

UNITED STATES OF AMERICA  
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING APPEAL BOARD

In the Matter of )  
PACIFIC GAS AND ELECTRIC COMPANY ) Docket Nos. 50-275 O.L.  
(Diablo Canyon Nuclear Power Plant ) 50-323 O.L.  
Unit Nos. 1 and 2 )

TESTIMONY OF PAO-TSIN KUO

Q. By whom are you employed, and describe the work you perform.

A. I am employed as a structural engineer in the Structural Engineering Branch, Division of Engineering, Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission. My work includes review of commercial nuclear power plants from a structural engineering perspective including the analysis of structural systems, static and dynamic analysis, design, and testing of safety-related structures. My work also includes the review and evaluation of the criteria developed and used for protection of nuclear power plants against the adverse effects associated with natural environmental loads and postulated failures of fluid systems for nuclear facilities.

Q. Would you detail your professional qualifications?

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A. A copy of my professional qualifications is attached. I also testified at the Atomic Safety and Licensing Board proceedings, and a copy of my professional qualifications are bound into the transcript following Tr. 8697. I was also a participant in the "Joint Affidavit of Robert T. Rothman and Pao-Tsin Kuo" dated May 5, 1980 attached to the May 5, 1980 "NRC Staff Response to Joint Intervenors Motion to Reopen" submitted in this proceeding. The purpose of that affidavit was to provide our evaluation at that time of the preliminary seismological data from the Imperial Valley Earthquake of October 15, 1978 and its implication on the adequacy of the seismic design criteria for the Diablo Canyon Nuclear Power Plant (DCNPP). That analysis was based on the preliminary data then available from the Imperial Valley Earthquake. It was my view then based on the preliminary data from the Imperial Valley Earthquake, that the data should not cause any concerns about the seismic design criteria used for the Diablo Canyon Nuclear Power Plant (DCNPP). Further analysis of the data has not changed my position. The Imperial Valley Earthquake does not provide a basis for me changing my conclusion that the seismic design criteria used for the reevaluation of DCNPP are adequate for engineering design purposes.

Q. How did you develop your testimony?

A. My testimony in response to the Appeal Board's questions was developed in cooperation and consultation with Dr. Robert Rothman, and under the direct supervision of Mr. James Knight, Assistant Director for Components and Structures Engineering, USNRC.

Q. Would you describe the scope of your testimony?

A. Yes. My testimony is directed specifically toward the structural engineering aspects of the questions raised by the Atomic Safety and Licensing Appeal Board (Appeal Board) in the Appendix to Pacific Gas and Electric Company (Diablo Canyon Nuclear Power Plant, Units 1 and 2), ALAB-598, Slip Op. (June 24, 1980).

Q. Which questions raised by the Appeal Board does your testimony address?

A. My testimony is directed toward questions 2, 4, 5, and 6. I also want to point out that Dr. Nathan M. Newmark, who acts as a consultant to the Nuclear Regulatory Commission Staff in structural engineering matters, is submitting separate testimony addressing the same Appeal Board's questions.

Q. Are there any significant difference in conclusions between Dr. Newmark's testimony and your testimony?

A. No. The conclusions arrived at in both testimonies are essentially the same although the bases used to draw the conclusions may be slightly different. My assessment shows that even in light of the IV-79 data the Diablo Canyon seismic design criteria reviewed during the Atomic Safety and Licensing Board hearings are adequate. The data generated from the recent Imperial Valley Earthquake of 1979 do not adversely affect the adequacy of the seismic design criteria used for the DCNPP.

Q. Do you have specific response to the Appeal Board's questions?

A. Yes, I do. They are as follows.

Q. Appeal Board Question 2 states:

2. Response spectra have been developed from the near field (1 to 11 km) ground motion records produced by IV-79. The records contain horizontal peak acceleration values in the range of 0.81g to about 0.2g. The applicant calculated a mean peak acceleration of 0.36 for IV-79 at the 5.8 km site-to-fault distance that characterizes the Diablo Canyon site (Applicant's Brief). Despite the fact that the IV-79 peak acceleration values are generally lower than the 1.15g peak acceleration or 0.75g zero-period acceleration used as the design basis for the Diablo Canyon plant (resulting from a postulated 7.5M event on the Hosgri fault), there are instances(although only those from the El Centro Arrays are significant) for which the IV-79 horizontal responses exceed the Newmark Design Response Spectrum for Diablo Canyon. (See Staff brief at p. 9; Brune affidavit, Attachments A and B.) In view of this, the parties should discuss whether the Newmark Spectrum is an appropriate and sufficiently conservative representation of the 7.5M event at Hosgri.35

