Attachment 3

UCID- 20482

TECHNICAL EVALUATION REPORT FOR DIRECT GENERATION OF FLOOR SPECTRUM FOR LONG TERM SERVICE SEISMIC REEVALUATION: SAN ONOFRE NUCLEAR GENERATING STATION UNIT 1

N. C. Tsai*
L. C. Shieh

June 1985

Lawrence Livermore National Laboratory

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

TECHNICAL EVALUATION REPORT FOR DIRECT GENERATION OF FLOOR SPECTRUM FOR LONG TERM SERVICE SEISMIC REEVALUATION

SAN ONOFRE NUCLEAR GENERATING STATION UNIT 1

By

N. C. Tsai
L. C. Shieh

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 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) presented their proposed 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 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 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 direct generation of floor response spectra. Our assessment is accomplished by reviewing the pertinent theory, methodologies, computer codes, and the licensee's planned applications to SONGS 1 LTS seismic reevaluation. 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 acceptable methodology.

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

The licensee has proposed to utilize the direct generation technique, which is implemented in the computer code FLORA (Ref. 3), to calculate the floor response spectra directly from ground response spectra.

The technique computes the maximum response of a light one-degree-of-freedom subsystem attached to a supporting structure having N degrees of freedom. The subsystem has an effective mass equal to EM. Given the modal properties of the supporting structure, FLORA determines the frequencies of the N+1 degree-of-freedom composite structure with the perturbation theory. It then directly determines the maximum response of the subsystem with a response spectrum

method of analysis of the composite system subject to the given ground response spectrum. The combination of the modal responses for the structure-piping system considers the correlation between modes that are analytically derived assuming the ground motion to be a certain random motion. For EM=0, i.e., a massless subsystem, the generated floor response spectrum has the same significance as the floor response spectrum conventionally generated from a time history analysis of the supporting structure. For a non-zero EM, the generated floor response spectrum includes the interaction effect between the subsystem and structure systems.

The methodology on which FLORA is based was first developed by Dr. Kiureghian, et al. (Refs. 4 and 5), at the University of California, Berkeley. For application to the analysis of a piping system, the determination of the subsystem modal mass is discussed in Ref. 6.

In FLORA, two solution algorithms are available, namely, the wide-band and narrow-band options. The wide-band option can be applied to any design ground spectrum similar to Regulatory Guide 1.60 spectra. If the input spectrum to the system corresponds to a typical in-structure response spectrum having a sharp peak, the narrow-band option is used. The wide-band solution is based on the assumption that the input motion is a white noise, which is an idealized random motion containing all frequencies having equal Fourier amplitude. That is, the power spectral density (PSD) function of the idealized white noise is a constant for all frequencies. This assumption greatly simplifies the analytical derivation. The narrow-band solution technique considers the actual PSD function of the input motion, which is usually a banded function centering about the dominant frequency of the input motion. It requires more sophisticated analytical derivations and, hence, appears more attractive from the technical point of view. According to the examples given in Ref. 3, the generated spectrum from the wide-band solution is usually more conservative than that from the narrow-band solution around the floor spectrum peaks.

3.0 TEST PROBLEM

3.1 Description

The test problem is to help assess the acceptability of the floor spectrum generated by the FLORA code for specified values of EM. To do this, we perform a time history analysis of the N+1 degree-of-freedom composite structure, and compare the maximum response of the single-degree-of-freedom secondary system with the FLORA wide-band solution. The time history technique is acceptable to the NRC.

The structural model used for direct floor response spectrum generation is an eleven-mass structure on a fixed base as shown in Fig. 1. A detailed description of the problem is in Appendix A. The licensee is required to calculate the 2% damping response spectra at two elevations (Nodes 11 and 4) directly from the ground response spectra given to the licensee. For each location, spectra are generated for three effective masses, namely, EM=0, 50 kips and 250 kips. NCT Engineering calculates the corresponding spectra using the time history analysis.

