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August 16, 1982

Director, Office of Nuclear Reactor Regulation
Attention: D. M. Crutchfield, Chief
Operating Reactors Branch No. 5
Division of Licensing
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

Gentlemen:

Subject: Docket No. 50-206
Seismic Safety Margins
San Onofre Nuclear Generating Station
Unit 1

By letter dated April 5, 1982, the NRC indicated that the .67g Housner response spectra being used for seismic reevaluation were generally appropriate except for small exceedances (up to 10%) in specified period ranges. Specifically, that letter indicated that the staff's best estimates of the 84th percentile response spectra would exceed the horizontal Housner spectra by up to 10% in the period range from 0.7 second to .25 second and the vertical Housner spectra by up to 10% in the period range from .05 second to 0.15 second. The NRC requested that we provide additional information related to the seismic safety margins in structures, systems and components considering these 10 percent exceedances of the Housner spectra.

The enclosure to this letter provides a detailed evaluation of the seismic safety margins in the seismic reevaluation program for San Onofre Unit 1. Based on the information in this report, it is concluded that the margins are adequate and the previous analyses will not be impacted by the exceedances of up to 10% over the specified period ranges. Based on this conclusion, it is SCE's intention to continue to utilize the 0.67g Housner response spectra for the seismic reevaluation of San Onofre Unit 1.

If you have any questions on any of this information, please let us know.

A001

Very truly yours,

RWKrieger for KPBaskin

Enclosure

SAN ONOFRE

NUCLEAR GENERATING STATION

UNIT 1

SEISMIC SAFETY MARGINS WITH RESPECT TO THE 84TH PERCENTILE INSTRUMENTAL SPECTRUM

AUGUST, 1982

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1.0 INTRODUCTION

This report describes the results of an evaluation of seismic safety margins and generic conservatisms in the seismic reevaluation program for San Onofre Unit 1. This evaluation was performed for the purpose of determining the significance of possible increases of up to 10 percent in the .67g Housner response spectrum in the period range of 0.07 to 0.25 second for the horizontal direction and in the period range of 0.05 to 0.15 second in the vertical direction. The report contains specific responses to four items included in a request for additional information which was enclosed in a letter from D. M. Crutchfield to R. Dietch dated April 5, 1982.

Section 2.0 provides a discussion of the overall effects of 10 percent exceedances of the Housner Spectrum. Section 3.0 contains the responses to the four specific items included in the request for additional information. Section 4.0 describes the conclusions of the report.

2.0 OVERALL EFFECT OF 10 PERCENT EXCEEDANCES OF THE HOUSNER SPECTRUM

This section provides a discussion of the nature of the possible exceedances of the Housner design spectra over the specified period ranges. Specifically, the magnitude of the exceedance as a function of damping and the shape of the exceedance are discussed. In addition, overall margins in the seismic reevaluation allowable stresses are addressed.

a. Magnitude of the Exceedances

In the reevaluation of the San Onofre Unit 1 structures, the damping values used were 7 percent for reinforced concrete structures, 7 percent for bolted and/or riveted steel structures and 4 percent for welded steel structures.

Newmark and Hall (Reference 1) recommend 7 to 10 percent damping for reinforced concrete structures, 10 to 15 percent damping for bolted and/or riveted steel with bolted joints, and 5 to 7 percent damping for welded steel structures, at or just below the yield point. Reference 2 states that the upper levels are considered to be average or slightly above average values, and are acceptable for evaluation of existing structures. A comparison of the SONGS 1 damping values with those recommended in Reference 1 shows the conservatism of the damping values, and thus the response parameters, used in the reevaluation of structures, systems and components. This factor alone would indicate that there is considerable margin in the seismic reevaluation program.

Soil structure interaction effects tend to increase the equivalent composite modal damping values of structures. Actual values of up to 50% have been observed. Therefore, the aforementioned critical damping values should be viewed as the minimum damping associated with the structures.

References 3 through 5 indicate that the exceedance of the Housner reanalysis spectrum decreases as spectral damping increases for the 84th percentile instrumental spectrum predictions. Therefore, based on the above discussions which indicate high damping for structures at San Onofre Unit 1, it is concluded that the exceedances will be less than 10 percent for the damping values of concern for San Onofre Unit 1 structures. In addition, this implies that any increases in the structural response parameters used for the evaluation of systems and components due to exceedances of the 84th percentile predictions will also be less than 10 percent.

b. Shape of the Exceedances

Review of References 3 through 5 shows that the 10 percent exceedances of the Housner spectra will be similar to a bell shape. These references would imply that the maximum exceedance of the horizontal Housner spectra should be around 0.12 second tapering to zero towards the specified limits of 0.07 and 0.25 second. This means that the magnitude of the exceedances can only approach 10 percent in the previously computed response parameters, if all the modes of importance are clustered around the point of maximum exceedance. This is not the case for SONGS 1 structures. Therefore, the actual increase in the responses will always be less than 10 percent.

The conclusions on the overall effects of magnitude and shape of the exceedances on the previously computed seismic responses are summarized as follows:

a. The minimum damping, including soil-structure interaction damping, for structures is 4 percent. Actually, values up to 50 percent have been observed in certain cases. Since exceedances of the Housner spectrum are less for higher dampings it is concluded that the actual increases for structures will be less than 10 percent.

b. Similarly, the increase, if any, in the seismic input to systems and components supported by structures will be less than 10 percent.

c. The fundamental periods of the structures at SONGS 1 are higher than 0.12 second. Therefore, no structure will actually see a 10% increase in response.

d. The only items which could conceivably be affected by as much as 10% exceedances of the Housner spectrum are items which are supported on the ground with periods around 0.12 second, at the peak of the exceedance range. The increase will be less than 10 percent for items having different periods.

Therefore, the overall effect of the 10 percent exceedances is minimal in almost all cases. Furthermore, most allowable stresses have safety margins of at least 2, and sometimes 3 or more, against failure. Therefore, in the few cases where the calculated stresses might approach or exceed the allowable limits as a result of the small exceedances, it is concluded that the likely result (not taking credit for any other conservatisms) would be to decrease the already large safety factors by a small amount.

It can be concluded, based on just these considerations, that the seismic safety margin in structures, systems and components are adequate, considering up to 10 percent exceedances of the horizontal Housner spectra in the period range from 0.07 second to 0.25 second and of the vertical Housner spectra in the period range from 0.05 second to 0.15 second. However, in the responses to the specific NRC questions in Section 3.0, the seismic safety margins of structures, systems and components were evaluated on a case by case basis. In spite of the above discussions, these evaluations were based on the following conservative assumptions:

a. The 10 percent exceedance of the Housner spectra was assumed to apply to all spectral damping values.

b. The 10 percent exceedance was assumed to be equal over the period range of 0.07 to 0.25 second for the horizontal Housner spectra and over the period range of 0.05 to 0.15 second for the vertical spectra.

c. Where reviewed, the previously computed responses of structures, systems and components were increased by 10 percent assuming that all modes of importance will fall into the specified period ranges.

d. The previously calculated design loads other than seismic forces were also increased by 10 percent.

3.0 RESPONSES TO NRC REQUEST FOR ADDITIONAL INFORMATION

3.1 Question 1:

Describe for each structure the effects of this increase in response spectra on the loadings (moments, shears, and bucklings, etc.), stresses and displacements which were calculated using linear elastic analysis and justify their adequacy.

Response 1:

The seismic safety margins of structures were evaluated on a case by case basis as discussed above. Since all conceptual modifications identified in previous reports are being installed during the current outage, this basis is reflected in these evaluations. In addition, the changes in the seismic safety margins of the elements of structures (walls, slabs, beams, etc.) which considered the ductility concept are also addressed herein, rather than in response to question 2.

Fuel Storage Building

The results of the evaluation of the fuel storage building were provided in Reference 6.

The seismic input used in the reevaluation of the fuel storage building envelops the 10 percent exceedances of the Housner design spectra over the specified period ranges. Thus, the margins associated with the seismic response of this structure will not be affected. The details of the comparisons of the input are presented in response to question 3b, which addresses the masonry walls of the fuel storage building.

Diesel Generator Building and Sphere Enclosure Building

The design response spectra which were employed for the design of the diesel generator building and sphere enclosure building were the SONGS 2 and 3 design spectra (Reference 7). These spectra conservatively envelop the 10 percent exceedances of the Housner design spectra over the specified period ranges. Thus, the margins associated with the responses of these structures will not be affected.

Ventilation Equipment Building

The results of the reevaluation, including the safety factors for the structural elements, of the ventilation equipment building were provided in Reference 8.

The safety factors in Reference 8 were reviewed to determine the effect of increasing the previously calculated forces by 10 percent. The minimum safety factor was computed to be 1.13 at an east-west masonry shear wall. Thus, the margins associated with the responses of the ventilation equipment building will not be affected by the 10 percent exceedances of the Housner design spectra over the specified period ranges.

Reactor Auxiliary Building, Circulating Water System Intake Structure and Seawall

The results of the reevaluation of these structures, including the safety factors for the structural elements, were provided in Reference 8.

For the reactor auxiliary building and the circulating water system intake structure the governing loading conditions applied to the external below grade peripheral walls and base slabs were due to seismic earth pressures and hydrodynamic pressures computed using the zero period acceleration (ZPA) of the ground design motion in accordance with Reference 9. Therefore, these structural components will not be affected by the 10 percent exceedances of the Housner design spectra over the specified period ranges. The governing loading condition on the below grade interior walls and floor slabs of these structures, as identified in Reference 9, is due to inertial forces and hydraulic pressures. Since the fundamental frequencies of the internal walls and floor slabs are in the unamplified region of the response spectrum for 7 percent damping, the ZPA of the ground design motion is also applicable for the computation of the inertial forces for these members. Again the margins for these structures will not be affected by the 10 percent exceedances of the Housner design spectra over the specified period ranges. Furthermore, since the ZPA was the applicable input for the evaluation of the intake structure, those elements which considered the reserve energy method to evaluate inelastic behavior will also not be affected.

