ESTIMATION OF SELECTED RESPONSE SPECTRAL VALUES AT THE SAN ONOFRE NUCLEAR GENERATING STATION

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H. Gene Hawkins
Southern California Edison Co.
Rosemead, California

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TERA CORPORATION

2150 Shattuck Avenue
Berkeley, California 94704
415·845·5200

Berkeley, California
Dallas, Texas
Bethesda, Maryland
Baton Rouge, Louisiana
New York, New York
Denver, Colorado
Los Angeles, California
Valley Forge, Pennsylvania

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INTRODUCTION

A multiple regression analysis similar to that performed by Campbell (1981) and TERA Corporation (1982) for horizontal peak ground acceleration (PGA) was used to develop near-source ground motion scaling (attenuation) relationships for horizontal pseudo-relative velocity response spectra (S_V) at four selected periods and three values of damping. The periods selected were 0.10, 0.12, 0.15 and 0.20 sec., representing frequencies of 5.0 to 10 Hz. The selected damping values were 2, 5 and 10 percent of critical.

The data base was essentially the same as that used to develop scaling relationships for peak ground acceleration (Campbell, 1981). Some revision of the data was necessary as a result of new information which had become available since the previous studies. Furthermore, in order that the predictions represent as closely as possible "free-field" conditions, neither recordings obtained in large buildings (greater than two stories) nor those obtained on either the abutments or toes of dams were included. Otherwise, the selection criteria were the same as those applied to the previously referenced study on peak acceleration.

Because they have not as yet been digitized, some of the recordings in the original data base were not used in this analysis. These undigitized records amounted to about 20 percent of the total number of original records and were recorded primarily from smaller earthquakes. A graphical comparison between the original (Campbell, 1981) PGA data base and the data base used in this study is presented in Figures 1 and 2, which show the magnitude and distance distributions of each data base. The earthquake data used in this study is summarized in Table 1 and consists of 62 recordings from 16 worldwide earthquakes of magnitude 5.0 to 7.7. As will be discussed in a later section, the net effect of these differing data bases on the prediction of S_V is considered negligible.

