Attachment 2

UCID- 20481

NRC

TECHNICAL EVALUATION REPORT FOR THE LICENSEE'S PROPOSED MODAL RESPONSE COMBINATION TECHNIQUES FOR LONG TERM SERVICE SEISMIC REEVALUATION: SAN ONOFRE NUCLEAR GENERATING STATION UNIT 1

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June 1985

Lawrence Livermore National Laboratory

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This work was supported by the United States Nuclear Regulatory Commission under a Memorandum of Understanding with the United States Department of Energy.

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TECHNICAL EVALUATION REPORT
FOR THE LICENSEE'S PROPOSED MODAL RESPONSE
COMBINATION TECHNIQUES FOR LONG TERM
SERVICE SEISMIC REEVALUATION

SAN ONOFRE NUCLEAR GENERATING STATION UNIT 1

By

N. C. Tsai

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Prepared for the U.S. Nuclear Regulatory Commission

1.0 INTRODUCTION

1.1 Background

In mid 1982, the San Onofre Nuclear Generating Station Unit 1 (SONGS 1) was shut down for upgrading of safety-related structures, systems and components to resist seismic loadings developed for the SONGS 1 seismic reevaluation. In 1984, the plant was allowed to return to service for refueling cycle, during which further upgrading was to be planned and prepared for by the licensee. In a meeting with the U.S. Nuclear Regulatory Commission (NRC) staff on February 12, 1985 (Ref. 1), and through a letter dated March 12, 1985 (Ref. 2), the licensee (Southern California Edison Company) proposed their criteria and analysis methodology for the Long Term Service (LTS) upgrading to ensure adequate seismic design margins for those safety-related structures, systems and components in the plant. A technical evaluation of the licensee's proposed plans is needed in order for the NRC to reach a decision regarding approval of the Full Term Operating license for the plant.

Assessment of technical adequacy of the licensee's proposed LTS criteria and analysis methodologies are given in the following three areas:

1. Soil-structure interaction analysis.

2. Direct generation of floor response spectra accounting for the interaction effect between the supporting structure and piping systems considered in the spectrum generation, and the application of the generated floor spectra to the response analysis of a secondary system within the supporting structure with the response spectrum method of analysis.

3. Modal and directional response combinations for the response analysis of the secondary system with the response spectrum method of analysis.

1.2 Criteria of Review

SONGS 1 is one of the NRC designated Systematic Evaluation Program (SEP) plants which was not designed to current codes, standards and NRC requirements. It is therefore necessary to perform "more realistic" or "best estimate" assessments of the seismic capacity of the facility and to consider any conservatism associated with the existing design. For the purpose of the SEP plant seismic review, the NRC developed a set of review criteria and guidelines, as follows:

a. NUREG/CR-0098, "Development of Criteria for Seismic Review of Selected Nuclear Power Plant," by N. M. Newmark and W. J. Hall, May, 1978.

b. "SEP Guidelines for Soil-Structure Interaction Review," by SEP Senior Seismic Review Team, December 8, 1980.

c. Letter from W. Paulson, NRC, to R. Dietch, SCE, "Systematic Evaluation Program Position Re: Consideration of Inelastic Response Using NRC NUREG/CR-0098 Ductility Factor Approach," June 23, 1982.

d. Letter from W. Paulson, NRC, to R. Dietch, SCE, "SEP Topic III-6. Seismic Design Considerations, Staff Guidelines for Seismic Evaluation Criteria for the SEP Group II Plants," July 26, 1982.

e. (Revision of Criteria (d) above, to be issued.) For cases that are not specifically covered by the above criteria, the following SRP sections and Regulatory Guides are used as the basis for our review:

    1. Standard Review Plan, Sections 2.5, 3.7 and 3.8, 3.9 and 3.10.

    2. Regulatory Guides 1.26, 1.29, 1.60, 1.92, 1.100, and 1.122.

In the event that the licensee's proposed methodology and criteria deviate from the aforementioned review criteria and guidelines, we have reviewed, based on our experience and best engineering judgment, the justifications presented by the licensee. We recognize that plant specific deviations on a case-by-case basis may be necessary and may be found acceptable so long as they reasonably meet the intents of the SEP review guidelines.

This technical evaluation report (TER) presents our conclusions on the technical adequacy of the methodology proposed by the licensee for Task 3, directional and modal response combination in the response analysis of secondary systems. Our assessment is accomplished by reviewing the pertinent theory, methodologies, computer codes, and the licensee's planned applications to SONGS 1. To help substantiate our assessment, we also designed a test problem that compares the solution from the licensee's proposed methodology with the solution from certain other methodology.

Section 2.0 discusses the licensee proposed methodology and associated computer codes. Section 3.0 describes the test problem and results of the comparison between the proposed and the independent methodologies. Section 4.0 presents our conclusions. Details of the test problem and analysis results are provided in Appendix A. Additional analysis results from Impell Corporation are included in Appendix B.

2.0 DISCUSSION OF LICENSEE'S PROPOSED METHODOLOGY

2.1 Methodology

For the analysis of the piping systems, the licensee proposed two options for the response calculation and response combination as explained in the following:

Option A -- The piping system is analyzed once using a single envelope spectrum input, which envelops the floor response spectra at all support locations. The CQC (Complete Quadratic Combination) method developed by Wilson et al. (Ref. 3), is proposed by the licensee to perform the combination of modal responses (Ref. 4). The CQC method was derived based on the random vibration theory with the assumption of a stationary white noise input. The method calculates the maximum combined modal response considering the correlation between modes and the algebraic signs of the modal responses. As an illustration, the CQC method combines the responses from two modes, R_1 and R_2, as follows:

$$R = \sqrt{R_1^2 + 2C_{12}R_1R_2 + R_2^2} \quad (1)$$

The correlation coefficient, C_{12}, is a function of the modal damping and frequencies. For two very closely spaced modes, the correlation coefficient approaches 1.0 and the combined response approaches the algebraic sum, i.e., R_1+R_2. For two modes having frequencies far apart from each other, the correlation coefficient approaches zero and the combined response approaches the SRSS of the modal responses, $\sqrt{R_1^2 + R_2^2}$.

<u>Option B</u> — The piping system is analyzed by the multi-level response spectrum (MLRS) method implemented in SUPERPIPE. In other words, the piping system is analyzed as many times as the number of support levels. In each analysis, only supports belonging to a support level are subjected to the corresponding floor response spectrum.

For each mode in each earthquake direction, the responses from all level analyses are then combined by the absolute sum method. The final result is obtained by combining modal responses and directional components according to the Regulatory Guide 1.92.

For the methodology of Option A, the acceptability of the CQC method for the modal response combination is assessed in this TER based on the results of the following test problem. As to our understanding, the proposed CQC method is not suitable for modes of high frequencies because the CQC method does not take into account the fact that the higher the modal frequencies, the stronger the correlation between modes becomes.

The acceptability of the methodology, Option B, is addressed in Reference 5.

3.0 TEST PROBLEM

The test problem was designed to assess the acceptability of the theory of the CQC modal combination method and its computer code implementation. In order to achieve this goal, we calculated the piping responses by using the time history analysis method and the response spectrum method with the CQC modal combination technique. The time history analysis method is acceptable to the NRC. The response spectrum method using the CQC modal combination techniques was intended to gain further confirmation with the code implementation of the licensee proposed CQC modal combination.

