

WESTINGHOUSE PROPRIETARY CLASS 3

PRESSURIZER SAFETY AND RELIEF LINE EVALUATION

SUMMARY REPORT


CAROLINA POWER AND LIGHT COMPANY

H. B. ROBINSON UNIT 2

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SECTION 1 INTRODUCTION

The pressurizer safety and relief valve (PSARV) discharge piping system for pressurized water reactors, located on 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.

This report is the response of the Carolina Power and Light Company to the US NRC plant-specific submittal request for piping evaluation and is applicable to the H. B. Robinson Unit 2 pressurizer safety and relief valve discharge piping system.

SECTION 2

PIPE STRESS CRITERIA

2.1 PIPE STRESS CALCULATION

The piping between the pressurizer nozzles and the pressurizer relief tank was analyzed according to the requirements of the appropriate equations of the ANSI B31.1-1967 Code (hereafter referred to as the Code). These equations establish limits for stresses from sustained loads, sustained plus occasional loads (including earthquake), thermal expansion loads, and sustained plus thermal expansion loads. The allowable stresses for use with the equations were determined in accordance with the requirements of the Code.

2.2 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. Definitions of the load abbreviations are 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

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

<u>Combination</u>	<u>Plant/System</u>		<u>Load Combination</u>	<u>Piping</u>
	<u>Operating Condition</u>			<u>Allowable Stress Intensity</u>
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	= Maximum of SOT _U and 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

-
- (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 all pertinent loadings. These loadings result from thermal expansion, pressure, weight, earthquake, 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 for various operating modes), define the required input data to perform the flexibility analysis for thermal expansion.

Because of the many possible operating modes, the system may experience many different thermal loadings. The temperatures used in the expansion analysis are based on all available information and include pertinent valve opening cases.

To provide the necessary high degree of integrity for the piping, 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 is based on a plant design life of 40 years.

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

A static seismic analysis is performed as defined in the FSAR. Static coefficients for the accelerations which had been determined from the dynamic analysis of the building structures are applied to the piping system in each of the three coordinate directions. The results from a horizontal direction are then added absolutely to the results from the vertical direction.

3.1.5 SAFETY AND RELIEF VALVE THRUST

The pressurizer safety and relief valve discharge piping system provides 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.

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.

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.

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.

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.

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 system. The deflection solution of the entire system is obtained and then 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 and equipment drawings. 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, thermal, and seismic 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:

$$\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} \Delta_0 \\ F_0 \end{bmatrix} + \begin{bmatrix} \delta_t \\ f_t \end{bmatrix} = \begin{bmatrix} \Delta_i \\ F_i \end{bmatrix}$$

or

$$T_1 B_0 + R_1 = B_1$$

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:

$$B_1 = T_1 B_0 + R_1$$

$$B_2 = T_2 B_1 + R_2 = T_2 T_1 B_0 + T_2 R_1 + R_2$$

$$B_3 = T_3 B_2 + R_3 = T_3 T_2 T_1 B_0 + T_3 T_2 R_1 + T_3 R_2 + R_3$$

or

$$B_n = \begin{pmatrix} n \\ \pi \\ 1 \end{pmatrix} T_r \cdot B_0 + \sum_{r=2}^n \left[\begin{pmatrix} n \\ \pi \\ r \end{pmatrix} T_r \cdot R_{r-1} \right] + R_n$$

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 PRESSURIZER SAFETY AND RELIEF LINE ANALYSIS

4.4.1 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 loop seal 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 characteristic equations:

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

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

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

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

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

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:

$$F_{cv} = \frac{1}{g_c} \frac{\partial}{\partial t} \int_V \rho V dv + \frac{1}{g_c} \int_V \rho V (V \cdot n dA)$$

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

$$F_{\text{pipe}} = \left. \frac{r_1 (1 - \cos \alpha_1)}{g_c \sin \alpha_1} \frac{\partial W}{\partial t} \right|_{\text{Bend 1}} + \left. \frac{r_2 (1 - \cos \alpha_2)}{g_c \sin \alpha_2} \frac{\partial W}{\partial t} \right|_{\text{Bend 2}} + \frac{1}{g_c} \int_{\text{pipe}}^{\text{straight}} \frac{\partial W}{\partial t} dl$$

- 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 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).

4.4.3 VALVE THRUST ANALYSIS

The safety and relief lines were modeled statically and dynamically as described in Sections 4.1 through 4.3. The mathematical model used for dynamic analyses 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 WESDYN2 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 determination.

The time-history internal forces and displacements of the WESDYN2 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 determination.

