EARTHQUAKE ENGINEERING AND STRUCTURAL DYNAMICS, VOL. 4, 455–471 (1976)

CORRELATIONS OF PEAK ACCELERATION, VELOCITY AND DISPLACEMENT WITH EARTHQUAKE MAGNITUDE, DISTANCE AND SITE CONDITIONS

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SUMMARY

A brief review of proposed correlations between peak accelerations and earthquake magnitude and distance has been presented. It has been found that most investigators agree favourably on what should be the amplitude of peak accelerations for the distance range between about 20 and 200 km. For distances less than 20 km, there is significant disagreement in the predicted peak amplitudes, reflecting the lack of data there and the uncertainties associated with the extrapolation.

Correlations of peak accelerations, peak velocities and peak displacements with earthquake magnitude, epicentral distance and the geologic conditions of the recording sites have been presented for 187 accelerograms recorded during 57 earthquakes. This data set describes strong earthquake ground motion in the Western United States during the period from 1933 to 1971.

For large earthquakes, dependence of peak acceleration, velocity and displacement amplitudes on earthquake magnitude seems to be lost. This suggests that the amplitudes of strong ground motion close to a fault are scaled primarily by the maximum dislocation amplitudes and the stress drop, rather than the overall 'size' of an earthquake as measured by magnitude.

The influence of geologic conditions at the recording station seems to be of minor importance for scaling peak accelerations, but it becomes noticeable for the peaks of velocity and even more apparent for the peaks of displacement.

INTRODUCTION

In this paper a brief discussion of the published scaling laws for peak accelerations is presented and the published correlations are compared with the trends indicated by the data which are now available for the Western United States. (A more detailed summary of these scaling laws may be found in the proceedings of the U.S. National Conference on Earthquake Engineering.[1]) By using this data the new scaling functions have been developed and the manner in which earthquake magnitude and attenuation with distance enter into these correlations has been examined.

The scaling functions, which characterize peak amplitudes studied in this paper, as well as in all previous studies, of course, contain only a limited amount of information on the spectral and time-dependent properties of strong ground motion. Therefore, this paper should not be interpreted to suggest that the peak amplitudes should be used, nor that they are adequate, to describe the characteristics of this motion. The purpose of this paper is merely to emphasize, again, that the data on peak amplitudes are characterized by large scatter and to examine to what extent the overall trends of these amplitudes depend on the limited number of scaling parameters which are frequently used in earthquake engineering. Finally, for traditional reasons and simplicity, it seems that the rough scaling of strong ground motion in terms of peak amplitudes may remain in use for some time. Therefore, it may be appropriate to outline here the uncertainties that are associated with such scaling.

Like most previous efforts, our present study suffers from the lack of an adequate number and distribution of recorded strong-motion data. Although much has been and will be learned from the strong-motion data so far recorded, it appears that at least an order of magnitude increase in the number of recorded earthquakes will be required to significantly improve the present situation. The only sound solution to this problem seems

Received 29 May 1975
Revised 8 July 1975

now to be the more vigorous deployment of strong-motion recording stations in the highly active seismic areas of the world and good maintenance of installed instrumentation networks during future decades.

A BRIEF SUMMARY OF PREVIOUS CORRELATION WORK

The work on correlating the peaks of recorded acceleration with other measures of earthquake size and intensity was initiated in the early 1930's when the first stong-motion accelerographs recorded earthquake ground shaking in Southern California. Since that time peak accelerations, Modified Mercalli intensity maps, earthquake magnitude and location together with other pertinent information have appeared in the annual report, U.S. Earthquakes, published by the U.S. Department of Commerce. These publications have served as a major data source for most subsequent studies. The majority of significant correlations between peak accelerations and Modified Mercalli intensity have been summarized by Barosh[2] and Trifunac and Brady[3] and will not be repeated here.

First correlations of peak accelerations with earthquake magnitude and distance were reported by Gutenberg and Richter in 1942[4] and 1956[6] and by Neumann in 1954.[5] The study by Gutenberg and Richter[6] in 1956 represents the first systematic analysis of peak accelerations. In that paper they introduced an important assumption which was that an average peak acceleration recorded by the U.S.C. & G.S. strong-motion accelerographs is to be reduced by a factor of 2·5 (by 0·4 on the logarithmic scale) to account for the fact that most strong-motion data at that time was recorded on alluvium. Since the instrumental records used in magnitude determinations have mostly resulted from stations founded on basement rocks, it was felt that for correlations with local magnitude the equivalent accelerations on hard rock should be used. Hence, the $\log_{10} a_0$ in equation (11) of their paper is 0·4 units lower than it would be for the raw data corrected for the epicentral distance only. The rate of decrease of acceleration with distance, which has been used by Gutenberg and Richter[6] [Figure 4(a) of their paper] and by Gutenberg,[7] may be somewhat smaller than is indicated by the most recent recordings, and the distance correction based on this rate may lead to an underestimate of epicentral accelerations a_0 by a factor between 1 and 2 for epicentral distances less than 100 km. For distances between 150 and 200 km this factor could be as large as 3. Combining this with the above-mentioned correction of 2·5, their equation (11) could be an underestimate of as much as 0·8 on the logarithmic scale.

Since 1965, numerous other correlations of peak accelerations with earthquake magnitude and distance have been presented by e.g. Housner,[8] Blume,[9] Kanai,[10] Milne and Davenport,[11] Esteva,[12] Donovan,[13,14] Schnabel and Seed,[15] Cloud and Perez[16] and others. These and other correlations have been summarized by Trifunac and Brady[1] and are compared in Figure 1 for a magnitude 6·5 earthquake. In this figure the distance and magnitude range for which the currently available data are available has been indicated by the cross-hatched area. Only a few isolated data points with epicentral distances less than 20 km lie outside this cross-hatched area and are not shown in this figure.

On the logarithmic scale (Figure 1) the differences between the epicentral and hypocentral distances and the distance to the fault are not significant, for very short distances (say less than 10 km), so that it is possible to compare the trend of different correlations and their overall amplitudes. For distances less than about 20 km, where only a small number of recorded points are now available, Figure 1 shows that the predicted peak accelerations begin to deviate from each other. At small distances from the source, say 1 km, these differences are as large as one order of magnitude. This appears to be due to two predominant factors. First, several authors seem to have placed much emphasis on a few recorded peaks close to the source in their extrapolation back to the source. For example, one such point is represented by the accelerogram obtained at Station No. 2 of the Cholame–Shandon array during the Parkfield, California, earthquake of 1966, which was located some 80 m from the fault cracks observed about 10 h after the earthquake. Recent studies have suggested, however, that the peak at this station could have resulted from the energy released as far as 30 km to the NW, in the epicentral region of this earthquake.[17] Second, most correlations presented in Figure 1 are based on an oversimplified description of amplitude attenuation with distance, which typically tends to R^{-2} for R greater than about 50 km and in most cases to a constant for $R = 0$. Since the overall amplitude of the peak accelerations versus distance is in all studies determined by fitting the hypothetical attenuation