3.1 Description

A piping model selected from the Zion Nuclear plant was analyz-- to test the CQC method. The piping system is shown in Fig. 1. The figur so indicates the locations where the resultant moments were calculated for the comparison study. The detailed description of the test em is in Appendix A.

Both the licensee and we calculated the piping resultant moments and support reactions independently by the response spectrum method of analysis with the CQC method of the modal combination. In addition, we calculated the same response quantities using the time history analysis.

The comparison of the results is discussed below.

3.2 Results

Table 1 summarizes the statistical mean and standard deviation for the resultant moment and support force ratios between the licensee's analysis (Ref. 6) and NCT's time history analysis. Thirty-one resultant moments and twenty-four upport forces were considered for each direction of earthquake input. Table 2 summarizes the corresponding statistics for the ratios between NCT's response spectrum analysis using the CQC method for modal combination and time history analysis. The results of Tables 1 and 2 show good agreement and are in line with other published comparison results between the CQC response spectrum analysis method and the time history analysis method (Refs. 3 and 4).

4.0 CONCLUSION

The methodology proposed by the licensee for the modal (CQC) response combination in the envelope response spectrum method of analysis appears sufficient.

5.0 ACKNOWLEDGEMENTS

The authors wish to thank Dr. M. S. Yang and Mr. W. L. Wong, both of NCT Engineering, for their contributions to this TER. They participated in generating the NCT portion of the test problem results and in preparing the draft report. In addition, Dr. Yang assisted in reviewing the licensee's proposed methodology.

6.0 REFERENCES

1. Memorandum from E. McKenna to C. I. Grimes, dated February 12, 1985.

2. Letter from M. Medford, SCE, to J. A. Zwolinski, NRC, dated March 12, 1985.

3. Wilson, E. L. et al., "Short Communications -- A Replacement for the SRSS Method in Seismic Analysis," Earthquake Engineering and Structural Dynamics, Vol. 9, 187-194, 1981.

4. Letter from M. Medford, SCE, to J. A. Zwolinski, NRC, dated March 29, 1985.

5. H. C. Tsai, L. C. Shieh, "Technical Evaluation Report for MLRS Piping Response Analysis Technique for Long Term Service Seismic Reevaluation, San Onofre Nuclear Generating Station Unit 1," Lawrence Livermore National Laboratory, Livermore, California, UCID-xxxx, June, 1985.

6. Letter from M. Medford, SCE, to J. A. Zwolinski, NRC, dated June 4, 1985.

Table 1 RESPONSE RATIOS BETWEEN LICENSEE'S CQC AND OUR TIME HISTORY ANALYSIS

		X(Horiz.) Input	Y(Vert.) Input	Z(Horiz.) Input	Overall
Moment	Mean	1.02	1.02	0.93	0.99
Resultant	σ*	0.25	0.09	0.18	0.19
Support	Mean	1.21	1.07	1.45	1.24
Force	σ*	0.49	0.20	1.02	0.68

*σ: Standard Deviation

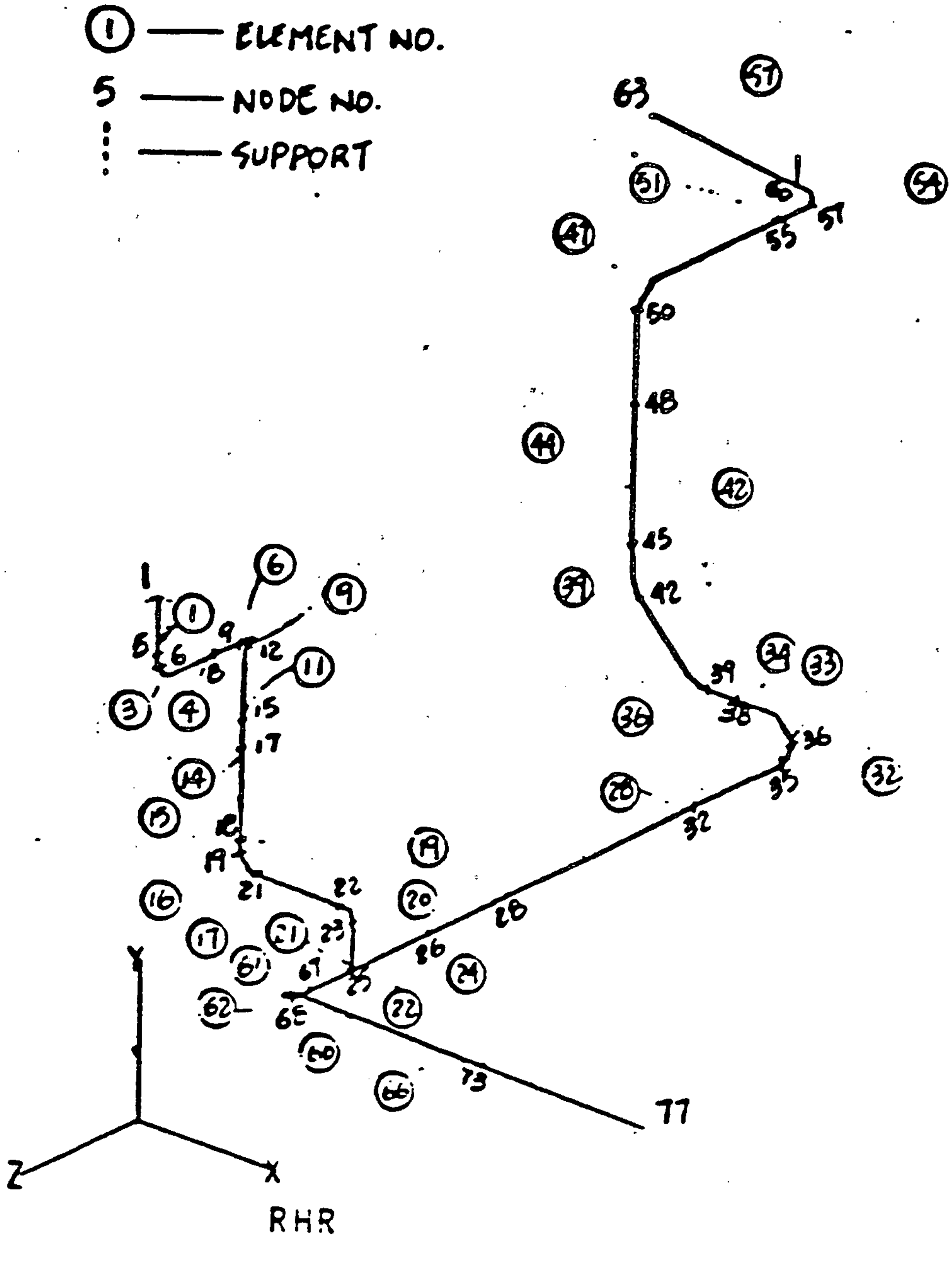

FIGURE 1 RHR Piping Model, Problem II

APPENDIX A

DETAILS OF TEST PROBLEM ANALYSIS

A.1 Problem Description

This problem involves the testing of the CQC modal combination method by analyzing the residual heat removal and safety injection piping system (RHR) of the Zion nuclear plant. For this problem, a listing of SAP4 input files presenting the geometry and properties of the RHR piping system is given in Table A.1. An isometric view of the piping system is shown in Figure 1. The figure indicates the locations where the output resultant moments are to be determined by both licensee and NCT Engineering for comparison study. Table A.2 is a listing of output locations of the pipe moments. Thirty-one resultant moments and all twenty-four support forces are considered in each direction of earthquake input. In addition, 3% modal dampings are used for both response spectrum analysis and time history analysis.

