WESTINGHOUSE PROPRIETARY CLASS 3

PRESSURIZER SAFETY AND RELIEF LINE
PIPING AND SUPPORT EVALUATION

SNUPPS UTILITIES

CALLAWAY UNIT 1 AND THE WOLF CREEK UNIT

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Systems Structural Analysis

This report is applicable to Callaway Unit 1 and the Wolf Creek Unit and contains the structural evaluation of ASME III Nuclear Class 1 piping analyzed to requirements of the ASME Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components, 1979 Edition, including applicable addenda; as well as NNS piping done to requirements of ANSI B31.1 Code, 1979 Edition. Results from the Safety and Relief Valve Test program, conducted by the Electric Power Research Institute (EPRI) and concluded on or before July 1, 1982, were factored into the analyses presented herein.

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SECTION 1
INTRODUCTION

The Pressurizer Safety and Relief Valve (PSARV) discharge piping system for pressurized water reactors, located on the top of the pressurizer, provides overpressure protection for the reactor coolant system. A water seal is maintained upstream of each pressurizer safety and relief valve to prevent a steam interface at the valve seat. This water seal practically eliminates the possibility of valve leakage. While this arrangement maximizes the plant availability, the water slug, driven by high system pressure upon actuation of the valves, generates severe hydraulic shock loads on the piping and supports.

Under NUREG 0737, Section II.D.1, "Performance Testing of BWR and PWR Relief and Safety Valves", all operating plant licensees and applicants are required to conduct testing to qualify the reactor coolant system relief and safety valves under expected operating conditions for design-basis transients and accidents. In addition to the qualification of valves, the functionability and structural integrity of the as-built discharge piping and supports must also be demonstrated on a plant specific basis.

In response to these requirements, a program for the performance testing of PWR safety and relief valves was formulated by EPRI. The primary objective of the Test Program was to provide full scale test data confirming the functionability of the reactor coolant system power operated relief valves and safety valves for expected operating and accident conditions. The second objective of the program was to obtain sufficient piping thermal hydraulic load data to permit confirmation of models which may be utilized for plant unique analysis of safety and relief valve discharge piping systems. Based on the results of the aforementioned EPRI Safety and Relief Valve Test Program, additional thermal hydraulic analyses are required to adequately define the loads on the piping system due to valve actuation.

This report is the response of the SNUPPS Utilities to the US NRC plant specific submittal request for piping and support evaluation and is applicable to the Callaway Unit 1 and the Wolf Creek Unit PSARV piping system.

SECTION 2
PIPE STRESS CRITERIA

2.1 PIPE STRESS CALCULATION - CLASS 1 PORTION

In general, the criteria for the structural evaluation of the Class 1 components is based upon two categories of loading. These are self-limiting loads and non-self-limiting loads. A non-self-limiting load produces a primary stress while a self-limiting load produces a secondary stress. In order to prevent catastrophic failure of the system, primary stress criteria must be satisfied, which can be accomplished by applying Equation (9) of paragraph NB-3652 of the ASME Boiler and Pressure Vessel Code Section III, up to and including the Summer 1979 Addenda. Fatigue failure may occur if the maximum stress from all loadings is so concentrated at one location that continued cycling of the loads produces a crack, which may then propagate through the wall and result in leakage. For protection against fatigue failure, cyclic stresses from both self-limiting and non-self-limiting loads must be considered. The component will cycle within acceptable limits for each specified loading combination if Equation (10), subparagraph NB-3653.1 of the Code is satisfied. This requirement insures that incremental distortion will not occur. The peak stress intensity defined by Equation (11) is then used for calculating the alternating stress intensity, S_{alt}. The value of S_{alt} is then used to calculate the usage factor for the load set under consideration. The cumulative usage factor is then obtained using Miner's rule by considering all other load sets. However, if Equation (10) is not satisfied, which means some plastic deformation occurs with each application of load, the alternate analysis, "Simplified Elastic-Plastic Discontinuity Analysis", described in subparagraph NB-3653.6 of the Code must be considered. To avoid the possibility of fatigue failure, the cumulative usage factor should not exceed 1.0.

2.2 PIPE STRESS CALCULATION - CLASS NNS PORTION

The piping between the valves and the pressurizer relief tank shall be analyzed to satisfy the requirements of the appropriate equations of the ANSI B31.1 Code. These equations establish limits for stresses from sustained loads and occasional loads (including earthquake), thermal expansion loads, and sustained plus thermal expansion loads, respectively. The allowable stresses for use with the equations were determined in accordance with the requirements of the ANSI B31.1 Code.

2.3 LOAD COMBINATIONS

In order to evaluate the pressurizer safety and relief valve piping, appropriate load combinations and acceptance criteria were developed. The load combinations and acceptance criteria are identical to those recommended by the piping subcommittee of the PWR PSARV test program and are outlined in Tables 2-1 and 2-2 with a definition of load abbreviation provided in Table 2-3.

TABLE 2-1

LOAD COMBINATIONS AND ACCEPTANCE CRITERIA FOR PRESSURIZER SAFETY AND RELIEF VALVE PIPING AND SUPPORTS - UPSTREAM OF VALVES

Combination	Plant/System Operating Condition	Load Combination	Piping Allowable Stress Intensity
1	Normal	N	1.5 S_m
2	Upset	N + OBE + SOT_U	1.8 S_m
3	Emergency	N + SOT_E	2.25 S_m
4	Faulted	N + MS/FWPB or DBPB + SSE + SOT_F	3.0 S_m
5	Faulted	N + LOCA + SSE + SOT_F	3.0 S_m

NOTES:

(1) Plants with an FSAR may use their original design basis in conjunction with the appropriate system operating transient definitions in Table 2-3; or they may use the proposed criteria contained in Tables 2-1 to 2-3.

(2) See Table 2-3 for SOT definitions and other load abbreviations.

(3) The bounding number of valves (and discharge sequence if setpoints are significantly different) for the applicable system operating transient defined in Table 2-3 should be used.

(4) Verification of functional capability is not required, but allowable loads and accelerations for the safety-relief valves must be met.

(5) Use SRSS for combining dynamic load responses.

TABLE 2-2

LOAD COMBINATIONS AND ACCEPTANCE CRITERIA
FOR PRESSURIZER SAFETY AND RELIEF VALVE PIPING
AND SUPPORTS - SEISMICALLY DESIGNED DOWNSTREAM PORTION

Combination	Plant/System Operating Condition	Load Combination	Piping Allowable Stress Intensity
1	Normal	N	1.0 S_h
2	Upset	N + SOT_U	1.2 S_h
3	Upset	N + OBE + SOT_U	1.8 S_h
4	Emergency	N + SOT_E	1.8 S_h
5	Faulted	N + MS/FWPB or DBPB + SSE + SOT_F	2.4 S_h
6	Faulted	N + LOCA + SSE + SOT_F	2.4 S_h

NOTES: (1) Plants with an FSAR may use their original design basis in conjunction with the appropriate system operating transient definitions in Table 2-3; or they may use the proposed criteria contained in Tables 2-1 to 2-3.

(2) This table is applicable to the seismically designed portion of downstream non-Category I piping (and supports) necessary to isolate the Category I portion from the non-seismically designed piping response, and to assure acceptable valve loading on the discharge nozzle.

(3) See Table 2-3 for SOT definitions and other load abbreviations.

(4) The bounding number of valves (and discharge sequence if setpoints are significantly different) for the applicable system operating transient defined in Table 2-3 should be used.

(4) Verification of functional capability is not required, but allowable loads and accelerations for the safety-relief valves must be met.

(5) Use SRSS for combining dynamic load responses.

TABLE 2-3

DEFINITIONS OF LOAD ABBREVIATIONS

N	=	Sustained loads during normal plant operation
SOT	=	System operating transient
SOT_U	=	Relief valve discharge transient(1)
SOT_E	=	Safety valve discharge transient(1), (2)
SOT_F	=	Max (SOT_U; SOT_E); or transition flow
OBE	=	Operating basis earthquake
SSE	=	Safe shutdown earthquake
MS/FWPB	=	Main steam or feedwater pipe break
DBPB	=	Design basis pipe break
LOCA	=	Loss-of-coolant accident
S_h	=	Basic material allowable stress at maximum (hot) temperature
S_m	=	Allowable design stress intensity

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(1) May also include transition flow, if determined that required operating procedures could lead to this condition.

(2) Although certain nuclear steam supply systems design transients (for example, loss of load) which are classified as upset conditions may actuate the safety valves, the extremely low number of actual safety valve actuations in operating pressurizer water reactors justifies the emergency condition from the ASME design philosophy and a stress analysis viewpoint. However, if actuation of safety valves would occur, a limitation must be placed to shut down the plant for examination of system integrity after an appropriate number of actuations. This number can be determined on a plant specific basis.

NOTE: Plants with an FSAR may use their original design basis in conjunction with the appropriate system operating transient definitions in Table 2-3; or they may use the proposed criteria contained in Tables 2-1 to 2-3.

SECTION 3
LOADING CONDITIONS ANALYZED

3.1 LOADING

The piping stress analyses described in this section consider the loadings specified in the design specification. These loadings result from thermal expansion, pressure, weight, earthquake, design basis accident (DBA), plant operational thermal and pressure transients, and safety valve and relief valve operation.

3.1.1 THERMAL EXPANSION

The thermal growth of the reactor coolant loop equipment and all connected piping is considered in the thermal analysis of this system.

The modulus of elasticity, (E), the coefficient of thermal expansion at the metal temperature, (α), the external movements transmitted to the piping as described above, and the temperature rise above the ambient temperature, (ΔT), define the required input data to perform the flexibility analysis for thermal expansion.

Due to different operating modes, the system may experience multiple thermal loadings. The temperatures used in the expansion analysis of the piping are based upon the information presented in the design documents.

3.1.2 PRESSURE

Pressure loading in this report is either design pressure or operating pressure. The design pressure is used in the calculation of longitudinal pressure stress in accordance with the Code. The range of operating pressure is used in calculating various stress intensities, as applicable.

3.1.3 WEIGHT

To meet the requirements of the Code, a weight analysis is performed by applying a 1.0 g uniformly distributed load downward on the complete piping system. The distributed weight characteristics of the piping system are specified as a function of its properties. This method provides a distributed loading to the piping system as a function of the weight of the pipe, insulation, and contained fluid during normal operating conditions.

3.1.4 SEISMIC

Seismic motion of the earth is treated as a random process. Certain assumptions reflecting the characteristics of typical earthquakes are made so these characteristics can be readily employed in a dynamic response spectrum analysis.

Piping rarely experiences the actual seismic motion at ground elevation, since it is supported by components attached to the containment building. Although a band of frequencies is associated with the ground earthquake motion, the building itself acts as a filter to this environment and will effectively transmit those frequencies corresponding to its own natural modes of vibration.

The forcing functions for the piping seismic analyses are derived from dynamic response analyses of the containment building when subjected to seismic ground motion. These forcing functions are in the form of floor response spectra. Response spectra are obtained by determining the maximum response of a single mass-spring-damper oscillator to a base motion time history. This single mass-spring-damper oscillator system represents a single natural vibration mode of the piping system. A plot of the maximum responses versus the natural frequencies of the oscillator forms the response spectrum for that particular base motion.

The intensity and character of the earthquake motion producing forced vibration of the equipment mounted within the containment building are specified in terms of the floor response spectrum curves at various elevations within the containment building.

The seismic floor response spectrum curves corresponding to the highest elevation at which the component or piping is attached to the containment building are used in the piping analysis.

Seismic loads must be known to calculate the resultant moment (Mi_3) used in the design equations The plant operating condition (full load) is the condition under which the specified earthquake is assumed to occur.

3.1.5 TRANSIENTS

To provide the necessary high degree of integrity for the NSSS, the transient conditions selected for secondary stress evaluation are based on conservative estimates of the magnitude and anticipated frequency of occurrence of the temperature and pressure transients resulting from the possible operating conditions.

The transients selected are conservative representations of transients for design purposes, and are used as a basis for piping secondary stress evaluation to provide assurance that the piping is acceptable for its application over the design life of the plant.

For purposes of piping evaluation, the number of transient occurrences are based on a plant design life of 40 years.

3.1.6 SAFETY AND RELIEF VALVE THRUST

The pressurizer safety and relief valve discharge piping system provide overpressure protection for the RCS. The three spring-loaded safety valves and two power-operated relief valves, located on top of the pressurizer, are designed to prevent system pressure from exceeding design pressure by more than 10 percent and 100 psi, respectively. A water seal is maintained upstream of each valve to minimize leakage. Condensate accumulation on the inlet side of each valve prevents any leakage of hydrogen gas or steam through the valves. The valve outlet side is sloped to prevent the formation of additional water pockets.

If the pressure exceeds the set point and the valves open, the water slug from the loop seal discharges. The water slug, driven by high system pressure, generates transient thrust forces at each location where a change in flow direction occurs.

The safety and relief lines are analyzed for various cases of thrust loadings to ensure the primary and secondary stress limits are not exceeded.

3.2 DESIGN CONDITIONS

The design conditions are the pressures, temperatures, and various mechanical loads applicable to the design of nuclear power plant piping.

3.2.1 DESIGN PRESSURE

The specified internal and external design pressures are not less than the maximum difference in pressure between the inside and outside of the component, which exists under the specified normal operating conditions. The design pressures are used in the computations made to show compliance with the Code (subparagraph 101.20 of the Code).

3.2.2 DESIGN TEMPERATURE

The specified design temperature is not less than the actual maximum metal temperature existing under the specified normal operating conditions for each area of the component considered. It is used in computations involving the design pressure and coincidental design mechanical loads (subparagraph 101.3 of the Code).

3.3 PLANT OPERATING CONDITIONS

3.3.1 NORMAL CONDITIONS

A normal condition is any condition in the course of system startup, design power range operation, hot standby, and system shutdown, other than upset, faulted, emergency, or testing conditions.

3.3.2 UPSET CONDITIONS

An upset condition is any deviation from normal conditions anticipated to occur often enough that design should include a capability to withstand the condition without operational impairment. Upset conditions include those transients resulting from any single operator error or control malfunction, transients caused by a fault in a system component requiring its isolation from the system, and transients due to loss of load or power. Upset conditions include any abnormal incidents not resulting in a forced outage and also forced outages for which the corrective action does not include any repair of mechanical damage.

3.3.3 EMERGENCY CONDITIONS

Emergency conditions are defined as those deviations from normal conditions which require shutdown for correction of the conditions or repair of damage in the system. The conditions have a low probability of occurrence but are included to provide assurance that no gross loss of structural integrity will result as a concomitant effect of any damage developed in the system. The total number of postulated occurrences for such events shall not cause more than 25 stress cycles (subparagraph NB-3113.3 of the code).

3.3.4 FAULTED CONDITIONS

Faulted conditions are those combinations of conditions associated with extremely low probability - postulated events whose consequences are such that the integrity and operability of the nuclear energy system may be impaired to the extent that considerations of public health and safety are involved.

SECTION 4
ANALYTICAL METHODS AND MODELS

4.1 INTRODUCTION

The analytical methods used to obtain a piping deflection solution consist of the transfer matrix method and stiffness matrix formulation for the static structural analysis. The response spectrum method is used for the seismic dynamic analysis.

The complexity of the piping system requires the use of a computer to obtain the displacements, forces, and stresses in the piping and support members. To obtain these results, accurate and adequate mathematical representations (analytical models) of the systems are required. The modeling considerations depend upon the degree of accuracy desired and the manner in which the results will subsequently be interpreted and evaluated. All static and dynamic analyses are performed using the WESTDYN computer program. This program, described in WCAP-8252, was reviewed and approved by the U.S. NRC (NRC letter, April 7, 1981 from R. L. Tedesco to T. M. Anderson).

The integrated piping/supports system model is the basic system model used to compute loadings on components, component and piping supports, and piping. The system model includes the stiffness and mass characteristics of the piping, attached equipment, and the stiffness of supports, which affects the system response. The deflection solution of the entire system is obtained for the various loading cases from which the internal member forces and piping stresses are calculated.

4.2 STATIC ANALYSIS

The piping system models, constructed for the WESTDYN computer program, are represented by an ordered set of data, which numerically describes the physical system.

The spatial geometric description of the piping model is based upon the isometric piping drawings referenced in this report and equipment drawings referenced in the design specification. Node point coordinates and incremental lengths of the members are determined from these drawings. Node point coordinates are put on network cards. Incremental member lengths are put on element cards. The geometrical properties along with the modulus of elasticity, E, the coefficient of thermal expansion, α, the average temperature change from the ambient temperature, ΔT, and the weight per unit length, w, are specified for each element. The supports are represented by stiffness matrices which define restraint characteristics of the supports. Plotted models for various parts of the safety and relief valve discharge piping are shown in figures in Section 6.

