4.0 REVIEW OF ACCELERATION MODELS

4.1 Intensity Based Models

Intensity Attenuation Relations

Development of an intensity attenuation model requires a relation of the form,

$$I_s = F(I_o \text{ or } M,\ R) \qquad (4\text{-}1)$$

The first consideration in the development of such a relation is whether $F(I_o,R)$ is to be derived from intensity data of a single well recorded earthquake, assuming all earthquakes of intensity I_o are the same, or from more limited data of several earthquakes. If one uses a single well recorded event, questions arise as to the appropriateness of the data in representing the attenuation characteristics of other earthquakes and how to scale the ground motion between earthquakes. If data from a number of earthquakes with sufficient variation in epicentral intensity is used, then these problems are taken care of. Unfortunately, this latter alternative is not viable at present, because even though considerable intensity data exists, very little of it is in a form that can be used to develop the required relations. Only a few studies have been made of individual earthquakes to develop the required equations, and no study that we are aware of has used individual intensity reports from a number of earthquakes to correctly estimate the coefficients of Eq. (4-1). Because of the large variation in intensities, considerable data are required--particularly at the lower intensity levels. Typically, such data are not available.

Because individual intensity data are seldom available, the coefficients of Eq. (4-1) are more commonly computed using an equivalent or average distance for each intensity. This "Equivalent-R" approach is convenient if, in place of intensity reports, one works with isoseismals. Isoseismals are useful because they have been developed for a number of earthquakes, including most of the significant historic earthquakes. Results based on the two approaches can be considerably different as illustrated by Fig. 4-1 taken from a study by Weston Geophysical Corp. as documented in Bernreuter (1981b). The curve labeled 1 was obtained by direct regression on the data for the Ossippee earthquake and the curve labeled 3 was obtained using distances to isoseismals. The triangles represent the individual intensity reports. As can be seen from Fig. 4-1, Eq. (4-1) is poorly constrained by the data.

Figure 4-2 shows the fit of the equation

$$I_s - I_o = C_1 + C_2 \ln R + C_3 R \qquad (4\text{-}2)$$

to the individual intensity data from each earthquake listed in Table 4-1. While no one has combined such data from a wide range of earthquakes to develop the required coefficients of Eq. (4-2), several investigators have used isoseismals to develop generic relations. Included in Fig. 4-2 is such a relation developed by Gupta and Nuttli (1976). Since the Gupta-Nuttli relation was based on isoseismal data rather than individual intensity reports, we have reduced the C_1 coefficient by 0.5 intensity units to make it compatible with the other expressions in Fig. 4.2. We will refer to this relation later as the modified Gupta-Nuttli relation.

GMP - Site Intensity Relations

To complete the intensity based ground motion models, one also needs a relation between site intensity and ground motion. As discussed in Section 2, there are several functional forms this relation can take. Also, there are several data sets that can be used. For example, Fig. 4-3 shows the data base developed by Cal Tech and Fig. 4-4 shows the data base developed by Murphy and O'Brien (1977) for NRC. (Note: only the U.S. data are shown in Fig. 4-4.) Each investigator has "customized" his data set. Nevertheless, Figs. 4-3 and 4-4 give an indication of how much data exists and how little data there are to define the relation between the GMP and site intensity at the more important higher intensity levels.

TABLE 4-1

Summary of Earthquakes Used in the Intensity Data Base

Name	Date	Maximum Intensity	Analysis Source
Southern Illinois	11/9/1968	VII	G. A. Bollinger
Ossippee	11/20/1940	VII	R. J. Holt
Giles County	5/31/1897	VII-VIII	G. A. Bollinger
Charleston	8/31/1886	X	B. A. Bollinger

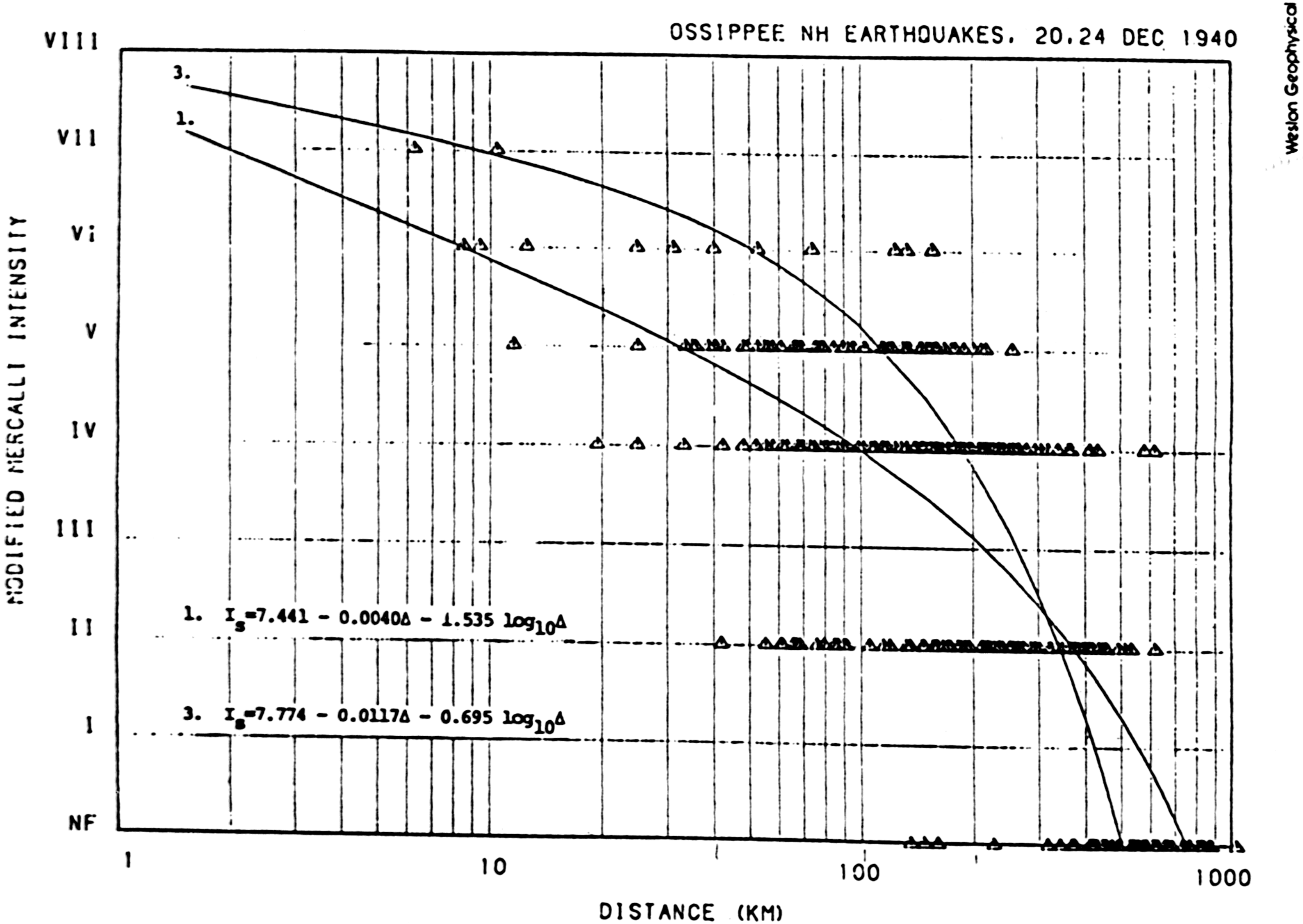

Fig. 4.1 Site intensity versus distance for the Ossippee N.H., earthquake of December 1940. Taken from Weston Geophysical Company

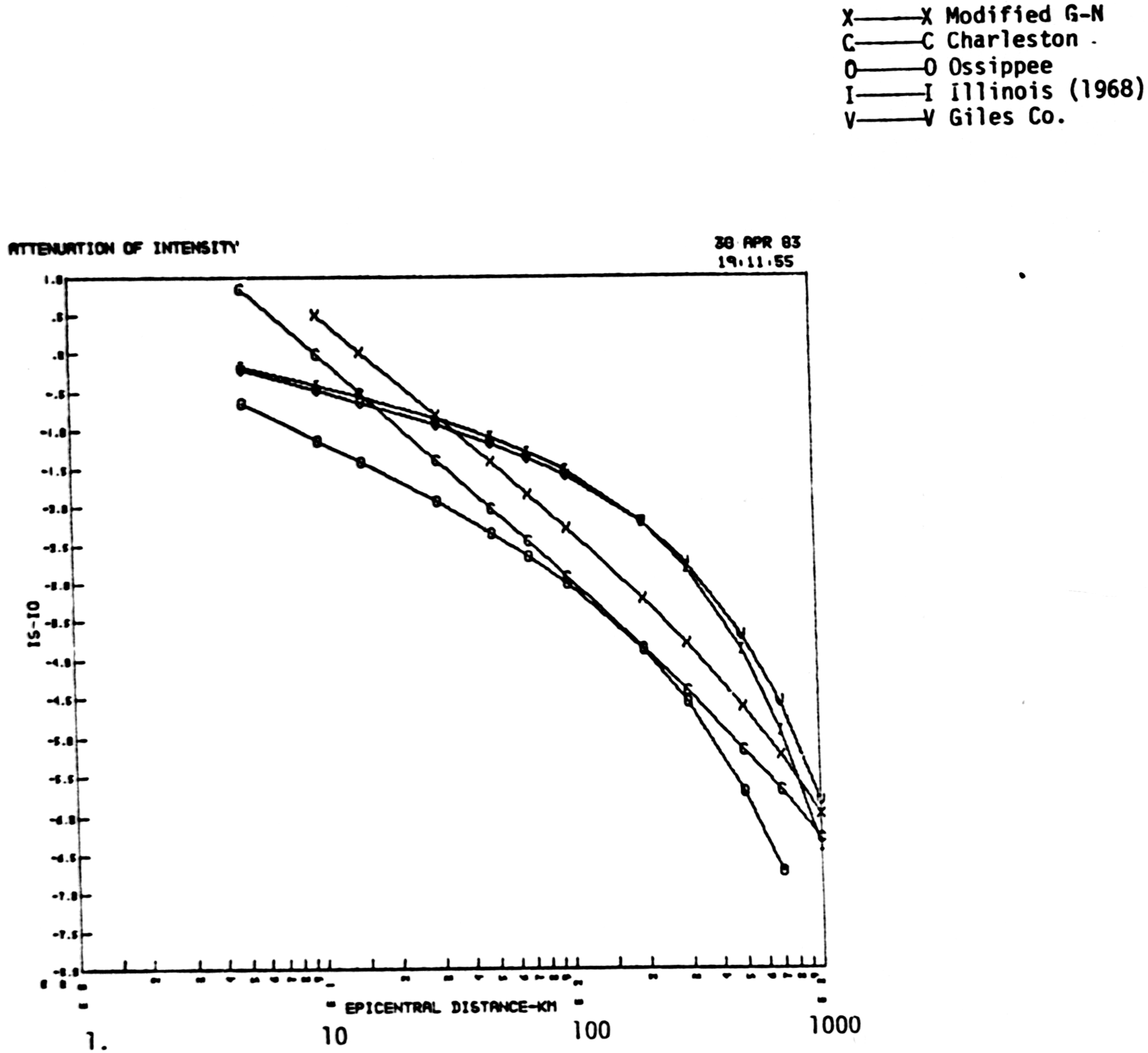

Fig. 4.2 Comparison of the "modified" Gupta-Nuttlı relations with available data.

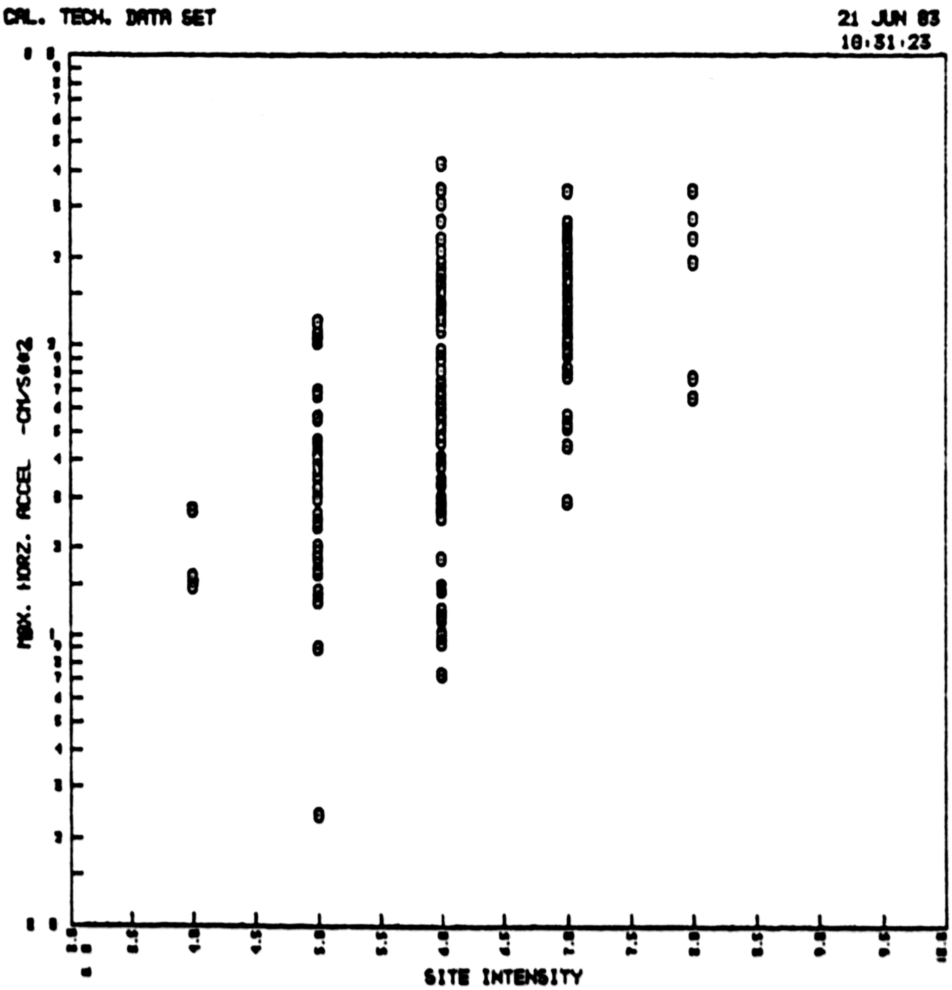

Fig. 4.3 Cal tech data base of acceleration versus site intensity.

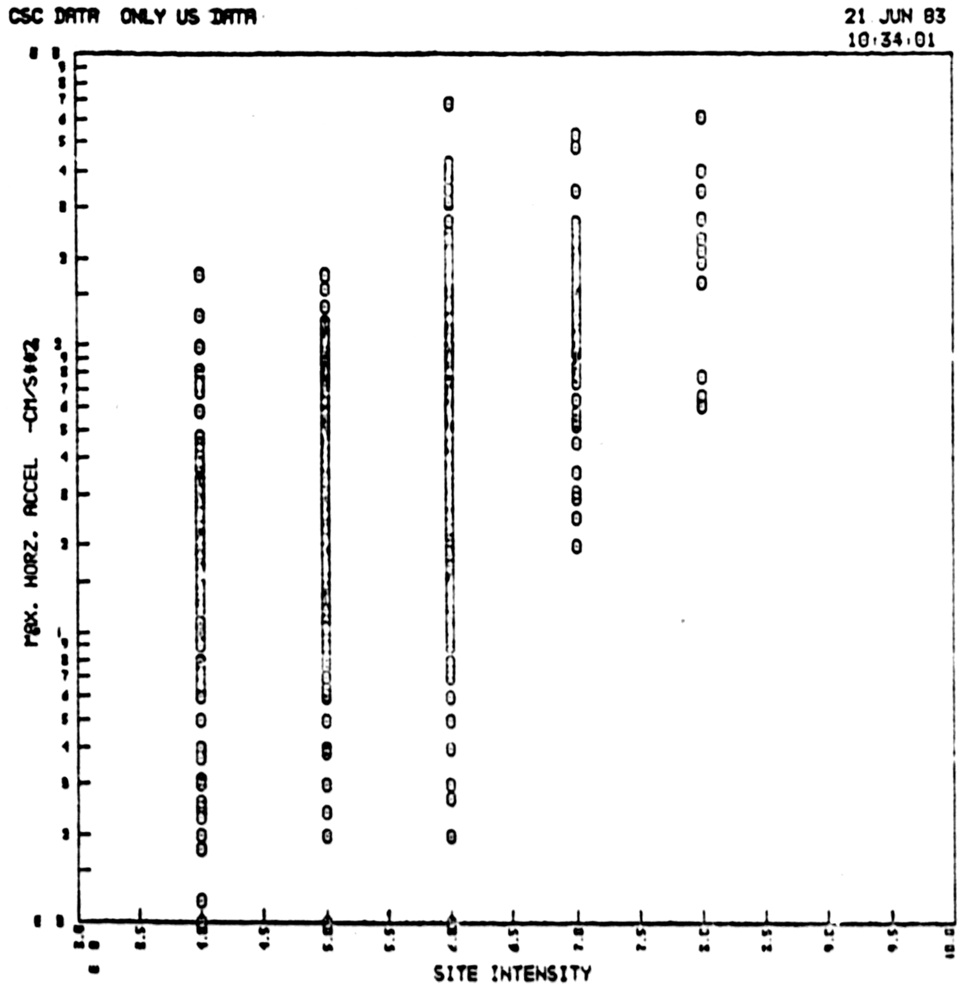

Fig. 4.4 Murphy and O'Brien data base of acceleration versus site intensity.

In addition to different data sets, there are a number of different ways the regression analysis can be performed to obtain estimates of the coefficients of the model. For example, McGuire (1977) found for medium sites

$$\ln(a) = -0.83 + 0.85\ I_s \tag{4-3}$$

and Trifunac (1976) found

$$\ln(a) = -0.19 + 0.67\ I_s + 0.33S \tag{4-4}$$

McGuire and Trifunac used approximately the same data set, however, the forms of the regression were different. McGuire separated his data into two sets (soft and medium sites) and performed separate regression analyses on each data set. Trifunac introduced a site variable S which has a value of 0, 1, or 2 depending upon the site type (see Sec. 7 for a definition of s). Trifunac and Brady (1975) used the same data set as Trifunac, but performed regression analyses on the logarithm of the mean acceleration for each intensity level, independent of site type. Their resulting expression was

$$\ln(a) = 0.032 + 0.69\ I_s \tag{4-5}$$

Murphy and O'Brien (1977) found by using a more extensive data set not segregated by site type

$$\ln(a) = 0.58 + 0.58\ I_s \tag{4-6}$$

Murphy and O'Brien used just the peak horizontal component, whereas McGuire, Trifunac, and Trifunac and Brady used both components.

Site type can have a significant effect on the derived relation. For example, McGuire found for soft sites

$$\ln(a) = 0.27 + 0.6\ I_s \tag{4-7}$$

which is significantly different than his expression for medium sites (Eq. 4-3). This dependence on site type may be an important consideration in the selection of the "best" relation between the GMPs and site intensity as these expressions should be derived in a manner consistent with Eq. (4-1). All of the available intensity attenuation relations were derived without regard to site type, because site data is not generally available for the intensity reports. In addition, it is doubtful in our opinion that the value of intensity assigned to each PCA value (a in the above expressions) in the various data bases can be said to be truly representative of the intensity at the recording site. For these reasons, one might prefer GMP-I_s relations that are developed without regard to site type.

An even more significant problem involves the use of low intensity data in the regression analysis. For example, the Cal Tech Data set used by Trifunac, McGuire, and Trifunac and Brady includes MM IV and V data. However, the ground motion data for these intensities may not be representative because the data set was developed using only digitized accelerograms. The criteria for selecting accelerograms to be digitized required that the level of ground shaking be "significant" or that the records be associated with an earthquake with "significant" damage. In our view, such a selection process would tend to bias the data towards high PGA records, particularly at the lower intensity levels. In the least squares fitting process this would tend to reduce the coefficient of the I_s term, thereby reducing the estimate of PGA at high intensity levels.

The data set developed by Murphy and O'Brien also has some bias. Although the set of MM IV and V data is more complete than the Cal Tech set, in order to be included, the accelerograph had to trigger, the records read, and the values reported. Such values are often only reported if the level of acceleration is at least 0.05g (this is standard practice for the USGS). Thus, The MM IV and V set of Murphy and O'Brien is probably also biased towards higher values of PGA. Eq. (4-6) suffers from a further bias because in performing their regression analysis Murphy and O'Brien <u>only</u> included PGA levels greater than 10 cm/sec^2.

To assess the impact of incompleteness at the lower intensity levels, we have recomputed the coefficients of Eq. (4-6) using U.S. data without the 10 cm/sec^2 cutoff. We found

$$\ln(a) = -1.69 + 0.86\, I_s \tag{4-8}$$

if MM IV-X data are included and

$$\ln(a) = -2.32 + 0.96\, I_s \tag{4-9}$$

if only MM V-X data are used.

Equations (4-3), (4-4), (4-6), (4-7) and (4-9) are compared in Fig. 4-5. Also shown on Fig. 4-5 are the mean log acceleration levels for MM V-VIII level based on the Murphy and O'Brien data for the U.S. shown on Fig. 4-4. A value of 1000 cm/sec^2 was chosen for MM X.

