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Preliminary Structural Evaluation of Trojan RCL Subject to Postulated RPV Support Failure

Prepared by S. C. Lu

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Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

This report describes a preliminary structural evaluation made to determine whether the reactor coolant loop (RCL) piping of the Trojan nuclear power plant is capable of transferring the loads normally carried by the reactor pressure vessel (RPV) supports to other component supports in the RCL system if the RPV supports should fail, say from radiation damage. For the evaluation, we use the computer model of the RCL system of Unit 1 of the Zion nuclear power plant because it is readily available; the RCL systems of these two plants closely resemble each other. As a bounding case in the evaluation we postulate that all four RPV supports have failed. Two load combinations are evaluated: (1) the combination of dead weight, operating pressure, and the safe-shutdown earthquake, and (2) the combination of dead weight, operating pressure, and a loss-of-coolant accident. Both load combinations are classified as Level D Service Limits in accordance with the ASME Boiler and Pressure Vessel Code. Static and dynamic linear elastic analyses are conducted to comply with rules specified by Subsection NB in conjunction with Appendix F, Division 1, Section III of the ASME Code. Results of this preliminary evaluation indicate that ASME Code Appendix F requirements are satisfied by each of the load combinations considered in the analysis, leading to the conclusion that the Trojan RCL piping is capable of transferring the RPV support loads to the steam generator and reactor coolant pump supports.

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EXECUTIVE SUMMARY

In order to evaluate the consequences of potential failure of reactor pressure vessel (RPV) supports in pressurized water reactor nuclear power plants due to effects of irradiation embrittlement, the Nuclear Regulatory Commission has selected the Trojan nuclear power plant for a pilot study. The evaluation starts with the structural integrity assessment of the reactor coolant loop (RCL) system to determine whether the RCL piping is capable of transferring (or redistributing) RPV support loads to other component supports in the RCL system. Because of its close resemblance to the Trojan RCL design and because there is a readily available computer model for it, the RCL system of Unit 1 of Zion nuclear plant has been analyzed to demonstrate the methodology as well as to obtain preliminary results regarding the structural evaluation.

As a bounding case in the evaluation, it is postulated that all four RPV supports have initially failed. Two load combinations are evaluated: (1) the combination of dead weight, operating pressure, and the safe shutdown earthquake, and (2) the combination of dead weight, pressure, and a loss-of-coolant-accident. Both load combinations are classified as Level D Service Limits in accordance with the ASME Boiler and Pressure Vessel Code, and rules contained in Subsection NB in conjunction with Appendix F, Division 1, Section III of the ASME Code, which permit linear elastic analyses, are followed by the evaluation.

Results of the evaluation indicate that the ASME Code Appendix F requirements are satisfied by both load combinations considered in the analysis, leading to the conclusion that the Zion RCL piping is capable of transferring RPV loads to steam generator (SG) and reactor coolant pump (RCP) supports. The same conclusion also appears to be applicable to the Trojan RCL design because (1) the two RCL systems are very similar and (2) both Zion and Trojan seismic input motions are considered by the analysis. It is cautioned that RPV movements may be considerably underestimated because of the linear elastic nature of the analysis. Additionally, the ability of SG and RCP supports to carry the additional loads transferred by the RCL piping has not been evaluated by the current study. However, it is felt that these supports should have sufficient design margins to accommodate the additional loads.

1.0 INTRODUCTION

The reactor pressure vessel (RPV) support embrittlement problem associated with pressurized water reactors (PWRs) in nuclear power plants was identified by the Nuclear Regulatory Commission (NRC) in 1978, designated as a candidate Unresolved Safety Issue in 1981, but assigned a LOW priority in 1983. Based on data and analyses developed by the Oak Ridge National Laboratory (ORNL) in April 1988 [1], the NRC staff concluded that the potential for RPV support embrittlement from neutron radiation damage could be greater than predictions based on pre-1988 data. A reevaluation of the issue conducted by the NRC finally concluded in December 1988 that this issue should be given a HIGH priority ranking.

The potential safety significance of this problem is that low-temperature irradiation of structural materials can result in RPV support structure embrittlement, increasing the potential for unstable propagation of flaws that might exist in the materials. The radiation-induced embrittlement may result in failure of the RPV supports and consequent movement of the reactor vessel, given the occurrence of a transient stress or shock such as could be experienced in a loss-of-coolant- accident (LOCA) or severe earthquake. A number of actions are currently funded by the NRC to resolve this generic safety issue. One of the actions is to conduct a consequence evaluation of embrittled RPV support failure.

The objective of the consequence evaluation of embrittled RPV support failure is to provide a sound technical basis for determining whether the failure of RPV supports could prevent safe shutdown or lead to unacceptable consequences during or following the design basis earthquake or pipe rupture. The work is sponsored by the Division of Engineering of the Office of Nuclear Regulatory Research of the NRC and executed by Lawrence Livermore National Laboratory (LLNL) under an interagency agreement between the NRC and the U.S. Department of Energy.

The evaluation is divided into two phases. Phase 1 is a pilot study on a selected nuclear plant. Phase 2 is a parametric study of critical variables undertaken in an attempt to generalize the pilot results to other nuclear units susceptible to neutron embrittlement d[illegible]e. The Trojan nuclear power plant has been selected for the pilot study because its RPV s[illegible]rts are located in the high radiation zone and are subject to high tensile stresses.

The pilot study comprises a structural evaluation and an effects evaluation for postulated failure of one or more RPV supports. Failure of an RPV support herein means the support has completely lost its load-bearing capacity. The structural evaluation determines (1) the ability of the reactor coolant loop (RCL) piping to transfer (or redistribute) the RPV support loads to steam generator (SG) supports, reactor coolant pump (RCP) supports, and, if applicable, the concrete shield wall, and (2) the ability of SG and RCP supports to carry the additional loads transferred by the RCL piping.

The effects evaluation will be conducted if the structural evaluation shows that the RPV support loads can be redistributed from the failed supports and that the SG and RCP supports are capable of carrying the additional loads. The effects evaluation will then (1) calculate the motions (translations and rotations) of the RPV associated with failure of specified RPV supports, and (2) assess consequences of the RPV motions such as, but not limited to, the ability to insert control rods for achieving hot shutdown and the ability of the reactor coolant pumps and any instrument lines and small-diameter piping attached to the RPV to maintain their integrity.

As a bounding case in the Phase 1 study, all four supports of the Trojan reactor pressure vessel are assumed to have initially failed. If it is shown that the RPV loads cannot be redistributed from the failed vessel supports, this bounding case will be abandoned and only one of the four supports will be assumed to have failed. The structural evaluation is based on a linear analysis following rules provided by Subsection NB and Appendix F, Division 1, Section III of the ASME Boiler and Pressure Vessel Code [2].

This report summarizes the structural evaluation of the bounding case for the Zion Unit 1 (Zion 1) nuclear plant. The reasons for doing this exercise are (1) the close resemblance between Zion 1 and Trojan (both are four-loop Westinghouse PWR plants), and (2) the existence of an RCL computer analysis model for Zion 1. The objectives of this evaluation are to demonstrate the methodology used in the structural evaluation and to obtain some quick and preliminary indications with regard to the structural integrity of the Trojan RCL system when all four RPV supports have failed. The analysis will be repeated when the development of the actual Trojan model is completed.

2.0 PLANT DESCRIPTION

The Zion 1 nuclear power plant utilizes a four-loop Westinghouse PWR nuclear steam supply system (NSSS). A typical four-loop Westinghouse NSSS is shown in Figure 1. The NSSS consists of the reactor pressure vessel, steam generators, reactor coolant pumps, the pressurizer, and the piping. The piping in each of the main loops of the NSSS contains the hot leg (RPV to SG), the cross-over leg (SG to RCP), and the cold leg (RCP to RPV). The surge line piping connects the pressurizer to the hot leg in one of the four loops. Figure 2 shows the plan view of the reactor coolant loops for the Zion 1 plant.

The Zion 1 RPV has four Type 4G supports (see Fig. 3) located at alternate nozzles according to the classification system described in [1]. Zion Unit 1 bears a great deal of resemblance to the Trojan plant in terms of the NSSS design. Table 1 presents a close comparison between the two NSSS systems based on [3] and [4]. Figure 4 shows the Type 4A RPV support design used by the Trojan plant.

3.0 DESCRIPTION OF COMPUTER ANALYSIS MODEL

The Zion Station RCL model was originally developed for LLNL's Load Combination Program [5] to be used to perform linear elastic analyses of the RCL system subject to either earthquake input motions or static loads such as dead weight, thermal loads, and internal pressure. The input format of the model is compatible with the finite-element computer code SAP4 [6] or GEMINI [7].

The original model has 339 nodes. The model utilizes beam elements to model component supports, stiffness elements to represent nozzle effects, and pipe elements to simulate piping, steam generators, reactor coolant pumps, the reactor pressure vessel, and the pressurizer. For the present analysis, the original model has been reduced by removing the surge line and the pressurizer. The reduced model has 282 nodes (234 unconstrained and 48 constrained), 33 beam elements for static analyses or 37 for dynamic analyses, 16 stiffness elements, and 224 straight and bent pipe elements. The reduced model is shown by Figure 5.