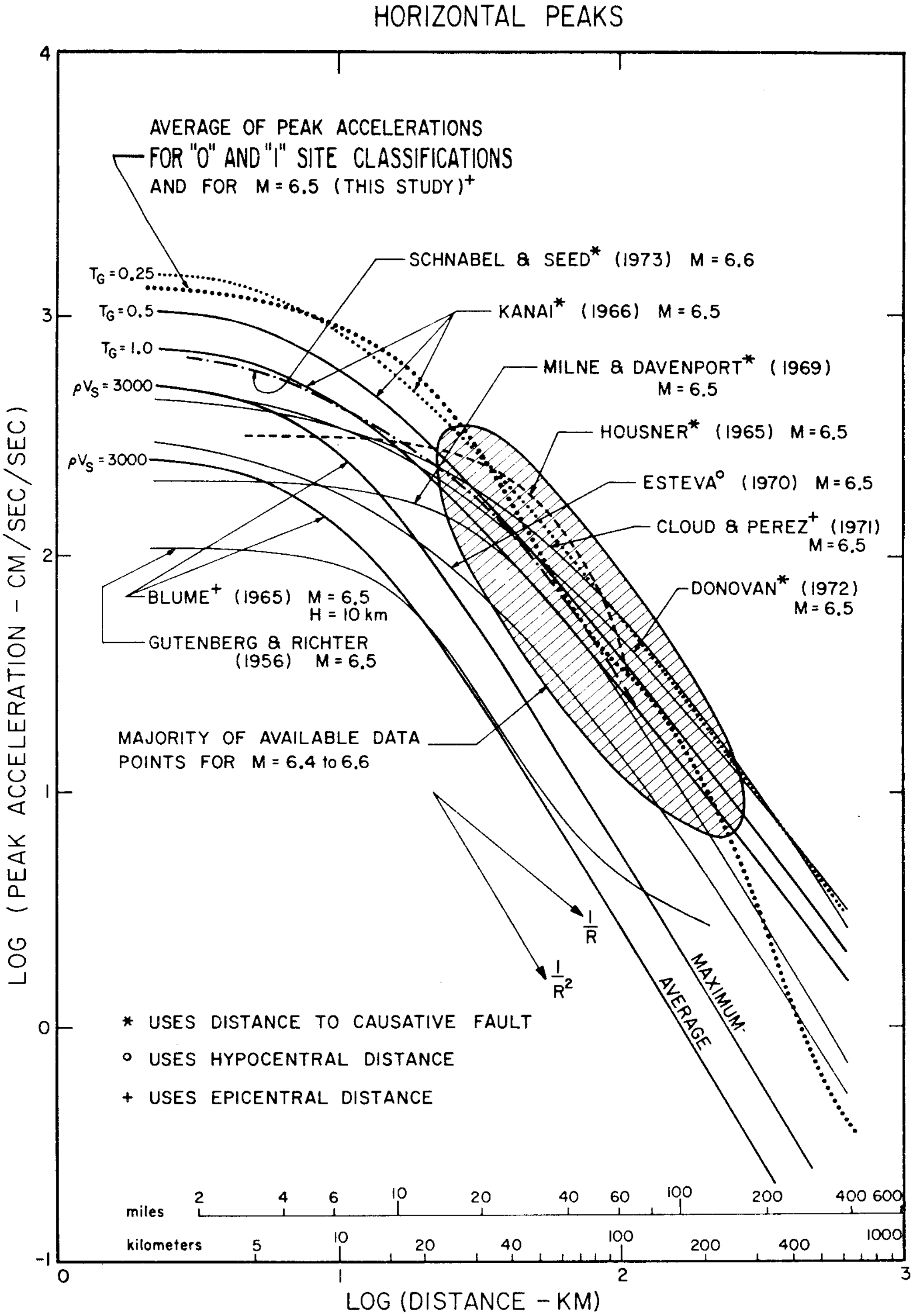

Figure 1. Comparison of the correlations, for a magnitude 6·5 earthquake, of peak acceleration and distance

curves to the limited number of available data points, it would not be surprising that most correlations tended to agree in the range where data points are available and disagree outside that range where some of these correlations simply do not apply. For the distance range between about 20 and 250 km, the spread of predicted peak accelerations in Figure 1 is almost twice the spread of observed peak accelerations. If one disregards the correlations proposed by Gutenberg and Richter[6] and by Blume,[9] the spread of the predicted accelerations reduces and, with the exception of Esteva's curve,[12] all correlations appear to be quite consistent with the mean data trend.

The precise nature of attenuation curves of acceleration versus distance, of course, depends on numerous factors such as, for example, the particular geologic region in question, fault dimensions, wave frequency, acceleration amplitudes (especially for small epicentral distances) and the characteristics of the recording site, and will be possible to determine empirically only when many more recorded accelerograms become available for analysis. Although in this paper we propose a new way of describing this attenuation with distance which seems to fit the trends of the available data well, we cannot unequivocally state that our method will stand the test of future recordings at short distances (say < 10 km) significantly better than some other correlations already proposed by previous investigators (Figure 1). The data available, so far, clearly indicate, however, that the correlations of Gutenberg and Richter[6] and Blume[9] predict peaks which are systematically smaller than indicated by the recorded data. The correlation presented by Esteva,[12] for $M = 6{\cdot}5$, also underestimates the mean of the data trend (Figure 1) by a factor of about 2 (by 0·3 on the logarithmic scale). All other correlations are in good agreement with the data trend for the distance range between 30 and 200 km, with the exception of Housner's[8] curve which tends to overestimate the average peak accelerations at distances between about 30 and 80 km.

AVAILABLE DATA

Since the beginning of strong-motion programs in the Western United States in 1933, the number of strong-motion accelerographs installed has been slowly increasing from about 50 in 1935 to some 100 instruments in 1965. From 1965 to the present the rate of growth of this accelerograph network has been much higher than prior to 1965, and in 1972 the total number of instruments operating in the Western United States had reached 860. The total number of accelerograms recorded in each year has fluctuated between a few and about 200 prior to the San Fernando earthquake of 1971 which produced over 270 excellent accelerograms.[1]

Prior to the San Fernando earthquake of 1971, for which 208 accelerograms have been digitized, there were on average only a few records per year which were selected for digitization and routine processing. If the strong-motion data recorded in tall buildings are eliminated, there remains a total of 187 accelerograms (117 of these recorded during the San Fernando earthquake), which can be used to study attenuation with distance, correlation with earthquake magnitude, effects of site conditions and other strong-motion parameters.

There are, of course, many other acceleration records registered elsewhere that are of use in such correlations. However, since the attenuation with distance varies from one geologic province to another and because the details of magnitude determinations are different in various countries, in this paper we will restrict our attention to earthquakes recorded in the Western United States only.

The 187 acceleration records studied in this paper are derived from the Volume II reports on strong-motion data[18] which contain integrated velocities and displacements as well. These data have been baseline corrected and the transducer response characteristics have also been removed. The average accelerogram is believed to be an accurate representation of the absolute ground acceleration in the frequency band between 0·07 and 25 cps, or between 0·125 and 25 cps in the case of the 35- and 70-mm records obtained during the San Fernando earthquake, 1971. Integrated velocity and displacement curves are also quite accurate representations of actual ground motion for ground displacements larger than about 1–2 cm.[19] For each recorded acceleration component, corrected acceleration and integrated velocity and displacement curves have been read off the Volume II tape[20] and peak acceleration, velocity and displacement stored for subsequent analysis. This has led to 373 horizontal and 187 vertical peaks for acceleration, velocity and displacement. These data have been plotted on the logarithmic scale versus epicentral distance in Figures 2, 3 and 4.

