Soil Dynamics and Earthquake Engineering **11** (1992) 101–110

A note on scaling peak acceleration, velocity and displacement of strong earthquake shaking by Modified Mercalli Intensity (MMI) and site soil and geologic conditions

M.D. Trifunac & V.W. Lee

University of Southern California, Civil Engineering Department, Los Angeles, California 90089-2531, USA

(Received 1 March 1991; revised version received 14 May 1991; accepted 16 May 1991)

It is shown that the overall trends of peak amplitudes of strong motion acceleration, velocity and displacement versus site intensity in the Western United States are consistent with our previous inferences,[18] but the larger present data base allows us to begin with identification of the additional changes of average peak amplitudes also in terms of the local soil and local geologic site conditions. These trends display a reversal of peak amplitude trends in going from small to large intensities, making it difficult to reconcile the simple scaling of design spectra in terms of peak ground acceleration.

INTRODUCTION

More than 15 years ago, we presented a study on the relationships between the peaks of the recorded strong motion amplitudes and the Modified Mercalli Intensity (MMI) at the recording site.[18] In that work, we found general agreement of our results with the overall trends reported by others, and somewhat larger peak amplitudes for strong ground motion recorded in the Western United States. Our study in 1975 used 186 strong motion accelerograms, recorded during 57 earthquakes which occurred between 1933 and 1971.

During the late 1970s and through the 1980s, the uniformly processed strong motion data base[9] grew steadily and, at present, it exceeds 1000 records. The process of collecting the local soil and geologic site conditions at all recording stations has been slow and some, although incomplete, data is now available only for the recordings up to about 1984.[14] For consistency, and to enable direct comparisons with other related results,[14,15,17] we will use this same data base here also. Between 1984 and present, excellent additional recordings have been obtained, but it may take years before the uniform data for local soil and local geologic site conditions are gathered and become available for use in this type of analysis.

Soil Dynamics and Earthquake Engineering 0267-7261/92/$05.00

Since the late 1950s, when the response spectrum was first proposed for use in the design of nuclear power plants, through the 1960s, 1970s and 1980s, the spectral characterization of strong earthquake staking amplitudes for earthquake resistant design become more wide spread. It was originally recommended that the scaling of response amplitudes be done in terms of spectral intensity.[7] However, the empirical equations on how spectral intensity should scale with magnitude and distance or with the MMI at the site, became available only some 20 years later.[19,24,25] On the other hand, the direct and simple relationship between the high frequency spectral amplitudes and the recorded peak acceleration could be used immediately. In the following years, this scaling in terms of peak ground acceleration was used by many, both in theoretical and in practical engineering uses of strong motion data. With this background, one aim of this paper is to examine whether this approach can be reconciled with what we know about the strong earthquake motion today, with emphasis on the scaling in terms of MMI at the site.

Through the 1970s and the 1980s, numerous contributions to detailed scaling of Fourier and response spectra of strong ground motion have been presented. It was shown that the spectral amplitudes and the spectral shapes depend on the size of the earthquake (scaled either by magnitude or by intensity), local geologic and local soil conditions,[12,14,15] vertical versus horizontal components of motion, distance from the earthquake and frequency of motion. These new results were soon incorporated into more advanced methods for estimation of seismic risk,[1,2] but, at present, they are still not included in any form in the design code provisions. In 1975, when we presented our first analysis of the peaks of strong motion scaled by MMI, the analyses on the detailed frequency dependent scaling of spectra were just initiated. Thus, it is also useful to examine how these developments of more refined and frequency dependent scaling could be used to further test the validity of the direct analysis of the peaks of acceleration, velocity and displacement in terms of MMI at the recording site.

In many countries, seemingly identical definitions of local magnitude, or of intensity scales are used.[4] When the strong motion data becomes available for a particular region, analysis may show significant differences in the amplitudes and in the shape of the response spectrum amplitudes. Since earthquake engineers frequently 'borrow' recorded accelerograms or empirical scaling equations from another region, where strong motion data is available, it becomes essential to document and to understand when such data are capable of simulating the local strong ground motion. As there may exist substantial and systematic differences in magnitude[10] and in intensity,[5,22,23] and in actually recorded spectra of strong motion in different tectonic regions, more detailed and careful studies of such differences are essential.

STRONG MOTION DATA

From 1976 the strong motion data processing laboratory of the University of Southern California has been engaged in the development of new digitization techniques,[20] creation of uniform strong motion data base[9] and dissemination of strong motion data to the users. The uniform data base considered in this work consists of 484 records from 106 earthquakes. The geologic site conditions $s = 0$ for sediments, $s = 2$ for basement rock and $s = 1$ for intermediate sites (see Ref. 18, for discussion and for the method of selecting $s = 0$, 1 and 2) are available for 425 of these records, while the soil site conditions ($s_L = 0$ for 'rock', $s_L = 1$ for stiff soil conditions and $s_L = 2$ for deep soil sites, see Seed *et al.*,[11] for definition of soil site conditions) are available only for 215 records. Out of 425 records, 73% have been recorded on sediments ($s = 0$), 17% in intermediate geologic environment ($s = 1$) and only 10% on the geologic basement rock ($s = 2$). For 215 records, for which the

