SITE RESPONSE STUDIES FOR PURPOSE OF REVISING NEHRP SEISMIC PROVISIONS

by

C.B. Crouse

Dames and Moore
500 Market Place Tower
2025 First Avenue
Seattle, WA 98121

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California Department of Conservation
Division of Mines and Geology
Office of Strong Motion Studies
801 K Street, MS 13-35
Sacramento, California 95814-3531

DIVISION OF MINES AND GEOLOGY
JAMES F. DAVIS
STATE GEOLOGIST

DISCLAIMER

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PREFACE

The California Strong Motion Instrumentation Program (CSMIP) in the Division of Mines and Geology of the California Department of Conservation promotes and facilitates the improvement of seismic codes through the Data Interpretation Project. The objective of the this project is to increase the understanding of earthquake strong ground shaking and its effects on structures through interpretation and analysis studies of CSMIP and other applicable strong motion data. The ultimate goal is to accelerate the process by which lessons learned from earthquake data are incorporated into seismic code provisions and seismic design practices.

The specific objectives of the CSMIP Data Interpretation Project are to:

1. Understand the spatial variation and magnitude dependence of earthquake strong ground motion.

2. Understand the effects of earthquake motions on the response of geologic formations, buildings and lifeline structures.

3. Expedite the incorporation of knowledge of earthquake shaking into revision of seismic codes and practices.

4. Increase awareness within the seismological and earthquake engineering community about the effective usage of strong motion data.

5. Improve instrumentation methods and data processing techniques to maximize the usefulness of SMIP data. Develop data representations to increase the usefulness and the applicability to design engineers.

This report is the thirteenth in a series of CSMIP data utilization reports designed to transfer recent research findings on strong-motion data to practicing seismic design professionals and earth scientists. CSMIP extends its appreciation to the members of the Strong Motion Instrumentation Advisory Committee and its subcommittees for their recommendations regarding the Data Interpretation Research Project.

Anthony F. Shakal
CSMIP Program Manager

Moh J. Huang
CSMIP Data Interpretation
Project Manager

ABSTRACT

A strong-motion database was compiled for California earthquakes of surface-wave magnitudes, $M_s \geq 6$, occurring from 1933 through 1992. The database consisted of horizontal peak ground acceleration and 5 percent damped response spectra of accelerograms recorded on four different local geologies: bedrock (class A), soft rock or stiff soil (class B), medium stiff soil (class C), and soft soil (class D). The results of regression analyses of the database within each of these site classes were used to derive a set of site-dependent spectral amplification factors for oscillator periods between 0.1 and 4.0 sec and ground acceleration levels between 0.1 and 0.4 g. The amplification factors at 0.3 and 1.0 sec periods are generally similar to those recommended during the 1992 NCEER Site Response Workshop.

APPLICATION TO CODES AND PRACTICE

Significant revisions to the site-amplification term of the base shear coefficient have been introduced to the 1994 edition of the National Earthquake Hazard Reduction Program (NEHRP) seismic provisions, which are published by the Building Seismic Safety Council. These revisions consist of new definitions of local site conditions as well as the introduction of acceleration-dependent amplification factors for both the acceleration- and velocity-controlled segments of the response spectrum. Values of the proposed factors were derived largely on the basis of site-response analysis with the SHAKE computer code and studies of strong motion data from the 1989 Loma Prieta earthquake. This study derives the factors from an empirical analysis of the strong motion data recorded during California earthquakes between 1933 and 1992. These empirically-based factors and the essentially theoretically-based factors currently proposed are intended for use by code committees making future revisions to the NEHRP provisions and the Uniform Building Code.

ACKNOWLEDGEMENTS

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INTRODUCTION

The National Center for Earthquake Engineering Research (NCEER) held a workshop on site response in November 1992 (Martin, 1994). The primary objectives of the workshop were to develop revised site categories, site coefficients, and site-dependent spectra for inclusion in the 1994 National Earthquake Hazards Reduction Program (NEHRP) seismic provisions. The results of recent and ongoing research by several engineers and seismologists who attended the workshop provided valuable information for making the revisions. In reviewing that research, which was largely based on numerical analysis using the computer program SHAKE (Schnabel et al., 1972) and on empirical studies of 1989 Loma Prieta earthquake data, it was discovered that a study of site response, using the wealth of strong-motion data recorded during the last 60 years, was not being conducted. This study was performed to complement the results of the research completed to date and to provide to the revision process the necessary empirical component, which was currently lacking or underdeveloped.

The site-response parameters appearing in the 1991 NEHRP provisions were based mostly on the site-dependent spectra developed by Seed, et al. (1974) and Mohraz (1976), who used strong-motion data recorded through 1971. The abundant strong-motion accelerogram data recorded since the 1971 San Fernando earthquake offered the opportunity to improve the existing knowledge on site response gained since the Seed and Mohraz studies.

To take advantage of this opportunity, more thorough statistical studies of the strong-motion data were conducted. The specific objectives of these studies were to develop a set of site coefficients or amplification factors (F_a and F_v), site-dependent spectra, and the associated site classifications for use in updating the NEHRP seismic provisions (Building Seismic Safety Council, 1991). In those provisions, the F_a and F_v amplification factors appear in the formulas for computing the lateral seismic forces at short and long oscillator periods, respectively. In the Uniform Building Code and in earlier versions of the NEHRP provisions, only one site amplification factor, S, was used to scale the lateral forces for local geology. A unique feature of the F_a and F_v factors is that they are dependent on the ground acceleration levels, A_a and A_v, respectively, which represent the severity of the ground-motion hazard at a site at short and long oscillator periods. These acceleration levels are similar to the seismic zonation coefficient, Z, that appears in the lateral force equation in the Uniform Building Code.

The site classifications and corresponding values of F_a and F_v that were recommended during the 1992 NCEER workshop are presented in Tables 1 and 2, respectively (Martin and Dobry, 1994). Note that the number of site classes has increased and their definitions are more quantitative than in earlier NEHRP provisions and other codes. The primary parameter in Table 1 to classify a site is $\bar{V}_s$, the average shear-wave velocity in the upper 100 feet of soil or rock. This parameter has been adopted in our study also.

The databases, analyses, and results of the empirical studies complementing the NCEER work are summarized in the remaining sections of this report.

Table 1. Site Classifications Recommended During 1992 NCEER Workshop

Site Class	Site Class Name/ Generic Description	Site Class Definition
A_0	Hard rock	$\bar{V}_s > 5{,}000$ ft/sec
A	Rock	$2{,}500$ ft/sec $< \bar{V}_s < 5{,}000$ ft/sec
B	Hard and/or stiff/very stiff soils; mostly gravels	$1{,}200$ ft/sec $< \bar{V}_s < 2{,}500$ ft/sec
C	Sands, silts and/or stiff/very stiff clays, some gravels	600 ft/sec $< \bar{V}_s < 1{,}200$ ft/sec
D_1	Profile containing a small-to-moderate total thickness H of soft/medium stiff clay	$\bar{V}_s < 600$ ft/sec and/or 10 ft $< H < 50$ ft
D_2	Profile containing a large total thickness H of soft/medium stiff clay	$\bar{V}_s < 600$ ft/sec and/or 50 ft $< H < 120$ ft
(E)	(E_1) - Soils Vulnerable to Potential Failure or Collapse Under Seismic Loading: (Liquefiable Soils, Quick and Highly Sensitive Clays, Collapsible Weakly-Cemented Soils, etc.)	
	(E_2) - Peats and/or Highly Organic Clays: ($H > 10$ ft of peat and/or highly organic clay)	
	(E_3) - Very high Plasticity Clays: ($H > 25$ ft with $PI > 75\%$)	
	(E_4) - Very Thick "Soft/Medium Stiff Clays" ($H > 120$ ft)	

Table 2. Amplification Factors, F_a and F_v, Recommended During 1992 NCEER Workshop (Martin and Dobry, 1994)

Amplification Factor, F_a					
Shaking Intensity ⇒ **Site Class ⇓**	**A_a = 0.1 g**	**A_a = 0.2 g**	**A_a = 0.3 g**	**A_a = 0.4 g**	**A_a = 0.5 g**
A_0	0.8	0.8	0.8	0.8	0.8
A	1.0	1.0	1.0	1.0	1.0
B	1.2	1.2	1.1	1.0	1.0
C	1.6	1.4	1.2	1.1	1.0
D_1	2.5	1.7	1.2	0.9	(--)[1]
D_2	2.0	1.6	1.2	0.9	(--)[1]
(E)	(--)[1]	(--)[1]	(--)[1]	(--)[1]	(--)[1]

Amplification Factor, F_v					
Shaking Intensity ⇒ **Site Class ⇓**	**A_a = 0.1 g**	**A_a = 0.2 g**	**A_a = 0.3 g**	**A_a = 0.4 g**	**A_a = 0.5 g**
A_0	0.8	0.8	0.8	0.8	0.8
A	1.0	1.0	1.0	1.0	1.0
B	1.7	1.6	1.5	1.4	1.3
C	2.4	2.0	1.8	1.6	1.5
D_1	3.5	3.2	2.8	2.4	(--)[1]
D_2	3.5	3.2	2.8	2.4	(--)[1]
(E)	(--)[1]	(--)[1]	(--)[1]	(--)[1]	(--)[1]

[1] Site-specific geotechnical investigations and dynamic site response analyses should be performed.

DATABASES

Two databases were compiled: (1) geotechnical, geophysical and geological data for strong-motion stations, and (2) horizontal peak ground acceleration (PGA) and 5 percent damped pseudovelocity (PSV) response spectra of accelerograms recorded during central and southern California earthquakes of surface-wave magnitude, $M_s \geq 6.0$. Based on the local site data, four site classifications (A,B,C,D) were selected that were similar to those of Boore et al. (1993) and those recommended during the 1992 NCEER Site-Response Workshop (Martin and Dobry, 1994). Abridged definitions of these site classes are as follows: A– rock, $\bar{V}_s \geq 2500$ fps; B– soft rock or stiff soil, $1200 \leq \bar{V}_s < 2500$ fps; C– medium stiff soils, $600 \leq \bar{V}_s < 1200$ fps; D– soft clay, $\bar{V}_s < 600$ fps. Because of the lack of strong motion data at hard rock sites, the distinction between the NCEER hard rock (A_o) and rock (A) categories was eliminated, and for this analysis, the two categories were combined. The geotechnical data for the soft soil sites were limited and in many cases insufficient to confidently place these sites into either the NCEER D_1 or D_2 categories; therefore, these two classes were combined into one class D category.

After carefully searching the strong-motion and local geologic databases, a total of 238 records from 16 earthquakes were chosen for the analysis. This selected strong-motion database is listed in Appendix A and includes the following information: (1) date, location, magnitude - M_s, and fault type of the causative earthquake; (2) name, I.D. designation, geographic coordinates, type of structure, and site class for the station recording the ground motion; (3) closest distance (R) from the station to the fault rupture of the causative earthquake; and (4) PGA values for both horizontal and vertical components.

With few exceptions, the data were recorded in small buildings up to three stories in height or in instrument shelters. The exceptions are (1) Vernon CMD terminal building in Los Angeles, which recorded the 1933 Long Beach, 1968 Borrego Mountain, 1971 San Fernando, and 1987 Whittier earthquakes, (2) Pasadena office building, which recorded the 1992 Landers earthquake, (3) San Bernardino Hall of Records building, which recorded the 1971 San Fernando earthquake, and (4) Watsonville commercial building, which recorded the 1989 Loma Prieta earthquake. The first three buildings are 6 stories and the Watsonville building is 4 stories. The selection criterion based on building height is intended to reduce the effects of soil-structure interaction on the recorded motions. Studies by the author have shown that the primary soil-structure interaction phenomenon that can have a significant effect on these motions is the filtering of high frequency motions by the foundation (Crouse and Jennings, 1975; Crouse, 1976, 1978). However, these studies also show that intermediate and long-period motions are not appreciably affected by soil-structure interaction. Furthermore, high frequency filtering will have little effect on the response spectra of motions recorded at large epicentral distances because the higher frequency motions are more greatly diminished due to anelastic attenuation than are the lower frequency motions (Crouse and Turner, 1978). With this background information, the few aforementioned records from the taller buildings were included in the database because these data were recorded during earthquakes in which data were limited for a certain site class or distance range. The possible filtering of high frequency motions is thought to be potentially significant only for the Vernon CMD terminal recordings of the 1933, 1971 and 1987 earthquakes; however, in view of the positive factors for the inclusion of these records in the database, this concern was not sufficient to eliminate them.

The 238 records were distributed among the earthquakes and site classifications as shown in Table 3. Data from several $M_s > 6$ California earthquakes were not included. For example, accelerograms recorded in the Eureka-Ferndale area of Northern California were excluded because of the possible association of the causative earthquake with the southern Cascadia Subduction Zone, which represents a different tectonic environment than found in central and southern California. Accelerograms from the 1980 Mammoth

Lakes sequence were excluded because this active volcanic region is atypical of the geological/tectonic regions of California where most of the accelerograms have been recorded. Accelerograms from the 1992 Big Bear and 1994 Northridge earthquakes were not available during the time the database was compiled.

Table 3. Number of Accelerograms Used in Analysis

				Soil Classification			
Date	**Earthquake Name**	**M_s**	**Type[1]**	**A**	**B**	**C**	**D**
1933.03.11	Long Beach	6.2	S		1	1	
1940.05.19	Imperial Valley	7.1	S			1	
1952.07.21	Kern County	7.7	R		3	1	
1966.06.28	Central California	6.1	S	1	3	3	
1966.08.07	Baja	6.3	S			1	
1968.04.09	Borrego Mountain	6.7	S		2	5	
1971.02.09	San Fernando	6.5	R	6	13	8	
1979.10.15	Imperial Valley	6.8	S	1	1	23	3
1981.04.26	Westmorland	6.0	S	1	1	2	2
1983.05.02	Coalinga	6.7	R	1	13	6	
1984.04.24	Morgan Hill	6.1	S	1	7	6	4
1986.07.08	Palm Springs	6.0	S	4	3	4	
1986.07.21	Chalfant Valley	6.2	S	1			
1987.10.01	Whittier	6.1	R	3	14	13	
1989.10.17	Loma Prieta	7.1	S	11	20	18	7
1992.06.28	Landers	7.6	S	3	7	9	
	Total			33	88	101	16

[1] *Note:* S = *strike slip;* R = *reverse*

One recording from the Tarzana Cedar Hills Nursery station was included in the database. The possible anomaly of this station was not well understood prior to the Northridge earthquake. During the Whittier earthquake, the horizontal PGA values recorded at this station were roughly an order of magnitude greater than the motions recorded at nearby stations. Because the records from the main aftershock of this event and from the 1992 Landers earthquake were not unusual, the thought was that there may have been some peculiar travel path effects near this station only during the Whittier earthquake mainshock. For this reason and partly because of the limited processed data available for the Landers earthquake, the Tarzana record from the Whittier event was excluded, but the record at this station from the 1992 Landers event was included in the database. If the Northridge earthquake had occurred before the database was compiled and analyzed, then this station may have been eliminated from consideration, however, the inclusion of only one, apparently normal, record from this station will not have any appreciable effect on the results of the analysis.

ANALYSES

Plots of the M_s–R distribution for the records within each site class in Table 3 are shown in Figure 1. Note that most of the records in each site class fall within the $M_s = 6 - 7.25$ and $R = 10 - 80$ km ranges. The numbers and distributions of these records suggested that the appropriate analysis procedure was to (1) conduct separate weighted nonlinear regressions of the more abundant class B and class C databases, and (2) compute factors to convert (i) class B response spectra to class A response spectra, and (ii) class C response spectra to class D response spectra.

REGRESSION MODEL

The regression model that was ultimately selected was

$$\ln Y = a + bM + d\ln\left(R + c_1 \exp\{c_2 M\}\right) + eF \qquad \textbf{(1)}$$

where: Y is the ground-motion parameter (i.e., PGA or PSV); M is surface-wave magnitude; R is closest distance from the site to the fault rupture in km; F is a binary fault-type parameter (1 for reverse earthquakes and 0 for strike-slip earthquakes) and a, b, c_1, c_2, d, and e are the regression coefficients. The weighting scheme for the regression of each database was a modified form of one used by Campbell (1990), who defined distance intervals and gave the recordings from each earthquake within each interval the same total weight. In our weighing scheme, both magnitude and distance intervals were defined and the recordings within each magnitude-distance interval pair were given the same total weight. The magnitude–distance intervals are indicated with dashed lines in Figure 1. The geometric mean of both horizontal component values for each record was used in the regression analysis.

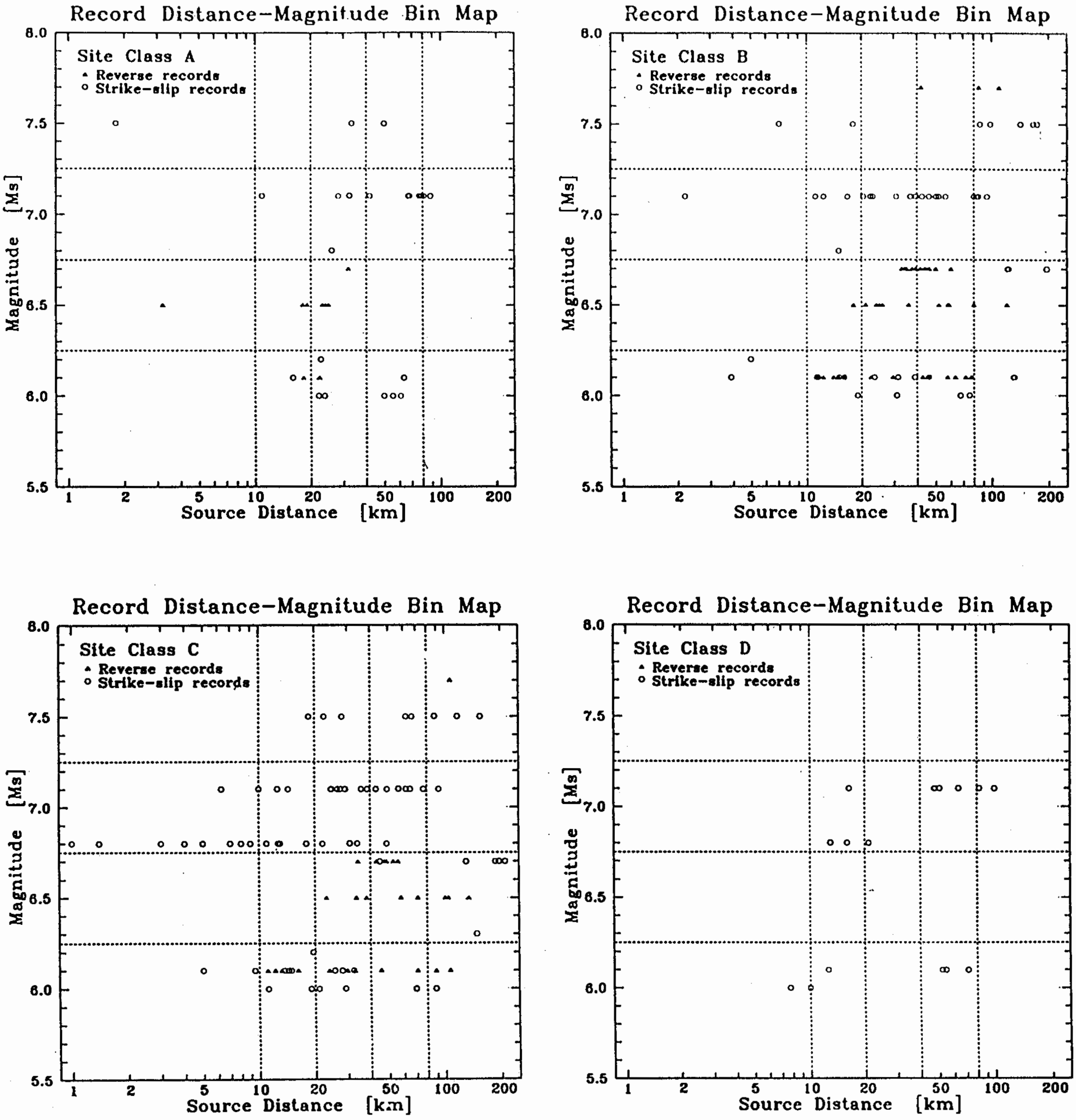


Figure 1. Distribution of Strong-Motion Data

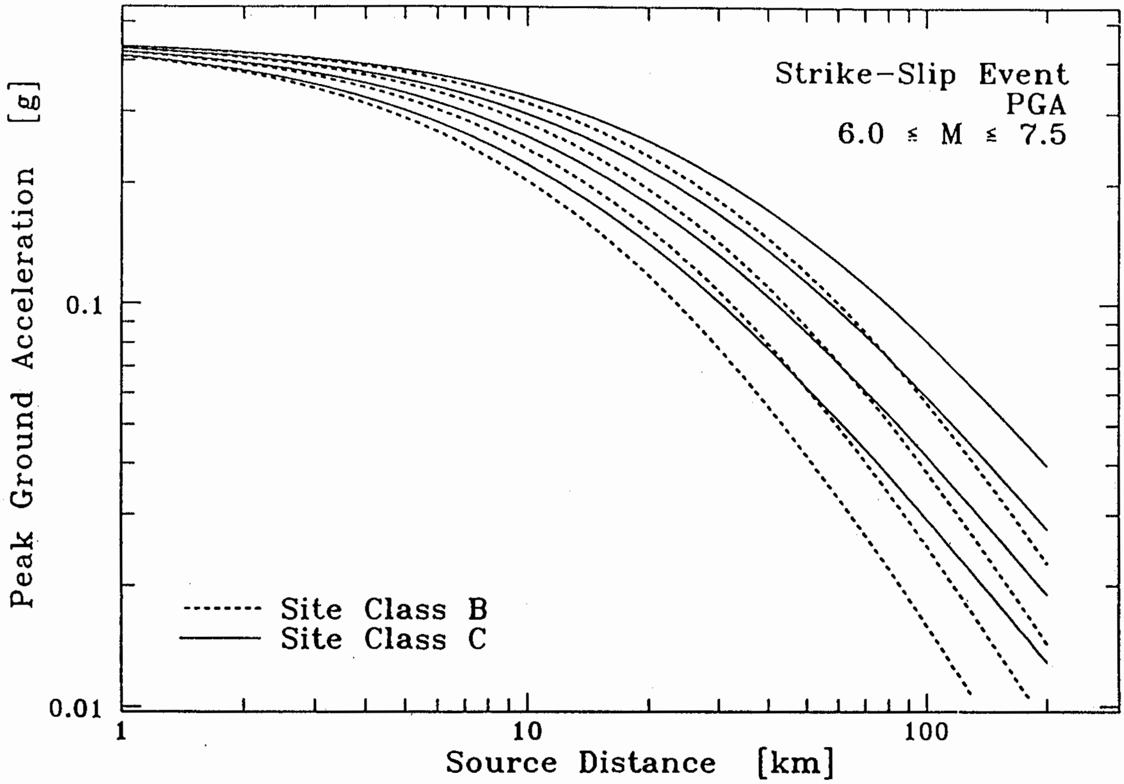
REGRESSION RESULTS

The nonlinear regressions on the class B and class C databases were performed using the BMDP Statistical Software program, 3R, (Dixon, 1986). The regressions were performed separately on PGA, and on the PSV data at each oscillator period considered (T = 0.04, 0.10, 0.15, 0.20, 0.30, 0.40, 0.50, 0.60, 0.80, 1.0, 1.5, 2.0, 3.0, and 4.0 sec). Constraints involving the coefficients, b, d, c_1, and c_2, were introduced for all regressions to ensure that Y was an increasing function of M for all $R \geq 0$ (see Appendix B for details).

The coefficients, a, b, c_1, c_2, d, and e, and standard error, $\sigma_{ln\,Y}$, from the regressions are listed in Table 4. The correlation matrices and standard deviations of these coefficients are provided in Appendix B. Selected plots of the residuals from the regressions are provided in Appendix C.

Plots of the PGA and PSV ($T = 1$ sec) attenuation curves for $M = 6.0$, 6.5, 7.0 and 7.5 strike-slip earthquakes are shown in Figure 2. These PGA and PSV figures are typical of the attenuation observed at short and long periods, respectively, where it can be seen that (1) the attenuation is slower for class C sites, and (2) the attenuation becomes slower with increasing oscillator period, T.

Values of the coefficient, e, in Table 4 were used to plot the ratio of reverse to strike-slip ground motion versus T (Figure 3) for class B and class C sites. The results for both site classes are similar in the sense that the ratios for $T < 1.0$ sec are generally greater than those for $T > 1.0$ sec, but the absolute values are different for the most part. Small values of $|e|$ (i.e., ratios ~ 1.0) were found statistically to not be significantly different from zero, but the general inconsistency in the class B and class C values makes it difficult to attach any significance of fault type on the level of ground motion from the results of this analysis.



