of parts.

From each heat four wedges will be tested in an anchor head to failure of the strand. Failure of the strand at 100 percent of guaranteed ultimate strength must be obtained. Only after successful completion of this test will the wedges from that heat be accepted.

6.5 FIELD QUALITY CONTROL

6.5.1 Materials

The Field Engineer will personally inspect sheathing, bearing plates, prestressing strand, anchor heads, wedges and grease for inspection tags and mill certificates to insure materials conform to plans and specifications.

6.5.2 Installation of Tendon Sheathing

a. Sheathing will be checked for appropriate inspection tags.

b. Sheathing will be tied to and supported by mild steel reinforcing and/or rebar chairs. The center of gravity of the tendon system shall be maintained as shown on shop drawings, and placement of individual sheaths shall be within a tolerance of ± 3/4" unless otherwise specified.

c. Open ends of duct shall be capped during construction.

d. Joints will be made watertight by use of an epoxy sealant.

e. Contractor will be required to exercise extreme care when vibrating concrete around tendon sheathing.

6.5.3 Installation of Bearing Plates

a. Bearing plates will be checked for appropriate inspection tags.

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b. The placement and orientation of all bearing plates will be exactly as shown on shop drawings. Precise positioning of bearing plates will in every instance take precedence over the positioning of contiguous mild steel reinforcement.

c. Tendon sheathing will be perpendicular to the bearing plate surface at point of entrance to the trumpet.

6.5.4 Cutting and Installing Strand

a. Preparatory to removing strands from reels and cutting to tendon lengths, suitable platform shall be arranged to prevent strands from picking up contaminants and moisture.

b. After strands are pulled into sheathing, tendon openings will be plugged with cloth to prevent circulation of air.

6.5.5 Installation of Anchor Heads and Wedges

a. Anchor heads will be checked for appropriate inspection tags.

b. Anchor heads will be inspected for dirt or grit. It shall not be necessary to remove light dust.

c. Anchor head will be drawn on over the ends of the strands and then drawn snugly against the bearing plate.

d. Wedges will be retained in position with a wedge retainer plate to prevent both the movement of the anchor head and the wedges themselves during application of the jack chair and jack.

e. At one end of the tendon, wedges may be installed in anchor heads in advance and kept in place with the retaining plate prior to placing anchor head over strand.

6.5.6 Jacking

a. The Field Engineer will check to insure he is using the proper calibration chart for the jack-pump combination being used and that the calibration chart is current. Jack-pumps are recalibrated every four months.

b. The jack force for each tendon shall be as shown on the plans and/or calculations. This force will be measured by the jack-pump hydraulic pressure gage (with appropriate calibration chart). It should be noted that only rarely does the actual elongation precisely equal the expected elongation for the given force. This results from the fact that the modulus of elasticity of a given strand will vary from the 28,000,000 psi average value used in the calculations. The gage will be used to measure the required force and the elongation used as a check. In no case shall an obtained elongation be adjusted to conform to the calculations. In the event that actual elongation varies more than ± 5 percent from that expected, the pump pressure gage in use shall be checked against a proof gage.

6.5.7 Applying Grease Corrosion Protection

a. Certificates of compliance will be obtained from the manufacturer of grease certifying that the material fulfills requirements of specifications.

b. During fabrication, temporary corrosion protection shall be applied to each individual strand.

c. As tendon sheathing annulus is filled with grease, grease will be circulated if required until all air has been removed from the sheathing. Provision will then be made on each tendon for thermal expansion of the grease.

6.5.8 Tendon Installation

a. A four-sided roller may be attached over the bearing plate into which tendon is to be pulled if required.

b. The tendon pulling operation will be arranged so as to insure that the tendon remains free of contamination.

c. All tendons will be precut and prefitted with a "Kellums Grips" on one end. Tendons shall then be wound on a fabrication reel.

d. Each tendon will be pulled into the structure in one 55-strand bundle.

e. All vertical tendons will have one anchor head installed prior to placement.

f. The procedure for field installing a 55-strand anchor head is as follows:

(1) Bolt anchor head support bracket onto bearing plate which bracket holds the anchor head rigidly and in line with the tendon 4 ft - 6 in. away from the bearing plate.

(2) Insert a short piece of 1/2 inch strand into the anchor head to hold the preplaced wedge open.

(3) Successively insert tendon strands into anchor head in hole in which the dummy strand is holding the wedge open.

(4) Care will be taken to insert strands into the anchor head in the same relative position which they assume in the tendon.

(5) Slide anchor head over strands until it is in contact with the bearing plate.

6.5.9 Stressing Procedure

a. Unbolt wedge retainer plate and slide plate away from the anchor head. Plate will keep the strands combed out inside the jack.

b. Install jack chair over anchor head. The jack chair bolts onto the bearing plate, centering the anchor head along the axis of the tendon.

c. Slip pulling head over strand installing jacking wedges.

d. For tendons that are to be stressed from both ends simultaneously (horizontal and dome), the tendon shall be stressed to 10 percent of design jacking force. Mark the tendon at both ends for an elongation datum. This shall be accomplished by putting a tape marker on one strand behind the pulling head and measuring to the jack base. For tendons stressed from one end the same procedure applies on the jacking end.

e. Stress the tendon to design jacking force and record the measured elongation on both ends and add 10 percent. Compare the total elongation with that calculated using the exact modulus of elasticity of the strand. The measured elongation should agree within ±5 percent of the calculated value.

f. Finally, the tendon is released, anchoring with a 1/4 inch seating loss.

7.0 CORROSION PROTECTION

The corrosion protection used is outlined in Section 5.1.3.3 of the PSAR, and in Section 5.5.7 and Part 7 of Attachment 1 to this appendix.

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8.0 SUMMARY

The District has reviewed the VSL system in detail and judged it to meet its requirement for use in the containment structure. Large capacity VSL tendons have been used throughout the United States and to date VSL have the largest capacity tendons installed in a completed structure.

The prime area of study was directed toward the action of the wedge type grippers from the standpoint of slippage and notching of the strand. Test results indicate slippage does not occur even under vibrating load once the wedge is scated. None of the ultimate load tests reviewed indicated a failure in a component other than in the strand. It should be noted that in almost every ultimate load test the strand failure occurred just in front of the wedge. This type failure is considered to be inherent in all strand systems and as previously stated the guaranteed ultimate strength of the strand is predicated on the use of this type of anchorage device. The comparison of the 55-strand tendon with single strand tendons indicates very little reduction in actual ultimate strength and the guaranteed minimum ultimate strength of the strand is still an appropriate value to use in design.

All material used in the system is high quality, fabricated to strict quality control procedures and designed with adequate margins of safety to develop the minimum ultimate strength of the strand.

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ATTACHMENT 1

EXCERPT FROM PROCUREMENT
SPECIFICATION C12.1A

"PRESTRESSED CONCRETE REACTOR BUILDING
POST TENSIONING SYSTEM"

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3.05 BID DATA

A. GENERAL

(1) The drawings and data submitted shall be in quadruplicate and in sufficient detail and clarity to enable making a complete and positive check with the technical provisions of the contract, and where hereinafter indicated, such data will be made a part of the Contract. If standard drawings and/or standard published descriptive data are submitted, any modifications required and intended by the bidder to meet the requirements of this invitation, shall be clearly indicated.

(2) Because of the nature of this equipment, full compliance with the requirements of this section is essential. Regardless of any statement by the bidder with respect to his intention or ability to comply, failure on his part to submit the drawings and data in quadruplicate prior to the time fixed for opening of bids, or failure of such drawings or data to conform substantially to the requirements of the invitation, will be sufficient cause for rejection of the bid for award.

(3) The preliminary design and drawings reflect BBRV tendon system which has been used as the basis for obtaining a preliminary construction permit from the Atomic Energy Commission. The bidder may submit an alternate system which meets the requirements of this Specification. However, costs to the District including possible delays associated with obtaining the Atomic Energy Commission's approval on an alternate system which has not been previously approved will be a consideration in the evaluation of the proposal.

Information and data provided for any system shall be in U.S. standard units and English for ease of comparison.

(4) In addition to the information normally supplied, the following data shall be submitted by the bidder with his bid. (if bidder's recommendations differ from those proposed, bidder shall so state):

(a) Resumes of key design, production, and field personnel that would be assigned to this project.

(b) A tabulation of prior jobs completed within the last three years showing the Client and Owner, a brief description of the project, and the approximate value of the bidder's contract.

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(c) A Quality Control Manual describing both shop and field fabrication and installation procedures and the associated quality control steps frequently necessary to produce a tendon system meeting the performance criteria as stated in this Specification. This manual should also contain 1) a flow chart indicating the flow of all components through the plant from the receiving to shipping, the quality control checkpoints, and the inspections made at each point, and 2) an organization chart showing how the quality control is implemented.

(d) A proposed fabricating and delivery schedule as required in paragraph 6.01C.

(e) The bidder shall state the estimated quantity of all materials in the summary of proposal. The bidder's quantity estimate shall be based upon criteria set in this Specification and data to be furnished by the Bidder as described herein.

(f) The bidder is required to base the bid on low-relaxation or stabilized wire or strand. The bidder may submit a bid using foreign wire or strand in lieu of domestic wire or strand, however, such wire or strand shall conform to the provisions of ASTM A-416 or A-421, latest edition.

B. TECHNICAL DATA

The bidder shall include the following dimensional and engineering data for his proposed prestressed post-tensioning system.

(1) Dimensional data for tendons giving type, diameter of wire or strand, number of wires or strands and tendon diameter.

(2) Dimensional data and material properties for anchorage assemblies and bearing plates.

(3) Certified test results of engineering data for the full size tendon including sectional area of wires or strands (sq. in.) ultimate strength, yield strength, stress-strain curve, load elongation curve including elongation at rupture. The proposed source of wire or strand shall also be stated.

Friction loss calculations may be based upon minimum coefficients of curvature and wobble of μ = 0.140 and K = 0.0003 providing the bidder can substantiate these values as specified herein. Relaxation loss calculations shall be based upon actual extrapolated test data using a minimum value of 4% calculated as a percentage of the anchorage stress (0.70 f's max.) measured at the anchorage for all tendons including the hoop tendons.

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Regardless of using the above minimum recommended values, the bidder shall provide the basis for losses due to steel relaxation, anchorage seating, friction (both curvature and wobble) including reductions associated with the selection of galvanized sheathing, in terms of tendon stress (ksi).

(a) Full information shall be provided in the form of test results and other applicable data for assurance that the friction and relaxation losses used in the design are accurate.

(b) If only short duration (1,000 hours) laboratory tests are to be used as the basis for relaxation losses, then justification shall be provided as to how this information is adjusted to provide for accurate losses in the real tendon for a period of 40 years.

(c) If only laboratory type tests or past information is to be used for determining friction losses, then justification shall be provided as to how this information is adjusted to provide for accurate losses. in the real tendons.

(4) Typical anchorage details and test results showing that the anchorage develop the minimum guaranteed ultimate strength of the tendon and the minimum elongation of 3% in a 10'-0" gage length. The bidder shall also submit data which compares the actual ultimate strength and elongation of the tendon system proposed with the actual ultimate strength and elongation of the wire or strand proposed. This comparison shall be made using identical loading rates. Valid information shall be provided showing there is no possibility of a brittle failure in any part of the anchorage assembly when the system is subjected to low temperatures in accordance with paragraph 7.04.

(5) Dynamic test results of smaller tendon anchorage assemblies showing no loss of stress based on 500 cycles of rapid loading from stress level 0.70 f's to stress level 0.75 f's and return to 0.70 f's. One complete cycle shall take place in 0.1 seconds. Test results should include deflection measurements of the concrete, bearing plate and anchorage assemblies, and should clearly demonstrate that the concrete has not failed and that the bearing plate deformation is essentially elastic.

(6) Clearance requirements for field anchorage attachment, if required.

(7) Clearance requirements for placing tendons.

(8) Clearance requirements for stressing operation.

(9) Outline drawings showing dimensions, weights, and clearance requirements for all installation and stressing equipment.

(10) Maintenance instructions and spare parts lists for all field installation equipment.

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(11) Scope drawings showing the following information:

(a) Number of vertical, horizontal and dome tendons.

(b) Number of vertical, horizontal and dome anchorages.

(c) Lineal footage of vertical, horizontal and dome sheathing.

(d) Tonnage of vertical, horizontal and dome tendons.

(e) Total quantity of sheathing filler.

(f) Minimum bonded reinforcement requirements at various anchorage conditions.

(12) Product name and manufacturer of tendon sheathing filler material. The bidder shall provide sufficient technical information from paragraph 6.01B for adequate evaluation.

C. QUALITY ASSURANCE

The bidder shall furnish a full description of the quality assurance procedures, program, organization, and equipment offered by him in respect to the design, manufacture, and erection of the equipment. The bidder's quality assurance program will be a consideration in the bid evaluation.

D. MANUFACTURING LOCATIONS

The bidder shall furnish the location (city, state or country) of the plant or plants at which the equipment will be manufactured, and if more than one plant is involved, describe fully each portion of the equipment manufactured in each plant and state what percent of total cost is represented by that portion.

E. FOREIGN SHIPMENT

For foreign shipment, the bidder shall include with his bid a complete breakdown of shipping information in quadruplicate including point or points of origin and United States port of entry or ports of entry through which shipment will be made.

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H. DESIGNATION OF SUBCONTRACTORS

With reference to paragraph 5.32, the following are the names and locations of places of business of all subcontractors who will perform work or labor or render service to the bidder in or about the work in an amount in excess of five thousand dollars ($5,000), together with a statement of the portion of the work to be done by each subcontractor.

Name	Location	Portion of Work

5.11 PROTECTION OF MATERIALS

The Contractor shall at all times take care to protect and preserve all materials, supplies, and equipment of every description (including property which may be furnished or owned by the District), and all work performed. All reasonable requests of the District to enclose or specially protect such property, shall be complied with. If, as determined by the District, material, equipment, supplies and work performed are not adequately protected by the Contractor, such property may be protected by the District, and the cost thereof may be charged to the Contractor or deducted from any payments due to him.

5.12 PACKING AND SHIPPING

The Contractor shall prepare and load all material and equipment for shipment, in such a manner as to protect them from damage in transit. Contractor shall be responsible for and make good any and all damage due to improper preparation or loading for shipment. Where necessary, heavy parts of equipment shall be mounted on skids or shall be crated, and any articles or materials that might otherwise be lost shall be boxed or wired in bundles and plainly marked for identification. Any part having a shipping weight exceeding four (4) tons shall have its gross weight painted thereon with white paint. All material and equipment shall be loaded so that it will not shift or become damaged during hauling. All parts exceeding two hundred (200) pounds gross weight shall be prepared for shipment, so that slings for handling by crane may be readily attached while the parts are on the car or on other methods of conveyance. Boxed parts, where it is unsafe to attach slings to the box, shall be packed with slings attached to the part, the slings to project through the box or crate so that attachment to the hoisting equipment can be readily made. All finished non-ferrous metalwork and devices subject to damage shall be suitably wrapped or otherwise protected from damage during shipment. Proper precautions shall be taken with all electrical equipment and instruments, to prevent damage during shipment. The moving elements of all meters and instruments shall be properly blocked or tied, to prevent damage during shipment.

It shall be the responsibility of the Contractor to verify and ascertain that all sections and parts shipped shall be of such size and dimensions as to provide sufficient clearances through all tunnels, underpasses, and all other restrictions that may be encountered in shipment of the contract items to the point of destination listed in the contract.

When items shall be disassembled for shipment. They shall be match-marked for ease of reassembly. All pieces, items and units, and their containers shall be piecemarked to an approved master numbering system, and shall be tagged with the District's purchase order number.

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The Contractor shall prepare and submit to the District at least thirty (30) calendar days prior to shipment, a summary of shipping points, shipping weights, classifications, proposed routings and shipping diagrams, if any. The District reserves the right to review and specify carriers to be used, as long as this does not increase the cost of shipment or the time required for shipment.

Where shipments originate in the United States or Canada, the Contractor shall also furnish the following information by telegram as early as possible, but not later than the day of shipment:

a. Date of shipment.

b. Routing.

c. Car number.

d. Point of origin.

e. Material being shipped.

For foreign shipments, the Contractor shall furnish the following information by TLX as early as possible, but not later than five days prior to shipment.

a. Description of shipment, including weights, measurement and packing.

b. Name of vessel and its nationality.

c. Port of shipment and scheduled date of departure.

d. Port of entry into United States and expected arrival date.

e. Stowage - whether on deck or below deck.

f. Bill of lading, number and date, and any exceptions noted thereon by carrier.

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5.14 INSPECTION AND TEST

a. The District reserves the right to perform such examination, inspection and tests of equipment, material and workmanship as it may desire to assure itself that the work meets all specified requirements.

b. The Contractor and all of his subcontractors and suppliers shall permit unrestricted access to the District or its duly authorized representative(s) for the purpose of conducting such examination, inspection and tests at any and all times and places where the work is in process of manufacture, fabrication, construction, assembly or erection; shall provide sufficient, safe and proper facilities such as ladders, scaffolds, openings, and drop lights for such access and inspection; and shall make available any and all data which is relevant to the performance of this contract.

c. If the Specifications, Laws, Ordinances, or any public authority require any work to be specifically done, tested or approved, the Contractor shall give the District sufficient advance notice of his readiness for inspection or test to permit the District scheduling of all necessary personnel. If any work shall be covered up without approval or consent, it must, if required by the District, be uncovered at the Contractor's expense. If due to reasons within the control of the Contractor the work is not ready for inspection when scheduled, the Contractor may be charged for any additional costs to the District, which result therefrom.

d. The District through its duly authorized representative shall have authority to reject materials and workmanship, which are defective or not in accordance with the specifications, and, to require their correction. Any material or work, which is rejected in writing due to stated defect or non-conformance with specified requirements, shall be satisfactorily corrected or replaced at once without any cost to the District. No other work connected to or dependent upon the rejected work shall be done until the rejected work has been corrected or replaced.

e. If the Contractor fails to proceed with the replacement of rejected material or the correction of defective workmanship, the District may, by contract or otherwise, replace such material and correct such workmanship and charge the cost thereof to the Contractor, and, may also at the District's option, terminate the right of the Contractor to proceed as provided in Sections 5.41 and 5.42 of this contract, the Contractor and Surety being liable for any damage to the same extent as provided in said Sections 5.41 and 5.42, for termination thereunder.

f. Inspection documents in the quality control files of the manufacturer shall be accessible for examination by the representative of the District.

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5.23 TRADE NAMES AND ALTERNATIVES

For ease of reference in the contract, certain equipment and materials may be designated by a trade name, manufacturer's name, manufacturer's catalog number, or other similar designation. The Contractor may make written request to the Engineer for approval of the use of alternative equipment or materials. Such request shall contain complete data intended to show that such alternative items are of a quality equal to or better than that specified, and have the required characteristics for the intended use. Upon request, the Contractor shall furnish to the Engineer such additional information relating to such alternative items, as the Engineer may require. Contractor shall make his request at least sixty (60) calendar days before approval is required, of any such alternative items. Within thirty (30) calendar days following receipt of all requested information from the Contractor, the Engineer will determine whether the proposed alternative meets the requirements of the contract, and will inform the Contractor in writing of his determination.

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6. SPECIAL CONDITIONS

6.01 SCOPE OF WORK

A. WORK INCLUDED

The work to be performed under this contract consists of furnishing all labor, materials, and equipment required to furnish and deliver the items specified, in strict accordance with the Contract The materials and equipment furnished shall be complete, of good materials, and fabricated with accurate workmanship, skillfully fitted, and properly connected and assembled. All work, materials, and services not expressly called for in the text or shown on the drawings, but which are necessary for proper operation of the post-tensioning system, shall be performed and furnished by the Contractor at no increase in cost to the District.

B. TECHNICAL DESCRIPTION

The Contractor shall include the furnishing of systems engineering, field equipment, shop-fabricated post-tensioning materials, and associated hardware for the post-tensioning system required for the prestressed concrete Reactor Building in accordance with these specifications and requirement drawings, and as defined in the following paragraphs.

1. Systems Engineering

   a. It shall be the responsibility of the Contractor to furnish engineering data for the utilization and optimization of the post-tensioning system with respect to all the applicable items listed in paragraph 3.05, Bid Data.

   b. Engineering and preparation of shop and field erection drawings of the complete post-tensioning system as optimized, to include the following items:

      - Tendons
      - Bearing Plates
      - Sheathing and Protective Caps
      - Air Vents and Vent Piping
      - Anchorage Assemblies
      - Sheathing Couplers, Trumpets, and Transition Cones
      - Tendon Sheathing Filler Retaining Caps
      - Corrosion Protection
      - Sheathing and Trumpet Placing Drawings
      - Post-Tensioning Sequence Drawings
      - Stressing Record Forms
      - Equipment Drawings

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c. A quality control manual describing both shop and field fabrication and installation procedures and the associated quality control steps necessary to produce a tendon system meeting the performance criteria as stated in this Specification.

2. Field Equipment

a. Furnishing and delivery including freight to and from the jobsite of required equipment for the duration of the placing, stressing and greasing operations. The Contractor shall set up performance criteria, develop and proof-test such equipment to meet the technical requirements and the construction schedule of the District for the prestressed concrete Reactor Building.

b. The Contractor shall be responsible for the proper functioning and quality of such equipment and shall make repairs as are necessary for the proper performance of the equipment such that the District's construction schedule will be maintained. Repair of damage to equipment caused by others is not the responsibility of this Contractor. Equipment used by others will be turned over to the Contractor upon completion in good working order with normal considerations for wear.

c. Equipment shall match available clearances indicated on the project requirement drawings and shall consist of, but is not limited to, the following:

(1) A sufficient amount of Stressing Jacks and Pumps including necessary accessories and spare parts such that three hoop or dome tendons may be jacked simultaneously.

(2) Fifty tendon shipping racks for transporting shop coiled, dipped and wrapped tendons from the shop to the jobsite. The racks shall incorporate means for slight separation of the individual tendons to permit easy attachment of slings for unloading. Racks shall be easily broken down for return shipment to factory by the Contractor.

(3) Three tendon uncoiler tubs for placing of shop coiled tendons. These tubs shall confine the coiled tendon during pulling and shall permit vertical, right-hand, or left-hand orientation of the tub during pulling. Capability shall be provided to control the feed of the vertical tendons during placing.

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(4) Three sets plus one spare of buttonheading or swaging equipment, if required, for field installation of anchorages. Buttonheading equipment shall consist of buttonheader capable of upsetting greasy wires, plus that specialized equipment necessary for the hand threading of wires and relocation of the tendon ready for stressing.

(5) Devices for attaching tendon to pulling cable, such as Kellum Grip, or similar. These gripping devices shall be attached in the shop to minimize field preparation of tendon for pulling.

(6) Complete greasing equipment as specified by the manufacturer of the tendon sheathing filler material.

(7) A bending machine if required for the fabrication of the tendon sheathing.

3. Materials

a. Furnishing and delivery from the Contractor's plant to the jobsite of approximately 2,200,000 pounds of ASTM A-421 Type BA prestressing wire or ASTM A-416 prestressing strand into tendon assemblies consisting of one of the following:

(1) Buttonheaded or Swaged Tendons - The anchorage assembly on one end of the tendon shall be shop assembled and shop attached to the tendon. The other anchorage assembly shall be shop fabricated to permit field installation using that equipment furnished by the Contractor in accordance with paragraph 2c of this section.

(2) Friction Anchorage Tendons - The shop fabricated anchorage assemblies for both ends shall be furnished for field installation. The strand shall be furnished grouped into fully assembled tendons, cut to proper length, dipped, coiled, and packaged to facilitate field handling and corrosion protection.

b. Furnishing and delivery from the Contractor's plant to the jobsite the required number of bearing plates, trumpet and transition pieces, sheathing material, and sheathing filler retainer caps including all gaskets, protective caps, couplers, fasteners, vent tubes and valves to form a complete post tension system.

c. Furnishing and delivery to the jobsite approximately 60,000 gallons of tendon sheathing filler material to provide continuous corrosion protection for the 40 year life of the plant in accordance with this Specification.

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4. Job Supervision

a. A Project Engineer shall be assigned to this work, for the main purpose of coordination, from the date of contract through completion of post-tensioning work (approximately 36 months). The Project Engineer shall be on jobsite for one month at the start of bearing plate and sheathing installation, one month during placing of tendons during concreting, and four months during placing, buttonheading, stressing and greasing at completion of concreting. Planned travel shall include approximately ten trips to Los Angeles or to system-approval meetings. If the Project Engineer cannot be available at the jobsite for all of the time mentioned above, services of another Project Engineer of equal qualifications, experience, and competence shall be furnished in lieu of the assigned Project Engineer.

   The Project Engineer shall be available on call for travel to the jobsite or other locations on a per diem basis plus expenses, as outlined in paragraph 5.33.

b. The services of two or more additional technicians who are qualified and experienced in post-tensioning operations may be needed for the training of the District's field crews. These men shall be available on call on a per diem basis plus expenses during the placing of the sheathing, assembling field end anchor, and during placing, stressing and filling of the tendons, as outlined in paragraph 5.33.

5. Detail Shop Drawings

The Contractor shall furnish the following detail and erection drawings to the District in accordance with paragraphs 5.24 and 5.26.

a. Complete details of the post-tensioning system, equipment, and materials to place tendons, install anchorage assemblies, stress the tendons, and place the sheathing filler material.

b. Details of anchorage assemblies, bearing plates, and sheaths, sheathing filler retainer cap, and other accessories pertinent to the post-tensioning system.

c. Erection drawings to be used for the placing, stressing and greasing operations, showing clearly the marking and positioning of tendons, bearing plates, anchorage assemblies, sheaths and details showing alignment, required bending radii of sheaths and setting tolerances required.

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d. All other pertinent design information affecting clearances and design requirements for placing, stressing and filling.

6. Shop Drawing Review

The Engineer will review the Contractor's drawings with respect to the requirements and general conformance to the Specifications and related requirement drawings as outlined in paragraph 5.24. The Engineer's approval does not relieve the Contractor of any responsibility for the completeness and accuracy of all dimensions and details.

7. Tendon Filler Material Requirements

a. The Contractor shall furnish the information for all the physical and the chemical properties listed below along with their proper ASTM Testing Method Numbers, for the product he proposes. The product delivered shall conform to all these values.

Physical Information	Chemical Information
1. Weight per Gallon	1. Nitrate (ppm)
2. Specific Gravity	2. Chloride (ppm)
3. Melting Point	3. Sulfide (ppm)
4. Flash Point	4. Major Constituents by Organic Analysis

b. The Contractor shall supply complete information describing the Manufacturer's Quality Control Methods for the material.

c. The Contractor shall provide the information on physical and chemical changes in the material due to aging and the effect of sustained hydrostatic or pumping pressure-head.

d. The Contractor shall quote at least five instances where the material performed under similar or worse conditions.

e. The Contractor shall submit manufacturer's recommendations for storing and handling the material at the site. The storage requirements shall cover information on sensitivity to moisture, heating and pumping.

f. The Contractor shall recommend a temporary corrosion protection material similar to Dearborn Chemical No-Ox-Id 500 to be used on the tendon wire for the two following exposures:

(1) The tendons will be coiled, banded, dipped in anti-corrosion compound, wrapped in plastic bags and stored in warehouses either at the manufacturer's plant or the construction site.

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(2) An approximate length of 5 feet will be left exposed to weather, sticking out of tendon sheathing, for a period of two months prior to prestressing operation. For an additional period of two months prior to prestressing, the tendons will be in the sheathing with both ends capped.

g. The Contractor shall provide the following:

(1) A product for removing temporary corrosion protection material just prior to buttonheading, from last one foot of wire length.

(2) A product for removing spilled tendon sheathing filler grease from concrete surfaces.

h. The Contractor shall recommend the methods for pumping the sheathing filler material; also the size and type of pumps, conveying hoses, and the loss of head per 100 feet of length of the conveying systems: or supply the kinematic vicosity for a pumping rate (5 gpm to 20 gpm) through a range of temperatures from 19°F to 120°F.

i. The Contractor shall provide the method of protection of the sheathing filler material against contamination in shipping containers.

C. SCHEDULE REQUIREMENTS

1. Construction Schedule

The attached Figure 6-1, "Reactor Building, Construction Schedule," is included in this Specification for use as a guide in scheduling and delivering material orders.

2. Detailing and Fabricating Schedule

The Contractor shall submit a fully itemized detailing, equipment procurement, and tendon fabricating schedule based upon the District's construction schedule, Figure 6-1. The Contractor's schedule shall include a monthly breakdown showing the time required for shop detailing, procurement, fabricating and delivery to the site of the tendons, hardware, and equipment.

3. Sheathing

Delivery of sheathing must be scheduled concurrently with the concrete placement but to prevent accumulation of more than 4 weeks' requirments of the District at any time. Varations in the Districts's Schedule shall not be a basis for additional payment to the Contractor.

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4. Monthly Progress Report

The Contractor shall submit a monthly progress report including a current schedule as required in the previous paragraph.

D. MANUAL SUBMITTALS

(1) The Contractor's attention is called to paragraph 5.26 and in particular to Item 17, Instruction Manuals and to Spare Parts Lists, paragraph 5.26B.

(2) The Contractor has the responsibility to furnish the required Instruction Manuals and Spare Parts Lists for every item which he furnishes hereunder.

(3) One copy of all instruction manuals and parts lists must be included with the equipment at time of shipment. This set is in addition to the copies required by paragraph 5.26.