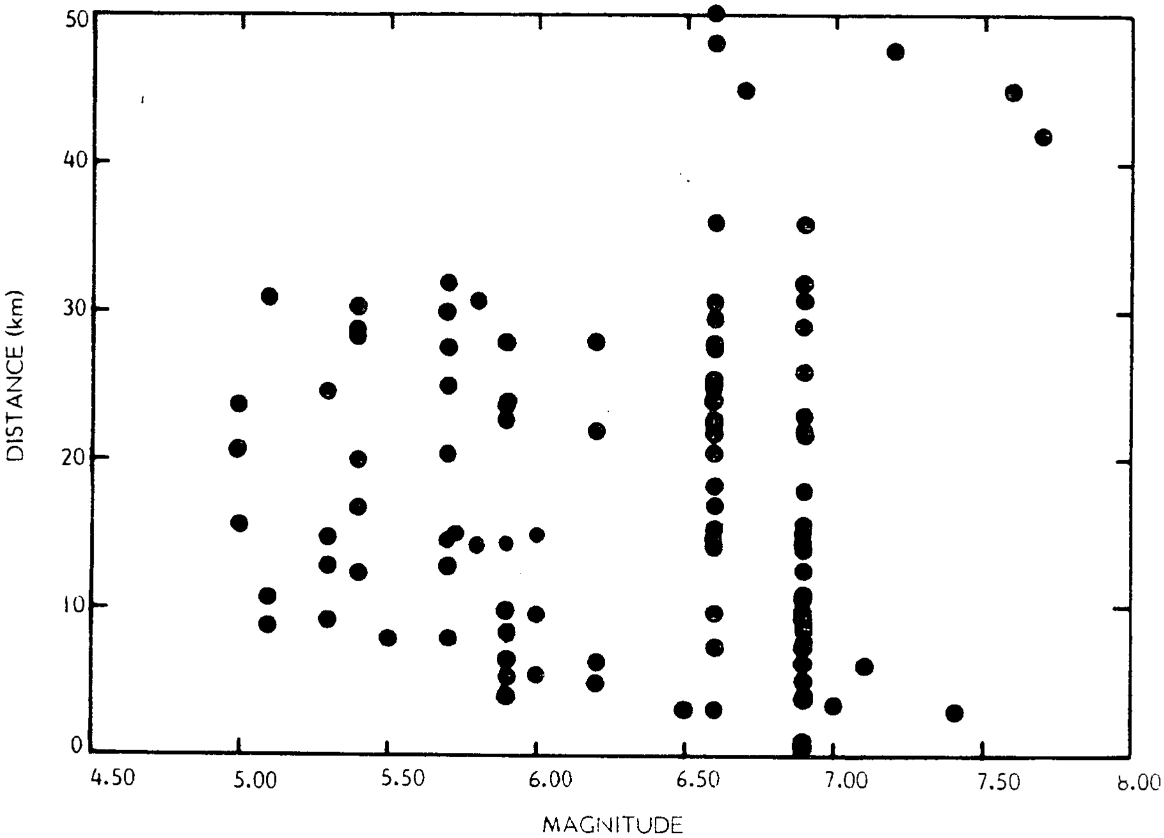

FIGURE 1

DISTRIBUTION OF DATA POINTS
PGA DATA BASE

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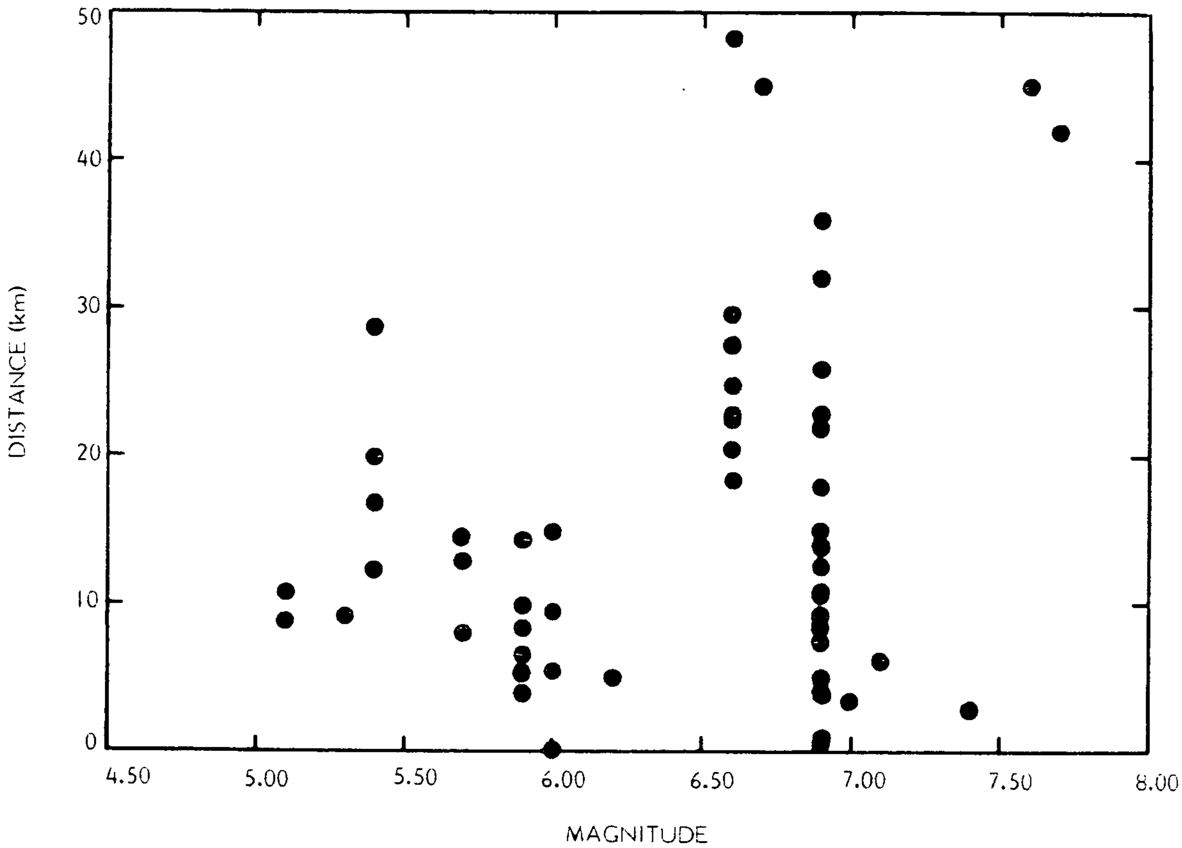