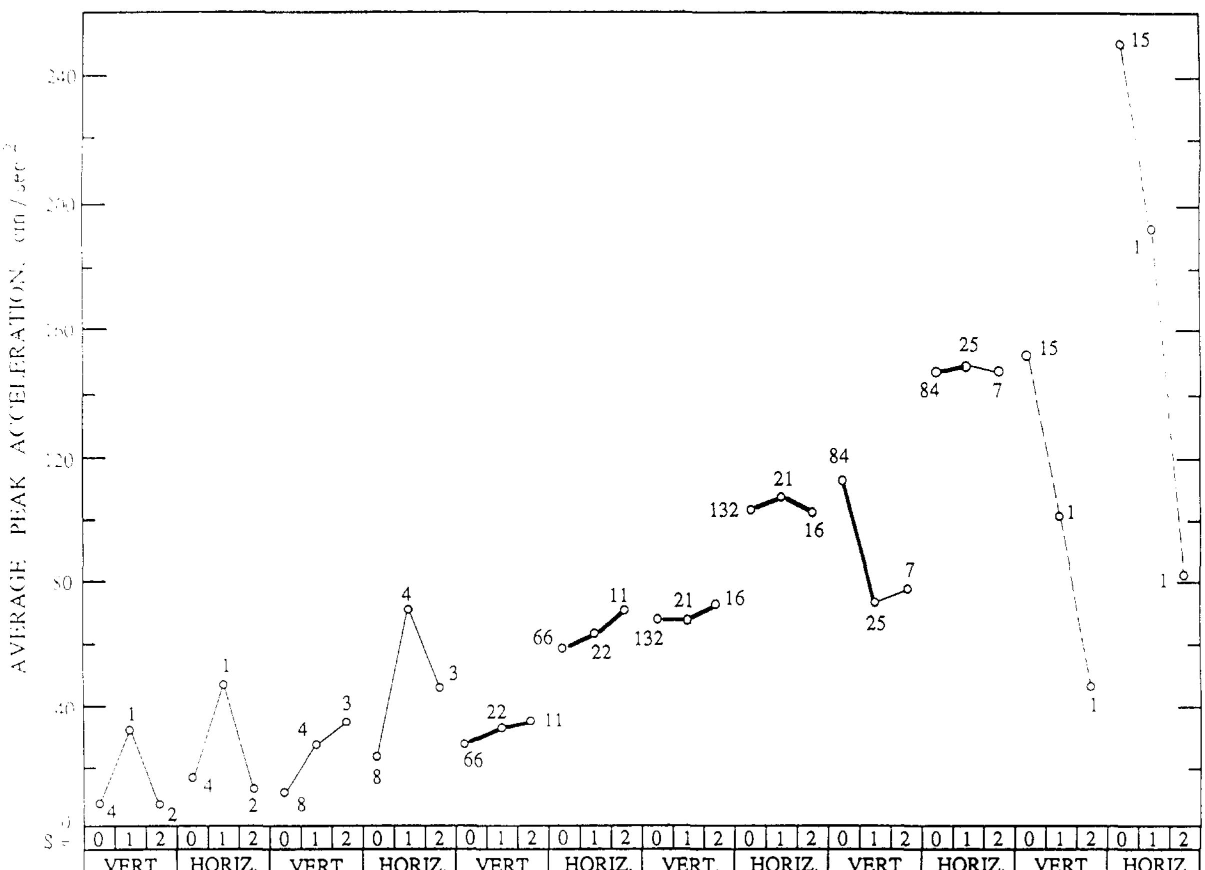

Fig. 1. Average peak accelerations versus Modified Mercalli Intensity, for vertical and horizontal ground motion and for sites on sediments ($s = 0$), intermediate rock ($s = 1$) and basement rock ($s = 2$). Numbers adjacent to the plotted points indicate the number of available records for calculating the above averages.

local soil classification is available, the distribution is as follows: 70% are over sediments ($s = 0$), 21% are over intermediate sites ($s = 1$) and 9% are on the basement rock sites ($s = 2$). With respect to the soil classification, 47% are on deep soil sites ($s_L = 2$), 38% are on stiff soil sites ($s_L = 1$) and 15% are on 'rock' soil sites ($s_L = 0$). In contrast to Japan, our strong motion data base has insignificant number of strong motion records over deep cohesionless soil sites.[11]

DEPENDENCE OF PEAK AMPLITUDES ON LOCAL GEOLOGIC CONDITIONS

Figure 1, Fig. 2, Fig. 3, and Table 1a present average peaks of acceleration, velocity and displacement versus MMI, levels III through VIII. For completeness of this presentation, Table 1a also lists the available data for intensities IX and X. It is seen that the average peak acceleration tends to increase slightly from sites on sediments ($s = 0$) to basement rock sites ($s = 2$) for intensities less than VII. For MMI = VII and larger intensities, this trend appears to be reversed. Peak velocities and peak displacements are larger on sediments. This trend becomes more significant with increasing site intensity. To emphasize and to focus readers attention on those trends for which more than 10 data points are available, average peak amplitudes in Fig. 1 through Fig. 3 have been connected by heavy lines.

In 1975 we found that for a given Modified Mercalli Intensity at a site, the average peak acceleration is larger for rock sites ($s = 2$) than it is at soft sedimentary sites ($s = 0$). These variation did not exceed a factor of about two. The large standard deviations showed that the observed differences cannot be considered to be significant in terms of a simple statistical test for the difference in the means of two populations, but the observed trend was systematic and clearly indicated an underlying physical cause. For completeness of this presentation and to help with direct comparison with data in Table 1a, we present here (Table 1b) the averages and standard deviations of peak acceleration, velocity and displacement from Trifunac & Brady.[18]

Comparison of Fig. 1 through Fig. 3 with our analysis in 1975 (see Table 1b) shows consistency and general agreement of the two studies. However, larger number of data in the present analysis allows one to observe also how these trends change with intensity. Clearly, much