4.0 LOADING CONDITIONS

Two load combinations are evaluated in the analyses: load combination 1 consists of dead weight, operating pressure, and the safe shutdown earthquake (SSE), and load combination 2 consists of dead weight, operating pressure, and a loss-of- coolant-accident (LOCA) load due to a small pipe break. Both load combinations are classified as Level D Service Limits in accordance with ASME Code definitions, and rules contained in Appendix F in conjunction with Subsection NB of the Code are to be used in evaluating the Service Loadings.

The operating pressure for Trojan is 2,235 psi. An operating temperature of 600°F is conservatively chosen to determine temperature-dependent material properties for the pipe, but thermally induced stresses are not considered in the piping evaluation because thermal stresses are classified as secondary stresses by the ASME Code and are not required to be considered by Appendix F evaluations. However, thermal effects due to the operating temperature are included in determinations of the RPV support forces (with supports intact) and the RPV vertical motion (with no RPV supports).

SSE loading is evaluated by the response spectrum method. The floor response spectra for Zion 1 with a base ground acceleration of 0.17 g horizontally and 0.11 g vertically are shown by Figure 6 [4]. The SSE at Trojan has a base ground acceleration of 0.25 g horizontally and 0.17 g vertically. The floor response spectra needed for the analyses were obtained from the PGE [8] and are shown in Figure 7.

A small-break loss-of-coolant-accident (SBLOCA) is assumed to occur in one of the auxiliary pipe lines attached to one reactor coolant loop. The specific auxiliary line to be considered by the evaluation was specified by the NRC to be the surge line. The location of the pipe break is assumed to occur at the joint between surge line and hot leg, although further studies may be required to determine whether this is the most unfavorable location.

Forcing functions for the thrust force induced by the pipe break at the break location were developed by Stevenson [9] and Holman [10]. Both results are based on double-ended guillotine break (DEGB), although the thrust force is applied vertically at the break location in the analyses to simulate the more unfavorable condition resulting from a slot break. The forcing function developed by Stevenson, shown by the curve identified as SBLOCA(DEGB1) in Figure 8, was based on simplified considerations, whereas that developed by Holman, shown by the curve identified as SBLOCA(DEGB2) in Figure 8, was based on a much more elaborate analysis conducted by Fletcher [11] of the Idaho National Engineering Laboratory (INEL) using the thermohydraulic computer code RELAP5. Fletcher has also performed a RELAP5 analysis to simulate a slot break in the surge line [12]. The forcing function for the slot break is shown by the curve SBLOCA(SLOT) in Figure 8.

5.0 ANALYTICAL METHOD

Rules contained in Appendix F and Subsection NB are provided for limiting the consequences of the specified events. They are intended to assure that violation of the pressure-retaining boundary will not occur, but are not intended to assure operability of components either during or following the specified event. Only limits on primary stresses are prescribed. Unless specifically required by the Appendix, self-relieving stresses (such as thermally induced stresses) resulting from loads for which Level D Service Limits are specified need not be considered. Linear analyses are permitted by Appendix F in performing the structural evaluation. For piping, Appendix F requires that Equation (9) of NB-3652 shall be satisfied using a stress limit of $3S_m$, i.e.,

$$B_1 (PD_o/2t) + B_2 (D_o M_i/2I) < 3S_m,$$

where B_1, B_2 = primary stress indices which are given the values of 0.5 and 1.0, respectively, in accordance with NB-3680,

P = pressure,

D_o = outside diameter,

t = pipe wall thickness,

I = moment of inertia of the pipe section,

M_i = resulting moment due to a combination of mechanical loads,

S_m = allowable stress intensity value per Table I-1.0 of the ASME Code.

It can be seen from the above equation that, in order to carry out the structural evaluation, we need to calculate bending moments in the pipe due to dead weight, SSE, and SBLOCA, individually, and then combine them appropriately.

For SG and RCP supports, it is tentatively assumed that they are capable of carrying the additional loads without failure. Appropriate failure criteria for component supports, however, will be developed for the structural evaluation of the Trojan plant.

Bending moments in the RCL piping are obtained by static analyses resulting from GEMINI, which is a computer program for calculation of static and dynamic response of linear elastic structures by the finite-element method.

Bending moments due to the SSE are obtained by floor response spectrum analysis. Fundamental frequencies of free vibration modes of the RCL model are calculated because they are required by the response spectrum analysis. The frequencies of the first 30 modes are given in Table 2, and the first three vibration modes are shown in Figures 9, 10, and 11. In the seismic evaluation, both Zion 1 floor response input (Figure 6) and the Trojan input (Figure 7) are analyzed. Variable and frequency-dependent modal damping ratios as depicted by Figure 12 are used in the current analysis. The variable damping ratios were developed by the Pressure Vessel Research Committee (PVRC) and recommended by the Seismic Design Task Group of the NRC Piping Review Committee [13] following ASME Code Case N-411.

Structural analysis of the SBLOCA load due to the surge line break is carried out by the modal time history integration method available in GEMINI. The analysis considers all three forcing functions of the thrust force induced by the SBLOCA, as shown by Figure 8, and determines the most critical one to be used.

6.0 RESULTS OF THE STRUCTURAL EVALUATION

Although the current evaluation deals mainly with the RCL system subject to postulated RPV support failure, the original RCL system with no RPV support failure is also analyzed in order to generate some useful information, such as RPV support forces resulting from various loading conditions as shown by Table 3. It is noted that both SBLOCA(DEGB2) and SBLOCA(SLOT) forcing functions produce almost identical RPV support forces, which are slightly higher than those produced by SBLOCA(DEGB1). Consequently, SBLOCA(SLOT) is selected as the small-pipe-break forcing function to be used throughout this evaluation.

Vertical displacements at locations of RPV outlet nozzles are listed in Table 4. Vertical support forces and overturning moments are listed in Tables 5 and 6, respectively, for steam generator supports. Table 7 shows stresses in the RCL piping at RPV outlet (or hot leg) nozzles calculated from bending moments.

7.0 DISCUSSION AND CONCLUSION

The results of the free vibration analysis (Table 2) indicate that the first three vibration modes, having frequencies of 3.76, 4.26, and 5.89 Hz, of the RCL model with postulated RPV support failure are clearly lower than all the frequencies associated with the vibration modes of the RCL model without RPV support failure. As anticipated, the first vibration mode, as shown by Figure 9, is dominated by the up-and-down motion of the reactor vessel whereas the other two modes, as shown by Figures 10 and 11, are basically rocking modes in two perpendicular directions.

Table 8, which summarizes the results of the ASME Code Equation (9) evaluation, shows that the Appendix F requirement is easily satisfied by each of the load combinations considered by the current structural evaluation, leading to the conclusion that Zion 1 RCL piping is capable of transferring the RPV support loads to the SG and RCP supports. The same conclusion appears to be applicable also to the Trojan RCL system because the RCL systems of the two plants are so much alike. The fact that the Trojan RCL pipe thicknesses are slightly less than those of Zion 1 probably will be compensated by the shorter distance between the RPV and the SG and the higher value for S_m associated with the Trojan plant. Table 8 also reveals that Load Combination 1 (with SSE) is more damaging than Load Combination 2 (with SBLOCA) for plants located in high seismic zones, such as in the case of the Trojan plant. However, just the opposite is true for Zion.

Displacements in Table 4 are listed simply for reference purposes, since they could be considerably underestimated by the linear analysis. The displacements will be rigorously assessed by a nonlinear analysis for the Trojan model at a later date.

Table 5 indicates that the maximum steam generator vertical support force shows an increase of 37% (based on the Load Combination 1 for Zion or 48% for Trojan SSE input) as the RPV loses all four supports. The increase in the maximum overturning moment, however, is much higher, i.e., 114% for Zion or 110% for Trojan, as indicated by Table 6. A study of the ultimate load capacity of component support structures is required in order to determine the ability of component supports to carry the additional loads transferred to them due to the postulated failure of the RPV supports. However, it is noted that SG or RCP supports were designed for a large-break LOCA which is now viewed as extremely unlikely. Large margins therefore exist to accommodate RPV support failure because the large-break LOCA load is now replaced by the SBLOCA load.

To conclude the consequence evaluation for the Trojan plant we will finish the following work:

- Structural Evaluation:
  - Complete the development of Trojan RCL model.
  - Conduct the structural evaluation including both the piping and the SG and RCP supports.
  - Include a study to determine the most unfavorable pipe break location along the length of the surge line.
- Effects Evaluation:
  - Identify critical components, instrument lines, and small pipes which are required for safe shutdown of the plant and are also affected by the RCL motions.
  - Determine the movements of the RCL system by a nonlinear structural analysis or other methods to evaluate the functionality or operability of the critical components, instrument lines and pipes.