A.2 Licensee Analysis

The licensee is involved in the calculation of piping resultant moments and support forces for the RHR piping system using the CQC method for modal response combination. The program SUPERPIPE is used to perform the response spectrum method of analysis. In order to obtain equivalent comparison between the results from SUPERPIPE and our analyses, the licensee has performed this task using the CQC method for modal combination without the consideration of missing the mass effect from higher modes.

The seismic input is a 3% damping horizontal and a 3% damping vertical floor spectra. The same horizontal spectrum is used for the two horizontal directions. Plots of input spectra are provided as shown in Figure A.1 and A.2. The piping resultant moments and support forces are calculated for each of the three earthquake inputs. The directional combination among the components is not performed. The results from the licensee using the CQC method for modal response combination are as shown in Table A.3.

A.3 NCT Analysis

In the analysis performed by NCT Engineering, the same RHR piping model is analyzed using the SAP4 time history method of analysis. The seismic input contains a horizontal and a vertical floor time history corresponding to the spectra shown in Figures A.1 and A.2. The same horizontal time history is used for the two horizontal directions. Plots of time history inputs are provided as shown in Figures A.3 and A.4. The resultant moments and support forces calculated using the SAP4 time history analysis are shown in Table A.3. In addition, NCT Engineering also calculate the piping resultant moments and support forces by the response spectrum analysis using the CQC method from RESCOM for the modal response combination. The input spectra are identical to those provided to the licensee as shown in Figures A.1 and A.2 in each earthquake direction. A comparison study among the three sets of response, namely, the licensee CQC, the NCT CQC, and the SAP4 time history results are discussed in the text. The statistical means and standard deviations of the response ratios of the licensee CQC to time history and the NCT CQC to time history are shown in Tables 1 and 2 in the text.

TABLE A.1

RHR Piping Model SAP4 Input Listing

Unit: FT-LB-SEC

Vertical: Y-Axis

A MACHINE 03/28/85 11:31:06 BOX Y66 NCT

ITLE = SI + RHR PIPING 1

96	2	0	18	1	0	0	0	1		
1	0	0	0	1	1	1	-46.5000	579.0000	-257.0000	0
2	1	1	1	1	1	1	-45.5000	579.0000	-257.0000	0
3	1	1	1	1	1	1	-46.5000	580.0000	-257.0000	0
4	1	1	1	1	1	1	-46.5000	579.0000	-256.0000	0
5	0	0	0	0	0	0	-46.5000	574.6670	-257.0000	0
6	0	0	0	0	0	0	-46.5000	574.3330	-257.0000	0
7	0	0	0	0	0	0	-46.5000	573.3330	-258.0000	0
8	0	0	0	0	0	0	-46.5000	573.3330	-261.7500	0
9	0	0	0	0	0	0	-46.5000	573.3330	-265.7500	0
10	0	0	0	0	0	0	-47.2071	572.6259	-266.7500	0
11	0	0	0	0	0	0	-47.5000	572.3330	-266.7500	0
12	0	0	0	0	0	0	-47.7071	572.1259	-266.7500	0
13	0	0	0	0	0	0	-48.0000	571.4188	-266.7500	0
14	0	0	0	0	0	0	-48.0000	570.9990	-266.7500	0
15	0	0	0	0	0	0	-48.0000	570.1870	-266.7500	0
16	0	0	0	0	0	0	-48.0000	569.5000	-266.7500	0
17	0	0	0	0	0	0	-48.0000	568.8120	-266.7500	0
18	0	0	0	0	0	0	-48.0000	559.0620	-266.7500	0
19	0	0	0	0	0	0	-48.0000	558.2500	-266.7500	0
20	0	0	0	0	0	0	-47.0000	557.2500	-266.7500	0
21	0	0	0	0	0	0	-46.6450	557.2500	-266.7500	0
22	0	0	0	0	0	0	-39.9142	557.2500	-266.7500	0
23	0	0	0	0	0	0	-39.2071	557.2500	-266.4571	0
24	0	0	0	0	0	0	-38.5000	556.2500	-265.7500	0
25	0	0	0	0	0	0	-38.5000	553.7500	-265.7500	0
26	0	0	0	0	0	0	-38.5000	553.7500	-270.5000	0
27	0	0	0	0	0	0	-38.5000	553.7500	-276.2183	0
28	0	0	0	0	0	0	-38.5000	553.7500	-281.9367	0
29	0	0	0	0	0	0	-38.5000	553.7500	-287.6550	0
30	0	0	0	0	0	0	-38.5000	553.7500	-291.0090	0
31	0	0	0	0	0	0	-38.5000	553.7500	-292.8420	0
32	0	0	0	0	0	0	-38.5000	553.7500	-296.9737	0
33	0	0	0	0	0	0	-38.5000	553.7500	-301.1053	0
34	0	0	0	0	0	0	-38.5000	553.7500	-305.2370	0
35	0	0	0	0	0	0	-38.5000	553.7500	-306.0290	0
36	0	0	0	0	0	0	-38.5000	554.7500	-307.0290	0
37	0	0	0	0	0	0	-40.0000	556.2500	-307.0290	0
38	0	0	0	0	0	0	-43.5000	556.2500	-307.0290	0
39	0	0	0	0	0	0	-45.6287	556.2500	-307.0290	0
40	0	0	0	0	0	0	-46.6893	556.6893	-307.0290	0
41	0	0	0	0	0	0	-48.7500	558.7500	-307.0290	0
42	0	0	0	0	0	0	-50.9520	560.9520	-307.0290	0
43	0	0	0	0	0	0	-51.4605	561.5483	-307.2395	0
44	0	0	0	0	0	0	-52.0000	562.3130	-307.7790	0
45	0	0	0	0	0	0	-52.4402	562.9369	-308.2192	0
46	0	0	0	0	0	0	-52.7500	563.9964	-308.5290	0
47	0	0	0	0	0	0	-52.7500	567.0010	-308.5290	0
48	0	0	0	0	0	0	-52.7500	570.8620	-308.5290	0
49	0	0	0	0	0	0	-52.7500	574.7230	-308.5290	0
50	0	0	0	0	0	0	-52.7500	578.5840	-308.5290	0
51	0	0	0	0	0	0	-52.7500	580.0840	-310.0290	0
52	0	0	0	0	0	0	-52.7500	580.0840	-311.0290	0
53	0	0	0	0	0	0	-52.7500	580.0840	-314.0290	0
54	0	0	0	0	0	0	-52.7500	580.0840	-317.0290	0
55	0	0	0	0	0	0	-52.7500	580.0840	-320.0290	0
56	0	0	0	0	0	0	-52.7500	580.0840	-323.0290	0
57	0	0	0	0	0	0	-52.7500	580.0840	-324.2367	0

TABLE A.1 (Cont.)