The static solutions for deadweight and thermal loading conditions are obtained by using the WESTDYN computer program. The WESTDYN computer program is based on the use of transfer matrices which relate a twelve-element vector [B] consisting of deflections (three displacements and three rotations) and loads (three forces and three moments) at one location to a similar vector at another location. The fundamental transfer matrix for an element is determined from its geometric and elastic properties. If thermal effects and boundary forces are included, a modified transfer relationship is defined as follows:

$$\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} \Delta_o \\ F_o \end{bmatrix} + \begin{bmatrix} \delta_t \\ f_t \end{bmatrix} = \begin{bmatrix} \Delta_i \\ F_i \end{bmatrix}$$

or

$$T_1 B_o + R_1 = B_1$$

where the T matrix is the fundamental transfer matrix as described above, and the R vector includes thermal effects and body forces. This B vector for the element is a function of geometry, temperature, coefficient of thermal expansion, weight per unit length, lumped masses, and externally applied loads.

The overall transfer relationship for a series of elements (a section) can be written as follows:

$$B_1 = T_1 B_o + R_1$$

$$B_2 = T_2 B_1 + R_2 = T_2 T_1 B_o + T_2 R_1 + R_2$$

$$B_3 = T_3 B_2 + R_3 = T_3 T_2 T_1 B_o + T_3 T_2 R_1 + T_3 R_2 + R_3$$

or

$$B_n = \left(\prod_{1}^{n} T_r \right) \cdot B_o + \sum_{r=2}^{n} \left[\left(\prod_{r}^{n} T_r \right) \cdot R_{r-1} \right] + R_n$$

A network model is made up of a number of sections, each having an overall transfer relationship formed from its group of elements. The linear elastic properties of a section are used to define the characteristic stiffness matrix for the section. Using the transfer relationship for a section, the loads required to suppress all deflections at the ends of the section arising from the thermal and boundary forces for the section are obtained. These loads are incorporated in the overall load vector.

After all the sections have been defined in this manner, the overall stiffness matrix, K, and associated load vector needed to suppress the deflection of all the network points is determined. By inverting the stiffness matrix, the flexibility matrix is determined. The flexibility matrix is multiplied by the negative of the load vector to determine the network point deflections due to the thermal and boundary force effects. Using the general transfer relationship, the deflections and internal forces are then determined at all node points in the system. The support loads, F, are also computed by multiplying the stiffness matrix, K, by the displacement vector, δ, at the support point.

4.3 DYNAMIC ANALYSIS

The models used in the static analyses are modified for use in the dynamic analyses by including the mass characteristics of the piping and equipment.

4.4 SEISMIC ANALYSIS

The lumping of the distributed mass of the piping systems is accomplished by locating the total mass at points in the system which will appropriately represent the response of the distributed system. Effects of the equipment motion, that is, the pressurizer, on the piping system are obtained by modeling the mass and the stiffness characteristics of the equipment in the overall system model.

The supports are again represented by stiffness matrices in the system model for the dynamic analysis. Mechanical shock suppressors which resist rapid motions are now considered in the analysis. The solution for the seismic disturbance employs the response spectra method. This method employs the lumped mass technique, linear elastic properties, and the principle of modal superposition.

From the mathematical description of the system, an overall stiffness matrix [K] is developed from the individual element stiffness matrices using the transfer matrix [K_R] associated with mass degrees-of-freedom only. From the mass matrix and the reduced stiffness matrix, the natural frequencies and the normal modes are determined. The modal participation factor matrix is computed and combined with the appropriate response spectra value to give the modal amplitude for each mode. Since the modal amplitude is shock direction dependent, the total modal amplitude is obtained conservatively by the absolute sum of the contributions for each direction of shock. The modal amplitudes are then converted to displacements in the global coordinate system and applied to the corresponding mass point. From these data the forces, moments, deflections, rotation, support reactions, and piping stresses are calculated for all significant modes.

The seismic response from each earthquake component is computed by combining the contributions of the significant modes.

4.5 THERMAL TRANSIENTS

Operation of a nuclear power plant causes temperature and/or pressure fluctuations in the fluid of the piping system. The transients for this system are defined in "Westinghouse Systems Standard Design Criteria 1.3" and referenced in the Design Specification and were used to define the various operating modes used in the thermal expansion analyses.

4.6 PRESSURIZER SAFETY AND RELIEF LINE ANALYSIS

4.6.1 PLANT HYDRAULIC MODEL

When the pressurizer pressure reaches the set pressure (2,500 psia for a safety valve and 2,350 psia for a relief valve) and the valve opens, the high pressure steam in the pressurizer forces the water in the water seal loop through the valve and down the piping system to the pressurizer relief tank. For the pressurizer safety and relief piping system, analytical hydraulic models, as shown in Figures 4-1 and 4-2, were developed to represent the conditions described above.

The computer code ITCHVALVE was used to perform the transient hydraulic analysis for the system. This program uses the Method of Characteristics approach to generate fluid parameters as a function of time. One-dimensional fluid flow calculations applying both the implicit and explicit characteristic methods are performed. Using this approach the piping network is input as a series of single pipes. The network is generally joined together at one or more places by two or three-way junctions. Each of the single pipes has associated with it friction factors, angles of elevation and flow areas.

Conservation equations can be converted to the following characterisitic equations:

$$\frac{dz}{dt} = V + c$$

$$\frac{dP}{dt} + \rho c \frac{dV}{dt} = c(F + \rho g \cos\theta) - \frac{q'''c^2}{\rho \frac{\partial h}{\partial \rho}}$$

$$\frac{dz}{dt} = V - c$$

$$\frac{dP}{dt} - \rho c \frac{dV}{dt} = -c(F + \rho g \cos\theta) - \frac{q'''c^2}{\rho \frac{\partial h}{\partial \rho}}$$

$$c^2 = \frac{-\ \partial h/\partial \rho}{\frac{\partial h}{\partial \rho} - \frac{1}{\rho J}}$$

z = variable of length measurement

t = time

V = fluid velocity

c = sonic velocity

p = pressure

ρ = fluid density

F = flow resistance

g = gravity

θ = angle off vertical

J = conversion factor for converting pressure units to equivalent heat units

h = enthalpy

q''' = rate of heat generation per unit pipe length

The computer program possesses special provisions to allow analysis of valve opening and closing situations.

Fluid acceleration inside the pipe generates reaction forces on all segments of the line that are bounded at either end by an elbow or bend. Reaction forces resulting from fluid pressure and momentum variations are calculated. These forces can be expressed in terms of the fluid properties available from the transient hydraulic analysis, performed using program ITCHVALVE. The momentum equation can be expressed in vector form as:

$$F_{cv} = \frac{1}{g_c} \frac{\partial}{\partial t} \int_v \rho V dv + \frac{1}{gc} \int \rho V(V \cdot ndA)$$

From this equation, the total force on the pipe can be derived:

$$F_{pipe} = \frac{r_1}{g_c} \frac{(1 - \cos \alpha_1)}{\sin \alpha_1} \frac{\partial W}{\partial t} \Bigg|_{Bend\ 1} + \frac{r_2}{g_c} \frac{(1 - \cos \alpha_2)}{\sin \alpha_2} \frac{\partial W}{\partial t} \Bigg|_{Bend\ 2}$$

$$+ \frac{1}{g_c} \int_{\substack{straight \\ pipe}} \frac{\partial W}{\partial t} dl$$

A = piping flow area

v = volume

F = force

r = radius of curvature of appropriate elbow

α = angle of appropriate elbow

W = mass acceleration

All other terms are previously defined.

Unbalanced forces are calculated for each straight segment of pipe from the pressurizer to the relief tank using program FORFUN. The time-histories of these forces are stored on tape to be used for the subsequent structural analysis of the pressurizer safety and relief lines.

4.6.2 COMPARISON TO EPRI TEST RESULTS

Piping load data has been generated from the tests conducted by EPRI at the Combustion Engineering Test Facility. Pertinent tests simulating dynamic opening of the safety valves for representative commercial upstream environments were carried out. The resulting downstream piping loadings and responses were measured. Upstream environments for particular valve opening cases of importance, which envelope the commercial scenarios, are:

A. Cold water discharge followed by steam - steam between the pressure source and the loop seal - cold loop seal between the steam and the valve,

B. Hot water discharge followed by steam - steam between the pressure source and the loop seal - hot loop seal between the steam and the valve.

C. Steam discharge - steam between the pressure source and the valve,

Specific thermal hydraulic and structural analyses have been completed for the Combustion Engineering Test Configuration. Figure 4-3 illustrates the placement of force measurement sensors at the test site. Figures 4-4, 4-5 and 4-6 illustrate a comparison of the thermal hydraulically calculated results using the ITCHVALVE and FORFUN computer programs versus experimental results for Test 908, the cold water discharge followed by steam case. Figure 4-4 shows the pressure time histories for PT9, which is located just downstream of the valve. Figures 4-5 and 4-6 illustrate, respectively, the force time histories of the horizontal run (WE28/WE29) and the long vertical run (WE32/WE33) immediately downstream of the safety valve. Significant structural damping in the third segment after the valve was noticed at the test and was verified by structural analyses. Consequently, a comparison of force WE30/WE31 was not presented here. No useable test data for sensor WE34/WE35 was available for Test 908.

Figures 4-7 through 4-11 illustrate a comparison of calculated versus experimental results for Test 917, the hot water discharge followed by steam case. Figure 4-7 shows the pressure time histories for PT9. Figures 4-8, 4-9, 4-10 and 4-11 illustrate, respectively, the thermal hydraulically calculated and the experimentally determined force time histories for (WE28/WE29), (WE32/WE33), (WE30/WE31) and (WE34/WE35). Blowdown forces were included in the total analytically calculated force for WE34/WE35 as this section of piping vents to the atmosphere. Although not presented here, comparisons were also made to the test data available for safety valve discharge without a loop seal (steam discharge).

The application of the ITCHVALVE and FORFUN computer programs for calculating the fluid-induced loads on the piping downstream of the safety and relief valves has been demonstrated. Although not presented here, the capability has also been shown by direct comparison to the solutions of classical problems.

The application of the structural computer programs (discussed in Section 4.6.3) for calculating the system response has also been demonstrated. Structural models representative of the Combustion Engineering Test Configuration were developed. Figures 4-12, 4-13 and 4-14 illustrate, respectively, a comparison of the structural analysis results and the experimental results for locations (WE28/WE29), (WE32/WE33) and (WE30/WE31) for test 908. No useable test data for sensor (WE34/WE35) was available. Figures 4-15, 4-16, 4-17 and 4-18 show for test 917, respectively, the structural analysis results versus the test results for locations (WE28/WE29), (WE32/WE33), (WE30/WE31) and (WE34/WE35).

4.6.3 VALVE THRUST ANALYSIS

The safety and relief lines were modeled statically and dynamically (seismically) as described in Sections 4.1 through 4.4. The mathematical model used in the seismic analysis was modified for the valve thrust analysis to represent the safety and relief valve discharge. The time-history hydraulic forces determined by FORFUN were applied to the piping system lump mass points. The dynamic solution for the valve thrust was obtained by using a modified-predictor-corrector-integration technique and normal mode theory.

The time-history solution was found using program FIXFM3. The input to this program consists of natural frequencies, normal modes, and applied forces. The natural frequencies and normal modes for the modified pressurizer safety and relief line dynamic model were determined with the WESTDYN program. The time-history displacement response was stored on magnetic tape for later use in computing the total system response due to the valve thrust conditions. The time-history displacements of the FIXFM3 program were used as input to the WESTDYN2 program to determine the time-history internal forces and deflections at each end of the piping elements. For this calculation, the displacements were treated as imposed deflections on the pressurizer safety and relief line masses. The solution was stored on tape for later use in the piping stress evaluation and piping support load evaluation.

The time-history internal forces and displacements of the WESTDYN2 program were used as input to the POSDYN2 program to determine the maximum forces, moments, and displacements that exist at each end of the piping elements and the maximum loads for piping supports. The results from program POSDYN2 are saved on TAPE14 for future use in piping stress analysis and support load evaluation.

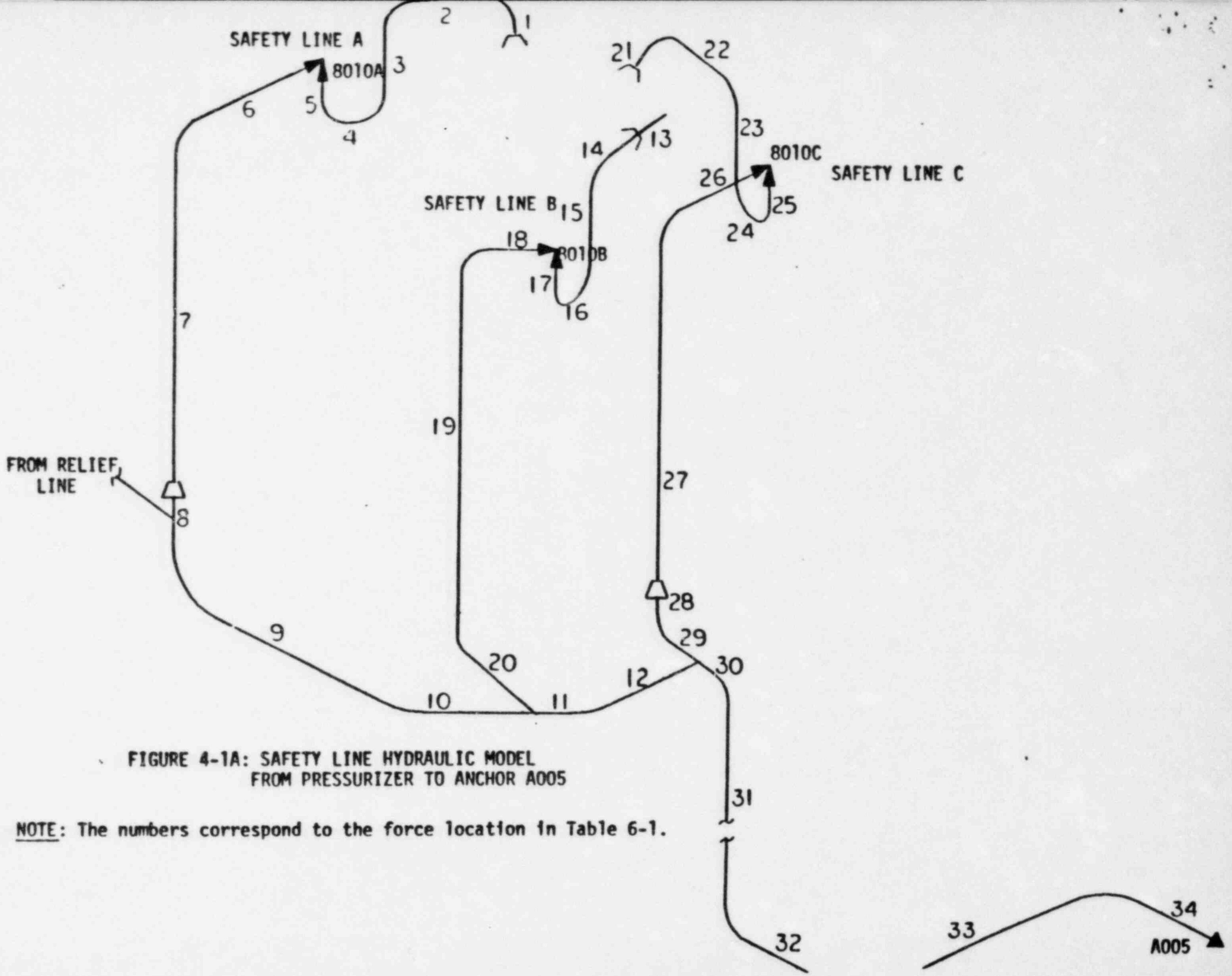


FIGURE 4-1A: SAFETY LINE HYDRAULIC MODEL FROM PRESSURIZER TO ANCHOR A005

<u>NOTE</u>: The numbers correspond to the force location in Table 6-1.