8.0 RERERENCES

1. R. D. Cheverton, J. G. Merkle, and R. K. Nanstad, "Evaluation of HFIR Pressure Vessel Integrity Considering Radiation Embrittlement," Report ORNL/TM-10444, Oak Ridge National Laboratory, April 1988.

2. ASME Boiler and Pressure Vessel Code, 1986 Edition.

3. Trojan Nuclear Plant Final Safety Analysis Report, Docket No. 50-344, Portland General Electric Company.

4. Zion Station Final Safety Analysis Report, Commonwealth Edison Company.

5. A. C. Eberhardt, "Probability of Pipe Fracture in the Primary Coolant Loop of a PWR Plant, Volume 2: Primary Coolant Loop Model," NUREG/CR-2189, Vol. 2, September 1981.

6. S. J. Sackett, "Users Manual for SAP4, A Modified and Extended Version of the U. C. Berkeley SAPIV Code," UCID- 18226, Lawrence Livermore National Laboratory, May 1979.

7. R. C. Murray, "GEMINI - A Computer Program for Two and Three Dimensional Linear Static and Seismic Structural Analysis," UCID-20338, Lawrence Livermore National Laboratory, October 1984.

8. Informal Technical Transmittal, PGE to LLNL, June 1989.

9. Letter from J. D. Stevenson, Stevenson and Associates, to J. A. O'Brien, the Nuclear Regulatory Commission, July 12, 1989.

10. Letter from G. S. Holman, LLNL to J. A. O'Brien, NRC, August 14, 1989.

11. C. D. Fletcher, "Data Supporting Calculation of Thrust Load Imposed by a Pressurizer Surge Line Break," CDF-07- 89, INEL Letter Report to J. A. O'Brien of NRC, July 28, 1989.

12. C. D. Fletcher, "Data Supporting Calculation of Thrust Load Imposed by a Hot Leg Break," CDF-12-89, INEL Letter Report to J. A. O'Brien of NRC, August 15, 1989.

13. The Seismic Design Task Group of the NRC Piping Review Committee (S. Hou, Chairman), "Report of the U.S. Nuclear Regulatory Commission Piping Review Committee, Volume 2: Evaluation of Seismic Designs - A Review of Seismic Design Requirements for Nuclear Power Plant Piping," NUREG-1061, Volume 2, April 1985.

Table 1 Comparison of Trojan and Zion RCL Systems

	Trojan	Zion
Core heat output	3,411 MWt	3,250 MWt
No. of fuel rods	39,372	39,372
Core diameter	132.7 in.	132.7 in.
Core height	144.0 in.	143.4 in.
RPV total height	43 ft-10 in.	43 ft-9.72 in.
RPV shell ID	173 in.	173 in.
RPV belt-line thickness	8.5 in.	8.44 in.
RPV support type	4A	4G
RPV dead load	2,120 kips	1,990 kips
SG model type	51	51
RCP capacity	88,500 gpm	87,500 gpm
RCP height	28 ft-6.6 in.	25 ft-5.05 in.
RCP dry weight	188,200 lb	169,200 lb
RCP motor power	6,000 hp	6,000 hp
Main piping material	ASTM A351 Grade CF8A	ASTM A376 Type 316
Surge line material	ASTM A376 Type 316	ASTM A376 Type 316
Hot leg ID	29.00 in.	29.00 in.
Hot leg OD	33.90 in.	34.00 in.
Hot leg thickness	2.45 in.	2.50 in.
Crossover leg ID	31.00 in.	31.00 in.
Crossover leg OD	36.20 in.	36.32 in.
Crossover leg thickness	2.60 in.	2.66 in.
Cold leg ID	27.50 in.	27.50 in.
Cold leg OD	32.14 in.	32.26 in.
Cold leg thickness	2.32 in.	2.38 in.
Surge line ID	11.188 in.	11.188 in.
Surge line OD	14.000 in.	14.000 in.
Surge line thickness	1.406 in.	1.406 in.
RPV to SG distance	31.250 ft	32.333 ft
RPV to RCP distance	34.502 ft	36.500 ft
RCP to SG distance	17.472 ft	17.445 ft

Table 2 Frequencies of First 30 Modes of Zion RCL Model

	Frequency (Hz)	
Mode No.	With RPV Support Failure	Without RPV Support Failure
1	3.76	7.26
2	4.26	7.29
3	5.89	7.29
4	7.10	7.31
5	7.19	9.09
6	7.29	9.09
7	7.31	9.09
8	9.08	9.10
9	9.09	9.47
10	9.09	9.48
11	9.11	9.49
12	9.30	9.49
13	9.40	9.90
14	9.49	9.93
15	9.51	9.96
16	9.66	9.97
17	9.83	13.89
18	9.96	13.92
19	10.07	13.94
20	10.51	13.94
21	12.89	15.91
22	13.51	16.23
23	13.94	18.71
24	13.95	19.54
25	13.96	19.54
26	14.01	19.54
27	19.54	19.56
28	19.54	20.24
29	19.54	20.77
30	19.56	20.96

Table 3 Vertical Forces in RPV Supports

	Support Force (kips)			
Load Case	Loop 1	Loop 2	Loop 3	Loop 4
Pres + Weight	556	550	556	549
SSE (Zion)	130	118	130	118
SSE (Trojan)	380	348	380	348
SBLOCA (DEGB1)	92	84	129	121
SBLOCA (DEGB2)	97	88	138	128
SBLOCA (SLOT)	98	88	138	128
Thermal	94	61	108	92
PWT* + SSE (Zion)	780	729	794	759
PWT + SSE (Troj)	1,030	959	1,044	989
PWT + SBLOCA (SLOT)	748	699	802	769

*PWT = Pressure + Weight + Thermal.

Table 4 Vertical Displacements at RPV Outlet Nozzles

Load Case	Displacement (inches)			
	Loop 1	Loop 2	Loop 3	Loop 4
Pres + Weight	0.828 (0.010)*	0.828 (0.012)	0.828 (0.010)	0.828 (0.012)
Thermal	0.136 (0.004)	0.133 (0.005)	0.138 (0.004)	0.142 (0.006)
SSE (Zion)	0.128 (0.002)	0.128 (0.003)	0.128 (0.002)	0.128 (0.003)
SSE (Trojan)	0.232 (0.007)	0.232 (0.008)	0.232 (0.007)	0.232 (0.008)
PWT**+ SSE (Zion)	1.092 (0.016)	1.089 (0.020)	1.094 (0.016)	1.098 (0.021)
PWT**+ SSE (Troj)	1.196 (0.021)	1.193 (0.025)	1.198 (0.021)	1.202 (0.026)
SBLOCA (SLOT)	0.119 (0.002)	0.098 (0.003)	0.136 (0.003)	0.160 (0.004)
PWT**+ SBLOCA	1.083 (0.016)	1.059 (0.020)	1.102 (0.017)	1.130 (0.022)

* Displacements without RPV support failure are shown inside parentheses. Numbers above parentheses are displacements with RPV support failure.

** PWT = Pressure + Weight + Thermal.

Table 5 Vertical Forces in SG Supports

Load Case	Support Forces (kips) Loop 1	Loop 2	Loop 3	Loop 4
Pres + Weight	1,267 (853)*	1,262 (853)	1,266 (851)	1,256 (856)
Thermal	7 (57)	8 (23)	10 (32)	4 (110)
SSE (Zion)	151 (110)	163 (102)	163 (131)	126 (82)
SSE (Troj)	497 (294)	550 (275)	549 (353)	374 (221)
PWT** + SSE (Zion)	1,425 (1,020)	1,433 (978)	1,439 (1,014)	1,386 (1,048)
PWT + SSE (Troj)	1,771 (1,204)	1,820 (1,151)	1,825 (1,236)	1,634 (1,187)
SBLOCA (SLOT)	86 (6)	65 (11)	107 (7)	317 (238)
PWT + SBLOCA	1,360 (916)	1,335 (887)	1,383 (890)	1,577 (1,204)

* Forces without postulated RPV support failure are shown in parentheses. Numbers above parentheses are forces with RPV support failure.

** PWT = Pressure + Weight + Thermal.

Table 6 Overturning Moments in SG Supports

Load Case	Overturning Moment (kips-in.) Loop 1	Loop 2	Loop 3	Loop 4
Pres + Weight	51,040 (490)*	52,660 (320)	51,880 (410)	52,900 (660)
Thermal	23,790 (32,270)	25,440 (33,790)	28,460 (36,560)	9,320 (18,090)
SSE (Zion)	1,940 (1,140)	2,110 (1,780)	1,970 (1,420)	2,160 (2,100)
SSE (Trojan)	5,100 (3,020)	5,570 (4,700)	5,200 (3,750)	5,700 (5,520)
PWT** + SSE (Zion)	76,770 (33,900)	80,210 (35,890)	82,310 (38,390)	64,380 (20,850)
PWT + SSE (Trojan)	79,930 (35,780)	83,670 (38,810)	85,540 (40,720)	67,920 (24,270)
SBLOCA (SLOT)	950 (260)	800 (170)	1,490 (50)	1,720 (560)
PWT + SBLOCA	75,780 (33,020)	78,900 (34,280)	81,830 (37,020)	63,940 (19,310)

* Overturning moments without RPV support failure are shown in parentheses. Numbers above parentheses are overturning moments with RPV failure.