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35/ In other words, if the various IV-79 near-field response spectra were used to generate a smoothed, average response spectrum for a zero-period acceleration appropriate to that event (in accordance with techniques explained in Blume's testimony fol. Tr. 6099 at page 6 and pages 39 and 40), and if this spectrum were scaled to a 0.75g zero-period acceleration, would the resulting response spectrum be bounded by the Newmark Spectrum for Diablo Canyon?

Q. Before you answer the questions, are there any clarifications you wish to make with respect to the question and footnote 35 to the question.

A. Yes. I did not perform the analysis requested by footnote 35 to question 2. I did not do this analysis because (1) I do not have the data available to complete such an analysis in the time required, and (2) I believe there is an equally convincing way to demonstrate that the Newmark Spectrum for DCNPP is appropriate and sufficiently conservative.

Q. Would you please explain?

A. Attachment 1 is a plot of an envelope of upper and lower bounds of all horizontal response spectra for 5% damping generated from the IV-79 motions recorded within 11 Kilometers of the fault. Plotted in the same graph is also a Newmark horizontal design spectrum for 5% damping used for the Diablo Canyon seismic reanalysis.

It can be seen that for periods in the range of interest (i.e., lower than 0.5 seconds), the Newmark design spectrum is for the most part above the upper bound envelope of the IV-79 data. For a few places where the Newmark design spectrum falls below the upper bound envelope, the differences are minor. Should a smoothed, average response spectrum be generated from the IV-79 data for a mean zero period acceleration scaled up to 0.75g as suggested on p. 22 of the ALAB-598 decision, in my opinion it would be bounded by the Newmark design spectrum for Diablo Canyon over the frequency range of interest (i.e., above 2 Hz for DCNPP). This is because the amplification factors exhibited in the

IV-79 data do not appear to be greater than those used in the Newmark design spectrum. Therefore, the few small exceedances shown in Attachment 1 will not be heavily weighted if a statistical averaging process were applied to the entire IV-79 data set.

Attachment 2 is a plot of the vertical response spectrum at El Centro Array 6 Station and the upper and lower bounds of all the remaining vertical response spectra for 5% damping generated from the IV-79 motions recorded within 11 kilometers of the fault. Plotted in the same graph is also a Newmark vertical design spectrum for 5% damping used for Diablo Canyon seismic reanalysis.

The same type of trends explained above for the horizontal response spectra can also be said for the vertical response spectra. Although it is seen that the vertical spectrum at the El Centro Array 6 station is considerably above the Newmark vertical spectrum, because of the peculiar geological environment at that station as explained in Dr. Rothman's testimony, this spectrum is considered nonrepresentative of the IV-79 data in general. More discussions on the vertical response spectra are given in my response to the Board's Question 4.

Furthermore, I am of the opinion that there are inherent conservatisms (e.g., elastic design, conservative loads and load combinations) in the nuclear design practice which are enough to alleviate any concerns caused by these occasional exceedances over small ranges of frequency.

It is also worth noting that Regulatory Guide 1.60 Design Spectra are not intended to be statistical upper bounds. They are instead design spectra of mean plus one standard deviation values. Therefore, there are a few spectral values in the statistical data used which actually exceed the Regulatory Guide 1.60 Design Spectra.

For the above reasons, my opinion is that, even in light of the IV-79 data, the Newmark design spectra for Diablo Canyon are appropriate and sufficiently conservative.