For the seawall the governing loading condition was also due to seismic earth pressures and hydrodynamic pressures computed using the ZPA of the ground design motion in accordance with Reference 9. Therefore, the seawall will not be affected by the 10 percent exceedances of the Housner design spectra over the specified period ranges.

Turbine Building, Control and Administration Building

The results of the reevaluation, including the safety factors for the structural elements of the turbine building and the control and administration building were provided in References 6 and 10, respectively.

The safety factors in References 6 and 10 were reviewed to determine the effect of increasing the previously calculated forces by 10 percent. Of the over 500 individual stress parameters reviewed, the only structural elements that could be affected by these 10 percent increases are shown in Tables 1 and 2. For the control and administration building the non-critical portions of the building were not reviewed since it was concluded in Reference 10 that the response or collapse of these structural members will not impair the integrity or function of seismic category A structures, systems and components. In addition, elements which considered the reserve energy method to evaluate inelastic behavior were included in the review.

For the turbine building, elements which are being or have been modified are not listed in Table 1 since the final design of the modifications considered at least a safety factor of 1.3 on the computed seismic forces. Also not shown in Table 1 are west heater platform bolt connection BC1 and east heater platform bolt connections BC3 and BC4, which had a margin of less than 10% in Reference 6. These are not listed because a detailed review of the calculations indicated that the previously reported safety factors for these connections were conservative and that the actual safety factors will be within the BOPSSR criteria in Reference 11 even when considering a 10 percent increase of the Housner spectra.

For the control and administration building, structural elements which were evaluated using the instructure response spectra were not listed in Table 2 since the seismic forces computed based on instructure response spectra remain valid, as discussed in response to question 4. Specific elements in this category which are identified in Reference 10 as having a safety factor of 1.1 or less are reinforced concrete walls WC-c-d, WC-5-a, WC-6 and WC-8; reinforced concrete slabs SC-1, SC-4, SC-10 and SC-12; and reinforced concrete beams BC-3, BC-15 and BC-20.

Several additional elements with safety factors of 1.1 or less in Reference 10 were shown by further evaluation to be acceptable. Specifically, walls WC-C-c, WC-C-d, WC-7.5 and WC-D and slabs SC-8 and SC-2 were found to be acceptable.

The decrease in the safety factors for the structural elements shown in Tables 1 and 2 are not considered to be significant. This conclusion is based on the discussions presented in Section 2 on the overall effects of 10 percent exceedances of the Housner spectrum, on the conservative manner in which the increase in the forces were calculated as explained in Section 2.0, and on the fact that such a limited subset of the total elements of the structures have even the potential for being affected.

Containment Sphere and Reactor Structure

The results of the reevaluation of the containment sphere and reactor structure were provided in Reference 12.

The fundamental modes of the structure are 0.29 second for the vertical direction and 0.27 and 0.28 for the horizontal direction. These periods are outside the period ranges of the 10 percent exceedances of the Housner spectra and therefore these structures are not affected. In addition, in the analyses of the steel sphere, 4 percent modal damping was used without taking into consideration the possible increases in composite modal damping due to soil-structure interaction affects. This fact ensures that additional margins exist for this structure.

Table 1 Turbine Buiding Safety Factors Based on Consideration of a 10% Spectra Increase

	Item		Safety Factor
1.	North Extension	Column B6	0.90
2.	North Extension	Column D8	0.96
3.	West Heater Platform	Bolt Connection BC1	0.91

Table 2 Control and Administration Building Safety Factors Based on Consideration of a 10% Spectra Increase

	Item	Safety Factor
1.	Reinforced concrete wall WC-6 above elevation 42'-0"	0.93 (Shear)
2.	Masonry wall WM-A-n	0.91 (Shear) 4.7 (Bending Ductility)
3.	Masonry wall WM-A-s	0.92 (Shear)
4.	Masonry wall WM-8-a	0.87 (Shear) 4.9 (Bending Ductility)
5.	Reinforced concrete beam BC-13	0.93 (Shear)
6.	Structural steel column CS-1	0.98 (Combined)
7.	Connection TS 6 x 3 x 1/4	0.95 (Combined)
8.	Connection 3/4 - Dia A307 bolts on insert plate	0.90 (Combined)

3.2 Question 2:

Describe for each of the structures, systems (e.g., reactor coolant loop), and components, the effects of this increase in response spectra on the calculated loadings (moments, shears, and bucklings, etc.), stresses and displacements when either a nonlinear analysis or an inelastic response spectrum analysis (using ductility concept) was used to account for inelastic behavior and justify their adequacy.

Response 2:

The only structure analyzed using a nonlinear inelastic analysis was the fuel storage building. The seismic safety margin for this building are addressed in the response to question 3b which evaluates the masonry walls of the fuel storage building. The reserve energy method of analysis (with the elastic Housner spectra as input) was used to evaluate the inelastic behavior of structural components. The seismic safety margins of these structural elements are addressed in response to question 1.

Nonlinear analysis methods were used for the evaluation of the reactor coolant loop. The comparisons of the Housner ground spectra and the spectra of the two horizontal and the vertical design time histories used in the evaluation of the reactor coolant loop are shown in Figures 1 through 3 for 2, 4 and 7 percent critical damping values.

Table 3 shows the average difference of the spectra of the design time histories and the horizontal Housner spectra in the period range from 0.07 second to 0.25 second and the vertical Housner spectra in the period range from 0.05 second to 0.15 second. The average differences over the specified period ranges were calculated considering the values at 20 specific periods for the horizontal spectra comparisons and at 18 specific periods for the vertical spectra comparisons. It is concluded that the spectra of the design time histories satisfactorily envelop the 10% exceedances of the Housner spectra over the specified period ranges. Thus the nonlinear evaluation of the reactor coolant loop will not be affected.

Table 3 Average Percent Envelope of Design Time Histories Used in Analysis of Reactor Coolant Loop

Direction	Percent Spectral Damping	Average Percent Envelope
Horizontal (Trace A)	2	24.7
	4	29.9
	7	19.3
Horizontal (Trace B)	2	25.9
	4	25.6
	7	13.9
Vertical	2	14.7
	4	29.6
	7	27.2

3.3 Question 3:

Describe the effects of this increase in response spectra on the calculated loadings (moments, shears, and buckling, etc.), stresses and displacements of masonry walls where nonlinear inelastic analyses were used. Justify that the integrity of these walls would not be compromised and equipment supported by or penetrating through these walls would not be adversely affected by the increase in response spectra.

Response 3:

a) Turbine Building, Ventilation Equipment Building and Reactor Auxiliary Building

The details of the nonlinear inelastic analyses of the masonry walls was presented in Reference 13. References 14 and 15 address the criteria and the analysis methodology, respectively.

The Design Basis Earthquake motion used to evaluate the masonry walls was the Housner response spectrum normalized to 0.67g. Earthquake acceleration records compatible with this design spectrum were required for the nonlinear inelastic analysis. The Housner spectra is a composite smoothed spectra derived from the horizontal components of the El Centro 1934, El Centro 1940, Olympia 1949 and Taft 1952 earthquakes. Therefore, the time histories for analysis of the masonry walls were developed using the following steps:

1. Each horizontal component for the four earthquake events was scaled to have an equal spectrum intensity to the Housner spectrum. This was achieved by computing a scale factor such that the area under the zero damped velocity spectrum curve for the particular component was equal to the equivalent area under the Housner velocity spectrum. The integration was carried out over the range of periods from 0.1 to 2.5 seconds, where most of the earthquake energy input is concentrated. The acceleration time histories used were obtained from the records digitized, filtered and corrected by the Earthquake Engineering Research Laboratory at the California Institute of Technology (EERL).

2. A single peak of the scaled time history was raised to 0.67g to obtain the same zero period acceleration as the normalized Housner response spectrum.

3. The time histories so obtained were used to produce 7 percent damped acceleration response spectra.

4. These 7 percent damped spectra were then compared with the Housner spectrum for the same damping.

5. The three earthquake components which collectively enveloped the Housner curve over the complete frequency range were selected for the inelastic analyses. These were:

EARTHQUAKE		COMPONENT	EERL DESIGNATION	SCALING FACTOR
El Centro	May 18, 1940	S00E	A001/S00E	1.57
Taft	July 21, 1952	S69E	A004/S69E	2.90
Olympia	April 13, 1949	N04W	B029/N04W	2.51

In Figure 4 the 7 percent damped Housner spectrum is plotted together with the three earthquake components listed above. It can be seen that the three components collectively envelop the Housner spectrum throughout the frequency range of interest. It should also be noted that the El Centro May 18, 1940 S00E time history by itself almost completely envelops the Housner 7 percent damped response spectrum and that the envelop of the three time-histories exceeds the Housner response spectrum by a substantial margin in the amplified region of the spectrum (at some periods by nearly 100%).

In Figure 5 the 7 percent spectra of the time histories are plotted together with the Housner spectrum increased by 10 percent in the period range from 0.07 second to 0.25 second. As shown, the three components collectively envelop the modified Housner spectrum throughout the frequency range of interest. Therefore, the calculated out-of-plane responses of the masonry walls will not increase due to the 10 percent exceedance of the horizontal ground design response spectra. Since the out-of-plane responses will not change, the previously computed seismic input to the equipment supported or penetrating through these walls remains valid. The effects of the combined loadings are reflected in the conclusions of the response to Question 1.

b) Fuel Storage Building

The details of the nonlinear inelastic analyses of the fuel storage building, including the masonry walls, were presented in Reference 6.

The computation of the responses was achieved using a suite of scaled earthquake records as shown in Table 4. The responses were calculated using a horizontal and a vertical model. For the horizontal response analyses the horizontal components of each earthquake were applied simultaneously to the major axes of the model. The records were then rotated 90 degrees relative to the model axis and the analyses were repeated for the same two components of the earthquake. For the vertical response computations the vertical model was subjected to the vertical component of each earthquake. Table 5 summarizes the analyses performed.