58	0	0	0	0	0	0	-54.0281	580.0840	-325.7202	0
59	0	0	0	0	0	0	-55.2641	580.0840	-325.9052	0
60	0	0	0	0	0	0	-56.5001	580.0840	-326.0902	0
61	0	0	0	0	0	0	-60.3328	580.0840	-326.6628	0
62	0	0	0	0	0	0	-64.1654	580.0840	-327.2355	0
63	0	0	0	1	1	1	-67.9981	580.0840	-327.8082	0
64	1	1	1	1	1	1	-66.9981	580.0840	-327.8082	0
65	1	1	1	1	1	1	-67.9981	581.0840	-327.8082	0
66	1	1	1	1	1	1	-67.9981	580.0840	-326.8082	0
67	0	0	0	0	0	0	-38.5000	553.7500	-260.7053	0
68	0	0	0	0	0	0	-38.5000	554.1893	-259.6447	0
69	0	0	0	0	0	0	-37.0000	555.2500	-258.5840	0
70	0	0	0	0	0	0	-36.5000	555.2500	-258.5840	0
71	0	0	0	0	0	0	-32.2500	555.2500	-258.5840	0
72	0	0	0	0	0	0	-29.1667	555.2500	-258.5840	0
73	0	0	0	0	0	0	-26.0833	555.2500	-258.5840	0
74	0	0	0	0	0	0	-23.0000	555.2500	-258.5840	0
75	0	0	0	0	0	0	-18.2500	555.2500	-258.5840	0
76	0	0	0	0	0	0	-13.5000	555.2500	-258.5840	0
77	0	0	0	1	1	1	-8.7500	555.2500	-258.5840	0
78	1	1	1	1	1	1	-7.7500	555.2500	-258.5840	0
79	1	1	1	1	1	1	-8.7500	556.2500	-258.584C	0
80	1	1	1	1	1	1	-8.7500	555.2500	-257.5840	0
81	0	0	0	0	0	0	-55.2641	582.0840	-325.9052	0
82	1	1	1	1	1	1	-48.0000	571.9990	-266.7500	0
83	1	1	1	1	1	1	-47.0000	570.9990	-265.7500	0
84	1	1	1	1	1	1	-47.0000	559.0620	-267.7500	0
85	1	1	1	1	1	1	-46.6450	558.2500	-266.7500	0
86	1	1	1	1	1	1	-38.5000	554.7500	-287.6550	0
87	1	1	1	1	1	1	-37.5000	553.7500	-291.0090	0
88	1	1	1	1	1	1	-38.5000	553.7500	-293.8420	0
89	1	1	1	1	1	1	-51.7500	567.0010	-308.5290	0
90	1	1	1	1	1	1	-52.7500	567.0010	-307.5290	0
91	1	1	1	1	1	1	-52.7500	581.0840	-311.0290	0
92	1	1	1	1	1	1	-52.7500	580.0840	-313.0290	0
93	1	1	1	1	1	1	-51.7500	580.0840	-314.0290	0
94	1	1	1	1	1	1	-52.7500	581.0840	-323.0290	0
95	1	1	1	1	1	1	-32.2500	555.2500	-257.5840	0
96	1	1	1	1	1	1	-32.2500	556.2500	-258.5840	0

9	71	1		6		
1		30455				
400.00		.4075E+10		.3000	.9590E-05	
1	1.0625		.0338		112.5000	3.4938
2	.7188		.0268		55.8800	1.7354
3	.7188		.0537		397.8000	12.3540 8 IN VALVE
4	1.0625		.2187		1222.0000	37.9503 12 IN VALVE
5	1.0625		.1093		207.9000	6.4565 12 IN PIPE
6	1.0625		.2187		0.0000	0.0000
0.00						
		0.00				
				0.00		
					0.00	

1	1	5	1	1	-400.00	100800.00
2	5	6	1	2	-400.00	100800.00
3B	6	7	1	2	-400.00	100800.00
1.0000	0	TI	-46.5000	0	573.3330	-257.0000
4	7	8	1	2	-400.00	100800.00
5	8	9	1	2	-400.00	100800.00
6B	9	10	1	2	-400.00	100800.00

TABLE A.1 (Cont.)

1.0000		TI	-46.5000		573.3330	-266.7500
7	10	11	1	2	-400.00	100800.00
8	11	12	1	2	-400.00	100800.00
9B	12	13	1	2	-400.00	100800.00
1.0000		TI	-48.0000		571.8330	-266.7500
10	13	14	1	2	-400.00	100800.00
11	14	15	1	2	-400.00	100800.00
12	15	16	1	3	-400.00	100800.00
13	16	17	1	3	-400.00	100800.00
14	17	18	1	2	-400.00	100800.00
15	18	19	1	2	-400.00	100800.00
16B	19	20	1	2	-400.00	100800.00
1.0000		TI	-48.0000		557.2500	-266.7500
17	20	21	1	2	-400.00	100800.00
18	21	22	1	2	-400.00	100800.00
19B	22	23	1	2	-400.00	100800.00
1.0000		TI	-39.5000		557.2500	-266.7500
20B	23	24	1	2	-400.00	100800.00
1.0000		TI	-38.5000		557.2500	-265.7500
21	24	25	1	2	-400.00	100800.00
22	25	26	1	1	-400.00	100800.00
23	26	27	1	1	-400.00	100800.00
24	27	28	1	1	-400.00	100800.00
25	28	29	1	1	-400.00	100800.00
26	29	30	1	1	-400.00	100800.00
27	30	31	1	1	-400.00	100800.00
28	31	32	1	1	-400.00	100800.00
29	32	33	1	1	-400.00	100800.00
30	33	34	1	1	-400.00	100800.00
31	34	35	1	1	-400.00	100800.00
32B	35	36	1	1	-400.00	100800.00
1.0000		TI	-38.5000		553.7500	-307.0290
33B	36	37	1	1	-400.00	100800.00
1.5000		TI	-38.5000		556.2500	-307.0290
34	37	38	1	1	-400.00	100800.00
35	38	39	1	1	-400.00	100800.00
36B	39	40	1	1	-400.00	100800.00
1.5000		TI	-46.2500		556.2500	-307.0290
37	40	41	1	1	-400.00	100800.00
38	41	42	1	1	-400.00	100800.00
39B	42	43	1	1	-400.00	100800.00
1.5000		TI	-51.2500		561.2500	-307.0290
40	43	44	1	1	-400.00	100800.00
41	44	45	1	1	-400.00	100800.00
42B	45	46	1	1	-400.00	100800.00
1.5000		TI	-52.7500		563.3760	-308.5290
43	46	47	1	1	-400.00	100800.00
44	47	48	1	1	-400.00	100800.00
45	48	49	1	1	-400.00	100800.00
46	49	50	1	1	-400.00	100800.00
47B	50	51	1	1	-400.00	100800.00
1.5000		TI	-52.7500		580.0840	-308.5290
48	51	52	1	1	-400.00	100800.00
49	52	53	1	1	-400.00	100800.00
50	53	54	1	1	-400.00	100800.00
51	54	55	1	1	-400.00	100800.00
52	55	56	1	1	-400.00	100800.00
53	56	57	1	1	-400.00	100800.00
54B	57	58	1	1	-400.00	100800.00
1.5000		TI	-52.7500		580.0840	-325.5290

