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DEVELOPMENT OF REGIONAL HARD ROCK ATTENUATION RELATIONS FOR CENTRAL AND EASTERN NORTH AMERICA, MID-CONTINENT AND GULF COAST AREAS

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Background

Due to the low rates of seismicity, a significant and currently unresolvable issue exists in the estimation of strong ground motions for specified magnitude, distance, and site conditions in central and eastern North America (CENA). The preferred approach to estimating design ground motions is through the use of empirical attenuation relations, perhaps augmented with a model based relation to capture regional influences. For western North America (WNA), particularly California, seismicity rates are such that sufficient strong motion recordings are available for ranges in magnitudes and distances to properly constrain regression analyses. Naturally, not enough recorded data are available at close distances ($\leq$ 10 km) to large magnitude earthquakes (**M** $\geq$ 6 3/4) so large uncertainty exists for these design conditions but, in general, ground motions are reasonably well defined. For CENA however, very few data exist and nearly all are for **M** $\leq$ 5.8 and distances exceeding about 50 km. This is a fortunate circumstance in terms of hazard but, because the potential exists for large, though infrequent, earthquakes in certain areas of CENA, the actual risk to life and structures is comparable to that which exists in seismically active WNA. As a result, the need to characterize strong ground motions is significant and considerable effort has been directed to developing appropriate attenuation relations for CENA conditions (Boore and Atkinson, 1987; Toro and McGuire, 1987; EPRI, 1993; Toro et al., 1997; Atkinson and Boore, 1997). Because the strong motion data set is sparse in the CENA, numerical simulations represent the only available approach and the stochastic point-source model (Appendix A) has generally been the preferred model used to develop attenuation relations. The process involves repeatedly exercising the model for a range in magnitude and distances as well as expected parameter values, adopting a functional form for a regression equation, and finally performing regression analyses to determine coefficients for median predictions as well as variability about the median. Essential elements in this process include: a physically realistic, reasonably robust and well-validated model (Silva et al., 1997; Schneider et al., 1993); appropriate parameter values and their distributions; and a statistically stable estimate of model variability (Appendix A). The model variability is added to the variability resulting from the regression analyses (parametric plus regression variability) to represent the total variability associated with median estimates of ground motions (Appendix A).

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Model Parameters

For the point-source model implemented here, parameters include stress drop ($\Delta\sigma$), source depth (H), path damping ($Q(f) = Q_o f^{\eta}$), shallow crustal damping (kappa), and crustal amplification. For the regional crust, the Midcontinent and Gulf Coast models from EPRI (1993; also in Toro et al., 1997) were adopted. The crustal models are listed in Table 1. The Moho is at a depth of about 40 km. Geometrical attenuation is assumed to be magnitude dependent, using a model based on inversions of the Abrahamson and Silva (1997) empirical attenuation relation with the point-source model. The model for geometrical attenuation is given by

$$R^{-(a + b(\mathbf{M} - 6.5))}, \; R \leq 80 \text{ km}; \quad R^{-(a + b(\mathbf{M} - 6.5))/2}, \quad R > 80 \text{ km} \tag{1}$$

where a = 1.0296, b = -0.0422, and 80 km reflects about twice the crustal thickness (Table 1).

The duration model is taken as the inverse corner frequency plus a smooth distance term of 0.05 times the hypocentral distance (Herrmann, 1985). Monotonic trends in both the geometrical attenuation and distance duration models produced no biases in the validation exercises using WNA and CENA recordings (Appendix A) and are considered appropriate when considerable variability in crustal structure that may exist over a region, as well as variability in source depth. Additionally, extensive modeling exercises have shown that the effects of source finiteness, coupled with variability in source depth and crustal structure, result in smooth attenuation with distance, accompanied by a large variability in ground motions (EPRI, 1993). More recently, regressions for peak acceleration, peak particle velocity, and peak displacement on WNA strong motion data (over 50 earthquakes, **M** ≈ 5.0 to 7.6), including the recent Chi-Chi, Taiwan and Koaceli and Duzce, Turkey earthquakes using a smooth monotonic distance dependency (Equation 3) showed symmetric distributions of residuals about zero (Silva et al., 2002). These results suggest a monotonic distance dependency adequately reflects strong motion distance attenuation when considering multiple earthquakes and variable crustal conditions and is an appropriate assumption for estimating strong ground motions for the next earthquake.

To model shallow crustal damping, a kappa value of 0.006 sec is assumed to apply for the crystalline basement and below (Silva and Darragh, 1995; EPRI, 1993). The Q(f) model is from Silva et al. (1997), based on inversions of CEUS recordings and is given by $Q(f) = 351 f^{0.84}$ for the Midcontinent region. For the Gulf Coast $Q(f) = 300 f^{0.81}$ based on inversions of regional LRSM recordings (EPRI 1993). Both magnitude independent and magnitude dependent stress drop models are used. For the magnitude dependent stress drop model, the stress drop varies from 160 bars for **M** 5.5 to 90 bars for **M** 7.5 and 70 bars for **M** 8.5 (the range in magnitudes for the simulations). The magnitude scaling of stress drop is based on point-source inversions of the Abrahamson and Silva (1997) empirical attenuation relation (Silva et al., 1997) and is an empirically driven mechanism to accommodate the observed magnitude saturation due to source finiteness. Similar point-source stress drop scaling has been observed by Atkinson and Silva (1997) using (WNA) recordings of strong ground motions and from inversions of the Sadigh et al., (1997) attenuation relation (EPRI, 1993). For the CEUS, the stress drop values are constrained by the **M** 5.5 stress drop of 160 bars. This value is from recent work of Gail Atkinson (personal communication, 1998) who determined CENA stress drops based on instrumental and intensity data. Since the majority of her data are from earthquakes below **M** 6 (**M** 4 to 7), it was assumed her average stress drop (≈ 180 bars adjusted for the regional crustal model to 160 bars) is appropriate for **M** 5.5. Table 2 shows the magnitude dependent as well as magnitude independent stress drops. The magnitude independent stress drop of 120 bars reflects the log average of the **M** 5.5, **M** 6.5, and **M** 7.5 stress drops (Table 2).

The single corner frequency model was also run with a constant stress drop for all magnitudes. A stress drop of 120 bars was applied to all four magnitudes. This is the same constant stress drop used in the Toro et al. (1997; EPRI, 1993) CEUS rock relations. To accommodate uncertainty (epistemic) in median stress drop (parameters) for CEUS earthquakes, both high and low median values were run using a 100% variation on the constant and variable stress drop models (Table 2). The high stress drop model is taken as 2 times the base case values with the low stress drop as the base case values divided by 2.

Source depth is also assumed to be magnitude dependent and is based on the depth distribution of stable continental interiors and margins (EPRI, 1993). The magnitude dependent depth distribution is shown in Table 2.

Another source model considered appropriate for CENA ground motions is the double corner model (Atkinson and Boore, 1995). In this model there is no variation of the stress drop with magnitude. Additionally, stress drop is not explicitly defined for this model and no uncertainties are given for the corner frequencies (which are magnitude dependent). As a result, the parametric uncertainty obtained from the regression analysis will underepresent the total parametric uncertainty. For this reason, the total parametric uncertainty for the two-corner model is taken as the total parametric uncertainty from the single corner model with variable stress drop, which is slightly larger than the parametric uncertainty for the single corner model with constant stress drop scaling (to avoid underestimating the two-corner parametric uncertainty).

To accommodate magnitude saturation in the double-corner and single-corner constant stress drop models, magnitude dependent fictitious depth terms were added to the source depths for simulations at **M** 6.5 and above. The functional form is given by

$$H = H' \, e^{a + bM} \qquad (2)$$

with

$$a = -1.250, \qquad b = 0.227.$$

H and H' are the fictitious and original source depths respectively and the coefficients are based on the Abrahamson and Silva (1997) empirical attenuation relation. The magnitude saturation built into the constant stress drop single corner and double corner models is then constrained empirically, accommodating source finiteness in a manner consistent with the WUS strong motion database. This approach to limiting unrealistically high ground motions for large magnitude earthquakes at close distances is considered more physically reasonable than limiting the motions directly, which can be rather arbitrary with specific limiting values difficult to defend on a physical basis.

Because of the manner in which the model validations were performed ($\Delta\sigma$, Q(f), and H were optimized), parametric variability for only $\Delta\sigma$, Q(f) and H are required to be reflected in the model simulations (Appendix B; EPRI, 1993; Roblee et. al., 1996). For source depth variability, a lognormal distribution is used with a σ_{ln} = 0.6 (EPRI, 1993). Bounds are placed on the distribution to prevent nonphysical realizations (Table 2).

The stress drop variability, σ_{ln} = 0.5 is from Silva et al. (1997) and is based on inversions of ground motions for stress drop using WNA earthquakes with **M** $\geq$ 5. The variability in Q(f) is taken in Q_o alone (σ_{ln} = 0.4) and is based on inversions in WNA for Q(f) models (Silva et al., 1997).

Attenuation Relations

To generate data, which consists of 5% damped spectral acceleration, peak acceleration, peak particle velocity, and peak displacements, for the regression analyses, 300 simulations reflecting parametric variability are made at distances of 1, 5, 10, 20, 50, 75, 100, 200, and 400 km. At each distance, five magnitudes are used: **M** 4.5, 5.5, 6.5, 7.5, and 8.5 (Table 2).

The functional form selected for the regressions which provided the best overall fit (from a suite of about 25) to the simulations is given by

$$\ln y = C_1 + C_2 \mathrm{M} + (C_6 + C_7 \mathrm{M}) * \ln (R + e^{C_4}) + C_{10} (\mathrm{M} - 6)^2, \quad (3)$$

where R is taken as a closest distance to the surface projection of the rupture surface, consistent with the validation exercises (Silva et al., 1997).

Figure 1 shows the simulations for peak accelerations as well as the model fits for the single corner model with variable stress drops for **M** 7.5 and the Midcontinent parameters. In general, the model fits the central trends (medians) of the simulations. Figure 2a summarizes the magnitude dependency of the peak acceleration estimates and saturation is evident, primarily due to the magnitude dependent stress drop. Also evident is the magnitude dependent far-field fall off with a decrease in slope as **M** increases (easily seen beyond 100 km). This feature is especially important in the CEUS where large contributions to the hazard can come from distant sources. The model predicts peak accelerations at a distance of 1 km of about 0.30, 0.70, 1.10, 1.50g for **M** 4.5, 5.5, 6.5, and 7.5, respectively.

For comparison, Figure 2a also shows the results for the Gulf Coast parameters with slightly higher peak accelerations within about 30 km. Beyond about 30 km, the Gulf Coast shows significantly lower motions, particularly at large distance (R $\geq$ 200 km). The higher close-in Gulf Coast motions are a result of larger crustal amplification while the crossover near 30 km is due to the lower Q(f) model or crustal damping.

Figure 2b illustrates the effect of median stress drop on the peak accelerations, about a factor of 2 (closer to 1.7 overall) at close distances and decreasing with increasing distance (likely due to a decrease in frequency content with increasing distance).

Examples of response spectra at 1 km for **M** 4.5, 5.5, 6.5, 7.5, and 8.5 are shown in Figure 3a for the Midcontinent and Gulf Coast regions. For **M** 7.5, the peak acceleration (Sa at 100 Hz) is about 1.8g with the peak in the spectrum near 0.04 sec. The jagged nature of the Midcontinent spectra is due to unsmoothed coefficients. Figure 3b shows the effect of median stress drop on the spectra for the Midcontinent parameters (effects on the Gulf Coast are quite similar). As expected the maximum effect is at high frequency, decreasing with increasing period, and approaching no effect at the magnitude dependent corner period.

The model regression coefficients are listed in Table 3 along with the parametric and total variability. The modeling variability is taken from Appendix A. The total variability, solid line in Figure Set 4, is large. For the Midcontinent, it ranges from about 2 at short periods to about 4 at a period of 10 sec, where it is dominated by modeling variability. For the Gulf Coast, the high frequency parametric (and total) variability is higher, about 2.5 for the total variability at peak acceleration (100 Hz). This is driven by the effects of the lower Q(f) model. The high frequency large distance motions are lower than the Midcontinent, driven down by the higher crustal damping. This is appropriately accommodated in an increased parametric variability and is a compelling case for a variability model which includes a distance dependency.

The large long period uncertainty is due to the tendency of the point-source model to overpredict low frequency motions at large magnitudes (**M** > 6.5; EPRI, 1993). This trend led Atkinson and Silva (1997, 2000) to introduce a double-corner point-source model for WUS crustal sources, suggesting a similarity in source processes for WUS and CEUS crustal sources, but with CEUS sources being more energetic by about a factor of two (twice WUS stress drops), on average.

The results for the single corner frequency model with constant stress drop scaling are shown in Figure Sets 5 to 8. The same plots are shown as were described for the previous model. These two models estimate similar values with the variable stress drop motions exceeding the constant stress drop motions at the lower magnitudes (**M** ≤ 6.5). The constant stress drop of 120 bars will result in about 30% to 50% higher rock motions at high frequency (> 1 Hz) for **M** 7.5 than the variable stress drop model, with a corresponding stress drop of 95 bars (EPRI, 1993). At small **M**, say **M** 5.5, the variable stress drop motions are higher, reflecting the 160 bar results of Atkinson for CEUS earthquakes with average **M** near 5.5. Also shown are the results for the model with saturation, reducing the large magnitude, close-in motions. The saturation reduces the **M** 7.5 and **M** 8.5 motions by 30 to 50% within about 10 km distance. The parametric variability is also similar to that of the variable stress drop model. The regression coefficients are given in Tables 4 and 5.

The regression results for the double corner frequency model are listed in Tables 6 and 7. The regression model fit to the peak acceleration data as shown in Figure 9 for the Midcontinent. The PGA model is shown in Figure 10, and Figure 12 is a plot of the uncertainty. Figure 11 shows the spectra at a distance of 1 km. At long period (> 1 sec) and large **M** (≥ 6.5) the motions are significantly lower than those of the single-corner models (Figures 3a and 7). The parametric variability was taken as the same as the single corner model with variable stress drop as distributions are not currently available to apply to the two corner frequencies associated with this model (Atkinson and Boore, 1997). Since the two corner frequency source model was not available when the validations were performed (Silva et al., 1997), the model variability for the single corner frequency source model was used. This is considered conservative as the total aleatory variability for the two corner model is likely to be lower than that of the single corner model, as comparisons using WUS data show it provides a better fit to recorded motions at low frequencies (≤ 1 Hz; Atkinson and Silva, 1997, 2000). This is, of course, assuming the aleatory parametric variability associated with the two corner frequencies is not significantly larger than that associated with the single corner frequency stress drop.

At long period (> 1 sec) the total variability is largely empirical, being driven by the modeling component or comparisons to recorded motions. While this variability may be considered large, it includes about 17 earthquakes with magnitudes ranging from **M** 5.3 to **M** 7.4, distances out to 500 km, and both rock and soil sites. The average **M** for the validation earthquakes is about **M** 6.5, near the magnitude where empirical aleatory variability has a significant reduction (Abrahamson and Shedlock, 1997). The magnitude independent point-source variability may then reflect the generally higher variability associated with lower magnitude (**M** ≤ 6.5) earthquakes, being conservative for larger magnitude earthquakes.

Epistemic variability or uncertainty in mean estimates of ground motions is assumed to be accommodated in the use of the three mean stress drop single corner models and the double corner model, all with appropriate weights. This assumption assumes the epistemic uncertainty in the spectral levels of the two corner frequency model are small (indeed zero) and can be neglected. This approach assumes the major contributors to epistemic uncertainty (variability in mean motions) for the CEUS are in single corner mean stress drop and shape of the source spectrum, as well as differences in crustal structure between the Midcontinent and Gulf Coast regions (Table 1). As a guide to estimating appropriate weights for the low, medium, and high median stress drops to accommodate epistemic variability in median CEUS single corner stress drops, the EPRI (1993) value for total variability (epistemic plus aleatory) of 0.7 at large magnitude (**M** ≥ 6.5) may be adopted. Based on the WUS aleatory value of 0.5 (Table 2; Silva et al., 1997), assuming similar aleatory variability in median stress drop for the CEUS, the remaining variability of 0.49 may be attributed to epistemic variability in the medium stress drop. For the factors of two above and below the medium stress drop (Table 2), an approximate three point weighting would have weights of 1/6, 2/3, 1/6 (Gabe Toro, personal communication).

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Table 1 CRUSTAL MODELS[*] MID-CONTINENT		
Thickness (km)	V_S (km/sec)	Density (cgs)
1.30	2.83	2.52
11.00	3.52	2.71
28.00	3.75	2.78
-----	4.62	3.35
GULF COAST[*]		
7.00	2.31	2.37
8.00	3.05	2.58
15.00	3.76	2.78
	4.74	3.40

[*] EPRI mid-continent and Gulf Coast (EPRI, 1993; Toro et al., 1997)

Table 2

PARAMETERS FOR CRYSTALLINE ROCK

OUTCROP ATTENUATION SIMULATIONS

M	4.5, 5.5, 6.5, 7.5, 8.5
D (km)	1, 5, 10, 20, 50, 75, 100, 200, 400

300 simulations for each **M**, *R* pair

Randomly vary source depth, $\Delta\sigma$, kappa, Q_o, η, profile

<u>Depth,</u> $\sigma_{\ln H} = 0.6$, Intraplate Seismicity (EPRI, 1993)

M	m_{blg}	Lower Bound (km)	$\overline{H}$ (km)	Upper Bound (km)
4.5	4.9	2	6	15
5.5	6.0	2	6	15
6.5	6.6	4	8	20
7.5	7.1	5	10	20
8.5	7.8	5	10	20

$\Delta\sigma$, $\sigma_{\ln} \Delta\sigma = 0.5$ (Silva et al., 1997)

M	m_{blg}	$\Delta\sigma$ (bars) Base Case Values
4.5	4.9	160, 120[*]
5.5	6.0	160, 120[*]
6.5	6.6	120, 120[*]
7.5	7.1	90, 120[*]
8.5	7.8	70, 120[*]

AVG. $\Delta\sigma$ (bars) = 123; Assumes **M** 5.5 = 160 bars (Atkinson, 1993) with magnitude scaling taken from WUS (Silva et al., 1997); constant stress drop model has $\Delta\sigma$ (bars) = 120. High and low stress drop models are 100% higher and 100% lower than base case values.

<u>Q(s),</u> = 351, $\eta = 0.84$, $\sigma_{\ln Qo} = 0.4$, (Mid-Continent; Silva et al., 1997)

<u>Q(s),</u> = 300, $\eta = 0.30$, $\sigma_{\ln Qo} = 0.4$, (Gulf Coast; EPRI, 1993)

Varying Q_o only sufficient, ± 1 σ covers range of CEUS inversions from 1 to 20 Hz

Kappa, $\overline{\kappa}$ = 0.006 sec (EPRI, 1993)

<u>Profile,</u> Crystaline Basement, randomize top 100 ft

Geometrical attenuation $R^{-(a + b(\mathbf{M} - 6.5))}$, a = 1.0296, b = -0.0422

$R^{-(a + b(\mathbf{M} - 6.5))/2}$, R > 80 km, approximately twice crustal thickness (Table1)

Based on inversions of the Abrahamson and Silva (1997) relation

[*]Constant Stress Drop Model

Table 3a MIDCONTINENT REGRESSION COEFFICIENTS FOR THE SINGLE CORNER MODEL WITH VARIABLE MEDIUM STRESS DROP AS A FUNCTION OF MOMENT MAGNITUDE (**M**)										
Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-19.07223	2.57205	2.10000	.00000	-1.41166	.05292	.00000	-.31205	.3559	1.3243
0.2000	-15.15004	2.27308	2.30000	.00000	-1.55609	.06043	.00000	-.38898	.3660	1.1933
0.3333	-11.84462	1.96000	2.40000	.00000	-1.70638	.07232	.00000	-.39806	.3892	1.0462
0.5000	-9.00041	1.66899	2.50000	.00000	-1.86794	.08623	.00000	-.37576	.4160	.9591
0.6250	-7.60788	1.50586	2.50000	.00000	-1.94031	.09384	.00000	-.35415	.4297	.8874
1.0000	-4.51914	1.13220	2.60000	.00000	-2.16445	.11502	.00000	-.29235	.4518	.8021
1.3333	-2.82095	.93101	2.60000	.00000	-2.25774	.12494	.00000	-.24823	.4610	.8050
2.0000	-.84738	.68960	2.60000	.00000	-2.39187	.13949	.00000	-.19435	.4714	.7551
2.5000	.13162	.57890	2.60000	.00000	-2.45001	.14539	.00000	-.16638	.4775	.7396
3.3333	1.12628	.45746	2.60000	.00000	-2.53338	.15420	.00000	-.13930	.4865	.7395
4.1667	1.79388	.38804	2.60000	.00000	-2.58195	.15895	.00000	-.12283	.4950	.7274
5.0000	2.27495	.34400	2.60000	.00000	-2.61448	.16182	.00000	-.11211	.5040	.7247
6.2500	3.13556	.27220	2.70000	.00000	-2.72838	.17012	.00000	-.10222	.5181	.7271
6.6667	3.26041	.25961	2.70000	.00000	-2.74131	.17129	.00000	-.09985	.5249	.7328
8.3333	3.65946	.22693	2.70000	.00000	-2.77660	.17414	.00000	-.09345	.5424	.7503
10.0000	3.92885	.20331	2.70000	.00000	-2.80630	.17658	.00000	-.08961	.5602	.7507
12.5000	4.20238	.17878	2.70000	.00000	-2.84105	.17938	.00000	-.08624	.5731	.7534
14.2857	4.33334	.16542	2.70000	.00000	-2.86188	.18110	.00000	-.08477	.5803	.7585
16.6667	4.89845	.12529	2.80000	.00000	-2.96230	.18763	.00000	-.08349	.5868	.7656
18.1818	4.96669	.11815	2.80000	.00000	-2.97508	.18865	.00000	-.08293	.5907	.7644
20.0000	5.03867	.11102	2.80000	.00000	-2.98849	.18968	.00000	-.08242	.5961	.7711
25.0000	5.20890	.09698	2.80000	.00000	-3.01742	.19172	.00000	-.08150	.6133	.7817
31.0000	5.37895	.08559	2.80000	.00000	-3.04366	.19337	.00000	-.08079	.6227	.7858
40.0000	6.02744	.04417	2.90000	.00000	-3.15877	.20038	.00000	-.08027	.6222	.7823
50.0000	6.07941	.03289	2.90000	.00000	-3.18403	.20265	.00000	-.08044	.6143	.7776
100.000	4.24805	.09552	2.70000	.00000	-2.99165	.19690	.00000	-.08748	.5644	.7392
PGA	4.03930	.10412	2.70000	.00000	-2.97465	.19631	.00000	-.08874	.5592	.7353
PGV	3.22720	.65905	2.40000	.00000	-2.73277	.20009	.00000	-.13903	.4408	--------

Table 3b MIDCONTINENT REGRESSION COEFFICIENTS FOR THE SINGLE CORNER MODEL WITH VARIABLE LOW STRESS DROP AS A FUNCTION OF MOMENT MAGNITUDE (**M**)										
Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-18.82818	2.50853	2.10000	.00000	-1.39437	.05155	.00000	-.35284	.3623	1.3261
0.2000	-14.90966	2.17243	2.30000	.00000	-1.51375	.05943	.00000	-.40726	.3774	1.1969
0.3333	-11.55820	1.83734	2.40000	.00000	-1.66484	.07203	.00000	-.39809	.4056	1.0524
0.5000	-8.74448	1.53854	2.50000	.00000	-1.82313	.08612	.00000	-.36309	.4307	.9656
0.6250	-7.14902	1.36498	2.50000	.00000	-1.93736	.09559	.00000	-.33624	.4415	.8932
1.0000	-4.48436	1.01787	2.60000	.00000	-2.10529	.11396	.00000	-.26954	.4580	.8056
1.3333	-2.60545	.81461	2.60000	.00000	-2.24962	.12651	.00000	-.22591	.4650	.8073
2.0000	-.82196	.59874	2.60000	.00000	-2.37729	.14040	.00000	-.17695	.4750	.7574
2.5000	.04301	.50444	2.60000	.00000	-2.43239	.14596	.00000	-.15344	.4816	.7423
3.3333	.91358	.40083	2.60000	.00000	-2.51171	.15434	.00000	-.13143	.4910	.7425
4.1667	1.49580	.34395	2.60000	.00000	-2.55688	.15868	.00000	-.11864	.4995	.7305
5.0000	1.91753	.30871	2.60000	.00000	-2.58706	.16126	.00000	-.11059	.5084	.7278
6.2500	2.71047	.24622	2.70000	.00000	-2.69634	.16908	.00000	-.10327	.5222	.7300
6.6667	2.81889	.23601	2.70000	.00000	-2.70814	.17011	.00000	-.10154	.5289	.7357
8.3333	3.17270	.20990	2.70000	.00000	-2.74034	.17258	.00000	-.09693	.5460	.7529
10.0000	3.41148	.19064	2.70000	.00000	-2.76748	.17469	.00000	-.09418	.5635	.7531
12.5000	3.65547	.17022	2.70000	.00000	-2.79941	.17715	.00000	-.09175	.5760	.7556
14.2857	3.77180	.15884	2.70000	.00000	-2.81861	.17867	.00000	-.09070	.5830	.7605
16.6667	4.31663	.12089	2.80000	.00000	-2.91626	.18495	.00000	-.08978	.5893	.7676
18.1818	4.37793	.11466	2.80000	.00000	-2.92815	.18586	.00000	-.08938	.5931	.7662
20.0000	4.44314	.10840	2.80000	.00000	-2.94065	.18679	.00000	-.08901	.5984	.7729
25.0000	4.60063	.09599	2.80000	.00000	-2.96783	.18862	.00000	-.08835	.6153	.7833
31.0000	4.76103	.08583	2.80000	.00000	-2.99272	.19011	.00000	-.08783	.6246	.7873
40.0000	5.39249	.04598	2.90000	.00000	-3.10501	.19687	.00000	-.08744	.6240	.7837
50.0000	5.43661	.03559	2.90000	.00000	-3.12848	.19893	.00000	-.08760	.6160	.7790
100.000	3.62958	.09547	2.70000	.00000	-2.93410	.19276	.00000	-.09342	.5661	.7405
PGA	3.42714	.10323	2.70000	.00000	-2.91721	.19218	.00000	-.09443	.5610	.7366
PGV	2.77820	.64929	2.40000	.00000	-2.66659	.19477	.00000	-.15404	.4441	--------

Table 3c MIDCONTINENT REGRESSION COEFFICIENTS FOR THE SINGLE CORNER MODEL WITH VARIABLE HIGH STRESS DROP AS A FUNCTION OF MOMENT MAGNITUDE (**M**)										
Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-18.80138	2.59958	2.30000	.00000	-1.51629	.05717	.00000	-.25763	.3585	1.3250
0.2000	-15.20886	2.34990	2.40000	.00000	-1.62679	.06230	.00000	-.35359	.3642	1.1928
0.3333	-11.97362	2.06358	2.50000	.00000	-1.77626	.07329	.00000	-.38117	.3821	1.0436
0.5000	-9.12315	1.78482	2.60000	.00000	-1.94059	.08684	.00000	-.37239	.4081	.9557
0.6250	-7.70148	1.62326	2.60000	.00000	-2.01584	.09460	.00000	-.35700	.4242	.8847
1.0000	-4.46472	1.24156	2.70000	.00000	-2.25138	.11635	.00000	-.30377	.4538	.8032
1.3333	-2.67167	1.03112	2.70000	.00000	-2.34731	.12639	.00000	-.26186	.4671	.8085
2.0000	-.51056	.76645	2.70000	.00000	-2.48971	.14173	.00000	-.20549	.4794	.7601
2.5000	.58917	.63923	2.70000	.00000	-2.55190	.14804	.00000	-.17378	.4851	.7445
3.3333	1.72806	.49782	2.70000	.00000	-2.64087	.15740	.00000	-.14160	.4934	.7441
4.1667	2.49641	.41405	2.70000	.00000	-2.69325	.16254	.00000	-.12105	.5013	.7317
5.0000	3.46126	.33544	2.80000	.00000	-2.80186	.16992	.00000	-.10713	.5099	.7289
6.2500	4.02502	.27487	2.80000	.00000	-2.85216	.17467	.00000	-.09403	.5238	.7311
6.6667	4.17095	.25933	2.80000	.00000	-2.86633	.17597	.00000	-.09083	.5305	.7369
8.3333	4.63032	.21818	2.80000	.00000	-2.90541	.17924	.00000	-.08205	.5480	.7543
10.0000	4.94207	.18877	2.80000	.00000	-2.93847	.18204	.00000	-.07672	.5658	.7549
12.5000	5.25826	.15855	2.80000	.00000	-2.97721	.18528	.00000	-.07200	.5789	.7578
14.2857	5.41104	.14236	2.80000	.00000	-3.00040	.18726	.00000	-.06993	.5861	.7629
16.6667	6.03843	.09752	2.90000	.00000	-3.11001	.19437	.00000	-.06812	.5929	.7703
18.1818	6.11753	.08905	2.90000	.00000	-3.12417	.19554	.00000	-.06731	.5968	.7691
20.0000	6.20019	.08062	2.90000	.00000	-3.13898	.19672	.00000	-.06658	.6022	.7758
25.0000	6.39121	.06416	2.90000	.00000	-3.17073	.19905	.00000	-.06525	.6195	.7866
31.0000	6.57730	.05102	2.90000	.00000	-3.19920	.20091	.00000	-.06426	.6289	.7907
40.0000	6.75933	.03739	2.90000	.00000	-3.23117	.20300	.00000	-.06354	.6285	.7873
50.0000	7.35410	-.00721	3.00000	.00000	-3.35245	.21111	.00000	-.06367	.6209	.7829
100.000	5.41652	.06158	2.80000	.00000	-3.15000	.20544	.00000	-.07217	.5713	.7445
PGA	5.19757	.07129	2.80000	.00000	-3.13247	.20485	.00000	-.07375	.5661	.7405
PGV	4.14085	.63457	2.50000	.00000	-2.88388	.20958	.00000	-.11455	.4471	--------