As seen by the scatter of data at each intensity level, the correlation between PGA and site intensity is poor. Different methods have been proposed to improve this correlation. For example, studies show that the residuals of GMP-I_s relations are strongly correlated with distance. This leads naturally to regressions of the form

$$\ln(a) = C_1 + C_2 \ln R + C_3\, I_s \tag{4-10}$$

which we have denoted as "distance weighted" models. For medium sites, McGuire (1977) found

$$\ln(a) = 1.45 - 0.359 \ln R + 0.68\, I_s \tag{4-11}$$

X E(Log A) for each intensity level (CSC data ∿ only USA)

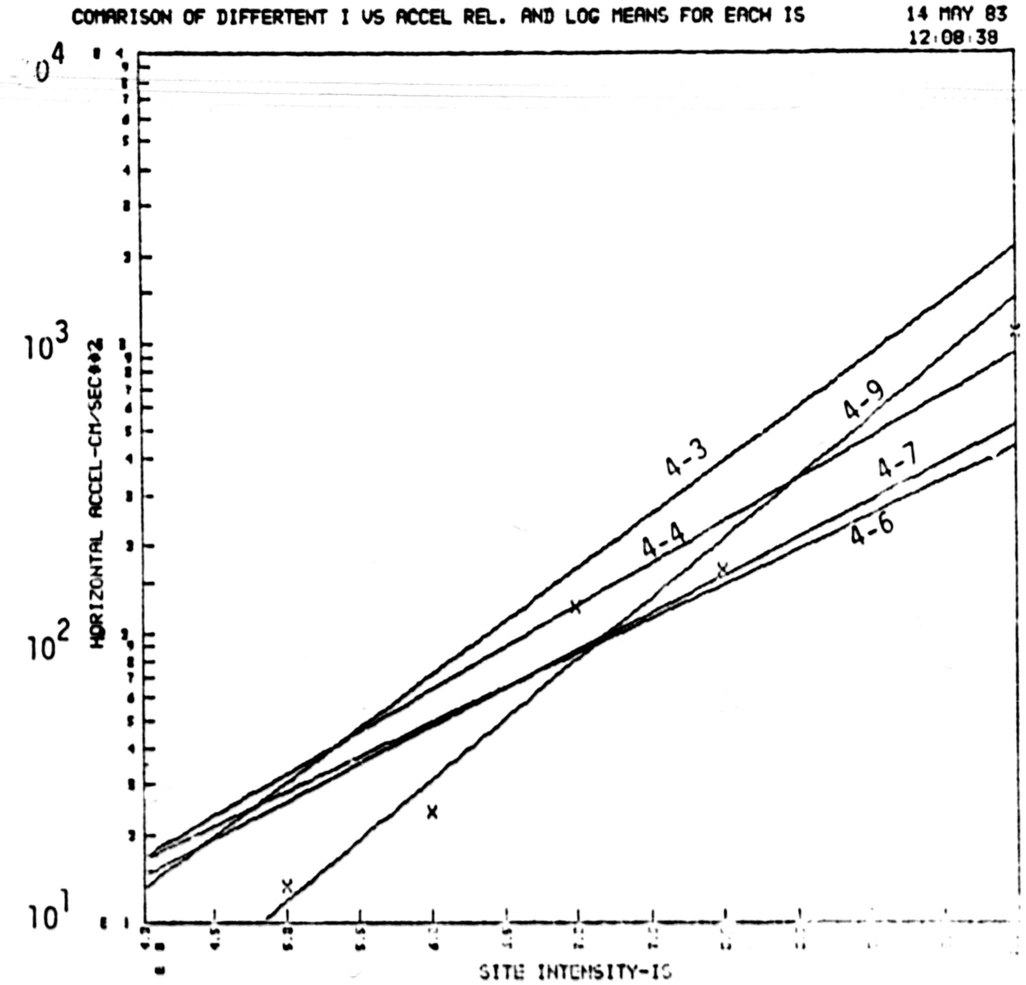

Fig. 4.5 Comparison of several accelerations versus site intensity equations.

and for soft sites

$$\ln(a) = 2.01 - 0.313 \ln R + 0.51 I_s \quad (4\text{-}12)$$

In our earlier study (Bernreuter 1981a) we found

$$\ln(a) = 1.79 - 0.323 \ln R + 0.57 I_s \quad (4\text{-}13)$$

Eq. (4-13) was obtained using the Cal Tech data set without regard to site type. It is in general agreement with McGuire's results, falling somewhere between his predictions for soft and medium sites. Neither Murphy and O'Brien, Trifunac, nor Trifunac and Brady considered a regression of the form of Eq. (4-10).

Our earlier study (Bernreuter 1981a) appears to be the only case which has considered a "magnitude-weighted" model of the form

$$\ln(a) = C_1 + C_2 M + C_3 I_s \quad (4\text{-}14)$$

We evaluated the coefficients of Eq. (4-14) using a modification of the Cal Tech data set and a weighted regression analysis to obtain

$$\ln(a) = 0.96 - 0.13M_L + 0.63 I_s \quad (4\text{-}15)$$

In addition to Eq. 4-6, Murphy and O'Brien also developed a relation of the form

$$\ln(a) = C_1 + C_2M + C_3 \ln R + C_4 I_s$$

They found for U.S. accelerations greater than 10 cm/sec^2

$$\ln(a) = 1.38 + 0.55M - 0.68 \ln R + 0.32I_s \quad (4\text{-}16)$$

The magnitude used is assumed to be M_L.

Battis (1981) introduced a different approach for using intensity data to develop a relation between GMP and site intensity. Battis assumed that the radius of the felt area of earthquakes could be defined by a constant level of acceleration equal to 6 cm/sec^2. This value was based on his extrapolation of the results of Trifunac and Brady (1975).

Combined Models

To get the required relation between the GMP, magnitude, and distance applicable in the EUS, we must combine an intensity attenuation relation with an expression relating GMP to I_s. As outlined above, there are a number of such combinations - each with their own assets and liabilities. The difference between the different intensity attenuation relations was illustrated in Fig. 4-2. To evaluate the difference between the various GMP-I_s relations we chose the modified Gupta-Nuttli curve shown in Fig. 4-2. It more or less represents an "average" between the different intensity attenuation relations. We combine the modified Gupta-Nuttli relation with Eqs. (4-3), (4-6) and (4-9) to develop three relations which approximately bound the different regression analysis results and assumptions. That is, we combine the different relations of the form

$$\ln(a) = C_1 + C_2 I_s \tag{4-17}$$

with the modified Gupta-Nuttli relation

$$I_s - I_o = 3.2 - 0.0011R - 1.17 \ln R \tag{4-18}$$

for $R \geq 15$ km

to obtain

$$\ln(a) = C_1 + C_2(I_o + 3.2 - 0.0011R - 1.17 \ln R) \tag{4-19}$$

Figure 4-6 shows this comparison for epicentral intensities of V, VII and IX. This figure indicates that the choice of the GMP-I_s relation has an important effect on both the rate of attenuation and how the ground motion scales with earthquakes of larger epicentral intensity - both being controlled by the coefficient C_2 of the I_s term in Eq. (4-17). To a large extent the coefficient C_2 is controlled by what data is included or excluded in the lower intensity ranges.

To illustrate the impact of "unweighted", "distance weighted" and "magnitude weighted" relations, we have compared the results using the modified Gupta-Nuttli attenuation model with the GMP-I_s acceleration relations given by Eqs. (4-4), (4-13), and (4-15). We use this set because all three regressions were performed using approximately the same data base. In making the required substitutions, we obtain

$$\ln(a) = C_1 + C_3 \ln R + C_4 M_L + C_2 [I_o + 3.2 - .0011R - 1.17 \ln R] \tag{4-20}$$

where the coefficients C_i are obtained from the regression between site intensity and PGA.

A problem occurs here in making a comparison between Eq. (4-15) and either Eq. (4-13) or Eq. (4-4) because Eq. (4-15) uses M_L while the other two relations are in terms of epicentral intensity. Some relation must be used to translate M_L into the appropriate I_o in the EUS. This is normally done in a two

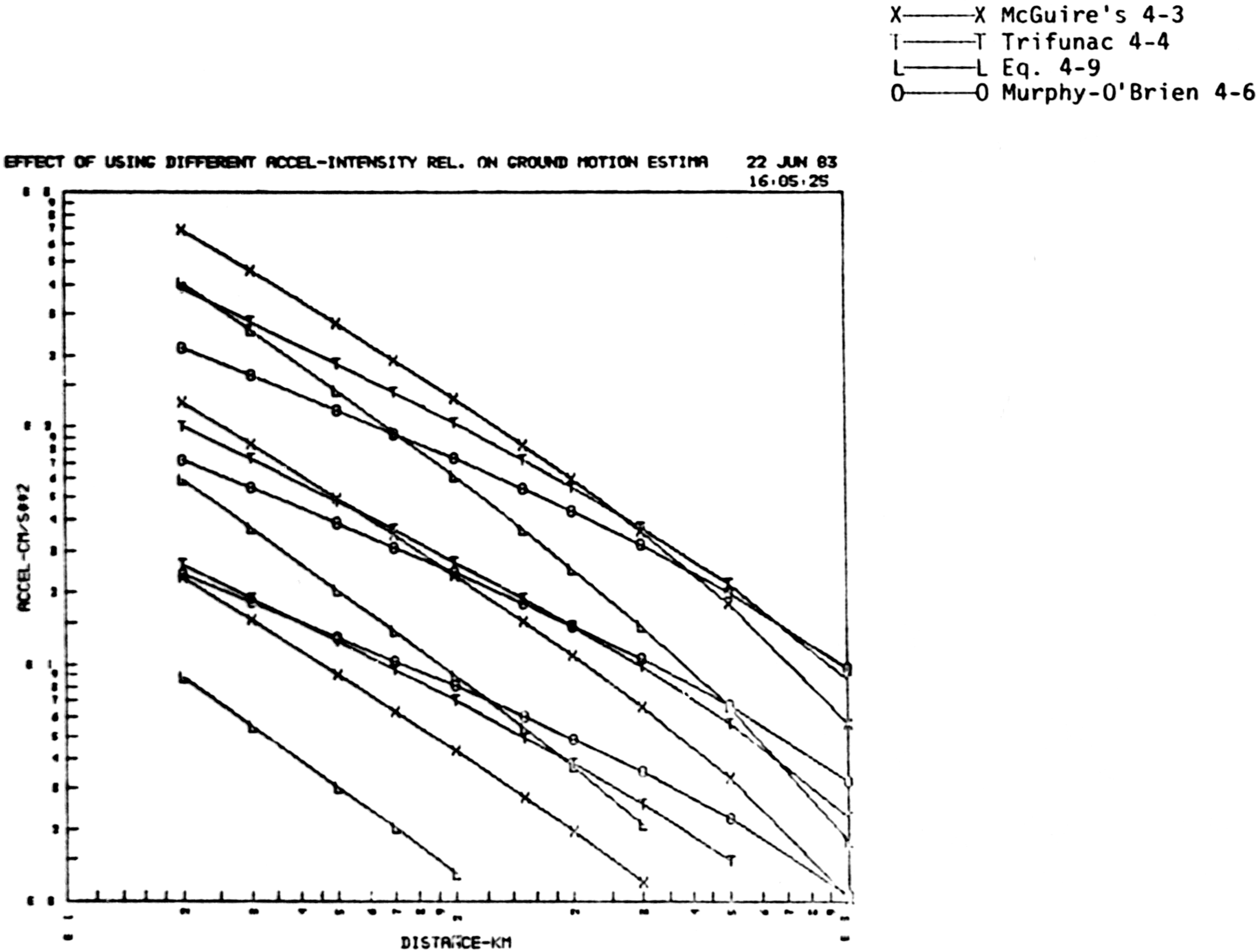

Fig. 4.6 Comparison of several combined models for intensities V, VII and IX.

step process. First the M_L is converted to an equivalent EUS m_{bLg} and then the m_{bLg} is converted to an equivalent I_o. As discussed earlier, it appears that

$$M_L \sim m_{bLg}$$

and in the past the relation

$$I_o = 2m_{bLg} - 3.5 \qquad (4\text{-}21)$$

has been widely used in the EUS. Figure 4-7 shows the comparison of the unweighted, distance-weighted and magnitude-weighted models made by combining Eqs. (4-4), (4-13) and (4-15) with Eq. (4-18), the modified Gupta-Nuttli attenuation relation. In the distance-weighted model, the R in Eq. (4-13) is assumed to be the same as the R in Eq. (4-18). This, as discussed earlier, is not strictly true.

The last set of models we need to compare are the intensity based semi-empirical models. These models form a somewhat disjoint set. One of the earliest semi-empirical models was developed by Nuttli and Herrmann (1978). They combined the relation

$$I_s - I_o = 3.1 - 1.07 \ln R \qquad (4\text{-}22)$$

which they felt approximates the Gupta-Nuttli relation, with Eqs. (4-16) and (4-21) and a free parameter. The use of Eq. (4-16) makes this essentially a "magnitude-and distance-weighted" approach. The free parameter was evaluated using judgment and available EUS data to obtain

$$\ln(a) = 1.47 + 1.2\, m_{bLg} - 1.02 \ln R; \; R > 15 \text{ km} \qquad (4\text{-}23)$$

Battis (1981) assumed the model

$$\ln(a) = C_1 + C_2 M + C_3 \ln(R + 25) \qquad (4\text{-}24)$$

M = appropriate magnitude scale
R = epicentral distance

To evaluate the coefficients in Eq. (4-24), Battis assumed that in the "near field" (i.e., $R = 10$ km) the ground motion is the same for all regions for the same epicentral intensity. In the "far field," at the limit of the felt area, he assumed that the ground motion is the same for all regions and sizes of earthquakes, using a value of 6 cm/sec^2. To obtain relations for both the central U.S. and the WUS, he used McGuire's (1974) relation to get PGA estimates at $R = 10$ km as a function of M_L. He used the relation between M_L and m_b derived by Brazee (1976) for California,

$$m_b = 1.28 + 0.75\, M_L, \qquad (4\text{-}25)$$

M——M Magnitude Weighting
D——D Distance Weighting
X——X No Weighting

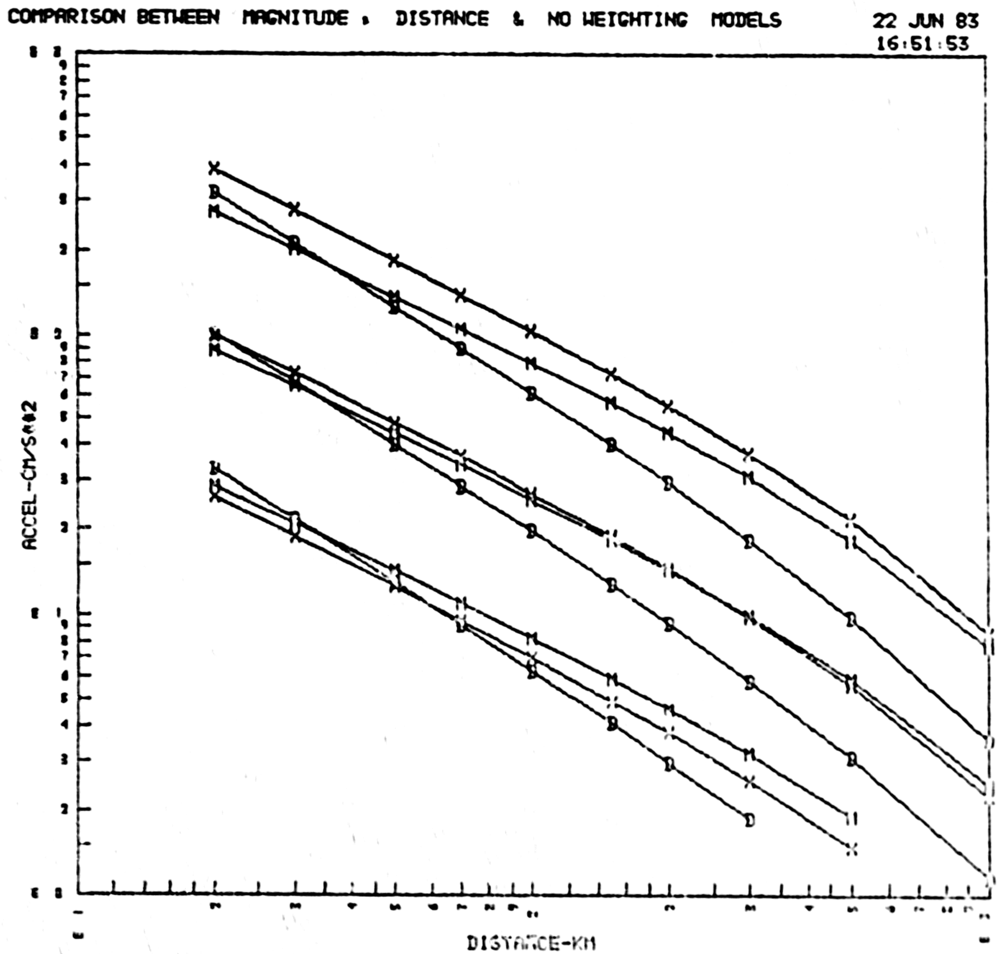

Fig. 4.7 Comparison of the magnitude weighted attenuation equations with the distance weighted and no weighting equations, for magnitudes 4.25, 5.25, and 6.25 (i.e., approximately source intensity $I_o \sim$ V, VII and IX).

and Brazee's relation between m_b and I_o,

$$m_b = 2.89 + 0.37\ I_o, \tag{4-26}$$

to relate the parameters M_L, m_b and I_o for the WUS.

Battis developed an approximate relation for the radius of felt area for the WUS. For the Central U.S., he used the relation

$$m_b = 2.6 + 0.34\ I_o \tag{4-27}$$

and determined the distance of the felt area using Nuttli and Zolweg's (1974) relation between the felt area and m_b

$$\ln R_f = -6.23 + 3.41\ m_b - 0.2\ m_b^2 \tag{4-28}$$

He evaluted the coefficients of Eq. (4-24) using a least squares process and obtained

$$\ln(a) = 3.16 + 1.24\ m_b - 1.24\ \ln(R + 25) \tag{4-29}$$

for the Central US. Fig. 4-8, taken from Battis, compares Eq. (4-29) to his result for the WUS,

$$\ln(a) = 5.83 + 1.21\ m_b - 2.08\ \ln(R + 25) \tag{4-30}$$

At 10 km the difference between Eqs. (4-29) and (4-30) arises because of the differences between Eqs. (4-26) and Eq. (4-27). For example at I_o = VII Eq. (4-26) results in m_b values that are about 0.5 units larger than those given by Eq. (4-27).

Weston Geophysical Corporation, Inc. (WGC) has proposed a model for New England. WGC based the attenuation of intensity on four New England earthquakes ranging in magnitude from 3.5 to 5.8. WGC used Eq. (4-11) (distance weighting) to convert from site intensity to ground motion. They noted that because of the small range of magnitudes of the earthquakes involved that the scaling with magnitude determined by the regression analysis was unreliable. To account for this, they changed the coefficient of m_b from the value of 0.7 determined from the regression to 1.1 and readjusted the constant so that the model with the 1.1 slope agreed with the 0.7 slope model at $m_b = 4.875$. Their resultant model is given by

$$\ln(a) = 1.47 + 1.1\ m_b - 0.88\ \ln R - 0.0017R \tag{4-31}$$

The Nuttli-Herrmann model, Eq. (4-23), the Battis model, Eq. (4-29), and the WGC model, Eq. (4-31), are compared in Fig. 4-9. Also shown in Fig. 4-9 for comparison is the magnitude-weighted model, Eqs. (4-15) and (4-20) expressed in terms of m_b through Eq. (4-21),

$$\ln(a) = 0.77 + 1.13\ m_b - 0.0007R - 0.74\ \ln R \tag{4-32}$$

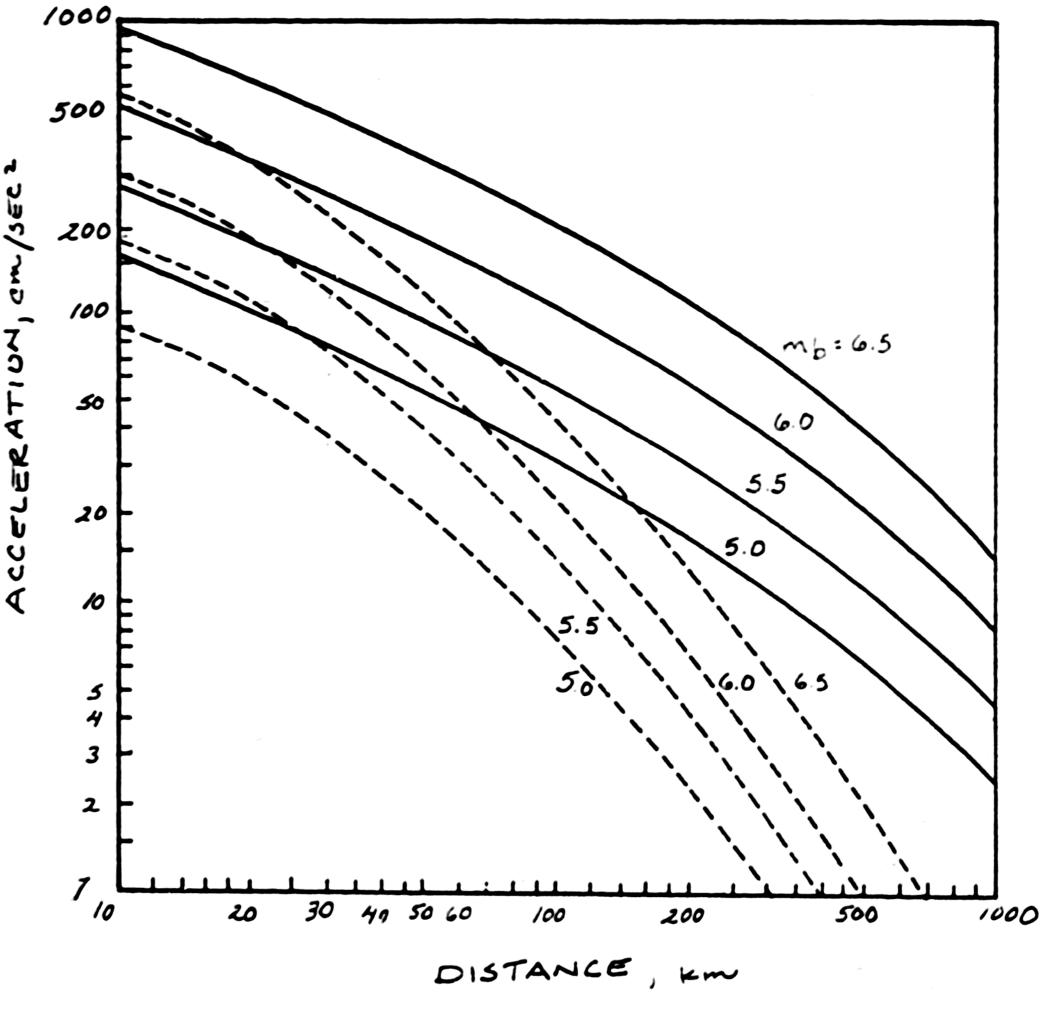

Figure. 4-8 Comparison of derived peak acceleration attenuation functions for the Central United States (solid curves) and California (dashed curves). Battis's Model.