** PWT = Pressure + Weight + Thermal.

Table 7 Bending Stresses in RCL Piping at RPV Outlet Nozzles

	Bending Stress (psi)			
Load Case	Loop 1	Loop 2	Loop 3	Loop 4
Dead Weight	22,580 (1,630)*	22,490 (1,440)	22,570 (1,630)	22,510 (1,420)
Thermal	1,380 (5,080)	1,570 (5,100)	1,270 (4,920)	1,780 (5,890)
SSE (Zion)	4,830 (330)	4,830 (350)	4,830 (350)	4,830 (330)
SSE (Trojan)	9,260 (930)	9,280 (980)	9,280 (970)	9,230 (950)
SBLOCA (DEGB1)	** (180)	** (210)	** (130)	** (210)
SBLOCA (DEGB2)	** (200)	** (280)	** (160)	** (310)
SBLOCA (SLOT)	4,210 (200)	3,390 (280)	5,700 (160)	7,320 (310)

* Stresses in parentheses are without RPV support failure. Numbers above parentheses are stresses with RPV support failure.

** Not calculated.

Table 8 ASME Code Equation (9) Evaluation

$B_1 (PD_0 /2T)+B_2 (M_i D_o /2I)$, (ksi)

Load Combination*	Loop 1	Loop 2	Loop 3	Loop 4	$3S_m$ (ksi)
Load Comb. 1 (Zion)	35.0 (9.6)*	34.9 (9.4)	35.0 (9.6)	34.9 (9.4)	51.0
Load Comb. 2 (Zion)	34.4 (9.4)	33.5 (9.4)	35.9 (9.4)	37.3 (9.3)	51.0
Load Comb. 1 (Trojan)	39.4 (10.2)	39.4 (10.0)	39.5 (10.2)	39.3 (10.0)	57.9
Load Comb. 2 (Trojan)	34.4 (9.4)	33.5 (9.4)	35.9 (9.4)	37.3 (9.3)	57.9

* See Section 4, Loading Conditions, for definitions of load combinations, i.e.,
Load Comb. 1 = DW + Pressure + SSE
Load Comb. 2 = DW + Pressure + SBLOCA

** Numbers in parentheses are stresses without postulated RPV support failure. Numbers above parentheses are stresses with RPV support failure.

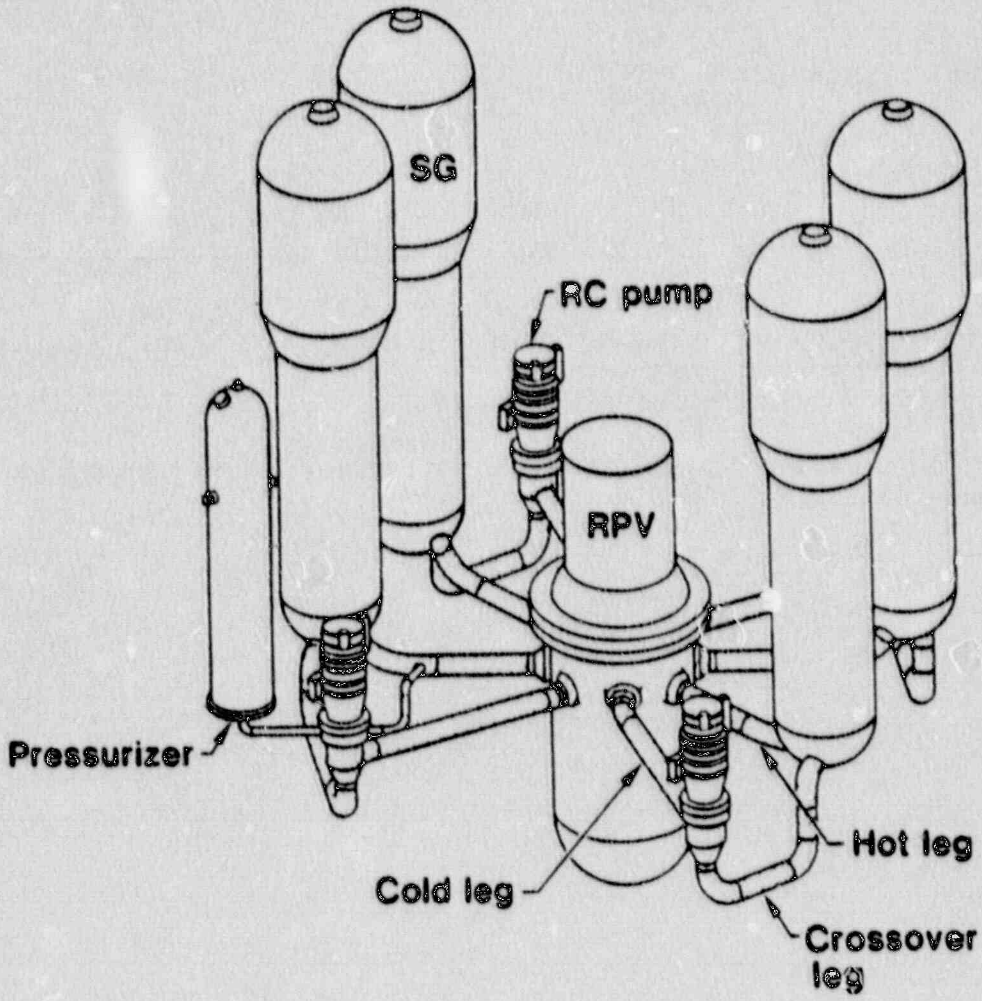


Figure 1 A Typical Westinghouse PWR NSSS.

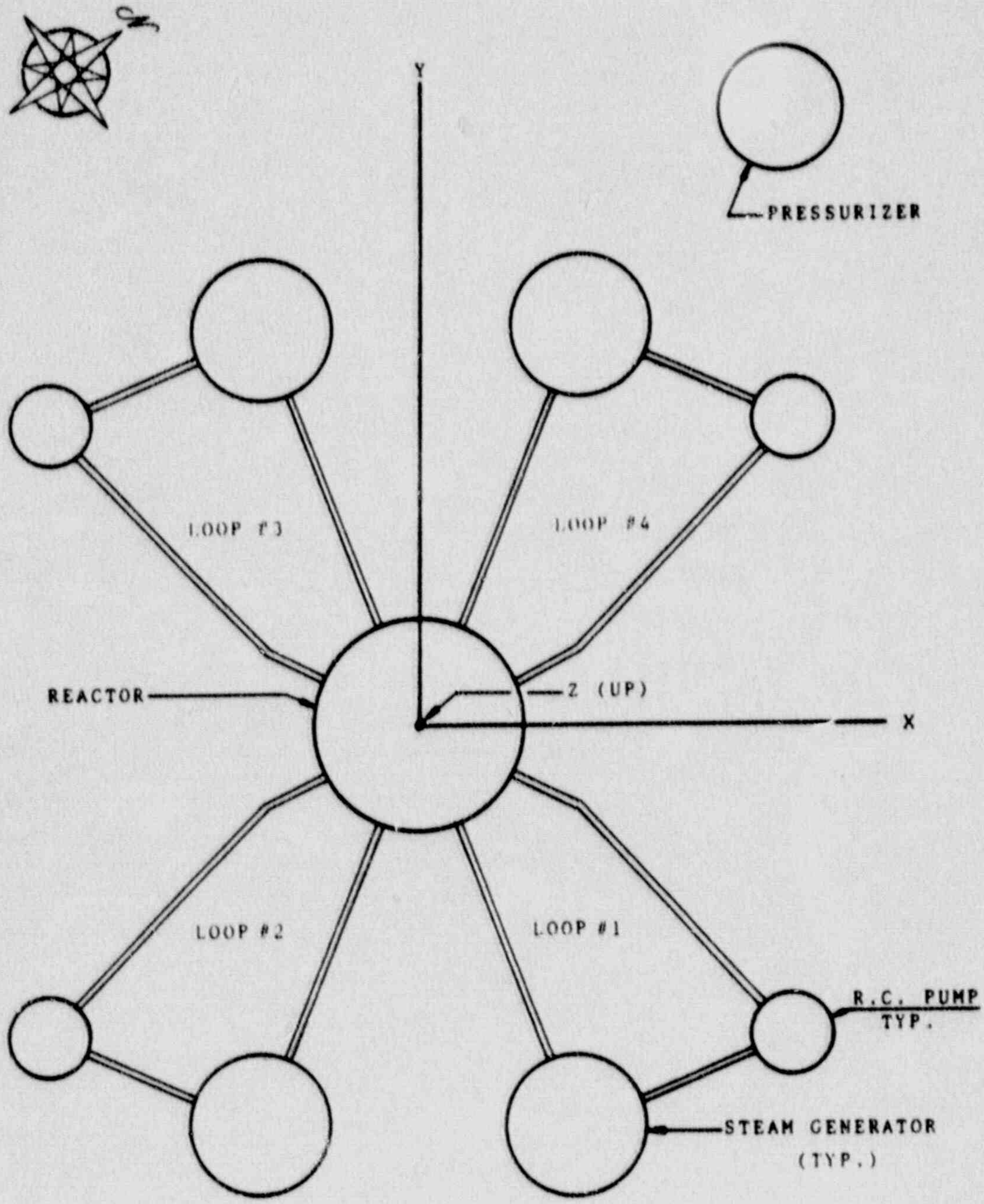


Figure 2 A Plan View of Zion 1 NSSS.