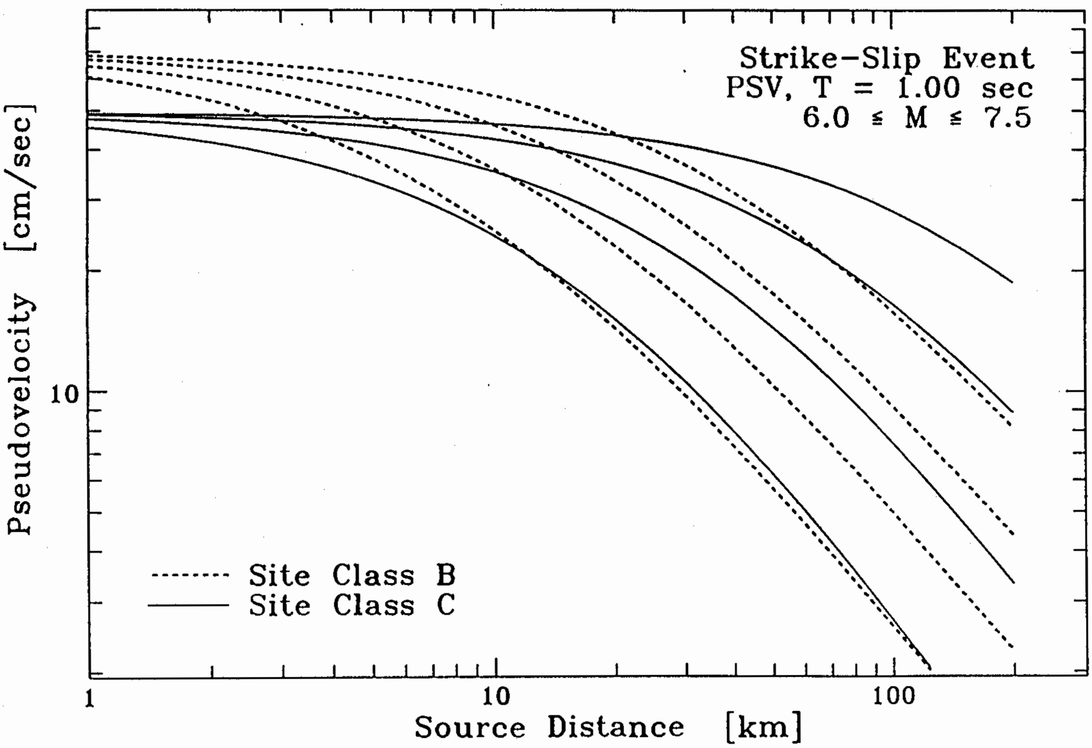


Figure 2. Median PGA and PSV ($T = 1$ sec) Attenuation Curves for $M = 6.0, 6.5, 7.0$, and 7.5 Strike-Slip Events

Table 4. Results of Regression Analyses

$$\ln Y^{\alpha,T} = a^{\alpha,T} + b^{\alpha,T}M + d^{\alpha,T}\ln\left(R + c_1^{\alpha,T}\exp\{c_2^{\alpha,T}M\}\right) + e^{\alpha,T}F$$

Site Class B

Ground-Motion Parameter, $Y^{B,T}$	Period T [sec]	Predictor Equation Parameters						
		$a^{B,T}$	$b^{B,T}$	$c_1^{B,T}$	$c_2^{B,T}$	$d^{B,T}$	$e^{B,T}$	$\sigma_{\ln Y}^{B,T}$
PGA	···	−2.342699	1.091713	0.413033	0.623255	−1.751631	0.087940	0.427787
PSV(T, $\xi=5\%$)	0.04	−0.472585	1.036917	0.387669	0.612898	−1.691826	0.108989	0.413926
⋮	0.10	7.571783	1.625135	4.612965	0.454664	−3.574364	0.033013	0.467394
⋮	0.15	9.070027	1.601903	5.449227	0.434297	−3.688497	−0.014652	0.490720
⋮	0.20	7.408577	1.468556	3.775168	0.464040	−3.164719	0.043634	0.472181
⋮	0.30	1.194880	1.086794	0.166050	0.706093	−1.539165	0.128310	0.467039
⋮	0.40	0.887084	1.026752	0.083872	0.757907	−1.354721	0.154355	0.495514
⋮	0.50	0.711154	1.055968	0.060623	0.788026	−1.340017	0.153348	0.509970
⋮	0.60	−0.070871	1.025031	0.048384	0.742853	−1.104581	0.187939	0.529652
⋮	0.80	−0.410607	0.936184	0.002278	1.044000	−0.896728	0.330569	0.577221
⋮	1.00	−1.829222	1.457603	0.008444	1.144165	−1.273945	0.112767	0.592915
⋮	1.50	−2.206094	1.262859	0.001634	1.287978	−0.922951	0.032286	0.595854
⋮	2.00	−3.886444	1.509735	0.000269	1.590216	−0.949390	0.014204	0.561973
⋮	3.00	−5.067456	1.651407	0.000080	1.807710	−0.907890	−0.135754	0.602980
PSV(T, $\xi=5\%$)	4.00	−5.707326	1.745192	0.000070	1.844360	−0.914570	−0.245670	0.633340

units of PGA: [PGA] = g; *units of PSV:* [PSV] = cm/sec

Site Class C

Ground-Motion Parameter, $Y^{C,T}$	Period T [sec]	Predictor Equation Parameters						
		$a^{C,T}$	$b^{C,T}$	$c_1^{C,T}$	$c_2^{C,T}$	$d^{C,T}$	$e^{C,T}$	$\sigma_{\ln Y}^{C,T}$
PGA	···	−2.353903	0.838847	0.305134	0.640249	−1.310188	−0.051707	0.416639
PSV(T, $\xi=5\%$)	0.04	−0.316018	0.775418	0.317517	0.607199	−1.277041	−0.010872	0.424616
⋮	0.10	4.844192	0.668470	4.045981	0.352728	−1.850579	−0.091919	0.453879
⋮	0.15	12.359194	1.064481	16.158960	0.310128	−3.432391	−0.231488	0.435481
⋮	0.20	6.529981	1.249258	4.378859	0.443090	−2.635199	−0.041310	0.474415
⋮	0.30	2.043062	0.838572	0.884282	0.454604	−1.285166	0.055896	0.496294
⋮	0.40	−0.449217	1.103279	0.015008	0.978334	−1.127712	0.227447	0.478698
⋮	0.50	−1.079692	1.198570	0.006383	1.092807	−1.096781	0.193853	0.468321
⋮	0.60	−1.495757	1.172313	0.001802	1.232590	−0.951097	0.159078	0.498147
⋮	0.80	−3.567871	1.612229	0.000749	1.487888	−1.083569	0.049774	0.558253
⋮	1.00	−7.286583	2.563514	0.000557	1.716614	−1.493355	−0.102444	0.569552
⋮	1.50	−6.200445	2.052788	0.000123	1.790362	−1.146577	−0.127769	0.545691
⋮	2.00	−5.888256	1.974398	0.000155	1.748081	−1.129466	−0.279244	0.564984
⋮	3.00	−6.088140	1.944268	0.000130	1.714319	−1.134134	−0.155093	0.692397
PSV(T, $\xi=5\%$)	4.00	−7.441490	2.122133	0.000092	1.779805	−1.119420	−0.107566	0.745120

units of PGA: [PGA] = g; *units of PSV:* [PSV] = cm/sec

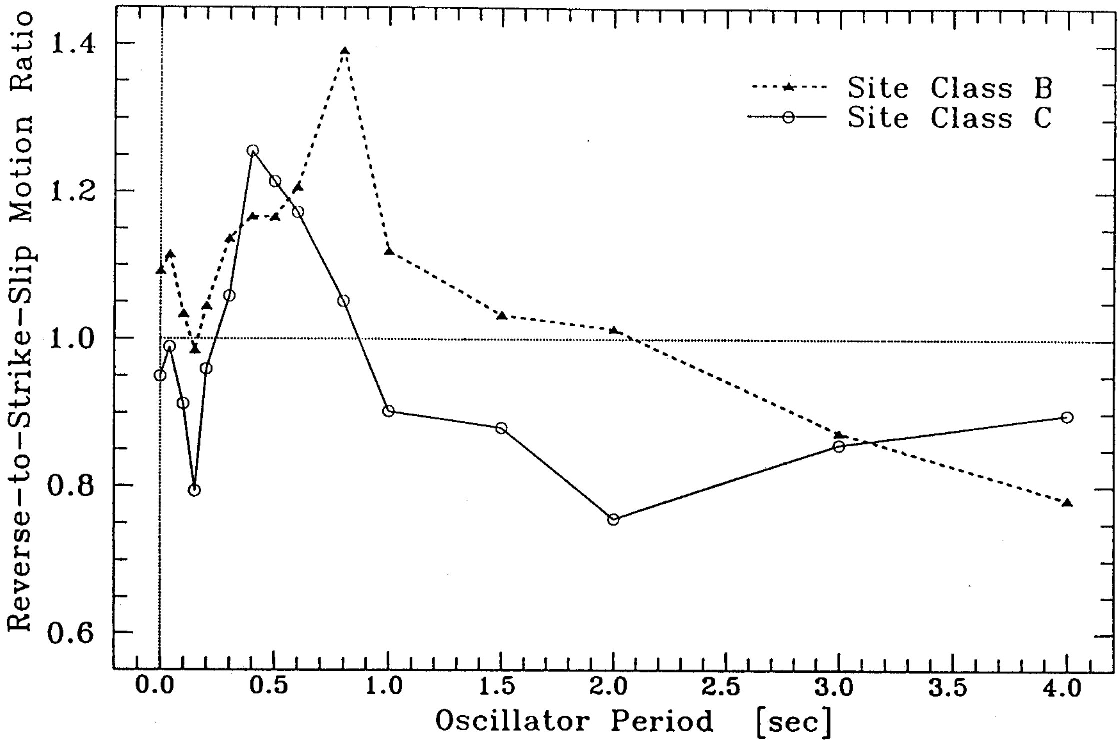


Figure 3. Ratio of Reverse to Strike-Slip Earthquake Ground Motion

The class B and class C regression equations were scaled to fit the class A and class D ground motion data. Specifically, the least-squares method was used to compute a factor k_1 such that $Y_A = k_1\ Y_B$. Similarly, a factor k_2 was computed such that $Y_D = k_2\ Y_C$. In these expressions, Y_i denotes ground-motion parameters for site class i. The k_1 and k_2 values were computed as a function of T and the median values are listed in Table 5. The possible dependence of k_i with the acceleration level was not obvious based on a visual examination of the residuals from the regressions. Plots of the median k_1 and k_2 values (including the ± 1σ limits) versus T are shown in the upper and lower frames, respectively, of Figure 4.

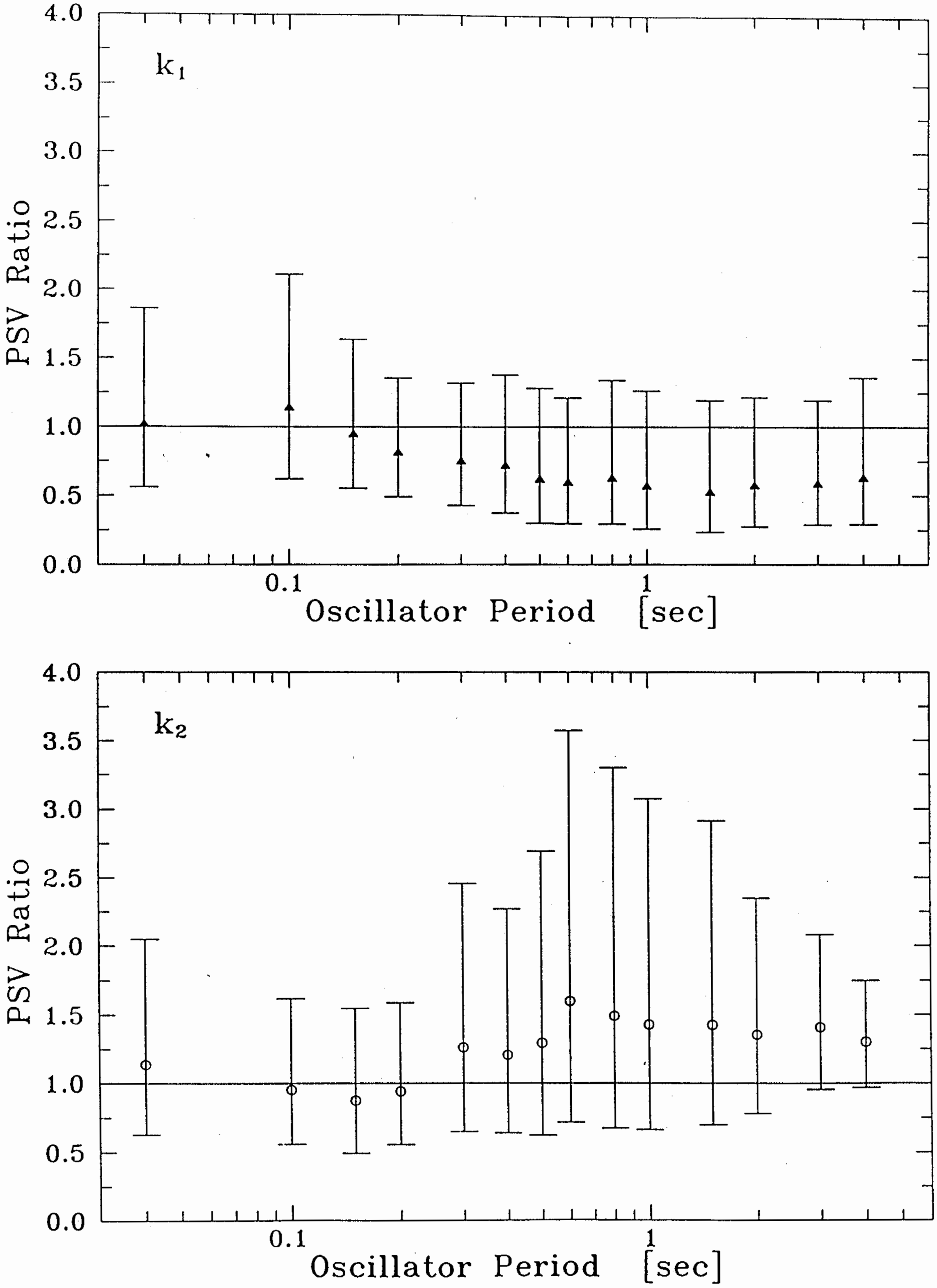


Figure 4. Median Values and ± 1 Sigma Limits of k_1 and k_2

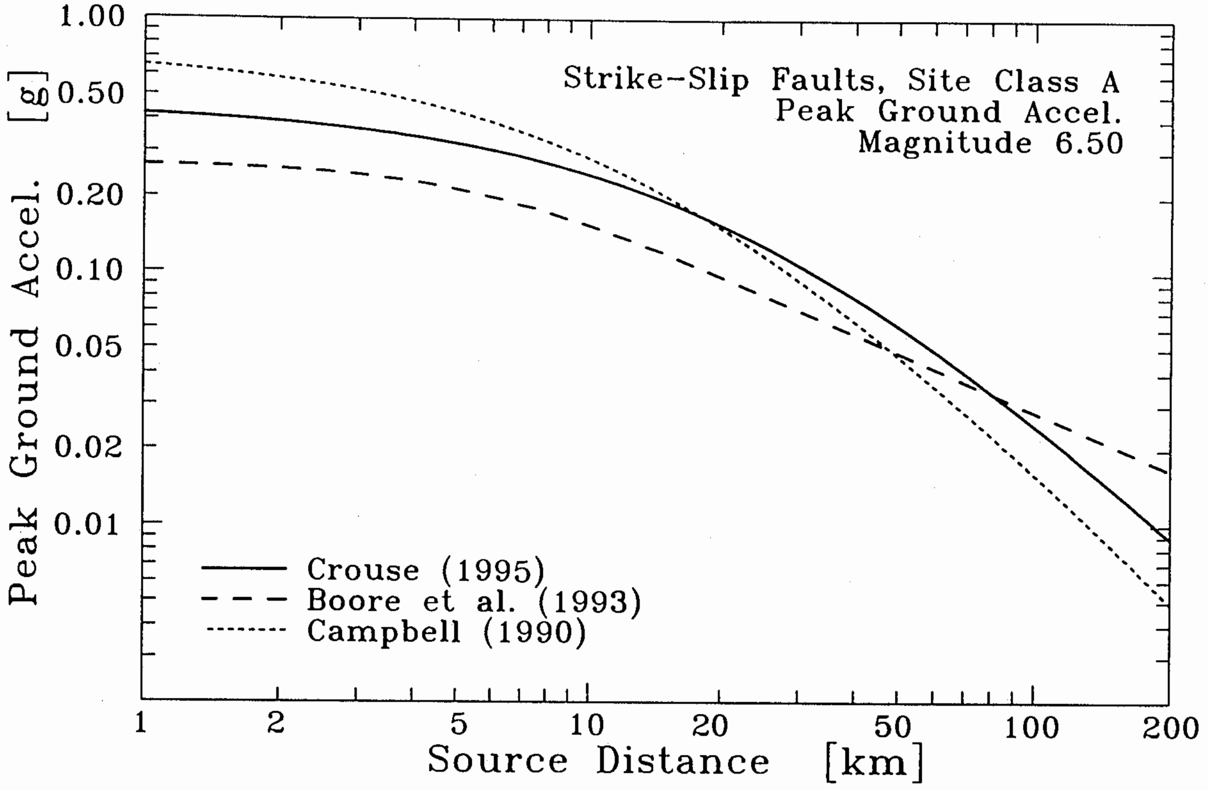
As expected from a visual examination of the results, the k_i are not significantly different from 1.0 at the 95th percentile confidence level for the shorter periods (i.e., $T \leq 0.15$ sec for k_1 and $T \leq 0.50$ sec for k_2). Values of k_1 significantly less than 1.0 at longer periods are consistent with results of Boore et al. (1993) who showed that longer period motions on rock sites are substantially less than those on soil sites.

Similarly, values of k_2 significantly greater than 1.0 at longer periods are consistent with Borcherdt's (1994) results for the 1989 Loma Prieta earthquake data, which showed that longer period motion on the soft soils were greater than those on the stiff soil.

COMPARISON WITH OTHER RELATIONSHIPS

The equations developed in this study were compared to those recently developed by Boore et al. (1993), Campbell (1990), Geomatrix (1992) and Idriss (1991). The Boore et al. equations pertain to site classes A, B and C; Campbell's equations pertain to soft rock (similar to site class B) and soil (similar to site class C). Geomatrix and Idriss state that their equations are applicable to rock sites although they do not present their databases to evaluate whether the equations are more suitable for hard rock (site class A) or soft rock (site class B) sites.

The attenuation of PGA and PSV (T = 1 sec) with distance for strike-slip earthquakes at $M = 6.5$ and 7.5 are compared in Figures 5, 6, 7 and 8 for site class A and in Figures 9 and 10 for site class C. The attenuation curves for Campbell are provided in Figures 5 and 7 with the knowledge that Campbell's equations (as mentioned above and explained in the next section) are more applicable to site class B than to site class A. The depth-to-basement-rock parameter, D, in Campbell's equations was set equal to zero for this case; to simulate site class C, it was set equal to 5 km. The attenuation curves at distances of 10



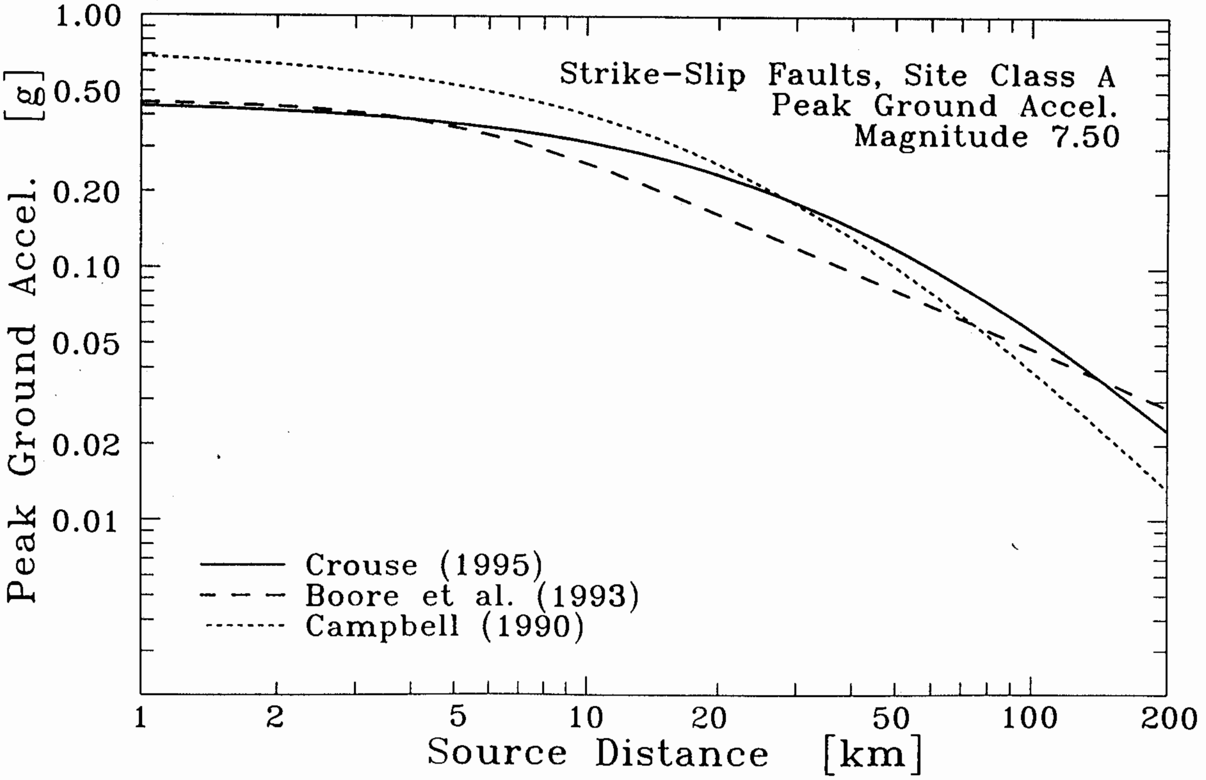
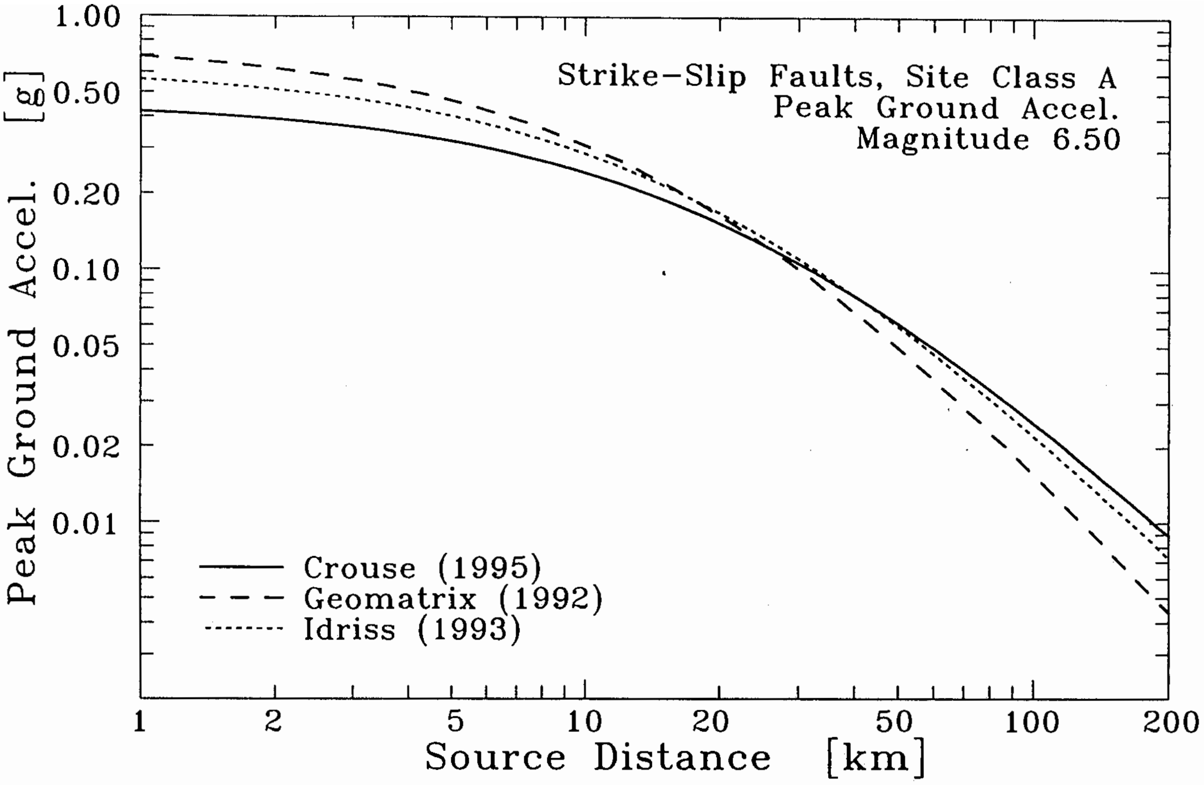


Figure 5. Comparison of Median PGA Attenuation Curves for this Study (Crouse, 1995), Boore et al. (1993), and Campbell (1990). Site Class A



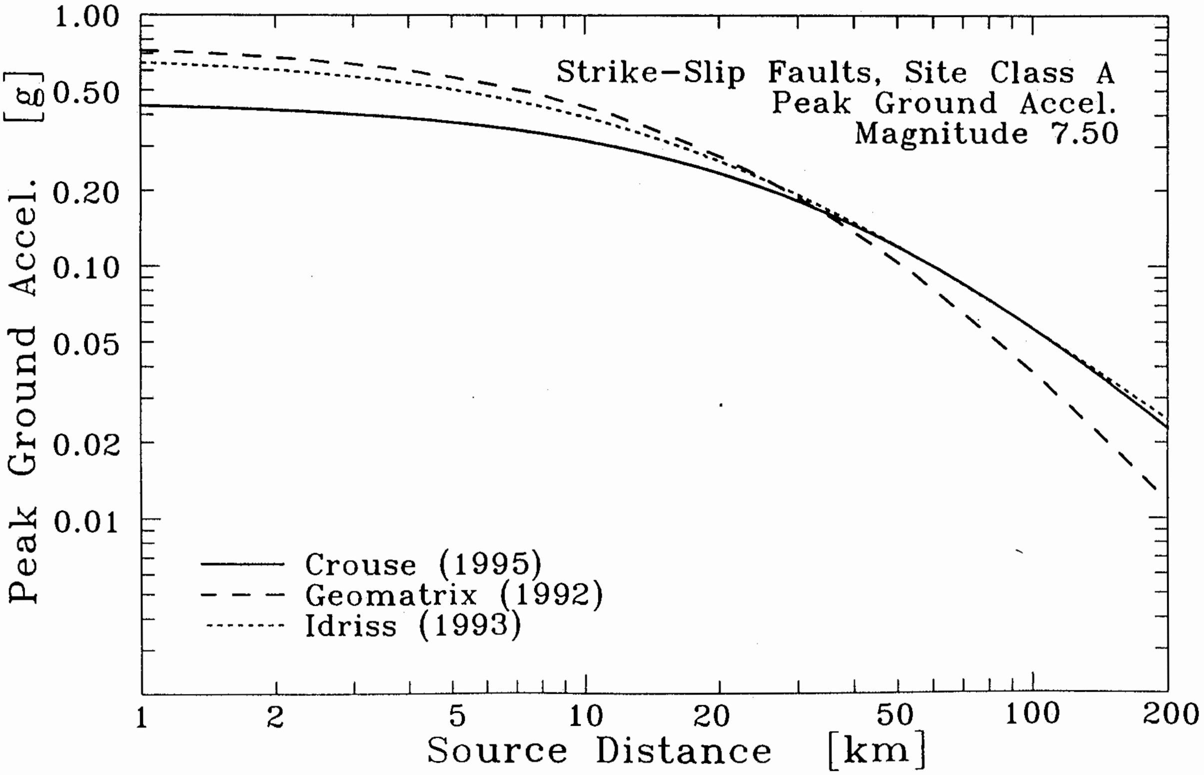


Figure 6. Comparison of Median PGA Attenuation Curves for this Study (Crouse, 1995), Geomatrix (1992), and Idriss (1993). Site Class A

