Attachment 4

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TECHNICAL EVALUATION REPORT FOR MLRS PIPING RESPONSE ANALYSIS TECHNIQUE FOR LONG TERM SERVICE SEISMIC REEVALUATION: SAN ONOFRE NUCLEAR GENERATING STATION UNIT 1

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TECHNICAL EVALUATION REPORT FOR
MLRS PIPING RESPONSE ANALYSIS TECHNIQUE FOR
LONG TERM SERVICE SEISMIC REEVALUATION

SAN ONOFRE NUCLEAR GENERATING STATION UNIT 1

By

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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 postulated seismic loadings developed for the SONGS 1 seismic reevaluation. In 1984, the plant was allowed to return to service for the 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.

Assessments of the 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 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 Plants," 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, .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 the piping response analysis using the SUPERPIPE multi-level response spectrum (MLRS) method of analysis with the modal response combination technique of the NRC Regulatory Guide 1.92 and the floor response spectra generated from FLORA. 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 the methodology acceptable to the NRC, e.g., the time history analysis.

Section 2.0 discusses the licensee's 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

As was discussed in another TER (Ref. 4), one option proposed by the licensee for the piping response analysis is the multi-level response spectrum (MLRS) technique implemented in the SUPERPIPE code. This methodology includes essential steps:

Step 1 - Based on the eigenvalues of the piping system and the primary structure, hand-calculate an equivalent modal mass, M_{iK}, for each piping mode, i, and each structure support level, K.

Step 2 - At each support level, K, determine the input floor spectrum value associated with M_{iK} for each piping mode using the FLORA code.

Step 3 - Perform the MLRS analysis of the piping system with the SUPERPIPE code, using the individual M_{iK} associated support level floor spectrum as input.

The formula for the M_{iK} calculations is based on Ref. 5 as described in detail in Appendix A. The calculated maximum M_{iK} value is limited to the total mass of the piping system whenever the latter is exceeded. The support level floor spectrum associated with the M_{iK} can be individually generated from the ground spectrum with the FLORA code or obtained by interpolation from existing floor spectra generated by FLORA that are associated with certain specified EM values. The M_{iK} is the equivalent modal mass, EM, for the i-th mode of piping and the K-th location of the supporting structure.

With the M_{iK} associated support level spectrum as input, the dynamic component of the piping response is calculated with the MLRS technique in the SUPERPIPE code. For the MLRS technique, the piping system is analyzed as many times as the total number of support levels. In each analysis, the same piping system eigenvalues are used, but only one support level floor spectrum is used as input. For each piping mode, the modal responses from all the support level analyses are combined by using the absolute sum. The modal responses are then combined according to the 10% method specified in the NRC Regulatory Guide 1.92. The directional combination for the three earthquake components is also combined in accordance with the Regulatory Guide 1.92. The effect of missing mass is included in the dynamic component of the piping response to account for the effects of the higher modes. Responses from lower modes and from higher modes (higher than 33 H_z) are combined by using the absolute sum technique in each direction of the three orthogonal earthquake components. The pseudostatic component of the piping response due to the differential seismic anchor movements (SAM) is determined from a static analysis of the piping system. The SAM is applied in such a manner that it produces the most critical piping response. For Songs 1 LTS seismic reevaluation, the dynamic and pseudostatic components are combined using the absolute sum rule for pipe support forces.

3.0 TEST PROBLEM

The test problem was designed to assess the acceptability of the licensee's proposed methodology in general, and its computer code implementation in particular. To achieve this goal, we used the time history method of analysis, which is acceptable to the NRC, to analyze the combined structure-piping model. The licensee's proposed methodology for the piping response analysis was to use the SUPERPIPE multi-level response spectrum method of analysis with the modal response combination of Regulatory Guide 1.92 and the floor response spectra generated from the FLORA computer code as described in Section 2.0.