Table 3d
GULF COAST
REGRESSION COEFFICIENTS FOR THE SINGLE CORNER MODEL WITH
VARIABLE MEDIUM STRESS DROP AS A FUNCTION OF MOMENT MAGNITUDE (**M**)

Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-14.54986	2.30998	2.80000	.00000	-2.15716	.09152	.00000	-.34105	.5243	1.3791
0.2000	-9.25169	1.88136	3.10000	.00000	-2.51971	.11010	.00000	-.38752	.5604	1.2665
0.3333	-5.31480	1.49937	3.20000	.00000	-2.79932	.12984	.00000	-.37439	.5958	1.1393
0.5000	-1.92096	1.16422	3.30000	.00000	-3.08551	.15079	.00000	-.33869	.6159	1.0612
0.6250	.25617	.96349	3.40000	.00000	-3.30857	.16627	.00000	-.31189	.6233	.9956
1.0000	4.21778	.55654	3.50000	.00000	-3.70387	.19724	.00000	-.24619	.6483	.9271
1.3333	6.01523	.35576	3.50000	.00000	-3.87179	.21222	.00000	-.20693	.6622	.9349
2.0000	9.10831	.06810	3.60000	.00000	-4.24952	.24024	.00000	-.15976	.6850	.9040
2.5000	10.18655	-.04192	3.60000	.00000	-4.37417	.25066	.00000	-.13932	.6996	.8991
3.3333	2.43075	-.21755	3.70000	.00000	-4.69883	.27269	.00000	-.11900	.7208	.9109
4.1667	13.29372	-.29360	3.70000	.00000	-4.81633	.28167	.00000	-.10754	.7389	.9111
5.0000	13.93331	-.34606	3.70000	.00000	-4.90830	.28841	.00000	-.10055	.7556	.9177
6.2500	15.82366	-.46920	3.80000	.00000	-5.21303	.30744	.00000	-.09434	.7783	.9306
6.6667	16.02650	-.48449	3.80000	.00000	-5.24545	.30976	.00000	-.09294	.7850	.9369
8.3333	16.69027	-.53555	3.80000	.00000	-5.35752	.31804	.00000	-.08918	.8064	.9587
10.0000	17.18425	-.57629	3.80000	.00000	-5.44841	.32521	.00000	-.08711	.8192	.9596
12.5000	17.71756	-.62387	3.80000	.00000	-5.55455	.33408	.00000	-.08558	.8294	.9628
14.2857	17.99875	-.64981	3.80000	.00000	-5.61318	.33907	.00000	-.08507	.8339	.9664
16.6667	18.29779	-.67629	3.80000	.00000	-5.67576	.34425	.00000	-.08473	.8396	.9730
18.1818	18.46167	-.68951	3.80000	.00000	-5.70923	.34685	.00000	-.08461	.8438	.9733
20.0000	18.64419	-.70300	3.80000	.00000	-5.74551	.34952	.00000	-.08451	.8491	.9799
25.0000	20.50874	-.81779	3.90000	.00000	-6.06641	.36944	.00000	-.08430	.8566	.9842
31.0000	20.89870	-.84219	3.90000	.00000	-6.14187	.37424	.00000	-.08421	.8572	.9821
40.0000	19.78142	-.78593	3.80000	.00000	-5.97732	.36646	.00000	-.08469	.8487	.9722
50.0000	19.88182	-.80582	3.80000	.00000	-6.01166	.37073	.00000	-.08525	.8430	.9685
100.000	16.81947	-.70860	3.70000	.00000	-5.55741	.35763	.00000	-.09091	.7733	.9088
PGA	15.27441	-.61726	3.60000	.00000	-5.30301	.34239	.00000	-.09155	.7666	.9031
PGV	11.09786	.03822	3.20000	.00000	-4.40038	.33709	.00000	-.14227	.5888	--------

Table 3e GULF COAST REGRESSION COEFFICIENTS FOR THE SINGLE CORNER MODEL WITH VARIABLE LOW STRESS DROP AS A FUNCTION OF MOMENT MAGNITUDE (**M**)										
Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-14.25163	2.23220	2.80000	.00000	-2.13620	.09013	.00000	-.37542	.5238	1.3790
0.2000	-9.24105	1.78174	3.00000	.00000	-2.43210	.10715	.00000	-.39711	.5660	1.2690
0.3333	-4.86624	1.36569	3.20000	.00000	-2.78892	.13082	.00000	-.36709	.6020	1.1426
0.5000	-1.52175	1.02753	3.30000	.00000	-3.07493	.15219	.00000	-.32102	.6191	1.0631
0.6250	.60771	.82916	3.40000	.00000	-3.29808	.16792	.00000	-.29094	.6251	.9968
1.0000	4.38270	.44249	3.50000	.00000	-3.68677	.19846	.00000	-.22467	.6480	.9268
1.3333	6.03088	.26122	3.50000	.00000	-3.84799	.21274	.00000	-.18860	.6618	.9346
2.0000	8.91163	.00198	3.60000	.00000	-4.21624	.23987	.00000	-.14814	.6857	.9045
2.5000	9.88541	-.09326	3.60000	.00000	-4.33601	.24975	.00000	-.13159	.7008	.9001
3.3333	11.99662	-.25104	3.70000	.00000	-4.65152	.27084	.00000	-.11582	.7220	.9119
4.1667	12.77568	-.31521	3.70000	.00000	-4.76255	.27903	.00000	-.10726	.7399	.9119
5.0000	13.35601	-.35932	3.70000	.00000	-4.84920	.28512	.00000	-.10218	.7562	.9182
6.2500	15.16957	-.47298	3.80000	.00000	-5.14508	.30322	.00000	-.09778	.7782	.9305
6.6667	15.35608	-.48604	3.80000	.00000	-5.17562	.30531	.00000	-.09680	.7848	.9367
8.3333	15.96772	-.53011	3.80000	.00000	-5.28098	.31278	.00000	-.09419	.8054	.9578
10.0000	16.42234	-.56572	3.80000	.00000	-5.36596	.31923	.00000	-.09279	.8177	.9583
12.5000	16.90986	-.60751	3.80000	.00000	-5.46428	.32715	.00000	-.09179	.8272	.9609
14.2857	17.16559	-.63027	3.80000	.00000	-5.51821	.33158	.00000	-.09148	.8313	.9642
16.6667	17.43775	-.65344	3.80000	.00000	-5.57562	.33613	.00000	-.09130	.8366	.9704
18.1818	18.95886	-.74635	3.30000	.00000	-5.83325	.35180	.00000	-.09125	.8406	.9705
20.0000	19.13672	-.75882	3.90000	.00000	-5.86837	.35426	.00000	-.09122	.8457	.9770
25.0000	19.56869	-.78618	3.90000	.00000	-5.95141	.35968	.00000	-.09113	.8530	.9811
31.0000	19.93414	-.80760	3.90000	.00000	-6.02190	.36387	.00000	-.09109	.8534	.9788
40.0000	18.81796	-.75053	3.80000	.00000	-5.85612	.35579	.00000	-.09155	.8448	.9688
50.0000	18.89574	-.76779	3.80000	.00000	-5.88521	.35942	.00000	-.09203	.8391	.9651
100.000	15.86483	-.67427	3.70000	.00000	-5.43083	.34620	.00000	-.09664	.7699	.9060
PGA	14.35825	-.58678	3.60000	.00000	-5.18268	.33157	.00000	-.09714	.7633	.9003
PGV	10.31697	.06538	3.20000	.00000	-4.25855	.32343	.00000	-.15899	.5854	---------

Table 3f GULF COAST REGRESSION COEFFICIENTS FOR THE SINGLE CORNER MODEL WITH VARIABLE HIGH STRESS DROP AS A FUNCTION OF MOMENT MAGNITUDE (**M**)										
Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-13.91863	2.33294	3.00000	.00000	-2.33817	.09908	.00000	-.29154	.5321	1.3821
0.2000	-9.02136	1.95631	3.20000	.00000	-2.64856	.11437	.00000	-.36070	.5624	1.2674
0.3333	-5.06249	1.59204	3.30000	.00000	-2.93546	.13367	.00000	-.36500	.5952	1.1390
0.5000	-1.56307	1.26035	3.40000	.00000	-3.23534	.15492	.00000	-.34181	.6174	1.0621
0.6250	.72588	1.05610	3.50000	.00000	-3.47121	.17081	.00000	-.32004	.6268	.9978
1.0000	4.94057	.63072	3.60000	.00000	-3.88811	.20282	.00000	-.25891	.6554	.9321
1.3333	6.90409	.41108	3.60000	.00000	-4.06719	.21878	.00000	-.21837	.6699	.9403
2.0000	10.33931	.08773	3.70000	.00000	-4.47467	.24889	.00000	-.16562	.6920	.9093
2.5000	11.55566	-.03985	3.70000	.00000	-4.60821	.26010	.00000	-.14124	.7057	.9039
3.3333	12.94874	-.17886	3.70000	.00000	-4.77368	.27355	.00000	-.11589	.7259	.9150
4.1667	15.04806	-.33259	3.80000	.00000	-5.08734	.29385	.00000	-.10095	.7440	.9152
5.0000	15.77669	-.39607	3.80000	.00000	-5.18780	.30141	.00000	-.09155	.7605	.9217
6.2500	16.59083	-.46325	3.80000	.00000	-5.30738	.31025	.00000	-.08296	.7833	.9348
6.6667	16.81254	-.48116	3.80000	.00000	-5.34165	.31279	.00000	-.08098	.7902	.9412
8.3333	18.86865	-.61723	3.90000	.00000	-5.68075	.33451	.00000	-.07559	.8121	.9635
10.0000	19.43335	-.66605	3.90000	.00000	-5.78203	.34275	.00000	-.07256	.8254	.9649
12.5000	20.04863	-.72294	3.90000	.00000	-5.90140	.35305	.00000	-.07023	.8362	.9687
14.2857	20.37544	-.75402	3.90000	.00000	-5.96788	.35891	.00000	-.06938	.8411	.9726
16.6667	20.72257	-.78585	3.90000	.00000	-6.03900	.36501	.00000	-.06877	.8471	.9795
18.1818	20.91108	-.80174	3.90000	.00000	-6.07691	.36809	.00000	-.06854	.8515	.9800
20.0000	21.11875	-.81789	3.90000	.00000	-6.11772	.37124	.00000	-.06833	.8568	.9866
25.0000	21.61053	-.85260	3.90000	.00000	-6.21225	.37806	.00000	-.06793	.8646	.9912
31.0000	22.02865	-.88044	3.90000	.00000	-6.29329	.38353	.00000	-.06773	.8653	.9892
40.0000	22.40623	-.91637	3.90000	.00000	-6.37768	.39115	.00000	-.06821	.8569	.9794
50.0000	22.54184	-.94055	3.90000	.00000	-6.41953	.39634	.00000	-.06885	.8514	.9758
100.000	17.92864	-.74769	3.70000	.00000	-5.71493	.36837	.00000	-.07577	.7814	.9157
PGA	17.56501	-.73081	3.70000	.00000	-5.65962	.36566	.00000	-.07661	.7747	.9100
PGV	12.88457	-.06337	3.30000	.00000	-4.71837	.36161	.00000	-.11586	.5984	---------

Table 4a
MIDCONTINENT
REGRESSION COEFFICIENTS FOR THE SINGLE CORNER MODEL WITH
CONSTANT MEDIUM STRESS DROP

Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-19.48096	2.63369	2.10000	.00000	-1.40816	.05251	.00000	-.27037	.3494	1.3226
0.2000	-15.60343	2.34394	2.30000	.00000	-1.55118	.05960	.00000	-.34570	.3630	1.1924
0.3333	-12.32672	2.03581	2.40000	.00000	-1.70046	.07122	.00000	-.35378	.3863	1.0451
0.5000	-9.51015	1.74832	2.50000	.00000	-1.86136	.08496	.00000	-.33001	.4110	.9570
0.6250	-8.14308	1.58833	2.50000	.00000	-1.93245	.09238	.00000	-.30768	.4231	.8842
1.0000	-5.12369	1.22405	2.60000	.00000	-2.15471	.11324	.00000	-.24573	.4432	.7972
1.3333	-3.47330	1.02939	2.60000	.00000	-2.24741	.12308	.00000	-.20234	.4523	.8000
2.0000	-1.58285	.79993	2.60000	.00000	-2.37885	.13729	.00000	-.15090	.4641	.7506
2.5000	-.65379	.69665	2.60000	.00000	-2.43570	.14303	.00000	-.12494	.4715	.7357
3.3333	.28490	.58358	2.60000	.00000	-2.51730	.15162	.00000	-.10016	.4819	.7365
4.1667	.91433	.51993	2.60000	.00000	-2.56449	.15619	.00000	-.08536	.4912	.7248
5.0000	1.74233	.45792	2.70000	.00000	-2.66338	.16286	.00000	-.07586	.5006	.7224
6.2500	2.19706	.41304	2.70000	.00000	-2.70779	.16694	.00000	-.06715	.5151	.7249
6.6667	2.31425	.40161	2.70000	.00000	-2.72023	.16804	.00000	-.06508	.5220	.7308
8.3333	2.69216	.37212	2.70000	.00000	-2.75418	.17072	.00000	-.05952	.5397	.7483
10.0000	2.94690	.35069	2.70000	.00000	-2.78273	.17300	.00000	-.05619	.5576	.7487
12.5000	3.20588	.32832	2.70000	.00000	-2.81616	.17563	.00000	-.05326	.5706	.7515
14.2857	3.75552	.29046	2.80000	.00000	-2.91238	.18175	.00000	-.05199	.5777	.7565
16.6667	3.88344	.27758	2.80000	.00000	-2.93512	.18355	.00000	-.05087	.5842	.7636
18.1818	3.94814	.27096	2.80000	.00000	-2.94748	.18451	.00000	-.05038	.5881	.7624
20.0000	4.01659	.26433	2.80000	.00000	-2.96045	.18549	.00000	-.04994	.5935	.7691
25.0000	4.18017	.25125	2.80000	.00000	-2.98855	.18741	.00000	-.04913	.6107	.7797
31.0000	4.34502	.24062	2.80000	.00000	-3.01413	.18897	.00000	-.04850	.6201	.7837
40.0000	4.98360	.20066	2.90000	.00000	-3.12766	.19576	.00000	-.04804	.6195	.7802
50.0000	5.03110	.19000	2.90000	.00000	-3.15204	.19790	.00000	-.04818	.6115	.7754
100.000	3.65796	.22258	2.80000	.00000	-3.03868	.19703	.00000	-.05457	.5613	.7369
PGA	3.00730	.25858	2.70000	.00000	-2.94208	.19152	.00000	-.05571	.5561	.7329
PGV	2.34185	.79105	2.40000	.00000	-2.69614	.19476	.00000	-.10359	.4380	--------

Table 4b MIDCONTINENT REGRESSION COEFFICIENTS FOR THE SINGLE CORNER MODEL WITH CONSTANT LOW STRESS DROP										
Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-19.09237	2.55127	2.10000	.00000	-1.41992	.05359	.00000	-.29994	.3543	1.3239
0.2000	-15.22296	2.22463	2.20000	.00000	-1.53646	.06087	.00000	-.35343	.3702	1.1946
0.3333	-11.90955	1.89523	2.30000	.00000	-1.68527	.07303	.00000	-.34299	.3983	1.0496
0.5000	-9.12644	1.60015	2.40000	.00000	-1.84330	.08701	.00000	-.30641	.4221	.9618
0.6250	-7.79761	1.44039	2.40000	.00000	-1.91307	.09450	.00000	-.27892	.4320	.8885
1.0000	-4.89906	1.08390	2.50000	.00000	-2.13693	.11627	.00000	-.21228	.4482	.8000
1.3333	-3.33687	.89916	2.50000	.00000	-2.23329	.12682	.00000	-.16950	.4562	.8022
2.0000	-1.58102	.68709	2.50000	.00000	-2.36933	.14193	.00000	-.12239	.4684	.7532
2.5000	-.72368	.59402	2.50000	.00000	-2.43076	.14840	.00000	-.10021	.4767	.7391
3.3333	.13269	.49251	2.50000	.00000	-2.51516	.15754	.00000	-.07959	.4879	.7405
4.1667	.71018	.43636	2.50000	.00000	-2.56429	.16246	.00000	-.06770	.4977	.7292
5.0000	1.13055	.40133	2.50000	.00000	-2.59747	.16549	.00000	-.06026	.5075	.7272
6.2500	1.90139	.34023	2.60000	.00000	-2.70593	.17349	.00000	-.05345	.5223	.7301
6.6667	2.00886	.33012	2.60000	.00000	-2.71828	.17461	.00000	-.05184	.5291	.7359
8.3333	2.36108	.30408	2.60000	.00000	-2.75216	.17736	.00000	-.04754	.5470	.7536
10.0000	2.59748	.28497	2.60000	.00000	-2.78005	.17962	.00000	-.04496	.5648	.7541
12.5000	2.83795	.26482	2.60000	.00000	-2.81238	.18218	.00000	-.04266	.5778	.7570
14.2857	2.95159	.25367	2.60000	.00000	-2.83154	.18373	.00000	-.04164	.5848	.7619
16.6667	3.47181	.21711	2.70000	.00000	-2.92538	.18980	.00000	-.04075	.5913	.7691
18.1818	3.53102	.21106	2.70000	.00000	-2.93706	.19071	.00000	-.04035	.5952	.7678
20.0000	3.59389	.20500	2.70000	.00000	-2.94929	.19162	.00000	-.03999	.6005	.7745
25.0000	3.74605	.19303	2.70000	.00000	-2.97578	.19341	.00000	-.03934	.6175	.7850
31.0000	3.90146	.18325	2.70000	.00000	-2.99999	.19487	.00000	-.03882	.6269	.7891
40.0000	4.50286	.14513	2.80000	.00000	-3.10735	.20134	.00000	-.03842	.6263	.7856
50.0000	4.54101	.13536	2.80000	.00000	-3.12969	.20328	.00000	-.03854	.6184	.7809
100.000	2.77858	.19423	2.60000	.00000	-2.94022	.19693	.00000	-.04397	.5680	.7420
PGA	2.57877	.20187	2.60000	.00000	-2.92333	.19630	.00000	-.04493	.5628	.7380
PGV	2.01678	.74196	2.30000	.00000	-2.65712	.19550	.00000	-.10331	.4439	--------

Table 4c MIDCONTINENT REGRESSION COEFFICIENTS FOR THE SINGLE CORNER MODEL WITH CONSTANT HIGH STRESS DROP										
Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-19.70343	2.68814	2.10000	.00000	-1.41959	.05456	.00000	-.23554	.3441	1.3212
0.2000	-16.02752	2.44418	2.30000	.00000	-1.55334	.06006	.00000	-.32899	.3574	1.1907
0.3333	-12.85572	2.16545	2.40000	.00000	-1.69535	.07035	.00000	-.35582	.3756	1.0412
0.5000	-10.06892	1.89280	2.50000	.00000	-1.85191	.08324	.00000	-.34592	.3980	.9514
0.6250	-8.68001	1.73516	2.50000	.00000	-1.92392	.09060	.00000	-.32977	.4113	.8786
1.0000	-5.55701	1.36536	2.60000	.00000	-2.14802	.11128	.00000	-.27558	.4357	.7931
1.3333	-3.81429	1.16106	2.60000	.00000	-2.24164	.12109	.00000	-.23358	.4473	.7972
2.0000	-1.74607	.90876	2.60000	.00000	-2.37871	.13582	.00000	-.17883	.4603	.7482
2.5000	-.70305	.78942	2.60000	.00000	-2.43840	.14185	.00000	-.14883	.4676	.7332
3.3333	.36441	.65805	2.60000	.00000	-2.52362	.15080	.00000	-.11897	.4780	.7340
4.1667	1.08397	.58122	2.60000	.00000	-2.57366	.15569	.00000	-.10026	.4874	.7223
5.0000	1.97802	.50970	2.70000	.00000	-2.67484	.16259	.00000	-.08779	.4971	.7200
6.2500	2.50153	.45480	2.70000	.00000	-2.72265	.16707	.00000	-.07615	.5121	.7228
6.6667	2.63659	.44078	2.70000	.00000	-2.73607	.16829	.00000	-.07333	.5192	.7288
8.3333	3.06506	.40391	2.70000	.00000	-2.77296	.17133	.00000	-.06565	.5375	.7468
10.0000	3.35414	.37757	2.70000	.00000	-2.80403	.17391	.00000	-.06102	.5558	.7474
12.5000	3.64678	.35047	2.70000	.00000	-2.84039	.17689	.00000	-.05692	.5693	.7505
14.2857	4.21631	.31022	2.80000	.00000	-2.93884	.18324	.00000	-.05514	.5766	.7556
16.6667	4.36033	.29517	2.80000	.00000	-2.96337	.18525	.00000	-.05357	.5834	.7630
18.1818	4.43278	.28752	2.80000	.00000	-2.97664	.18632	.00000	-.05287	.5875	.7619
20.0000	4.50882	.27990	2.80000	.00000	-2.99056	.18741	.00000	-.05224	.5930	.7687
25.0000	4.68655	.26499	2.80000	.00000	-3.02045	.18954	.00000	-.05109	.6105	.7795
31.0000	4.86194	.25301	2.80000	.00000	-3.04739	.19126	.00000	-.05023	.6201	.7837
40.0000	5.51533	.21155	2.90000	.00000	-3.16325	.19826	.00000	-.04959	.6197	.7803
50.0000	5.57118	.19995	2.90000	.00000	-3.18948	.20062	.00000	-.04972	.6119	.7757
100.000	4.18329	.23483	2.80000	.00000	-3.08048	.20033	.00000	-.05744	.5616	.7371
PGA	3.52033	.27213	2.70000	.00000	-2.98288	.19476	.00000	-.05886	.5564	.7140
PGV	2.71517	.80995	2.40000	.00000	-2.74660	.19917	.00000	-.09791	.4373	--------

Table 4d GULF COAST REGRESSION COEFFICIENTS FOR THE SINGLE CORNER MODEL WITH CONSTANT MEDIUM STRESS DROP										
Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-14.97295	2.37485	2.80000	.00000	-2.14967	.09041	.00000	-.29863	.5217	1.3782
0.2000	-9.72740	1.95572	3.10000	.00000	-2.51098	.10865	.00000	-.34332	.5587	1.2658
0.3333	-5.83777	1.58067	3.20000	.00000	-2.78845	.12797	.00000	-.32881	.5920	1.1373
0.5000	-2.48893	1.25139	3.30000	.00000	-3.07316	.14866	.00000	-.29199	.6097	1.0576
0.6250	-.33936	1.05439	3.40000	.00000	-3.29591	.16405	.00000	-.26496	.6163	.9913
1.0000	3.53746	.65933	3.50000	.00000	-3.68869	.19464	.00000	-.20041	.6409	.9219
1.3333	5.26938	.46791	3.50000	.00000	-3.85384	.20926	.00000	-.16290	.6556	.9302
2.0000	8.26540	.19447	3.60000	.00000	-4.22696	.23667	.00000	-.11889	.6802	.9004
2.5000	9.29703	.09136	3.60000	.00000	-4.34955	.24683	.00000	-.10023	.6958	.8962
3.3333	11.47972	-.07511	3.70000	.00000	-4.66998	.26828	.00000	-.08198	.7177	.9085
4.1667	12.30467	-.14553	3.70000	.00000	-4.78472	.27690	.00000	-.07185	.7363	.9090
5.0000	12.91716	-.19398	3.70000	.00000	-4.87438	.28333	.00000	-.06574	.7531	.9156
6.2500	14.76997	-.31160	3.80000	.00000	-5.17479	.30176	.00000	-.06037	.7758	.9285
6.6667	14.96522	-.32579	3.80000	.00000	-5.20638	.30397	.00000	-.05917	.7825	.9348
8.3333	15.60406	-.37326	3.80000	.00000	-5.31533	.31184	.00000	-.05594	.8038	.9565
10.0000	16.07898	-.41128	3.80000	.00000	-5.40344	.31863	.00000	-.05418	.8166	.9574
12.5000	16.58985	-.45572	3.80000	.00000	-5.50586	.32700	.00000	-.05288	.8266	.9604
14.2857	16.85850	-.47991	3.80000	.00000	-5.56225	.33169	.00000	-.05245	.8310	.9639
16.6667	17.14437	-.50458	3.80000	.00000	-5.62237	.33654	.00000	-.05218	.8365	.9704
18.1818	18.68342	-.59824	3.90000	.00000	-5.88319	.35235	.00000	-.05209	.8407	.9706
20.0000	18.86815	-.61146	3.90000	.00000	-5.91969	.35496	.00000	-.05201	.8459	.9771
25.0000	19.31416	-.64033	3.90000	.00000	-6.00557	.36070	.00000	-.05184	.8533	.9814
31.0000	19.69186	-.66304	3.90000	.00000	-6.07864	.36517	.00000	-.05176	.8538	.9791
40.0000	18.57590	-.60707	3.80000	.00000	-5.91373	.35737	.00000	-.05222	.8453	.9692
50.0000	18.66451	-.62536	3.80000	.00000	-5.94544	.36127	.00000	-.05272	.8395	.9655
100.000	15.61583	-.53024	3.70000	.00000	-5.49076	.34812	.00000	-.05781	.7697	.9057
PGA	14.09083	-.44176	3.60000	.00000	-5.23954	.33332	.00000	-.05839	.7630	.9000
PGV	10.05725	.19114	3.20000	.00000	-4.32766	.32682	.00000	-.10589	.5846	--------