Q. Appeal Board Question 4 states:

The magnitudes of vertical and horizontal acceleration values measured at IV-79 are generally comparable. (Mean values calculated at a distance of 5.8 km from the fault are virtually identical.)<sup>36/</sup> The response spectra developed for vertical motion within 11 km of the Imperial Fault during IV-79 appear to show generally equivalent values of vertical and horizontal response for periods less than about 0.2 seconds (i.e., frequencies in excess of 5 cps).<sup>37/</sup> Finally, in some instances the higher frequency portions of the IV-79 response spectra for vertical motion exceed comparable portions of the Diablo Canyon Design Response Spectrum.<sup>38/</sup>

Observations made of the IV-79 data and response spectra appear to be consistent with the criteria set forth in NRC Regulatory Guide 1.60. These require that vertical accelerations in the higher frequency range be equal to horizontal accelerations. As the guide states:

It should be noted that the vertical Design Response Spectra are 2/3 those of the horizontal Design Response Spectra for frequencies less than 0.25; for frequencies higher than 3.5 they are the same, while the ratio varies between 2/3 and 1 for frequencies between 0.25 and 3.5.<sup>39/</sup>

The references to vertical motion made in the Diablo Canyon record, however, indicate that a 2/3 ratio between vertical and horizontal

motion was apparently utilized at all frequencies.<sup>40/</sup> The parties should address this apparent inconsistency and explain it, if possible. Should there be substantive and relevant analyses suggesting that vertical motion records do not reflect the true vertical motion, these should be provided.<sup>41/</sup> [footnotes deleted]

Q. Is it correct that Regulatory Guide 1.60 specifies that vertical accelerations in the higher frequency range be equal to horizontal accelerations?

A. Yes. That is correct.

Q. Then would you explain how the staff's position on vertical motion adopted for Diablo Canyon of 2/3rds the horizontal acceleration value is consistent with the established staff position?

A. The position adopted for Diablo Canyon is not inconsistent with the staff position. But the overall staff position was changed after Regulatory Guide 1.60 was issued (and revised in December 1973). After Regulatory Guide 1.60 was issued, the staff had contracted with N.M. Newmark Consulting Engineering Services to perform additional statistical studies of recorded earthquake motions. The final report resulting from this contract was entitled "Statistical Studies of Vertical and Horizontal Earthquake Spectra" and was issued in January 1976 by NRC as Report No. NUREG-003.

One of the conclusions and recommendations of this report was that the response spectra for vertical motions can be taken as 2/3rds of the response spectra for horizontal motions over the entire frequency range for sites in the Western United States. This finding was adopted as the branch position on July 22, 1976. Attachment 3 is a copy of the memorandum by the Branch Chief reflecting the branch position. The memorandum indicates that "we will allow applicants the option of taking the vertical design response spectrum as 2/3rds of the horizontal response spectrum over the entire range of frequencies in the Western United States only. For other locations, the vertical response spectra will be the same as given in Regulatory Guide 1.60".

The basis for the branch position was the extensive study by Newmark involving a large statistical population of the earthquake records available at the time of the study.

Q. Are there any substantive and relevant analyses suggesting that vertical motion records do not reflect the true vertical motion?

A. Yes. With regard to the records of the observed vertical motions, Newmark (1973)<sup>1/</sup> and Bolt and Hansen (1977)<sup>2/</sup> demonstrated in their papers that an upthrow of objects could physically occur during earthquakes even if the vertical ground motions did not attain the value of 1g. This implies that an overregistration by recording instruments is entirely possible, especially if the instruments rest directly on the earth without any anchors.

Q. Have the new data generated by IV-79 altered the NRC Staff conclusion with respect to the Newmark vertical design response spectrum for Diablo Canyon?

A. No. Although the IV-79 data show in some instances comparable vertical and horizontal acceleration values and resulted in three vertical response spectra (Stations 6, 7, and El Centro Differential Array) which exceeded the Newmark vertical design spectrum, these data do not serve as an adequate basis for altering the previous conclusion that the Newmark design response spectra are adequate.

Q. What is the basis for this Staff conclusion:

A. The basis for the Staff conclusion is as follows:

(1) Geological differences between Imperial Valley and the Diablo Canyon site. This is discussed in detail in Dr. Rothman's response to ALAB Question 3; but in general, the high vertical peak acceleration in Imperial Valley may be due to the high seismic velocity gradient (Archuleta 1980).

(2) Inclusion of IV-79 data in the Newmark Statistical Study will not likely alter the finding of that study significantly. Of the many data recorded from IV-79, only three data points exceed the Newmark design spectrum.