3.1 Description

The structure model of the test problem is shown in Figure 1. The piping system is attached to the supporting structure at three support points (Nodes 11, 7, and 4). The piping system is shown in Figure 2. It is represented by both a crude (5 nodes) and a refined (34 nodes) model in order to study the sensitivity of the piping response to the number of nodes in the model. The detailed description of the test problem is given in Appendix A.

For this test problem, the licensee is required to calculate the piping moments at the ten locations specified in Fig. 2 and the axial forces in all three horizontal pipe elements connecting the piping to the supporting structure. The structure is subjected to a horizontal ground input in terms of a set of ground response spectra. The support level spectra needed for the analysis of the piping systems are generated from the ground spectra by the FLORA computer code based on the M_{iK} parameters calculated by hand.

At NCT Engineering, the corresponding piping responses are calculated from a time history analysis of the coupled primary-secondary system. A detailed description of the analyses performed by the licensee and NCT Engineering is described in Appendix A.

3.2 Results

Tables 1(a) and 1(b) compare the moments and support forces, respectively, between the licensee's (Appendix B) and NCT's results for the crude model. In the licensee's results, the pseudostatic components shown in Table 1 are based on the most critical piping responses due to the seismic anchor movements. Similarly, Table 2 compares the results for the refined piping model.

It can be seen from Tables 1(a) and 2(a) that the licensee's results are much higher than those of time history approach. Note that the comparison is based on total seismic response (sum of inertial and pseudostatic response) since the coupled structure-piping model was analyzed through the time history method (NCT). For a coupled model it is difficult, if not impossible, to separate inertial response from the total response. In Table 1(b), for the crude model, the pipe support loads of the licensee's results are still higher than that of the time history results, even though the margins are not as much as that of piping moments. The margins of conservatism of the pipe support loads from the licensee's results are further reduced for the refined model as shown in Table 3(b). Closely examining the trend of response from the crude model to the refined model, we find an inconsistency between the NCT time history and the licensee MLRS analysis, except in the two locations at the center of the two vertical spans. The cause of this inconsistency is still unknown.

4.0 CONCLUSIONS

Based on our review of the licensee's proposed methodology and Reference 3, and the results from the test problem, we conclude that the application of the FLORA generated spectrum to the piping analysis appears to be sufficient. However, we could not reach any conclusion on the SUPERPIPE multiple level response spectrum method of analysis using the Regulatory Guide 1.92 modal and directional combination techniques due to the inconsistent response trend from the crude to the refined model between the NCT results and the licensee's.

5.0 ACKNOWLEDGEMENTS

The authors wish to thank Dr. M. A. 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 Mark Medford, SCE, to John Zwolinski, NRC, dated March 12, 1985.

3. "Report of the U.S. Nuclear Regulatory Commission Piping Review Committee--Evaluation of Other Dynamic Loads and Load Combinations", NUREG-1061, Volume 4, December, 1984.

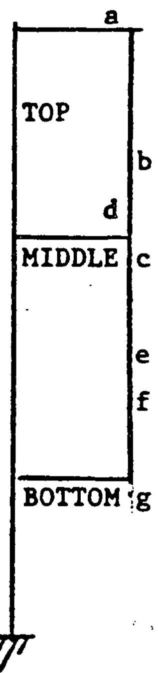
4. N. C. Tsai and L. C. Shieh, "Technical Evaluation Report for the Licensee's Proposed Modal Response Combination Techniques for Long Term Service Seismic Reevaluation, San Onofre Nuclear Generating Station Unit 1", Lawrence Livermore National Laboratory, Livermore, CA, UCID-Draft, May, 1985.

5. A. Asfura and A. Der Kiureghian, "A New Floor Response Spectrum Method for Seismic Analysis of Multiple Supported Secondary Systems", Report No. UCB/EERC-84/04, University of California, Berkeley, June 1984.