3.2 Results

Figures 2 and 3 compare the FLORA generated floor response spectra with the corresponding time history analysis results. For EM=50 and 250 kips, the time history solution was calculated only at three frequencies, namely, 5.00, 5.26 and 16.2 Hz, because the spectrum is not as sensitive to the value of EM at frequencies other than the dominant structure frequencies as evidenced in Figs. 2 and 3. For the dominant spectrum peak around the first structure mode, the licensee solutions (Ref. 7) do not always occur at the same frequency as the time history solution. The slight discrepancy in peak frequency, however, is immaterial in applications due to the fact that the spectrum peaks must be broadened prior to piping analysis. Therefore, it is sufficient to compare the spectrum peak values between the two solutions. For the dominant spectrum peak, the FLORA solution based on the wide-band technique differs from the time history solution by 3%, -1% and -1% for EM=0, 50 and 250 kips, respectively, at Node 11, and by 0%, 5%, and 8% at Node 4.

In other words, for EM=0, the FLORA spectrum is in close agreement with the time history solution throughout the entire frequency range. For non-zero EM values, the FLORA solution is, on the average, slightly more conservative than the time history solution.

4.0 CONCLUSIONS

Based on our review of the theory and the results from the test problem, we conclude that the FLORA direct spectrum generation, including the effect of secondary mass coupling, is sufficient for applications to the SONGS 1 LTS seismic reevaluation provided that the wide-band solution technique in FLORA is used.

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, E. McKenna to C. I. Grimes, NRC, dated February 12, 1985.

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

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

4. Der Kiureghian, A., Sackman, J. L., and Nour-Omid, B., "Dynamic Response of Light Equipment in Structures", Report No. UCB/EERC-81/05, Earthquake Engineering Research Center, University of California, Berkeley, California, April 1981.

5. Der Kiureghian, A., "Structural Response to Stationary Excitation", Journal of the Engineering Mechanics Division, ASCE, Vol. 106, No. EM6, Proc. Paper 15898, December 1980, pp. 1195-1213.

6. N. C. Tsai, L. C. Shieh, "Technical Evaluation Report for MLRS Piping Response Analysis Technique for Long Term Service Seismic Evaluation", Lawrence Livermore National Laboratory, Livermore, California, UCID- June, 1985.

7. Letter from M. Medford, SCE, to J. A. Zwolinski, NRC, "Docket No. 50-206, SEP Topic III-6, Seismic Design Considerations, Long-Term Seismic Criteria and Methodology, SONGS 1", dated June 4, 1985.