(3) Uncertainties about the representative characteristics of the records as explained in Rothman-Kuo Affidavit, pages 9-10. They are (a) El Centro Differential Array Station and (b) difference between corrected and uncorrected data.

Q. Appeal Board Question 5 states:

Peak horizontal acceleration values measured at the base of the Imperial Valley Services Building during IV-79 exceed those measured in the free field 103 meters away from the building. The motion records are described as showing similar amplitudes but greater low frequency motion in the building than in the free field.<sup>42/</sup> No response spectra for the two recording locations have been provided. The acceleration data, however, may be taken to indicate that no reduction in building motion due to the tau effect was realized in this instance.

Based on these observations, intervenors question the validity of the tau concept as well as its use to reduce the higher frequency portions of the Diablo Canyon Design Spectrum. The Staff and the applicant answer that, because the Imperial County Services Building was supported on piles in a deep soil structure, these observations are irrelevant to the use of a tau effect in the seismic reanalysis of Diablo Canyon, which is built on a rock site.<sup>43/</sup> Staff witness Newmark, however, used recorded earthquake motions at the Hollywood Storage Building to demonstrate the use of a tau effect analysis.<sup>44/</sup> The Hollywood Storage Building itself is built on piles in soil. Thus, the "built-on-piles" rationale appears insufficient to explain why no tau effect was evident at the Imperial Valley Services Building.

One feature distinguishing the two buildings that no party commented upon is that the Hollywood Storage Building has a partial basement and the Services Building does not. Intervenors' witness, Dr. Luco, used this fact to explain in part why he believes the Hollywood building should have a large tau value.<sup>45/</sup> Rojahn and Ragsdale's discussion implies that to some extent ground level instrumental responses within the Imperial Valley Services Building may have been influenced by the response (and failure) of the building itself.<sup>46/</sup>

In any event, given the apparent similarities between the structural foundations of the two buildings, the explanations provided thus

far for a seeming lack of a tau effect at the Imperial Valley Services Building are inadequate. The parties should provide additional information on this point and relate their analyses to both geologic and structural conditions prevailing at the Diablo Canyon site.

- 42/ See "A Preliminary Report on Strong-Motion Records from the Imperial County Services Building by Christopher Rojahn, U.S. Geological Survey and J.D. Ragsdale, California Division of Mines and Geology (undated but issued early January 1980), pp. 7 and 8.
- 43/ Blume Affidavit, Para. 10; Rothman - Kuo Affidavit, p. 7.
- 44/ SER Supplement 5, Appendix C.
- 45/ Tr. 8949.
- 46/ Rojahn and Ragsdale, pp. 7 and 8. That report also reflects information regarding the Services Building asymmetric structure (at pp. 2 and 3) which may explain why it was susceptible to damage (see Newmark Testimony fol. Tr. 8552, Attachment B, pp. 14 and 15).

Q. The Appeal Board's question indicates that the answer given in the Rothman-Kuo affidavit does not sufficiently explain why no Tau effect is evident at the Imperial County Services Building (ICSB). Do you have any more information to add?

A. Yes. I would like to point out that the structural response recorded during the IV-79 earthquake at the Imperial County Services Building is very complex in nature due to its design and structural failure during the earthquake. The dynamic response of the building could have been influenced by a number of factors such as "Tau", torsion, yielding and cracking of structural members, failure of columns, and soil-pile-structure interaction. The fact that no Tau effect was evident at ICSB

can be attributed to the masking influence of any one or a combination of these factors. For example, Dr. Newmark's testimony attributes the lack of ability to identify the Tau effect to the influence of torsion, yielding, and failure of columns. In Roman-Kuo's affidavit on Page 7, we attributed the apparent lack of the Tau effect to the influence of piles. This was based on our preliminary assessment. We have since examined the situation that occurred at ICSB more closely. It is my opinion that what appears to have happened to the dynamic response recorded at ICSB was a combination of the influences from all these factors. Attachment 4 is a comparison of the response spectra for 5% damping, generated from the motion recorded at the ground floor of the Imperial County Service Building and in the free field (Response Spectra were taken from a preliminary data report by California Division of Mining and Geology.<sup>3/</sup>). In the north-south direction, the response spectra at the ground level is above the free field spectrum for periods longer than about 1.3 seconds, while in the east-west direction, the response spectrum at the ground floor oscillates about the free field response spectrum. The comparisons demonstrate the complex nature of the response characteristics of the Imperial County Service Building while it was undergoing failure.