Table 1(a) RESULTANT MOMENT

CRUDE MODEL (UNIT = K-FT)

LOCATION	(1) NCT	(2) LICENSEE ǂ	(3)	(4)	(5) RATIO
	TIME HIST.	DYNAMIC INERTIA	SAM* MOST CRITICAL	$\sqrt{(2)^2 + (3)^2}$	(4)/(1)
a.	237	894	238	925	3.903
b.	433	477	38	479	1.106
c.	362	779	314	840	2.320
d.	259	1440	1	1440	5.560
e.	217	790	316	851	3.922
f.	229	444	39	446	1.948
g.	196	914	237	944	4.816



MEAN = 3.37

STD.DEV.= 1.62

Table 1(b) HORIZONTAL AXIAL FORCE

CRUDE MODEL (UNIT = KIP)

LOCATION	(1) NCT	(2) LICENSEE ǂ	(3)	(4)	(5)
	TIME HIST.	DYNAMIC INERTIA	SAM MOST CRITICAL	$\|(2)\| + \|(3)\|$	RATIO (4)/(1)
TOP	46.1	63.8	8.7	72.5	1.57
MIDDLE	59.0	60.9	18.0	78.9	1.32
BOTTOM	24.6	41.1	9.2	50.3	2.02

ǂ See Reference 4

MEAN = 1.65

STD.DEV. = 0.36

*SAM = SEISMIC ANCHOR MOVEMENT

Table 2(a) RESULTANT MOMENT

REFINED MODEL (UNIT = K.FT)

	(1)	(2)	(3)	(4)	(5)
LOCATION	NCT	LICENSEE ‡			RATIO
	TIME HIST.	DYNAMIC INERTIA	SAM* MOST CRITICAL	$\sqrt{(2)^2+(3)^2}$	(4)/(1)
a.	314	814	238	848	2.701
b.	347	362	38	364	1.049
c.	488	739	314	803	1.645
d.	274	1290	1	1290	4.708
e.	249	748	316	812	3.261
f.	179	350	39	352	1.967
g.	221	830	237	863	3.906

MEAN = 2.75

STD.DEV. = 1.30

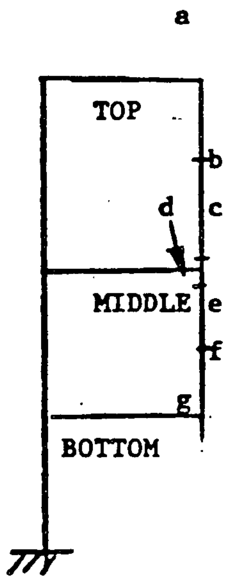


Table 2(b) HORIZONTAL AXIAL FORCE

REFINED MODEL (UNIT = KIP)

	(1)	(2)	(3)	(4)	(5)
LOCATION	NCT	LICENSEE ‡			RATIO
	TIME HIST.	DYNAMIC INERTIA	SAM* MOST CRITICAL	$\lvert(2)\rvert+\lvert(3)\rvert$	(4)/(1)
TOP	64.9	60.5	8.7	69.2	1.06
MIDDLE	76.3	65.7	18.0	83.7	1.09
BOTTOM	30.0	45.0	9.2	54.2	1.80