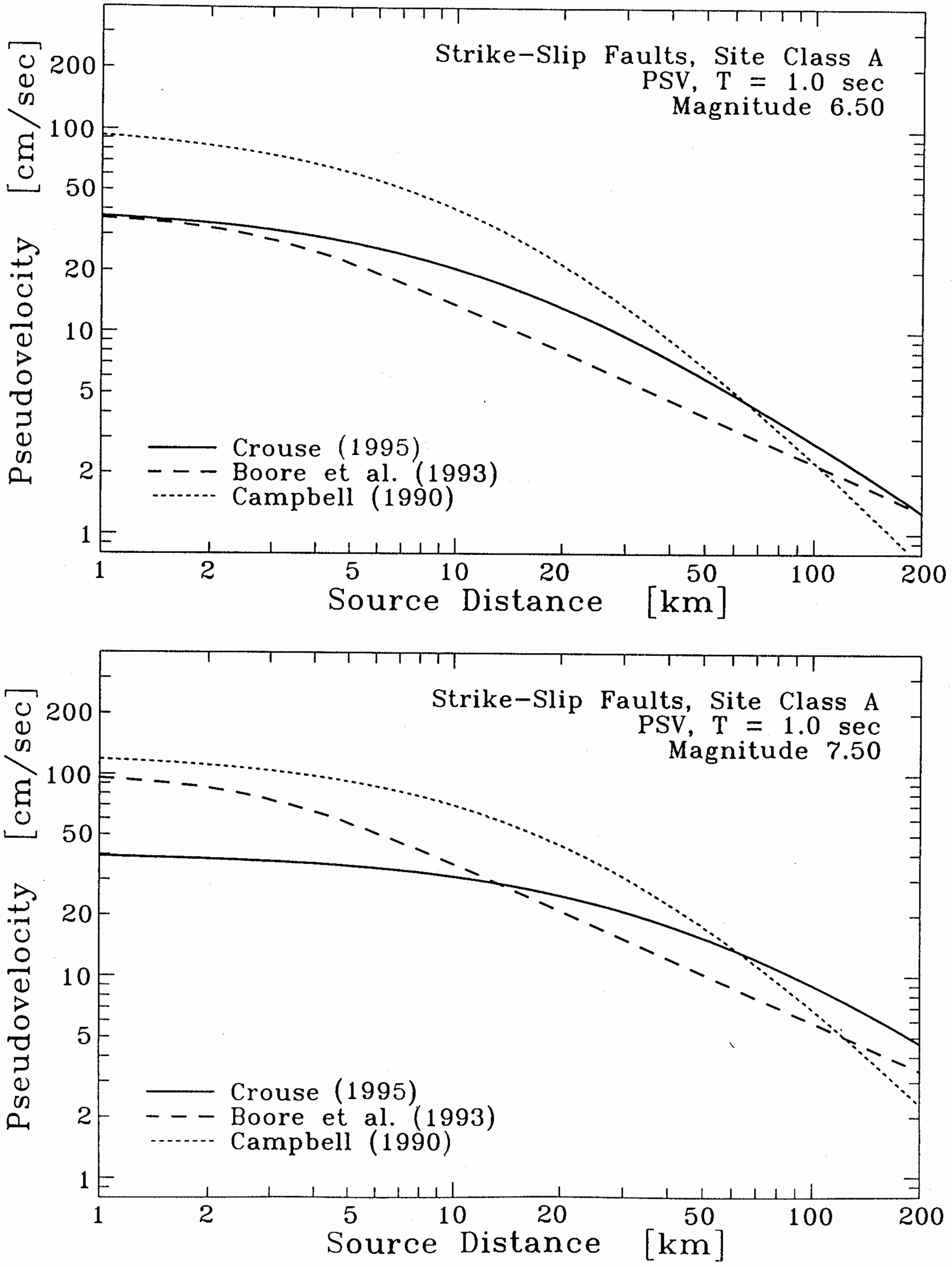


Figure 7. Comparison of Median PSV (T = 1 sec) Attenuation Curves for this Study (Crouse, 1995), Boore et al. (1993), and Campbell (1990). Site Class A

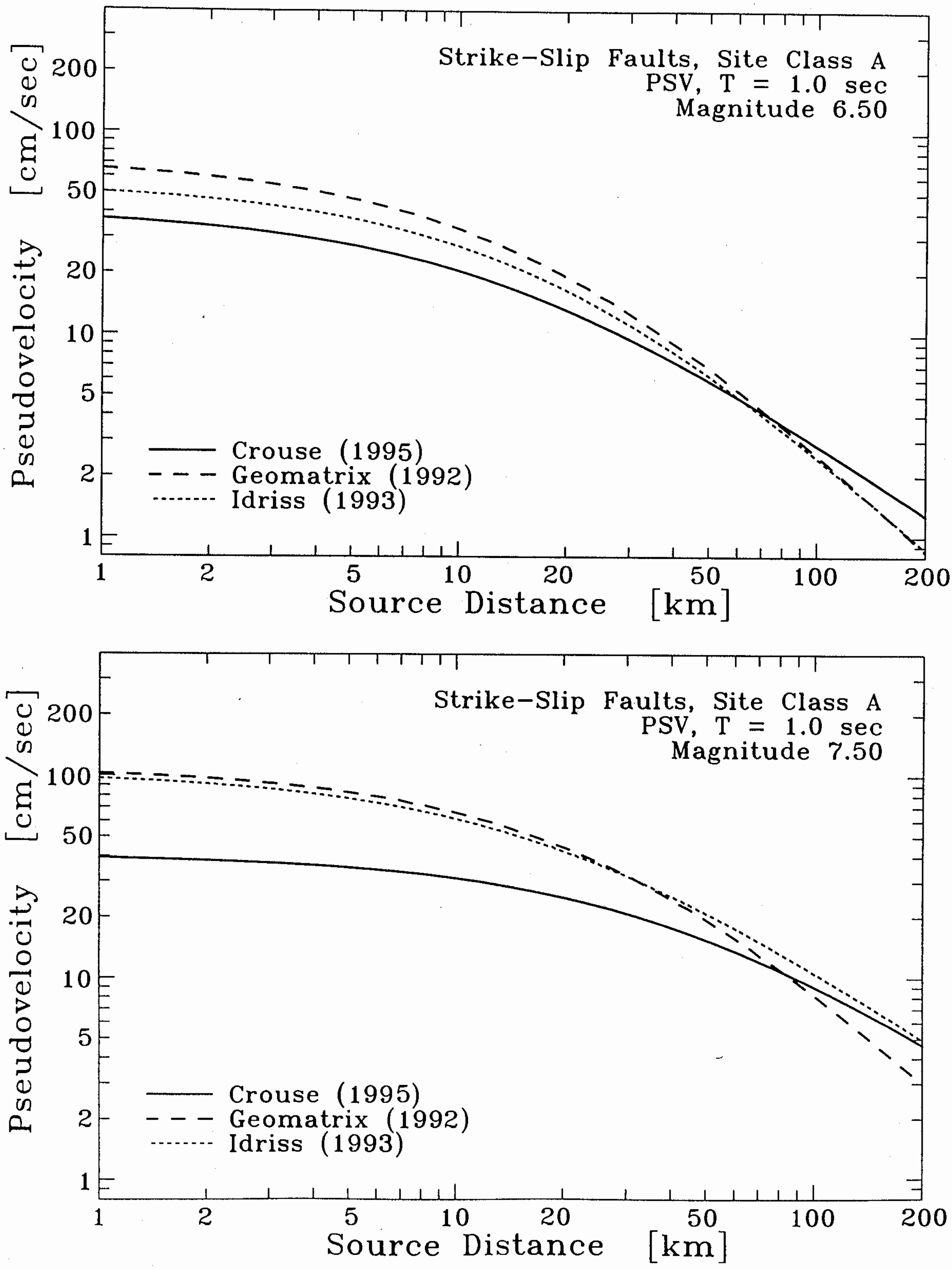


Figure 8. Comparison of Median PSV ($T = 1$ sec) Attenuation Curves for this Study (Crouse, 1995), Geomatrix (1992), and Idriss (1993). Site Class A

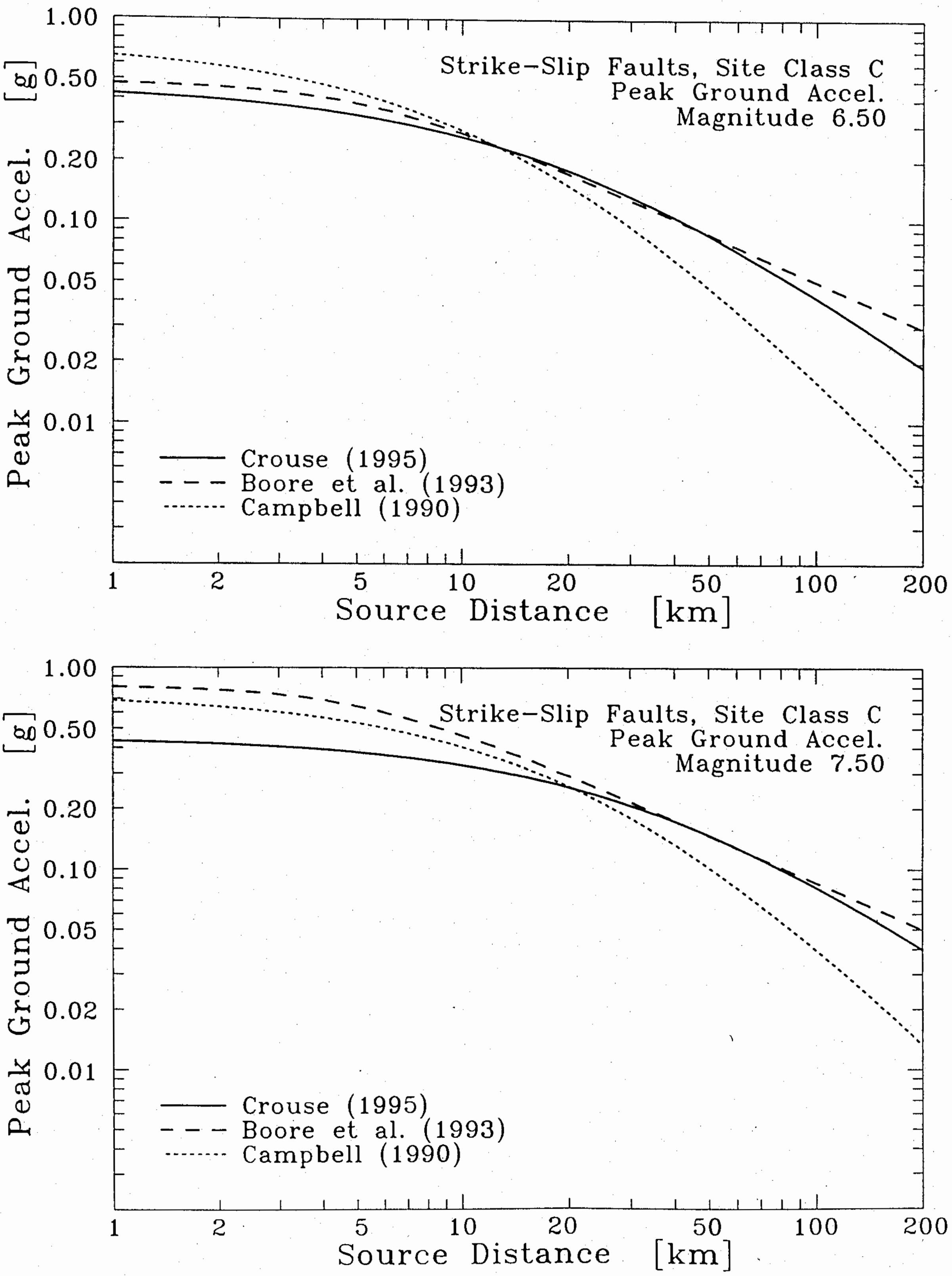
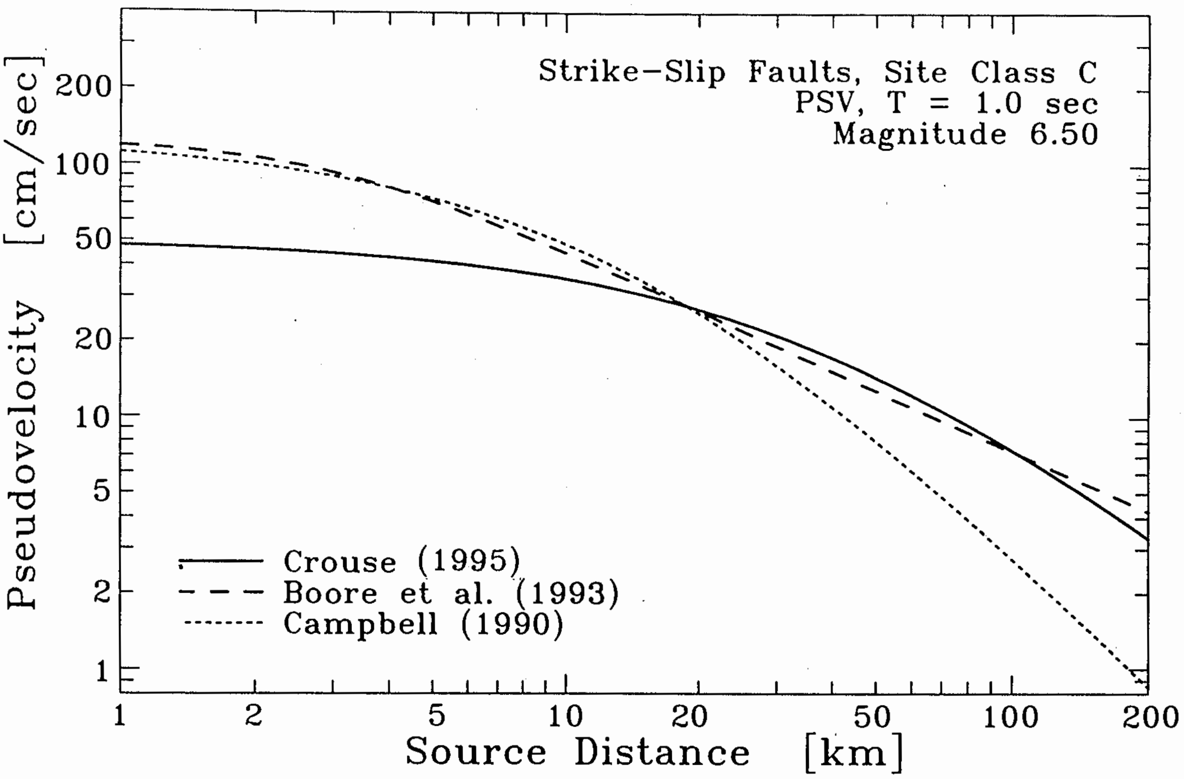


Figure 9. Comparison of Median PGA Attenuation Curves for this Study (Crouse, 1995), Boore et al. (1993), and Campbell (1990). Site Class C



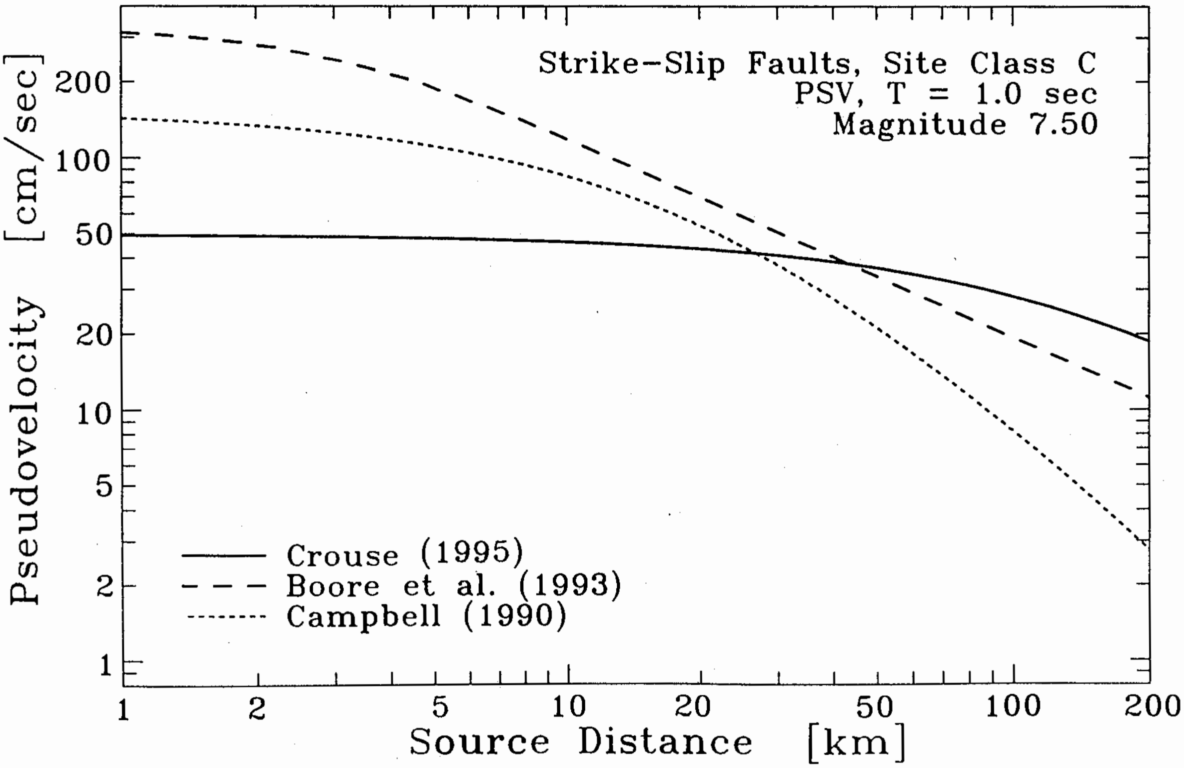


Figure10. Comparison of Median PSV ($T = 1$ sec) Attenuation Curves for this Study (Crouse, 1995), Boore et al. (1993), and Campbell (1990). Site Class C

to 80 km (where most of the data have been recorded) generally define a range of predicted ground motions that is a factor of two between the lowest and highest estimates. These differences are reasonable given the different databases, different regression models and analysis, and in some cases, different definitions of source-to-site distance and magnitude parameters among the relationships.

Table 5. Regression Results for k_1 and k_2

$$\begin{aligned} Y^{\mathrm{A},T} &= k_1^T \, Y^{\mathrm{B},T} \\ Y^{\mathrm{D},T} &= k_2^T \, Y^{\mathrm{C},T} \end{aligned}$$

Ground-Motion Parameter, $Y^{\alpha,T}$	Period T [sec]	k_1^T	k_2^T
PGA	...	0.998638	1.200678
PSV(T, ξ=5%)	0.04	1.023352	1.135611
⋮	0.10	1.144851	0.951057
⋮	0.15	0.952255	0.872571
⋮	0.20	0.817204	0.939360
⋮	0.30	0.753139	1.261232
⋮	0.40	0.719723	1.204849
⋮	0.50	0.620631	1.293272
⋮	0.60	0.600028	1.598795
⋮	0.80	0.629231	1.490827
⋮	1.00	0.572224	1.428036
⋮	1.50	0.529423	1.425156
⋮	2.00	0.578300	1.352620
⋮	3.00	0.589383	1.408488
PSV(T, ξ=5%)	4.00	0.632419	1.300720

units of PGA: g; *units of PSV:* cm/sec

AMPLIFICATION FACTORS AND RESPONSE SPECTRA

AMPLIFICATION FACTORS

The PGA and PSV equations for site classes A, B, C and D were then used to generate amplification factors, F_a and F_v , analogous to those originally recommended during the 1992 NCEER workshop. The workshop values of F_a and F_v were primarily derived from the results of SHAKE computer analyses of soil profiles representative of the different site classes and to a lesser extent from empirical studies of the 1989 Loma Prieta earthquake ground motions (Borcherdt, 1994); these values were functions of the ground acceleration level (0.1 g, 0.2 g, 0.3 g, 0.4 g, and 0.5 g). The F_a values from the present study were derived from similar rock-site acceleration levels (median $PGA_A = 0.1$ g, 0.2 g, 0.3 g, and 0.4 g) by computing the ratio PSV_i / PSV_A (where i = site classes B, C, and D) at period T = 0.3 sec for selected magnitude–distance combinations that yielded the proper acceleration values. Specifically, for each acceleration level, PGA_A, three magnitude values (M = 6.5, 7.0, and 7.5) and three acceleration values (PGA_A and $PGA_A \pm 0.05$ g) were considered; for each magnitude, the value of R required to yield each of the three acceleration values was computed. Thus, for a given acceleration level, nine (M, R) ordered pairs were used to compute nine values of PSV_i / PSV_A, which in turn were averaged to obtain the value of F_a for a given site class i. In this manner, values of F_a were determined at each acceleration level for site classes i = B, C, and D.

The F_v values were computed in a similar manner using the PSV (T = 1 sec) predictions. The strong-motion data were insufficient to estimate factors for PGA = 0.5 g. Our computed F_a and F_v factors are summarized in Table 6; the adjacent values in parentheses are the recommendations from the 1992

NCEER workshop (Martin and Dobry, 1994). The NCEER values listed for site class D are averages of the values for site classes D_1 and D_2 in Table 2.

Table 6. Amplification Factors, F_a and F_v

Amplification Factor, F_a, at $T = 0.3$ sec				
Site Class	Acceleration Level			
	0.1 g	0.2 g	0.3 g	0.4 g
A	1.0 (1.0)	1.0 (1.0)	1.0 (1.0)	1.0 (1.0)
B	1.3 (1.2)	1.3 (1.2)	1.3 (1.1)	1.3 (1.0)
C	1.6 (1.6)	1.5 (1.4)	1.4 (1.2)	1.3 (1.1)
D	2.1 (2.25)	1.9 (1.65)	1.8 (1.2)	1.7 (0.9)
Amplification Factor, F_v, at $T = 1.0$ sec				
A	1.0 (1.0)	1.0 (1.0)	1.0 (1.0)	1.0 (1.0)
B	1.8 (1.7)	1.8 (1.6)	1.8 (1.5)	1.8 (1.4)
C	2.3 (2.4)	1.7 (2.0)	1.4 (1.8)	1.2 (1.6)
D	3.2 (3.5)	2.5 (3.2)	2.1 (2.8)	1.8 (2.4)

Note: Values in ( ) are from the 1992 NCEER Workshop (Martin and Dobry, 1994)

For the most part, the computed values are similar to those recommended by NCEER. Differences in NCEER's and our values are greater than 20% for only three cases: 0.3 g - class D, 0.4 g - class B, and 0.4 g - class D. With one exception (0.1 g - class D), our F_a values are greater than NCEER's values, and the differences become greater as the acceleration level increases, which may be attributed to greater nonlinear response estimated by the analytical models employed in the NCEER studies. Such effects would not be revealed for site class B in our study because of the manner in which our F_a factors for this site class were derived. A constant factor, k_1, was computed to scale the class B regression equation to fit the class A data as explained in the previous section. Because of the lack of class A data, this factor was, of necessity, independent of acceleration level, which resulted in the calculation of a constant value of F_a for site class B.

For acceleration levels of 0.2 g, 0.3 g and 0.4 g, our F_v values for site Class C are smaller than our F_v values for site Class B, whereas, the opposite, more intuitive, trend is observed in the NCEER values. This characteristic of our results was also noted and addressed in the response spectral comparisons in the following subsection.

SITE - DEPENDENT SPECTRA AND REVISED F_v VALUES

To provide an indication of the differences in site-dependent spectra, response spectra for site classes A, B, C, and D were computed for several values of M and R by substituting these values into the equations derived in the previous section (see Tables 4 and 5). A typical example is shown in Figure 11 for an $M = 7.0$ strike-slip event at $R = 10$ km. In this figure the differences in the spectra, which are representative of the 0.3 g acceleration level, are fairly consistent with the differences in the F_a and F_v values in Table 4. Note that at $T = 1.0$ sec, the spectral acceleration for site class C is less than the spectral acceleration for site class B , which is consistent with the F_v values for 0.3 g in Table 6 for classes B and C. However, in Figure 11 the class C spectra are larger than the class B spectra at $T > 1.0$ sec, which is intuitively expected and which was consistently observed in the spectra computed at other (M, R) values. Because the F_v values proposed in the 1992 NCEER workshop were intended to represent the amplification over the intermediate period (constant spectral velocity) range of the spectrum, some revisions to several of the F_v values in Table 6 are required. The revision consisted of repeating the calculations of F_v values at $T = 2.0$ and 3.0 sec and averaging the results for $T = 1.0$, 2.0 and 3.0 sec. The resulting values of F_v are listed in Table 7.