B———B Battis 4-29
——— Nuttli-Herrmann 4-23
G———G WGC model 4-31
M———M Magnitude Weighting 4-32

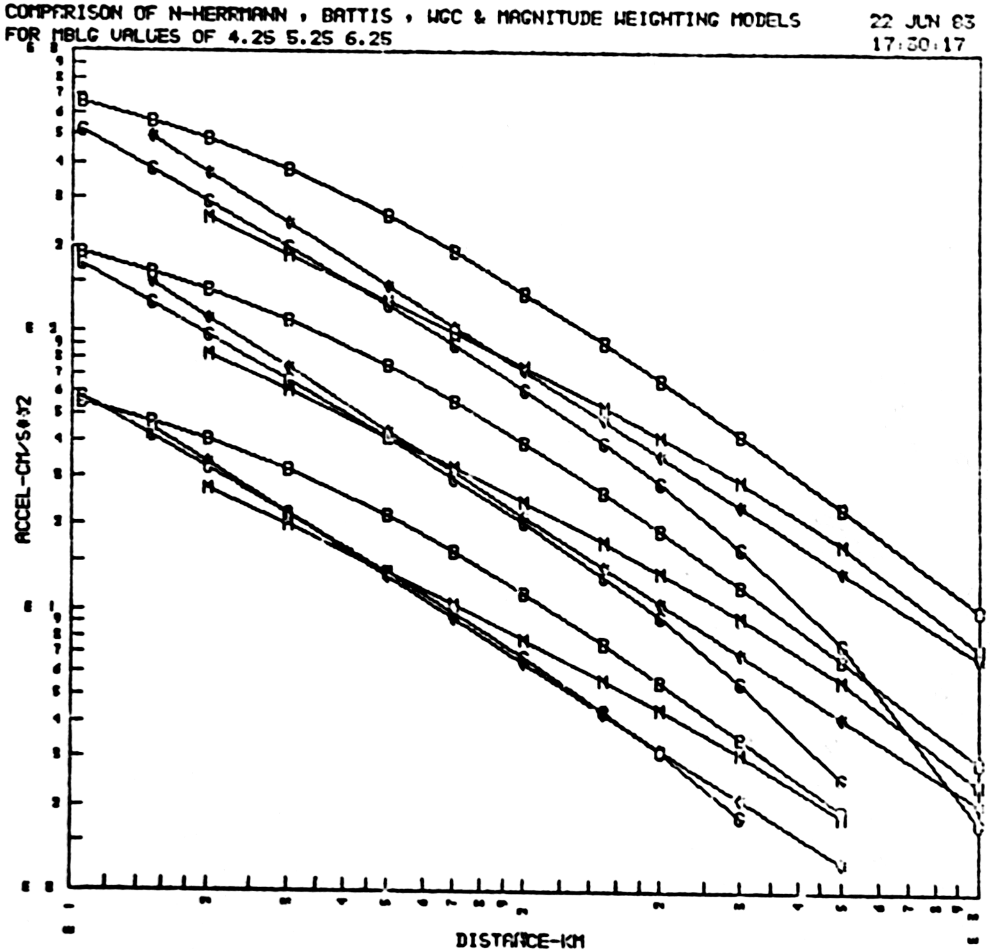

Fig. 4.9 Comparison of the magnitude weighting mdoel (M, Eq. 4-39) with Battis' model (B, Eq. 4-29), the Nuttli-Herrmann model (*, Eq. 4-23) and the Weston Geophysical model (G, Eq. 4-31).

4.2 Direct Models

Although there are many possible models in the categories referred to as D-1 and D-2, in fact, only a few have been formally developed. Recall that category D-1 includes those semi-empirical models that do not use site intensity as an intermediate variable and assume that differences between the ground motion from EUS and WUS earthquakes are only related to the differences in attenuation between the two regions. Category D-2 includes those models which assume that in addition to attenuation differences between the two regions there are also differences in magnitude scaling.

Nuttli (1979) assumes that

$$GMP\ (R) = A_o R^{-5/6} \exp(-\gamma R) \tag{4-33}$$

where γ is a regional absorption coefficient. Eq. (4-33) is a theoretical attenuation curve for Lg waves.

Nuttli further assumes that

$$\log A_{max} \propto 0.5 m_b$$

$$\log V_{max} \propto 1.0 m_b \ .$$

In addition, he assumes that the source spectra of EUS earthquakes are the same as for WUS earthquakes, so that the ground motions observed in the near-source region are the same for both areas. Nuttli also assumes that the predominate frequency of the ground motion for identical magnitude earthquakes is the same between the two regions.

The constant A_o in Eq. (4-33) was assumed to be proportional to m_b as given in the above relations and calibrated using the San Fernando earthquake. The appropriate absorption coefficient for the central US was taken from Nuttli and Dwyer (1978). Nuttli's (1979) model is given by the following equations:

$$\ln(a) = 1.481 + 1.15\ m_b - \gamma R - 5/6\ \ln(R)$$

$$\text{where } \gamma = 0.0136 - 0.00172\ m_b \tag{4-34}$$

In addition to Nuttli's (1979) model we are aware of four other models that fall into category D-1, one that we developed for SSMRP, Campbell's (1981b) and (1982) models, and the model used by Algermissen and Perkins (1976). We exclude the model by Algermissen and Perkins because it is nonanalytical and would be difficult to use in the hazard analysis. The model is based on the relation of Schnabel and Seed (1973) with a regional correction for attenuation. Figure 4-10 taken from Algermissen et al. (1982) compares this model to that of Nuttli and Herrmann (1981). Aglermissen et al. do not indicate what relation they used to go from m_b to M_s.

In developing the SSMRP model we started with Nuttli's (1979) suggestion that

$$GMP = A_o(m_b)\ R^{-5/6}\ \exp(-\gamma\ R) \tag{4-35}$$

Nuttli suggested that $A_o(m_b)$ could be determined from WUS data using the assumption that the only difference between WUS and EUS earthquakes is a difference in regional attenuation. To develop the SSMRP model we repeated the regression analysis on the data set of Joyner and Boore (1981) ($M_L \geq$ 5.0) using an approach similar to theirs. However, in our analysis the coefficient of geometrical attenuation was taken to be -5/6 (in agreement with Nuttli's model) rather than the value of -1 assumed by Joyner and Boore. The purpose of this change was to put the model in the same form as assumed by Nuttli when he determined the regional absorption coefficients for the EUS and WUS. In addition, a value of m_b appropriate for the EUS (or an estimate of this value) was used for the measure of the size of the earthquakes. We determined the best fit relation

$$\ln(a) = 3.99 + 0.59\ m_b - 5/6\ \ln R - 0.007R \tag{4-36}$$

where

$$R^2 = [d^2 + h^2]^{1/2}$$
$$h = 5.3$$

and d is the shortest distance between the site and the surface projection of the fault rupture plane.

Nuttli (1979) obtained a similar estimate for γ in the WUS. For the central U.S. (CUS) Nuttli (1982) estimates $\gamma = 0.003$. If indeed the ground motion from CUS earthquakes scales the same with magnitude as WUS earthquakes, we can convert the above relation into a CUS ground motion model simply by replacing γ with an appropriate value for the CUS. This gives

$$\ln(a) = 3.99 + 0.59\ m_b - 5/6\ \ln R - 0.003\ R \tag{4-37}$$

where

$$R^2 = [d^2 + h^2]^{1/2}$$
$$h = 5.3$$

Campbell (1981b) uses a different functional form than that used by Nuttli (1979) or Joyner and Boore (1981). He takes as his relationship for modeling the attenuation of peak acceleration with distance the expression

$$\ln(a) = a + bM - d\ \ln[R + C(M)] - \gamma R \tag{4-38}$$

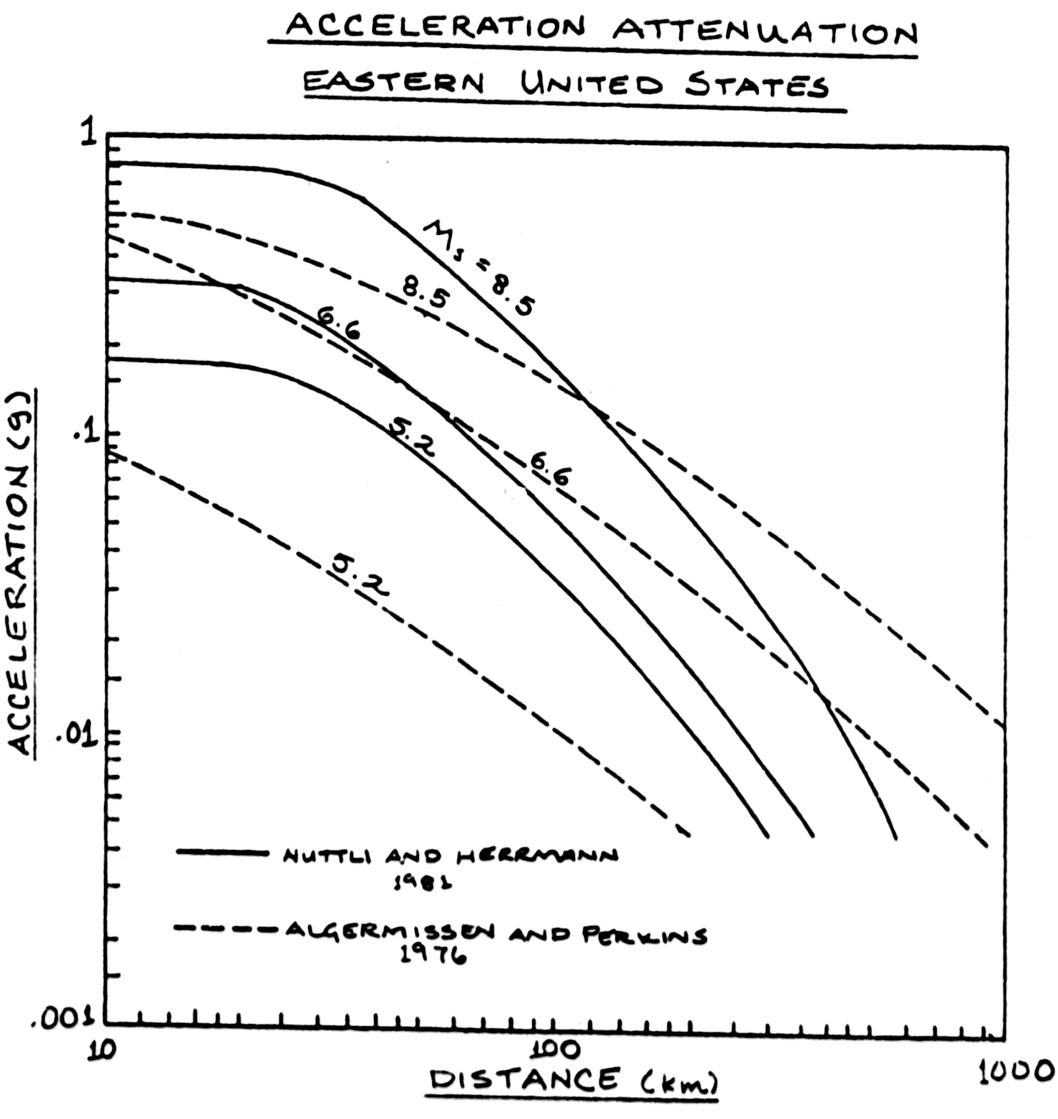

Figure. 10 Comparison of Algermissen and Perkins (1976) and Nuttli and Herrmann (1981) Acceleration Attenuation Curves for the Eastern and Central United States.

Campbell selected this functional form because it is capable of modeling nonlinear magnitude and distance scaling effects in the near field that may be supported by the data. The far-field properties of this relationship are characterized by the coefficient b which controls magnitude scaling, the coefficient d which controls the geometrical attenuation rate, and the coefficient γ which controls the rate of attenuation due to absorption.

C(M) modulates the attenuation of acceleration at distances close to the source where little geometrical attenuation is expected (Hadley and Helmberger, 1980). Since the distance at which the transition from far-field to near-field attenuation occurs is probably proportional to the size of the fault rupture zone, and since fault rupture dimensions scale exponentially with magnitude, Campbell used the following relationship to model C(M):

$$C(M) = C_1 \exp(C_2 M) \tag{4-39}$$

Eq. (4-38) differs from Nuttli's relationship (Eq. 4-34) in two ways. The first is that the geometrical attenuation term d is not fixed but rather was determined from the regression analysis. The second is the addition of the C(M) parameter. Both of these differences are required to accommodate the near-source effects of extended fault rupture in the case of large earthquakes and accommodate the depth of the source in the case of small events.

He based his analysis on the near-source data base of Campbell (1981a). Earthquakes were selected only if their magnitude was equal to or greater than 5.0. Distances were restricted to be no further than 30 km from the fault rupture plane for $5.0 \leq M < 6.25$ and no further than 50 km from the fault for $M \geq 6.25$. Analyses were conducted separately for two definitions of distance: the closest distance to the fault rupture surface, referred to as fault distance, and epicentral distance. He considered peak acceleration to be regionally invariant at the source (i.e., at $R = 0$). He used the values of absorption proposed by Nuttli (1979) in the WUS to establish γ, from which he developed the relation

$$\gamma_{WUS} = 0.042 - 0.009M + 0.00057M^2 \tag{4-40}$$

Using a weighted regression analysis similar to that of Campbell (1981a) he found the following expression for the median (50th-percentile) value of peak acceleration in cm/s^2 in terms of <u>fault distance</u>:

$$\ln(a) = 2.64 + 0.79M - 0.862 \ln [R + 0.0286 \exp(0.778M)] - \gamma R \tag{4-41}$$

with a standard error of ln(a) of 0.409.

The results of the regression analysis for <u>epicentral distance</u> yielded the following expression for the median value of peak acceleration:

$$\ln(a) = 4.39 + 0.922M - 1.27 \ln [R + 25.7] - \gamma R \tag{4-42}$$

where C_2 was found to be equal to zero. The standard error of ln(a) was found to be 0.548.

Since the standard measure for earthquake size in the CUS is m_b, Campbell's application of Eqs. (4-41) and (4-42) to this region required a conversion from m_b to M, the magnitude scale used in the development of these relationships. The magnitude scale used in the above equations was defined as M_s when both M_s and M_L were larger than 6.0 and M_L when both were below this value. Campbell used the relationships between magnitude scales developed by Nuttli (1979) and his definition of M to develop the following conversion relation

$$M = \begin{cases} 1.64\ m_b - 3.16 & (m_b \geq 5.59) \\ 1.02\ m_b + 0.30 & (m_b < 5.59) \end{cases} \qquad (4\text{-}43)$$

An appropriate ground motion model for the CUS was obtained by substituting values of γ for the CUS proposed by Nuttli (1979) using the expression

$$\gamma_{CUS} = 0.023 - 0.0048M + 0.00028\ M^2 \qquad (4\text{-}44)$$

This analysis was later revised by Campbell (1982) using a frequency dependent expression for γ of the form

$$\gamma = \frac{\pi T^{\eta}}{Q_o T_o^{\ \eta} TU} \qquad (4\text{-}45)$$

where T is the period of the wave, U is the group velocity, Q_o is a reference value for the quality factor Q, T_o is a reference value for period, and η is defined by the expression

$$Q = Q_o \left(\frac{T_o}{T}\right)^{\eta} \qquad (4\text{-}46)$$

The predominant period of PGA for sites located on rock was modified from a plot given by Seed et al. (1969), resulting in the relation

$$T = \begin{cases} -0.229 + 0.0650M + (0.000556M - 0.00172)R & (M \geq 7.0) \\ -0.043 + 0.0382M + (0.000556M - 0.00172)R & (M < 7.0) \end{cases} \qquad (4\text{-}47)$$

An expression for γ appropriate for California was obtained by substituting the values $Q_o = 150$, $\eta = 0.55$, $U = 3.5$ km/sec and $T_o = 1$ sec. into Eq. (4-45) based on the regionalization of Q for the United States by Singh and Herrmann (1983). Using this expressionfor γ and the relation for period given by Eq. (4-47), the analysis of Campbell (1981b) was revised, resulting in the following expression for peak acceleration (g):

$$\ln(a) = -4.290 + 0.777M - 0.797\ \ln[R + 0.012\ \exp(0.898M)] - \gamma R \qquad (4\text{-}48)$$

where R is fault distance as defined previously. The standard error for ln(a) in this analysis was 0.405.

While Campbell only applied Eq. (4-48) to the estimation of PGA in the northcentral Utah region, this expression may be applied to other regions of the U.S. by selecting an appropriate value for Q_o and η from Singh and Herrmann (1983) (or some other source if appropriate) and selecting an appropriate value or relation for the predominant period of PGA. Then γ may be estimated from Eq. (4-45) and substituted into Eq. (4-48) to estimate PGA. A conversion between M and m_b may be taken from Eq. (4-43) or from more current relations proposed by Nuttli (1983 a,b).

Figure 4-11 compares Campbell's Eqs. (4-41) and (4-42) and the SSMRP model given by Eq. (4-37) for an m_b of 4.25, 5.25, and 6.25. In making this plot several items need to be noted. First, Eq. (4.37) is plotted as a function of the distance R. This is consistent with the distance R in Eq. (4-38) for EUS earthquakes where earthquakes do not rupture to the surface. In Fig. 4-11 the epicentral distance R in Eq. (4-42) is different than either of the other two definitions, but it is plotted as R for reference. For a discussion of the differences in the definition of distance as it relates to the prediction of strong ground motion, the reader is referred to Appendices B and C and Shakal and Bernreuter (1981). Second, it should be noted that we have extrapolated beyond the data to plot the curves for $m_b = 4.25$. However, as an extended data set is not readily available, it is not possible at this time to revise these models using smaller magnitude data. At some point in your response to us you should note if it is necessary for us to extend these models.

As can be seen from Fig 4-11 there is a considerable difference between all three models. One notable difference is how the ground motion scales with magnitude. For Eqs. (4-41) and (4-42) the m_b was converted to the magnitude M used by Campbell based on Eq. (4-43).

This is believed to contribute to the differences in the magnitude scaling properties of Eq. (4-37) and Eqs. (4-41) and (4-42). In the SSMRP model it was assumed that $M_L = m_{bLg}$, whereas for the Campbell models M was determined using the magnitude conversion relations developed by Nuttli (1979) resulting in an m_b approximately 0.3 to 0.4 units smaller than M_L. In order to see what impact this might have on the results we replot Campbell's models on Fig. 4-12 using $M = m_b$ (Note: this is only strictly valid for $M < 6.0$ where $M = M_L$). As seen from Fig. 4-12 the scaling of PGA with magnitude is still significantly different between all three models. We may conclude from these comparisons that the relations used to convert between scales is an important consideration in the development of a ground motion model in the EUS.

We only know of one model that falls into Category D-2. This is the latest version of the model of Dr. Nuttli and is part of a long developmental process. Appendix C-A gives the details of the model and some other reflections on the questions before this panel by Dr. Nuttli. Figure 4-13 compares Nuttli's (App. C-A) model with his 1979 model given by Eq. (4-34).