‡ SEE REFERENCE 4

MEAN = 1.31

STD.DEV. = 0.42

* SAM = SEISMIC ANCHOR MOVEMENT

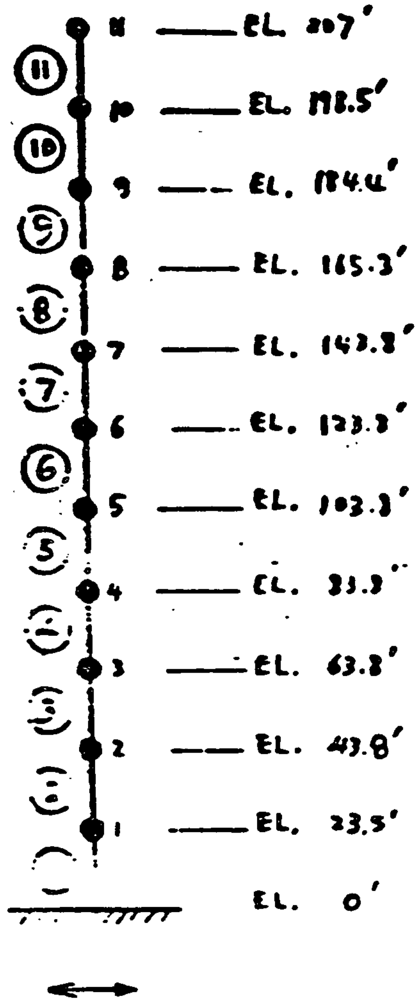
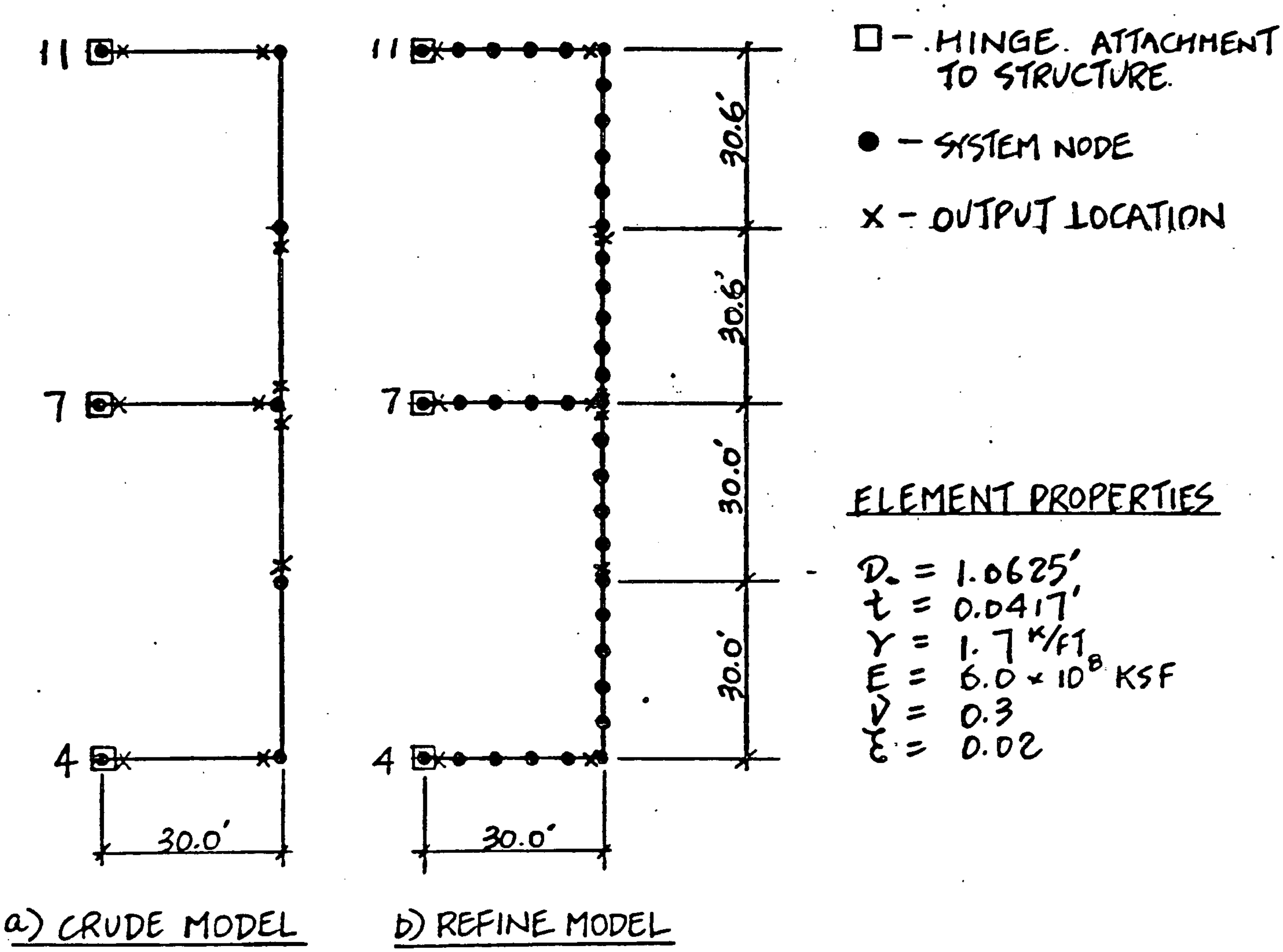