In Figure 6 the 7 percent damped Housner spectrum is plotted together with the envelop spectrum of the six horizontal components of the earthquakes listed in Table 4. It can be seen that the six components collectively envelop the Housner spectrum throughout the frequency range of interest. Figure 7 shows the envelop spectrum together with the Housner spectrum increased by 10 percent in the period range from 0.07 second to 0.25 second. As is shown, the modified Housner spectrum is enveloped by the collective spectra of the horizontal components. Figures 8 and 9 show the 7 percent envelop spectrum of the three vertical components together with the corresponding Housner spectrum and the Housner spectrum increased by 10 percent in the period range from 0.05 second to 0.15 second, respectively. As is shown, the collective spectra of the vertical time histories envelop the modified region of the Housner spectrum in this frequency range. Therefore, the calculated out-of-plane responses of the masonry walls will not increase due to the 10 percent exceedance of the horizontal ground design spectra.

Since the responses of the masonry walls will not change, the previously computed seismic input to the equipment supported by or penetrating through these walls remain valid.

Table 4 Time Histories Used in the Fuel Storage Building Analyses

EARTHQUAKE NO.	NAME	COMPONENT	SCALING FACTOR	PEAK ACCELERATION
1	El Centro	S00E*	1.57	0.67
2	May 18, 1940	S90W	1.57	0.36
3		V	1.57	0.33
4	Olympia	N04W*	2.51	0.67
5	April 13, 1949	S86E	2.51	0.70
6		V	2.51	0.23
7	Taft	S69E*	2.90	0.67
8	July 21, 1952	N21W	2.90	0.45
9		V	2.90	0.30

*Principal component

Table 5 Fuel Storage Building Analyses

ANALYSIS NUMBER	MODEL TYPE	EARTHQUAKE TIME HISTORY APPLIED*		
		MODEL DIRECTION		
		NS	EW	V
1	Horizontal	1	2	-
2	Horizontal	2	1	-
3	Vertical	-	-	3
4	Horizontal	4	5	-
5	Horizontal	5	4	-
6	Vertical	-	-	6
7	Horizontal	7	8	-
8	Horizontal	8	7	-
9	Vertical	-	-	9

*See Table 3.1 for earthquake time history designation

3.4 Question 4:

Describe the effects of this increase in free field response spectra on the floor response spectra that were used for the qualifications and/or analysis of walls, piping, mechanical and electrical equipment and justify that the walls, piping, mechanical and electrical equipment are adequately designed.

Response 4:

The methodology used in the development of the instructure response spectra for the reevaluation and design of systems and components was provided in Reference 16. The following paragraphs discuss the effects of the 10 percent exceedances of the Housner design spectra over the specified period ranges on the instructure response spectra.

Reactor Building, Administration and Control Building, Ventilation Equipment Building, and Turbine Building

The comparison of the horizontal Housner design spectra and the spectra of the design time history used in developing instructure response spectra is shown in Figure 10 for 2, 4, 7 and 10 percent critical damping values. The comparison of the vertical design time history is identical since it is taken as 2/3 of the horizontal design time history.

Table 6 shows the average difference of the spectra of the design time history and the horizontal Housner spectra in the period range from 0.07 second to 0.25 second and the vertical Housner spectra in the period range from 0.05 second to 0.15 second. The average difference values in the specified period ranges were calculated considering the values at 31 specific periods for the horizontal spectra comparisons and at 25 specific periods for the vertical spectra comparisons.

Table 6 Average Percent Envelope of Design Time History Used to Develop In Structure Response Spectra

Direction	Percent Spectral Damping	Average Percent Envelope
Horizontal	2	15.5
	4	17.9
	7	9.7
	10	8.0
Vertical	2	14.3
	4	11.1
	7	7.0
	10	5.7

As may be seen, the spectra of the design time history conservatively envelop the Housner spectra. The margins decrease for higher damping values, especialy in the vertical direction. However, the overall effects of exceedances of the Housner spectrum by up to 10% are not considered to be significant because the spectra of the design time history are within a few percent of these exceedances and because of the conservatisms discussed below for the evaluation of systems and components.

Fuel Storage Building

The response to question 3b showed that the collective spectra of the time-histories used for the development of instructure response spectra for this building conservatively enveloped the 10 percent exceedances in the Housner spectra. Therefore, the instructure response spectra for this structure will not be affected.

Reactor Auxiliary Building, Circulating Water Intake Structure, Nonstructural Slabs and Equipment Foundations at Grade.

The instructure response spectra for these structures were the Housner ground design spectra as described in Reference 16. The 10 percent exceedances in the Housner ground spectra will exceed the instructure spectra by the same percentage.

The overall effects of exceedances of the Housner spectrum by up to 10 percent on the evaluation of systems and components are not considered to be significant. This was discussed in detail in section 2. The following specific considerations are also applicable.

a) In the evaluation of electrical raceways and electrical equipment anchorages an equivalent static load method of analysis was used. For a large number of these items, the peak spectral value increased by 1.5 was selected as the seismic coefficient for the analysis. For rigid equipment the ZPA of the ground design spectrum was used. Therefore, these items, which represent the majority of items at ground level, will not be affected by 10 percent exceedances of the Housner spectrum.

b) Where modifications for piping supports are required, the final design of the supports considers a factor of 1.15 on all the loads computed. Therefore, the margin is sufficient to allow for 10 percent exceedances of the Housner Spectrum.

c) Damping values used at San Onofre Unit 1 for the evaluation of piping and equipment are conservative as discussed in the Appendix. For example, the majority of the piping at San Onofre Unit 1 is less than 12" and 2 percent critical damping was used in the evaluation. References 1 and 2 suggest that a damping value of 3 percent is more appropriate, although an even higher value could be considered as discussed in the Appendix. Assuming that the amplification due to damping of ground design motion is proportional to the square root of the damping, one obtains a margin of 1.2 when using 2 percent critical damping. This would be sufficient to allow for 10 percent exceedances of the Housner spectrum.

d) The majority of fundamental structural frequencies are not in the period intervals where the maximum exceedances are expected to occur.

4.0 CONCLUSIONS

Based on the previous discussions the following specific conclusions can be made about the seismic safety margins of structures, systems and components with respect to 10 percent exceedances of the Housner design spectra over the specified period ranges:

1. Almost all structural analyses are unaffected by the increase over the Housner spectrum. In only a limited number of cases were items identified which even have the potential to be affected by increasing the previously calculated forces by 10 percent. Since most allowable stresses have safety margins of at least 2, and sometimes 3 or more, against failure, it is concluded that this would only decrease the already large safety factors by a small amount in those few cases where the calculated stresses could exceed the allowable limits.

2. The seismic input to the majority of systems and components are the instructure response spectra which are developed using synthetic time histories which conservatively envelop the Housner spectra. The majority of fundamental structural frequencies are not in the period intervals where maximum exceedances are identified. For items using ground spectra as input, the analyses of the majority of the items incorporate conservatisms which would accommodate the exceedances.

It is concluded that the seismic safety margins in structures, systems and components are adequate, considering up to 10 percent exceedances of the horizontal Housner spectra in the period range from 0.07 second to 0.25 second and of the vertical Housner spectra in the period range from 0.05 second to 0.15 second.

5.0 REFERENCES

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2. "Recommended Revisions to Nuclear Regulatory Commission Seismic Design Criteria", Lawrence Livermore Laboratory, University of California, NUREG/CR-1161, May 1980.

3. "Development of Instrumental Response Spectra for the San Onofre Site", Woodward-Clyde Consultants, June 1982. Forwarded by letter from K. P. Baskin to D. M. Crutchfield dated June 29, 1982.

4. "Estimation of Selected Spectral Values at the San Onofre Nuclear Generating Station", Tera Corporation, June 1982. Forwarded by letter from K. P. Baskin to D. M. Crutchfield dated June 29, 1982.

5. Letter from K. P. Baskin to D. M. Crutchfield dated August, 9, 1982.

6. Enclosure to letter from K. P. Baskin (SCE) to D. M. Crutchfield (NRC) dated April 30, 1982.

7. Final Safety Analysis Report, San Onofre Nuclear Generating Station, Units 2 and 3.

8. Enclosure to letter from K. P. Baskin (SCE) to D. M. Crutchfield (NRC) dated December 8, 1981.

9. "Balance of Plant (BOP) SONGS Unit 1 Soil Structure Interaction Methodology Report" Rev. 1, July 20, 1978, Woodward-Clyde Consultants, Orange, California.

10. Enclosure to letter from R. W. Krieger (SCE) to D. M. Crutchfield (NRC) dated February 9, 1982.

11. "Balance of Plant Structures Seismic Reevaluation Criteria" San Onofre Nuclear Generating Station, Unit 1, February 17, 1981.

12. "San Onofre Nuclear Generating Station, Unit 1, NRC Docket 50-206, Seismic Reevaluation and Modification", April 29, 1977.

13. Computech Engineering Services, Inc., "San Onofre Nuclear Generating Station Unit 1, Seismic Evaluation of Reinforced Concrete Masonry Walls, Volume 3: Masonry Wall Evaluation", forwarded by letter from K. P. Baskin to D. M. Crutchfield dated January 11, 1982.