TABLE A.1 (Cont.)

```
55       58       59        1         4      -400.00  100800.00
56       59       60        1         4      -400.00  100800.00
57       60       61        1         5      -400.00  100800.00
58       61       62        1         5      -400.00  100800.00
59       62       63        1         5      -400.00  100800.00
60       25       67        1         1      -400.00  100800.00
61B      67       68        1         1      -400.00  100800.00
   1.5000         TI   -38.5000     553.7500  -260.0840
62B      68       69        1         1      -400.00  100800.00
   1.5000         TI   -38.5000     555.2500  -258.5840
63       69       70        1         1      -400.00  100800.00
64       70       71        1         1      -400.00  100800.00
65       71       72        1         1      -400.00  100800.00
66       72       73        1         1      -400.00  100800.00
67       73       74        1         1      -400.00  100800.00
68       74       75        1         1      -400.00  100800.00
69       75       76        1         1      -400.00  100800.00
70       76       77        1         1      -400.00  100800.00
71       59       81        1         6      -400.00  100800.00
 7       24
 1        2                             100000          0.000000   0.000000  .1200E+12
 1        3                             100000          0.000000   0.000000  .1200E+12
 1        4                             100000          0.000000   0.000000  .1200E+12
63       64                             100000          0.000000   0.000000  .1200E+12
63       65                             100000          0.000000   0.000000  .1200E+12
63       66                             100000          0.000000   0.000000  .1200E+12
77       78                             100000          0.000000   0.000000  .1200E+12
77       79                             100000          0.000000   0.000000  .1200E+12
77       80                             100000          0.000000   0.000000  .1200E+12
14       82                             100000          0.000000   0.000000  .1200E+12
14       83                             100000          0.000000   0.000000  .1200E+12
18       84                             100000          0.000000   0.000000  .1200E+12
21       85                             100000          0.000000   0.000000  .1200E+12
29       86                             100000          0.000000   0.000000  .1200E+12
30       87                             100000          0.000000   0.000000  .1200E+12
31       88                             100000          0.000000   0.000000  .1200E+12
47       89                             100000          0.000000   0.000000  .1200E+12
47       90                             100000          0.000000   0.000000  .1200E+12
52       91                             100000          0.000000   0.000000  .1200E+12
53       92                             100000          0.000000   0.000000  .1200E+12
53       93                             100000          0.000000   0.000000  .1200E+12
56       94                             100000          0.000000   0.000000  .1200E+12
71       95                             100000          0.000000   0.000000  .1200E+12
71       96                             100000          0.000000   0.000000  .1200E+12
81        0     31.615      31.615        31.615         0.000      0.000      0.000

          0                    33.00
```

TABLE A.2

Output Locations of Pipe Moment Resultants

No.	Pipe Element No. *	Node No. *
1	1	5
2	3	6
3	4	8
4	6	9
5	9	12
6	11	15
7	14	17
8	15	18
9	16	19
10	17	21
11	19	22
12	20	23
13	21	25
14	22	26
15	24	28
16	28	32
17	32	35
18	33	36
19	34	38
20	36	39
21	39	42
22	42	45
23	44	48
24	47	50
25	51	55
26	54	57
27	57	60
28	60	25
29	61	67
30	62	68
31	66	73

*Refer to the SAP4 input listing of the RHR model.

NCT ENGINEERING

PROJECT SONGS SUBJECT PROB ① COMPARISON REV. △ SHEET NO
COMPUTED BY U. D CHECKED BY DATE 6/26/85 RL.

TABLE A.3 RHR PIPE MOMENT RESULTANTS (UNIT = #-FT)

SAP4	X-HORZ. DIR			Y-VERT. DIR.			Z-HORZ DIR.		
ELE. NO.	IMPELL CQC	NCT TIME HIST.	CQC / T.H.	IMPELL CQC	NCT TIME HIST.	CQC / T.H.	IMPELL CQC	NCT TIME HIST.	CQC / T.H.
1	687	511	1.34	188	168	1.12	396	392	1.01
3	592	428	1.38	185	168	1.10	282	318	0.89
4	515	330	1.56	147	138	1.07	269	313	0.86
6	802	450	1.78	180	152	1.18	507	522	0.97
9	541	656	0.82	194	194	1.00	219	180	1.22
11	1086	1001	1.08	201	172	1.17	795	631	1.25
14	1162	915	1.27	174	140	1.24	882	737	1.20
15	1089	1065	1.02	400	393	1.02	452	562	0.80
16	1107	1110	1.00	428	433	0.99	407	435	0.94
17	3363	3404	0.99	156	174	0.90	492	436	1.13
19	1167	1420	0.82	450	507	0.89	331	394	0.84
20	1480	1703	0.87	610	682	0.89	365	393	0.93
21	2231	2748	0.81	914	925	0.99	563	810	0.70
22	6577	7398	0.89	2801	3104	0.90	1127	948	1.19
24	13096	14251	0.92	6028	5967	1.01	1521	1590	0.96
28	5848	7038	0.83	2625	2423	1.08	984	724	1.36
32	4548	5477	0.83	2104	2141	0.98	937	1018	0.92
33	5181	6218	0.83	2394	2441	0.98	1014	1098	0.92
34	4493	5463	0.82	2166	2060	1.05	1037	1160	0.89
36	4378	5088	0.86	2246	2152	1.04	1267	1385	0.91
39	7557	8638	0.87	3555	3581	0.99	1012	1279	0.79
42	9142	10994	0.83	4225	4340	0.97	1066	[illegible]	[illegible]

NCT ENGINEERING

PROJECT SONGS SUBJECT P.O.3.① COMPARISON REV.① SHEET NO
COMPUTED BY D.D. CHECKED BY DATE 4/11/85 REV

TABLE A.3 RHR PIPE MOMENT RESULTANTS (UNIT = #-FT)

SAP4	X-HORZ. DIR			Y-VERT. DIR.			Z-HORZ. DIR.		
ELE NO.	IMPELL CQC	NCT TIME HIST	CQC / T.H.	IMPELL CQC	NCT TIME HIST.	CQC / T.H.	IMPELL CQC	NCT TIME HIST.	CQC / T.H.
44	8413	10650	0.80	4036	3873	1.04	1647	1748	0.94
47	1638	1607	1.02	909	861	1.06	306	286	1.07
51	2525	2589	0.98	1526	1516	1.01	633	866	0.73
54	423	463	0.91	332	355	0.94	598	798	0.75
57	955	680	1.40	1317	1409	0.93	2281	3066	0.74
60	3746	4264	0.88	1510	1648	0.92	1095	1336	0.82
61	2405	2609	0.92	1058	1060	1.00	624	939	0.66
62	2877	3349	0.86	1242	1272	0.98	613	912	0.67
66	2450	1938	1.26	1261	1136	1.11	847	793	1.07

$\bar{X} = 1.015$ $\sigma_x = 0.251$ $COV_x = 0.248$	$\bar{Y} = 1.018$ $\sigma_y = 0.087$ $COV_y = 0.086$	$\bar{Z} = 0.933$ $\sigma_z = 0.181$ $COV_z = 0.194$

OVERALL X + Y + Z DIRECTION

MEAN $\bar{M}$ = 0.989
STANDARD DEV. σ = 0.188
COV = 0.190

NCT ENGINEERING

PROJECT: SONGS — SUBJECT: PROB. ① COMPARISON REV① — SHEET NO: ____

COMPUTED BY: D. C. — CHECKED BY: SUPPORT FORCES — DATE: 6/24/85 — REV. ____

TABLE A.3 RHR SUPPORT FORCES (UNIT = LB)