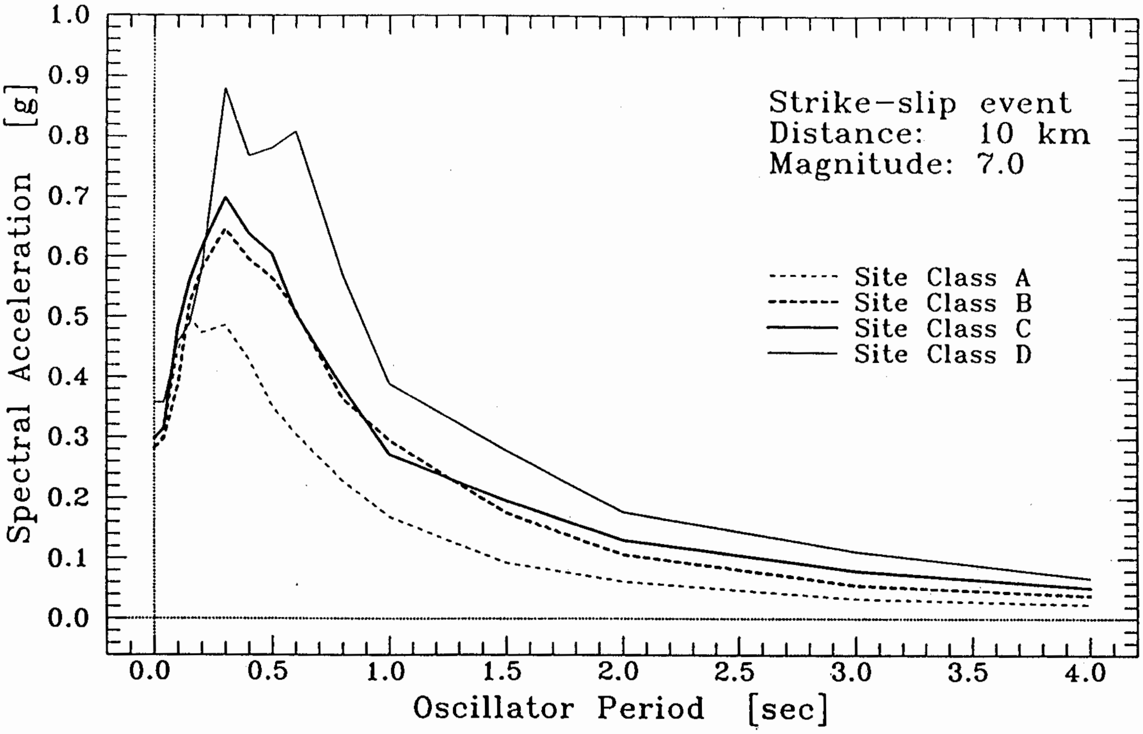


Figure 11. Median Site-Dependent Response Spectra for 5% Damping

Table 7. Average of F_v Values Computed at T = 1.0, 2.0 and 3.0 sec

Site Class	Acceleration Level 0.1 g	0.2 g	0.3 g	0.4 g
A	1.0 (1.0)	1.0 (1.0)	1.0 (1.0)	1.0 (1.0)
B	1.7 (1.7)	1.7 (1.6)	1.7 (1.5)	1.7 (1.4)
C	2.0 (2.4)	2.0 (2.0)	1.9 (1.8)	1.9 (1.6)
D	2.9 (3.5)	2.7 (3.2)	2.6 (2.8)	2.6 (2.4)

Note: Values in ( ) are from the 1992 NCEER Workshop (Martin and Dobry, 1994)

The values in this table are consistent with the expectation of increasing amplification for decreasing soil stiffness for a given acceleration level. The values are also more consistent with those from the 1992 NCEER workshop, and in no cases are they more than 20% different from the NCEER values. Again, some of the differences in our results and NCEER's may be due to greater nonlinear response resulting from the analytical models used in the NCEER studies.

COMPARISONS WITH RESPONSE SPECTRA PREDICTED BY OTHER RELATIONSHIPS

Site-dependent response spectra estimated with the equations developed in this study were compared with spectra estimated from the same attenuation equations considered in the previous section (i.e., Boore et al., 1993; Campbell, 1990; Geomatrix, 1992; Idriss, 1993). An example is shown in Figures 12 and 13 for the $M = 7.0$ strike-slip event at $R = 10$ km. Figure 12 shows the spectra predicted for class A while Figure 13 shows the spectra for class C sites. As previously explained, the depth-to-basement-rock parameter (D) in Campbell's equations was set equal to zero in an attempt to simulate site class A; to simulate site class C, the parameter D was set equal to 5 km. The differences among the spectra in Figures 12 and 13 are expected given the differences in databases, regression equations and analyses, and parameter definitions such as magnitude and distance. For example, for site class A, the Crouse and Boore et al. spectra are similar and both are significantly lower than the Campbell, Geomatrix and Idriss spectra. The much larger Campbell spectrum is believed to be primarily the result of his rock database, which he defines as soft rock. Most of his soft rock data would fall into the site class B category rather than into site class A. Thus, Campbell's (1990) equations are not recommended for class A sites.

The Geomatrix and Idriss spectra in Figure 12 are more similar to the Campbell spectrum than to the Crouse or Boore et al. spectrum. Based on observation in the previous paragraph regarding Campbell's database, this result at first glance suggests that the Geomatrix and Idriss databases consist of mainly records from soft rock sites. However, this is pure speculation because the Geomatrix and Idriss databases have not been published and other factors may be affecting the results.

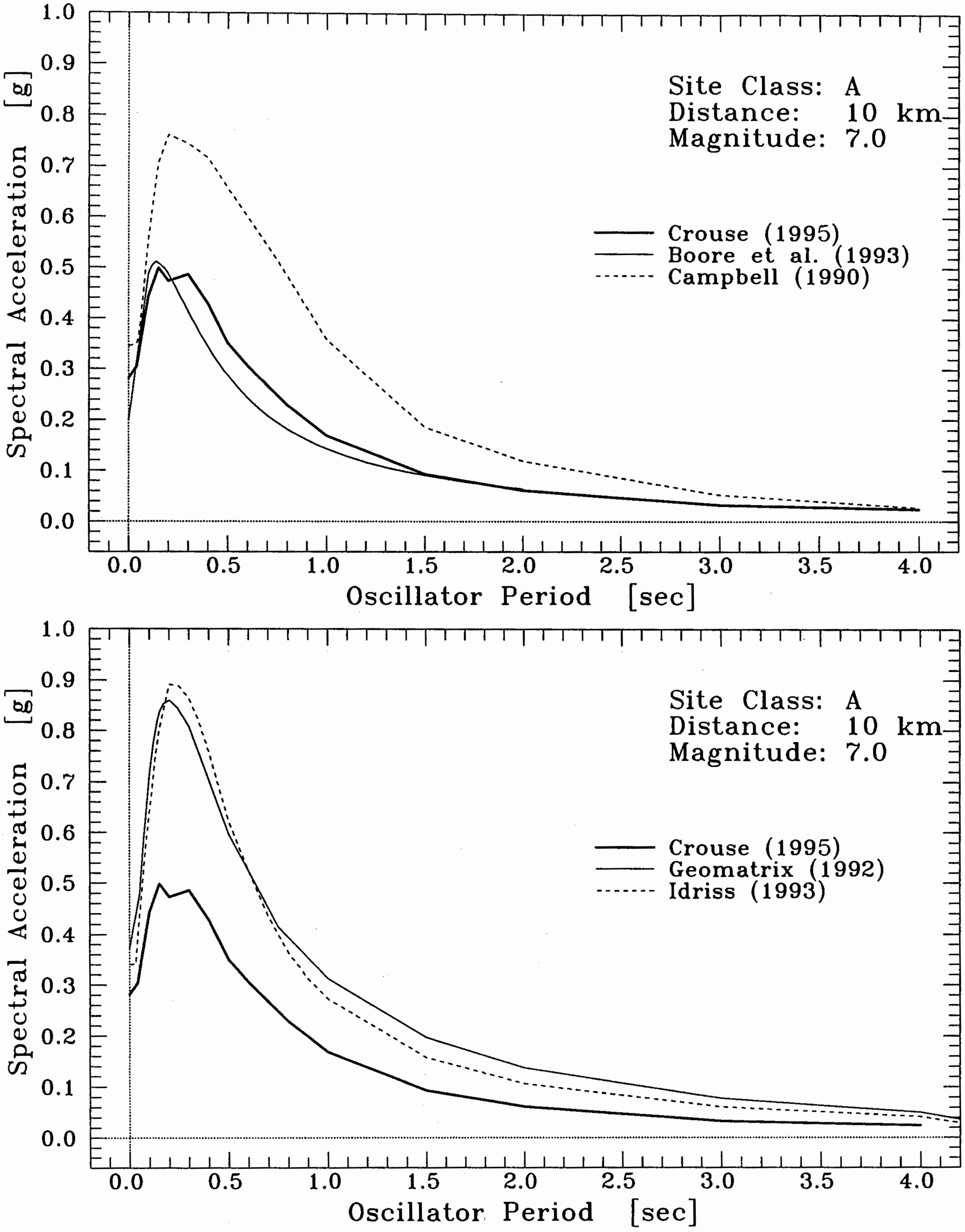


Figure 12. Comparison of 5% Damped Median Response Spectra for Magnitude 7.0 Strike-Slip Earthquake. Site Class A

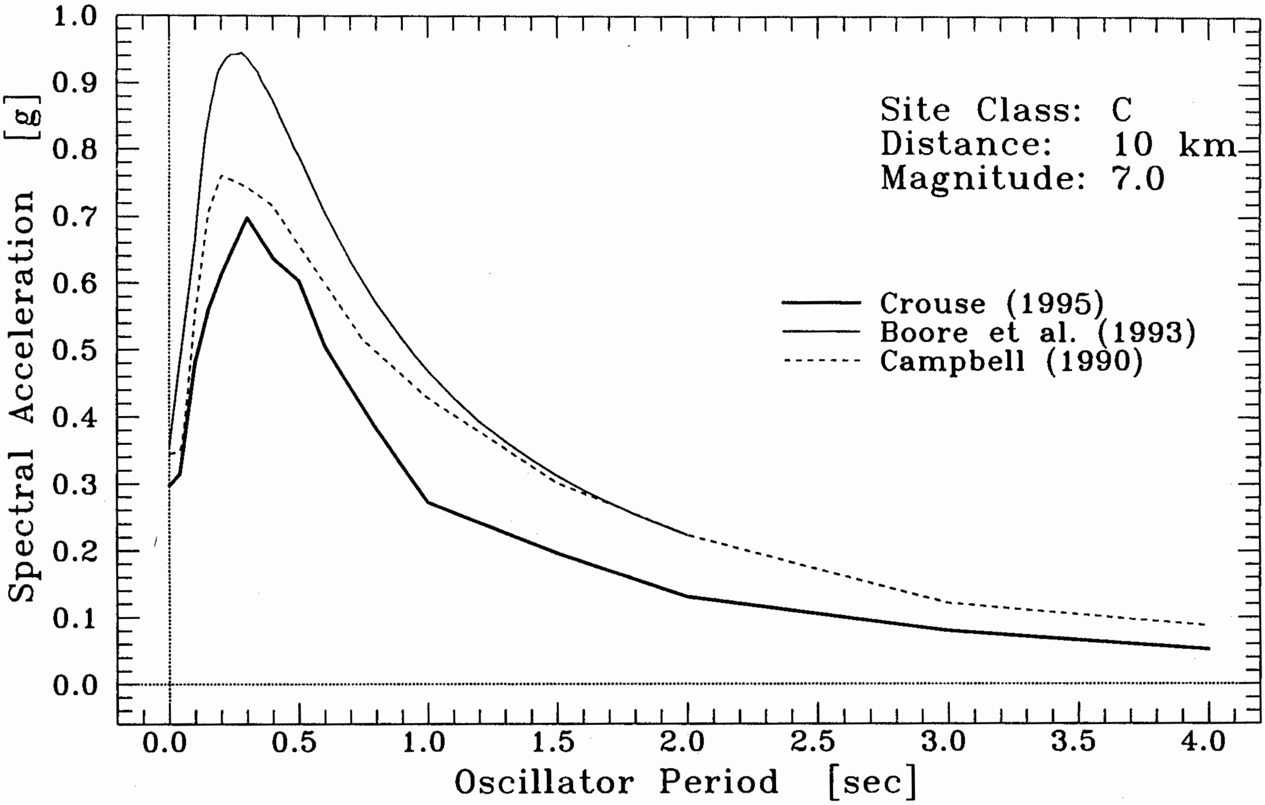


Figure 13. Comparison of 5% Damped Median Response Spectra for Magnitude 7.0 Strike-Slip Earthquake. Site Class C

Precise reasons for the differences in the class C spectra in Figure 13 are less obvious. The reason the Boore et al. spectrum is greater than the Crouse spectrum may be due to the different magnitude scales employed. Boore et al. use the moment magnitude scale and their magnitude values are less than the M_s values used in this study with one minor exception. Thus, other factors being equal, the Boore et al. equations would estimate higher spectra for a given magnitude value than the equations developed for this study. Further analysis would be required to explain the differences in Figure 13, especially with regard to the spectrum of Campbell, whose magnitude definition is similar to that employed in this study. Such analysis was outside the scope of this study.

CONCLUSIONS

The results of this study provide estimates of the spectral amplification due to differences in local geology. The amount and distribution of the strong-motion data suggest that the results are more reliable for ground acceleration levels of approximately 0.1 to 0.3 g for class A, B, and C sites. These acceleration levels roughly correspond to the $M = 6 - 7.25$ and $R = 10 - 80$ km ranges where a reasonable amount of data exist. The results for 0.4 g and for class D sites at all acceleration levels are more uncertain. As a final note, the equations presented herein were developed to estimate site amplification factors and were not developed for seismic hazard analyses. The author cautions potential users of these equations for such analyses, especially for near-field conditions ($R < 10$ km), where the database used to derive the equations is recognized as being limited.

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APPENDIX A. STRONG MOTION DATABASE

The strong motion database used in the regression analyses is listed in Table A1 on the following pages. Explanations of some of the column headings are provided in the Notes section at the end of the table. References for the strong motion data and local station geology follow Table A1.

TABLE 1A. STRONG MOTION DATABASE

Earthquake			Fault	Station		Structure	Station Location		Site	Geologic	Closest Approach	PGA [g]			Strong Motion
Yr.Mo.Dy	Location	Ms	Type	Desig.	Name	Code	Latitude	Longitude	Class	Reference	Distance [km]	H1	H2	V	Data Source
66.06.28	Central California	6.1	S	1083	San Luis Obispo, City Recreation Bldg	2/	35.280 °N	120.660 °W	A	(2),(15),(20)	63.6	0.01	0.01	0.01	(7),(4)
71.02.09	San Fernando	6.5	R	279	Pacoima Dam		34.334 °N	118.396 °W	A	(15),(20)	3.2	1.17	1.08	0.71	(7),(4)
71.02.09	San Fernando	6.5	R	141	Los Angeles, Griffith Park Observatory		34.120 °N	118.300 °W	A	(7)	18.0	0.18	0.17	0.12	(7),(4)
71.02.09	San Fernando	6.5	R	266	Pasadena, CIT Kresge (Old) Seism. Lab.	2/1	34.149 °N	118.171 °W	A	(7),(15),(20),(28)	19.0	0.09	0.19	0.09	(7),(4)
71.02.09	San Fernando	6.5	R	127	Lake Hughes, Array Station 9	1/0	34.608 °N	118.558 °W	A	(7),(27),(19)	23.0	0.12	0.11	0.07	(7),(4)
71.02.09	San Fernando	6.5	R	126	Lake Hughes, Array Station 4	1/0	34.640 °N	118.480 °W	A	(15)	24.0	0.17	0.15	0.15	(7),(4)
71.02.09	San Fernando	6.5	R	104	Arcadia, Santa Anita Reservoir		34.190 °N	118.020 °W	A	(8),(28)	25.0	0.14	0.17	0.05	(7),(4)
79.10.15	Imperial Valley	6.8	S	286	Superstition Mountain	1/	32.955 °N	115.823 °W	A	(27),(8)	26.0	0.11	0.19	0.08	(7),(5)
81.04.26	Westmorland	6.0	S	286	Superstition Mountain	1/	32.955 °N	115.823 °W	A	(27),(8)	22.0	0.11	0.09	0.06	(7)
83.05.02	Coalinga	6.7	R	46175	Slack Canyon		36.034 °N	120.590 °W	A	(8)	31.9	0.17	0.14	0.05	(1)
84.04.24	Morgan Hill	6.1	S	47379	Gilroy #1, Gavilan College Water Tank		36.973 °N	121.572 °W	A	(3),(6)	16.0	0.10	0.07	0.10	(1)
86.07.08	Palm Springs	6.0	S	12206	Silent Valley, Poppet Flat		33.851 °N	116.852 °W	A	(28)	23.7	0.12	0.15	0.10	(1)
86.07.08	Palm Springs	8.0	S	13200	Winchester, Hidden Valley Farms, Newport Rd.		33.681 °N	117.056 °W	A	(1)	49.8	0.08	0.09	0.04	(1)
86.07.08	Palm Springs	6.0	S	13199	Winchester, Bergman Ranch		33.640 °N	117.094 °W	A	(1)	55.3	0.10	0.07	0.08	(1)
86.07.08	Palm Springs	6.0	S	13198	Murrieta Hot Springs, Collins ranch		33.599 °N	117.132 °W	A	(1)	61.0	0.05	0.05	0.03	(1)
86.07.21	Chalfant Valley	6.2	S	54214	Long Valley Dam (Upper Left Abutment)		37.588 °N	118.705 °W	A	(8)	22.6	0.07	0.08	0.08	(1)
87.10.01	Whittier	6.1	R	80054	Pasadena, CIT Kresge (Old) Seism. Lab.	2/1	34.149 °N	118.171 °W	A	(7),(15),(20),(28)	18.2	0.11	0.09	0.08	(1)
87.10.01	Whittier	6.1	R	24399	Mt Wilson, CIT Seismic Station		34.224 °N	118.057 °W	A	(28)	22.1	0.18	0.13	0.12	(1)
87.10.01	Whittier	6.1	R	141	Los Angeles, Griffith Park Observatory		34.120 °N	118.300 °W	A	(7)	22.3	0.12	0.14	0.06	(7)
89.10.17	Loma Prieta	7.1	S	47379	Gilroy #1, Gavilan College Water Tank		36.973 °N	121.572 °W	A	(3),(6)	10.9	0.49	0.43	0.22	(1)
89.10.17	Loma Prieta	7.1	S	1032	Hollister SAGO Vault (Tunnel)		36.785 °N	121.446 °W	A	(3)	28.2	0.06	0.04	0.05	(7)
89.10.17	Loma Prieta	7.1	S	47189	Hollister, SAGO South, Cinega Road (Surface)		36.753 °N	121.396 °W	A	(3),(26)	32.4	0.07	0.07	0.06	(1)
89.10.17	Loma Prieta	7.1	S	47377	Monterey City Hall	1/	36.597 °N	121.897 °W	A	(3),(26)	41.8	0.07	0.07	0.03	(1)
89.10.17	Loma Prieta	7.1	S	1476	Bear Valley Stn #7, Pinnacles Natl. Monument		36.483 °N	121.180 °W	A	(3)	67.1	0.04	0.06	0.03	(7)
89.10.17	Loma Prieta	7.1	S	58539	South San Francisco, Sierra Point		37.674 °N	122.388 °W	A	(3),(26)	68.2	0.11	0.06	0.05	(1)
89.10.17	Loma Prieta	7.1	S	58130	San Francisco, Diamond Heights	2/	37.740 °N	122.433 °W	A	(3),(26)	76.6	0.11	0.10	0.05	(1)
89.10.17	Loma Prieta	7.1	S	58338	Piedmont, Piedmont Jr. High Grounds		37.823 °N	122.233 °W	A	(3),(26)	77.9	0.08	0.07	0.03	(1)
89.10.17	Loma Prieta	7.1	S	58151	San Francisco, Rincon Hill		37.786 °N	122.391 °W	A	(3),(26)	79.2	0.09	0.08	0.03	(1)
89.10.17	Loma Prieta	7.1	S	58131	San Francisco, Pacific Heights	2/	37.790 °N	122.429 °W	A	(3),(26)	81.2	0.05	0.06	0.03	(1)
89.10.17	Loma Prieta	7.1	S	58043	Point Bonita		37.820 °N	122.520 °W	A	(3),(26)	88.1	0.07	0.07	0.03	(1)
92.06.28	Landers	7.5	S	SCE–L	Lucerne Valley		34.568 °N	116.812 °W	A	(28)	1.8	0.74	0.84	0.75	(6)
92.06.28	Landers	7.5	S	22161	Twentynine Palms, Park Maintennance Bldg	1/	34.021 °N	116.009 °W	A	(1)	33.4	0.07	0.09	0.04	(1)
92.06.28	Landers	7.5	S	12206	Silent Valley, Poppet Flat		33.851 °N	116.852 °W	A	(8),(28)	49.9	0.05	0.06	0.05	(1)
33.03.11	Long Beach	6.2	S	131	Long Beach, Utility Bldg	3/1	33.770 °N	118.190 °W	B	(2),(8)	5.0	0.20	0.16	0.29	(7),(9)
52.07.21	Kern County	7.7	R	1094	Taft, Lincoln School Tunnel	2/0	35.150 °N	119.460 °W	B	(27),(2),(18),(6),(20)	42.0	0.16	0.18	0.10	(7),(4)
52.07.21	Kern County	7.7	R	283	Santa Barbara Courthouse	2/1	34.420 °N	119.700 °W	B	(27),(2),(18),(7),(20)	85.0	0.09	0.13	0.04	(7),(4)
52.07.21	Kern County	7.7	R	475	Pasadena, CIT Athenaeum	2/1	34.139 °N	118.121 °W	B	(2),(7)	109.0	0.05	0.05	0.03	(7),(4)
66.06.28	Central California	6.1	S	1097	Parkfield, Cholame (Shandon Temblor)		35.710 °N	120.170 °W	B	(6)	11.3	0.27	0.35	0.13	(7),(4)
66.06.28	Central California	6.1	S	1016	Parkfield, Cholame 12W (Shandon Sta. 12)		35.639 °N	120.404 °W	B	(23),(6),(8)	15.0	0.05	0.06	0.05	(7),(4)
66.06.28	Central California	6.1	S	1094	Taft, Lincoln School Tunnel	2/0	35.150 °N	119.460 °W	B	(27),(2),(18),(6),(20)	131.0	0.01	0.01	0.01	(7),(4),(9)
66.04.09	Borrego Mountain	6.7	S	280	San Onofre, SCE Power Plant	1/0	33.370 °N	117.560 °W	B	(15)	122.0	0.04	0.05	0.06	(7),(4)
68.04.09	Borrego Mountain	6.7	S	475	Pasadena, CIT Athenaeum	2/1	34.139 °N	118.121 °W	B	(2),(7)	196.0	0.01	0.01	0.00	(7),(4)
71.02.09	San Fernando	6.5	R	122	Glendale, 633 E Broadway	3/1	34.150 °N	118.250 °W	B	(15),(18),(20)	18.0	0.27	0.21	0.13	(7),(4)
71.02.09	San Fernando	6.5	R	128	Lake Hughes, Array Station 12	1/0	34.570 °N	118.560 °W	B	(15),(28)	21.0	0.35	0.28	0.11	(7),(4)
71.02.09	San Fernando	6.5	R	262	Palmdale Fire Station	1/0	34.580 °N	118.110 °W	B	(5)	24.0	0.11	0.14	0.09	(7),(4)
71.02.09	San Fernando	6.5	R	475	Pasadena, CIT Athenaeum	2/1	34.139 °N	118.121 °W	B	(2),(7)	24.0	0.10	0.11	0.09	(7),(4)
71.02.09	San Fernando	6.5	R	125	Lake Hughes, Array Station 1	1/0	34.680 °N	118.440 °W	B	(5),(19),(20)	25.0	0.15	0.11	0.09	(7),(4)
71.02.09	San Fernando	6.5	R	110	Castaic, Old Ridge Route	1/	34.560 °N	118.660 °W	B	(7),(15),(20)	28.0	0.32	0.27	0.16	(7),(4)
71.02.09	San Fernando	6.5	R	585	Pearblossom Pump Plant	1/0	34.510 °N	117.920 °W	B	(5)	36.0	0.09	0.12	0.05	(7),(4)
71.02.09	San Fernando	6.5	R	411	Palos Verdes Estates, 2518 Via Tejon	2/	33.800 °N	118.380 °W	B	(7),(15),(20)	52.0	0.03	0.04	0.02	(7),(4)
71.02.09	San Fernando	6.5	R	131	Long Beach, Utility Bldg	3/1	33.770 °N	118.190 °W	B	(2),(8)	58.0	0.03	0.02	0.01	(7),(4)
71.02.09	San Fernando	6.5	R	290	Wrightwood, 6074 Park Dr.	2/0	34.360 °N	117.630 °W	B	(7)	59.0	0.04	0.06	0.02	(7),(4)
71.02.09	San Fernando	6.5	R	1102	Wheeler Ridge, Ground Station		35.030 °N	119.010 °W	B	(7)	80.0	0.03	0.03	0.01	(7),(4)
71.02.09	San Fernando	6.5	R	282	Goleta, UCSB Fluid Mech. Lab.	1/	34.410 °N	119.850 °W	B	(15),(20)	120.0	0.02	0.02	0.01	(7),(4)