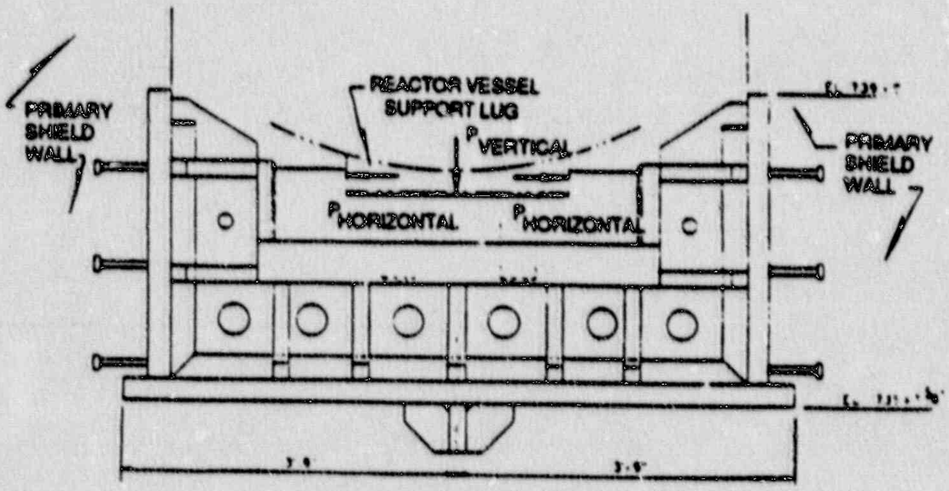


Figure 3 Type 4G PWR Reactor Vessel Support.

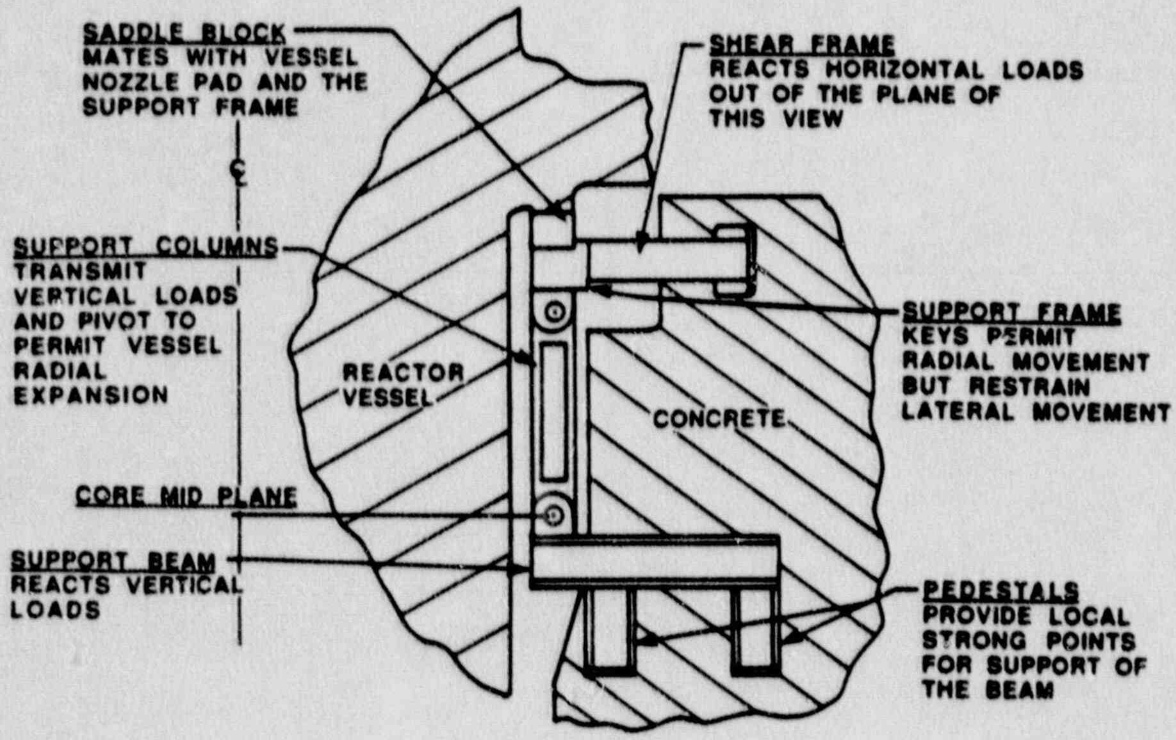


Figure 4 Type 4A PWR Reactor Vessel Support.

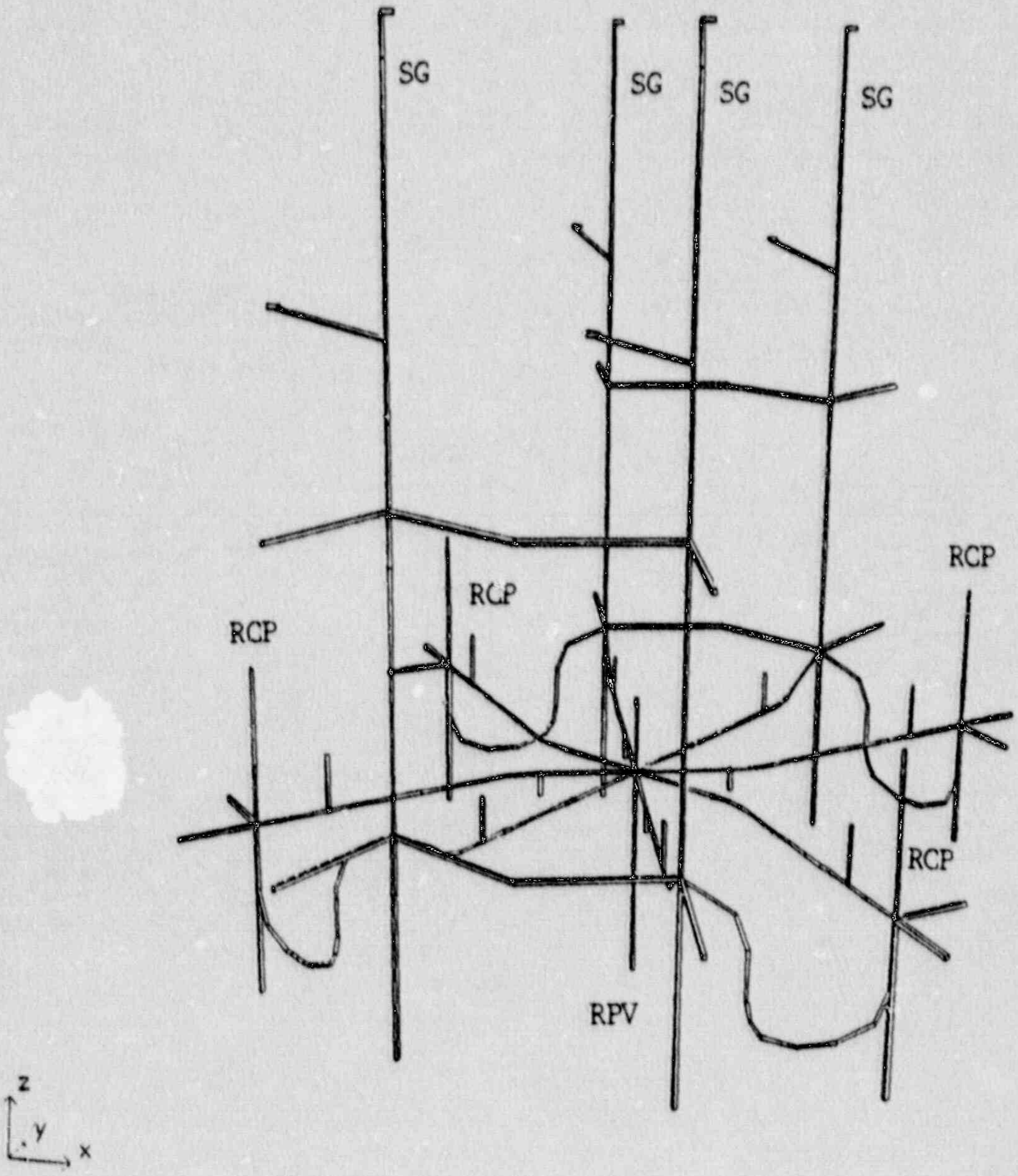


Figure 5 Zion 1 Reactor Coolant Loop Model.

