WESTINGHOUSE PROPRIETARY CLASS 3

PRESSURIZER SAFETY AND RELIEF LINE EVALUATION

SUMMARY REPORT

NORTHERN STATES POWER COMPANY

PRAIRIE ISLAND NUCLEAR GENERATING STATION

UNIT 1

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Systems Structural Analysis

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SECTION 1
INTRODUCTION

The pressurizer safety and relief valve discharge piping system for pressurized water reactors provides overpressure protection for the reactor coolant system. A water seal is usually maintained upstream of each safety and relief valve to prevent a steam interface at the valve seat. These water seals practically eliminate any unwanted steam leakage through the valves and, in doing so, maximize plant availability. Driven by a high system pressure which actuates the valves, however, the water slugs can generate severe hydraulic shock loads on both piping and supports.

Under US NRC 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 during 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 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 the Electric Power Research Institute. The primary objective of the test program was to provide full scale test data confirming the functionability of reactor coolant system power operated relief valves and spring loaded safety valves for expected operating and accident conditions. The second objective was to obtain sufficient piping thermal hydraulic load data to permit confirmation of the accuracy of computer codes and analytical methods which might be utilized for plant unique analyses of safety and relief valve discharge piping systems.

This report summarizes both the results of and the analytical methods used in the thermal hydraulic analysis and structural evaluation of the Prairie Island Nuclear Generating Station Unit 1 pressurizer safety and relief valve discharge piping system. In particular, this report is the response of the Northern States Power Company to the US NRC plant specific request for piping evaluation.

SECTION 2
PIPING EVALUATION CRITERIA

2.1 PIPE STRESS CALCULATIONS AND LOAD COMBINATIONS

The pressurizer safety and relief valve piping was analyzed according to the requirements of the ANSI B31.1.0-1967 Power Piping Code with one exception: allowable stresses for load combinations which include hydraulic shock loading from valve discharge were adjusted to agree with those recommended by the piping subcommittee of the EPRI test program. Stress equations from the Code were used to establish limits for stresses from pressure plus sustained moment loads, pressure plus sustained moment plus occasional moment loads, and either thermal expansion moment loads or pressure plus sustained moment plus thermal expansion moment loads.

In order to evaluate the effects which hydraulic shock loading from valve discharge could have on piping, appropriate load combinations must be considered. The load combinations and allowable stresses used for this evaluation are identical to those recommended by the piping subcommittee of the EPRI test program.

The complete list of load combinations and allowable stresses is shown in Tables 2-1 and 2-2. Definitions for all abbreviations are provided in Table 2-3.

2.2 DESIGN CONDITIONS

2.2.1 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.

2.2.2 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.

2.3 PLANT OPERATING CONDITIONS

2.3.1 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.

2.3.2 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, or 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.

2.3.3 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.

2.3.4 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.

TABLE 2-1

LOAD COMBINATIONS AND ALLOWABLE STRESSES FOR PRESSURIZER SAFETY AND RELIEF VALVE PIPING UPSTREAM OF VALVES

Plant/System Operating Condition	Load Combination	Allowable Stress
Normal	P + WT	1.0 S_h
Upset	P + WT + OBE + SOT_U	1.2 S_h
Emergency	P + WT + SOT_E	1.8 S_h
Faulted	P + WT + MS/FWPB or DBPB or LOCA + SSE + SOT_F	2.4 S_h
All	TH	1.0 S_a
All	P + WT + TH	1.0 S_h + 1.0 S_a

NOTES: (1) Definitions for all abbreviations are provided in Table 2-3.

(2) The square-root-sum-of-the-squares method (SRSS) is used for combining dynamic load responses.

TABLE 2-2

LOAD COMBINATIONS AND ALLOWABLE STRESSES FOR PRESSURIZER SAFETY AND RELIEF VALVE PIPING DOWNSTREAM OF VALVES

Plant/System Operating Condition	Load Combination	Allowable Stress
Normal	P + WT	1.0 S_h
Upset	P + WT + SOT_U	1.2 S_h
Upset	P + WT + OBE + SOT_U	1.8 S_h
Emergency	P + WT + SOT_E	1.8 S_h
Faulted	P + WT + MS/FWPB or DBPB or LOCA + SSE + SOT_F	2.4 S_h
All	TH	1.0 S_a
All	P + WT + TH	1.0 S_h + 1.0 S_a

NOTES: (1) Definitions for all abbreviations are provided in Table 2-3.

(2) The square-root-sum-of-the-squares method (SRSS) is used for combining dynamic load responses.

TABLE 2-3

DEFINITIONS OF LOAD ABBREVIATIONS

P	=	Pressure loads
WT	=	Weight loads during normal operation
SOT	=	System operating transient shock loads
SOT_U	=	Relief valve discharge shock loads
SOT_E	=	Safety valve discharge shock loads(1)
SOT_F	=	Maximum of SOT_U and SOT_E; or transition flow
OBE	=	Operating basis earthquake loads
SSE	=	Safe shutdown earthquake loads
MS/FWPB	=	Main steam or feedwater pipe break loads
DBPB	=	Design basis pipe break loads
LOCA	=	Loss of coolant accident loads
TH	=	Range of loads between thermal transients
S_c	=	Basic material allowable stress at minimum temperature
S_h	=	Basic material allowable stress at maximum temperature
S_a	=	$f\ (1.25\ S_c + .25\ S_h)$ where f is a stress range reduction factor

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(1) Although certain nuclear steam supply system 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 pressurized water reactors justifies the emergency condition from both the ASME design philosophy and a stress analysis viewpoint. If actuation of safety valves would occur, however, 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.

SECTION 3
LOADING CONDITIONS ANALYZED

3.1 PRESSURE

Pressure loading considered in the analysis was from either the design or maximum operating pressures. These pressures were used in the calculation of longitudinal pressure stresses.

3.2 WEIGHT

A weight analysis was performed by applying a 1.0 g uniformly distributed downward acceleration to the distributed mass of the piping system. The distributed mass of the piping includes the mass of the pipe, insulation, and contained fluid during normal operating conditions.

3.3 SEISMIC

Seismic motion of the earth is treated as a random process. Certain assumptions reflecting the characteristics of typical earthquakes are made so that these characteristics can be readily employed in a response spectra 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 effectively transmits only those frequencies corresponding to its own natural modes of vibration.

Forcing functions for piping seismic analyses are usually 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. A response spectrum is obtained by determining the maximum response of a single mass-spring-damper oscillator to a time history base motion. This single mass-spring-damper oscillator represents a single natural mode of vibration of

the piping system. A plot of the maximum response versus the natural frequency of oscillator forms the response spectrum for that particular base motion.

The intensity and character of the earthquake motion producing forced vibration of equipment mounted within the containment building are specified in terms of floor response spectrum curves at various elevations within the containment building. 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. The response spectrum curves used in this seismic analysis were taken from the report by John A. Blume and Associates, Engineers, entitled "Prairie Island Nuclear Generating Plant Earthquake Analysis: Reactor-Auxiliary-Turbine Building Response Acceleration Spectra," Report JAB-PS-04, revised February 16, 1971.

3.4 SAFETY AND RELIEF VALVE THRUST

The two spring loaded safety valves and two power operated relief valves, located on top of the pressurizer, are designed to prevent system pressure from exceeding set values. A water seal formed by condensate accumulation on the inlet side of each valve is maintained to prevent any leakage of hydrogen gas or steam through the valve. If the pressure exceeds the set point and a valve opens, the slug of fluid in the water seal discharges. This 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 were analyzed for two cases of thrust loading. One case assumes the simultaneous opening of both relief valves, and the other case assumes the simultaneous opening of both safety valves.

3.5 THERMAL EXPANSION

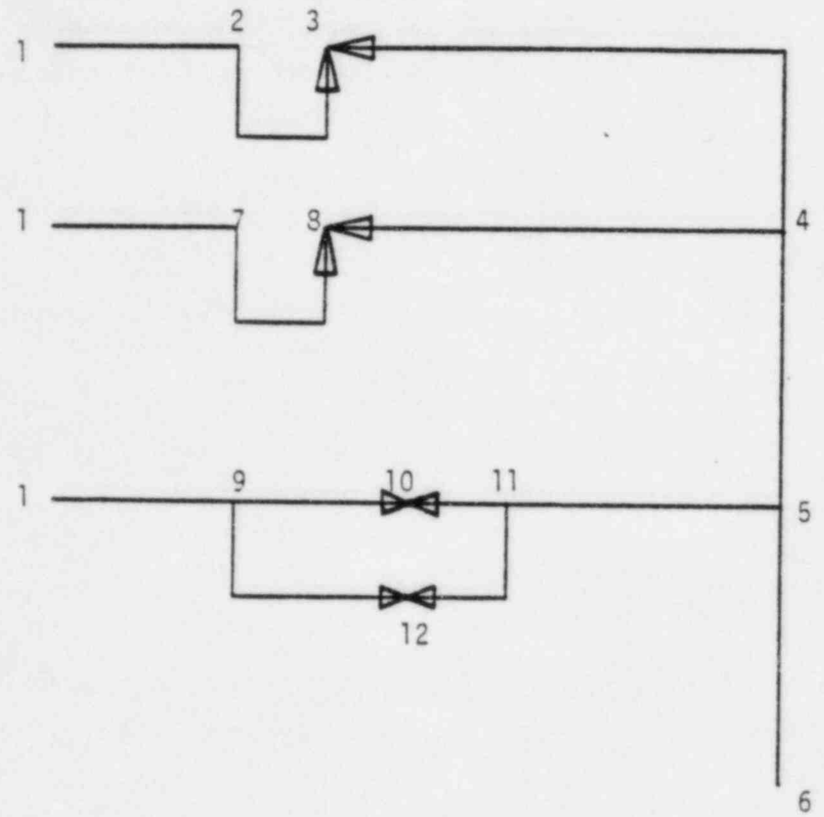
A thermal analysis was performed by conservatively applying steady state temperature distributions to the piping. The distributions used in the expansion analyses are based on available information and include pertinent

valve opening cases. Because of many possible operating modes, the system may experience many different thermal transients. Temperature distributions used to represent possible operating transients are shown in Figure 3-1 and Table 3-1.

Thermal growth of the pressurizer, pressurizer relief tank, and intermediate safety and relief valve piping was considered. The modulus of elasticity, coefficient of thermal expansion, external movements transmitted to the piping, and temperature rise above ambient temperature define the required data to perform a flexibility analysis for thermal expansion of a model.

FIGURE 3-1

SECTIONS FOR THERMAL CASES



The points correspond to the point numbers and section numbers shown in Table 3-1.

TABLE 3-1

TEMPERATURES FOR THERMAL CASES

CASE	DESCRIPTION
1	Normal Operation
2	Safety valve at point 3 open
3	Safety valve at point 8 open
4	Safety valves at points 3 and 8 open
5	Relief valve at point 10 open
6	Relief valve at point 12 open
7	Relief valves at points 10 and 12 open

	TEMPERATURES (°F) FOR EACH CASE						
SECTION	1	2	3	4	5	6	7
1-2	650	670	670	670	670	670	670
2-3	350	670	350	670	350	350	350
3-4	70	450	70	450	70	70	70
4-5	70	450	450	450	70	70	70
5-6	70	450	450	450	400	400	400
1-7	650	670	670	670	670	670	670
7-8	350	350	670	670	350	350	350
8-4	70	70	450	450	70	70	70
1-9	650	670	670	670	670	670	670
9-10	200	200	200	200	670	200	670
10-11	70	70	70	70	400	70	400
11-5	70	70	70	70	400	400	400
9-12	200	200	200	200	200	670	670
12-11	70	70	70	70	70	400	400

The point numbers and section numbers correspond to the points shown in Figure 3-1.

SECTION 4
ANALYTICAL METHODS AND MODELS

4.1 PIPING SYSTEM MODEL

The complexity of a safety and relief valve piping system requires the use of a computer to obtain the displacements, loads, and stresses caused by a given type of loading. To achieve accurate results, an adequate mathematical representation of the system is required. The modelling considerations involved depend upon the degree of accuracy desired and the manner in which the results will be interpreted and evaluated. All static and dynamic analyses were performed using the WESTDYN computer program. This program has been reviewed and approved by the US NRC (NRC letter dated April 7, 1981 from R. L. Tedesco to T. M. Anderson).

A piping system model constructed for WESTDYN is represented by an ordered set of data which numerically describes the physical system. The geometric description of a model is based upon isometric piping drawings and equipment drawings. Node point coordinates and incremental lengths of members are determined from these drawings. Node point coordinates are placed on network cards; incremental member lengths are placed on element cards. The spatial properties along with the modulus of elasticity, coefficient of thermal expansion, average temperature change from ambient temperature, and weight per unit length are specified for each element. The distributed mass of the piping is combined into a series of lumped masses, and these are spaced throughout the model so that they accurately represent the distributed mass of the system. Supports are represented by stiffness matrices which define their restraint characteristics. A plotted model for the safety and relief valve discharge piping system is shown in Figure 6-1.

4.2 DEADWEIGHT AND THERMAL ANALYSES

Static solutions for deadweight and thermal loading conditions are obtained using WESTDYN. This program is based on the use of transfer matrices which relate a twelve element vector consisting of displacements, three translations 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, and the R vector includes thermal effects and boundary forces. The B vector for an 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 into the overall load vector.

After all of the sections have been defined in this manner, the overall stiffness matrix and associated load vector needed to suppress the deflection of all of 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 thermal and boundary force effects. Using the general transfer relationship, the displacements and internal loads are then determined at all node points in the system. Support loads are computed by multiplying the support stiffness matrix by the displacement vector at the support point.

4.3 SEISMIC ANALYSIS

The solution for a seismic disturbance uses the response spectra method. This method employs the lumped mass technique, linear elastic properties, and principle of modal superposition.