Table 4e GULF COAST REGRESSION COEFFICIENTS FOR THE SINGLE CORNER MODEL WITH CONSTANT LOW STRESS DROP										
Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-14.51574	2.27743	2.80000	.00000	-2.16004	.09156	.00000	-.32210	.5189	1.3771
0.2000	-9.56051	1.83677	3.00000	.00000	-2.45407	.10808	.00000	-.34227	.5606	1.2666
0.3333	-5.22266	1.42630	3.20000	.00000	-2.81135	.13160	.00000	-.31057	.5946	1.1387
0.5000	-1.89095	1.08997	3.30000	.00000	-3.10319	.15363	.00000	-.26352	.6106	1.0581
0.6250	-.39847	.92377	3.30000	.00000	-3.22226	.16458	.00000	-.23333	.6166	.9915
1.0000	3.27417	.54493	3.40000	.00000	-3.60867	.19579	.00000	-.16807	.6406	.9217
1.3333	5.67074	.32399	3.50000	.00000	-3.90708	.21814	.00000	-.13325	.6561	.9306
2.0000	7.67899	.11381	3.50000	.00000	-4.13972	.23879	.00000	-.09489	.6821	.9018
2.5000	8.63053	.02055	3.50000	.00000	-4.26127	.24915	.00000	-.07940	.6984	.8982
3.3333	10.65378	-.13196	3.60000	.00000	-4.56857	.27022	.00000	-.06472	.7206	.9108
4.1667	11.41205	-.19463	3.60000	.00000	-4.67925	.27864	.00000	-.05678	.7393	.9114
5.0000	13.03902	-.29926	3.70000	.00000	-4.94340	.29508	.00000	-.05208	.7561	.9181
6.2500	13.69482	-.34602	3.70000	.00000	-5.04794	.30235	.00000	-.04799	.7783	.9306
6.6667	13.87411	-.35857	3.70000	.00000	-5.07762	.30440	.00000	-.04708	.7849	.9368
8.3333	14.45860	-.40049	3.70000	.00000	-5.17926	.31164	.00000	-.04464	.8058	.9582
10.0000	16.11475	-.50595	3.80000	.00000	-5.46456	.32967	.00000	-.04331	.8180	.9586
12.5000	16.59372	-.54655	3.80000	.00000	-5.56147	.33740	.00000	-.04233	.8274	.9611
14.2857	16.84332	-.56847	3.80000	.00000	-5.61422	.34167	.00000	-.04202	.8314	.9642
16.6667	17.10860	-.59071	3.80000	.00000	-5.67026	.34603	.00000	-.04182	.8366	.9705
18.1818	17.25532	-.60178	3.80000	.00000	-5.70035	.34821	.00000	-.04176	.8406	.9705
20.0000	17.42110	-.61316	3.80000	.00000	-5.73333	.35047	.00000	-.04171	.8457	.9770
25.0000	17.82567	-.63820	3.80000	.00000	-5.81156	.35548	.00000	-.04159	.8529	.9810
31.0000	18.16727	-.65766	3.80000	.00000	-5.87782	.35931	.00000	-.04152	.8532	.9786
40.0000	18.45810	-.68363	3.80000	.00000	-5.94442	.36483	.00000	-.04192	.8446	.9686
50.0000	17.18549	-.61880	3.70000	.00000	-5.74801	.35480	.00000	-.04232	.8390	.9650
100.000	14.28559	-.52896	3.60000	.00000	-5.31196	.34179	.00000	-.04658	.7693	.9054
PGA	13.95924	-.51587	3.60000	.00000	-5.26211	.33959	.00000	-.04706	.7628	.8999
PGV	9.08776	.19911	3.10000	.00000	-4.16032	.31577	.00000	-.10714	.5825	--------

Table 4f
GULF COAST
REGRESSION COEFFICIENTS FOR THE SINGLE CORNER MODEL WITH
CONSTANT HIGH STRESS DROP

Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-14.92343	2.43027	2.90000	.00000	-2.22382	.09485	.00000	-.26850	.5246	1.3793
0.2000	-10.18213	2.06757	3.10000	.00000	-2.51603	.10917	.00000	-.33532	.5581	1.2655
0.3333	-6.35091	1.71518	3.20000	.00000	-2.78676	.12722	.00000	-.33853	.5890	1.1358
0.5000	-2.37232	1.36543	3.40000	.00000	-3.17502	.15221	.00000	-.31410	.6076	1.0564
0.6250	-.80232	1.19788	3.40000	.00000	-3.29152	.16227	.00000	-.29176	.6151	.9905
1.0000	3.21915	.78973	3.50000	.00000	-3.68683	.19276	.00000	-.23069	.6418	.9225
1.3333	5.08922	.58119	3.50000	.00000	-3.85783	.20794	.00000	-.19127	.6568	.9311
2.0000	8.29484	.28003	3.60000	.00000	-4.23968	.23616	.00000	-.14131	.6810	.9010
2.5000	9.43320	.16200	3.60000	.00000	-4.36652	.24675	.00000	-.11874	.6963	.8966
3.3333	11.74743	-.02246	3.70000	.00000	-4.69411	.26892	.00000	-.09568	.7183	.9090
4.1667	12.66006	-.10531	3.70000	.00000	-4.81457	.27820	.00000	-.08232	.7373	.9098
5.0000	13.33561	-.16266	3.70000	.00000	-4.90916	.28523	.00000	-.07402	.7547	.9170
6.2500	15.26405	-.29006	3.80000	.00000	-5.21720	.30448	.00000	-.06652	.7780	.9303
6.6667	15.47703	-.30669	3.80000	.00000	-5.25065	.30691	.00000	-.06481	.7850	.9369
8.3333	16.17236	-.36176	3.80000	.00000	-5.36632	.31558	.00000	-.06017	.8071	.9592
10.0000	16.69021	-.40538	3.80000	.00000	-5.46052	.32310	.00000	-.05758	.8206	.9608
12.5000	17.25027	-.45606	3.80000	.00000	-5.57097	.33242	.00000	-.05561	.8315	.9646
14.2857	18.92158	-.56453	3.90000	.00000	-5.85972	.35100	.00000	-.05491	.8363	.9685
16.6667	19.25288	-.59416	3.90000	.00000	-5.92801	.35673	.00000	-.05441	.8422	.9753
18.1818	19.43335	-.60894	3.90000	.00000	-5.96446	.35961	.00000	-.05422	.8466	.9757
20.0000	19.63311	-.62400	3.90000	.00000	-6.00383	.36256	.00000	-.05406	.8520	.9824
25.0000	20.10895	-.65650	3.90000	.00000	-6.09544	.36898	.00000	-.05373	.8598	.9870
31.0000	20.51285	-.68238	3.90000	.00000	-6.17374	.37408	.00000	-.05357	.8604	.9849
40.0000	19.40352	-.62778	3.80000	.00000	-6.01142	.36670	.00000	-.05403	.8521	.9752
50.0000	19.51657	-.64891	3.80000	.00000	-6.04880	.37128	.00000	-.05461	.8464	.9715
100.000	16.44069	-.55019	3.70000	.00000	-5.59549	.35834	.00000	-.06084	.7761	.9112
PGA	16.08302	-.53416	3.70000	.00000	-5.54089	.35572	.00000	-.06160	.7693	.9054
PGV	10.74525	.17413	3.20000	.00000	-4.45009	.33923	.00000	-.09819	.5915	--------

Table 5a MIDCONTINENT REGRESSION COEFFICIENTS FOR THE SINGLE CORNER MODEL WITH CONSTANT MEDIUM STRESS DROP AND SATURATION										
Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-17.91423	2.37754	2.30000	.00000	-1.71861	.10433	.00000	-.28182	.3597	1.3253
0.2000	-13.91070	2.07364	2.50000	.00000	-1.88340	.11388	.00000	-.35716	.3757	1.1963
0.3333	-10.54155	1.75532	2.60000	.00000	-2.04882	.12727	.00000	-.36524	.4010	1.0506
0.5000	-7.62375	1.45642	2.70000	.00000	-2.22717	.14299	.00000	-.34147	.4264	.9637
0.6250	-6.23481	1.29417	2.70000	.00000	-2.30231	.15083	.00000	-.31913	.4385	.8917
1.0000	-3.08744	.91539	2.80000	.00000	-2.54658	.17419	.00000	-.25719	.4583	.8057
1.3333	-1.41000	.71797	2.80000	.00000	-2.64410	.18452	.00000	-.21379	.4674	.8087
2.0000	.51857	.48452	2.80000	.00000	-2.78232	.19943	.00000	-.16236	.4790	.7599
2.5000	1.46377	.37971	2.80000	.00000	-2.84201	.20543	.00000	-.13639	.4863	.7453
3.3333	2.42583	.26430	2.80000	.00000	-2.92775	.21443	.00000	-.11161	.4964	.7461
4.1667	3.06862	.19946	2.80000	.00000	-2.97730	.21920	.00000	-.09681	.5054	.7345
5.0000	3.53193	.15880	2.80000	.00000	-3.01048	.22207	.00000	-.08732	.5147	.7322
6.2500	4.46498	.08019	2.90000	.00000	-3.13934	.23200	.00000	-.07861	.5289	.7348
6.6667	4.58602	.06845	2.90000	.00000	-3.15246	.23315	.00000	-.07654	.5356	.7405
8.3333	4.97456	.03821	2.90000	.00000	-3.18830	.23596	.00000	-.07097	.5530	.7580
10.0000	5.23836	.01612	2.90000	.00000	-3.21848	.23835	.00000	-.06764	.5706	.7585
12.5000	5.50813	-.00703	2.90000	.00000	-3.25386	.24112	.00000	-.06471	.5834	.7612
14.2857	5.63835	-.01981	2.90000	.00000	-3.27511	.24282	.00000	-.06344	.5906	.7664
16.6667	6.30181	-.07040	3.00000	.00000	-3.39174	.25111	.00000	-.06233	.5972	.7736
18.1818	6.37083	-.07735	3.00000	.00000	-3.40488	.25213	.00000	-.06184	.6011	.7724
20.0000	6.44374	-.08429	3.00000	.00000	-3.41866	.25316	.00000	-.06139	.6063	.7790
25.0000	6.61705	-.09799	3.00000	.00000	-3.44851	.25520	.00000	-.06059	.6231	.7894
31.0000	6.79091	-.10914	3.00000	.00000	-3.47572	.25685	.00000	-.05996	.6323	.7934
40.0000	6.96175	-.12090	3.00000	.00000	-3.50625	.25870	.00000	-.05949	.6320	.7901
50.0000	7.60902	-.17372	3.10000	.00000	-3.63508	.26806	.00000	-.05964	.6240	.7853
100.000	5.56137	-.09020	2.90000	.00000	-3.40512	.25856	.00000	-.06603	.5741	.7467
PGA	5.35011	-.08193	2.90000	.00000	-3.38707	.25794	.00000	-.06717	.5689	.7427
PGV	4.40490	.47616	2.60000	.00000	-3.09544	.25711	.00000	-.11505	.4493	--------

Table 5b MIDCONTINENT REGRESSION COEFFICIENTS FOR THE SINGLE CORNER MODEL WITH CONSTANT LOW STRESS DROP AND SATURATION										
Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-17.52612	2.29529	2.30000	.00000	-1.73008	.10536	.00000	-.31139	.3654	1.3269
0.2000	-13.58249	1.96072	2.40000	.00000	-1.85975	.11403	.00000	-.36489	.3842	1.1990
0.3333	-9.90982	1.60565	2.60000	.00000	-2.07280	.13069	.00000	-.35444	.4138	1.0556
0.5000	-7.30278	1.31553	2.60000	.00000	-2.19863	.14381	.00000	-.31786	.4378	.9688
0.6250	-5.63265	1.13348	2.70000	.00000	-2.32961	.15521	.00000	-.29038	.4474	.8961
1.0000	-2.93381	.78321	2.70000	.00000	-2.51701	.17588	.00000	-.22374	.4634	.8086
1.3333	-1.34540	.59571	2.70000	.00000	-2.61803	.18691	.00000	-.18095	.4712	.8109
2.0000	.44711	.37973	2.70000	.00000	-2.76056	.20271	.00000	-.13385	.4831	.7625
2.5000	1.32039	.28510	2.70000	.00000	-2.82477	.20944	.00000	-.11167	.4912	.7485
3.3333	2.19908	.18130	2.70000	.00000	-2.91311	.21897	.00000	-.09104	.5021	.7499
4.1667	2.78943	.12398	2.70000	.00000	-2.96449	.22409	.00000	-.07915	.5117	.7389
5.0000	3.21855	.08824	2.70000	.00000	-2.99921	.22724	.00000	-.07171	.5213	.7369
6.2500	3.64126	.04811	2.70000	.00000	-3.04474	.23151	.00000	-.06490	.5358	.7398
6.6667	3.75047	.03785	2.70000	.00000	-3.05739	.23266	.00000	-.06330	.5426	.7456
8.3333	4.56076	-.02108	2.80000	.00000	-3.17249	.24111	.00000	-.05900	.5601	.7632
10.0000	4.80550	-.04079	2.80000	.00000	-3.20187	.24348	.00000	-.05641	.5777	.7638
12.5000	5.05581	-.06166	2.80000	.00000	-3.23598	.24617	.00000	-.05411	.5906	.7668
14.2857	5.17534	-.07324	2.80000	.00000	-3.25620	.24779	.00000	-.05310	.5976	.7718
16.6667	5.29605	-.08523	2.80000	.00000	-3.27840	.24954	.00000	-.05220	.6042	.7791
18.1818	5.35709	-.09141	2.80000	.00000	-3.29040	.25047	.00000	-.05181	.6081	.7779
20.0000	5.92808	-.13394	2.90000	.00000	-3.39211	.25767	.00000	-.05145	.6133	.7844
25.0000	6.08901	-.14646	2.90000	.00000	-3.42020	.25956	.00000	-.05080	.6300	.7949
31.0000	6.25258	-.15669	2.90000	.00000	-3.44589	.26109	.00000	-.05027	.6391	.7989
40.0000	6.41230	-.16752	2.90000	.00000	-3.47458	.26279	.00000	-.04987	.6388	.7956
50.0000	7.01484	-.21767	3.00000	.00000	-3.59567	.27165	.00000	-.04999	.6309	.7908
100.000	5.03603	-.13680	2.80000	.00000	-3.37101	.26174	.00000	-.05542	.5808	.7518
PGA	4.83071	-.12898	2.80000	.00000	-3.35311	.26108	.00000	-.05639	.5755	.7477
PGV	3.99963	.43627	2.50000	.00000	-3.04259	.25625	.00000	-.11476	.4549	--------

Table 5c MIDCONTINENT REGRESSION COEFFICIENTS FOR THE SINGLE CORNER MODEL WITH CONSTANT HIGH STRESS DROP AND SATURATION										
Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-17.92122	2.41939	2.40000	.00000	-1.76932	.10861	.00000	-.24700	.3539	1.3238
0.2000	-14.33292	2.17359	2.50000	.00000	-1.88598	.11439	.00000	-.34044	.3691	1.1943
0.3333	-11.07071	1.88506	2.60000	.00000	-2.04376	.12639	.00000	-.36727	.3895	1.0463
0.5000	-8.18384	1.60124	2.70000	.00000	-2.21757	.14122	.00000	-.35737	.4130	.9578
0.6250	-6.43297	1.42055	2.80000	.00000	-2.35414	.15261	.00000	-.34123	.4266	.8859
1.0000	-3.52171	1.05720	2.80000	.00000	-2.53979	.17215	.00000	-.28704	.4510	.8016
1.3333	-1.75176	.85016	2.80000	.00000	-2.63826	.18244	.00000	-.24504	.4627	.8060
2.0000	.35595	.59376	2.80000	.00000	-2.78233	.19789	.00000	-.19028	.4757	.7578
2.5000	1.41567	.47284	2.80000	.00000	-2.84495	.20419	.00000	-.16028	.4829	.7431
3.3333	2.50733	.33905	2.80000	.00000	-2.93443	.21356	.00000	-.13042	.4931	.7439
4.1667	3.24100	.26094	2.80000	.00000	-2.98696	.21867	.00000	-.11171	.5023	.7324
5.0000	3.76921	.21066	2.80000	.00000	-3.02221	.22178	.00000	-.09924	.5118	.7302
6.2500	4.77362	.12203	2.90000	.00000	-3.15491	.23211	.00000	-.08761	.5265	.7331
6.6667	4.91274	.10766	2.90000	.00000	-3.16905	.23338	.00000	-.08479	.5334	.7389
8.3333	5.35255	.06996	2.90000	.00000	-3.20795	.23656	.00000	-.07711	.5513	.7567
10.0000	5.65135	.04288	2.90000	.00000	-3.24075	.23928	.00000	-.07247	.5693	.7575
12.5000	5.95548	.01492	2.90000	.00000	-3.27916	.24241	.00000	-.06838	.5826	.7606
14.2857	6.10266	-.00018	2.90000	.00000	-3.30216	.24432	.00000	-.06659	.5900	.7659
16.6667	6.25069	-.01554	2.90000	.00000	-3.32741	.24639	.00000	-.06502	.5969	.7734
18.1818	6.86357	-.06114	3.00000	.00000	-3.43540	.25399	.00000	-.06433	.6009	.7723
20.0000	6.94435	-.06911	3.00000	.00000	-3.45017	.25514	.00000	-.06369	.6063	.7790
25.0000	7.13246	-.08472	3.00000	.00000	-3.48193	.25740	.00000	-.06255	.6234	.7897
31.0000	7.31723	-.09725	3.00000	.00000	-3.51057	.25921	.00000	-.06168	.6328	.7938
40.0000	7.49863	-.11031	3.00000	.00000	-3.54270	.26124	.00000	-.06105	.6326	.7906
50.0000	8.16024	-.16443	3.10000	.00000	-3.67439	.27088	.00000	-.06117	.6248	.7859
100.000	6.09264	-.07836	2.90000	.00000	-3.44793	.26192	.00000	-.06890	.5749	.7473
PGA	5.87466	-.06918	2.90000	.00000	-3.42987	.26131	.00000	-.07032	.5697	.7433
PGV	4.79171	.49399	2.60000	.00000	-3.14834	.26171	.00000	-.10937	.4492	-------

Table 5d GULF COAST REGRESSION COEFFICIENTS FOR THE SINGLE CORNER MODEL WITH CONSTANT MEDIUM STRESS DROP AND SATURATION										
Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-12.36761	2.03153	3.10000	.00000	-2.63877	.15707	.00000	-.31008	.5339	1.3828
0.2000	-7.18334	1.59845	3.30000	.00000	-2.98527	.17746	.00000	-.35477	.5716	1.2715
0.3333	-3.08593	1.20331	3.40000	.00000	-3.29709	.20010	.00000	-.34026	.6050	1.1441
0.5000	1.25366	.80656	3.60000	.00000	-3.74757	.23195	.00000	-.30344	.6221	1.0648
0.6250	2.84583	.63403	3.60000	.00000	-3.87433	.24315	.00000	-.27642	.6282	.9987
1.0000	7.02300	.20984	3.70000	.00000	-4.31520	.27841	.00000	-.21186	.6525	.9300
1.3333	8.82898	.01214	3.70000	.00000	-4.49285	.29408	.00000	-.17435	.6669	.9382
2.0000	12.13819	-.29103	3.80000	.00000	-4.91519	.32617	.00000	-.13035	.6911	.9086
2.5000	13.22694	-.39862	3.80000	.00000	-5.04733	.33707	.00000	-.11168	.7063	.9044
3.3333	14.47052	-.51361	3.80000	.00000	-5.20994	.34992	.00000	-.09344	.7278	.9165
4.1667	16.60473	-.66904	3.90000	.00000	-5.54036	.37238	.00000	-.08331	.7461	.9169
5.0000	17.26232	-.72060	3.90000	.00000	-5.63758	.37933	.00000	-.07720	.7626	.9235
6.2500	18.00368	-.77536	3.90000	.00000	-5.75279	.38735	.00000	-.07183	.7850	.9362
6.6667	18.20699	-.79010	3.90000	.00000	-5.78572	.38965	.00000	-.07062	.7917	.9425
8.3333	20.35514	-.93590	4.00000	.00000	-6.14146	.41343	.00000	-.06740	.8126	.9639
10.0000	20.87722	-.97756	4.00000	.00000	-6.23744	.42083	.00000	-.06563	.8251	.9646
12.5000	21.44261	-1.02649	4.00000	.00000	-6.34895	.42994	.00000	-.06434	.8350	.9676
14.2857	21.74098	-1.05317	4.00000	.00000	-6.41027	.43505	.00000	-.06391	.8394	.9711
16.6667	22.05839	-1.08042	4.00000	.00000	-6.47563	.44033	.00000	-.06363	.8448	.9775
18.1818	22.23245	-1.09401	4.00000	.00000	-6.51064	.44297	.00000	-.06354	.8489	.9777
20.0000	22.42674	-1.10792	4.00000	.00000	-6.54872	.44569	.00000	-.06346	.8540	.9841
25.0000	22.89529	-1.13831	4.00000	.00000	-6.63833	.45168	.00000	-.06330	.8613	.9883
31.0000	23.29188	-1.16219	4.00000	.00000	-6.71452	.45635	.00000	-.06322	.8618	.9861
40.0000	23.64102	-1.19389	4.00000	.00000	-6.79201	.46299	.00000	-.06368	.8532	.9761
50.0000	23.74361	-1.21411	4.00000	.00000	-6.82593	.46721	.00000	-.06417	.8477	.9726
100.000	18.80216	-.98785	3.80000	.00000	-6.06348	.43296	.00000	-.06926	.7782	.9130
PGA	18.44350	-.97271	3.80000	.00000	-6.00839	.43044	.00000	-.06984	.7716	.9073
PGV	13.42744	-.26637	3.40000	.00000	-4.94368	.41289	.00000	-.11734	.5929	--------

Table 5e
GULF COAST
REGRESSION COEFFICIENTS FOR THE SINGLE CORNER MODEL
WITH CONSTANT LOW STRESS DROP AND SATURATION

Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-12.34486	1.95845	3.00000	.00000	-2.57317	.15404	.00000	-.33355	.5320	1.3821
0.2000	-7.12762	1.49148	3.20000	.00000	-2.91057	.17493	.00000	-.35373	.5744	1.2728
0.3333	-2.46635	1.04807	3.40000	.00000	-3.32053	.20386	.00000	-.32203	.6080	1.1457
0.5000	1.09160	.68925	3.50000	.00000	-3.64922	.22956	.00000	-.27498	.6233	1.0655
0.6250	2.63452	.51855	3.50000	.00000	-3.77700	.24128	.00000	-.24479	.6289	.9992
1.0000	6.58784	.11210	3.60000	.00000	-4.20864	.27695	.00000	-.17953	.6525	.9300
1.3333	9.24442	-.13451	3.70000	.00000	-4.54798	.30336	.00000	-.14471	.6676	.9387
2.0000	11.35480	-.35323	3.70000	.00000	-4.79775	.32541	.00000	-.10635	.6930	.9101
2.5000	12.35996	-.45077	3.70000	.00000	-4.92830	.33648	.00000	-.09086	.7090	.9065
3.3333	14.67303	-.63086	3.80000	.00000	-5.28067	.36186	.00000	-.07617	.7309	.9190
4.1667	15.48361	-.69729	3.80000	.00000	-5.40014	.37090	.00000	-.06824	.7493	.9195
5.0000	16.08791	-.74305	3.80000	.00000	-5.49275	.37755	.00000	-.06353	.7658	.9261
6.2500	18.11166	-.87999	3.90000	.00000	-5.82243	.39947	.00000	-.05945	.7878	.9385
6.6667	18.30605	-.89356	3.90000	.00000	-5.85465	.40170	.00000	-.05854	.7942	.9446
8.3333	18.94247	-.93912	3.90000	.00000	-5.96502	.40954	.00000	-.05610	.8148	.9657
10.0000	19.41416	-.97570	3.90000	.00000	-6.05319	.41621	.00000	-.05476	.8269	.9662
12.5000	19.91774	-1.01826	3.90000	.00000	-6.15421	.42427	.00000	-.05379	.8362	.9687
14.2857	20.18058	-1.04126	3.90000	.00000	-6.20917	.42872	.00000	-.05347	.8403	.9719
16.6667	20.45986	-1.06460	3.90000	.00000	-6.26753	.43327	.00000	-.05328	.8454	.9780
18.1818	20.61413	-1.07622	3.90000	.00000	-6.29889	.43554	.00000	-.05322	.8493	.9781
20.0000	20.78819	-1.08818	3.90000	.00000	-6.33324	.43789	.00000	-.05317	.8543	.9844
25.0000	21.21243	-1.11449	3.90000	.00000	-6.41476	.44311	.00000	-.05305	.8614	.9884
31.0000	21.57041	-1.13489	3.90000	.00000	-6.48374	.44710	.00000	-.05297	.8618	.9861
40.0000	21.87723	-1.16223	3.90000	.00000	-6.55296	.45285	.00000	-.05337	.8530	.9759
50.0000	21.95228	-1.17915	3.90000	.00000	-6.58099	.45634	.00000	-.05377	.8474	.9723
100.000	17.30516	-.96734	3.70000	.00000	-5.85881	.42361	.00000	-.05803	.7783	.9131
PGA	16.96725	-.95374	3.70000	.00000	-5.80700	.42132	.00000	-.05852	.7718	.9075
PGV	12.26101	-.23705	3.30000	.00000	-4.74443	.39834	.00000	-.11859	.5911	--------

Table 5f
GULF COAST
REGRESSION COEFFICIENTS FOR THE SINGLE CORNER MODEL
WITH CONSTANT HIGH STRESS DROP AND SATURATION

Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-12.65135	2.09962	3.10000	.00000	-2.65372	.15931	.00000	-.27995	.5362	1.3837
0.2000	-7.63385	1.70983	3.30000	.00000	-2.99118	.17807	.00000	-.34677	.5704	1.2710
0.3333	-2.92833	1.29933	3.50000	.00000	-3.40943	.20580	.00000	-.34999	.6013	1.1422
0.5000	.76119	.94998	3.60000	.00000	-3.74466	.23048	.00000	-.32555	.6196	1.0634
0.6250	2.38331	.77804	3.60000	.00000	-3.87013	.24129	.00000	-.30322	.6270	.9980
1.0000	6.70599	.34088	3.70000	.00000	-4.31367	.27643	.00000	-.24215	.6534	.9306
1.3333	8.65230	.12586	3.70000	.00000	-4.49751	.29269	.00000	-.20273	.6683	.9392
2.0000	12.17467	-.20531	3.80000	.00000	-4.92914	.32564	.00000	-.15276	.6921	.9094
2.5000	13.37181	-.32798	3.80000	.00000	-5.06579	.33699	.00000	-.13019	.7071	.9050
3.3333	14.74399	-.46111	3.80000	.00000	-5.23503	.35058	.00000	-.10713	.7288	.9173
4.1667	16.97448	-.62936	3.90000	.00000	-5.57259	.37377	.00000	-.09378	.7475	.9181
5.0000	17.69717	-.69006	3.90000	.00000	-5.67505	.38135	.00000	-.08547	.7645	.9250
6.2500	18.50771	-.75440	3.90000	.00000	-5.79682	.39016	.00000	-.07798	.7875	.9383
6.6667	20.19141	-.86646	4.00000	.00000	-6.07056	.40801	.00000	-.07627	.7944	.9448
8.3333	20.94827	-.92609	4.00000	.00000	-6.19648	.41744	.00000	-.07162	.8162	.9669
10.0000	21.51625	-.97369	4.00000	.00000	-6.29904	.42562	.00000	-.06904	.8294	.9683
12.5000	22.13508	-1.02936	4.00000	.00000	-6.41929	.43578	.00000	-.06706	.8401	.9721
14.2857	22.46355	-1.05978	4.00000	.00000	-6.48596	.44153	.00000	-.06636	.8449	.9760
16.6667	22.81270	-1.09092	4.00000	.00000	-6.55721	.44750	.00000	-.06586	.8508	.9827
18.1818	23.00275	-1.10647	4.00000	.00000	-6.59524	.45051	.00000	-.06568	.8551	.9831
20.0000	23.21284	-1.12231	4.00000	.00000	-6.63632	.45359	.00000	-.06551	.8603	.9896
25.0000	23.71273	-1.15652	4.00000	.00000	-6.73191	.46030	.00000	-.06519	.8679	.9941
31.0000	24.13701	-1.18374	4.00000	.00000	-6.81358	.46562	.00000	-.06503	.8687	.9922
40.0000	24.51845	-1.21926	4.00000	.00000	-6.89791	.47308	.00000	-.06549	.8601	.9822
50.0000	24.64848	-1.24267	4.00000	.00000	-6.93799	.47804	.00000	-.06606	.8546	.9786
100.000	19.65149	-1.01014	3.80000	.00000	-6.17228	.44358	.00000	-.07230	.7848	.9186
PGA	19.28060	-.99348	3.80000	.00000	-6.11546	.44085	.00000	-.07305	.7781	.9129
PGV	14.16517	-.28835	3.40000	.00000	-5.07478	.42615	.00000	-.10965	.6001	--------