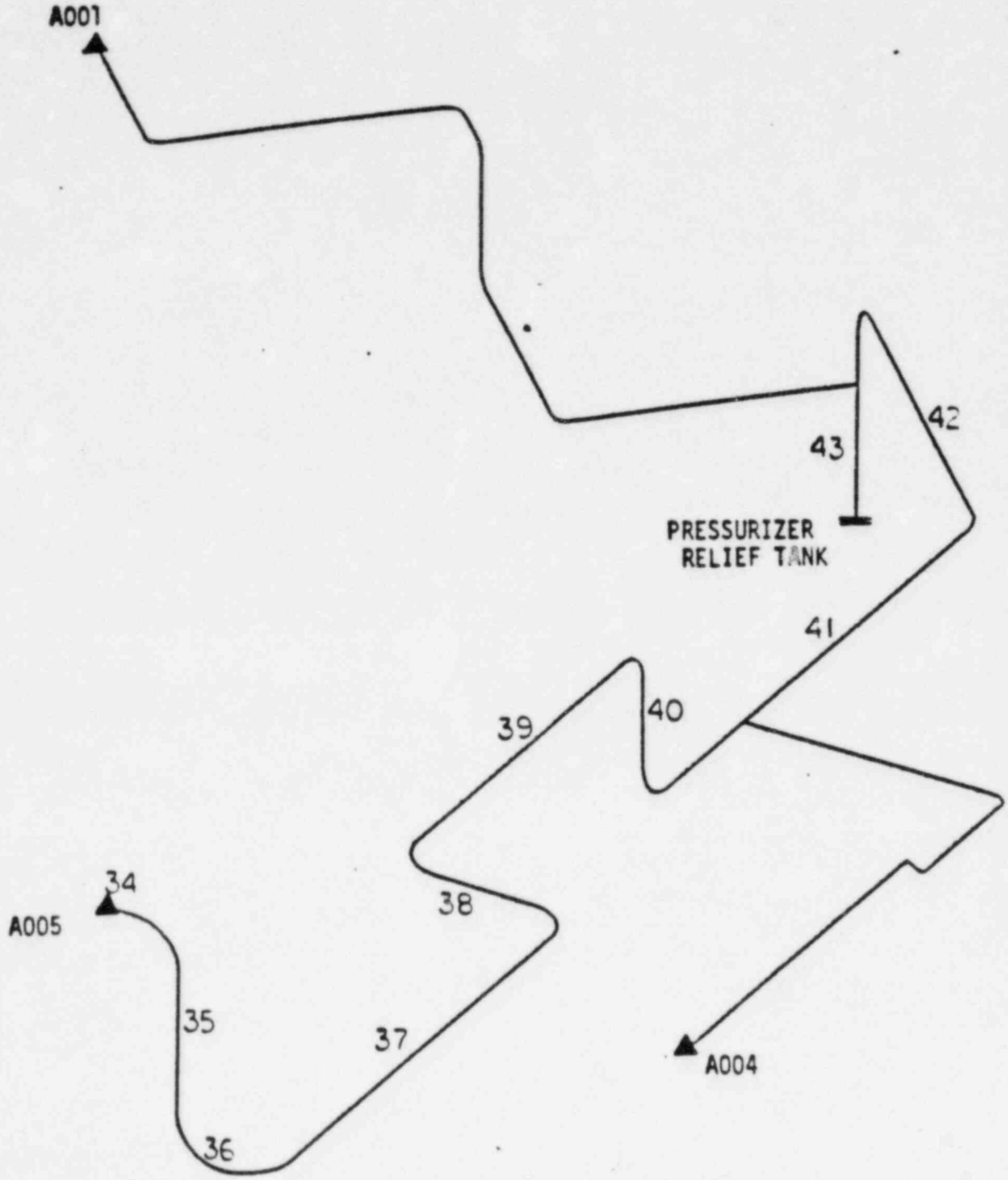
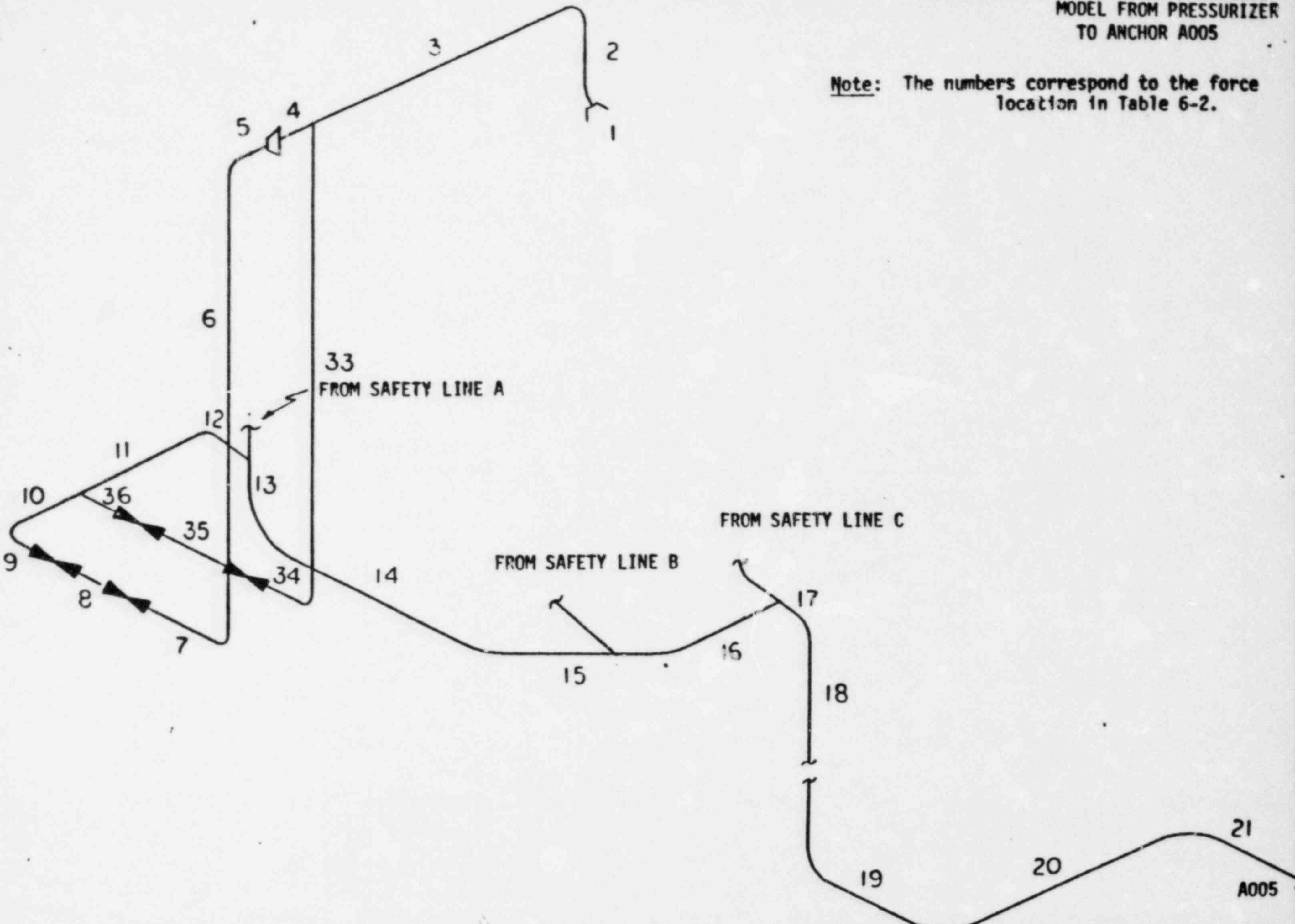


FIGURE 4-1B: SAFETY LINE HYDRAULIC MODEL
FROM ANCHOR A005 TO RELIEF TANK

Note: The numbers correspond to the force location in Table 6-1.

FIGURE 4-2A: RELIEF LINE HYDRAULIC MODEL FROM PRESSURIZER TO ANCHOR A005

<u>Note</u>: The numbers correspond to the force location in Table 6-2.



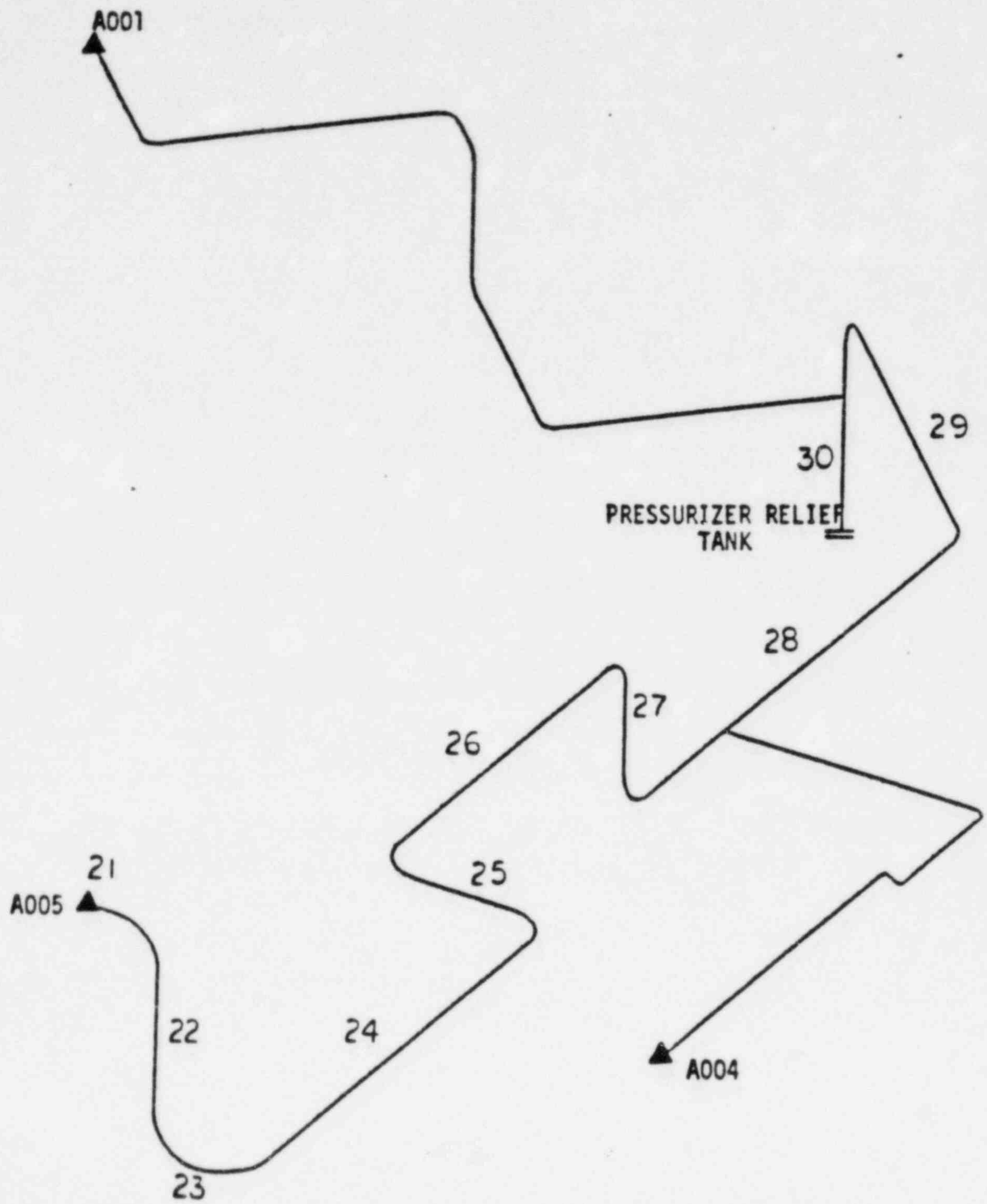


FIGURE 4-2B: RELIEF LINE HYDRAULIC MODEL
FROM ANCHOR A005 TO RELIEF TANK

Note: The numbers correspond to the force location in Table 6-2.

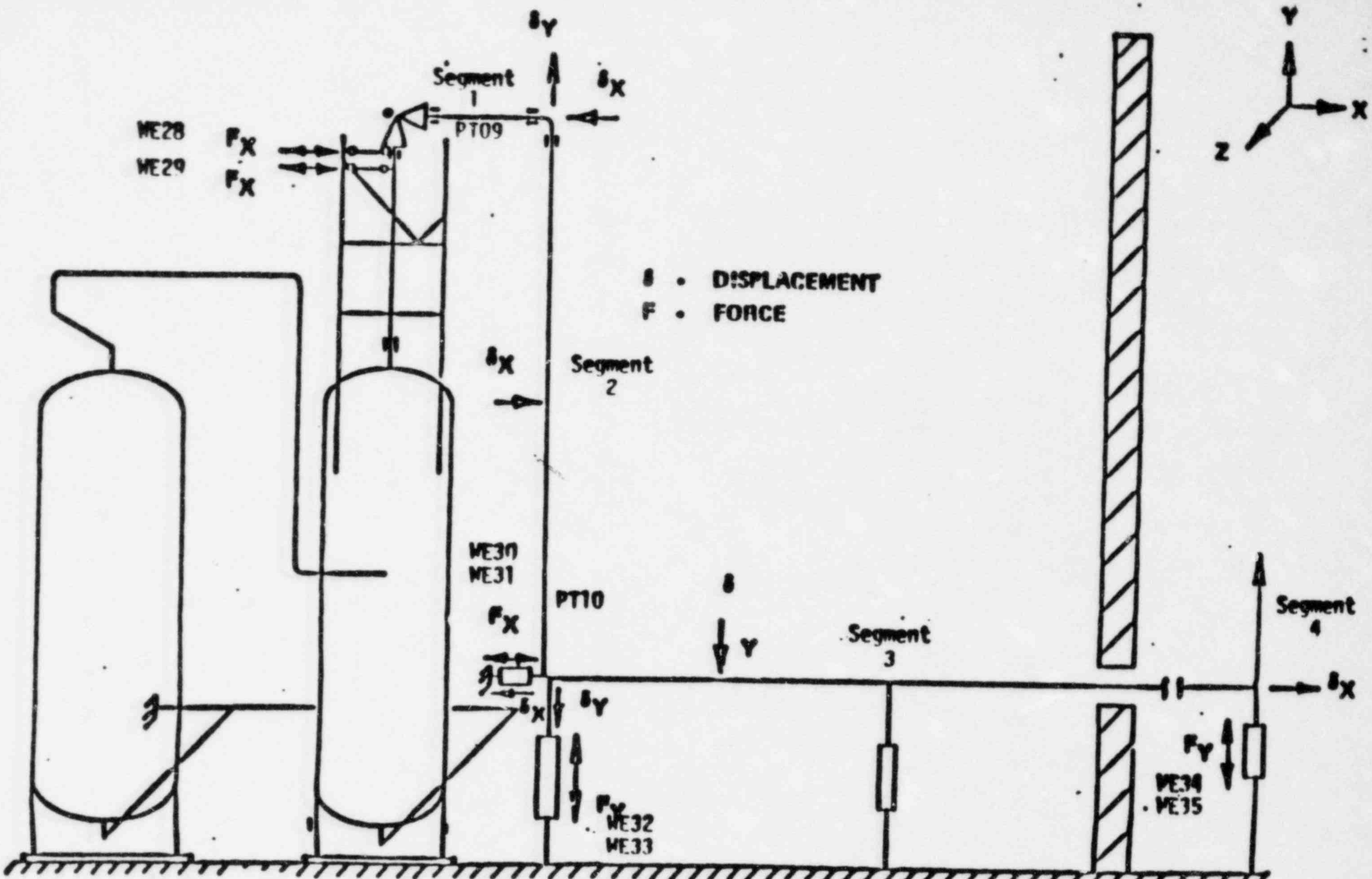


FIGURE 4-3: STRUCTURAL RESPONSE - FORCE MEASUREMENT LOCATIONS - EPRI TESTS

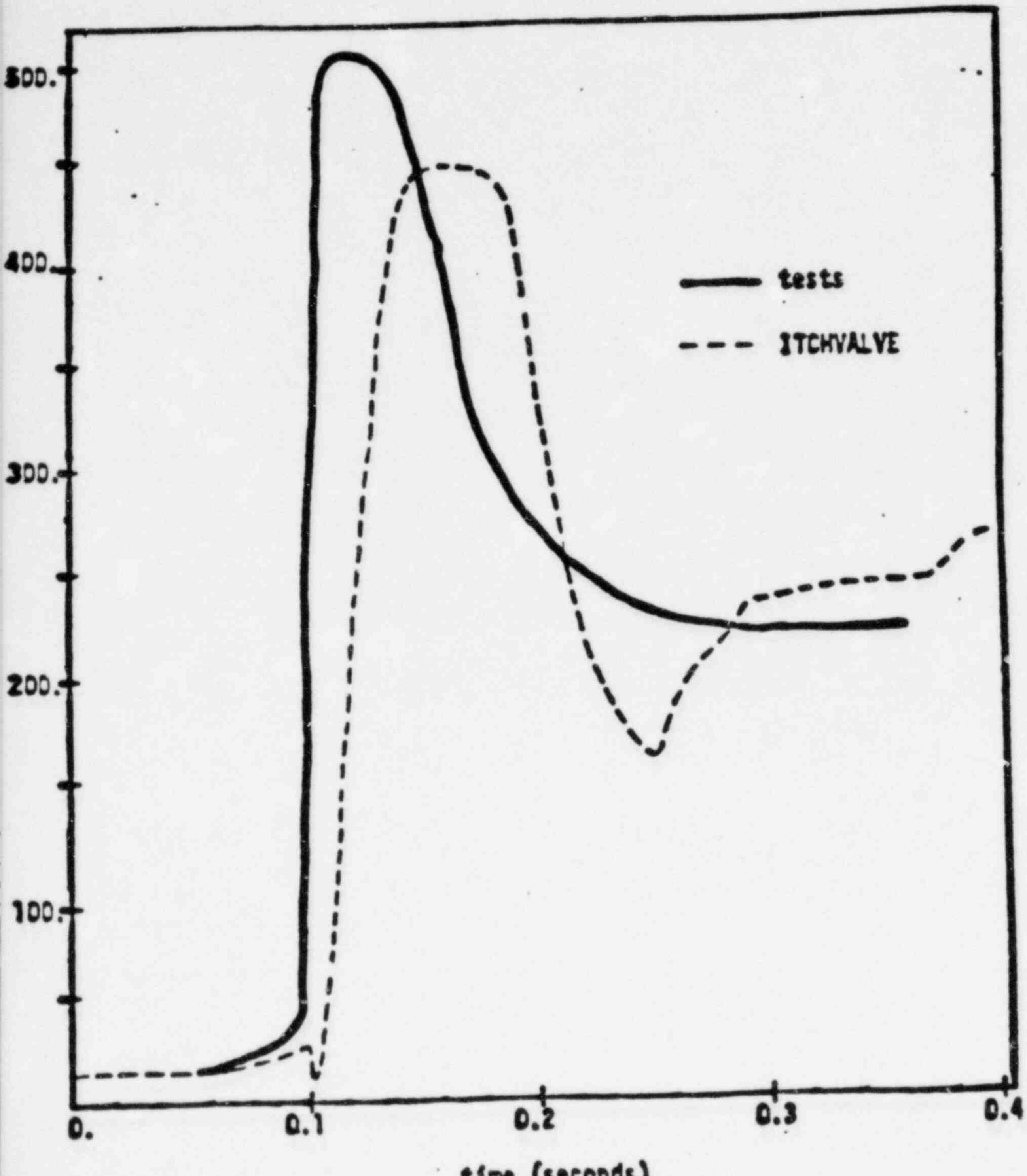


FIGURE 4-4 : Comparison of the EPRI Pressure Time-History for PT09 from Test 908 with the ITCHVALVE Predicted Pressure Time-History