From the mathematical description of the system, an overall stiffness matrix is developed from the individual element stiffness matrices using the transfer matrix associated with mass degrees of freedom only. From the mass matrix and reduced stiffness matrix, the natural frequencies and normal modes are determined. The modal participation factor matrix is computed and combined with the appropriate response spectrum 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 summation 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, translations, rotations, 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 significant modes.

4.4 PRESSURIZER SAFETY AND RELIEF LINE ANALYSIS

4.4.1 PLANT HYDRAULIC MODEL

When the pressure in the pressurizer reaches a set value (2,500 psia for a safety valve and 2,350 psia for a relief valve) and a valve opens, high pressure steam forces any condensate in the water seal through the valve, down the piping, and into 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 modelled 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:

$$\vec{F} = \frac{1}{g_c} \frac{\partial}{\partial t} \int_v \rho \vec{V} dv + \frac{1}{gc} \int \rho \vec{V}(\vec{V} \cdot \vec{n} dA)$$

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

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

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

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.

4.4.2 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 loads and responses were measured. Upstream environments for particular valve opening cases of importance, which envelope the commercial scenarios, are:

A. <u>Cold water discharge followed by steam</u> - 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 pressure and 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 ITCHVALVE and FORFUN versus experimental results for Test 908, the cold water discharge followed by steam case. Figure 4-4 shows the pressure time history for PT09, a sensor located just downstream of the valve. Figures 4-5 and 4-6 illustrate, respectively, the force time histories on sensors WE28/WE29 and WE32/WE33. Significant structural damping in the third segment after the valve was noticed at the test and was verified by structural analyses. Consequently, no comparison of force on sensor WE30/WE31 is 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 history for PT09. Figures 4-8, 4-9, 4-10, and 4-11 illustrate, respectively, the thermal hydraulically calculated and the experimentally determined force time histories for sensors WE28/WE29, WE32/WE33, WE30/WE31, and WE34/WE35. Blowdown forces were included in the total analytically calculated force for WE34/WE35 since 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 4.4.3) 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.

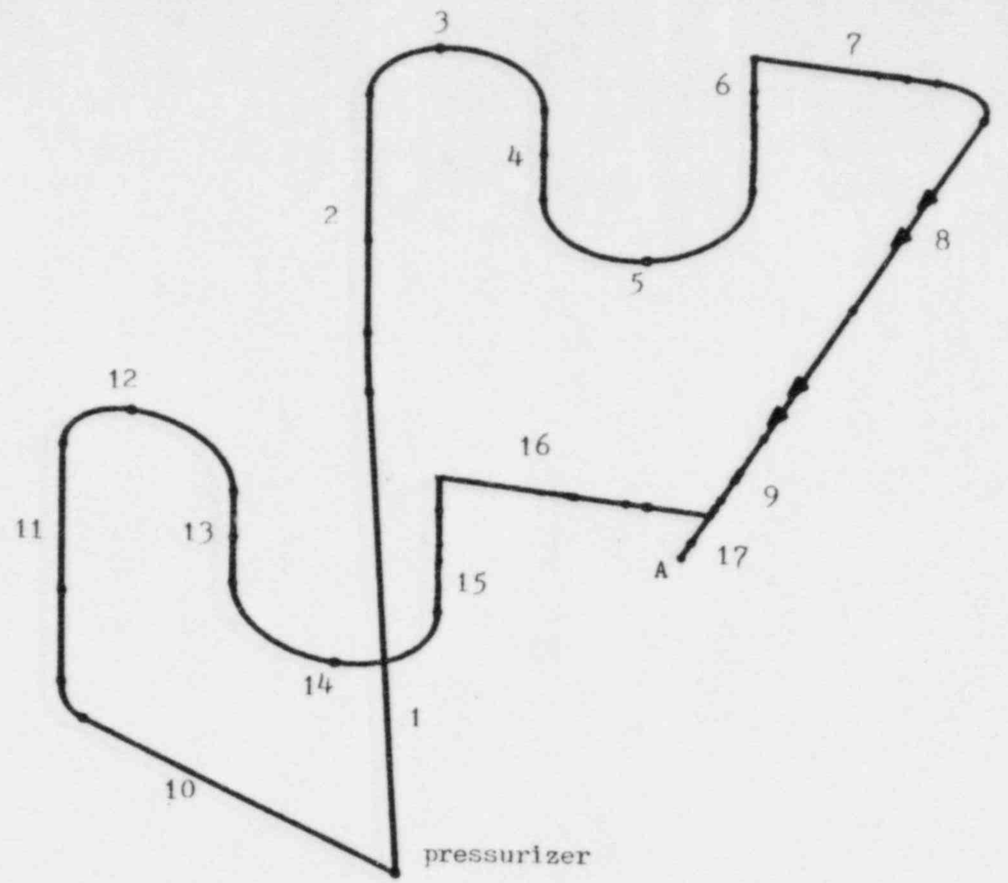
4.4.3 VALVE THRUST ANALYSIS

The safety and relief lines were modelled statically and dynamically as described in Sections 4.1 through 4.3. The mathematical model used for dynamic analyses was also used for valve thrust analyses. Time history hydraulic forces determined by FORFUN were applied to the piping system lumped mass points. Dynamic solutions for valve thrust were obtained by using a modified predictor-corrector integration technique and normal mode theory.

Time history solutions were found using program FIXFM3. Input to this program consists of natural frequencies, normal modes, and applied forces; output consists of time history displacements at lumped mass points. The natural frequencies and normal modes for the pressurizer safety and relief line dynamic model were determined in WESTDYN.

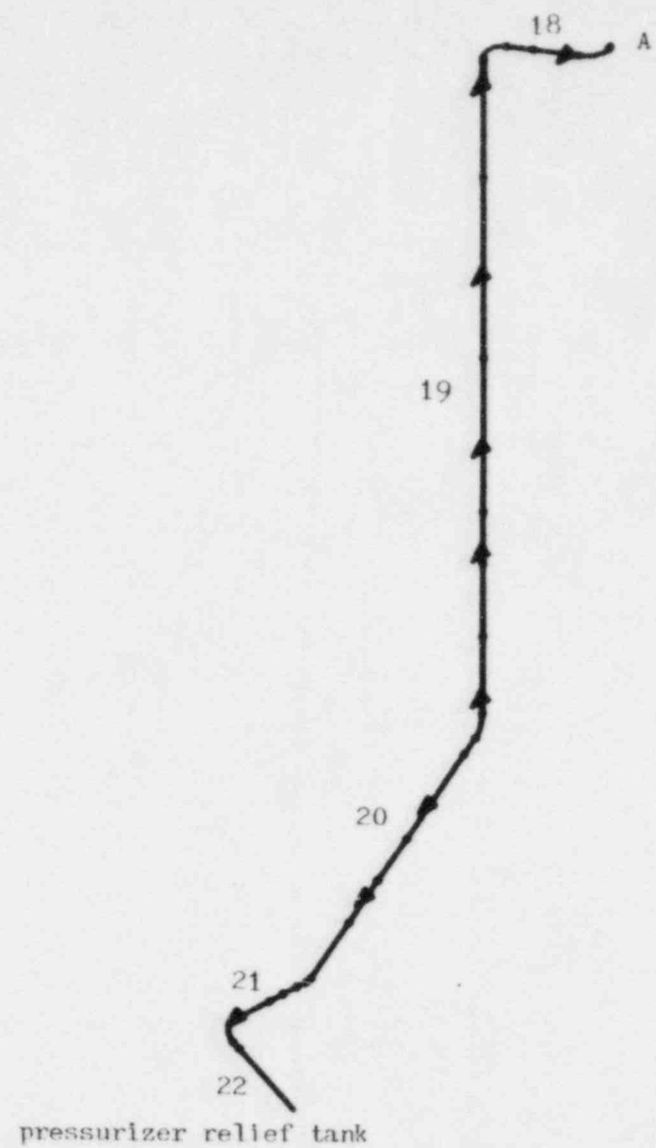
Time history displacements from FIXFM3 were used as input to program WESDYN2 to determine time history internal forces and deflections at the ends of each piping element. For this calculation, the displacements were treated as imposed deflections on the pressurizer safety and relief line masses.

Time history internal forces and displacements from WESDYN2 were used as input to program POSDYN2 to determine the maximum forces, moments, and displacements that exist at each end of the piping elements and to determine the maximum loads for piping supports. The results from POSDYN2 were saved for use in pipe stress calculations and support load summaries.



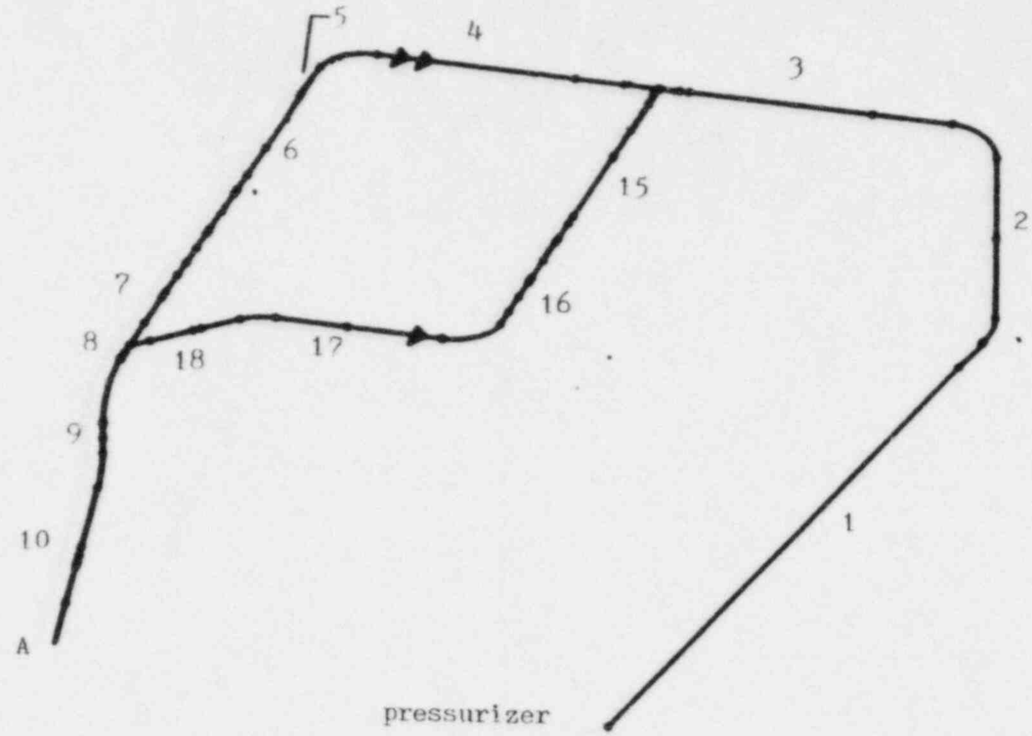
The numbers correspond to the force numbers in Table 6-1.