Fig. 1 The Supporting Structure



ELEMENT PROPERTIES

$D_o = 1.0625'$
$t = 0.0417'$
$\gamma = 1.7\ ^{K}/_{FT}$
$E = 6.0 \times 10^{8}$ KSF
$\nu = 0.3$
$\xi = 0.02$

Fig. 2 The Secondary Piping System for Test Problem

APPENDIX A

DETAILS OF THE TEST PROBLEM ANALYSIS

A.1 Problem Description

The primary structure is an eleven-mass stick model shown in Figure 1 in the text of this report.

The properties of the structure are given in Tables A.1 and A.2. The structure damping is 5% for all modes. The seismic input ground motion is a 15-second time history shown in Figure A.1, and the response spectra corresponding to 0.005, 0.02, 0.03, and 0.05 damping ratios are shown in Figure A.2. The secondary system is shown in Figure 2 in the text, and its damping is 2%. The three horizontal pipe elements are hinged at the structural attachment points. Thus, there is no moment connection between the primary structure and the piping. As mentioned in the text, a 5-node crude model and a 34-node refined model are used to represent the piping system in both the licensee's and NCT's analyses. (See Figure 2.)

A.2 Licensee Analysis

Given the primary structure shown in Figure 1, the secondary piping systems, shown in Figure 2, and the ground spectra shown in Figure A.2, the licensee is required to calculate the piping resultant moments at specified locations as shown in Figure 2 in the text and the axial forces in the horizontal pipe elements. The multi-level response spectrum (MLRS) method in SUPERPIPE is used to analyze the piping system. The missing mass effect and the differential anchor movement effects are considered in the analysis. The methodology for the licensee's analysis was discussed in the text. The damping used in their analysis is 2% for all modes.

The primary-secondary structure interaction is accounted for by generating floor response spectra using FLORA for all appropriate M_{iK}. The M_{iK} is the equivalent secondary modal mass, EM, for the i-th mode of the secondary piping and the K-th supporting location of the primary structure. The M_{iK} is calculated by the following equation:

$$M_{iK} = \frac{(\phi_i^T K_c \phi_I)^2}{M_i \omega_i^4 \phi_{KI}^2}$$

where M_i, W_i, $_i$ are the i-th modal mass, frequency, and mode shape of the secondary piping, respectively. $_I$ is a column matrix containing the I-th mode shape of the primary structure at all supporting points where the piping is attached. The i-th structure mode is the one which has a frequency closest to that of i-th mode of the piping. $_{KI}$ is the entry of $_I$ vector corresponding to the support degree of freedom, K. k_c is the connecting stiffness matrix. Each column of k_c represents the forces generated in piping degrees of freedom by one unit of displacement along a support degree of freedom with all other piping and support degrees of freedom held fixed. The M_{iK} values required for the FLORA input are manually calculated by the licensee using the equation described above. The calculated M_{iK} values are tabulated in Table A.3. The FLORA code is then used to generate the support level spectrum value associated with each M_{iK} at Nodes 4, 7, and 11 for use as input to the MLRS piping analysis.

A.3 <u>NCT Engineering Analysis</u>

At NCT Engineering, the composite structure, i.e., primary structure with piping attached, is analyzed to calculate the same response quantities to compare with the licensee's results. The LLNL computer code SAP4 is used to perform the time history analysis of the composite structure.