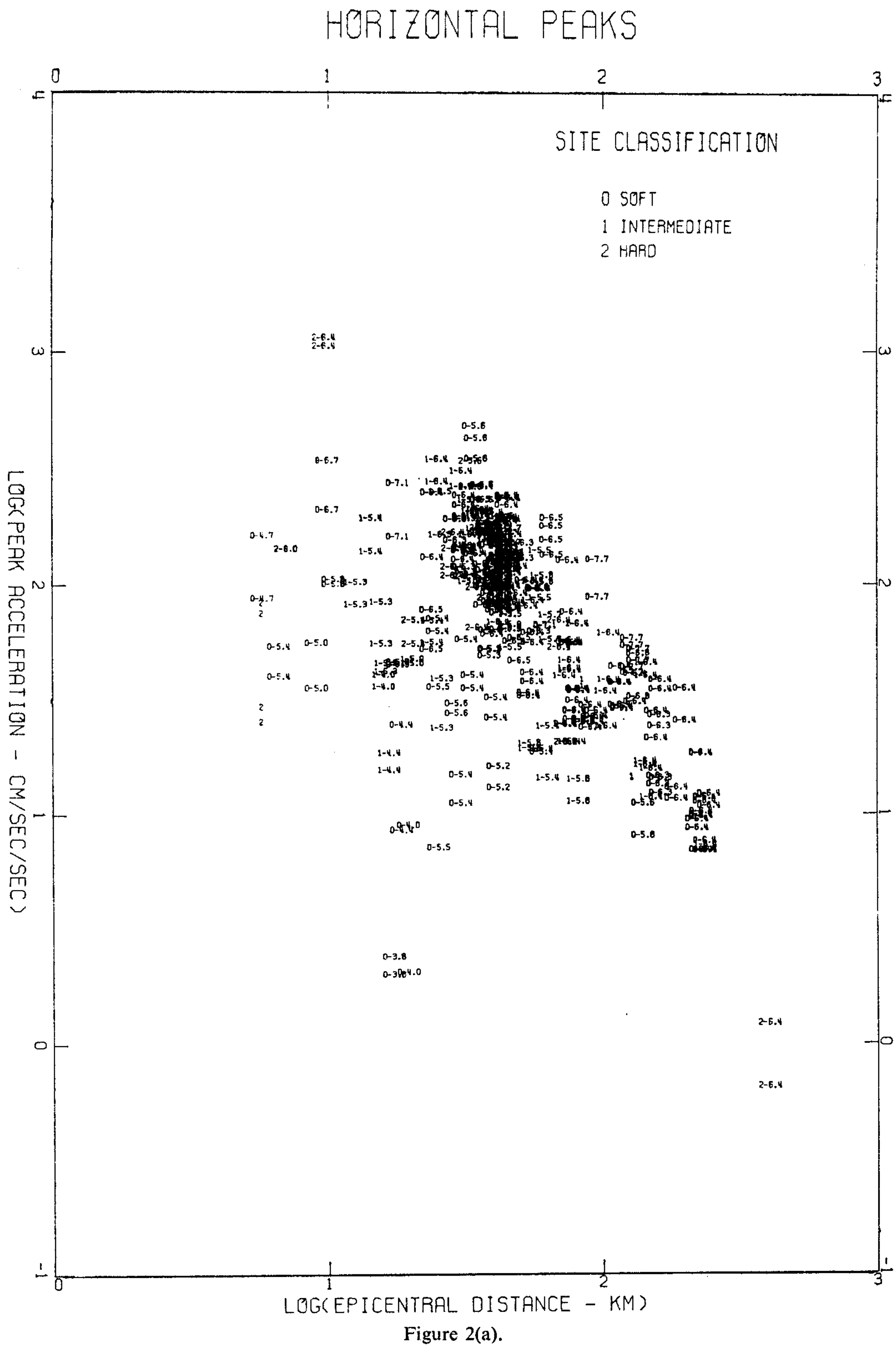
HORIZONTAL PEAKS
SITE CLASSIFICATION
0 SOFT
1 INTERMEDIATE
2 HARD
LOG(PEAK ACCELERATION - CM/SEC/SEC)
LOG(EPICENTRAL DISTANCE - KM)

Figure 2(a).

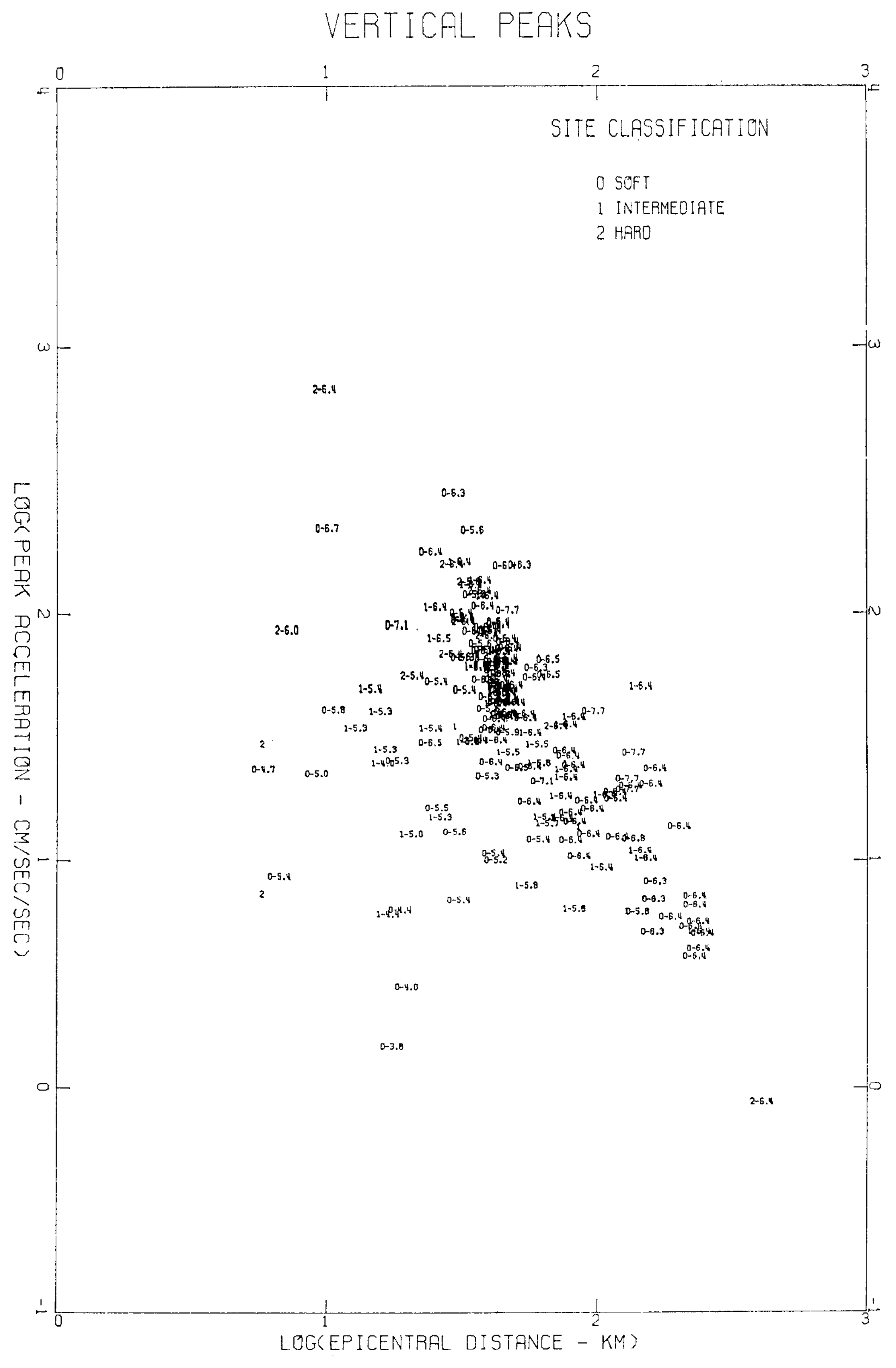

Figure 2(b).

Figure 2 (a) Horizontal and (b) vertical peak accelerations *vs* epicentral distance. Each plotted point has the site classification and magnitude, when available