FIGURE 4-1 PRESSURIZER SAFETY LINE HYDRAULIC MODEL



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

FIGURE 4-1 (cont.) PRESSURIZER SAFETY LINE HYDRAULIC MODEL



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

FIGURE 4-2 PRESSURIZER RELIEF LINE HYDRAULIC MODEL

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

FIGURE 4-2 (cont.) PRESSURIZER RELIEF LINE HYDRAULIC MODEL

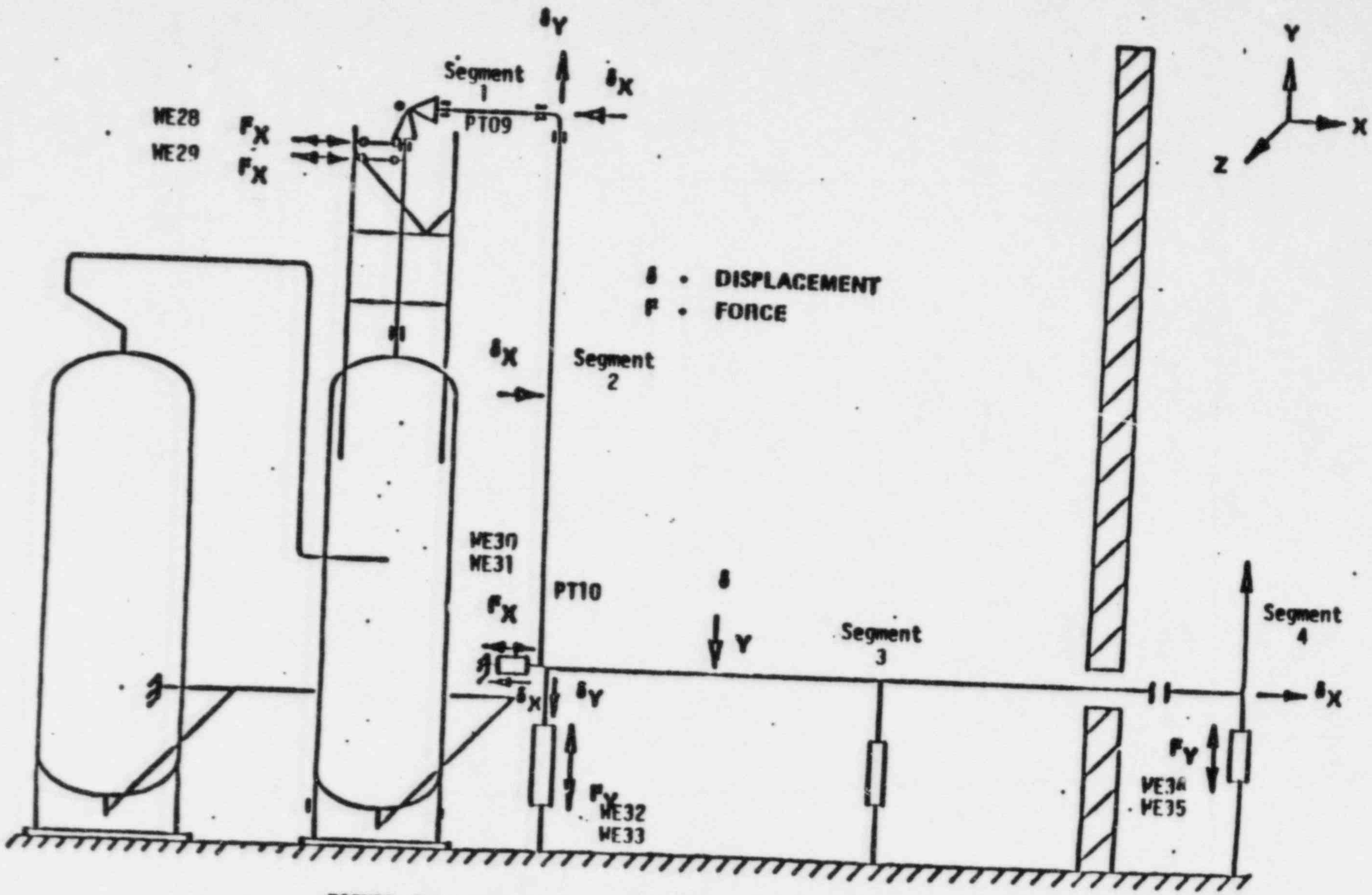


FIGURE 4-3: STRUCTURAL RESPONSE - FORCE MEASUREMENT LOCATIONS - EPRI TESTS

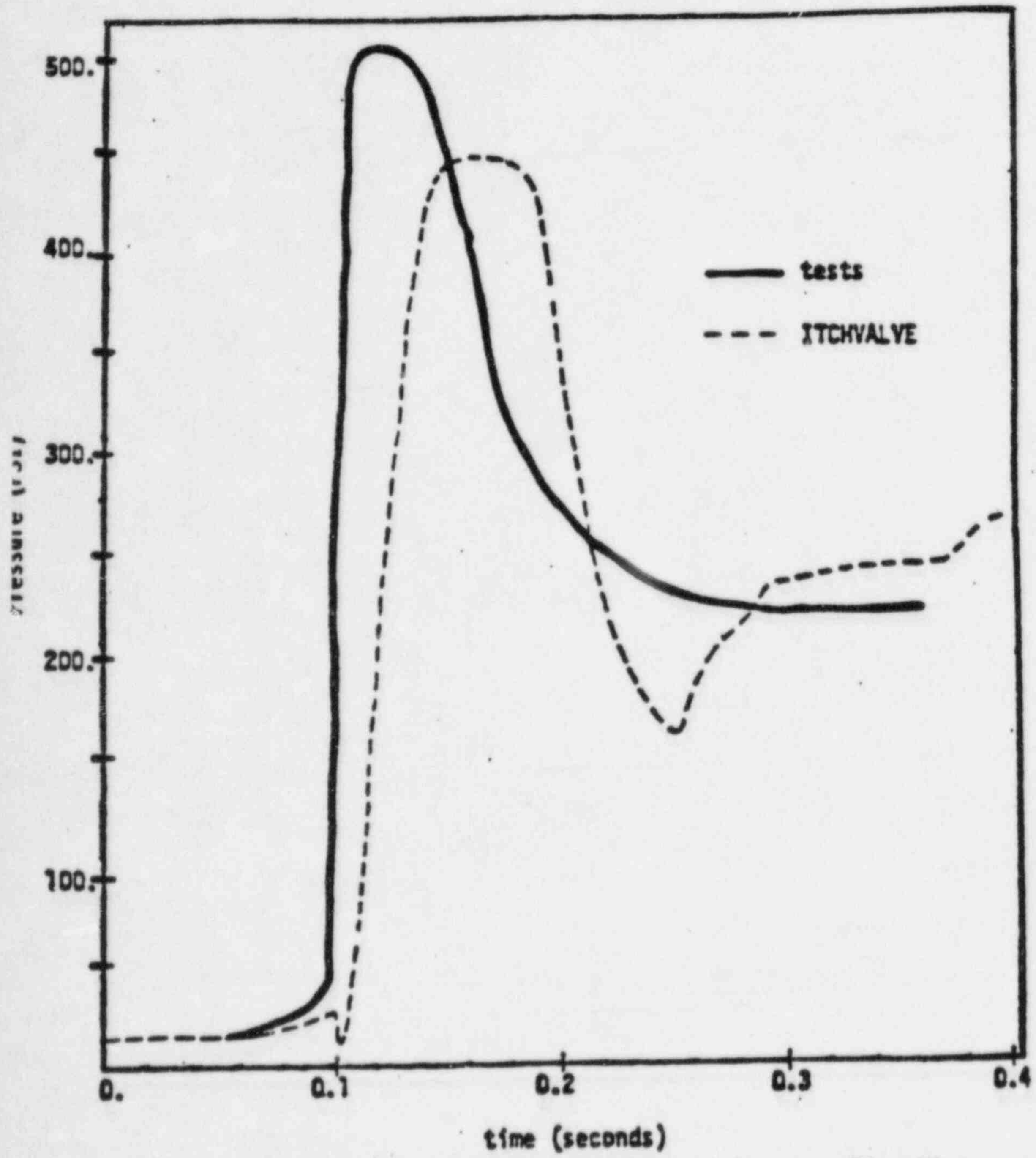


FIGURE 4-4 : Comparison of the EPRI Pressure Time-History for PT09 from Test 908 with the ITCHVALVE Predicted Pressure Time-History

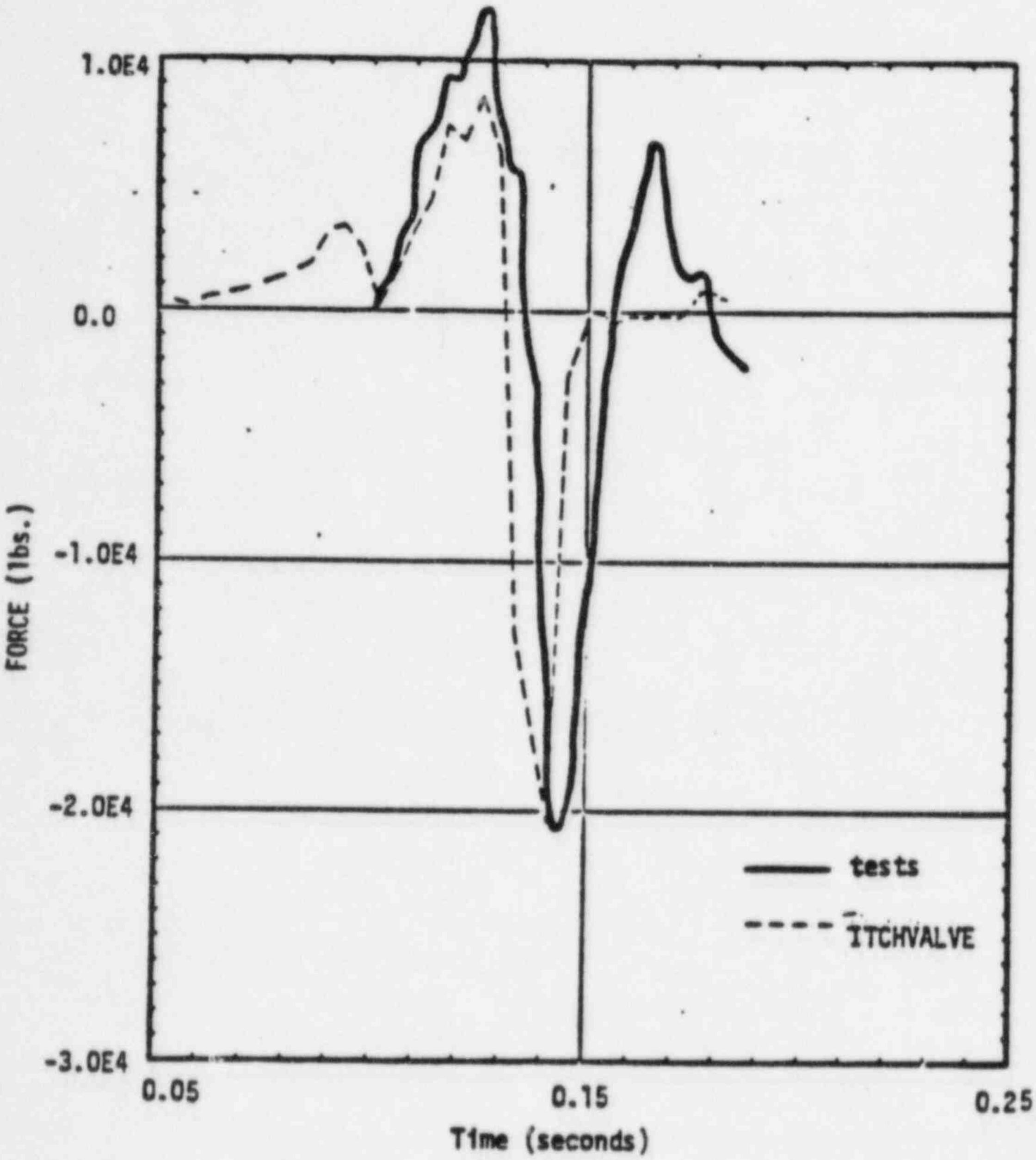


FIGURE 4-5: COMPARISON OF THE EPRI FORCE TIME-HISTORY FOR WE28 and WE29 FROM TEST 908 WITH THE ITCHVALVE PREDICTED FORCE TIME-HISTORY

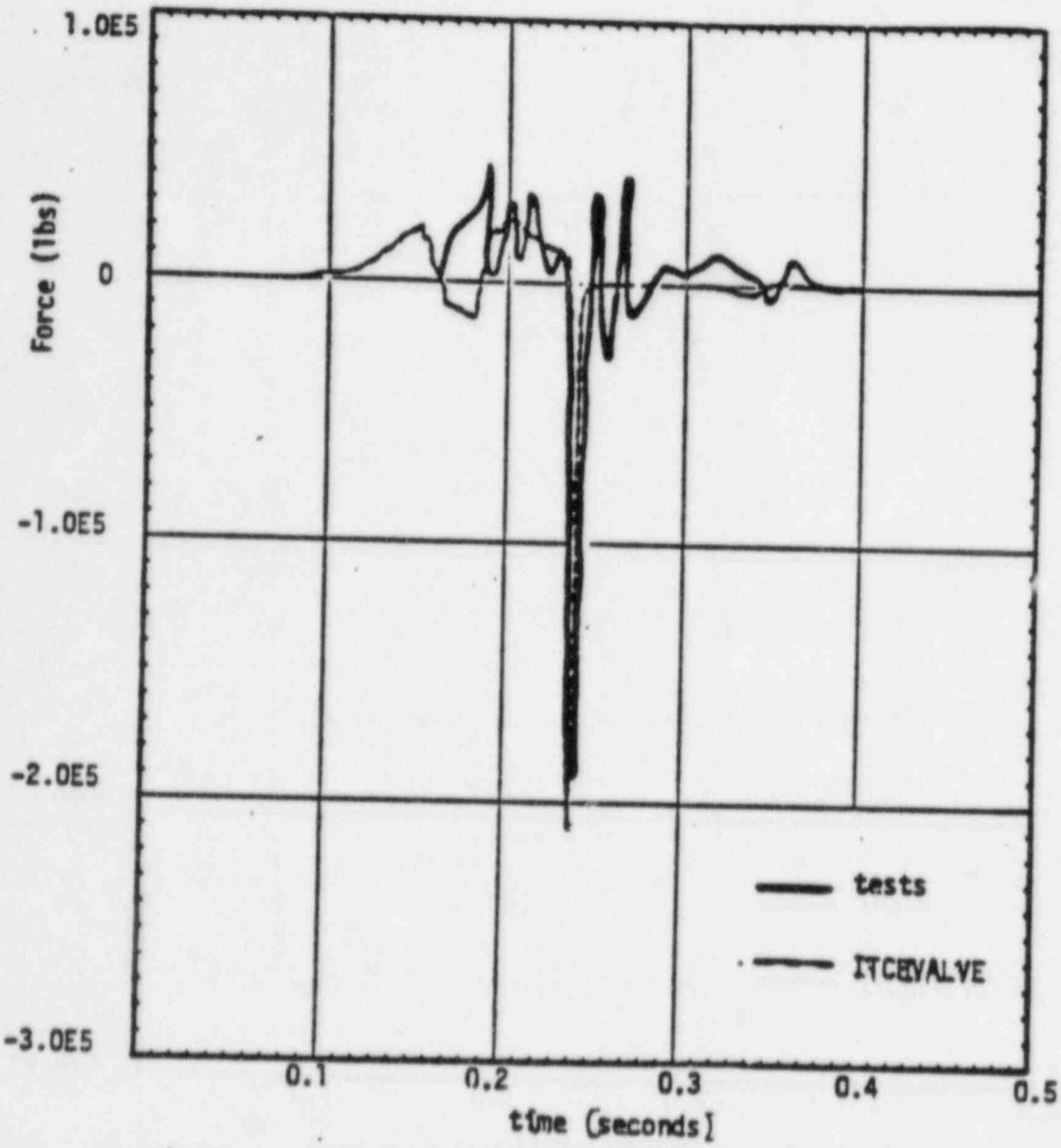


FIGURE 4-6: COMPARISON OF THE EPRI FORCE TIME-HISTORY FOR WE32 AND WE33 FROM TEST 908 WITH THE ITCHVALVE PREDICTED FORCE TIME-HISTORY