E———E Campbell's Epicentral Model (4-41)
C———C Campbell's Closest Approach (4-42)
——— SSMRP Model (4-35)

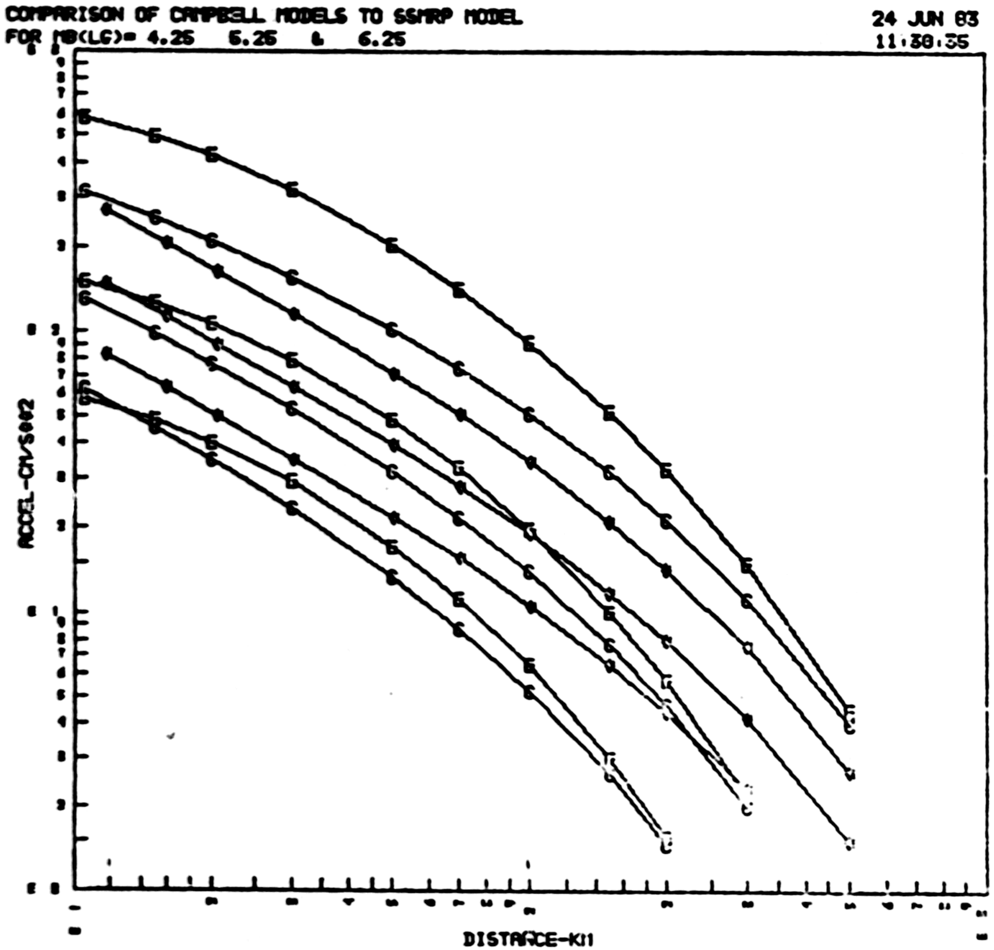

Fig. 4.11 Comparison of Campbell models to SSMRP model.

E——E Campbell's Epicentral Model
C——C Campbell's Closest Approach
—— SSMRP Model

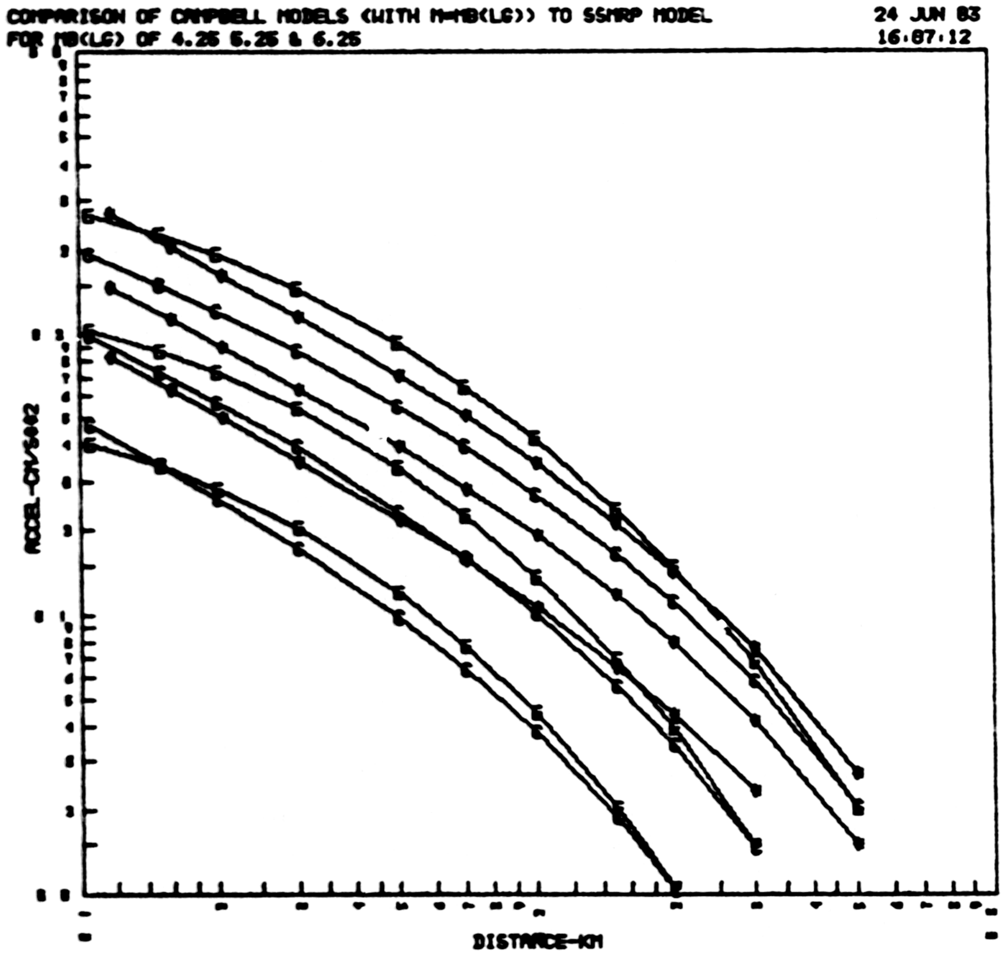

Fig. 4.12 Comparison of Campbell models to SSMRP model.

N———N (83) Model
X———X (79) Model

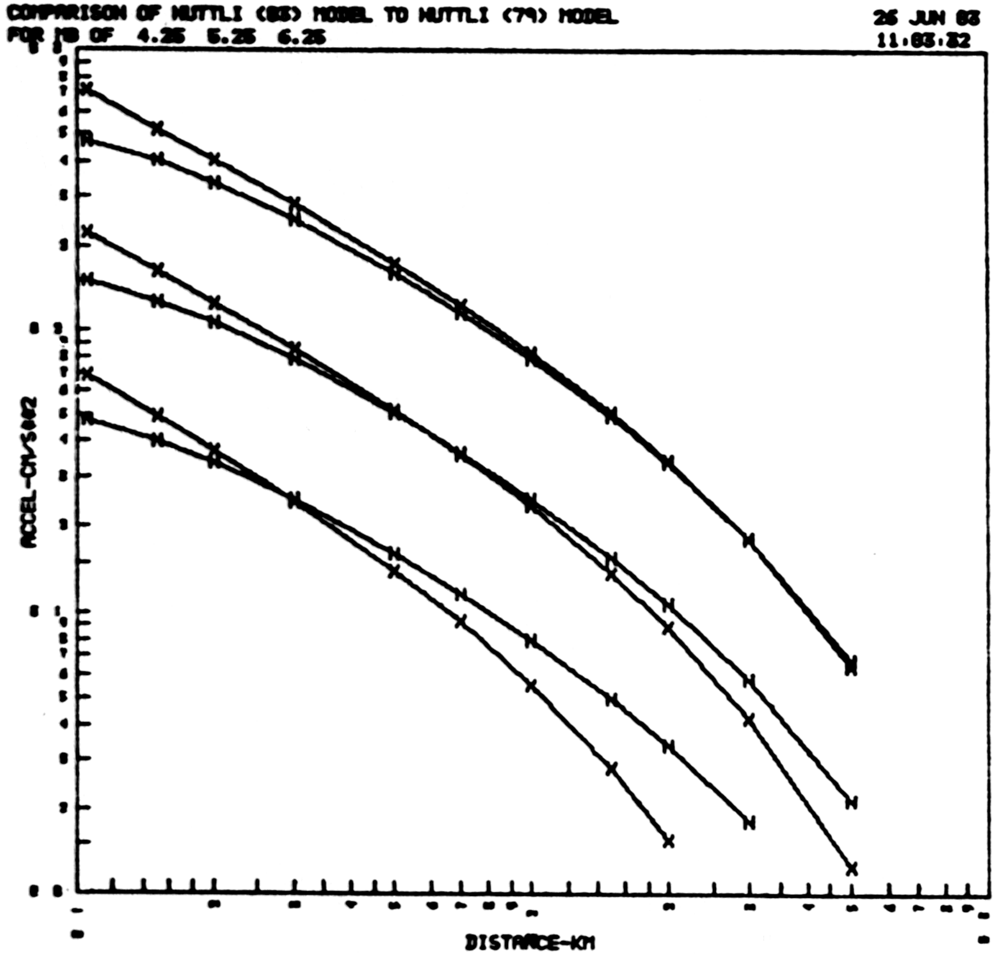

Fig. 4.13 Comparison of Nuttli model (83) to (79) model.

To make this plot we assume a depth of h = 12 km in his App. C-A model and take the distance R in both models to be the same. The models are found to be very similar--the differences arise primarily from the inclusion of the depth term and the change to a constant value for anelastic attenuation in the App. C-A model.

Figure 4-14 compares Campbell's epicentral model, Eq. (4-42), the SSMRP model, Eq. (4-37), Nuttli's App. C-A model and the Intensity Based Magnitude-Weighted Model, Eq. (4-32). The models of Campbell and Nuttli are very similar, except for differences in anelastic attenuation at the smaller magnitudes. The SSMRP model exhibits substantially less magnitude scaling and the magnitude-weighted model exhibits substantially less attenuation than the other models.

To facilitate making additional comparisons we have provided you with clear overlays of several of the key figures.

E——E Campbell's Epicentral Model
L——L SSMRP Model
N——N Nuttli's 83 Model (Appendix A)

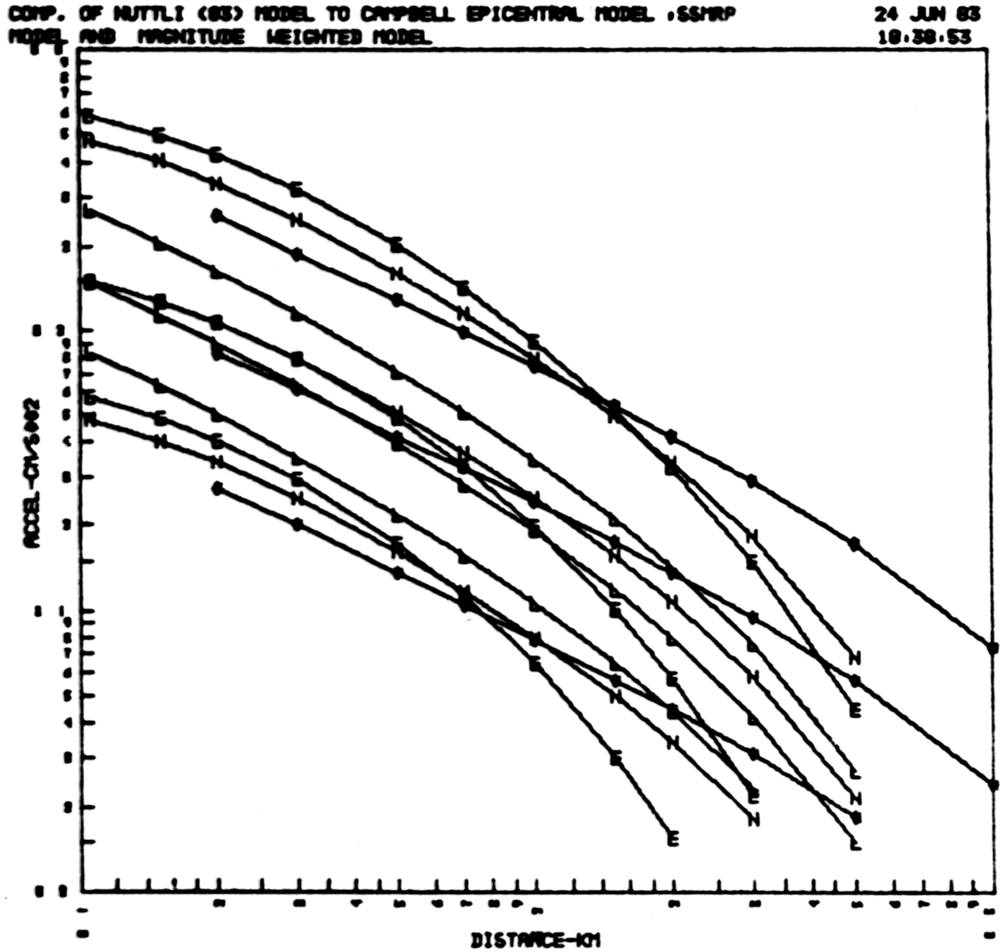

Fig. 4.14 Comparison of Campbell's epicentral model, SSMRP model and magnitude weighted model.

5.0 REVIEW OF VELOCITY AND SPECTRAL MODELS

Only a few of the investigators referenced in Section 4 have developed scaling relationships for peak velocity and response spectral ordinates. This creates a dilemma, since it is the probabilistic prediction of response spectra that is ultimately required for the characterization of seismic hazards in the EUS.

Since a discussion of peak velocity relations would be very similar to the previous discussion on peak acceleration, no presentation of actual models will be made here. Rather, the reader may refer to the Questionnaire Section 7 for a list of available models.

Of all the investigations referred to in Section 4, only three present models for response spectral ordinates. Two of these, the "distance-weighted" and "magnitude-weighted" intensity models of Bernreuter (1981b), were developed for the previous SEP study. The only other available model is a "no-weighted" intensity model based on the approach taken by Trifunac and Brady (1975) to develop similar relations for peak ground motion parameters. Because of the importance of response spectra, we feel it necessary to augment these limited models with models based on standard response spectral shapes.

Three spectral shapes will be considered; these are (1) the shape recommended by the Nuclear Regulatory Commission for the seismic design of Nuclear Power Plants (USAEC, 1973), (2) the shape recommended by the Applied Technology Council for the seismic design of buildings (NBS, 1978), and (3) the shape recommended by Newmark and Hall (1982) for the seismic design of all types of buildings (although originally developed for the design of nuclear power plants). While other spectral shape models exist, these three comprise those commonly used in practice. Of course, if you feel another model should be considered, you may indicate so in the Questionnaire. The following is a brief discussion of each model.

5.1 Nuclear Regulatory Commission

The response spectral shape recommended by the Nuclear Regulatory Commission (NRC) for the design of nuclear power plants is described in U. S. Atomic Energy Commission Regulatory guide 1.60 (USAEC, 1973). This shape is based on a statistical analysis of response spectra of strong-motion earthquakes as described by Newmark et al. (1973a). It is a broad-band spectrum, encompassing earthquakes of various sizes and distances. The NRC regulatory staff has determined this shape to be acceptable for defining the Design Response Spectra representing the effects of the vibratory motion of the Safe Shutdown Earthquake (SSE), one-half the SSE, and the Operating Basis Earthquake (OBE) for sites underlain by either rock or soil deposits and covering all frequencies of interest. They further indicate that this shape should not be used for sites that are relatively close to the epicenter of an expected earthquake or have physical characteristics that could significantly affect the spectral pattern of input motion, such as being underlain by poor soil deposits.

The spectrum shape recommended in Regulatory Guide 1.60 was selected to represent an 84th percentile spectrum when anchored to a median value of PGA. This makes this spectrum incompatible with the requirements of our project, which is designed to estimate a median or "best estimate" spectrum for a given probability of exceedance and to specify appropriate confidence limits. The 50th percentile (median) spectral shape consistent with Regulatory Guide 1.60 was obtained from Newmark et al. (1973a). To meet the program objectives the median amplification factors for each frequency control point was estimated from the ratio of the 84.1% and 50% amplification factors given in the original studies used to establish the amplification factors for each control point. This resulted in 5%-damped median amplification factors that are 23% and 26% lower in the acceleration domain (control points at 9 Hz and 2.5 Hz, respectively) and 31% lower in the displacement domain (control point at 0.25 Hz) than the corresponding 84.1% amplification factors. This median spectral shape will be referred to as the Modified Regulatory Guide 1.60 spectrum.

The spectrum based on an 84th percentile shape is shown in Fig. 5.1 for damping values of 0.5, 2, 5, 7 and 10% and a peak horizontal acceleration of 1g. The spectrum may be adjusted to any other value of PGA by linearly scaling Fig. 5-1 in proportion to the desired value of peak acceleration. Thus, the shape remains independent of magnitude, distance, and site characteristics. The applicable amplification factors and control points used to construct the spectrum for a specified PGA is given in Table 5-1.

5.2 Applied Technology Council

The response spectral shapes recommended by the Applied Technology Council (ATC) for the seismic design of buildings is described in National Bureau of Standards Special Publication 510 (NBS, 1978). Spectral shapes representative of different soil conditions were selected on the basis of a statistical study of the spectral shapes developed on such soils close to the seismic source zone in past earthquakes (Seed et al., 1976; Hayashi et al., 1971). They represent smoothed spectral shapes for the following three soil profiles.

Soil Profile Type S_1: Rock of any characteristic, either shale-like or crystalline in nature (such material may be characterized by a shear wave velocity greater than 2500 ft/sec); or stiff soil conditions where the soil depth is less than 200 ft and the soil types overlying rock are stable deposits of sand, gravels, or stiffer clays.

Soil Profile Type S_2: Deep cohesionless or stiff clay soil conditions, including sites where the soil depth exceeds 200 ft and the soil types overlying rock are stable deposits of sands, gravels, or stiff clays.

Soil Profile Type S_3: Soft-to-medium stiff clays and sands, characterized by 30 ft or more of soft-to-medium-stiff clay with or without intervening layers of sand or other cohesionless soils.

TABLE 5-1

SPECTRUM AMPLIFICATION FACTORS FOR HORIZONTAL
ELASTIC RESPONSE

(Taken in Part from Newmark et al., 1973 a)

Damping	One Sigma (84.1%)				Median (50%)			
% Critical		Accel.		Displ.		Accel.		Displ.
	33 Hz	9 Hz	2.5Hz	0.25 Hz	33 Hz	9 Hz	2.5 Hz	0.25 Hz
0.5	1.0	4.96	5.95	3.20	1.0	3.11	3.84	2.11
2.0	1.0	3.54	4.25	2.50	1.0	2.53	2.93	1.67
5.0	1.0	2.61	3.13	2.05	1.0	2.01	2.32	1.41
7.0	1.0	2.27	2.72	1.88	1.0	1.91	2.09	1.32
10.0	1.0	1.90	2.28	1.70	1.0	1.62	1.73	1.21

Note: Maximum ground displacement is taken proportional to maximum ground acceleration, and is 36 in. for ground acceleration of 1g.

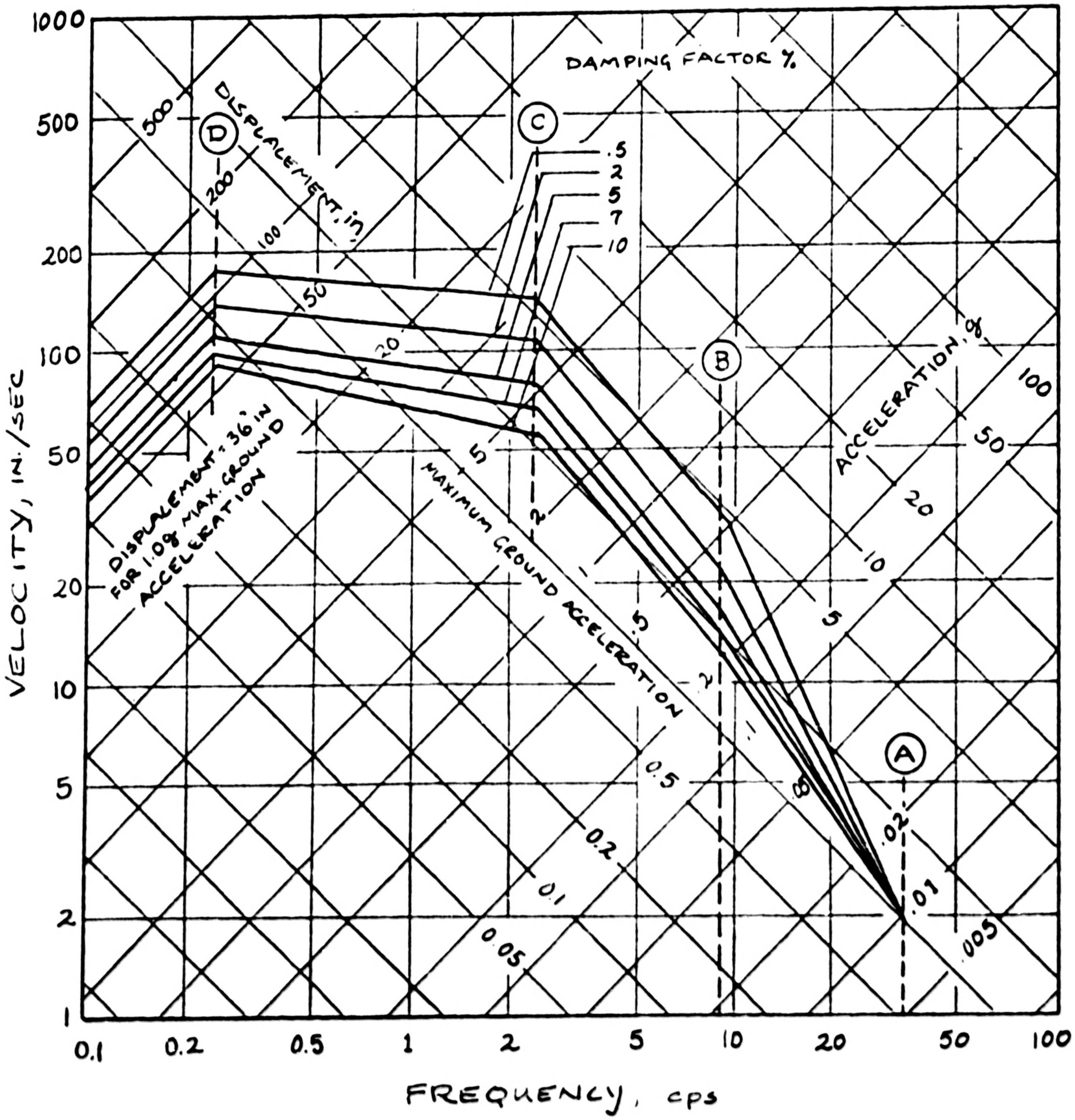

FIGURE 5-1. Horizontal design response spectra-scaled to 1g horizontal ground acceleration (USAEC, 1973).