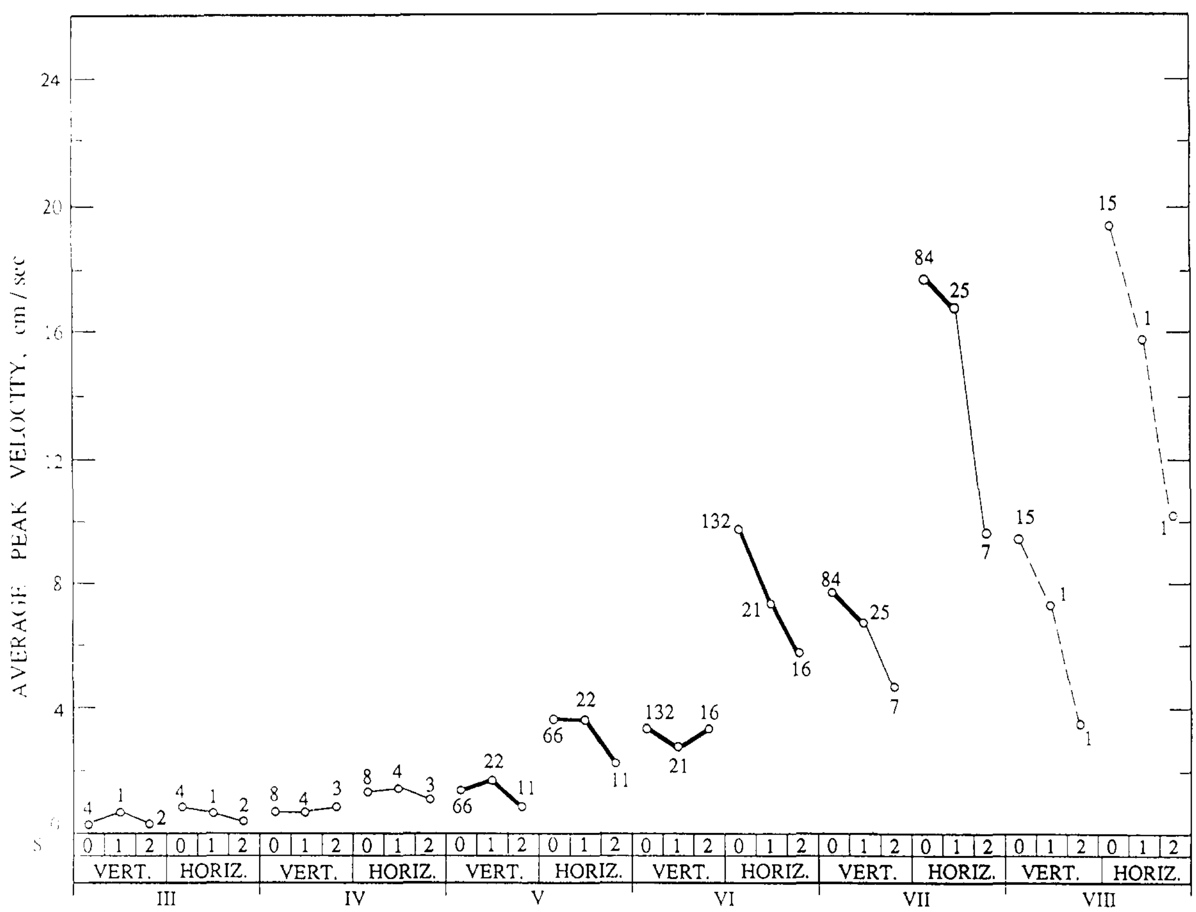

Fig. 2. Average peak velocities versus Modified Mercalli Intensity, for vertical and horizontal ground motion and for sites on sediments ($s = 0$), intermediate rock ($s = 1$) and basement rock ($s = 2$). Numbers adjacent to the plotted points indicate the number of available records for calculating the above averages.

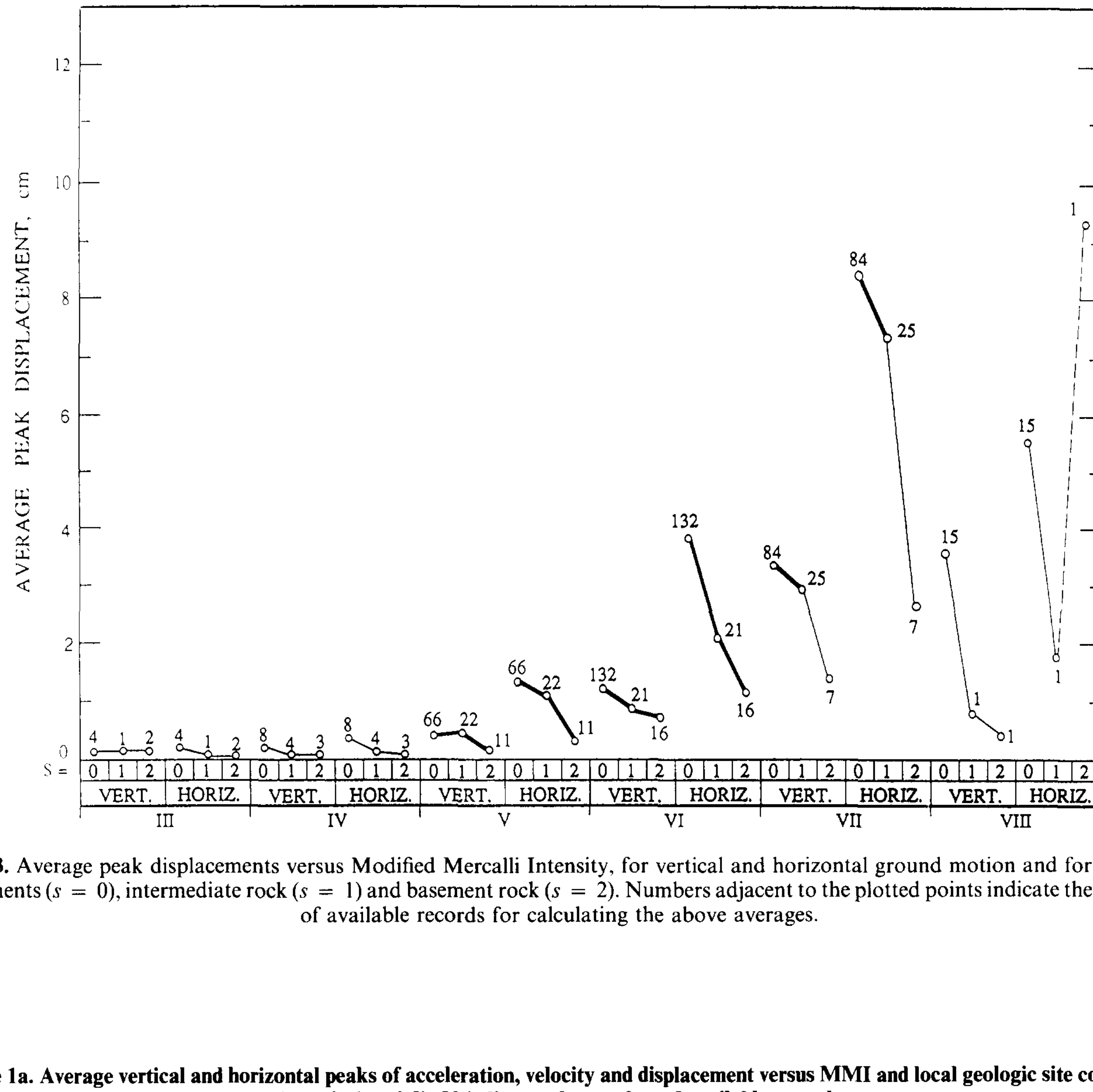

Fig. 3. Average peak displacements versus Modified Mercalli Intensity, for vertical and horizontal ground motion and for sites on sediments ($s = 0$), intermediate rock ($s = 1$) and basement rock ($s = 2$). Numbers adjacent to the plotted points indicate the number of available records for calculating the above averages.