E. WORK NOT INCLUDED

The following items of work and equipment are not included:

(1) All Field labor
(2) Concrete and form work
(3) Non-prestressed reinforcing
(4) Liner plate
(5) Miscellaneous embedments and pipe sleeves
(6) Storage of materials at the jobsite
(7) Scaffolding, hoists, cranes and access towers
(8) Field measurement of cast-in-place sheathing, if required

6.02 REACTOR BUILDING DESCRIPTION

The general configuration and dimensions of the Reactor Building are as shown in the project requirement drawings. The structure is a concrete vertical right cylinder with a flat base slab and a shallow domed roof. A 1/4 inch welded steel liner plate is attached to the inside face of the concrete shell to ensure a high degree of leak tightness. The cylinder wall and the dome are prestressed post-tensioned. The concrete base slab is reinforced with non-prestressed high strength reinforcing

6.03 PROJECT REQUIREMENT DRAWINGS

The following requirement drawings, which form a part of this Specification, are prepared to show the general orientation of the tendon system, typical details, the type of construction, the available clearances, the desired preliminary average residual prestressing forces for tendons, the anticipated losses, and some of the information to be furnished by the Contractor.

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Final tendon spacing and details shall be based in part upon the Systems Engineering portion of this Specification.

Drawing No.	Title	Comments
C-100	Location Map	(For General Information)
C-432	Reactor Building Containment Structure-Area 1 Dome Prestressing Requirements	
C-433	Reactor Building Containment Structure-Area 1 Wall Prestressing Requirements	
C-435	Reactor Building Containment Structure-Area 1 Equipment Hatch and Personnel Lock-Prestressing Requirements	
C-470	Reactor Building Containment Structure Tendon Access Shafts Plan, Sections and Details	(For Clearance Information Only)
C-471	Reactor Building Containment Structure Tendon Access Shafts Sections and Details	(For Clearance Information Only)
C-472	Reactor Building Containment Structure Tendon Access Gallery Plan, Sections, and Details	(For Clearance Information Only)
C-476	Reactor Building Containment Structure Wall Liner Plate - Penetration Schedule	(For Penetration Information Only)
C-477	Reactor Building Containment Structure Wall Liner Plate and Penetrations - Sheet 1	(For Penetration Information Only)
C-478	Reactor Building Containment Structure Wall Liner Plate and Penetrations - Sheet 2	(For Penetration Information Only)

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6.04 SITE INFORMATION

a. The plant site is accessible via State Highway 104 and by the Southern Pacific Railway. A railroad spur should be available to the Contractor from August 1, 1969.

b. A paved plant access road, with a maximum grade of 5%, connects to State Highway 104.

c. The plant elevation is approximately 165 feet above mean sea level.

d. The climate in the area is generally that of the Great Central Valley California with hot summers and mild winters with the rainy season between October and May. Typical climate information is as follows:

(1) Average of data from 1931-1960 period indicate a maximum normal temperature of 78F occurring during July.

(2) Average of data from 1931-1960 period indicate a minimum normal temperature of 44F occurring during January.

(3) The highest temperature extreme based upon six years record is 115F.

(4) The lowest temperature extreme based upon six years record is 19F.

(5) The normal precipitation may be taken as 16.3 inches.

(6) The maximum rainfall intensity may be taken as 3.6 inches in a 24 hour period.

e. Maximum wind pressures on the Reactor Building are 14.5 psf from 0 feet (grade) to 50 feet and 19.8 psf from 50 feet to 150 feet.

6.05 CONSTRUCTION METHOD

a. The construction method of the containment structure is based on casting the cylindrical wall in 60 degree to 120 degree arcs in lifts of ten feet. Accordingly, the vertical sheaths will be installed in 10 foot lengths.

b. The hoop sheaths will have a field splice at each trumpet extension and at six points in between. This results in hoop sheaths of approximately 40 foot lengths.

c. The dome sheaths will be spliced at the trumpet extension, and at such intermediate points as expedient. The dome sheaths will be installed in approximately 45 foot lengths.

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6.06 SHIPMENT

a. The Contractor shall prepare and weatherize all articles for shipment in such a manner as to protect flanges, nozzles, machined surfaces, and other finished parts from any damage to which they might reasonably be subjected, both in transit and handling. The Contractor shall be responsible for, and shall repair or replace at his own expense, any and all damaged equipment which was damaged because of improper preparation for shipment.

b. Each piece of equipment shall be identified with a permanently attached metal tag, bearing the purchase order or subcontract number and item number or the appropriate equipment number as specified. Packing slips showing all equipment and/or material shipped shall accompany all shipments.

c. Material and equipment shall be furnished in the maximum sizes consistent with shipping restrictions. Shop fabrication shall be to maximum practicable extent to minimize field erection or installation.

d. Field storage space for material or equipment specified herein, whether indoors or outdoors, will be provided by the District.

6.07 QUALITY ASSURANCE

A. GENERAL

As required by the Atomic Energy Commission, this project will have a Quality Assurance Program. This program will apply to the extent specified in the detailed specifications. As part of the program, a Bechtel Corporation Quality Assurance Engineer will be resident at the project site. He will have the authority to stop work and assure correction of material and/or workmanship which do not meet the requirements of the plans and specifications.

B. QUALITY ASSURANCE PROGRAM SPECIFICATION

Before any material is released for fabrication, the Contractor shall submit his detailed Quality Assurance Program Specification including his organization and equipment for applying the program. The Specification shall include all phases of shop manufacturing and field erection to assure the quality requirements of the material and equipment are met or exceeded as set forth by the applicable contract specification drawings and related documents. The specification shall include, but not be limited to, materials certification and their release; qualification of welding procedures, welders, welding operators, inspection procedures and inspectors; in process and final inspections to be performed during fabrication, processing and field erection; testing at various in-process or final stages, control for shipment, control of Vendor and

Subcontractor components and/or fabricated assemblies; and communication procedures for action to be taken when quality criteria are not met. The procedure for submittal and approval shall be as described under paragraph 5.24, B.

6.08 EVALUATION CONSIDERATIONS

The award of this contract will be based on the following considerations:

a. Compliance with paragraph 3.05A "Bid Data". Inadequacy of the technical data submitted is cause for disqualification of a proposal.

b. Evaluation of the total estimated installed cost of the tendon system. This estimate cost will consist of the proposed value of the Bid Package, the District's estimate of licensing costs, and the District's estimate of the field labor costs to install the complete system.

c. The number of tendons considered for each system bid will be based on developing equal ultimate strength, inspectability and surveillance characteristics in the containment structure.

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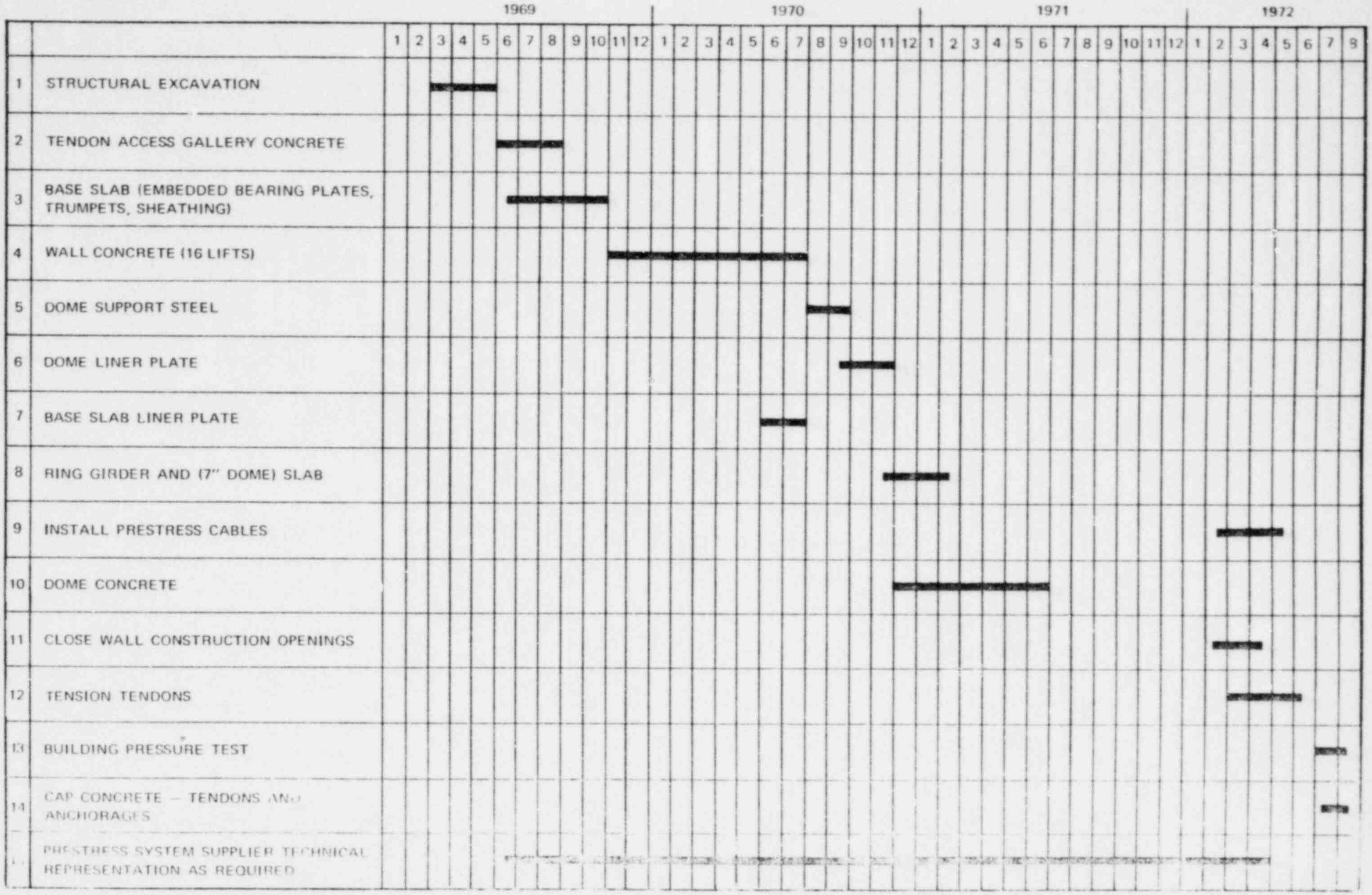
REACTOR BUILDING CONSTRUCTION SCHEDULE

Bechtel Corporation

RANCHO SECO NUCLEAR STATION UNIT 1



NOTE–EMBEDDED MATERIALS REQUIRED BY SPFC WILL BE AT THE CONSTRUCTION SITE BY THE FOLLOWING DATES: BASE SLAB–JULY 15, 1969 WALL FIRST LIFT–OCTOBER 31, 1969 REMAINING LIFTS AT TWO WEEK INTERVALS OR LESS IN SUCCESSION. DOME–NOVEMBER 30, 1970

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7. TECHNICAL PROVISIONS

7.01 GENERAL

A. MATERIALS

All materials used in manufacturing the equipment shall be new, suitable for work, the best of their respective kinds, and shall be subject to the approval of the Engineer. All materials, supplies and articles not manufactured by the Contractor shall be the products of recognized reputable manufacturers.

B. POST-TENSIONING SYSTEM

The prestressing system shall have anchorages outside of the structure and shall be so designed and furnished that the prestressing steel can be installed and post-tensioned after the concrete work is completed.

1. Arrangements of Prestressing Tendons

The configuration of the tendons in the dome is based on a three-way system consisting of three groups of tendons oriented at 120 degrees with respect to each other. The vertical cylinder wall is provided with a system of vertical and horizontal (hoop) tendons. Hoop tendons are placed in a 240 degree system in which 3 tendons form two complete rings using three buttresses for anchoring the tendons as shown in the referenced drawings, paragraph 6.03. In general, the tendon center to center spacing will not exceed 60 inches nor will any tendon be closer than 6 inches from the outer edge of any penetration unless otherwise noted.

2. Control of Stressing

Stressing of tendons shall be done by methods and related equipment that are generally accepted to be in conformance with the prestressing system to be supplied by the Contractor and approved by the Engineer.

3. Sheathing

The sheathing system shall provide a void in the concrete wherein the prestressing tendons may be placed, stressed and greased after the concrete is placed. The sheaths shall be cut to the required lengths and shipped to the site in straight lengths. The sheaths are classified as concrete forms, and as such, are not subject to standard design codes although standard design loads for concrete forms are applicable.

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4. Tendon Sheathing Filler Material

The tendon sheathing filler material will be used to fill the space left between the post-tensioned tendons and the interior wall of the steel tendon sheathing. The purpose is to enclose the tendons and provide continuous corrosion protection. The material provided shall be capable of being contained for the 40 year design life of the plant without any chemical or physical changes or deterioration of its corrosion protection capabilities

7.02 STANDARDS

a. All work shall be performed by mechanics skilled in their various trades. Except where otherwise provided herein, all parts shall be made accurately to USA Standard gauge, so as to facilitate replacement and repairs. All bolts, nuts, screws, rivets, threads, pipes, gauges, gears and measurements or dimensions shown on the drawings not conforming to the latest United States standards shall be subject to approval by the Engineer.

b. All equipment, materials, and labor specified herein shall be designed and constructed to comply with the applicable codes, laws, and regulations to insure lawful use by the District in the State of California. Except as otherwise noted, all work shall be in accordance with the following codes and specifications:

(1) ACI 318-63 "Building Code Requirements for Reinforced Concrete"

(2) ACI 301-64 "Specifications for Structural Concrete for Buildings"

(3) Recommended practices of the Prestressed Concrete Institute.

7.03 POST-TENSIONING

A. MATERIALS AND FABRICATION

1. Wire

Wire shall be cold-drawn, of the low-relaxation or stabilized type, having a guaranteed minimum ultimate tensile strength (f's) of 240,000 psi and the minimum yield strength shall not be less than 0.80 f's. Wire shall conform to ASTM Designation A421 Type BA or Type WA, latest revision. Elongation at ultimate failure shall not be less than that given in ASTM A421.

2. Strand

Strand shall be of the seven-wire low-relaxation or stabilized type, having a guaranteed minimum ultimate tensile strength (f's) of 250,000 psi or greater based on the nominal steel area of strand and the minimum yield strength shall not be less than 0.85 f's. Strand shall conform to ASTM Designation A416, latest revision. Elongation at ultimate failure shall not be less than that given in ASTM A416.

3. Tendons

All tendons shall be furnished in continuous lengths without splices. They shall leave the plant completely fabricated and protected from mechanical damage and corrosion in accordance with this Specification. The tendons shall be in accordance with one of the following systems.

a. Tendons for post-tensioning shall consists of 1/4" minimum diameter parallel lay wire in accordance with the above. End anchorage at one end shall be provided by means of shop button heads cold formed after threading through the stressing washer. End anchorage at the other end shall be provided by means of field button-heads formed after the tendon has been placed in the structure.

b. Tendons for post-tensioning shall consist of 1/2" nominal diameter seven-wire strands in accordance with the above. Swaged end anchorage shall be shop attached on one end and field attached on the other. Friction end anchorages shall be field attached to both ends.

4. Button Heads

The Contractor shall submit for the Engineer's approval, engineering data and test data for the forming of the button heads from which the Engineer and Contractor will establish quality control, performance and acceptance criteria for the button heads. The heads shall be formed symmetrically about the axis of the wires and shall be free from harmful seams, fracture or other flaws. No heading procedure shall be used that causes serious indentations in the wires. All wires improperly installed shall be rejected on inspection. At least one test shall be made from each end of each coil of wire to establish the suitability and acceptance of the wire for buttonheading.

5. Friction Cones or Similar Devices

The friction cones and bearing blocks shall be manufactured with sufficient tolerance control such that it will develop the guaranteed minimum ultimate strength and required elongation of each individual strand.

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6. Swaged Anchors

Swaged anchors shall be manufactured such that the guaranteed minimum ultimate strength and required elongation of each individual strand is developed without slippage of the strands relative to the swaged collar or each other.

B. PROTECTION

Prestressing steel tendons shall be protected from mechanical damage and corrosion during shipment and storage. A thin film of NO-OX-ID 500, as manufactured by Dearborn Chemical Company or approved equal, shall be applied on the prestressing steel after fabrication in accordance with Manufacturer's instruction. The tendons shall then be shipped to site in visqueen bags. The tendons shall not be handled, shipped or stored in a manner that will cause a permanent set or notch, change its material properties, or expose it to inclement weather or injurious agents such as chloride containing solutions. Damaged or corroded tendons shall be rejected.

7.04 ANCHORAGES AND BEARING PLATES

A. ANCHORAGES

Anchorages shall develop the minimum guaranteed ultimate strength of the prestressing steel without permanent deformation other than initial set, and without excessive slip. The total elongation of the tendon under this load shall not be less than 3 percent when measured in a minimum gage length of 10 feet. No more than 2 percent wire breaks at this elongation shall be allowed for acceptance. The anchorage gripping shall function in such a way that no harmful notching will occur on the tendon. The anchorage system shall be capable of maintaining the prestressing force under sustained and fluctuating load and the effect of shock as required by paragraph 3.05.

Documentary evidence or certified testing at low temperatures shall substantiate that the anchorage assembly, including the bearing plate, is capable of transmitting the ultimate load of the tendon into the structure without brittle fracture. The anticipated lowest service temperature for the anchorages is 19F for this structure. Low temperature testing shall be done at -11F or lower.

End anchorages shall be so designed that prestressing forces may be varied during construction without replacement of the tendon.

The outside edge of any hole for prestressing wire through a stressing washer or through an unthreaded bearing ring or plate shall be not less than 1/4 inch from the root of the thread of the washer or from the edge of the ring or plate. The outside edge of any hole for a friction cone through an anchor head shall not be less than 0.75 of the maximum cone diameter from the outside edge of the anchor head.

B. BEARING PLATES AND TRUMPETS

Bearing plates shall be capable of developing the ultimate strength of the tendon and distributing the bearing load fairly uniformly over the bearing surface of the concrete. Bearing plates or assemblies shall conform to the following requirements:

(1) The transfer unit compressive stress of the concrete directly underneath the plate or assembly shall be in conformance with the ACI Code 318-63. The compressive strength of the concrete for the wall, dome and the base slab is indicated on the referenced drawings.

(2) Bending stresses in the plates induced by the pull of the prestressing steel shall not exceed 22,000 psi for structural steel and 15,000 psi for cast steel except as experimental data required in paragraph 3.05 may indicate that higher stresses are satisfactory. For higher strength steel, correspondingly higher stresses may be permitted.

(3) Materials shall meet requirements of ASTM A-36 for structural shapes or ASTM A-148 Grade 80-40 for cast steel, or higher quality materials approved by the Engineer to meet strain and brittle fracture requirements.

(4) Design and fabrication shall meet the requirements of the latest AISC "Specification for the Design, Fabrication and Erection of Structural Steel for Building". All structural welding shall conform to the American Welding Society Standards AWS D1.0 latest edition, including Qualification Test of Welders.

C. SHEATHING FILLER RETAINER CAPS

Sheathing filler retainer caps shall be furnished by the Contractor to provide a continuous corrosion protection environment for the tendon and anchorage. The caps and gaskets shall be of materials that will not deteriorate in a petroleum and/or atmospheric environment during the 40 year plant life. Sample designs shall be tested to substantiate that the cap and gasket will not fail or leak when tested to 150 percent of the required pumping pressure. The Contractor shall provide protection necessary to maintain the gasket surfaces on the bearing plate and cap during installation and exposure to weather prior to filling of the tendons.

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7.05 TENDON SHEATHING

A. MATERIALS

(1) Sheaths for post-tensioning tendons shall be galvanized spiral wrapped, semi-rigid, corrugated tubing and shall be ferrous metal conforming to ASTM A-366-66T, 24 guage or 22 guage cold rolled carbon steel, or approved equal.

(2) The sheathing system shall be compatible with the post-tensioning system submitted in the proposal. The sheathing diameter, clear of corrugations or intrusions, shall be sufficiently large to install the tendons and perform field anchorage with minimal field difficulty.

(3) Estimated quantities shall be included in the summary of proposal for the sheathing.

(4) Sheaths shall be rigid enough to withstand field handling, installing and the placing of concrete without becoming ovate, misaligned, or excessively dented. A dent of 3/8 inch shall be considered excessive. Concrete placement of 50F at a pour rate of 2 feet vertically per hour will result in a pressure of the sheathing of approximately 4 psi. Joints, seams, and splices shall not leak laitance.

B. COUPLERS

(1) Coupling devices shall be provided at all field splices inherent in the erection. The coupler shall provide a means to make a field splice which is easily and quickly sealed against leakage and which maintains the alignment of the parent sheath.

(2) Field welding of sheathing to form a splice will not be permitted.

(3) The coupler shall be so detailed that a segment of sheathing may be spliced between two other segments which are rigidly fixed in concrete.

C. PROTECTIVE DEVICES AND AIR VENTS

(1) Protective devices shall be provided to prevent damage to the ends of the sheaths and couplings during handling operations and to prevent entry of sand, rain, snow, etc. during storage.

(2) Protective caps shall be provided for use as splash caps or covers to prevent concrete from being splashed into vertical sheaths while concrete is being placed.

(3) Air vents and pipe caps shall be provided for a complete installation as required. The Contractor shall determine the number and location subject to the approval of the Engineer.

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D. CORROSION PROTECTION

(1) All materials shall be free from excessive rust, scale, manufacturing residue and foreign material to the extent that it can be put into place without further cleaning.

(2) The inside of the tendon sheaths shall be coated with a thin film of NO-OX-ID 500, as manufactured by Dearborn Chemical Company, or approved equal.

(3) The Contractor may propose alternative means to afford corrosion protection such as oil spray, oil dip, etc. Such alternatives must provide adequate corrosion protection for the time the materials are exposed to the atmosphere at the site prior to their being encased in concrete, and shall be compatible with the tendon sheathing filler material selected for the post-tensioning system.

E. FIELD FABRICATION

The sheaths will be cut to length and bent to shape without wrinkling the metal by others. Dented or wrinkled sheaths will be replaced. Finished bent or straight dimensions will be in accordance with Contractor's approved drawings.

F. INSTALLATION

Sheaths will be accurately installed in the forms by others at the location shown on the plans to a tolerance of ± three-quarter inch except as otherwise indicated on the drawings. The sheath will be supported in such a manner as to prevent displacement during concrete placement. The sheath will be supported at the ends and at such intervals as are necessary to maintain alignment. Special instructions required for a complete installation shall be specified by the Contractor.

G. CLEANING AND VENTING

Water will be prevented from accumulating in the sheaths by furnishing drain tubes at low points of deflected tendons. Just prior to insertion of the tendon the sheath shall be cleaned of accumulated water by the use of compressed air or other suitable means. All high points of the sheath will be provided with vent tubing and temporary valves supplied by the Contractor for release of trapped air during pressure greasing. All drain and vent tubes will be of non-rusting material.

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7.06 TENDON SHEATHING FILLER MATERIAL

A. SERVICE CONDITIONS

(1) The purposes of the tendon sheathing filler are as follows:

(a) To exclude air and water from the tendon surface and the sheathing void. (Moisture and concrete contamination may be present on the inside surface of the sheathing).

(b) To prevent the migration of air and water to the tendon surface, and the sheathing void during the life of the structure.

(2) The material shall be designed to be stable against physical and chemical changes for the plant life which will be in excess of 40 years. Service temperature will range from 19F to 120F. The expected integrated radiation dose is $1.0 \times 10^{+6}$ R.

(3) The sheathing filler shall be formulated to prevent leakage at ambient temperature through these type of joints which are surrounded by a minimum concrete thickness of 6 inches, and which may be subjected to pressure due to filling and hydrostatic effects in the vertical tendons.

(4) Due to thermal expansion or contraction, or the pumping process, voids may be present in the filler material or within the bundle of pre-dipped tendon wires. Consideration shall be given to the formulation of a filler with a liquid vapor phase inhibitor for the prevention of corrosion within these voids.

(5) The sheathing filler will be injected into the sheaths and around the anchorages under a pressure of approximately 100 psi measured at the anchorage inlet at a minimum placement temperature recommended by the Manufacturer.

(6) Material must be compatible with the Dearborn Chemical NO-OX-ID 500, or approved equal, tentatively designated as the interior coating of the sheathing as well as the temporary corrosion protection coating for the tendons.

(7) The District will reserve the right to accept or to reject the bid based on the information supplied by the Contractor. Representative samples taken at a frequency of one sample per 5000 gallons tested by an independent laboratory shall be used as a basis for plant quality control.

B. MATERIAL REQUIREMENTS

1. Physical Limitations

a. Melting Point	120 F Minimum	ASTM D-127
b. Flash Point	400 F Minimum	ASTM D-92

2. Chemical Limitations

COMPOUNDS	ALLOWABLE MAXIMUM	TEST METHOD
a. Water Soluble Chlorides (Cl)	5.0 ppm	ASTM Method D-512-62T (Limit of Accuracy 0.5 ppm)
b. Water Soluble Nitrates (NO_3)	0.05 mg per liter	ASTM Method D-992-52 (Limit of Accuracy 0.01 mg per liter)
c. Water Soluble Sulfides (S)	5.0 ppm	ASTM Method D-1255 (Limit of Accuracy 1.0 ppm)

3. Moisture

In low points of tendon sheathing, there may be moisture due to condensation, but drains shall be provided at these locations by the Contractor for use by others. Prior to filling with the sheathing filler, air will be blown through the sheathing by others if recommended by the Contractor.

4. Acceptable Products

The following products will satisfy the requirements of this Specification:

(1) Dearborn Chemical NO-OX-ID CM Casing Filler
(Dearborn Chemical Company)

(2) Visconorust 2090
(Viscosity Oil Company)

(3) Texaco Rustproof Compound "H"
(Texaco Oil Company)

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7.07 PRESTRESSING (Performed by Others)

A. TENSIONING SCHEDULE AND DETAILS

After approval of the Contractor's drawings, the Contractor shall furnish a detailed sequence of tensioning for each tendon in accordance with the general sequence shown on the post-tensioning requirement drawings.

The Engineer will furnish the Contractor the anticipated concrete elastic losses to be allowed for during the post-tensioning sequence. Prepared stressing record forms furnished by the Contractor shall indicate the overstress required for compensation of friction and the seating stress to allow for elastic losses to provide as uniform as possible final effective prestress in the wall or dome.

B. PRESTRESSING LIMITS

Temporary and effective stresses in the tendons shall be limited to those values stated in the ACI Code 318-63, Section 2606. The maximum stress due to the temporary jacking force shall be limited to 0.80 f's measured at the anchorage, but shall not be greater than the maximum value recommended by the manufacturer of the steel or of the anchorages. The maximum stress in the tendon immediately after anchoring shall be limited to 0.70 f's after elastic shortening losses, measured at the anchorage. The maximum effective stress which may be considered in the tendon shall be limited to the smaller of 0.60 f's or 0.80 fsy, measured along the entire tendon trajectory, regardless of the calculated value.

C. FORCE AND STRESS MEASUREMENTS

The jacks furnished by the Contractor shall be capable of force and stress measurements using the measurement of elongation of the prestressing steel after taking up initial slack and comparing it with the force indicated by the jack dynamometer or pressure gage. The gage shall indicate the pressure in the jack within plus or minus two percent. Force-jack pressure gage or dynamometer combinations shall be calibrated by an approved independent testing laboratory against known precise standards just before application of prestressing forces begins and all calibrations shall be so certified prior to use. Pressure gages and jacks so calibrated will always be used together. During stressing, records will be made of elongations as well as pressures obtained. Jack-dynamometer or gage combinations will be checked against elongation of the tendons and the cause of any discrepancy

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exceeding plus or minus 5 percent of that predicted by calculation (using average load elongation curves) shall be corrected and if caused by differences in load-elongation from averages, shall be so documented. Calibration of the jack-dynamometer or pressure gage combinations shall be maintained accurate within the above limits and if necessary, shall be recalibrated or newly calibrated combinations substituted during and at the end of the tensioning operations.

D. FINAL EFFECTIVE PRESTRESS

Upon final approval of the tendon placing drawings, the Contractor shall prepare drawings showing the calculated final effective prestress to be applied to the structure. Such drawings shall show the general final effective prestress and any variations due to curvature or wobble losses including any reductions from the use of galvanized sheathing.

7.08 TESTS, SAMPLES, INSPECTIONS AND SURVEILLANCE

A. POST-TENSIONING MATERIALS

(1) All post-tensioning materials for testing shall be furnished by the Contractor at his expense. The Contractor shall submit certified test results as outlined below for the Engineer's approval in accordance with Paragraph 5.26. The Contractor shall have no claim for additional compensation in the event his work is delayed awaiting approval of these certified results.

(2) Sampling and testing of the tendon wire shall conform to ASTM Standard A-421 and as specified herein.

(3) Sampling and testing of the tendon strand shall conform to ASTM Standard A-416 and as specified herein.

(4) Fully instrumented certified load tests shall be submitted for the Engineer's approval for bearing plates and anchorage assemblies to substantiate that the tendon will perform in accordance with Paragraph 7.04. All load tests of tendon assemblies shall be representative of the actual alignment and tolerances permitted in the fabrication and installation of the tendon. All such variations built into the test sample shall be identified in the test report. Detailed deflection measurements of the concrete, bearing plate, and anchorage assembly shall be recorded during these tests and shall demonstrate clearly that the concrete has not failed and that the bearing plate deformation is essentially elastic. All testing specified herein shall be conducted by the Contractor and reviewed by the Engineer prior to the delivery of the bearing plate assemblies to the jobsite. Bearing plate thickness increases greater than those shown in the proposal resulting from this test data shall be provided by the Contractor at no cost to the District.