The spectral shapes are used by ATC in conjunction with two indeces - A_a, a parameter numerically equal to Effective Peak Acceleration (specified in units of g), and A_v, a parameter related to Effective Peak Velocity--in defining a design response spectrum. However, the similarity of the spectral shapes to those recommended by Seed et al. (1976) suggests that they may be used in conjunction with PGA to adequately represent ground motion spectra for use in our project. Spectra for an Effective Peak Acceleration of 0.4g (A_a=0.4) and 5% damping are shown in Fig. 5.2. The value of A_a for Soil Profile Type S_3 has been reduced by 20% as recommended by ATC. This would not be required when anchoring the spectral shapes to PGA, as this parameter would already contain the effects of site characteristics. The spectra may be adjusted to any other value of A_a or PGA by linearly scaling Fig. 5-2 in proportion to the desired value of acceleration. However, for relatively large distances where $A_v > A_a$, ATC recommends that the velocity portion of the spectra (the horizontal portion in Fig. 5-2) be multiplied by the ratio of A_v to A_a and the remainder of the spectra extended to maintain the same overall form. This takes into account the change in spectral shape that has been observed to occur at large distances. However, the shapes remain independent of earthquake magnitude.

5.3 Newmark-Hall

The response spectral shapes recommended by Newark and Hall for the seismic design of buildings is described in a Monograph published by The Earthquake Engineering Research Institute (Newmark and Hall, 1982). The development of these shapes has been an evolutionary process, but has been primarily based on the statistical studies of Newmark et al. (1973 b), Hall et al., (1976) and Newmark and Hall (1978). They recommend that appropriate regions of the spectra be scaled by peak acceleration, peak velocity, and peak displacement. This enables the shape to vary with magnitude, distance, and site characteristics in accordance with the variation in these peak parameters.

While Newmark and Hall give amplification factors for both median and 84th percentile shapes, the median values are of interest in our study. Table 5-2 presents these amplification factors for various values of damping. The factors labeled A, V and D represent amplification factors based on peak acceleration, peak velocity and peak displacement, respectively. These domains are defined in fig. 5-3 which gives the 84th percentile, 5%-damped spectrum for a peak acceleration of 0.5g, a peak velocity of 61 cm/sec, and a peak displacement of 45 cm. The corresponding median spectrum would be reduced by 22% in the acceleration domain (A), 28% in the velocity domain (V), and 31% in the displacement domain (D) with respect to the 84th percentile spectrum.

Newmark and Hall recommend that, lacking other information, values of peak velocity (v) may be estimated from peak acceleration (a) by taking a v/a ratio of 48 in/sec/g for competent soil conditions and a v/a ratio of 36 in/sec/g for rock. Peak displacement (d) may be estimated by taking the ratio ad/v^2 to equal about 6.0. The recommendation concerning v/a will be followed when

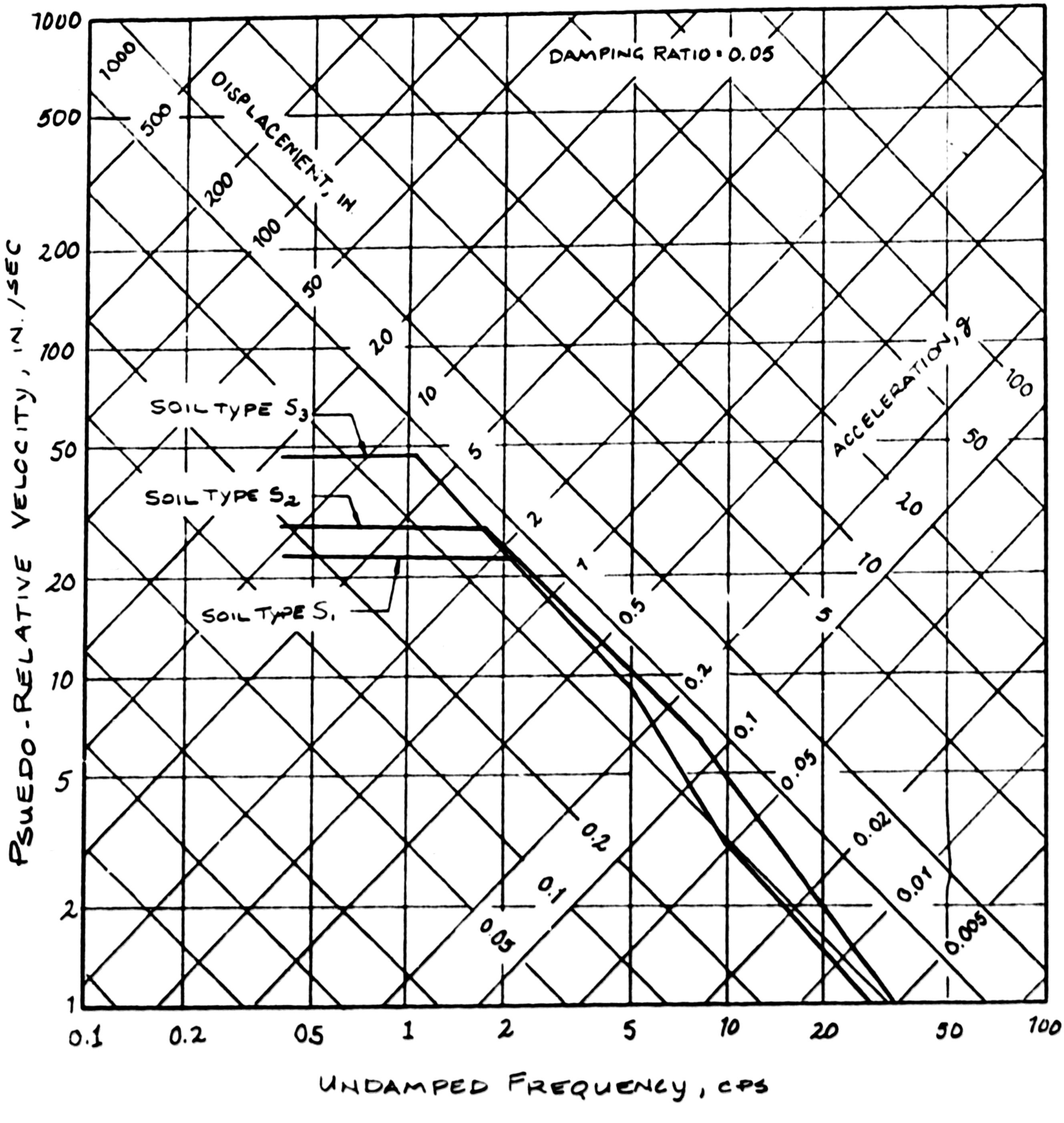

FIGURE 5-2. Ground motion spectra for Map Area 7 (A α = 0.4), (NBS, 1978).

ground motion models for peak velocity are not available. Since we are not interested in frequencies less than 0.5 Hz, it will not be necessary to estimate peak displacements.

A comparison of the three median spectral shapes for a PGA of 1g, and a damping value of 5% may be found in Fig. 5-4 for competent soil conditions and Fig. 5-5 for rock. These figures indicate that the only major disagreement among the models is for frequencies greater than 10 Hz, where the ATC shape exhibits more high-frequency content than the other two. The effect of rock is to reduce the spectral ordinates in the velocity domain for those spectra incorporating site conditions. The site-independent shape represented by the Modified Regulatory Guide 1.60 spectrum tends to fall between the soil and rock spectra of the Newmark-Hall and ATC studies. Because of the classification of stiff soil with rock in the ATC study, spectra representing both stiff soils (S_1) and deep soils (S_2) appear in Fig. 5-4. The ATC spectra are found to bracket both the site-independent Modified Reg. Guide 1.60 spectrum and the soil spectrum of Newmark-Hall.

TABLE 5-2

SPECTRUM AMPLIFICATION FACTORS FOR HORIZONTAL ELASTIC RESPONSE

(Newmark and Hall, 1982)

Damping,	One Sigma (84.1%)			Median (50%)		
% Critical	A	V	D	A	V	D
0.5	5.10	3.84	3.04	3.68	2.59	2.01
1	4.38	3.38	2.73	3.21	2.31	1.82
2	3.66	2.92	2.42	2.74	2.03	1.63
3	3.24	2.64	2.24	2.46	1.86	1.52
5	2.71	2.30	2.01	2.12	1.65	1.39
7	2.36	2.08	1.85	1.89	1.51	1.29
10	1.99	1.84	1.69	1.64	1.37	1.20
20	1.26	1.37	1.38	1.17	1.08	1.01

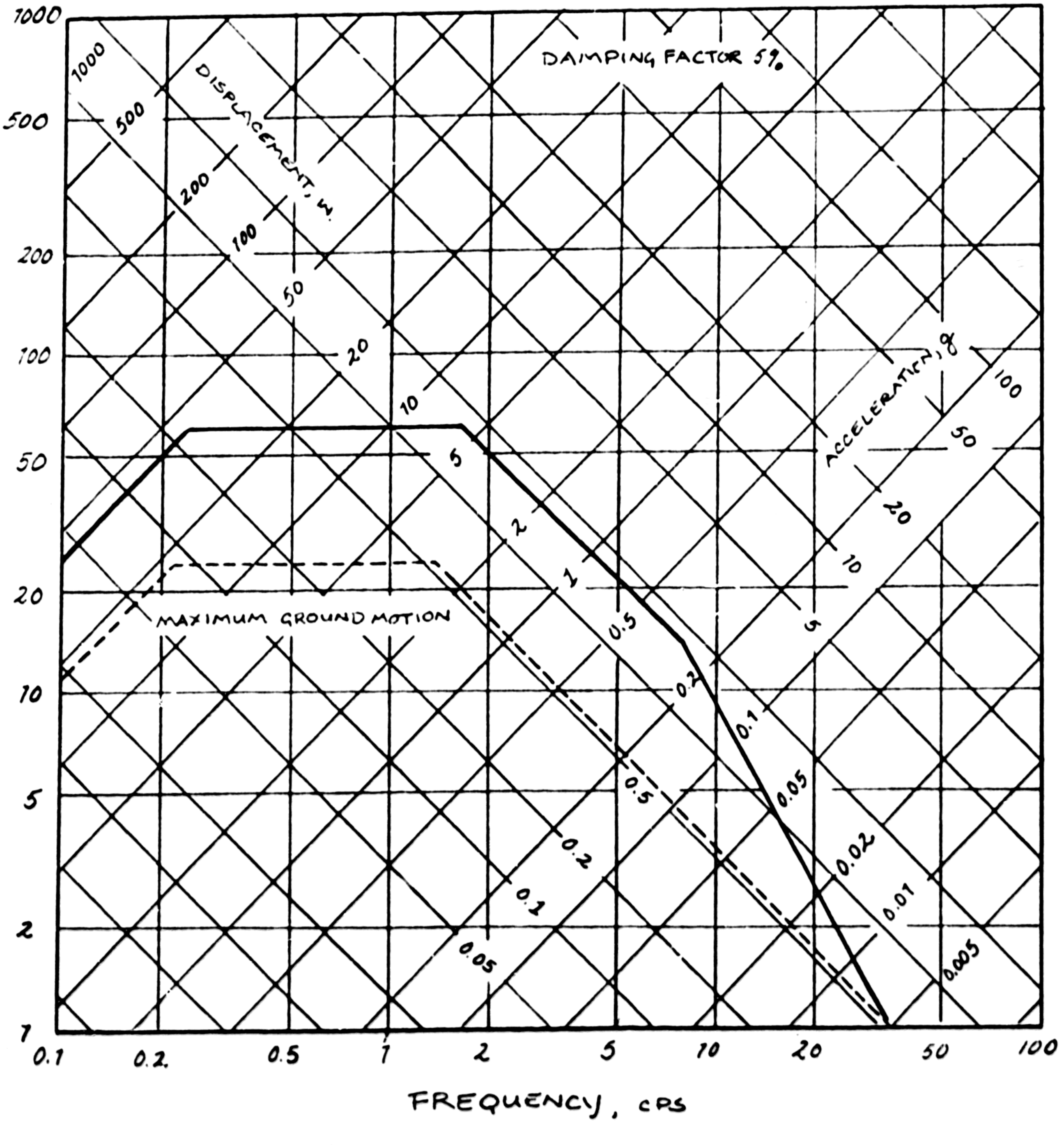

FIG. 5-3. ELASTIC DESIGN SPECTRUM, HORIZONTAL MOTION, FOR 0.5g MAXIMUM ACCELERATION, 5% DAMPING, ONE SIGMA CUMULATIVE PROBABILITY (NEWMARK AND HALL, 1982).

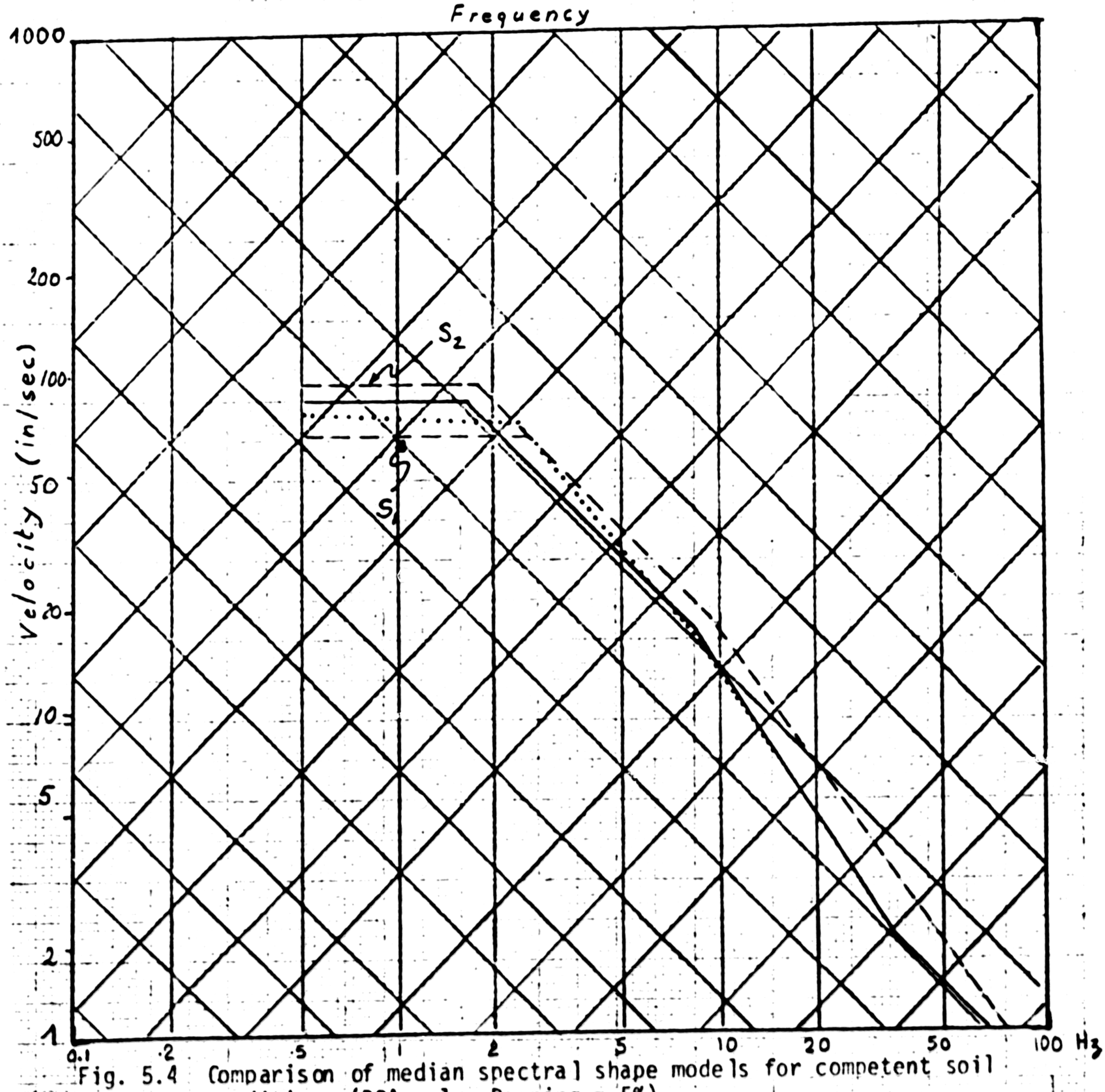

Fig. 5.4 Comparison of median spectral shape models for competent soil conditions (PGA = 1g, Damping = 5%)

——— Newmark-Hall
– – – ATC
······ Modified Reg. Guide 1.60

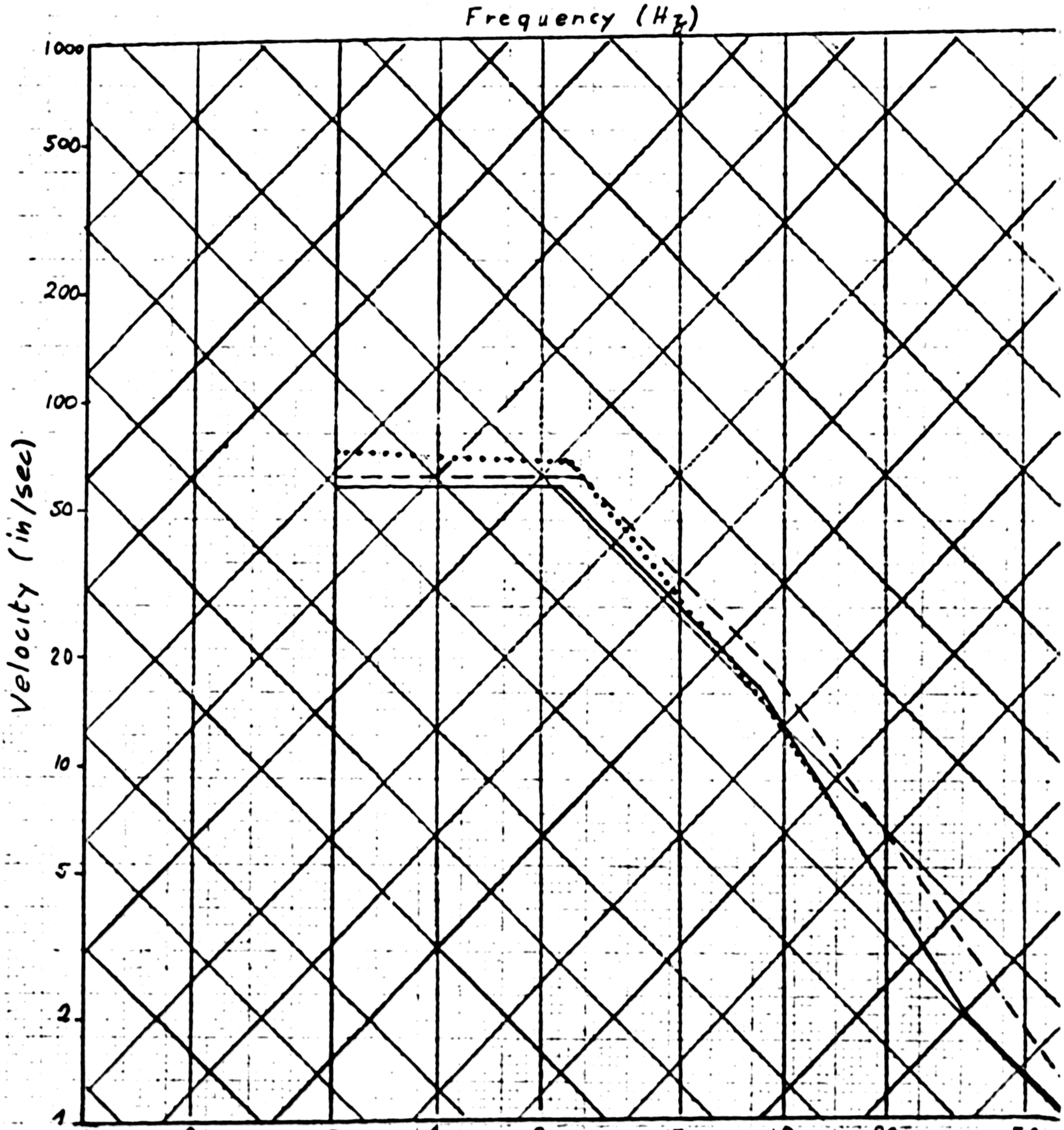

Fig. 5.5 Comparison of median spectral shape models for rock (PGA = 1 Damping = 5%)

—— Newmark-Hall

– – – ATC

····· Modified Reg. Guide 1.60

6.0. EASTERN U.S STRONG-MOTION DATA

There is very little strong-motion data available in the EUS. Table 6-1 summarizes what data are currently available for earthquakes of $m_b \geq 3.0$. The recent New Brunswick aftershocks and Gaza, New Hampshire earthquake have substantially increased this data set from the three earthquakes that had been recorded prior to 1983.