Table 6a MIDCONTINENT REGRESSION COEFFICIENTS FOR THE DOUBLE CORNER MODEL										
Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-17.74463	2.22485	2.10000	.00000	-1.40084	.05305	.00000	-.31641	.3559	1.3243
0.2000	-13.88893	1.89859	2.30000	.00000	-1.54772	.06068	.00000	-.28960	.3660	1.1933
0.3333	-11.04809	1.64665	2.40000	.00000	-1.70010	.07272	.00000	-.22943	.3892	1.0462
0.5000	-8.76880	1.45200	2.50000	.00000	-1.86494	.08722	.00000	-.18125	.4160	.9591
0.6250	-7.68301	1.34978	2.50000	.00000	-1.94573	.09603	.00000	-.16127	.4297	.8874
1.0000	-5.47019	1.12590	2.50000	.00000	-2.13473	.11710	.00000	-.13830	.4518	.8021
1.3333	-3.77355	.98718	2.60000	.00000	-2.28113	.13007	.00000	-.13323	.4610	.8050
2.0000	-1.95968	.80810	2.60000	.00000	-2.41132	.14449	.00000	-.12529	.4714	.7551
2.5000	-.96872	.71370	2.60000	.00000	-2.46500	.15003	.00000	-.11749	.4775	.7396
3.3333	.10920	.59537	2.60000	.00000	-2.54120	.15808	.00000	-.10506	.4865	.7395
4.1667	.86777	.52085	2.60000	.00000	-2.58506	.16235	.00000	-.09484	.4950	.7274
5.0000	1.42831	.46988	2.60000	.00000	-2.61380	.16486	.00000	-.08671	.5040	.7247
6.2500	1.99361	.41219	2.60000	.00000	-2.65510	.16868	.00000	-.07801	.5181	.7271
6.6667	2.14018	.39715	2.60000	.00000	-2.66676	.16973	.00000	-.07573	.5249	.7328
8.3333	2.60454	.35667	2.60000	.00000	-2.69927	.17238	.00000	-.06929	.5424	.7503
10.0000	3.30684	.30373	2.70000	.00000	-2.79751	.17893	.00000	-.06512	.5602	.7507
12.5000	3.62400	.27369	2.70000	.00000	-2.83163	.18170	.00000	-.06128	.5731	.7534
14.2857	3.77510	.25773	2.70000	.00000	-2.85226	.18339	.00000	-.05952	.5803	.7585
16.6667	3.92454	.24169	2.70000	.00000	-2.87495	.18521	.00000	-.05791	.5868	.7656
18.1818	3.99907	.23357	2.70000	.00000	-2.88734	.18619	.00000	-.05717	.5907	.7644
20.0000	4.07670	.22547	2.70000	.00000	-2.90040	.18720	.00000	-.05647	.5961	.7711
25.0000	4.69293	.18262	2.80000	.00000	-3.00672	.19396	.00000	-.05520	.6133	.7817
31.0000	4.86717	.17018	2.80000	.00000	-3.03252	.19560	.00000	-.05434	.6227	.7858
40.0000	5.03119	.15779	2.80000	.00000	-3.06134	.19746	.00000	-.05377	.6222	.7823
50.0000	5.06834	.14806	2.80000	.00000	-3.08409	.19935	.00000	-.05361	.6143	.7776
100.000	3.74623	.18152	2.70000	.00000	-2.98867	.19854	.00000	-.05734	.5644	.7392
PGA	3.54103	.18904	2.70000	.00000	-2.97418	.19819	.00000	-.05814	.5592	.7353
PGV	4.06989	.46794	2.50000	.00000	-2.77481	.19743	.00000	-.07606	.4408	--------

NOTE: PARAMETRIC SIGMA VALUES ARE FROM THE 1 CORNER VARIABLE STRESS DROP MODEL

Table 6b GULF COAST REGRESSION COEFFICIENTS FOR THE DOUBLE CORNER MODEL										
Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-16.41379	2.20767	2.50000	.00000	-1.74567	.06829	.00000	-.33131	.5243	1.3791
0.2000	-12.20468	1.83553	2.70000	.00000	-1.95111	.07737	.00000	-.29415	.5604	1.2665
0.3333	-8.83853	1.54958	2.90000	.00000	-2.21747	.09356	.00000	-.23217	.5958	1.1393
0.5000	-6.28665	1.33826	3.00000	.00000	-2.43987	.10973	.00000	-.18303	.6159	1.0612
0.6250	-5.10947	1.24004	3.00000	.00000	-2.53021	.11775	.00000	-.16323	.6233	.9956
1.0000	-2.15831	.99778	3.10000	.00000	-2.82918	.14191	.00000	-.13999	.6483	.9271
1.3333	-.12511	.83880	3.20000	.00000	-3.05030	.15823	.00000	-.13454	.6622	.9349
2.0000	1.93674	.64984	3.20000	.00000	-3.22152	.17312	.00000	-.12608	.6850	.9040
2.5000	2.99580	.55002	3.20000	.00000	-3.30621	.17993	.00000	-.11838	.6996	.8991
3.3333	4.87830	.39924	3.30000	.00000	-3.51506	.19281	.00000	-.10565	.7208	.9109
4.1667	5.74732	.31977	3.30000	.00000	-3.58708	.19746	.00000	-.09504	.7389	.9111
5.0000	7.09082	.22710	3.40000	.00000	-3.76365	.20689	.00000	-.08680	.7556	.9177
6.2500	7.79199	.16914	3.40000	.00000	-3.83080	.21046	.00000	-.07794	.7783	.9306
6.6667	7.97786	.15425	3.40000	.00000	-3.85005	.21146	.00000	-.07567	.7850	.9369
8.3333	9.36118	.06628	3.50000	.00000	-4.05250	.22188	.00000	-.06891	.8064	.9587
10.0000	9.79610	.03112	3.50000	.00000	-4.11197	.22526	.00000	-.06459	.8192	.9596
12.5000	10.26367	-.00857	3.50000	.00000	-4.18673	.22992	.00000	-.06062	.8294	.9628
14.2857	10.51625	-.03055	3.50000	.00000	-4.23161	.23289	.00000	-.05885	.8339	.9664
16.6667	11.69837	-.10103	3.60000	.00000	-4.43516	.24410	.00000	-.05724	.8396	.9730
18.1818	11.85646	-.11325	3.60000	.00000	-4.46406	.24596	.00000	-.05650	.8438	.9733
20.0000	12.02874	-.12544	3.60000	.00000	-4.49489	.24783	.00000	-.05578	.8491	.9799
25.0000	12.42738	-.15043	3.60000	.00000	-4.56505	.25176	.00000	-.05445	.8566	.9842
31.0000	13.81046	-.22653	3.70000	.00000	-4.80279	.26447	.00000	-.05370	.8572	.9821
40.0000	14.14384	-.25488	3.70000	.00000	-4.87587	.26995	.00000	-.05318	.8487	.9722
50.0000	14.33926	-.28175	3.70000	.00000	-4.93249	.27571	.00000	-.05331	.8430	.9685
100.000	11.07839	-.18783	3.50000	.00000	-4.49420	.26735	.00000	-.05801	.7733	.9088
PGA	9.90148	-.12757	3.40000	.00000	-4.30771	.25806	.00000	-.05882	.7666	.9031
PGV	8.13980	.18271	3.00000	.00000	-3.72218	.26644	.00000	-.08657	.5888	-------

NOTE: PARAMETRIC SIGMA VALUES ARE FROM THE 1 CORNER VARIABLE STRESS DROP MODEL (MEDIUM STRESS DROP)

Table 7a MIDCONTINENT REGRESSION COEFFICIENTS FOR THE DOUBLE CORNER MODEL WITH SATURATION										
Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-16.16329	1.96535	2.30000	.00000	-1.71374	.10547	.00000	-.32832	.3559	1.3243
0.2000	-12.17910	1.62451	2.50000	.00000	-1.88291	.11564	.00000	-.30150	.3660	1.1933
0.3333	-9.24347	1.36201	2.60000	.00000	-2.05193	.12954	.00000	-.24133	.3892	1.0462
0.5000	-6.86049	1.15548	2.70000	.00000	-2.23472	.14610	.00000	-.19315	.4160	.9591
0.6250	-5.75016	1.05061	2.70000	.00000	-2.32003	.15540	.00000	-.17317	.4297	.8874
1.0000	-3.10841	.79561	2.80000	.00000	-2.58562	.18195	.00000	-.15020	.4518	.8021
1.3333	-1.68010	.66971	2.80000	.00000	-2.68318	.19261	.00000	-.14513	.4610	.8050
2.0000	.17104	.48663	2.80000	.00000	-2.81997	.20773	.00000	-.13719	.4714	.7551
2.5000	1.17695	.39078	2.80000	.00000	-2.87626	.21352	.00000	-.12940	.4775	.7396
3.3333	2.27626	.27031	2.80000	.00000	-2.95623	.22193	.00000	-.11697	.4865	.7395
4.1667	3.04705	.19471	2.80000	.00000	-3.00223	.22639	.00000	-.10675	.4950	.7274
5.0000	3.61568	.14311	2.80000	.00000	-3.03239	.22900	.00000	-.09861	.5040	.7247
6.2500	4.19281	.08441	2.80000	.00000	-3.07579	.23300	.00000	-.08991	.5181	.7271
6.6667	4.34277	.06911	2.80000	.00000	-3.08805	.23409	.00000	-.08764	.5249	.7328
8.3333	4.81663	.02793	2.80000	.00000	-3.12224	.23686	.00000	-.08119	.5424	.7503
10.0000	5.13706	-.00173	2.80000	.00000	-3.15185	.23929	.00000	-.07703	.5602	.7507
12.5000	5.94942	-.06741	2.90000	.00000	-3.27328	.24822	.00000	-.07318	.5731	.7534
14.2857	6.10708	-.08387	2.90000	.00000	-3.29509	.25000	.00000	-.07142	.5803	.7585
16.6667	6.26384	-.10044	2.90000	.00000	-3.31911	.25192	.00000	-.06982	.5868	.7656
18.1818	6.34238	-.10886	2.90000	.00000	-3.33222	.25295	.00000	-.06908	.5907	.7644
20.0000	6.42423	-.11726	2.90000	.00000	-3.34604	.25401	.00000	-.06838	.5961	.7711
25.0000	6.61204	-.13370	2.90000	.00000	-3.37593	.25613	.00000	-.06711	6133	.7817
31.0000	7.33736	-.18563	3.00000	.00000	-3.49824	.26456	.00000	-.06625	.6227	7858
40.0000	7.51145	-.19862	3.00000	.00000	-3.52888	.26652	.00000	-.06568	.6222	.7823
50.0000	7.55648	-.20898	3.00000	.00000	-3.55306	.26853	.00000	-.06551	.6143	.7776
100.000	6.12213	-.16489	2.90000	.00000	-3.43941	.26601	.00000	-.06925	.5644	.7392
PGA	5.91196	-.15727	2.90000	.00000	-3.42401	.26564	.00000	-.07004	.5592	.7353
PGV	5.79531	.17529	2.60000	.00000	-3.11215	.25573	.00000	-.08796	.4408	-------

NOTE: PARAMETRIC SIGMA VALUES ARE FROM THE 1 CORNER VARIABLE STRESS DROP MODEL

Table 7b GULF COAST REGRESSION COEFFICIENTS FOR THE DOUBLE CORNER MODEL WITH SATURATION										
Freq. Hz	C1	C2	C4	C5	C6	C7	C8	C10	Parametric Sigma	Total Sigma
0.1000	-14.54243	1.91703	2.70000	.00000	-2.10859	.12608	.00000	-.34322	.5243	1.3791
0.2000	-9.76826	1.50496	3.00000	.00000	-2.41187	.14194	.00000	-.30605	.5604	1.2665
0.3333	-6.54516	1.21492	3.10000	.00000	-2.65122	.15876	.00000	-.24408	.5958	1.1393
0.5000	-3.83140	.98710	3.20000	.00000	-2.90058	.17769	.00000	-.19493	.6159	1.0612
0.6250	-2.06630	.85356	3.30000	.00000	-3.09220	.19167	.00000	-.17514	.6233	.9956
1.0000	.53026	.62351	3.30000	.00000	-3.32873	.21370	.00000	-.15190	.6483	.9271
1.3333	2.74561	.44592	3.40000	.00000	-3.57911	.23302	.00000	-.14644	.6622	.9349
2.0000	4.87153	.25189	3.40000	.00000	-3.76122	.24875	.00000	-.13799	.6850	.9040
2.5000	5.96206	.14984	3.40000	.00000	-3.85124	.25592	.00000	-.13028	.6996	.8991
3.3333	8.03762	-.01963	3.50000	.00000	-4.09059	.27175	.00000	-.11756	.7208	.9109
4.1667	8.93501	-.10061	3.50000	.00000	-4.16740	.27663	.00000	-.10695	.7389	.9111
5.0000	9.59190	-.15735	3.50000	.00000	-4.22645	.28002	.00000	-.09871	.7556	.9177
6.2500	11.20299	-.27131	3.60000	.00000	-4.44627	.29278	.00000	-.08984	.7783	.9306
6.6667	11.39716	-.28656	3.60000	.00000	-4.46693	.29383	.00000	-.08758	.7850	.9369
8.3333	12.01553	-.33472	3.60000	.00000	-4.53955	.29762	.00000	-.08082	.8064	.9587
10.0000	13.46434	-.43179	3.70000	.00000	-4.76782	.31108	.00000	-.07649	.8192	.9596
12.5000	13.96635	-.47347	3.70000	.00000	-4.84844	.31607	.00000	-.07252	.8294	.9628
14.2857	14.23988	-.49678	3.70000	.00000	-4.89689	.31927	.00000	-.07075	.8339	.9664
16.6667	14.53975	-.52162	3.70000	.00000	-4.95186	.32294	.00000	-.06914	.8396	.9730
18.1818	15.83611	-.60342	3.80000	.00000	-5.16886	.33606	.00000	-.06840	.8438	.9733
20.0000	16.02362	-.61652	3.80000	.00000	-5.20228	.33809	.00000	-.06769	.8491	.9799
25.0000	16.45698	-.64342	3.80000	.00000	-5.27833	.34234	.00000	-.06636	.8566	.9842
31.0000	16.84962	-.66794	3.80000	.00000	-5.35052	.34658	.00000	-.06561	.8572	.9821
40.0000	17.20090	-.69766	3.80000	.00000	-5.42663	.35229	.00000	-.06508	.8487	.9722
50.0000	17.40998	-.72596	3.80000	.00000	-5.48554	.35830	.00000	-.06521	.8430	.9685
100.000	13.83032	-.59892	3.60000	.00000	-4.99790	.34481	.00000	-.06992	.7733	.9088
PGA	13.52127	-.58872	3.60000	.00000	-4.95888	.34391	.00000	-.07073	.7666	.9031
PGV	10.31841	-.16678	3.10000	.00000	-4.13550	.33428	.00000	-.09848	.5888	--------

NOTE: PARAMETRIC SIGMA VALUES ARE FROM THE 1 CORNER VARIABLE STRESS DROP MODEL-MEDIUM STRESS DROP

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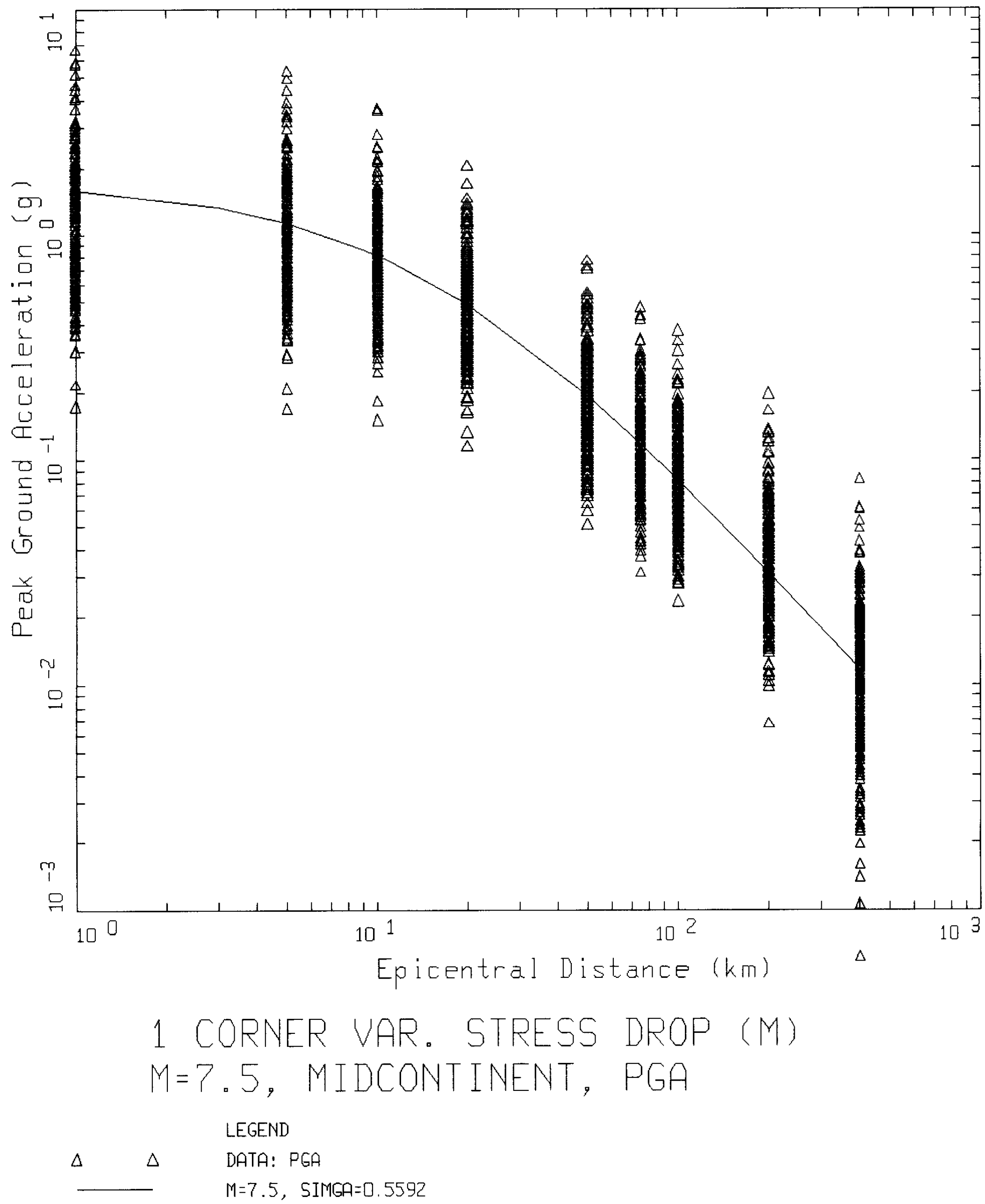

Figure 1. Peak acceleration estimates and regression fit at **M** 7.5 for the single corner model with variable (medium) stress drop, Midcontinent.

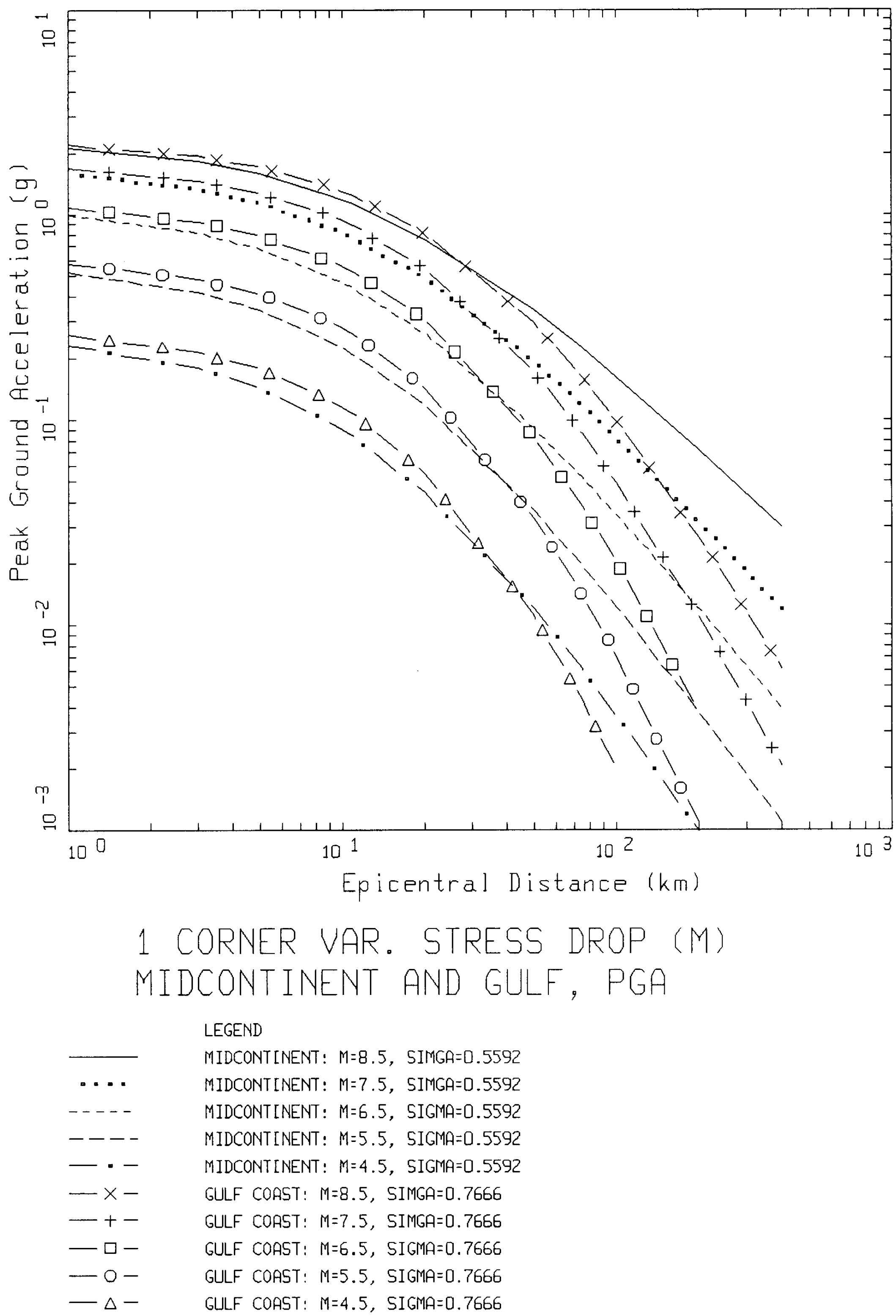

Figure 2a. Attenuation of median peak horizontal accelerations at **M** 4.5, 5.5, 6.5, 7.5 and 8.5 for the single corner model with variable (medium) stress drop, Midcontinent and Gulf Coast.

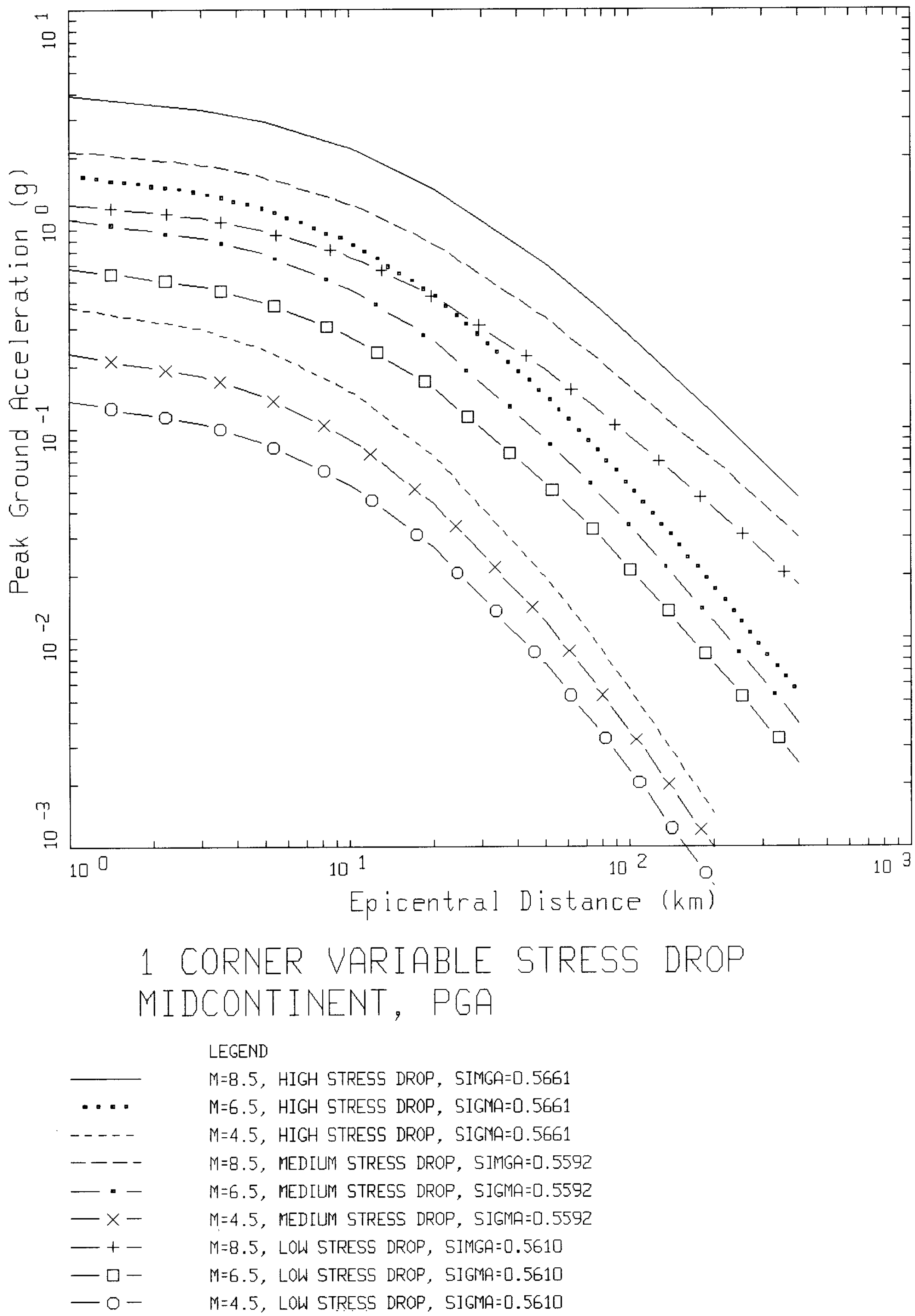

Figure 2b. Attenuation of median peak horizontal accelerations at **M** 4.5, 5.5, 6.5, 7.5 and 8.5 for the single corner model with variable (medium) stress drop, Midcontinent, effect of stress drop.

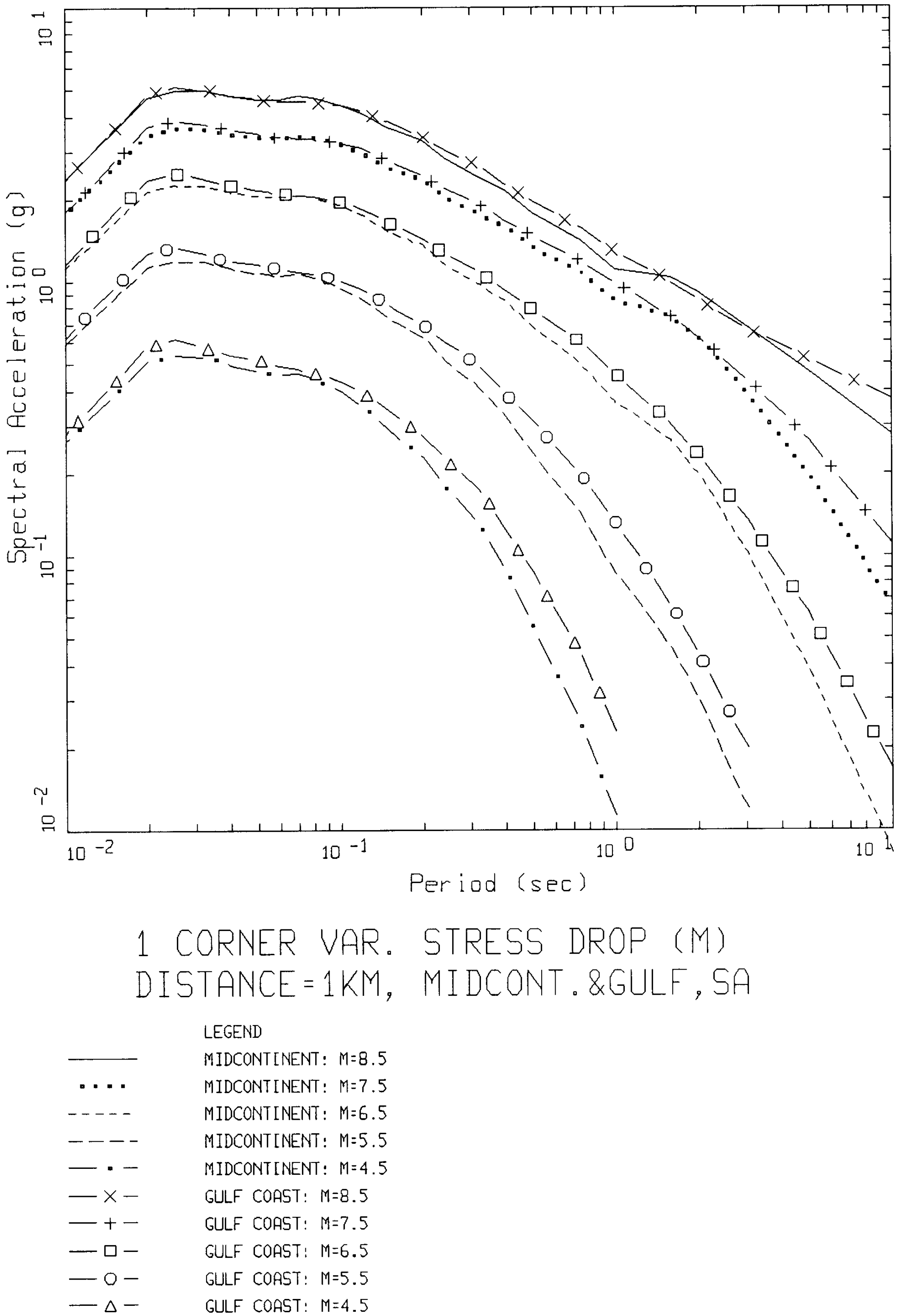

Figure 3a. Median response spectra (5% damping) at a distance of 1 km for magnitudes **M** 4.5, 5.5, 6.5, 7.5, and 8.5 for the single corner model with variable (medium) stress drop, Midcontinent and Gulf Coast.