- Q. How do you explain the fact that the dynamic response characteristics are so different for two buildings, i.e., the ICSB and the Hollywood Storage Building, with the apparent similarities between the structural foundations?

- A. Although both the Hollywood Storage Building and the Imperial County Services Building were founded on piles, the construction of the pile foundations for the two buildings were quite different. At the Hollywood Storage Building, the tops of the piles were encased in the foundation slab; while at the Imperial County Service Building, the piles were linked together by concrete beams. This difference alone in my opinion was enough to cause the different dynamic response characteristics. Moreover, the Imperial County Service Building has serious stiffness discontinuities between the 1st and 2nd floors and its columns failed during the earthquake. The column failure inevitably increased the eccentricity in the building. It is my opinion that all these factors have contributed to the difference in response characteristics between the two buildings.
- Q. What is the conclusion, then, based on your assessment of the IV-79 data as it affects the ICSB?
- A. My opinion as expressed on Page 8 of the Rothman-Kuo affidavit is that the records at the ICSB for the IV-79 earthquake can neither validate nor invalidate the use of the "Tau" effect as an engineering equivalent factor at this time. But the absence of a record showing the Tau effect at ICSB does not detract from properly taking account of the Tau effect for the design of buildings.

Q. Appeal Board Question No. 6 states:

Throughout the Licensing Board hearings, parties stressed the role of soil-structure interactions as a mechanism that would reduce the magnitude of structure motion relative to ground motion (e.g., Tr. 8878; 8947-46). Staff and applicant's arguments (in response to intervenors' suggestion of the apparent lack of tau effect during IV-79) point to soil-structure interactions as the reason for building motion exceeding that of the ground (Blume Affidavit, para. 10; Rothman-Kuo Affidavit, p. 7). (a) Describe and explain the circumstances in which soil-structure interactions produce enhanced or reduced structural response. (b) Discuss the relevance and applicability for such interactions to the seismic response assumed for Diablo Canyon.

Q. To what do you attribute the apparent lack of Tau effect in the Imperial County Services Building?

A. In the Rothman-Kuo affidavit referred to in the Appeal Board's question, I initially indicated that "The motions recorded at the Imperial County Services Building foundation, it appears, are the amplified responses from the earthquake motions through the piles." Since that time, as indicated in my response above to question 5, we have examined the situation at ICSB more closely. As I indicated, what appears to have happened to the dynamic response recorded at ICSB was a combination of a number of factors in which the Tau effect was masked.

Q. Describe and explain the circumstances in which soil-structure interactions produce enhanced or reduced structural response.

A. The effect of soil-structure interaction is also a very complex phenomenon. There are many different modeling techniques being used to analyze such phenomenon. A great deal of engineering judgement is involved in each of these techniques. In general, it has been my experience that for structures founded on soft soil and especially with basements, the effect of soil-structure interaction reduces the structural response at the foundation level. On the other hand the response at high elevations in a structure may be enhanced due to the fact that the relatively soft soil allows the structure to rock on its foundation.