Table 1a. Average vertical and horizontal peaks of acceleration, velocity and displacement versus MMI and local geologic site conditions (s = 0, 1 and 2). N indicates the number of available records

		$s = 0$				$s = 1$				$s = 2$		
MMI	N	$\bar{a}_V$ $\bar{a}_H$	$\bar{v}_V$ $\bar{v}_H$	$\bar{d}_V$ $\bar{d}_H$	N	$\bar{a}_V$ $\bar{a}_H$	$\bar{v}_V$ $\bar{v}_H$	$\bar{d}_V$ $\bar{d}_H$	N	$\bar{a}_V$ $\bar{a}_H$	$\bar{v}_V$ $\bar{v}_H$	$\bar{d}_V$ $\bar{d}_H$
III	4	9·01	0·33	0·03	1	32·14	0·64	0·04	2	8·93	0·19	0·01
		15·81	0·84	0·13		48·32	0·74	0·04		13·00	0·29	0·01
IV	8	12·68	0·57	0·18	4	27·19	0·57	0·04	3	35·33	0·71	0·03
		24·28	1·36	0·30		70·84	1·49	0·14		45·01	1·10	0·05
V	66	28·85	1·31	0·45	22	31·56	1·57	0·48	11	33·67	0·95	0·08
		59·92	3·65	1·31		61·96	3·61	1·06		70·08	2·39	0·33
VI	132	67·67	3·27	1·20	21	68·31	2·85	0·81	16	73·99	3·30	0·76
		119·44	9·88	3·85		138·74	7·33	2·04		110·17	5·71	1·11
VII	84	113·11	7·66	3·28	25	73·51	6·83	2·99	7	77·59	4·58	1·46
		148·90	17·66	8·41		148·24	16·75	7·33		144·35	9·53	2·67
VIII	15	156·87	9·48	3·59	1	101·18	7·23	0·71	1	46·76	2·74	0·48
		253·82	19·46	5·50		191·18	15·99	1·73		80·98	10·30	9·37
IX	1	243·24	5·89	0·65								
		401·13	15·73	2·14								
X									1	695·97	58·30	19·3
										1101·50	85·48	24·20

Table 1b. Mean values and standard deviations of peak acceleration, velocity and displacement for various site classifications during shaking of different Modified Mercalli Intensities

M.M. Int. site classification	Component	Acceleration – cm/sec^2		Velocity – cm/sec		Displacement – cm		No. of data points used
		$\bar{a}$	σ	$\bar{v}$	σ	$\bar{d}$	σ	
V-0	Vert.	15·44	8·05	1·84	1·36	1·38	0·96	17
	Horiz.	34·56	26·96	3·82	3·61	2·41	2·82	34
V-1	Vert.	21·43	11·98	1·43	0·64	1·21	0·45	14
	Horiz.	40·18	32·28	3·21	1·81	1·43	0·92	28
V-2	Vert.	25·00	12·50	1·25	0·00	1·00	0·50	2
	Horiz.	37·50	25·00	2·50	1·25	1·25	0·83	4
VI-0	Vert.	32·27	29·31	3·05	2·55	2·03	1·42	43
	Horiz.	65·99	71·24	7·70	6·13	4·22	3·36	86
VI-1	Vert.	44·84	39·07	3·01	1·66	1·68	0·98	17
	Horiz.	113·97	92·14	7·57	6·13	2·97	2·48	34
VI-2	Vert.	66·07	33·88	4·82	2·95	1·79	0·70	7
	Horiz.	107·14	35·58	6·79	4·45	2·21	1·28	14
VII-0	Vert.	68·50	34·48	7·35	4·59	3·70	2·14	50
	Horiz.	128·41	60·25	16·50	8·49	8·83	4·39	100
VII-1	Vert.	62·50	31·62	7·12	3·47	3·50	1·67	20
	Horiz.	131·87	53·18	17·81	8·21	8·60	4·40	40
VII-2	Vert.	87·50	41·83	5·25	2·55	2·10	1·02	5
	Horiz.	157·50	89·30	11·00	6·84	3·50	2·28	10

[a] From Trifunac & Brady.[18]

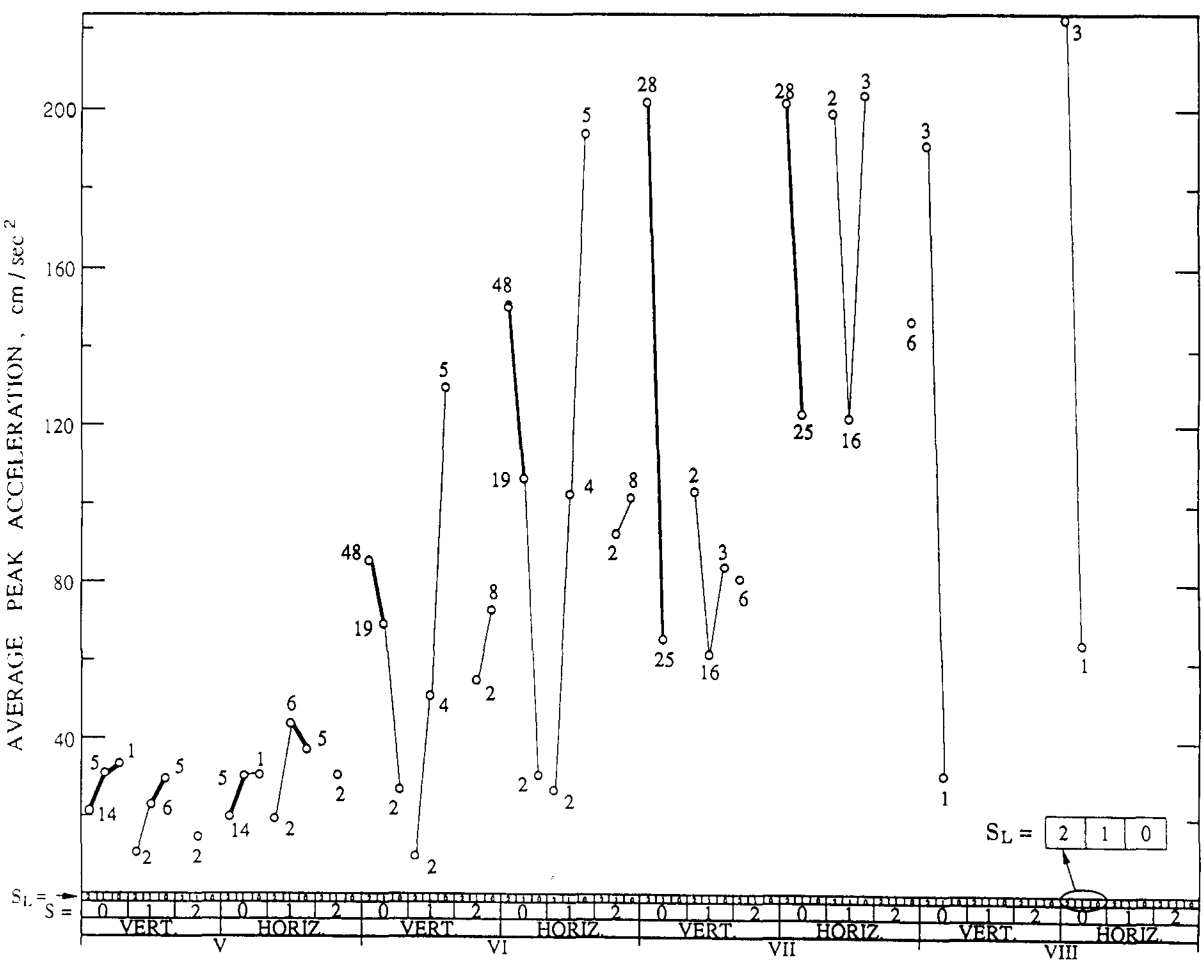

Fig. 4. Average peak accelerations as in Fig. 1, but with additional dependence on the local soil site condition (s_L = 0, 1, 2).

more data would be required to refine and to complete these plots for larger site intensities, and to interpret the observed trends on the basis of the peak amplitudes alone.