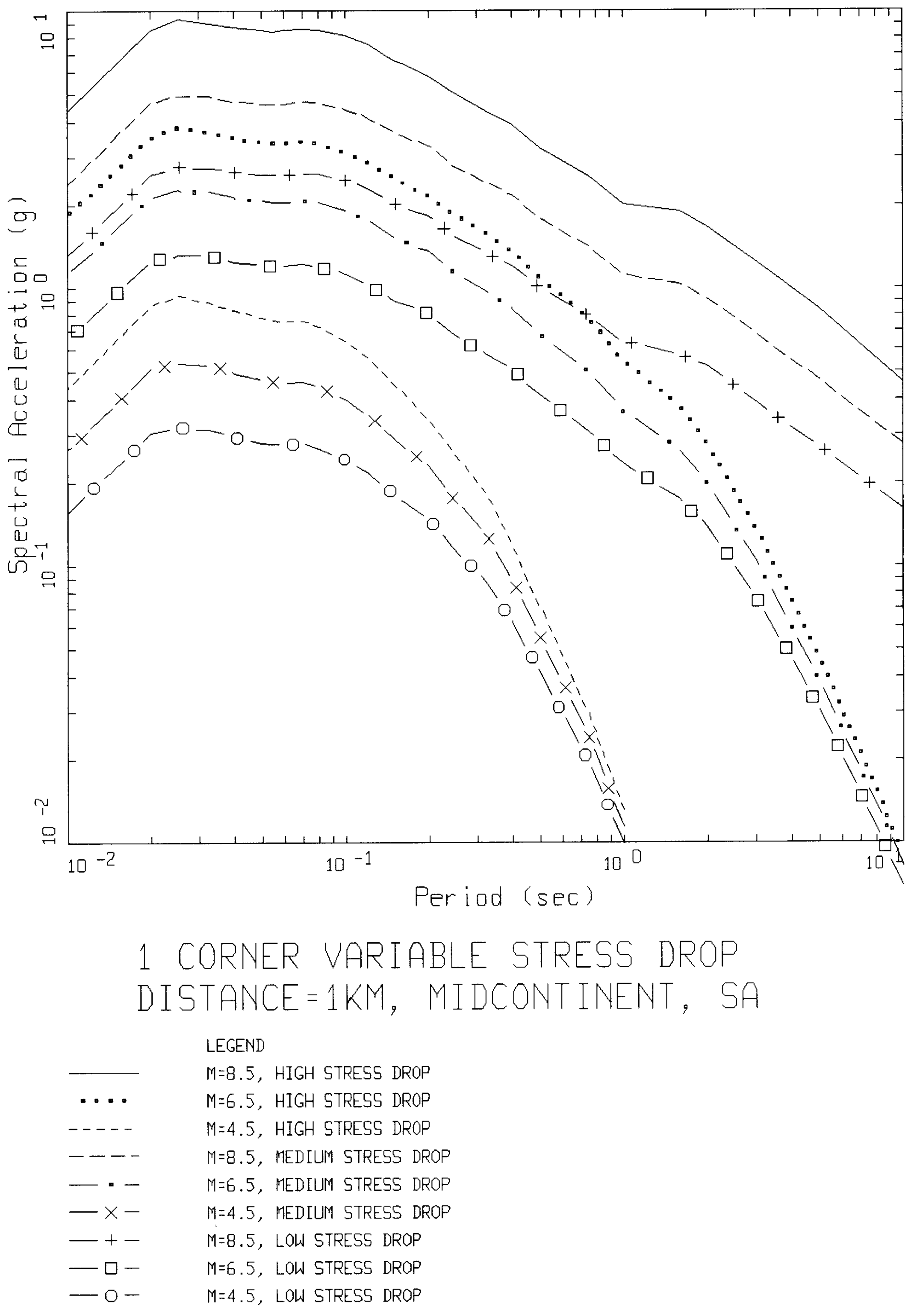

Figure 3b. Median response spectra (5% damping) at a distance of 1 km for magnitudes **M** 4.5, 5.5, 6.5, 7.5, and 8.5 for the single corner model with variable (medium) stress drop, Midcontinent, effect of stress drop.

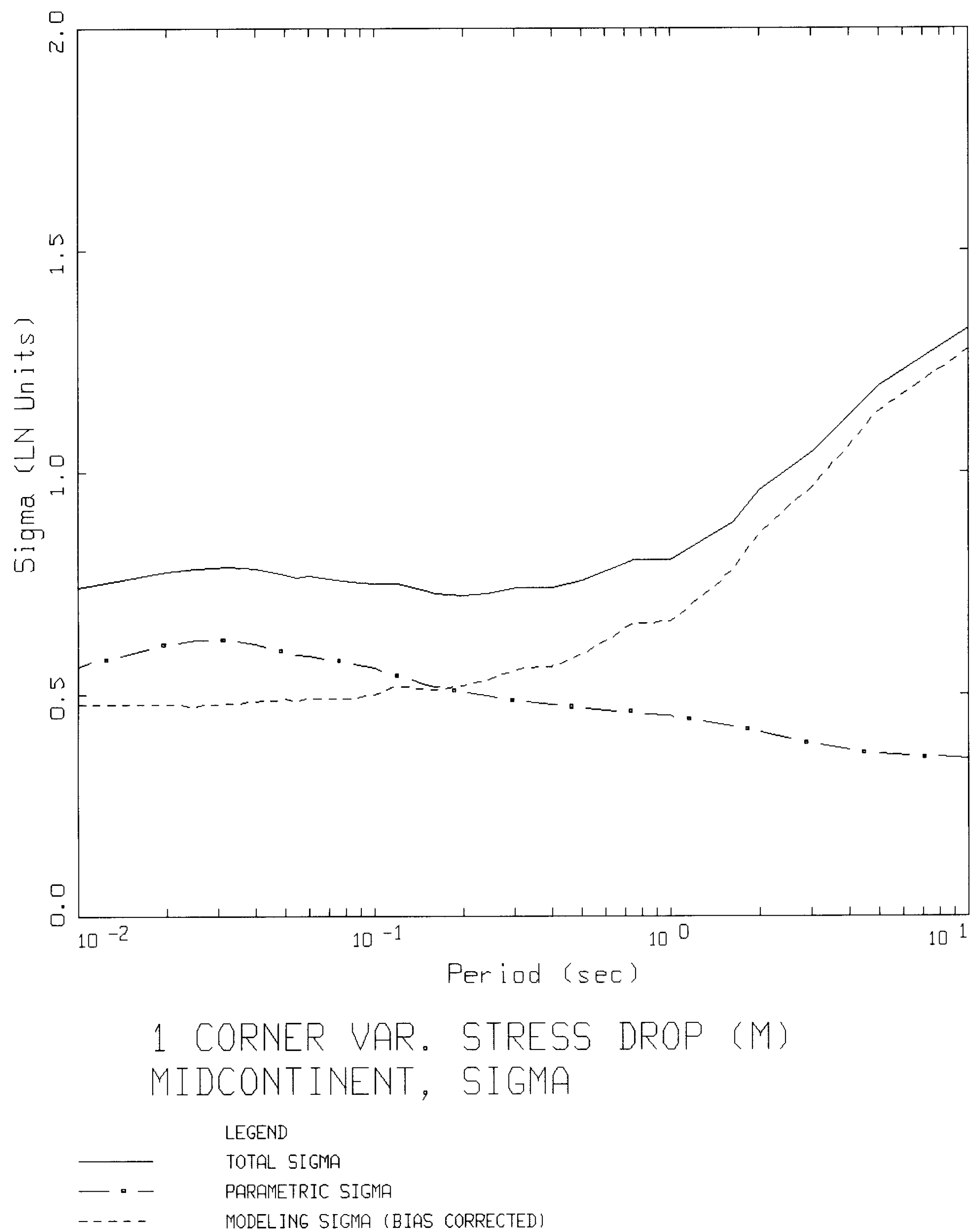

Figure 4a. Estimates of total variability (uncertainty) for the Midcontinent attenuation model. Parametric variability is due to variation of variable (medium) stress drop, single corner frequency point-source parameters (Table 2), and fit of regression model (Table 3a). Model variability is from validation exercises with 16 earthquakes (**M** 5.3 to 7.4) at 500 sites over the fault distance range of 1 to 460 km (Appendix B).

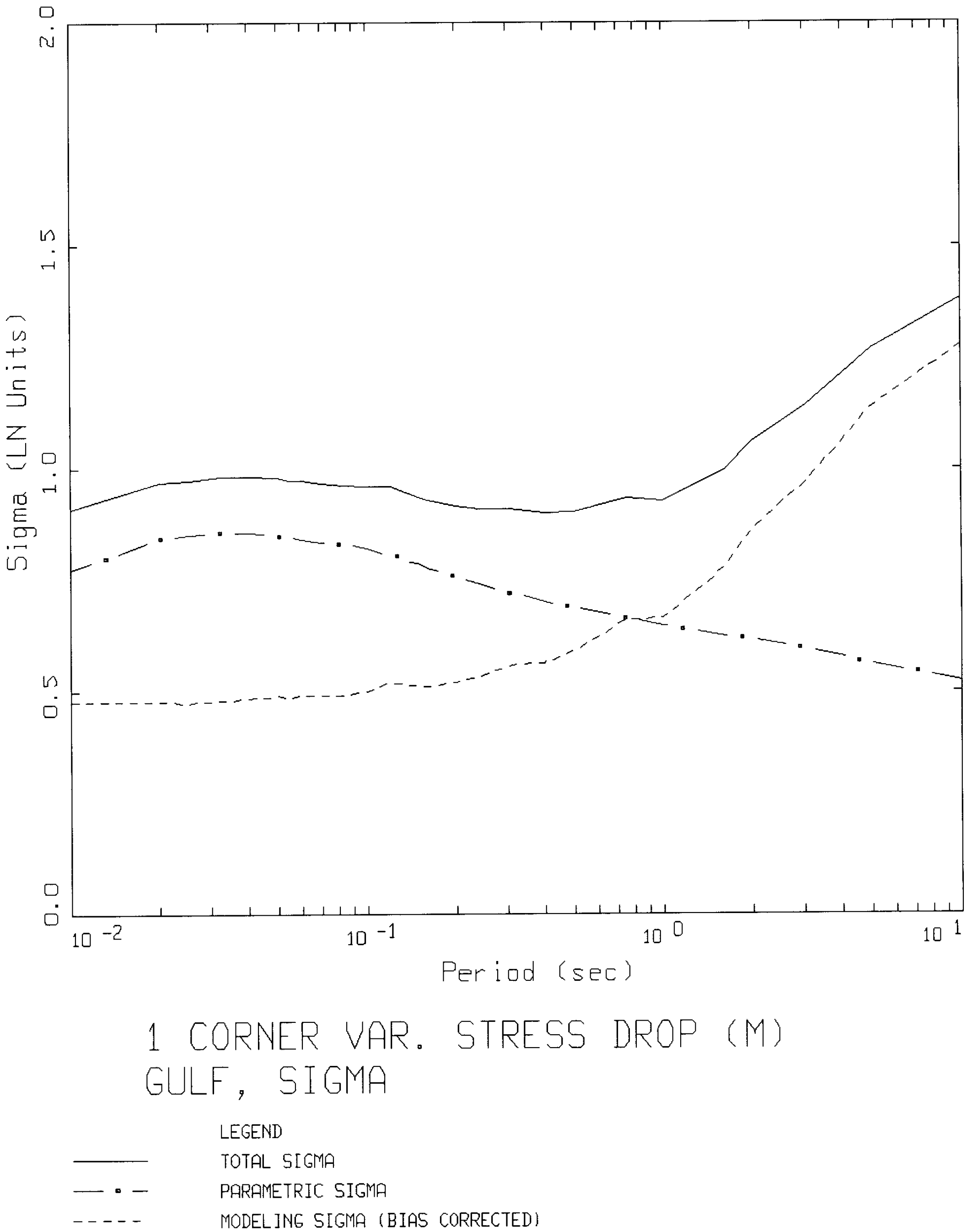

Figure 4b. Estimates of total variability (uncertainty) for the Gulf Coast attenuation model. Parametric variability is due to variation of variable (medium) stress drop, single corner frequency point-source parameters (Table 2), and fit of regression model (Table 3d). Model variability is from validation exercises with 16 earthquakes (**M** 5.3 to 7.4) at 500 sites over the fault distance range of 1 to 460 km (Appendix B).

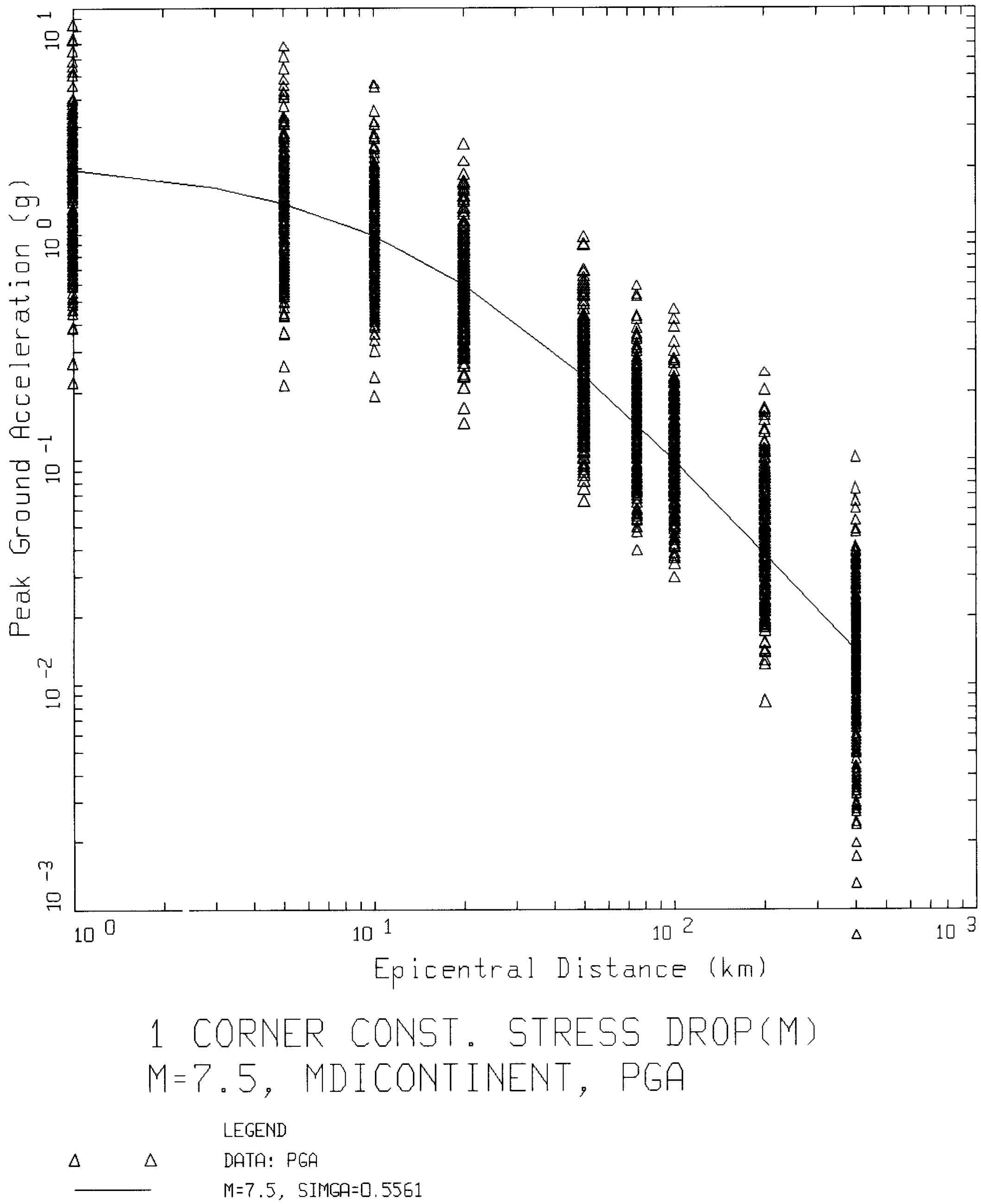

Figure 5. Peak acceleration estimates and regression fit at **M** 7.5 for the single corner model with constant (medium) stress drop, Midcontinent.

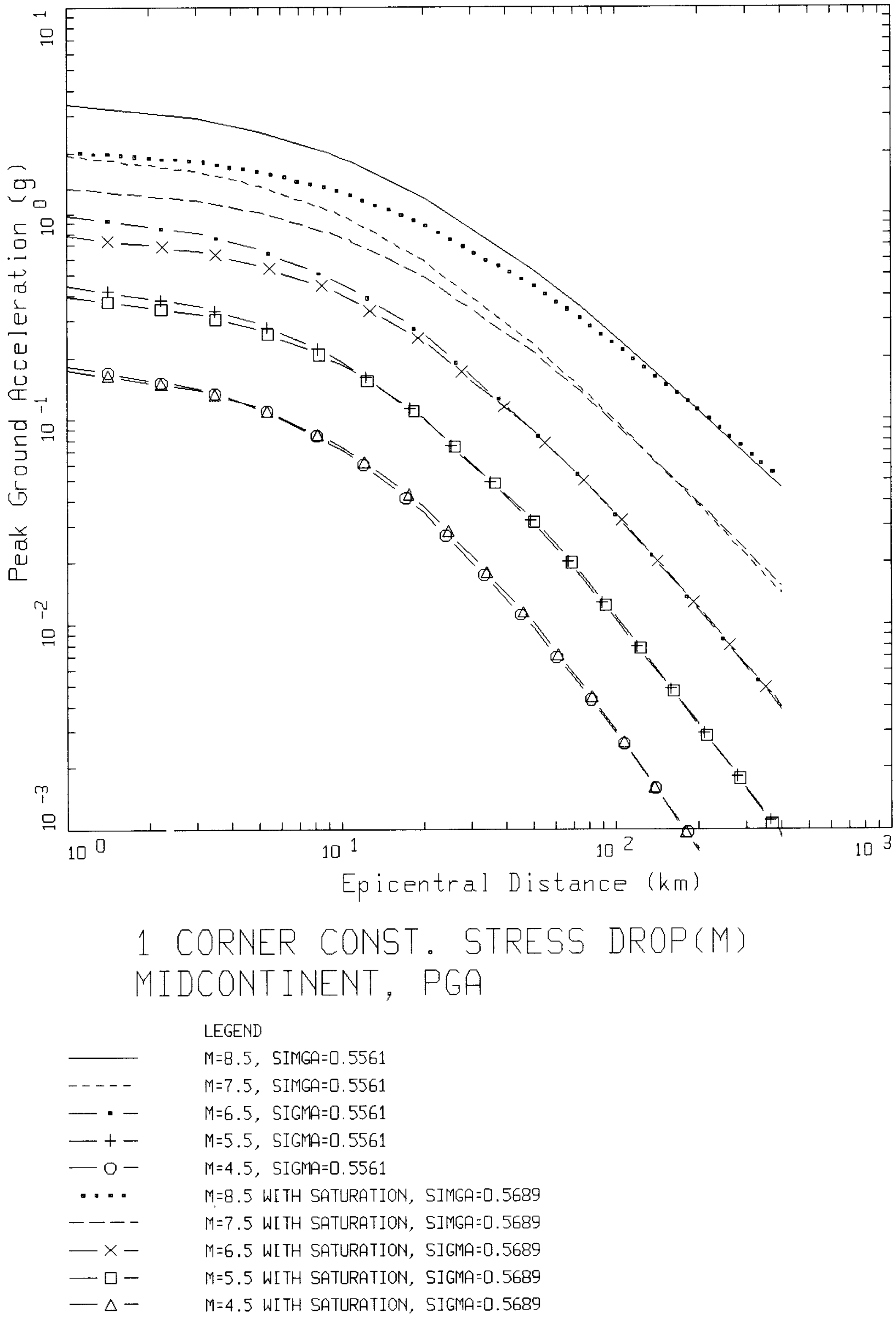

Figure 6. Attenuation of median peak horizontal accelerations at **M** 4.5, 5.5, 6.5, 7.5, and 8.5 for the single corner model with constant (medium) stress drop, with and without saturation, Midcontinent.

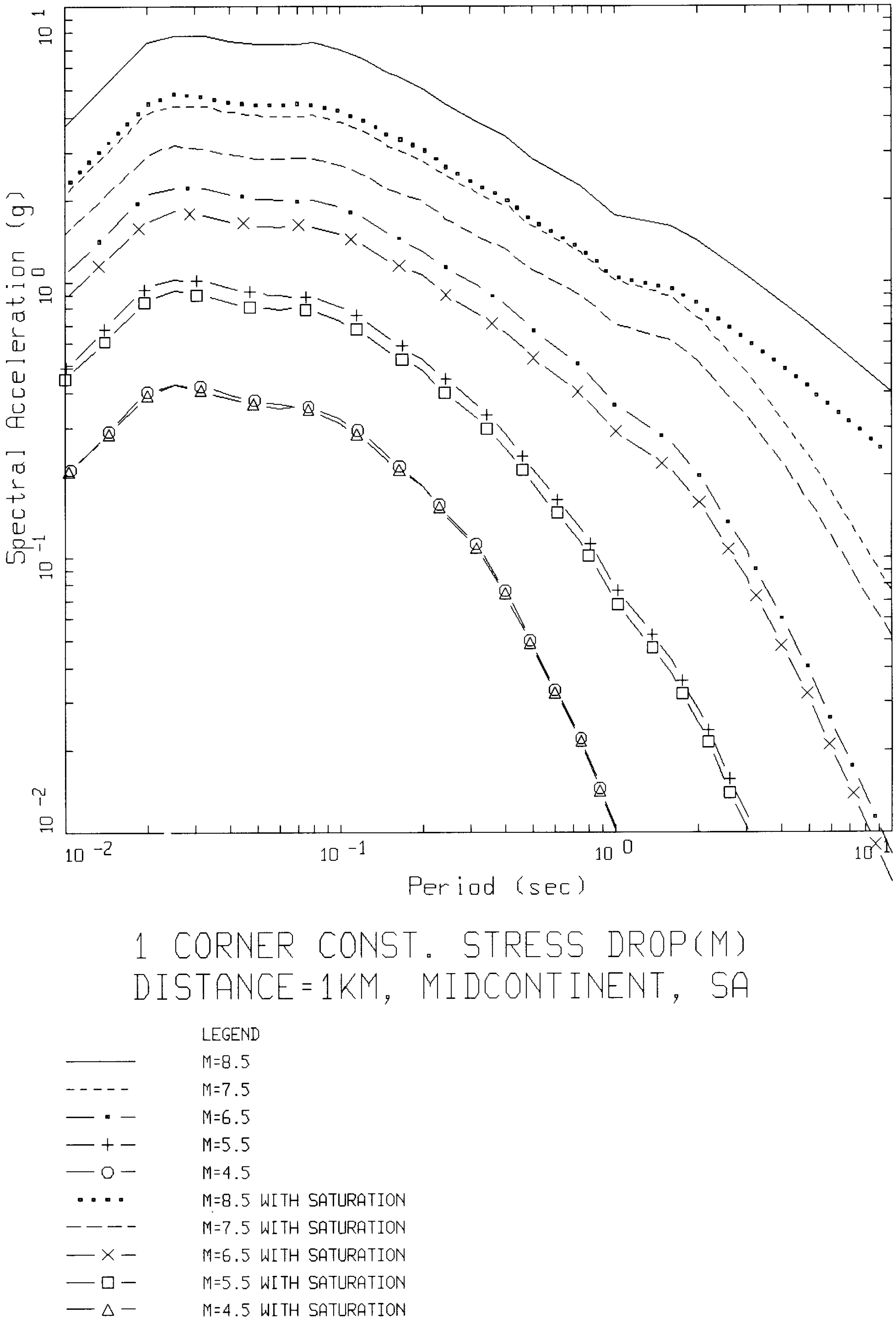

Figure 7. Median response spectra (5% damping) at a distance of 1 km for magnitudes **M** 4.5, 5.5, 6.5, 7.5, and 8.5 for the single corner model with constant (medium) stress drop, with and without saturation.

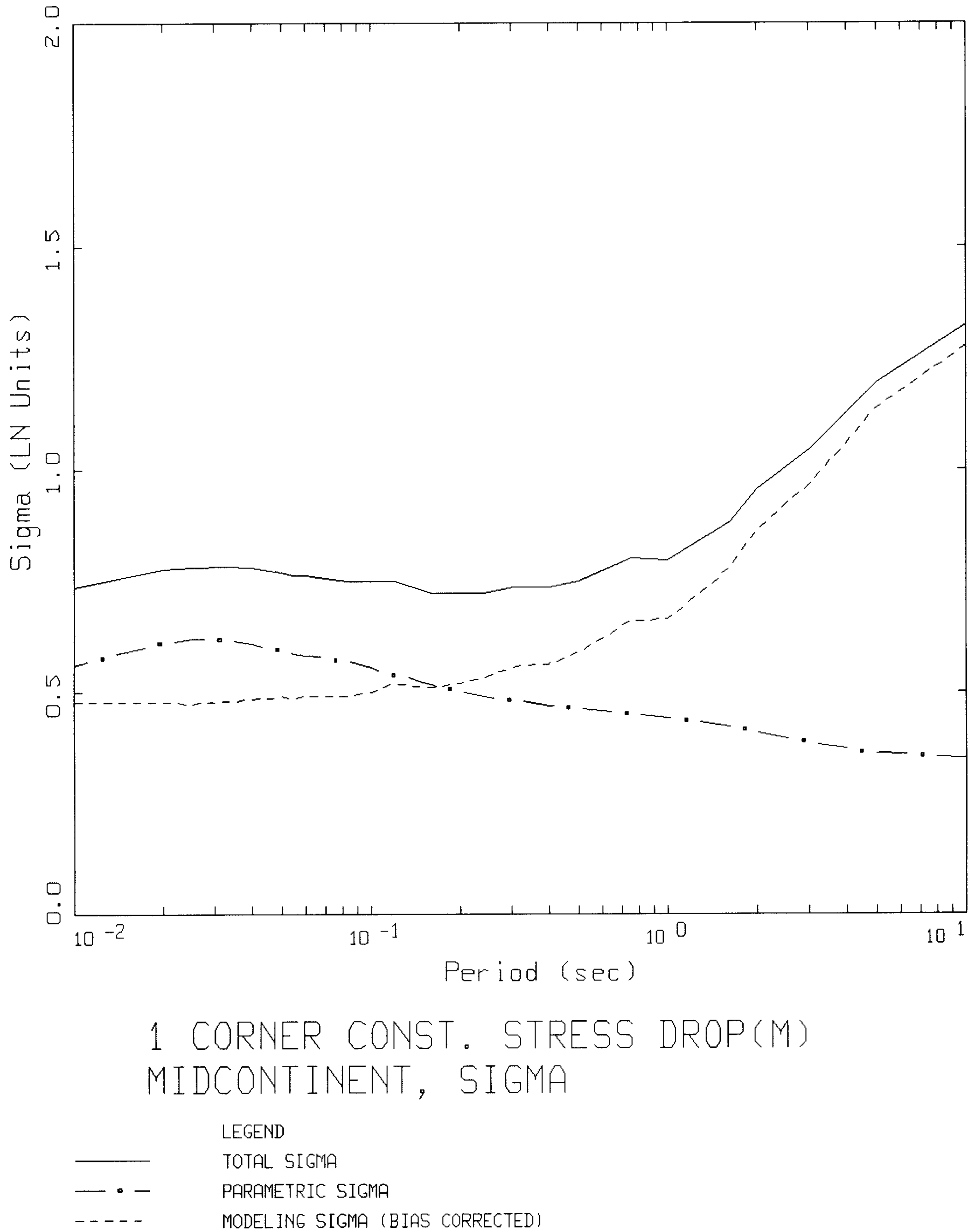

Figure 8a. Estimates of total variability (uncertainty) for the Midcontinent attenuation model. Parametric variability is due to variation of constant (medium) stress drop, single corner frequency point-source parameters (Table 2), and fit of regression model (Table 4a). Model variability is from validation exercises with 16 earthquakes (**M** 5.3 to 7.4) at 500 sites over the fault distance range of 1 to 460 km (Appendix B).