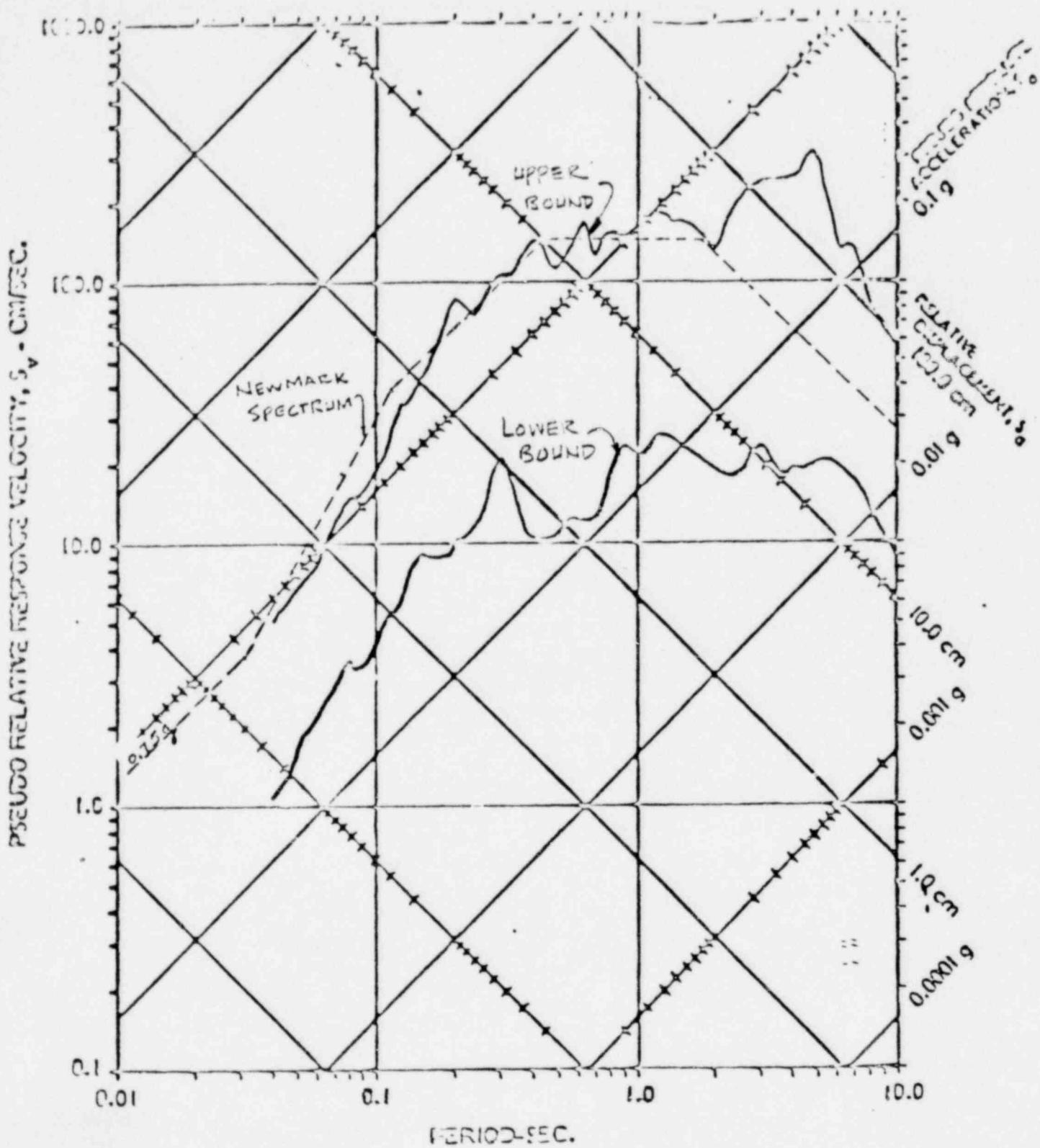
Q. Discuss the relevance and applicability for such interactions to the seismic response assumed for Diablo Canyon.

A. Since all major structures for Diablo Canyon are founded on a rock site which is generally recognized as having little or no soil-structure interaction effect, the discussion of such effect does not apply to the seismic response assumed for the design of Diablo Canyon facility.