The assignment of a damping value to each mode is based on the inspection of the mode shape of the composite structure with the mode shapes of both the primary structure and the piping system. If the composite mode shape is dominantly of the primary structure, the modal damping is assigned to be 5%. Similarly, if the composite mode shape is primarily of the piping, 2% damping is assigned.

TABLE A-1

BEAM ELEMENT PROPERTIES OF THE STRUCTURE

Element No.	Section Area (ft^2)	Shear Area (ft^2)	Moment of Inertia (ft^2)
1 - 7	1400	700	2.8×10^6
8	990	500	1.9×10^6
9	990	500	1.5×10^6
10	990	500	0.8×10^6
11	990	500	0.2×10^6

TABLE A.2

NODAL MASSES OF THE STRUCTURE

Node No.	Nodal Mass (Kips)
1	4,600
2	4,200
3	4,200
4	4,200
5	4,200
6	4,200
7	4,610
8	3,020
9	2,470
10	2,120
11	190
Base	20,000

$I_{base} = 4.5 \times 10^6$ kip-ft^2

TABLE A.3

M_{iK} Values

(a) Refined Piping Model

Location	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
11	0.006	0.409	0	0.071	0.162	0.010
7	0.012	0.735	0.153	0.139	0.137	0.019
4	0.040	2.57	0	4.14	9.45	0.562

(b) Crude Piping Model

Location	Mode 1	Mode 2	Mode 3
11	0.007	0.346	1.42
7	0.013	0.671	2.75
4	0.041	2.17	8.89