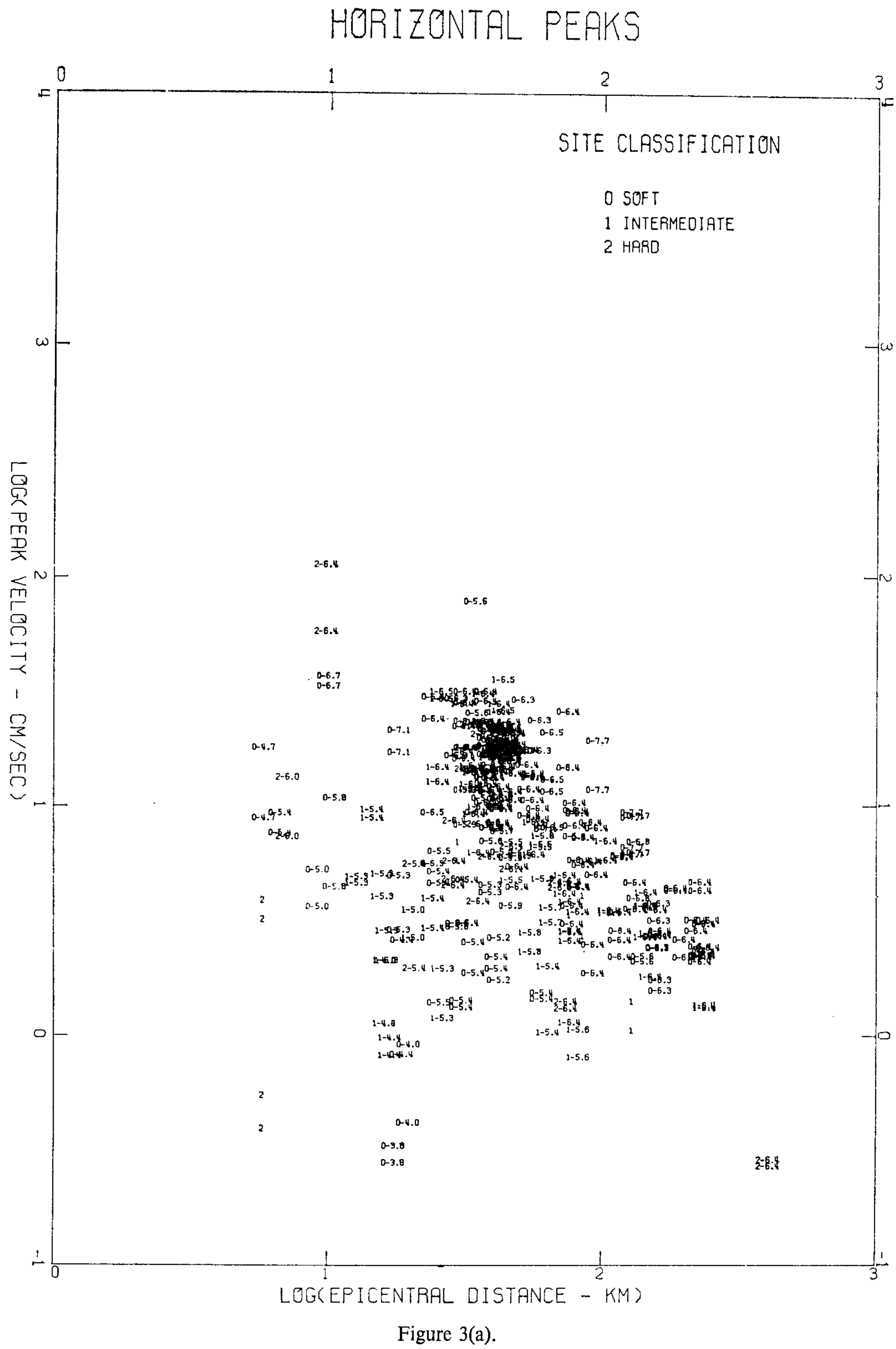
HORIZONTAL PEAKS
SITE CLASSIFICATION
0 SOFT
1 INTERMEDIATE
2 HARD
LOG(PEAK VELOCITY - CM/SEC)
LOG(EPICENTRAL DISTANCE - KM)
0
1
2
3
-1
4

Figure 3(a).

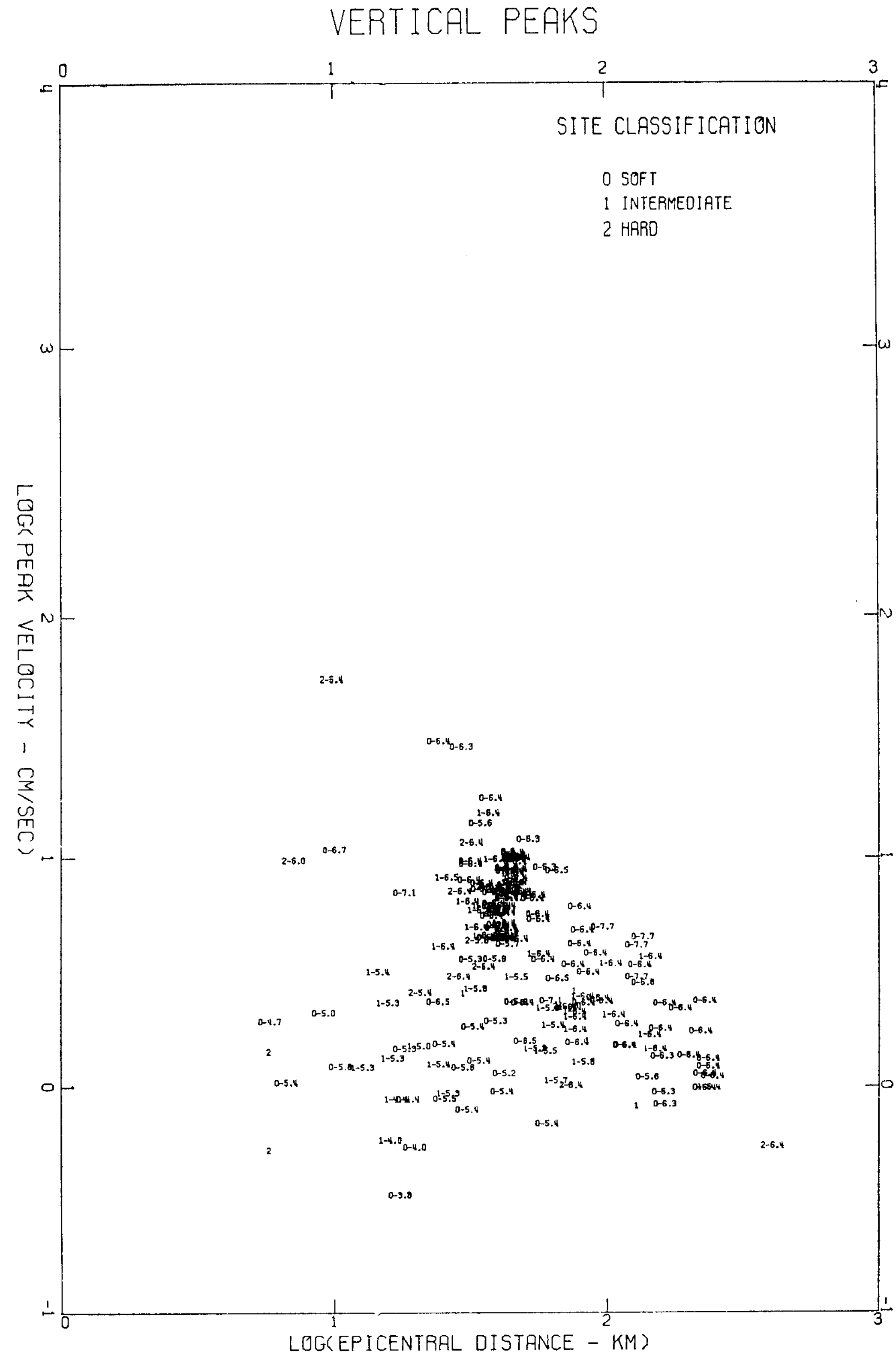

Figure 3(b).