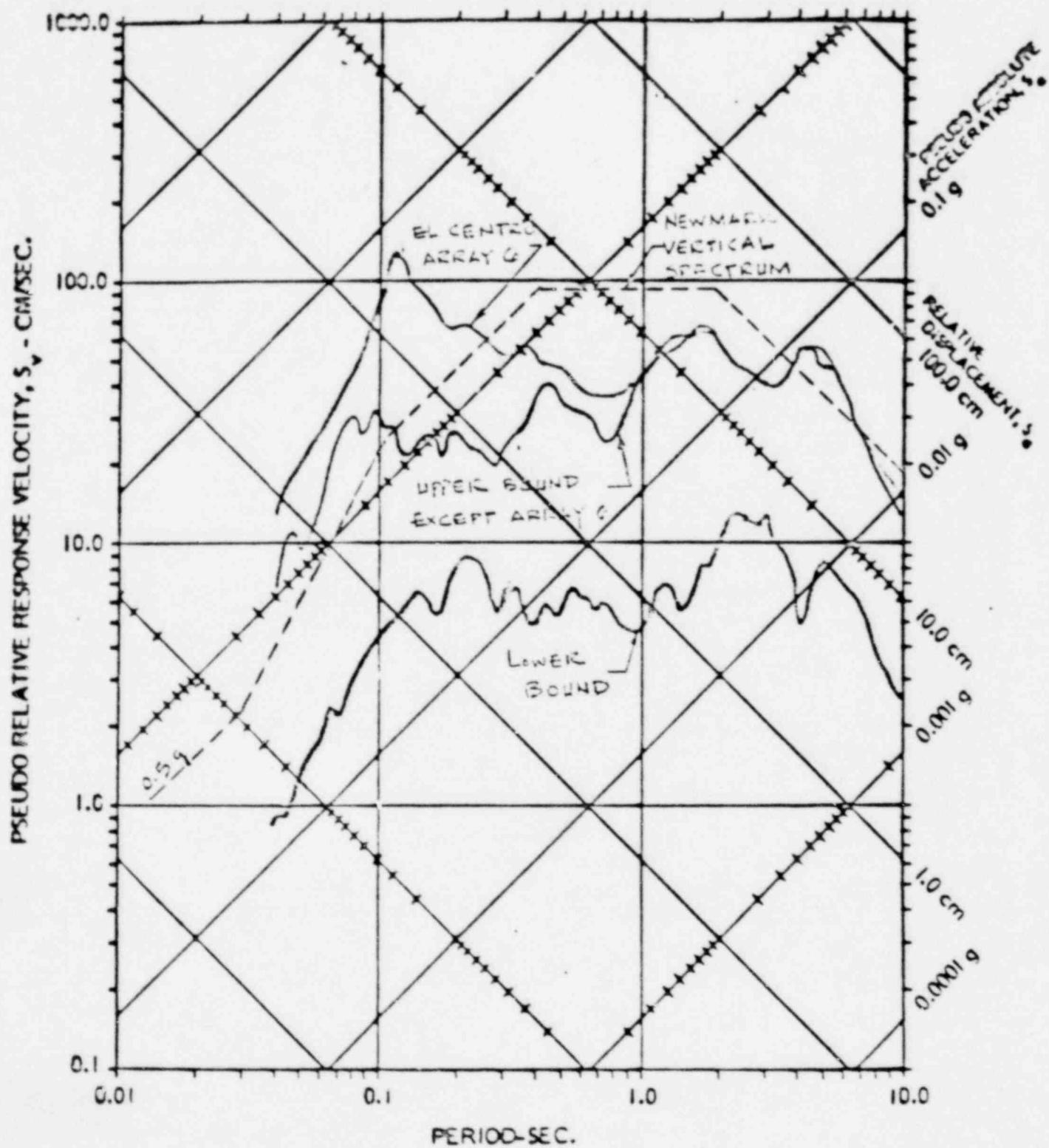
## REFERENCES

1. Newmark, N. M., Interpretation of Apparent Upthrow of Objects in Earthquakes, 5th. World Conference on Earthquake Engineering, Rome, Italy.
2. Bolt, B. A. and Hansen, R. A., The Upthrow of Objects in Earthquakes, Bulletin of the Seismological Society of America, Vol. 67, No. 5, October 1977.
3. Preliminary Data, Partial Film Records and Preliminary Data, Imperial Valley Earthquake of 15 Octobe 1979, Imperial County Services Building, Department of Conservation, Division of Mines and Geology, Sacramento, California.

Attachment 1



IMPERIAL VALLEY EARTHQUAKE 15 OCT 79 - ENVELOPE OF ACCELERATIONAL RESPONSE SPECTRA (5% DAMPING) OF ELEVEN STATIONS WITHIN ELEVEN KILOMETERS OF THE FAULT TRACE.



COMPARISON OF NEWMACK VERTICAL SPECTRUM AND  
VERTICAL SPECTRA DEVELOPED FROM THE IV-79 DATA  
ALL FOR 5% OF CRITICAL DAMPING