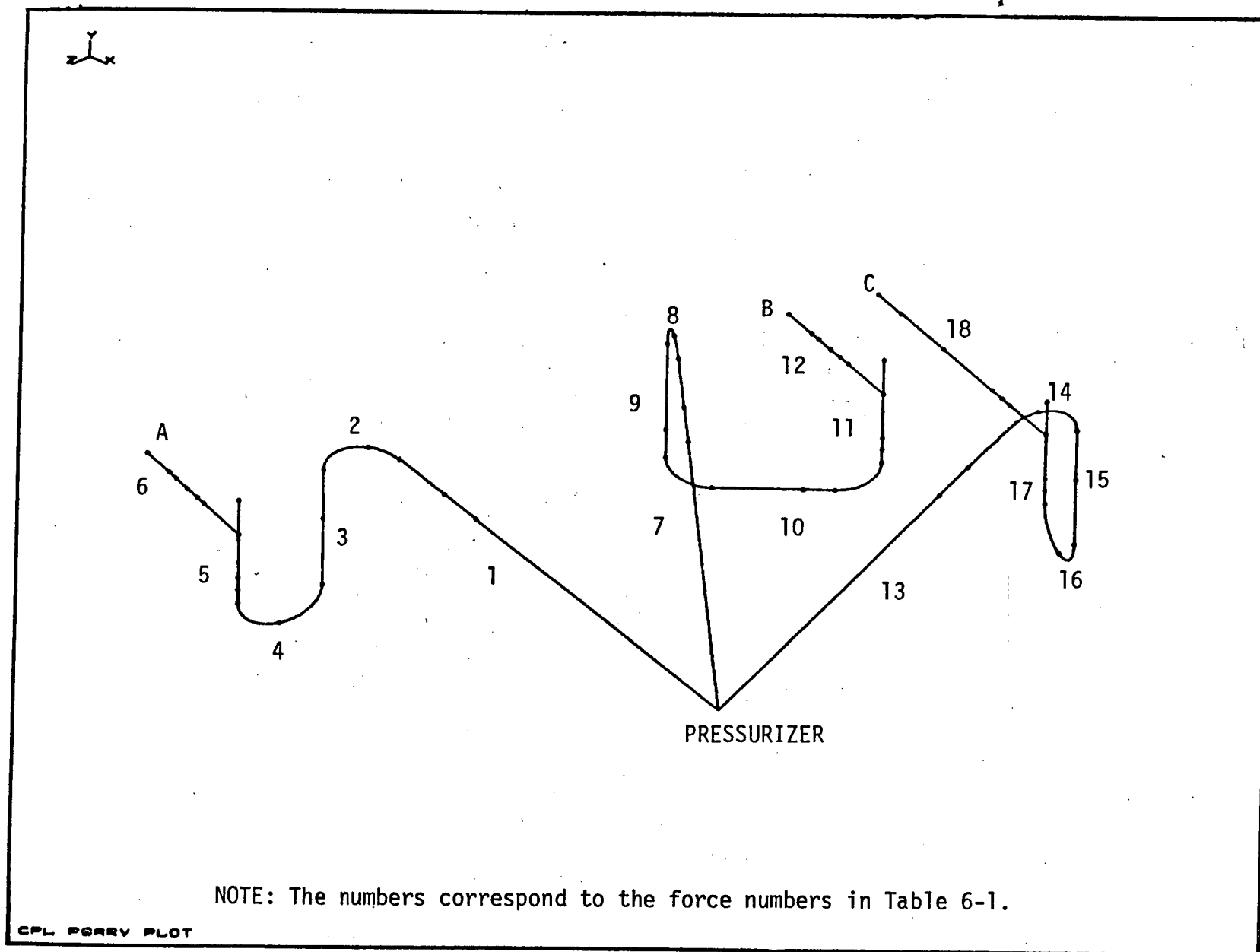


FIGURE 4-1: HYDRAULIC MODEL, SAFETY LINE

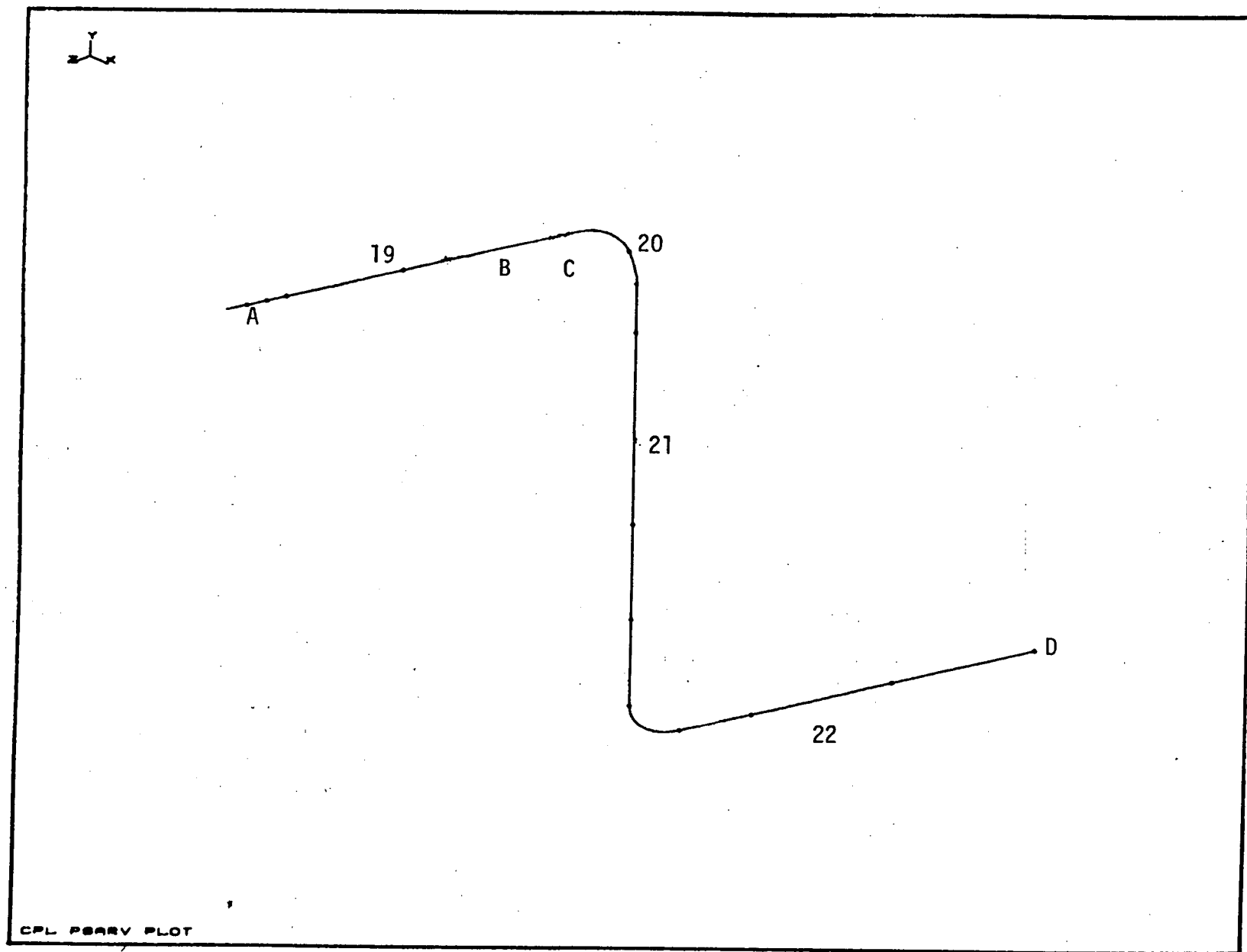


FIGURE 4-1: (CONT.) HYDRAULIC MODEL, SAFETY LINE

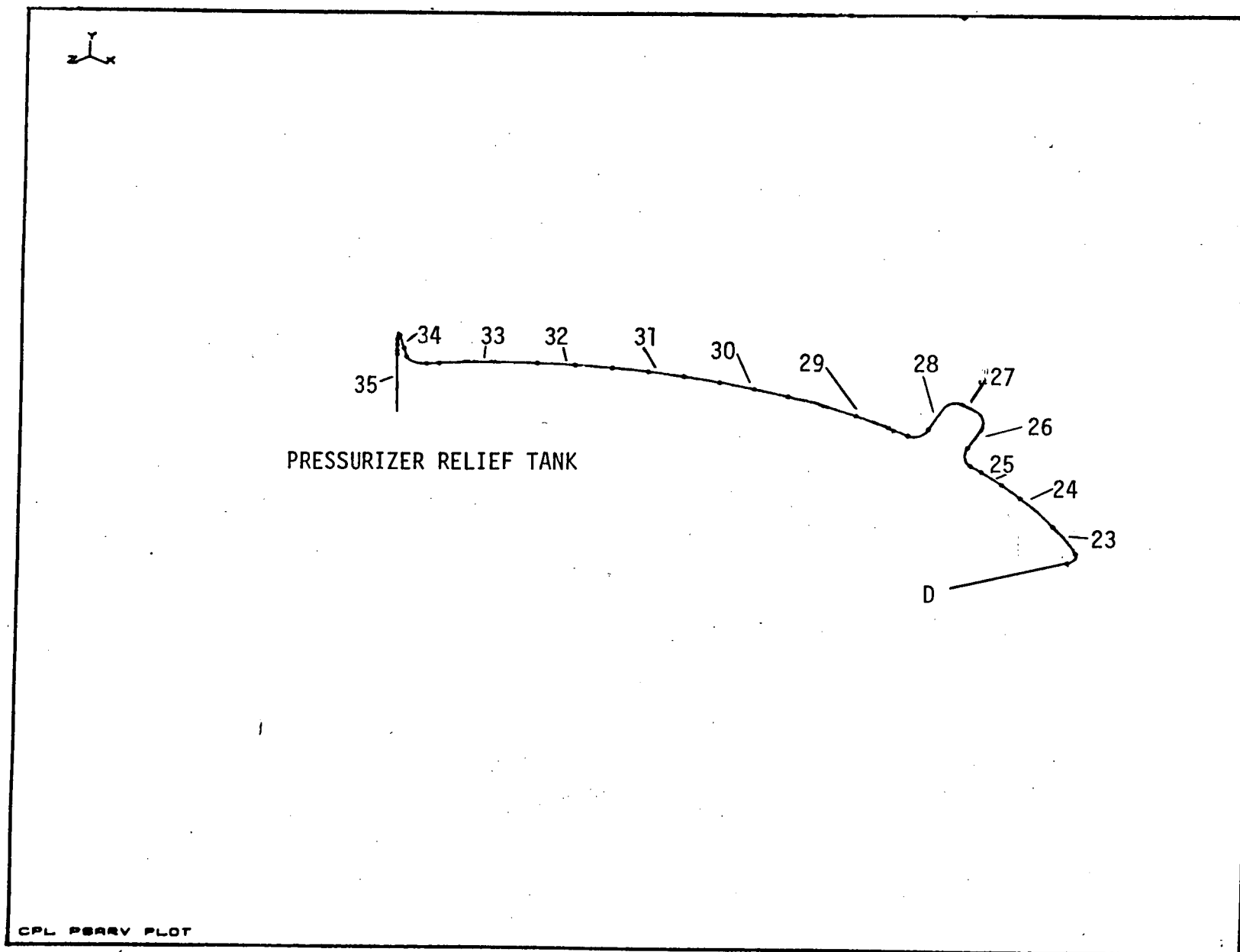


FIGURE 4-1: (CONT.) HYDRAULIC MODEL, SAFETY LINE

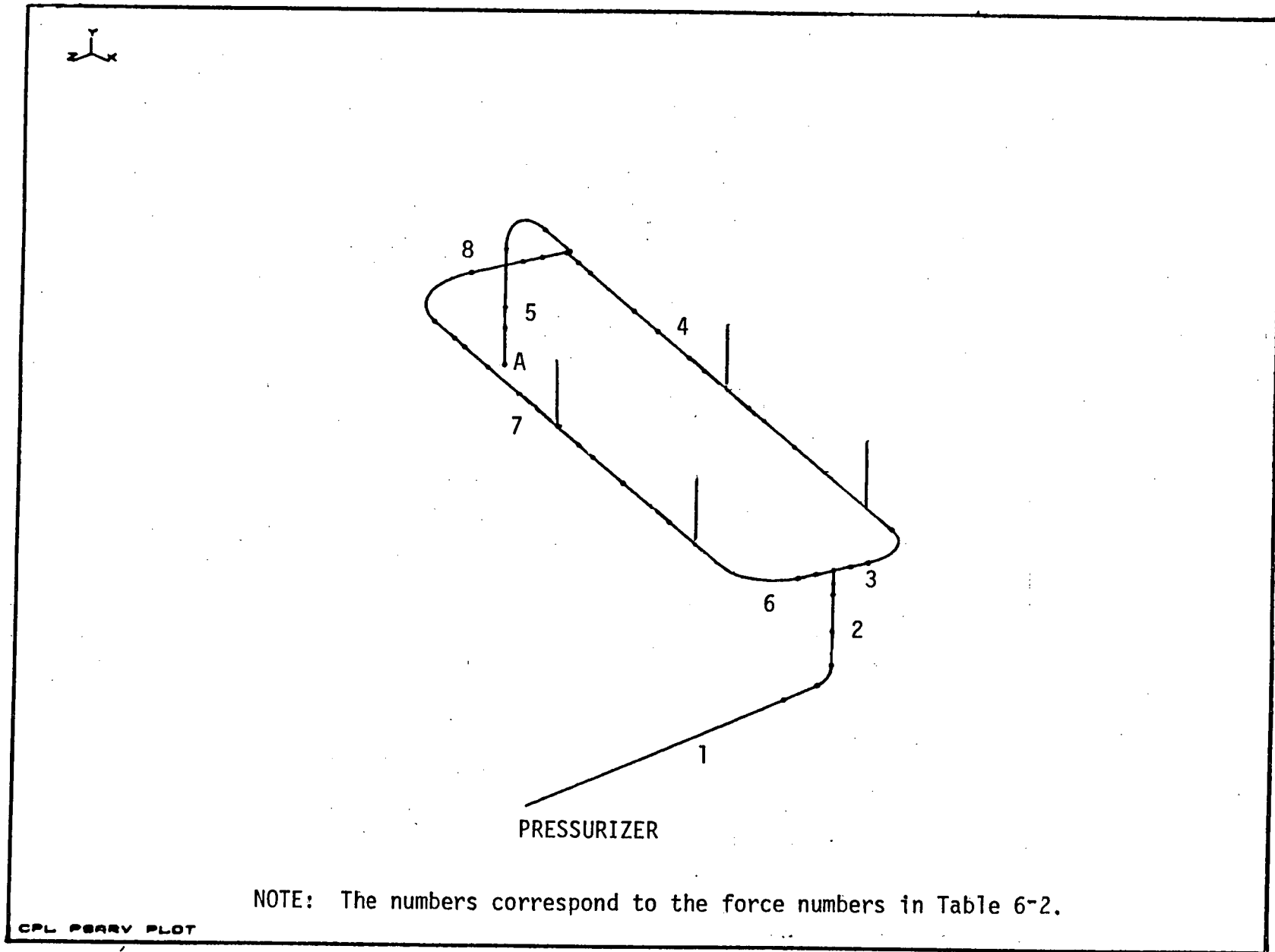


FIGURE 4-2: HYDRAULIC MODEL, RELIEF LINE

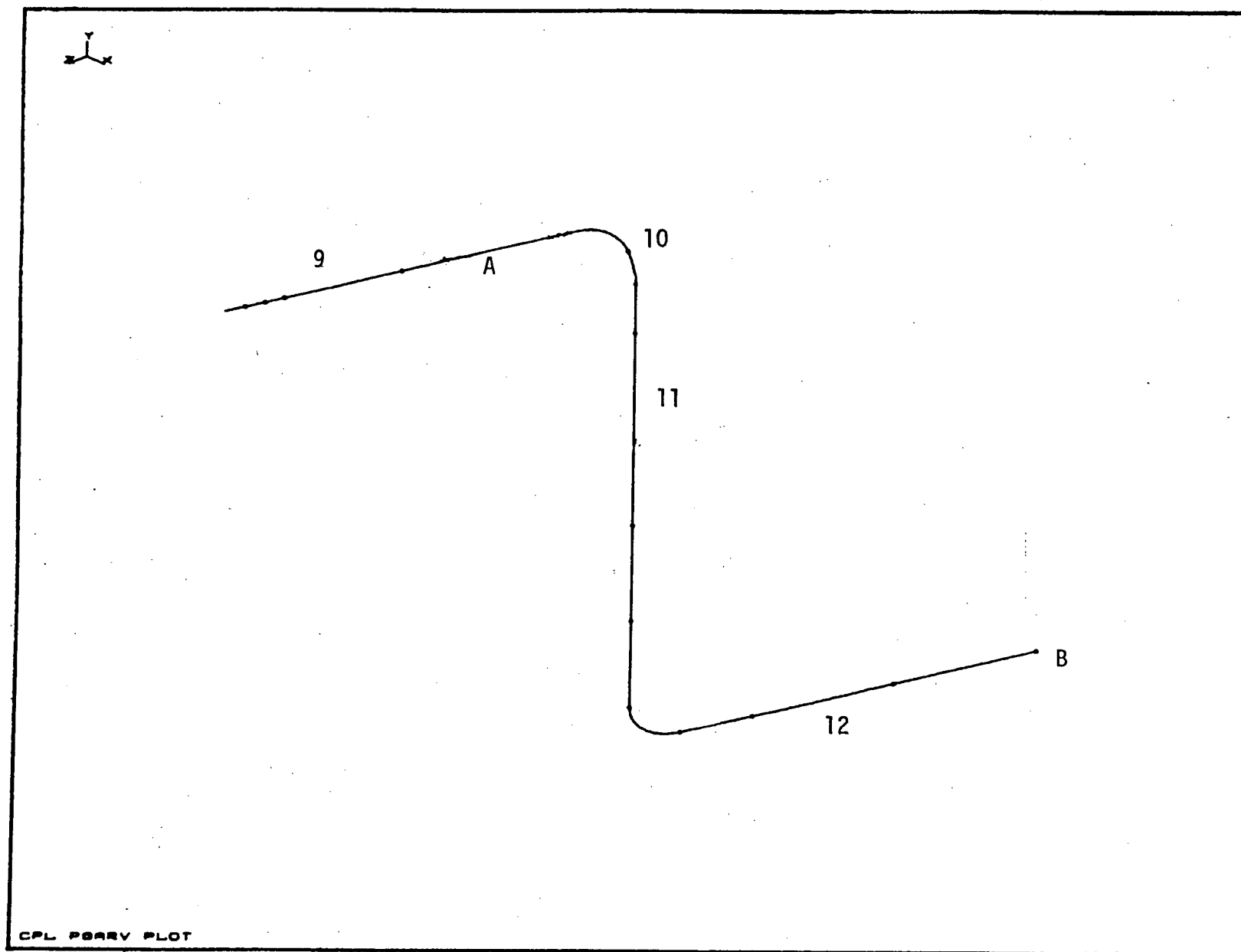


FIGURE 4-2: (CONT.) HYDRAULIC MODEL, RELIEF LINE

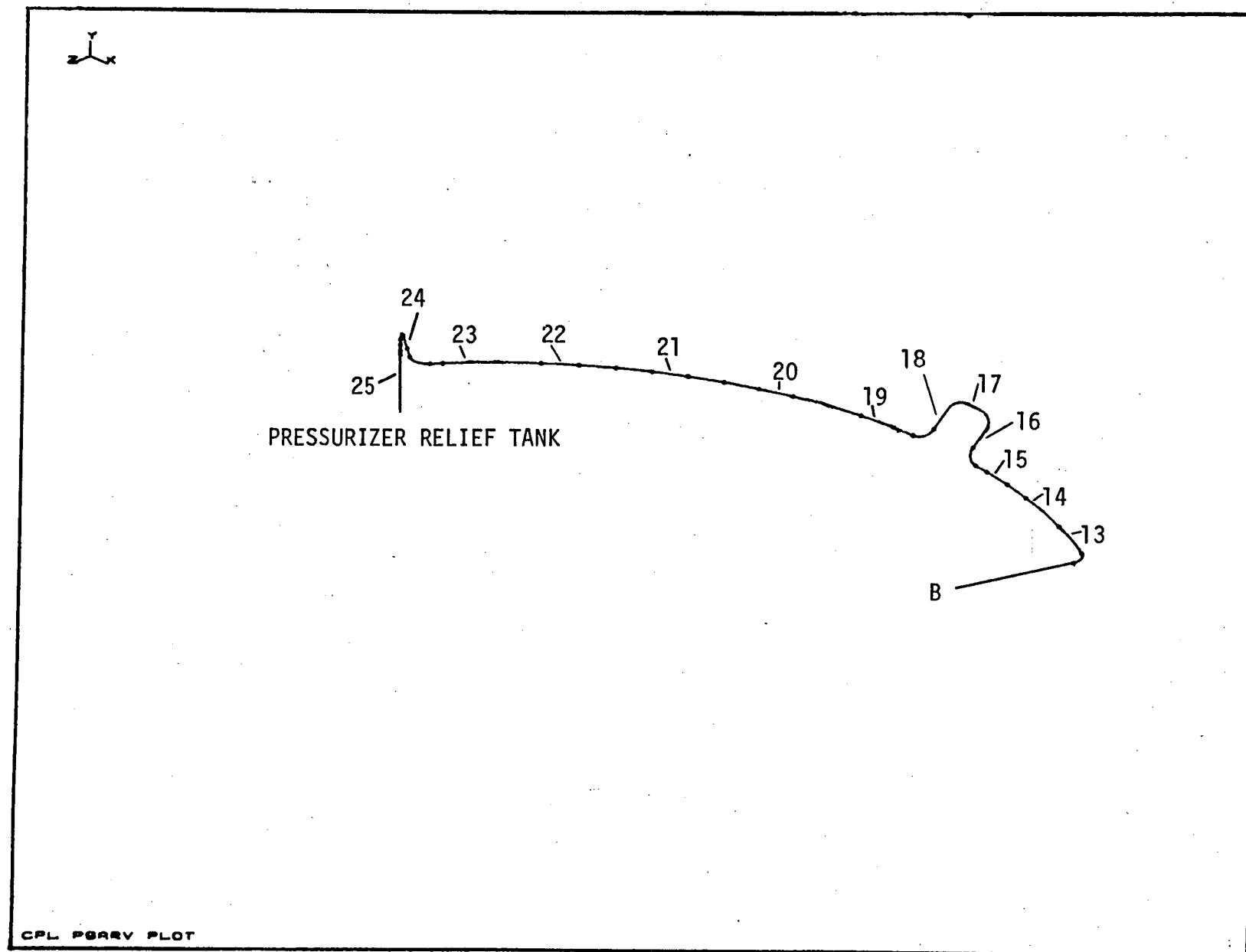


FIGURE 4-2: (CONT.) HYDRAULIC MODEL, RELIEF LINE

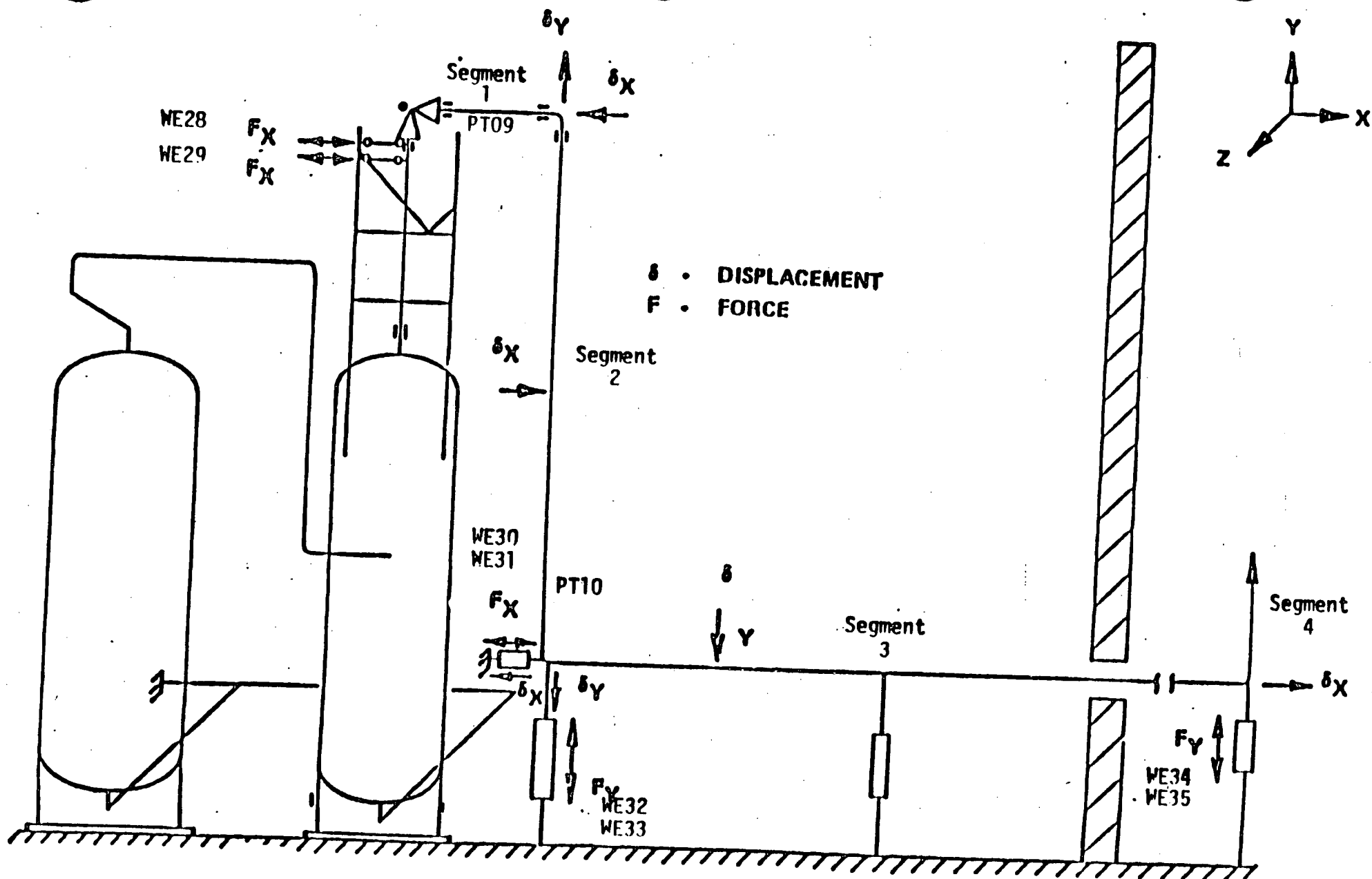