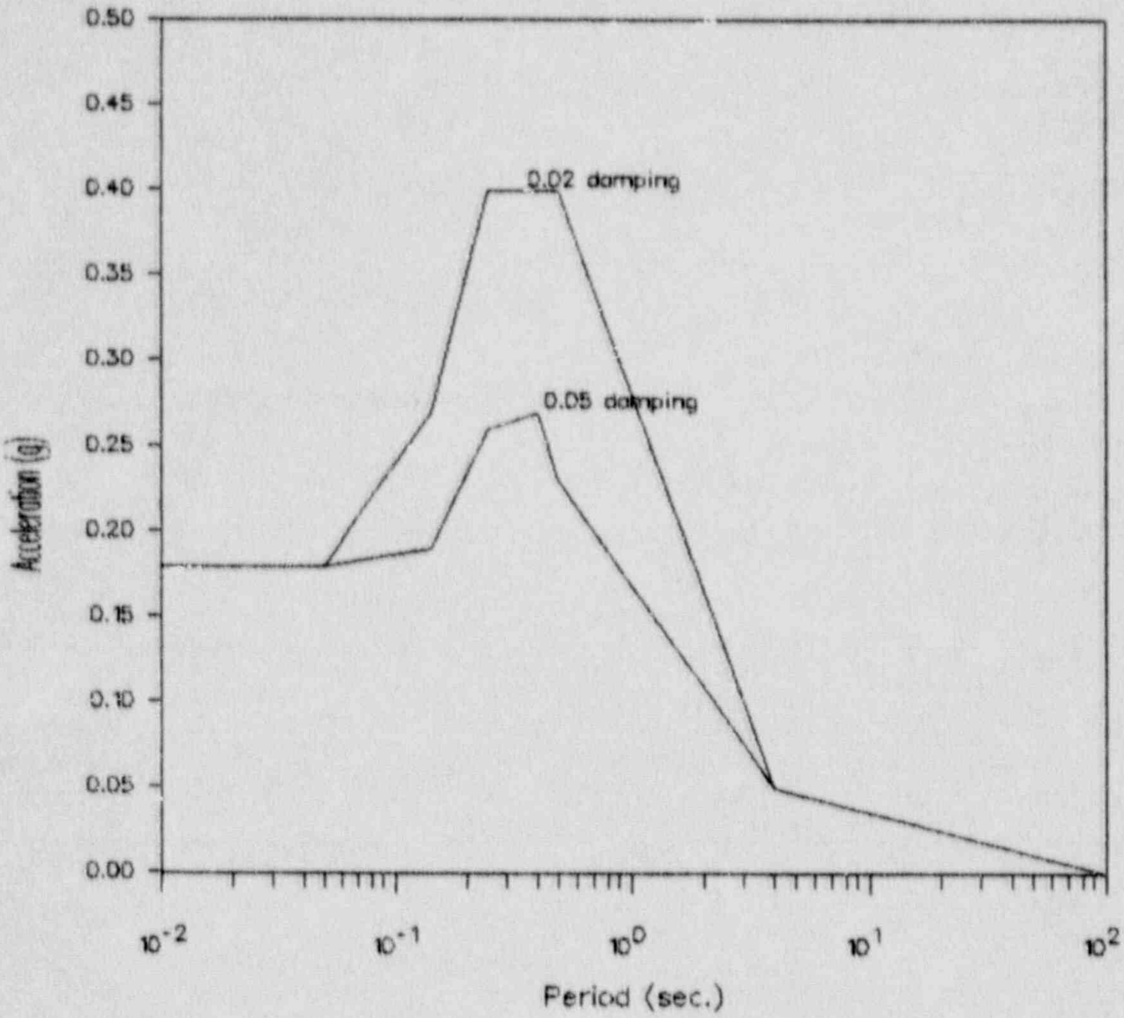


Figure 6 Zion 1 RCL Floor Response Spectra.

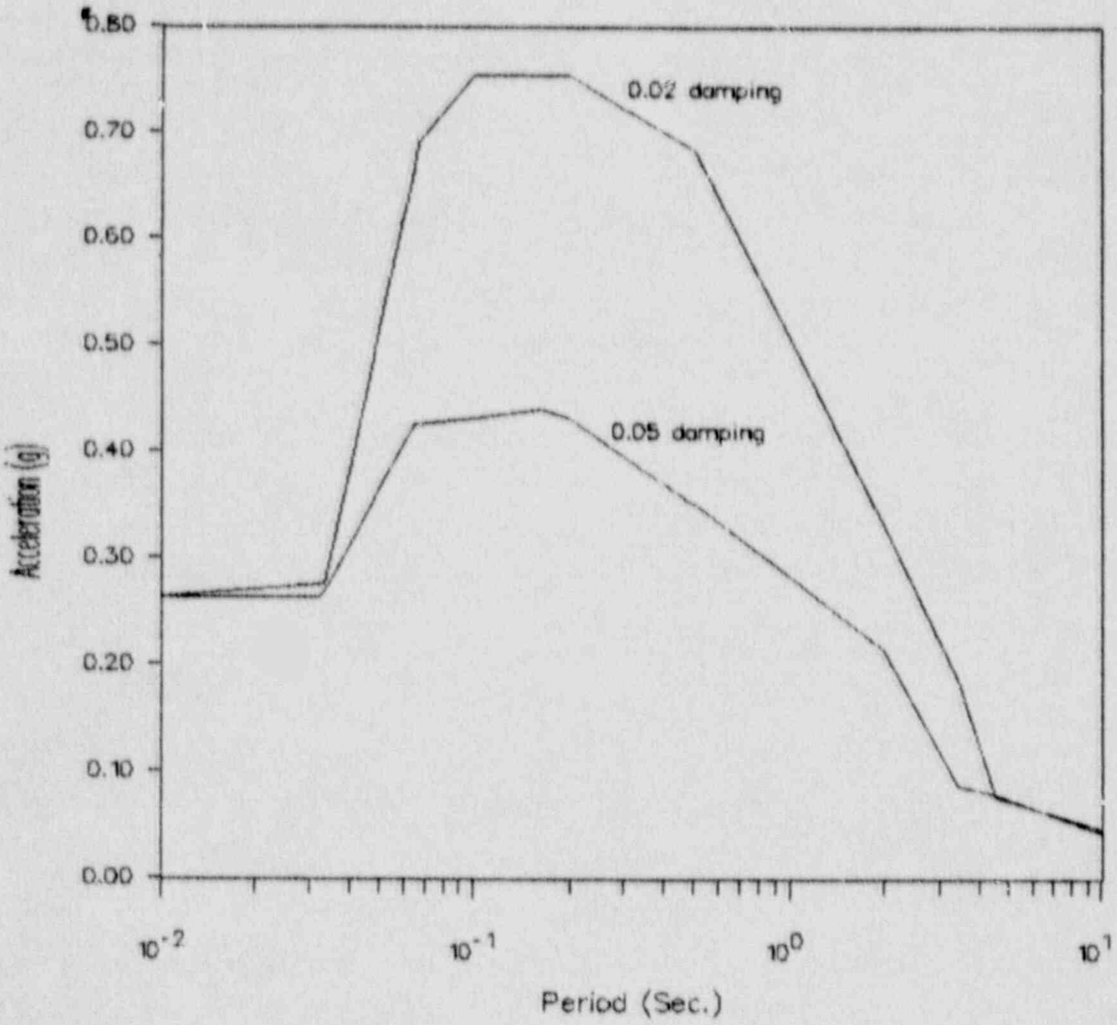


Figure 7 Trojan RCL Floor Response Spectra.