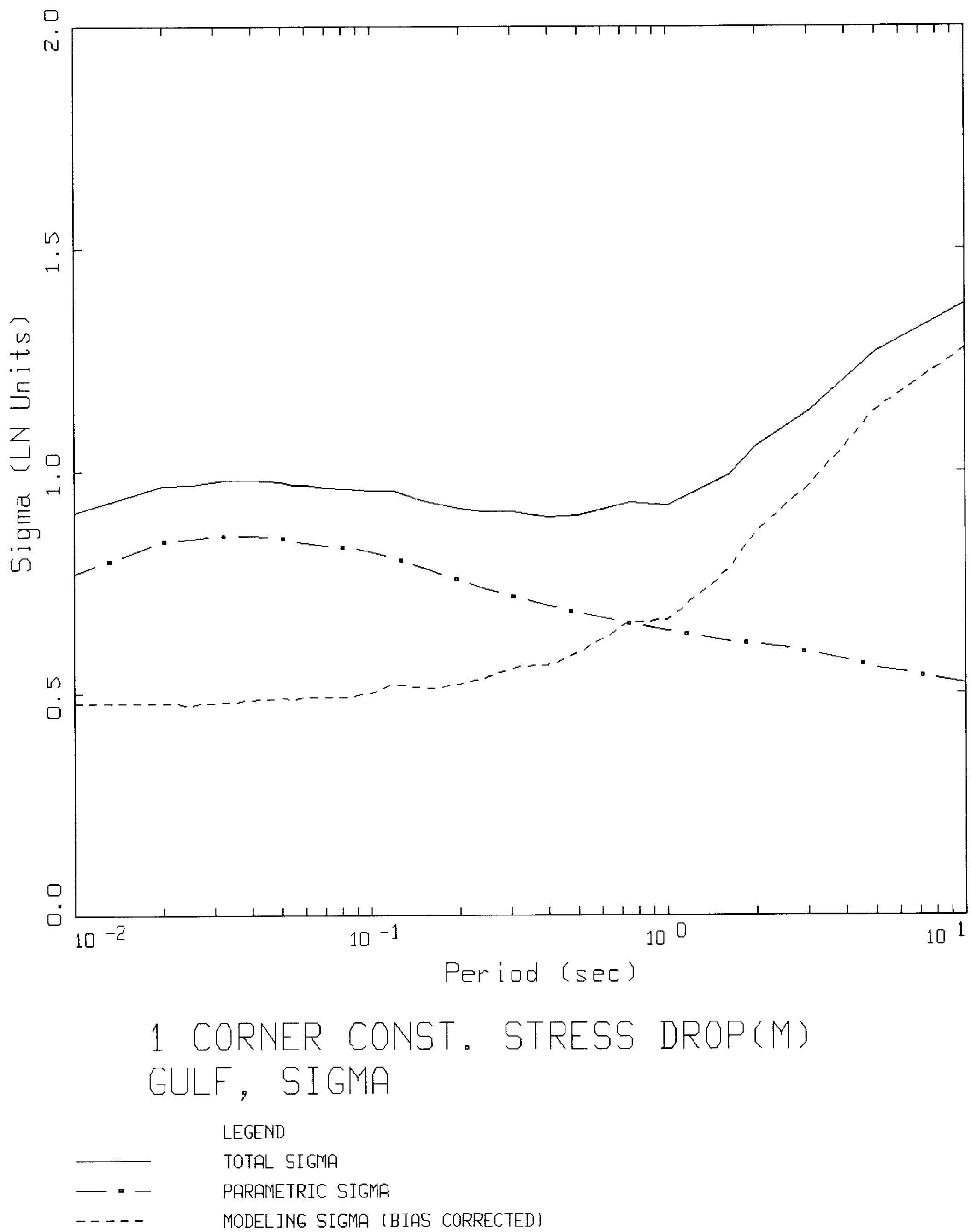

Figure 8b. Estimates of total variability (uncertainty) for the Gulf Coast attenuation model. Parametric variability is due to variation of constant (medium) stress drop, single corner frequency point-source parameters (Table 2), and fit of regression model (Table 4d). Model variability is from validation exercises with 16 earthquakes (**M** 5.3 to 7.4) at 500 sites over the fault distance range of 1 to 460 km (Appendix B).

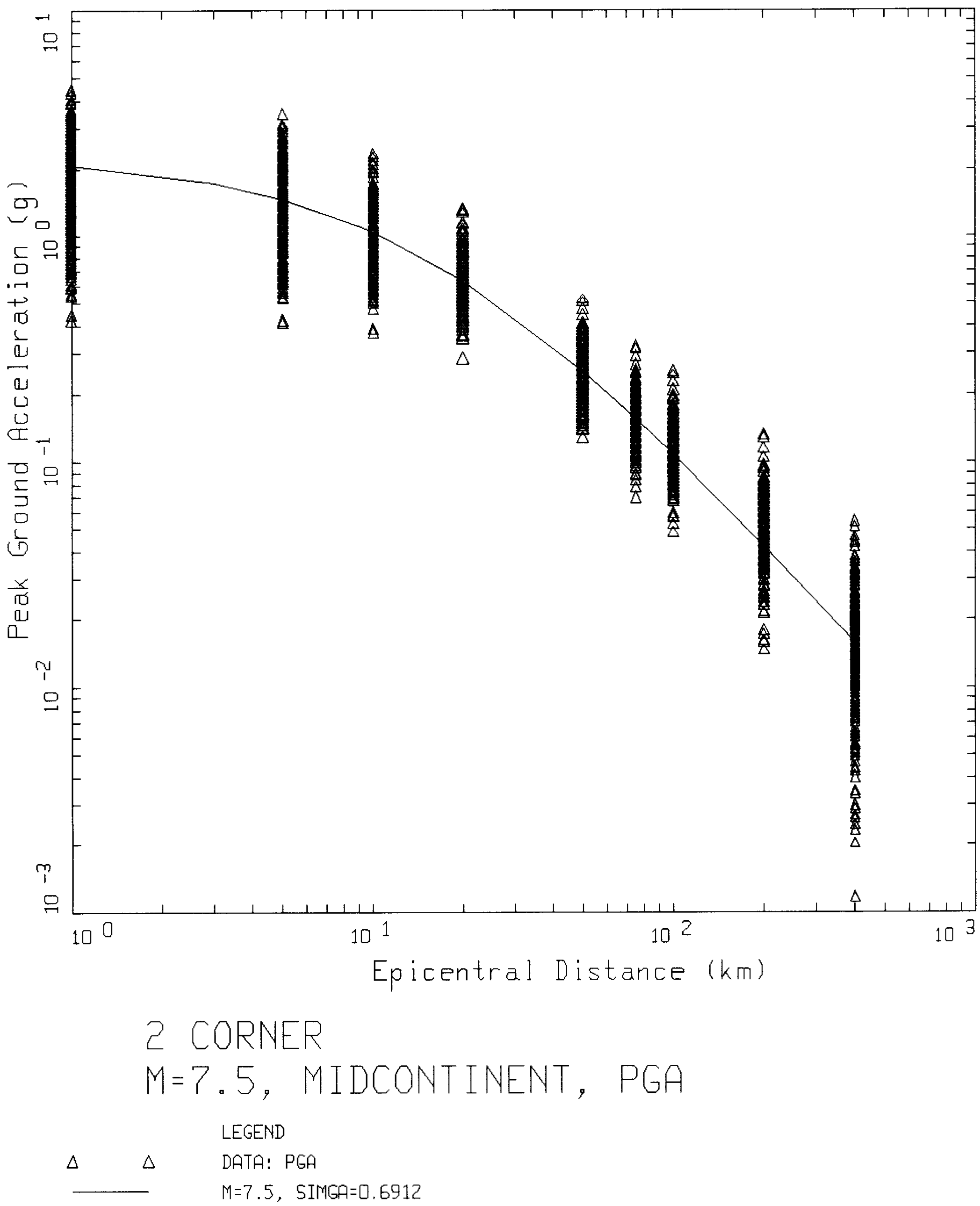

Figure 9. Peak acceleration estimates and regression fit at **M** 7.5 for the double corner model, Midcontinent.

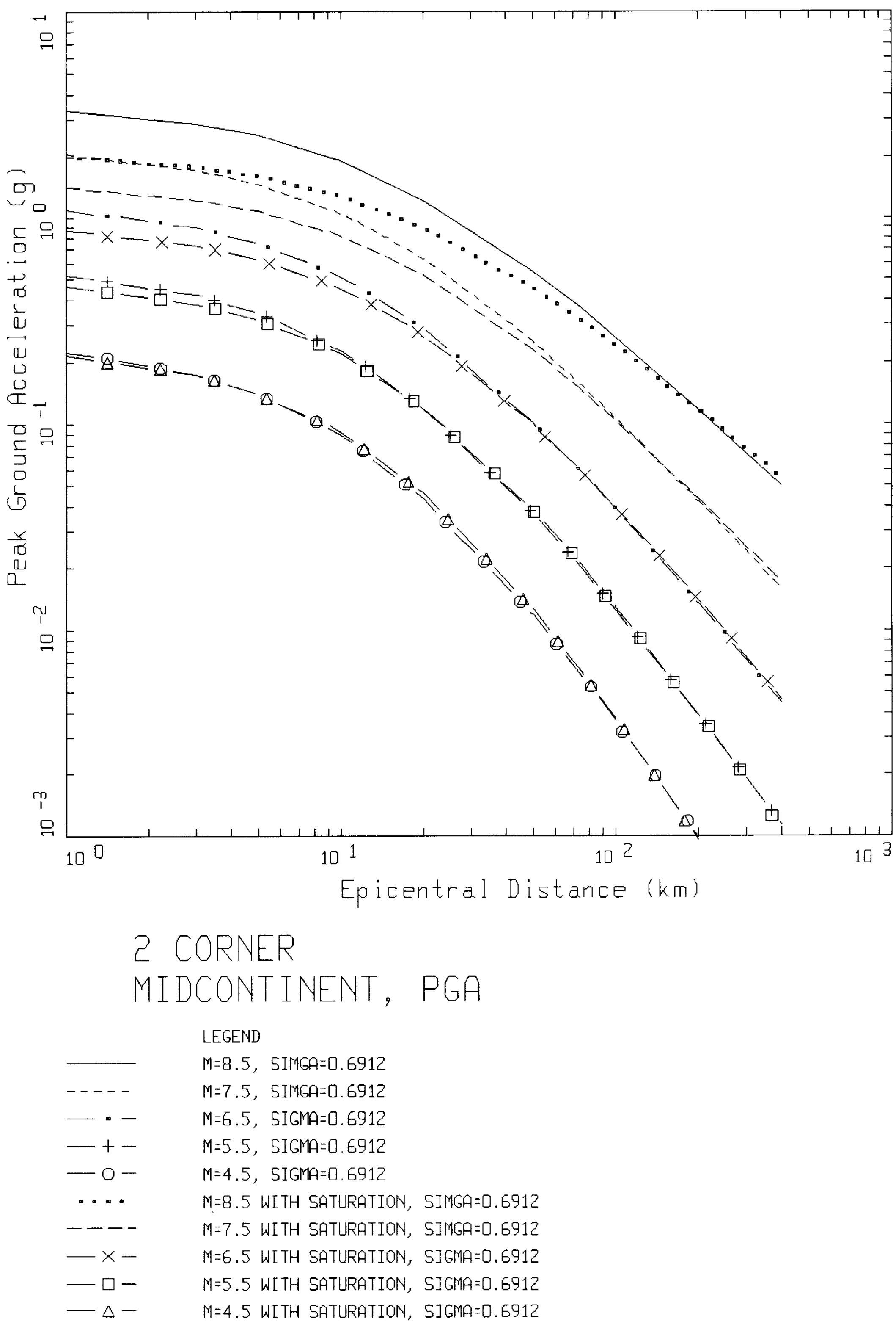

Figure 10. Attenuation of median peak horizontal accelerations at **M** 4.5, 5.5, 6.5, 7.5, and 8.5 for the double corner model, with and without saturation, Midcontinent.

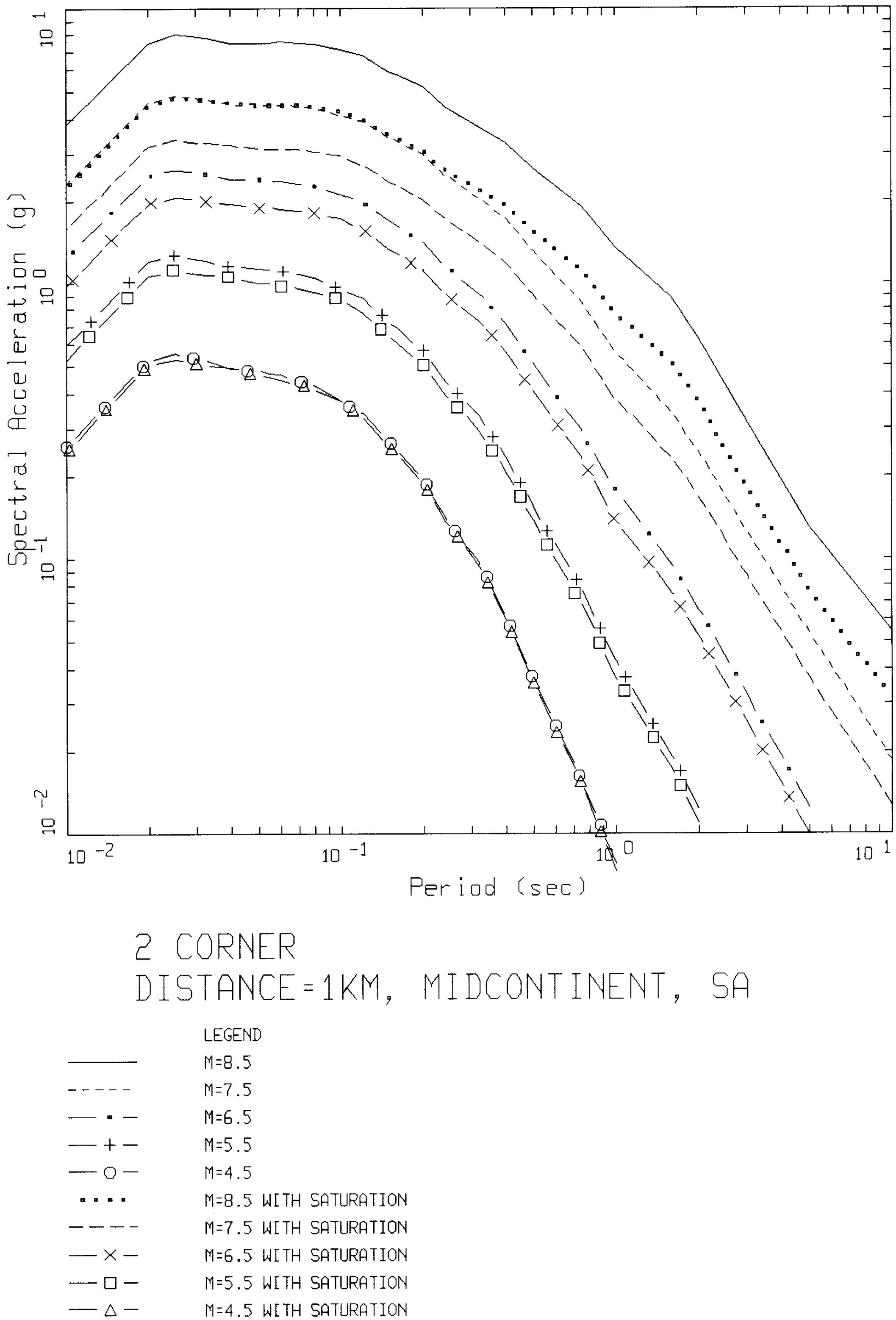

Figure 11. Median response spectra (5% damping) at a distance of 1 km for magnitudes **M** 4.5, 5.5, 6.5, 7.5, and 8.5 for the double corner model, Micontinent.

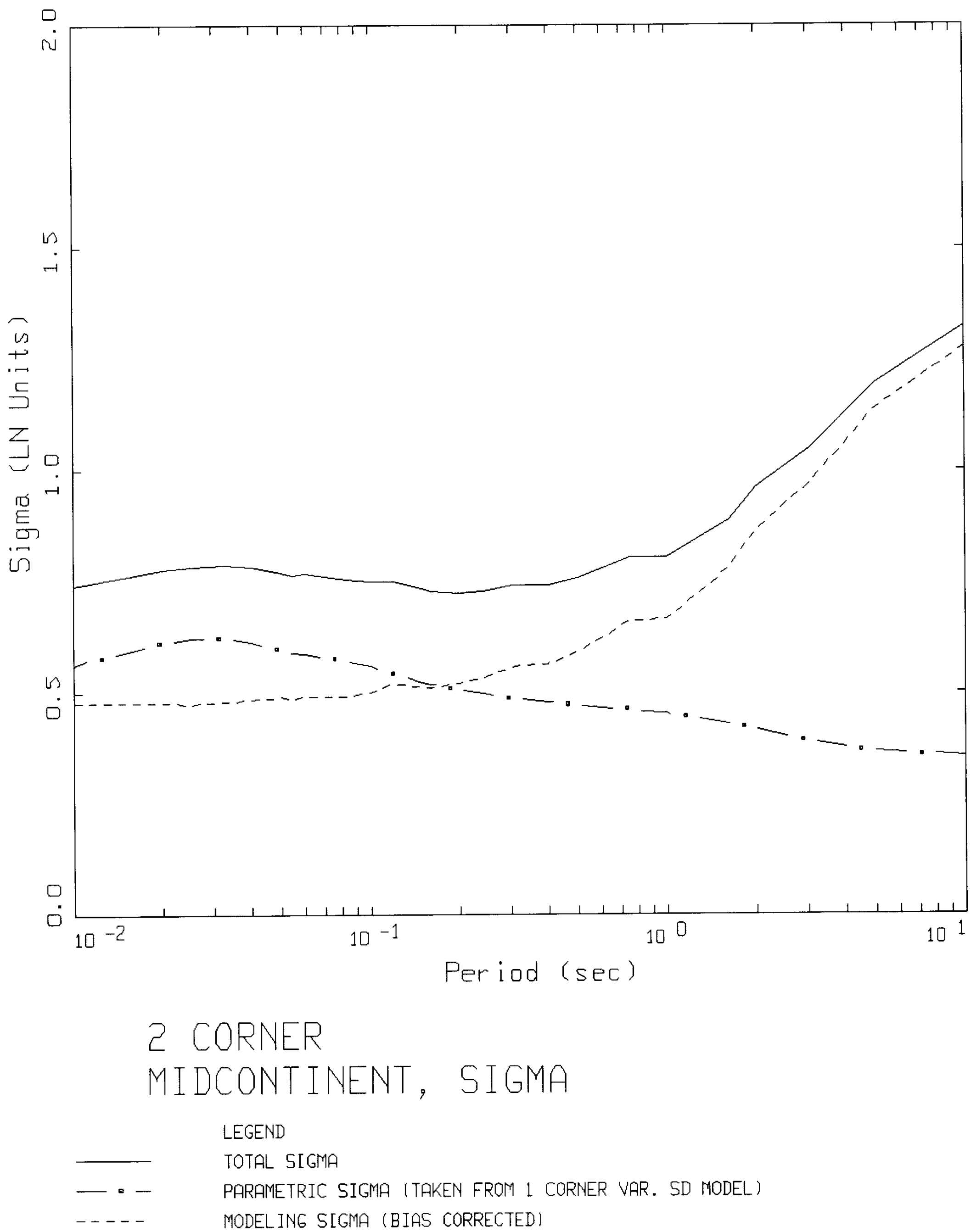

Figure 12a. Estimates of total variability (uncertainty) for the Midcontinent attenuation model. Parametric variability is due to variation of variable stress drop, single corner frequency point-source parameters (Table 2) and fit of regression model (Table 6a). Model variability is from validation exercises with 16 earthquakes (**M** 5.3 to 7.4) at 500 sites over the fault distance range of 1 to 460 km using the single corner frequency model (Appendix B).

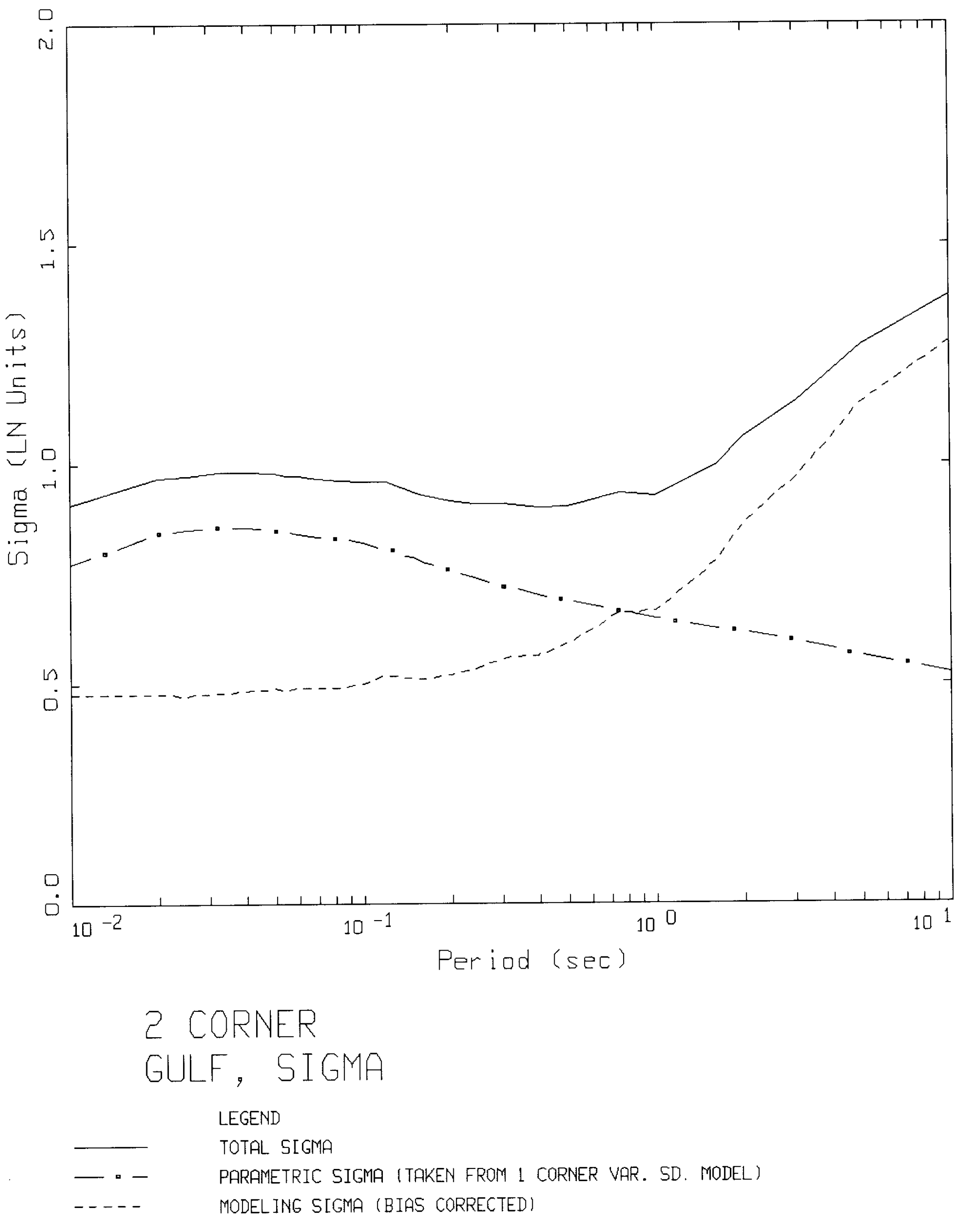

Figure 12b. Estimates of total variability (uncertainty) for the Gulf Coast attenuation model. Parametric variability is due to variation of variable stress drop, single corner frequency point-source parameters (Table 2) and fit of regression model (Table 6b). Model variability is from validation exercises with 16 earthquakes (**M** 5.3 to 7.4) at 500 sites over the fault distance range of 1 to 460 km using the single corner frequency model (Appendix B).

APPENDIX A

STOCHASTIC GROUND MOTION MODEL DESCRIPTION

Background

In the context of strong ground motion, the term "stochastic" can be a fearful concept to some and may be interpreted to represent a fundamentally incorrect or inappropriate model (albeit the many examples demonstrating that it works well; Boore, 1983, 1986). To allay any initial misgivings, a brief discussion seems prudent to explain the term stochastic in the stochastic ground motion model.

The stochastic point-source model may be termed a spectral model in that it fundamentally describes the Fourier amplitude spectral density at the surface of a half-space (Hanks and McGuire, 1981). The model uses a Brune (1970, 1971) omega-square description of the earthquake source Fourier amplitude spectral density. This model is easily the most widely used and qualitatively validated source description available. Seismic sources ranging from **M** = -6 (hydrofracture) to **M** = 8 have been interpreted in terms of the Brune omega-square model in dozens of papers over the last 30 years. The general conclusion is that it provides a reasonable and consistent representation of crustal sources, particularly for tectonically active regions such as plate margins. A unique phase spectrum can be associated with the Brune source amplitude spectrum to produce a complex spectrum which can be propagated using either exact or approximate (1-2- or 3-D) wave propagation algorithms to produce single or multiple component time histories. In this context the model is not stochastic, it is decidedly deterministic and as exact and rigorous as one chooses. A two-dimensional array of such point-sources may be appropriately located on a fault surface (area) and fired with suitable delays to simulate rupture propagation on an extended rupture plane. As with the single point-source, any degree of rigor may be used in the wave propagation algorithm to produce multiple component or average horizontal component time histories. The result is a kinematic[1] finite-source model which has as its basis a source time history defined as a Brune pulse whose Fourier amplitude spectrum follows an omega-square model. This finite-fault model would be very similar to that used in published inversions for slip models if the 1-D propagation were treated using a reflectivity algorithm (Aki and Richards, 1980). This algorithm is a complete solution to the wave equation from static offsets (near-field terms) to an arbitrarily selected high frequency cutoff (generally 1-2 Hz).

Alternatively, to model the wave propagation more accurately, recordings of small earthquakes at the site of interest and with source locations distributed along the fault of interest may be used as empirical Green functions (Hartzell, 1978). To model the design earthquake, the empirical Green functions are delayed and summed in a manner to simulate rupture propagation (Hartzell, 1978). Provided a sufficient number of small

[1]Kinematic source model is one whose slip (displacement) is defined (imposed) while in a dynamic source model forces (stress) are defined (see Aki and Richards 1980 for a complete description).

earthquakes are recorded at the site of interest, the source locations adequately cover the expected rupture surface, and sufficient low frequency energy is present in the Green functions, this would be the most appropriate procedure to use if nonlinear site response is not an issue. With this approach the wave propagation is, in principle, exactly represented from each Green function source to the site. However, nonlinear site response is not treated unless Green function motions are recorded at a nearby rock outcrop with dynamic material properties similar to the rock underlying the soils at the site or recordings are made at depth within the site soil column. These motions may then be used as input to either total or effective stress site response codes to model nonlinear effects. Important issues associated with this approach include the availability of an appropriate nearby (1 to 2 km) rock outcrop and, for the downhole recordings, the necessity to remove all downgoing energy from the at-depth soil recordings. The downgoing energy must be removed from the downhole Green functions (recordings) prior to generating the control motions (summing) as only the upgoing wavefields are used as input to the nonlinear site response analyses. Removal of the downgoing energy from each recording requires multiple site response analyses which introduce uncertainty into the Green functions due to uncertainty in dynamic material properties and the numerical site response model used to separate the upgoing and downgoing wavefields.