FIGURE 4-3: STRUCTURAL RESPONSE - FORCE MEASUREMENT LOCATIONS - EPRI TESTS

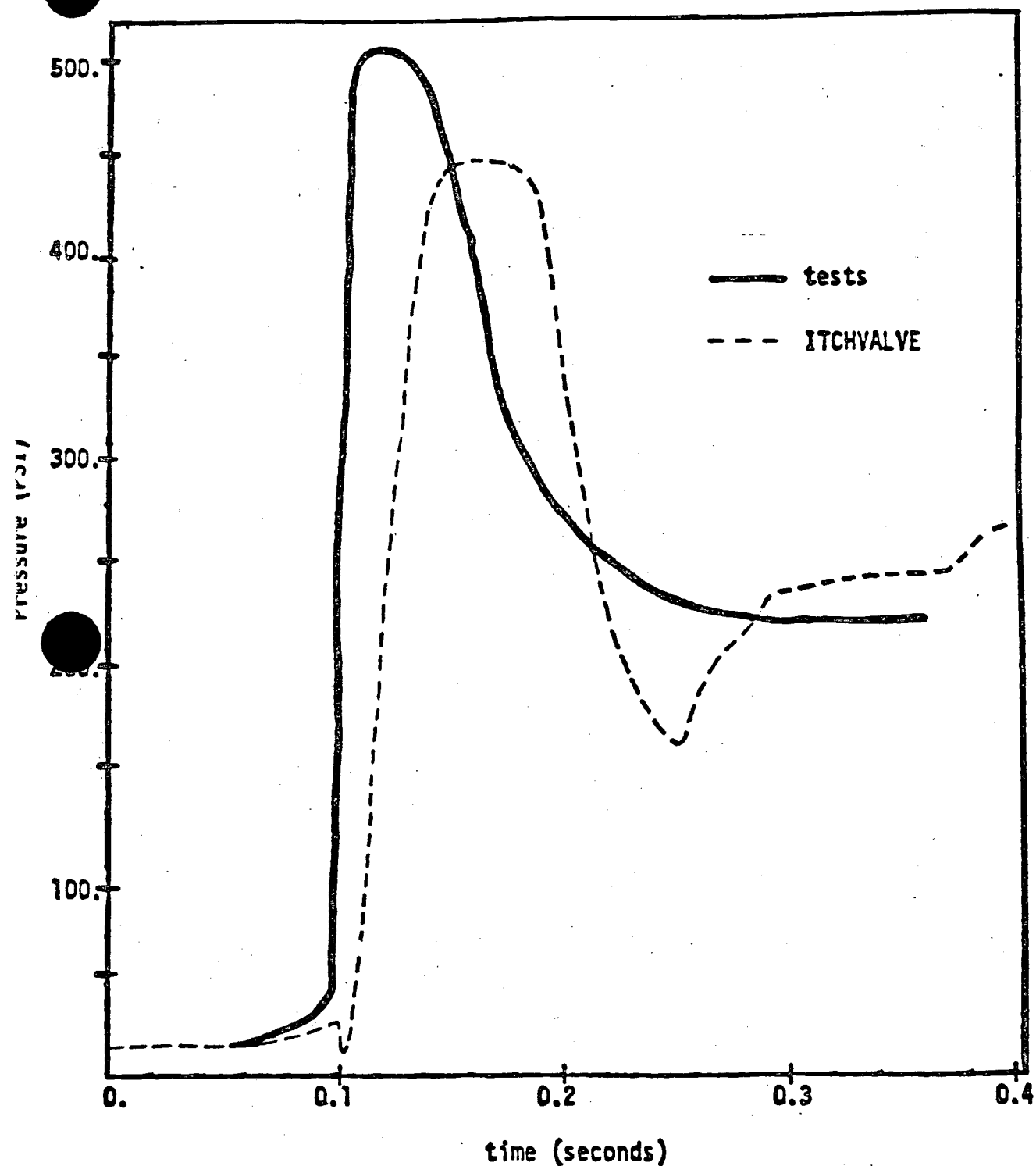


FIGURE 4-4 : Comparison of the EPRI Pressure Time-History for PT09 from Test 908 with the ITCHVALVE Predicted Pressure Time-History

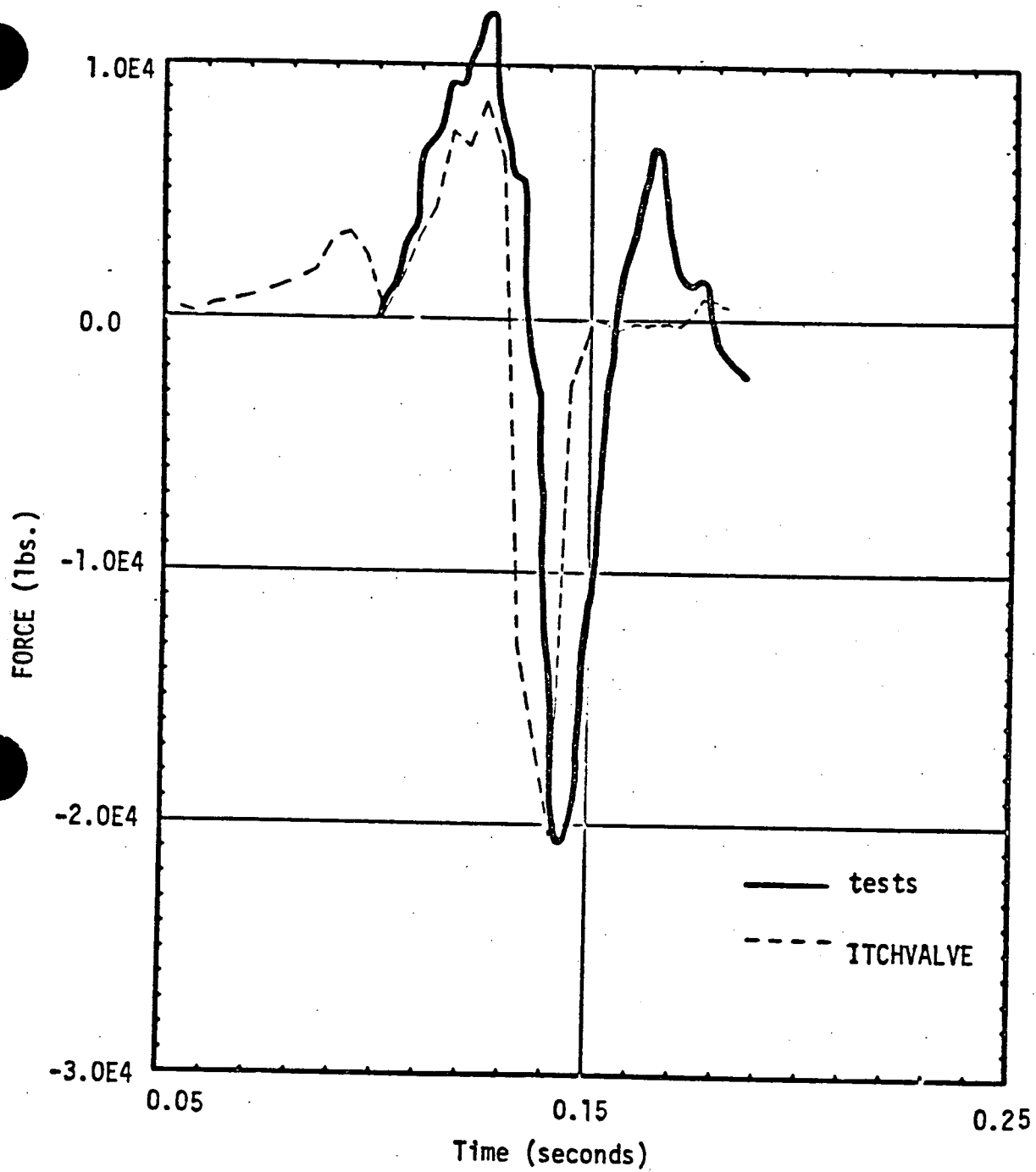


FIGURE 4-5: COMPARISON OF THE EPRI FORCE TIME-HISTORY FOR WE28 and WE29 FROM TEST 908 WITH THE ITCHVALVE PREDICTED FORCE TIME-HISTORY

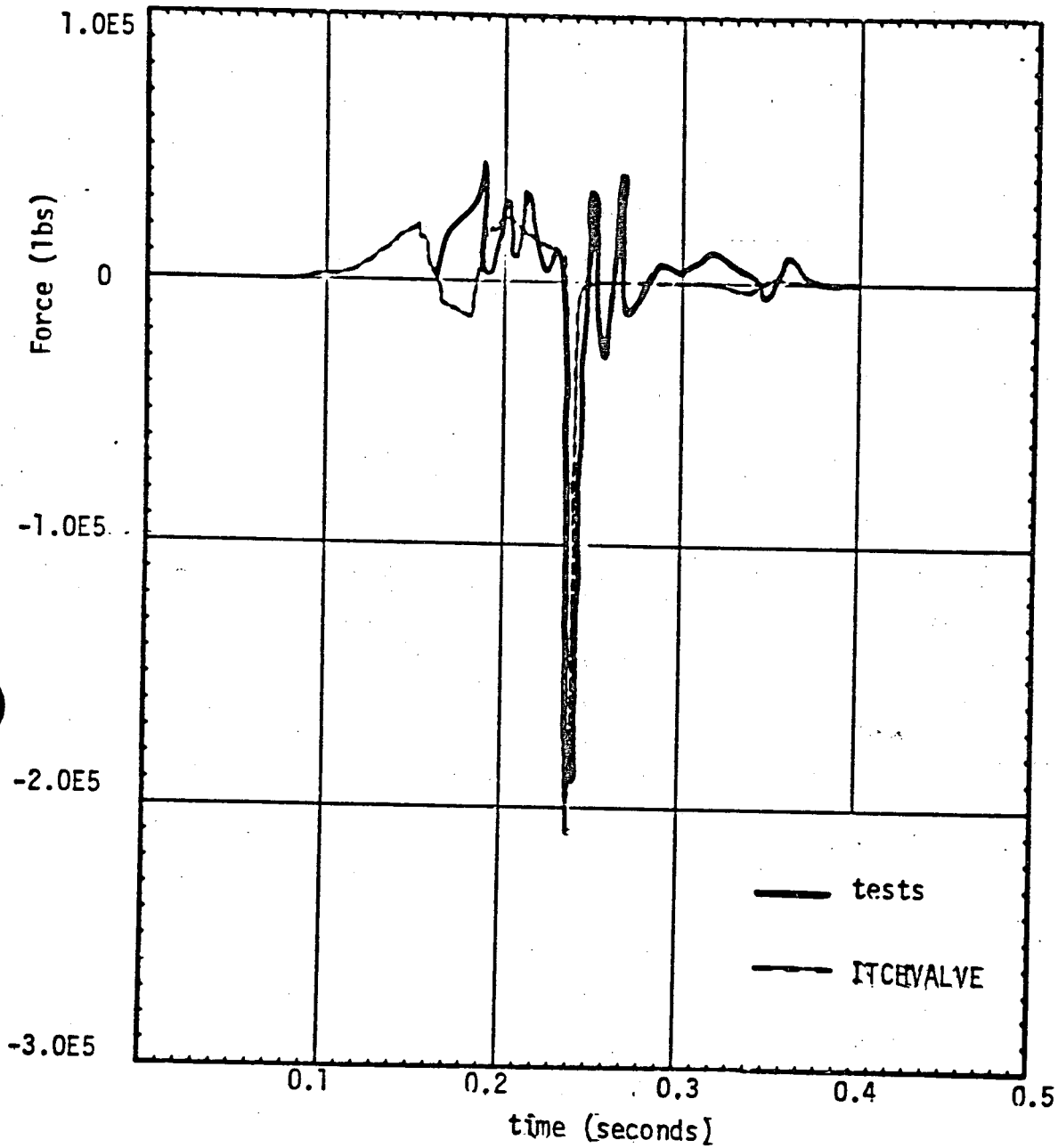


FIGURE 4-6: COMPARISON OF THE EPRI FORCE TIME-HISTORY FOR WE32 AND WE33 FROM TEST 908 WITH THE ITCHVALVE PREDICTED FORCE TIME-HISTORY