DEPENDENCE OF PEAK AMPLITUDES ON LOCAL SOIL CONDITIONS

Further refinement in the description of the local site conditions involves the use of local site conditions[11] together with the local geologic site conditions.[14,15] This allows one to examine yet another dimension of the trends shown in Fig. 1 through Fig. 3. By dividing all available data further, into three additional subgroups (corresponding to $s_L = 2$, 1 and 0) within each MMI level and for each local geologic site classification ($s = 0$, 1 and 2), it is possible to compute the average peak amplitudes and to plot them as in Fig. 4 through Fig. 6, and to tabulate them as in Table 2.

As it can be seen from Fig. 4, Fig. 5 and Fig. 6, the number of the available data points is now even more marginal than for the analysis with respect to the local geologic conditions. Nevertheless, the overall trends are remarkably consistent with our previous inferences on how $s_L = 2$, 1 and 0 'rotate' and deform the shape of the average Fourier spectrum (Fig. 7(a)) of strong motion acceleration.[14,15] Thus, for small intensities, with ground motion closer to the source and associated with smaller earthquakes, peak accelerations tend to increase from $s_L = 2$ (deep soil) to $s_L = 0$ ('rock'). But, as the site intensity increases and, with it, the spectral amplitudes progressively become richer with long period motion, the peak acceleration also becomes more affected by longer period spectral components, and for large intensities it becomes larger at sites with $s_L = 2$ relative to the sites with $s_L = 0$. Analogous, but more pronounced, trends of the same type are seen in Fig. 5 and Fig. 6 for peak velocities and for peak displacements.

DISCUSSION AND CONCLUSIONS

Theoretical analysis of the functional form, and of the probability distribution function of the peaks of a random function and of the parameters of this function,[3,6] shows that peak amplitudes increase first with the root-mean-square of the function, and, through Parsevals

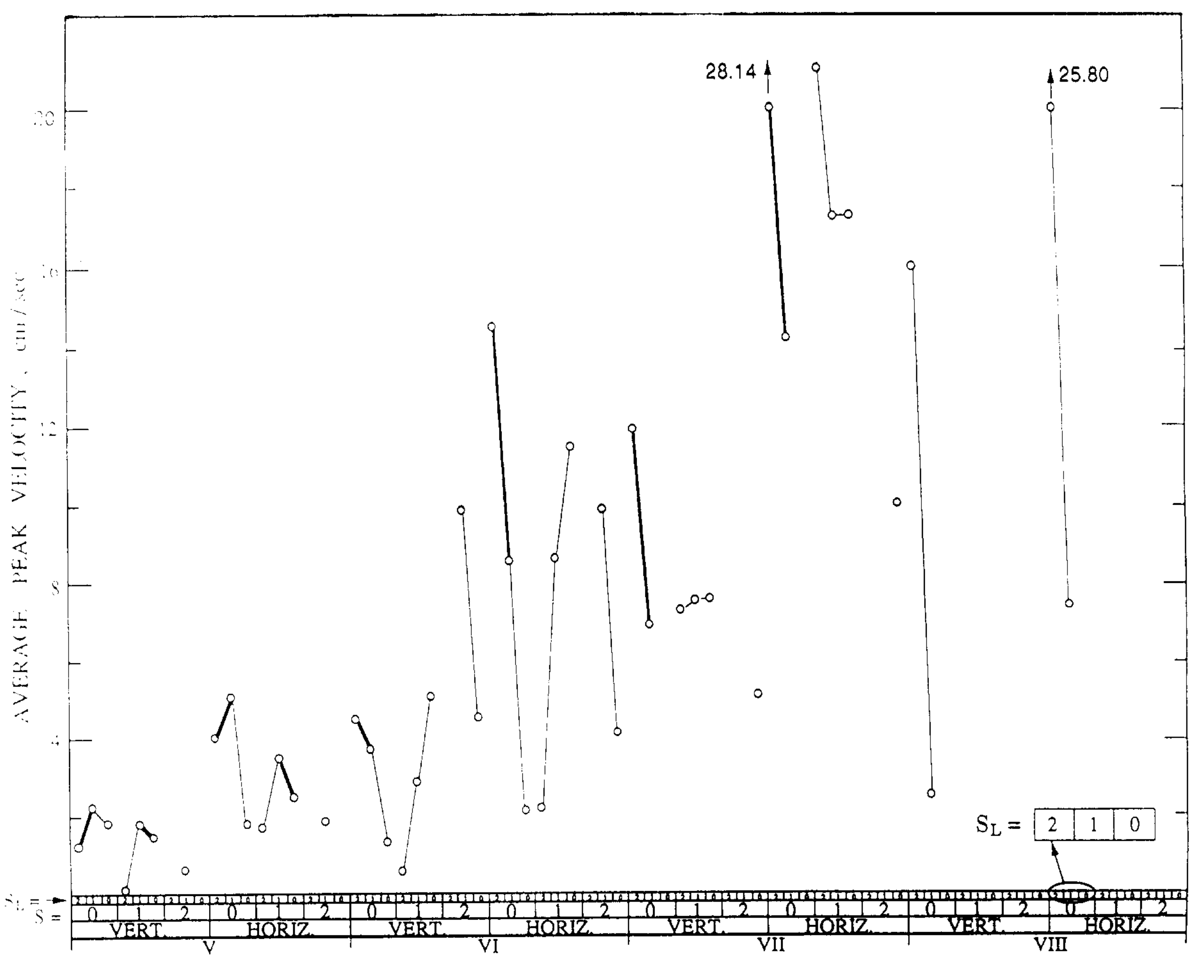

Fig. 5. Average peak velocities as in Fig. 2, but with additional dependence on the local soil site condition ($s_L = 0, 1, 2$).