In Figures 6-1 to 6-3, we compare selected maximum values of horizontal PGA, listed in Table 6-1, with the ground motion model of Nuttli App. C-A. Fig. 6-1 presents data from the New Brunswick aftershock of March 31, 1982 (m_b=4.8), Fig. 6-2 presents data from the Gaza, N.H., earthquake (m_b = 4.7), and Fig. 6-3 presents data from four New Brunswick aftershocks of m_b = 4.0-4.6.

To facilitate further comparisons, horizontal PGA data listed in Table 6-1 are plotted in groups of one-half magnitude units in Figures 6-4 to 6-7. These groups represent magnitude ranges of 3.0-3.4, 3.5-3.9, 4.0-4.4, and 4.5-5.0. These plots are drawn at the same scale as those displaying the ground motion models in Section 4. We have included clear copies of these data plots so that they may be easily overlain on any plot in Section 4 to facilitate comparison of the various ground motion models with these data.

Table 6-1

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
6/13/75	New Madrid	4-4.25	9	S83W	43		Herrmann (1977)
New Madrid Area		D=9		Down	31		
				S02E	64		
3/25/76	Arkabutla	5.0	99	S28W	41		
0041 UT	Dam, Ms			Down	10		
	Toe	D=12		S62E	22		
	Crest		99	S28W	21		
				Down	6		
				S62E	10		

Table continued on next page

Table 6-1 (Continued)

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
	Right abut.		99	S28W	11		
				Down	6		
				SG2E	11		
	Tiptonville TN		130	S70W	11		
				Down	12		
				S20E	17		
	New Madrid MO		131	S88W	13		
				Down	10		
				S03E	11		

Table continued on next page

Table 6-1 (Continued)

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
	Wappapello	5.0	150	S38W	10		
	Dam Mo	D=12		Down	5		
	Rt. Toe			S52E	12		
	Right		150	S38W	6		
	Crest			Down	5		
				S52E	6		
3/25/76	Arkabutta	4.5	99	S28W	10		
0100 UT	Dam			Down	4		
	Left Toe	D=14		S62E	5		

Table continued on next page

Table 6-1 (Continued)

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
3/31/82	Holmes	4.8	6	L	178	1.3	Weichert et al (1982)
New Brunswick	Lake			V	151	0.5	
				T	340	1.4	
	Mitchell		4	L	149	1.8	The acceleration
	Lake Rd.			V	571	2.9	values given are
				T	230	1.9	corrected values and are often significantly
	Loggie		6	L	292	1.8	higher than the raw
	Lodge			V	302	1.8	uncorrected records.
				T	564	4.1	

Table continued on next page

Table 6-1 (Continued)

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
	Indian		3	L	417	2.7	
	Brook			V	144	0.9	
				T	405	3.11	
	Bear Lakes		12	L	58	0.4	These are shallow
				V	-	-	earthquakes with
				T	138	1.1	depths of 0--4 km
4/2/82	Mitchell	4.3	4	L	66	0.3	Late trigger
New Brunswick	Link			V	54	0.3	Missed Most
	Road			T	77	0.5	of record

Table continued on next page

Table 6-1 (Continued)

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
	Bear Lakes		12	L	-	-	
				V	-	-	
				T	44	0.4	
4/11/82	Bear Lakes	4.1	12	T	77	0.5	Late Trigger
4/28/82	Holmes Lake	3.4	6	L	74	0.3	Late Trigger
				V	41	0.2	
				T	56	0.3	

Table continued on next page

Table 6-1 (Continued)

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
5/6/82	Holms	4.0	6	L	42	0.3	Weichert et al. (1982)
New Brunswick	Lake			V	24	0.2	
				T	71	0.7	Late Trigger
	Mitchell		4	L	54	0.4	
	Lk. Rd.			T	176	0.6	
				V	33	0.2	
	Loggie		7	L	115	1.4	
	Lodge			V	66	0.7	
				T	146	1.8	

Table continued on next page

Table 6-1 (Continued)

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
7/28/82	Indian Brook	3.7	1	L	300		
				V	180		
				T	230		
6/16/82 New Brunswick	Mitchell Lake Rd.	4.6	25	L	48	0.3	
				V	26	0.2	
				T	10	0.08	
	Indian Brook		27	L	15	0.2	
				V	27	0.2	
				T	17	0.1	

Table continued on next page

Table 6-1 (Continued)

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
New Brunswick	7A	3.5	8	V	83	0.4	Cranswick et. al
1/17/82		D=3.5		H1	83	1.2	(1982)
13:33:56.2GMT				H2	60	0.9	A number of recordings
	8A		10	V	18	0.1	were made for small
				H1	18	0.2	earthquakes. Only the
				H2	14	0.2	largest for which an
							estimate of the
							magnitude is
							available, is listed
1/19/82	Franklin	4.7	8	L	288		Toksoz (1982) and
Gaza, NH	Falls Dam	D=5		V	173		digitized records
	Abut.			T	540		obtained from the NRC
	Franklin		8	L	141		
	Falls Dam			V	271		
	Downstream			T	378		

Table continued on next page

Table 6-1 (Continued)

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
	Franklin		8	L	124		
	Falls Dam			V	114		
	Crest			T	307		
	Union		60	L	37		
	Village			V	29		
	Dam Down-			T	23		
	stream						
	Abutment		60	L	9		
				V	6		
				T	8		
	Crest		60	L	22		
				V	23		
				T	25		

Table continued on next page

Table 6-1 (Continued)

DATA FROM EUS EARTHQUAKES LARGER THAN MAGNITUDE 3.0

Date & Location	Instrument Loc.	Magnitude & Depth	Approx. Distance (km)	Comp	A_{max} (cm/s^2)	V_{max} (cm/s)	Reference & Remarks
	North Hart Dam Abut.		61	L	11		
				V	4		
				T	7		
	Crest		61	L	37		
				V	16		
				T	38		
	N. Springfield Dam Downstream		76	L	31		
				V	14		
				T	23		
	Crest		76	L	24		
				V	22		
				T	22		

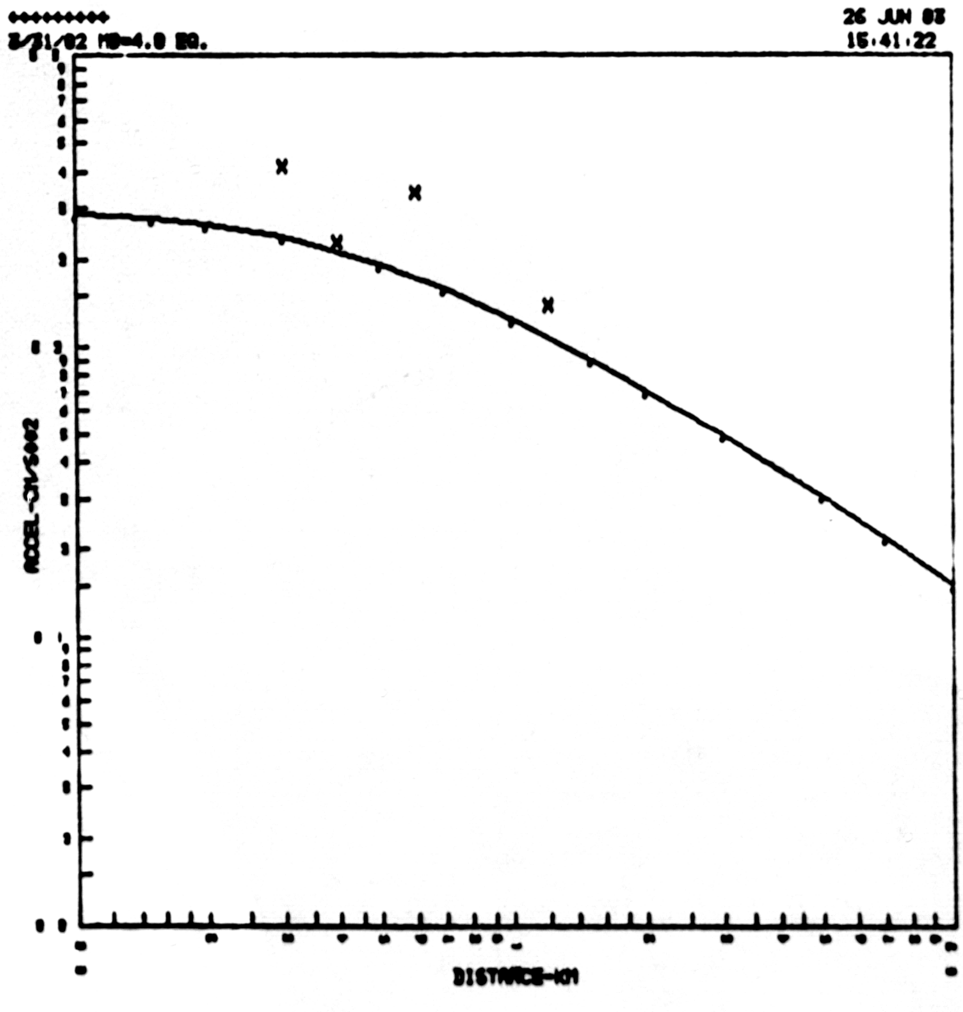

Figure 6-1 Nuttli's (App. C-A) model compared to data from the New Brunswick aftershock of 3/31/82 (m_b = 4.8).

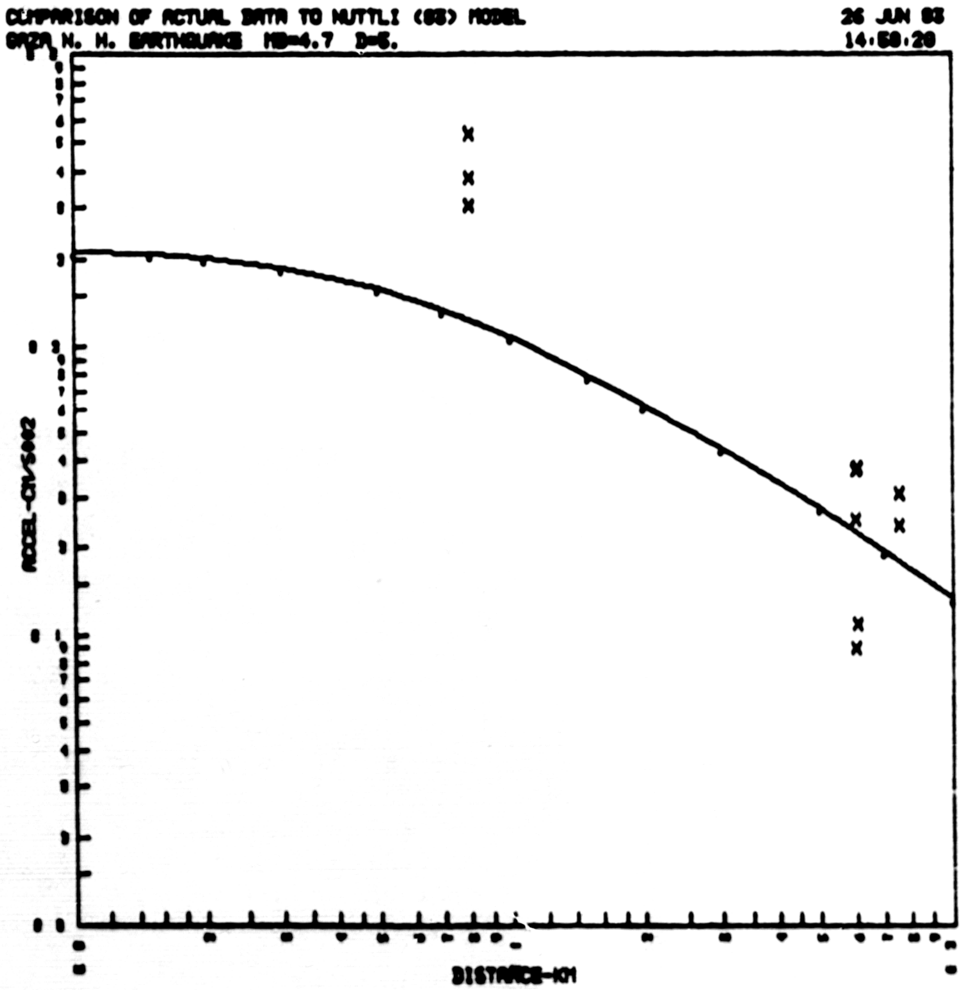

Figure 6-2 Nuttli's (App. C-A) model compared to data from the Gaza, N.H., earthquake (m_b = 4.7).

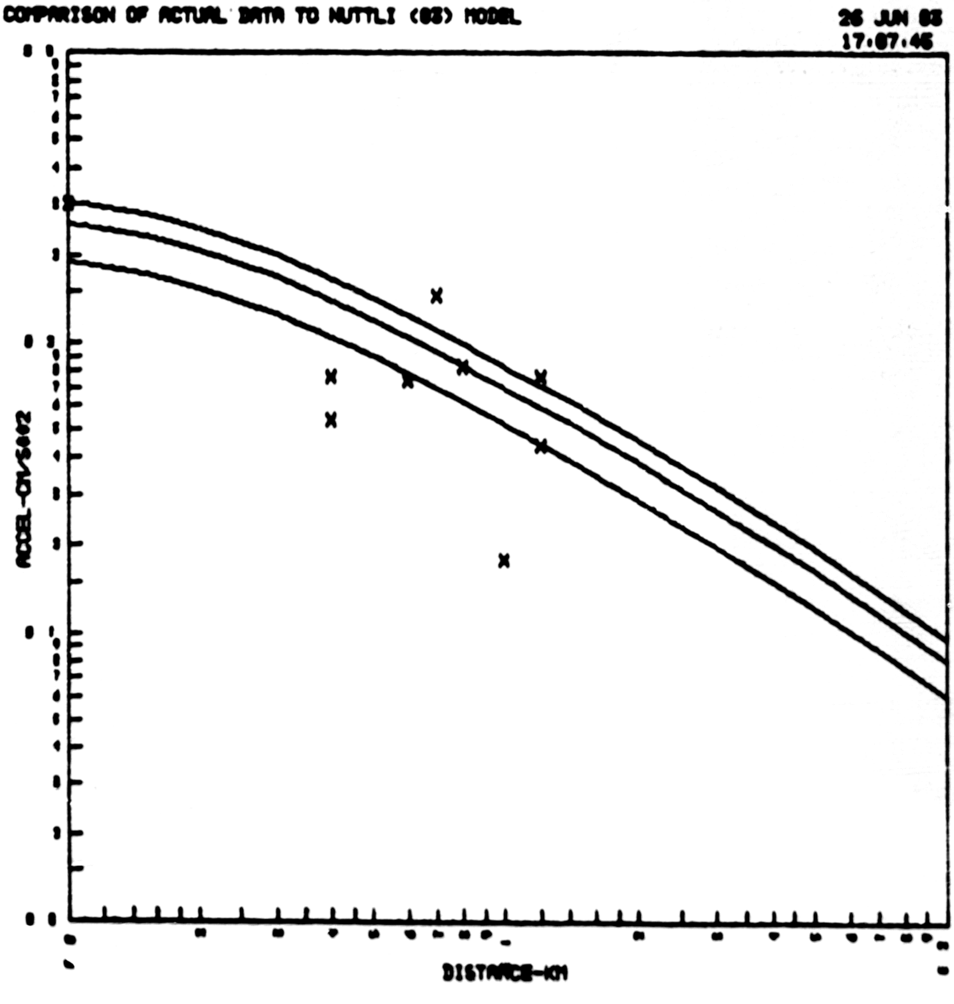

Figure 6-3 Data from New Brunswick aftershocks (m_b = 4.0 - 4.6) compared to Nuttli's (App. C-A) model for m_b = 3.5, 4.0, 4.3 D=2km.

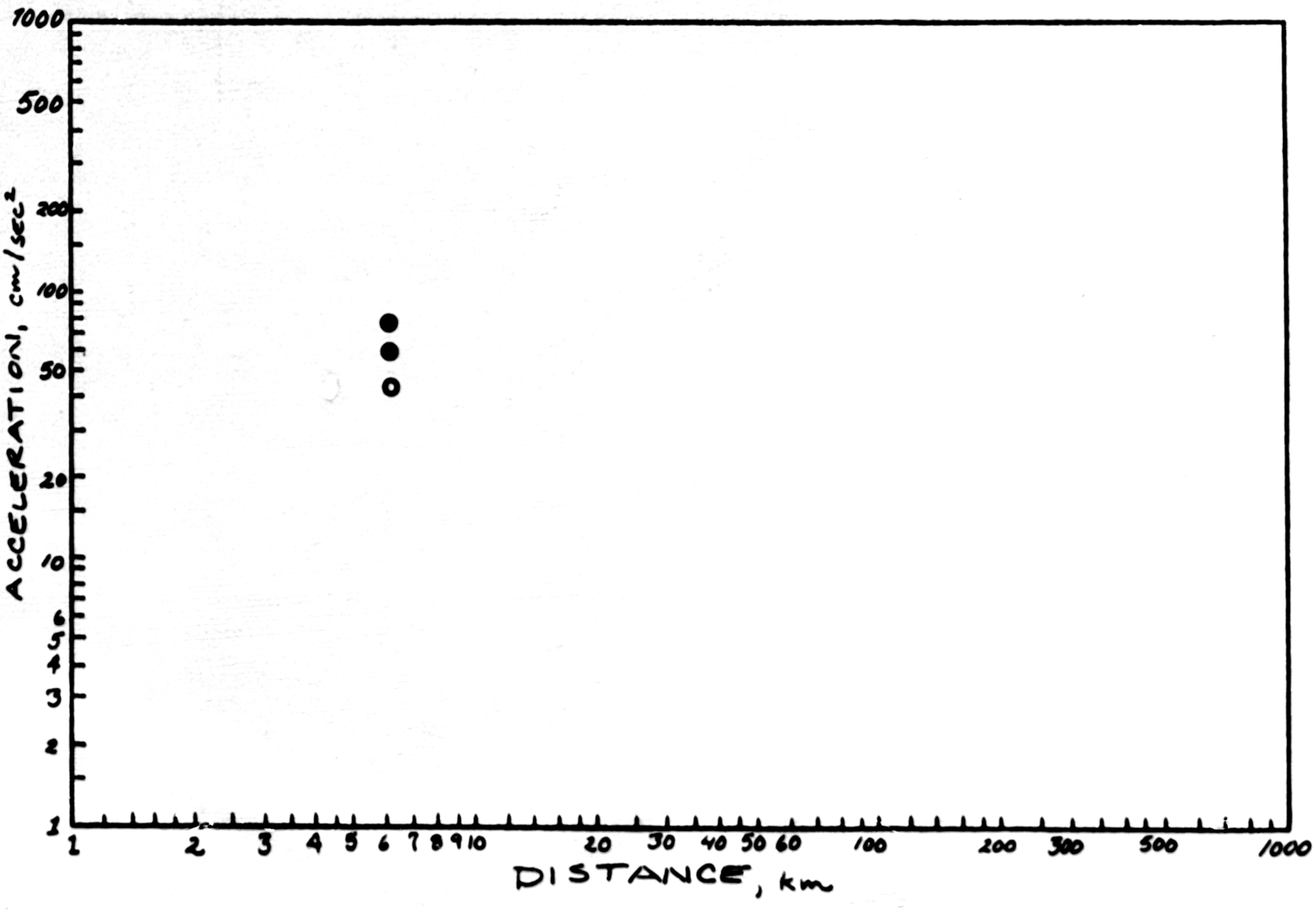

Figure 6.4 EUS strong motion data from earthquakes of m_b = 3.0 - 3.4.