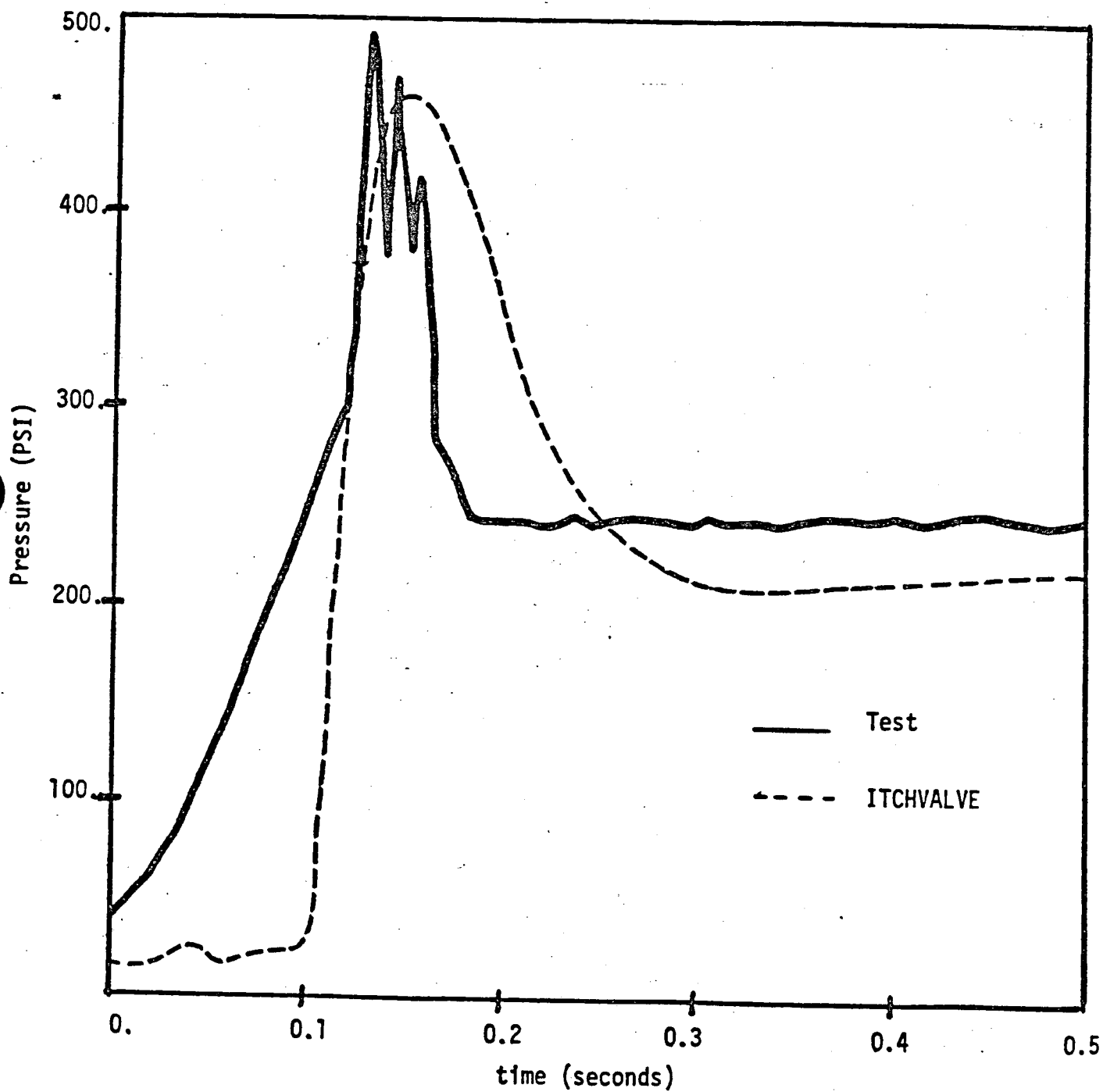


FIGURE 4-7 : Comparison of the EPRI Pressure Time-History from PT09 from Test 917 with the ITCHVALVE Predicted Pressure Time-History

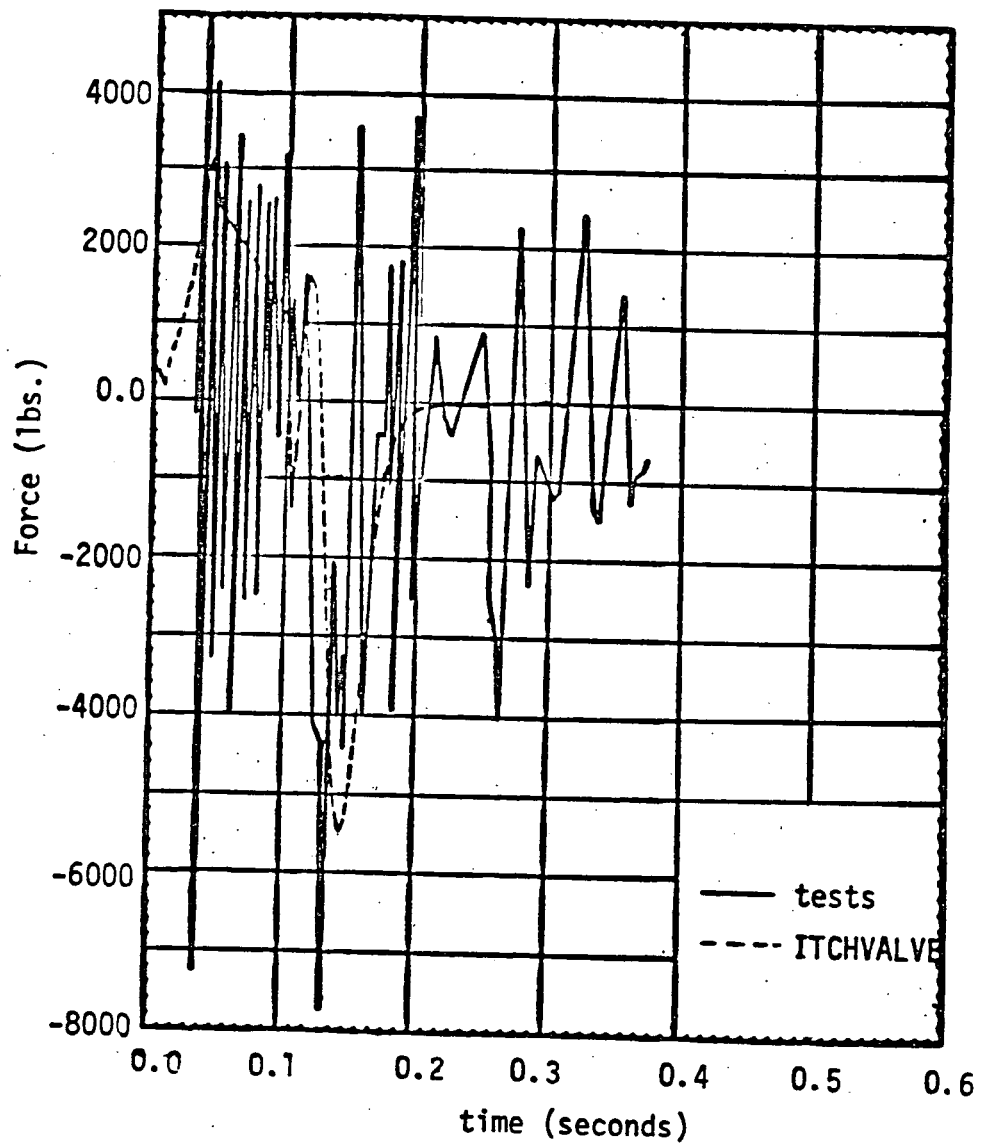


FIGURE 4-8 : Comparison of the EPRI Force Time-History for WE28 and WE29 from Test 917 with the ITCHVALVE Predicted Force Time-History

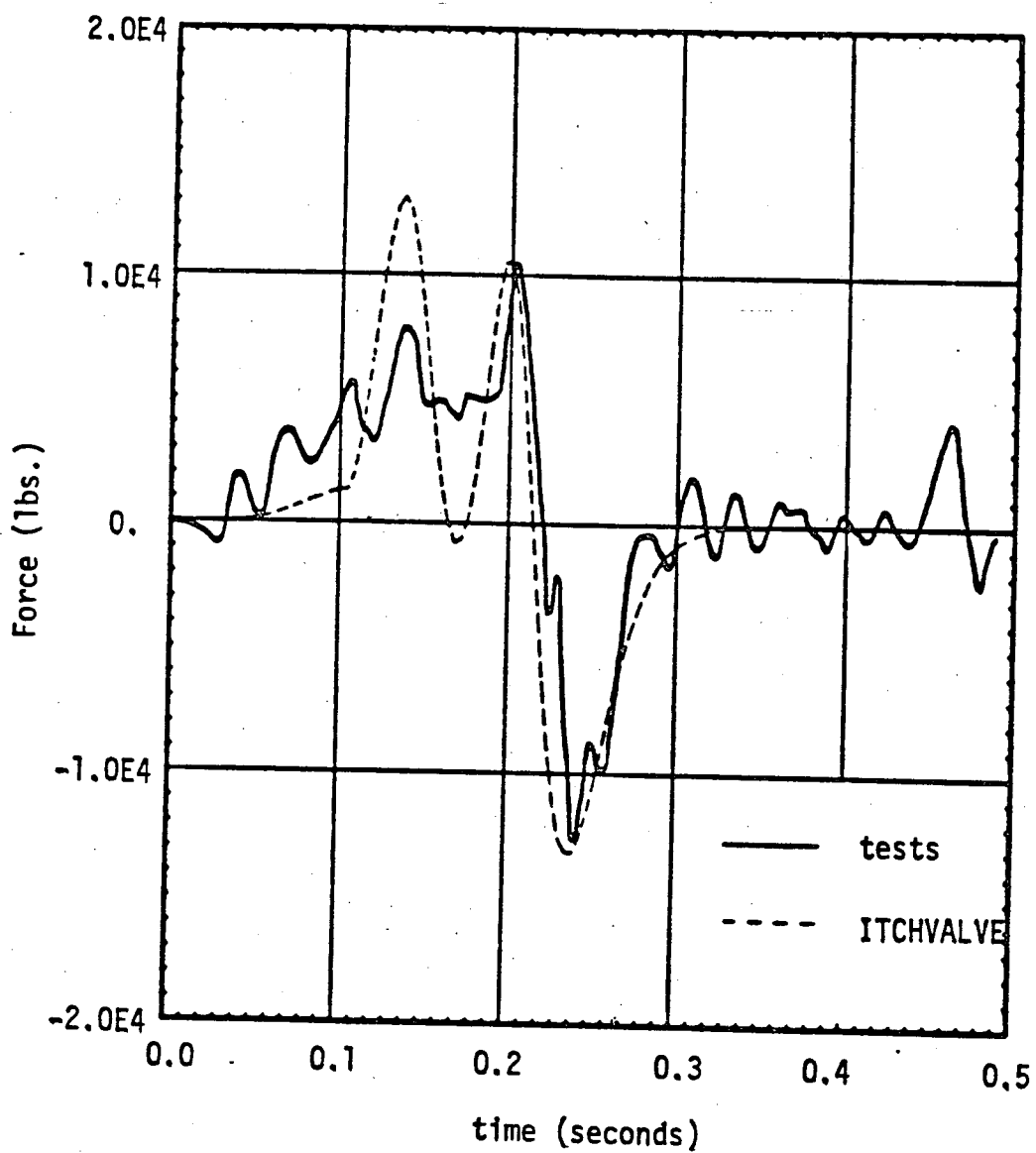


FIGURE 4-9 : Comparison of the EPRI Force Time-History for WE32 and WE33 from Test 917 with the ITCHVALVE Predicted Force Time-History

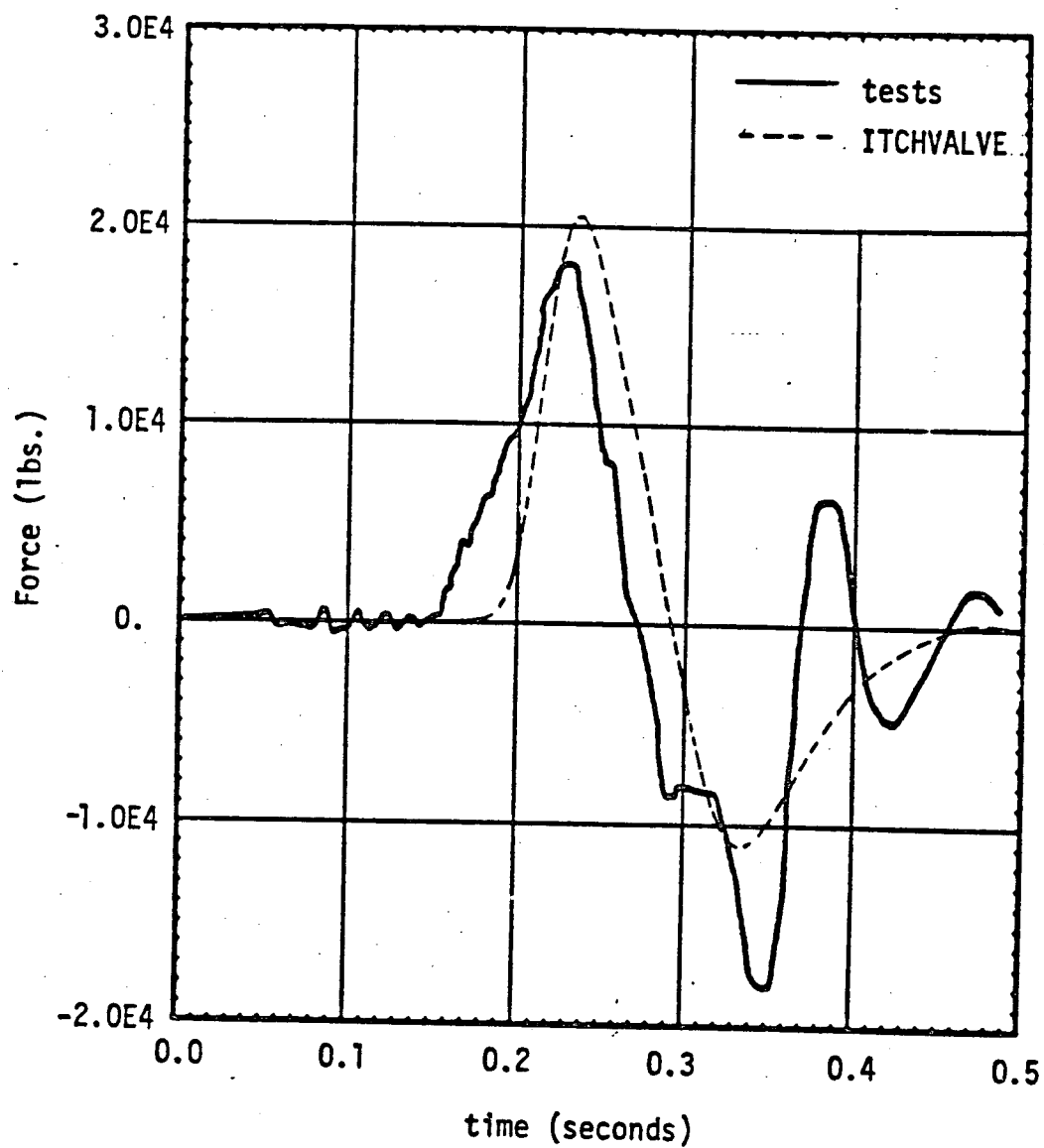


FIGURE 4-10: Comparison of the EPRI Force Time-History For WE30 and WE31 From Test 917 with the ITCHVALVE Predicted Force Time-History