TABLE 1A. STRONG MOTION DATABASE

Earthquake			Fault	Station		Structure	Station Location		Site	Geologic	Closest Approach	PGA [g]			Strong Motion
Yr.Mo.Dy	Location	Ms	Type	Desig.	Name	Code	Latitude	Longitude	Class	Reference	Distance [km]	H1	H2	V	Data Source
71.02.09	San Fernando	6.5	R	280	San Onofre, SCE Power Plant	1/0	33.370 °N	117.560 °W	B	(15)	121.0	0.01	0.02	0.01	(7),(4)
79.10.15	Imperial Valley	6.8	S	5051	El Centro, Parachute Test Facility	1/	32.930 °N	115.700 °W	B	(14)	15.0	0.20	0.11	0.16	(7),(9)
81.04.26	Westmorland	6.0	S	5051	El Centro, Parachute Test Facility	1/	32.930 °N	115.700 °W	B	(14)	19.0	0.23	0.16	0.16	(1)
83.05.02	Coalinga	6.7	R	36453	Parkfield, Fault Zone 11		35.896 °N	120.398 °W	B	(8)	33.1	0.09	0.08	0.04	(1)
83.05.02	Coalinga	6.7	R	36439	Parkfield, Gold Hill 3E		35.870 °N	120.334 °W	B	(8)	34.1	0.07	0.10	0.06	(1)
83.05.02	Coalinga	6.7	R	36438	Parkfield, Stone Corral 4E		35.855 °N	120.281 °W	B	(8)	35.1	0.07	0.07	0.03	(1)
83.05.02	Coalinga	6.7	R	36454	Parkfield, Fault Zone 6		35.859 °N	120.420 °W	B	(8)	37.6	0.06	0.06	0.03	(1)
83.05.02	Coalinga	6.7	R	36414	Parkfield, Fault Zone 4		35.836 °N	120.395 °W	B	(8)	39.2	0.12	0.07	0.05	(1)
83.05.02	Coalinga	6.7	R	36416	Parkfield, Gold Hill 2W		35.812 °N	120.391 °W	B	(8)	41.6	0.08	0.08	0.04	(1)
83.05.02	Coalinga	6.7	R	36420	Parkfield, Gold Hill 3W		35.796 °N	120.411 °W	B	(8)	43.8	0.12	0.14	0.07	(1)
83.05.02	Coalinga	6.7	R	36450	Parkfield, Cholame 3E		35.770 °N	120.247 °W	B	(8)	44.4	0.05	0.04	0.03	(1)
83.05.02	Coalinga	6.7	R	36433	Parkfield, Gold Hill 4W		35.785 °N	120.444 °W	B	(8)	46.0	0.10	0.06	0.03	(1)
83.05.02	Coalinga	6.7	R	36441	Parkfield, Vineyard Canyon 6W		35.861 °N	120.600 °W	B	(8)	46.3	0.08	0.05	0.04	(1)
83.05.02	Coalinga	6.7	R	36230	Parkfield, Cholame 2E (Temblor II)		35.752 °N	120.264 °W	B	(8)	46.4	0.04	0.03	0.02	(1)
83.05.02	Coalinga	6.7	R	36411	Parkfield, Cholame 4W		35.718 °N	120.304 °W	B	(8)	50.3	0.13	0.13	0.04	(1)
83.05.02	Coalinga	6.7	R	36229	Parkfield, Cholame 12W (Shandon Sta. 12)		35.639 °N	120.404 °W	B	(23),(6),(8)	60.4	0.05	0.02	0.04	(1)
84.04.24	Morgan Hill	6.1	S	1652	Anderson Dam, Downstream		37.166 °N	121.628 °W	B	(3),(8)	3.9	0.29	0.42	0.21	(7),(2)
84.04.24	Morgan Hill	6.1	S	57383	Gilroy #6, San Ysidro Microwave Site		37.026 °N	121.484 °W	B	(3),(6)	11.5	0.29	0.23	0.43	(1),(2)
84.04.24	Morgan Hill	6.1	S	47006	Gilroy, Gavilan College Phys. Sci. Bldg.	1/	36.973 °N	121.568 °W	B	(3),(20)	16.0	0.12	0.10	0.12	(1)
84.04.24	Morgan Hill	6.1	S	57007	Corralitos, Eureka Canyon Road		37.046 °N	121.803 °W	B	(3),(8),(12)	23.5	0.11	0.08	0.05	(1),(2)
84.04.24	Morgan Hill	6.1	S	57064	Fremont, Mission San Jose	1/	37.530 °N	121.919 °W	B	(3),(8),(26)	31.6	0.03	0.02	0.02	(1),(2)
84.04.24	Morgan Hill	6.1	S	47125	Capitola Fire Station	1/	36.974 °N	121.952 °W	B	(8),(26)	38.9	0.14	0.10	0.04	(1)
84.04.24	Morgan Hill	6.1	S	58135	Santa Cruz, UCSC Lick Lab.	1/	37.001 °N	122.060 °W	B	(3)	46.0	0.04	0.08	0.03	(1)
86.07.08	Palm Springs	6.0	S	22170	Joshua Tree Fire Station	1/	34.131 °N	116.314 °W	B	(1)	31.1	0.07	0.05	0.04	(1),(2)
86.07.08	Palm Springs	6.0	S	12166	Puerta La Cruz, USFS Storage Bldg	1/	33.324 °N	116.683 °W	B	(1)	67.9	0.06	0.08	0.04	(1)
86.07.08	Palm Springs	6.0	S	13123	Riverside Airport	1/	33.951 °N	117.446 °W	B	(28)	75.7	0.04	0.05	0.03	(1)
87.10.01	Whittier	6.1	R	709	Garvey Reservoir Abutment Bldg	1/	34.050 °N	118.110 °W	B	(8),(28)	11.3	0.37	0.48	0.38	(7)
87.10.01	Whittier	6.1	R	24461	Alhambra, Fremont School	1/	34.070 °N	118.150 °W	B	(8),(26)	12.3	0.40	0.29	0.20	(1),(2)
87.10.01	Whittier	6.1	R	5244	Los Angeles, 4407 Jasper Street		34.081 °N	118.188 °W	B	(8),(28)	14.0	0.33	0.22	0.12	(7)
87.10.01	Whittier	6.1	R	24401	San Marino, Southwestern Academy	1/	34.115 °N	118.130 °W	B	(8),(28)	14.9	0.19	0.14	0.14	(1),(2)
87.10.01	Whittier	6.1	R	80053	Pasadena, CIT Athenaeum	2/1	34.139 °N	118.121 °W	B	(2),(7)	16.0	0.11	0.18	0.15	(1)
87.10.01	Whittier	6.1	R	14196	Inglewood, Union Oil Yard		33.905 °N	118.279 °W	B	(8),(28)	22.5	0.23	0.26	0.07	(1),(2)
87.10.01	Whittier	6.1	R	14241	Long Beach Recreation park		33.778 °N	118.133 °W	B	(8),(28)	29.6	0.06	0.06	0.04	(1),(2)
87.10.01	Whittier	6.1	R	13197	Huntington Beach, Lake St Fire Station	1/	33.662 °N	117.997 °W	B	(8),(28)	42.8	0.04	0.05	0.03	(1)
87.10.01	Whittier	6.1	R	24514	Sylmar, Olive View Medical Center	1/	34.326 °N	118.444 °W	B	(8)	45.9	0.05	0.06	0.04	(1)
87.10.01	Whittier	8.1	R	13123	Riverside Airport	1/	33.951 °N	117.446 °W	B	(28)	57.8	0.06	0.05	0.05	(1)
87.10.01	Whittier	6.1	R	24396	Malibu, Point Dume School	1/	34.013 °N	118.800 °W	B	(28)	63.6	0.05	0.05	0.03	(1)
87.10.01	Whittier	6.1	R	24526	Lancaster, Medical Office Bldg FF		34.688 °N	118.156 °W	B	(28)	72.2	0.06	0.06	0.03	(1)
87.10.01	Whittier	6.1	R	24278	Castaic, Old Ridge Route	1/	34.564 °N	118.642 °W	B	(7),(15),(20)	77.3	0.07	0.07	0.03	(1)
87.10.01	Whittier	6.1	R	24271	Lake Hughes, #1 – Fire Station #78	1/	34.674 °N	118.430 °W	B	(5),(19),(20)	78.2	0.03	0.04	NA	(1)
89.10.17	Loma Prieta	7.1	S	57007	Corralitos, Eureka Canyon Road		37.046 °N	121.803 °W	B	(3),(8),(12)	2.2	0.49	0.64	0.46	(1)
89.10.17	Loma Prieta	7.1	S	47006	Gilroy, Gavilan College Phys. Sci. Bldg.	1/	36.973 °N	121.568 °W	B	(3),(20)	11.2	0.37	0.33	0.20	(1)
89.10.17	Loma Prieta	7.1	S	58065	Saratoga, Aloha Ave	1/	37.255 °N	122.031 °W	B	(3),(8)	12.4	0.33	0.53	0.41	(1),(3)
89.10.17	Loma Prieta	7.1	S	58135	Santa Cruz, UCSC Lick Lab.	1/	37.001 °N	122.060 °W	B	(3)	16.8	0.43	0.46	0.39	(1)
89.10.17	Loma Prieta	7.1	S	57383	Gilroy #6, San Ysidro Microwave Site		37.026 °N	121.484 °W	B	(3),(6)	20.5	0.17	0.13	0.10	(1)
89.10.17	Loma Prieta	7.1	S	1652	Anderson Dam, Downstream		37.166 °N	121.628 °W	B	(3),(8)	22.4	0.26	0.25	0.17	(7),(3)
89.10.17	Loma Prieta	7.1	S	57504	Coyote Lake Dam, Downstream		37.118 °N	121.550 °W	B	(3),(8)	23.1	0.18	0.16	0.10	(1),(3)
89.10.17	Loma Prieta	7.1	S	1227	Palo Alto, VA Hospital, Bldg 1		37.400 °N	122.140 °W	B	(9),(26)	31.0	0.38	0.34	0.20	(7),(3)
89.10.17	Loma Prieta	7.1	S	1687	Calaveras Array, Calaveras Reservoir		37.452 °N	121.807 °W	B	(3),(8)	36.9	0.13	0.08	0.07	(7),(3)
89.10.17	Loma Prieta	7.1	S	58127	Woodside Fire Station	1/	37.429 °N	122.258 °W	B	(3),(8),(12)	39.4	0.08	0.08	0.05	(1)
89.10.17	Loma Prieta	7.1	S	57064	Fremont, Mission San Jose	1/	37.530 °N	121.919 °W	B	(3),(8),(26)	42.6	0.11	0.13	0.09	(1),(3)
89.10.17	Loma Prieta	7.1	S	1161	Crystal Springs Reservoir (APEEL 9)		37.470 °N	122.320 °W	B	(27),(3),(8)	46.3	0.11	0.12	0.06	(7)
89.10.17	Loma Prieta	7.1	S	1688	Calaveras Array, Sunol Fire Station		37.597 °N	121.880 °W	B	(3),(8)	50.4	0.07	0.10	0.03	(7)
89.10.17	Loma Prieta	7.1	S	1474	Bear Valley Stn #5, Callens Ranch		36.673 °N	121.195 °W	B	(3)	52.1	0.07	0.07	0.04	(7),(3)

TABLE 1A. STRONG MOTION DATABASE

Earthquake Yr.Mo.Dy	Earthquake Location	Ms	Fault Type	Station Desig.	Station Name	Structure Code	Station Location Latitude	Station Location Longitude	Site Class	Geologic Reference	Closest Approach Distance [km]	PGA [g] H1	PGA [g] H2	PGA [g] V	Strong Motion Data Source
89.10.17	Loma Prieta	7.1	S	58219	Hayward, CSUH Stadium Grnds (APEEL 3E)		37.657 °N	122.061 °W	B	(3),(10)	56.7	0.08	0.08	0.05	(1)
89.10.17	Loma Prieta	7.1	S	58163	Yerba Buena Island		37.807 °N	122.361 °W	B	(9)	80.2	0.07	0.03	0.03	(1)
89.10.17	Loma Prieta	7.1	S	1005	UC Berkeley, Strawberry Canyon		37.870 °N	122.240 °W	B	(3)	83.1	0.04	0.08	0.02	(7)
89.10.17	Loma Prieta	7.1	S	58471	Berkeley, Lawrence Berkeley Lab.		37.876 °N	122.249 °W	B	(3)	83.9	0.12	0.05	0.04	(1)
89.10.17	Loma Prieta	7.1	S	1678	San Francisco, Golden Gate Bridge		37.806 °N	122.472 °W	B	(3)	84.6	0.24	0.12	0.06	(7),(3)
89.10.17	Loma Prieta	7.1	S	1448	Martinez VA Hospital		37.993 °N	122.115 °W	B	(26)	94.3	0.07	0.05	0.03	(7)
92.06.28	Landers	7.5	S	22170	Joshua Tree Fire Station	1/	34.131 °N	116.314 °W	B	(1)	7.1	0.29	0.28	0.19	(1)
92.06.28	Landers	7.5	S	MVH	Morongo valley		34.053 °N	116.572 °W	B	(28)	18.0	0.19	0.14	0.16	(8)
92.06.28	Landers	7.5	S	12168	Puerta La Cruz, USFS Storage Bldg	1/	33.324 °N	116.683 °W	B	(1)	86.5	0.05	0.05	0.04	(1)
92.06.28	Landers	7.5	S	13123	Riverside Airport	1/	33.951 °N	117.446 °W	B	(28)	98.1	0.04	0.05	0.05	(1)
92.06.28	Landers	7.5	S	24541	Pasadena, 6−story office bldg	6/1	34.146 °N	118.147 °W	B	(28)	142.4	0.03	0.04	0.02	(1)
92.06.28	Landers	7.5	S	14196	Inglewood, Union Oil Yard		33.905 °N	118.279 °W	B	(8),(28)	166.0	0.03	0.05	0.01	(1)
92.06.28	Landers	7.5	S	24436	Tarzana, Cedar Hills Nursery		34.160 °N	118.534 °W	B	(4)	174.0	0.04	0.06	0.03	(1)
33.03.11	Long Beach	6.2	S	288	Vernon, Cmd Terminal	6/1	33.999 °N	118.196 °W	C	(2),(5),(28)	19.5	0.13	0.15	0.15	(7),(4)
40.05.19	Imperial Valley	7.1	S	117	El Centro, Imperial Valley Irrigation District	2/0	32.790 °N	115.550 °W	C	(25),(27),(2),(14),(17),(20)	10.0	0.35	0.21	0.21	(7),(4)
52.07.21	Kern County	7.7	R	135	Los Angeles, Hollywood Storage PE Lot		34.090 °N	118.339 °W	C	(2),(5),(21),(20)	107.0	0.06	0.04	0.02	(7),(4)
66.06.28	Central California	6.1	S	1013	Parkfield, Cholame 2WA (Shandon Sta. 2)		35.733 °N	120.290 °W	C	(23),(17),(20),(8)	0.1	0.49	NA	0.21	(7),(4)
66.06.28	Central California	6.1	S	1014	Parkfield, Cholame 5W (Shandon Sta. 5)		35.697 °N	120.328 °W	C	(23),(8)	5.0	0.35	0.43	0.12	(7),(4)
66.06.28	Central California	6.1	S	1015	Parkfield, Cholame 8W (Shandon Sta. 8)	1/0	35.671 °N	120.359 °W	C	(23),(6),(8)	9.5	0.24	0.27	0.08	(7),(4)
66.08.07	Baja	6.3	S	117	El Centro, Imperial Valley Irrigation District	2/0	32.790 °N	115.550 °W	C	(25),(27),(2),(14),(17),(20)	148.0	0.01	0.02	0.00	(7),(4),(9)
68.04.09	Borrego Mountain	6.7	S	117	El Centro, Imperial Valley Irrigation District	2/0	32.790 °N	115.550 °W	C	(25),(27),(2),(14),(17),(20)	45.0	0.13	0.06	0.03	(7),(4)
68.04.09	Borrego Mountain	6.7	S	113	Colton, SCE	1/0	34.060 °N	117.320 °W	C	(2),(7)	130.0	0.02	0.03	0.02	(7),(4)
88.04.09	Borrego Mountain	6.7	S	130	Long Beach, Terminal Island	1/1	33.770 °N	118.230 °W	C	(2),(13)	187.0	0.01	0.01	0.01	(7),(4)
68.04.09	Borrego Mountain	6.7	S	288	Vernon, Cmd Terminal	6/1	33.999 °N	118.196 °W	C	(2),(5),(28)	196.0	0.02	0.02	0.01	(7),(4)
68.04.09	Borrego Mountain	6.7	S	135	Los Angeles, Hollywood Storage PE Lot		34.090 °N	118.339 °W	C	(2),(5),(21),(20)	211.0	0.01	0.01	0.00	(7),(4)
71.02.09	San Fernando	6.5	R	135	Los Angeles, Hollywood Storage PE Lot		34.090 °N	118.339 °W	C	(2),(5),(21),(20)	23.0	0.17	0.21	0.09	(7),(4)
71.02.09	San Fernando	6.5	R	288	Vernon, Cmd Terminal	6/1	33.999 °N	118.196 °W	C	(2),(5),(28)	33.5	0.11	0.08	0.04	(7),(4)
71.02.09	San Fernando	6.5	R	289	Whittier, Whittier Narrows Dam (Upstream)		34.030 °N	118.050 °W	C	(28)	38.0	0.10	0.10	0.06	(7),(4)
71.02.09	San Fernando	6.5	R	130	Long Beach, Terminal Island	1/1	33.770 °N	118.230 °W	C	(2),(13)	58.0	0.03	0.03	0.02	(7),(4)
71.02.09	San Fernando	6.5	R	281	Santa Ana, Engineering Bldg	3/1	33.750 °N	117.870 °W	C	(28)	71.5	0.03	0.03	0.02	(7),(4)
71.02.09	San Fernando	6.5	R	274	San Bernardino, Hall of Records	6/1	34.110 °N	117.290 °W	C	(28)	100.0	0.04	0.04	0.02	(7),(4)
71.02.09	San Fernando	6.5	R	465	San Juan Capistrano, City Hall	1/	33.490 °N	117.670 °W	C	(28)	104.0	0.04	0.03	0.02	(7),(4)
71.02.09	San Fernando	6.5	R	123	Hemet, Stetson Av Fire Station	1/	33.729 °N	116.979 °W	C	(8),(28)	134.0	0.04	0.04	0.03	(7),(4)
79.10.15	Imperial Valley	6.6	S	1336	El Centro, Rt8/Meloland Road Overcrossing		32.773 °N	115.448 °W	C	(30)	0.5	0.30	0.32	0.23	(1)
79.10.15	Imperial Valley	8.8	S	5158	El Centro #6, 551 Huston Road		32.839 °N	115.487 °W	C	(14)	1.0	0.44	0.38	1.69	(7),(9)
79.10.15	Imperial Valley	6.8	S	5028	El Centro #7, Imperial Valley College	1/	32.829 °N	115.504 °W	C	(25),(14)	1.0	0.46	0.33	0.51	(7),(9)
79.10.15	Imperial Valley	6.8	S	6616	Aeropuerto		32.650 °N	115.330 °W	C	(1)	1.4	0.26	0.33	0.16	(7),(5)
79.10.15	Imperial Valley	6.8	S	5054	Bonds Corner	1/	32.893 °N	115.338 °W	C	(14)	3.0	0.79	0.59	0.35	(7),(9)
79.10.15	Imperial Valley	6.8	S	952	El Centro #5, James Road	1/	32.855 °N	115.466 °W	C	(14)	4.0	0.37	0.53	0.44	(7),(9)
79.10.15	Imperial Valley	6.8	S	5159	El Centro #8, Cruickshank Road	1/	32.811 °N	115.532 °W	C	(14)	4.0	0.47	0.61	0.41	(7)
79.10.15	Imperial Valley	6.8	S	5165	El Centro, Dogwood Road	1/	32.800 °N	115.540 °W	C	(24),(14)	5.0	0.49	0.35	0.66	(7),(9)
79.10.15	Imperial Valley	6.8	S	955	El Centro #4, Anderson Road	1/	32.860 °N	115.430 °W	C	(14)	7.0	0.36	0.49	0.20	(7),(9)
79.10.15	Imperial Valley	6.8	S	5060	Brawley Municipal Airport	1/	32.988 °N	115.509 °W	C	(14)	7.0	0.22	0.17	0.15	(7),(9)
79.10.15	Imperial Valley	6.8	S	5055	Holtville Post Office	1/	32.810 °N	115.380 °W	C	(14)	8.0	0.22	0.25	0.23	(7),(9)
79.10.15	Imperial Valley	6.8	S	412	El Centro #10, Community Hospital		32.780 °N	115.567 °W	C	(25),(14)	9.0	0.17	0.23	0.10	(7),(9)
79.10.15	Imperial Valley	6.8	S	5053	Calexico Fire Station		32.699 °N	115.492 °W	C	(14)	11.0	0.20	0.27	0.18	(7),(9)
79.10.15	Imperial Valley	6.8	S	6617	Cucupah		32.550 °N	115.230 °W	C	(1)	11.0	0.31	NA	0.14	(7),(5)
79.10.15	Imperial Valley	6.8	S	5057	El Centro #3, Pine Union School	1/	32.894 °N	115.380 °W	C	(14)	12.7	0.22	0.27	0.13	(7),(5)
79.10.15	Imperial Valley	6.8	S	5058	El Centro #11, McCabe Union School	1/	32.752 °N	115.594 °W	C	(14)	13.0	0.38	0.36	0.14	(7),(9)
79.10.15	Imperial Valley	6.8	S	931	El Centro #12, 907 Brockman Road	1/	32.710 °N	115.630 °W	C	(14)	18.0	0.12	0.14	0.07	(7),(9)
79.10.15	Imperial Valley	6.8	S	5056	El Centro #1, Borchard Ranch	1/	32.960 °N	115.319 °W	C	(1)	22.0	0.14	0.14	0.04	(7),(9)
79.10.15	Imperial Valley	6.8	S	5059	El Centro #13, Strobel Residence	1/	32.709 °N	115.683 °W	C	(14)	22.0	0.14	0.12	0.04	(7),(5)
79.10.15	Imperial Valley	6.8	S	6622	Compuertas		32.573 °N	115.083 °W	C	(1)	22.0	0.19	0.07	0.15	(7),(5)
79.10.15	Imperial Valley	6.8	S	5052	Plaster City Storehouse	1/	32.790 °N	115.850 °W	C	(1)	31.0	0.06	0.04	0.03	(7),(9)

TABLE 1A. STRONG MOTION DATABASE

Earthquake			Fault	Station		Structure	Station Location		Site	Geologic	Closest Approach	PGA [g]			Strong Motion
Yr.Mo.Dy	Location	Ms	Type	Desig.	Name	Code	Latitude	Longitude	Class	Reference	Distance [km]	H1	H2	V	Data Source
79.10.15	Imperial Valley	6.8	S	11023	Niland Fire Station	1/	33.239 °N	115.512 °W	C	(1)	34.0	0.11	0.07	0.03	(1)
79.10.15	Imperial Valley	6.8	S	5066	Coachella Canal #4	1/	33.360 °N	115.590 °W	C	(1)	49.0	0.13	0.12	0.04	(7),(5)
81.04.26	Westmorland	6.0	S	5060	Brawley, Municipal Airport	1/	32.988 °N	115.509 °W	C	(14)	19.0	0.18	0.16	0.11	(1)
81.04.26	Westmorland	6.0	S	11023	Niland Fire Station	1/	33.239 °N	115.512 °W	C	(1)	21.0	0.19	0.11	0.13	(7)
83.05.02	Coalinga	6.7	R	36138	Parkfield, Fault Zone 12		35.899 °N	120.433 °W	C	(8)	34.2	0.11	0.11	0.07	(1)
83.05.02	Coalinga	6.7	R	36413	Parkfield, Fault Zone 2		35.787 °N	120.334 °W	C	(8)	43.1	0.14	0.12	0.04	(1)
83.05.02	Coalinga	6.7	R	36452	Parkfield, Cholame 1E		35.743 °N	120.277 °W	C	(8)	47.4	0.09	0.09	0.06	(1)
83.05.02	Coalinga	6.7	R	36228	Parkfield, Cholame 2WA (Shandon Sta. 2)		35.733 °N	120.290 °W	C	(23),(17),(20),(8)	48.6	0.11	0.11	0.04	(1)
83.05.02	Coalinga	6.7	R	36227	Parkfield, Cholame 5W (Shandon Sta. 5)		35.697 °N	120.328 °W	C	(23),(8)	52.9	0.14	0.14	0.03	(1)
83.05.02	Coalinga	6.7	R	36226	Parkfield, Cholame 8W (Shandon Sta. 8)	1/	35.671 °N	120.359 °W	C	(23),(6),(8)	56.1	0.10	0.10	0.03	(1)
84.04.24	Morgan Hill	6.1	S	57425	Gilroy #7, Mantelli Ranch, Jamison Rd		37.033 °N	121.434 °W	C	(8),(12)	13.7	0.11	0.19	0.45	(1),(2)
84.04.24	Morgan Hill	8.1	S	47361	Gilroy #3, Gilroy Sewage Treatment Plant		36.987 °N	121.536 °W	C	(3),(6)	14.4	0.20	0.20	0.39	(1),(2)
84.04.24	Morgan Hill	6.1	S	47380	Gilroy #2, Hwy 101/Bolsa Road Motel		36.982 °N	121.556 °W	C	(3),(6),(9)	14.9	0.22	0.17	0.60	(1),(2)
84.04.24	Morgan Hill	6.1	S	57066	Agnews, Agnews State Hospital	1/	37.397 °N	121.952 °W	C	(3),(8),(26)	25.5	0.03	0.03	0.02	(1),(2)
84.04.24	Morgan Hill	6.1	S	1656	Hollister Airport Differential Array		36.888 °N	121.413 °W	C	(3)	28.0	0.10	0.09	0.23	(7),(2)
84.04.24	Morgan Hill	6.1	S	1575	Hollister City Hall Annex		36.851 °N	121.402 °W	C	(27),(3),(21),(20)	32.3	0.07	0.07	0.54	(7)
86.07.08	Palm Springs	6.0	S	12025	Palm Springs Airport		33.829 °N	116.501 °W	C	(8),(28)	11.2	0.20	0.17	0.19	(1),(2)
86.07.08	Palm Springs	8.0	S	12331	Hemet, Stetson Av Fire Station	1/	33.729 °N	116.979 °W	C	(8),(28)	29.2	0.14	0.15	0.10	(1)
86.07.08	Palm Springs	6.0	S	13172	Temecula, CDF Fire Station		33.496 °N	117.149 °W	C	(1)	69.9	0.10	0.11	0.03	(1)
86.07.08	Palm Springs	6.0	S	23497	Rancho Cucamonga, Law and Justice Center F		34.104 °N	117.574 °W	C	(8),(28)	89.1	0.02	0.02	NA	(1)
87.10.01	Whittier	6.1	R	289	Whittier, Whittier Narrows Dam (Upstream)		34.030 °N	118.050 °W	C	(28)	11.1	0.30	0.23	0.53	(7)
87.10.01	Whittier	6.1	R	5129	Bell, Los Angeles Buk Mail Center		33.990 °N	118.160 °W	C	(8),(28)	12.2	0.33	0.45	0.53	(7)
87.10.01	Whittier	6.1	R	288	Vernon, Cmd Terminal	6/1	33.999 °N	118.196 °W	C	(2),(5),(28)	13.2	0.27	0.24	0.14	(7)
87.10.01	Whittier	6.1	R	14368	Downey, County Maintennance Bldg	1/	33.924 °N	118.167 °W	C	(8),(28)	16.2	0.16	0.21	0.16	(1),(2)
87.10.01	Whittier	6.1	R	24303	Los Angeles, Hollywood Storage PE Lot		34.090 °N	118.339 °W	C	(2),(5),(21),(20)	23.8	0.12	0.21	0.08	(1),(2)
87.10.01	Whittier	6.1	R	24390	Century City, LA Country Club South		34.062 °N	118.416 °W	C	(8),(28)	29.6	0.07	0.06	0.03	(1),(2)
87.10.01	Whittier	6.1	R	23525	Pomona, 4th and Locust FF		34.056 °N	117.748 °W	C	(8),(28)	29.9	0.06	0.07	0.06	(1)
87.10.01	Whittier	6.1	R	14395	Long Beach, Harbor Administration Bldg		33.754 °N	118.200 °W	C	(8),(28)	32.8	0.07	0.05	0.03	(1)
87.10.01	Whittier	6.1	R	23497	Rancho Cucamonga, Law and Justice Center		34.104 °N	117.574 °W	C	(8),(28)	45.5	0.06	0.05	0.04	(1)
87.10.01	Whittier	6.1	R	24087	Arleta, Nordhoff Ave. Fire Station	1/	34.236 °N	118.439 °W	C	(8)	45.7	0.09	0.09	0.09	(1)
87.10.01	Whittier	6.1	R	23516	San Bernardino, Sunwest Office Bldg	3/0	34.065 °N	117.289 °W	C	(28)	70.9	0.03	0.03	0.02	(1)
87.10.01	Whittier	6.1	R	24274	Rosamond, Goode Ranch		34.827 °N	118.265 °W	C	(28)	89.0	0.05	0.08	0.02	(1)
87.10.01	Whittier	6.1	R	12331	Hemet, Stetson Av Fire Station	1/	33.729 °N	116.979 °W	C	(8),(28)	106.0	0.04	0.03	0.03	(1)
89.10.17	Loma Prieta	7.1	S	47459	Watsonville, 4-story commercial bldg	4/0	36.909 °N	121.756 °W	C	(28)	6.3	0.28	0.39	0.66	(1),(3)
89.10.17	Loma Prieta	7.1	S	47380	Gilroy #2, Hwy 101/Bolsa Road Motel		36.982 °N	121.556 °W	C	(3),(6),(9)	12.6	0.33	0.37	0.30	(1),(3)
89.10.17	Loma Prieta	7.1	S	47381	Gilroy #3, Gilroy Sewage Treatment Plant		36.987 °N	121.536 °W	C	(3),(6)	14.4	0.37	0.55	0.37	(1),(3)
89.10.17	Loma Prieta	7.1	S	1656	Hollister Airport Differential Array		36.888 °N	121.413 °W	C	(3)	24.5	0.29	0.27	0.16	(7),(3)
69.10.17	Loma Prieta	7.1	S	57425	Gilroy #7, Mantelli Ranch, Jamison Rd		37.033 °N	121.434 °W	C	(8),(12)	24.7	0.33	0.23	0.12	(1),(3)
89.10.17	Loma Prieta	7.1	S	1575	Hollister City Hall Annex		36.851 °N	121.402 °W	C	(27),(3),(21),(20)	26.6	0.25	0.23	0.22	(7),(3)
89.10.17	Loma Prieta	7.1	S	57066	Agnews, Agnews State Hospital	1/	37.397 °N	121.952 °W	C	(3),(8),(26)	27.6	0.16	0.17	0.10	(1),(3)
89.10.17	Loma Prieta	7.1	S	1695	Sunnyvale, Colton Avenue		37.340 °N	121.756 °W	C	(3),(8)	29.1	0.19	0.22	0.10	(7),(3)
89.10.17	Loma Prieta	7.1	S	47179	Salinas, John and Work St.	1/	36.671 °N	121.642 °W	C	(3),(8)	29.3	0.12	0.09	0.11	(1),(3)
89.10.17	Loma Prieta	7.1	S	1601	Stanford University, SLAC Test Lab		37.419 °N	122.205 °W	C	(3),(8)	35.7	0.19	0.29	0.10	(7),(3)
89.10.17	Loma Prieta	7.1	S	1230	Menlo Park VA Hospital, Bldg 137		37.468 °N	122.157 °W	C	(8),(26)	38.5	0.12	0.27	0.10	(7),(3)
89.10.17	Loma Prieta	7.1	S	1686	Fremont, Calaveras Array, Emerson Ct.		37.535 °N	121.929 °W	C	(3),(8)	43.0	0.15	0.20	0.07	(7),(3)
69.10.17	Loma Prieta	7.1	S	1481	Bear Valley Stn #12, Williams Ranch		36.658 °N	121.249 °W	C	(3)	49.2	0.17	0.16	0.10	(7),(3)
89.10.17	Loma Prieta	7.1	S	58393	Hayward, John Muir School	1/	37.657 °N	122.081 °W	C	(3)	56.9	0.14	0.18	0.10	(1),(3)
89.10.17	Loma Prieta	7.1	S	1689	Calaveras Array, Dublin Fire Station		37.709 °N	121.932 °W	C	(3)	62.2	0.08	0.09	0.03	(7),(3)
89.10.17	Loma Prieta	7.1	S	1479	Bear Valley Stn #10, Webb Residence		38.532 °N	121.143 °W	C	(3)	65.5	0.10	0.13	0.05	(7),(3)
89.10.17	Loma Prieta	7.1	S	58224	Oakland 2 story	2/	37.806 °N	122.267 °W	C	(3),(26)	77.0	0.25	0.20	0.15	(1),(3)
89.10.17	Loma Prieta	7.1	S	58505	Richmond City Hall Parking Lot		37.935 °N	122.342 °W	C	(3),(26)	92.7	0.11	0.13	0.04	(1),(3)
92.06.28	Landers	7.5	S	SCE-C	Coolwater SCE		34.852 °N	116.858 °W	C	(28)	18.6	0.28	0.42	0.18	(6)
92.06.28	Landers	7.5	S	22074	Yermo Fire Station	1/	34.903 °N	116.823 °W	C	(28)	22.4	0.15	0.25	0.16	(1)
92.06.28	Landers	7.5	S	12025	Palm Springs Airport		33.829 °N	116.501 °W	C	(8),(28)	28.2	0.09	0.09	0.11	(1)