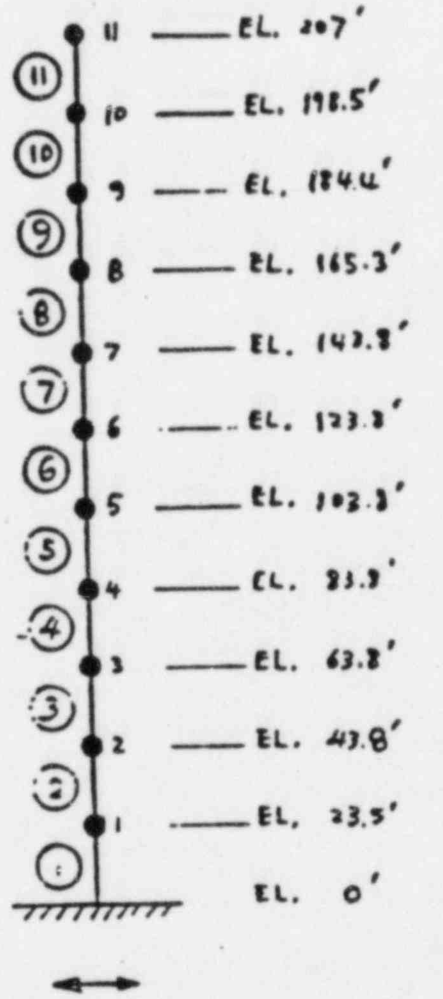

FIGURE 1. The Supporting Structure

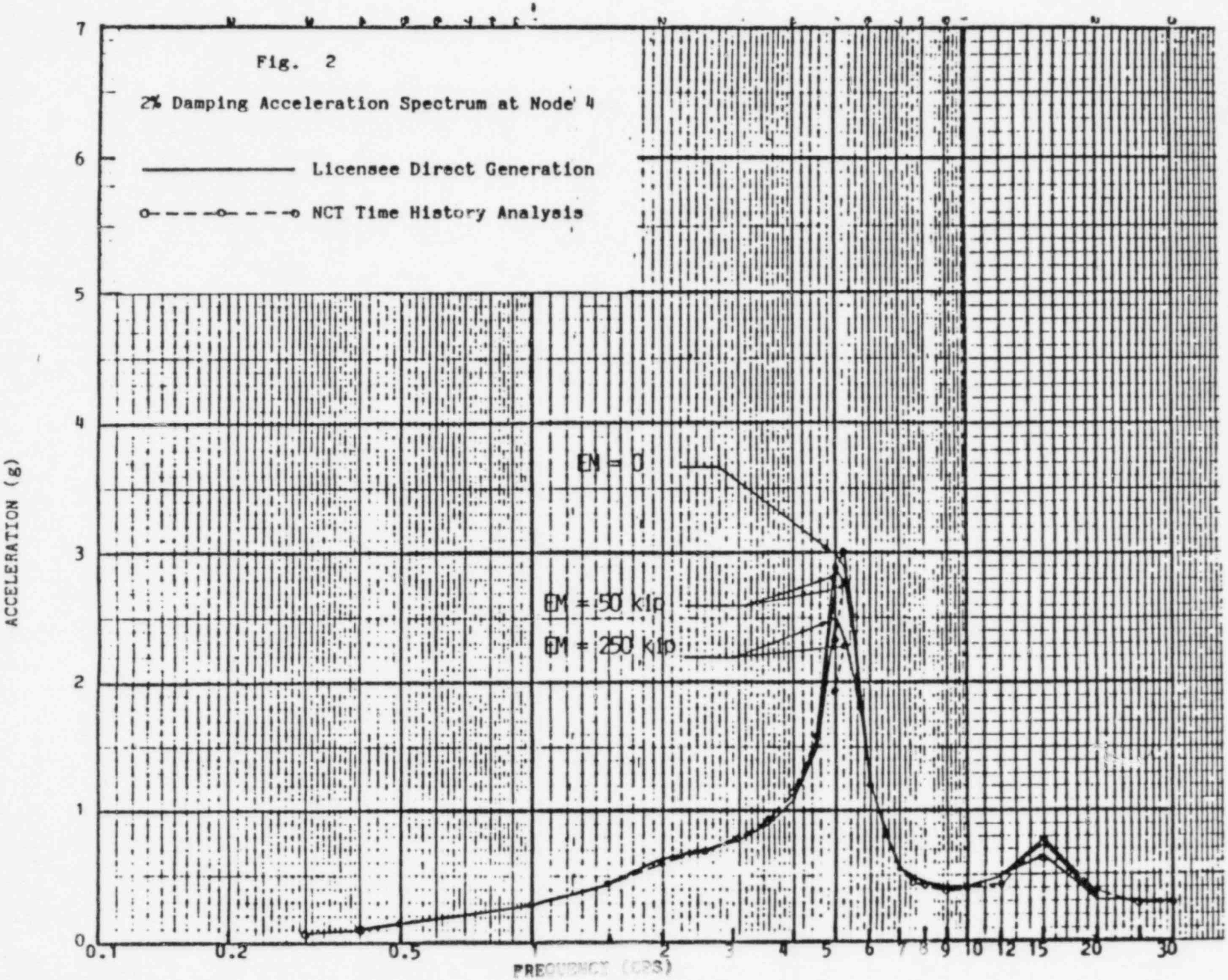
Fig. 2
2% Damping Acceleration Spectrum at Node 4
Licensee Direct Generation
NCT Time History Analysis
EN = 0
EM = 50 kip
EM = 250 kip
ACCELERATION (g)
FREQUENCY (CPS)
0
1
2
3
4
5
6
7
0.1
0.2
0.5
1
2
3
4
5
6
7
8
9
10
12
15
20
30