Unit = kip-sec^2/ft

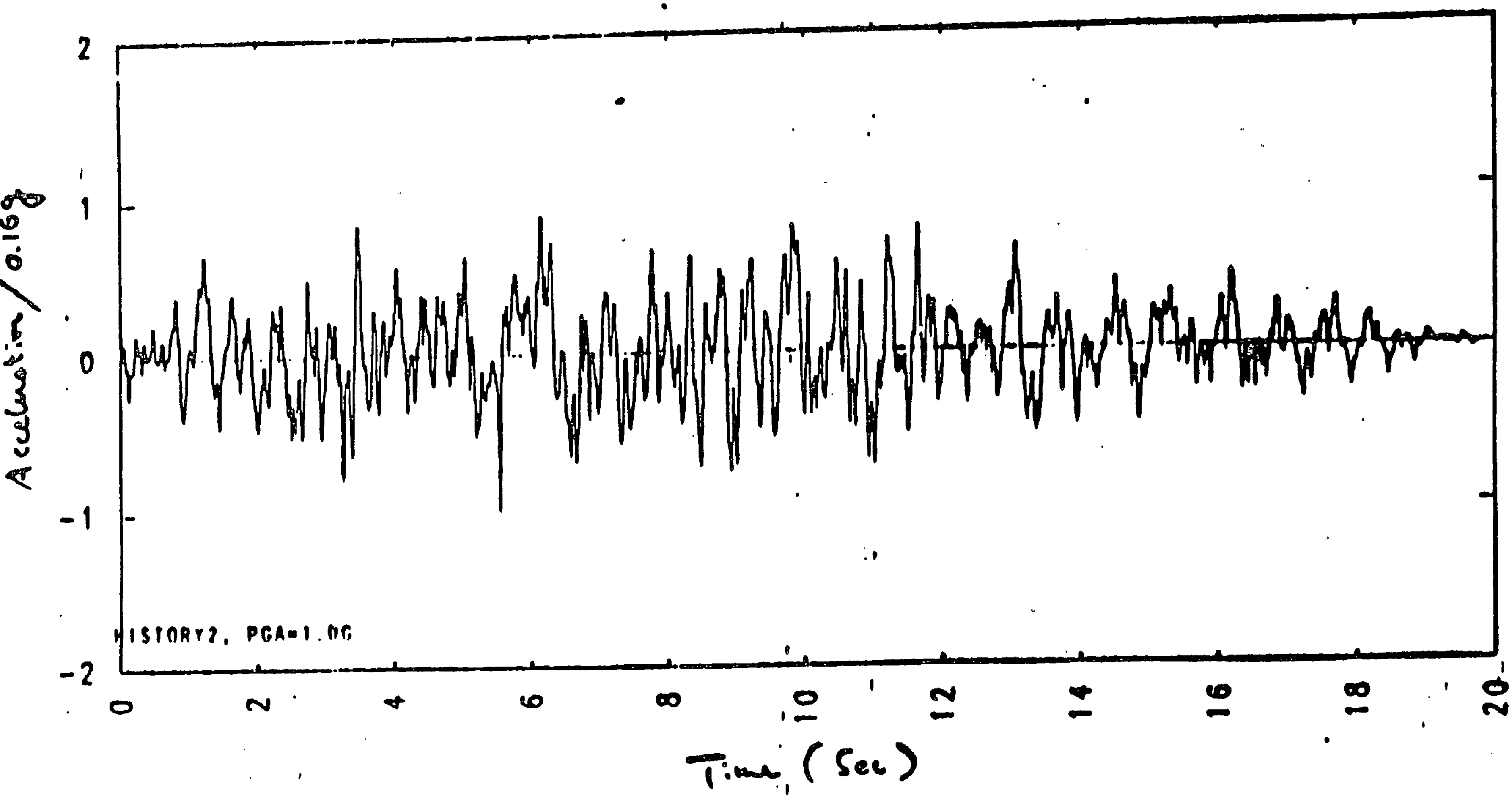
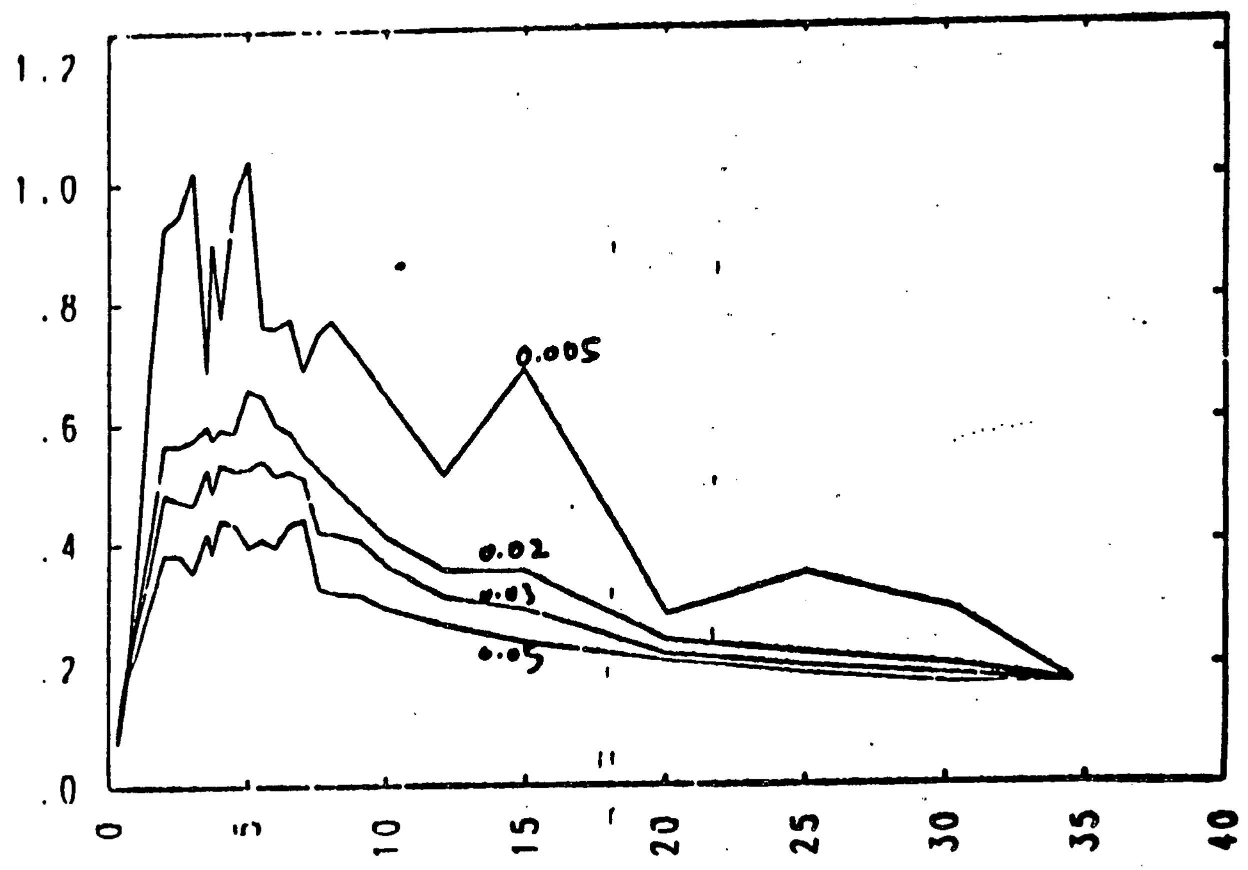