FIGURE 2

DISTRIBUTION OF DATA POINTS
SPECTRAL DATA BASE

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TABLE I

EARTHQUAKE DATA USED IN THE SPECTRAL REGRESSION

Earthquake	Date	Magnitude	Fault Type	Number of Records
Imperial Valley	05-19-40	7.1	Strike Slip	1
Kern County	07-21-52	7.7	Reverse Oblique	1
Daly City	03-02-57	5.3	Reverse Oblique	1
Parkfield	06-28-66	6.0	Strike Slip	4
Borrego Mountain	04-09-68	6.7	Strike Slip	1
Lytle Creek	09-12-70	5.4	Strike Slip	4
San Fernando	02-09-71	6.6	Reverse	8
Sitka, Alaska	07-30-72	7.6	Reverse Oblique	1
Managua, Nicaragua	12-23-72	6.2	Strike Slip	1
Hollister	11-28-74	5.1	Strike Slip	3
Oroville	08-01-75	5.7	Normal	1
Gazli, U.S.S.R.	05-17-76	7.0	Reverse	1
Santa Barbara	08-13-78	5.7	Reverse	2
Tabas, Iran	09-16-78	7.4	Reverse	1
Coyote Lake	08-06-79	5.9	Strike Slip	6
Imperial Valley	10-15-79	6.9	Strike Slip	26

On the basis of our multiple regression analyses, for the individual spectral and damping values investigated we find that the 0.67g Housner Reanalysis Spectrum (HRS) for SONGS Unit 1 falls within our 72nd and 89th percentile "free-field" predictions for SONGS. This can be contrasted against the 0.67 g zero-period value of the HRS which represents our 98th-percentile prediction for peak ground acceleration (PGA).

ANALYSIS

The ground motion model is the same as that used previously to develop a scaling relationship for peak acceleration,

$$\ln S_V = a + bM - d \ln \left[R + c_1 \exp(c_2 M)\right] \qquad (1)$$

S_V was defined as the mean of the response spectral values selected from the two horizontal components in cm/sec. As in the previous studies, the parameters M and R represent Richter magnitude and closest distance to the fault rupture surface in kilometers, respectively.

Our analysis indicated significant systematic bias associated with reverse/reverse-oblique fault types and embedded instruments. Therefore, scaling variables were added to the above expression to account for this bias based on the expression,

$$\ln S_V = eF + fE + g(M,R) \qquad (2)$$

where e and f are the scaling variables, F and E are variables representing the classification by fault type and embedment, and g(M,R) is the function of M and R given by Equation (1). The parameters F and E are equal to 0 or 1, depending upon the classification: F = 0 for strike-slip, normal and normal-oblique fault types, F = 1 for reverse and reverse-oblique fault types, E = 0 for ground-level instruments, and E = 1 for buried instruments or instruments in the basement of small buildings (1-2 stories). The scaling variables and the coefficients of Equation (1) were statistically determined from weighted nonlinear regression analyses based on the method of least squares, without the imposition of further physical considerations or constraints. Accordingly, using the terminology of Campbell (1981), the model is "unconstrained." Use of the constrained regression model would result in even lower predictions.

In our previous analysis on peak acceleration we found that records obtained in areas of steep topographic relief were systematically high with respect to PGA obtained from other records. To explore this further for spectral ordinates we classified all rock sites into four categories based on the topography of the region:

I. Sites located on the top of hills, ridges or steep slopes,

II. Sites located on the side of such features,

III. Sites located at the bottom of such features, and

IV. Sites located in relatively flat terrain.

Our preliminary analyses of both S_V and PGA have indicated that recordings obtained on the top and side of hills or slopes (Classes I and II) were higher than those obtained at the bottom of slopes or on relatively flat ground (Classes III and IV). Although at present there are very little data for the last two categories, we have conservatively chosen to leave topographically affected sites in the data base for the present analyses even though the SONGS site is not affected by topography. Considering the low residuals associated with sites considered to be more similar to SONGS, we conclude the final SONGS results reflect a conservative estimate of both the median and 84th-percentile value for both S_V and PGA.

The median and 84th-percentile predictions of S_V and PGA based on the current scaling relationships for "free-field" conditions appropriate for SONGS (E=0, F=0) are tabulated in Table 2. The 84th-percentile values are plotted for the 0.12-second, five-percent damped spectral value in Figure 3 for magnitudes of 5.0, 6.0, and 7.0. The 84th-percentile values are compared to the Housner Reanalysis Spectra in Table 3. This comparison is shown graphically in Figure 4.