Figure 3. (a) Horizontal and (b) vertical peak velocities *vs* epicentral distance. Each plotted point has the site classification and magnitude, when available

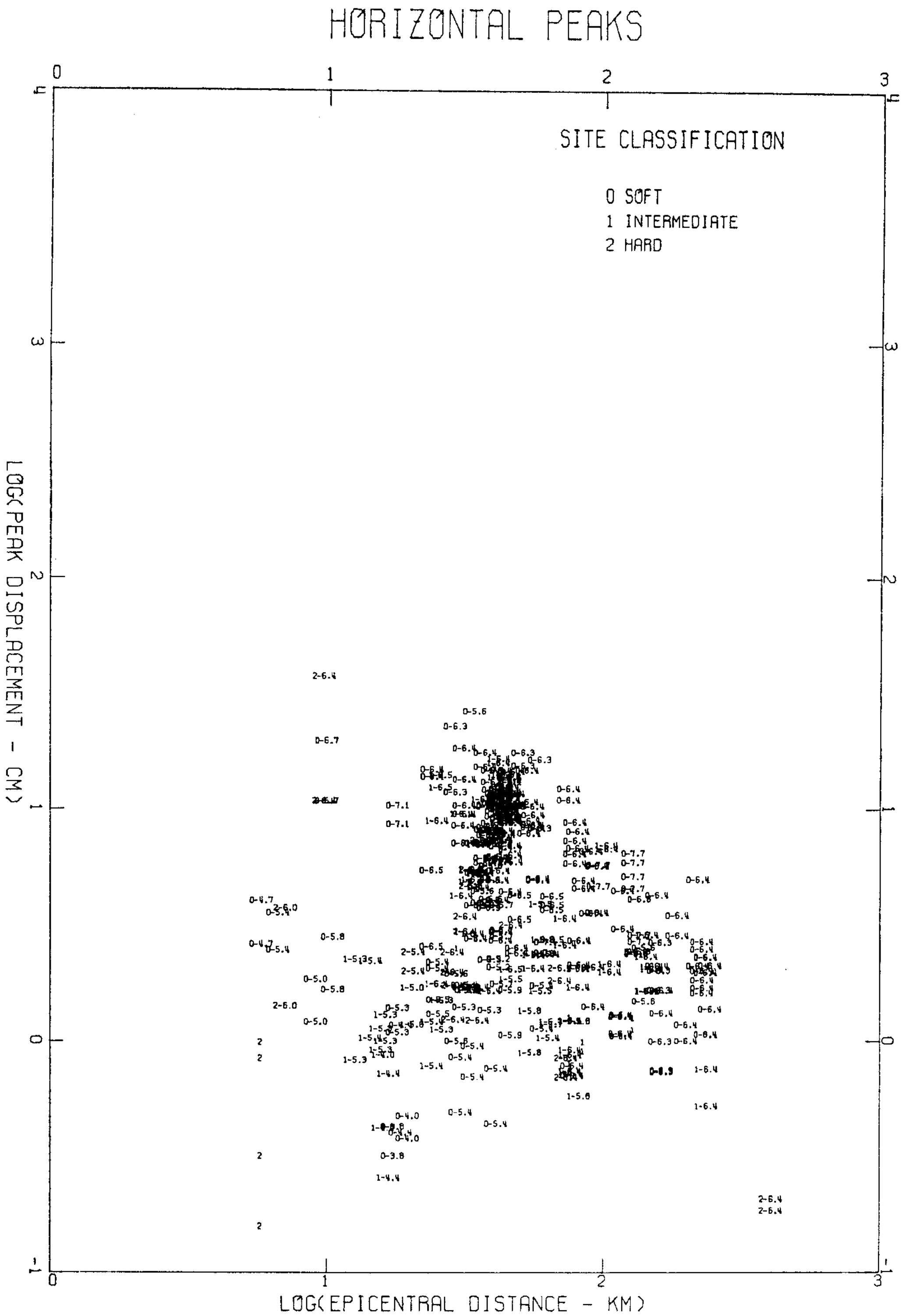
HORIZONTAL PEAKS
SITE CLASSIFICATION
0 SOFT
1 INTERMEDIATE
2 HARD
LOG(PEAK DISPLACEMENT - CM)
LOG(EPICENTRAL DISTANCE - KM)

Figure 4(a).

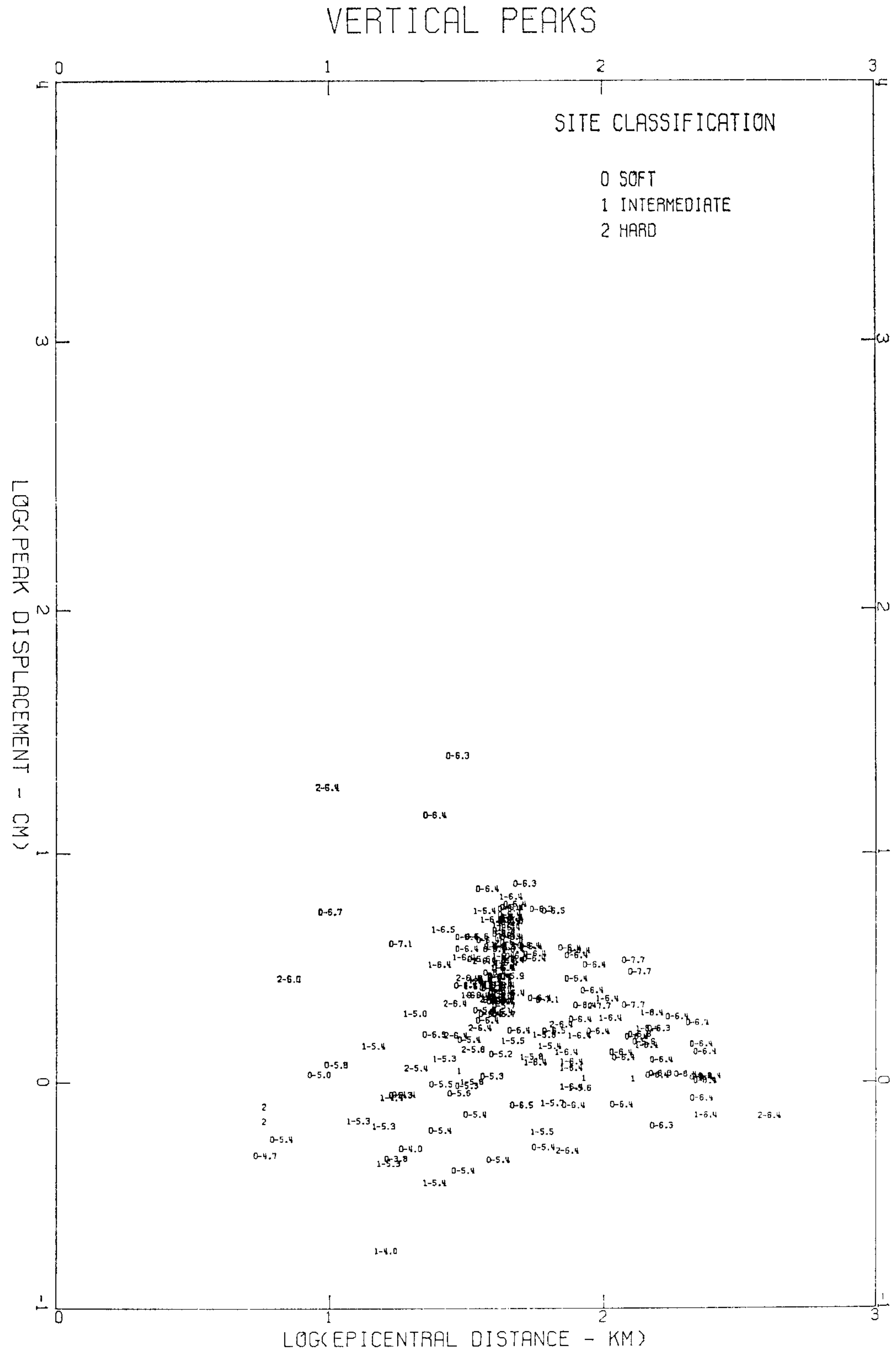

Figure 4(b).

Figure 4. (a) Horizontal and (b) vertical peak displacements *vs* epicentral distance. Each plotted point has the site classification and magnitude, when available

To study the possible effects of local site conditions on the trends of recorded peaks of strong ground motion, we used the site classification scheme which we employed in our previous paper[3] and which consists of three groups. The first group consists of sites located on alluvium or other low velocity 'soft' deposits and is labelled by a symbol '0'. The second group consists of sites on 'intermediate' type rock and is labelled by '1', while the sites belonging to the third group are located on solid, 'hard', basement rock and are labelled by '2'. Detailed description of all sites used in this study and the respective classifications have been presented in our previous paper[3] and will not be repeated here.

In Figures 2, 3 and 4 each peak is identified by a '0', '1' or '2' and the published earthquake magnitude when available. Of all data used in this study 63 per cent has been recorded in a 'soft' geological environment, 23 per cent came from the sites located on 'intermediate' and only 8 per cent from the sites on 'hard' basement rocks.