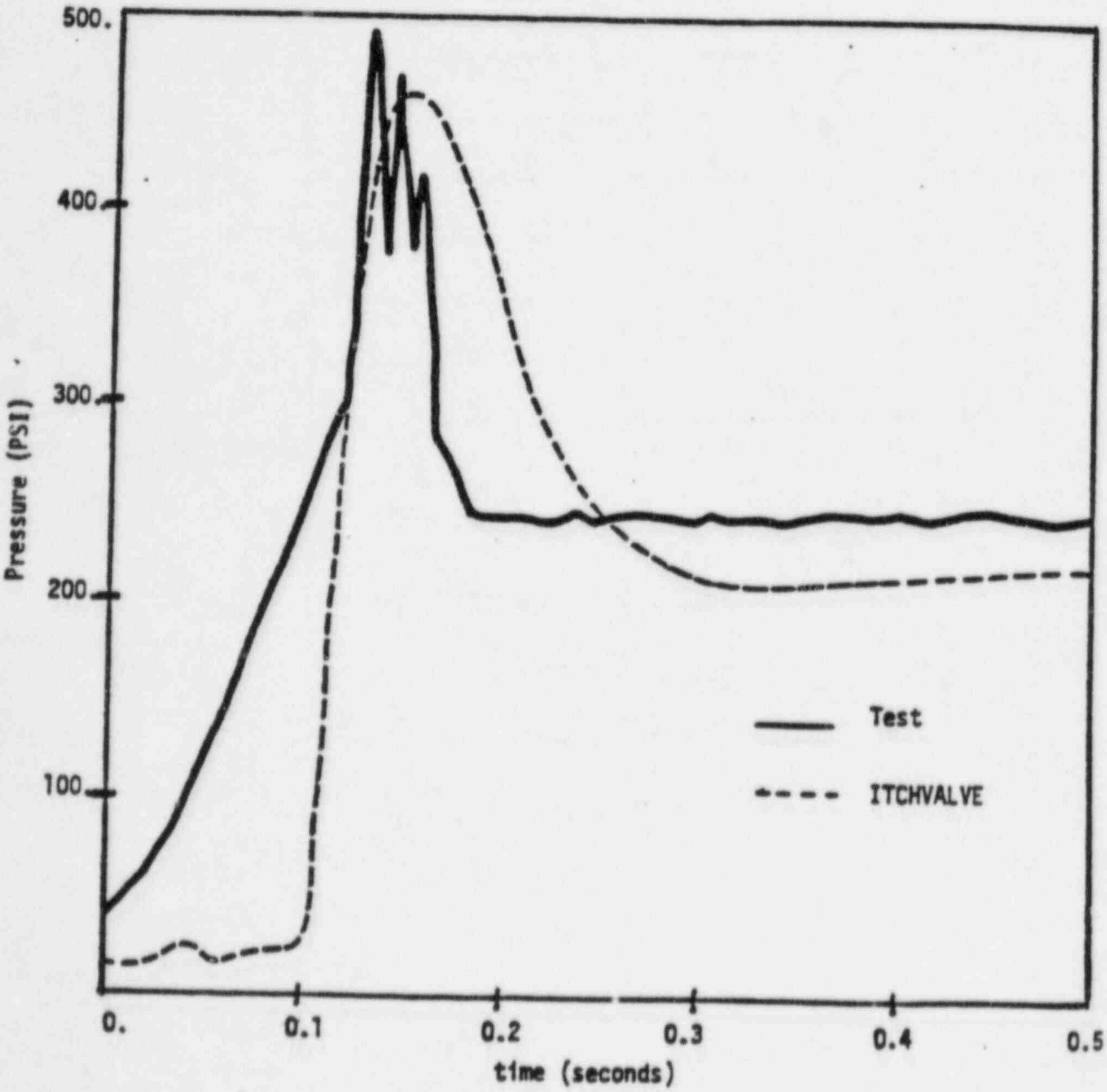


FIGURE 4-7 : Comparison of the EPRI Pressure Time-History from PT09 from Test 917 with the ITCHVALVE Predicted Pressure Time-History

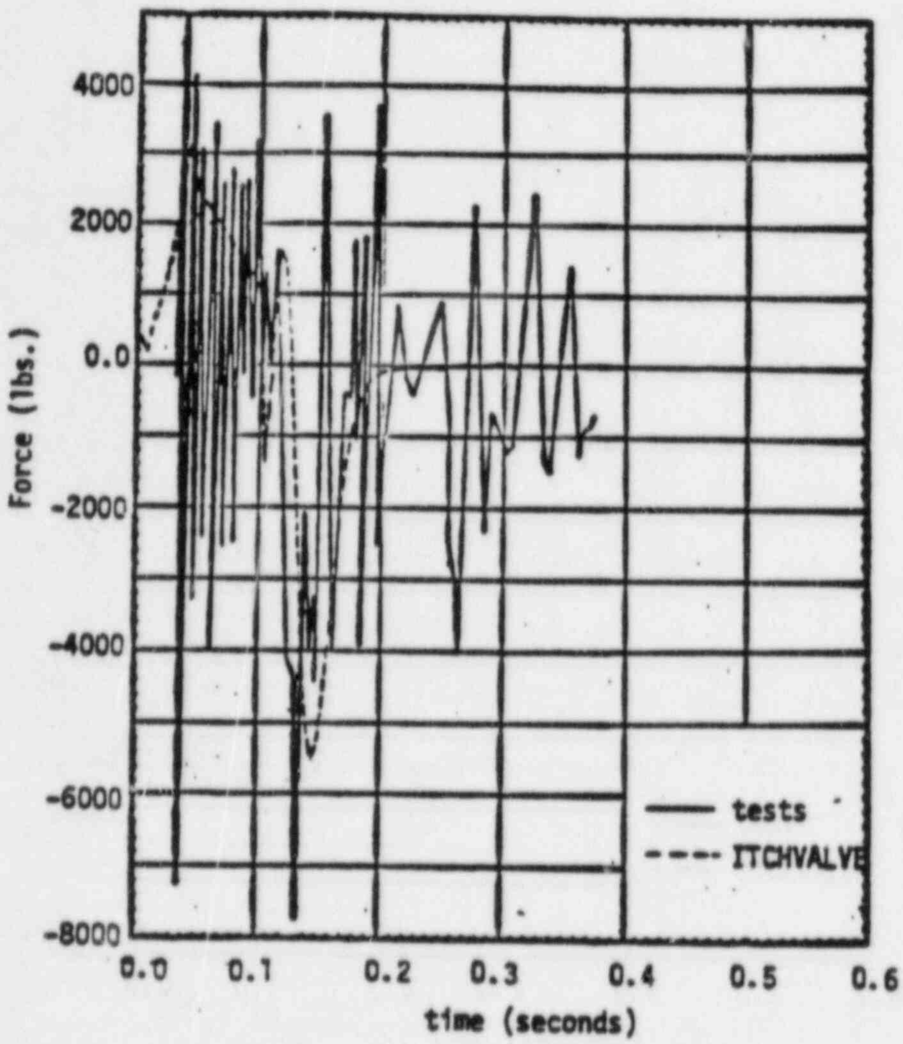


FIGURE 4-8 : Comparison of the EPRI Force Time-History for WE28 and WE29 from Test 917 with the ITCHVALVE Predicted Force Time-History

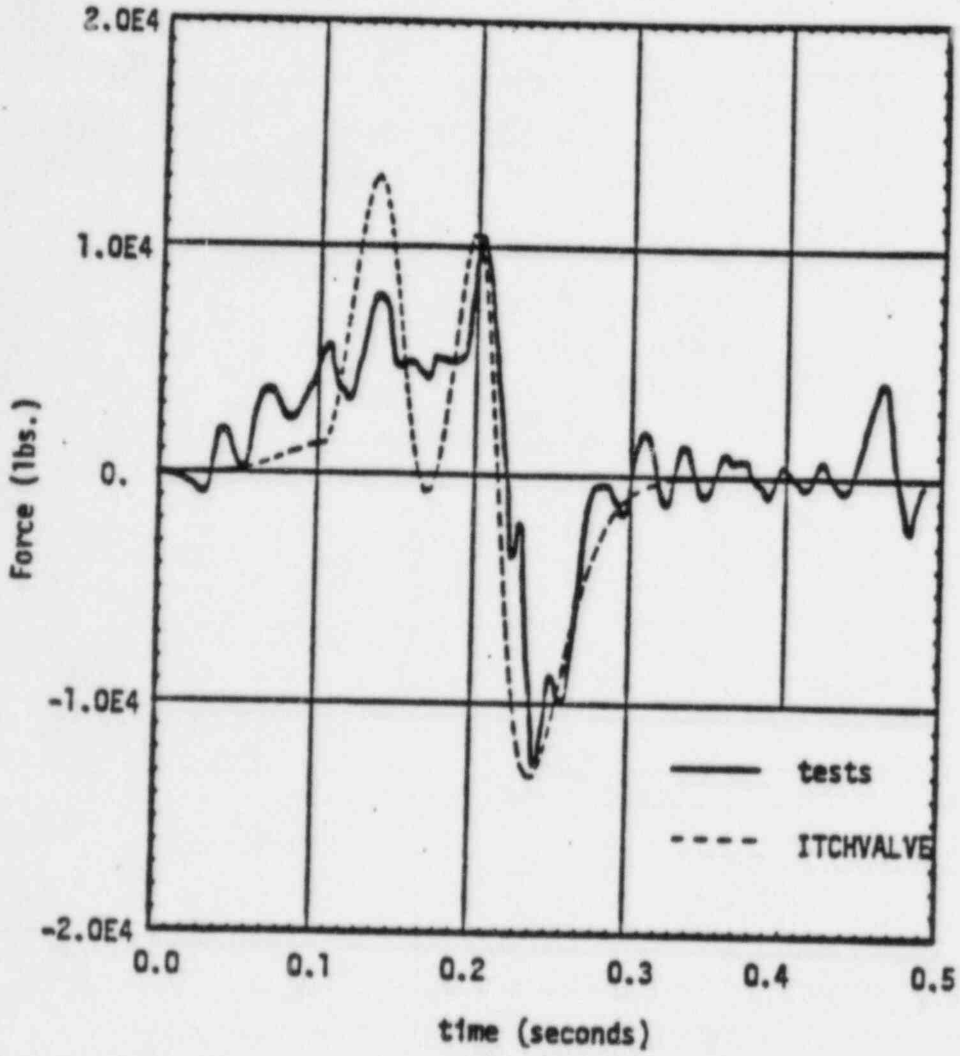


FIGURE 4-9 : Comparison of the EPRI Force Time-History for WE32 and WE33 from Test 917 with the ITCHVALVE Predicted Force Time-History

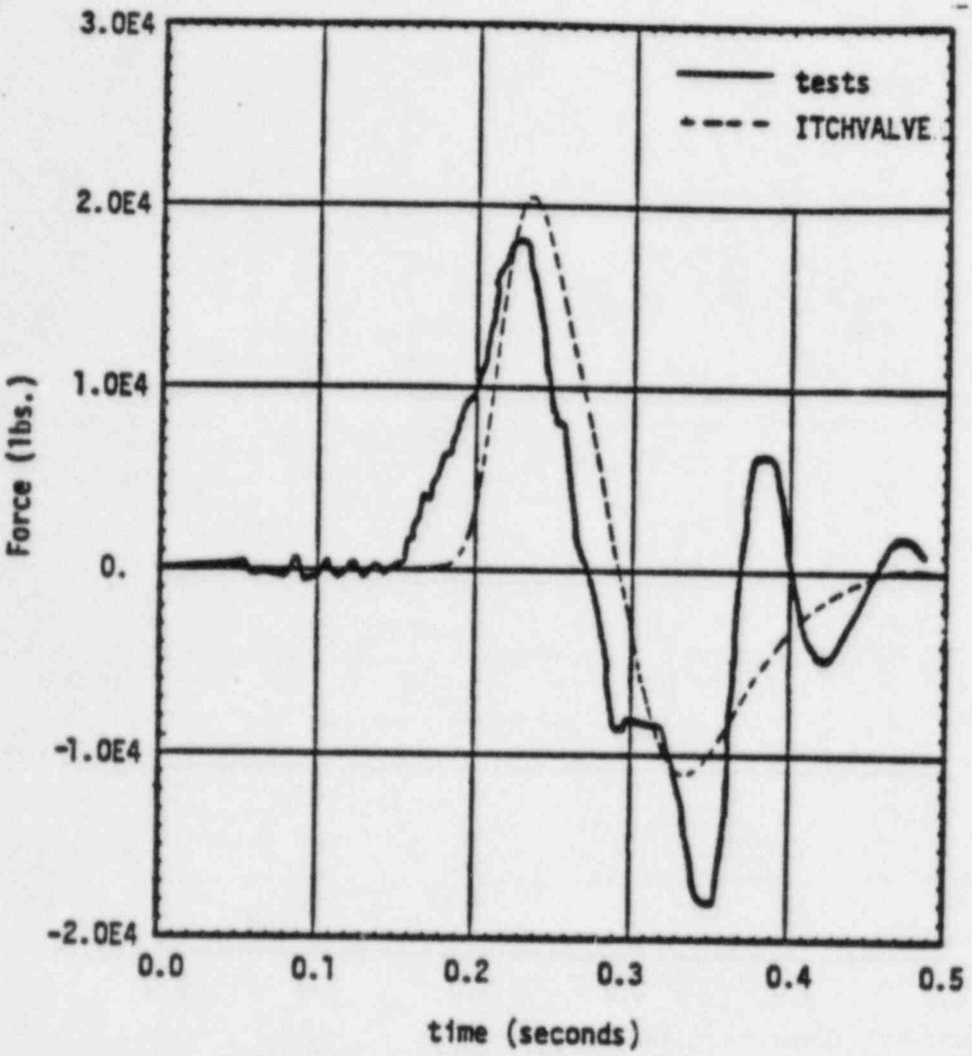


FIGURE 4-10: Comparison of the EPRI Force Time-History For WE30 and WE31 From Test 917 with the ITCHVALVE Predicted Force Time-History