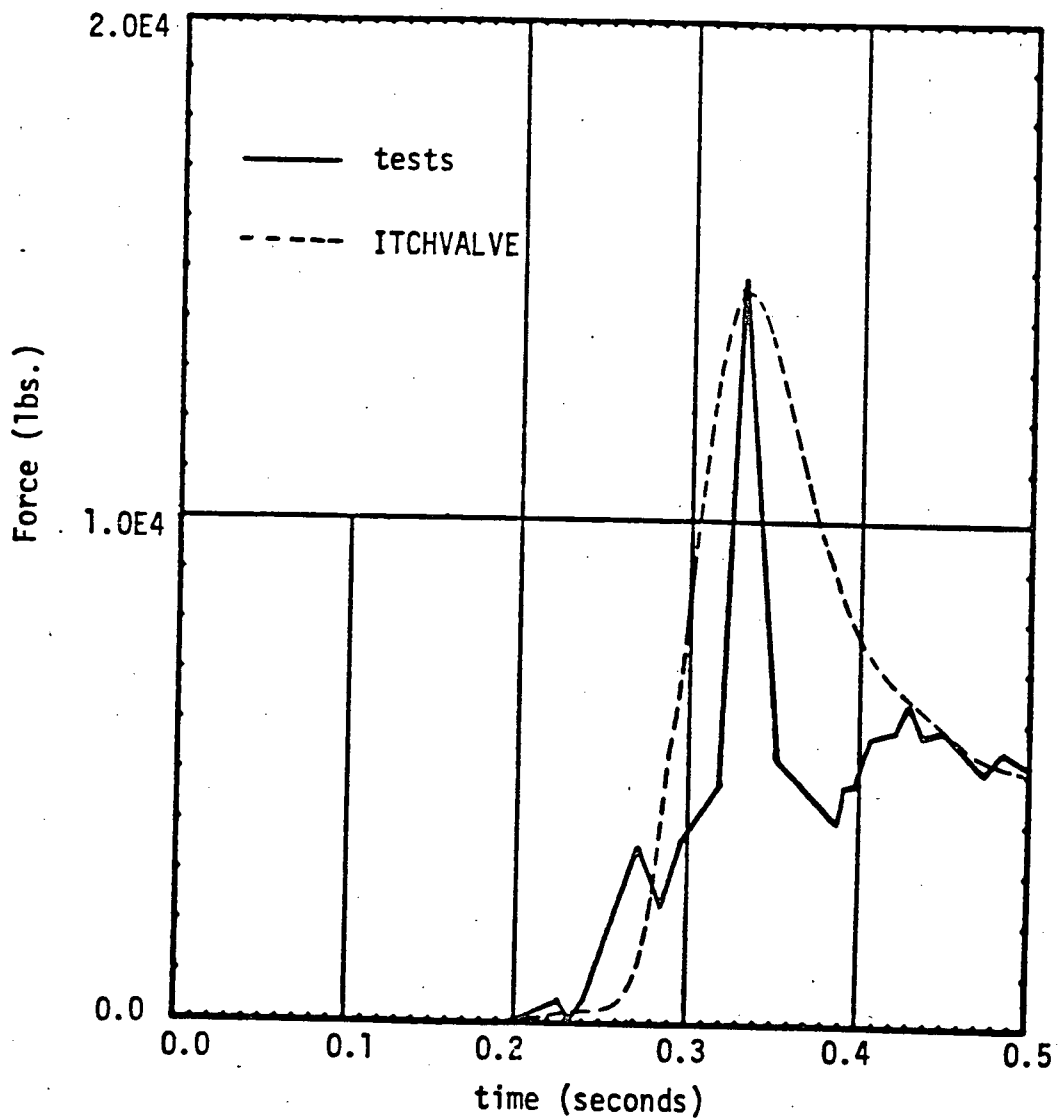


FIGURE 4-11: Comparison of the EPRI Force Time-History For WE34 and WE35 from Test 917 with the ITCHVALVE Predicted Force Time-History

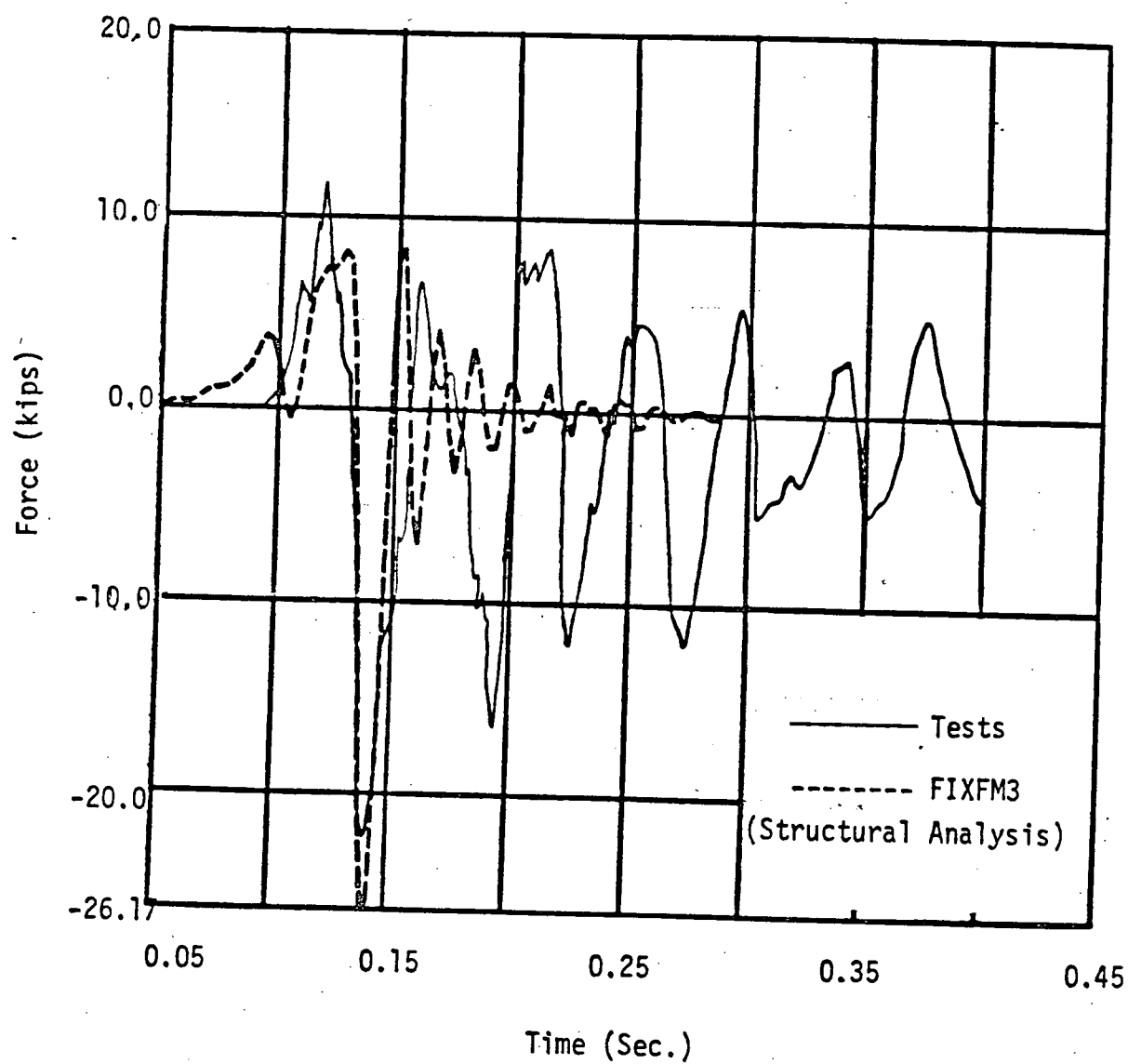


FIGURE 4-12: Comparison of the EPRI Force Time-History for WE28 and WE29 from Test 908 with the FIXFM3 Predicted Force Time-History

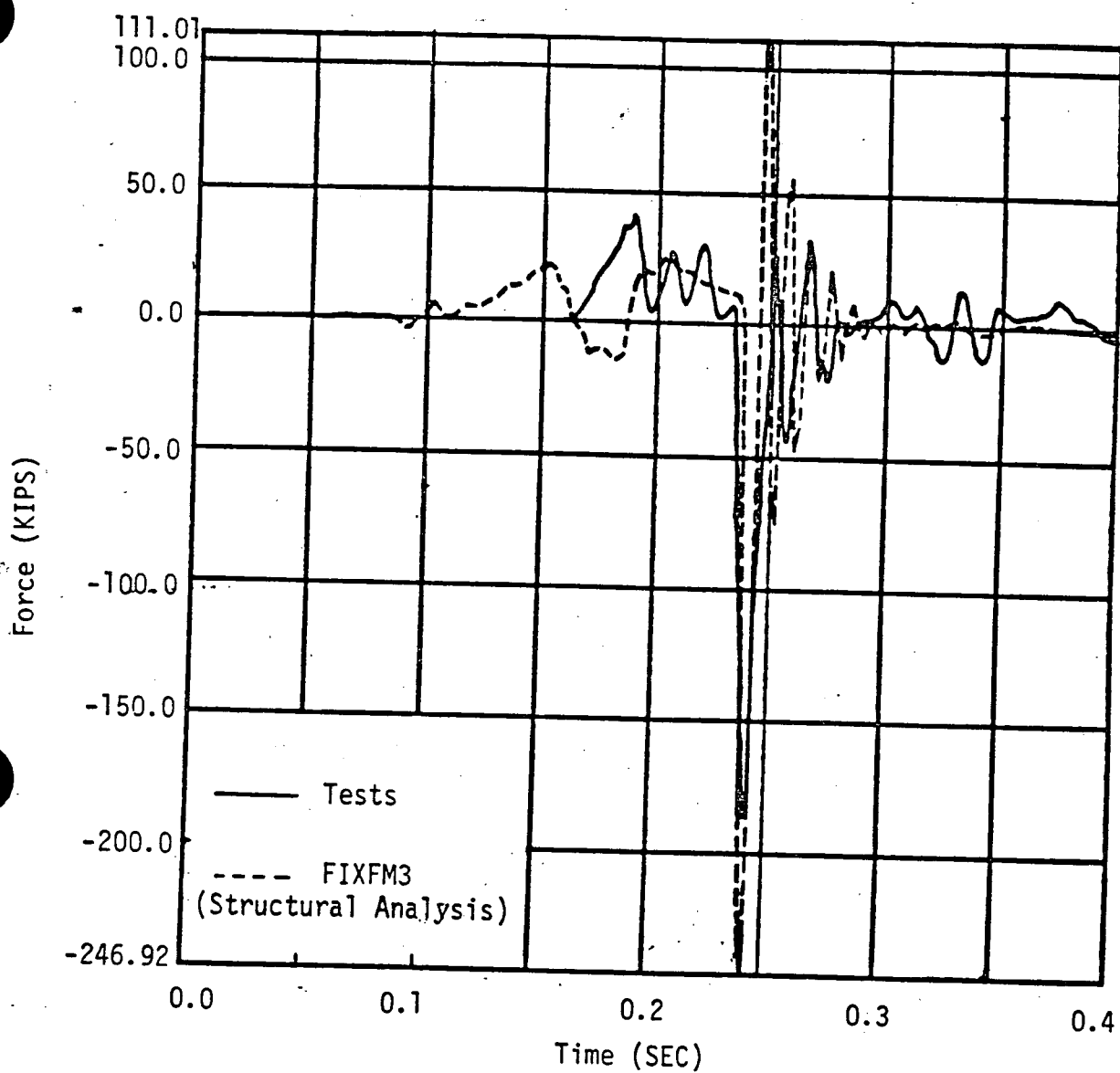


Figure 4-13: Comparison of the EPRI Force Time-History For WE32 and WE33 From Test 908 With the FIXFM3 Predicted Force Time-History

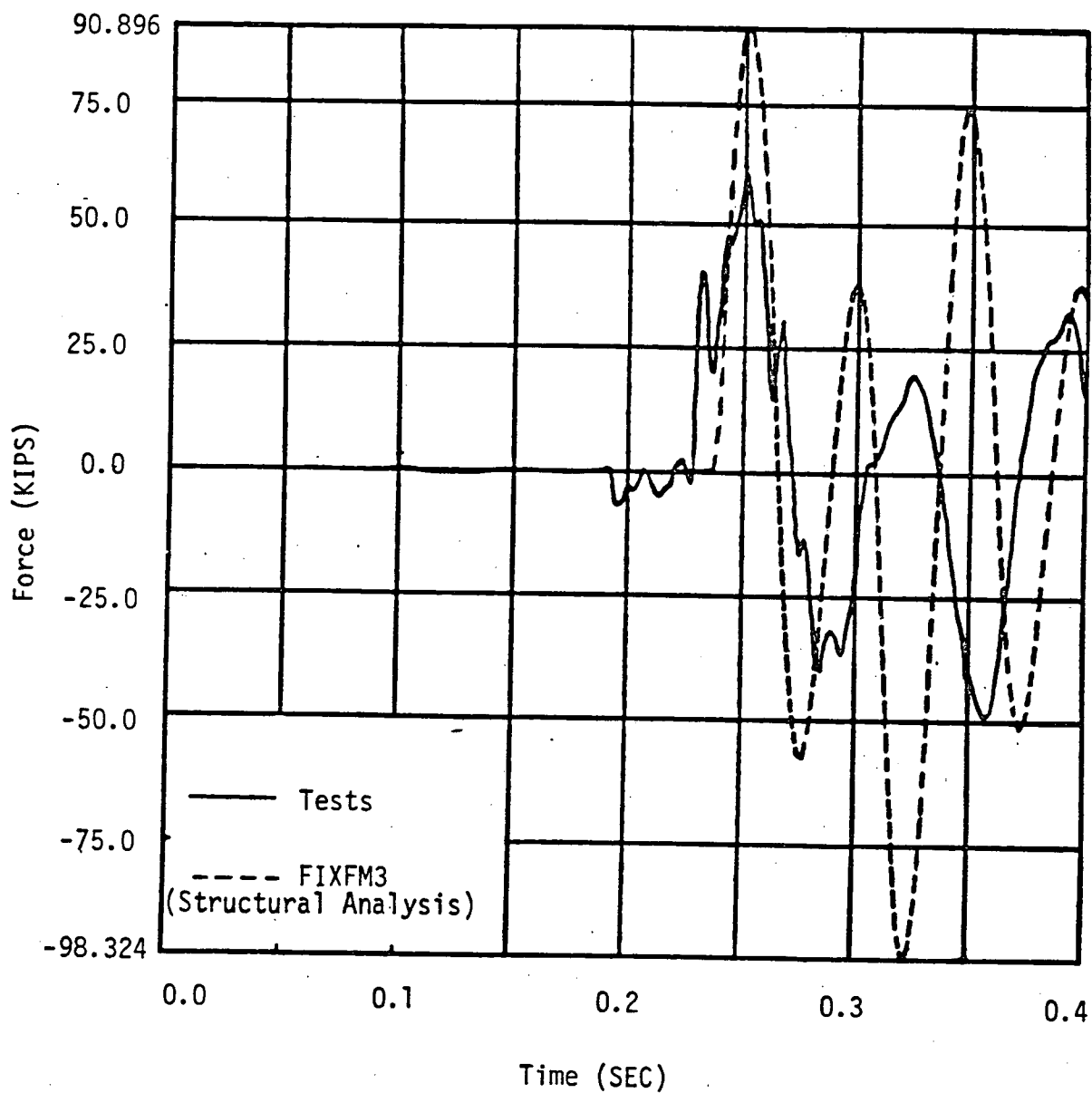


Figure 4-14: Comparison of the EPRI Force Time-History For WE30 and WE31 From Test 908 With the FIXFM3 Predicted Force Time-History