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(5) Button head rupture tests from each reel of wire shall be made by the Contractor and submitted for Engineer's approval.

(6) Rupture tests from each reel of strand shall be made by the Contractor and submitted for Engineer's approval.

(7) Each size of wire from each mill heat and all strands from each manufactured reel to be shipped to the site shall be assigned an individual lot number and tagged in such a manner that each such lot can be accurately identified. All unidentified prestressing steel or anchorage assemblies received at the jobsite shall be rejected.

(8) Random samples as specified in the ASTM Standards stated above, shall be taken by the Contractor from each lot of prestressing steel to be used in the work. With each sample of prestressing steel wires that are tested, there shall be submitted a certificate stating the manufacturer's minimum guaranteed ultimate tensile strength of the sample to be tested.

(9) The District at its own expense may desire to test a certain number of completely fabricated tendons including anchorage assemblies for conformance to the requirements stated in this Specification. The Contractor shall cooperate with the District in the furnishing and testing of these test specimens.

(10) The District and Engineer shall at all times have access to the work for inspection while it is in preparation or progress and the Contractor shall provide proper facilities for such access and inspection.

(11) For prefabricated tendons, the Contractor shall give the Engineer at least seven (7) days notice before the shipment of these to the site, so that the Engineer will arrange for the required shop inspection.

(12) No prefabricated tendon shall be loaded for shipment to the site without first having been released by the Engineer and each tendon shall be tagged or stamped before shipment for identification purposes. The release of any material by the Engineer shall not preclude subsequent rejection if the material is later found to be defective. Any damage in transit will be for Contractor's account.

(13) The Contractor shall submit mill test reports identifying all materials by conformance to ASTM Specification, to industry standards of similar detail, or by measured physical and chemical properties necessary to define the materials to a degree equivalent to that given by such specifications or standards.

(14) The following additional quantity of tendons shall be supplied by the Contractor for surveillance. The tendons will be available for inspection and lift-off readings:

(a) Horizontal - three 240 degree tendons comprising two complete hoop systems.

(b) Vertical - three tendons spaced approximately 120 degree apart.

(c) Dome - three tendons spaced approximately 120 degree apart.

B. TENDON SHEATHING FILLER MATERIAL

1. Plant Quality Control

The Contractor shall perform tests for every batch of factory production and furnish certified test reports with each shipment. The tests shall be in accordance with Paragraph 7.06.

2. Field Quality Control

At the jobsite, the District will conduct the following acceptance tests.

a. Water soluble Chloride (Cl) will be determined by ASTM Method D512-62T with a limit of accuracy with 0.5 ppm.

b. Water Soluble Nitrates (NO_3) will be determined by ASTM Method D-992-52 with a limit of accuracy of 0.01 mg per liter.

c. Finally, Water Soluble Sulfides (S) will be determined by ASTM Method D-1255 with a limit of accuracy of 1.0 ppm.

3. Field Test Sampling Procedure

a. One drum will be selected from each 30 drums received and a 4 oz. sample will be withdrawn. If a shipment contains material from more than one batch then a sample will be taken from each batch. If filler is shipped in bulk, a sample will be taken from each shipment.

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b. Procedure

(1) Insert a clean sample tube (positive suction tube of 2 inch diameter) to approximately 24 inches below the surface.

(2) Place the sample material in a clean 4 oz. glass container. Clean all sample tubes between samplings.

(3) Reseal the drum or tank and the sample container.

(4) Mark suitably the drum and the sample.

(5) Analyze the same in accordance with Paragraph 7.06.

c. Failure of the material to meet these tests shall be the cause for rejection of that material. The Contractor shall bear the cost of removal and disposal of the material offsite.

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ATTACHMENT 2

ULTIMATE STRENGTH TESTS ON VSL ANCHORAGES

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The following are the results of a series of tests performed for the VSL Corporation on various capacity VSL E5 series post-tensioning anchorages by independent testing laboratories. These tests have been performed to demonstrate, in both single and multiple configurations, the capability of this anchorage to develop 100% of the guaranteed ultimate strength of 1/2" 270 ksi strand. The importance of guaranteed versus actual ultimate strength derives from the fact that the majority though not all of strand failures at ultimate load occur at the wedge grips. Accordingly post-tensioning strand is designed by its manufacturer to produce the strength they wish to guarantee using the wedge grip devices in common use by the post-tensioning industry. Should a cruder device than wedges such as a vice be used in testing a sample, a strength less than that guaranteed would be obtained. Should on the other hand a strand be bonded with epoxy into steel sleeves prior to testing an ideal situation is created where strengths appreciably higher than guaranteed could be obtained in a laboratory test. In point of fact VSL wedges are used by two major testing laboratories in performing tests to determine the so-called actual ultimate strength of strand.

Number of Strands in Tendon	Load at Failure	% of Guaranteed Ultimate Strength
1	42,300	102.42
1	41,700	100.96
1	45,000	108.95
1	44,000	106.54
1	45,000	108.95
1	43,500	105.33
1	43,750	105.93
1	44,500	107.75
1	43,800	106.10
1	44,100	106.78
1	43,650	105.70
1	41,250	99.88
1	41,500	100.48
1	41,900	101.45

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Number of Strands in Tendon	Load at Failure	% of Guaranteed Ultimate Strength
1	42,600	103.14
1	42,080	101.88
1	43,270	104.77
1	43,740	105.91
1	42,700	103.39
1	42,400	102.66
1	43,800	106.05
1	43,500	105.33
1	44,000	106.54
1	44,000	106.54
1	42,500	102.91
1	43,950	106.42
1	43,370	105.01
1	44,030	106.61
1	43,900	106.30
1	43,990	106.51
1	43,080	104.31
1	44,750	108.35
1	43,250	104.72
1	44,500	107.75
1	44,000	106.54
1	43,000	104.12
1	41,500	100.48
1	43,000	104.12
1	43,250	104.72
1	41,250	99.88
1	42,250	102.30
1	43,750	105.93
1	43,400	105.08
1	43,500	105.33
3	127,750	103.08
3	128,750	103.89
4	166,680	100.87
4	172,300	104.27
4	170,000	102.88
6	250,960	101.25
19	790,000	100.65
31	1,336,000	104.33
31	1,318,000	102.92
55	2,284,000	100.53
55	2,284,000	100.53

Complete results on the two 55-strand tests in the above lists are tabulated below:

Samples:

Two 55-strand tendons 120.5 inches long composed of 1/2" 270 ksi low-relaxation stabilized strand. Guaranteed ultimate strength: 2,272,050 lbs.

Results of Test No. 1:

Ultimate load	=	2,284,000 pounds
% of f's	=	100.6%
Number of broken wires	=	4 wires
% of total wires broken	=	1.04%
Elongation	=	4.64 inches
% elongation at Actual UTS	=	3.86%

Results of Test No. 2:

Ultimate load	=	2,284,000 pounds
% of f's	=	100.6%
Number of broken wires	=	8 wires
% of total wires broken	=	2.08%
Elongation	=	5.16 inches
% elongation at Actual UTS		4.28%

0104

00020

DYNAMIC TESTS ON VSL ANCHORAGES

~~00021~~

0105

Supplement 2

The purpose of dynamic testing is to demonstrate the capability of wedge grips to withstand the impact of cyclic load variations without slipping or unseating. In point of fact slipping is the only probable mode of failure. For a wedge to become unseated it would be necessary first that the strand go completely slack and then it would be further necessary to apply between 1500 to 2000 pounds per strand to unseat the wedges. The first of these two conditions would be possible only if there is prior total failure of concrete around the tendon.

Because of the lack of availability of pulse-vibrators of sufficient capacity it was not possible to test a full scale 55-strand tendon. However all VSL anchorages from single through fifty-five strands are multiples of the same basic wedge and cone configuration and because of this similitude, representative tests were performed on two 12-strand tendons.

Test Equipment:

One Amsler slow-cycling Pulsator capable of 1.7 load cycles per minute.

Two coupled Amsler Pulsators capable of 250 load cycles per minute.

Two coupled Amsler Pulsators capable of 500 load cycles per minute.

Two Amsler 50-ton jacks.

Three tendons composed of twelve 1/2" 270 ksi stabilized strands, two 134 inches long and the third 168 inches long.

Four VSL E5-12 strand anchorages and clamping rings to reduce the strand pattern in simulation of conditions within a bearing plate trumpet.

Results:

After injecting NO-OX-ID grease into and around the anchorages, both of the 134 inch tendons were suscepted to stress level variations ranging from .60 f's to .66 f's at 250 cycles/minute and from .49 f's to .71 f's at 1.7 cycles/minute.

~~00022~~

0106

On the first tendon 501,800 cycles between .60 f's and .66 f's were run at 250 cpm. This run was then followed by 50 cycles between .49 f's and .71 f's at 1.7 cpm. There was no wire breakage in either situation.

With the second tendon the order was reversed and the low frequency test was run first and the high frequency test second -- amplitudes and number of cycles remaining the same as in the first test. Once again, there was no wire breakage in either situation. The high frequency test was thereupon extended from 501,800 to 938,600 cycles at which time one wire in one of the twelve strands broke. The test was then further extended from 938,600 to 1,259,100 cycles with no further breakage of wires.

The third test utilized the 168 inch tendon with stress level variations ranging from .70 f's to .75 f's at 500 cycles/minute. In this test the upper anchorage in the test stand rested on a concrete block, and strain measurements were made on the anchor head, bearing plate and the concrete block. The test was run through 500 cycles with no breakage of strand wire or damage to the anchorage or concrete.

Subsequent to dynamic loading the reinforced concrete block (13-3/4' x 13-3/4" x 22") had sustained an average unit decrease in height of 34 micro inches per inch and an average unit increase in thickness of 87 micro inches per inch. At the same time, the bearing plate and anchor head had deflected into the concrete .0012 inches, and the six-inch diameter of the anchor head had increased .0024 inches.

0107

RELATIVE DEFLECTIONS, STRAINS AND STRESSES
IN A VSL E5-55 STRAND BEARING PLATE

~~00021~~

0108

Supplement 2

Date and Location of Tests: March 11, 1969 and June 3, 1969 at
University of California
Structural Research Laboratory
Richmond, California

Purpose: To test the acceptability of the VSL E5-55 strand bearing plate whose dimensions and composition are as follows (typical for both Tests No. 1 and No. 2):

Carbon	=	.20
Manganese	=	1.25
Phosphorus	=	.02
Sulphur	=	.25
Tensile Strength	=	67,000 psi
Yield Point	=	45,000 psi
Elongation in 2"	=	30%
Reduction of Area	=	60%
Brinell Hardness	=	149
E_s	=	30×10^6 (max.)
Dimensions of Plate	=	24" x 24" x 3-1/2" with a 9" diameter center hole

0109

~~00025~~

These tests were performed to demonstrate the acceptability of the VSL E5-55 Strand Bearing Plate. The investigation was conducted in two parts. In Test No. 1, relative deflections of the surface of the bearing plate were measured as various percentages of the ultimate load for a 55-strand tendon were applied. In Test No. 2, a second identical plate was loaded in the same fashion except in this instance, strain gage measurements were made on the top surface and edges. Loads were applied to the anchor heads on both tests with a ram. In both tests the plates had no transition trumpets, and the concrete blocks on which they were tested had exactly the same cross-section as the plates themselves including center holes. Neither of these conditions is presumed to have offered structural advantages to the sample plate not present in an actual field condition. Of equal importance to these deflection and stress spot checks was a general inspection of the plates from both tests after the load had been released to ascertain the location and magnitude of any permanent deformations or cracks which would indicate yield, relaxation or brittle failure.

Test No. 1 - Deflection Test

Measurements were made by placing a straight edge along numbered lines on the plate surface and measuring with a feeler gage the gap between the straight edge and the plate surface. The corners of the plate were used as datum. Edge of plate elevations for straight edge position parallel to edges of the plate were calculated assuming a parabolic curve from the corners to the measured low point on the center of each edge. To these calculated deflections were added the feeler gage measurements.

At 100% f's (2,272 K) the corners of the plate were observed to have lifted clear of the concrete 0.014 inches. This gap reduced to zero about 2 inches down each edge from the corner. Upon release of load, the plate evidenced no permanent deformation other than permissible initial set. The concrete block on which the bearing plate was tested was 24' x 24' x 24'. Interfaces between the block and bearing plate and the block and floor were grouted level with hydrostone.

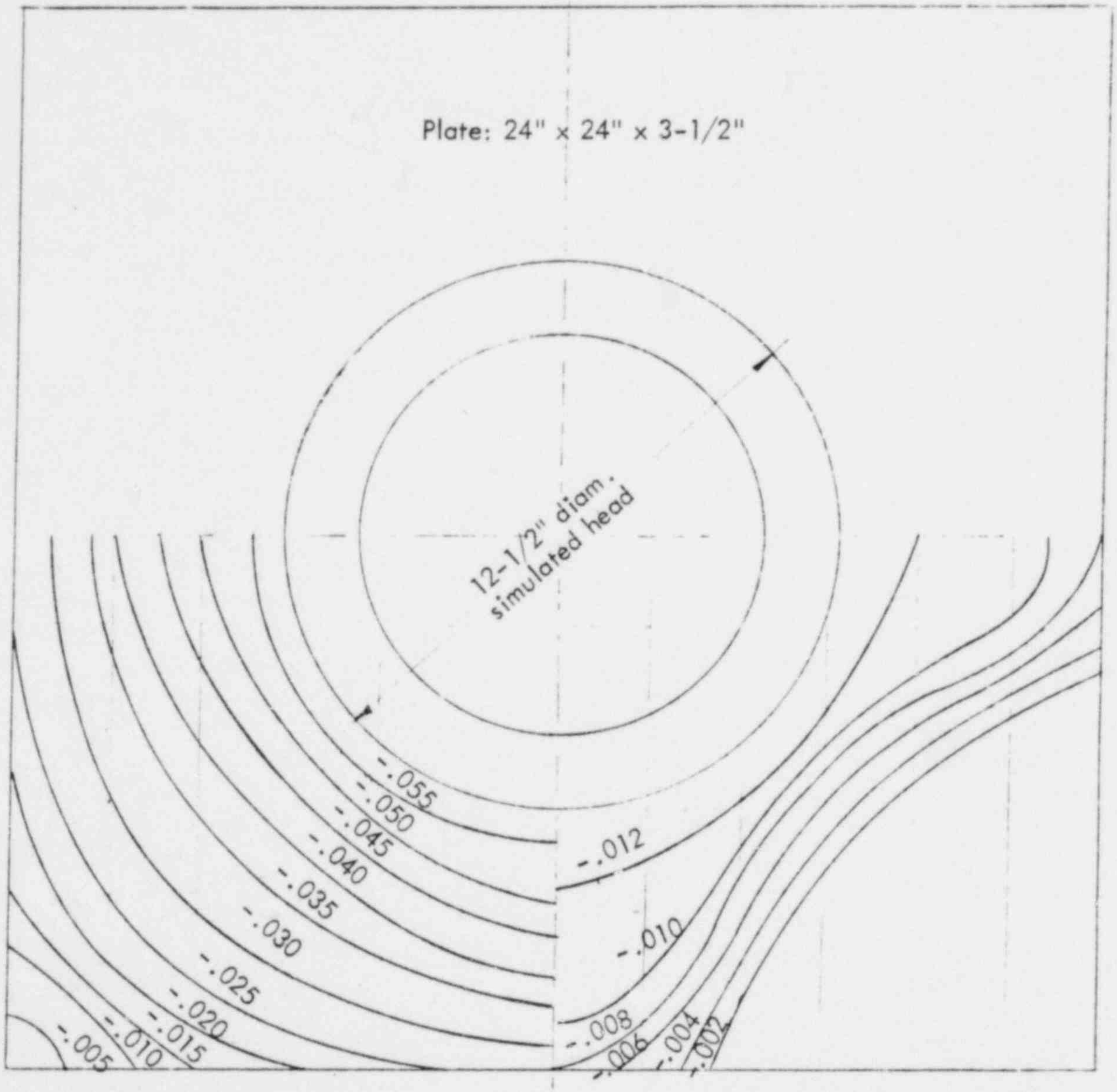
Block failed after about 10 minutes of sustained load at 2,272,000 pounds. Failure was non-explosive in nature, there being no sound of fragmentation. Cause was apparently insufficient curing time, as the second test block being reinforced in the same fashion did not fail at 109% of f's. The most important conclusions from Test No. 1 were that the top surface of the plate, from a plot of contours, appeared to be concave toward the concrete. This assessment was later borne out to be correct on Test No. 2 which indicated radial tension and circumferential compression over the entire top surface of the plate.

After removal of 2,272 K load, there was no visible deformation of the bearing plate other than permissible initial set, indicating an essentially elastic action.

VSL Corporation
Los Gatos, California

REDUCED DEFLECTION DATA

For conditions of maximum loading of 2,272 K and 0.00 K after removal of loading.



Load = 2,272 K

Load = 0.00 K

Absolute deflections were obtained by assuming a parabolic curve between datum corners along an edge, calculating the deflection of points of bearing of straight edge and adding to them the feeler gage measurements.

Test No. 2 - Stresses Associated with Strain Gage Readings

This test was conducted in the same fashion as Test No. 1. A plate identical to that used in Test No. 1 was centered on the test block, the anchor head centered on the plate and then the ram force applied in incremental percentages of the 2,272,000 pound ultimate load. On this test, however, strains in the planes of the top surface and the edges were measured rather than vertical deflections of points on the top surface. Initial set deflections on this plate were measured with a straight edge after the final load of 2,470,000 pounds (109% f's) had been removed. These final deformations were marginally less than those in Test No. 1. The concrete block in this test, having attained its 28-day strength, showed only hairline cracks under maximum load. The maximum stress resolved from observed strain gage readings was 47,900 psi compression at 109% of f's. After removal of the 2,470,000 pound load, there was no visible deformation of the bearing plate other than permissible initial set, indicating an essentially elastic action.

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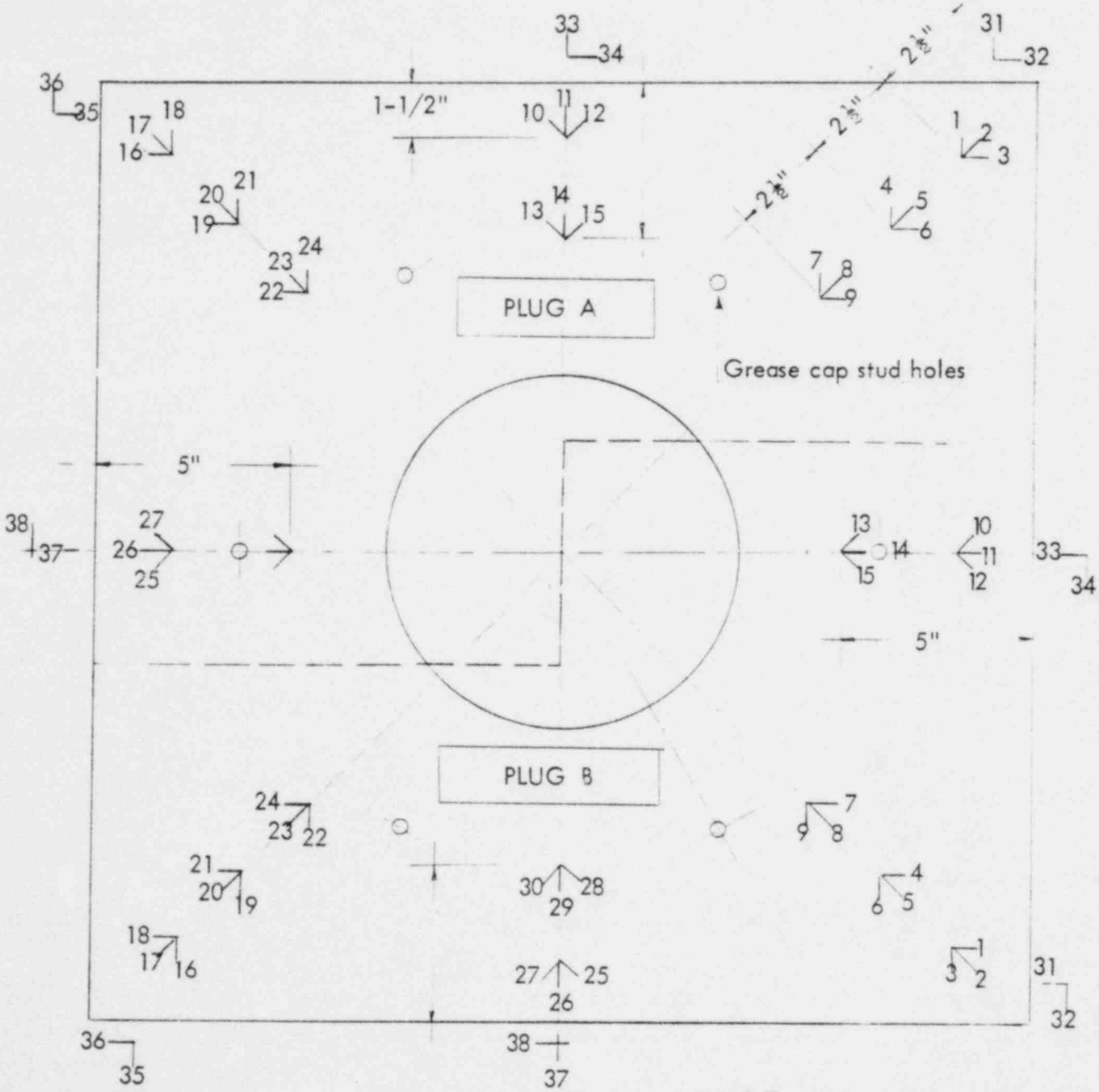
0112

Supplement 2

VSL Corporation
Los Gatos, California

VSL E5-55 BEARING PLATE
LOCATION OF STRAIN GAGES

Tested on June 3, 1969 at University of California Structural Research Laboratory, Richmond, California.



0113

Strain Gage Readings in Micro Inches Per Inch

Plug A

% f's Load (kips)	Zero	680	910	40% 1,135	1,360	60% 1,590	1,710	80% 1,820	1,930	90% 2,020	2,160	100% 2,270	2,370	2,470
1	1745	1720	1710	1700	1695	1690	1685	1690	1680	1675	1670	1655	1650	1640
2	3005	3005	3020	3030	3035	3040	3040	3045	3050	3060	3070	3085	3090	3110
3	2190	2170	2160	2155	2150	2145	2145	2145	2145	2140	2135	2125	2120	2115
4	2760	2720	2720	2720	2710	2690	2675	2660	2650	2640	2620	2600	2585	2555
5	1740	1760	1765	1775	1790	1810	1820	1845	1850	1870	1885	1910	1925	1960
6	2775	2755	2760	2760	2760	2745	2735	2725	2725	2715	2700	2690	2680	2660
7	2300	2245	2235	2220	2210	2190	2180	2170	2160	2140	2115	2080	2060	2025
8	3420	3465	3500	3530	3555	3580	3590	3610	3625	3645	3670	3705	3725	3770
9	1480	1465	1460	1450	1445	1440	1435	1435	1425	1415	1395	1375	1360	1335
10	2100	2035	2030	2020	2010	1975	1960	1940	1925	1910	1890	1855	1835	1780
11	2910	2940	2955	2970	2985	3015	3030	3050	3060	3075	3095	3110	3130	3165
12	3210	3175	3170	3160	3145	3115	3100	3090	3080	3060	3045	3015	3000	2970
13	2140	2055	2035	2015	2000	1965	1945	1920	1900	1870	1845	1795	1770	1705
14	2745	2820	2855	2885	2915	2950	2965	2980	2995	3010	3035	3070	3095	3150
15	3060	3025	3000	2975	2950	2915	2900	2890	2875	2850	2820	2790	2765	2740
16	1940	1915	1920	1920	1915	1905	1895	1890	1885	1880	1870	1860	1855	1845
17	1570	1570	1570	1575	1575	1590	1595	1610	1615	1620	1630	1645	1655	1675
18	2550	2530	2535	2535	2535	2520	2515	2510	2505	2500	2495	2490	2480	2475
19	1530	1500	1490	1480	1475	1470	1465	1465	1460	1450	1440	1425	1415	1400
20	1965	1995	2020	2035	2050	2060	2065	2080	2090	2100	2115	2140	2155	2185
21	1110	1080	1070	1060	1050	1040	1035	1030	1020	1005	990	965	950	930
22	2205	[illegible]	2150	2140	2130	2110	2100	2085	2075	2060	2045	2025	2010	1980
23	1770	1815	1835	1850	1870	1905	1920	1940	1955	1970	2000	2030	2050	2085
24	2435	2410	2415	2410	2400	2380	2365	2350	2340	2320	2300	2275	2255	2230
25	2220	2165	2145	2130	2115	2095	2085	2075	2065	2050	2030	2005	1985	1945
26	2770	2815	2840	2860	2880	2895	2900	2915	2925	2940	2960	2985	3000	3030
27	1180	1120	1110	1095	1080	1065	1060	1055	1050	1035	1020	1000	985	955
28	2845	2760	2745	2720	2690	2620	2585	2535	2500	2445	2360	2325	2325	2320
29	1290	1350	1370	1380	1385	1380	1375	1360	1350	1335	1295	1310	1345	1430
30	2040	1940	1920	1900	1870	1815	1780	1740	1715	1680	1625	1625	1600	1635
31	1640	1620	1615	1615	1610	1615	1615	1620	1620	1620	1620	1620	1620	1620
32	3170	3150	3160	3165	3165	3160	3150	3150	3150	3150	3150	3145	3145	3145
33	1630	1610	1605	1600	1595	1590	1585	1585	1585	1580	1575	1560	1555	1540
34	2080	2090	2110	2130	2145	2160	2165	2175	2185	2195	2210	2230	2245	2270
35	1025	1010	1005	1005	1000	1005	1005	1010	1015	1010	1010	1010	1010	1010
36	1680	1665	1675	1675	1680	1670	1665	1660	1665	1660	1660	1655	1660	1655
37	1695	1680	1675	1670	1670	1660	1650	1650	1645	1635	1620	1605	1590	1560
38	2290	2290	2305	2315	2330	2355	2365	2380	2395	2410	2435	2470	2500	2550

0114 ~~00030~~

Strain Gage Readings in Micro Inches Per Inch

Plug B

% f's Load (kips)	Zero	680	910	40% 1,135	1,360	60% 1,590	1,710	80% 1,820	1,930	90% 2,020	2,160	100% 2,270	2,370	2,470
1	1945	1925	1915	1910	1905	1900	1900	1900	1900	1900	1890	1890	1880	1880
2	3355	3360	3370	3380	3385	3390	3390	3395	3400	3405	3420	3425	3440	3450
3	1860	1835	1825	1820	1815	1810	1805	1800	1800	1800	1785	1780	1770	1765
4	2720	2695	2700	2695	2685	2670	2660	2655	2645	2640	2625	2620	2605	2600
5	1395	1415	1420	1430	1440	1460	1475	1490	1505	1515	1535	1550	1580	1595
6	2825	2800	2810	2805	2800	2780	2765	2760	2745	2740	2720	2710	2685	2675
7	1945	1920	1900	1895	1880	1870	1865	1870	1855	1850	1825	1820	1800	1790
8	2655	2700	2735	2760	2785	2805	2820	2835	2855	2870	2900	2920	2965	2990
9	2480	2455	2445	2435	2420	2410	2395	2390	2370	2365	2335	2320	2290	2270
10	3085	3035	3030	3015	3000	2970	2950	2940	2920	2910	2880	2865	2835	2820
11	2295	2320	2335	2350	2370	2390	2410	2430	2445	2455	2485	2500	2535	2555
12	3120	3090	3085	3080	3070	3045	3025	3015	3000	2990	2960	2945	2910	2890
13	1975	1900	1860	1830	1790	1750	1720	1700	1650	1615	1525	1450	1270	1190
14	2905	2970	3000	3030	3050	3060	3055	3050	3040	3035	3010	2990	3000	3040
15	2220	2175	2150	2130	2090	2055	2020	2000	1955	1925	1830	1780	1645	1545
16	2360	2350	2355	2355	2350	2345	2330	2330	2325	2320	2310	2310	2300	2295
17	2620	2625	2625	2630	2630	2645	2650	2665	2670	2680	2690	2700	2720	2730
18	2540	2525	2530	2525	2520	2510	2500	2500	2490	2490	2480	2475	2460	2455
19	1870	1850	1840	1835	1820	1810	1805	1805	1795	1785	1760	1745	1720	1700
20	2855	2885	2910	2930	2940	2955	2965	2975	2990	3000	3020	3040	3065	3085
21	1905	1870	1860	1850	1840	1835	1830	1830	1820	1815	1800	1795	1780	1770
22	2280	2280	2285	2280	2270	2255	2235	2220	2205	2190	2160	2140	2095	2065
23	2010	2060	2080	2100	2120	2150	2170	2195	2215	2225	2260	2280	2310	2335
24	2100	2050	2045	2040	2030	2015	2000	1990	1980	1970	1950	1945	1920	1910
25	1920	1890	1875	1860	1840	1825	1815	1810	1800	1790	1760	1740	1710	1690
26	2450	2485	2510	2535	2550	2570	2580	2590	2610	2620	2645	2665	2690	2710
27	2380	2330	2310	2295	2280	2260	2255	2250	2240	2230	2210	2195	2170	2150
28	3810	3790	3785	3775	3750	3720	3695	3680	3660	3645	3600	3570	3540	3530
29	3210	3270	3290	3310	3340	3370	3395	3415	3440	3455	3490	3510	3630	3700
30	2955	2885	2870	2855	2830	2800	2770	2750	2730	2715	2670	2635	2610	2610
31	3275	3265	3260	3255	3255	3255	3260	3265	3265	3260	3260	3260	3260	3265
32	2785	2775	2780	2785	2785	2780	2770	2770	2770	2770	2765	2770	2770	2765
33	2195	2190	2180	2180	2170	2170	2170	2170	2170	2165	2155	2150	2140	2130
34	2355	2350	2365	2380	2390	2405	2415	2425	2435	2445	2465	2480	2505	2530
35	1830	1820	1815	1810	1810	1810	1815	1820	1820	1820	1820	1820	1820	1820
36	2495	2485	2490	2495	2495	2490	2480	2480	2480	2480	2480	2480	2480	2475
37	1920	1910	1900	1895	1890	1885	1880	1880	1870	1865	1840	1825	1800	1780
38	2600	2610	2630	2645	2660	2670	2680	2695	2715	2725	2760	2780	2815	2845