Table 2. Average vertical and horizontal peaks of acceleration, velocity and displacement versus MMI, local geologic ($s = 0, 1, 2$) and local soil ($s_L = 0, 1, 2$) site conditions. N indicates the number of available records

			$s = 0$				$s = 1$				$s = 2$		
MMI	s_L	N	$\bar{a}_V$ $\bar{a}_H$	$\bar{v}_V$ $\bar{v}_H$	$\bar{d}_V$ $\bar{d}_H$	N	$\bar{a}_V$ $\bar{a}_H$	$\bar{v}_V$ $\bar{v}_H$	$\bar{d}_V$ $\bar{d}_H$	N	$\bar{a}_V$ $\bar{a}_H$	$\bar{v}_V$ $\bar{v}_H$	$\bar{d}_V$ $\bar{d}_H$
III	2	1	5·95	0·32	0·20								
			32·59	1·25	0·10								
	1	1	5·34	0·60	0·09								
			9·50	1·65	0·39								
IV	2	2	6·33	0·56	0·12								
	1		20·08	2·33	0·58								
	0					1	10·39	0·73	0·13				
							14·01	1·59	0·41				
V	2	14	20·50	1·18	0·45	2	10·76	0·63	0·07				
			53·67	4·05	1·44		19·75	1·78	0·40				
	1	5	30·06	2·28	1·03	6	23·18	1·82	0·85	2	15·65	0·74	0·05
			61·60	5·68	3·38		44·40	3·57	1·58		32·02	1·85	0·26
	0	1	20·04	1·00	0·12	5	29·04	1·58	0·35				
			33·09	1·82	0·20		37·97	2·56	0·77				
VI	2	48	84·96	4·54	1·99	2	8·88	0·47	0·06				
			152·21	14·87	6·76		26·69	2·12	0·31				
	1	19	68·66	3·76	1·51	4	53·60	2·93	1·50	2	55·48	6·31	1·46
			107·76	8·53	3·59		102·78	8·52	3·60		92·48	9·82	1·58
	0	2	27·71	1·39	0·16	5	129·10	5·50	1·72	8	73·05	3·39	1·05
			31·50	2·07	0·36		194·43	11·56	3·31		101·57	4·43	1·41
VII	2	28	201·35	11·96	5·38	2	103·93	7·28	3·62				
			201·52	28·14	13·69		191·02	21·02	8·56				
	1	25	65·21	6·89	3·38	16	60·80	7·50	3·71				
			123·60	15·43	8·70		121·67	17·68	9·09				
	0					3	84·47	7·54	1·80	6	80·89	4·94	1·66
							203·37	17·62	4·26		146·06	10·34	3·03
VIII	2	3	192·25	16·01	12·00								
			222·81	25·80	14·04								
	1	1	31·94	2·54	0·89								
			64·88	7·44	3·94								
	0												
IX	2												
	1												
	0												
X	2												
	1									1	695·97	58·30	19·32
	0										1101·50	85·48	24·24

theorem, with the area under the Fourier amplitude spectrum squared of the corresponding time function. Second, the expected or the most probable peak amplitudes increase with the total number of sampled peaks, i.e. with the duration of the time function.

With increasing MMI, the energy content of Fourier spectra of strong shaking becomes more abundant with the long period waves. For intermediate (near one second) and longer periods (5 sec and longer), the spectral amplitudes are larger on sediments ($s = 0$) than on the basement rock sites ($s = 2$) (Fig. 7b). This results in progressively larger root-mean-square amplitudes on sediments ($s = 0$) with increasing site intensity. The duration of strong shaking is also longer on sediments ($s = 0$) than on the basement rock ($s = 0$),[24,25] and this means that the number of peaks in strong motion increases when going from $s = 2$ to $s = 0$. These two effects combine, causing reversal of peak amplitude trends in Fig. 1, when going from small to larger site intensities, for the peaks of strong motion acceleration. Analogous changes are seen in Fig. 2 and Fig. 3 for the peak velocities and the peak displacements.

Because of the 'counter-clockwise rotation' of the Fourier amplitude spectra is similar in going from $s = 2$ (basement rocks) to $s = 0$ (sediments), and from $s_L = 0$ ('rock') to $s_L = 2$ (deep soil) (see Figs 7(a) and 7(a)), the trends seen in Figs 1, 2 and 3 are further amplified in Figs 4, 5 and 6, which combine both soil and geologic site effects. Thus, to scale the spectra of ground motion in terms of site intensity and peaks of ground motion, one would have to incorporate all these factors into regression equations of peak amplitudes and of spectral shapes,