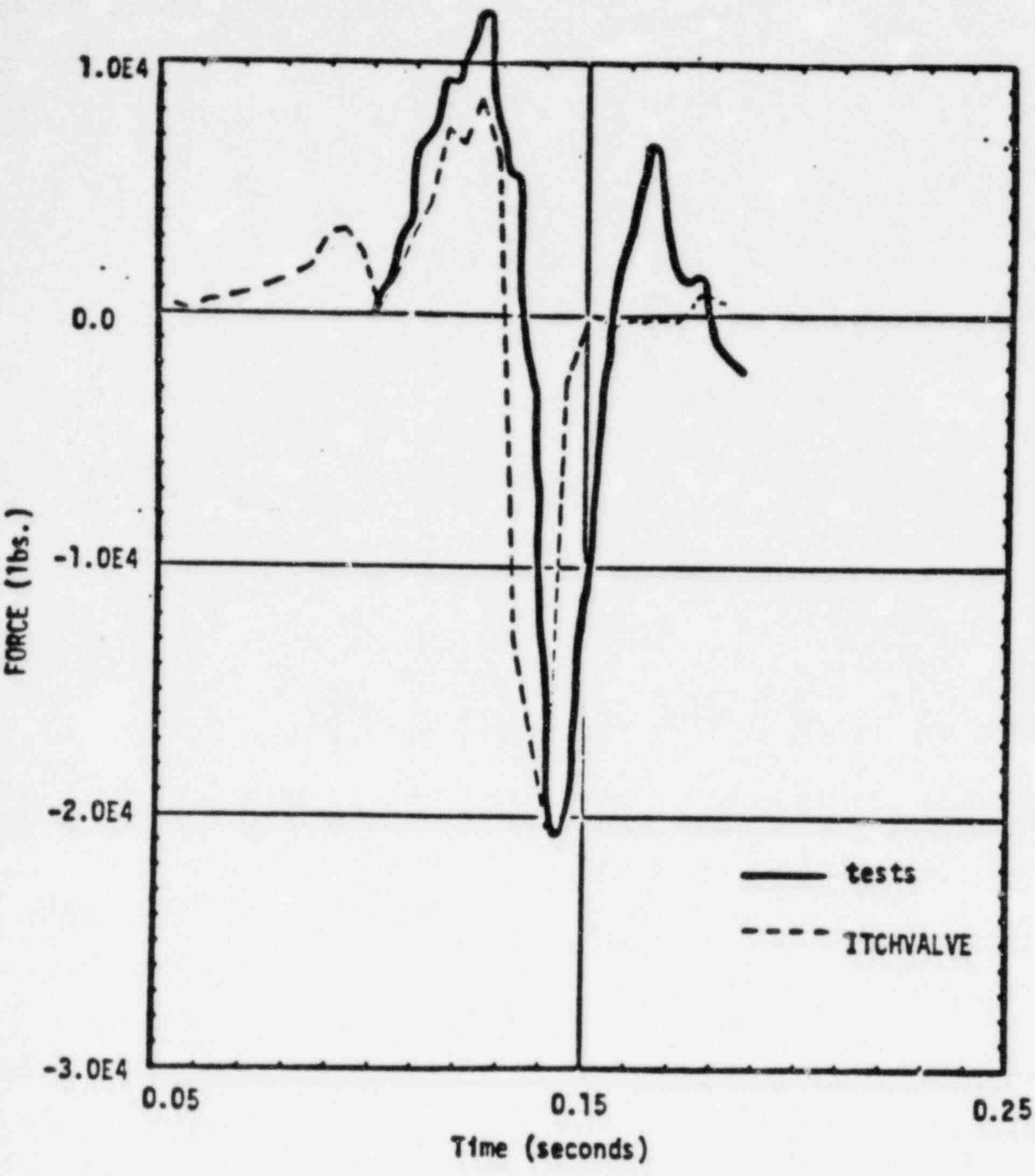


FIGURE 4-5: COMPARISON OF THE EPRI FORCE TIME-HISTORY FOR WE28 and WE29 FROM TEST 908 WITH THE ITCHVALVE PREDICTED FORCE TIME-HISTORY

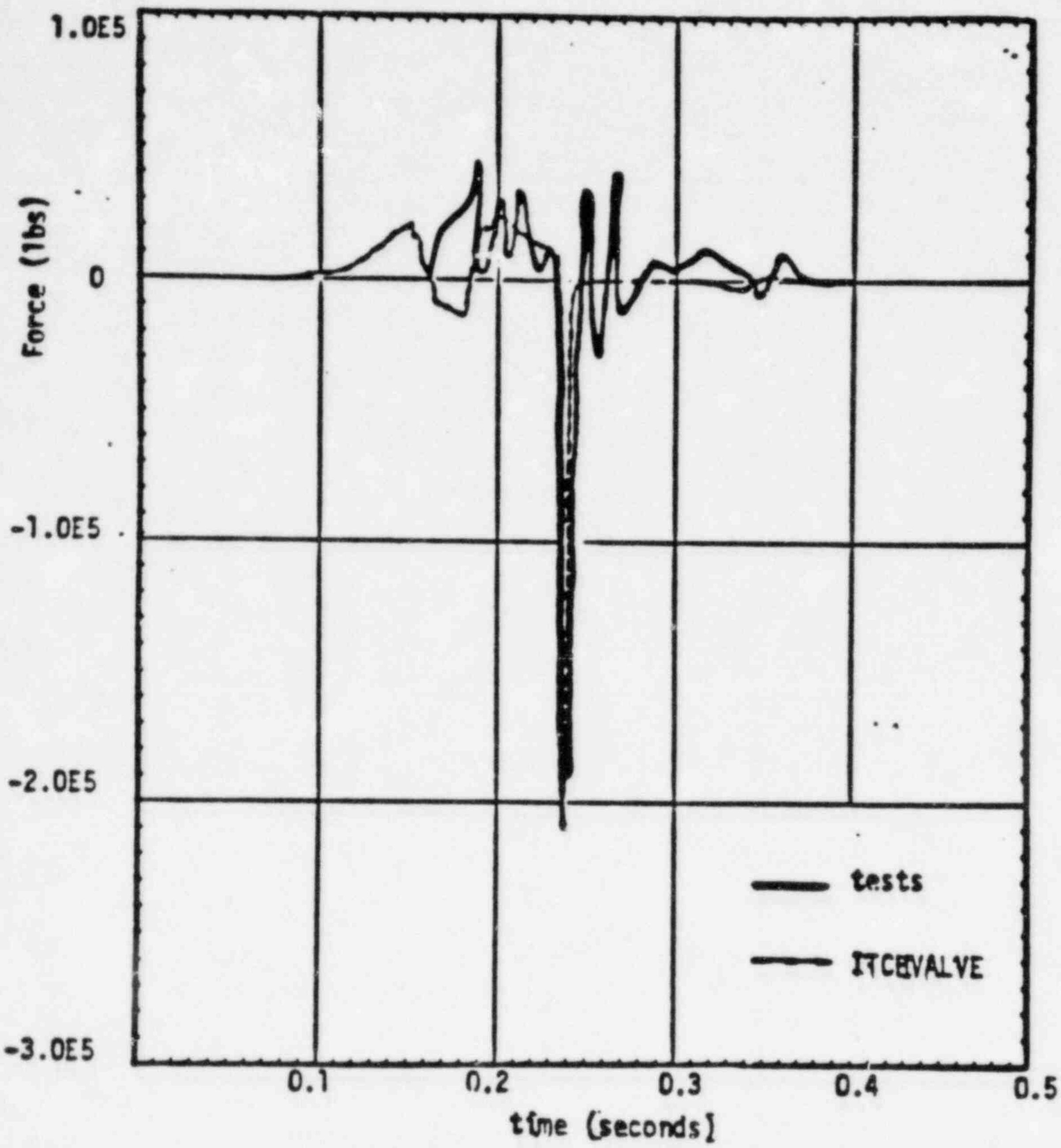


FIGURE 4-6: COMPARISON OF THE EPRI FORCE TIME-HISTORY FOR WE32 AND WE33 FROM TEST 908 WITH THE ITCHVALVE PREDICTED FORCE TIME-HISTORY

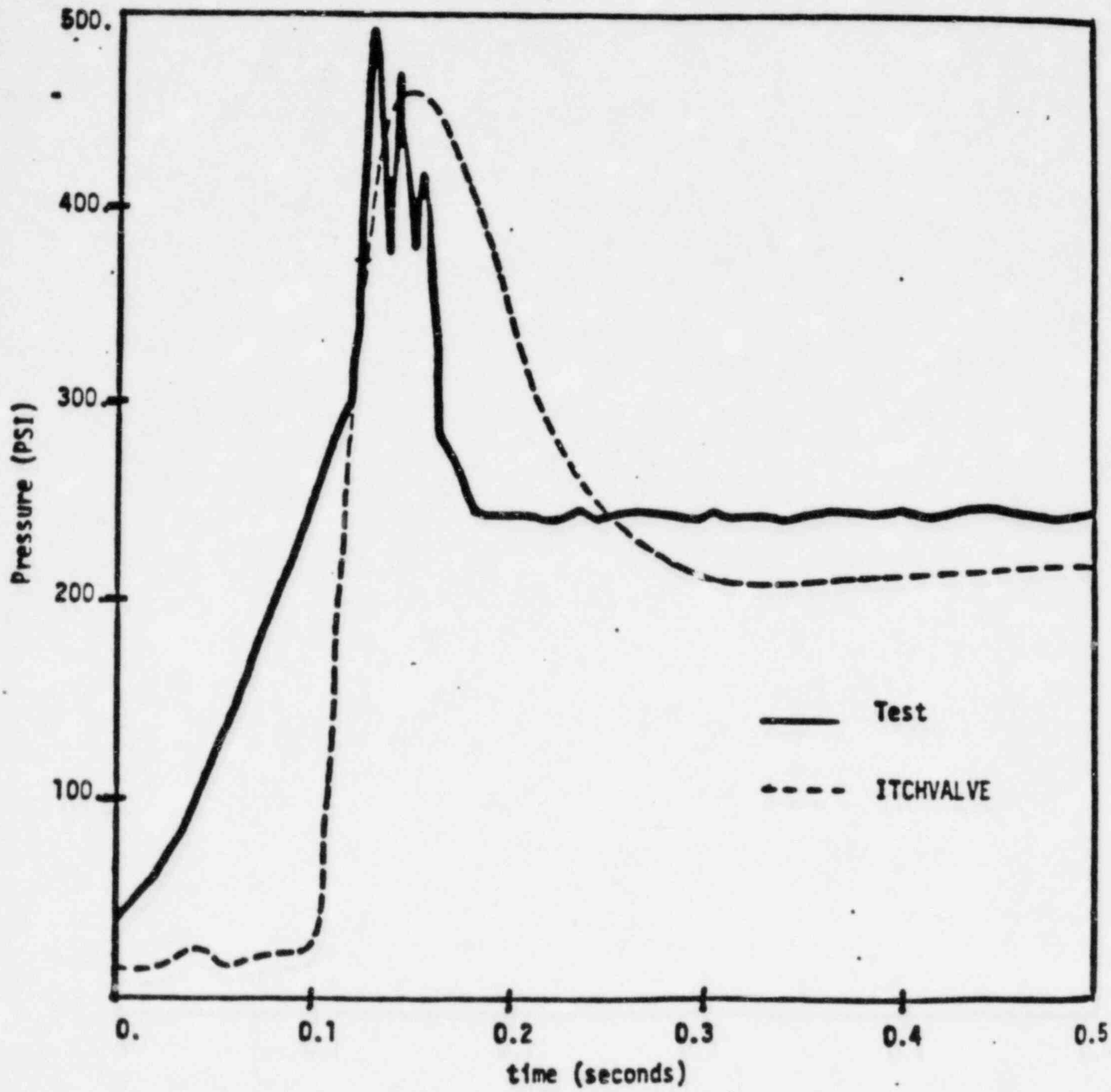


FIGURE 4-7 : Comparison of the EPRI Pressure Time-History from PT09 from Test 917 with the ITCHVALVE Predicted Pressure Time-History

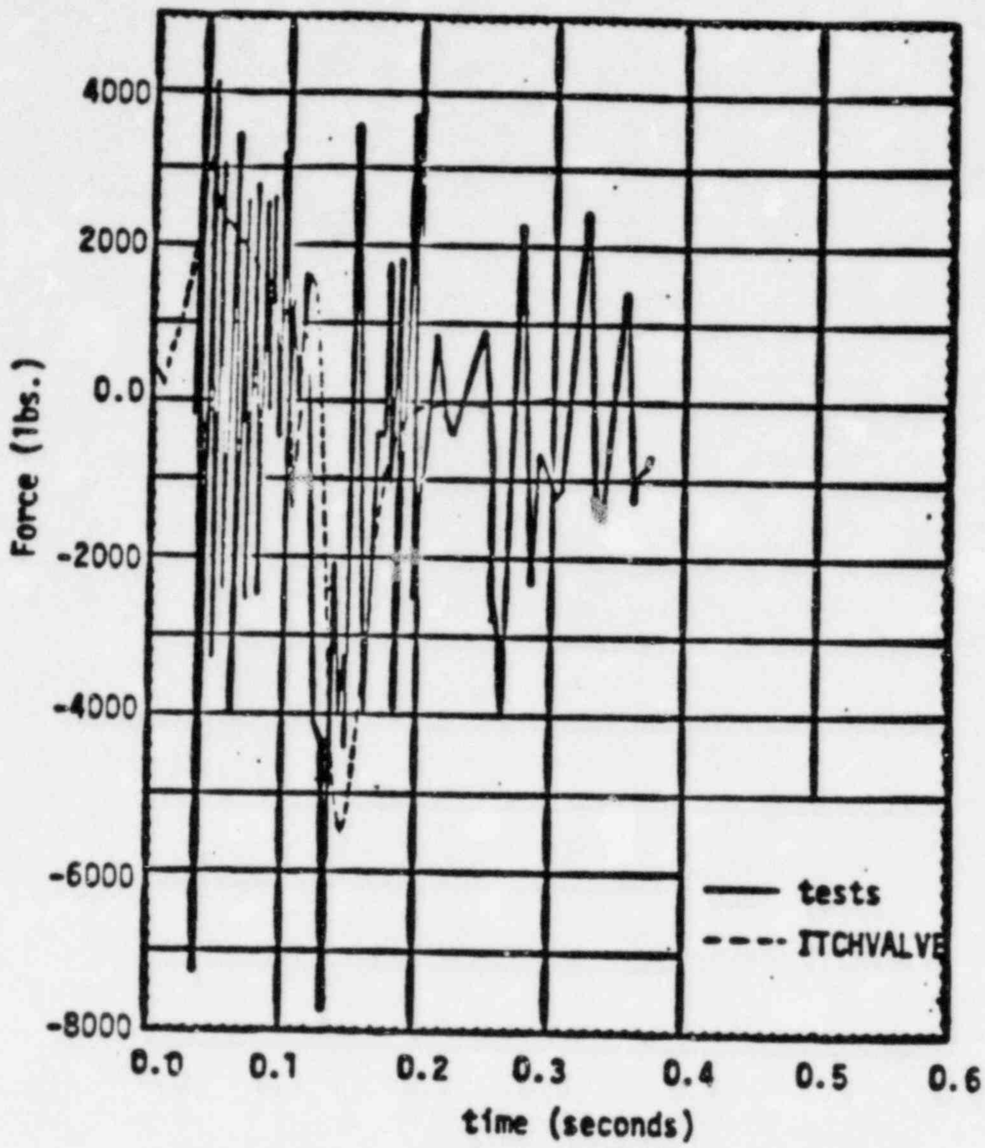


FIGURE 4-8 : Comparison of the EPRI Force Time-History for WE28 and WE29 from Test 917 with the ITCHVALVE Predicted Force Time-History