Stresses in psi = Difference in Strain Gage Readings in Micro Inches Per Inch

Plug A

%f's			40%		60%		80%		90%		100%		
Load (kips)	680	910	1,135	1,360	1,590	1,710	1,820	1,930	2,020	2,160	2,270	2,370	2,470
1	-750	-1050	-1350	-1500	-1650	-1800	-1650	-1950	-2100	-2250	-2700	-2850	-3150
2	0	+450	+750	+900	+1050	+1050	+1200	+1350	+1650	+1950	+2400	+2550	+3150
3	-600	-900	-1050	-1200	-1350	-1350	-1350	-1350	-1500	-1650	-1950	-2100	-2250
4	-1200	-1200	-1200	-1500	-2100	-2550	-3000	-3300	-3600	-4200	-4800	-5250	-6150
5	+600	+750	+1050	+1500	+2100	+2400	+3150	+3300	+3900	+4350	+5100	+5550	+6600
6	-600	-450	-450	-450	-900	-1200	-1500	-1500	-1800	-2250	-2550	-2850	-3450
7	-1650	-1500	-2400	-2700	-3300	-3600	-3900	-4200	-4800	-5550	-6600	-7200	-8250
8	+1350	+2400	+3300	+4050	+4800	+5100	+5700	+6150	+6750	+7500	+8550	+9150	+10500
9	-450	-600	-900	-1050	-1200	-1350	-1350	-1650	-1950	-2550	-3150	-3600	-4350
10	-1950	-2100	-2400	-2700	-3750	-4200	-4800	-5250	-5700	-6300	-7350	-7950	-9600
11	+900	+1350	+1800	+2250	+3150	+3600	+4200	+4500	+4950	+5550	+6000	+6600	+7650
12	-1950	-1200	-1500	-1950	-2850	-3300	-3600	-3900	-4500	-4950	-5850	-6300	-7200
13	-2550	-3150	-3750	-4200	-5250	-5850	-6600	-7200	-7100	-7950	-10350	-11110	-13050
14	+2250	+3300	+4200	+7100	+6150	+6600	+7050	+7500	+7950	+8700	+9750	+10500	+12150
15	-1050	-1800	-2550	-3300	-4350	-4800	-5100	-5550	-6300	-7200	-8100	-8850	-9600
16	-750	-600	-600	-750	-1050	-1350	-1500	-1650	-1800	-2100	-2400	-2550	-2850
17	0	0	+150	+150	+600	+750	+1200	+1350	+1500	+1800	+2250	+2550	+3150
18	-600	-450	-450	-450	-900	-1050	-1200	-1350	-1500	-1650	-1800	-2100	-2250
19	-900	-1200	-1500	-1650	-1800	-1950	-1650	-2100	-2400	-2700	-3150	-3450	-3900
20	+900	+750	+1200	+1650	+1950	+2100	+3450	+3750	+4050	+450	+5250	+5700	+6600
21	-900	-1200	-1500	-1800	-2100	-2250	-2400	-2700	-3150	-3600	-4350	-4800	-5400
22	-1650	-1650	-1950	-2250	-2850	-3150	-3600	-3900	-4350	-4800	-5400	-4850	-6750
23	+1350	+1950	+2400	+3000	+4050	+4500	+5100	+5550	+6000	+6900	+7800	+8400	+9450
24	-750	-600	-750	-1050	-1650	-2100	-2550	-2850	-3450	-4050	-4800	-5400	-6150
25	-1650	-2250	-2700	-3150	-3750	-4050	-4350	-4650	-5100	-5700	-6450	-6750	-8250
26	+1350	+2100	+2700	+3300	+3750	+3900	+4350	+4650	+5100	+5700	+6450	+6900	+7800
27	-1800	-2100	-2550	-3000	-3450	-3600	-3750	-3900	-4350	-4800	-5400	-5850	-6750
28	-2550	-3000	-3750	-4470	-6750	-7800	-9300	-10350	-12000	-14550	-15600	-15600	-15750
29	+1800	+2400	+2700	+2850	+2700	+2550	+2100	+1800	+1350	+150	+ 600	+1650	+4200
30	-3000	-3600	-4200	-5100	-6750	-7800	-9000	-9750	-10800	-12450	-12450	-17600	-12150
31	-600	-750	-750	-900	-750	-750	-600	-600	-600	-600	-600	-600	-600
32	-600	-300	-150	-150	-300	-600	-600	-600	-600	-600	-750	-750	-750
33	-600	-750	-900	-1050	-1600	-1350	-1350	-1350	-1500	-1650	-2100	-2250	-2700
34	+300	+900	+1500	+1950	+2400	+2550	+2850	+3150	+2550	+3900	+4500	+4950	+5700
35	-450	-600	-600	-750	-600	-600	-450	-300	-450	-450	-450	-450	-450
36	-450	-150	-150	0	-300	-450	-600	-450	-600	-600	-750	-600	-750
37	-450	-600	-450	-750	-1050	-1350	-1350	-1500	-1800	-2250	-2700	-3150	-1050
38	0	+450	+750	+1600	+1950	+2250	+2700	+3150	+3600	+4350	+5400	+6300	+7800

Stresses in psi = Difference in Strain Gage Readings in Micro Inches Per Inch

Plug B

% f's Load (kips)	680	910	1,135	1,360	1,590	1,710	1,820	1,930	2,020	2,160	2,270	2,370	2,470
			40%		60%		80%		90%		100%		
1	-600	-900	-1050	-1200	-1350	-1350	-1350	-1350	-1350	-1650	-1650	-1950	-1950
2	+150	+450	+750	+900	+1050	+1050	+1200	-1350	+1500	+1950	+2100	+2550	+2850
3	-750	-1050	-1200	-1350	-1500	-1650	-1800	-1800	-1800	-2250	-2400	-2700	-2850
4	-750	-600	-750	-1050	-1500	-1800	-1950	-2250	-2400	-2850	-3000	-3450	-3600
5	+600	+750	+1050	+1350	+1950	+2400	+2850	+3300	+6600	+4200	+4650	+5550	+6000
6	-750	-450	-600	-750	-1350	-1800	-1950	-2400	-2550	-3150	-3450	-4200	-4500
7	-750	-1350	-1500	-1950	-2250	-2400	-2250	-2700	-2850	-3600	-3750	-4350	-4650
8	+1350	+2400	+3150	+3900	+4500	+4950	+5400	+6000	+6450	+7350	+7950	+9300	+10050
9	-750	-1050	-1350	-1800	-2100	-2550	-2700	-3300	-3450	-4350	-4800	-5700	-6300
10	-1500	-1650	-2100	-2550	-3450	-4050	-4350	-4950	-5250	-6150	-6600	-7500	-7950
11	+750	+1200	+1650	+2250	+2850	+3450	+4050	+4500	+4800	+5700	+6150	+7200	+7800
12	-900	-1050	-1200	-1500	-2250	-2850	-3150	-3600	-3900	-4800	-5250	-6300	-6900
13	-2250	-3450	-4350	-5550	-6750	-7650	-7250	-9750	-10800	-13500	-15750	-21150	-23550
14	+1950	+2850	+4050	+4350	+4950	+4500	+4350	+4050	+3900	+3150	+2550	+2850	+4050
15	-1350	-2100	-2700	-3900	-4950	-6000	-6600	-7950	-8850	-11500	-13200	-17250	-20250
16	-300	-150	-150	-300	-450	-900	-900	-1050	-1200	-1500	-1500	-1800	-1950
17	+150	+150	+300	+300	+750	+900	+1350	+1500	+1800	+2100	+2400	+3000	+3300
18	-450	-300	-450	-300	-900	-1200	-1200	-1500	-1500	-1800	-1950	-2400	-2550
19	-600	-900	-1050	-1500	-1800	-1950	-1950	-2250	-2550	-3300	-3750	-4500	-5100
20	+900	+1650	+2250	+2250	+3000	+3300	+3600	+4050	+4350	+4950	+5550	+6300	+6900
21	-1050	-1350	-1650	-1950	-2100	-2250	-2250	-2550	-2700	-3150	-3300	-3750	-4050
22	0	+150	0	-300	-750	-1350	-1800	-2250	-2700	-3600	-4200	-5550	-6450
23	+1500	+2100	+2700	+3300	+4200	+4800	+5550	+6150	+6450	+7500	+8100	+9000	+9750
24	-1500	-1650	-1800	-2100	-2550	-3000	-3600	-3600	-3900	-4500	-4650	-5400	-5700
25	-900	-1350	-1800	-2400	-2850	-3150	-3300	-3600	-3900	-4800	-5400	-6300	-6900
26	+1050	+1800	+2550	+3000	+3600	+3900	+4200	+1600	+5100	+5850	+6450	+7200	+7800
27	-1500	-2100	-2550	-3000	-3600	-3750	-3900	-4200	-4500	-5100	-5550	-6300	-6900
28	-600	-750	-1050	-1800	-2700	-3450	-3900	-4500	-4950	-6300	-7200	-7100	-8400
29	+1800	+2400	+3000	+3900	+4800	+5550	+6150	+6900	+7350	+8400	+9000	+12600	+14700
30	-2100	-2550	-3000	-3750	-4650	-5550	-6150	-6750	-7200	-7550	-9600	-10350	-10350
31	-300	-450	-600	-600	-600	-450	-300	-300	-450	-450	-450	-450	-300
32	-300	-450	0	0	-150	-450	-450	-450	-450	-600	-450	-450	-600
33	-150	-450	-450	-750	-750	-750	-750	-750	-900	-1200	-1350	-1500	-1950
34	-150	+300	+750	+1050	+1500	+1800	+2100	+2400	+2700	+3300	+3750	+4500	+5250
35	-300	-450	-600	-600	-600	-450	-300	-300	-300	-300	-300	-300	-300
36	-300	-150	0	0	-150	-450	-450	-450	-450	-450	-450	-450	-600
37	-300	-600	-750	-900	-1050	-1200	-1200	-1500	-1950	-2400	-2850	-3600	-4200
38	+300	+900	+1350	+1800	+2100	+2400	+2850	+3450	+3750	+4800	+5400	+6450	+7350

0117

Test No. 3 - Computer Analysis

As a supplement to Tests No. 1 and No. 2, a three-dimensional stress analysis of the VSL E5-55 strand bearing plate was made at the University of Stuttgart in Germany. The Finite Element Method was applied to the analysis of deformations, using the following characteristics:

E_{plate}	$= 29.0 \times 10^6$ psi
Poisson's $Ratio_{plate}$	$= 0.3$
E_{head}	$= 29.0 \times 10$
Poisson's $Ratio_{head}$	$= 0.3$
$E_{concrete}$	$= 5.5 \times 10^6$ psi
Poisson's $Ratio_{concrete}$	$= 0.15$
Axial Load	$= 2.2715 \times 10^6$ L6

The stresses were studied in the plane of six different sections of the thickness of the plate, the first and sixth being the top and bottom surfaces.

It is apparent from the results of this study that vertical, radial, circumferential and shear stresses in and on the planes of Sections 2 through 6 are within the elastic range of the steel. Excessive stress values appear in the top fiber (Section 1) only and, moreover, only at the points of discontinuity at the edges of the anchor head and the edge of the central hole of the bearing plate.

The highest value of stresses obtained (80,000 psi) occur as circumferential and vertical compression stresses located on the top fiber, on the edges of the anchor hear bearing area.

Since the high stresses occur only at points and do not extend either into or across the plate, they are not considered detrimental to the performance of the plate. The stresses, as can be seen from the attached stress distribution graphs, are as observed in Tests No. 1 and No. 2, essentially elastic.

The first six of these graphs show the Von Mises Equivalent Stresses.

0118

~~00034~~

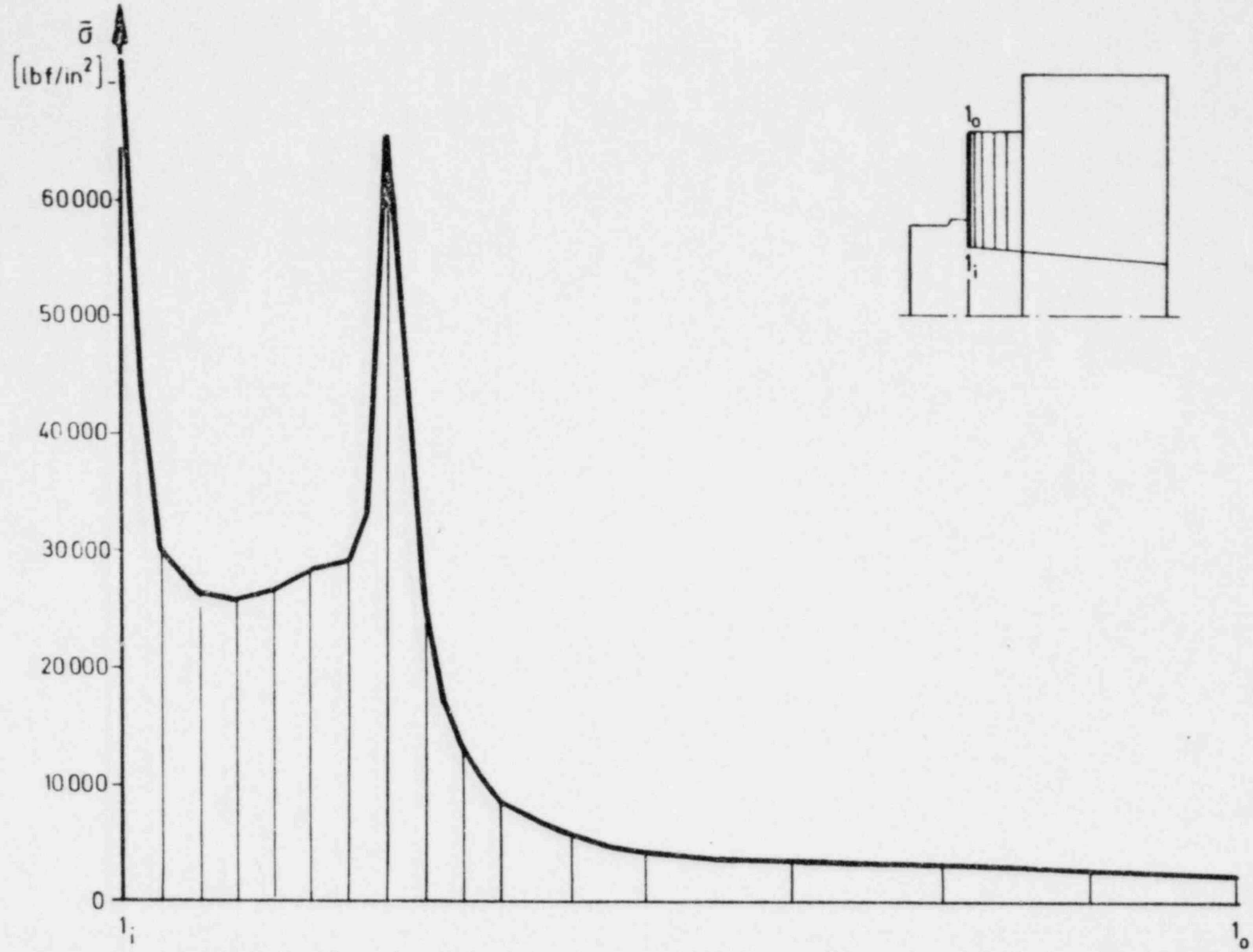


FIGURE 1.

Bearing Plate

Equivalent Stress $\bar{\sigma}$ in Cross Section 1

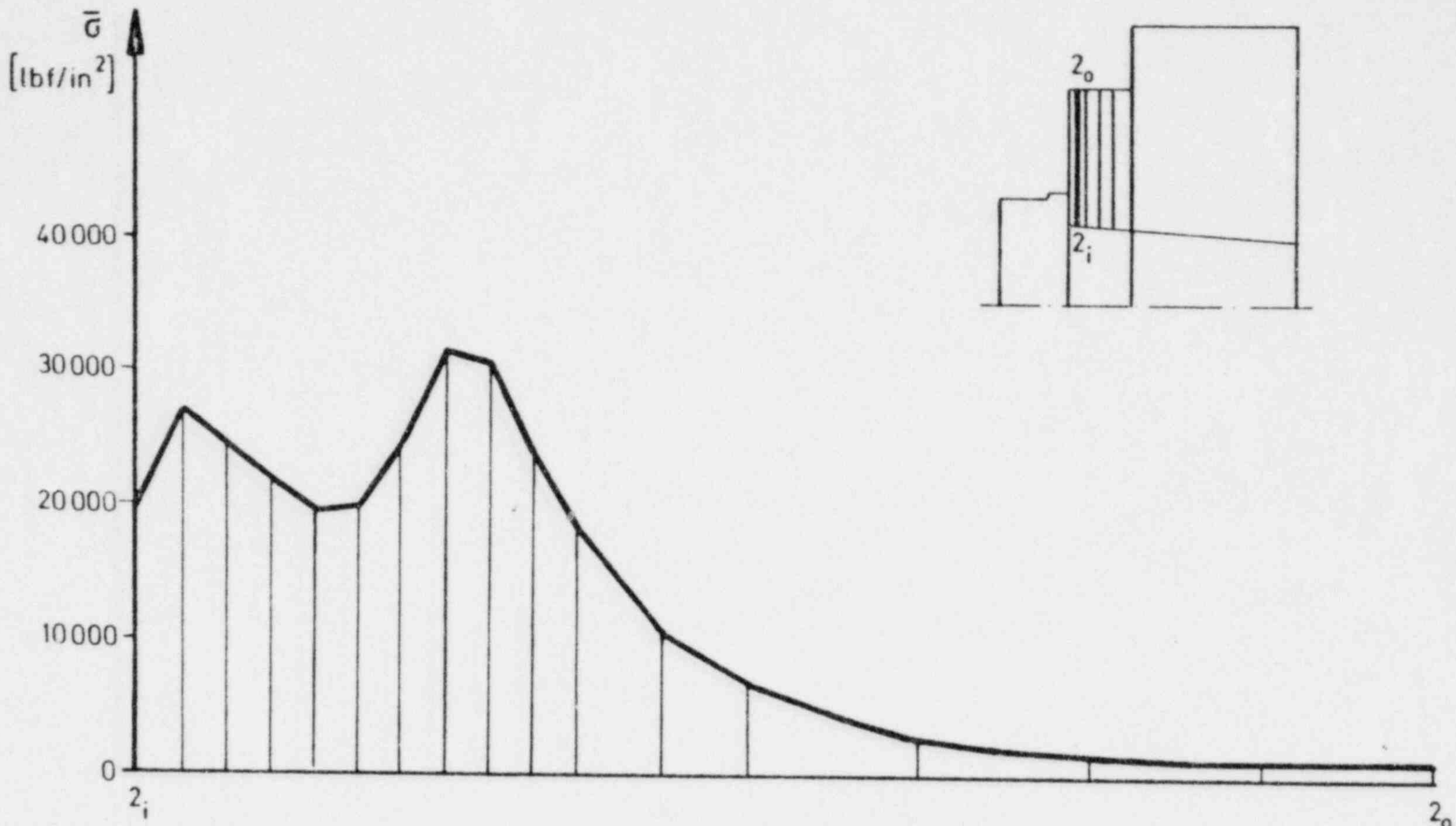


FIGURE 2.

Bearing Plate

Equivalent Stress $\bar{\sigma}$ in Cross Section 2

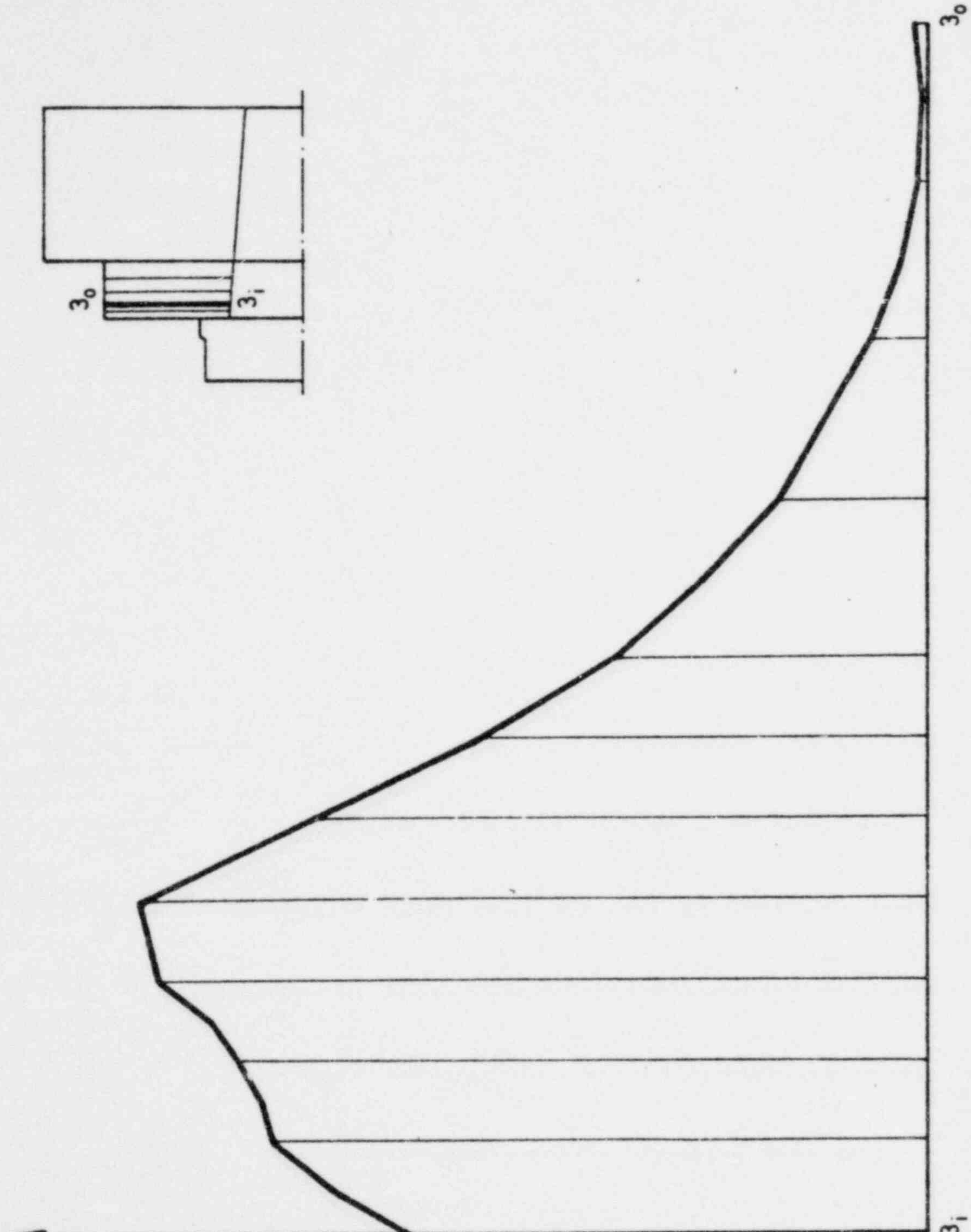


FIGURE 3.

Bearing Plate

Equivalent Stress $\bar{\sigma}$ in Cross Section 3

0131

00

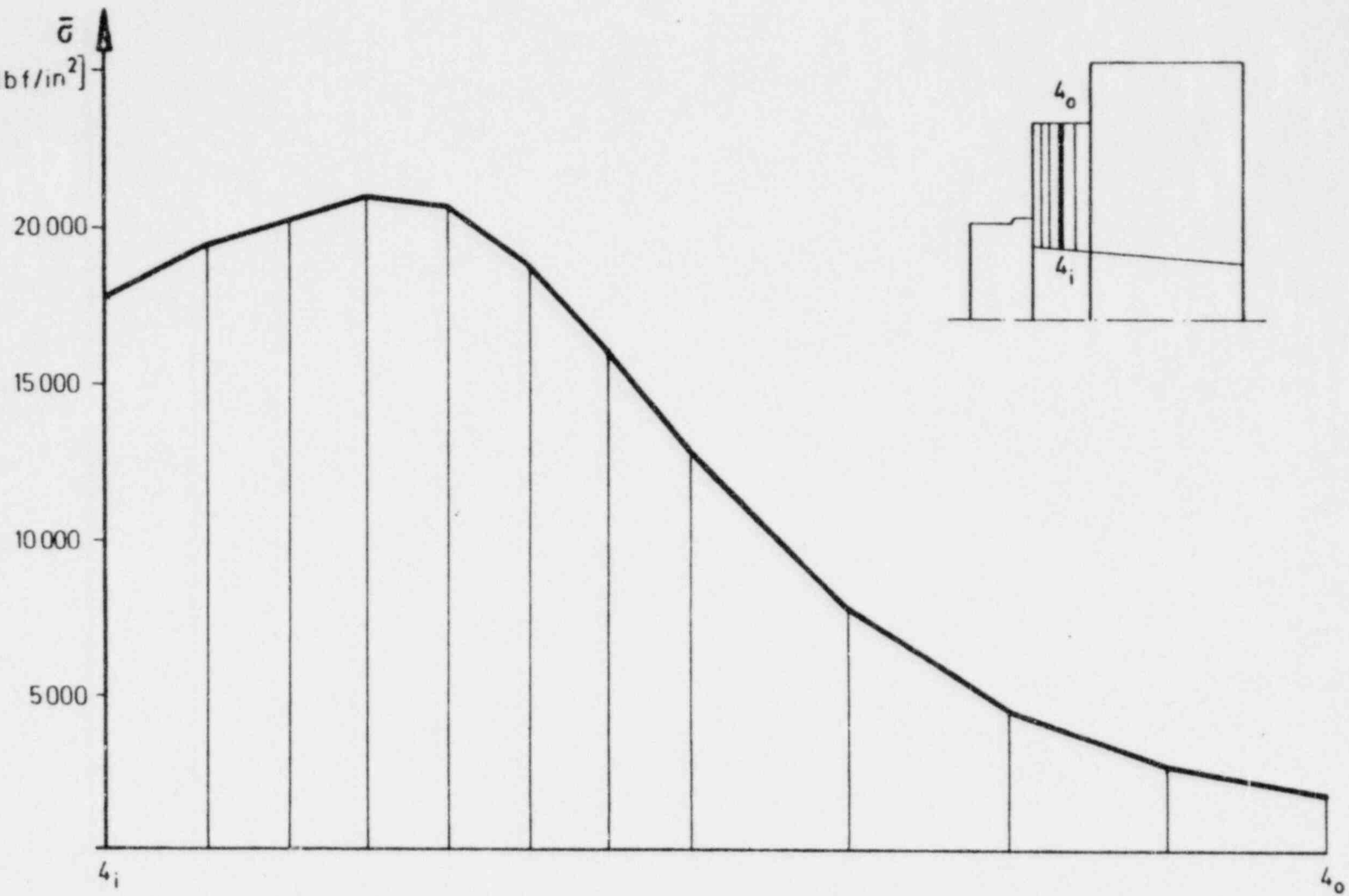


FIGURE 4.