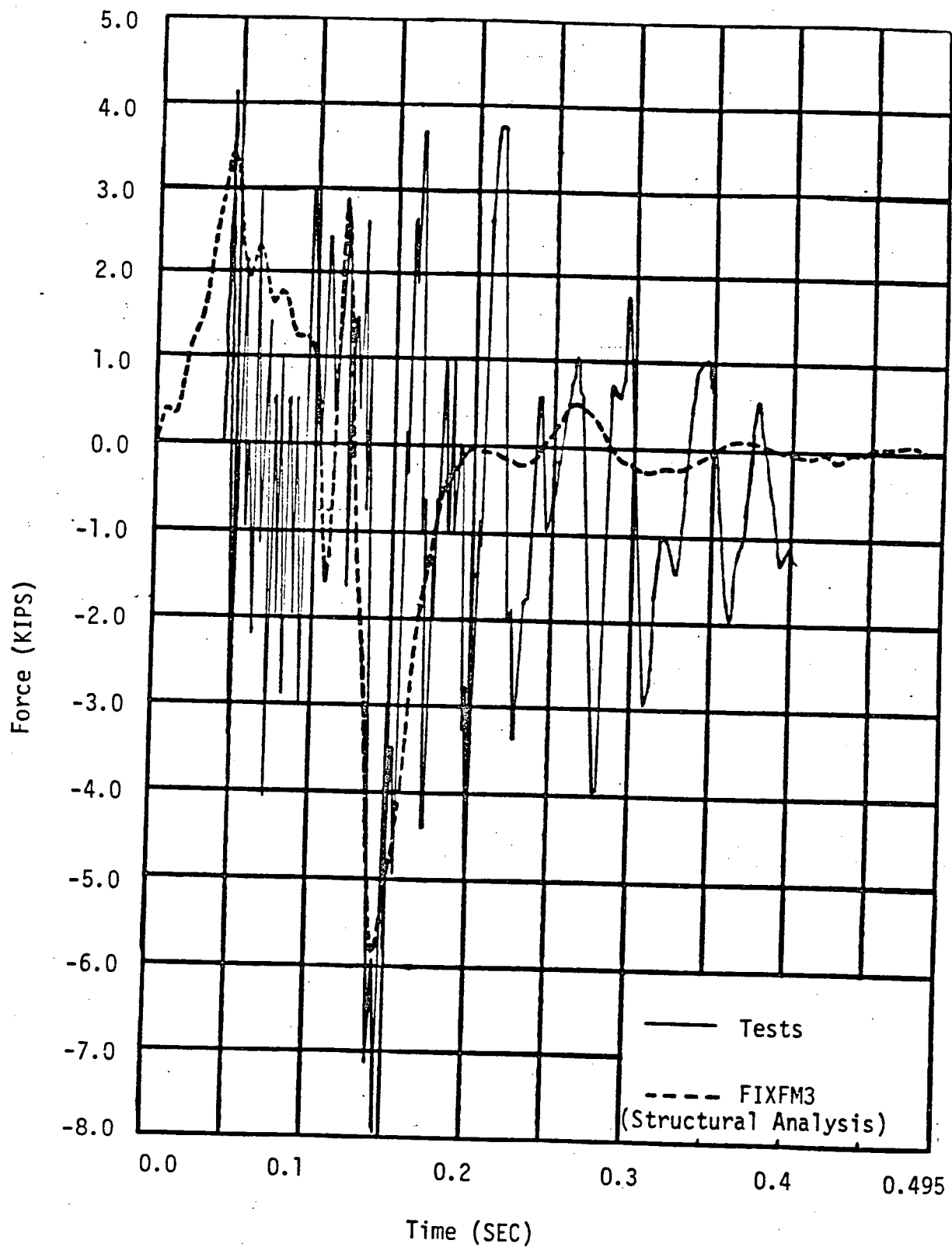


Figure 4-15: Comparison of the EPRI Force Time-History For WE28 and WE29 From Test 917 With the FIXFM3 Predicted Force Time-History

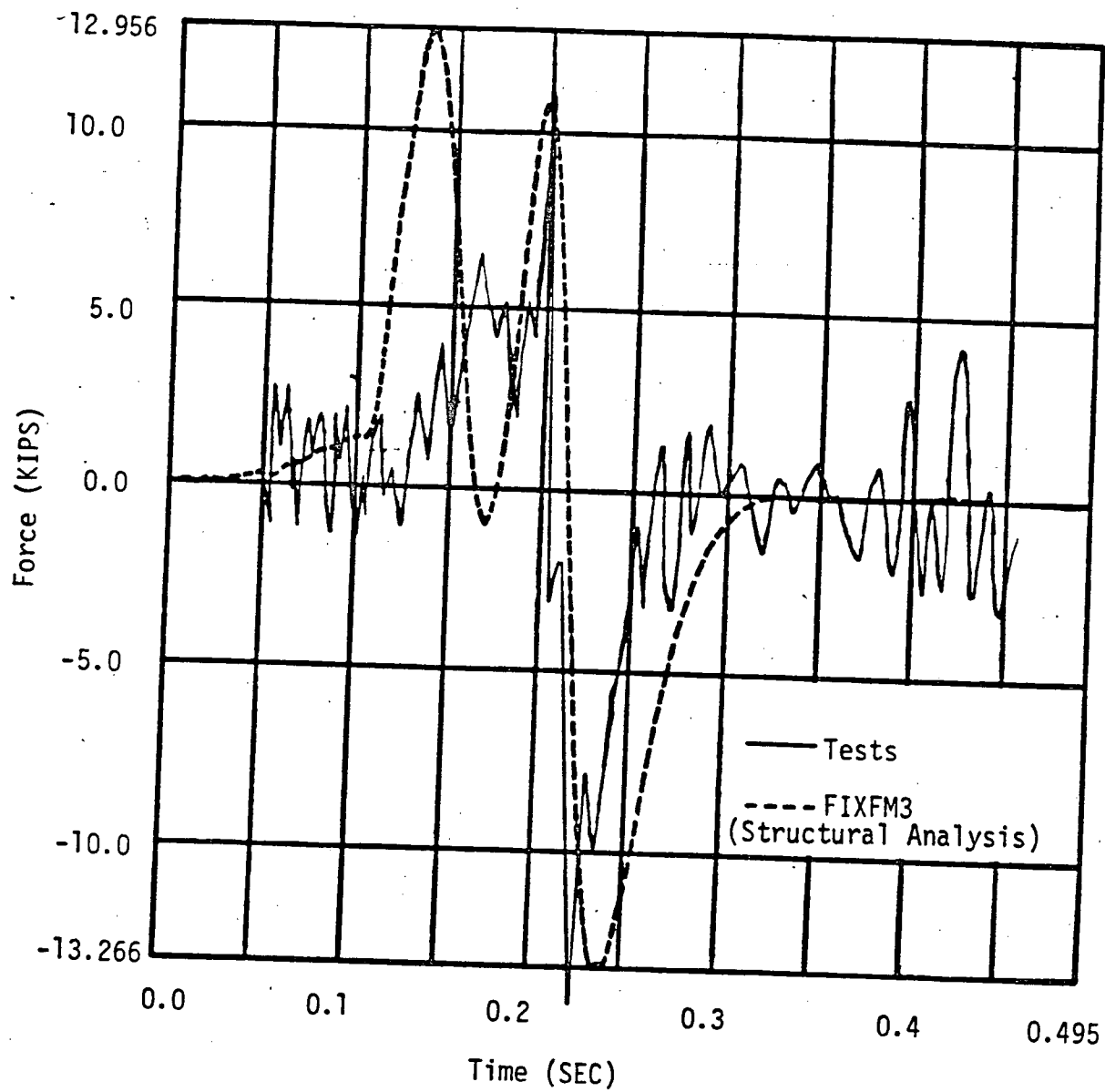


Figure 4-16: Comparison of the EPRI Force Time-History For WE32 and WE33 From Test 917 With the FIXFM3 Predicted Force Time-History

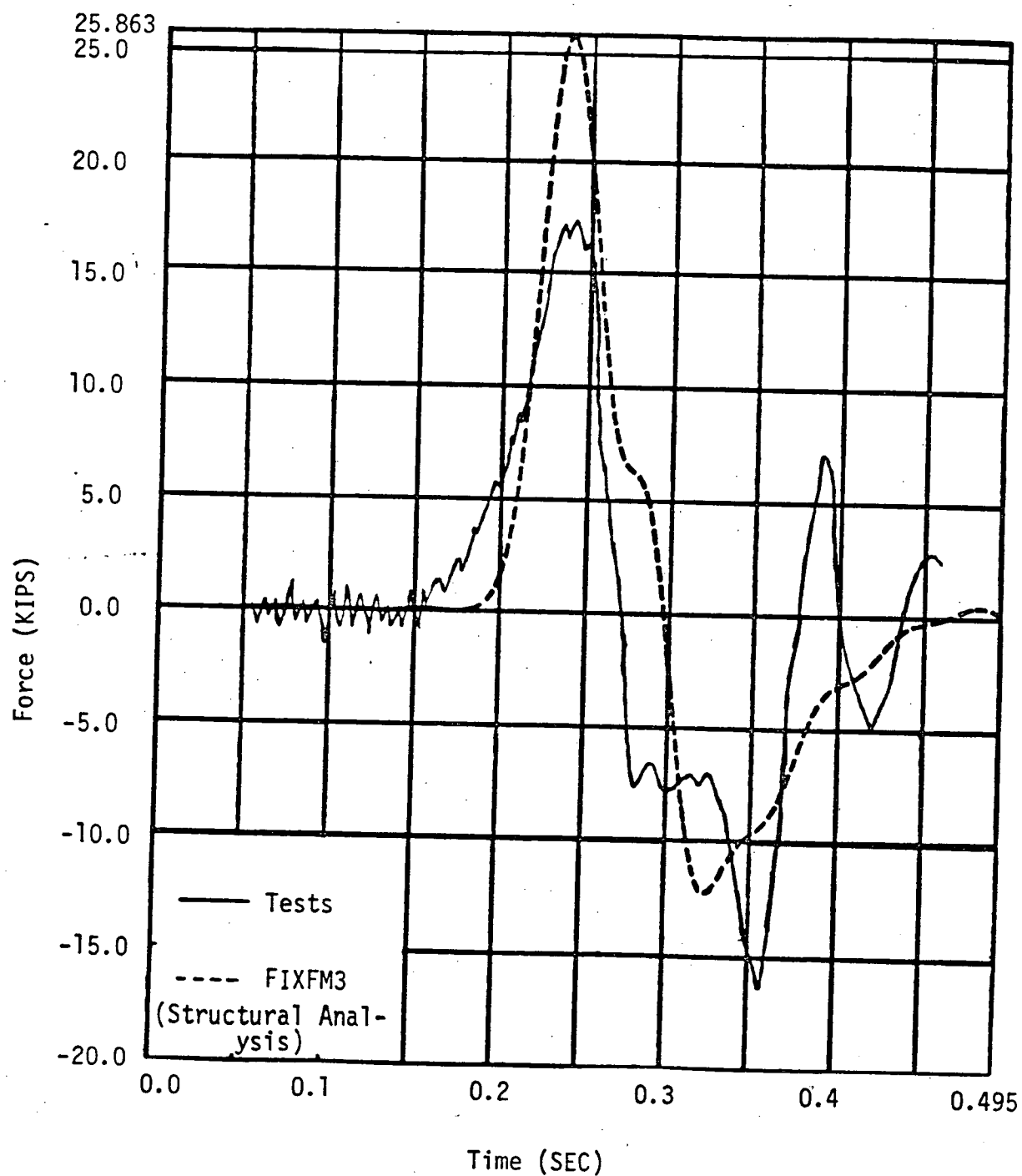


Figure 4-17: Comparison of the EPRI Force Time-History For WE30 and WE31 From Test 917 With the FIXFM3

Predicted Force Time-History

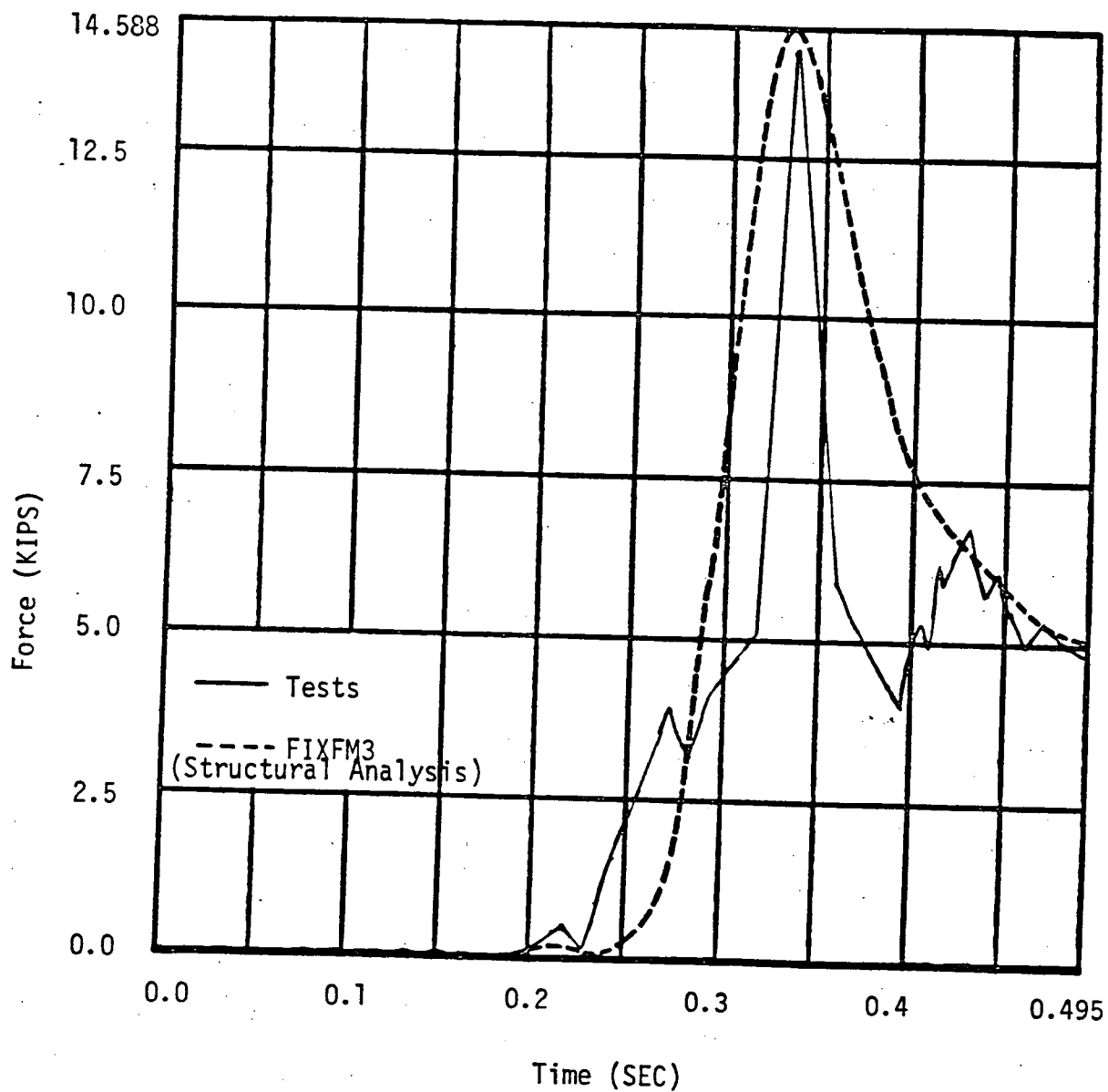


Figure 4-18: Comparison of the EPRI Force Time-History For WE34 and WE35 From Test 917 With the FIXFM3 Predicted Force Time-History