TABLE 1A. STRONG MOTION DATABASE

Earthquake			Fault	Station		Structure	Station Location		Site	Geologic	Closest Approach	PGA [g]			Strong Motion
Yr.Mo.Dy	Location	Ms	Type	Desig.	Name	Code	Latitude	Longitude	Class	Reference	Distance [km]	H1	H2	V	Data Source
92.06.28	Landers	7.5	S	24577	Fort Irwin		35.268 °N	116.684 °W	C	(28)	62.2	0.12	0.11	0.06	(1)
92.06.28	Landers	7.5	S	12331	Hemet, Stetson Av Fire Station	1/	33.729 °N	116.979 °W	C	(8),(28)	66.8	0.10	0.09	0.08	(1)
92.06.28	Landers	7.5	S	32075	Baker Fire Station	1/	35.272 °N	116.066 °W	C	(26)	88.1	0.11	0.11	0.06	(1)
92.06.28	Landers	7.5	S	33083	Boron, Fire Station	1/	35.002 °N	117.650 °W	C	(28)	88.2	0.09	0.13	0.05	(1)
92.06.28	Landers	7.5	S	23525	Pomona, 4th and Locust FF		34.056 °N	117.748 °W	C	(8),(26)	117.0	0.05	0.07	0.04	(1)
92.06.28	Landers	7.5	S	14368	Downey, County Maintennance Bldg	1/	33.924 °N	118.167 °W	C	(8),(28)	156.0	0.04	0.06	0.02	(1)
79.10.15	Imperial Valley	6.8	S	11369	Westmorland Fire Station	1/	33.037 °N	115.623 °W	D	(14)	13.0	0.11	0.08	0.09	(1)
79.10.15	Imperial Valley	6.8	S	5115	El Centro #2, Keystone Road	1/	32.910 °N	115.360 °W	D	(14)	16.0	0.41	0.32	0.11	(7),(5)
79.10.15	Imperial Valley	6.8	S	5061	Calipatria Fire Station	1/	33.130 °N	115.520 °W	D	(14)	21.0	0.08	0.13	0.05	(7),(9)
81.04.26	Westmorland	6.0	S	5169	Westmorland Fire Station	1/	33.037 °N	115.623 °W	D	(14)	7.8	0.49	0.39	0.80	(1)
81.04.26	Westmorland	6.0	S	5062	Salton Sea	1/	33.180 °N	115.620 °W	D	(14)	10.0	0.20	0.19	0.22	(1)
84.04.24	Morgan Hill	6.1	S	57382	Gilroy #4, San Ysidro School	1/	37.005 °N	121.522 °W	D	(3),(6)	12.6	0.36	0.40	0.23	(1),(2)
84.04.24	Morgan Hill	6.1	S	58376	Hayward, Pt. Eden Way (APEEL 1E)		37.623 °N	122.130 °W	D	(10),(8)	52.1	0.03	0.04	0.02	(1)
84.04.24	Morgan Hill	6.1	S	58375	Redwood City (Foster City, Redwood Shores)		37.545 °N	122.231 °W	D	(27),(3),(11)	54.6	0.04	0.06	0.02	(1)
84.04.24	Morgan Hill	6.1	S	58223	San Francisco, International Airport	1/	37.622 °N	122.398 °W	D	(9)	71.6	0.05	0.05	0.02	(1)
89.10.17	Loma Prieta	7.1	S	57382	Gilroy #4, San Ysidro School	1/	37.005 °N	121.522 °W	D	(3),(6)	16.4	0.22	0.42	0.17	(1),(3)
89.10.17	Loma Prieta	7.1	S	1002	Redwood City (APEEL 2)		37.520 °N	122.250 °W	D	(22),(27),(3),(11)	47.4	0.28	0.23	0.08	(7)
89.10.17	Loma Prieta	7.1	S	58375	Redwood City (Foster City, Redwood Shores)		37.545 °N	122.231 °W	D	(27),(3),(11)	48.0	0.29	0.26	0.11	(1)
89.10.17	Loma Prieta	7.1	S	1515	Foster City, 355 Menhaden Ct.		37.555 °N	122.248 °W	D	(3),(8)	50.7	0.12	0.11	0.09	(7)
89.10.17	Loma Prieta	7.1	S	58223	San Francisco, International Airport	1/	37.622 °N	122.398 °W	D	(9)	63.9	0.33	0.24	0.07	(1)
89.10.17	Loma Prieta	7.1	S	58117	Treasure Island	1/	37.825 °N	122.373 °W	D	(9)	82.4	0.16	0.10	0.02	(1)
89.10.17	Loma Prieta	7.1	S	1590	Larkspur Ferry Terminal		37.948 °N	122.508 °W	D	(3)	99.7	0.10	0.14	0.06	(7)

Notes:

Ms:	Earthquake surface-wave magnitude
Fault Type:	Code indicating the earthquake focal mechanism: S = strike-slip, R = reverse
Station Desig.:	U.S. Geological Survey station number, California Dept. of Mines and Geology station number, or an assigned alpha-numeric station code
Structure Code:	Code describing the structure housing the recording instrument (e.g. "3/1" refers to a 3-story structure with 1 sub-ground level; "3/" refers to a structure with either no sub-ground levels or an unknown number of sub-ground levels; no entry indicates an instrument shelter in most cases, but may refer to a small structure)
Site Class:	See text for definition
Closest Approach Distance:	Closest distance from station to fault rupture
PGA:	Peak ground acceleration for horizontal (H1 and H2) and vertical (V) components

Geologic References

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APPENDIX B. RESULTS OF REGRESSION ANALYSES

The following pages present more results of the regression analyses for the site classes B and C databases. The pages are copies of a relevant portion of the output of the BMDP - 3R computer program for the PGA and PSV regressions. The first line on each page identifies the regression (e.g., the identifier, B: PGA, means PGA regression of site class B data; the identifier, C: $T = 0.50$, means PSV regression of site class C data at oscillator period, $T = 0.50$ sec). The information after the first line includes (1) the asymptotic correlation matrix of the parameters, (2) residual mean square of the regression, (3) degrees of freedom, and (4) parameter estimates and their associated standard deviations.

The regression model was given by Equation (1) in the main text of this report and is

$$\ln Y = a + bM + d\ln\left(R + c_1 \exp\{c_2 M\}\right) + eF$$

where the variables, Y, M, R and F, were defined in the main text and where a, b, d, c_1, c_2, and e were the regression coefficients. As stated in the text, constraints were introduced on the coefficients b, d, c_1, and c_2 to ensure that the ground motion, Y, was an increasing function of magnitude, M. The parameters, $g = b/d$ and $H \geq 0$, were defined, and the parameters c_1, c_2, d and g were constrained as follows: $c_1 \geq 0$, $c_2 \geq 0$, $d \leq 0$, $g \leq 0$, and $g + c_2 + H = 0$. The later constraint was derived by relaxing a constraint proposed by Campbell (1981); his constraint, $g + c_2 = 0$, resulted in Y = constant at $R = 0$ independent of M. The relaxed constraint, $g + c_2 + H = 0$, along with the other above constraints, allowed Y to increase with increasing magnitude at $R = 0$. Thus, the form of the regression model input to the BMDP-3R computer program was

$$\ln Y = a + d\left[gM + \ln\left(R + c_1 \exp\{c_2 M\}\right)\right] + eF$$

In the following pages of regression results, note that the BMDP - 3R program did not provide the detailed output for the site class B, T = 3.0 and 4.0 sec, regressions due to the program's perceived linear dependency in parameters (presumably c_1, and c_2 based on trends shown in Table 2 for these coefficients). Although the model could have been revised as suggested in the output pages, it was considered preferable to retain the model for consistency after it was demonstrated that the resulting attenuation curves and magnitudes and distribution of residuals were reasonable.

Values of the parameters a, d, g, c_1, c_2, e and H resulting from the regression analysis are listed in the following pages. These values and the constraint equations were used to obtain the values reported in Table 4. The values for the parameter, a, in the following pages reflect the units on the dependent variable Y used in the regressions; the units on Y = PGA were cm/sec^2 , and the units on Y = PSV were in/sec. In Table 4, the values of the parameter, a, have been revised to reflect units of g for PGA and units of cm/sec for PSV.

```
B: PGA

PAGE   3  BMDP3R Soil Type B Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                    A           G           D           C1          C2          E           H

                         1           2           3           4           5           6           7
A          1        1.0000
G          2        0.9582      1.0000
D          3       -0.6328     -0.4007      1.0000
C1         4        0.9784      0.8818     -0.7706      1.0000
C2         5       -0.9582     -1.0000      0.4007     -0.8818      1.0000
E          6       -0.3520     -0.2194      0.4354     -0.3922      0.2194      1.0000
H          7        0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE              0.183107

DEGREES OF FREEDOM                83

THE RESIDUAL MEAN SQUARE,  0.18311     , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER        ESTIMATE        ASYMPTOTIC          TOLERANCE
                            STANDARD DEVIATION

A                 4.545532        1.350996       0.0011400227
G                -0.623255        0.098285       0.0010348095
D                -1.751631        0.342360       0.0556400871
C1                0.413033        0.382234       0.0026080032
C2                0.623255        0.098285       0.0019536208
E                 0.087940        0.109018       0.4909375748
H                 0.000000        0.000000       0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO
```

```
B: T = 0.04 sec

PAGE   3  BMDP3R Soil Type B Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                    A           G           D           C1          C2          E           H

                         1           2           3           4           5           6           7
A          1        1.0000
G          2        0.9606      1.0000
D          3       -0.6166     -0.3906      1.0000
C1         4        0.9755      0.8797     -0.7647      1.0000
C2         5       -0.9606     -1.0000      0.3906     -0.8797      1.0000
E          6       -0.3464     -0.2151      0.4296     -0.3898      0.2151      1.0000
H          7        0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE              0.171439

DEGREES OF FREEDOM                83

THE RESIDUAL MEAN SQUARE,  0.17144     , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER        ESTIMATE        ASYMPTOTIC          TOLERANCE
                            STANDARD DEVIATION

A                -1.404749        1.229413       0.0012889399
G                -0.612898        0.093471       0.0011543428
D                -1.691826        0.299423       0.0617067365
C1                0.387669        0.340092       0.0031722286
C2                0.612898        0.093471       0.0022650587
E                 0.108989        0.105467       0.4911298752
H                 0.000000        0.000000       0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO
```

B: T = 0.10 sec

```
PAGE    3  BMDP3R Soil Type B Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                   A           G           D           C1          C2          E           H

                       1           2           3           4           5           6           7
A          1      1.0000
G          2      0.7033      1.0000
D          3     -0.9374     -0.4142      1.0000
C1         4      0.9799      0.8268     -0.8498      1.0000
C2         5     -0.7033     -1.0000      0.4142     -0.8268      1.0000
E          6     -0.4522     -0.2290      0.4558     -0.4181      0.2290      1.0000
H          7      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE             0.218924

DEGREES OF FREEDOM              83

THE RESIDUAL MEAN SQUARE,  0.21892     , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER        ESTIMATE        ASYMPTOTIC          TOLERANCE
                             STANDARD DEVIATION

A                 6.639619         5.623865       0.0000786576
G                -0.454664         0.091603       0.0003253851
D                -3.574364         1.445714       0.0003309252
C1                4.612965         4.761745       0.0003206296
C2                0.454664         0.091603       0.0004484352
E                 0.033013         0.117916       0.5017225080
H                 0.000000         0.000000       0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO
```

B: T = 0.15 sec

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PAGE    3  BMDP3R Soil Type B Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                   A           G           D           C1          C2          E           H

                       1           2           3           4           5           6           7
A          1      1.0000
G          2      0.6828      1.0000
D          3     -0.9444     -0.4069      1.0000
C1         4      0.9766      0.8199     -0.8521      1.0000
C2         5     -0.6828     -1.0000      0.4069     -0.8199      1.0000
E          6     -0.4537     -0.2261      0.4555     -0.4188      0.2261      1.0000
H          7      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE             0.240981

DEGREES OF FREEDOM              83

THE RESIDUAL MEAN SQUARE,  0.24098     , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER        ESTIMATE        ASYMPTOTIC          TOLERANCE
                             STANDARD DEVIATION

A                 8.137863         6.330456       0.0000683330
G                -0.434297         0.093921       0.0003195291
D                -3.688497         1.586010       0.0002583720
C1                5.449227         5.837767       0.0003044499
C2                0.434297         0.093921       0.0004379079
E                -0.014652         0.123653       0.5022209119
H                 0.000000         0.000000       0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO
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B: T = 0.20 sec

PAGE    3  BMDP3R Soil Type B Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                     A           G           D           C1          C2          E           H

                       1           2           3           4           5           6           7
A          1       1.0000
G          2       0.7308      1.0000
D          3      -0.9221     -0.4127      1.0000
C1         4       0.9841      0.8360     -0.8395      1.0000
C2         5      -0.7308     -1.0000      0.4127     -0.8360      1.0000
E          6      -0.4506     -0.2297      0.4573     -0.4171      0.2297      1.0000
H          7       0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE             0.222955

DEGREES OF FREEDOM               83

THE RESIDUAL MEAN SQUARE,   0.22295     , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER        ESTIMATE        ASYMPTOTIC         TOLERANCE
                             STANDARD DEVIATION

A                 6.476413         4.749934      0.0001122946
G                -0.464040         0.096918      0.0003799500
D                -3.164719         1.232855      0.0005501351
C1                3.775168         4.005621      0.0004159027
C2                0.464040         0.096918      0.0005392669
E                 0.043634         0.119275      0.4993847256
H                 0.000000         0.000000      0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO

B: T = 0.30 sec

PAGE    3  BMDP3R Soil Type B Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                     A           G           D           C1          C2          E           H

                       1           2           3           4           5           6           7
A          1       1.0000
G          2       0.9901      1.0000
D          3      -0.4846     -0.4004      1.0000
C1         4       0.9333      0.8876     -0.7577      1.0000
C2         5      -0.9901     -1.0000      0.4004     -0.8876      1.0000
E          6      -0.2894     -0.2080      0.4103     -0.3753      0.2080      1.0000
H          7       0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE             0.218243

DEGREES OF FREEDOM               83

THE RESIDUAL MEAN SQUARE,   0.21824     , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER        ESTIMATE        ASYMPTOTIC         TOLERANCE
                             STANDARD DEVIATION

A                 0.262716         1.180095      0.0017808357
G                -0.706093         0.110231      0.0012414752
D                -1.539165         0.278655      0.0313416491
C1                0.166050         0.168138      0.0042014725
C2                0.706093         0.110231      0.0024853997
E                 0.128310         0.118500      0.4952470358
H                 0.000000         0.000000      0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO
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B: T = 0.40 sec

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PAGE    3  BMDP3R Soil Type B Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                  A           G           D           C1          C2          E           H

                      1           2           3           4           5           6           7
A          1    1.0000
G          2    0.9939      1.0000
D          3   -0.3819     -0.3949      1.0000
C1         4    0.8906      0.8867     -0.7496      1.0000
C2         5   -0.9939     -1.0000      0.3949     -0.8867      1.0000
E          6   -0.2461     -0.1944      0.3801     -0.3585      0.1944      1.0000
H          7    0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE              0.245767

DEGREES OF FREEDOM                83

THE RESIDUAL MEAN SQUARE,  0.24577    , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER        ESTIMATE       ASYMPTOTIC          TOLERANCE
                             STANDARD DEVIATION

A                -0.045080        1.089198       0.0023541188
G                -0.757907        0.121529       0.0013720510
D                -1.354721        0.233500       0.0242965367
C1                0.083872        0.092667       0.0064671364
C2                0.757907        0.121529       0.0027128759
E                 0.154355        0.124922       0.5018410620
H                 0.000000        0.000000       0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO
```

B: T = 0.50 sec

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PAGE    3  BMDP3R Soil Type B Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                  A           G           D           C1          C2          E           H

                      1           2           3           4           5           6           7
A          1    1.0000
G          2    0.9919      1.0000
D          3   -0.3376     -0.3957      1.0000
C1         4    0.8688      0.8867     -0.7478      1.0000
C2         5   -0.9919     -1.0000      0.3957     -0.8867      1.0000
E          6   -0.2273     -0.1886      0.3663     -0.3504      0.1886      1.0000
H          7    0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE              0.260961

DEGREES OF FREEDOM                83

THE RESIDUAL MEAN SQUARE,  0.26096    , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER        ESTIMATE       ASYMPTOTIC          TOLERANCE
                             STANDARD DEVIATION

A                -0.221010        1.073256       0.0025744656
G                -0.788026        0.123304       0.0013265963
D                -1.340017        0.221628       0.0213082091
C1                0.060623        0.067692       0.0074969793
C2                0.788026        0.123304       0.0024684402
E                 0.153348        0.128283       0.5053053587
H                 0.000000        0.000000       0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO
```

```
B: T = 0.60 sec

PAGE    3  BMDP3R Soil Type B Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                   A           G           D           C1          C2          E           H

                      1           2           3           4           5           6           7
A          1       1.0000
G          2       0.9841      1.0000
D          3      -0.5185     -0.6491      1.0000
C1         4       0.8481      0.8627     -0.6082      1.0000
C2         5      -0.8487     -0.8470      0.5056     -0.9905      1.0000
E          6      -0.2464     -0.2418      0.3334     -0.2131      0.1628      1.0000
H          7       0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE           0.281844

DEGREES OF FREEDOM             82

THE RESIDUAL MEAN SQUARE,   0.28184     , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER       ESTIMATE       ASYMPTOTIC          TOLERANCE
                           STANDARD DEVIATION

A               -1.003035         1.407919      0.0016157381
G               -0.927982         0.211788      0.0007075764
D               -1.104581         0.196003      0.0108541974
C1               0.048384         0.223640      0.0010804265
C2               0.742853         0.609954      0.0001690189
E                0.187939         0.132655      0.5103612011
H                0.185129         0.000000      0.0000000000
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B: T = 0.80 sec

PAGE    3  BMDP3R Soil Type B Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                   A           G           D           C1          C2          E           H

                      1           2           3           4           5           6           7
A          1       1.0000
G          2       0.9373      1.0000
D          3      -0.0871     -0.4118      1.0000
C1         4       0.6494      0.8330     -0.7738      1.0000
C2         5      -0.9373     -1.0000      0.4118     -0.8330      1.0000
E          6      -0.1382     -0.1138      0.1641     -0.2496      0.1138      1.0000
H          7       0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE           0.334992

DEGREES OF FREEDOM             83

THE RESIDUAL MEAN SQUARE,   0.33499     , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER       ESTIMATE       ASYMPTOTIC          TOLERANCE
                           STANDARD DEVIATION

A               -1.342771         0.912195      0.0045748494
G               -1.044000         0.165690      0.0000566954
D               -0.896728         0.122850      0.0178662826
C1               0.002278         0.003618      0.0405627904
C2               1.044000         0.165690      0.0000575324
E                0.330569         0.138606      0.5556326010
H                0.000000         0.000000      0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO
```

```
B: T = 1.00 sec

PAGE   3  BMDP3R Soil Type B Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                    A           G           D           C1          C2          E           H

                          1           2           3           4           5           6           7
A           1       1.0000
G           2       0.8801      1.0000
D           3       0.0017     -0.4635      1.0000
C1          4       0.6588      0.9240     -0.7471      1.0000
C2          5      -0.8801     -1.0000      0.4635     -0.9240      1.0000
E           6      -0.0725     -0.1853      0.3641     -0.3182      0.1853      1.0000
H           7       0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE              0.355126

DEGREES OF FREEDOM                83

THE RESIDUAL MEAN SQUARE,  0.35513    , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER        ESTIMATE       ASYMPTOTIC          TOLERANCE
                            STANDARD DEVIATION

A                -2.761386        1.392726       0.0020805068
G                -1.144165        0.189147       0.0000557593
D                -1.273945        0.296527       0.0031870315
C1                0.008444        0.013498       0.0038657035
C2                1.144165        0.189147       0.0000573235
E                 0.112767        0.148425       0.5136740293
H                 0.000000        0.000000       0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO
```

```
B: T = 1.50 sec

PAGE   3  BMDP3R Soil Type B Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                    A           G           D           C1          C2          E           H

                          1           2           3           4           5           6           7
A           1       1.0000
G           2       0.8872      1.0000
D           3      -0.3467     -0.7362      1.0000
C1          4       0.7433      0.8932     -0.7515      1.0000
C2          5      -0.7832     -0.8936      0.6891     -0.9945      1.0000
E           6      -0.2122     -0.3062      0.3841     -0.3303      0.2966      1.0000
H           7       0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE              0.358340

DEGREES OF FREEDOM                82

THE RESIDUAL MEAN SQUARE,  0.35834    , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER        ESTIMATE       ASYMPTOTIC          TOLERANCE
                            STANDARD DEVIATION

A                -3.138258        1.572639       0.0016464714
G                -1.368284        0.353827       0.0000018990
D                -0.922951        0.249141       0.0021171849
C1                0.001643        0.011446       0.0006071790
C2                1.287978        0.904015       0.0000002915
E                 0.032286        0.152289       0.4923551591
H                 0.080306        0.000000       0.0000000000
```

B: T = 2.00 sec

```
PAGE    3  BMDP3R Soil Type B Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                    A           G           D           C1          C2          E           H

                    1           2           3           4           5           6           7
A         1      1.0000
G         2      0.7065      1.0000
D         3      0.2547     -0.4990      1.0000
C1        4      0.4658      0.9434     -0.7325      1.0000
C2        5     -0.7065     -1.0000      0.4990     -0.9434      1.0000
E         6      0.0162     -0.1334      0.2712     -0.2374      0.1334      1.0000
H         7      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE              0.319095

DEGREES OF FREEDOM                83

THE RESIDUAL MEAN SQUARE,   0.31910     , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER        ESTIMATE        ASYMPTOTIC          TOLERANCE
                             STANDARD DEVIATION

A                -4.818608        1.300331       0.0021445204
G                -1.590216        0.235624       0.0000000775
D                -0.949390        0.187533       0.0021348479
C1                0.000269        0.000502       0.0056882862
C2                1.590216        0.235624       0.0000000775
E                 0.014204        0.137142       0.5406305140
H                 0.000000        0.000000       0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO
```

B: T = 3.00 sec

```
PAGE    3  BMDP3R Soil Type B Averaged Components


*** ERROR IN COMPUTING ASYMPTOTIC CORRELATION MATRIX
DUE TO THE
LINEAR DEPENDENCY IN PARAMETERS; TRY TO REPARAMETERIZE YOUR PROBLEM.

CPU TIME USED       16.480 SECONDS
```

VALUES OF THE PARAMETERS WERE NOT STORED IN THE PRINTOUT FILE;
THE VALUES IN TABLE 4 WERE FROM THE LAST ITERATION OF THE PROGRAM
BEFORE THE CALCULATION WAS TERMINATED.