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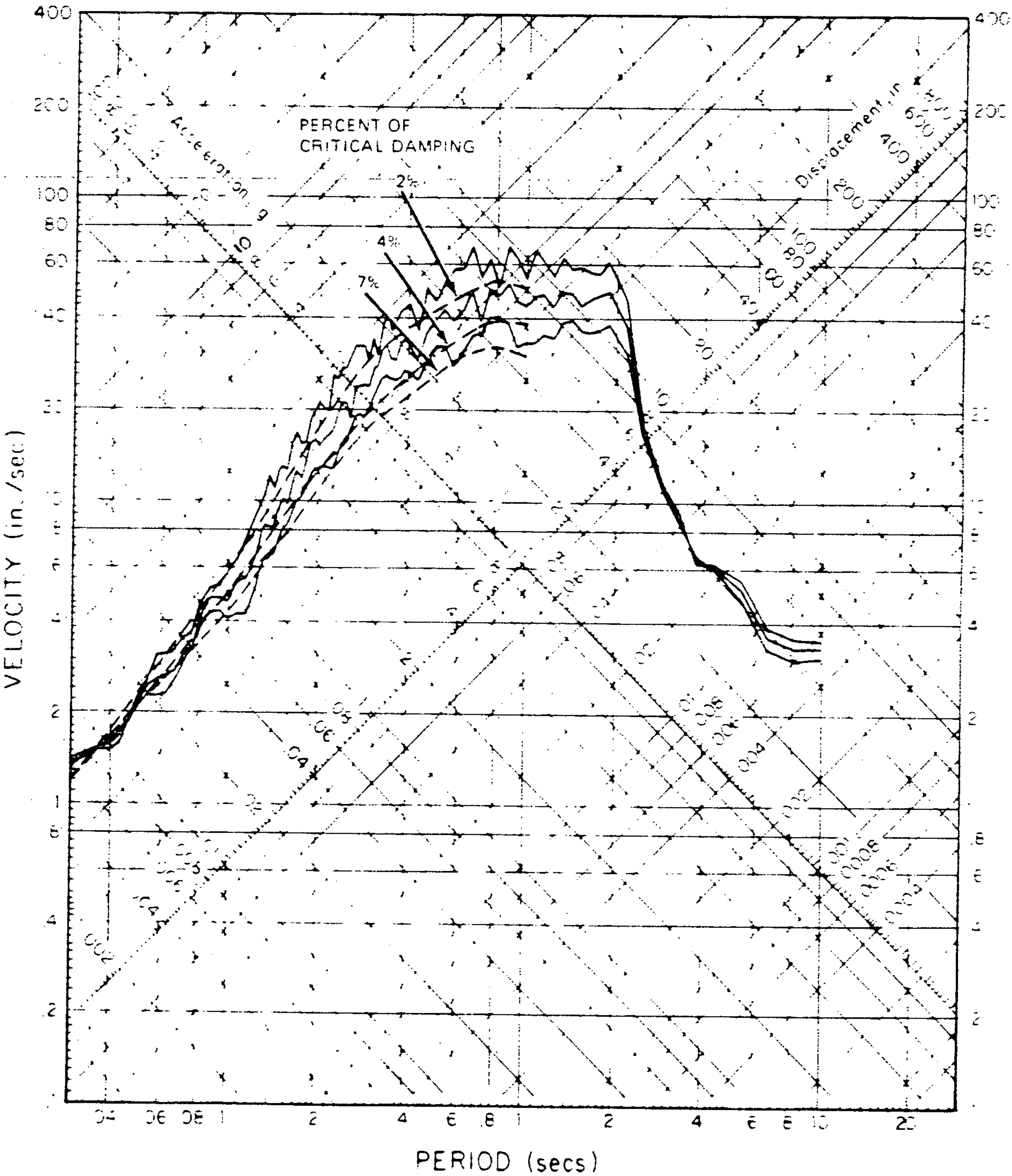

FIGURE 1

GROUND-MOTION SPECTRA, HORIZONTAL TRACE A
(MAXIMUM ACCELERATION 0.67g)

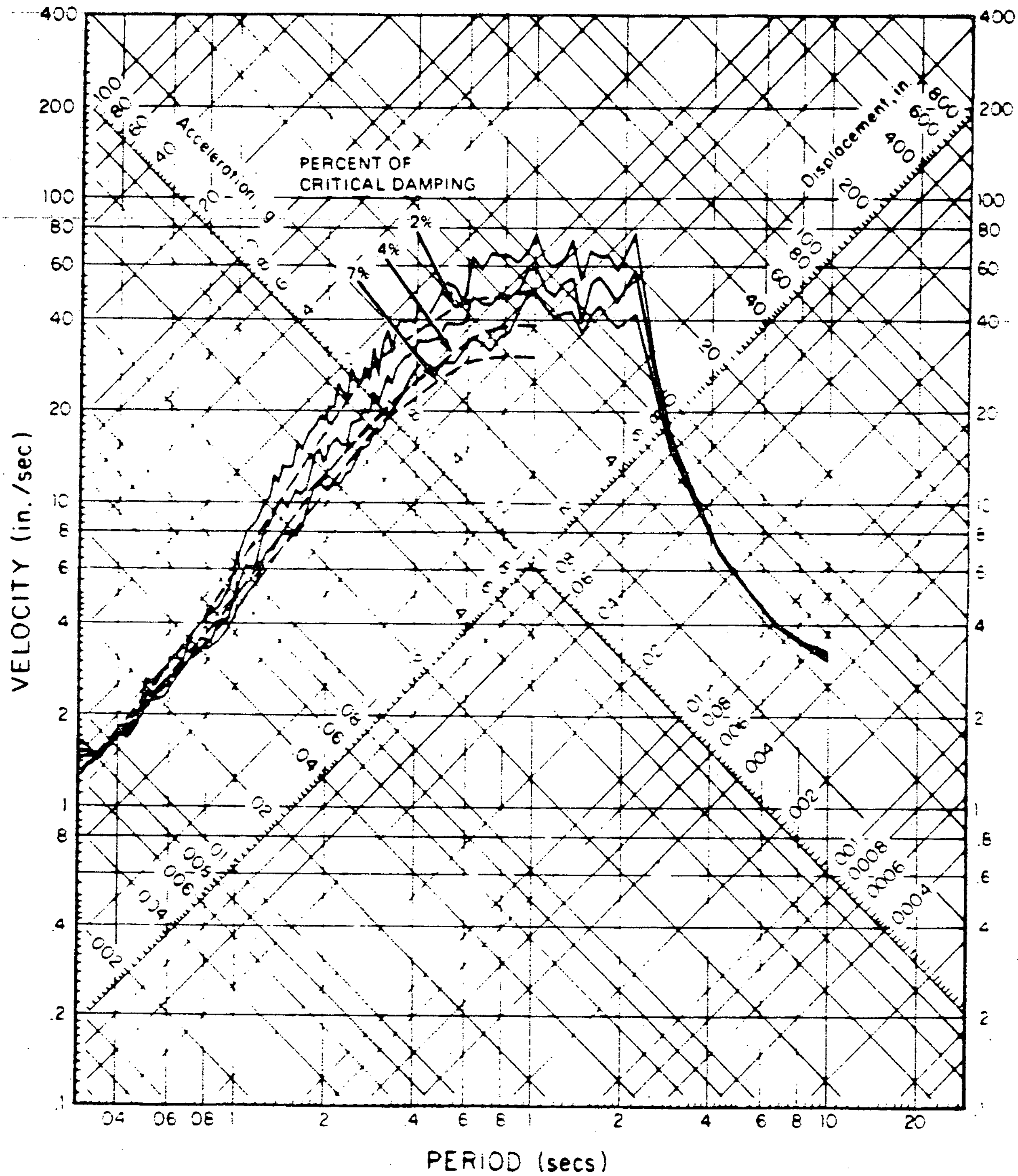

FIGURE 2-2

GROUND-MOTION SPECTRA, HORIZONTAL TRACE B
(MAXIMUM ACCELERATION 0.67g)

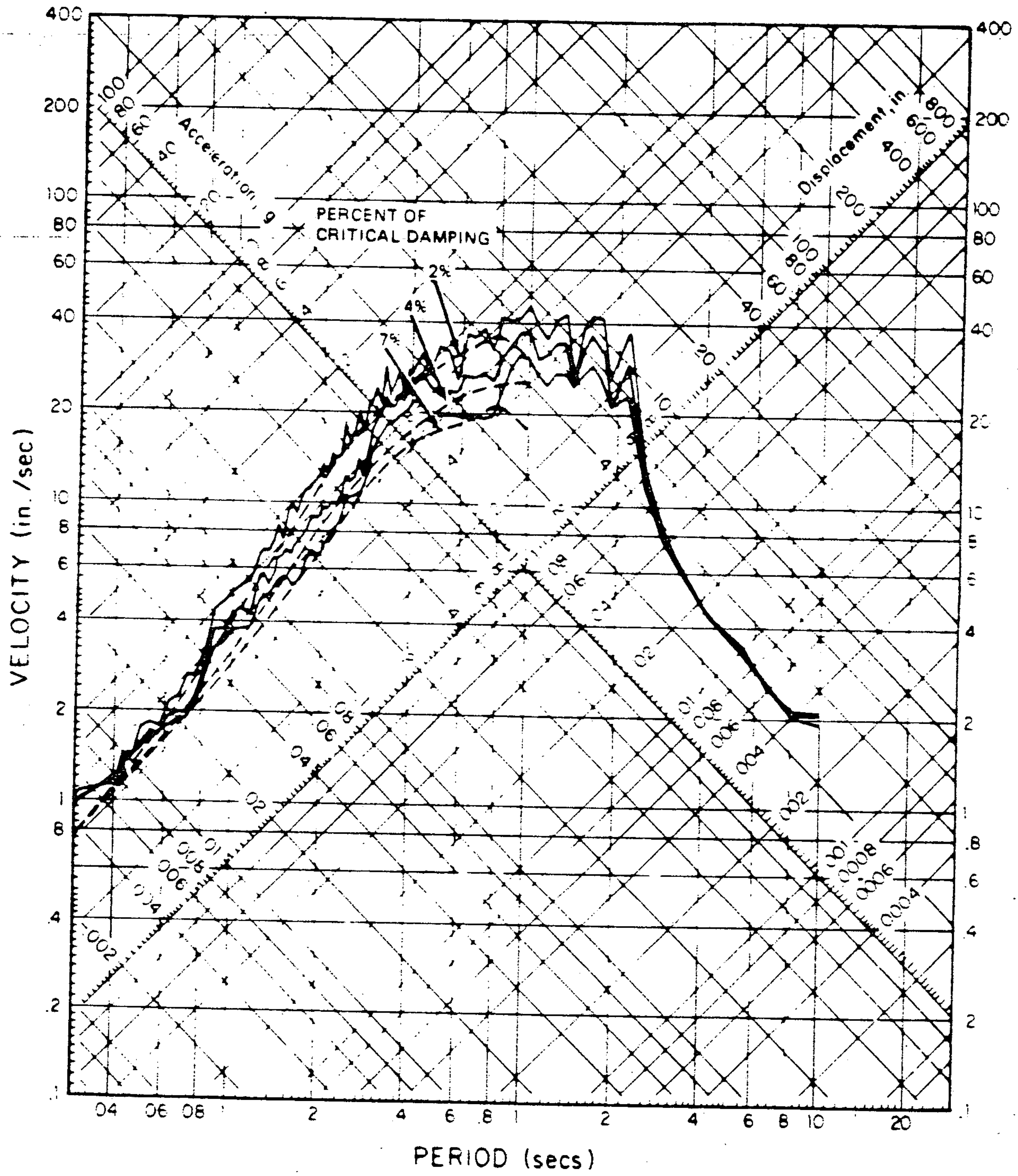

FIGURE 3

GROUND-MOTION SPECTRA, VERTICAL
(MAXIMUM ACCELERATION 0.44g)