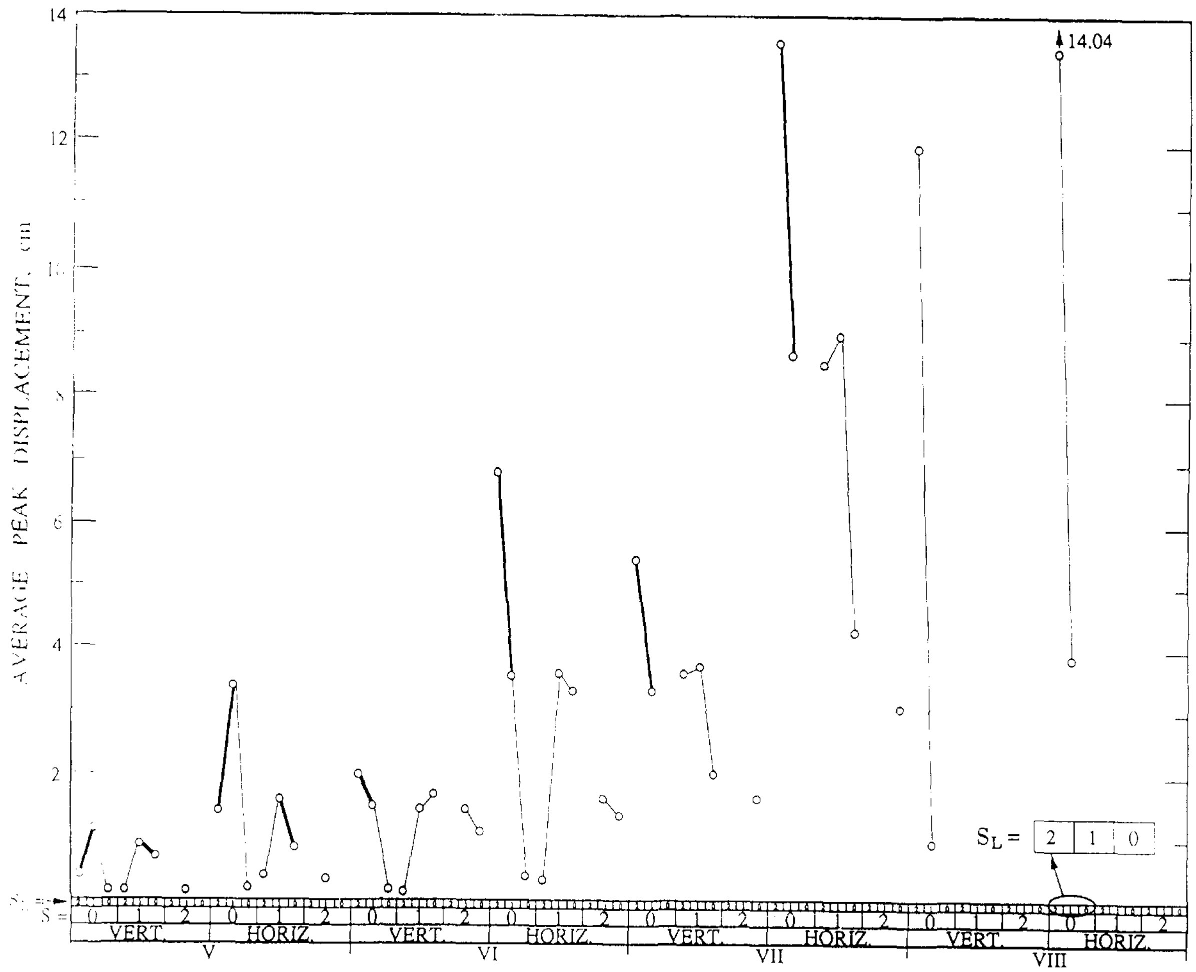

Fig. 6. Average peak displacements as in Fig. 3, but with additional dependence on the local soil site condition (s_L = 0, 1, 2).

with explicit dependence on site intensity. This is not only difficult, but the volume of the currently available data is not sufficient to make this effort feasible.

Perusal of numerous variations in the steps taken by different investigators will show that the process of deriving the design spectral amplitudes typically revolves around the following steps:

1) Determine the 'governing' combination (a number) of earthquakes which will most likely contribute to strong shaking at a site.
2) Use one or several (from many published) peak acceleration (peak velocity) attenuation equations to compute the corresponding peak acceleration (velocity) at the site.
3) Use the average and the average plus one standard deviation of the resulting peak acceleration at the site as scaling parameters to determine the amplitude of the design spectrum using some standard spectrum shape, as required by a design code, by a regulatory guide, or determined by a special study.

A more advanced approach might involve a probabilistic seismic risk analysis, that determines the probability distribution function of the site intensities, which, via empirical relationships between site intensity and peak acceleration, then can be used to 'scale' the standard shape design spectrum. We note that, in this discussion, we are not concerned with further reduction or modification of the peak acceleration, or of the spectral amplitudes for the purposes of incorporating the non-linear response capacity of structures and other applicable engineering considerations, but we focus our attention only on the steps involved in arriving at the spectral amplitudes corresponding to, or closest to the actual spectra of the expected strong ground motion at the site.

The methodology[1,2] and the computer programs have been developed,[8,21] and illustrated,[16] in a realistic tectonic environment for computation of the distribution functions of spectral amplitudes of strong motion at a site, but using the attenuation and scaling of spectral amplitudes directly in terms of MMI or magnitude. In that work, peak accelerations were never used directly or indirectly for any scaling at any stage in the process. The trends of the data on peak acceleration, velocity and displacement in this paper, thus illustrate the difficulties

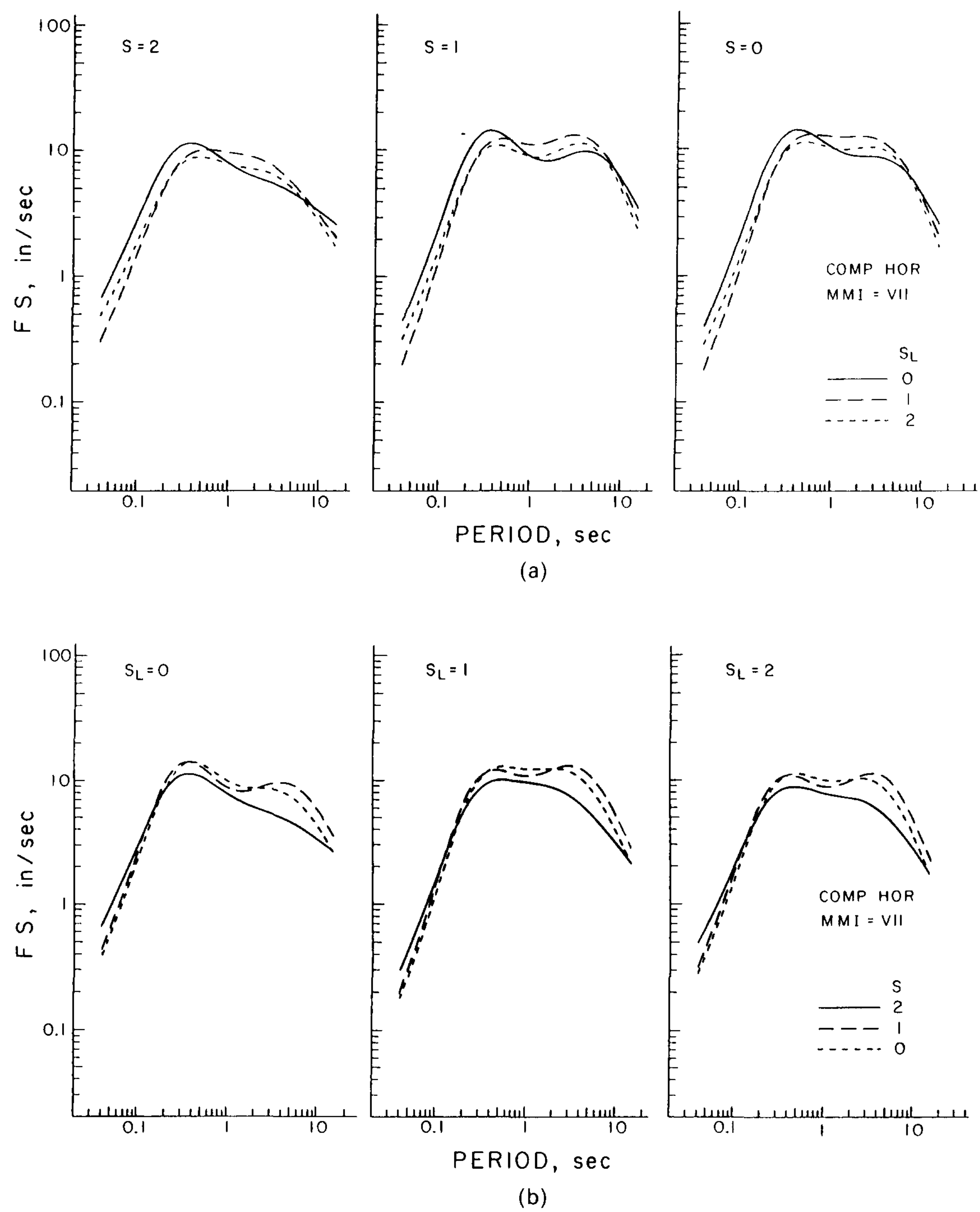

Fig. 7. (a) Average Fourier amplitude spectra for MMI = VII, horizontal motions, 'rock' sites (s_L = 0) (full lines), stiff soil sites (s_L = 1) and deep soil sites (s_L = 2) (long dashed lines), and for basement rock sites (s = 2) (left), intermediate sites (s = 1) (center) and sites on sediments (s = 0) (right) (from Trifunac[15]); (b) Average Fourier amplitude spectra for MMI = VII, horizontal motions, 'rock' sites (s = 2) (full lines), intermediate sites (s = 1) and sites on sediment (s = 0) (short dashed lines) and for 'rock' soil sites (s_L = 0) (left), stiff soil (s_L = 1) (center) and deep soil sites (s_L = 2) (right) (from Trifunac[15]).

and the errors which will result from simplified scaling of design spectra by peak acceleration.