B: T = 4.00 sec

```
PAGE    3  BMDP3R Soil Type B Averaged Components


*** ERROR IN COMPUTING ASYMPTOTIC CORRELATION MATRIX
DUE TO THE
LINEAR DEPENDENCY IN PARAMETERS; TRY TO REPARAMETERIZE YOUR PROBLEM.

CPU TIME USED       17.740 SECONDS
```

VALUES OF THE PARAMETERS WERE NOT STORED IN THE PRINTOUT FILE;
THE VALUES IN TABLE 4 WERE FROM THE LAST ITERATION OF THE PROGRAM
BEFORE THE CALCULATION WAS TERMINATED.

```
C: PGA

PAGE    3  BMDP3R Soil Type C Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                    A           G           D           C1          C2          E           H

                         1           2           3           4           5           6           7
A          1      1.0000
G          2      0.9773      1.0000
D          3     -0.5349     -0.3673      1.0000
C1         4      0.9635      0.8893     -0.7304      1.0000
C2         5     -0.9773     -1.0000      0.3673     -0.8893      1.0000
E          6     -0.5028     -0.4586      0.2064     -0.4734      0.4586      1.0000
H          7      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE              0.174258

DEGREES OF FREEDOM                96

THE RESIDUAL MEAN SQUARE,   0.17426     , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER        ESTIMATE       ASYMPTOTIC          TOLERANCE
                            STANDARD DEVIATION

A                 4.534328        1.137278       0.0013339464
G                -0.640249        0.115081       0.0011449243
D                -1.310188        0.265706       0.0677149867
C1                0.305134        0.326982       0.0037627145
C2                0.640249        0.115081       0.0024480990
E                -0.051707        0.112768       0.4895850503
H                 0.000000        0.000000       0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO

C: T = 0.04 sec

PAGE    3  BMDP3R Soil Type C Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                    A           G           D           C1          C2          E           H

                         1           2           3           4           5           6           7
A          1      1.0000
G          2      0.9749      1.0000
D          3     -0.5220     -0.3413      1.0000
C1         4      0.9646      0.8858     -0.7135      1.0000
C2         5     -0.9749     -1.0000      0.3413     -0.8858      1.0000
E          6     -0.4991     -0.4589      0.1778     -0.4669      0.4589      1.0000
H          7      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE              0.180873

DEGREES OF FREEDOM                96

THE RESIDUAL MEAN SQUARE,   0.18087     , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER        ESTIMATE       ASYMPTOTIC          TOLERANCE
                            STANDARD DEVIATION

A                -1.248182        1.091549       0.0015030226
G                -0.607199        0.112710       0.0013165037
D                -1.277041        0.236902       0.0866447848
C1                0.317517        0.331126       0.0049851064
C2                0.607199        0.112710       0.0029881264
E                -0.010872        0.114464       0.4932196601
H                 0.000000        0.000000       0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO
```

```
C: T = 0.10 sec

PAGE   3  BMDP3R Soil Type C Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                     A           G           D           C1          C2          E           H

                        1           2           3           4           5           6           7
A          1       1.0000
G          2       0.7942      1.0000
D          3      -0.7674     -0.2236      1.0000
C1         4       0.8675      0.9187     -0.4278      1.0000
C2         5      -0.6671     -0.9285      0.1012     -0.9397      1.0000
E          6      -0.4203     -0.3205      0.2980     -0.2584      0.1510      1.0000
H          7       0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE               0.206780

DEGREES OF FREEDOM                 95

THE RESIDUAL MEAN SQUARE,  0.20678    , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER        ESTIMATE       ASYMPTOTIC          TOLERANCE
                           STANDARD DEVIATION

A                 3.912028        2.732935      0.0002741122
G                -0.361222        0.143669      0.0004293075
D                -1.850579        0.543389      0.0016474625
C1                4.045981        6.977912      0.0005716918
C2                0.352728        0.233892      0.0002910755
E                -0.091919        0.124500      0.4766249070
H                 0.008494        0.000000      0.0000000000
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C: T = 0.15 sec

PAGE   3  BMDP3R Soil Type C Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                     A           G           D           C1          C2          E           H

                        1           2           3           4           5           6           7
A          1       1.0000
G          2       0.5543      1.0000
D          3      -0.9669     -0.3252      1.0000
C1         4       0.9490      0.7843     -0.8373      1.0000
C2         5      -0.5543     -1.0000      0.3252     -0.7843      1.0000
E          6      -0.4482     -0.4825      0.3526     -0.5224      0.4825      1.0000
H          7       0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE               0.190095

DEGREES OF FREEDOM                 96

THE RESIDUAL MEAN SQUARE,  0.19010    , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER        ESTIMATE       ASYMPTOTIC          TOLERANCE
                           STANDARD DEVIATION

A                11.427032        8.424849      0.0000265171
G                -0.310128        0.097299      0.0002374775
D                -3.432391        1.775397      0.0000626558
C1               16.158957       18.441209      0.0002046936
C2                0.310128        0.097299      0.0003206568
E                -0.231488        0.117796      0.4894545425
H                 0.000000        0.000000      0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO
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```
C: T = 0.20 sec

PAGE    3  BMDP3R Soil Type C Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                     A          G          D          C1         C2         E          H

                         1          2          3          4          5          6          7
A          1       1.0000
G          2       0.7986     1.0000
D          3      -0.8572    -0.3771     1.0000
C1         4       0.9147     0.9402    -0.6051     1.0000
C2         5      -0.6803    -0.9597     0.2310    -0.9120     1.0000
E          6      -0.4114    -0.3067     0.3461    -0.3030     0.1745     1.0000
H          7       0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000

RESIDUAL MEAN SQUARE             0.225385

DEGREES OF FREEDOM               95

THE RESIDUAL MEAN SQUARE,  0.22538    , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER       ESTIMATE       ASYMPTOTIC         TOLERANCE
                           STANDARD DEVIATION

A                5.597817       4.989423      0.0000896402
G               -0.474066       0.157469      0.0001862424
D               -2.635199       1.154889      0.0005779664
C1               4.378859       7.405645      0.0002213609
C2               0.443090       0.207464      0.0001587921
E               -0.041310       0.130383      0.4736840950
H                0.030976       0.000000      0.0000000000
```

```
C: T = 0.30 sec

PAGE    3  BMDP3R Soil Type C Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                     A          G          D          C1         C2         E          H

                         1          2          3          4          5          6          7
A          1       1.0000
G          2       0.9909     1.0000
D          3      -0.4960    -0.3974     1.0000
C1         4       0.8540     0.8786    -0.2462     1.0000
C2         5      -0.7550    -0.8092     0.0129    -0.9694     1.0000
E          6      -0.4087    -0.3669     0.1859    -0.1977     0.1328     1.0000
H          7       0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000

RESIDUAL MEAN SQUARE             0.246607

DEGREES OF FREEDOM               95

THE RESIDUAL MEAN SQUARE,  0.24661    , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER       ESTIMATE       ASYMPTOTIC         TOLERANCE
                           STANDARD DEVIATION

A                1.110898       1.638654      0.0009093048
G               -0.652501       0.177890      0.0007185084
D               -1.285166       0.284220      0.0597444154
C1               0.884282       2.205172      0.0011923751
C2               0.454604       0.361893      0.0004025111
E                0.055896       0.133921      0.4912579697
H                0.197897       0.000000      0.0000000000
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C: T = 0.40 sec

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PAGE    3  BMDP3R Soil Type C Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                A           G           D           C1          C2          E           H

                      1           2           3           4           5           6           7
A          1     1.0000
G          2     0.9458      1.0000
D          3    -0.0945     -0.3964      1.0000
C1         4     0.7564      0.9053     -0.7102      1.0000
C2         5    -0.9458     -1.0000      0.3964     -0.9053      1.0000
E          6    -0.4517     -0.3794      0.0557     -0.3732      0.3794      1.0000
H          7     0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE               0.229308

DEGREES OF FREEDOM                96

THE RESIDUAL MEAN SQUARE,   0.22931     , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER        ESTIMATE        ASYMPTOTIC          TOLERANCE
                             STANDARD DEVIATION

A                -1.381381         0.929654      0.0026269643
G                -0.978334         0.131126      0.0003842360
D                -1.127712         0.171791      0.0095470445
C1                0.015008         0.017393      0.0096380501
C2                0.978334         0.131126      0.0004502938
E                 0.227447         0.126835      0.5092637380
H                 0.000000         0.000000      0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO
```

C: T = 0.50 sec

```
PAGE    3  BMDP3R Soil Type C Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                A           G           D           C1          C2          E           H

                      1           2           3           4           5           6           7
A          1     1.0000
G          2     0.9027      1.0000
D          3    -0.0003     -0.4187      1.0000
C1         4     0.6863      0.9109     -0.7156      1.0000
C2         5    -0.9027     -1.0000      0.4187     -0.9109      1.0000
E          6    -0.4362     -0.3552      0.0330     -0.3487      0.3552      1.0000
H          7     0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE               0.219548

DEGREES OF FREEDOM                96

THE RESIDUAL MEAN SQUARE,   0.21955     , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER        ESTIMATE        ASYMPTOTIC          TOLERANCE
                             STANDARD DEVIATION

A                -2.011856         0.894744      0.0027152500
G                -1.092807         0.132233      0.0000902794
D                -1.096781         0.157074      0.0067276330
C1                0.006383         0.007375      0.0102804024
C2                1.092807         0.132233      0.0000935401
E                 0.193853         0.123793      0.5118474012
H                 0.000000         0.000000      0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO
```

```
C: T = 0.60 sec

PAGE    3  BMDP3R Soil Type C Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                     A            G            D            C1           C2           E            H

                        1            2            3            4            5            6            7
A           1       1.0000
G           2       0.8515       1.0000
D           3       0.0828      -0.4430       1.0000
C1          4       0.6153       0.9141      -0.7201       1.0000
C2          5      -0.8515      -1.0000       0.4430      -0.9141       1.0000
E           6      -0.4307      -0.3195      -0.0281      -0.3029       0.3195       1.0000
H           7       0.0000       0.0000       0.0000       0.0000       0.0000       0.0000       0.0000

RESIDUAL MEAN SQUARE             0.248155

DEGREES OF FREEDOM               96

THE RESIDUAL MEAN SQUARE,  0.24815     , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER        ESTIMATE       ASYMPTOTIC         TOLERANCE
                            STANDARD DEVIATION

A               -2.427921          0.906180      0.0029920722
G               -1.232590          0.155896      0.0000103839
D               -0.951097          0.139361      0.0058698816
C1               0.001802          0.002436      0.0142738473
C2               1.232590          0.155896      0.0000104238
E                0.159078          0.130907      0.5173708101
H                0.000000          0.000000      0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO
```

```
C: T = 0.80 sec

PAGE    3  BMDP3R Soil Type C Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                     A            G            D            C1           C2           E            H

                        1            2            3            4            5            6            7
A           1       1.0000
G           2       0.6763       1.0000
D           3       0.3099      -0.4849       1.0000
C1          4       0.4153       0.9370      -0.7320       1.0000
C2          5      -0.6763      -1.0000       0.4849      -0.9370       1.0000
E           6      -0.3056      -0.2915       0.0874      -0.3202       0.2915       1.0000
H           7       0.0000       0.0000       0.0000       0.0000       0.0000       0.0000       0.0000

RESIDUAL MEAN SQUARE             0.311698

DEGREES OF FREEDOM               96

THE RESIDUAL MEAN SQUARE,  0.31170     , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER        ESTIMATE       ASYMPTOTIC         TOLERANCE
                            STANDARD DEVIATION

A               -4.500035          1.315597      0.0017830664
G               -1.487888          0.199766      0.0000005245
D               -1.083569          0.224010      0.0016778603
C1               0.000749          0.001229      0.0046254419
C2               1.487888          0.199766      0.0000005247
E                0.049774          0.148170      0.5072477299
H                0.000000          0.000000      0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO
```

```
C: T = 1.00 sec

PAGE   3  BMDP3R Soil Type C Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                A           G           D           C1          C2          E           H

                      1           2           3           4           5           6           7
A          1    1.0000
G          2    0.3984      1.0000
D          3    0.6339     -0.4540      1.0000
C1         4    0.0896      0.9433     -0.7130      1.0000
C2         5   -0.3984     -1.0000      0.4540     -0.9433      1.0000
E          6    0.0124     -0.2515      0.2653     -0.3343      0.2515      1.0000
H          7    0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE                0.324495

DEGREES OF FREEDOM                  96

THE RESIDUAL MEAN SQUARE,  0.32450     , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER       ESTIMATE        ASYMPTOTIC          TOLERANCE
                           STANDARD DEVIATION

A               -8.218747        2.785176        0.0004141728
G               -1.716614        0.255351        0.0000000463
D               -1.493355        0.511629        0.0002560333
C1               0.000557        0.001117        0.0008062921
C2               1.716614        0.255351        0.0000000463
E               -0.102444        0.153819        0.4899951244
H                0.000000        0.000000        0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO
```

```
C: T = 1.50 sec

PAGE   3  BMDP3R Soil Type C Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                A           G           D           C1          C2          E           H

                      1           2           3           4           5           6           7
A          1    1.0000
G          2    0.9947      1.0000
D          3    0.0000      0.0000      0.0000
C1         4    0.9947      0.9833      0.0000      1.0000
C2         5   -0.9947     -1.0000      0.0000     -0.9833      1.0000
E          6   -0.2807     -0.2161      0.0000     -0.3027      0.2161      1.0000
H          7    0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE                0.298838

DEGREES OF FREEDOM                  97

THE RESIDUAL MEAN SQUARE,  0.29884     , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER       ESTIMATE        ASYMPTOTIC          TOLERANCE
                           STANDARD DEVIATION

A               -7.132609        1.377524        0.0015592504
G               -1.790362        0.185151        0.0000000115
D               -1.146577        0.000000        0.0000000000
C1               0.000123        0.000143        0.0064708925
C2               1.790362        0.185151        0.0000000115
E               -0.127769        0.144466        0.5115740026
H                0.000000        0.000000        0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO
```

C: T = 2.00 sec

```
PAGE    3  BMDP3R Soil Type C Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                A           G           D           C1          C2          E           H

                    1           2           3           4           5           6           7
A          1    1.0000
G          2    0.5461      1.0000
D          3    0.4480     -0.5000      1.0000
C1         4    0.2882      0.9485     -0.7243      1.0000
C2         5   -0.5461     -1.0000      0.5000     -0.9485      1.0000
E          6   -0.2189     -0.2436      0.0938     -0.2851      0.2436      1.0000
H          7    0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE              0.323042

DEGREES OF FREEDOM                96

THE RESIDUAL MEAN SQUARE,   0.32304     , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER        ESTIMATE        ASYMPTOTIC         TOLERANCE
                             STANDARD DEVIATION

A               -6.820420        1.560947       0.0013126875
G               -1.748081        0.219187       0.0000000151
D               -1.129466        0.231499       0.0010031527
C1               0.000155        0.000267       0.0033824196
C2               1.748081        0.219187       0.0000000151
E               -0.279244        0.150875       0.5070228559
H                0.000000        0.000000       0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO
```

C: T = 3.00 sec

```
PAGE    3  BMDP3R Soil Type C Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                A           G           D           C1          C2          E           H

                    1           2           3           4           5           6           7
A          1    1.0000
G          2    0.5945      1.0000
D          3    0.3818     -0.5114      1.0000
C1         4    0.3407      0.9446     -0.7344      1.0000
C2         5   -0.5945     -1.0000      0.5114     -0.9446      1.0000
E          6   -0.2925     -0.2440      0.0322     -0.2688      0.2440      1.0000
H          7    0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE              0.486754

DEGREES OF FREEDOM                96

THE RESIDUAL MEAN SQUARE,   0.48675     , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER        ESTIMATE        ASYMPTOTIC         TOLERANCE
                             STANDARD DEVIATION

A               -7.020304        1.638163       0.0017958641
G               -1.714319        0.235886       0.0000000180
D               -1.134134        0.233322       0.0015104933
C1               0.000130        0.000245       0.0055681005
C2               1.714319        0.235886       0.0000000180
E               -0.155093        0.184165       0.5127399643
H                0.000000        0.000000       0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO
```

```
C: T = 4.00 sec

PAGE   3  BMDP3R Soil Type C Averaged Components

ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS


                 A           G           D           C1          C2          E           H

                    1           2           3           4           5           6           7
A        1     1.0000
G        2     0.0000      0.0000
D        3     0.9939      0.0000      1.0000
C1       4    -0.8402      0.0000     -0.8894      1.0000
C2       5    -0.1900      0.0000     -0.1187     -0.1190      1.0000
E        6    -0.1900      0.0000     -0.1187     -0.1190      1.0000      1.0000
H        7     0.0000      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000

RESIDUAL MEAN SQUARE              0.559805

DEGREES OF FREEDOM              97

THE RESIDUAL MEAN SQUARE,  0.55980     , IS USED IN COMPUTING
STANDARD DEVIATIONS.

PARAMETER         ESTIMATE       ASYMPTOTIC          TOLERANCE
                              STANDARD DEVIATION

A                -8.373654         1.592623       0.0021851888
G                -1.895743         0.000000       0.0000000000
D                -1.119420         0.207272       0.0016517826
C1                0.000092         0.000061       0.0497522215
C2                1.779805         0.000000       0.0000012668
E                -0.107566         0.192751       0.5383300186
H                 0.115937         0.000000       0.0000000000

IF LINEAR DEPENDENCE IS FOUND OR IF A PARAMETER IS
ON THE BOUNDARY IT IS ASSIGNED A STANDARD DEVIATION OF ZERO
```

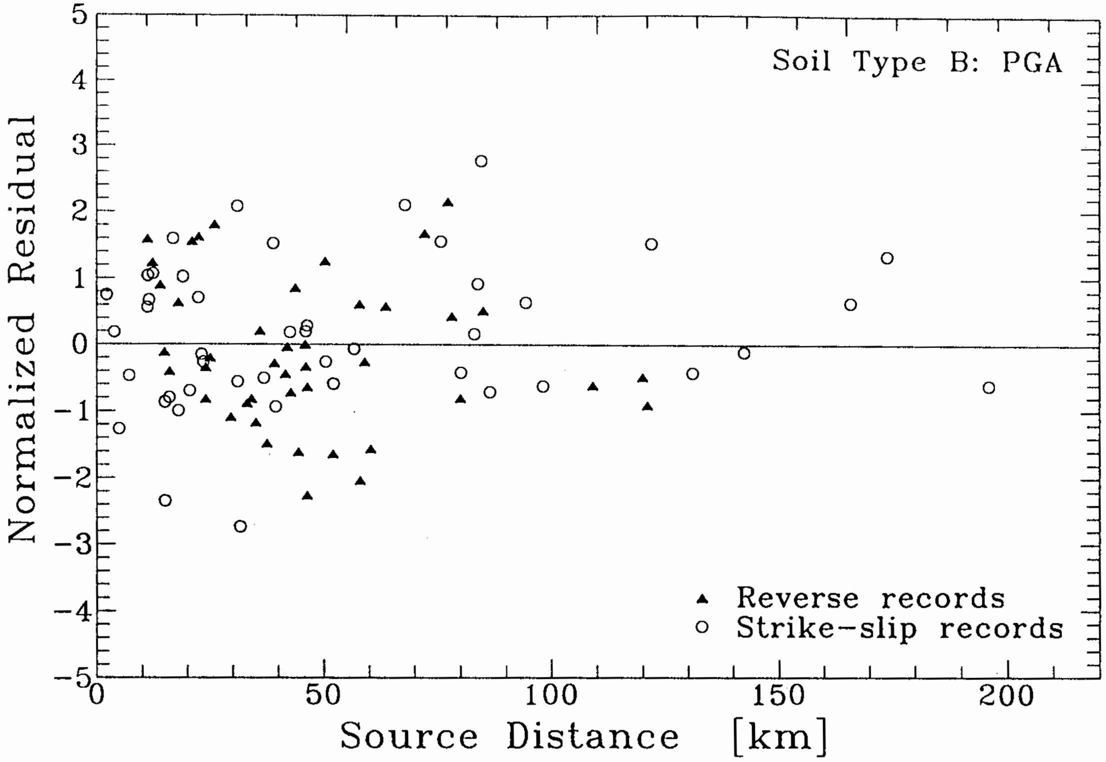
APPENDIX C. PLOTS OF RESIDUALS

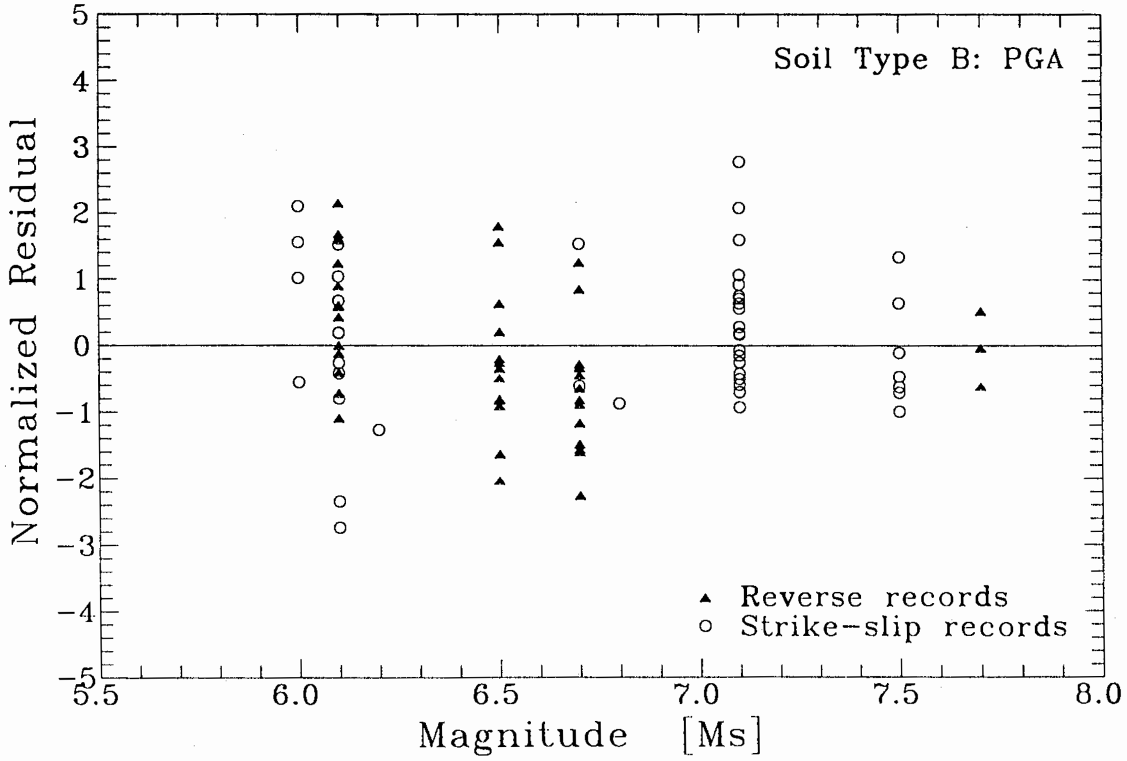
Plots of the residuals from the site classes B and C regression analyses for PGA, PSV (T = 0.3 sec), and PSV (T = 1 sec) are shown on the following pages. The residual for the i th datum, Φ_i, was computed as

$$\Phi_i = (\ln Y_{i,Obs.} - \ln Y_{i,Pred.}) / \sigma_{\ln Y}$$

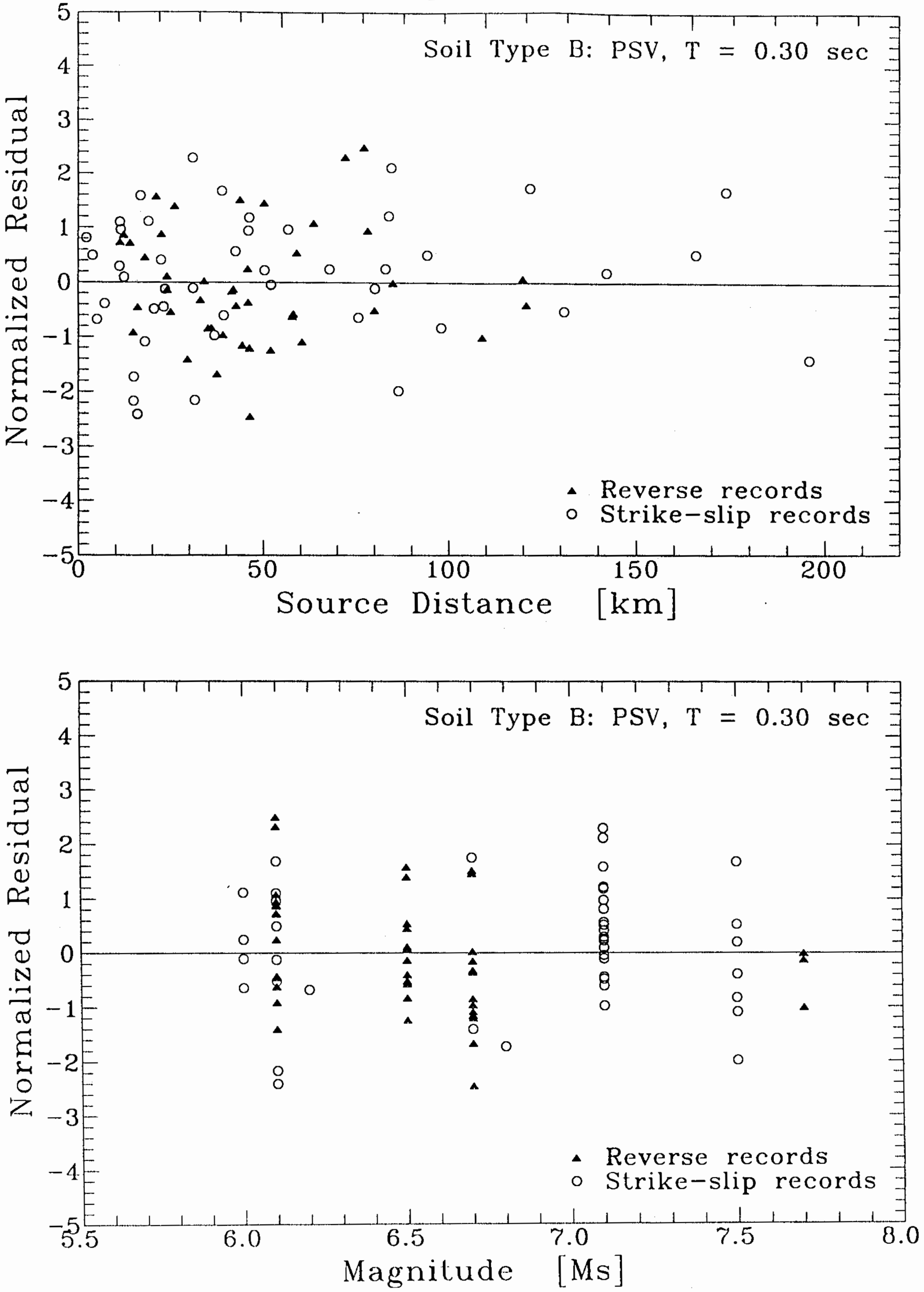
where $Y_{i,Obs.}$ is the i th observed value of PGA or PSV, $Y_{i,Pred.}$ is the corresponding value predicted by the regression equation, and $\sigma_{\ln Y}$ is the standard error of the regression. The top frame of each plot shows the residuals plotted versus distance, R, and the bottom frame shows the residuals plotted versus magnitude, M.