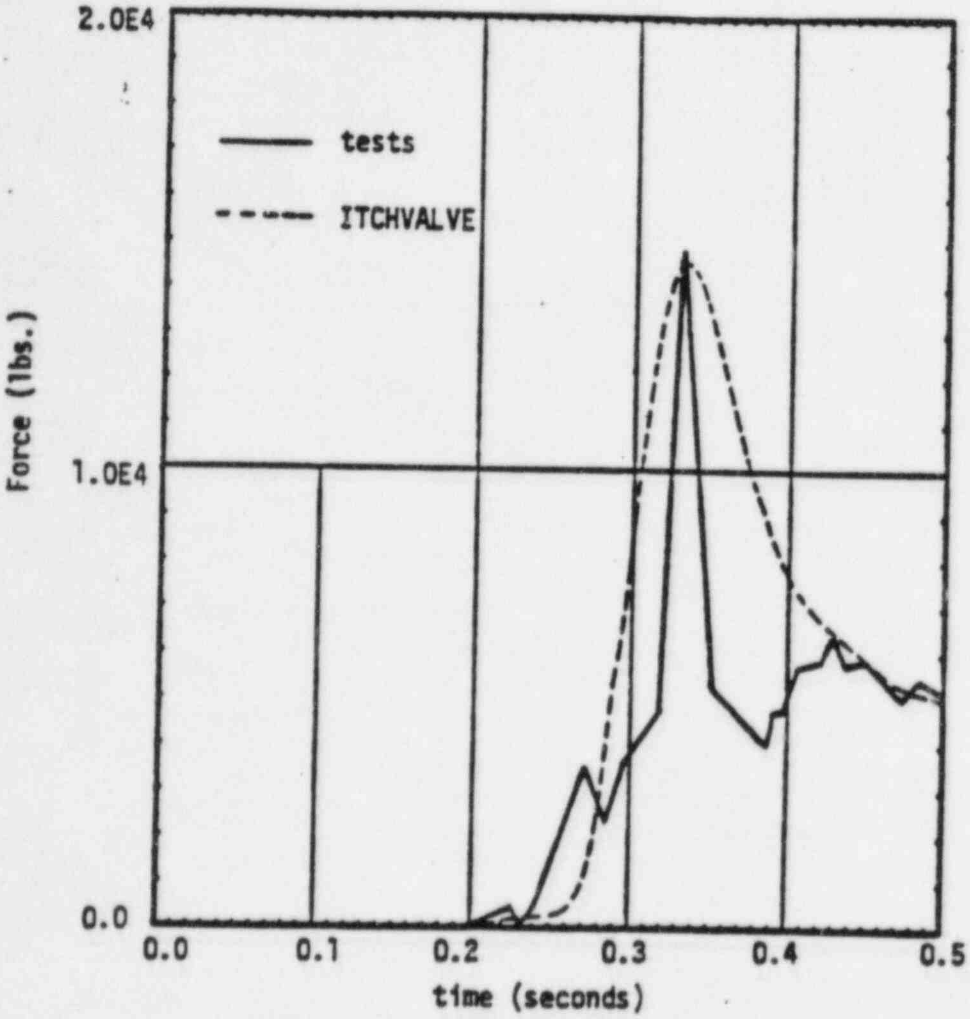


FIGURE 4-11: Comparison of the EPRI Force Time-History For WE34 and WE35 from Test 917 with the ITCHVALVE Predicted Force Time-History

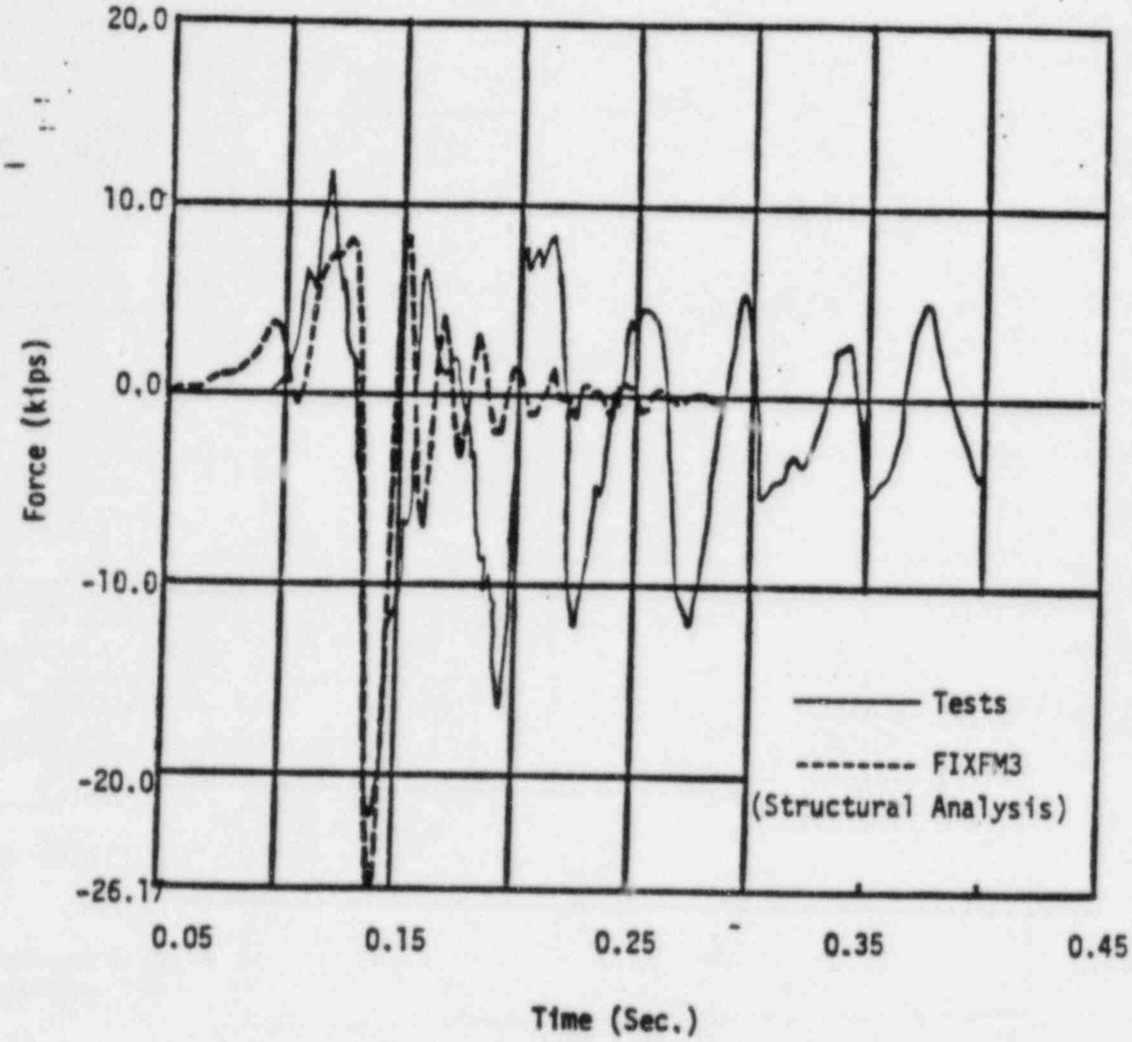


FIGURE 4-12: Comparison of the EPRI Force Time-History for WE28 and WE29 from Test 908 with the FIXFM3 Predicted Force Time-History

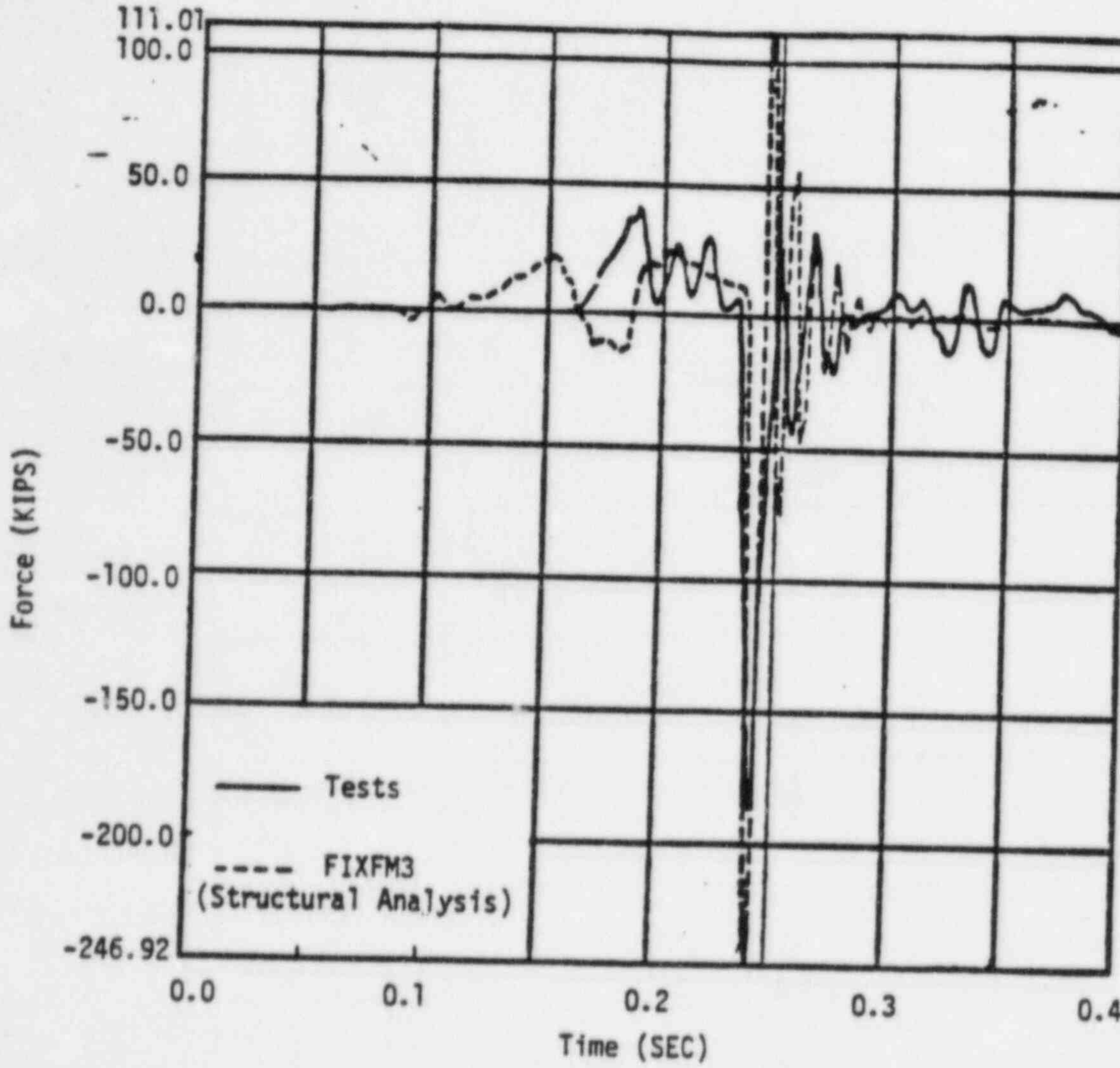


Figure 4-13: Comparison of the EPRI Force Time-History For WE32 and WE33 From Test 908 With the FIXFM3 Predicted Force Time-History

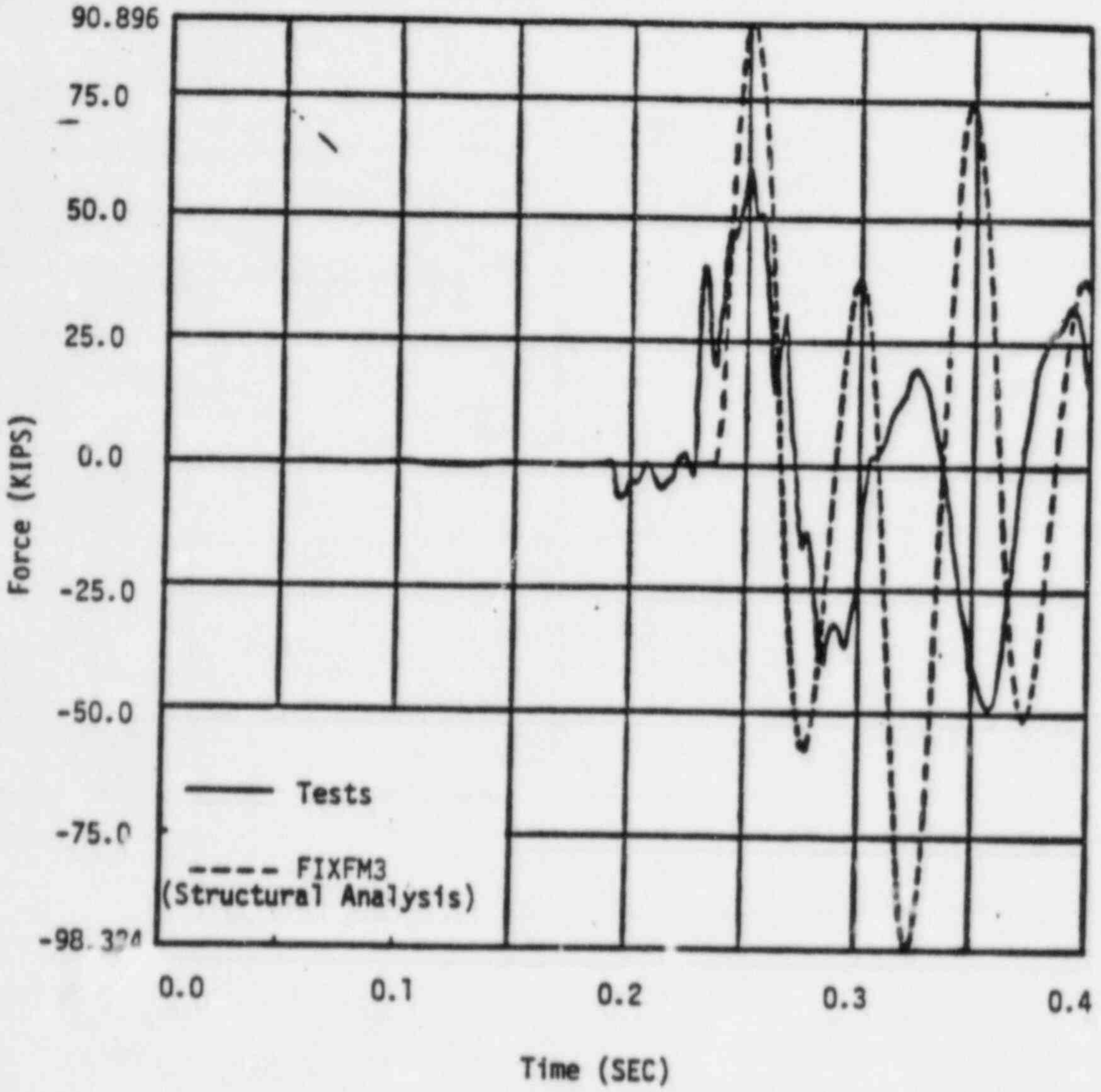


Figure 4-14: Comparison of the EPRI Force Time-History For WE30 and WE31 From Test 908 With the FIXFM3 Predicted Force Time-History

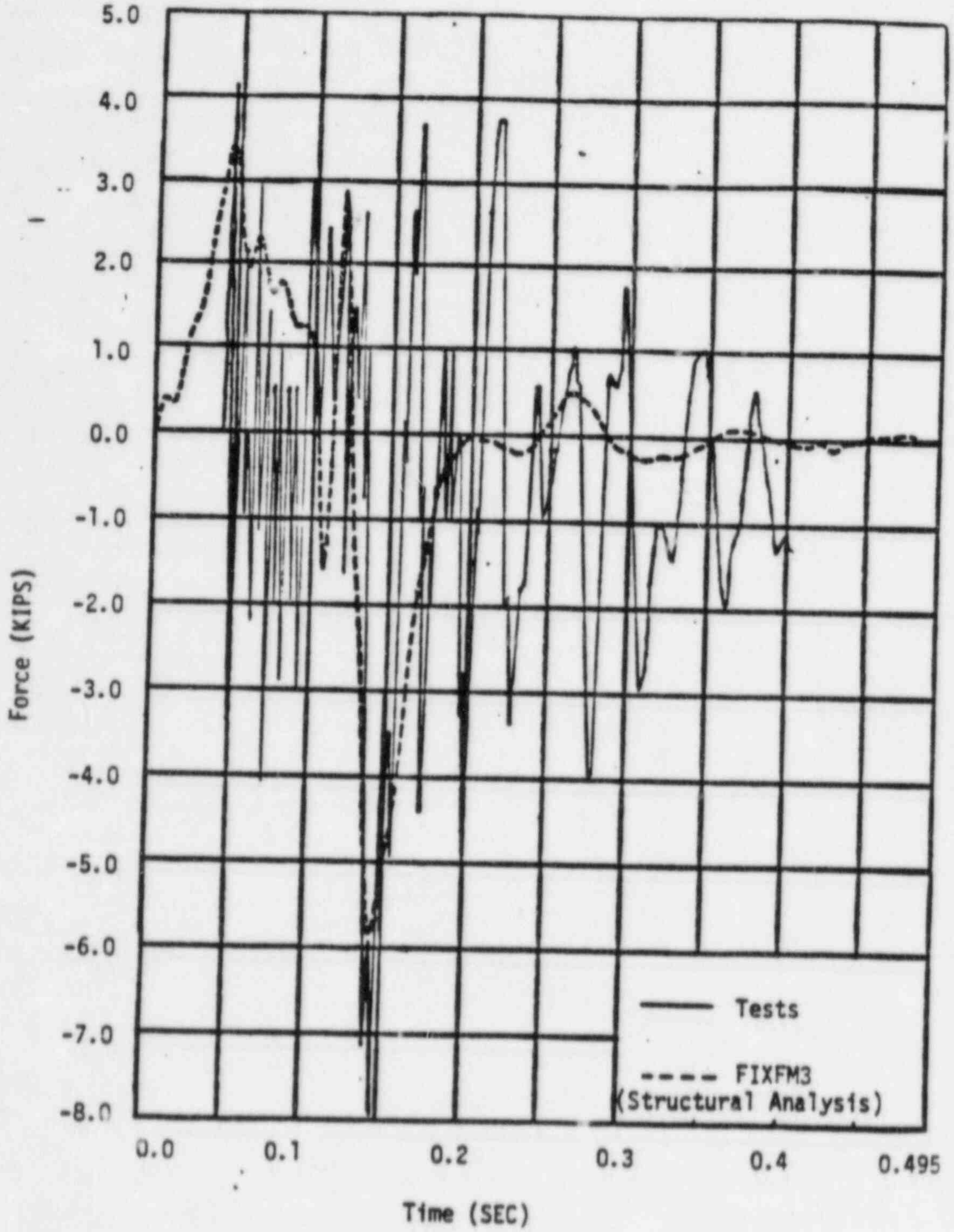


Figure 4-15: Comparison of the EPRI Force Time-History For WE28 and WE29 From Test 917 With the FIXFM3 Predicted Force Time-History

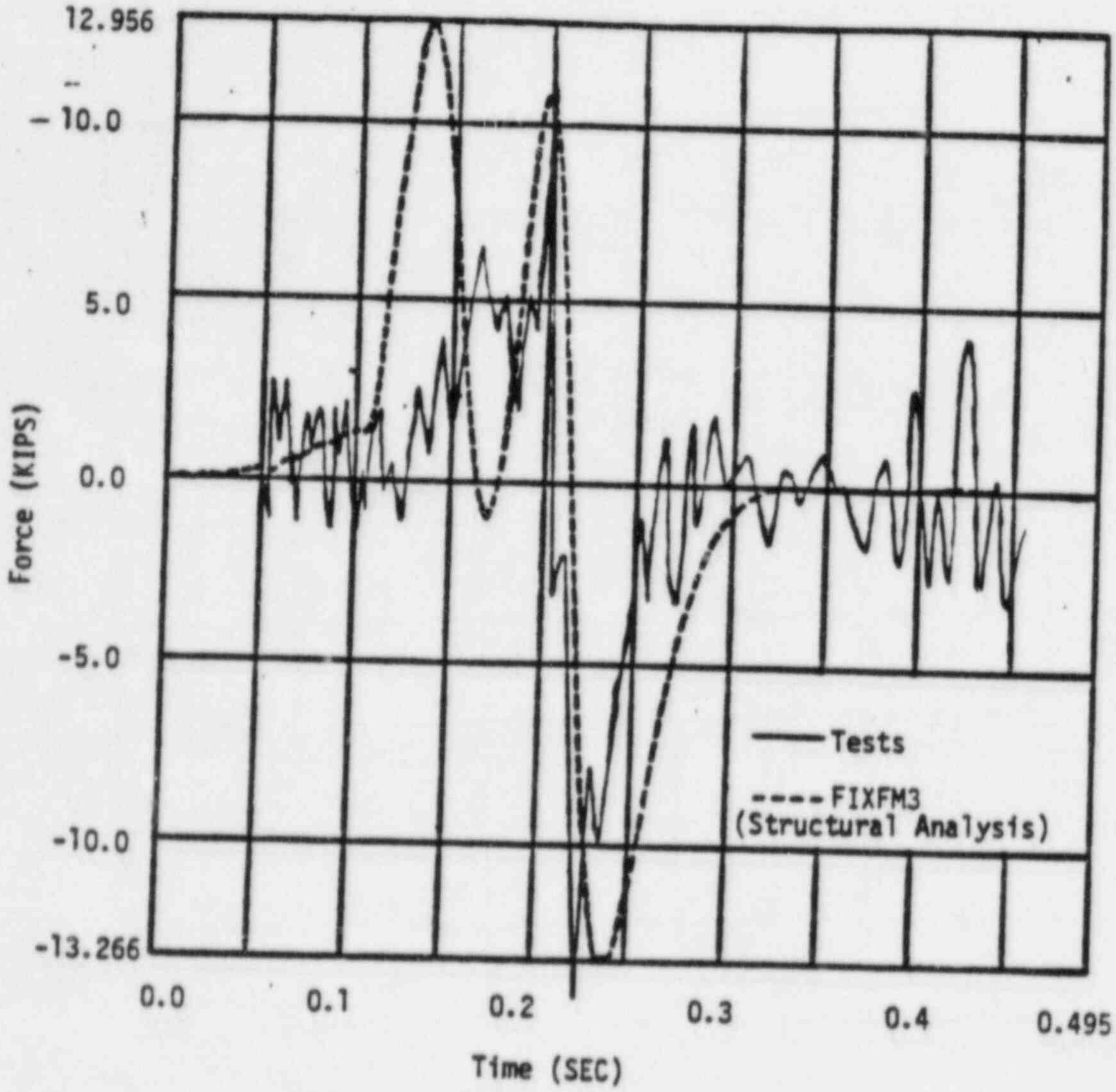


Figure 4-16: Comparison of the EPRI Force Time-History For WE32 and WE33 From Test 917 With the FIXFM3 Predicted Force Time-History

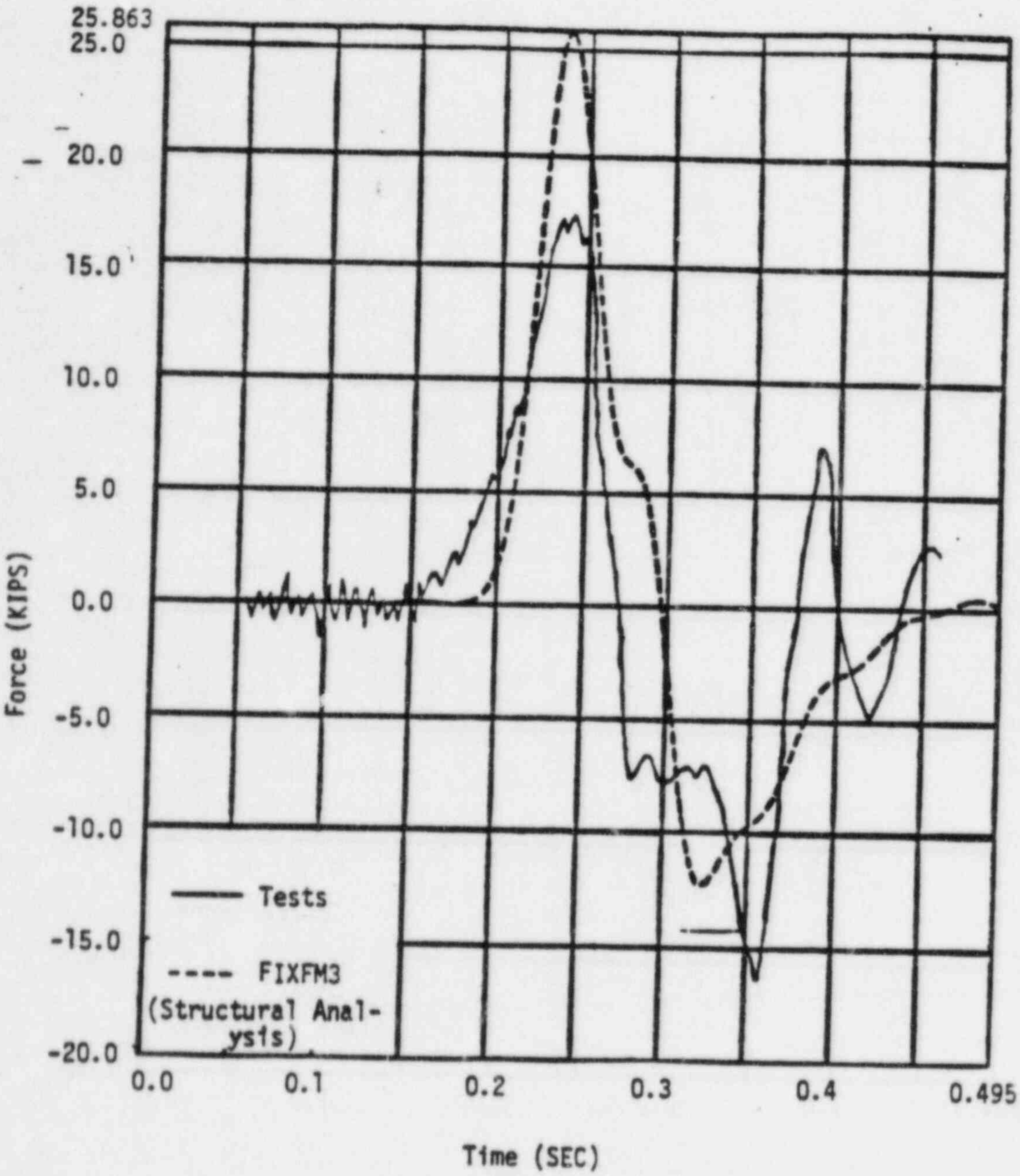


Figure 4-17: Comparison of the EPRI Force Time-History For WE30 and WE31 From Test 917 With the FIXFM3 Predicted Force Time-History

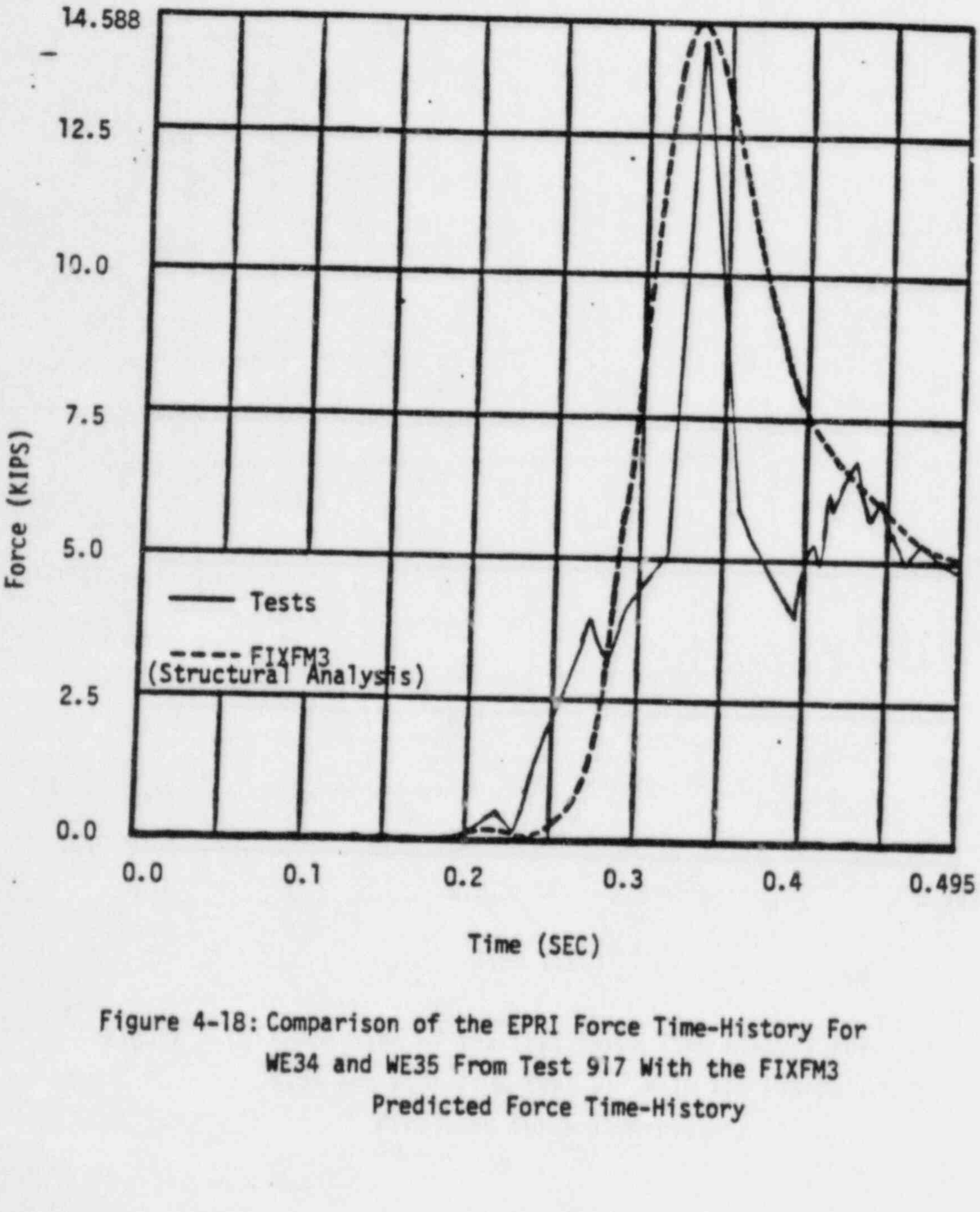


Figure 4-18: Comparison of the EPRI Force Time-History For WE34 and WE35 From Test 917 With the FIXFM3 Predicted Force Time-History

SECTION 5
METHOD OF STRESS EVALUATION

5.1 PRIMARY STRESS EVALUATION

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

5.1.1 DESIGN CONDITIONS

Combined stresses due to primary loadings of pressure, weight, and any other design mechanical loads, calculated using applicable stress intensification factors, must not exceed the allowable limit. The resultant moment, M_i, 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

5.1.2 UPSET CONDITIONS

Combined stresses due to primary loadings of pressure, weight, operating basis earthquake, and relief valve thrust, calculated using applicable stress intensification factors, must not exceed the allowables. The resultant moment, M_i, is calculated as shown below.

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

where

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

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

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

5.1.3 EMERGENCY CONDITIONS

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

5.1.4 FAULTED CONDITIONS

Combined stresses due to primary loadings of pressure, weight, safe shutdown earthquake, and SOT_F, using applicable stress intensification factors, must not exceed the allowable limits. The magnitude of the resultant moment, M_i, is calculated from the three moment components as shown below.

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

where

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

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

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

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

5.2 SECONDARY STRESS EVALUATION

Combined stresses due to all thermal loadings, using applicable stress intensification factors, must not exceed the allowable limit of S_A for thermal only or $(S_h + S_A)$ for thermal, pressure, and weight. 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

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SECTION 6
RESULTS

6.1 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 either the simultaneous opening of both safety valves or the simultaneous opening of both relief valves since each of these represents the worst probable valve discharge shock loading for its applicable plant operating condition.

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

Cold water seals were assumed to exist upstream of the relief valves.

Hot water seals were assumed to exist upstream of the safety valves. The loop seal temperature distribution for this case was presumed to be consistent with the distribution in EPRI Test 917. That is, the fluid temperature at the valve inlet was about 300°F, and, approximately eight feet upstream, the fluid temperature was near the system saturation temperature of 655°F. Based upon engineering judgement, significant flashing of hot water to steam occurred near the valve for Test 917, thus reducing 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 permissible pressure. The piping between the pressurizer nozzles and the inlets of the safety valves is 6-inch schedule 160. The calculated maximum upstream pressure for this size

of pipe is below the maximum permissible 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 STRUCTURAL RESULTS

Stress summaries for all loading cases considered are provided in Tables 6-3 through 6-24. A plot of the structural model is shown in Figure 6-1.

For the purpose of providing stress summaries, the system was divided into the following four sections:

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

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

Section 3: Piping between the pressurizer and the safety valve outlet nozzles (upstream of valves).

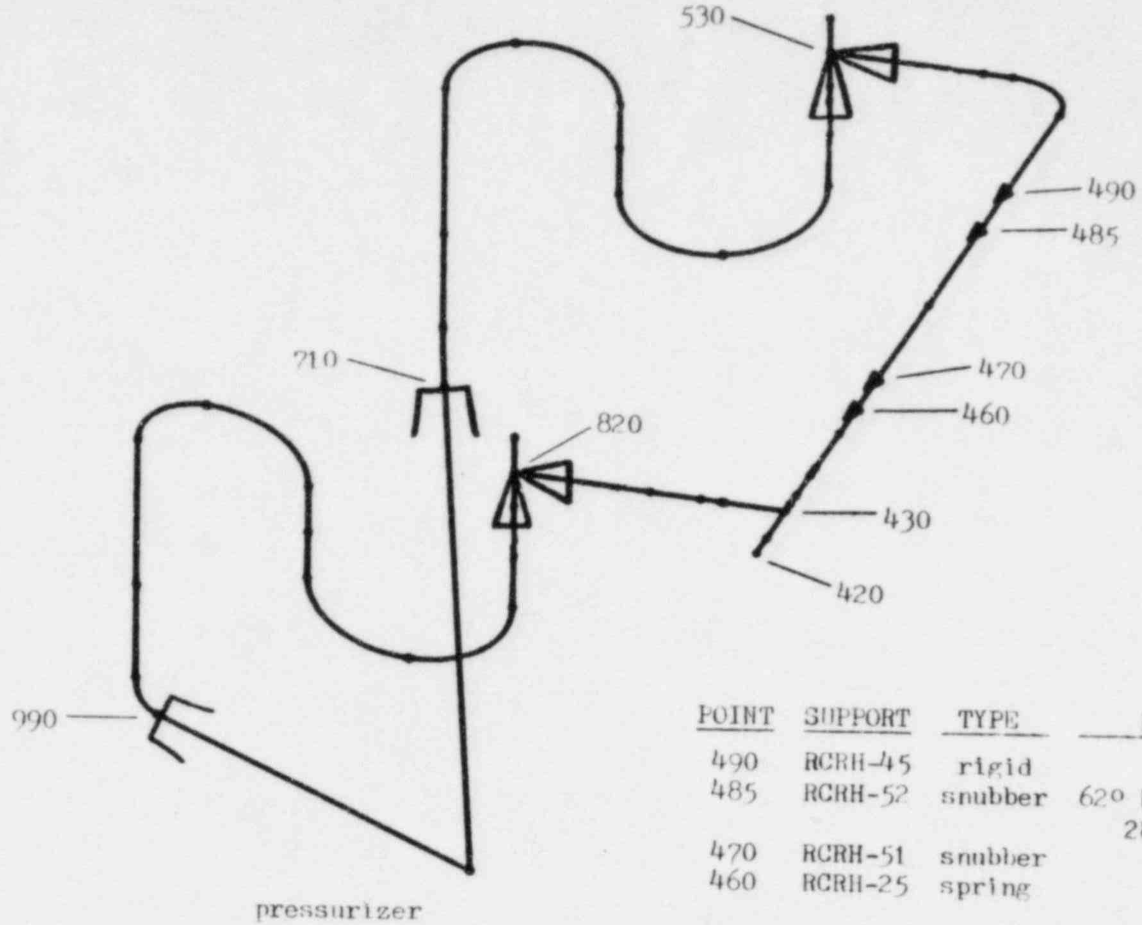
Section 4: Piping between the safety valve outlet nozzles and the pressurizer relief tank (downstream of valves).

Our evaluation conducted prior to the completion of the structural analysis and based upon the thermal hydraulic loadings for the simultaneous discharge of either both safety valves or both relief valves indicated that the piping could be qualified. The structural analyses have been completed and have confirmed and quantified this as shown in Tables 6-3 through 6-24.

In addition, the acceptability of the valve nozzles, valve accelerations, and equipment nozzles was assured for the applied loads.

6.3 SUMMARY OF RESULTS AND CONCLUSIONS

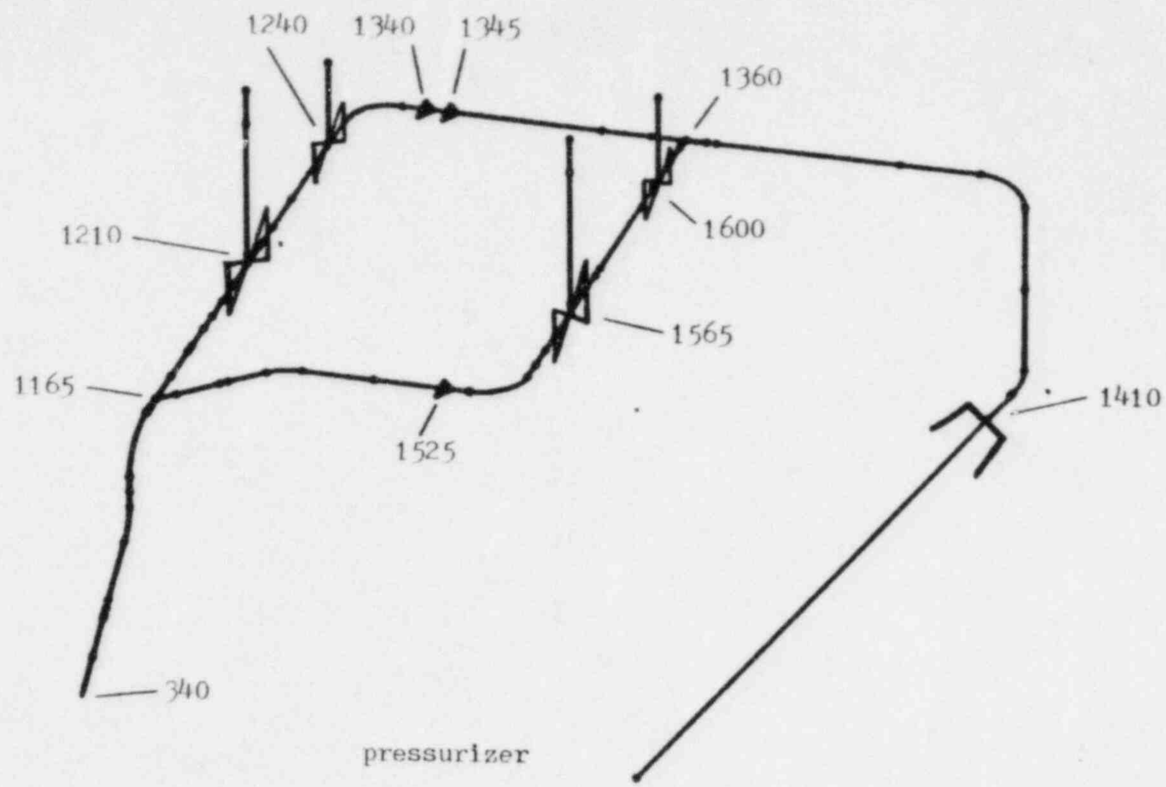
The thermal hydraulic analysis and structural evaluation of the Prairie Island Unit 1 pressurizer safety and relief valve discharge piping system have been completed. In summary, the operability and structural integrity of the system have been ensured for all applicable loadings and load combinations including all pertinent safety and relief valve discharge cases.