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 combinations as discussed in Section 2.2. 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 any other design mechanical loads, calculated using applicable stress intensity 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

5.2.2 UPSET CONDITIONS

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

For seismic and relief valve thrust loading:

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

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

5.2.3 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:

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

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 the primary loadings of pressure, weight, safe shutdown earthquake (SSE), 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:

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

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

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 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 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

SECTION 6

RESULTS

6.1 EVALUATION PRIOR TO EPRI TEST PROGRAM

The H. B. Robinson Unit 2 safety valve discharge piping system had received a detailed thermal hydraulic analysis and structural evaluation in 1974. The analysis and evaluation were based on 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 the simultaneous opening of all safety valves since this represents the worst applicable loading condition for the piping. These forcing functions were then used as input to the structural evaluation in which the primary stresses were determined. 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.

6.2 EVALUATION SUBSEQUENT TO EPRI TEST PROGRAM

The H. B. Robinson Unit 2 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 relief valves opening case, cold loop seals were assumed to exist upstream of the valves.

For the safety valves opening case, hot loop seals were assumed to exist upstream of the valves. This assumption was made because the piping is insulated. 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 permissible pressure. The piping between the pressurizer nozzle and the inlet of the safety valves is 4-inch schedule 120. The calculated maximum upstream pressure for this size of piping 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.

6.2.2 STRUCTURAL RESULTS

Stress summaries for the valve discharge loading cases considered are provided in Tables 6-3 through 6-20. 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).

Our evaluation conducted prior to the completion of the structural analysis and based on the thermal hydraulic loadings for the simultaneous discharge of either all three 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 6-20.

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 H. B. Robinson Unit 2 pressurizer safety and relief valve discharge piping system have been completed. In summary, contingent upon support adequacy, 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.