To alleviate these difficulties one can use recordings well distributed in azimuth at close distances to a small earthquake and correct the recordings back to the source by removing wave propagation effects using a simple approximation (say 1/R plus a constant for crustal amplification and radiation pattern), to obtain an empirical source function. This source function can be used to replace the Brune pulse to introduce some natural (although source, path, and site specific) variation into the dislocation time history. If this is coupled to an approximate wave propagation algorithm (asymptotic ray theory) which includes the direct rays and those which have undergone a single reflection, the result is the empirical source function method (EPRI, 1993). Combining the reflectivity propagation (which is generally limited to frequencies ≤ 1-2 Hz due to computational demands) with the empirical source function approach (appropriate for frequencies ≥ 1 Hz; EPRI, 1993) results in a broad band simulation procedure which is strictly deterministic at low frequencies (where an analytical source function is used) and incorporates some natural variation at high frequencies through the use of an empirical source function (Sommerville et al., 1995).

All of these techniques are fundamentally similar, well founded in seismic source and wave propagation physics, and importantly, they are all approximate. Simply put, all models are wrong (approximate) and the single essential element in selecting a model is to incorporate the appropriate degree of rigor, commensurate with uncertainties and variabilities in crustal structure and site effects, through extensive validation exercises. It is generally felt that more complicated models produce more accurate results, however, the implications of more sophisticated models with the increased number of parameters which must be specified is often overlooked. This is not too serious a consequence in modeling past earthquakes since a reasonable range in parameter space can be explored to give the "best" results. However for future predictions, this increased rigor may carry undesirable baggage in increased parametric variability (Roblee et al., 1996). The effects of lack of knowledge (epistemic uncertainty; EPRI, 1993) regarding parameter values for future occurrences results in uncertainty or variability in ground motion predictions. It may easily be the case that a very simple model, such as the point-source model can have comparable, or even smaller, total variability (modeling plus parametric) than a much more rigorous model with an increased number of parameters (EPRI, 1993). What is desired in a model is sufficient sophistication such that it captures the dominant and stable features of source, distance, and site dependencies observed in strong ground motions. It is these considerations which led to the development of the stochastic point- and finite-source models and, in part, leads to the stochastic element of the models.

The stochastic nature of the point- and finite-source RVT models is simply the assumption made about the character of ground motion time histories that permits stable estimates of peak parameters (e.g. acceleration, velocity, strain, stress, oscillator response) to be made without computing detailed time histories (Hanks and McGuire, 1981; Boore, 1983). This process uses random vibration theory to relate a time domain peak value to the time history root-mean-square (RMS) value (Boore, 1983). The assumption of the character of the time history for this process to strictly apply is that it be normally distributed random noise and stationary (its statistics do not change with time) over its duration. A visual examination of any time history quickly reveals that this is clearly not the case: time histories (acceleration, velocity, stress, strain, oscillator) start, build up, and then diminish with time. However poor the assumption of stationary Gaussian noise may appear, the net result is that the assumption is weak enough to permit the approach to work surprisingly well, as numerous comparisons with recorded motions and both qualitative and quantative validations have shown (Hanks and McGuire, 1981; Boore, 1983, 1986; McGuire et al., 1984; Boore and Atkinson, 1987; Silva and Lee, 1987; Toro and McGuire, 1987; Silva et al., 1990; EPRI, 1993; Schneider et al., 1993; Silva and Darragh, 1995; Silva et al., 1997). Corrections to RVT are available to accommodate different distributions as well as non-stationarity and are usually applied to the estimation of peak oscillator response in the calculated response spectra (Boore and Joyner, 1984; Toro, 1985).

Point-source Model

The conventional stochastic ground motion model uses an ω-square source model (Brune, 1970, 1971) with a single corner frequency and a constant stress drop (Boore, 1983; Atkinson, 1984). Random vibration theory is used to relate RMS (root-mean-square) values to peak values of acceleration (Boore, 1983), and oscillator response (Boore and Joyner, 1984; Toro, 1985; Silva and Lee, 1987) computed from the power spectra to expected peak time domain values (Boore, 1983).

The shape of the acceleration spectral density, a(f), is given by

$$a(f) = C \frac{f^2}{1+\left(\frac{f}{f_0}\right)^2} \frac{MSUB0}{R} P(f)\, A(f)\, e^{-\frac{\pi f R}{\beta_0 Q(f)}} \qquad \text{(A-1)}$$

where

C $= (\frac{1}{\rho_0 \beta_0^3}) \bullet (2) \bullet (0.55) \bullet (\frac{1}{\sqrt{2}}) \bullet \pi.$

M_0 = seismic moment,
R = hypocentral distance,
β_0 = shear-wave velocity at the source,
ρ_0 = density at the source
Q(f) = frequency dependent quality factor (crustal damping),
A(f) = crustal amplification,
P(f) = high-frequency truncation filter,
f_o = source corner frequency.

C is a constant which contains source region density (ρ_0) and shear-wave velocity terms and accounts for the free-surface effect (factor of 2), the source radiation pattern averaged over a sphere (0.55) (Boore, 1986), and the partition of energy into two horizontal components ($1/\sqrt{2}$).

Source scaling is provided by specifying two independent parameters, the seismic moment (M_0) and the high-frequency stress parameter or stress drop ($\Delta\sigma$). The seismic moment is related to magnitude through the definition of moment magnitude **M** by the relation

$\log M_0 = 1.5\, \mathbf{M} + 16.05$ (Hanks and Kanamori, 1979) (A - 2).

The stress drop ($\Delta\sigma$) relates the corner frequency f_0 to M_0 through the relation

$f_0 = \beta_0 (\Delta\sigma / 8.44\, M_0)^{1/3}$ (Brune; 1970, 1971) (A - 3).

The stress drop is sometimes referred to as the high frequency stress parameter (Boore, 1983) (or simply the stress parameter) since it directly scales the Fourier amplitude spectrum for frequencies above the corner frequency (Silva, 1991; Silva and Darragh 1995). High (> 1 Hz) frequency model predictions are then very sensitive to this parameter (Silva, 1991; EPRI, 1993) and the interpretation of it being a stress drop or simply a scaling parameter depends upon how well real earthquake sources (on average) obey the omega-square scaling (Equation A-3) and how well they are fit by the single-corner-frequency model (Atkinson and Silva, 1997). If earthquakes truly have single-corner-frequency omega-square sources, the stress drop in Equation A-3 is a physical parameter and its values have a physical interpretation of the forces (stresses) accelerating the relative slip across the rupture surface. High stress drop sources are due to a smaller source (fault) area (for the same **M**) than low stress drop sources (Brune, 1970). Otherwise, it simply a high frequency ($f > f_o$) scaling or fitting parameter.

APPENDIX A

The spectral shape of the single-corner-frequency ω-square source model is then described by the two free parameters M_0 and $\Delta\sigma$. The corner frequency increases with the shear-wave velocity and with increasing stress drop, both of which may be region dependent.

The crustal amplification accounts for the increase in wave amplitude as seismic energy travels through lower- velocity crustal materials from the source to the surface. The amplification depends on average crustal and near surface shear-wave velocity and density (Boore, 1986).

The P(f) filter is used in an attempt to model the observation that acceleration spectral density appears to fall off rapidly beyond some region- or site-dependent maximum frequency (Hanks, 1982; Silva and Darragh, 1995). This observed phenomenon truncates the high frequency portion of the spectrum and is responsible for the band-limited nature of the stochastic model. The band limits are the source corner frequency at low frequency and the high frequency spectral attenuation. This spectral fall-off at high frequency has been attributed to near-site attenuation (Hanks, 1982; Anderson and Hough, 1984) or to source processes (Papageorgiou and Aki, 1983) or perhaps to both effects. In the Anderson and Hough (1984) attenuation model, adopted here, the form of the P(f) filter is taken as

$$P(f, r) = e^{-\pi\kappa(r)f} \qquad \text{(A-4).}$$

Kappa (r) (κ(r) in Equation A-4) is a site and distance dependent parameter that represents the effect of intrinsic attenuation upon the wavefield as it propagates through the crust from source to receiver. Kappa (r) depends on epicentral distance (r) and on both the shear-wave velocity (β) and quality factor (Q_S) averaged over a depth of H beneath the site (Hough et al., 1988). At zero epicentral distance kappa (κ) is given by

$$\kappa(0) = \frac{H}{\bar{\beta}\,\bar{Q}_S} \qquad \text{(A-5),}$$

and is referred to as κ.

The bar in Equation A-5 represents an average of these quantities over a depth H. The value of kappa at zero epicentral distance is attributed to attenuation in the very shallow crust directly below the site (Hough and Anderson, 1988; Silva and Darragh, 1995). The intrinsic attenuation along this part of the path is not thought to be frequency dependent and is modeled as a frequency independent, but site and crustal region dependent, constant value of kappa (Hough et al., 1988; Rovelli et al., 1988). This zero epicentral distance kappa is the model implemented in this study.

The crustal path attenuation from the source to just below the site is modeled with the frequency- dependent quality factor Q(f). Thus the distance component of the original κ(r) (Equation A-4) is accommodated by Q(f) and R in the last term of Equation A-1:

$$\kappa(r) = \frac{H}{\bar{\beta}\,\bar{Q}_S} + \frac{R}{\beta_0\, Q(f)} \qquad \text{(A-6).}$$

The Fourier amplitude spectrum, a(f), given by Equation A-1 represents the stochastic ground motion model employing a Brune source spectrum that is characterized by a single corner frequency. It is a point source and models direct shear-waves in a homogeneous half-space (with effects of a velocity gradient captured by the A(f) filter, Equation A-1). For horizontal motions, vertically propagating shear-waves are assumed. Validations using incident inclined SH-waves accompanied with raytracing to find appropriate incidence angles leaving the source showed little reduction in uncertainty compared to results using vertically propagating shear-waves. For vertical motions, P/SV propagators are used coupled with raytracing to model incident inclined plane waves (EPRI, 1993). This approach has been validated with recordings from the 1989 **M** 6.9 Loma Prieta earthquake (EPRI, 1993).

Equation A-1 represents an elegant ground motion model that accommodates source and wave propagation physics as well as propagation path and site effects with an attractive simplicity. The model is appropriate for an engineering characterization of ground motion since it captures the general features of strong ground motion in terms of peak acceleration and spectral composition with a minimum of free parameters (Boore, 1983; McGuire et al., 1984; Boore, 1986; Silva and Green, 1988; Silva et al., 1988; Schneider et al., 1993; Silva and Darragh, 1995). An additional important aspect of the stochastic model employing a simple source description is that the region-dependent parameters may be evaluated by observations of small local or regional earthquakes. Region-specific seismic hazard evaluations can then be made for areas with sparse strong motion data with relatively simple spectral analyses of weak motion (Silva, 1992).

In order to compute peak time-domain values, i.e. peak acceleration and oscillator response, RVT is used to relate RMS computations to peak value estimates. Boore (1983) and Boore and Joyner (1984) present an excellent development of the RVT methodology as applied to the stochastic ground motion model. The procedure involves computing the RMS value by integrating the power spectrum from zero frequency to the Nyquist frequency and applying Parsevall's relation. Extreme value theory is then used to estimate the expected ratio of the peak value to the RMS value of a specified duration of the stochastic time history. The duration is taken as the inverse of the source corner frequency (Boore, 1983).

Factors that affect strong ground motions such as surface topography, finite and propagating seismic sources, laterally varying near-surface velocity and Q gradients, and random inhomogeneities along the propagation path are not included in the model. While some or all of these factors are generally present in any observation of ground motion and may exert controlling influences in some cases, the simple stochastic point-source model appears to be robust in predicting median or average properties of ground motion (Boore

1983, 1986; Schneider et al., 1993; Silva and Stark, 1993; Silva et al., 1997). The motivation for comprehensive validation exercises involving many earthquakes with a wide range in magnitudes, rupture distances, and site conditions is to capture unmodeled effects. The unmodeled effects which are random are captured in estimates of model uncertainty and those which are pervasive are captured in the estimates of model bias (see later sections). The combination of realistic, albeit simple, model physics with comprehensive validation exercises makes the stochastic point source ground motion model a powerful predictive and interpretative tool for engineering characterization of strong ground motion.

Finite-source Model Ground Motion Model

In the near-source region of large earthquakes, aspects of a finite-source including rupture propagation, directivity source-receiver geometry, and saturation of high-frequency ($\geq$ 1 Hz) motions with increasing magnitude can be significant and may be incorporated into strong ground motion predictions. To accommodate these effects, a methodology that combines the aspects of finite-earthquake-source modeling techniques (Hartzell, 1978; Irikura 1983) with the stochastic point-source ground motion model has been developed to produce response spectra as well as time histories appropriate for engineering design (Silva et al., 1990; Silva and Stark, 1993; Schneider et al., 1993). The approach is very similar to the empirical Green function methodology introduced by Hartzell (1978) and Irikura (1983). In this case however, the stochastic point-source is substituted for the empirical Green function and peak amplitudes; PGA, PGV, and response spectra (when time histories are not produced) are estimated using random process theory.

Use of the stochastic point-source as a Green function is motivated by its demonstrated success in modeling ground motions in general and strong ground motions in particular (Boore, 1983, 1986; Silva and Stark, 1993; Schneider et al., 1993; Silva and Darragh, 1995) and the desire to have a model that is truly site- and region-specific. The model can accommodate a region specific Q(f), Green function sources of arbitrary moment or stress drop, and site specific kappa values and soil profiles. The necessity for having available regional and site specific recordings distributed over the rupture surface of a future earthquake or modifying possibly inappropriate empirical Green functions is eliminated.

For the finite-source characterization, a rectangular fault is discretized into NS subfaults of moment M_0^S. The empirical relationship

$$\log (A) = \mathbf{M} - 4.0, \quad A \text{ in km}^2 \qquad \text{(A-7)}$$

is used to assign areas to both the target earthquake (if its rupture surface is not fixed) as well as to the subfaults. This relation results from regressing log area on **M** using the data of Wells and Coppersmith (1994). In the regression, the coefficient on **M** is set to unity which implies a constant static stress drop of about 30 bars (Equation A-9). This is consistent with the general observation of a constant static stress drop for earthquakes based on aftershock locations (Wells and Coppersmith 1994). The static stress drop, defined by Equation A-10, is related to the average slip over the rupture surface as well as rupture area. It is theoretically identical to the stress drop in Equation A-3 which defines the omega-square source corner frequency assuming the rupture surface is a circular crack model (Brune, 1970; 1971). The stress drop determined by the source corner frequency (or source duration) is usually estimated through the Fourier amplitude spectral density while the static stress drop uses the moment magnitude and an estimate of the rupture area. The two estimates for the same earthquake seldom yield the same values with the static generally being the smaller. In a recent study (Silva et al., 1997), the average stress drop based on Fourier amplitude spectra determined from an empirical attenuation relation (Abrahamson and Silva, 1997) is about 70 bars while the average static stress drop for the crustal earthquakes studied by Wells and Coppersmith (1994) is about 30 bars. These results reflect a general factor of about 2 on average between the two values. These large differences may simply be the result of using an inappropriate estimate of rupture area as the zone of actual slip is difficult to determine unambiguously. In general however, even for individual earthquakes, the two stress drops scale similarly with high static stress drops (> 30 bars) resulting in large high frequency (> 1 Hz for **M** ≥ 5) ground motions which translates to high corner frequencies (Equation A-3).

The subevent magnitude M_S is generally taken in the range of 5.0-6.5 depending upon the size of the target event. M_S 5.0 is used for crustal earthquakes with **M** in the range of 5.5 to 8.0 and M_S 6.4 is used for large subduction earthquakes with **M** > 7.5. The value of NS is determined as the ratio of the target event area to the subfault area. To constrain the proper moment, the total number of events summed (N) is given by the ratio of the target event moment to the subevent moment. The subevent and target event rise times (duration of slip at a point) are determined by the equation

$$\log \tau = 0.33 \log M_0 - 8.54 \qquad \text{(A-8)}$$

which results from a fit to the rise times used in the finite-fault modeling exercises, (Silva et al., 1997). Slip on each subfault is assumed to continue for a time τ. The ratio of target-to-subevent rise times is given by

$$\frac{\tau}{\tau^s} = 10^{0.5\,(\mathrm{M - MSUPs})} \qquad \text{(A-9)}$$

and determines the number of subevents to sum in each subfault. This approach is generally referred to as the constant-rise-time model and results in variable slip velocity for nonuniform slip distributions. Alternatively, one can assume a constant slip velocity (as do Beresnev and Atkinson, 2002) resulting in a variable-rise-time model for heterogenous slip distributions. This approach was implemented and validations resulted in an overall “best” average slip velocity of about 70 cm/sec, with no significant improvement over a magnitude dependent rise time (Equation A-8). The feature is retained as an option in the simulation code.

Recent modeling of the Landers (Wald and Heaton, 1994), Kobe (Wald, 1996) and Northridge (Hartzell et al. 1996) earthquakes suggests that a mixture of both constant rise time and constant slip velocity may be present. Longer rise times seem to be associated with areas of larger slip with the ratio of slip-to-rise time (slip velocity) being depth dependent. Lower slip velocities (longer rise times) are associated with shallow slip resulting in relatively less short period seismic radiation. This result may explain the general observation that shallow slip is largely aseismic. The significant contributions to strong ground motions appear to originate at depths exceeding about 4 km (Campbell, 1993; Boore et al., 1994) as the fictitious depth term in empirical attenuation relation (Abrahamson and Silva, 1997; Boore et al., 1997). Finite-fault models generally predict unrealistically large strong ground motions for large shallow (near surface) slip using rise times or slip velocities associated with deeper (> 4 km) zones of slip. This is an important and unresolved issue in finite-fault modeling and the general approach is constrain the slip to relatively small values in the top 2 to 4 km. For the composite source model, the approach is to taper the subevent stress drop to zero at the ground surface (Yehua Zeng, personal communication 1999). A more thorough analysis is necessary, ideally using several well validated models, before this issue can be satisfactorily resolved.

To introduce heterogeneity of the earthquake source process into the stochastic finite-fault model, the location of the sub-events within each subfault (Hartzell, 1978) are randomized as well as the subevent rise time ($\sigma_{\ln} = 0.8$). The stress drop of the stochastic point-source Green function is taken as 30 bars, consistent with the static value based on the **M** 5.0 subevent area using the equation

$$\Delta\sigma = \frac{7}{16}\left(\frac{M_e}{R_e^3}\right) \qquad \text{(Brune, 1970, 1971)} \qquad \text{(A-10)}$$

where R_e is the equivalent circular radius of the rectangular sub-event.

Different values of slip are assigned to each subfault as relative weights so that asperities or non-uniform slip can be incorporated into the methodology. For validation exercises, slip models are taken from the literature and are based on inversions of strong motion as well as regional or teleseismic recordings. To produce slip distributions for future earthquakes, random slip models are generated based on a statistical asperity model with parameters calibrated to the published slip distributions. This approach has been validated by comparing the modeling uncertainty and bias estimates for the Loma Prieta and Whittier Narrows earthquakes using motion at each site averaged over several (30) random slip models to the bias and uncertainty estimates using the published slip model. The results show nearly identical bias and uncertainty estimates suggesting that averaging the motions over random slip models produces as accurate a prediction at a site as a single motion computed using the "true" slip model which is determined from inverting actual recordings.

The rupture velocity is taken as depth independent at a value of 0.8 times the shear-wave velocity, generally at the depth of the dominant slip. This value is based on a number of studies of source rupture processes which also suggest that rupture velocity is non-uniform. To capture the effects of non-uniform rupture velocity, a random component is added through the randomized location of the subevents within each subfault. The radiation pattern is computed for each subfault, a random component added, and the RMS applied to the motions computed at the site when modeling an average horizontal component. To model individual horizontal components, the radiation pattern for each subfault is used to scale each subfaults contribution to the final summed motion.

The ground-motion time history at the receiver is computed by summing the contributions from each subfault associated with the closest Green function, transforming to the frequency domain, and convolving with the appropriate Green function spectrum (Equation A-1). The locations of the Green functions are generally taken at center of each subfault for small subfaults or at a maximum separation of about 5 to 10 km for large subfaults. As a final step, the individual contributions associated with each Green function are summed in the frequency domain, multiplied by the RMS radiation pattern, and the resultant power spectrum at the site is computed. The appropriate duration used in the RVT computations for PGA, PGV, and oscillator response is computed by transforming the summed Fourier spectrum into the time domain and computing the 5 to 75% Arias intensity (Ou and Herrmann, 1990).

As with the point-source model, crustal response effects are accommodated through the amplification factor (A(f)) or by using vertically propagating shear waves through a vertically heterogenous crustal structure. Propagation path damping, through the Q(f) model, is incorporated from each fault element to the site. Near-surface crustal damping is incorporated through the kappa operator (Equation A-1). To model crustal propagation path effects, the raytracing method of Ou and Herrmann (1990) is applied from each subfault to the site.

Time histories may be computed in the process as well by simply adding a phase spectrum appropriate to the subevent earthquake. The phase spectrum can be extracted from a recording made at close distance to an earthquake of a size comparable to that of the subevent (generally **M** 5.0 to 6.5). Interestingly, the phase spectrum need not be from a recording in the region of interest (Silva et al., 1989). A recording in WNA (Western North America) can effectively be used to simulate motions appropriate to ENA (Eastern North America). Transforming the Fourier spectrum computed at the site into the time domain results in a computed time history which then includes all of the aspects of rupture propagation and source finiteness, as well as region specific propagation path and site effects.

For fixed fault size, mechanism, and moment, the specific source parameters for the finite-fault are slip distribution, location of nucleation point, and site azimuth. The propagation path and site parameters remain identical for both the point- and finite-source models.

Partition and assessment of ground motion variability

APPENDIX A

An essential requirement of any numerical modeling approach, particularly one which is implemented in the process of defining design ground motions, is a quantative assessment of prediction accuracy. A desirable approach to achieving this goal is in a manner which lends itself to characterizing the variability associated with model predictions. For a ground motion model, prediction variability is comprised of two components: modeling variability and parametric variability. Modeling variability is a measure of how well the model works (how accurately it predicts ground motions) when specific parameter values are known. Modeling variability is measured by misfits of model predictions to recorded motions through validation exercises and is due to unaccounted for components in the source, path, and site models (i.e. a point-source cannot model the effects of directivity and linear site response cannot accommodate nonlinear effects). Results from a viable range of values for model parameters (i.e., slip distribution, soil profile, G/G_{max} and hysteretic damping curves, etc). Parametric variability is the sensitivity of a model to a viable range of values for model parameters. The total variability, modeling plus parametric, represents the variance associated with the ground motion prediction and, because it is a necessary component in estimating fractile levels, may be regarded as important as median predictions.

Both the modeling and parametric variabilities may have components of randomness and uncertainty. Table A.1 summarizes the four components of total variability in the context of ground motion predictions. Uncertainty is that portion of both modeling and parametric variability which, in principle, can be reduced as additional information becomes available, whereas randomness represents the intrinsic or irreducible component of variability for a given model or parameter. Randomness is that component of variability which is intrinsic or irreducible <u>for a given model.</u> The uncertainty component reflects a lack of knowledge and may be reduced as more data are analyzed. For example, in the point-source model, stress drop is generally taken to be independent of source mechanism as well as tectonic region and is found to have a standard error of about 0.7 (natural log) for the CEUS (EPRI, 1993). This variation or uncertainty plus randomness in $\Delta\sigma$ results in a variability in ground motion predictions for future earthquakes. If, for example, it is found that normal faulting earthquakes have generally lower stress drops than strike-slip which are, in turn, lower than reverse mechanism earthquakes, perhaps much of the variability in $\Delta\sigma$ may be reduced. In extensional regimes, where normal faulting earthquakes are most likely to occur, this new information may provide a reduction in variability (uncertainty component) for stress drop, say to 0.3 or 0.4 resulting in less ground motion variation due to a lack of knowledge of the mean or median stress drop. There is, however, a component of this stress drop variability which can <u>never</u> be reduced in the context of the Brune model. This is simply due to the heterogeneity of the earthquake dynamics which is not accounted for in the model and results in the randomness component of parametric variability in stress drop. A more sophisticated model may be able to accommodate or model more accurately source dynamics but, perhaps, at the expense of a larger number of parameters and increased parametric uncertainty (i.e. the finite-fault with slip model and nucleation point as unknown parameters for future earthquakes). That is, more complex models typically seek to reduce modeling randomness by more closely modeling physical phenomena. However, such models often require more comprehensive sets of observed data to constrain additional model parameters, which generally leads to increased parametric variability. If the increased parametric variability is primarily in the form of uncertainty, it is possible to reduce total variability, but only at the additional expense of constraining the additional parameters. Therefore, existing knowledge and/or available resources may limit the ability of more complex models to reduce total variability.

The distinction of randomness and uncertainty is model driven and somewhat arbitrary. The allocation is only important in the context of probabilistic seismic hazard analyses as uncertainty is treated as alternative hypotheses in logic trees while randomness is integrated over in the hazard calculation (Cornell, 1968). For example, the uncertainty component in stress drop may be treated by using an N-point approximation to the stress drop distribution and assigning a branch in a logic tree for each stress drop and associated weight. A reasonable three point approximation to a normal distribution is given by weights of 0.2, 0.6, 0.2 for expected 5%, mean, and 95% values of stress drop respectively. If the distribution of uncertainty in stress drop was such that the 5%, mean, and 95% values were 50, 100, and 200 bars respectively, the stress drop branch on a logic tree would have 50, and 200 bars with weights of 0.2 and 100 bars with a weight of 0.6. The randomness component in stress drop variability would then be formally integrated over in the hazard calculation.

Assessment of Modeling Variability

Modeling variability (uncertainty plus randomness) is usually evaluated by comparing response spectra computed from recordings to predicted spectra and is a direct assessment of model accuracy. The modeling variability is defined as the standard error of the residuals of the log of the average horizontal component (or vertical component) response spectra. The residual is defined as the difference of the logarithms of the observed average 5% damped acceleration response spectra and the predicted response spectra. At each period, the residuals are squared, and summed over the total number of sites for one or all earthquakes modeled. Dividing the resultant sum by the number of sites results in an estimate of the model variance. Any model bias (average offset) that exists may be estimated in the process (Abrahamson et al., 1990; EPRI, 1993) and used to correct (lower) the variance (and to adjust the median as well). In this approach, the modeling variability can be separated into randomness and uncertainty where the bias corrected variability represents randomness and the total variability represents randomness plus uncertainty. The uncertainty is captured in the model bias as this may be reduced in the future by refining the model. The remaining variability (randomness) remains irreducible for this model. In computing the variance and bias estimates only the frequency range between processing filters at each site (minimum of the 2 components) should be used.

Assessment of Parametric Variability

Parametric variability, or the variation in ground motion predictions due to uncertainty and randomness in model parameters is difficult to assess. Formally, it is straight-forward in that a Monte Carlo approach may be used with each parameter randomly sampled about its mean (median) value either individually for sensitivity analyses (Silva, 1992; Roblee et al., 1996) or in combination to estimate the total parametric variability (Silva, 1992; EPRI, 1993). In reality, however, there are two complicating factors.

The first factor involves the specific parameters kept fixed with all earthquakes, paths, and sites when computing the modeling variability. These parameters are then implicitly included in modeling variability provided the data sample a sufficiently wide range in source, path, and site conditions. The parameters which are varied during the assessment of modeling variation should have a degree of uncertainty and randomness associated with them for the next earthquake. Any ground motion prediction should then have a variation reflecting this lack of knowledge and randomness in the free parameters.

An important adjunct to fixed and free parameters is the issue of parameters which may vary but by fixed rules. For example, source rise time (Equation A-8) is magnitude dependent and in the stochastic finite-source model is specified by an empirical relation. In evaluating the modeling variability with different magnitude earthquakes, rise time is varied, but because it follows a strict rule, any variability associated with rise time variation is counted in modeling variability. This is strictly true only if the sample of earthquakes has adequately spanned the space of magnitude, source mechanism, and other factors which may affect rise time. Also, the earthquake to be modeled must be within that validation space. As a result, the validation or assessment of model variation should be done on as large a number of earthquakes of varying sizes and mechanisms as possible.