Bearing Plate

Equivalent Stress $\bar{\sigma}$ in Cross Section 4

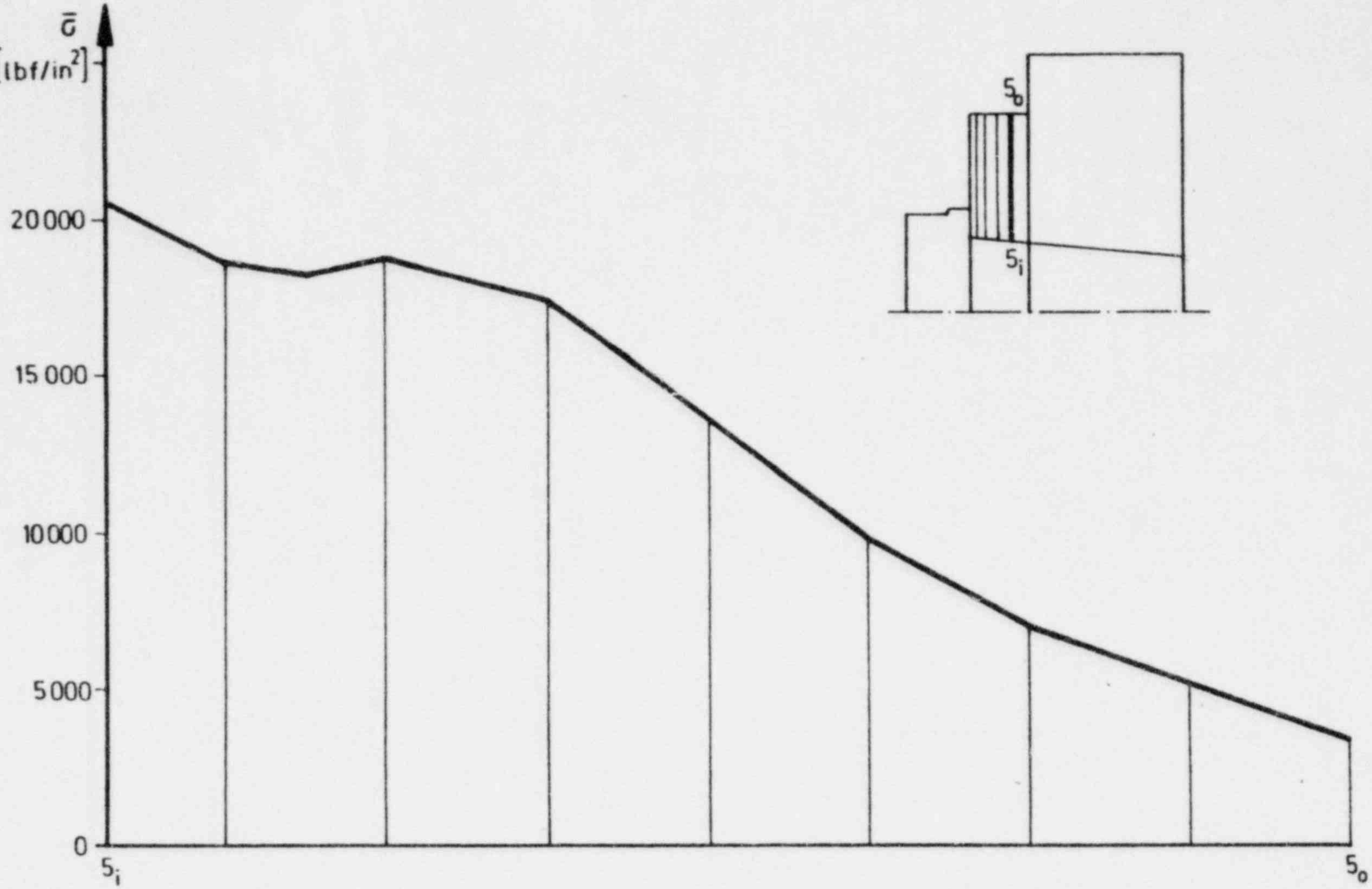


FIGURE 5.

Bearing Plate

Equivalent Stress $\bar{\sigma}$ in Cross Section 5

0123

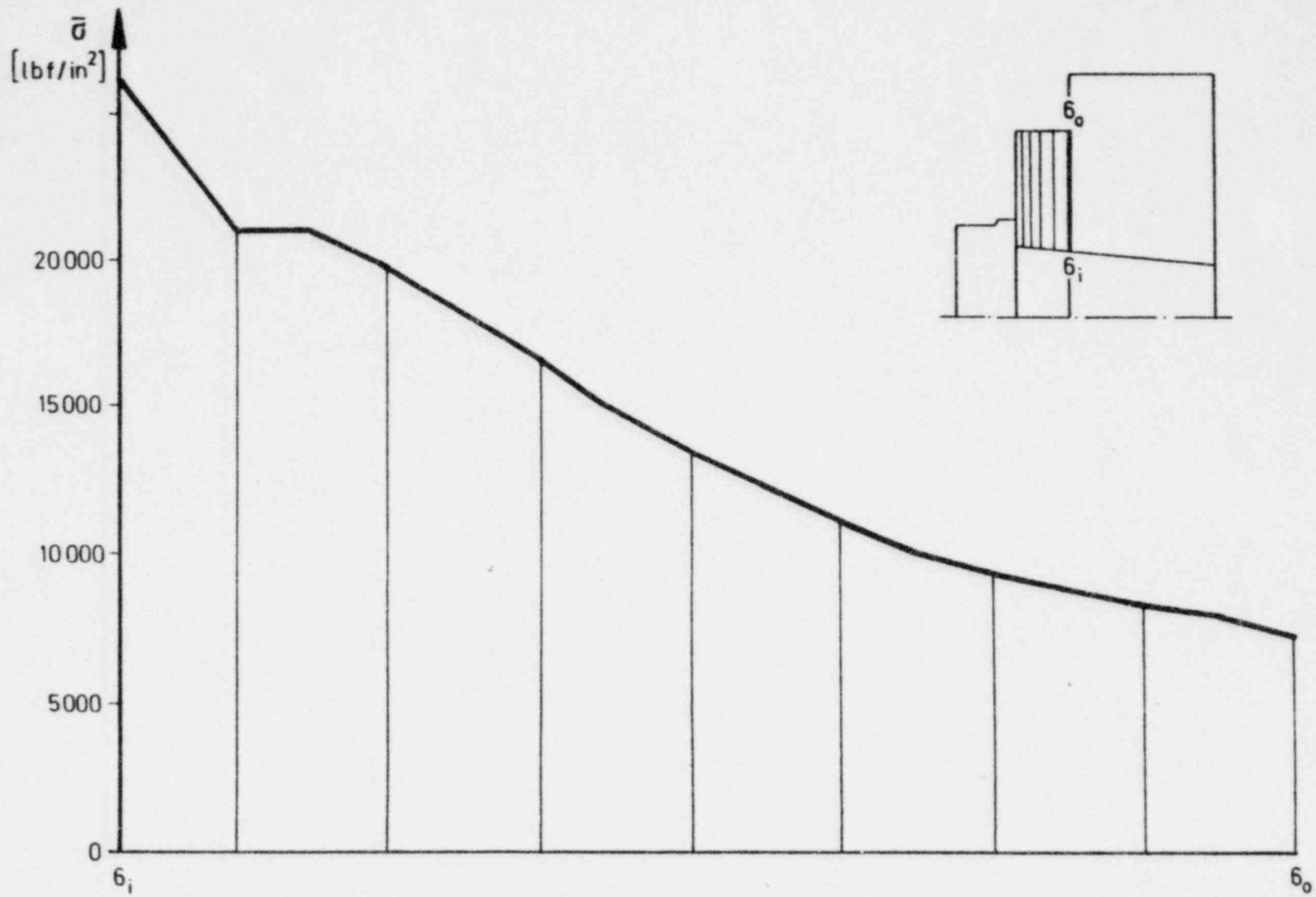


FIGURE 6.

Bearing Plate

Equivalent Stress σ̄ in Cross Section 6

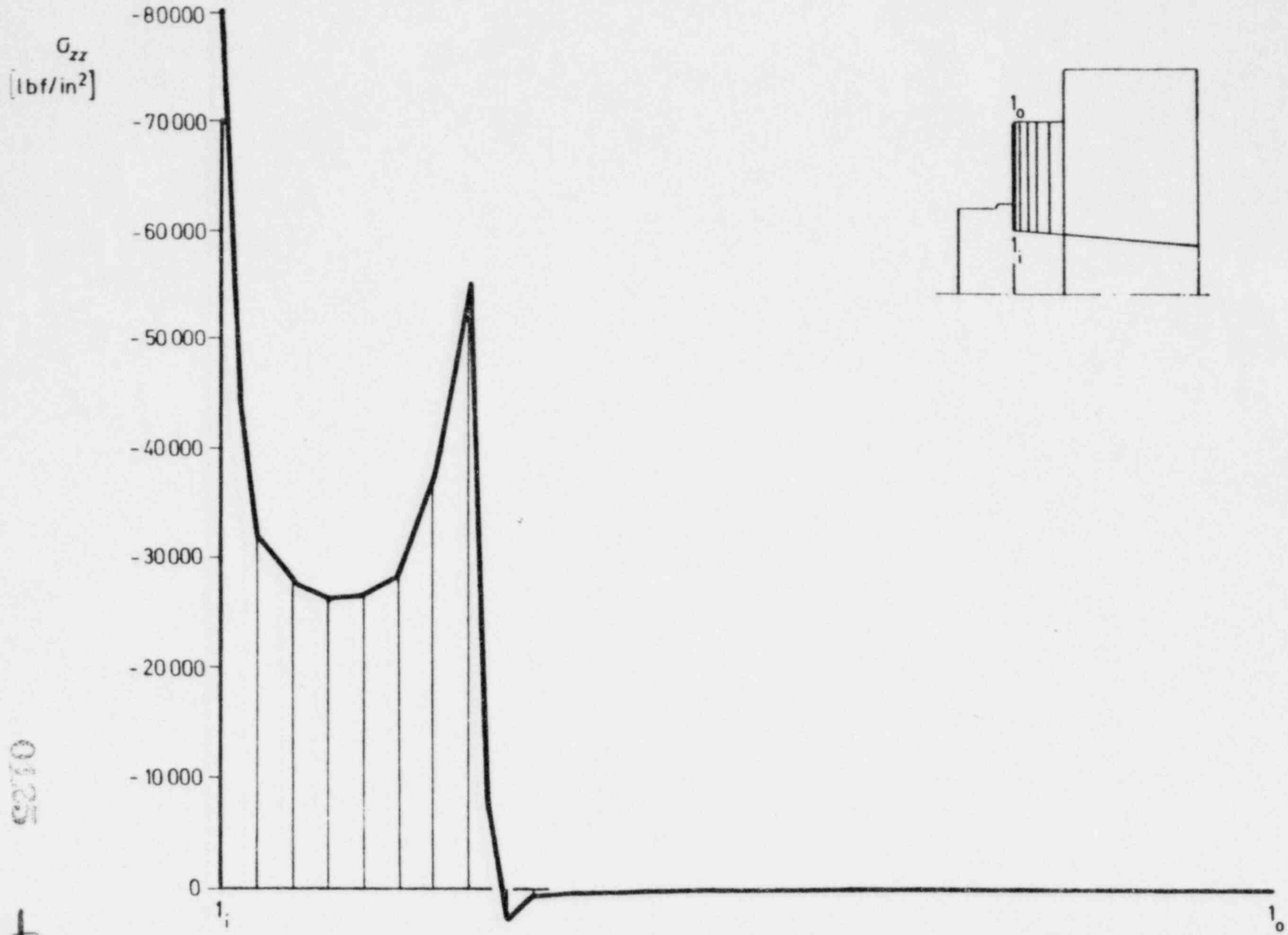


FIGURE 7.

Bearing Plate

Vertical Normal Stress σ_{zz} in Cross Section 1

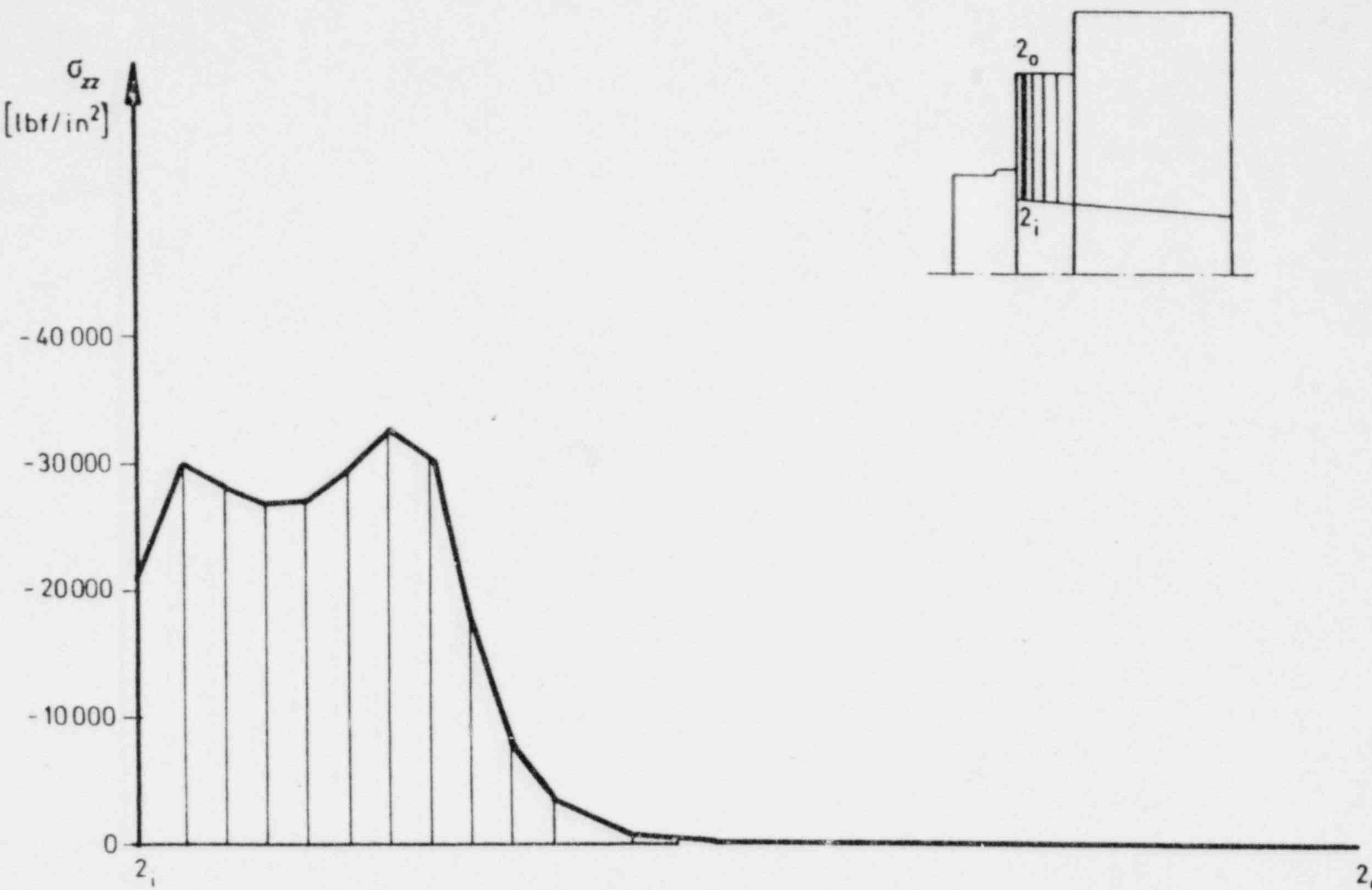


FIGURE 8.

Bearing Plate

Vertical Normal Stress σ in Cross Section 2

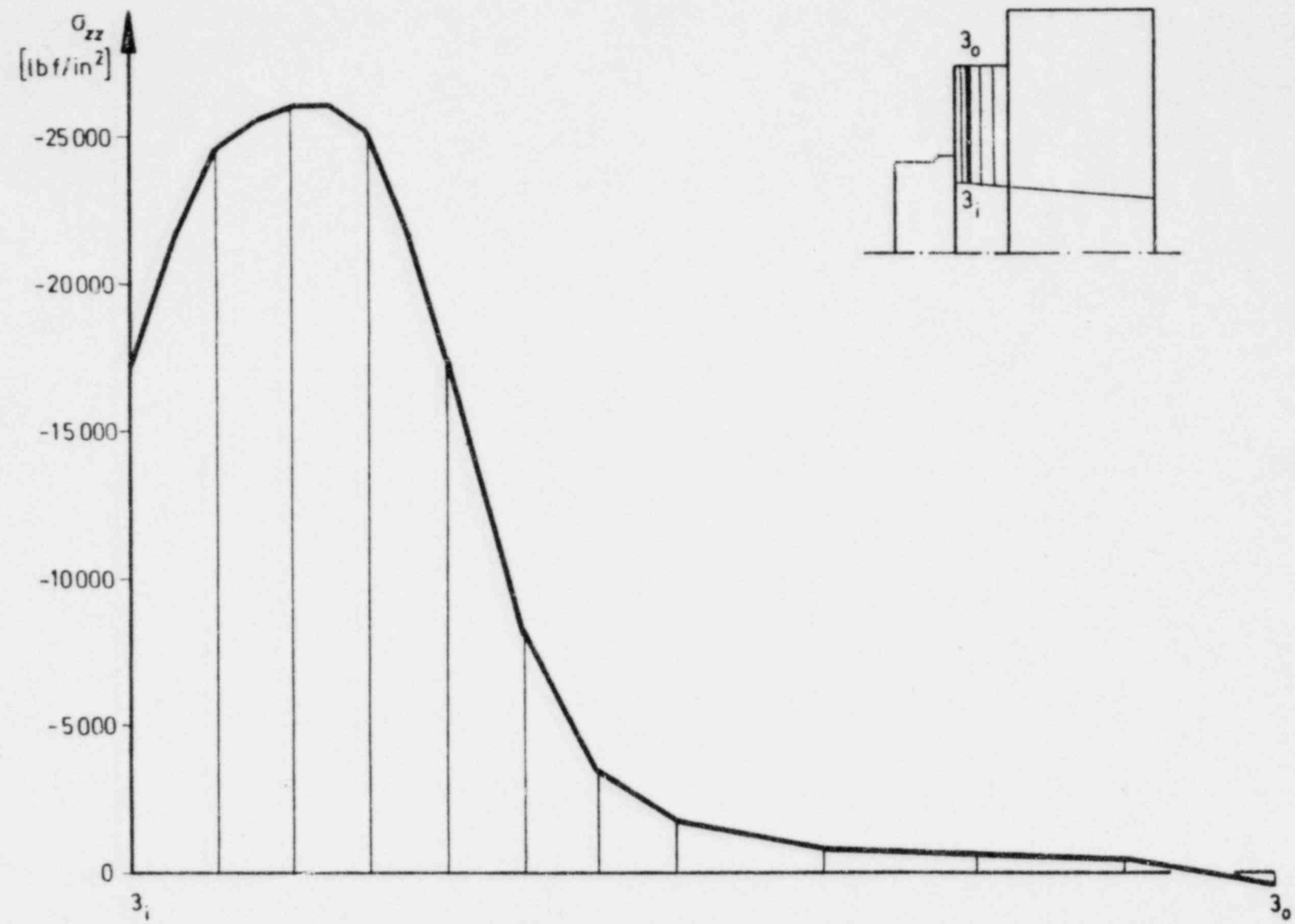


FIGURE 9. **Bearing Plate**

Vertical Normal Stress σ_{zz} in Cross Section 3

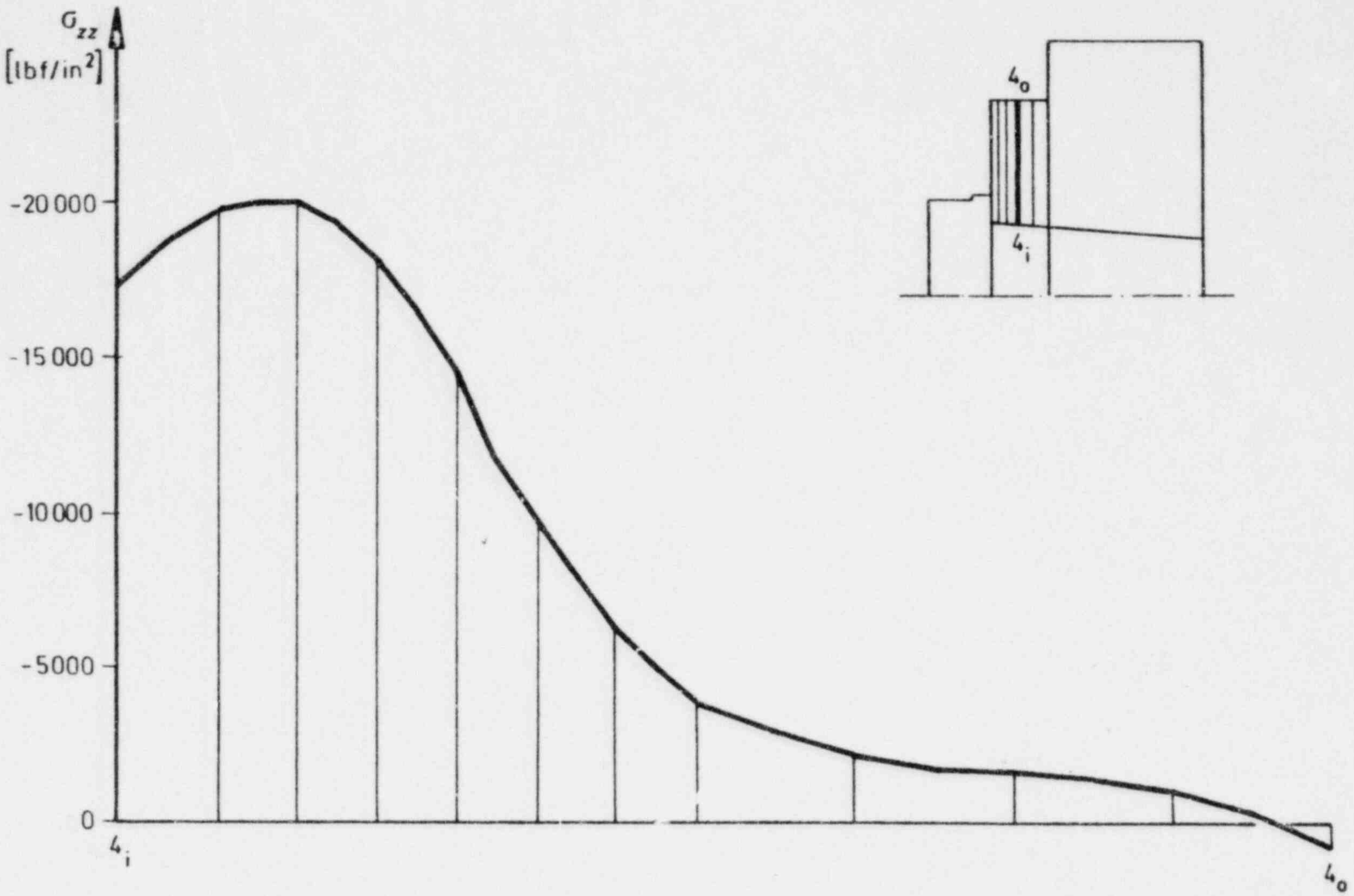


FIGURE 10.

Bearing Plate

Vertical Normal Stress σ_{zz} in Cross Section 4

0128

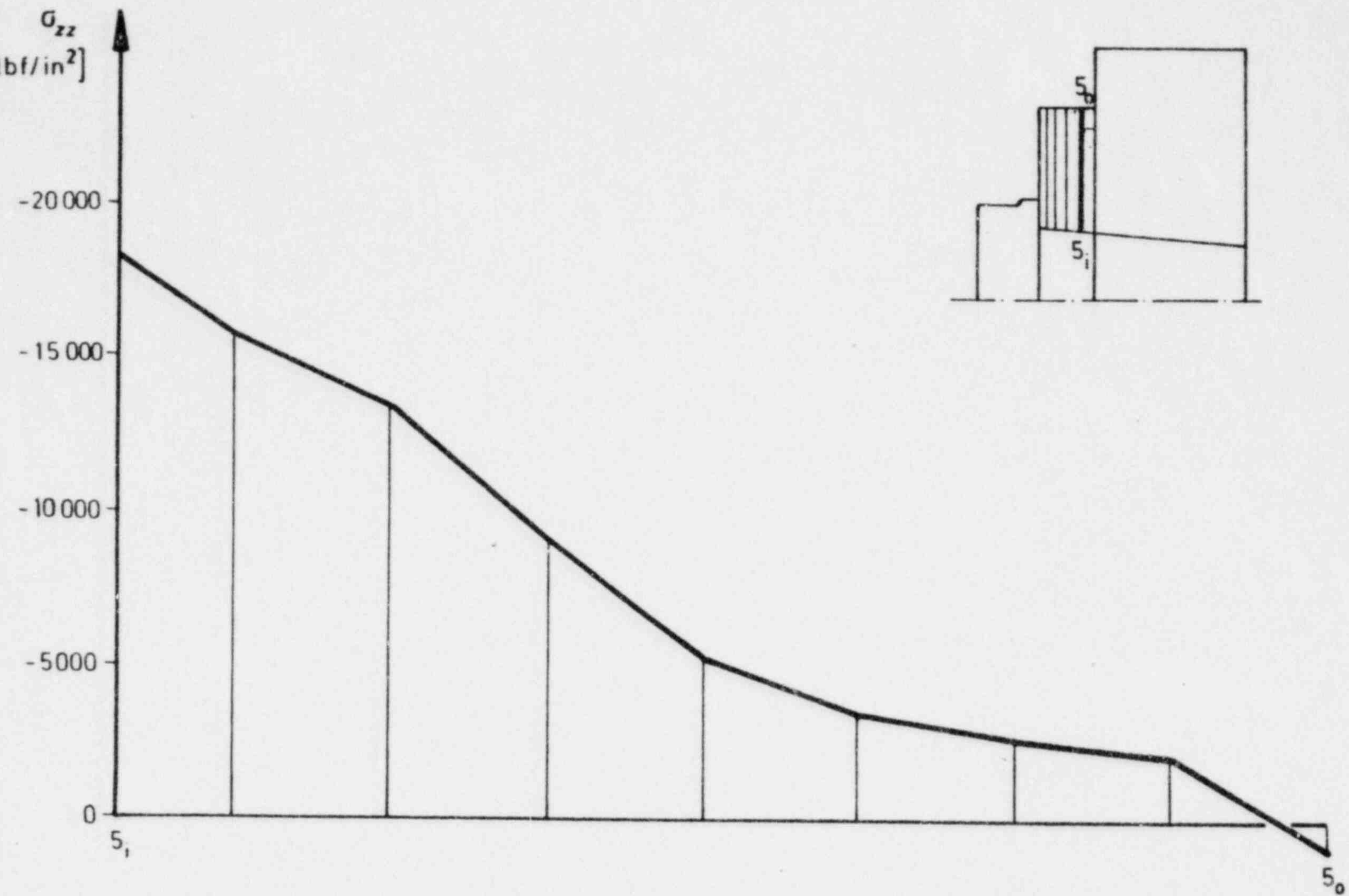


FIGURE 11. **Bearing Plate**

Vertical Normal Stress σ_{zz} in Cross Section 5

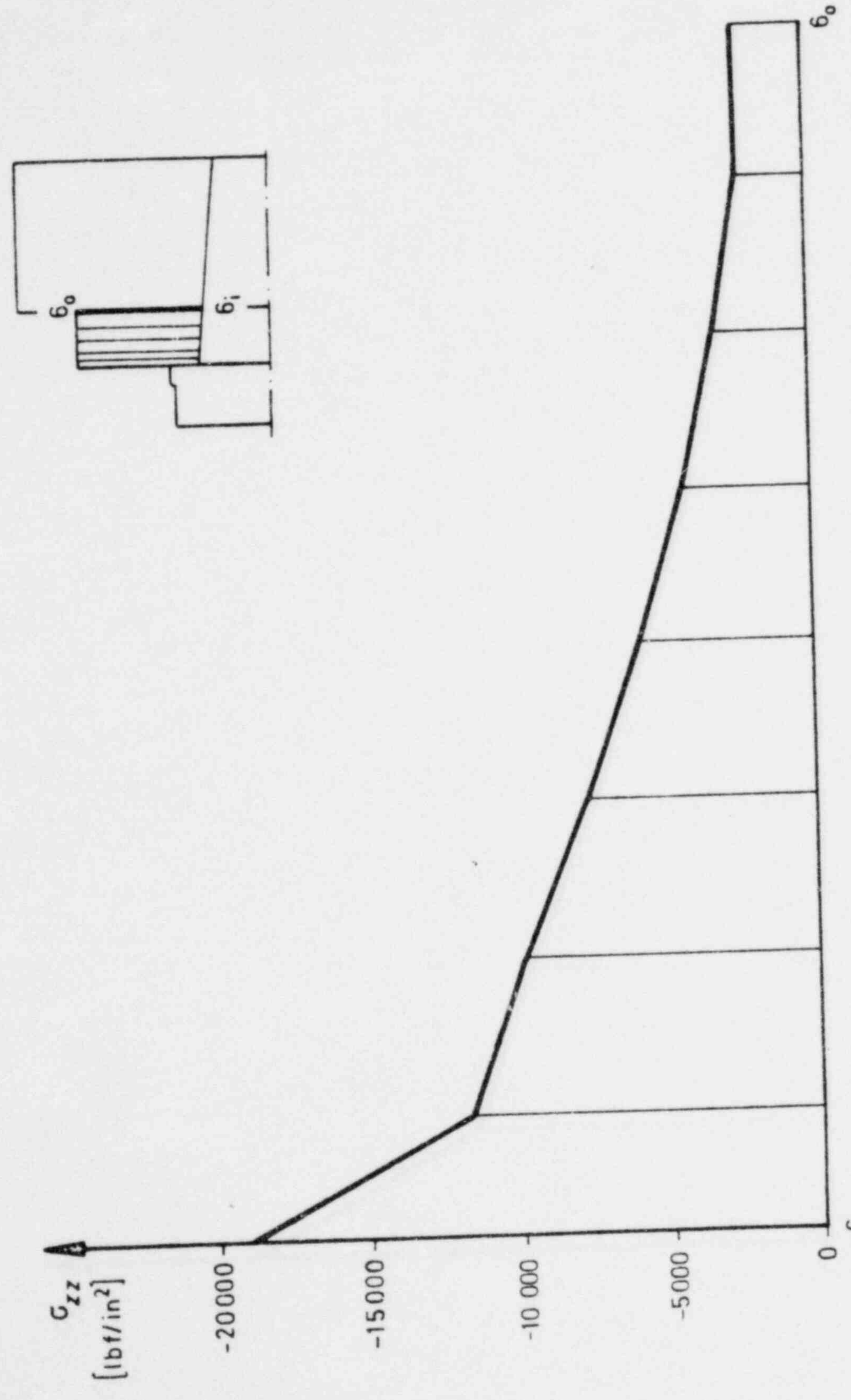


FIGURE 12.