SAP4	X-HORZ. DIR.			Y-VERT. DIR.			Z-HORZ. DIR.		
ELE. NO.	IMPELL CQC	NCT T.H.	CQC / T.H.	IMPELL CQC	NCT T.H.	CQC / T.H.	IMPELL CQC	NCT T.H.	CQC / T.H.
1	36	35.4	1.02	16	18.1	0.88	14	6.4	2.19
2	121	65.7	1.84	23	21.9	1.05	82	76.1	1.08
3	684	448.0	1.53	84	65.1	1.29	525	474.0	1.11
4	582	629.1	0.93	272	256.5	1.06	270	317.2	0.85
5	179	65.9	2.72	302	324.2	0.93	125	49.8	2.51
6	192	192.3	1.00	85	94.6	0.90	503	689.2	0.73
7	870	1163	0.75	291	284.8	1.02	220	224.6	0.98
8	287	170.1	1.69	184	156.9	1.17	71	17.5	4.06
9	143	101.3	1.41	81	53.3	1.52	363	368.5	0.99
10	3188	3218	0.99	1489	1591	0.94	435	517.1	0.84
11	526	498.8	1.05	96	70.1	1.37	396	293.5	1.35
12	317	192.3	1.65	98	71.9	1.36	208	252.8	0.82
13	3729	3752	0.99	1746	1893	0.92	464	552.6	0.84
14	1563	1710	0.91	766	705.3	1.08	190	159.6	1.19
15	1417	2204	0.64	607	569.0	1.07	264	313.9	0.84
16	759	835.6	0.91	354	358.5	0.99	381	96.8	3.94
17	1605	2202	0.73	865	823.5	1.05	245	300.5	0.82
18	464	531.2	0.87	220	240.3	0.92	466	494.9	0.94
19	1271	1204	1.06	678	642.9	1.05	226	293.7	0.77
20	165	124.5	1.33	97	66.2	1.47	1070	1303	0.82
21	1538	1712	0.90	726	696.9	1.04	283	256.3	1.10
22	457	233.5	1.96	641	588.5	0.92	215	62.9	2.36

TABLE A.3 RHR SUPPORT FORCES (UNIT = LB)

SAP4	X-HORZ. DIR.			Y-VERT. DIR.			Z-HORZ. DIR.		
ELE. NO	IMPELL CQC	NCT T.H.	CQC / T.H.	IMPELL CQC	NCT T.H.	CQC / T.H.	IMPELL CQC	NCT T.H.	CQC / T.H.
23	856	984.5	0.87	379	384.8	0.98	548	692.4	0.79
24	714	533.6	1.33	384	537.3	0.71	135	71.1	1.90

X-HORZ.	Y-VERT.	Z-HORZ.
$\bar{X} = 1.212$	$\bar{Y} = 1.070$	$\bar{Z} = 1.451$
$\sigma_X = 0.485$	$\sigma_Y = 0.199$	$\sigma_Z = 1.016$
$COV_X = 0.400$	$COV_Y = 0.186$	$COV_Z = 0.701$