TABLE 2

SUMMARY OF EMPIRICAL FREE-FIELD PREDICTIONS
OF PSEUDO-RELATIVE VELOCITY FOR SONGS

Period (sec)	Damping (%)	S_V for M = 7.0, R = 8 km (cm/sec)	
		median	84th percentile
0.10	2	11.05	16.42
	5	8.57	12.24
	10	7.05	9.96
0.12	2	14.96	22.72
	5	11.46	16.67
	10	9.29	13.27
0.15	2	20.68	31.98
	5	15.35	23.16
	10	12.24	18.11
0.20	2	29.61	45.40
	5	22.13	33.34
	10	16.96	25.49
PGA(g)		0.313	0.456

TABLE 3

A COMPARISON OF THE 84TH-PERCENTILE PREDICTIONS OF PSEUDO-RELATIVE VELOCITY FOR SONGS WITH THE SONGS UNIT 1 0.67g HOUSNER REANALYSIS SPECTRA

Period (sec)	Damping (%)	S_V for M = 7.0, R = 8 km (cm/sec)		Ratio 84th/HRS
		Housner (HRS)	TERA (84th)	
0.10	2	14.19	16.42	1.16
	10	10.77	9.96	0.92
0.12	2	19.08	22.72	1.19
	10	13.12	13.27	1.01
0.15	2	27.43	31.98	1.17
	10	16.86	18.11	1.07
0.20	2	43.31	45.40	1.05
	10	23.86	25.49	1.07
PGA (g)		0.667	0.456	0.68