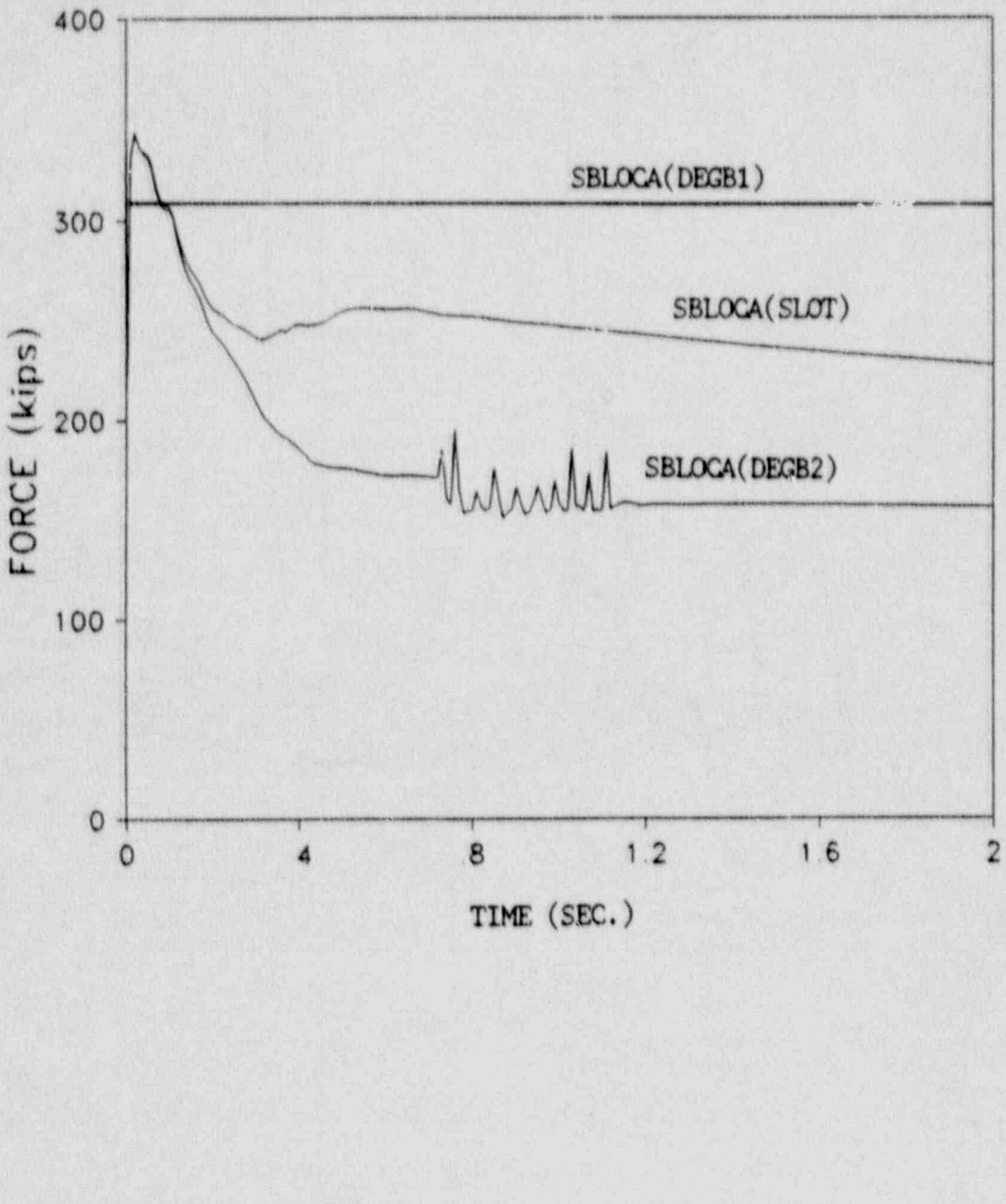
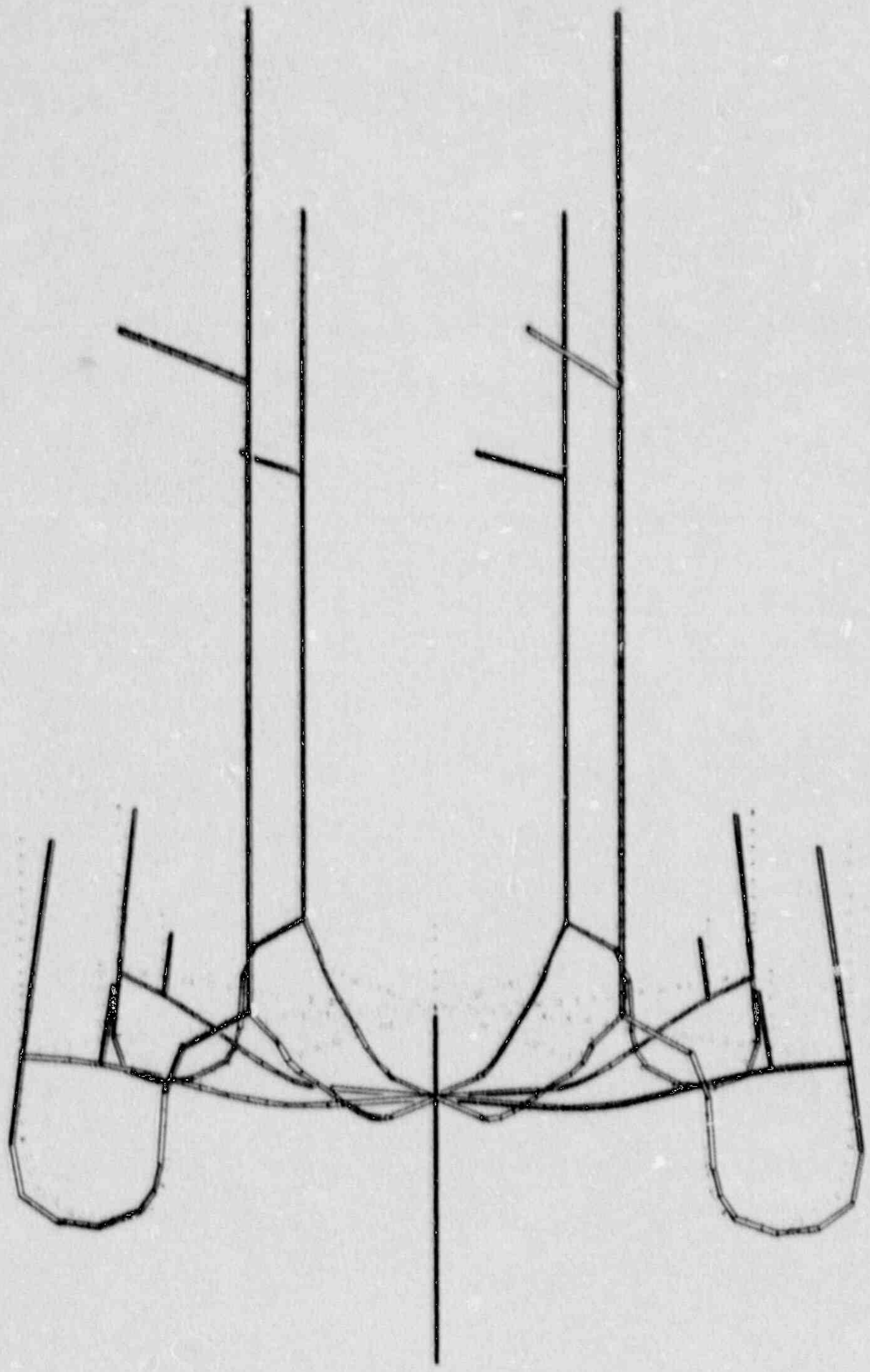
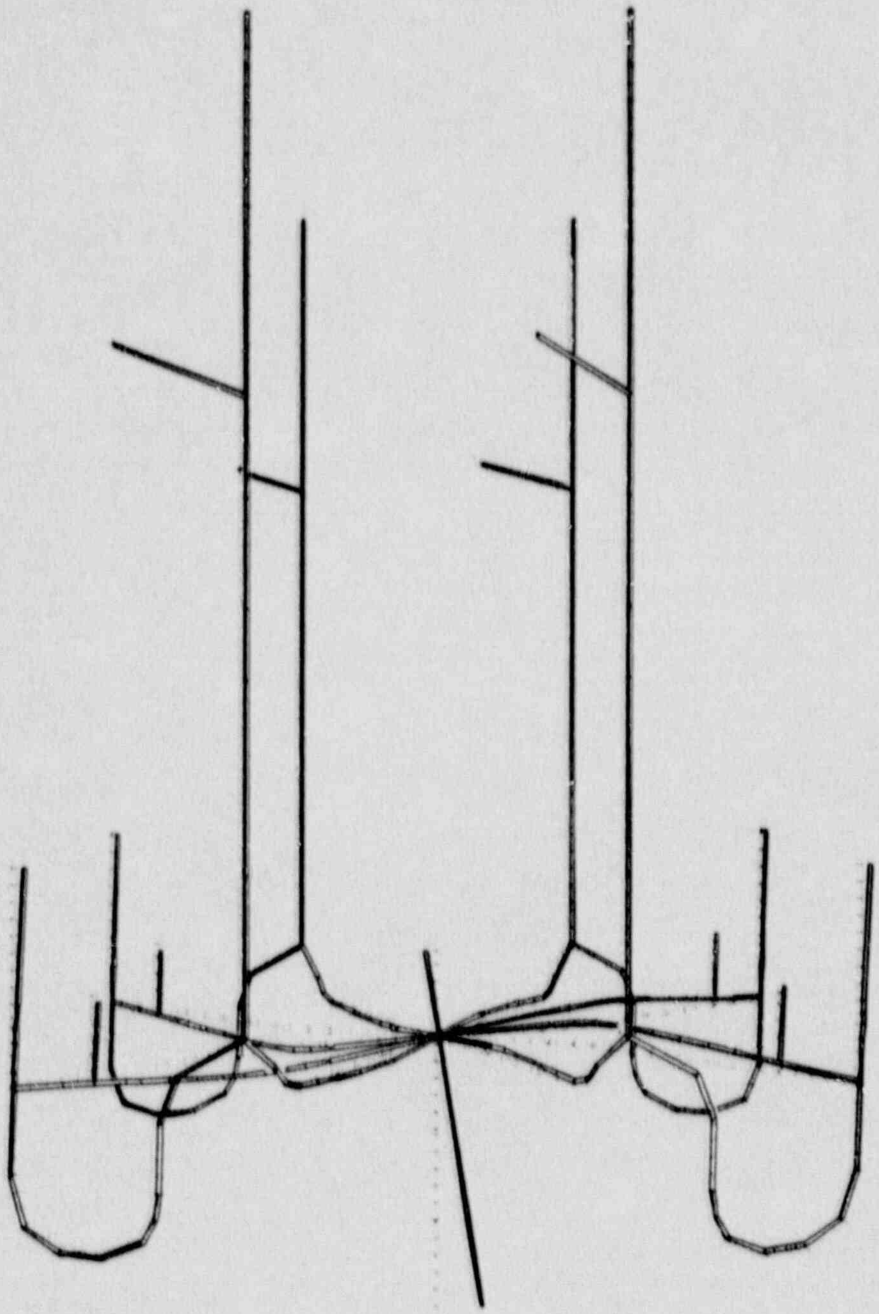


Figure 8 Surge Line LOCA Forcing Functions.