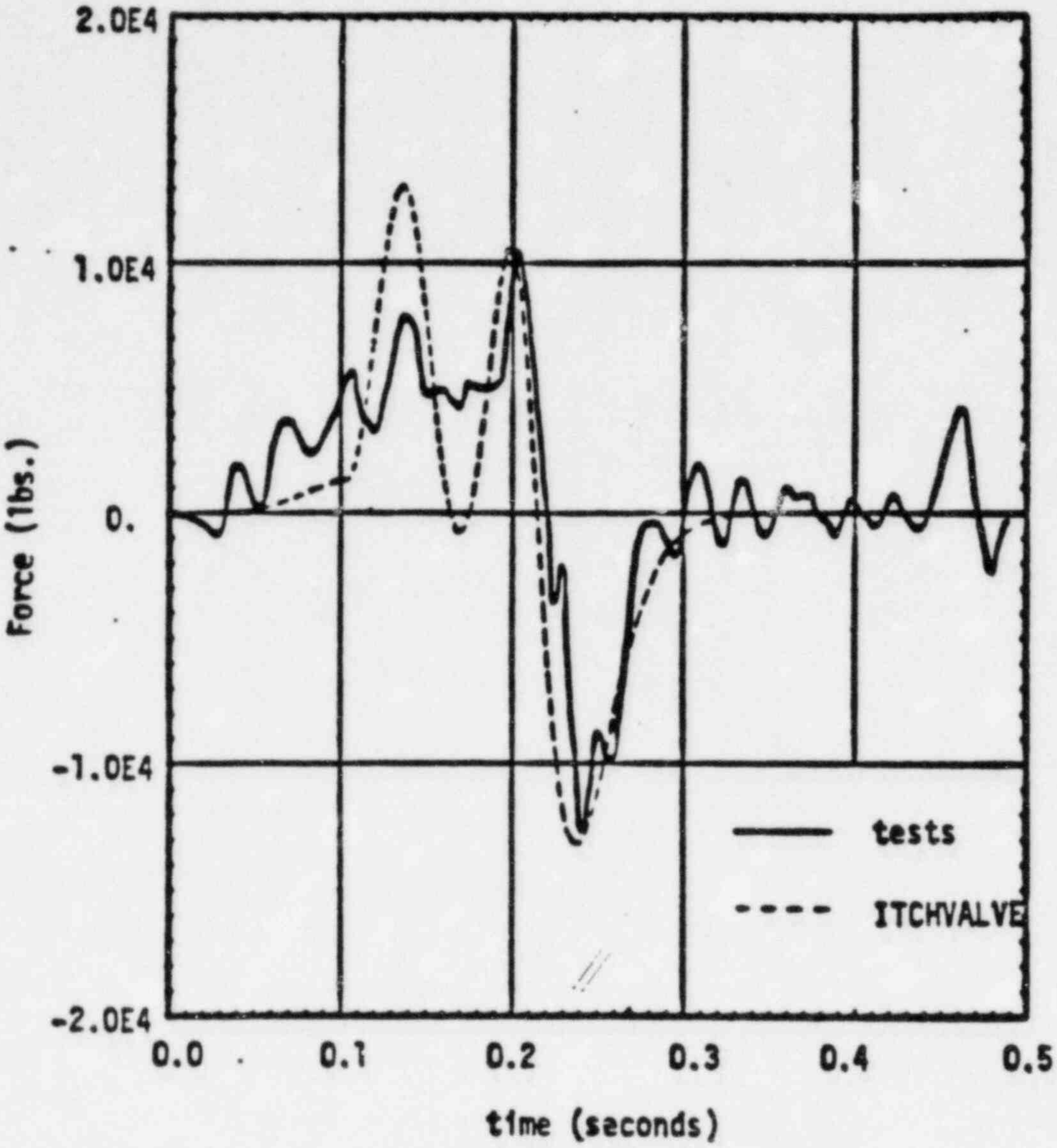


FIGURE 4-9 : Comparison of the EPRI Force Time-History for WE32 and WE33 from Test 917 with the ITCHVALVE Predicted Force Time-History

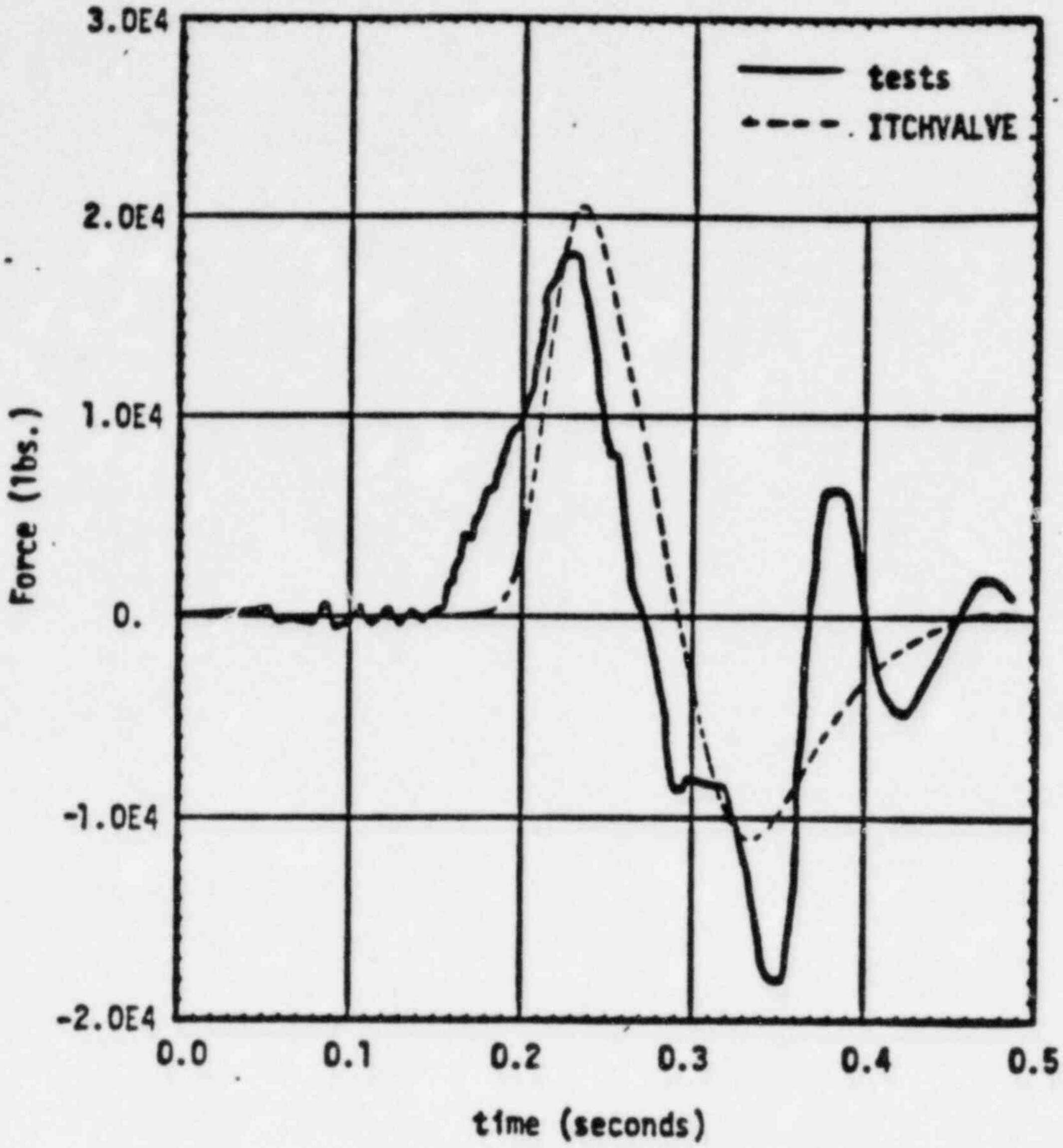


FIGURE 4-10: Comparison of the EPRI Force Time-History For WE30 and WE31 From Test 917 with the ITCHVALVE Predicted Force Time-History

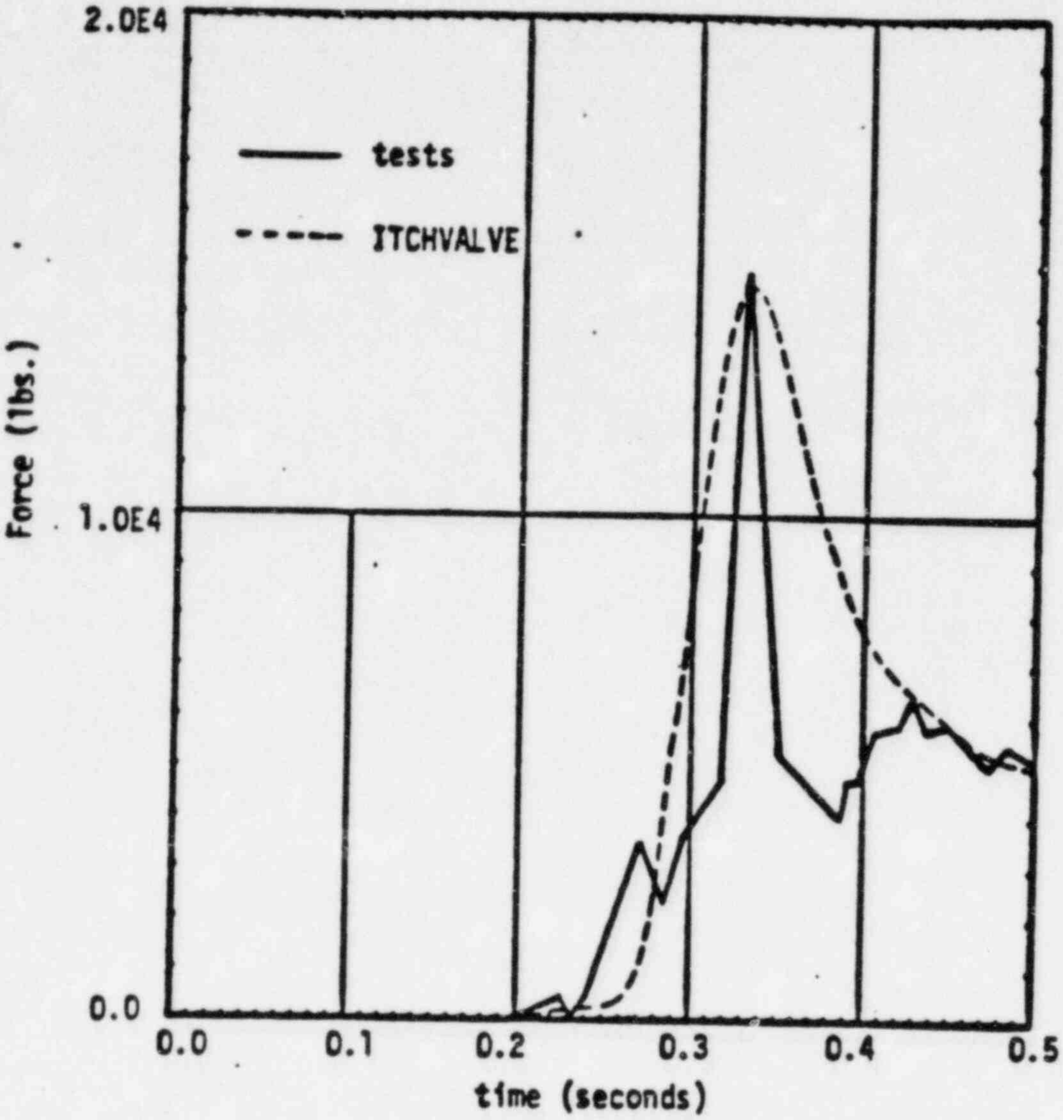


FIGURE 4-11: Comparison of the EPRI Force Time-History For WE34 and WE35 from Test 917 with the ITCHVALVE Predicted Force Time-History

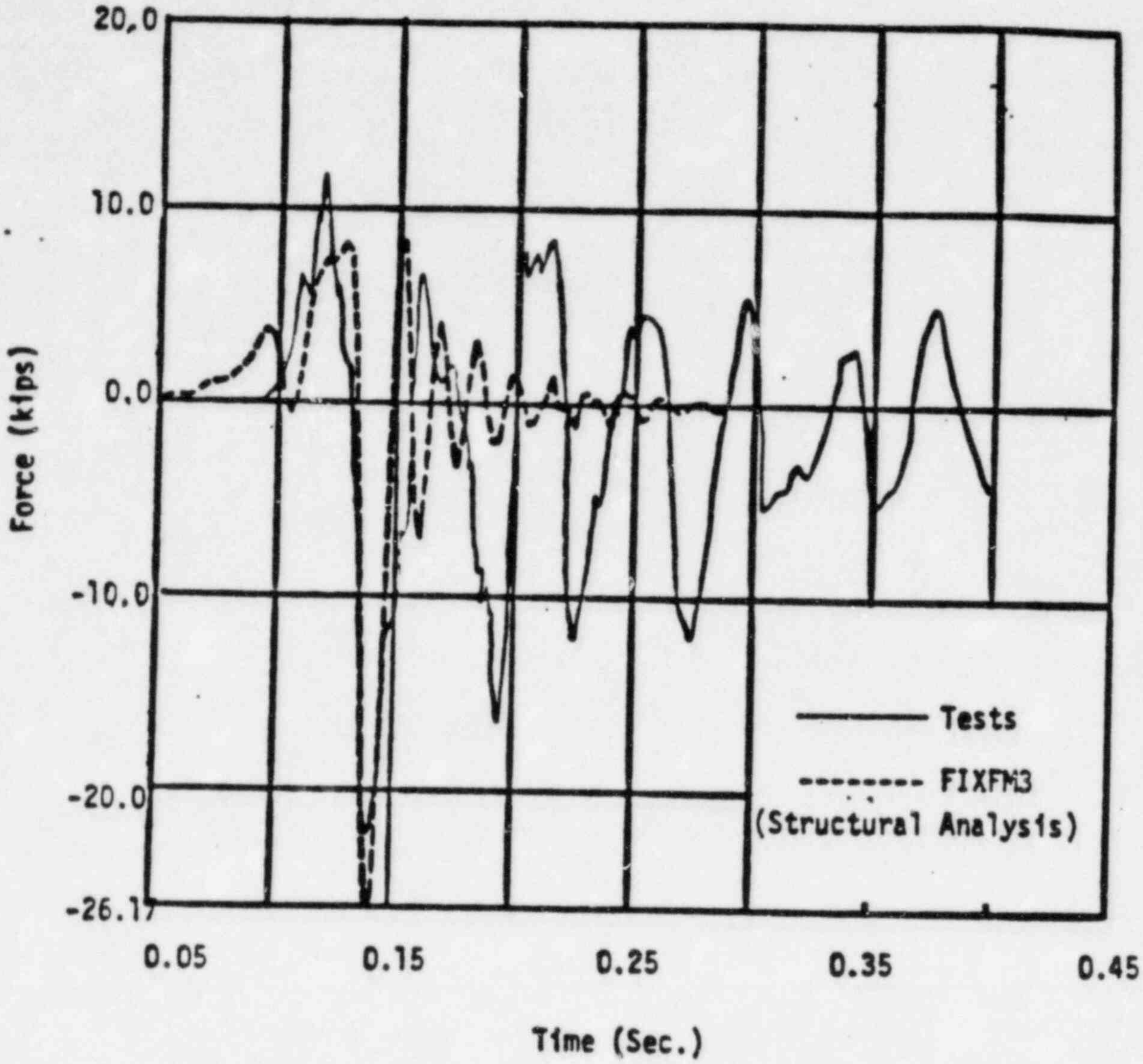


FIGURE 4-12: Comparison of the EPRI Force Time-History for WE28 and WE29 from Test 908 with the FIXFM3 Predicted Force Time-History