OVERALL X + Y + Z DIRECTION 72 ELEMENTS

MEAN, M = 1.244
STANDARD DEV, σ = 0.679
COV. = 0.546

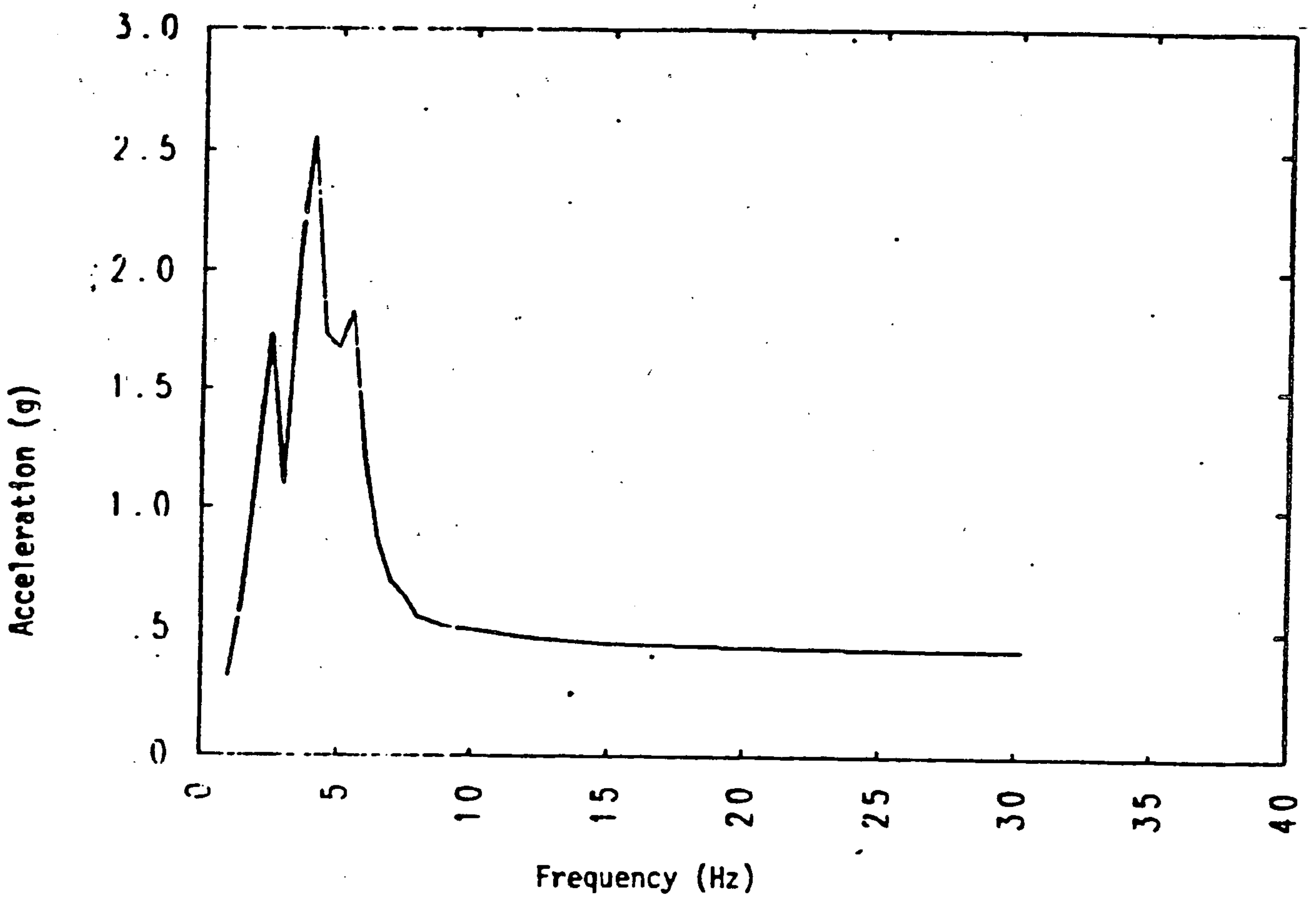

FIGURE A-1 History 2. Top of Sacrificial Shield (Horiz-XdZ) 3%

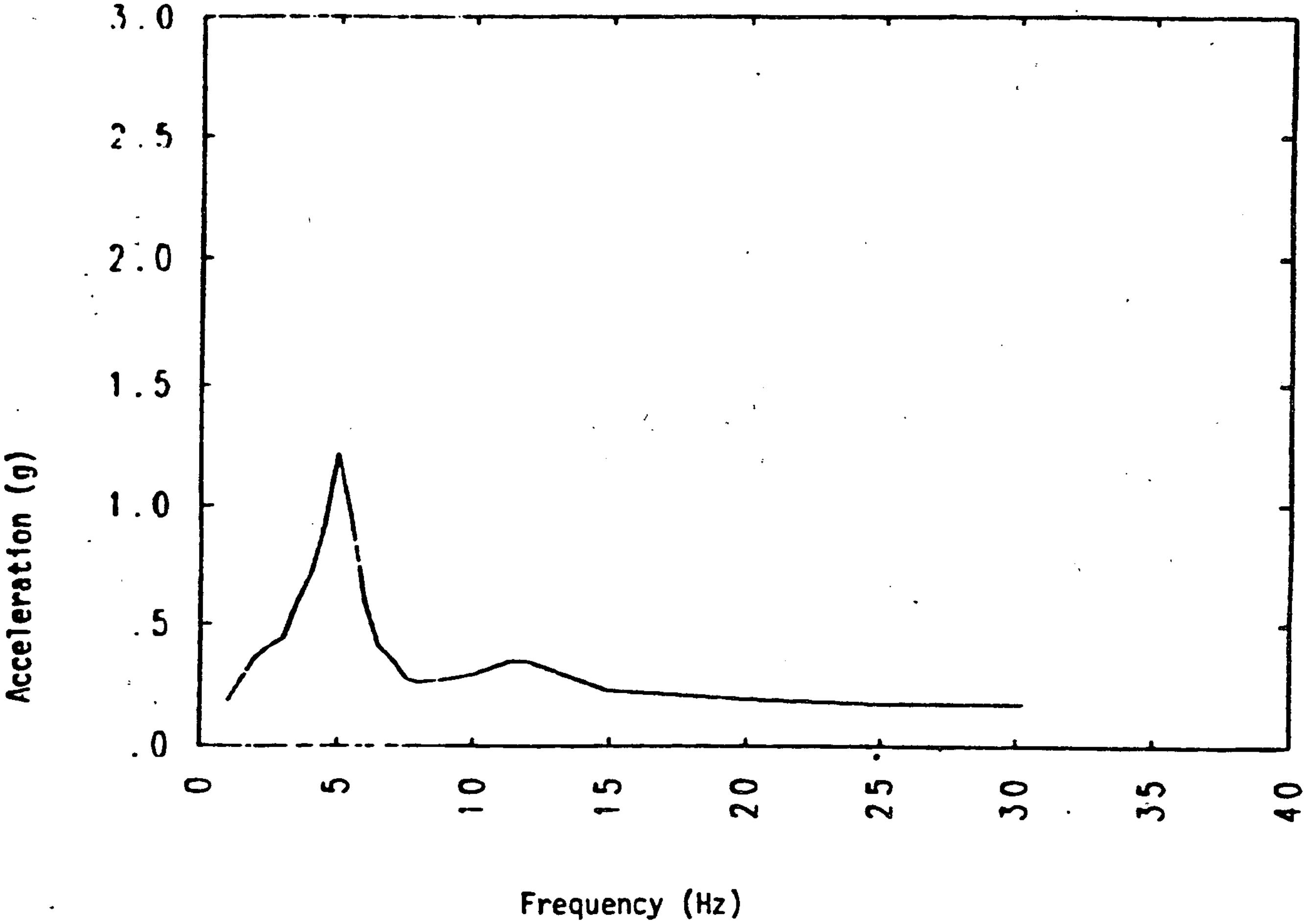

FIGURE A-2 History 2. Top of Sacrificial Shield (Vert-Y) 3%

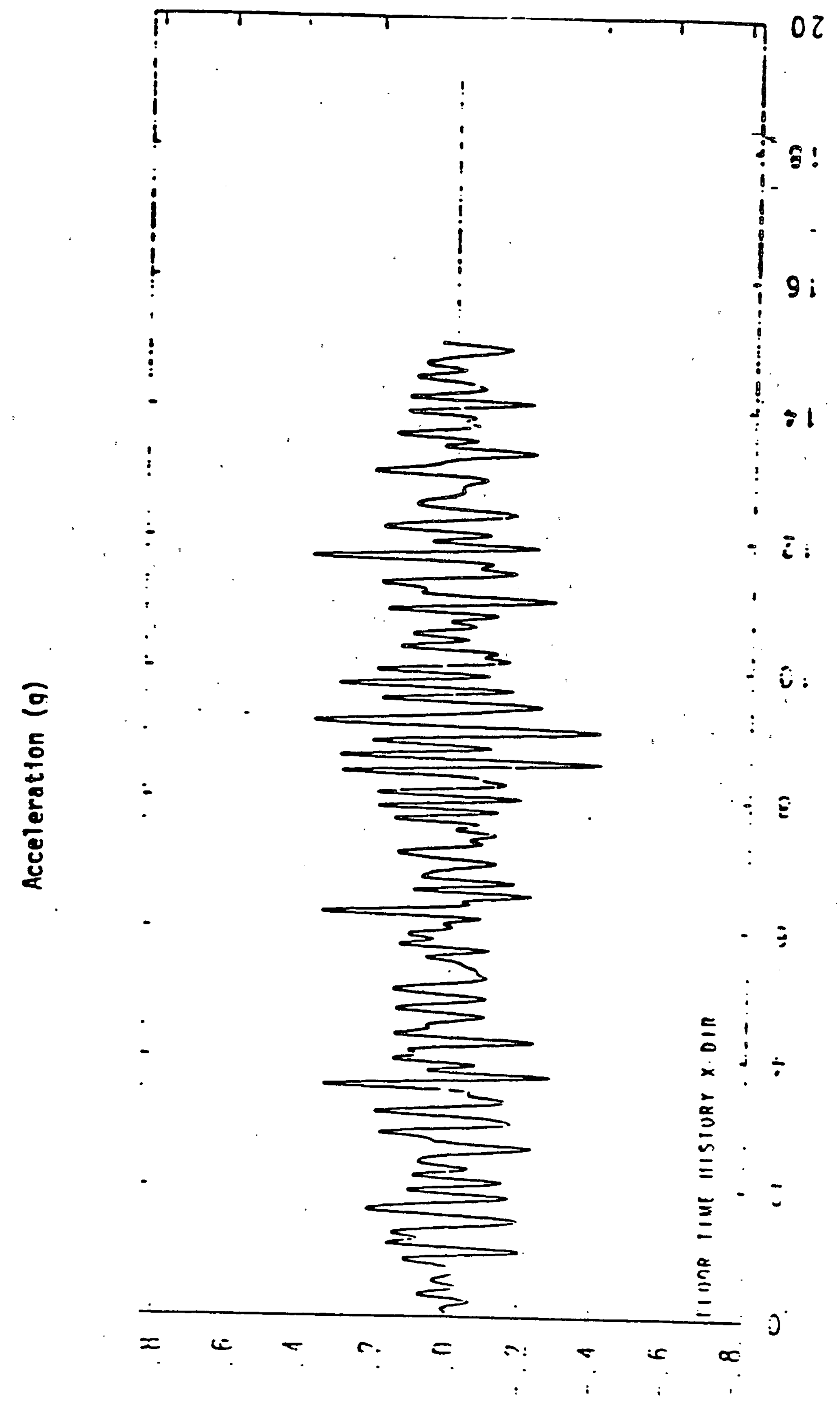

FIGURE A-3 Horizontal Flow Time History

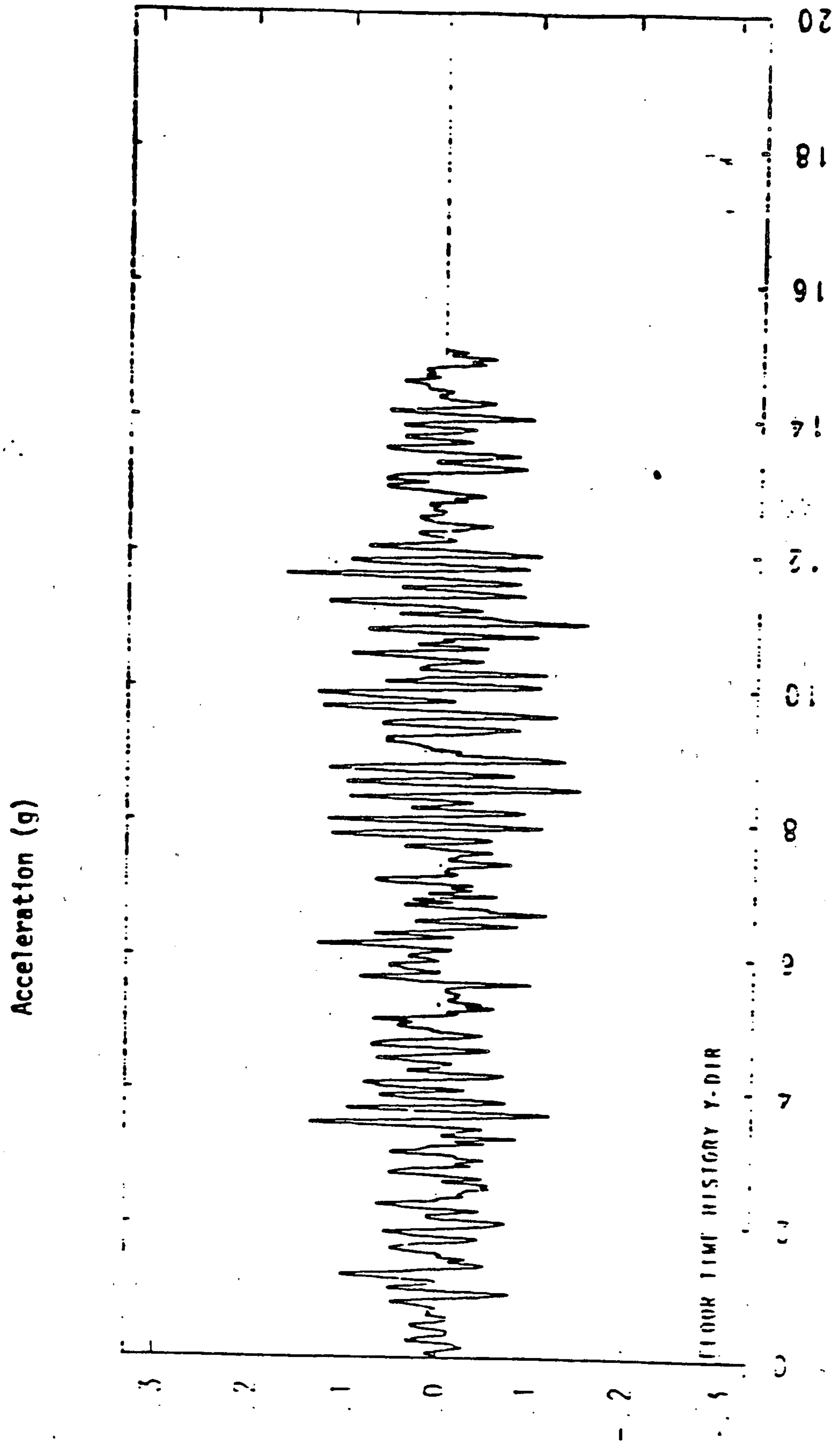

FIGURE A-4 Vertical Flow Time History

APPENDIX B

IMPELL ANALYSIS RESULTS

The Analysis Results data transmitted by Impell for the test problem include:

- Piping moment resultants for the pipe element specified in the text.
- All pipe support loads of the piping model.

REV (1) | 4/26/85 | Test Problem

PIPE MOMENT RESULTANTS PROBLEM II

FT-LB

NODE POINT	WITHOUT MISSING MASS, ELBOW FLEXIBILITY INCLUDED		
	X-LOAD	Y-LOAD	Z-LOAD
5	687	188	396
6	592	185	282
8	515	147	269.
9	902	180	507
12	541	194	219
15	1086.	201	795
17	1162.	174	882
18	1089	400	452
19	1107	428	407
21	3363.	1561	492
22	1167	450	331
23	1480	610	365
25 (dem 21)	2231	914	563
26	6577	2801	1127
28	13,096	6028	1521
32	5848	2625	984
35	4548	2104	937
36	5181	2394	1014

47 0496 (beside 5)
47931 (beside 6)
470496 (beside 26)

SCE SONGS 1 Problem I

REV	BY	DATE	CHECKED	DATE
1	KH	4/24/85	AA	4/25/85

IMPELL CORPORATION

JOB NO 0310-063
CALC NO
PAGE
OF

WT DW96

NODE POINT	WITHOUT MISSING MASS, ELBOW FLEXIBILITY INCLUDED		
	X-LOAD	Y-LOAD	Z-LOAD