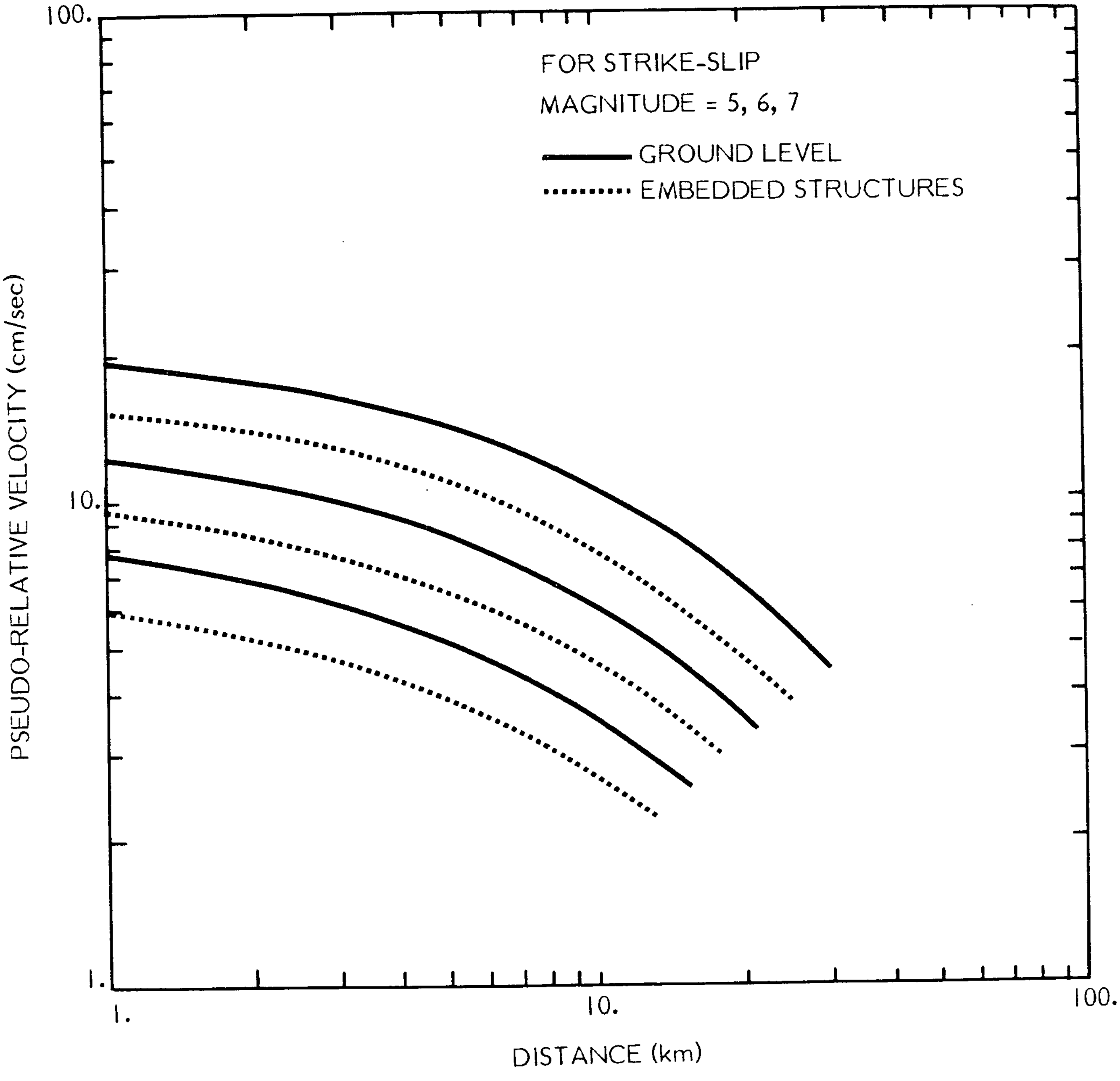

FIGURE 3

SCALING RELATIONSHIP AT 5 PERCENT DAMPING
FOR 0.12-SECOND RESPONSE SPECTRAL ORDINATE

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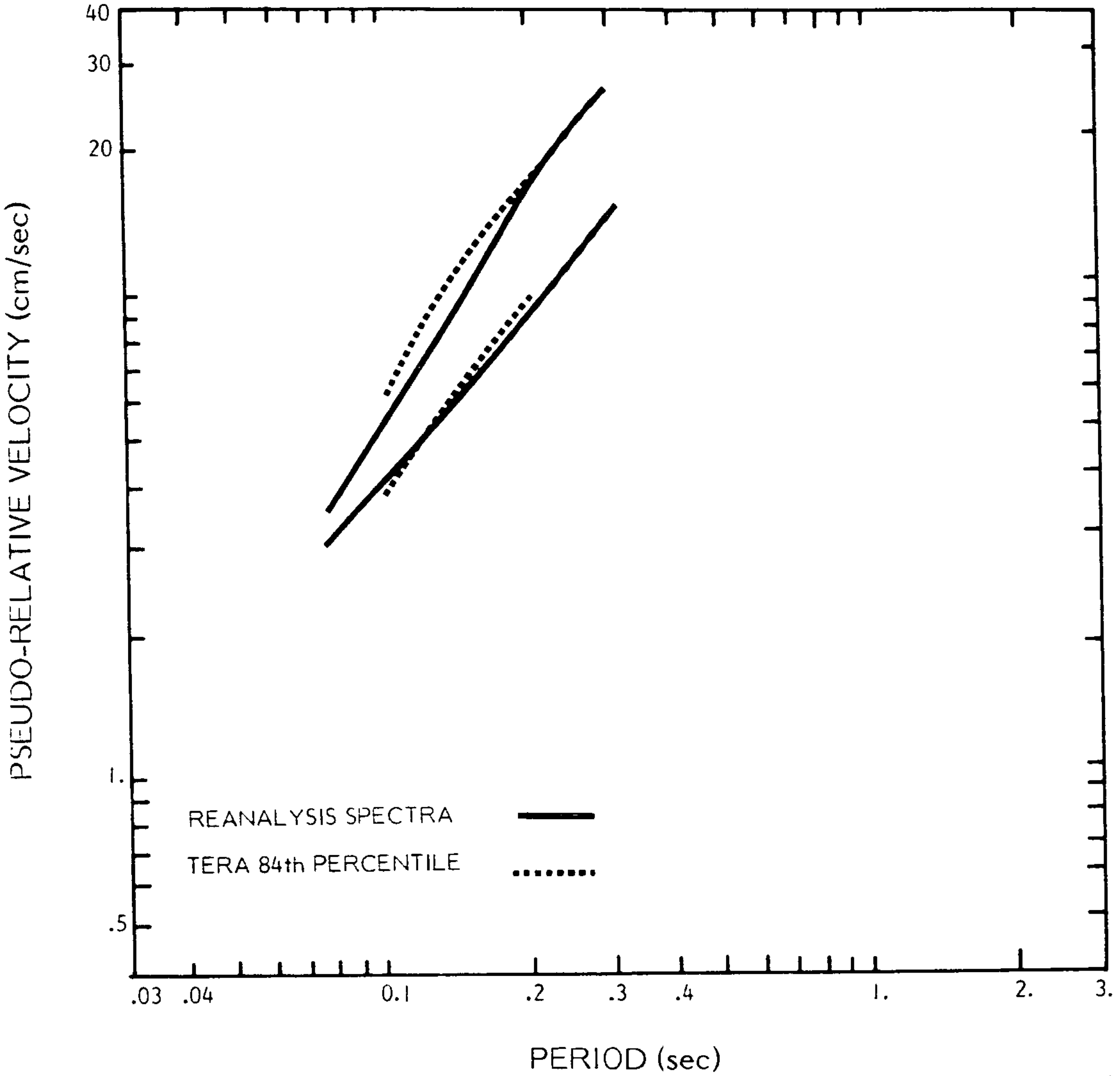

FIGURE 4

COMPARISON OF SONGS1 REANALYSIS SPECTRA
WITH TERA 84th PERCENTILE PREDICTIONS
2% AND 10% DAMPING

The 84th-percentile predictions of S_V are found to exceed the Housner Reanalysis Spectra by no more than 19 percent for the 2-percent damped spectrum, and by no more than 7 percent for the 10-percent damped spectrum.