Acceleration / 0.16g
2
1
0
-1
-2
HISTORY2, PGA=1.0G
0
2
4
6
8
10
12
14
16
18
20
Time (Sec)

Fig. A.1



HORIZONTAL GROUND SPECTRA (NCT:HISTORY2)

APPENDIX B

IMPELL ANALYSIS RESULTS

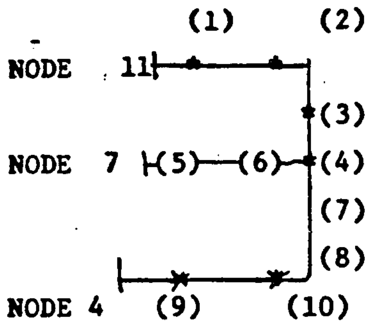
The data of the analysis results for the test problem include the following for both the crude and refined secondary system model:

- Inertial component of the piping moments and horizontal member axial forces from the multi-level response spectrum method with FLORA generated floor spectra and Regulatory Guide 1.92 modal response combination technique.

- Pseudostatic components of the moments and axial forces due to seismic anchor movements.

- $\dot{M}_{iK}$ values (secondary system modal mass) at all three structure support locations (Nodes 11, 7, 4).

The data are based on a telephone conversation between M. S. Yang of NCT Engineering and A. Asfura of Impell Corporation of Walnut Creek, May 9, 1985.



* = moment output location

Table B.1 Licensee's Piping Response

Responses	Output Location	Dynamic Comp. (Inc. missing mass) Crude Model	Refined Model	Pseudostatic Comp. SAM Out-of-Phase (same for both models)
	(1)	0	0	0
	(2)	894	814	238
	(3)	477	362	38
	(4)	1779	739	314
Moment(k-ft)	(5)	0	0	0
	(6)	1440	1290	1
	(7)	790	748	316
	(8)	444	350	39
	(9)	0	0	0
	(10)	914	830	237
Horiz. Member	Tip Member	63.8	60.5	8.7
Axial Force	Mid Member	60.9	65.7	18.0
(kip)				
	Bottom Member	41.1	45.0	9.2

Table B.2 Licensee's M_{iK} Values (kip-sec 2/ft)

Location K	Crude Model Mode 1	Mode 2	Mode 3	Refined Model Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
11	0.007	1.346	1.42	0.006	0.409	0.	0.071	0.162	0.010
7	0.013	0.671	2.75	0.012	0.795	0.153	0.139	0.317	0.019
4	0.041	2.17	8.89	0.040	2.57	0.	4.14	9.45	0.562