CORRELATION OF PEAKS OF STRONG GROUND MOTION WITH EARTHQUAKE MAGNITUDE AND SITE CLASSIFICATION

To correlate the recorded peak amplitudes of strong ground motion with earthquake magnitude one has to make an assumption that there is a direct or implicit link between the physical quantities which are measured by magnitude and those of strong ground motion. Since for most earthquakes studied in this paper the published magnitude corresponds to the local Richter magnitude, M_L,[21] we shall use the definition of this magnitude,

$$M_L = \log_{10} A - \log_{10} A_0(R) \tag{10}$$

as a means for developing such scaling laws of peak acceleration, velocity and displacement. In (10) A is the amplitude in mm recorded on a standard Wood–Anderson seismometer ($T_n = 0{\cdot}8$ sec, $\zeta = 0{\cdot}8$–$1{\cdot}0$ and $V_s = 2{,}800$) and $A_0(R)$ (Table I) represents the amplitude in mm with which a standard seismometer would register an earthquake of magnitude zero. The second and third decimal places in this table have no statistical significance and are kept merely to preserve smoothness of $A_0(R)$ amplitudes when plotted *vs* R.

We shall assume that the attenuations of acceleration, velocity and displacement with distance can all be described by the functional shape of $A_0(R)$ given in Table I. This certainly represents an over-simplification, since it is well known that the high frequency waves (acceleration) should be attenuated faster than the

Table I. $\log_{10} A_0(R)$ vs epicentral distance R

R (km)	$-\log_{10} A_0(R)$	R (km)	$-\log_{10} A_0(R)$	R (km)	$-\log_{10} A_0(R)$
0	1·400	140	3·230	370	4·336
5	1·500	150	3·279	380	4·376
10	1·605	160	3·328	390	4·414
15	1·716	170	3·378	400	4·451
20	1·833	180	3·429	410	4·485
25	1·955	190	3·480	420	4·518
30	2·078	200	3·530	430	4·549
35	2·199	210	3·581	440	4·579
40	2·314	220	3·631	450	4·607
45	2·421	230	3·680	460	4·634
50	2·517	240	3·729	470	4·660
55	2·603	250	3·779	480	4·685
60	2·679	260	3·827	490	4·709
65	2·746	270	3·877	500	4·732
70	2·805	280	3·926	510	4·755
80	2·920	290	3·975	520	4·776
85	2·958	300	4·024	530	4·797
90	2·989	310	4·072	540	4·817
95	3·020	320	4·119	550	4·835
100	3·044	330	4·164	560	4·853
110	3·089	340	4·209	570	4·869
120	3·135	350	4·253	580	4·885
130	3·182	360	4·295	590	4·900

low frequency waves (displacements). However, the attenuation with distance of peak accelerations, velocities and displacements appears to follow the $A_0(R)$ curve quite closely, and it seems that numerous additional recordings at short distances ($R < 20$ km) and large distances ($R > 200$ km) will be necessary before it will be possible to distinguish apparently minor differences in attenuation of peak accelerations, velocities and displacements.

Using $A_0(R)$ (Table I) to describe the peak attenuation with distance has important physical, empirical, as well as regional, advantages, since this curve has been developed for the Southern California region,[21] where most of the strong-motion used in this study has been recorded. This curve is based on a larger data base than is now available for strong-motion data. It has been developed for use with the standard Wood–Anderson seismometer, which gives records with significant content in the intermediate frequency band (up to several cps). Finally, this curve is of special value for correlations with other data recorded in the same geologic province, since it empirically accounts for the average velocity structure in Southern California.

We propose to characterize the amplitudes of peak acceleration, $a_{\max}$, velocity, $v_{\max}$, and displacement, $d_{\max}$, by using

$$\log_{10}\left\{\begin{array}{c} a_{\max} \\ v_{\max} \\ d_{\max} \end{array}\right\} = M + \log_{10} A_0(R) - \log_{10}\left\{\begin{array}{c} a_0(M) \\ v_0(M) \\ d_0(M) \end{array}\right\} \tag{11}$$

where M is the earthquake magnitude and $a_0(M)$, $v_0(M)$ and $d_0(M)$ are magnitude-dependent scaling constants which empirically take into account such things as the frequency band for which the strong-motion data are available, the transfer function properties of the Wood–Anderson seismometer, the physical units used (cm and sec) and the magnitude-dependent corner frequency of the source spectrum. Geometrical dependence of attenuation with distance on the source size (i.e. magnitude) can be only approximately accounted for by having a_0, v_0 and d_0 magnitude-dependent. A more accurate approach would consist of having $A_0(R)$ depend on magnitude, wave frequency, peak amplitudes and the conditions at the recording site, but the empirical definition of such a function may have to wait until more abundant strong-motion data become available.

Contrary to the linear or exponential scaling of peak accelerations with magnitude, we believe that the magnitude dependence of the recorded peaks of strong ground motion close to the source should gradually disappear as the magnitude increases and/or as the observation point approaches the fault plane[22] in agreement with our early work[23] which was based on the simple semi-static source theory of Brune.[24] It will be shown below that such trends also seem to be indicated by the strong-motion data.

Dependence of $\log_{10}[a_0(M)]$, $\log_{10}[v_0(M)]$ and $\log_{10}[d_0(M)]$ on magnitude and for different site conditions has been calculated by dividing the acceleration records into nine groups and by computing the corresponding averages and standard deviations for the magnitude intervals 4–4·9, 5–5·9, 6–6·9 and 7–7·9. The results are shown in Table II and in Figures 5, 6 and 7. As seen from Table II, the number of data points is barely adequate to suggest the possible amplitudes for the magnitude ranges 4–5 and 7–8.

The shapes of $\log_{10}[a_0(M)]$, $\log_{10}[v_0(M)]$ and $\log_{10}[d_0(M)]$ in Figures 5, 6 and 7 respectively are quite similar and increase for larger magnitudes. The change of averages from those for $M = 6$–$6{\cdot}9$ to those for $M = 7$–$7{\cdot}9$ is close to one magnitude unit. This suggests that peak acceleration, velocity and displacement of strong ground motion essentially may reach their magnitude-independent maxima in this magnitude range. For low magnitudes the amplitudes of these scaling functions seem to level off and may reach a constant level for some magnitude less than about 4. This behaviour of $\log_{10}[a_0(M)]$, $\log_{10}[v_0(M)]$ and $\log_{10}[d_0(M)]$ is in excellent agreement with the current rough interpretation of the source mechanism[23,24] which can be outlined by the two independent parameters: seismic moment and stress drop. This theory states that for low frequencies displacement spectral amplitudes behave like $1/\omega$ (Near Field) or are constant (Far Field) and are proportional to the maximum dislocation (Near Field) or to the seismic moment, i.e. earthquake magnitude (Far Field). For high frequencies, the displacement spectra decay approximately like $1/\omega^2$ and the respective amplitudes are proportional to the stress drop. Because the corner frequency[23,24] is inversely proportional to the size of the dislocation, for large earthquakes the corner frequency becomes small.