Predictions for small embedded structures (E = 1) were found to be approximately 20 to 30 percent lower for S_V and 20-percent lower for PGA than those obtained on ground-level instruments. As with our previous studies, predictions of PGA for reverse faults were found to be approximately 40 percent higher compared to other fault types; the effect on S_V was found to be similar. The net effect of including these scaling variables was to lower the prediction of S_V and PGA for "free-field" conditions appropriate for SONGS by approximately ten percent or less, based on the revised data base. We conclude that the current results more accurately represent "free-field" ground motion than did our earlier, generally more conservative results (TERA Corporation, 1982), in which scaling variables were not included and a more general data base was used.

As an independent verification of the multiple regression analyses we also used a spectral ratio technique for estimating S_V. The method, identical to that employed by Woodward-Clyde Consultants (1982), uses the ratio S_V/PGA, or normalized response spectral value, to estimate S_V through the relationship,

$$\ln S_V = \ln \bar{S}_V - \ln PGA \qquad (3)$$

where $\bar{S}_V$ is the normalized response spectral value. An advantage to this technique is that PGA may be estimated from a broader data set than S_V, while $\bar{S}_V$, being relatively insensitive to many of the earthquake and recording parameters for small periods, may be estimated from the smaller digitized data set without significant bias. In fact, for the distances and magnitudes used in this study, embedment was the only parameter associated with $\bar{S}_V$ found to be statistically significant. For the present study, the comparison of the median predictions using Equation (3) and those based on multiple regression analysis is restricted to the 0.10-second, five-percent damped spectral value. A comparison of the median values obtained from both techniques found them to be within three percent of each other, in remarkably close agreement. The results of this independent approach lends further confidence to the results of the multiple regression analysis and indicates that the smaller data set used in the analysis has apparently not seriously biased the median estimates for SONGS.

SENSITIVITY ANALYSIS

Based on the analysis of PGA, we find that the net result of accommodating data revisions since our previous analyses has been to increase predictions by about ten percent. To assess the impact of further selection from the data base and the introduction of scaling parameters on the results of our analyses, we have sequentially invoked the additional selection criteria, repeated our analyses, and compared the median and 84th-percentile predictions. This comparison for the 0.12-second, five-percent damped spectral value and for PGA appears in Table 4. This table, which presents the incremental percent changes associated with each step, quantifies the conservatisms in the previous PGA studies by showing the conservative bias associated with reverse faults and large buildings or dams.

CONCLUSIONS

The results of our analysis indicate that the 84th-percentile predictions of S_V for SONGS Unit I exceed the 0.67g Housner Reanalysis Spectra for the range of periods and damping values investigated by no more than 19 percent for the 2-percent damped spectrum and by no more than 7 percent for the 10-percent damped spectrum. Therefore, for individual spectral values, the Reanalysis Spectrum falls within our 72nd- and 89th-percentile "free-field" predictions for SONGS. To put this result in context, it should be noted that our analyses also indicate that the Reanalysis Spectrum always exceeds our 84th-percentile predictions for basements of one- or two-story buildings for the range of periods and damping values investigated. This latter result represents a more realistic but still conservative comparison of our predictions with SONGS design spectra than the one based on our "free-field" predictions.

TABLE 4

SUMMARY OF SENSITIVITY STUDIES FOR PGA AND S_V (0.12 SEC., 5% DAMPING)

Description	Percent variation*			
	S_V		PGA	
	Median	84th	Median	84th
Base Case (Revised Data Base)	0	0	0	0
With Scaling Variables	3	2	-4	-5
Without Large Buildings	-8	-12	-3	-3
Without Dam Abutments	-4	-7	-3	-6

* The variation represents the incremental percent change in the median or 84th-percentile prediction for SONGS after invoking the additional criterion described. Positive variations represent an incremental increase while negative variations represent an incremental decrease in predicted values.

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