During the time when strong motion data was not available for sufficient range of the recording site conditions, simplified scaling in terms of peak acceleration was justified. However, at present, with new data and with the availability of the detailed interpretations of this data, it is obvious that the amplitude of design spectra and of the Fourier spectra of strong ground motion should be determined without any (explicit or implicit) use of peak amplitudes of strong ground motion. Clearly, *mutatis mutandis*, identical requiem can be written for the scaling in terms of peak acceleration using earthquake magnitude and source to stations distance.

REFERENCES

1. Anderson, J.G. & Trifunac, M.D. Uniform risk functionals for characterization of strong earthquake ground motion, *Bull. Seism. Soc. Amer.*, 1978, **68**, 205–218.
2. Anderson, J.G. & Trifunac, M.D. A note on probabilistic computation of earthquake response spectrum amplitude, *Nuclear Eng. and Design*, 1979, **51**, 285–294.
3. Amini, A. & Trifunac, M.D. Distribution of peaks in linear earthquake response, *ASCE*, 1981, **107**, EM1, 207–227.
4. Evernden, J.F. & Thomson, J.M. Predictive model for important ground motion parameters associated with large and great earthquakes, *U.S. Geological Survey Bull*, 1988, **1838**, 1–27.
5. Gupta, I.D. & Trifunac, M.D. Attenuation of intensity with epicentral distance in India, *Int. J. Soil Dynamics and Earthquake Eng.*, 1988, **7**(3), 162–169.
6. Gupta, I.D. & Trifunac, M.D. Order statistics of peaks in earthquake response, *ASCE*, EMD, 1988, **114**(10), 1605–1627.
7. Housner, G.W. Behavior of structures during earthquakes, *Proc. ASCE*, EM4, 1959, **85**, 109–129.
8. Lee, V.W. Seismic microzonation method based on Modified Mercalli Intensity scaling, *Earthquake Eng. and Engineering Vibration*, 1989, **7**(3), 47–63.
9. Lee, V.W. & Trifunac, M.D. EQINFOS (The strong motion earthquake data information system), Dept. Civil Eng. Rep. No. 82-01, Univ. Southern California, Los Angles, California, 1982.
10. Lee, V.W., Trifunac, M.D., Herak, M., Živčvić, M. & Herak, D. M_L^{SM} in Yugoslavia *Int. J. Earthquake Eng. and Structural Dynamics*, 1990, **19**(8), 1167–1179.
11. Seed, H.B., Ugas, C. & Lysmer, J. Site dependent spectra for earthquake resistant design, EERC 74-12, U.C. Berkeley, Berkeley, California, 1974.
12. Trifunac, M.D. Preliminary empirical model for scaling Fourier amplitude spectra of strong ground acceleration in terms of earthquake magnitude, source to station distance and recording site conditions, *Bull. Seism. Soc. Amer.*, 1976, **66**, 1343–1373.
13. Trifunac, M.D. An instrumental comparison of the Modified Mercalli (MMI) and Medvedev-Karnik-Sponhener (M.K.S.) intensity scales, *Sixth World Conf. Earthquake Eng.*, N. Delhi, India, 1977, 2–359.
14. Trifunac, M.D. Dependence of Fourier spectrum amplitudes of recorded strong earthquake acceleration on magnitude, local soil conditions and on depth of sediments, *Int. J. Earthquake Eng. and Structural Dynamics*, 1989, **18**, 999–1016.
15. Trifunac, M.D. Scaling strong motion Fourier spectra by Modified Mercalli Intensity, local soil and geologic site conditions, *Structural Eng./Earthquake Eng.*, JSCE, 1989, **6**(2), 217–224.
16. Trifunac, M.D. A microzonation method based on uniform risk spectra, *Int. J. Soil Dynamics and Earthquake Eng.*, 1990, **9**(1), 34–43.
17. Trifunac, M.D. Empirical scaling of Fourier spectrum amplitudes of recorded strong earthquake acceleration in terms of Modified Mercalli Intensity, local soil conditions and depth of sediments, *Int. J. Soil Dynamics and Earthquake Eng.*, 1991, **10**(1), 65–72.
18. Trifunac, M.D. & Brady, A.G. On the correlation of seismic intensity scales with the peaks of recorded strong ground motion, *Bull. Seism. Soc. Amer.*, 1975, **65**, 139–162.
19. Trifunac, M.D. & Brady, A.G. A study on the duration of strong earthquake ground motion, *Bull. Seism. Soc. Amer.*, 1975, **65**, 581–626.
20. Trifunac, M.D. & Lee, V.W. Automatic digitization and processing of strong-motion accelerograms, Dept. of Civil Eng., Rep. No. 79-15 Parts I and II, Univ. of Southern California, Los Angeles, California, 1979.
21. Trifunac, M.D. & Lee, V.W. Uniform risk spectra of strong earthquake ground motion, Dept. of Civil Eng., Rep. No. 85-05, Univ. of Southern California, Los Angeles, California, 1985.
22. Trifunac, M.D. & Todorovska, M.I. Attenuation of seismic intensity in Albania and Yugoslavia, *Int. J. Structural Dynamics and Earthquake Eng.*, 1989, **18**(5), 617–631.
23. Wong, H.L. & Trifunac, M.D. A comparison of the Modified Mercalli (MMI) and the Japanese Meteorological Agency (JMA) Intensity Scales, *Int. J. Earthquake Eng. and Structural Dynamics*, 1979, **7**, 15–83.
24. Westermo, B.D. & Trifunac, M.D. A note on the correlation of frequency dependent duration of strong ground motion with the Modified Mercalli Intensity and the geologic conditions at the recording stations, *Bull. Seism. Soc. Amer.*, 1977, **67**, 917–927.
25. Westermo, B.D. & Trifunac, M.D. Duration of strong earthquake shaking, *Int. J. Soil Dynamics and Earthquake Eng.*, 1982, **2**(3), 117–121.