The second, more obvious factor in assessing parametric variability is a knowledge of the appropriate distributions for the parameters (assuming correct values for median or mean estimates are known). In general, for the stochastic models, median parameter values and uncertainties are based, to the extent possible, on evaluating the parameters derived from previous earthquakes (Silva, 1992; EPRI, 1993).

The parametric variability is site, path, and source dependent and must be evaluated for each modeling application (Roblee et al., 1996). For example, at large source-to-site distances, crustal path damping may control short-period motions. At close distances to a large fault, both the site and finite-source (asperity location and nucleation point) may dominate, and, depending upon site characteristics, the source or site may control different frequency ranges (Silva, 1992; Roblee et al., 1996). Additionally, level of control motion may affect the relative importance of G/G_{max} and hysteretic damping curves.

In combining modeling and parametric variations, independence is assumed (covariance is zero) and the variances are simply added to give the total variability.

$$_{\ln}\sigma^2_T = {}_{\ln}\sigma^2_{\mathbf{M}} + {}_{\ln}\sigma^2_P \quad \text{(A-11)},$$ [2]

[2]Strong ground motions are generally considered to be log normally distributed.

where

$_{ln}\sigma^2_{\mathbf{M}}$ = modeling variation,

$_{ln}\sigma^2_{P}$ = parametric variation.

Validation Of The Point- and Finite-Source Models

In a recent Department of Energy sponsored project (Silva et al., 1997), both the point- and finite-source stochastic models were validated in a systematic and comprehensive manner. In this project, 16 well recorded earthquakes were modeled at about 500 sites. Magnitudes ranged from **M** 5.3 to **M** 7.4 with fault distances from about 1 km out to 218 km for WUS earthquakes and 460 km for CEUS earthquakes. This range in magnitude and distance as well as number of earthquakes and sites results in the most comprehensively validated model currently available to simulate strong ground motions.

For these exercises, regional Q(f) models and point source stress drops were determined through inversions using the strong motion recordings (Silva et al., 1997). Small strain WUS rock and soil kappa values were set to 0.04 sec, the average from the inversions of small strain data. CEUS rock site kappa values were fixed at inversion values, which averaged about 0.02 sec and ranged from 0.004 to 0.06 sec. For the finite source parameters, slip models and nucleation points were taken from the literature (Silva et al., 1997). Point-source depths were taken as the depth of the center of the largest asperity in the slip models while point-source distance used the closest distance to the surface projection of the rupture surface.

A unique aspect of this validation is that rock and soil sites were modeled using generic rock and soil profiles and equivalent-linear site response. Validations done with other simulation procedures typically neglect site conditions as well as nonlinearity resulting in ambiguity in interpretation of the simulated motions.

Point-Source Model

Final model bias and variability estimates for the point-source model are shown in Figure A1. Over all the sites (Figure A1) the bias is slightly positive for frequencies greater than about 10 Hz and is near zero from about 10 Hz to 1 Hz. Below 1 Hz, a stable point-source overprediction is reflected in the negative bias. The analyses are considered reliable down to about 0.3 Hz (3.3 sec) where the point-source shows about a 40% overprediction.

The model variability is low, about 0.5 above about 3 to 4 Hz and increases with decreasing frequency to near 1 at 0.3 Hz. Above 1 Hz, there is little difference between the total variability (uncertainty plus randomness) and randomness (bias corrected variability) reflecting the near zero bias estimates. Below 1 Hz there is considerable uncertainty contributing to the total variability suggesting that the model can be measurably improved as its predictions tend to be consistently high at very low frequencies (≤ 1 Hz). This stable misfit may be interpreted as the presence of a second corner frequency for WNA sources (Atkinson and Silva, 1997).

Finite-Source Model

For the finite-fault, Figure A2 shows the corresponding bias and variability estimates. For all the sites, the finite-source model provides slightly smaller bias estimates and, surprisingly, slightly higher variability for frequencies exceeding about 5 Hz. The low frequency (≤ 1 Hz) point-source overprediction is not present in the finite-source results, indicating that it is giving more accurate predictions than the point-source model over a broad frequency range, from about 0.3 Hz (the lowest frequency of reliable analyses) to the highest frequency of the analyses.

In general, for frequencies of about 1 Hz and above the point-source and finite-source give comparable results: the bias estimates are small (near zero) and the variabilities range from about 0.5 to 0.6. These estimates are low considering the analyses are based on a data set comprised of earthquakes with **M** less than **M** 6.5 (288 of 513 sites) and high frequency ground motion variance decreases with increasing magnitude, particularly above **M** 6.5 (Youngs et al., 1995) Additionally, for the vast majority of sites, generic site conditions were used (inversion kappa values were used for only the Saguenay and Nahanni earthquake analyses, 25 rock sites). As a result, the model variability (mean = 0) contains the total uncertainty and randomness contribution for the site. The parametric variability due to uncertainty and randomness in site parameters: shear-wave velocity, profile depth, G/G_{max} and hysteretic damping curves need not be added to the model variability estimates. It is useful to perform parametric variations to assess site parameter sensitivities on the ground motions, but only source and path damping Q(f) parametric variabilities require assessment on a site specific basis and added to the model variability. The source uncertainty and randomness components include point-source stress drop as well as source depth and finite-source slip model and nucleation point (Silva, 1992).

The general approach taken in these validations is to have few free parameters and accept a relatively large model misfit. This approach relaxes the need to develop appropriate distributions for poorly resolved parameters such as spatially varying rise times and rupture velocity as well as non-planar rupture surfaces (e.g. Landers, Kobe, and Kocaeli earthquakes). An alternative approach is to adjust these suites of parameters, which naturally improves the fits to recorded motions and results in smaller modeling uncertainties. However, unless independent information is available to constrain these parameters for future earthquakes, they <u>must</u> be <u>appropriately</u> counted as parametric variability. This may result in the total variability remaining comparable between the two approaches. This concept parallels the utility of increased model complexity, i.e., simple verses complex models. More complex models may increase an understanding of physical processes but, in the context of predicting motions due to the <u>next</u> earthquake, increased model complexity may not provide more accurate estimates of strong ground motions, again unless independent information is available to constrain potential ranges in some or all of the free parameters.

A summary of fixed and free parameters for the implementation of the stochastic point and finite source models presented here is listed in Table 2.

Empirical Attenuation Model

As an additional assessment of the stochastic models, bias and variability estimates were made over the same earthquakes (except Saguenay since it was not used in the regressions) and sites using a recently develop empirical attenuation relation (Abrahamson and Silva, 1997). For all the sites, the estimates are shown in Figure A3. Interestingly, the point-source overprediction below about 1 Hz is present in the empirical relation perhaps suggesting that this suite of earthquakes possess lower than expected motions in this frequency range as the empirical model does not show this bias over all earthquakes ($\approx$ 50) used in its development. Comparing these results to the point- and finite-source results (Figures A1 and A2) show comparable bias and variability estimates. For future predictions, source and path damping parametric variability must be added to the numerical simulations which will contribute a σ_{ln} of about 0.2 to 0.4, depending upon frequency, source and path conditions, and site location. This will raise the modeling variability from about 0.50 to the range of 0.54 to 0.64, about 10 to 30%. These values are still comparable to the variability of the empirical relation indicating that the point- and finite-source numerical models perform about as well as a recently developed empirical attenuation relation for the validation earthquakes and sites.

These results are very encouraging and provide an additional qualitative validation of the point- and finite-source models. Paranthetically this approach provides a rational basis for evaluating empirical attenuation models.

APPENDIX A

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Table A.1

CONTRIBUTIONS TO TOTAL VARIABILITY
IN GROUND MOTION MODELS

	Modeling Variability	Parametric Variability
Uncertainty *(also Epistemic Uncertainty)*	Modeling Uncertainty: Variability in predicted motions resulting from particular model assumptions, simplifications and/or fixed parameter values. *Can be reduced by adjusting or "calibrating" model to better fit observed earthquake response.*	Parametric Uncertainty: Variability in predicted motions resulting from incomplete data needed to characterize parameters. *Can be reduced by collection of additional information which better constrains parameters*
Randomness *(also Aleatory Uncertainty)*	Modeling Randomness: Variability in predicted motions resulting from discrepancies between model and actual complex physical processes. *Cannot be reduced for a given model form.*	Parametric Randomness: Variability in predicted motions resulting from inherent randomness of parameter values. *Cannot be reduced a priori*[***] *by collection of additional information.*

[***]Some parameters (e.g. source characteristics) may be well defined after an earthquakes.

Table A.2

FIXED AND FREE PARAMETERS

Fixed Parameters

Regional Curstal Model
Rock and Soil Generic Profiles
Kappa
G/Gmax and Hysteric Damping Curves
Finite Source Rise Time
Finite Source Rupture Velocity

Free Parameters

Regional Q(f) Model
Point Source Stress Drop and Depth
Finite Source Slip Model and Nucleation Point

APPENDIX A

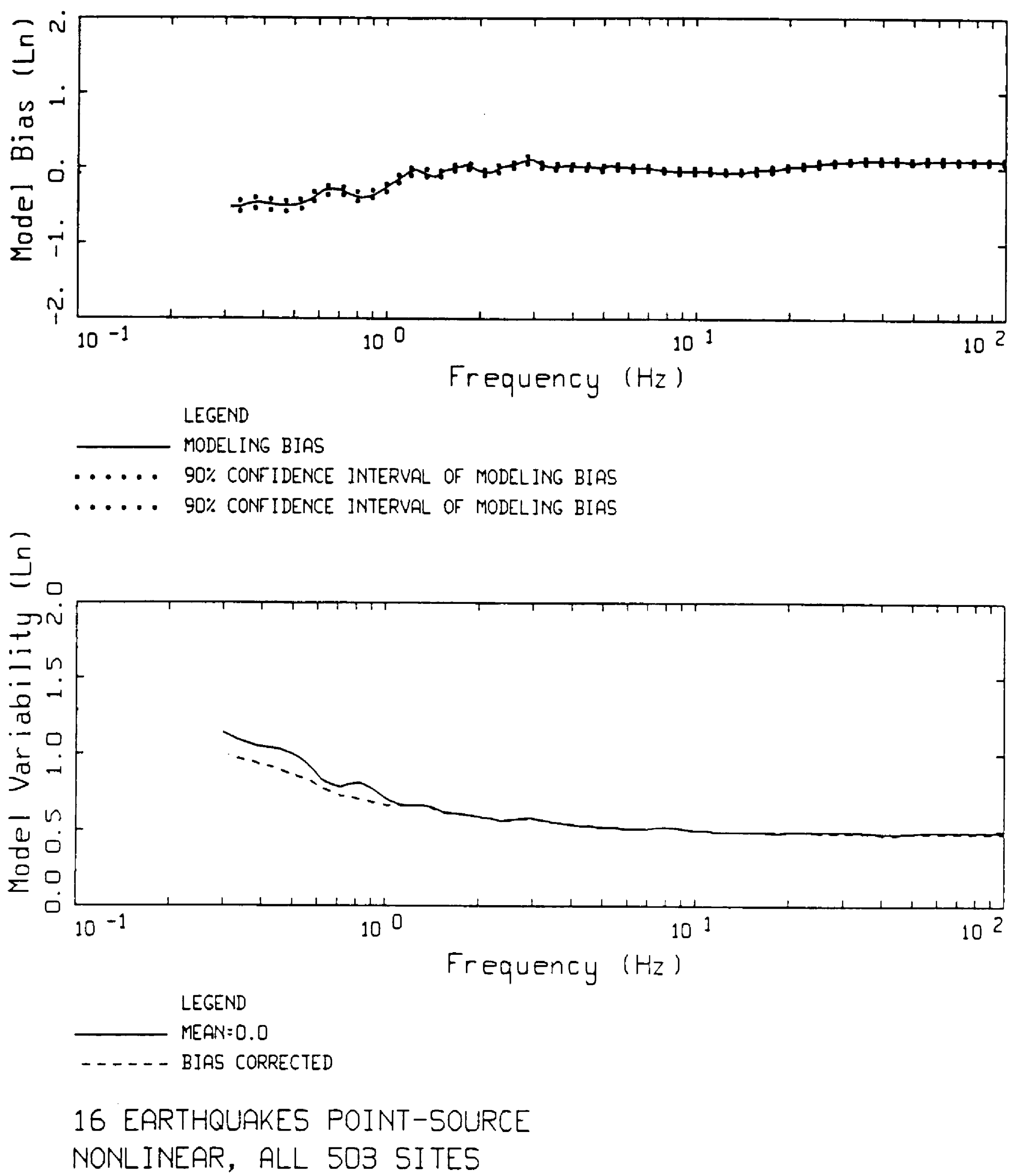

Figure A1. Model bias and variability estimates for all earthquakes computed over all 503 sites for the point-source model.

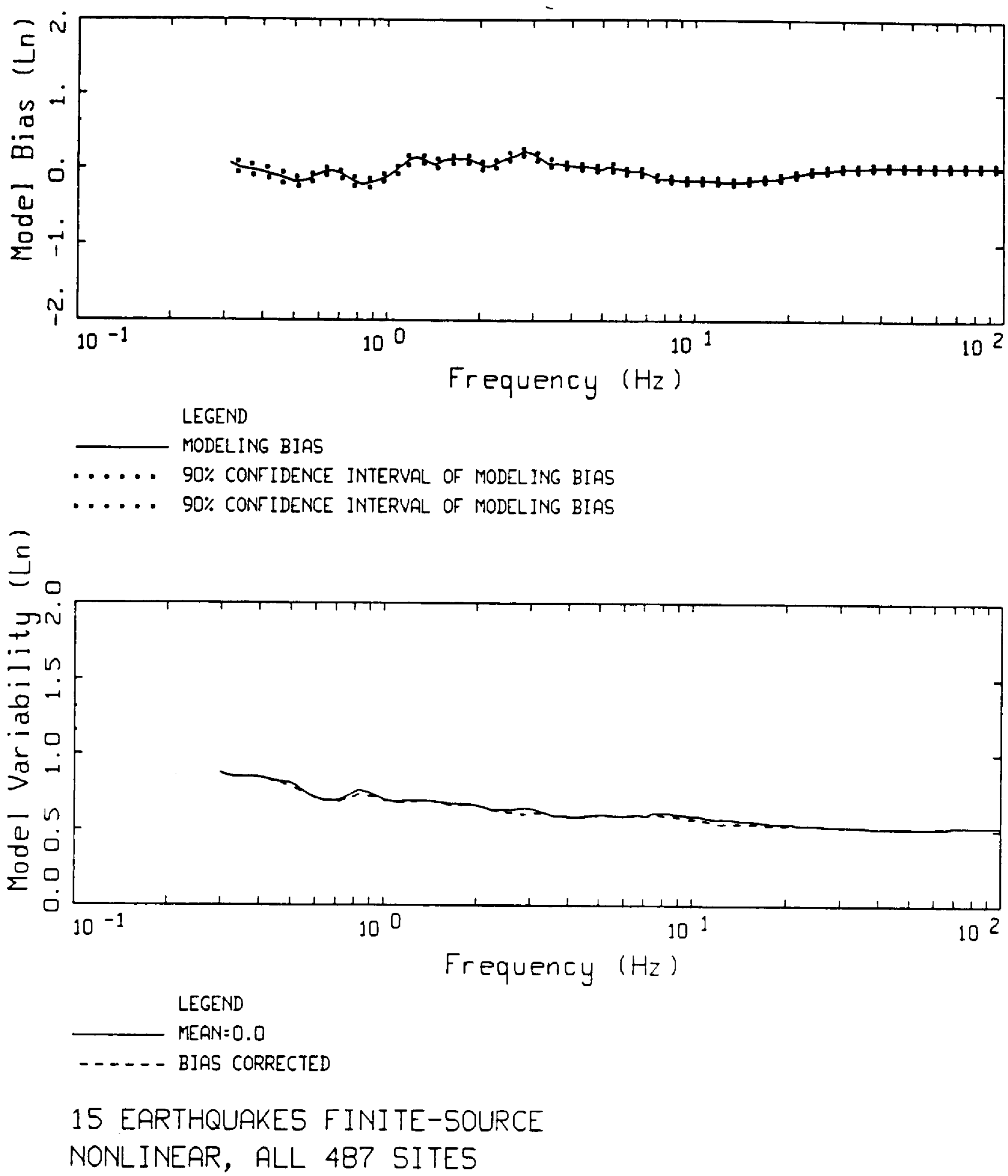

Figure A2. Model bias and variability estimates for all earthquakes computed over all 487 sites for the finite-source model.

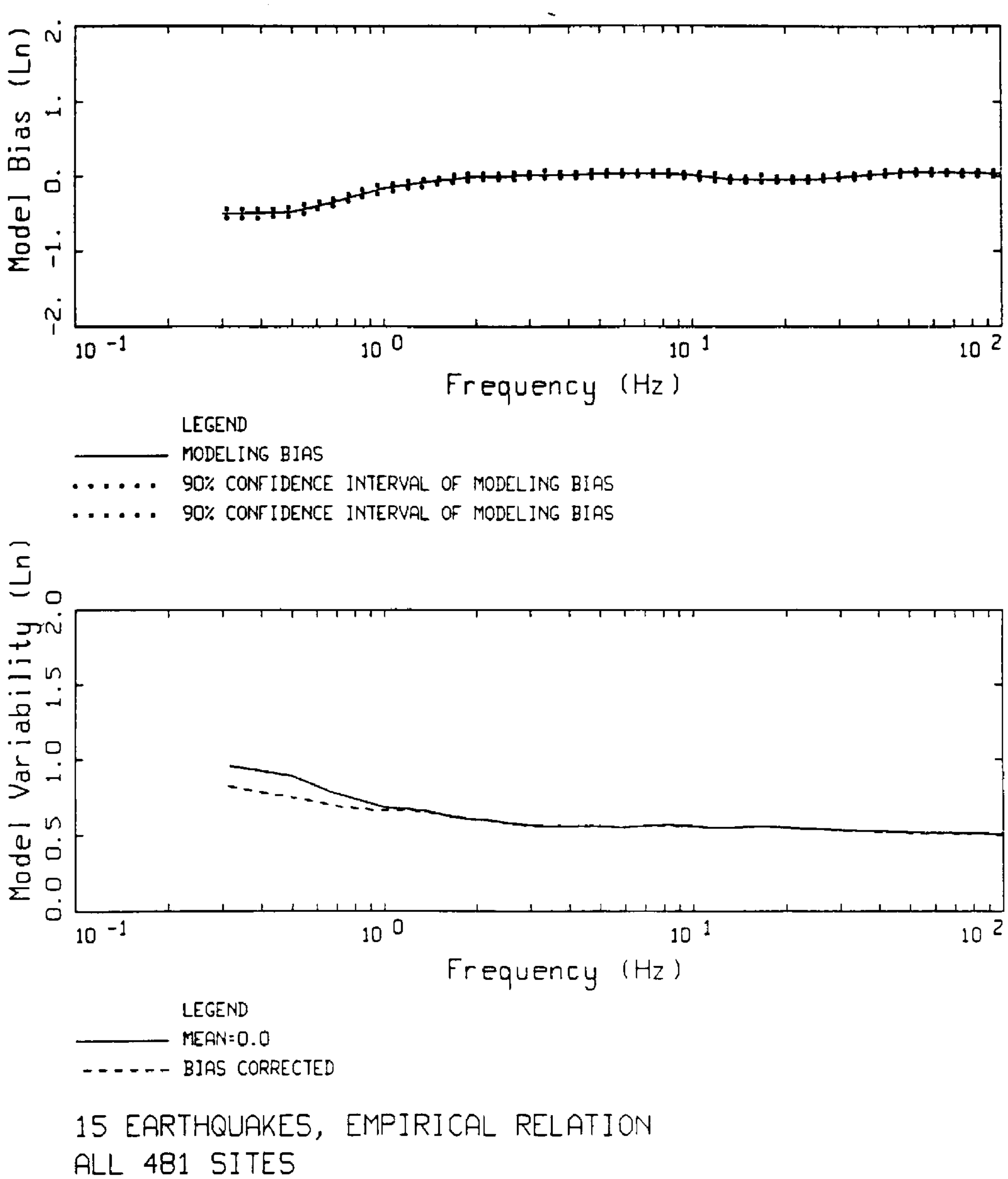

Figure A3. Model bias and variability estimates for all earthquakes computed over all 481 sites for the empirical model.

APPENDIX B

SITE RESPONSE ANALYSIS METHOD

Development of Site Specific Soil Motions

The conventional approach to estimating the effects of site-specific site conditions on strong ground motions involves development of a set (1, 2, or 3 component) of time histories compatible with the specified outcrop response spectra to serve as control (or input) motions. The control motions are then used to drive a nonlinear computational formulation to transmit the motions through the profile. Simplified analyses generally assume vertically propagating shear-waves for horizontal components and vertically propagating compression-waves for vertical motions. These are termed one-dimensional site response analyses.

Equivalent-Linear Computational Scheme

The computational scheme which has been most widely employed to evaluate one-dimensional site response assumes vertically-propagating plane shear-waves. Departures of soil response from a linear constitutive relation are treated in an approximate manner through the use of the equivalent-linear approach.

The equivalent-linear approach, in its present form, was introduced by Seed and Idriss (1970). This scheme is a particular application of the general equivalent-linear theory developed by Iwan (1967). Basically, the approach is to approximate a second order nonlinear equation, over a limited range of its variables, by a linear equation. Formally this is done in such a way that the average of the difference between the two systems is minimized. This was done in an ad-hoc manner for ground response modeling by defining an effective strain which is assumed to exist for the duration of the excitation. This value is usually taken as 65% of the peak time-domain strain calculated at the midpoint of each layer, using a linear analysis. Modulus reduction and hysteretic damping curves are then used to define new parameters for each layer based on the effective strain computations. The linear response calculation is repeated, new effective strains evaluated, and iterations performed until the changes in parameters are below some tolerance level. Generally a few iterations are sufficient to achieve a strain-compatible linear solution.

This stepwise analysis procedure was formalized into a one-dimensional, vertically propagating shear-wave code called SHAKE (Schnabel et al., 1972). Subsequently, this code has easily become the most widely used analysis package for one-dimensional site response calculations.

The advantages of the equivalent-linear approach are that parameterization of complex nonlinear soil models is avoided and the mathematical simplicity of a linear analysis is preserved. A truly nonlinear approach requires the specification of the shapes of hysteresis curves and their cyclic dependencies through an increased number of material parameters. In the equivalent-linear methodology the soil data are utilized directly and, because at each iteration the problem is linear and the material properties are frequency independent, the damping is rate independent and hysteresis loops close.

Careful validation exercises between equivalent-linear and fully nonlinear formulations using recorded motions from 0.05 to 0.50g showed little difference in results (EPRI, 1993). Both formulations compared very favorably to recorded motions suggesting both the adequacy of the vertically propagating shear-wave model and the approximate equivalent-linear formulation. While the assumptions of vertically propagating shear-waves and equivalent-linear soil response certainly represent approximations to actual conditions, their combination has achieved demonstrated success in modeling observations of site effects and represent a stable, mature, and reliable means of estimating the effects of site conditions on strong ground motions (Schnabel et al., 1972; Silva et al., 1988; Schneider et al., 1993; EPRI, 1993).

To accommodate both uncertainty and randomness in dynamic material properties, analyses are typically done for the best estimate shear-wave velocity profile as well as upper- and lower-range profiles. The upper- and lower-ranges are usually specified as twice and one-half the best estimate shear-wave moduli. Depending upon the nature of the structure, the final design spectrum is then based upon an envelope or average of the three spectra.

For vertical motions, the SHAKE code is also used with compression-wave velocities and damping substituted for the shear-wave values. To accommodate possible nonlinear response on the vertical component, since modulus reduction and hysteretic damping curves are not generally available for the constrained modulus, the low-strain Poisson's ratio is usually fixed and strain compatible compression-wave velocities calculated using the strain compatible shear moduli from the horizontal component analyses combined with the low-strain Poisson's ratios. In a similar manner, strain compatible compression-wave damping values are estimated by combining the strain compatible shear-wave damping values with the low-strain damping in bulk or pure volume change. This process assumes the loss in bulk (volume change) is constant or strain independent. Alternatively, zero loss in bulk is assumed and the equation relating shear- and compression-wave damping (η_S and η_P) and velocities (V_S and V_P)

$$\eta_P \approx \frac{4}{3}\frac{V_S}{V_P}\eta_S, \qquad \text{(B-1)}$$

is used.

RVT Based Computational Scheme

The computational scheme employed to compute the site response for this project uses an alternative approach employing random vibration theory (RVT). In this approach the control motion power spectrum is propagated through the one-dimensional soil profile using the plane-wave propagators of Silva (1976). In this formulation only SH waves are considered. Arbitrary angles of incidence may be specified but normal incidence is used throughout the present analyses.

In order to treat possible material nonlinearities, an RVT based equivalent-linear formulation is employed. Random process theory is used to predict peak time domain values of shear-strain based upon the shear-strain power spectrum. In this sense the procedure is analogous to the program SHAKE except that peak shear-strains in SHAKE are measured in the time domain. The purely frequency domain approach obviates a time domain control motion and, perhaps just as significant, eliminates the need for a suite of analyses based on different input motions. This arises because each time domain analysis may be viewed as one realization of a random process. Different control motion time histories reflecting different time domain characteristics but with nearly identical response spectra can result in different nonlinear and equivalent-linear response.

In this case, several realizations of the random process must be sampled to have a statistically stable estimate of site response. The realizations are usually performed by employing different control motions with approximately the same level of peak accelerations and response spectra.

In the case of the frequency domain approach, the estimates of peak shear-strain as well as oscillator response are, as a result of the random process theory, fundamentally probabilistic in nature. For fixed material properties, stable estimates of site response can then be obtained with a single run.

In the context of the RVT equivalent-linear approach, a more robust method of incorporating uncertainty and randomness of dynamic material properties into the computed response has been developed. Because analyses with multiple time histories are not required, parametric variability can be accurately assessed through a Monte Carlo approach by randomly varying dynamic material properties. This results in median as well as other fractile levels (e.g. 16th, mean, 84th) of smooth response spectra at the surface of the site. The availability of fractile levels reflecting randomness and uncertainty in dynamic material properties then permits a more rational basis for selecting levels of risk.

In order to randomly vary the shear-wave velocity profile, a profile randomization scheme has been developed which varies both layer velocity and thickness. The randomization is based on a correlation model developed from an analysis of variance on about 500 measured shear-wave velocity profiles (EPRI, 1993; Silva et al., 1997). Profile depth (depth to competent material) is also varied on a site specific basis using a uniform distribution. The depth range is generally selected to reflect expected variability over the structural foundation as well as uncertainty in the estimation of depth to competent material.

To model parametric variability for compression-waves, the base-case Poisson's ratio is generally fixed. Suites of compatible random compression- and shear-wave velocities are then generated based on the random shear-wave velocities profiles.

APPENDIX B

To accommodate variability in modulus reduction and hysteretic damping curves on a generic basis, the curves are independently randomized about the base case values. A log normal distribution is assumed with a σ_{ln} of 0.35 at a cyclic shear strain of 3 x 10^{-2}%. These values are based on an analysis of variance on a suite of laboratory test results. An upper and lower bound truncation of 2σ is used to prevent modulus reduction or damping models that are not physically possible. The random curves are generated by sampling the transformed normal distribution with a σ_{ln} of 0.35, computing the change in normalized modulus reduction or percent damping at 3 x 10^{-2}% shear strain, and applying this factor at all strains. The random perturbation factor is reduced or tapered near the ends of the strain range to preserve the general shape of the median curves (Silva, 1992).

To model vertical motions, incident inclined compression- and shear (SV)-waves are assumed. Raytracing is done from the source location to the site to obtain appropriate angles of incidence. In the P-SV site response analyses, linear response is assumed in both compression and shear with the low-strain shear-wave damping used for the compression-wave damping (Johnson and Silva, 1981). The vertical and horizontal motions are treated independently in separate analyses. Validation exercises with a fully 3-D soil model using recorded motions up to 0.50%g showed these approximations to be validate (EPRI, 1993).

In addition, the site response model for the vertical motions has been validated at over 100 rock and soil sites for three large earthquakes: 1989 **M** 6.9 Loma Prieta, 1992 **M** 7.2 Landers, and the 1994 Northridge earthquakes. In general, the model performs well and captures the site and distance dependency of vertical motions over the frequency range of about 0.3 to 50.0 Hz and the fault distance range of about 1 to 100 km.

APPENDIX B

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