Table II

		Magnitude	4.0-4.9			5.0-5.9			6.0-6.9			7.0-7.9		
		Site Classif.	0	1	2	0	1	2	0	1	2	0	1	2
Acceleration cm/sec^2	Vert.	$\overline{\log a_0}$	1.80	1.39	-	1.83	1.94	1.60	2.21	2.25	2.25	3.21	-	-
		σ	0.036	0.519	-	0.494	0.253	0.213	0.270	0.253	0.332	0.107	-	-
	Horz.	$\overline{\log a_0}$	1.38	1.07	-	1.56	1.54	1.41	1.94	1.94	2.05	2.87	-	-
		σ	0.309	0.368	-	0.503	0.313	0.390	0.278	0.205	0.331	0.163	-	-
Velocity cm/sec	Vert.	$\overline{\log v_0}$	2.69	2.62	-	3.00	3.07	3.01	3.10	3.21	3.30	4.15	-	-
		σ	0.177	0.101	-	0.519	0.327	0.158	0.331	0.288	0.440	0.230	-	-
	Horz.	$\overline{\log v_0}$	2.32	2.41	-	2.59	2.73	2.65	2.77	2.88	3.18	3.76	-	-
		σ	0.256	0.326	-	0.478	0.310	0.443	0.308	0.258	0.415	0.220	-	-
Displacement cm	Vert.	$\overline{\log d_0}$	2.89	2.88	-	3.21	3.30	3.44	3.33	3.46	3.63	4.31	-	-
		σ	0.441	0.147	-	0.491	0.436	0.085	0.405	0.325	0.573	0.262	-	-
	Horz.	$\overline{\log d_0}$	2.68	2.77	-	3.01	3.14	3.02	3.01	3.20	3.62	4.09	-	-
		σ	0.171	0.328	-	0.484	0.390	0.223	0.368	0.348	0.508	0.221	-	-
No. of Data Used		Vert.	3	2		24	15	2	82	34	12	7		
		Horz.	6	4		47	30	4	164	68	24	14		

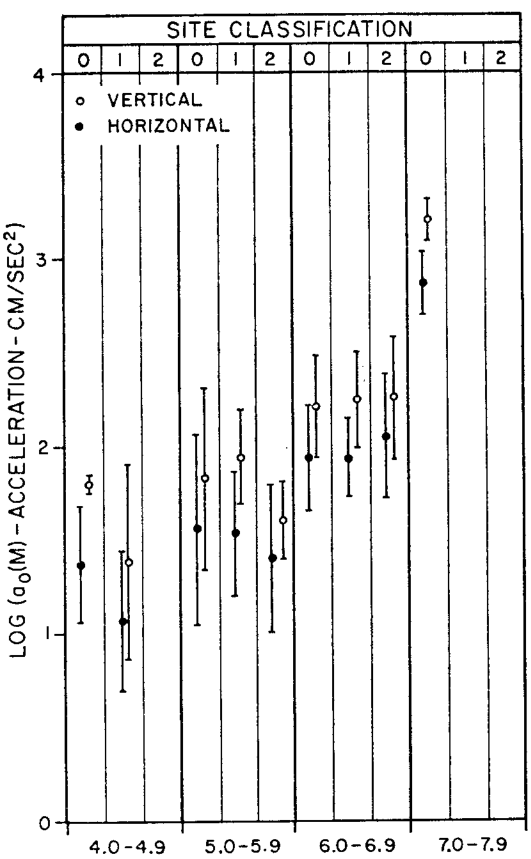

Figure 5. Mean and standard deviation of the magnitude-dependent scaling function $a_0(M)$ for vertical and horizontal accelerations, with different site classification and magnitude

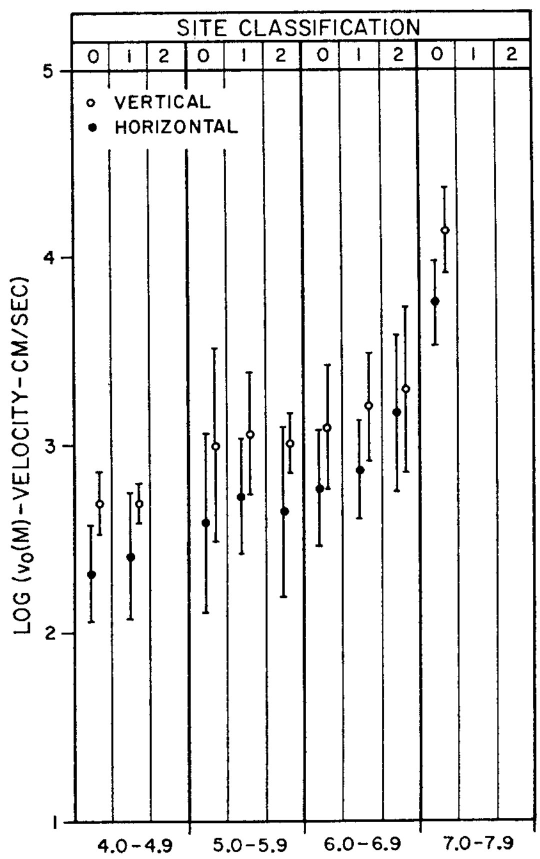

Figure 6. Mean and standard deviation of the magnitude-dependent scaling function $v_0(M)$ for vertical and horizontal velocities, with different site classification and magnitude

Consequently, for large earthquakes (say $M > 7$) the amplitudes of strong ground motion may cease to be dependent on earthquake magnitude and are scaled primarily by the effective stress[24] and local dislocation maxima.[23] For smaller earthquakes the corner frequency increases and the significant portion of the frequency band representing strong ground motion is now influenced by the flat (Far Field) or $1/\omega$ (Near Field) spectral amplitudes which are proportional to the moment, overall fault displacements and earthquake magnitude. Recent source mechanism studies based on the recorded strong ground motion have confirmed that the above simplified theory[24] may represent a reasonable first-order approximation to the observed spectra if the radiation pattern and propagation effects are accounted for.[17,25–28]

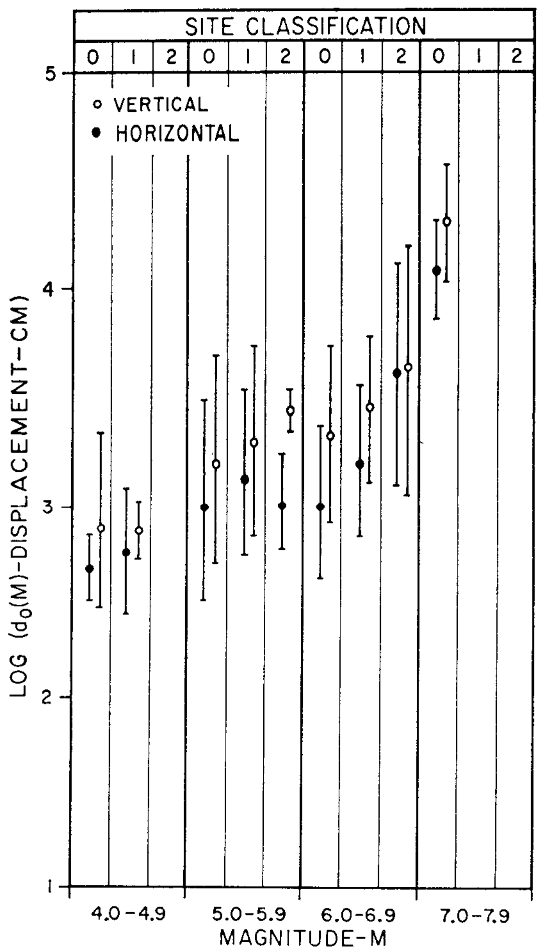

Figure 7. Mean and standard deviation of the magnitude-dependent scaling function $d_0(M)$ for vertical and horizontal displacements, with different site classification and magnitude

For magnitudes less than 6 it seems that $\log_{10}[a_0(M)]$ may consistently be larger for '0' sites than for '2' sites. This implies [see equation (11)] that the average peak accelerations for sites on hard basement rocks would be higher than those recorded on alluvium. These effects of site classification[3] on the recorded peaks are shown in Figures 5, 6 and 7. For $\log_{10}[v_0(M)]$ and $\log_{10}[d_0(M)]$ and in the same magnitude range ($M < 6$) no noticeable differences seem to exist between the 'soft' and 'hard' sites (Figures 6 and 7). For magnitudes larger than 6, presumably for reasons associated with the greater number of peaks, i.e. increased duration,[29] and more efficient excitation of long waves (low frequencies), amplification effects associated with the waves propagating into soft alluvium layers become more important. In this magnitude range $\log_{10}[a_0(M)]$ ceases to be larger for alluvium sites, and in fact it seems that peak accelerations recorded on the three different site types are all the same. For velocity and displacement peaks and $M > 6$, however, alluvium sites appear