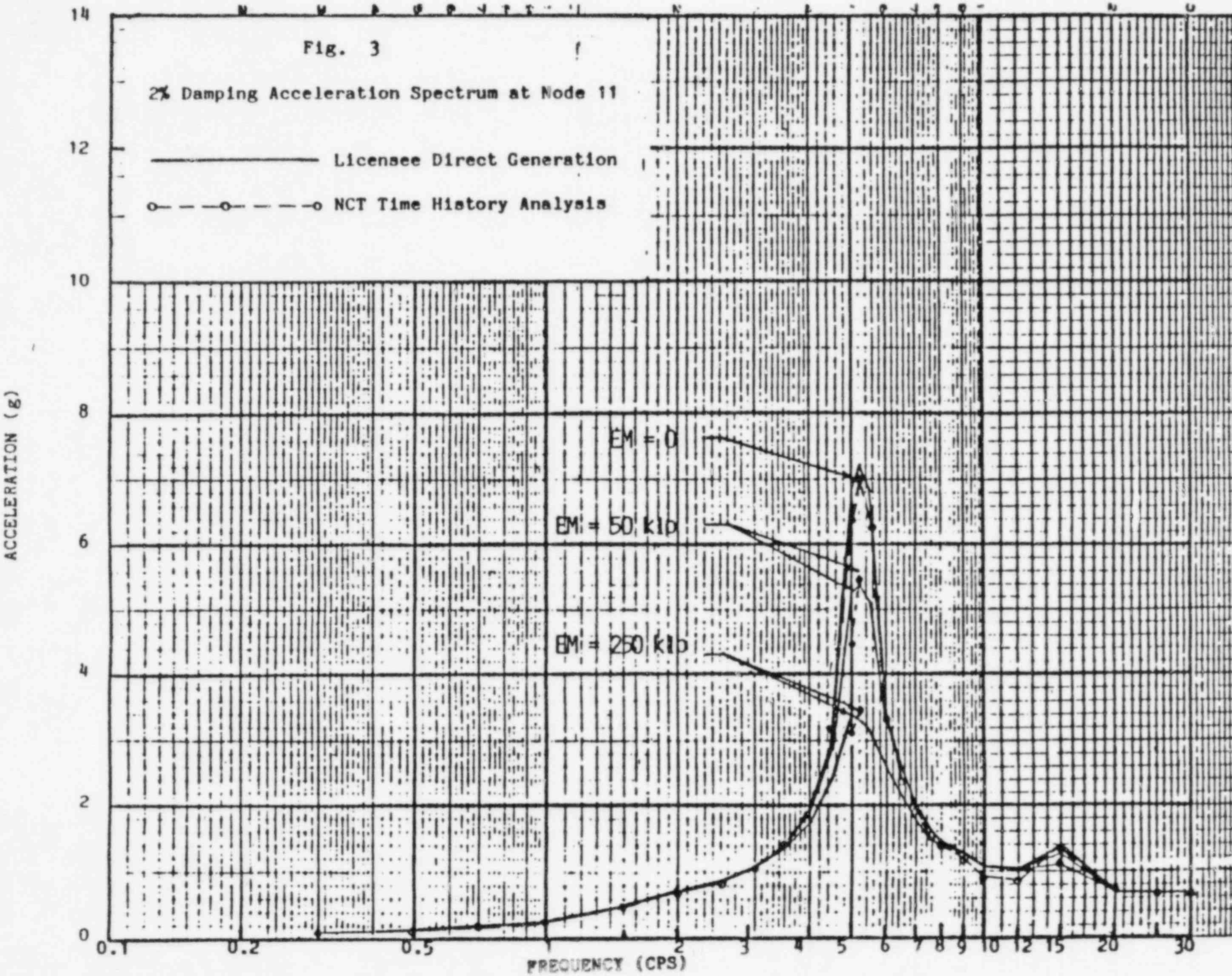

Fig. 3

2% Damping Acceleration Spectrum at Node 11

APPENDIX A

DETAILS OF TEST PROBLEM ANALYSIS

The test problem is to assess the FLORA methodology of direct floor response spectrum generation.

A.1 Problem Description

The primary structure is an eleven-mass stick model consisting of eleven massless beams as shown in Figure 1 in the text.

The properties of the structure are given in Tables A.1 and A.2. The structure damping is 5% per mode. The seismic input is a 15-second horizontal motion as shown in Figure A.1, with the corresponding 0.005, 0.02, 0.03, and 0.05 damping response spectra as shown in Figure A.2. The peak ground acceleration is 0.16 g.

A.2 Licensee Analysis

Given the structure and the ground response spectra, the licensee is required to generate, directly from ground spectra, the floor response spectra corresponding to the following parameters:

Damping Ratio:	0.02
Location (Node #):	4, 11
EM:	0, 50, 250 kips
FRAQ:	0

Thus, there are six response spectra to be generated. EM is the mass of the one-degree-of-freedom oscillator to account for the interaction between the primary and the oscillator. FRAQ is the probability of exceedance of the generated floor spectra. FRAQ = 0 indicates that the mean response spectra are to be calculated. The licensee applied the wide-band solution algorithm to the test problem.

A.3 NCT Analysis

Using the time history method of analysis, NCT Engineering calculates the floor response spectra for the case of EM=0. For EM=50, 250 kips, the spectral values are calculated at only three frequencies, i.e., 5.00, 5.26 and 16.2 Hz (5.26 and 16.2 Hz are the first two structure frequencies). The response spectral values for non-zero EM values are calculated by analyzing the composite structure. The composite structure is obtained by attaching the one-degree-of-freedom oscillator having the required mass EM and frequency to the primary structure at Node 4 or 11. Because the oscillator frequency is close or perfectly tuned to one of the frequencies of the primary structure, a pair of closely spaced modes is created for the composite structure. The geometric mean of the primary structure modal damping and the oscillator damping is assigned as the composite modal damping to this pair of modes of the composite structure when their frequencies differ by less than 10% from each other. In this test problem, the structure damping is 5% per mode, and the oscillator damping ratio is 2%. Thus, the geometric mean is 3.16%. When the pair of modes differ in frequency by more than 10%, the lower mode is assigned the 2% damping and the higher mode 5%. To modes other than the two modes in the pair, the 5% structure damping is assigned. Results of NCT analysis are shown in Figures 2 and 3 in the text, to compare with the licensee's FLORA results.

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

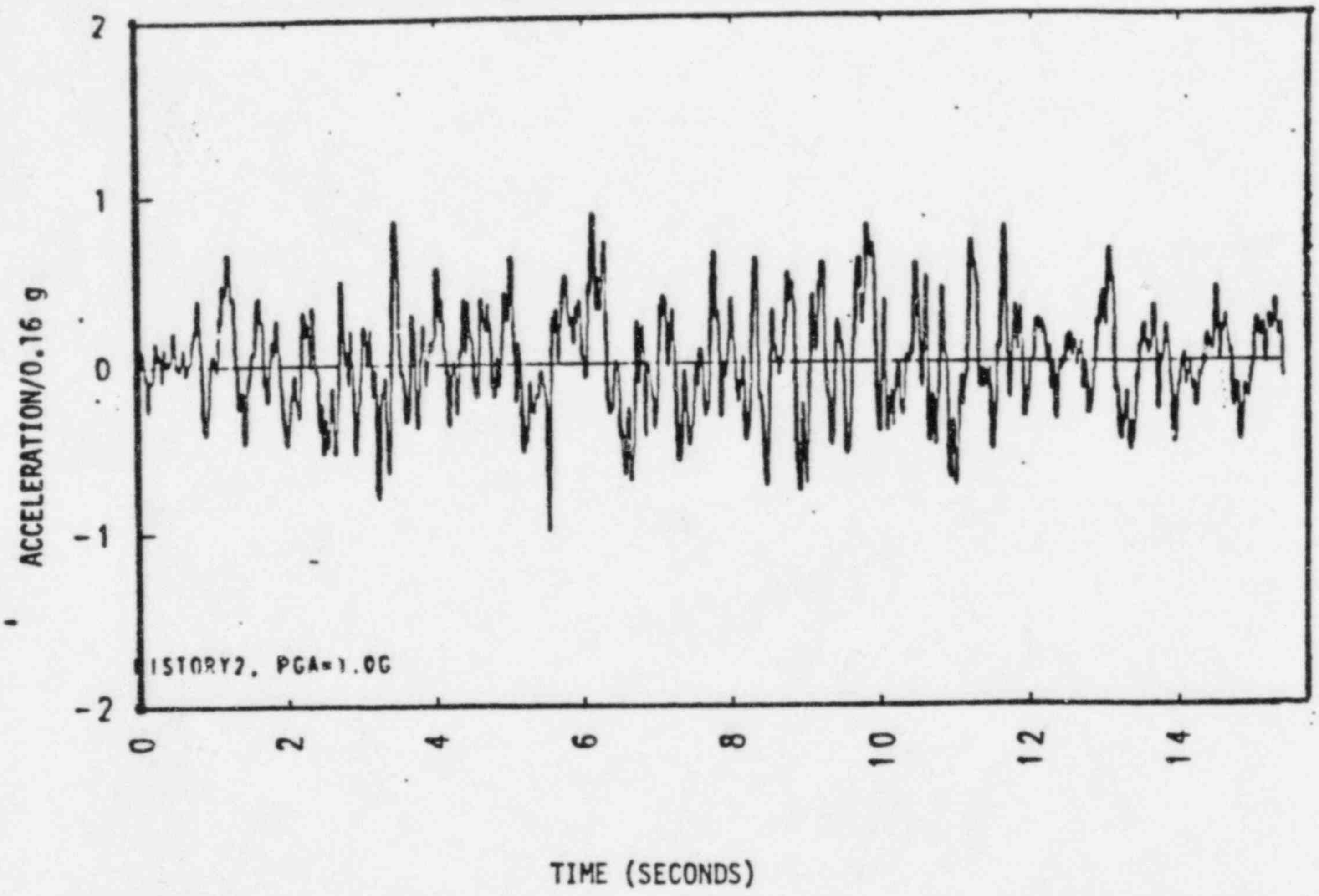

FIGURE A.1. Horizontal Free Field Time History

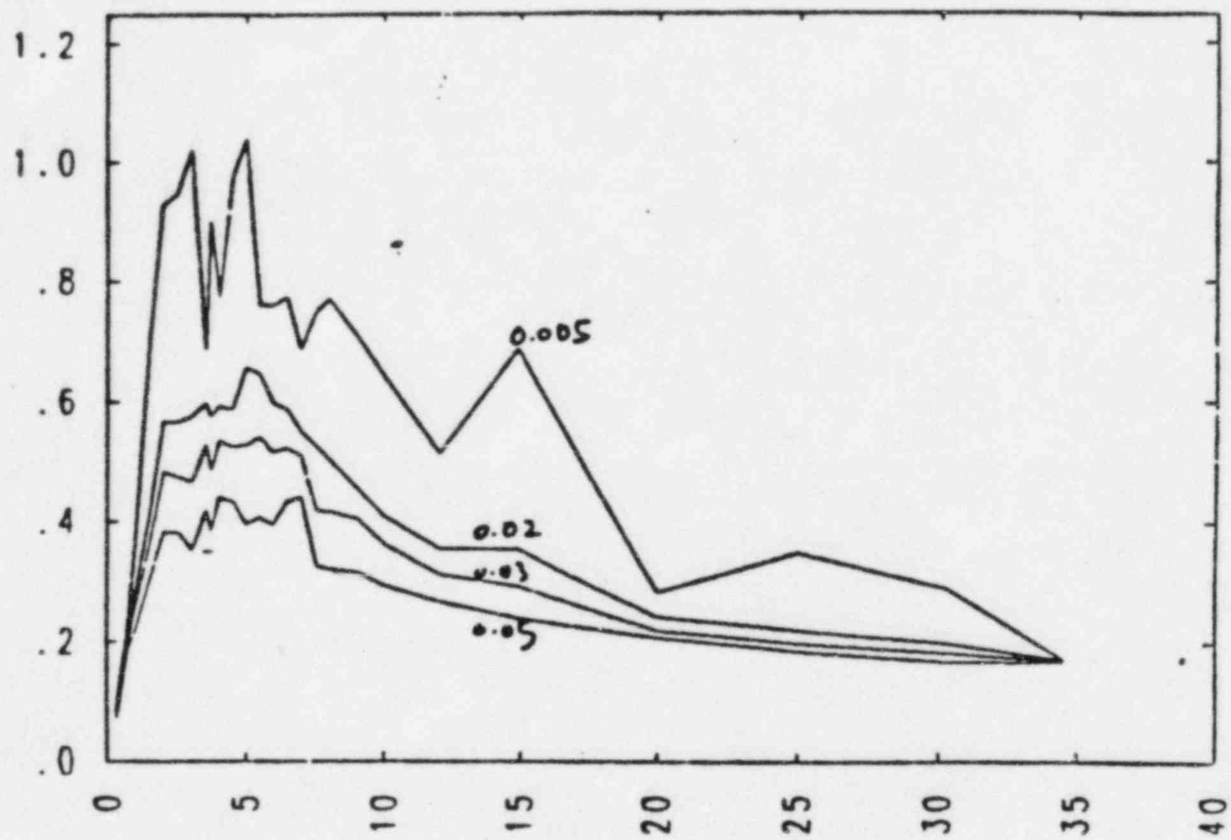

FIGURE A.2. Horizontal Ground Spectra (NCT: History 2)