38	4493	2166	1037
39	4378	2246	1267
42	7557	3555	1012
45	9142	4225	1056
48	8473	4036	1647
50	1638	909	306
55	2525	1526	633
57	423	332	598
60	955	1317	2281
25	3746	1510	1095
67	2405	1058	624
68	2877	1242	613
73	2450	1261	847

[illegible]

REV	BY	DATE	CHECKED	DATE
1	KH	6/24/85	AA	6/25/85

IMPELL CORPORATION

JOB NO 0210-068

CALC NO

PAGE OF

REV	BY	DATE	CHECKED	DATE
1	KH	4/4/85	[illegible]	4/25/85

IMPELL CORPORATION

JOB NO 0310-068

CALC NO

PAGE

OF

F = LBS
M = IN-LBS

REACTIONS AT SUPPORTS.

SUPPORT NODE	X-LOAD Fx/Mx	X-LOAD Fy/My	X-LOAD Fz/Mz	Y-LOAD Fx/Mx	Y-LOAD Fy/My	Y-LOAD Fz/Mz	Z-LOAD Fx/Mx	Z-LOAD Fy/My	Z-LOAD Fz/Mz
1	36/40300	121/5817	684/2145	16/5023 ✓	23/1806 ✓	84/439 ✓	14/31055	82/2684	525/1325
77	870/7451	287/11587	143/24429	291/3076 ✓	184/6167 ✓	81/14599 ✓	220/2152	71/23809	363/5265
63	582/2205	179/7633	192/12955	272/4148 ✓	302/3421 ✓	85/22785 ✓	270/6409	125/28872	503/8094
14(ZX)	372		372	68 ✓		68 ✓	280		280
14(Y)		3188			1489 ✓			435	
18 (ZX)	224		224	69 ✓		69 ✓	147		147
21		3729			1746 ✓			464	
29		1563			766 ✓			190	
30	1417			607 ✓			264		
31			759			354 ✓			381
47	1605		464	865 ✓		220 ✓	245		466
52		1271			678 ✓			226	
53	1538		165	726 ✓		97 ✓	283		1070

SUPPORT NO.	X-LOAD			Y-LOAD			Z-LOAD		
	F_x	F_y	F_z	F_x	F_y	F_z	F_x	F_y	F_z
56		457			541			215	
71		714	856		384	379		135	568

REV	BY	DATE	CHECKED	DATE
1	KH	4/24/85	AA	4/25/85

SCE SONGS 1 Problem I

IMPELL CORPORATION

JOB NO 0310-061

CALC NO