Bearing Plate

Vertical Normal Stress σ_{zz} in Cross Section 6

Supplement 2

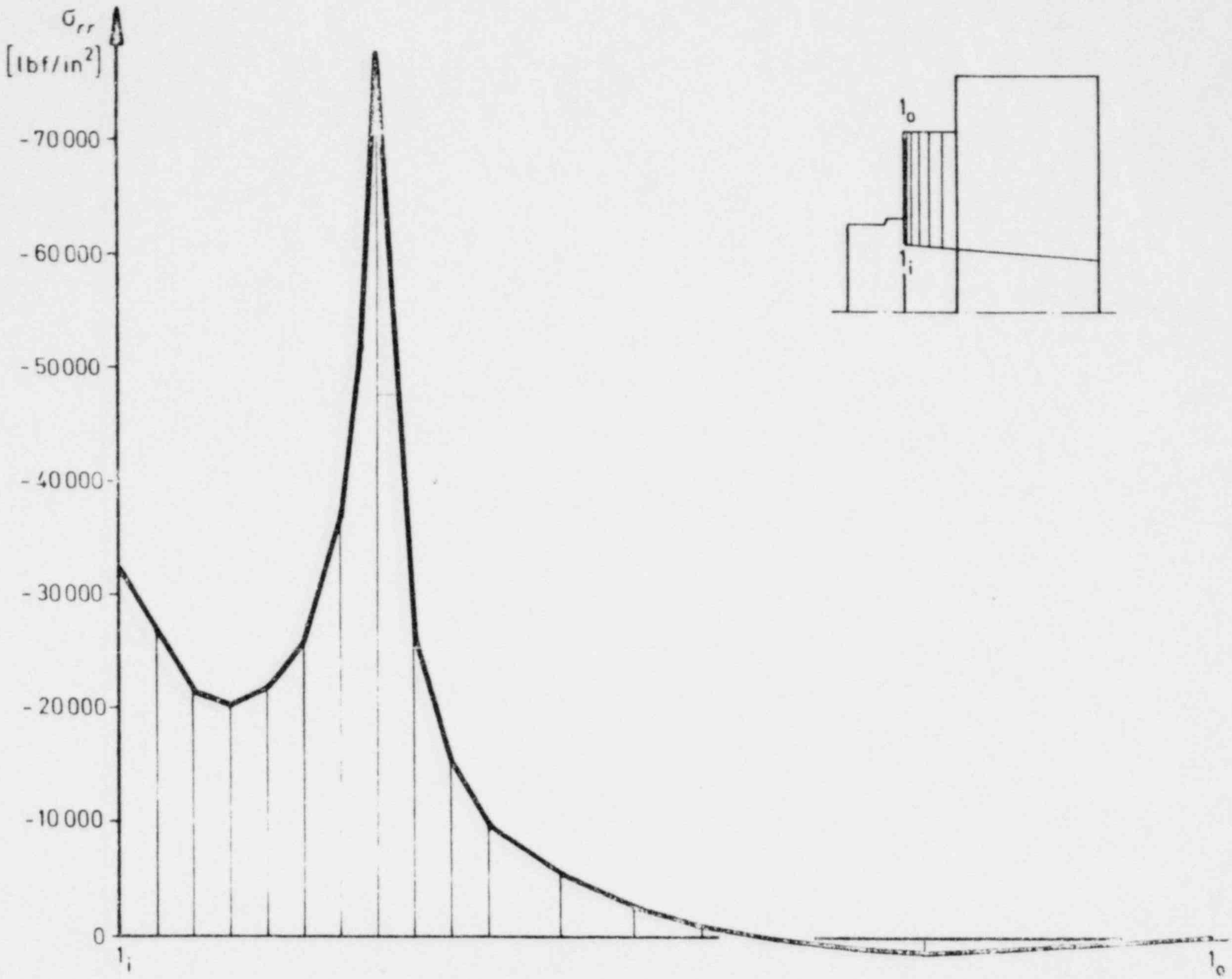


FIGURE 13.

Bearing Plate

Radial Normal Stress σ_{rr} in Cross Section I

0131

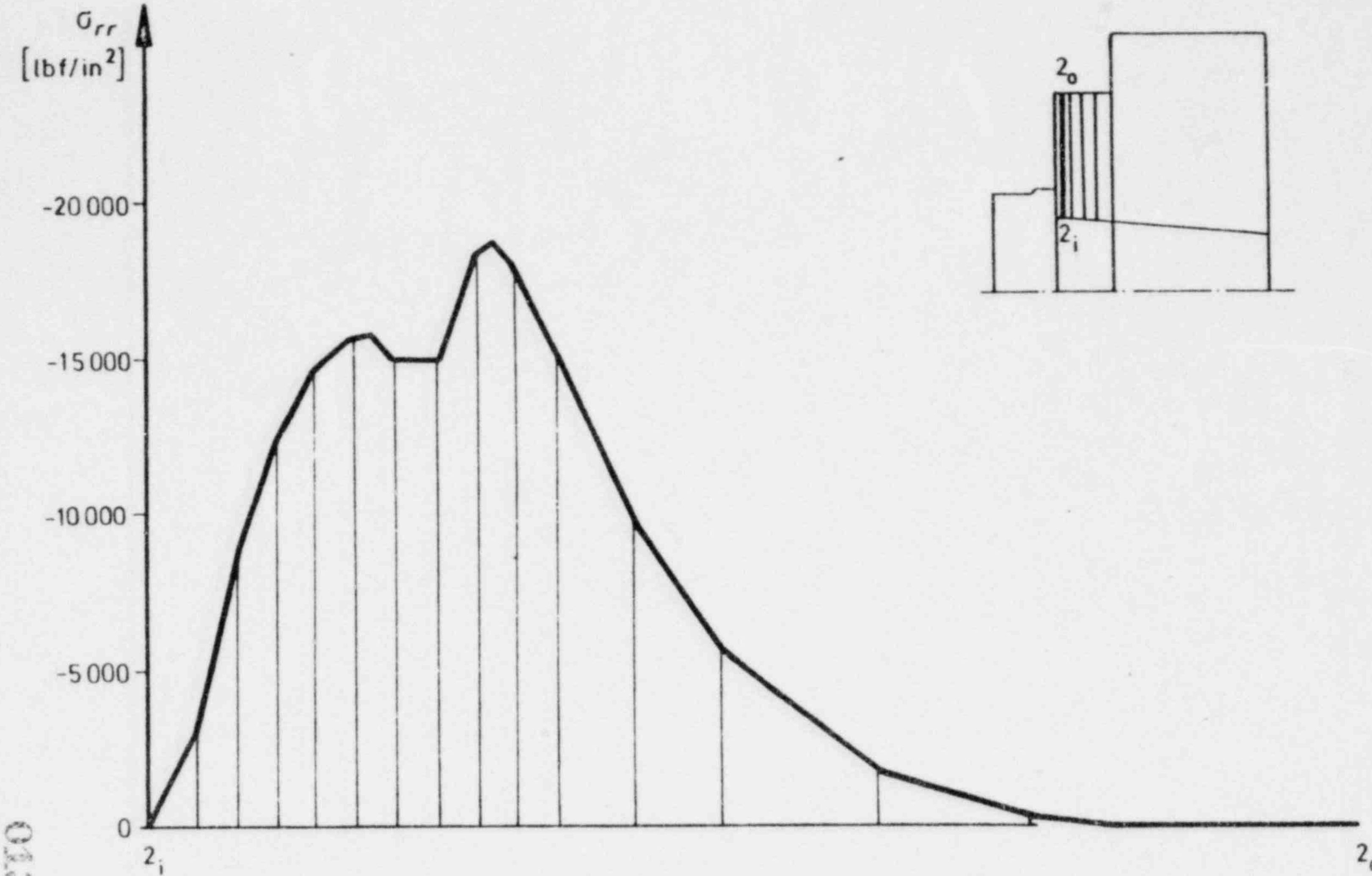


FIGURE 14.

Bearing Plate

Radial Normal Stress σ_{rr} in Cross Section 2

0132

00048

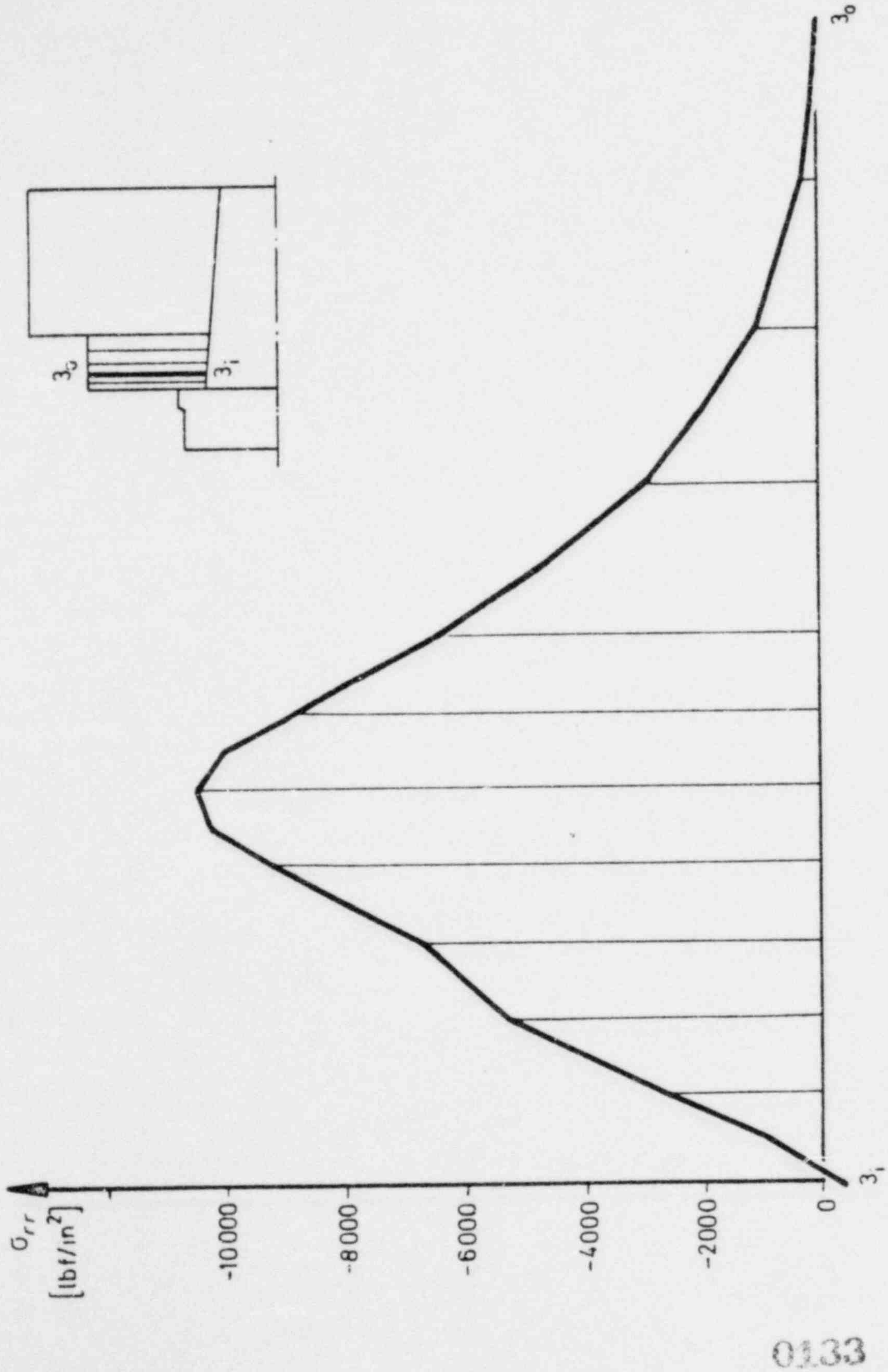


FIGURE 15. **Bearing Plate**

Radial Normal Stress σ_{rr} in Cross Section 3

0133

00049

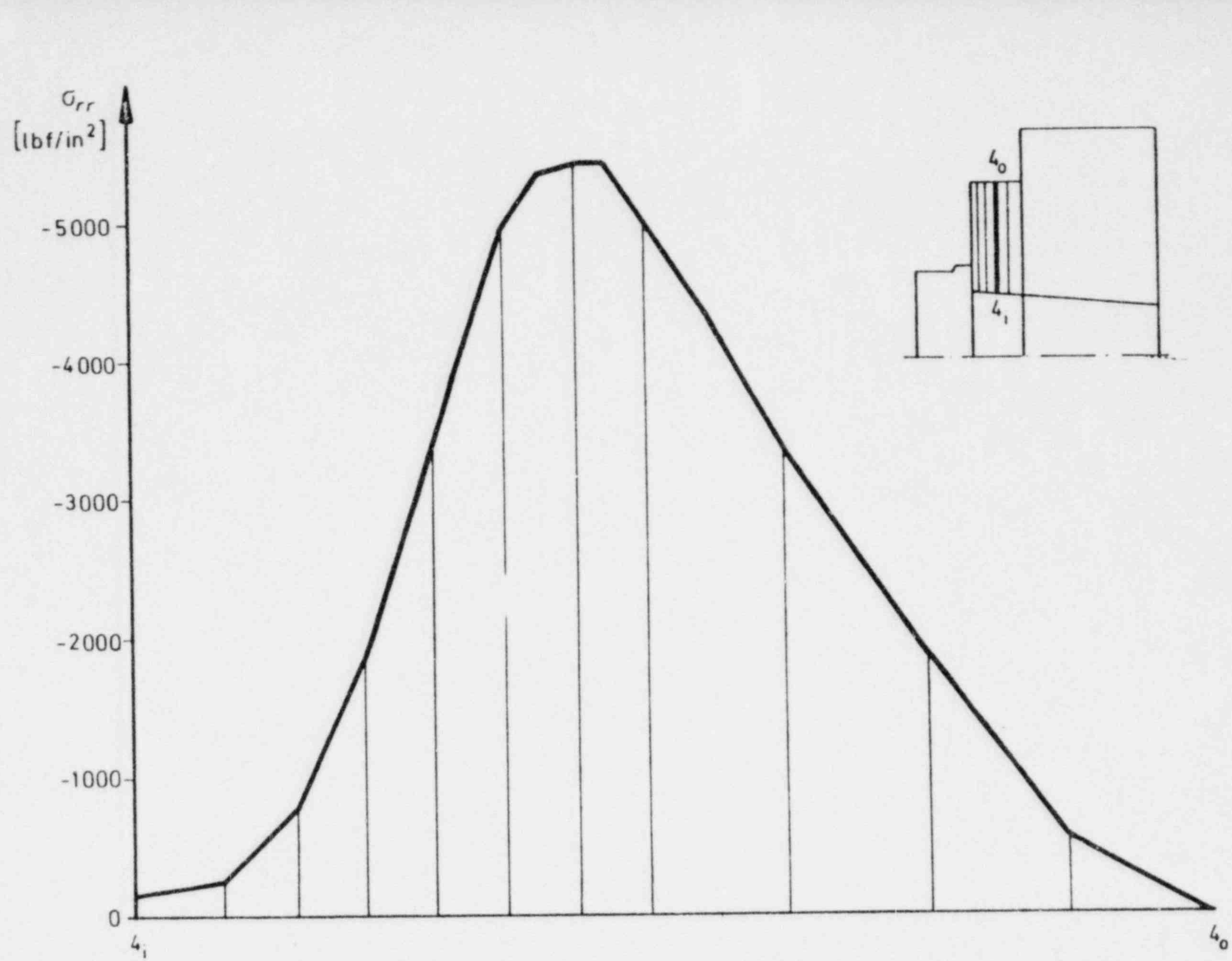


FIGURE 16.

Bearing Plate

Radial Normal Stress σ_{rr} in Cross Section 4

0134

00050

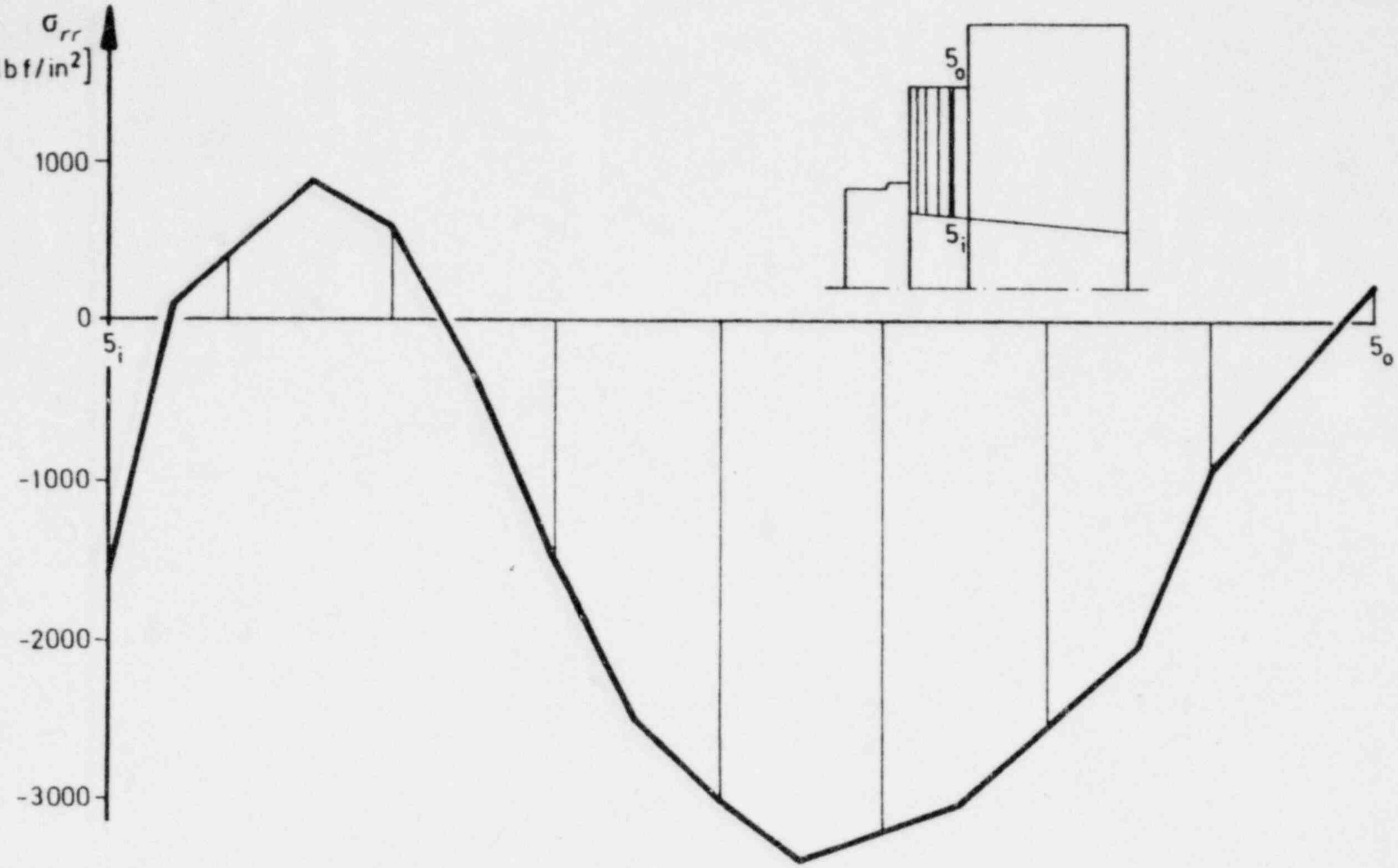


FIGURE 17.

Bearing Plate

Radial Normal Stress σ_{rr} in Cross Section 5

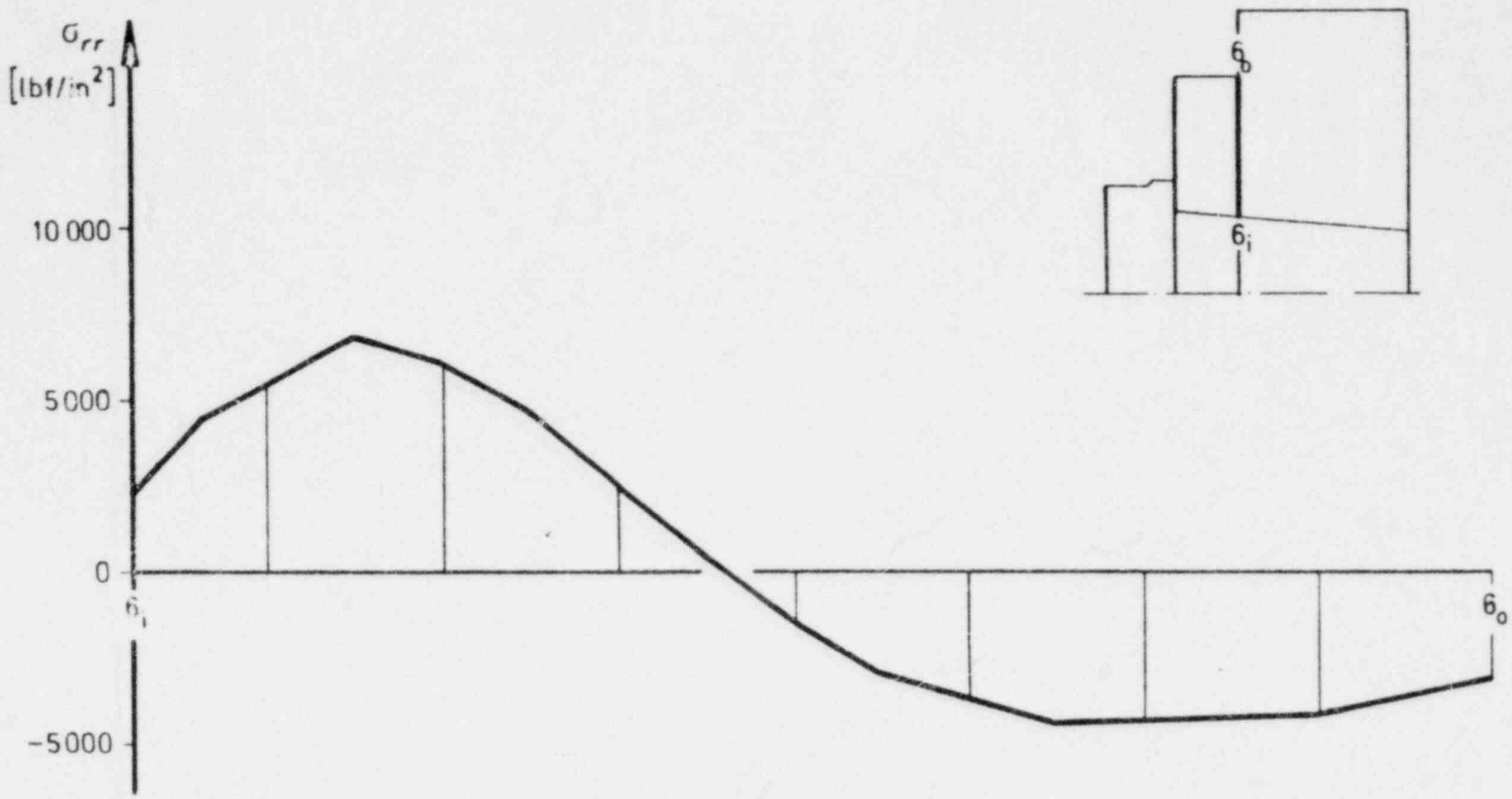


FIGURE 18.

Bearing Plate

Radial Normal Stress σ_{rr} in Cross Section 6

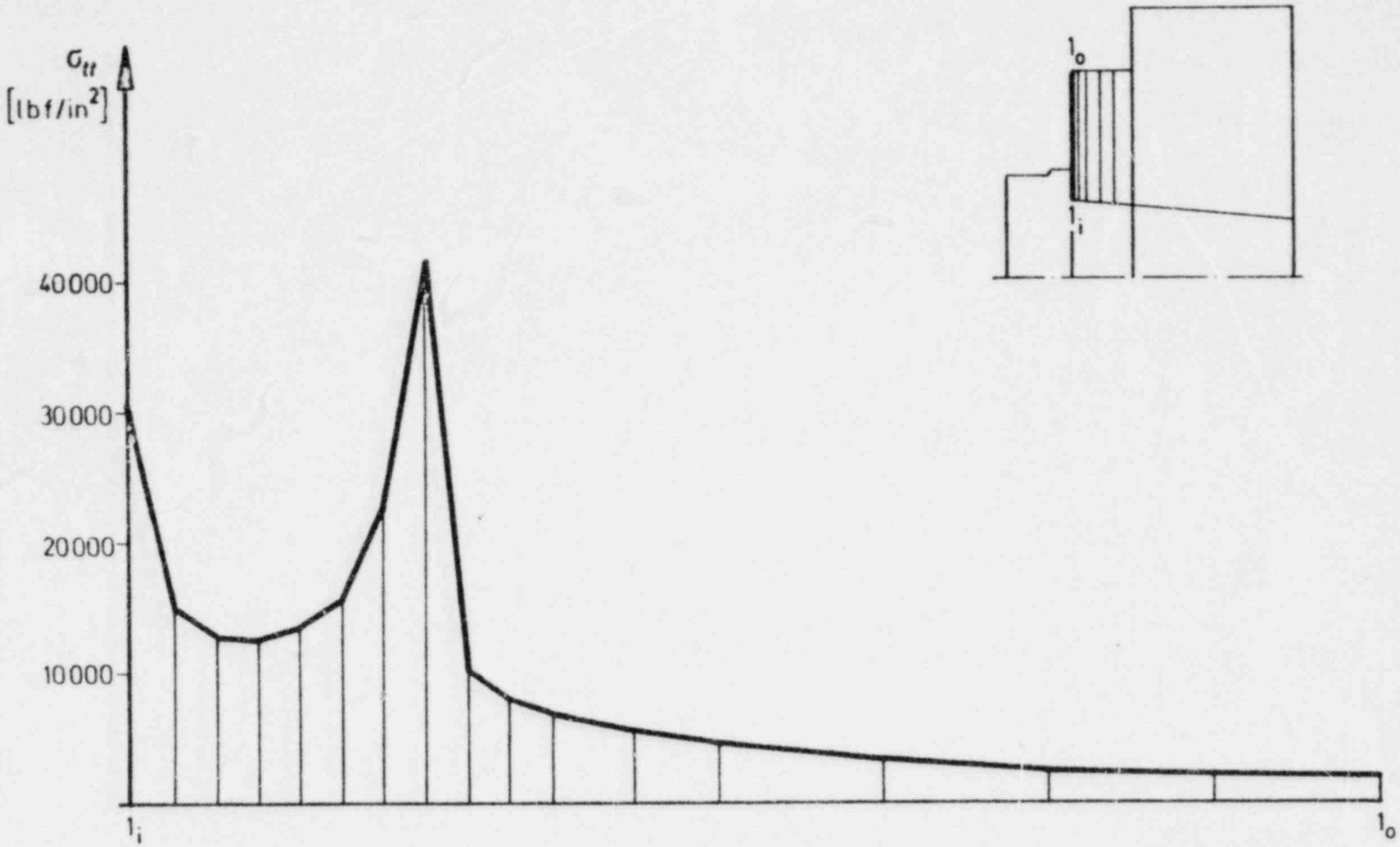


FIGURE 19.

Bearing Plate

Circumferential Normal Stress σ_{tt} in Cross Section 1

0137

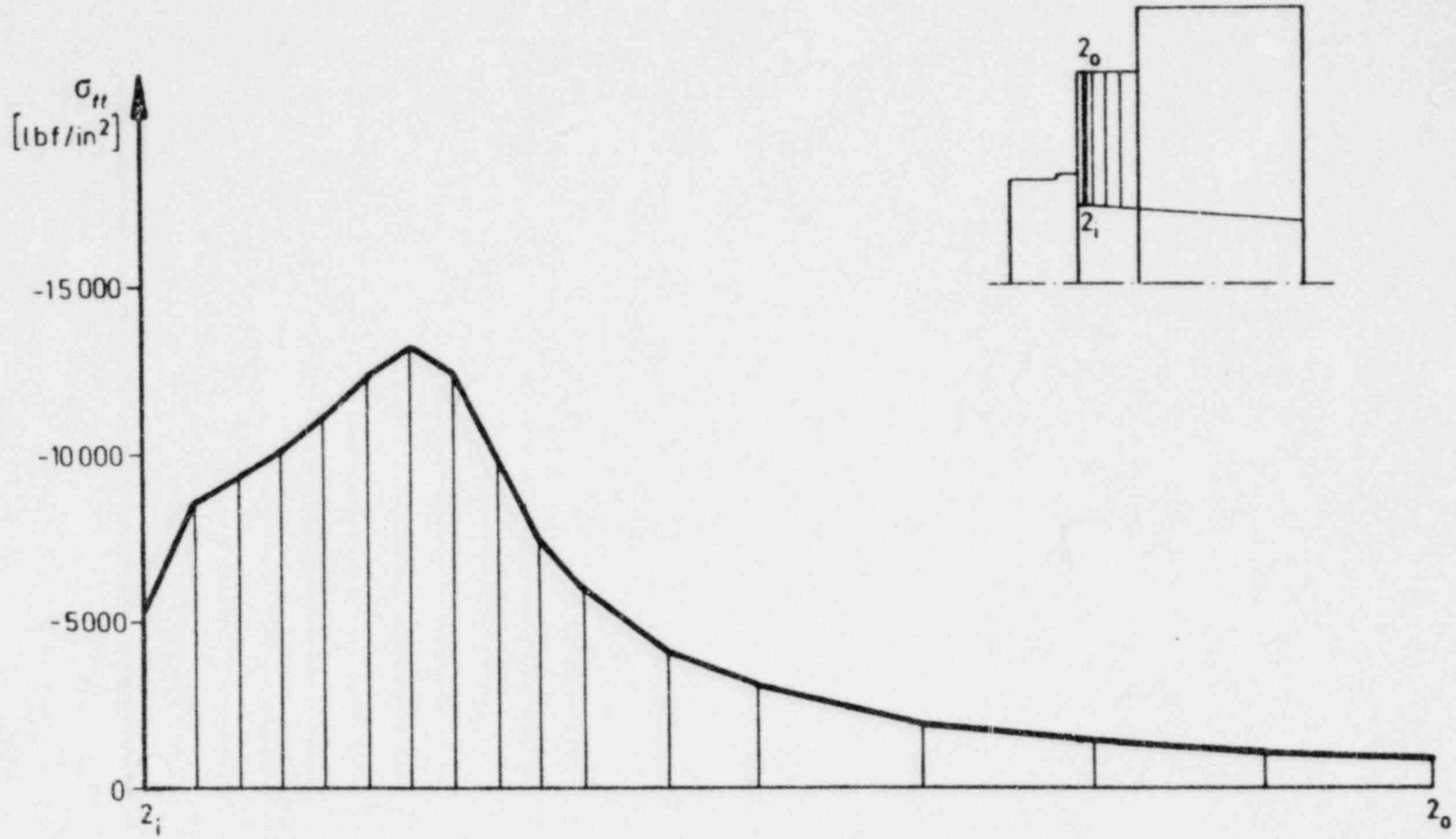


FIGURE 20.

Bearing Plate

Circumferential Normal Stress σ_{tt} in Cross Section 2

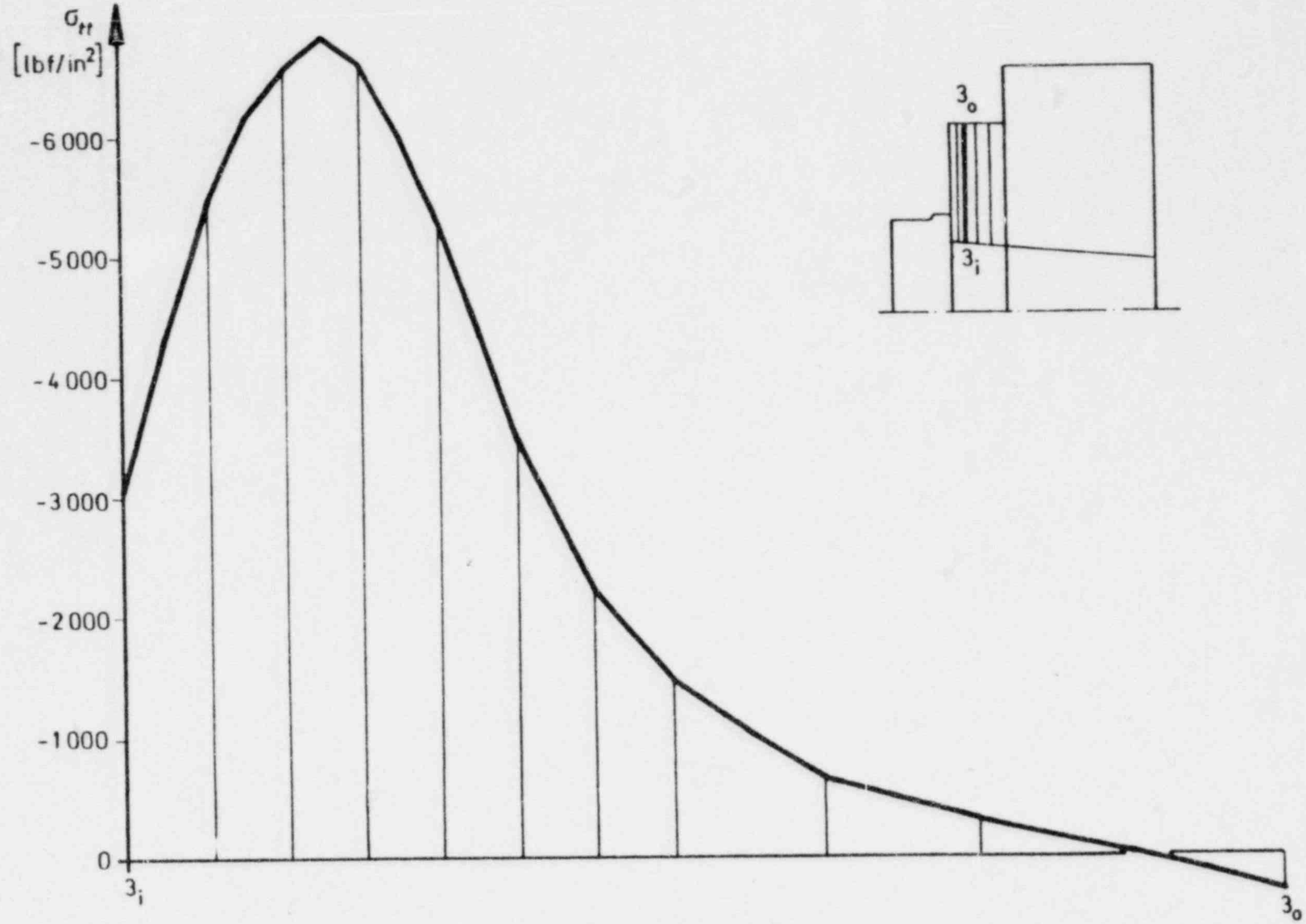


FIGURE 21. **Bearing Plate**

Circumferential Normal Stress σ_{tt} in Cross Section 3

0139

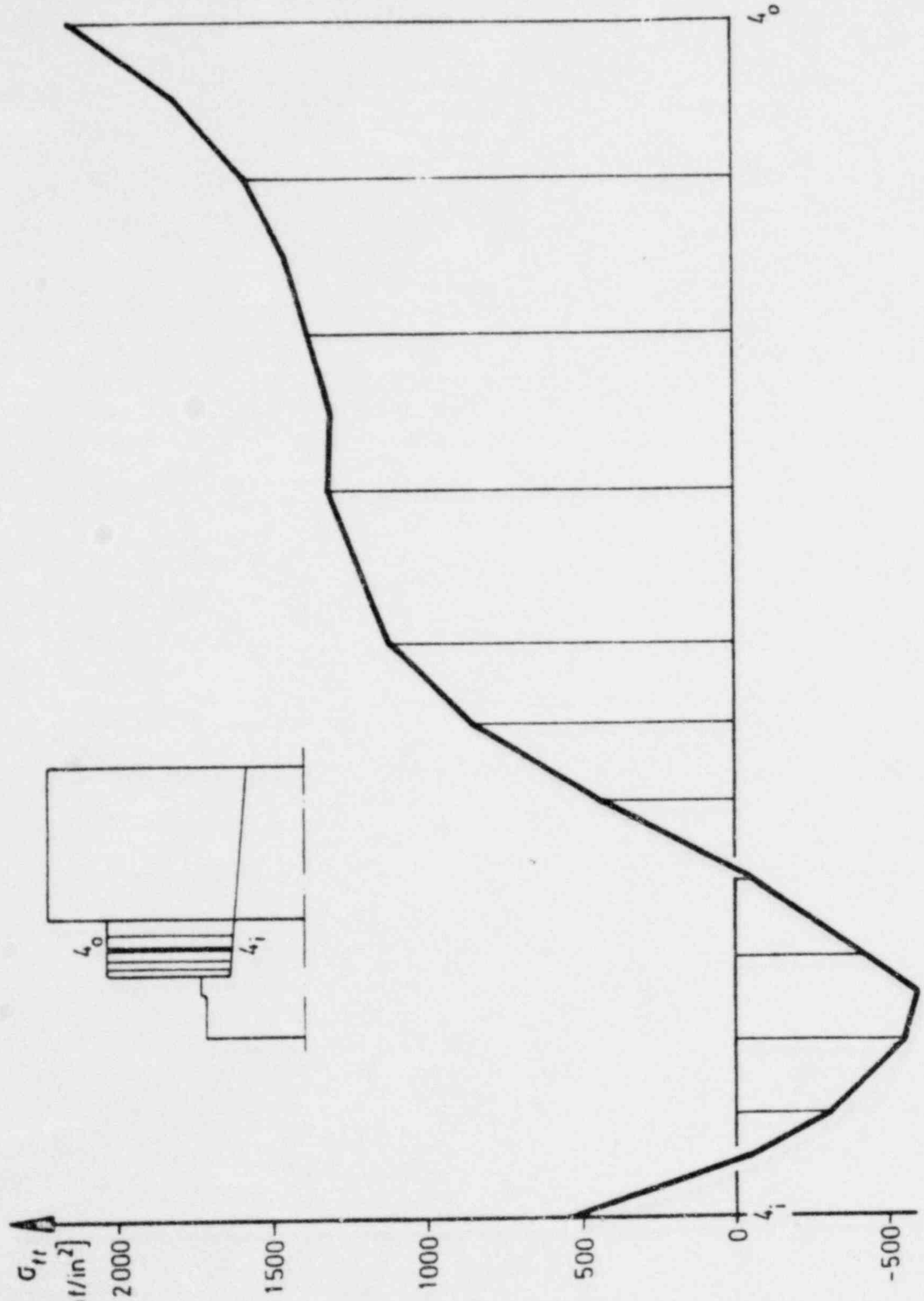


FIGURE 22. **Bearing Plate**

Circumferential Normal Stress σ_{tt} in Cross Section 4

0140

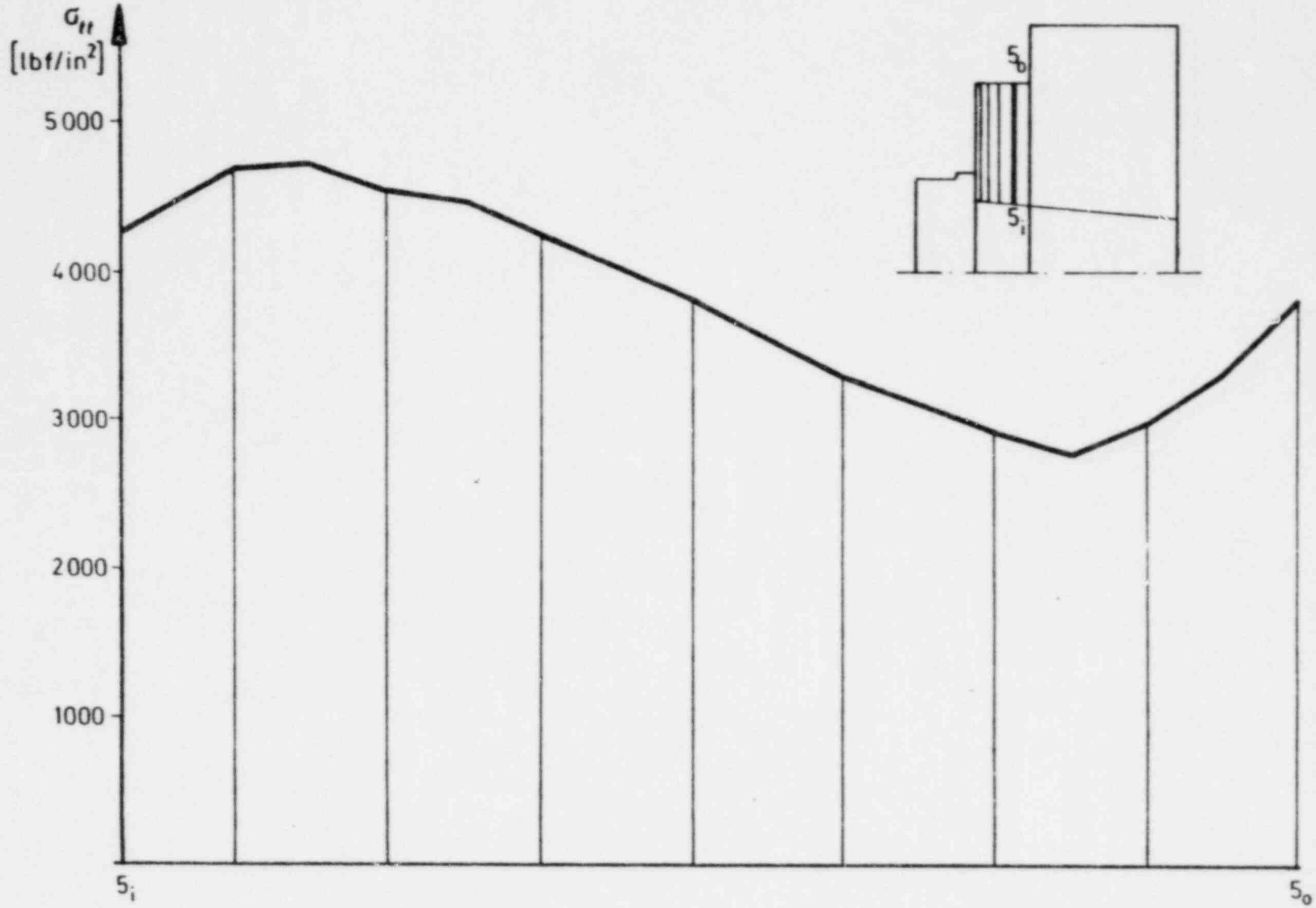


FIGURE 23. **Bearing Plate**

Circumferential Normal Stress σ_{tt} in Cross Section 5

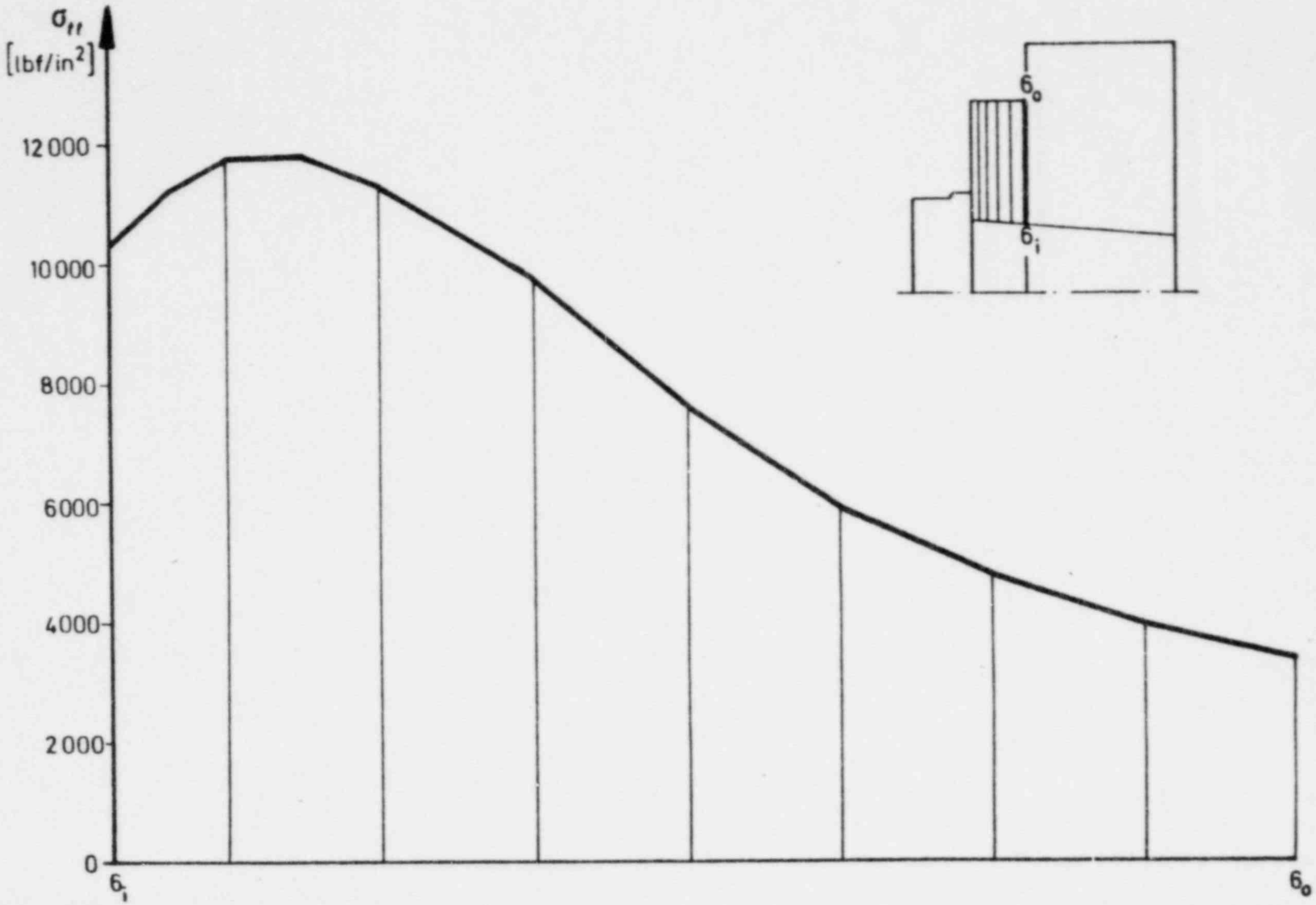


FIGURE 24.

Bearing Plate

Circumferential Normal Stress σ_{tt} in Cross Section 6

0142

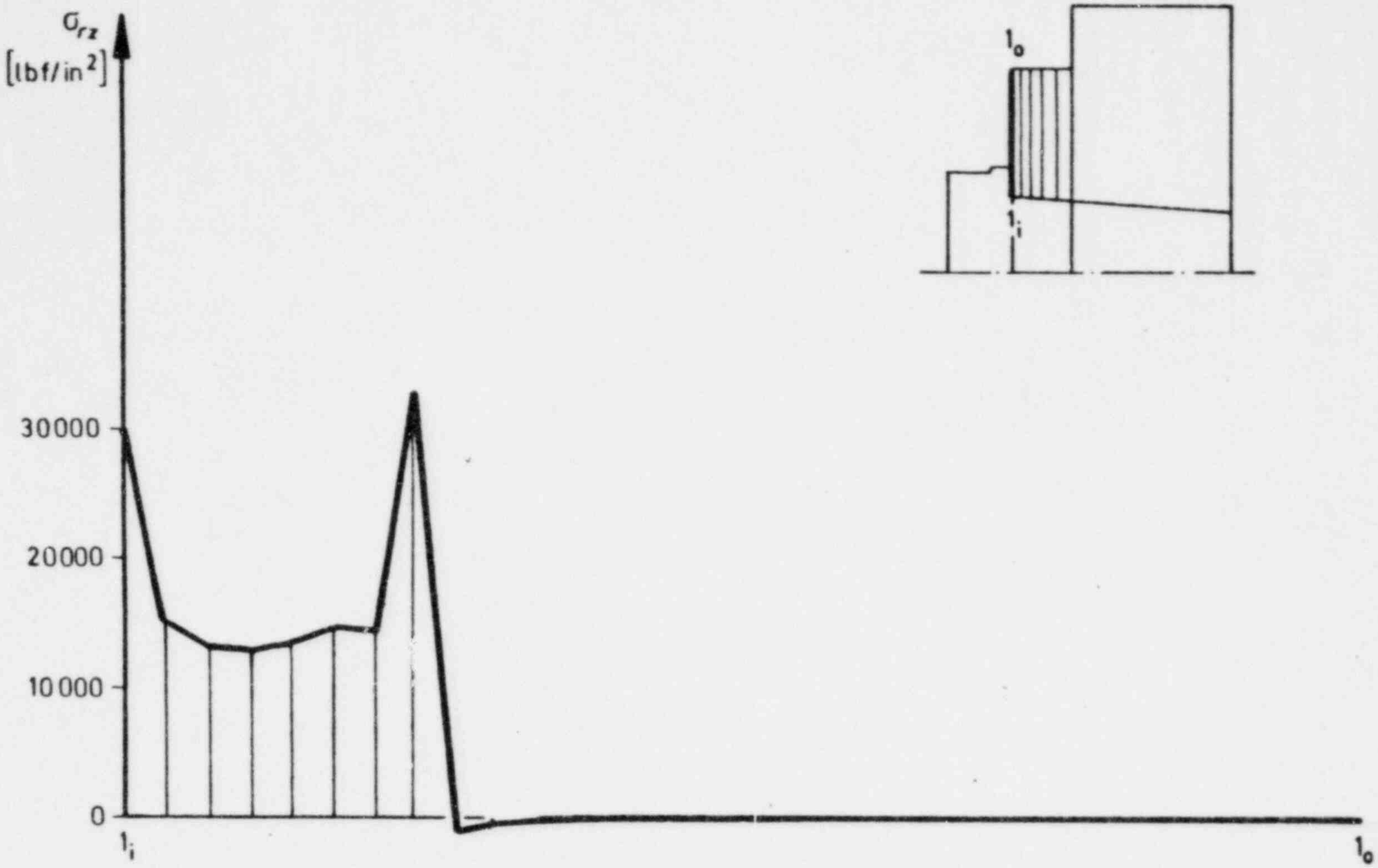


FIGURE 25. **Bearing Plate**

Shear Stress σ_{rz} in Cross Section 1

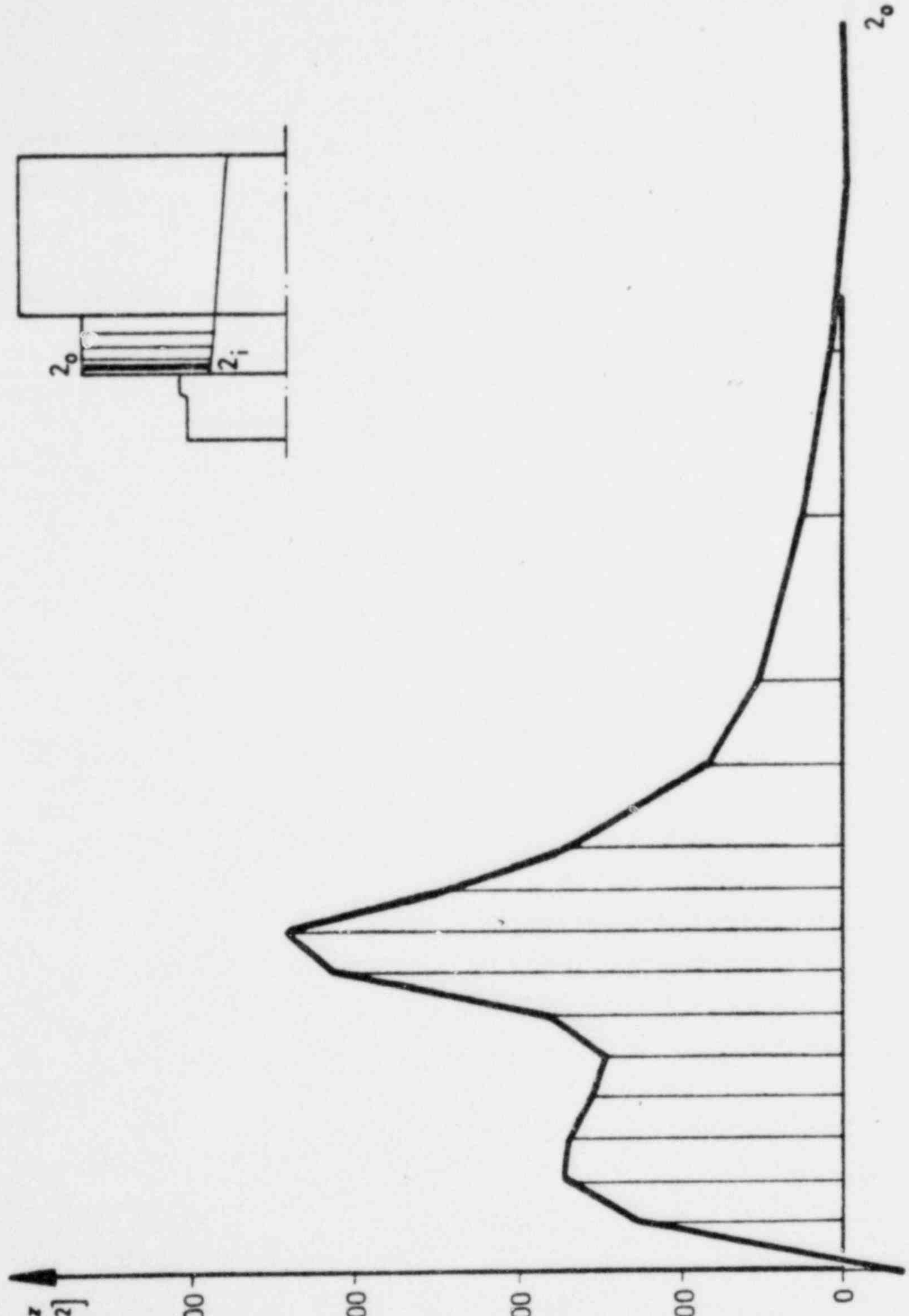


FIGURE 26.

Bearing Plate

Shear Stress σ_{rz} in Cross Section 2

0144

Supplement 2

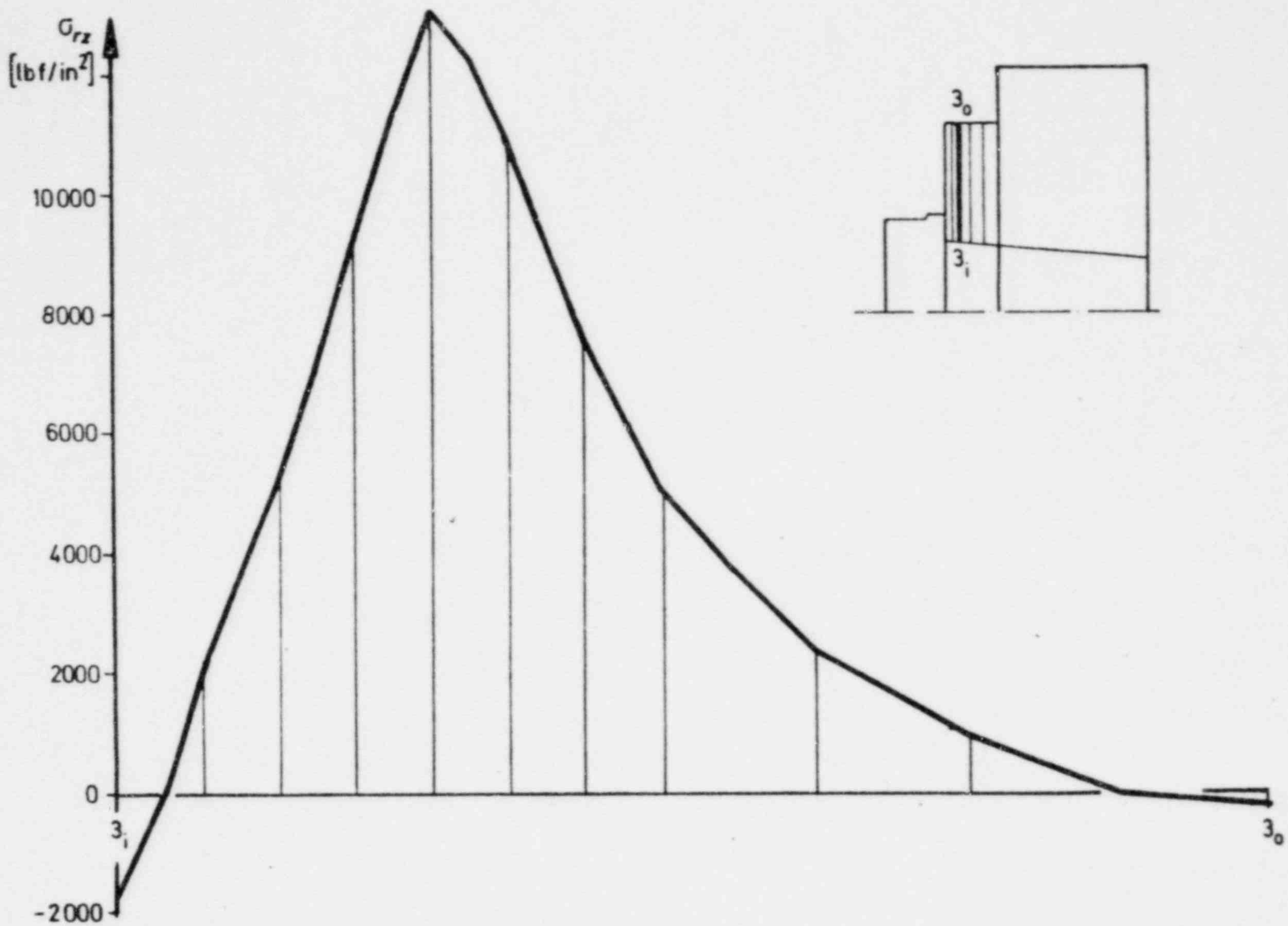


FIGURE 27. **Bearing Plate**

Shear Stress σ_{rz} in Cross Section 3

0145

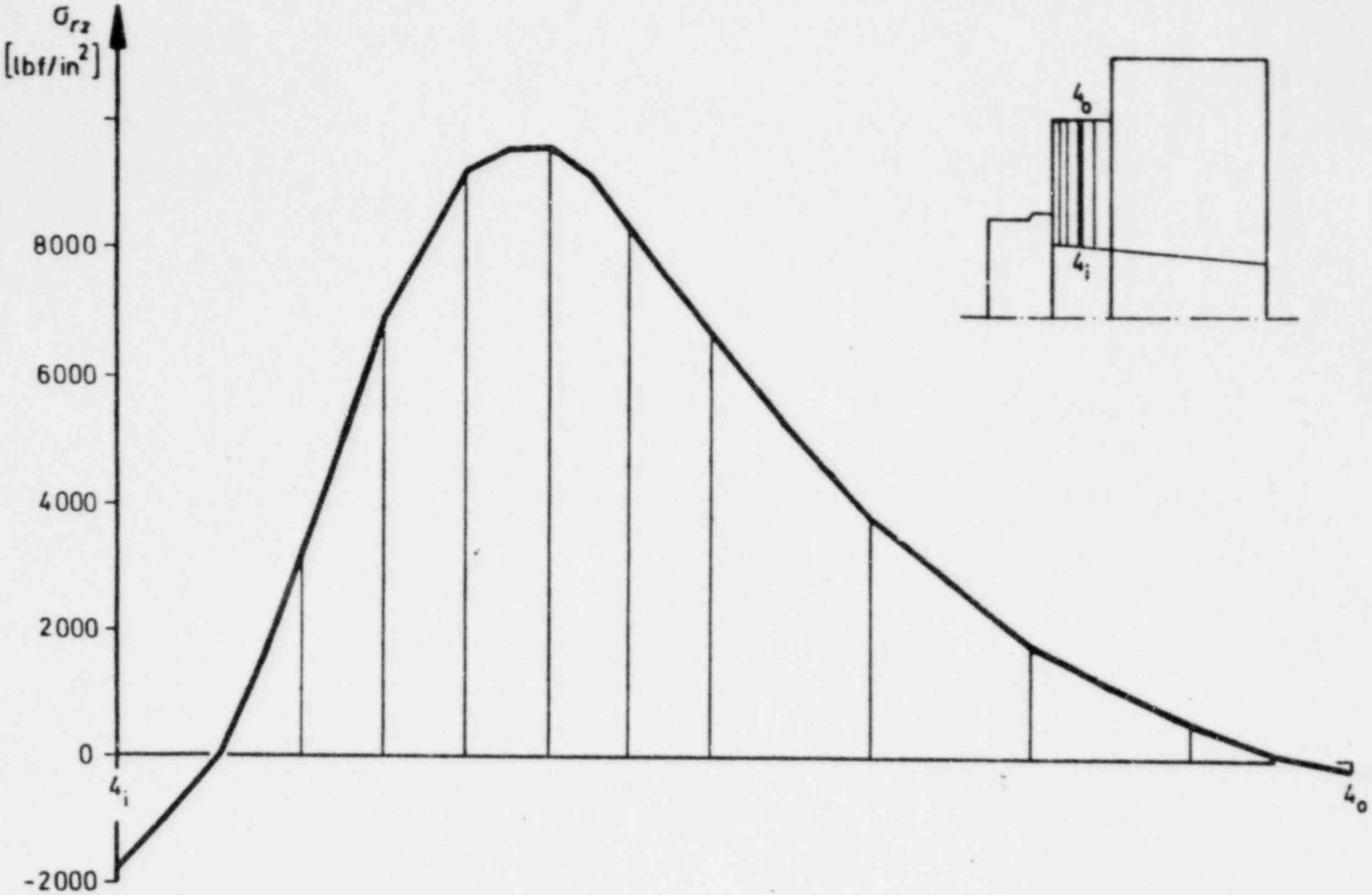


FIGURE 28.

Bearing Plate

Shear Stress σ_{rz} in Cross Section 4

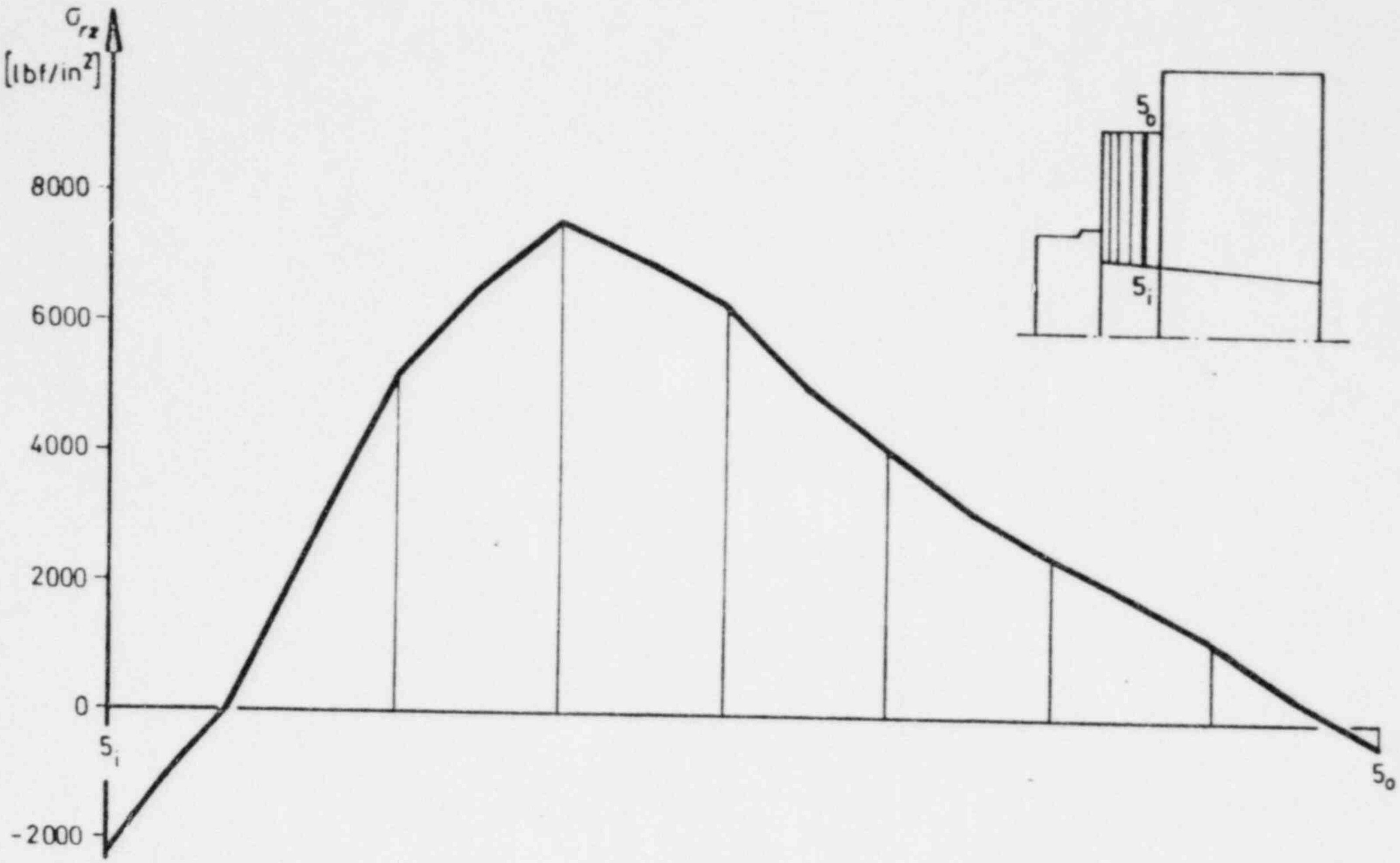


FIGURE 29.

Bearing Plate

Shear Stress σ_{rz} in Cross Section 5

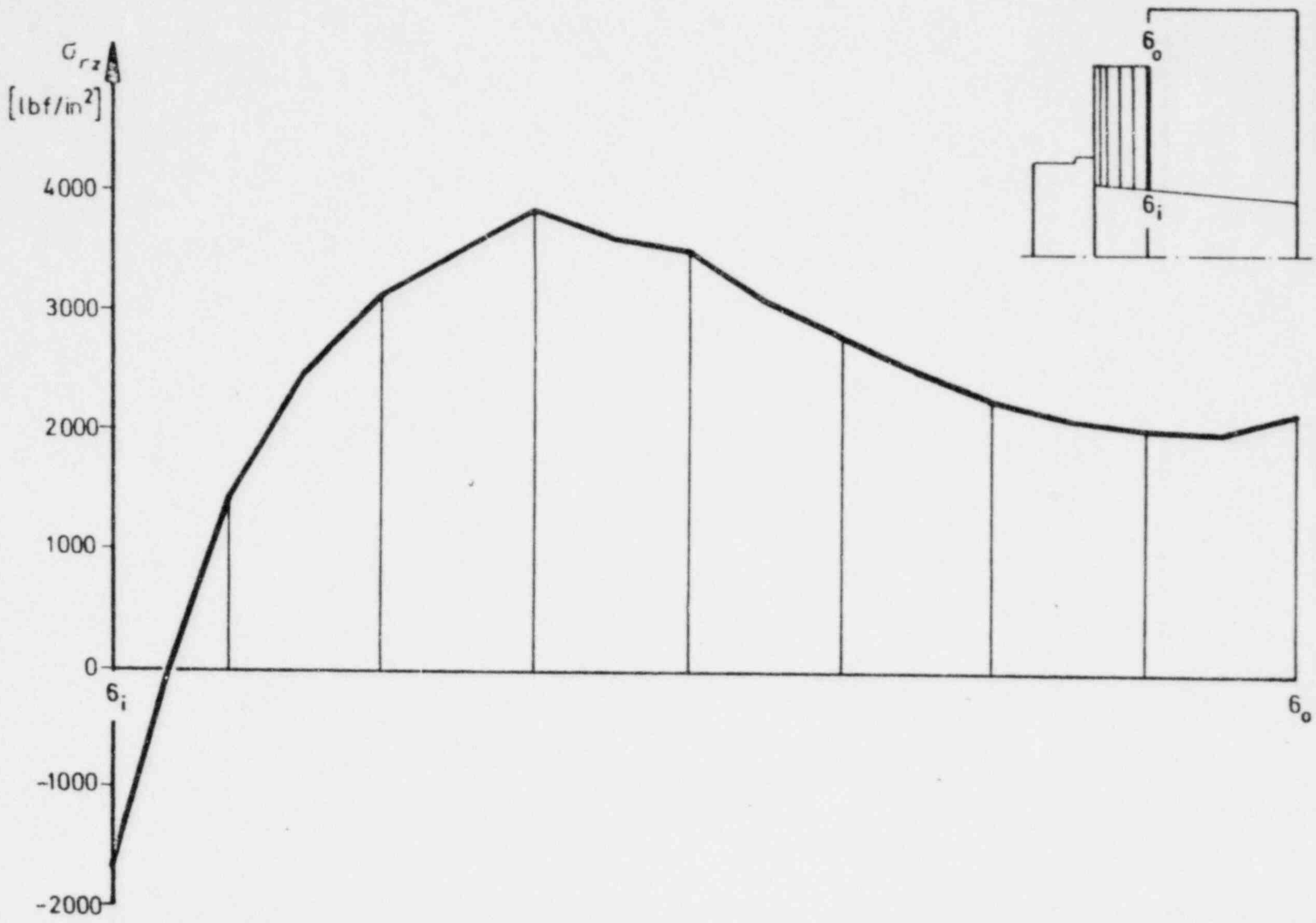


FIGURE 30.

Bearing Plate

Shear Stress σ_{rz} in Cross Section 6

LOW TEMPERATURE TESTS

The purpose of these tests was to determine the acceptability of anchorage steel at low temperature and under ultimate loads.

In the first test, a tendon with three 1/2" 270 ksi stabilized strands was used with two VSL Standard E5-3 Anchorages. One anchorage was installed at the lower end, and the other, for low temperature testing, was installed at the upper end. The latter was enclosed in a container filled with alcohol and dry ice to provide a temperature of -67° F. The chemical composition of the Cold Test Anchorage was as follows:

Bearing Plate (High Strength Low Alloy Structural Steel, Normalized, fully killed):

C	=	0.14 - 0.20	S	=	0.040 max.
Si	=	0.40 - 0.55	Cr	=	0.030 max.
Mn	=	1.20 - 1.50	Ni	=	0.030 max.
P	=	0.040 max.	Cu	=	0.030 max.

Anchor Head (Alloy Steel, Quenched and Tempered):

C	=	0.22 - 0.29	S	=	0.035 max.
Si	=	0.20 - 0.40	Cr	=	0.90 - 1.20
Mn	=	0.50 - 0.80	Mo	=	0.15 - 0.25
P	=	0.035 max.			

At the load of 126.8 kips (102.5% of f's), a strand in a wedge of the lower end broke. No visual distortion and no damage was observed at the top anchorage, which was exposed to the -67° F. temperature during the test.

Test No. 2 was similar to the former except that the tendon used had twelve 1/2" 270 ksi stabilized strands, and one anchorage was cooled to a temperature of -31° F. The chemical properties of the bearing plate were the same as those in Test No. 1; however, the anchor head was a standard VSL E5-12 (non-heat treated.)

At the load of 502.6 kips (101.5% of f's), the first wire rupture occurred. No visual distortion or damage was observed to anchor heads, bearing plates, wedges or to the concrete test block.

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FRICTION TESTS ON VSL TENDONS

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Supplement 2

The purpose of these friction tests was to determine appropriate values for coefficients μ and K.

Test No. 1

In this test, a curved reinforced girder was equipped with jacks and gauges on each end. However, no anchor head or wedges were used (except jack pulling heads) so that no anchorage friction had to be taken into consideration. Thus, knowing the input force at the stressing jack and the output at the dead end jack, various values of K were assumed and the basic stress formula then solved for values of μ.

Number of strands	=	31
Diameter of duct	=	3.94" I.D.
L_{girder}	=	34.25'
α	=	1.0472 rad.
K	=	0.0001, 0.0002, 0.0003
P_{jack}, $P_{dead\ end}$	=	given by the test

$$P_{jack} = P_{dead\ end} \times e^{\mu\alpha + KL} \quad \text{(basic formula)}$$

Solving for μ we get:

$$\mu = \frac{\log_e \frac{P_{jack}}{P_{dead\ end}} - KL}{\alpha}$$

Input Force at Jack No. 1	Force at Dead End	K = .0001	K = .0002	K = .0003
Kips	Kips	μ	μ	μ
110.23	95.68	.1317	.1285	.1252
220.46	189.16	.1430	.1398	.1365
330.69	285.06	.1384	.1352	.1319
440.93	379.20	.1406	.1374	.1341
551.16	475.10	.1384	.1352	.1319
661.39	572.32	.1347	.1314	.1282
771.62	655.22	.1528	.1496	.1463
	Average:	.1399	.1367	.1334

The conclusions that may be drawn from the above results are that on short, highly curved tendons the value of K is not important. The solved values for μ are consistently in a range between .13 and .14. One could not determine from the above results which would be most appropriate of the assumed values for K. A value for K will be determined on Test No. 2 with tendons 710 and 692 feet long (the longest post-tensioned bridge in the United States). Here, the value for K is obviously of major importance and the angular change substantial as well, providing an ideal cross comparison with Test No. 1.

Test No. 2

This test, conducted on a bridge structure, began by stressing the tendons from one end only to a force of 960 kips. The dead end jack was then stressed just enough to lift the dead end anchor head off its bearing plate. In this operation, the anchor head, wedges and strand moved as a unit since the wedges had been seated when jacking previously from the other end. When the dead end anchor just cleared the bearing plate, the dead end reading was taken. Thus, anchorage friction loss (3%) occurred on the live end only.

Number of strands		=	31
Diameter of sheathing		=	4.0" I.D.
Left Bridge:	L	=	710'
	α	=	0.74 rad.
	K	=	0 0001, .0002, .0003
Right Bridge:	L	=	692'
	α	=	0.79
	K	=	.0001, .0002, .0003

Initial force at the live end = 960 kips

Force at the live end minus 3% anchorage friction = 931.20 kips

	Force at Live End	Readings at Dead End	K = .0001	K = .0002	K = .0003
	Kips	Kips	μ	μ	μ
Left Bridge	931.20	792.0	.1227	.0267	<0
	931.20	789.0	.1279	.0190	<0
Right Bridge	931.20	824.0	.0673	<0	<0
	931.20	783.0	.1320	.0446	<0
	931.20	814.0	.0827	<0	<0
	931.20	805.0	.0968	.0094	<0

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The conclusions which may be drawn from the results of Test No. 2 are that although values of K = .0002 and .0003 might have seemed possible in Test No. 1, they give negative solutions for μ in Test No. 2 and therefore must be excluded. At the same time, it should be noted that the maximum value of μ obtained assuming K = .0001 was .1320 which agrees with the values of μ obtained in Test No. 1

Based on the results of the above, the values of μ = .14 and K = .0003 currently in use in design on nuclear containment structures appear quite conservative.

APPENDIX 5L
DESIGN OF LINER PLATE ANCHORS

1.0 DESIGN CRITERIA

The anchors will be designed to preclude failure when subjected to the worst possible loading combinations. The anchors will also be designed such that in the event of a missing or failed anchor the total integrity of the anchorage system will not be jeopardized by the failure of adjacent anchors. Please refer to the answer to Question 5J.7.4.

1.1 LOADING CONDITIONS

The following loading conditions will be considered in the design of the anchorage system:

1. Prestress
2. Pressure
3. Shrinkage and creep of concrete
4. Thermal gradients
5. Dead load
6. Earthquake
7. Wind
8. Vacuum

1.2 FACTORS AFFECTING ANCHORS

The following factors will be considered in the design of the anchorage system:

1. Initial inward curvature of the liner plate between anchors due to fabrication and erection inaccuracies.
2. Variation of anchor spacing
3. Misalignment of liner plate seams
4. Variation of plate thickness
5. Variation of liner plate material yield stress
6. Variation of Poisson's ratio for liner plate material
7. Cracking of concrete in anchor zone
8. Variation of the anchor stiffness

1.3 DESIGN CONDITIONS

The anchorage system will satisfy the following conditions:

1. The anchor will have sufficient strength and ductility so that its energy absorbing capability is sufficient to restrain the maximum force and displacement resulting from the condition where a panel with initial outward curvature is adjacent to a panel with initial inward curvature.

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2. The anchor will have sufficient strength to resist the bending moment which will result from Condition 1.

3. The anchor will have sufficient strength to resist radial pull-out force.

2.0 MATHEMATICAL METHOD OF ANALYSIS

When the liner plate moves inward radially as shown in Figure 1, the sections will develop membrane stress due to the fact that the anchors have moved closer together. Due to initial inward curvature, the section between 1 and 4 will deflect inward giving a longer length than adjacent sections and some relaxation of membrance stress will occur. It should be noted here that section 1-4 cannot reach an unstable condition due to the manner in which it is loaded.

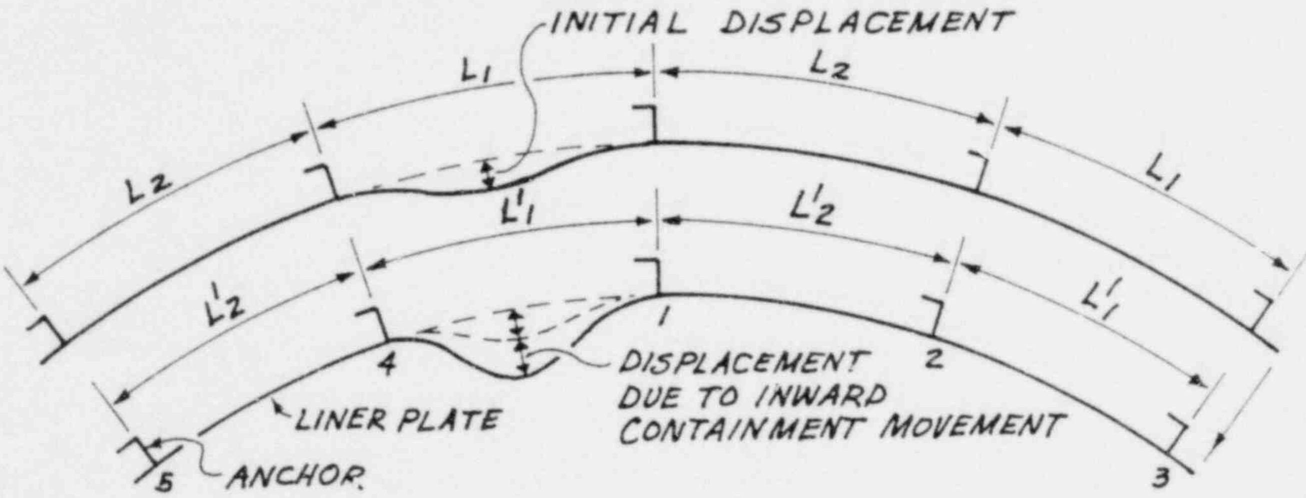

Figure 1

The first part of the solution for the liner plate and anchorage system is to calculate the amount of relaxation that occurs in section 1-4, since this value will also be the force across anchor 1 if it is infinitely stiff. The above solution can be obtained by solving the general differential equation for beams and the use of calculus to simulate relaxation or the lengthening of section 1-4. Figure 2 shows the symbols for the forces that result from the first step in the solution.

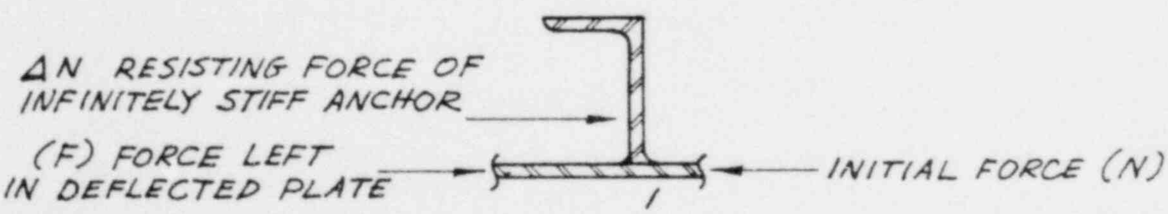

Figure 2

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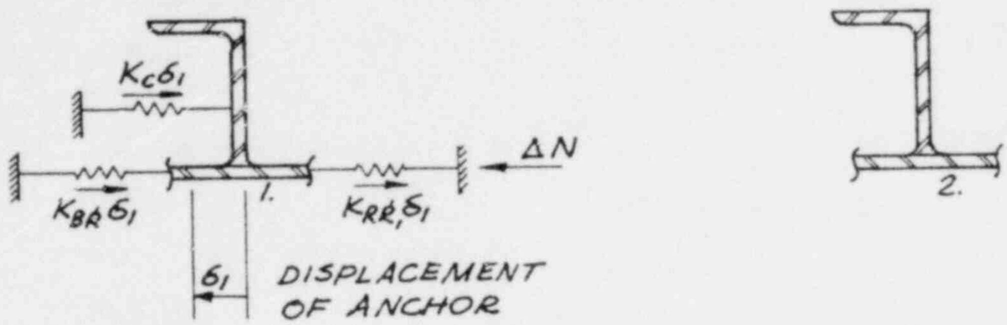
Using the model shown in Figure 3 and evaluating the necessary spring constants, the anchor can now be allowed to displace.



K_c - Spring constant of anchor

$K_{B\ell}$ - Spring constant of deformed plate

$K_{R\ell}$ - Relaxation of section 1-2 due to δ_1

Figure 3

The solution will now yield a force and displacement at anchor 1, but the force in section 1-2 is now $(N)-K_{R\ell_1}\delta_1$, and anchor 2 is not in force equilibrium.

The model shown in Figure 4 may be used to allow anchor 2 to displace and then find the effects on anchor 1.

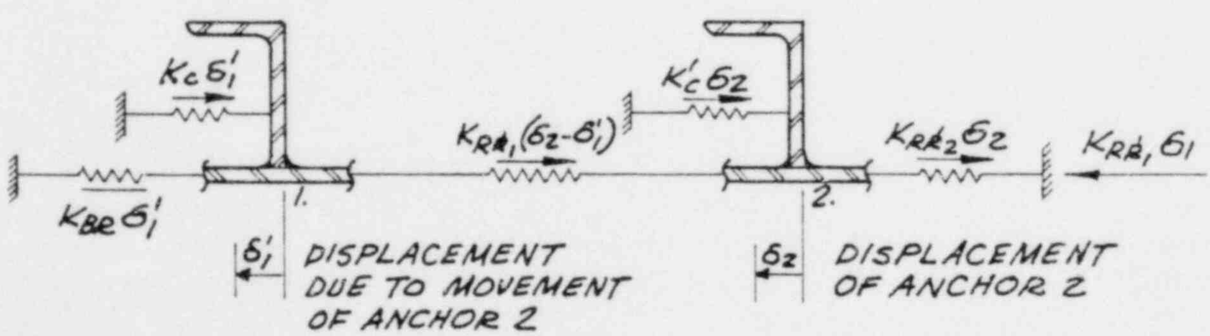


Figure 4

The displacement of anchor 1 is now $\delta_1 + \delta_1'$ and force on anchor 1 is $K_c\ (\delta_1 + \delta_1')$. Now anchor 3 is not in force equilibrium and the solution may continue to the next anchor.

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After the solution was found for displacing anchor 2 and anchor 3, the pattern was established with respect to the effect on achor 1 and by inspection, the solution considering an infinite amount of anchors was obtained in the form of a series solution.

The preceding solution will yield all necessary results. The most impor tant results will be the displacement and force on the anchor 1.

3.0 FINAL METHOD OF ANALYSIS

The method outlined in section 2.0 produces an equation that is a very useful tool in designing the anchorage system. By varying the different variables which are contained in the equation, their effect on the design may be determined. If the conservative assumption is made that the spring constant $K_{B\ell}$ is small relative to the anchor spring constants K_c and K'_c, then the solution is fully dependent on the stiffness of the anchor.

Since the capacity of the anchor is both a function of its displacement and the applied force, the design must be based on energy considerations.

References 1, 2, 3, and 4 can be used to evaluate an anchor spring constant. By using the equation obtained previously with the chosen spring constant, the amount of energy required to be absorbed by the anchor may be evaluated.

By applying reasonable variations to the anchor spring constant, the most probable maximum energy may be found.

References 1, 2, 3, and 4 may also be used to conservatively evaluate the amount of energy that the anchor system will absorb.

By dividing the amount of energy that the system will absorb by the most probable maximum energy the result will then yield the factor of safety.

4.0 ANCHORAGE SYSTEM FACTOR OF SAFETY AGAINST FAILURE

Early testing by Bechtel Corporation indicated that the total available energy calculated by integrating the area under the load displacement curve could conservatively be taken as 700 in. lbs./in. (Ref. 1). A recent series of tests (Ref. 4) were conducted to include the effects of the concrete and verify that the energy value given in the initial test program would not be reduced by the composite effect with concrete. The results of the additional tests confirm that the value of 700 in. lb./in. is conservative being exceeded in some cases by a factor of two.

The most probable maximum energy input was calculated by integrating the area under the calculated load-displacement curve using the following input information:

$K_{BPL} = 0$, $K_{RPL} = 0.500X10^3$ K/in./in.

$K_c = K'_c$ varied from $0.0825X10^3$ K/in./in. to $0.345X10^3$ K/in./in. for analysis.

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The anchorage system factor of safety against failure was calculated by dividing the amount of energy that the system will absorb by the most probable maximum energy input conservatively taken as 700 in. lb/in. It should be noted that the factors of safety for the various cases have been increased substantially by the selection of the low yield ASTM A-285 Grade A, Firebox Quality liner plate for the Rancho Seco containment structure.

5.0 RESULTS OF ANALYSIS

By considering the worst possible loading condition which results from section 3.1.1 and the conditions stated below, Table 1 was obtained.

Case I — Simulates the perfect plate with a yield stress of 24KSI and no variation of any other parameters.

Case II — Simulates a 1.25 increase in yield stress and no variation of any other parameters.

Case III — Simulates a 1.25 increase in yield stress, a 1.16 increase in plate thickness and a 1.08 increase for all other parameters. This case should adequately simulate the worst condition on the liner plate.

Case IV — Simulates a 1.88 increase in yield stress with no variation of any other parameter. The occurence of this situation is considered highly unlikely since the maximum ultimate strength of the liner plate material is 45KSI. This case is not considered as a design situation, but the anchor is still adequate.

Case V — Is the same as Case III except the anchor spacing has been doubled to simulate what happens if an anchor is missing or has failed.

LINER PLATE CALCULATIONS - RESULTS

TABLE 1

Case	Nominal Plate Thickness (in)	Initial Inward Displacement (in)	Anchor Spacing L_1 (in)	Anchor Spacing L_2 (in)	Factor of Safety Against Failure
I	.25	.125	15	15	86.5
II	.25	.125	15	15	43.3
III	.25	.125	15	15	24.8
IV	.25	.125	15	15	15.2
V	.25	.25	30	15	8.3

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REFERENCES

1. Answer to question 5J.7.4, Amendment 3 of the PSAR.

2. "Amendment No. 2 to application of Public Service Company of Colorado for construction permit and Class 104 license for the Fort St. Vrain Nuclear Generating Station."

3. "Liner Design and Development for the Oldbury Vessels" R. P. Hardingham, J. V. Parker, and T. W. Spruce, Group J, Paper 56, London Conference on Prestressed Concrete Pressure Vessels.

4. Liner ℄. Anchorage Tests for Job No. 6600 Arkansas Nuclear One, Arkansas Power and Light Company; Job No. 6292 Rancho Seco Nuclear Station--Unit 1, Sacramento Municipal Utilities District; Job No. 6750 Calvert Cliffs--Units 1 and 2, Baltimore Gas and Electric Company . . . Prepared by Bechtel Corporation San Francisco, Calif. (April 18, 1969)

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