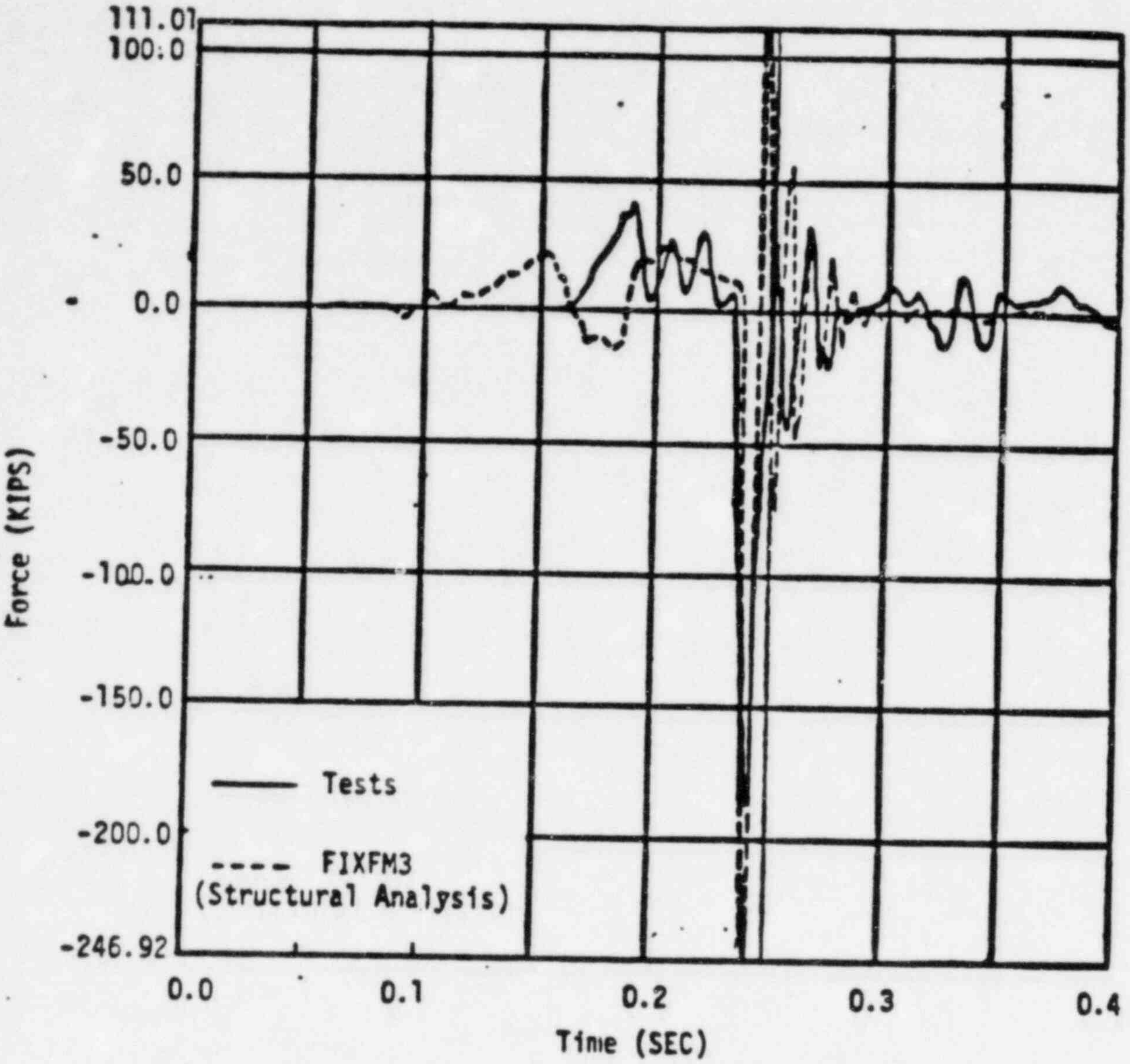


Figure 4-13: Comparison of the EPRI Force Time-History For WE32 and WE33 From Test 908 With the FIXFM3 Predicted Force Time-History

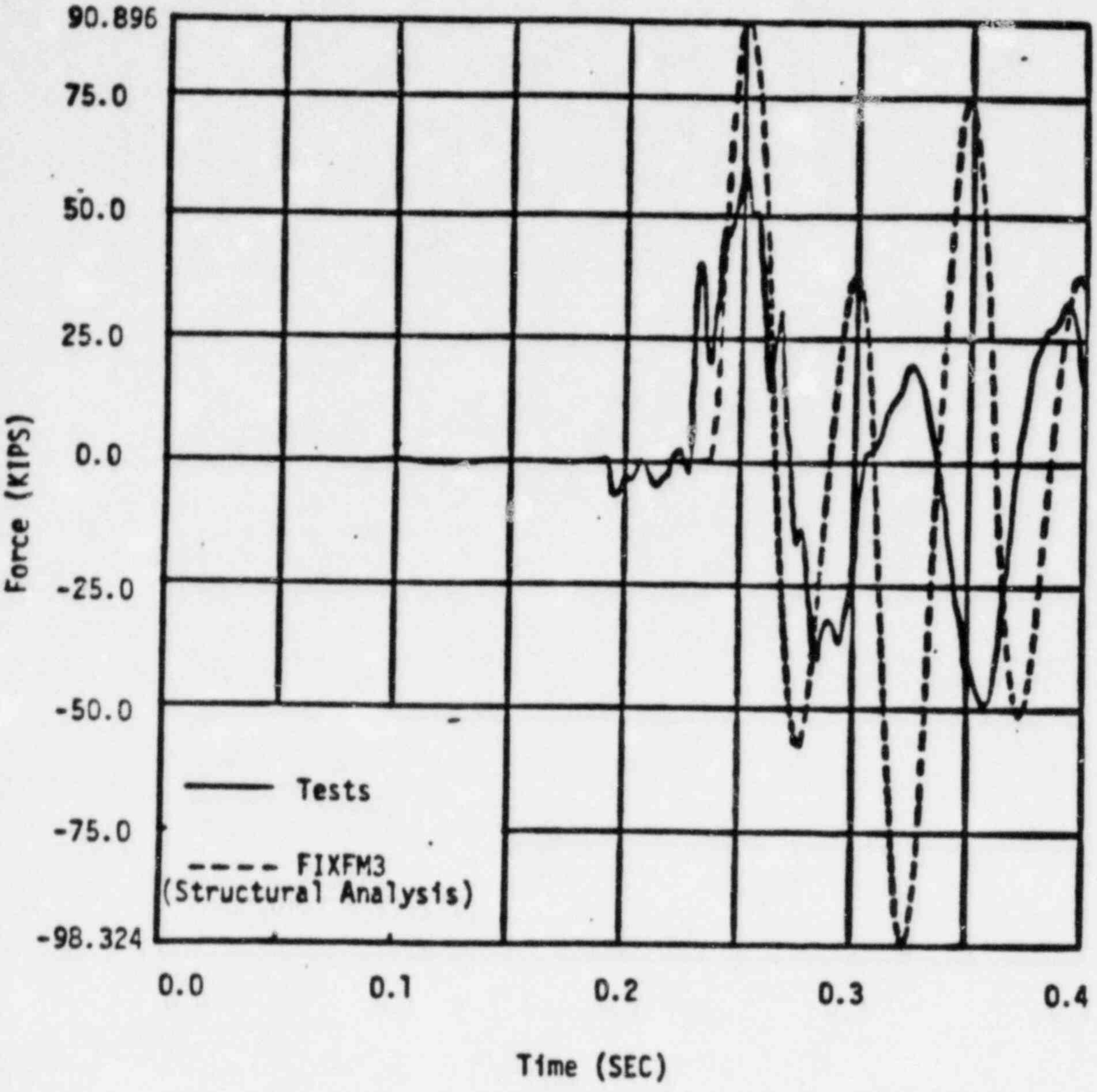


Figure 4-14: Comparison of the EPRI Force Time-History For WE30 and WE31 From Test 908 With the FIXFM3 Predicted Force Time-History

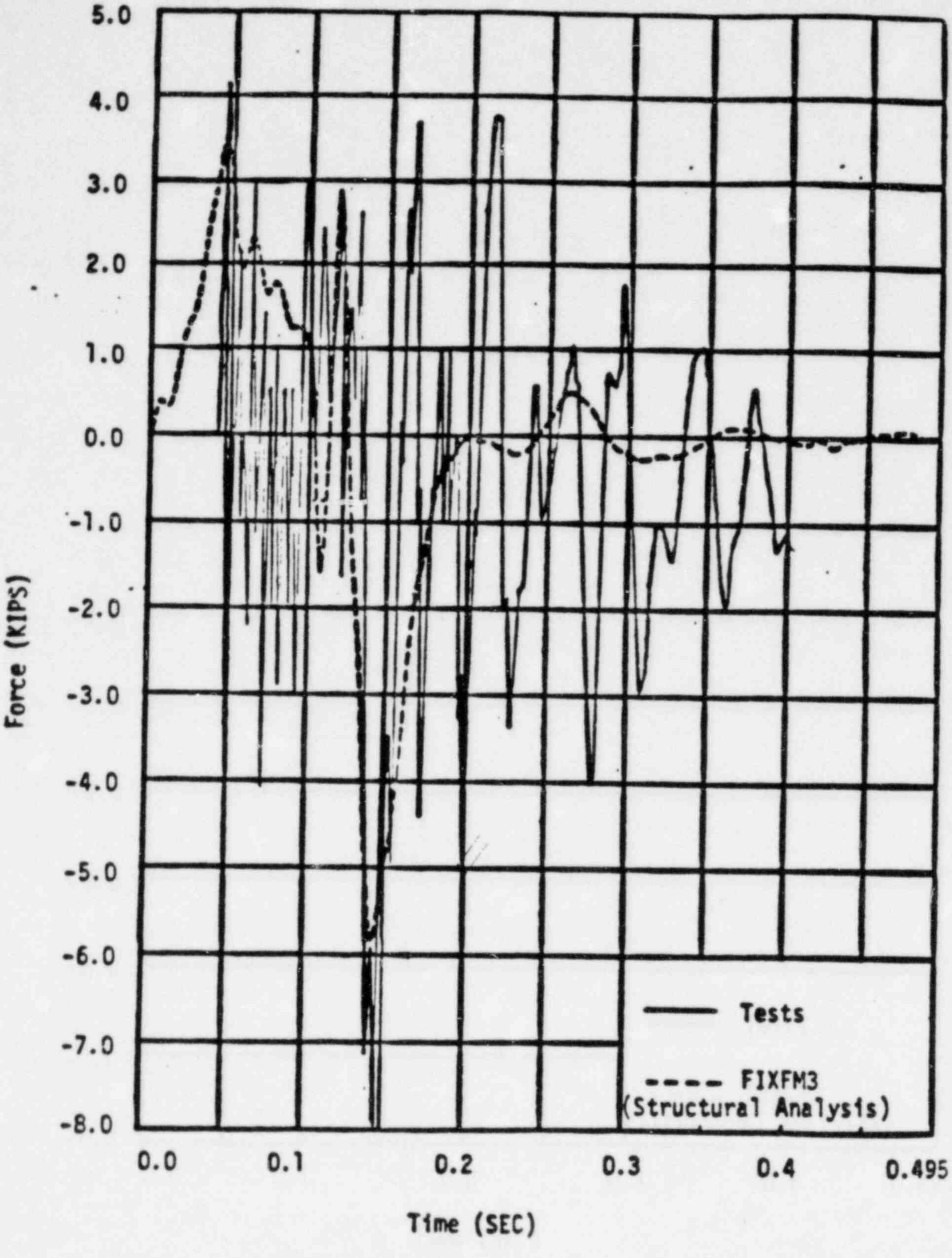


Figure 4-15: Comparison of the EPRI Force Time-History For WE28 and WE29 From Test 917 With the FIXFM3 Predicted Force Time-History

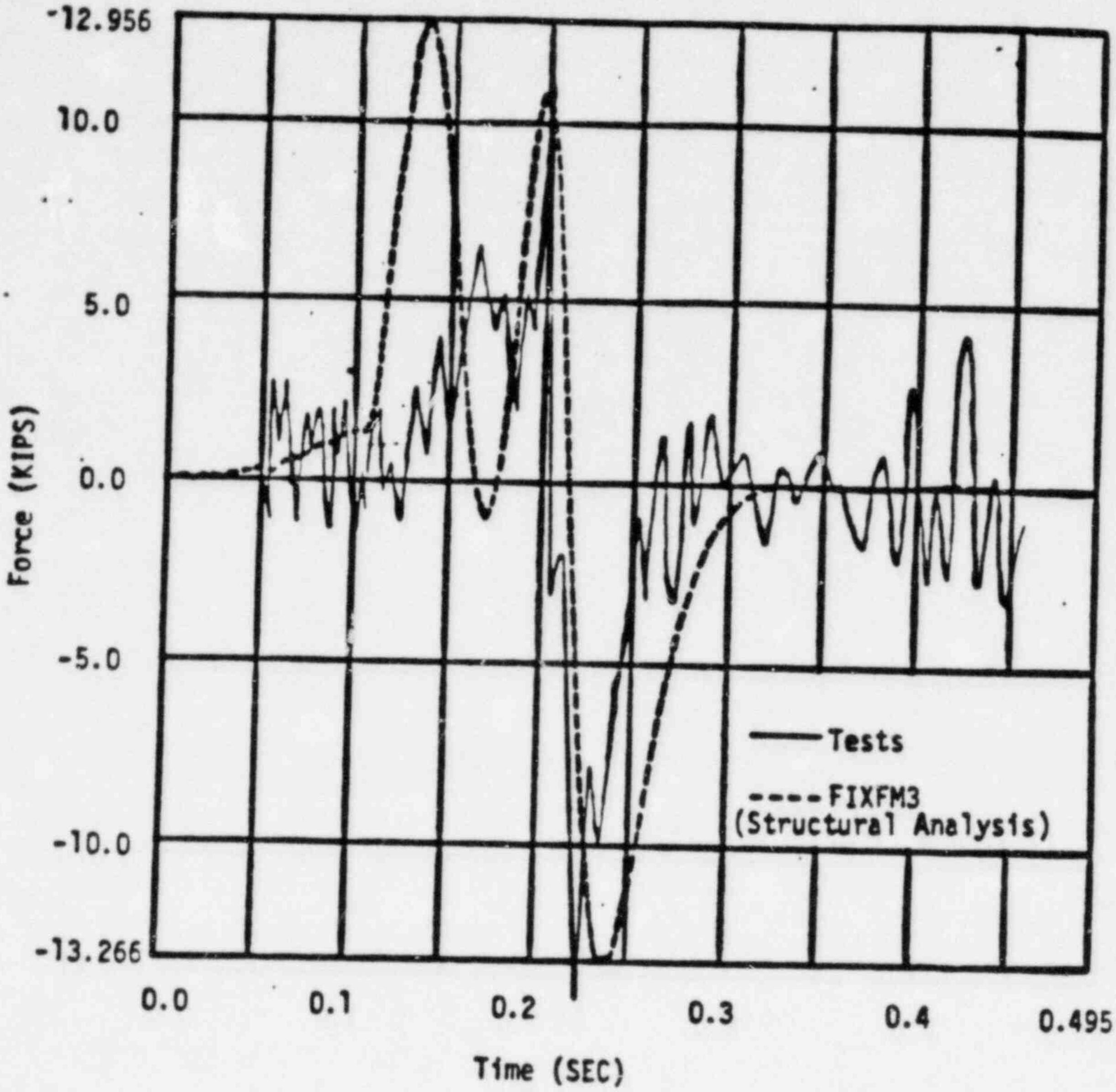


Figure 4-16: Comparison of the EPRI Force Time-History For WE32 and WE33 From Test 917 With the FIXFM3 Predicted Force Time-History