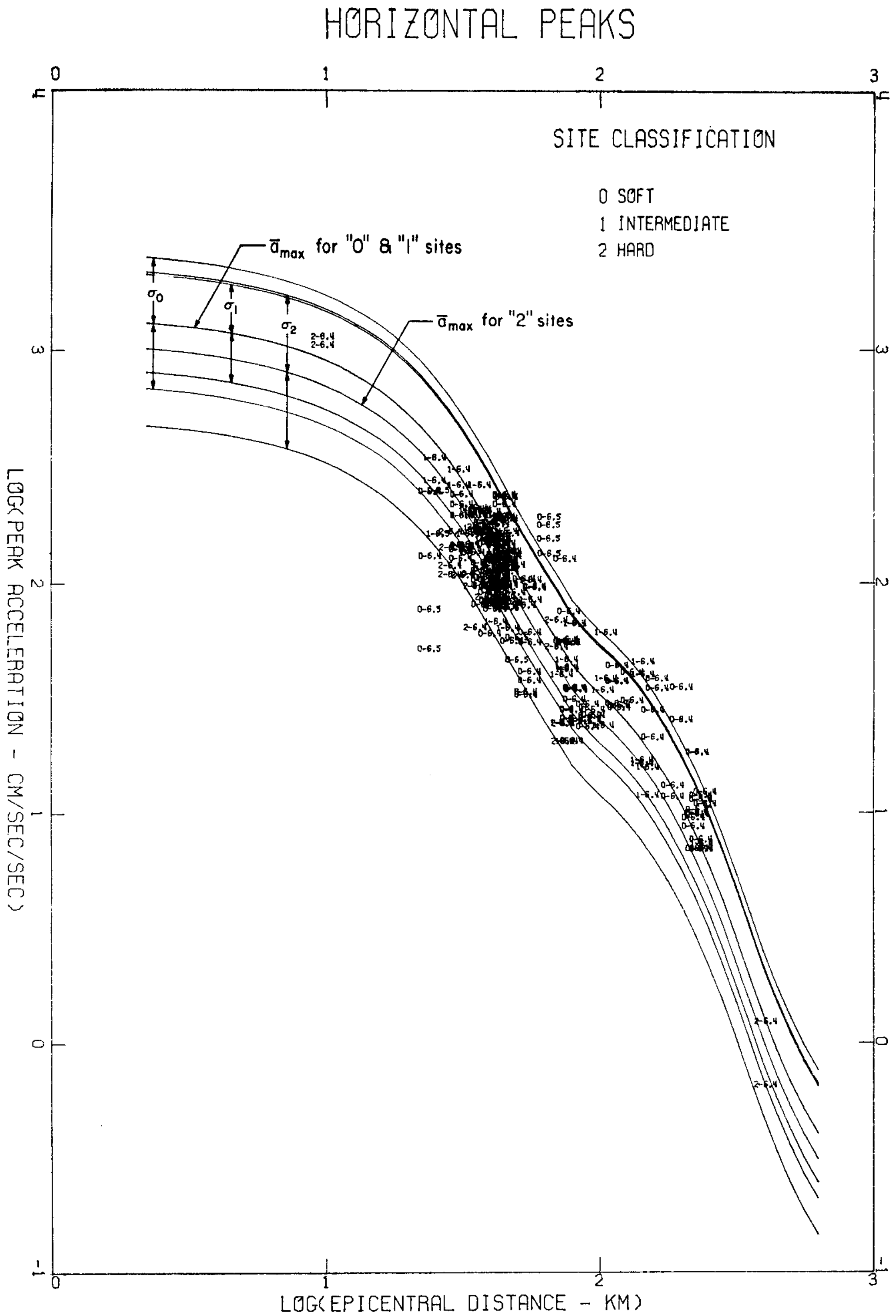

Figure 8. Computed average peak acceleration *vs* distance and standard deviations, for magnitude $M = 6{\cdot}5$, and '0', '1', '2' site conditions, using equation (11) and Tables I and II. Data points for $M = 6{\cdot}4$ to $6{\cdot}6$ are also plotted

to experience larger amplitudes, since $\log_{10}[v_0(M)]$ and $\log_{10}[d_0(M)]$ are consistently smaller for alluvium than for basement rock sites (Figures 6 and 7).

Figure 8 represents an example of using equation (11) and Tables I and II to compute peak acceleration versus distance for magnitude $M = 6{\cdot}5$ and '0', '1' and '2' site conditions. For comparison, all recorded peak accelerations for magnitudes ranging from 6·4 to 6·6 have also been plotted.

CONCLUSIONS

An attempt has been made to compare most well-known relationships for predicting peak accelerations of strong earthquake ground motion at a given distance and as a function of earthquake magnitude. We found that for the distance range of about 20–200 km, with only two exceptions,[6,9] all previous correlations appear to be within a factor of about two from the mean trends indicated by the available data. However, for distances less than about 20 km, where virtually no strong motion data are now available, extrapolations of these relationships (in some cases outside the range of their intended use) diverge considerably. For a magnitude 6·5 earthquake, for example, and at a distance of 1 km, estimates of maximum peak acceleration range from about 0·1 *g*[6] to well above 1 *g*.[10] For distances greater than about 30 km, all proposed amplitudes decay approximately as $1/R^2$.

Assuming that $\log_{10} A_0(R)$ (Table I) represents an acceptable first-order approximation for the amplitude *vs* distance decay in the Western United States (which seems to be confirmed by the data used in this study for epicentral distances between 20 and 200 km), then our present study suggests that most previous investigators may have underestimated the peak accelerations for distances less than about 40 km.

A systematic study of all the data shows that the peaks of strong ground motion do not grow linearly with earthquake magnitude. Equation (11) and Figures 5, 6 and 7 indicate that the average maxima of strong-motion acceleration, velocity and displacement seem to be reached for magnitude 6·5–7·0 shocks. Consequently, amplitudes of accelerograms such as El Centro (1940), Taft (1952) or Pacoima Dam (1971), for example, might represent the maximum amplitudes possible at their respective distances for the largest earthquake that might occur in Southern California. However, from the duration viewpoint, these accelerograms are clearly too short[29] to be representative of the shaking that would result from a fault comparable to that for the 1906 California earthquake, for example.

For a magnitude 7·5 earthquake, analysis in this paper suggests that the average peak accelerations at the fault ($R = 0$) could be 1·75 *g* and that the interval corresponding to one standard deviation is from about 1·2 *g* to 2·5 *g*. However, these rough estimates must be taken with reservation, because they depend on the assumed validity of $\log_{10} A_0(R)$ for R less than about 20 km. At these short distances neither seismological nor strong-motion data are available now to test unequivocally the adequacy of this empirical attenuation law.

The data studied in this paper suggest that for intermediate and small magnitude earthquakes peaks recorded on hard rock may be higher, but not significantly, than the peaks recorded on alluvium (Figure 5). This is in accord with our previous study[3] where we demonstrated that for a given modified Mercalli intensity level peak accelerations recorded on a hard rock site are on the average higher than the same recorded on alluvium.

Peak displacements, on the other hand, are consistently larger on alluvium sites than on hard basement rocks (Figure 7), again in agreement with our previous study, where we correlated peak displacements with modified Mercalli intensity for the same site.[3]

When using equation (11) and Table II to estimate the expected peak amplitudes of strong ground motion, one should bear in mind that our results are of a preliminary nature because the number and the range of the available strong-motion data which we used is quite limited. We believe, however, that our results do represent the real nature of the physical problem at hand. Therefore, when more accurate data become available, it will be possible to improve the accuracy of our present estimates, to extend the tables over a broader magnitude range, to formulate a continuous functional dependence of $\log_{10}[a_0(M)]$, $\log_{10}[v_0(M)]$ and $\log_{10}[d_0(M)]$ on magnitude and site conditions, and to correct and improve our too-simple assumption that $\log_{10} A_0(R)$ describes attenuation with distance for acceleration, velocity and displacement peaks.

ACKNOWLEDGEMENTS

We thank D. E. Hudson for critical reading of the text and some useful comments.

This research has been supported by grants from the National Science Foundation and Earthquake Research Affiliates Program at the California Institute of Technology.

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