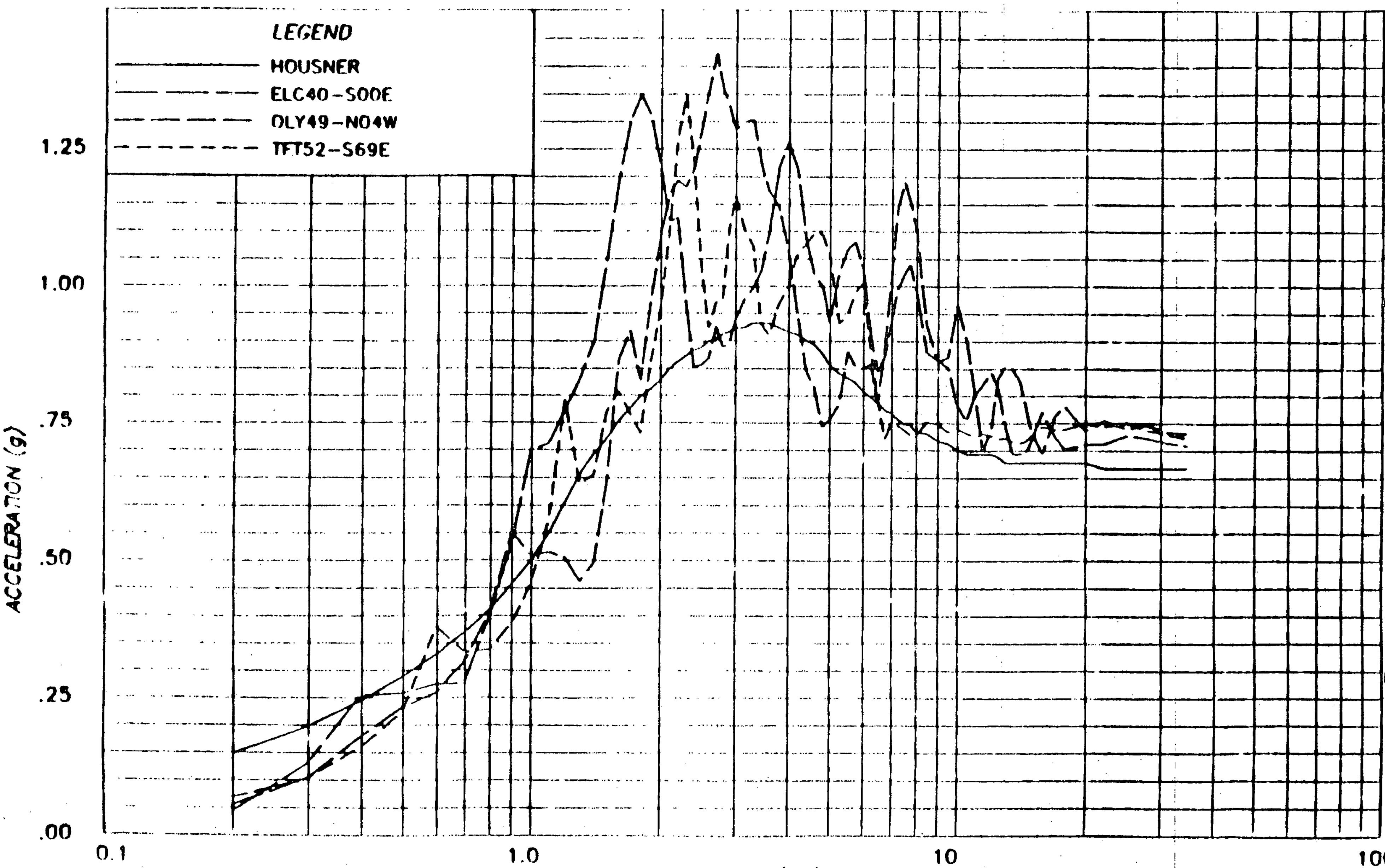

FIGURE 4 COMPARISON OF SCALED EARTHQUAKES WITH HOUSNER

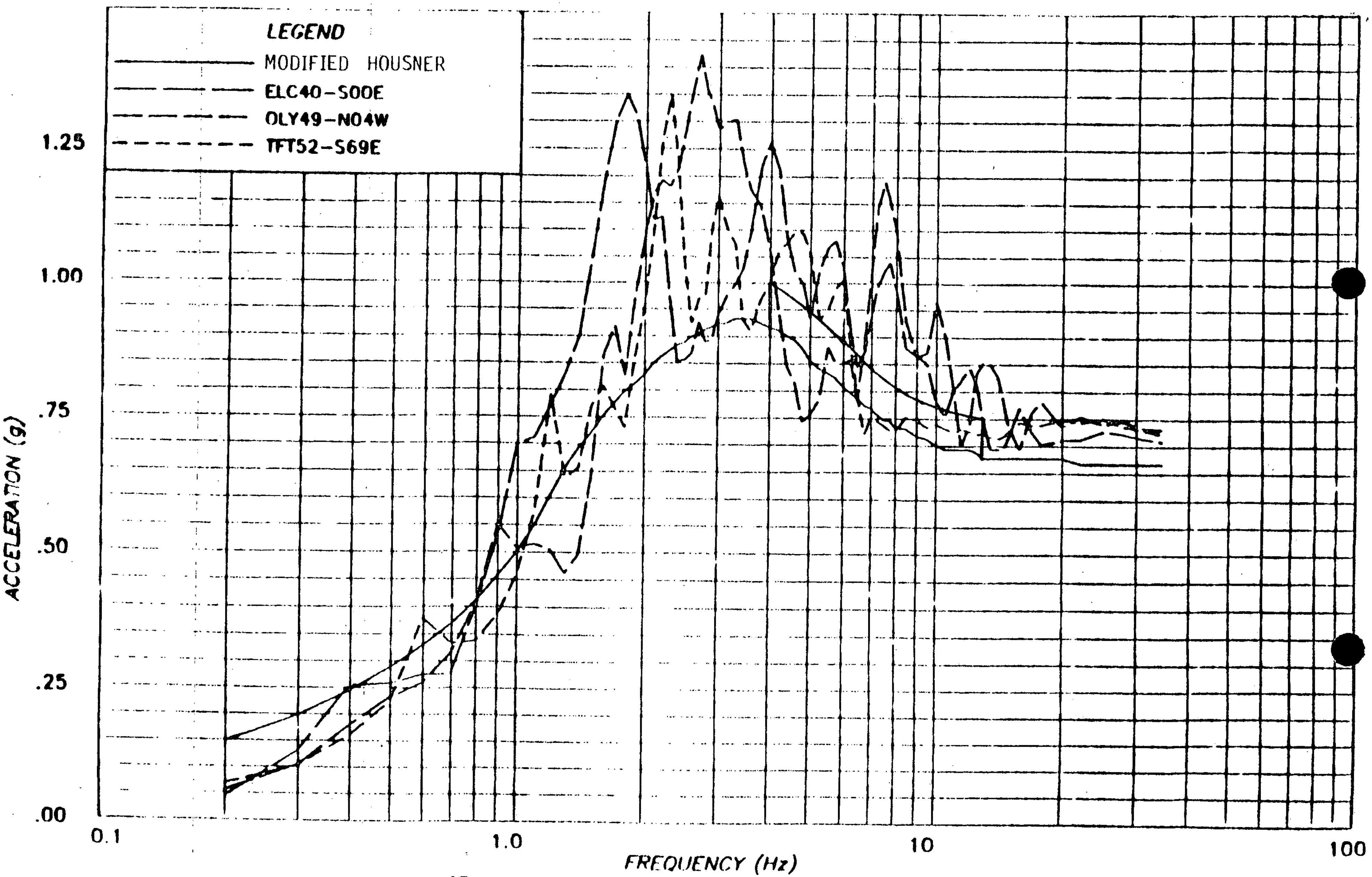

FIGURE 5 COMPARISON OF SCALED EARTHQUAKES WITH MODIFIED HOUSNER

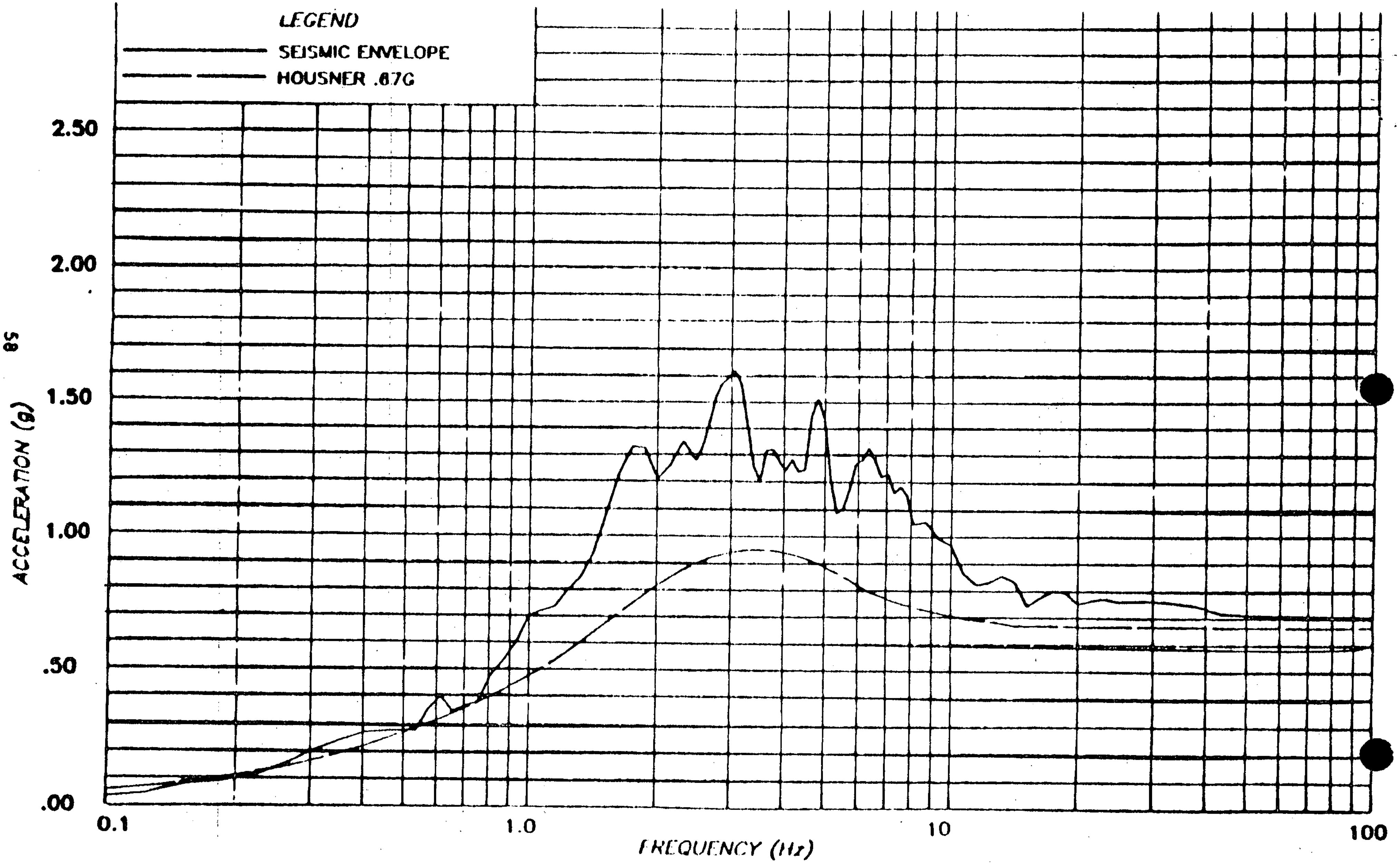

FIGURE 6 HORIZONTAL COMPONENT 7% ENVELOPE SPECTRUM FOR FUEL STORAGE BUILDING

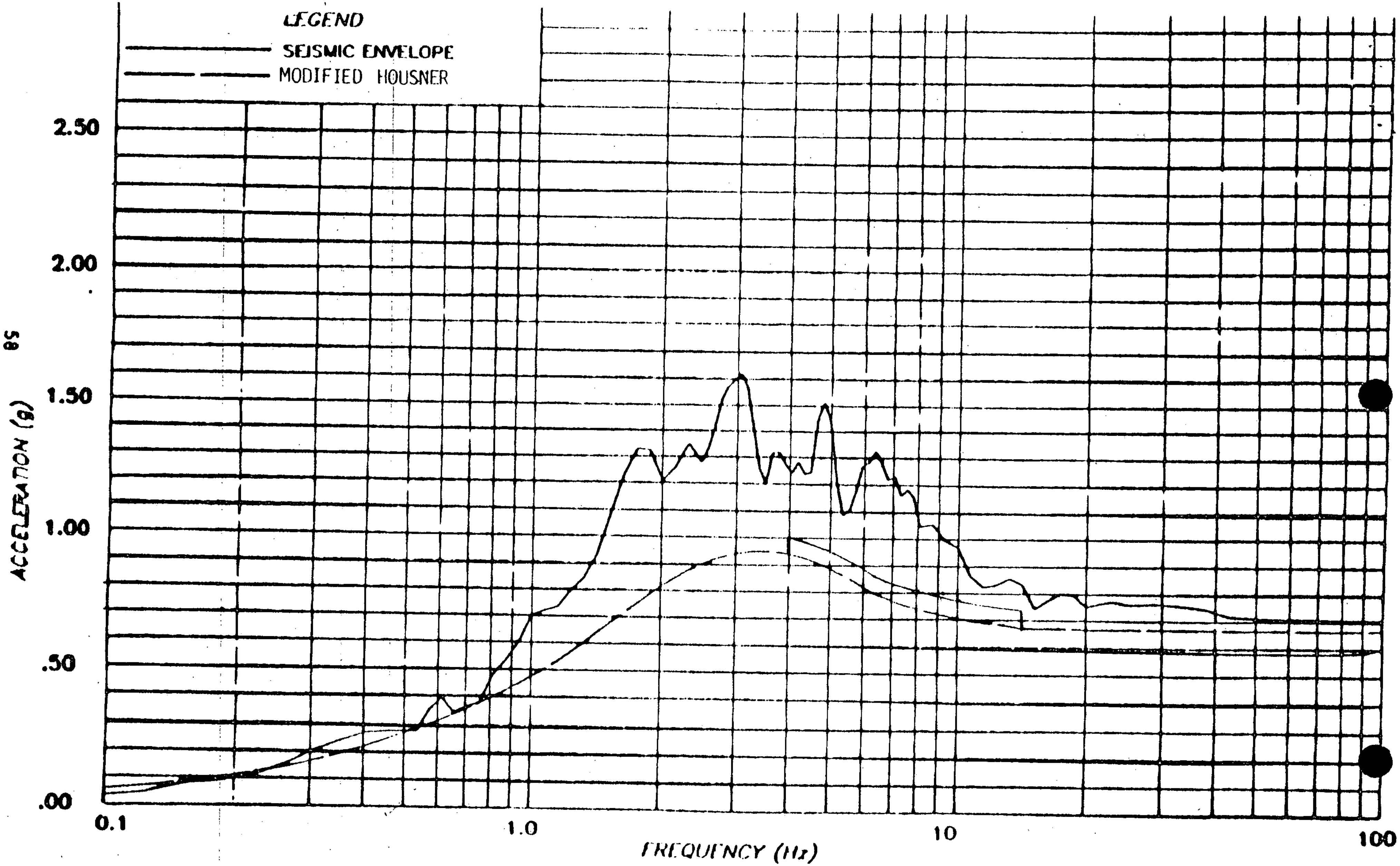

FIGURE 7 HORIZONTAL COMPONENT 7% ENVELOPE SPECTRUM FOR FUEL STORAGE BUILDING

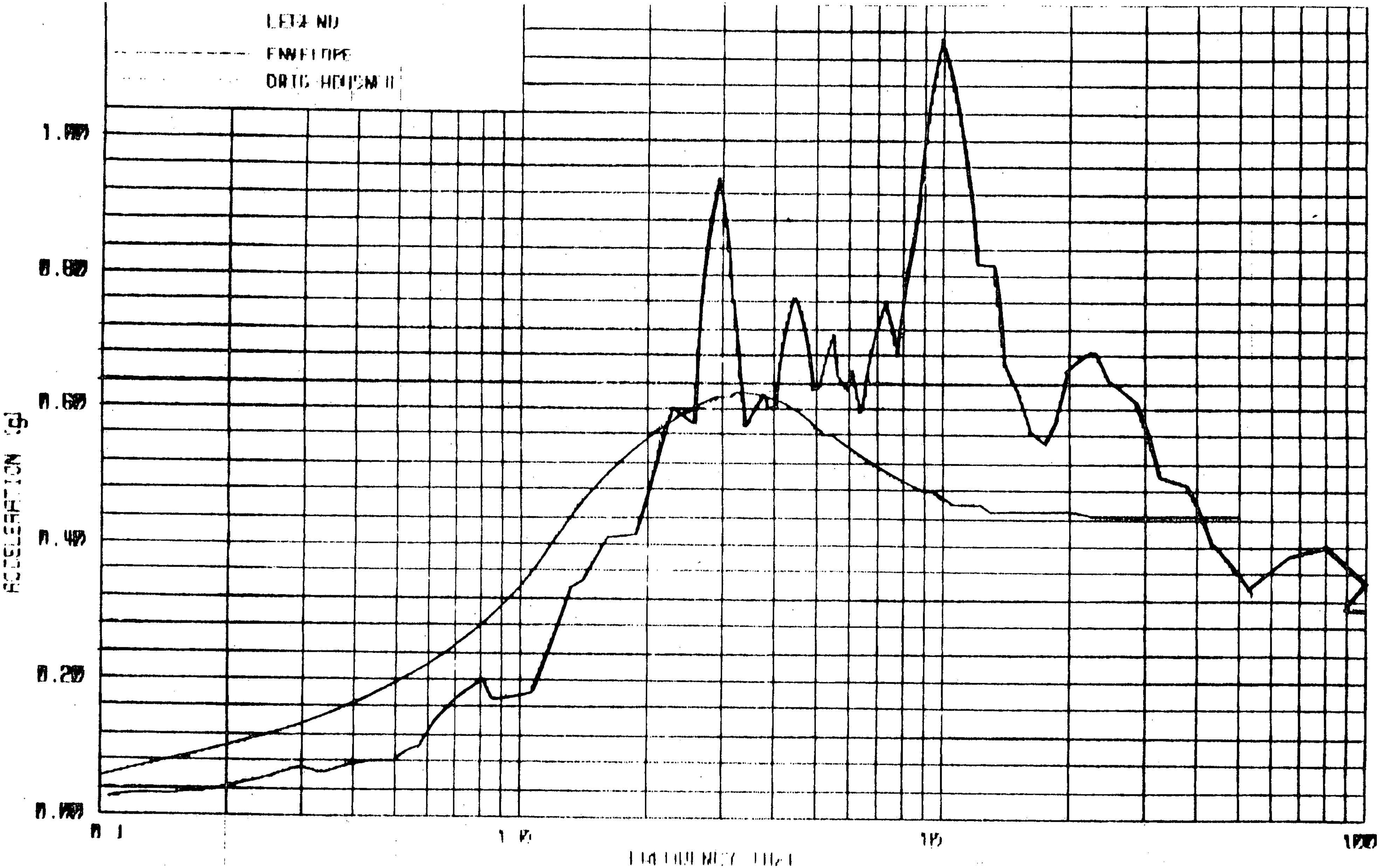

FIGURE 8 VERTICAL COMPONENT 7% ENVELOPE SPECTRUM
FOR FUEL STORAGE BUILDING

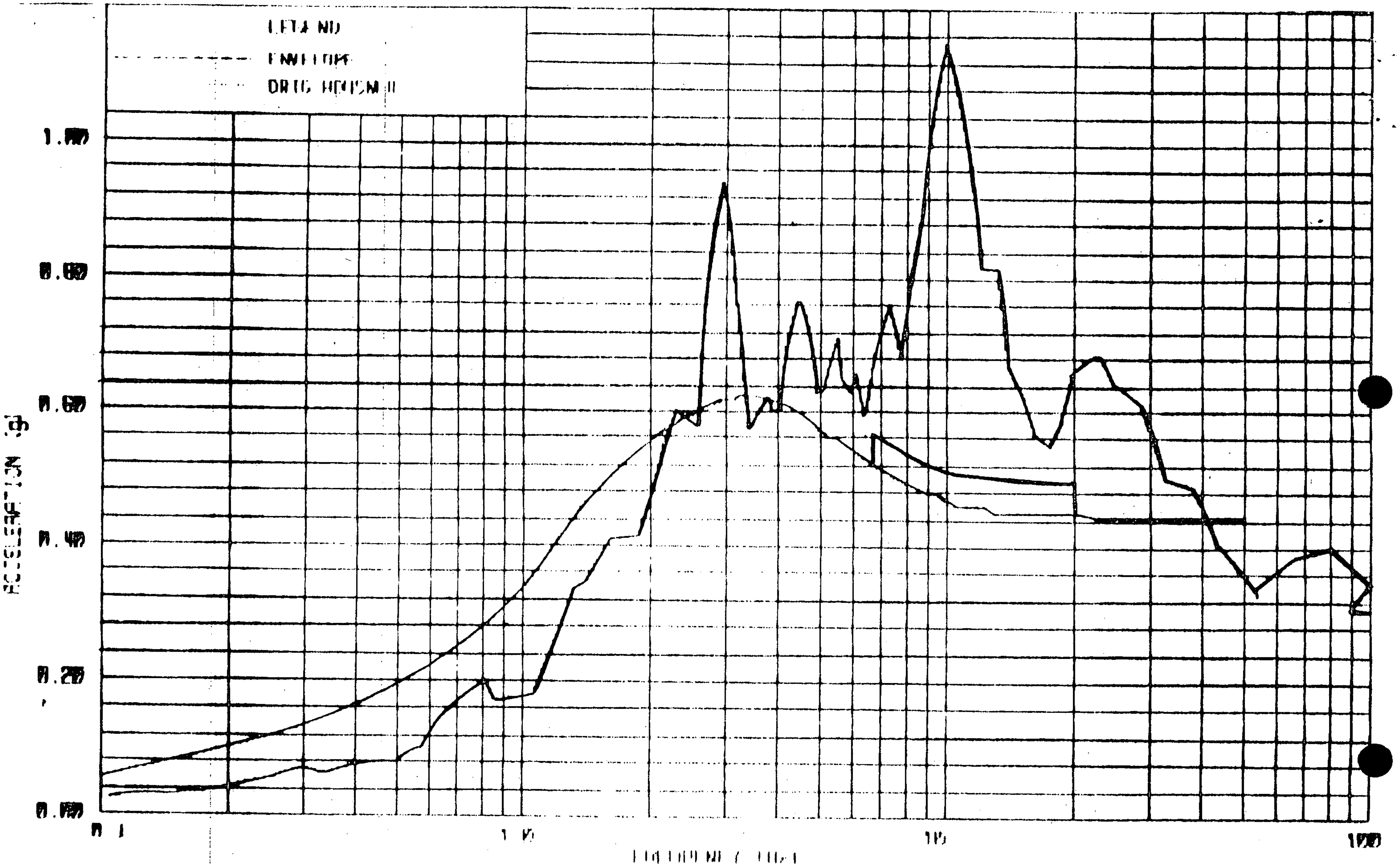

FIGURE 9 VERTICAL COMPONENT 7% ENVELOPE SPECTRUM
FOR FUEL STORAGE BUILDING

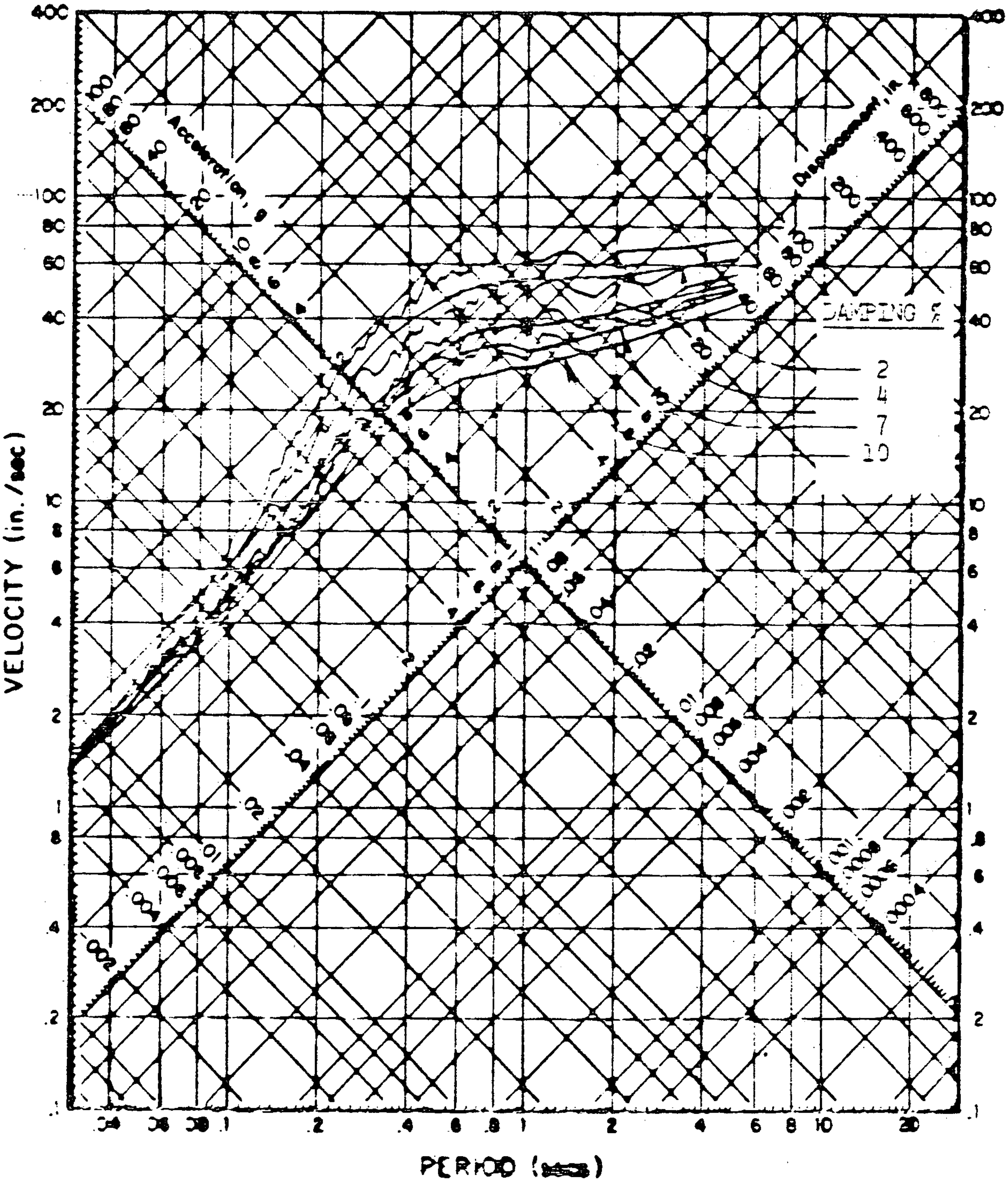

FIGURE 10
DESIGN TIME HISTORY RESPONE
SPECTRUM

APPENDIX

RATIONALE FOR THE SPECIFICATION OF STRUCTURAL DAMPING FOR SONGS 1 SEISMIC REEVALUATION

RATIONALE FOR THE SPECIFICATION OF STRUCTURAL DAMPING FOR SONGS I SEISMIC REEVALUATION

I. INTRODUCTION

Nonlinearities below the threshold of overall elastic structural response have been found to dissipate significant energy. Energy absorption below elastic limits is represented through structural damping. For convenience, structural damping is typically approximated assuming it is viscous/velocity dependent and is expressed as a percentage of critical damping.

Structural damping represents a complex physical process that depends upon the properties of the material, the magnitude of internal and applied stress, the stress history and stress frequency. The geometric configuration, boundary conditions, joint slippage, gaps, and friction play an important role.

The appropriate specification of structural damping in the seismic evaluation of nuclear power plant structures, systems, and components is an important consideration because it is a determining factor in how well linear elastic dynamic analysis can approximate experimental results and observations. Historically, structural damping has been specified with conservatism. This has been in part due to a lack of data and also an attempt to deal with the dispersion data.

Current regulatory guidance embodied in Regulatory Guide 1.61 present damping values which should be considered conservative lower bounds. These damping values are suitable for use in the design of new facilities in the absence of real data. Over the years, more data has become available both experimentally and through observations during actual earthquakes. Accordingly, many earthquake engineers have recommended the use of higher structural damping values to more accurately represent the response behavior of structues.

The following discussion focuses on a summary of existing structural damping data for nuclear facilities and components, an evaluation of the data, recommendations by experts, a rationale for the specification of damping values for seismic reevaluation for SONGS I, and an estimate of margins associated with a conservative specification of structural damping values.

II. SUMMARY AND DISCUSSION OF AVAILABLE DATA

The initial vibration tests of nuclear facility structures, systems, and components were conducted in the mid-1960s. These tests, along with limited data taken during actual earthquakes, have provided valuable insight into parameters such as structural damping which cannot be directly calculated. The vast portion of available data has been measured at relatively low response levels ($\sim$0.1 x Yield for Components and Piping, 0.25 x Yield For Concrete Structures). In view of the fact that structural damping mechanisms tend to increase in magnitude with increasing stress levels, damping anticipated at stress levels corresponding to that of the design earthquake are generally unknown because structural elements have not been stressed to this degree. Several investigators have suggested means of extrapolating the low level data to higher levels. While these estimates are largely unconfirmed, they are supported by observations of structural response during actual earthquakes. It follows that direct utilization of available data is generally conservative for the seismic response modeling of nuclear power facilities.

A search of available nuclear facility experimental and observed data was performed. This data was collected at the facilities listed in Table I. A summary comparison of this data with current regulatory requirements and various recommendations by the technical community is presented in Table 2.

From these data, it is evident that recent recommendations made by Newmark and Hall in NUREG/CR-0098 and experts providing input to the NRC's Task Action Plan A-40 in NUREG/CR-1161 are conservatively based. Notwithstanding the fact that these experimentally measured data are taken at low response levels, a significant portion meets or exceeds the expert's recommendations. Of particular interest are measured data that have been normalized to a 0.9 yield stress level which corresponds to that expected during a design earthquake

(Item 4, Table 2). This estimate is believed to be more realistic for higher response levels and would more accurately reflect the true seismic response during the design earthquake.

The NUREG/CR-0098 and NUREG/CR-1161 recommendations tabulated under Item 2, Table 2, are considered to be conservative median damping values. NUREG/CR-1706, Subsystem Response Review, characterizes the associated logarithmic standard deviation to be 0.4. This corresponds to a 16% and 84% exceedance range of 1.49 and 0.67 times the median, respectively. Accordingly, the one standard deviation ranges expressed in terms of percent critical damping would be:

piping	2-4.5%
mechanical components	4.7-10%
concrete structures	6.7-15%

The higher end of the above ranges more closely agrees with the estimates presented in Item 4, Table 2, with the exception of piping. It is expected that in addition to loading magnitude and history, piping damping estimates would be extremely sensitive to parameters such as geometry, support configuration, flooding, and insulation. Therefore, while the 12.7% estimate of Item 4, Table 2, may be valid for the sample, in the absence of site specific information its use may be slightly unconservative.

Item 14 in Table 2 is worth noting, in that it reflects data for SONGS 1 recorded from both historical earthquakes (San Fernando and Lytle Creek) and tests, typically at very low response levels. For the higher levels of response associated with the design earthquake, these values are expected to increase to levels consistent with those suggested in the following section.

Vibration tests of large bore piping at the Heissdampfreaktor (HDR) suggest that a damping of 7% for piping is required to obtain agreement between analytical predictions and experimental data. Data collected at Kernkraftwerk/Phillippsberg I and Fugen further support piping damping in the range of 6 to 9% for both large and small bore piping.

III. BASES FOR THE SPECIFICATION OF STRUCTURAL DAMPING VALUES FOR REEVALUATION OF SONGS I

The philosophy of the Systematic Evaluation Program is based upon application of a median centered, yet conservative methodology for the evaluation of many design basis events (The seismic event is considered a DBE). The intent is to conduct a more realistic evaluation to represent and explain response behavior without stacking up conservatisms at each stage in the process. The approach recognizes the conservatism associated with current licensing criteria and practical considerations for evaluating and possibly backfitting older facilities. Decisions relative to required levels of conservatism are made during an integrated assessment of all DBEs at the end of the review. Accordingly, the NRC's SEP seismic review process has attempted to more realistically quantify unclaimed factors such as structural damping which contribute to seismic resistance capability. Clearly, the mode has been to consider median centered parameters in the review process rather than bounding values which are common in the review of new plants.

The NRC has adopted NUREG/CR-0098 criteria for the SEP seismic evaluation. The damping criteria of this NUREG is supported by recommendations of NRC consultants participating in TAP A-40 (NUREG/CR-1161). Conservative, median damping values have been considered in the ongoing SEP reviews corresponding to the values tabulated in Item 2, Table 2. Notwithstanding this, the SONGS I seismic reevaluation program has considered damping values which correspond to the even more conservative values specified in Regulatory Guide 1.61 (Item I, Table I). It follows that significant margin exists between the NUREG/CR-0098 and Regulatory Guide 1.61 values. Even further margin can be justified in consideration of the data presented in Section II.

During a large seismic event, the stress in structural elements will vary throughout the plant. Higher stressed elements will dissipate relatively more energy. On the average, this energy will approach a level that can best be represented by a "median" damping value. In view of the higher seismic setting at the SONGS site, it can reasonably be assumed that a larger portion of structural elements will see higher stress levels. Accordingly, it may be expected that damping would approach levels considered higher than a median level, approaching and possibly exceeding the values presented in Item 4, Table 2.

It is believed that the NUREG/CR-0098 damping values (Item 2, Table 2) are conservative median values and that the one standard deviation values may more closely approximate a "true" median. Accordingly, in consideration of the above points and the previously discussed piping data, it is suggested that the following damping values used in conjunction with an appropriate analysis may more accurately represent and predict the seismic response of SONGS I during a major earthquake:

piping	7%
mechanical components	10%
concrete structures	15%

IV. SUMMARY

A review of existing structural damping data for nuclear facilities and components indicates that significant margins exist between the damping values used in the SONGS I reevaluation and those which would be expected to appropriately represent the seismic response of SONGS I during a major earthquake. While the exact margins attributable to damping conservatisms are a function of the specific structures, systems, and components of interest, the general use of Regulatory Guide 1.61 damping values for the seismic reevaluation of SONGS I represents a significant structural margin. Accordingly, any increases of loading could be offset by this factor as well as many others that have not been discussed, such as ductility and modeling considerations.

TABLE I

NUCLEAR FACILITIES FOR WHICH STRUCTURAL DAMPING DATA HAVE BEEN COLLECTED

Enrico Fermi
Indian Point I and 2
Madras Atomic Power Project
San Onofre Unit I
Oak Ridge Experimental Gas-Cooled Reactor
Carolinas-Virginia Tube Reactor
Rajasthan Power Project
Diablo Canyon I
Tsuruga Nuclear Power Plant
Heissdampfreaktor (HDR)
Kernkraftwerk
Fukashima I
Shimane
Fugen
Hamaoka
Humboldt Bay
Enel IV
Tokai
UCLA Reactor
Kuosheng

TABLE 2

COMPARISON OF AVAILABLE NUCLEAR FACILITY EXPERIMENTALLY MEASURED DAMPING WITH REGULATORY REQUIREMENTS AND RECOMMENDATIONS

Data, Requirement, or Recommendation	Best Estimate or Median Damping Values (% Critical): Piping > 12"Ø	Piping < 12"Ø	Mechanical Components	Concrete Structures
1. R.G. 1.61[1] for stress levels at:				
a. ~ 0.5 yield (OBE)	2	1	2	4
b. ~ 0.9 yield (SSE)	3	2	4	7
2. NUREGS/CR-0098[2], CR-1161[3] for stress levels at:				
a. ~ 0.5 yield	2	2	3	5
b. at or just below yield	3	3	7	10
3. Average of measured data for stress levels at or less than 0.1 x yield for components and piping and 0.25 x yield for concrete[4] (n = sample size)	3.4 (n=4)	6.2 (n=2)	3.8 (n=35)	5.2 (n=31)
4. Measured data from (3) normalized to 0.9 yield stress[4]	12.7	--	7.7	18.7
5. Heissdampfreaktor (HDR)				
a. measured[5,6,11,12]	≤ 5.5	--	≤ 2.0 (Reactor Vessel)	≤ 7.1 (0.06g)
b. inferred by analysis[7]	7	--		--
6. Laboratory tests of small bore piping for stress levels at:				
a. ~ 0.5 yield	--	1(½"OD) 1-2(2"OD)	-	-
b. ~ 0.9 yield		12(½"OD) 2-3½(2"OD)	-	-
7. Diablo Canyon[4,9]	--	3-15	½-15	-
8. Indian Point 1&2[4,10] (Stress ~ 0.2 yield)	1-5	2	1-5	--

TABLE 2
(continued)

Data, Requirement, or Recommendation	Best Estimate or Median Damping Values (% Critical) Piping >12"Ø	<12"Ø	Mechanical Components	Concrete Structures
9. Kernkraftwerk/ Phillipsberg I[13]	--	6-9	--	--
10. Fukushima[14]	--	--	--	5-8(10^{-4}g)
11. Fugen[15]	6-8 (0.1g)	≤ 4.5 (0.02g)	--	--
12. Hamaoka[16]				∿ 20(10^{-3}g) (Str.-Str. Int.)
13. Tokai 2[19]				15-20 (.01g) (Soil-Str. Int.)
14. SONGS I[17,18,20,21]	1.5-4.0 (10^{-2}-10^{-1}g)	--	3-9* 1-2.5 (10^{-4}-10^{-3}g)	6-20 (Soil-Str. Int.)
15. Kuosheng Nuclear Power Station[22]	--	--	1.5-9	--

*Based on data recorded from actual earthquakes.

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