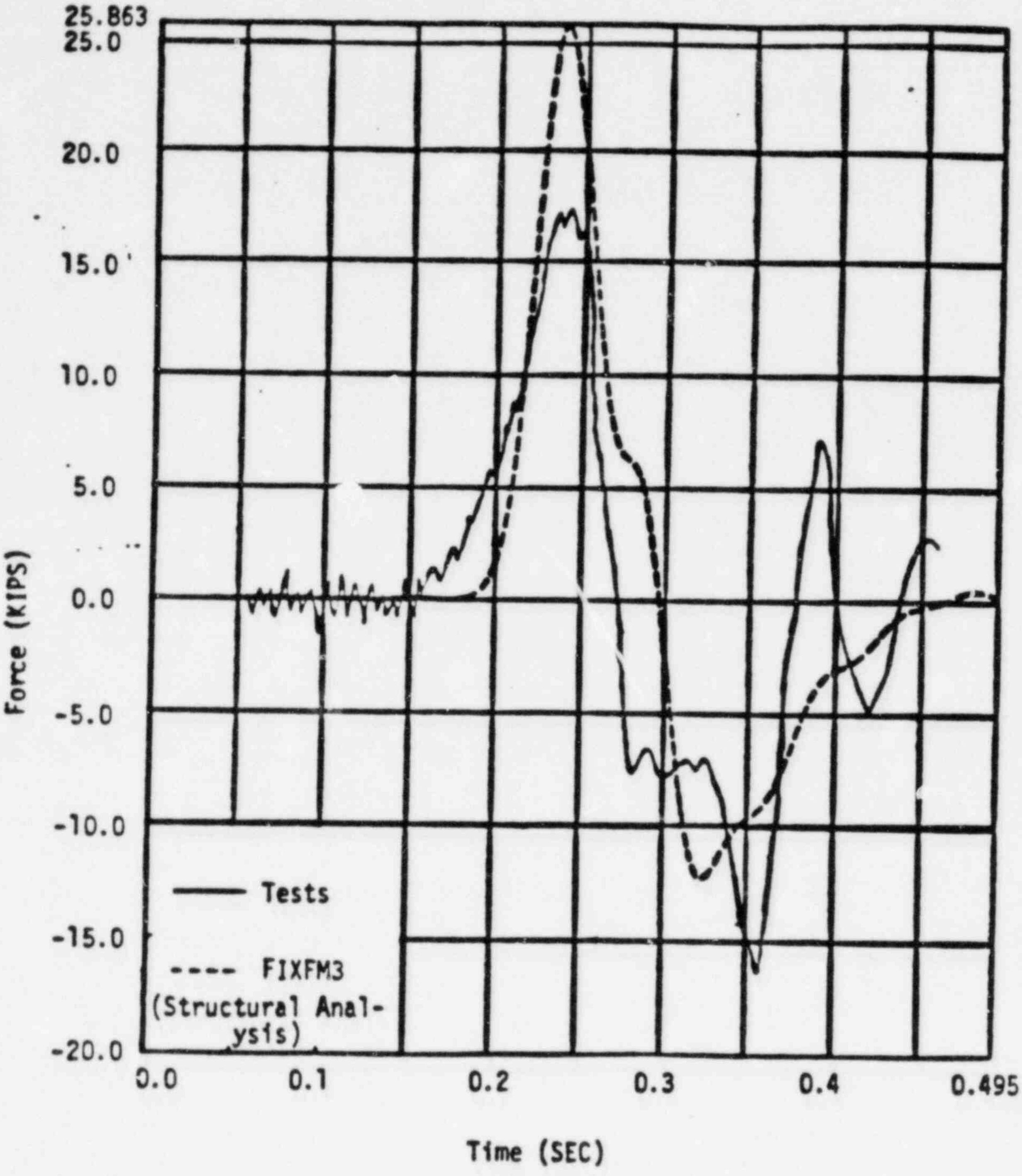


Figure 4-17: Comparison of the EPRI Force Time-History For WE30 and WE31 From Test 917 With the FIXFM3 Predicted Force Time-History

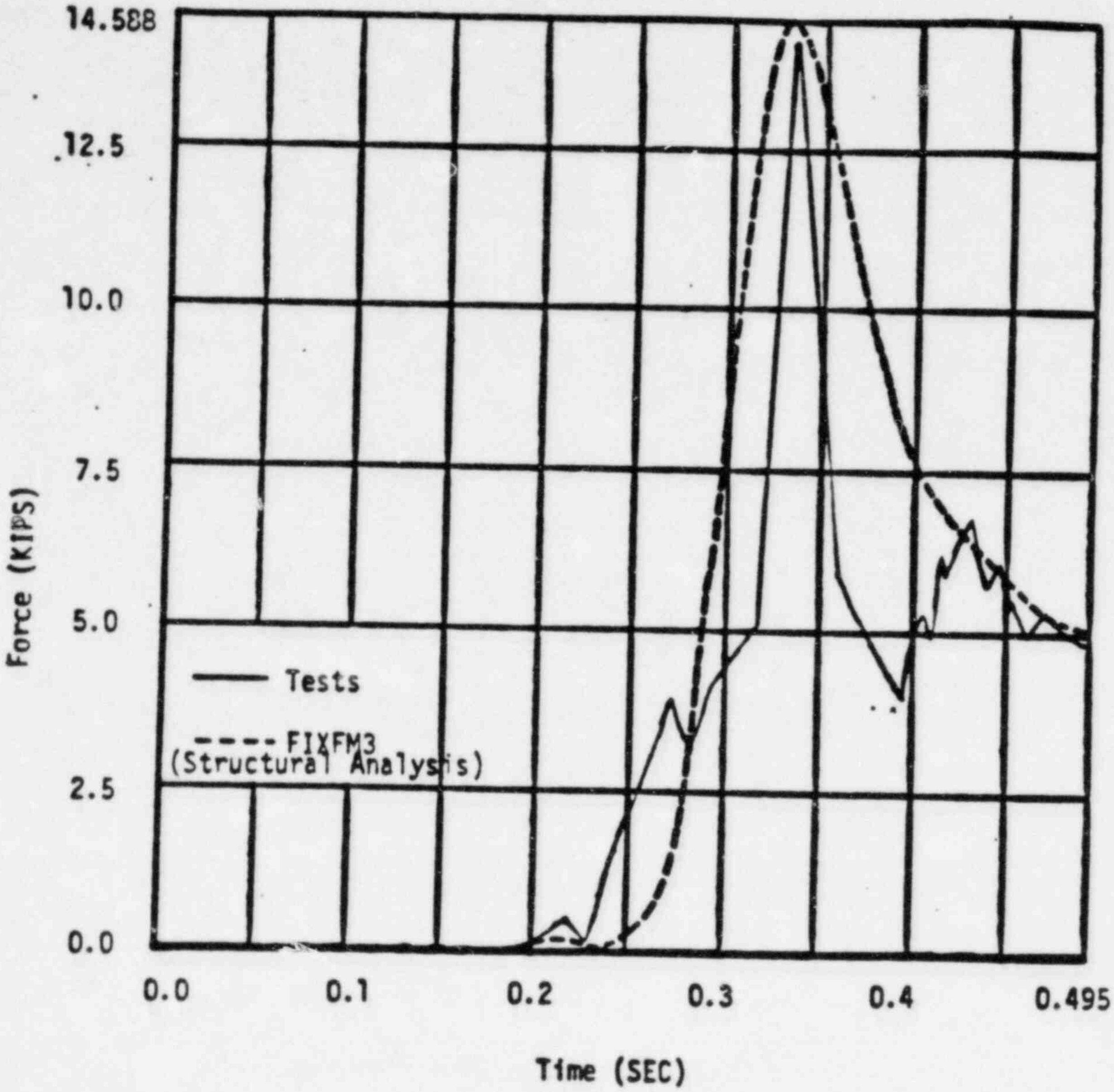


Figure 4-18: Comparison of the EPRI Force Time-History For WE34 and WE35 From Test 917 With the FIXFM3 Predicted Force Time-History

SECTION 5
METHOD OF STRESS EVALUATION

5.1 INTRODUCTION

The method used to combine the primary loads to evaluate the adequacy of the piping system is described in this section.

5.2 PRIMARY STRESS EVALUATION

In order to perform a primary stress evaluation in accordance with the rules of the Code, definitions of stress combinations are required for the normal, upset, emergency and faulted plant conditions as defined in Section 3. Tables 2-1 and 2-2 illustrate the allowable stress intensities for the appropriate combination. Table 2-3 defines all pertinent terms.

5.2.1 DESIGN CONDITIONS

The piping minimum wall thickness, t_m, is calculated in accordance with the Code. The actual pipe minimum wall thickness meets the Code requirement.

The combined stresses due to primary loadings of pressure, weight, and design mechanical loads calculated using applicable stress intensity factors must not exceed the allowable limit. The resultant moment, M_i, due to loads caused by weight and design mechanical loads is calculated using the following equation:

$$M_i = \left[\left(M_{x_{wt}} + M_{x_{DML}}\right)^2 + \left(M_{y_{wt}} + M_{y_{DML}}\right)^2 + \left(M_{z_{wt}} + M_{z_{DML}}\right)^2 \right]^{1/2}$$

where

$M_{x_{wt}}, M_{y_{wt}}, M_{z_{wt}}$ = deadweight moment components

$M_{x_{DML}}, M_{y_{DML}}, M_{z_{DML}}$ - design mechanical load moment components

The maximum stresses due to pressure, weight, and DML in the piping system are reported on tables in Section 6.

5.2.2 UPSET CONDITIONS

The combined stresses due to the primary loadings of pressure, weight, OBE seismic, and relief valve thrust loadings calculated using the applicable stress intensity factors must not exceed the allowables. The resultant moments, M_i, due to loads caused by these loadings are calculated as shown below.

For seismic and relief valve thrust loading:

$$M_i = \left[\left(\left|M_{x_{wt}}\right| + \left(M^2_{x_{OBE}} + M^2_{x_{SOT_U}}\right)^{1/2}\right)^2 + \left(\left|M_{y_{wt}}\right| + \left(M^2_{y_{OBE}} + M^2_{y_{SOT_U}}\right)^{1/2}\right)^2 + \left(\left|M_{z_{wt}}\right| + \left(M^2_{z_{OBE}} + M^2_{z_{SOT_U}}\right)^{1/2}\right)^2\right]^{1/2}$$

where

$M_{x_{wt}}, M_{y_{wt}}, M_{z_{wt}}$ = deadweight moment components

$M_{x_{OBE}}, M_{y_{OBE}}, M_{z_{OBE}}$ = inertial OBE moment components

$M_{x_{SOT_U}}, M_{y_{SOT_U}}, M_{z_{SOT_U}}$ = relief line operation moment components

5.2.3 EMERGENCY CONDITIONS

The combined stresses due to primary loadings of pressure, weight and safety valve thrust, using applicable stress intensification factors, must not exceed the allowable limits. The magnitude of the resultant moment, M_i is calculated from the moment components as shown below:

$$M_i = \left[\left(M_{x_{SOT_E}} + \left| M_{x_{wt}} \right| \right)^2 + \left(M_{y_{SOT_E}} + \left| M_{y_{wt}} \right| \right)^2 + \left(M_{z_{SOT_E}} + \left| M_{z_{wt}} \right| \right)^2 \right]^{1/2}$$

where

$M_{x_{wt}}, M_{y_{wt}}, M_{z_{wt}}$ = deadweight moment components

$M_{x_{SOT_E}}, M_{y_{SOT_E}}, M_{z_{SOT_E}}$ = safety line operation moment components

5.2.4 FAULTED CONDITIONS

The combined stresses due to primary loadings of pressure, weight, SSE and SOT_F, using applicable stress intensification factors must not exceed the allowable limits. For the resultant moment loading, M_i, the SSE and SOT_F moments are combined using the square-root-of-the-sum-of-the-squares (SRSS) addition and added absolutely with deadweight for each moment component (M_x, M_y, M_z). The magnitude of the resultant moment, M_i, is calculated from the three moment components, as shown below:

$$M_i = \left[\left(\left(M_{x_{SOT_F}}^{\ 2} + M_{x_{SSE}}^{\ 2} \right)^{1/2} + \left| M_{x_{wt}} \right| \right)^2 \right.$$

$$+ \left(\left(M_{y_{SOT_F}}^{\ 2} + M_{y_{SSE}}^{\ 2} \right)^{1/2} + \left| M_{y_{wt}} \right| \right)^2$$

$$+ \left(\left(M_{z_{SOT_F}}^{\ 2} + M_{z_{SSE}}^{\ 2} \right)^{1/2} + \left| M_{z_{wt}} \right| \right)^2 \Bigg]^{1/2}$$

where

$M_{x_{wt}}, M_{y_{wt}}, M_{z_{wt}}$ = deadweight moment components

$M_{x_{SSE}}, M_{y_{SSE}}, M_{z_{SSE}}$ = inertial SSE moment components

$M_{x_{SOT_F}}, M_{y_{SOT_F}}, M_{z_{SOT_F}}$ = maximum of SOT_U or SOT_E moment components

For the safety and relief piping, the faulted condition load combination of pressure, weight, and valve thrust is considered as given in Tables 2-1 and 2-2 and defined in Table 2-3. The pipe break loads (MS/FWPB or LOCA) can be ignored for the PSARV system. These loads have very little impact on the pressurizer safety and relief system when compared to the loading conditions discussed in this report.

5.3 SECONDARY STRESS EVALUATION

The combined stresses due to the secondary loadings of thermal, pressure, and deadweight using applicable stress intensification factors must not exceed the allowable limit. For the resultant moment loading, M_i, thermal moments are combined as shown below:

$$M_i = \left[\left(M_{x_{MAX}} - M_{x_{MIN}} \right)^2 + \left(M_{y_{MAX}} - M_{y_{MIN}} \right)^2 + \left(M_{z_{MAX}} - M_{z_{MIN}} \right)^2 \right]^{1/2}$$

$M_{x_{MAX}}, M_{y_{MAX}}, M_{z_{MAX}}$ = maximum thermal moment considering all thermal cases including normal operation

$M_{x_{MIN}}, M_{y_{MIN}}, M_{z_{MIN}}$ = minimum thermal moment considering all thermal cases including normal operation

This, M_1, is then substituted into the appropriate equations of the applicable code.

SECTION 6
RESULTS

6.1 EVALUATION PRIOR TO EPRI TEST PROGRAM

The Callaway Unit 1 and the Wolf Creek Unit safety and relief valve discharge piping system has received a very detailed thermal hydraulic and structural dynamic evaluation to insure the operability and structural integrity of the as-designed system. This structural evaluation, including the thermal hydraulic analysis, was based on the criteria and methods that were current prior to the availability of the data from the EPRI Test Program. The thermal hydraulic forcing functions were generated assuming simultaneous opening of either the safety valves or the relief valves, since they represent the worst applicable loading conditions for the piping and supports for this specific layout. These forcing functions were then used as input to the structural evaluation in which the primary and secondary stresses were determined. The methods used and the loadings considered are consistent with Section 2.0 and Section 3.0 of this report, respectively. Results of this extensive analysis and evaluation have demonstrated that the PSARV piping meets all the applicable design limits for the various loading cases. In addition, the acceptability of the valve nozzles and equipment nozzles was assured for the applied loads.

6.2 EVALUATION SUBSEQUENT TO EPRI TEST PROGRAM

The Callaway Unit 1 and the Wolf Creek Unit pressurizer safety and relief valve discharge piping system has received a detailed thermal hydraulic analysis and structural evaluation to ensure the operability and structural integrity of the system. The methods used and the loadings considered are consistent with Sections 2, 3, 4, and 5 of this report.

6.2.1 THERMAL HYDRAULIC RESULTS

The thermal hydraulic analysis used computer programs which have been shown to match the results of the EPRI Test Program (Section 4.4.2). Hydraulic forcing functions were generated assuming the simultaneous opening of either the safety valves or the relief valves since these represent the worst applicable loading cases for the piping and supports of this specific layout.

Table 6-1 shows the maximum forces on each straight run of pipe for the simultaneous opening of all three safety valves while Table 6-2 shows the maximum forces for the simultaneous opening of both relief valves. To account for uncertainties in the valve flow capacities due to tolerances and deviations, a conservative factor of over 1.20 was included in the maximum rated valve mass flow rate for these cases. This results in conservative forcing functions.

For the safety valves opening case, hot loop seals were assumed to exist upstream of the valves since the piping has been insulated to eliminate cold loop seals which can induce severe hydraulic forces on the pipng system. The loop seal temperature distribution for this case was presumed to be consistent with the distribution in EPRI test 917. That is, the loop seal temperature at the valve inlet was about 300°F, and approximately eight feet upstream, the loop seal liquid temperature was near the system saturation temperature of 655°F. Based upon engineering judgement, significant flashing of hot water near the valve occurred for test 917, thus reducing the downstream loads significantly.

Based on analytical work and tests to date, all acoustic pressures in the upstream piping calculated or observed prior to and during safety valve hot or cold loop seal discharge are below the maximum permissable pressure. The piping between the pressurizer nozzle and the inlet of the safety valves is 6-inch schedule 160. The calculated maximum upstream pressure for this size of piping is below the maximum permissable pressure. A similar evaluation of this inlet piping phenomenon, applicable for temperatures below 300°F, was conducted and the results are documented in a report entitled "Review of Pressurizer

Safety Valve Performance as Observed in the EPRI Safety and Relief Valve Test Program", WCAP-10105, dated June 1982.

6.2.2 STRUCTURAL RESULTS

Stress summaries for the valve discharge loading cases considered are provided in Tables 6-3 through 6-15. Plots of the structural models are shown in Figures 6-1 and 6-2.

For purposes of providing stress summaries, the system was broken up into the following three sets of sections:

Section 1: Piping between the pressurizer and the safety valve outlet nozzles (upstream of valves).