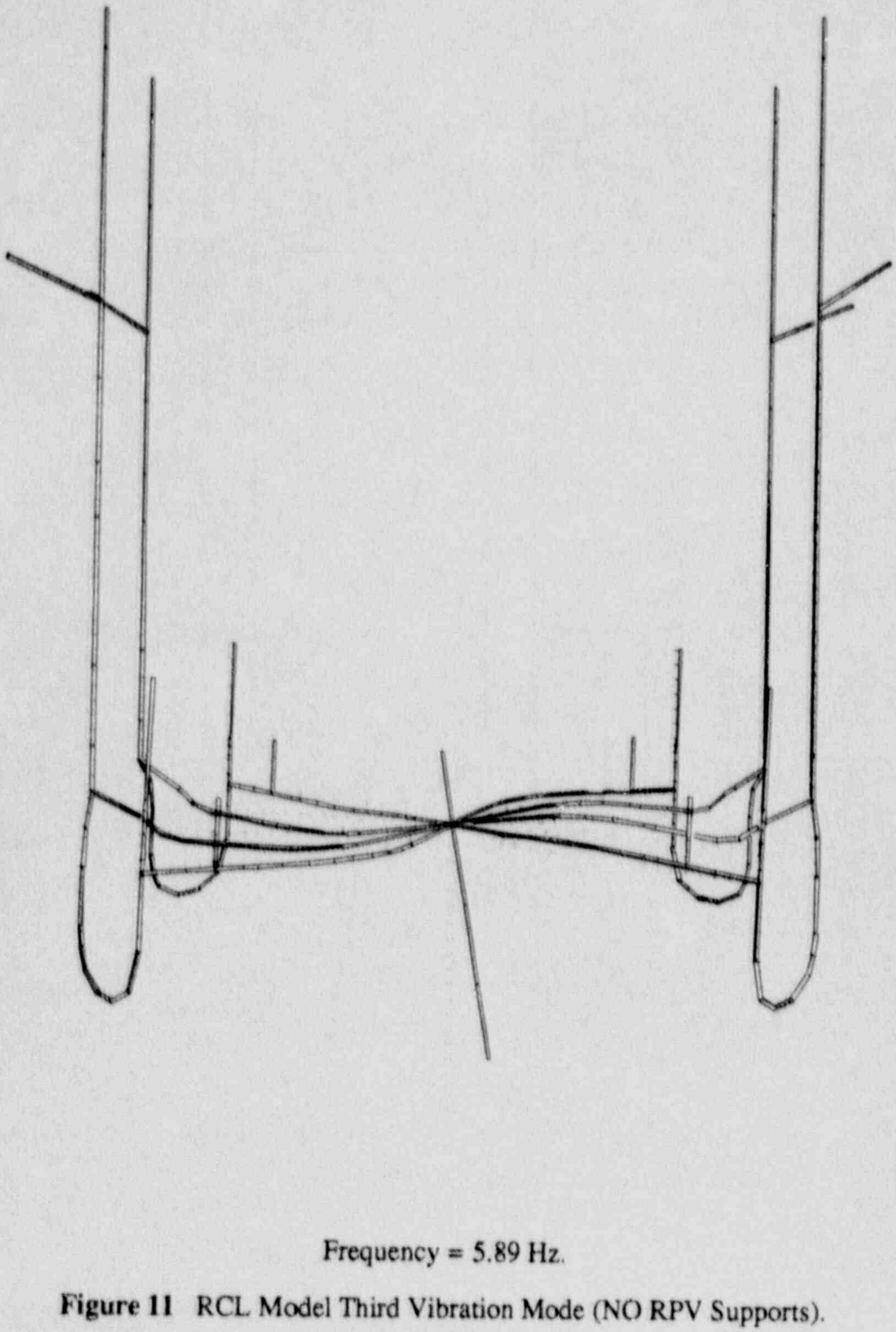
Frequency = 3.76 Hz.

Figure 9 RCL Model First Vibration Mode (No RPV Supports).



Frequency = 4.26 Hz.

Figure 10 RCL Model Second Vibration Mode (NO RPV Supports).



Frequency = 5.89 Hz.

Figure 11 RCL Model Third Vibration Mode (NO RPV Supports).

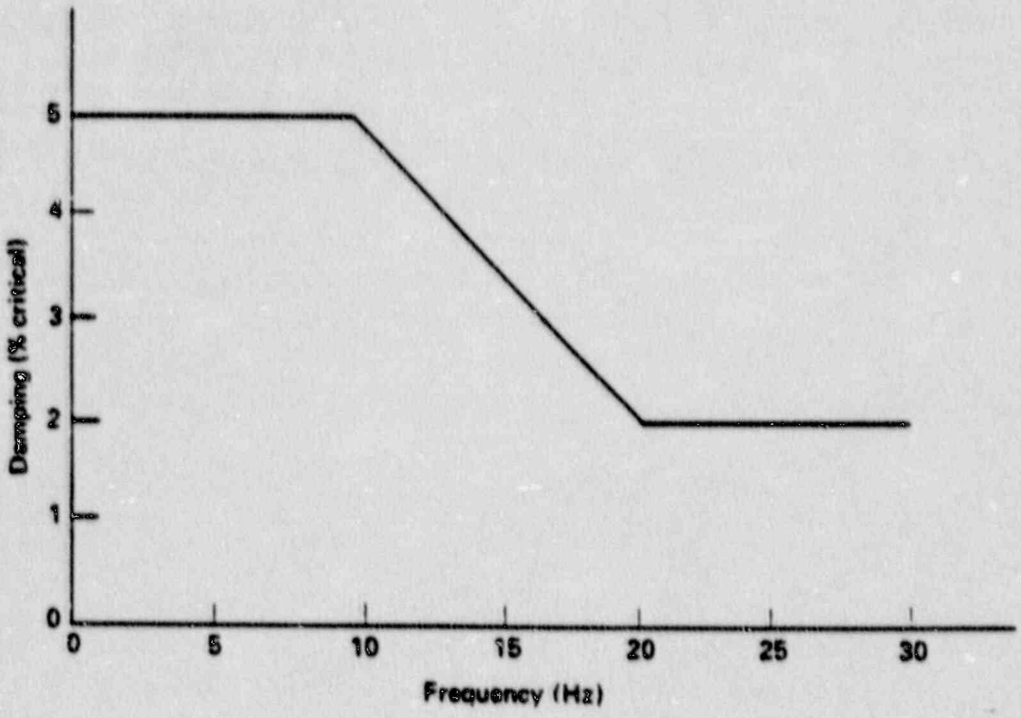


Figure 12 PVRC Recommended Damping.

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10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

This report describes a preliminary structural evaluation made to determine whether the reactor coolant loop (RCL) piping of the Trojan nuclear power plant is capable of transferring the loads normally carried by the reactor pressure vessel (RPV) supports to other component supports in the RCL system if the RPV supports should fail, say from radiation damage. For the evaluation, we use the computer model of the RCL system of Unit 1 of the Zion nuclear power plant because it is readily available; the RCL systems of these two plants closely resemble each other. As a bounding case in the evaluation we postulate that all four RPV supports have failed. Two load combinations are evaluated: (1) the combination of dead weight, operating pressure, and the safe-shutdown earthquake, and (2) the combination of dead weight, operating pressure, and a loss-of-coolant accident. Both load combinations are classified as Level D Service Limits in accordance with the ASME Boiler and Pressure Vessel Code. Static and dynamic linear elastic analyses are conducted to comply with rules specified by Subsection NB in conjunction with Appendix F, Division 1, Section III of the ASME Code. Results of this preliminary evaluation indicate that ASME Code Appendix F requirements are satisfied by each of the load combinations considered in the analysis, leading to the conclusion that the Trojan RCL piping is capable of transferring the RPV support loads to the steam generator and reactor coolant pump supports.

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PRELIMINARY STRUCTURAL EVALUATION OF TROJAN RCL SUBJECT TO POSTULATED RPV SUPPORT FAILURE

JANUARY 1990