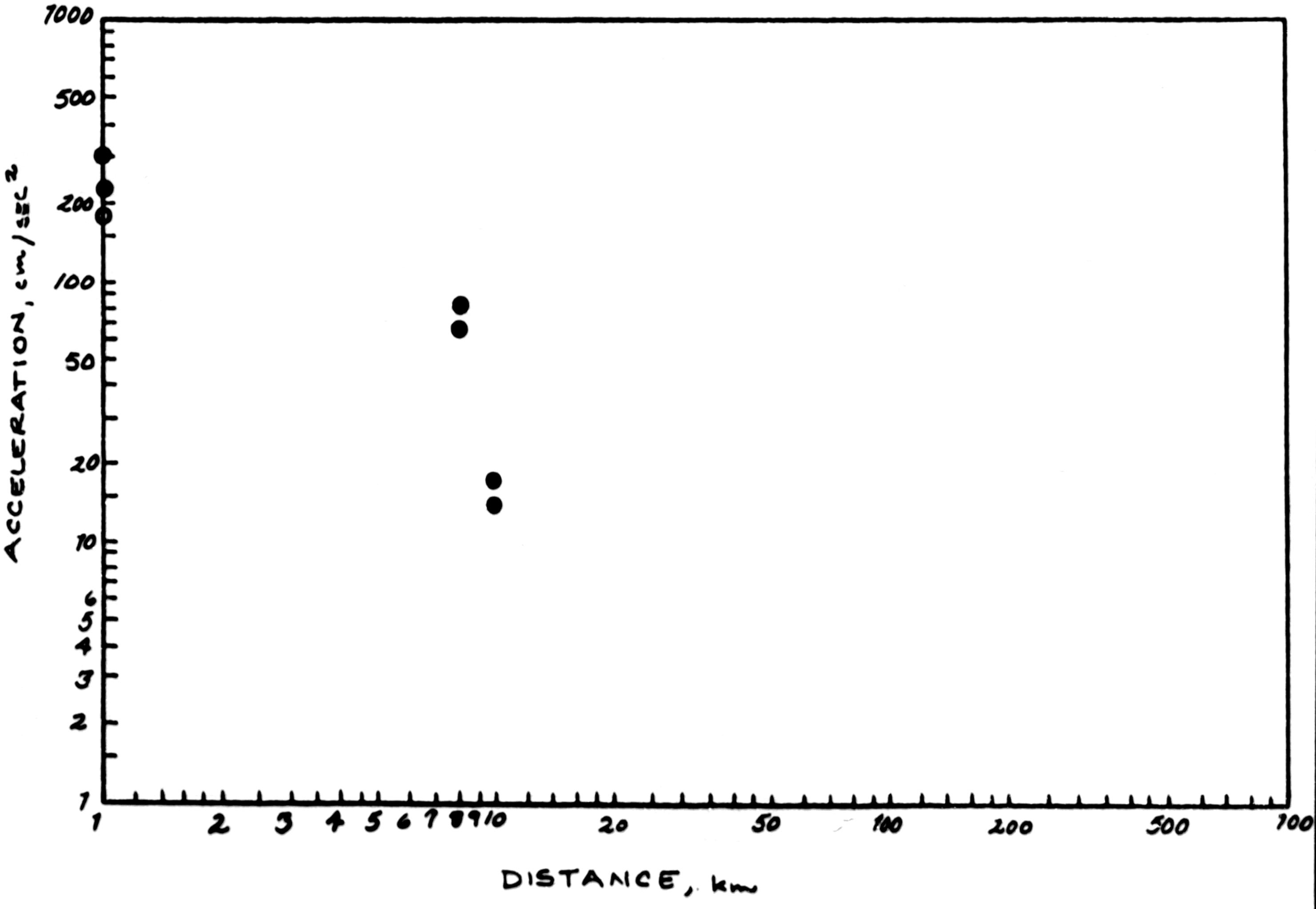

Figure 6.5 EUS strong motion data from earthquakes of m_b = 3.5 - 3.9.

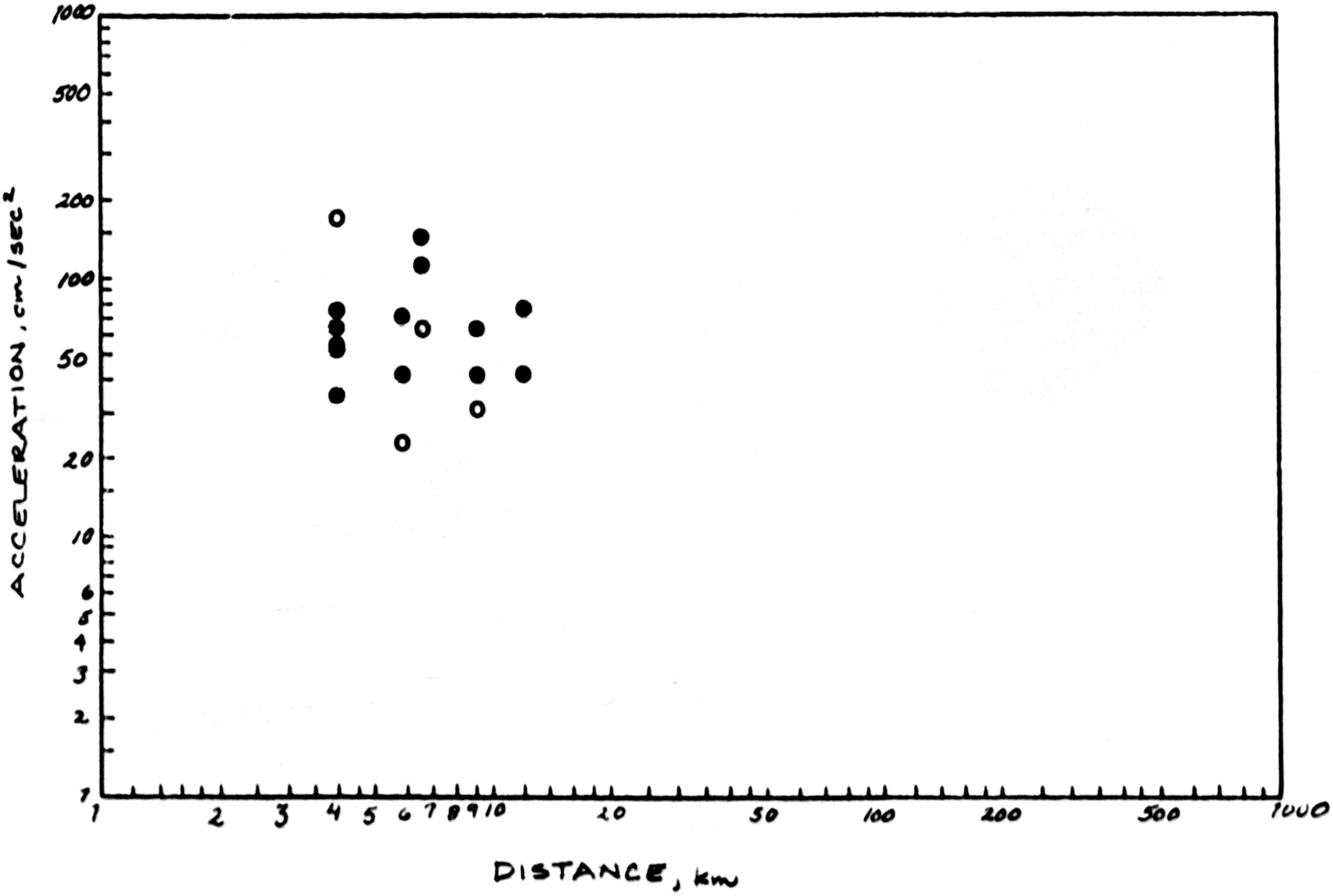

Figure 6.6 EUS strong motion data from earthquakes of m_b = 4.0 - 4.4.

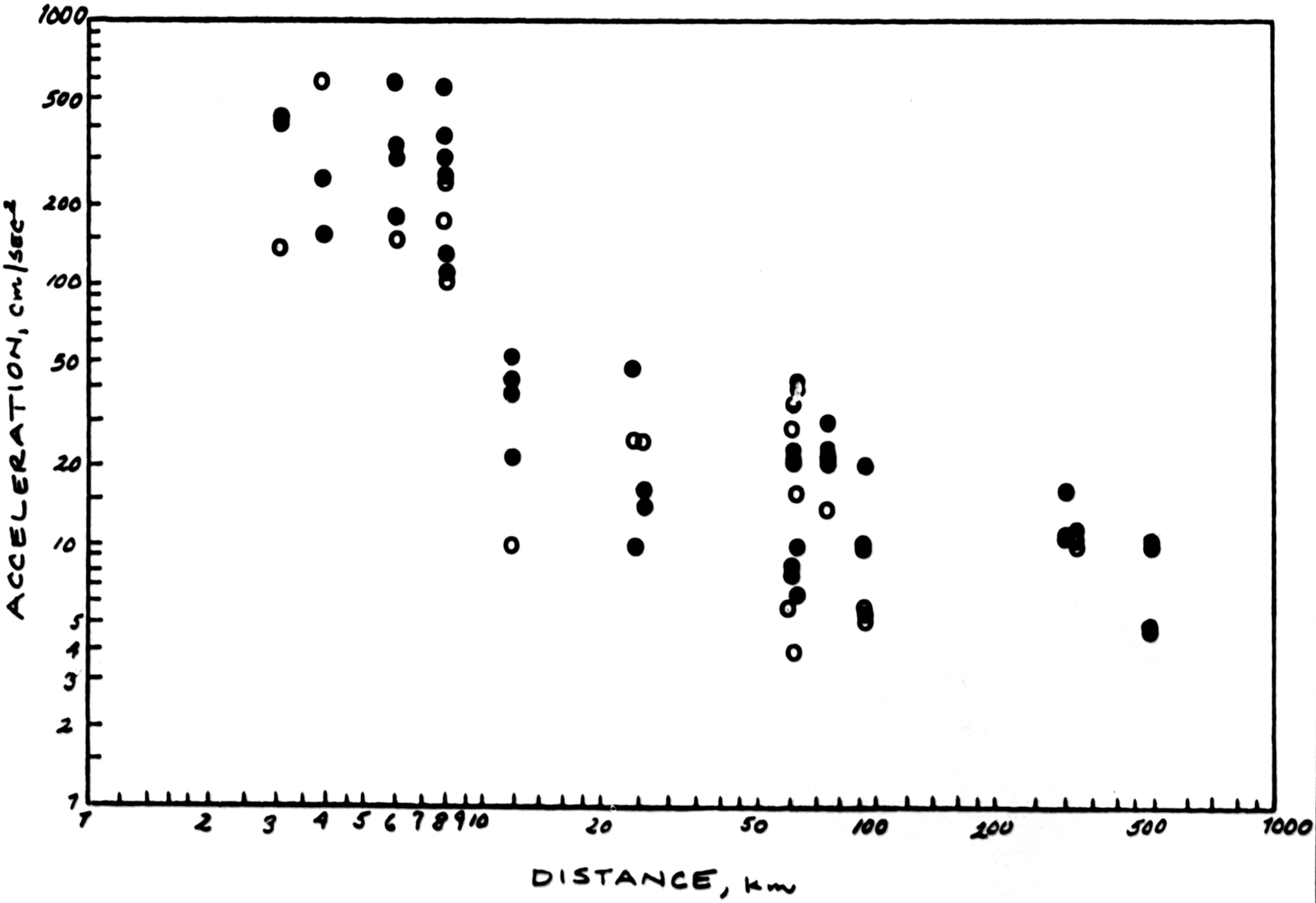

Figure 6.7 EUS strong motion data from earthquakes of m_b = 4.5 - 5.0.

7.0 QUESTIONNAIRE

7.1 INTRODUCTION

As part of the seismic hazard characterization of the Eastern United States, it is necessary to select an appropriate set of ground motion models to be used in assessing the seismic hazard at a specified site. This questionnaire is designed to elicit your opinion about the selection of the most appropriate models.

The previous sections contain a general discussion, based primarily on PGA, of EUS ground motion models which we would like you to consider in making your recommendations for the most appropriate models. We also will ask you to provide additional models if you feel they are needed. The collection of models chosen for your consideration were based on the discussion during the meeting of the panel, January 11-13, 1983, our review of the literature, and our judgment of the validity of the models to describe the attenuation of seismic energy and the ground motion at locations throughout the EUS.

As discussed in the previous sections, we have found it appropriate to partition the available ground motion models into two major categories:

1. <u>Intensity Based Models</u>

   Models based on using intensity as an intermediary variable to model ground motion as a function of the earthquake parameters. Most such models involve a combination of

   o an intensity-attenuation relation, $I_s = F(I_o,R)$, which relates site intensity to source intensity, and

   o a ground motion parameter-site intensity relation, GMP = $G(I_s,M,R)$ which relates ground motion parameters to site intensity and, perhaps, other earthquake characteristics such as magnitude and distance.

2. <u>Direct Models</u>

   Models based on using available data to model directly the ground motion parameter in terms of the earthquake parameters such as magnitude and source-to-site distance. Such models are generally based on the "theoretical attenuation curve"

   $$GMP = K(M)R^{-a} \exp(-\gamma R)$$

   where γ is the absorption coefficient and K(M) is a scale factor which is often expressed as a function of magnitude.

The former category, the Intensity Based Models, have been subdivided into five subcategories:

1-1. <u>No Weighting</u>: model combinations

$$I_s = F(I_o,R)$$
$$GMP = G(I_s)$$

in which the ground motion parameter is related to site intensity only.

1-2. <u>Distance Weighting</u>: model combinations

$$I_s = F(I_o,R)$$
$$GMP = G(I_s,R)$$

in which the ground motion parameter is related to site intensity and source-to-site distance.

1-3. <u>Magnitude Weighting</u>: model combinations

$$I_s = F(I_o,R)$$
$$GMP = G(I_s,M)$$

in which the ground motion parameter is related to site intensity and source magnitude.

1-4. <u>Magnitude and Distance Weighting</u>: model combinations

$$I_s = F(I_o,R)$$
$$GMP = G(I_s,M,R)$$

in which the ground motion parameter is related to site intensity, source magnitude, and source-to-site distance.

1-5. <u>Semi-Empirical</u>: models

$$GMP = H(M,R)$$

relating the ground motion parameter to earthquake magnitude and distance, but based on using intensity as an intermediary variable.

Note that subgroups 1-1 through 1-4 involve a pair of models which, in our hazard analysis, will be combined to relate the ground motion parameter to the earthquake parameters M and R. Since the intensity-attenuation model is derived independently of the ground motion parameter-site intensity model, any one of a number of intensity models can be combined with any of the ground motion parameter models.

The latter category group, the Direct Models, have been subdivided into two subcategories, based on the parameters which are expected to vary between the WUS and the EUS:

- o models in which only the absorption coefficient γ (or the quality factor Q) is assumed to be different for WUS and EUS;

- o models in which both the absorption coefficient γ and the scale parameter K(M) varies between the WUS and EUS.

Considering all possible combinations, we have identified 59 models for the peak ground acceleration PGA. Ideally, for each of these there would be a corresponding model for PGV and a corresponding set of spectra models. Unfortunately, not all PGA models have a corresponding model for PGV and there are only a few spectra models. Ideally, the same type of model would be used for all 3 parameters in the hazard analysis. However, to give you as much flexibility as possible in choosing the most appropriate models we will ask you to rank the models separately for PGA, PGV and spectra.

In characterizing the seismicity within a zone, the earthquake size is expressed in either magnitude or epicentral intensity. To estimate the hazard at a site it is necessary to assess the hazard based on each of the ground motion models. Since some ground motion models are expressed in terms of epicentral intensity and others in magnitude, a conversion of magnitude scales is required at some level. After consideration of the alternatives, we have chosen to make this conversion at the ground motion level. Thus, it is necessary to express each ground motion model in terms of both epicentral intensity and magnitude. To accomplish this conversion, we asked each member of our EUS Seismicity Panel to provide the proper conversions between scales. Since you may not feel that a ground motion model expressed in epicentral intensity to be as appropriate when converted to a model involving magnitude or vice versa, we will be asking you to select a separate set of models for intensity and magnitude.

Another issue which must be addressed in the selection of ground motion models is the question of the distance measure. Our hazard analysis is based on treating earthquakes as point sources so that the distance R in the ground motion model is treated as an epicentral distance. It must be recognized that some of the ground motion models are based on fault distance rather than epicentral distance. Thus, our treatment of R as epicentral distance may influence your choice of appropriate models. See Section 1.0 for additional discussion on this issue.

Finally, as discussed in Section 2.4, the choice of the ground motion model has a direct influence on the outcome of the hazard analysis. This influence is a function of the model as well as the extent of the random variation in the ground motion parameter (GMP). For purposes of the hazard analysis, we are approximating the random variation in the ground motion parameter by a lognormal distribution for which the ground motion model describes the expected value of the logarithm of GMP, given the earthquake parameters. Random variation is the inherent variation in GMP about its expected value due to a lot of unidentifiable factors. The extent of the random variation in GMP is described by the standard deviation of the logarithm of GMP (which is approximately the coefficient of variation of GMP). We will be asking you to estimate this standard deviation. In making an estimate it is important to recognize that the standard deviation associated with a specific ground motion model usually has both a random variation component as well as a modeling uncertainty component (see Section 2.4 of the accompanying report). It is the random component of this uncertainty that is of interest in this study. The modeling uncertainty is accounted for in the use of several models.

7.2 SELECTION PROCESS

We have identified four regions in the EUS, shown in Fig.7.1, for which it may be appropriate to change the values of some of the model coefficients, e.g., γ in the direct models. Also, a particular ground motion model may be appropriate for one region but not applicable in another. Thus, we will be asking you to select appropriate models for each of the four regions. We recognize that the actual physical situation is much more complex and the boundaries cannot be simply drawn, however, at this stage of the analysis we will limit the complexity of our model by partitioning the EUS into the four identified regions.

We have limited our analysis to the use of two "magnitude" scales, intensity (MMI) and body wave magnitude (m_b). It should be noted that (as discussed in Section 3.4) we are assuming m_{bLg} and m_b to be essentially equivalent. For simplicity we use the term m_b even though most of the magnitudes in the catalogs are in fact m_{bLg}.

Weighing the merits of using all the models available to describe ground motion versus (1) our capability to handle a large number of models in the hazard analysis and (2) your ability to reasonably distinguish between the models so as to rate them for their appropriateness has led us to the following method for eliciting your opinion about the ground motion models.

We have divided the ground motion models into seven subcategories identified in Section 7.1, five subgroups of Intensity Based Models and two subgroups of Direct Models. The models in each subcategory are catalogued in Section 7.3. For each of the two magnitude scales in each of the four regions (a total of 8 combinations) we would like you to:

For peak ground acceleration and peak ground velocity,

- Select from among <u>all</u> the models the <u>one</u> model which you consider the <u>most appropriate</u>. This is labeled the <u>Best Estimate Model</u>. (Note: if this model is an Intensity Based Ground Motion Model, the Best Estimate would consist of 2 models, an attenuation model and a GMP model.)

- For each of the seven (7) classes of models identified above, select the most appropriate model within the subcategory. Assign a <u>relative</u> "level of confidence" to each of the models. (Note: the sum of the confidences over the seven subcategories should equal 1.0.)

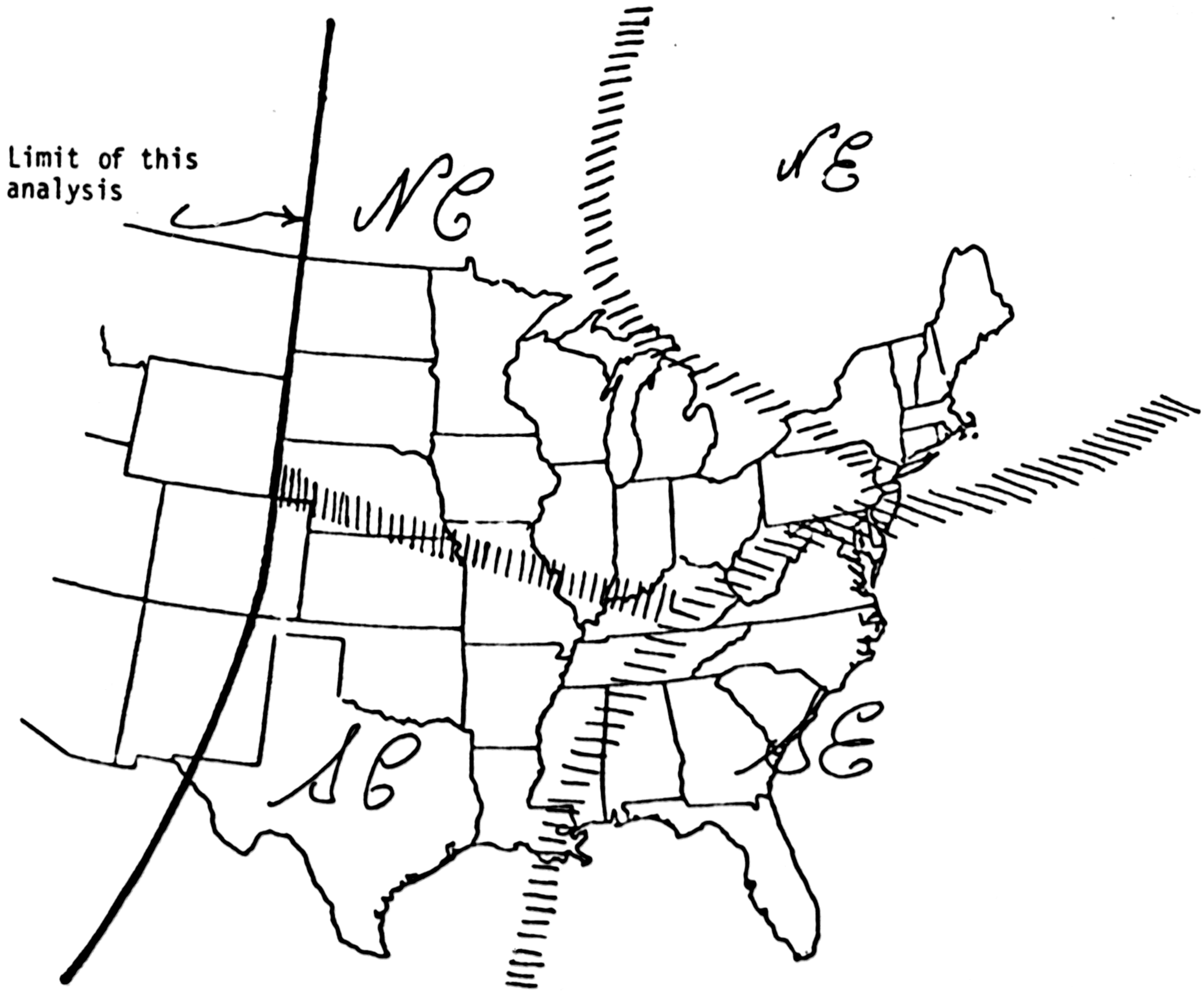

Fig. 7.1 Identification of four regions of the Eastern U.S. based on a compilation of the seismic zonation expert maps developed in this study, combined with a map of Q_o-contours from Singh & Herrmann (1983).