POINT	SUPPORT	TYPE	DIRECTION
490	RCRH-45	rigid	axial
485	RCRH-52	snubber	62° horizontal and 28° vertical
470	RCRH-51	snubber	vertical
460	RCRH-25	spring	vertical

POINT	VALVE
530	RC-10-2
820	RC-10-1

FIGURE 6-1 PRESSURIZER SAFETY AND RELIEF LINE STRUCTURAL MODEL



POINT	SUPPORT	TYPE	DIRECTION
1345	RCRH-34	snubber	242° horizontal and 41° vertical
1340	RCRH-33	spring	vertical
1525	RCRH-35	spring	vertical

POINT	VALVE
1240	MV-32196
1210	CV-31232
1600	MV-32195
1565	CV-31231

FIGURE 6-1 (cont.) PRESSURIZER SAFETY AND RELIEF LINE STRUCTURAL MODEL

POINT	SUPPORT	TYPE	DIRECTION
400	RCRH-46	rigid	axial
330	RCRH-27	snubber	88° horizontal
331	RCRH-27	snubber	318° horizontal
310	RCRH-47	snubber	vertical
290	RCRH-28	rigid	0° horizontal
291	RCRH-28	rigid	90° horizontal
275	RCRH-29	spring	vertical
250	RCRH-30	rigid	45° horizontal
210	RCRH-48	snubber	axial
185	RCRH-32	rigid	62° horizontal
185	RCRH-32	spring	vertical
135	RCRH-49	rigid	axial

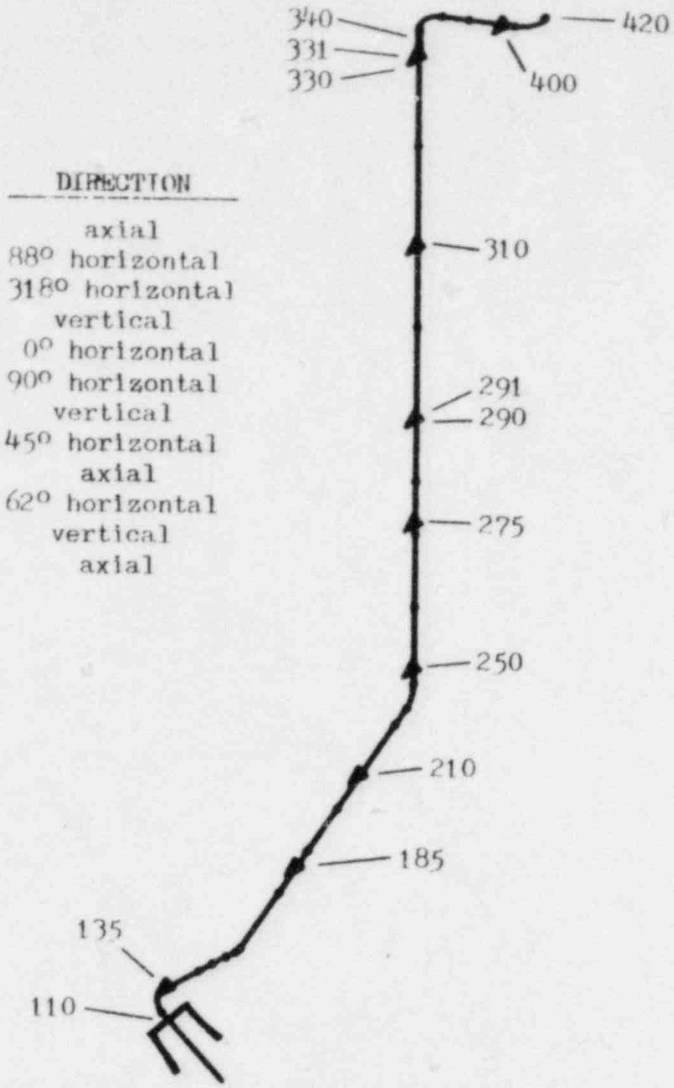


FIGURE 6-1 (cont.) PRESSURIZER SAFETY AND RELIEF LINE STRUCTURAL MODEL

TABLE 6-1

HYDRAULIC FORCES
PRESSURIZER SAFETY LINE

Force No.	Force (lbf)
1	50
2	360
3	190
4	2840
5	2690
6	2680
7	2330
8	5780
9	7160
10	50
11	360
12	180
13	2880
14	2680
15	2690
16	2530
17	4220
18	17700
19	49700
20	53400
21	14200
22	15800

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

TABLE 6-2

HYDRAULIC FORCES
PRESSURIZER RELIEF LINE

Force No.	Force (lbf))
1	220
2	330
3	250
4	500
5	770
6	320
7	630
8	490
9	850
10	1100
11	16000
12	1000
13	220
14	240
15	250
16	500
17	870
18	710

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

TABLE 6-3

STRESS SUMMARY
PRESSURIZER RELIEF LINE
UPSTREAM OF VALVES
$P + WT < 1.0\ S_h$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
1225	Straight run	5.2	15.9
1225	Butt weld	5.2	15.9
1220	Socket Weld	7.0	15.9
1330	Elbow	4.2	15.9
1220	Reducer	9.9	15.9
1360	Tee	4.6	15.9

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

TABLE 6-4

STRESS SUMMARY
PRESSURIZER RELIEF LINE
UPSTREAM OF VALVES
$P + WT + OBE + SOT_U < 1.2\ S_h$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
1365	Straight run	13.0	19.1
1410	Butt weld	14.7	19.1
1220	Socket weld	16.7	19.1
1400	Elbow	10.4	19.1
1220	Reducer	19.6	19.9
1360	Tee	11.1	19.1

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

TABLE 6-5

STRESS SUMMARY
PRESSURIZER RELIEF LINE
UPSTREAM OF VALVES
$P + WT + SOT_E < 1.8\ S_h$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
1365	Straight run	7.0	28.6
1365	Butt weld	7.0	28.6
1220	Socket weld	9.6	28.6
1400	Elbow	5.5	28.6
1220	Reducer	13.7	28.6
1360	Tee	6.3	28.6

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

TABLE 6-6

STRESS SUMMARY
PRESSURIZER RELIEF LINE
UPSTREAM OF VALVES
$P + WT + SSE + SOT_F < 2.4\ S_h$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
1395	Straight run	16.8	38.2
1410	Butt weld	21.2	38.2
1220	Socket weld	18.4	38.2
1400	Elbow	14.8	38.2
1220	Reducer	27.0	38.2
1360	Tee	11.9	38.2

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

TABLE 6-7

STRESS SUMMARY
PRESSURIZER RELIEF LINE
UPSTREAM OF VALVES
$P + WT + TH < 1.0\ S_h + 1.0\ S_a$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
1395	Straight run	28.7	43.4
1410	Butt weld	34.7	43.4
1575	Socket Weld	32.1	43.4
1400	Elbow	19.3	43.4
1575	Reducer	36.2	43.4
1360	Tee	18.1	43.4

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

TABLE 6-8

STRESS SUMMARY
PRESSURIZER RELIEF LINE
DOWNSTREAM OF VALVES
$P + WT < 1.0 S_h$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
185	Straight run	4.0	15.9
160	Butt weld	3.6	15.9
1200	Socket weld	6.5	15.9
160	Elbow	3.8	15.9
1200	Reducer	6.3	15.9
150	Tee	3.7	15.9
340	Branch connection	3.5	15.9

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

TABLE 6-9

STRESS SUMMARY
PRESSURIZER RELIEF LINE
DOWNSTREAM OF VALVES
$P + WT + SOT_U < 1.2\ S_h$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
1530	Straight run	10.6	19.1
1530	Butt weld	10.6	19.1
1200	Socket weld	22.5	22.6
1510	Elbow	7.8	19.1
1200	Reducer	22.5	22.6
150	Tee	4.9	19.1
1165	Branch connection	15.3	19.1

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

TABLE 6-10

STRESS SUMMARY
PRESSURIZER RELIEF LINE
DOWNSTREAM OF VALVES
$P + WT + OBE + SOT_U < 1.8\ S_h$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
1530	Straight run	10.8	28.6
1530	Butt weld	10.8	28.6
1200	Socket weld	24.2	28.6
1510	Elbow	8.1	28.6
1200	Reducer	28.5	28.6
150	Tee	4.9	28.6
1165	Branch connection	15.6	28.6

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

TABLE 6-11

STRESS SUMMARY
PRESSURIZER RELIEF LINE
DOWNSTREAM OF VALVES
$P + WT + SOT_E < 1.8\ S_h$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
170	Straight run	7.8	28.6
170	Butt weld	7.8	28.6
1555	Socket weld	14.0	28.6
170	Elbow	9.8	28.6
1555	Reducer	13.5	28.6
150	Tee	7.6	28.6
340	Branch connection	8.1	28.6

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

TABLE 6-12

STRESS SUMMARY
PRESSURIZER RELIEF LINE
DOWNSTREAM OF VALVES
$P + WT + SSE + SOT_F < 2.4\ S_h$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
1530	Straight run	11.4	38.2
1530	Butt weld	11.4	38.2
1200	Socket weld	31.9	38.2
170	Elbow	9.9	38.2
1200	Reducer	30.6	38.2
150	Tee	7.7	38.2
340	Branch connection	18.3	38.2

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

TABLE 6-13

STRESS SUMMARY
PRESSURIZER RELIEF LINE
DOWNSTREAM OF VALVES
$P + WT + TH < 1.0\ S_h + 1.0\ S_a$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
1530	Straight run	37.4	43.4
1530	Butt weld	37.4	43.4
1555	Socket weld	43.3	43.4
230	Elbow	17.8	43.4
1555	Reducer	36.2	43.4
150	Tee	8.6	43.4
1165	Branch connection	35.3	43.4

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

TABLE 6-14

STRESS SUMMARY
PRESSURIZER SAFETY LINE
UPSTREAM OF VALVES
$P + WT < 1.0\ S_h$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
670	Straight run	5.4	16.5
670	Butt weld	5.4	16.5
670	Elbow	5.1	16.5

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

TABLE 6-15

STRESS SUMMARY
PRESSURIZER SAFETY LINE
UPSTREAM OF VALVES
$P + WT + OBE + SOT_U < 1.2\ S_h$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
690	Straight run	6.4	19.8
700	Butt weld	6.7	19.8
700	Elbow	6.0	19.8

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

TABLE 6-16

STRESS SUMMARY
PRESSURIZER SAFETY LINE
UPSTREAM OF VALVES
$P + WT + SOT_E < 1.8\ S_h$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
690	Straight run	13.1	29.6
700	Butt weld	14.9	29.6
700	Elbow	12.1	29.6

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

TABLE 6-17

STRESS SUMMARY
PRESSURIZER SAFETY LINE
UPSTREAM OF VALVES
$P + WT + SSE + SOT_F < 2.4 S_h$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
690	Straight run	13.4	39.5
700	Butt weld	15.1	39.5
700	Elbow	12.2	39.5

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

TABLE 6-18

STRESS SUMMARY
PRESSURIZER SAFETY LINE
UPSTREAM OF VALVES
$P + WT + TH < 1.0\ S_h + 1.0\ S_a$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
970	Straight run	15.6	44.1
980	Butt weld	17.6	44.1
980	Elbow	12.3	44.1

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

TABLE 6-19

STRESS SUMMARY
PRESSURIZER SAFETY LINE
DOWNSTREAM OF VALVES
$P + WT < 1.0\ S_h$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
455	Straight run	5.2	15.9
455	Butt weld	5.2	15.9
510	Elbow	4.2	15.9
455	Reducer	6.2	15.9
150	Tee	3.7	15.9
340	Branch connection	3.5	15.9

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

TABLE 6-20

STRESS SUMMARY
PRESSURIZER SAFETY LINE
DOWNSTREAM OF VALVES
$P + WT + SOT_U < 1.2\ S_h$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
455	Straight run	7.3	19.1
455	Butt weld	7.3	19.1
240	Elbow	5.3	19.1
455	Reducer	8.6	19.1
430	Tee	5.3	19.1
340	Branch connection	12.8	19.1

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

TABLE 6-21

STRESS SUMMARY
PRESSURIZER SAFETY LINE
DOWNSTREAM OF VALVES
$P + WT + OBE + SOT_U < 1.8\ S_h$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
455	Straight run	7.6	28.6
455	Butt weld	7.6	28.6
510	Elbow	5.6	28.6
455	Reducer	8.9	28.6
430	Tee	5.3	28.6
340	Branch connection	14.2	28.6

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

TABLE 6-22

STRESS SUMMARY
PRESSURIZER SAFETY LINE
DOWNSTREAM OF VALVES
$P + WT + SOT_E < 1.8\ S_h$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
455	Straight run	19.7	28.6
455	Butt weld	19.7	28.6
510	Elbow	10.8	28.6
455	Reducer	22.3	28.6
430	Tee	11.1	28.6
340	Branch connection	8.1	28.6

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

TABLE 6-23

STRESS SUMMARY

PRESSURIZER SAFETY LINE

DOWNSTREAM OF VALVES

$P + WT + SSE + SOT_F < 2.4\ S_h$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
455	Straight run	19.9	38.2
455	Butt weld	19.9	38.2
510	Elbow	11.1	38.2
455	Reducer	22.5	38.2
430	Tee	11.2	38.2
340	Branch connection	18.3	38.2

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

TABLE 6-24

STRESS SUMMARY
PRESSURIZER SAFETY LINE
DOWNSTREAM OF VALVES
$P + WT + TH < 1.0\ S_h + 1.0\ S_a$

Node Point	Piping Component	Maximum Stress (ksi)	Allowable Stress (ksi)
455	Straight run	20.3	43.4
805	Butt weld	21.1	43.4
230	Elbow	17.8	43.4
450	Reducer	23.6	43.4
430	Tee	21.2	43.4
340	Branch connection	26.6	43.4

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