Weighted Regression Results

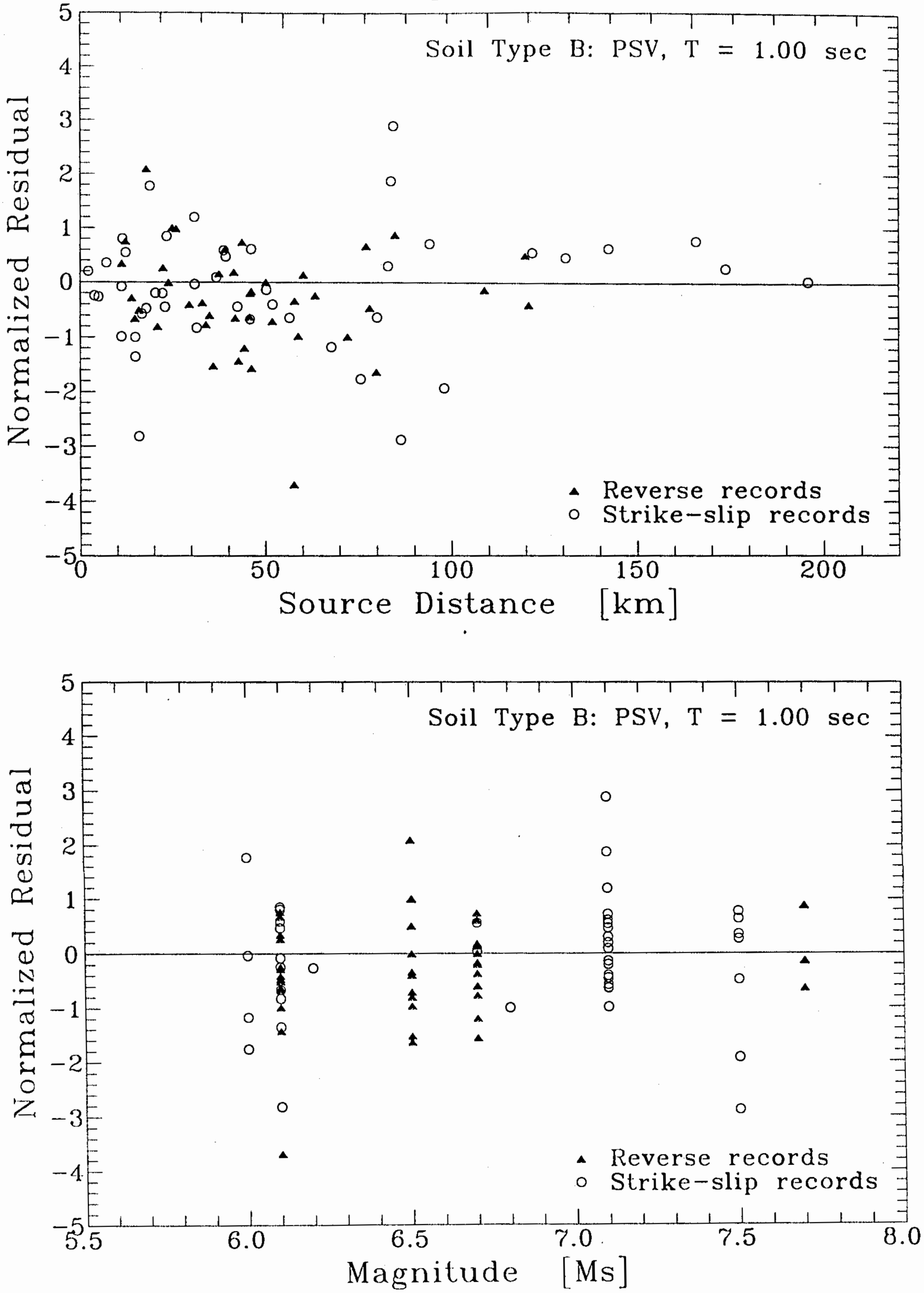




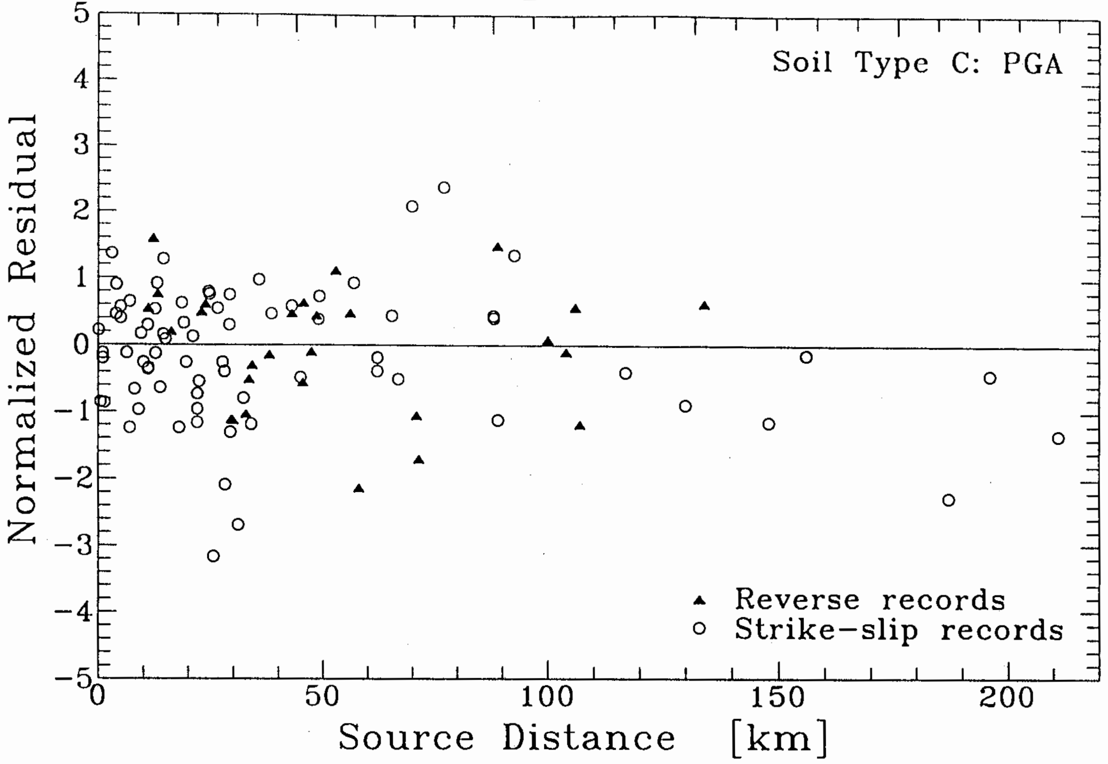
Weighted Regression Results

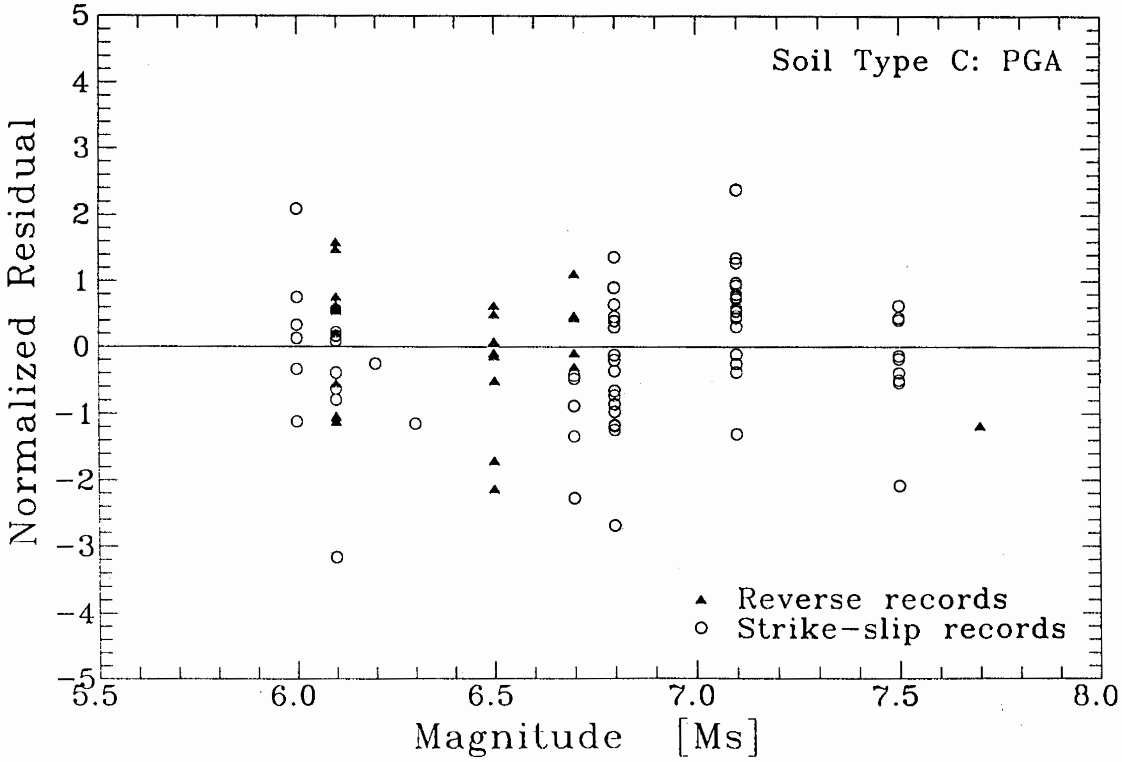


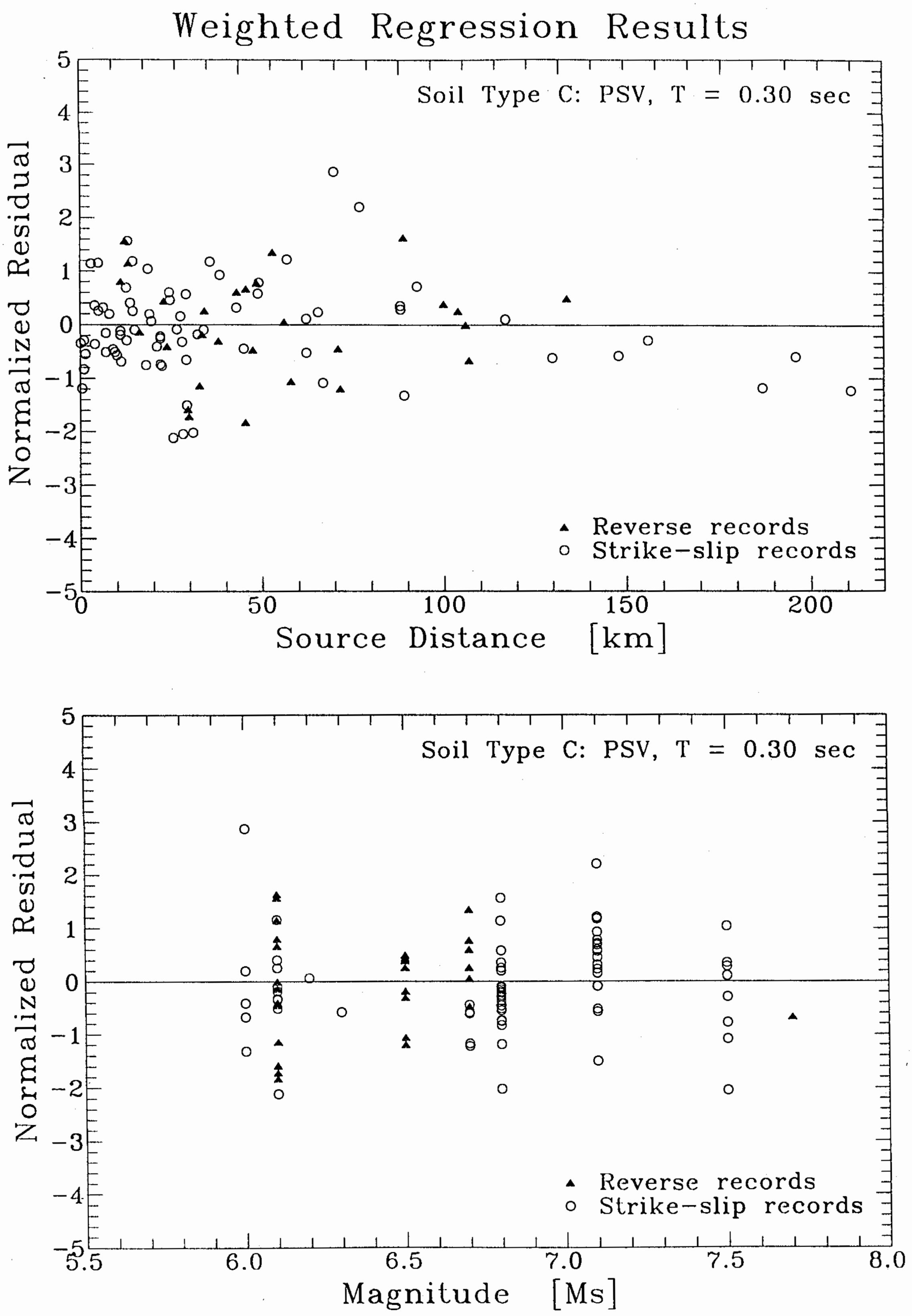
Weighted Regression Results



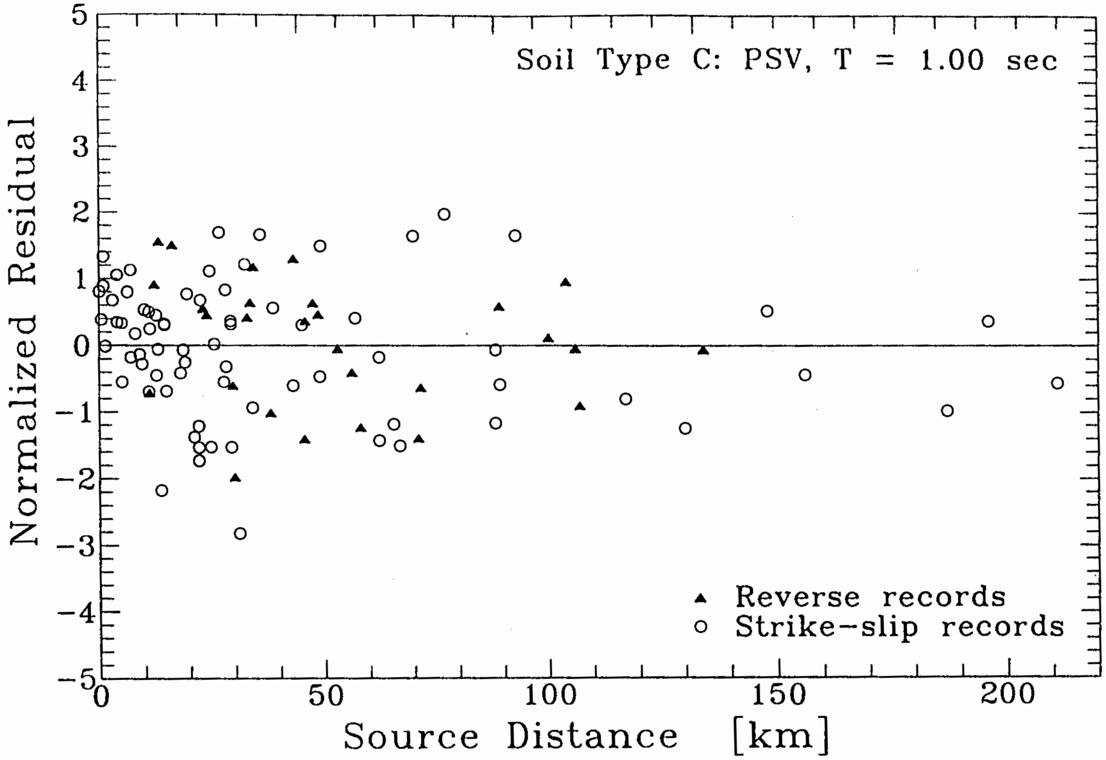
Weighted Regression Results

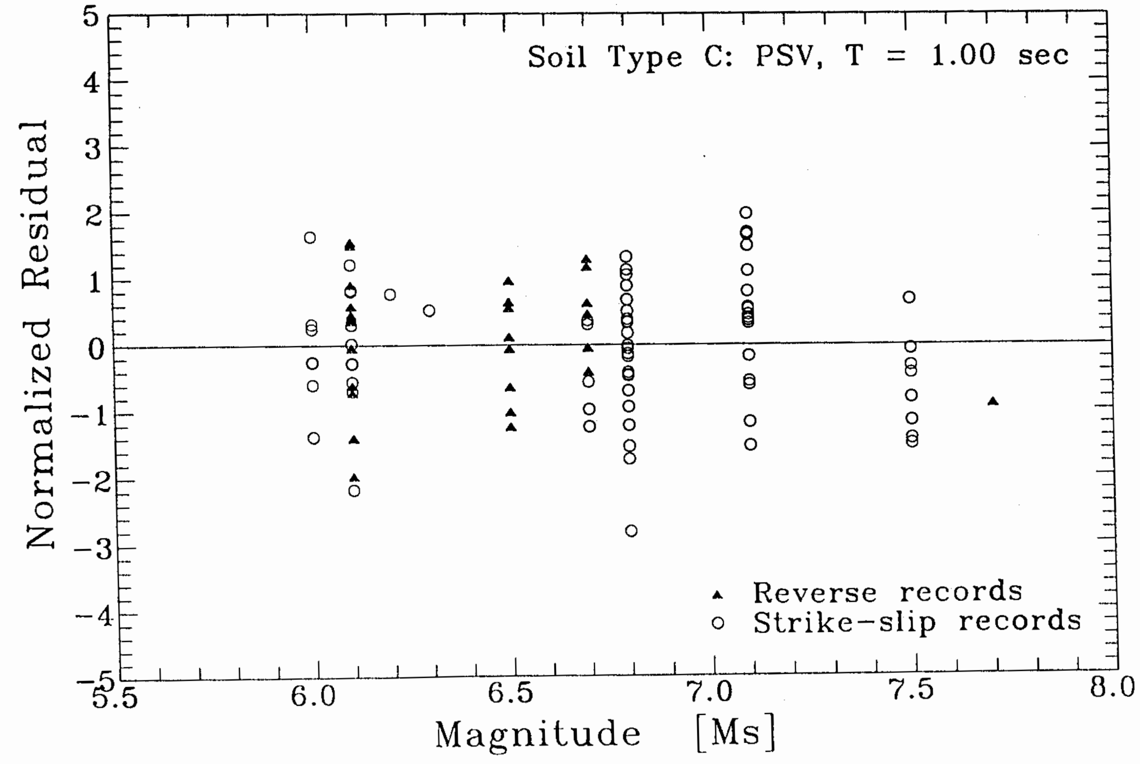





Weighted Regression Results
Soil Type C: PSV, T = 0.30 sec
Normalized Residual
5
4
3
2
1
0
−1
−2
−3
−4
−5
0
50
100
150
200
Source Distance [km]
▲ Reverse records
○ Strike-slip records
Soil Type C: PSV, T = 0.30 sec
Normalized Residual
5.5
6.0
6.5
7.0
7.5
8.0
Magnitude [Ms]
▲ Reverse records
○ Strike-slip records

Weighted Regression Results





LIST OF CSMIP DATA UTILIZATION REPORTS

California Department of Conservation
Division of Mines and Geology
Office of Strong Motion Studies
California Strong Motion Instrumentation Program (CSMIP)

The California Strong Motion Instrumentation Program (CSMIP) publishes data utilization reports as part of the Data Interpretation Project. These reports were prepared by investigators funded by CSMIP. Results obtained by the investigators were summarized in the papers included in the proceedings of the annual seminar. These reports and seminar proceedings are available from CSMIP at nominal cost. Requests for the reports, seminar proceedings and/or for additional information should be addressed to: Data Interpretation Project Manager, Office of Strong Motion Studies, Division of Mines and Geology, California Department of Conservation, 801 K Street, MS 13-35, Sacramento, California 95814-3531. Phone: (916)322-3105

CSMIP/92-01	**"Evaluation of Soil-Structure Interaction in Buildings during Earthquakes,"** by G. Fenves and G. Serino, June 1992, 57 pp.
CSMIP/92-02	**"Seismic Performance Investigation of the Hayward BART Elevated Section,"** by W. Tseng, M. Yang and J. Penzien, September 1992, 61 pp.
CSMIP/93-01	**"Influence of Critical Moho Reflections on Strong Motion Attenuation in California,"** by P. Somerville, N. Smith and D. Dreger, December 1993, 84 pp.
CSMIP/93-02	**"Investigation of the Response of Puddingstone Dam in the Whittier Narrows Earthquake of October 1, 1987,"** by J. Bray, R. Seed and R. Boulanger, December 1993, 60 pp.
CSMIP/93-03	**"Investigation of the Response of Cogswell Dam in the Whittier Narrows Earthquake of October 1, 1987,"** by R. Boulanger, R. Seed and J. Bray, December 1993, 53 pp.
CSMIP/94-01	**"Torsional Response Characteristics of Regular Buildings under Different Seismic Excitation Levels,"** by H. Sedarat, S. Gupta, and S. Werner, January 1994, 43 pp.
CSMIP/94-02	**"Degradation of Plywood Roof Diaphragms under Multiple Earthquake Loading,"** by J. Bouwkamp, R. Hamburger and J. Gillengerten, February 1994, 32 pp.
CSMIP/94-03	**"Analysis of the Recorded Response of Lexington Dam during Various Levels of Ground Shaking,"** by F. Makdisi, C. Chang, Z. Wang and C. Mok, March 1994, 60 pp.

LIST OF CSMIP DATA UTILIZATION REPORTS (continued)

CSMIP/94-04	**"Correlation between Recorded Building Data and Non-Structural Damage during the Loma Prieta Earthquake of October 17, 1989,"** by S. Rihal, April 1994, 65 pp.
CSMIP/94-05	**"Simulation of the Recorded Response of Unreinforced Masonry (URM) Infill Buildings,"** by J. Kariotis, J. Guh, G. Hart and J. Hill, October 1994, 149 pp.
CSMIP/95-01	**"Seismic Response Study of the Hwy 101/Painter Street Overpass Near Eureka Using Strong-Motion Records,"** by R. Goel and A. Chopra, March 1995, 70 pp.
CSMIP/95-02	**"Evaluation of the Response of I-10/215 Interchange Bridge Near San Bernardino in the 1992 Landers and Big Bear Earthquakes,"** by G. Fenves and R. Desroches, March 1995, 132 pp.
CSMIP/95-03	**"Site Response Studies for Purpose of Revising NEHRP Seismic Provisions,"** by C.B. Crouse, March 1995, 68 pp.
SMIP89	"SMIP89 Seminar on Seismological and Engineering Implications on Recent Strong-motion Data," Preprints, Sacramento, California, May 9, 1989
SMIP90	"SMIP90 Seminar on Seismological and Engineering Implications on Recent Strong-motion Data," Preprints, Sacramento, California, June 8, 1990
SMIP91	"SMIP91 Seminar on Seismological and Engineering Implications on Recent Strong-motion Data," Preprints, Sacramento, California, May 30, 1991
SMIP92	"SMIP92 Seminar on Seismological and Engineering Implications on Recent Strong-motion Data," Proceedings, Sacramento, California, May 21, 1992
SMIP93	"SMIP93 Seminar on Seismological and Engineering Implications on Recent Strong-motion Data," Proceedings, Sacramento, California, May 20, 1993, 114 pp.
SMIP94	"SMIP94 Seminar on Seismological and Engineering Implications on Recent Strong-motion Data," Proceedings, Los Angeles, California, May 26, 1994, 120 pp.