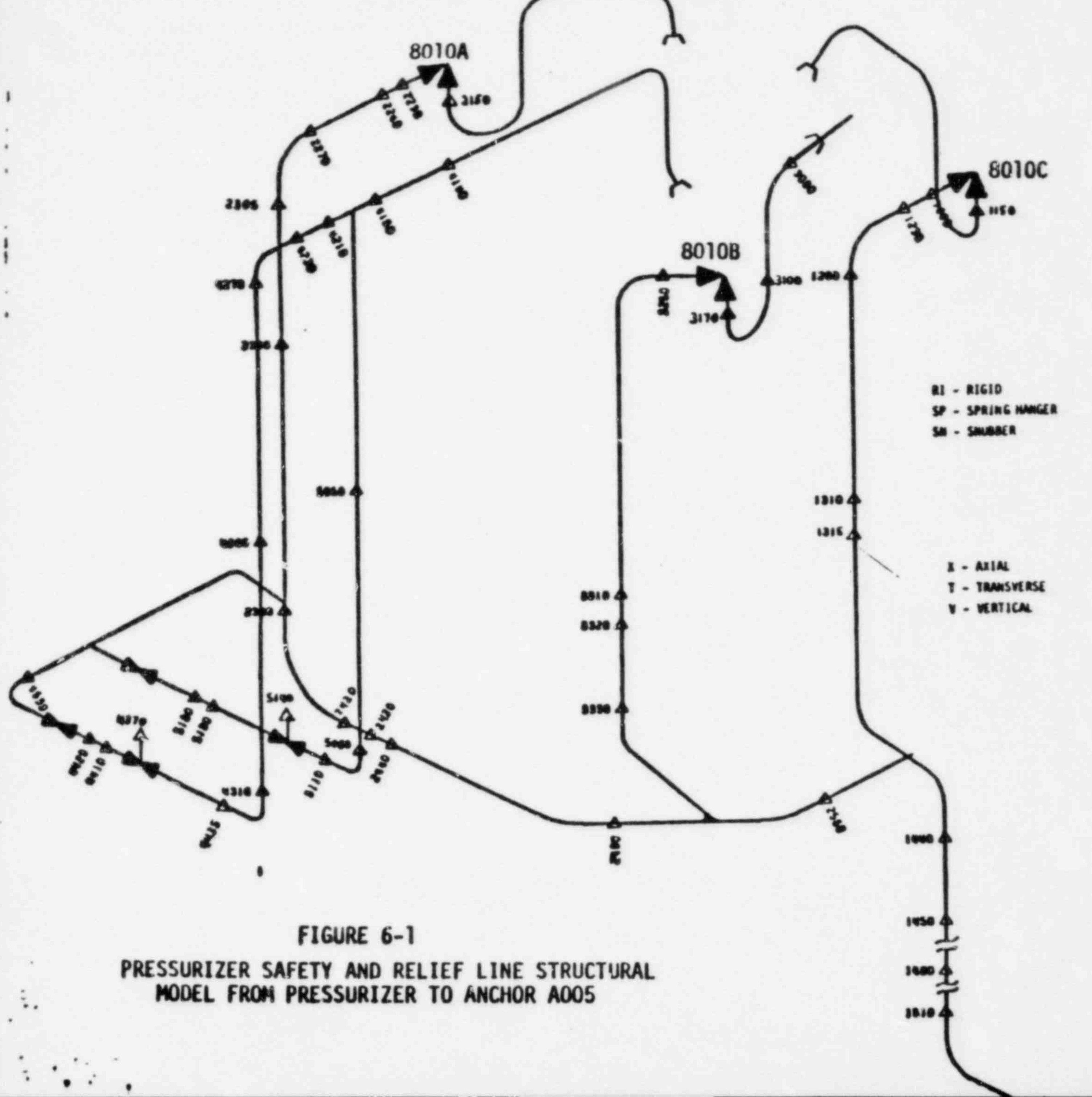
Section 2: Piping between the pressurizer and the relief valve outlet nozzles (upstream of valves).

Section 3: Piping between the safety and relief valve outlet nozzles and the pressurizer relief tank (seismically designed downstream portion).

The results of this extensive analysis and evaluation demonstrated that the piping met the applicable design limits for the various loading cases. In addition, the acceptability of the valve nozzles and equipment nozzles was assured for the applied loads.

6.3 SUMMARY OF RESULTS AND CONCLUSIONS

The thermal hydraulic analysis and structural evaluation of the Callaway Unit 1 and the Wolf Creek Unit pressurizer safety and relief valve discharge piping system have been completed, except for reconciliation to the as-built conditions, which will be performed when such information is provided. In summary, contingent upon support adequacy, the operability and structural integrity of the as-designed system have been ensured for all applicable loadings and load combinations including all pertinent safety and relief valve discharge cases.



NODE	SUPPORT	TYPE
1150	R029	SN T
1220	R008	SN V
1230	H004	SP V
1280	R004	RI T
1310	R023	RI T
1315	R036	SN X
1440	R015	RI T
1450	R016	SN X
1480	R017	RI T
1510	R018	RI T
1610	R019	RI T
2150	R027	SN T
2230	R005	SN V
2240	H003	SP V
2270	R006	RI T
2305	R035	SN X
2330	R007	RI T
2380	R009	RI T
2420	R010	SN V
2430	R026	RI X
2440	H005	SP V
2480	R003	SN X
2560	H002	SP V
3060	H001	SP V
3100	R001	SN T
3170	R028	SN T
3250	R002	SN V
3310	H009	SP V
3320	R024	SN T
3330	R025	SN X
4140	R011	RI T
4160	R012	SN V
4210	H006	SP V
4230	R013	RI T
4270	R014Q	SN T
4290	R018Q	SN T
4310	R016Q	SN T
4335	R034	SN V
4370	R030	SN T
4410	R020Q	SN T
4420	H007	SP V
4530	R021	SN V
5050	R017Q	SN T
5080	R015Q	SN T
5110	R019Q	SN T, V
5140	R032	SN T
5180	H008	SP V
5190	R022	SN V, T
1630	A005	Anchor

FIGURE 6-1

PRESSURIZER SAFETY AND RELIEF LINE STRUCTURAL MODEL FROM PRESSURIZER TO ANCHOR A005

NODE	SUPPORT	TYPE
1000	A005	Anchor
1080	R004	RI T
1120	C004	RI V, T
1160	R006	SN T
1200	R014	RI X
1210	C003	RI V, T
1310	R003	SN T
1340	H003	SP V
1420	R002	RI T
2090	H004	SP V
2150	C006	SP V SN T
2180	A004	Anchor
3070	H002	SP V
3130	H001	SP V
3160	R001	RI T
3230	C002	RI V, T
3280	C001	RI V, T
3310	A001	Anchor

RI - RIGID
SP - SPRING HANGER
SN - SNUBBER

X - AXIAL
T - TRANSVERSE
V - VERTICAL

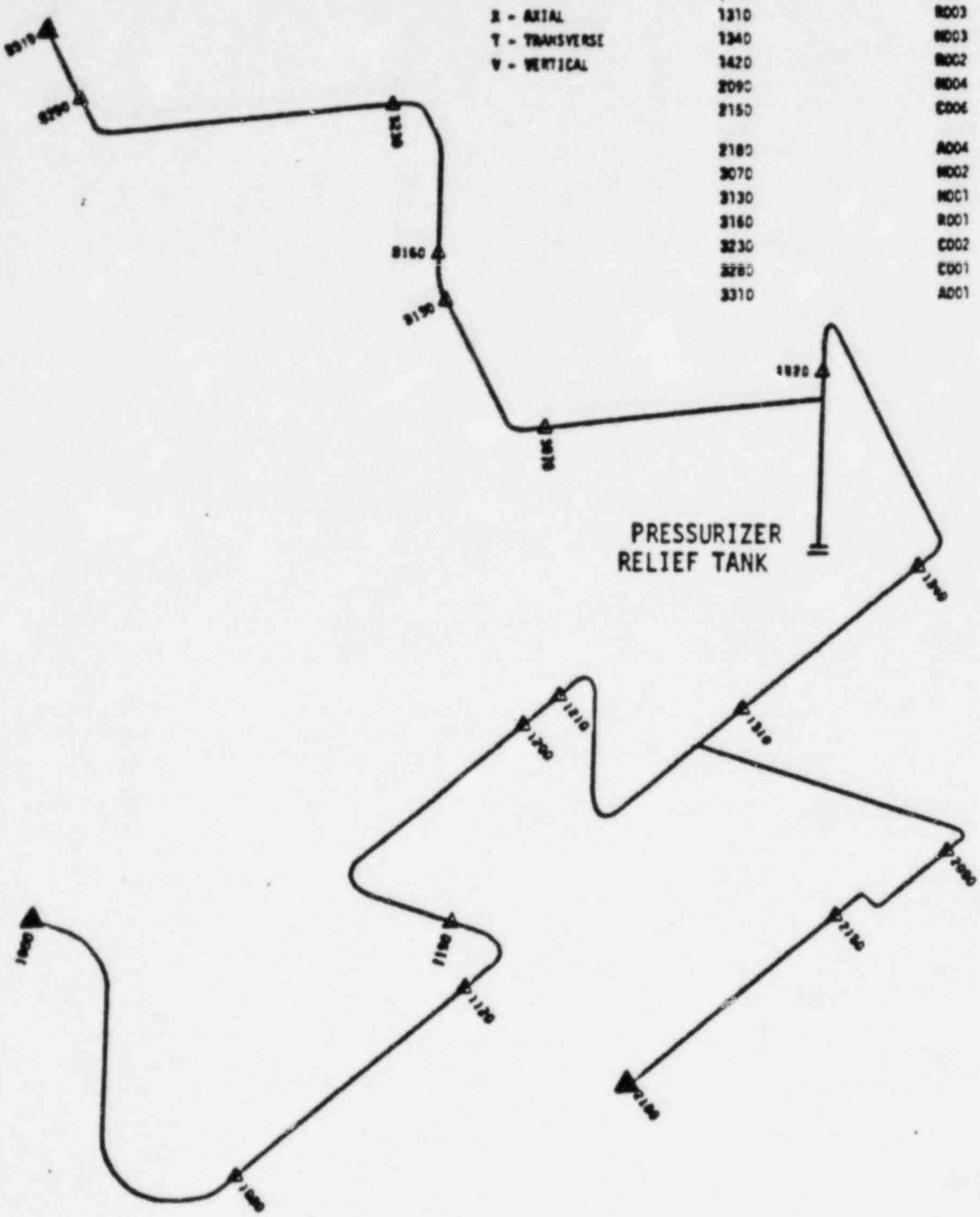


FIGURE 6-2

PRESSURIZER SAFETY AND RELIEF LINE MODEL FROM ANCHOR A005 TO RELIEF TANK

TABLE 6-1

HYDRAULIC FORCES - SAFETY LINE

Force No.	Force (LBF)	Force No.	Force (LBF)
1	280	23	3400
2	630	24	3400
3	3400	25	3400
4	3400	26	4500
5	3400	27	11000
6	5000	28	1000
7	10000	29	3400
8	3900	30	5200
9	5300	31	59000
10	6200	32	14000
11	7400	33	19000
12	17000	34	13000
13	290	35	8000
14	680	36	2800
15	3400	37	13500
16	3400	38	4100
17	3400	39	8500
18	3700	40	2900
19	9000	41	9000
20	4000	42	6000
21	290	43	3500
22	680		

The force numbers correspond to the segment numbers on Figure 4-1A and B.

TABLE 6-2
HYDRAULIC FORCES - RELIEF LINE

Force No.	Force (LBF)	Force No.	Force (LBF)
1	45	18	12000
2	150	19	3300
3	530	20	4800
4	30	21	3400
5	50	22	2000
6	480	23	700
7	650	24	3500
8	770	25	1100
9	630	26	2300
10	1300	27	800
11	5000	28	2300
12	2700	29	1500
13	2500	30	1000
14	8000	33	480
15	6000	34	620
16	4200	35	760
17	1200	36	600

The force numbers correspond to the segment numbers on Figure 4-2A and B.

TABLE 6-3

PRIMARY STRESS SUMMARY - UPSTREAM OF VALVES

Piping System: Pressurizer Relief Line

Combination 1 - N

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
4430	Butt weld	7.7	24.1
4050	Elbow	6.0	24.1
5000	Tee	6.0	24.1
4210	Reducer	14.4	24.1
4420	Straight run	8.0	24.1

See Tables 2-1 through 2-3 for load combinations and definitions.

TABLE 6-4

PRIMARY STRESS SUMMARY - UPSTREAM OF VALVES

Piping System: Pressurizer Relief Line

Combination 2 - N + OBE + SOT_U

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
4230	Straight run	9.9	28.9
4430	Butt weld	8.6	28.9
4250	Elbow	10.2	28.9
4210	Reducer	16.7	28.9
5000	Tee	7.2	28.9

See Tables 2-1 through 2-3 for load combinations and definitions.

TABLE 6-5

PRIMARY STRESS SUMMARY - UPSTREAM OF VALVES

Piping System: Pressurizer Relief Line

Combination 3 - N + SOT_E

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
4420	Straight run	8.3	36.2
4430	Butt weld	7.9	36.2
4050	Elbow	6.2	36.2
4210	Reducer	15.1	36.2
5000	Tee	6.5	36.2

See Tables 2-1 through 2-3 for load combinations and definitions.

TABLE 6-6

PRIMARY STRESS SUMMARY - UPSTREAM OF VALVES

Piping System: Pressurizer Relief Line

Combinations 4 and 5 - N + LOCA + SSE + SOT_F

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
4230	Straight run	9.7	48.2
4430	Butt weld	8.8	48.2
4250	Elbow	10.1	48.2
4210	Reducer	16.7	48.2
5000	Tee	7.2	48.2

See Tables 2-1 through 2-3 for load combinations and definitions.

TABLE 6-7

PRIMARY STRESS SUMMARY - UPSTREAM OF VALVES

Piping System: Pressurizer Safety Line

Combination 1 - N

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
3070	Butt weld	6.4	24.1
3070	Elbow	6.8	24.1
3060	Straight run	6.5	24.1

See Tables 2-1 through 2-3 for load combinations and definitions.

TABLE 6-8

PRIMARY STRESS SUMMARY - UPSTREAM OF VALVES

Piping System: Pressurizer Safety Line

Combination 2 - N + OBE + SOT_U

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
3130	Straight run	17.6	28.9
3140	Butt weld	17.6	28.9
3120	Elbow	24.7	28.9

See Tables 2-1 through 2-3 for load combinations and definitions.

TABLE 6-9

PRIMARY STRESS SUMMARY - UPSTREAM OF VALVES

Piping System: Pressurizer Safety Line

Combination 3 - N + SOT_E

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
3160	Straight run	12.5	36.2
3020	Butt weld	11.5	36.2
3150	Elbow	14.6	36.2

See Tables 2-1 through 2-3 for load combinations and definitions.

TABLE 6-10

PRIMARY STRESS SUMMARY - UPSTREAM OF VALVES

Piping System: Pressurizer Safety Line

Combinations 4 and 5 - N + LOCA + SSE + SOT_F

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
3130	Straight run	17.2	48.2
3020	Butt weld	17.2	48.2
3120	Elbow	24.1	48.2

See Tables 2-1 through 2-3 for load combinations and definitions.

TABLE 6-11

PRIMARY STRESS SUMMARY - SEISMICALLY DESIGNED DOWNSTREAM PORTION

Piping System: Pressurizer Safety and Relief Line

Combination 1 - N

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
1630	Butt weld	4.7	15.9
1360	Elbow	4.1	15.9
1340	Reducer	6.2	15.9
1390	Tee	3.9	15.9
1230	Straight run	4.0	15.9

See Tables 2-1 through 2-3 for load combinations and definitions.

TABLE 6-12

PRIMARY STRESS SUMMARY - SEISMICALLY DESIGNED DOWNSTREAM PORTION

Piping System: Pressurizer Safety and Relief Line

Combination 2 - N + SOT_U

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
1610	Straight run	5.1	19.1
2350	Butt weld	5.6	19.1
1590	Elbow	5.2	19.1
1340	Reducer	7.7	19.1
2370	Tee	7.2	19.1

See Tables 2-1 through 2-3 for load combinations and definitions.

TABLE 6-13

PRIMARY STRESS SUMMARY - SEISMICALLY DESIGNED DOWNSTREAM PORTION

Piping System: Pressurizer Safety and Relief Line

Combination 3 - N + OBE + SOT_U

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
3250	Straight run	17.2	28.6
3260	Butt weld	21.4	28.6
3260	Elbow	19.7	28.6
1340	Elbow	8.9	28.6
2370	Tee	7.3	28.6

See Tables 2-1 through 2-3 for load combinations and definitions.

TABLE 6-14

PRIMARY STRESS SUMMARY - SEISMICALLY DESIGNED DOWNSTREAM PORTION

Piping System: Pressurizer Safety and Relief Line

Combination 4 - N + SOT_E

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
1220	Straight run	11.8	28.6
3240	Butt weld	15.7	28.6
1590	Elbow	9.1	28.6
1340	Reducer	16.4	28.6
1390	Tee	8.4	28.6

See Tables 2-1 through 2-3 for load combinations and definitions.

TABLE 6-15

PRIMARY STRESS SUMMARY - SEISMICALLY DESIGNED DOWNSTREAM PORTION

Piping System: Pressurizer Safety and Relief Line

Combinations 5 and 6 - N + LOCA + SSE + SOT_F

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
3250	Straight run	16.6	38.2
3240	Butt weld	24.4	38.2
3260	Elbow	19.0	38.2
1340	Reducer	16.6	38.2
2520	Tee	8.6	38.2

See Tables 2-1 through 2-3 for load combinations and definitions.