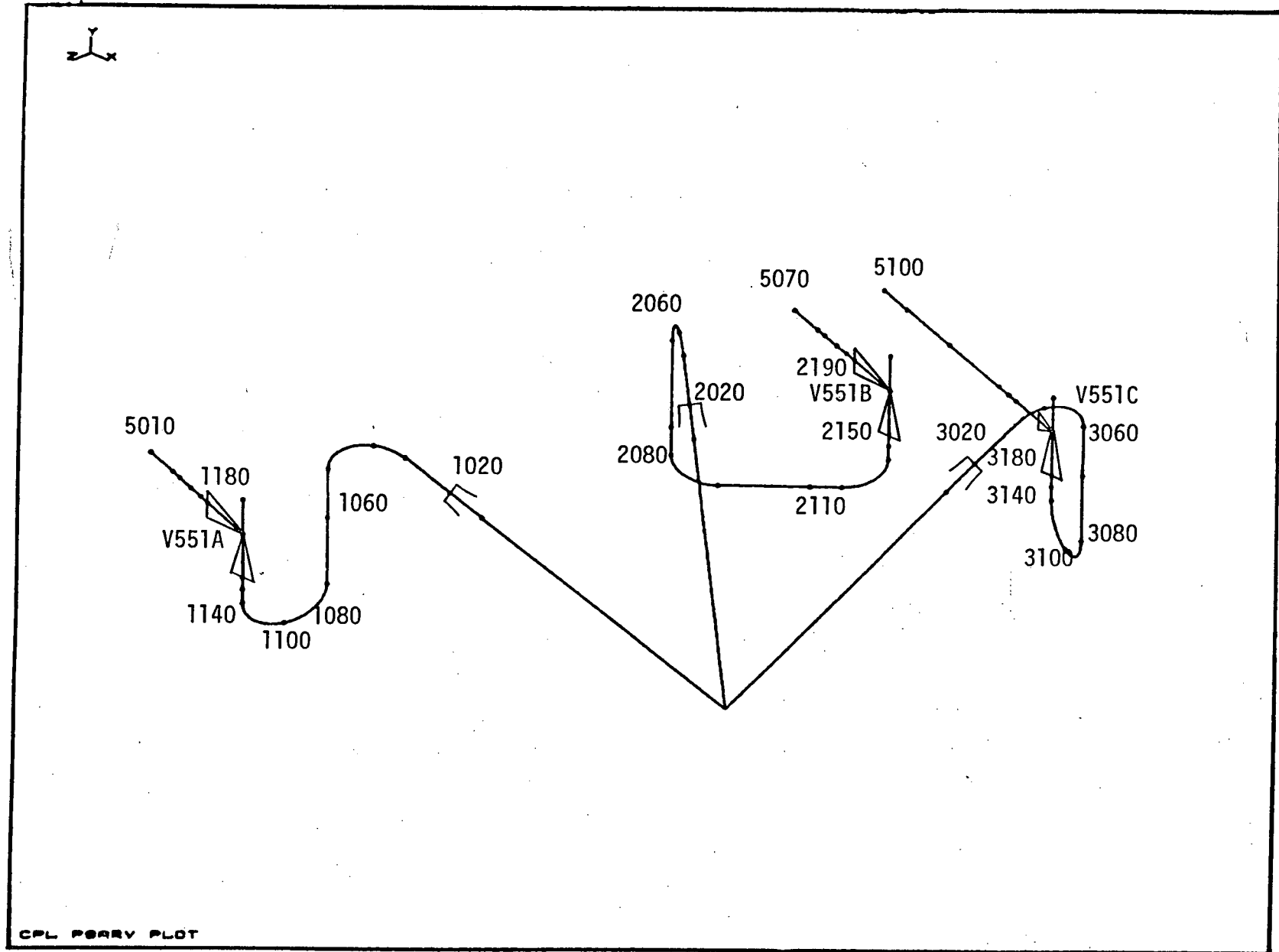


FIGURE 6-1: STRUCTURAL MODEL, SAFETY LINE

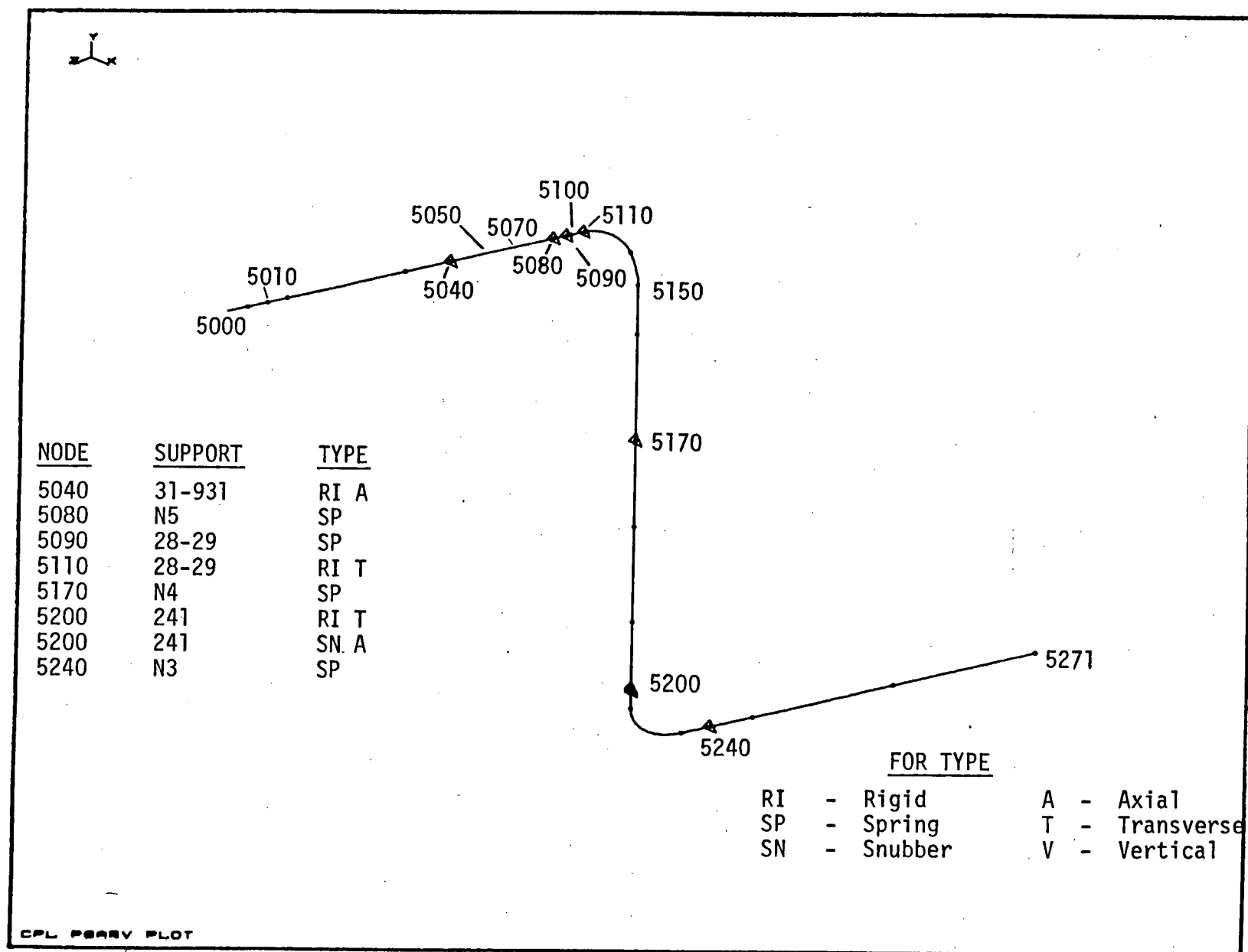


FIGURE 6-1: (CONT.) STRUCTURAL MODEL, COMMON HEADER

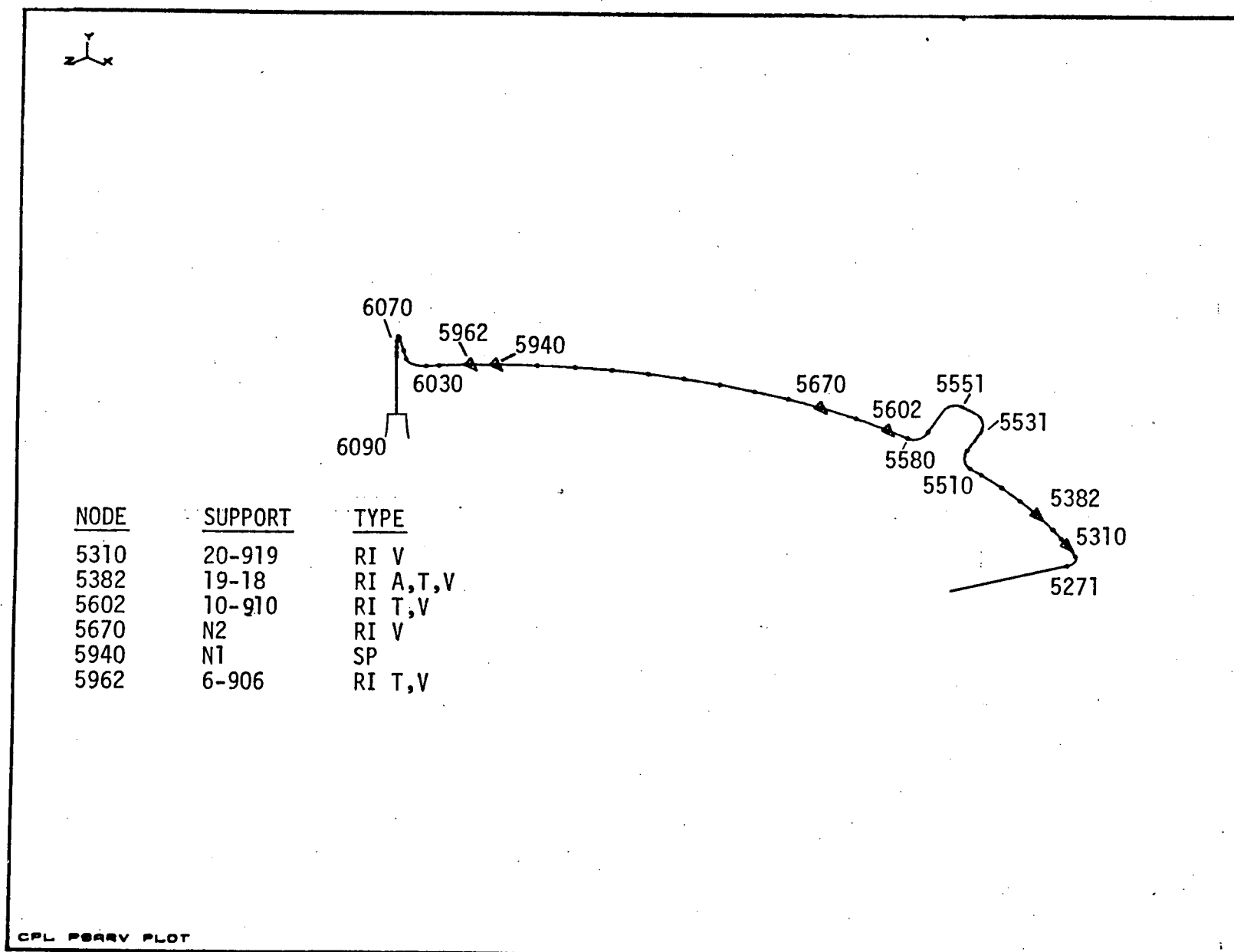


FIGURE 6-1: (CONT.) STRUCTURAL MODEL, COMMON HEADER

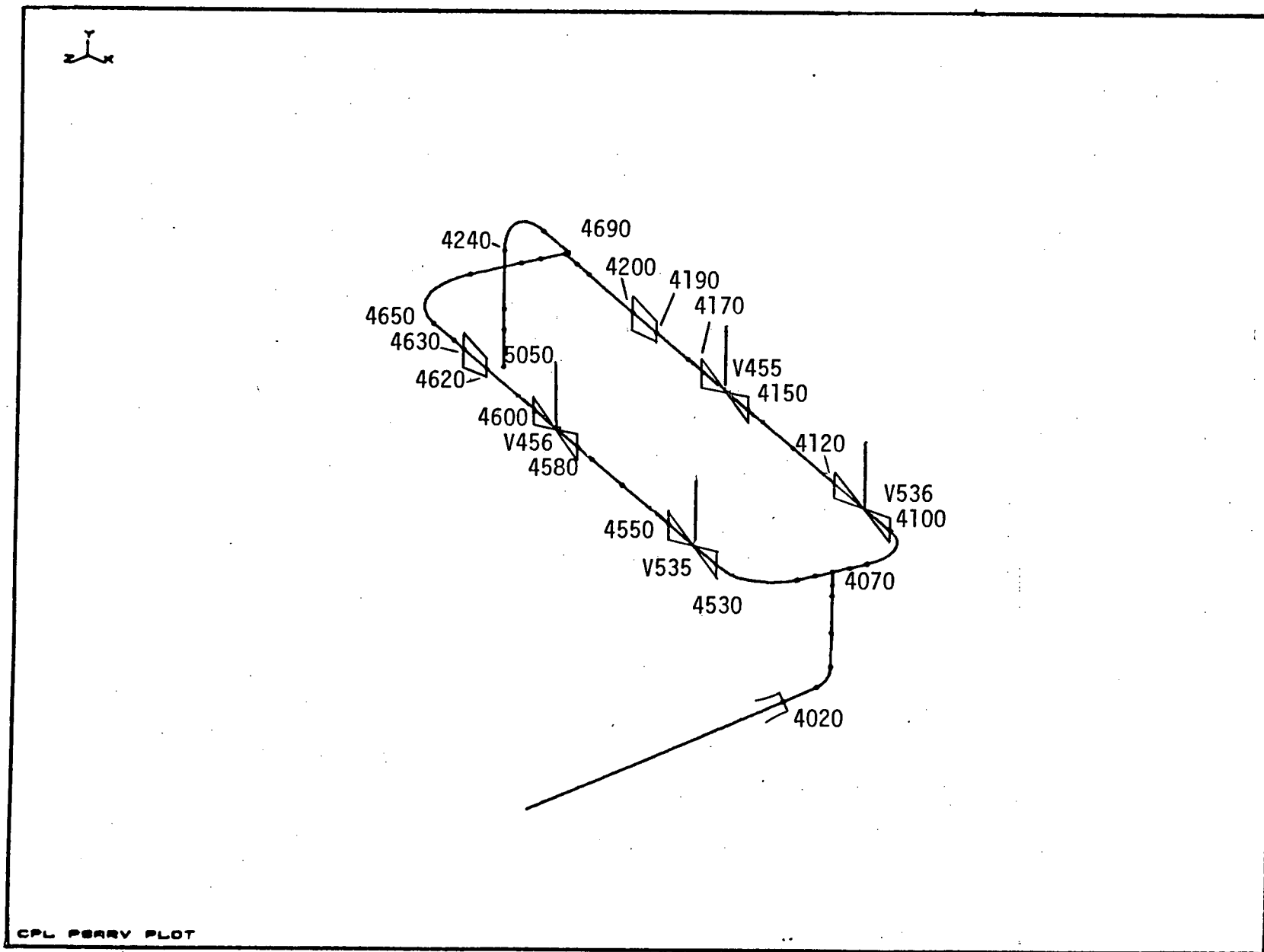


FIGURE 6-2: STRUCTURAL MODEL, RELIEF LINE

TABLE 6-1
HYDRAULIC FORCES - SAFETY LINE

<u>Force No.</u>	<u>Force (LBF)</u>	<u>Force No.</u>	<u>Force (LBF)</u>
1	70	19	27500
2	50	20	13100
3	2540	21	44600
4	3860	22	27800
5	4100	23	13600
6	6130	24	11500
7	70	25	6820
8	50	26	6110
9	2440	27	5170
10	3940	28	5150
11	4180	29	7100
12	3260	30	6410
13	70	31	6140
14	50	32	6140
15	2530	33	6100
16	3850	34	4700
17	4100	35	2370
18	6500		

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

TABLE 6-2
HYDRAULIC FORCES - RELIEF LINE

<u>Force No.</u>	<u>Force (LBF)</u>	<u>Force No.</u>	<u>Force (LBF)</u>
1	30	9	1040
2	230	10	1030
3	80	11	3950
4	1350	12	1460
5	3220	13	730
6	80	14	500
7	870	15	240
8	1030	16	150
		17	100
		18	140
		19	250
		20	260
		21	300
		22	250
		23	180
		24	110
		25	40

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

TABLE 6-3

PRIMARY STRESS SUMMARY - UPSTREAM OF VALVESPiping System: Pressurizer Relief LineCombination 1 - N

<u>Node Point</u>	<u>Piping Component</u>	<u>Maximum Stress (ksi)</u>	<u>Allowable Stress (ksi)</u>
4510	Straight run	6.0	16.4
4065	Butt weld	7.4	16.4
4511	Elbow	5.7	16.4
4580	Reducer	8.5	16.4
4070	Tee	6.9	16.4

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

TABLE 6-4

PRIMARY STRESS SUMMARY - UPSTREAM OF VALVESPiping System: Pressurizer Relief LineCombination 2 - N + OBE + SOT_U

<u>Node Point</u>	<u>Piping Component</u>	<u>Maximum Stress (ksi)</u>	<u>Allowable Stress (ksi)</u>
4050	Straight run	9.1	19.7
4020	Butt weld	14.6	19.7
4030	Elbow	12.0	19.7
4580	Reducer	18.7	19.7
4070	Tee	10.6	19.7

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

TABLE 6-5

PRIMARY STRESS SUMMARY - UPSTREAM OF VALVESPiping System: Pressurizer Relief LineCombination 3 - N + SOT_E

<u>Node Point</u>	<u>Piping Component</u>	<u>Maximum Stress (ksi)</u>	<u>Allowable Stress (ksi)</u>
4560	Straight run	8.8	29.6
4020	Butt weld	12.2	29.6
4030	Elbow	10.2	29.6
4150	Reducer	25.2	29.6
4070	Tee	10.6	29.6

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

TABLE 6-6

PRIMARY STRESS SUMMARY - UPSTREAM OF VALVESPiping System: Pressurizer Relief LineCombinations 4 and 5 - N + LOCA + SSE + SOT_F

<u>Node Point</u>	<u>Piping Component</u>	<u>Maximum Stress (ksi)</u>	<u>Allowable Stress (ksi)</u>
4050	Straight run	11.1	39.4
4020	Butt weld	21.2	39.4
4030	Elbow	16.9	39.4
4150	Reducer	31.7	39.4
4070	Tee	13.9	39.4

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

TABLE 6-7

PRIMARY STRESS SUMMARY - SEISMICALLY DESIGNED DOWNSTREAM PORTIONPiping System: Pressurizer Relief LineCombination 1 - N

<u>Node Point</u>	<u>Piping Component</u>	<u>Maximum Stress (ksi)</u>	<u>Allowable Stress (ksi)</u>
5386	Straight run	5.8	15.0
5042	Butt weld	5.1	15.0
5520	Elbow	5.4	15.0
4600	Reducer	6.3	16.6
5050	Tee	5.6	15.0

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

TABLE 6-8

PRIMARY STRESS SUMMARY - SEISMICALLY DESIGNED DOWNSTREAM PORTIONPiping System: Pressurizer Relief LineCombination 2 - N + SOT_U

<u>Node Point</u>	<u>Piping Component</u>	<u>Maximum Stress (ksi)</u>	<u>Allowable Stress (ksi)</u>
5040	Straight run	7.3	18.0
4270	Butt weld	7.6	18.0
5130	Elbow	6.9	18.0
4600	Reducer	15.2	19.9
5050	Tee	9.1	18.0

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

TABLE 6-9

PRIMARY STRESS SUMMARY - SEISMICALLY DESIGNED DOWNSTREAM PORTIONPiping System: Pressurizer Relief LineCombination 3 - N + OBE + SOT_U

<u>Node Point</u>	<u>Piping Component</u>	<u>Maximum Stress (ksi)</u>	<u>Allowable Stress (ksi)</u>
5040	Straight run	7.4	27.0
4270	Butt weld	8.8	27.0
6070	Elbow	9.6	27.0
4600	Reducer	16.0	29.9
5050	Tee	10.0	27.0

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

TABLE 6-10

PRIMARY STRESS SUMMARY - SEISMICALLY DESIGNED DOWNSTREAM PORTIONPiping System: Pressurizer Relief LineCombination 4 - N + SOT_E

<u>Node Point</u>	<u>Piping Component</u>	<u>Maximum Stress (ksi)</u>	<u>Allowable Stress (ksi)</u>
6080	Straight run	26.9	27.0
6090	Butt weld	26.6	27.0
6070	Elbow	27.0	27.0
4170	Reducer	14.7	29.9
5050	Tee	16.7	27.0

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

TABLE 6-11

PRIMARY STRESS SUMMARY - SEISMICALLY DESIGNED DOWNSTREAM PORTIONPiping System: Pressurizer Relief LineCombinations 5 and 6 - N + LOCA + SSE + SOT_F

<u>Node Point</u>	<u>Piping Component</u>	<u>Maximum Stress (ksi)</u>	<u>Allowable Stress (ksi)</u>
6080	Straight run	27.3	36.0
6090	Butt weld	29.4	36.0
6070	Elbow	36.0	36.0
4170	Reducer	18.3	39.8
5050	Tee	18.8	36.0

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

TABLE 6-12

PRIMARY STRESS SUMMARY - UPSTREAM OF VALVESPiping System: Pressurizer Safety LineCombination 1 - N

<u>Node Point</u>	<u>Piping Component</u>	<u>Maximum Stress (ksi)</u>	<u>Allowable Stress (ksi)</u>
2070	Straight run	4.9	16.4
1020	Butt weld	7.2	16.4
1110	Elbow	5.5	16.4

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

TABLE 6-13

PRIMARY STRESS SUMMARY - UPSTREAM OF VALVESPiping System: Pressurizer Safety LineCombination 2 - N + OBE + SOT_U

<u>Node Point</u>	<u>Piping Component</u>	<u>Maximum Stress (ksi)</u>	<u>Allowable Stress (ksi)</u>
2050	Straight run	6.5	19.7
1020	Butt weld	13.2	19.7
1030	Elbow	9.7	19.7

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

TABLE 6-14

PRIMARY STRESS SUMMARY - UPSTREAM OF VALVESPiping System: Pressurizer Safety LineCombination 3 - N + SOT_E

<u>Node Point</u>	<u>Piping Component</u>	<u>Maximum Stress (ksi)</u>	<u>Allowable Stress (ksi)</u>
2050	Straight run	11.6	29.6
3020	Butt weld	23.6	29.6
1090	Elbow	14.5	29.6

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

TABLE 6-15

PRIMARY STRESS SUMMARY - UPSTREAM OF VALVESPiping System: Pressurizer Safety LineCombinations 4 and 5 - N + LOCA + SSE + SOT_F

<u>Node Point</u>	<u>Piping Component</u>	<u>Maximum Stress (ksi)</u>	<u>Allowable Stress (ksi)</u>
2050	Straight run	12.3	39.4
3020	Butt weld	23.9	39.4
1090	Elbow	17.8	39.4

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

TABLE 6-16

PRIMARY STRESS SUMMARY - SEISMICALLY DESIGNED DOWNSTREAM PORTIONPiping System: Pressurizer Safety Line

<u>Combination 1 - N</u>			
<u>Node</u> <u>Point</u>	<u>Piping Component</u>	<u>Maximum</u> <u>Stress (ksi)</u>	<u>Allowable</u> <u>Stress (ksi)</u>
5386	Straight run	5.8	15.0
5042	Butt weld	5.1	15.0
5520	Elbow	5.4	15.0
5050	Tee	5.6	15.0

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

TABLE 6-17

PRIMARY STRESS SUMMARY - SEISMICALLY DESIGNED DOWNSTREAM PORTIONPiping System: Pressurizer Safety LineCombination 2 - N + SOT_U

<u>Node Point</u>	<u>Piping Component</u>	<u>Maximum Stress (ksi)</u>	<u>Allowable Stress (ksi)</u>
5040	Straight run	7.3	18.0
5042	Butt. weld	7.0	18.0
5130	Elbow	6.9	18.0
5050	Tee	9.1	18.0

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

TABLE 6-18

PRIMARY STRESS SUMMARY - SEISMICALLY DESIGNED DOWNSTREAM PORTIONPiping System: Pressurizer Safety LineCombination 3 - N + OBE + SOT_U

<u>Node Point</u>	<u>Piping Component</u>	<u>Maximum Stress (ksi)</u>	<u>Allowable Stress (ksi)</u>
5040	Straight run	7.4	27.0
1230	Butt weld	7.7	27.0
6070	Elbow	9.6	27.0
5050	Tee	9.3	27.0

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

TABLE 6-19

PRIMARY STRESS SUMMARY - SEISMICALLY DESIGNED DOWNSTREAM PORTIONPiping System: Pressurizer Safety LineCombination 4 - N + SOT_E

<u>Node Point</u>	<u>Piping Component</u>	<u>Maximum Stress (ksi)</u>	<u>Allowable Stress (ksi)</u>
6080	Straight run	26.9	27.0
6090	Butt weld	26.6	27.0
6070	Elbow	27.0	27.0
5070	Tee	24.5	27.0

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

TABLE 6-20

PRIMARY STRESS SUMMARY - SEISMICALLY DESIGNED DOWNSTREAM PORTIONPiping System: Pressurizer Safety LineCombinations 5 and 6 - N + LOCA + SSE + SOT_F

<u>Node Point</u>	<u>Piping Component</u>	<u>Maximum Stress (ksi)</u>	<u>Allowable Stress (ksi)</u>
6080	Straight run	27.3	36.0
6090	Butt weld	29.4	36.0
6070	Elbow	36.0	36.0
5070	Tee	25.2	36.0

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