The "level of confidence" we ask you to express for each model is considered to reflect your degree of belief that the data, the modeling process, your knowledge of seismic attenuation and ground motion and any other relevant information supports the use of the specific model to describe ground motion within the given region. We expect that your "level of confidence" will reflect, to some degree, your opinions about the use of each of the different types of models (based on different modeling philosophies) for modeling ground motion. At a later date we will ask you to provide weights for all of the models (including any that different panel members may suggest).

For the spectra models,

- o Select the set (one for each frequency) of models which you consider most appropriate.
- o Assign a relative "level of confidence" to each of the models (Note: a zero level of confidence is acceptable).

7.3 MODELS

7.3.1 Peak Ground Acceleration

I. Intensity Based Models

Except for the models in Subcategory I-5, a ground motion model is a combination of (a) an intensity-attenuation model and (b) a ground motion parameter-site intensity model. The latter models form the basis of the Subcategories I-1 through I-4. The former models are:

A1. Bollinger (Charleston, South Carolina earthquake)

$$I_s = 2.87 + I_o - 0.00052R - 1.25 \ln R \qquad , R \geq 10$$

$$I_s = I_o \qquad , R < 10$$

A2. Bollinger (Giles County, Virginia earthquake)

$$I_s = 0.35 + I_o - 0.0038R - 0.34 \ln R$$

A3. Modified Gupta-Nuttli (Central U.S.)

$$I_s = 3.2 + I_o - 0.0011R - 1.17 \ln R \qquad , R \geq 15$$

$$I_s = I_o \qquad , R < 15$$

A4. LLNL (Southern Illinois earthquake)

$$I_s = 0.35 + I_o - 0.0046R - 0.31 \ln R$$

A5. Weston Geophysical Corporation (Ossippee earthquake)

$$I_s = 0.441 + I_o - 0.004R - 0.67 \ln R$$

Subcategory I-1. No Weighting (Equation number from Section 4)

G11. LLNL (1983) (Eq. 4-8)

$$\ln(a) = -1.69 + 0.86\ I_s$$

G12. LLNL (1983) (Eq. 4-9)

$$\ln(a) = -2.32 + 0.96\ I_s$$

G13. McGuire (1977) (Eqs. 4-3 and 4-7)

$$\ln(a) = \begin{cases} -0.83 + 0.85\ I_s & \text{(medium sites)} \\ 0.27 + 0.6\ I_s & \text{(soft sites)} \end{cases}$$

G14. Trifunac and Brady (1975) (Eq. 4-5)

$$\ln(a) = 0.032 + 0.69\ I_s$$

G15. Murphy and O'Brien (1977) (Eq. 4-6)

$$\ln(a) = 0.58 + 0.58\ I_s$$

G16. Trifunac (1976) (Eq. 4-4)

$$\ln(a) = -0.19 + 0.67\ I_s + 0.33S$$

S = 0 (alluvium)
S = 1 (intermediate rock sites)
S = 2 (basement rock sites)

Subcategory I-2. Distance Weighting

G21. Bernreuter (1981a) (Eq. 4-13)

$$\ln(a) = 1.79 + 0.57\ I_s - 0.323 \ln R$$

G22. McGuire (1977) (Eqs. 4-11 and 4-12)

$$\ln(a) = \begin{cases} 1.45 + 0.68\ I_s - 0.359 \ln R & \text{(medium sites)} \\ 2.01 + 0.51\ I_s - 0.313 \ln R & \text{(soft sites)} \end{cases}$$

Subcategory I-3. Magnitude Weighting

G31. Bernreuter (1981a) (Eq. 4-15)

$$\ln(a) = 0.96 + 0.63\ I_s - 0.13\ M_L$$

Subcategory I-4. Magnitude and Distance Weighting

G41. Murphy and O'Brien (1978) (Eq. 4-16)

$$\ln(a) = 1.38 + 0.32\ I_s + 0.55\ M_L - 0.68 \ln R$$

Subcategory I-5. Semi-Empirical

G51. Battis (1981) (Eq. 4-29)

$$\ln(a) = 3.16 + 1.24\ m_b - 1.24 \ln (R + 25)$$

G52. Nuttli and Herrmann (1978) (Eq. 4-23)

$$\ln(a) = 1.47 + 1.2\, m_{bLg} - 1.02 \ln R;\; R > 15 \text{ km}$$

G53. Weston Geophysical Corp. (Eq. 4-31)

$$\ln(a) = 1.47 + 1.1\, m_b - 0.0017R - 0.88 \ln R$$

II. Direct Models

Subcategory II-1. γ Variable

D11. Campbell (1981b) (Eq. 4-41)

$$\ln(a) = 2.64 + 0.79M - (0.023 - 0.0048M + 0.00028\, M^2)R - 0.862 \ln [R + 0.0286 \exp(0.778M)]$$

where R = closest distance to fault rupture

D12. Campbell (1981b) (Eq. 4-42)

$$\ln(a) = 4.39 + 0.922M - 0.023R + 0.0048RM - 0.00028RM^2 - 1.27 \ln (R + 25.7)$$

where R is epicentral distance, and for both D11 and D12

$$M = \begin{cases} 1.02\, m_b + 0.30 & (m_b < 5.59) \\ 1.64\, m_b - 3.16 & (m_b \geq 5.59) \end{cases}$$

D13. Campbell (1982) (Eq. 4-48)

$$\ln(a) = -4.29 + 0.777M - 0.797 \ln[R + 0.012 \exp(0.898M)] - \gamma R$$

where R = closest distance to fault rupture and
γ = frequency-dependent absorption coefficient (e.g. Singh and Herrmann, 1983)

D14. Nuttli (1979) (Eq. 4-34)

$$\ln l(a) = 1.481 + 1.15\, m_b - (0.0136 - 0.00172\, m_b)R - 0.833 \ln R$$

D15. SSMRP (Eq. 4-37)

$$\ln(a) = 3.99 + 0.59\, m_b - 0.003\, (R^2 + 28.09)^{1/2} - 0.833 \ln (R^2 + 28.09)^{1/2}$$

where R = closest distance to surface projection of fault rupture.

Subcategory II-2. γ and m_b Variable

D21. Nuttli (App. C-A)

$$\ln(a) = \begin{cases} 3.892 + 0.576\, m_b - 0.834 \ln [R^2 + \exp(-4.371 + 1.308\, m_b)]^{1/2} - 0.00281\,(R-1) & m_b \leq 4.4 \\ 1.313 + 1.15\, m_b - 0.833 \ln [R^2 + \exp(-7.968 + 2.100\, m_b)]^{1/2} - 0.00281\,(R-1) & 4.4 < m_b \leq 7.4 \end{cases}$$

7.3.2 Peak Ground Velocity

I. Intensity-attenuation models, A1 through A5 are the same as in Section 7.3.1.

Subcategory I-1. No Weighting

GV11. McGuire (1977)

$$\ln(v) = \begin{cases} -4.02 + 0.952\ I_s & \text{(medium sites)} \\ -1.51 + 0.543\ I_s & \text{(soft sites)} \end{cases}$$

GV12. Trifunac (1976)

$$\ln(v) = -2.25 + 0.67\ I_s + 0.032\ S$$

S = 0 (alluvium)

S = 1 (intermediate rock sites)

S = 2 (basement rock sites)

GV13. Trifunac and Brady (1975)

$$\ln\ (v) = -1.45 + 0.58\ I_s$$

Subcategory I-2. Distance Weighting

GV21. Bernreuter (1981a)

$$\ln\ (v) = -2.94 + 0.76\ I_s + 0.06\ \ln R$$

GV22. McGuire (1977)

$$\ln(v) = \begin{cases} -3.61 + 0.923\ I_s - 0.064\ \ln R & \text{(medium sites)} \\ -1.11 + 0.521\ I_s - 0.072\ \ln R & \text{(soft sites)} \end{cases}$$

Subcategory I-3. Magnitude Weighting

GV31. Bernreuter (1981a)

$$\ln(v) = -2.62 + 0.51\ I_s + 0.17\ M_L$$

Subcategory I-4. Magnitude and Distance Weighting
(No models)

Subcategory I-5. Semi-Empirical

GV51. Nuttli - Herrmann (1978)

$$\ln(v) = -6.72 + 2.3\, m_b - \ln R$$

GV52. Western Geophysical Corporation

$$\ln(v) = -0.924 + .95\, m_b - .0023R - .765 \ln R + .923E_1 + E_2$$

where E_1 and E_2 are random variables with mean zero and standard deviation σ_1 and σ_2. E_1 and E_2 represent the error terms in the fit of site intensity versus source intensity and distance, and the fit of site intensity as a function of magnitude and distance, respectively.

II. Direct Models

Subcategory II-1.

DV11. Nuttli (1979)
This model only appears in the form of a set of curves of velocity versus distance and magnitude. The reader is referred to the publication (Nuttli, 1979).

DV12. SSMRP(a)

$$\ln(v) = -7.86 + 2.3\, m_b - C_v R - .835 \ln R$$

where $C_v = .0076 - .00099\, m_b$

DV13. SSMRP(b)

$$\ln(v) = -\ .963 + 1.15\, m_b - C_v R - .833 \ln R$$

Subcategory II-2.

DV21. Nuttli (App. C-A)

$$\ln(v) = \begin{cases} -3.11 + 1.15 m_b - 0.833 \ln [R^2 + \exp(-4.371 + 1.308\, m_b)]^{1/2} - 0.00122(R-1) & m_b \leq 4.4 \\ -8.29 + 2.3\, m_b - 0.833 \ln [R^2 + \exp(-7.968 + 2.100\, m_b)]^{1/2} - 0.00122(R-1) & 4.4 < cm_b < 7.4 \end{cases}$$

7.3.3 <u>Response Spectra</u>

RS1 Modified Reg. Guide 1.60 (spectral shape anchored to PGA)
RS2 NBS, 1978 - ATC (spectral shape anchored to PGA)
RS3 Newmark and Hall (1982) (spectral shape anchored to PGA and PGV)
RS4 Bernreuter (1981a): Distance-weighted model

$\ln(SA) = C_1 + C_2 I_o + C_3 R + C_4 \ln R$
where SA = pseudo-absolute acceleration in cm/sec^2

Frequency (Hz)	C_1	C_2	C_3	C_4
25.0	2.35	0.55	-0.0025	-0.542
20.0	2.49	0.55	-0.0025	-0.565
12.5	2.84	0.56	-0.0026	-0.612
10.0	2.98	0.56	-0.0025	-0.605
5.0	2.87	0.56	-0.0026	-0.487
3.3	2.27	0.62	-0.0028	-0.433
2.5	1.60	0.65	-0.0030	-0.346
1.0	-1.21	0.816	-0.0038	-0.100
0.5	-3.19	0.886	-0.0041	0.061

RS5 Bernreuter (1981a) Magnitude-weighted model

$\ln(SA) = C_1 + C_2 I_o + C_3 R + C_4 \ln R$

Frequency (Hz)	C_1	C_2	C_3	C_4
25.0	2.67	0.59	-0.0007	-0.760
20.0	2.73	0.58	-0.0007	-0.761
12.5	3.04	0.57	-0.0007	-0.768
10.0	3.20	0.56	-0.0007	-0.775
5.0	3.84	0.52	-0.0007	-0.740
3.3	3.63	0.57	-0.0007	-0.762
2.5	3.34	0.57	-0.0007	-0.719
1.0	1.23	0.71	-0.0006	-0.637
0.5	-0.34	0.74	-0.0005	-0.536

7.4 QUESTIONS

Based on your opinion of the data and methods used to develop a model, the ability of a model to accurately reflect the attenuation and ground motion within a region, and any other information you deem appropriate to judge the models, please respond to the following questions using the included Questionnaire Reply Forms.

7.4.1 Peak Ground Acceleration

For each of the four regions and two magnitude scales,

Question 1. Among the peak ground acceleration models catalogued in Section 7.3.1, indicate the one model (or attenuation/ground motion pair) which you consider to be the most appropriate ground motion model, i.e., select the "best estimate" model for peak ground acceleration.

Question 2. For each of the seven subcategories (types) of peak ground acceleration models, I-1 through I-5, II-1, and II-2, select the one model within the subcategory which you consider to be most appropriate (Note: for subcategories I-1 through I-4, this should be a pair of models).

Question 3. For each of the seven subcategories, indicate a confidence level which you associate with that type of model.

Notes: (1) See the discussion of confidence level in Section 7.2

(2) For each region, magnitude scale pair, if $C_1, C_2, \ldots, C_7$ denote the confidence levels for the seven subgroups

- o any C_i can be zero
- o the sum of the C_i's should equal 1.0

Question 4. Indicate any ground motion models for PGA which were not included in the catalogue in Section 7.3.1 and which you consider worthy of consideration by the panel at a future time.

7.4.2 Peak Ground Velocity

For each of the four regions and two magnitude scales,

Question 5 Among the peak ground velocity models catalogued in Section 7.3.2, indicate the one model (or attenuation/ground motion pair) which you consider to be the most appropriate ground motion model, i.e., select the "best estimate" model for peak ground velocity.

Question 6 For each of the seven subcatagories of peak ground velocity models I-1 through I-5, II-1, and II-2, select the one model within the subcatagory which you consider to be most appropriate (Note: for subcatagories I-1 through I-4, this should be a pair of models).

Question 7 For each of the seven subcatagories, indicate a confidence level which you associate with that type of model. (See the Note after Question 3)

Question 8 Indicate any ground motion models for PGV which were not included in the catalogue in Section 7.3.2 and which you consider worthy of consideration by the panel at a future time.

7.4.3 Spectra

Response for each of the four regions and two magnitude scales,

Question 9. Among the response spectra models catalogued in Section 7.3.3, indicate the spectral shape model (or attenuation/spectra pair) which you consider to be the most appropriate response spectra model.

Question 10 For each of the response spectra models in Section 7.33, indicate a confidence level which you associate with that type of model (see the notes after Question 3).

Question 11 Indicate any response spectra models which were not included in the catalogue in Section 7.3.3 and which you consider worthy of consideration by the panel at a future time.

7.4.4 Random Variation

As discussed in Section 7.1, the standard deviation of the error associated with a model includes both a measure of the random variation in the GMP about its expected or average value as well as a measure of the adequacy of the model. It is important in doing the hazard analysis that only the random variation component be used when making the probability calculations. Thus, we need to elicit your opinions about the magnitude of the random variation associated with each of the ground motion parameters.

Since the GMP is a function of earthquake magnitude and distance, we are interested in the random variation in GMP conditional on magnitude and distance. Our hazard analysis assumes that the GMP random variation is independent of magnitude and distance as well as the site, although we do allow for regional variation by asking you to provide your estimates on a regional basis.

Since we will be modeling the random variation in the GMP by a lognormal distribution, we would like you to provide your estimates of the random variation either in terms of

- o the standard deviation of the lnGMP, σ
- o the coefficient of variation of the GMP, COV

Using Table 7.1, included in this Questionaire, for each of the GMP's and each of the four regions, Question 12 Give your best estimate of the random variation (either σ or COV) in the GMP at a site.

Question 13 Give an interval which you believe, with a high degree of confidence, represents the possible range of σ or COV.

Question 14 Do you agree with our choice of the lognormal distribution to describe the random variation in the GMP's? If not, please indicate a distribution which is more appropriate.

7.5 Self-Rating

In our hazard analysis it will be necessary to combine the risks at a site based on the different ground motion models chosen by a panel member as well as combining over the the opinions provided by all panel members. Combining the risks estimate using the different models suggested by an individual member will be based on the confidence levels you provide. To combine over all the panel members we propose to use a weighted average procedure. Of course, this requires an appropriate set of weights.

Although there are several weighting schemes (e.g., equal weights, LLNL derived weights), the set of weights we propose to use is based on your appraisal, i.e., self- rating, of your expertise about the utility of ground motion models.

We recognize some of the weaknesses and difficulties in eliciting and using self-rating, however, most alternative weighting schemes are also subjective and involve some of the same problems as self-rating. Overall, we believe self-rating to be a viable means of developing weights for combining the results derived from your opinions about the ground motion models. Thus, we would like you to indicate your level of expertise with regard to assessing the utility of the ground motion models.

In appraising your level of expertise, we ask that you use a 1-10 scale where low values indicate a low level of expertise and high values a high level of expertise. An integer value is not necessary, although not more than one decimal place (e.g., 7.3) is appropriate.

Question 15. Please indicate your level of expertise with regard to assessing the utility of ground motion models.

Table 7.1
(Questions 12 and 13)

Parameter		Northeast	Southeast	North Central	South Central
		Region			
PGA	Best Estimate:				
	Confidence Bounds:				
PGV	Best Estimate:				
	Confidence Bounds:				

Spectra

A. **PEAK GROUND ACCELERATION**

		PEGION							
		Northeast		Southeast		Northcentral		Southcentral	
		MMI	m_b	MMI	m_b	MMI	m_b	MMI	m_b
Question 1									
"Best Estimate" Model									
Questions 2 and 3									
I. **Intensity Based Models**									
I-1. **No Weighting**									
	Models[1]	(,)	(,)	(,)	(,)	(,)	(,)	(,)	(,)
	Confidence								
I-2. **Distance Weighting**									
	Models[1]	(,)	(,)	(,)	(,)	(,)	(,)	(,)	
	Confidence								
I-3. **Magnitude Weighting**									
	Models[1]	(,)	(,)	(,)	(,)	(,)	(,)	(,)	
	Confidence								
I-4. **Magnitude + Distance Weighting**									
	Models[1]	(,)	(,)	(,)	(,)	(,)	(,)	(,)	(,)
	Confidence								
I-5. **Semi-Empirical**									
	Model								
	Confidence								
II. **Direct Models**									
II.1. **γ Variable**									
	Model								
	Confidence								
II.2 **γ K(M) Variable**									
	Model								
	Confidence								

(1) For categories I-1 thru I-4, a ground motion model consists of (a) an intensity-attenuation relation and (b) a PGA site intensity relation.

B. **PEAK GROUND VELOCITY**

	REGION							
	Northeast		Southeast		Northcentral		Southcentral	
Question 5	MMI	m_b	MMI	m_b	MMI	m_b	MMI	m_b
"Best Estimate" Model								
Questions 6 and 7								
I. **Intensity Based Models**								
I-1. **No Weighting**								
Models(1)	(,)	(,)	(,)	(,)	(,)	(,)	(,)	(,)
Confidence								
I-2. **Distance Weighting**								
Models(1)	(,)	(,)	(,)	(,)	(,)	(,)	(,)	(,)
Confidence								
I-3. **Magnitude Weighting**								
Models(1)	(,)	(,)	(,)	(,)	(,)	(,)	(,)	(,)
Confidence								
I-4. **Magnitude + Distance Weighting**								
Models(1)	(,)	(,)	(,)	(,)	(,)	(,)	(,)	(,)
Confidence								
I-5. **Semi-Empirical**								
Model								
Confidence								
II. **Direct Models**								
II.1. **γ Variable**								
Model								
Confidence								
II.2 **γ K(M) Variable**								
Model								
Confidence								

(1) For categories I-1 thru I-4, a ground motion model consists of (a) an intensity-attenuation relation and (b) a PGV-site intensity relation.

Question 4 **Additional Peak Ground Acceleration Models**

Question 8 **Additional Peak Ground Velocity Models**

C. RESPONSE SPECTRA

	REGION							
	Northeast		Southeast		Northcentral		Southcentral	
Question 9	MMI	m_b	MMI	m_b	MMI	m_b	MMI	m_b
"Best Estimate" Model								
Question 10								
RS1. Reg. Guide 1.60								
Confidence								
RS2. NBS, 1978 - ATC								
Confidence								
RS3. Newmark-Hall								
Confidence								
RS4. Distance-Weighting								
Confidence								
RS5. Magnitude-Weighting								
Confidence								
RS6 Westermo, et al.								
Confidence								

Question 11 Additional Response Spectra Models

D. RANDOM VARIATION

		REGION		
	Northeast	Southeast	Northcentral	Southcentral
Questions 12 and 13				
1. Peak Ground Acceleration				
Best Estimate				
"Confidence" Bounds				
Peak Ground Velocity				
Best Estimate				
"Confidence" Bounds				
Response Spectra				
Best Estimate				
"Confidence" Bounds				

Question 14

Is lognormal distribution an adequate description of random variation?

If no, what is a more appropriate distribution?

E. SELF RATING

Question 15

Self-Rating: