A NOTE ON THE RANGE OF PEAK AMPLITUDES OF RECORDED ACCELERATIONS, VELOCITIES AND DISPLACEMENTS WITH RESPECT TO THE MODIFIED MERCALLI INTENSITY SCALE

by

M. D. Trifunac

ABSTRACT

Correlations of the logarithms of acceleration, velocity and displacement peak amplitudes of recorded strong earthquake ground motion with the Modified Mercalli Intensity scale, I_{MM}, are characterized by large scatter of data points. For a given I_{MM} level this scatter is equal to about one order of magnitude on the linear amplitude scale. Correlations have been presented that are valid for the range of intensities IV $\le I_{MM} \le$ VIII, which correspond to 187 strong-motion accelerograms recorded during 57 earthquakes in the Western United States. Extrapolation of these correlations on the logarithmic scale to the largest Modified Mercalli intensity level I_{MM} = XII lead to strong-motion amplitudes which are not contradicted by other independent estimates of these largest amplitudes.

INTRODUCTION

Numerous empirical correlations of the peaks of recorded strong earthquake ground motion with the Modified Mercalli intensity, or its equivalent, have been presented in the literature (e.g., Barosh, 1969). Though the majority of these correlations concentrate on average amplitudes, several studies have presented the expected range of peak amplitudes (Medvedev and Sponheuer, 1969; JMA-Okamoto, 1973) or the corresponding standard deviations (Trifunac and Brady, 1975). The distribution of currently available peak amplitudes about the mean levels may not be of any simple known type. Consequently, knowledge of standard deviations alone does not enable one to calculate the approximate bounds on peak amplitudes for a selected confidence level.

The purpose of this brief note is, therefore, to present an attempt to approximate the bounds on peak amplitudes for the selected confidence levels. Because the spread of the recorded peak amplitudes recorded so far is considerable, it seems worthwhile to describe this large scatter by means of simple regression analysis.

The fact that the Modified Mercalli Intensity scale is only a qualitative and descriptive measure of the severity of strong ground motions at a point and that there is no direct physical law indicating that it should be correlated with the recorded peaks of strong ground motion has been discussed elsewhere (Trifunac and Brady, 1975). Nevertheless, with only a few exceptions (Western United States and Japan), this scale or its equivalent still represents the only available measure of past earthquakes that can be used to estimate the level of seismic activity in a region. It seems worthwhile then to describe the uncertainties inherent in the characterization of strong-motion amplitudes in terms of the Modified Mercalli Intensity scale and to show what might be the range of peak amplitudes in terms of selected confidence levels, geologic environment of a station, and component direction.

The work presented in this paper should not be interpreted to mean that the amplitudes of strong ground shaking should be characterized by the peaks of acceleration, velocity and displacement alone, nor that these peak amplitudes should be derived from the knowledge of what may be the expected Modified Mercalli Intensity at a given site. The motivation for this paper results from the fact that in routine earthquake engineering applications the most frequent empirical method for scaling the level of strong shaking is in terms of the Modified Mercalli Intensity or its equivalent. Consequently, we believe that those who employ such scaling methods should become aware of the uncertainties involved and the range of amplitudes that may be expected from such approximate methods. For this reason, in this paper these uncertainties will be presented by a direct analysis of the strong-motion data available so far.

The data on the levels of the Modified Mercalli Intensity scale which have been used in this study are from the publication entitled "United States Earthquakes," which is issued by the United States Department of Commerce, and are all for earthquakes which occurred in the Western United States. Since there may exist systematic differences in the methods of evaluating the Modified Mercalli intensity at a site for earthquakes in the Western, Central and Eastern United States and especially for earthquakes in other countries which employ the same scale (Trifunac and Brady, 1975), it should be emphasized that the correlations presented here apply only to the Western United States and for the period between 1933 and 1971. Although, formally, the definition of the Modified Mercalli Intensity scale does not depend on the geographic area under investigation, such factors as different types of and practices in the building construction as well as the methods of data collection and investigation by different agencies may all introduce systematic differences in the final assignment of the Modified Mercalli Intensity level at a site. Therefore, before such systematic differences become known for different parts of the world, the results presented in this paper should not be used for estimation of peak amplitudes outside the Western United States.

PROPOSED REGRESSION EQUATIONS

As an approximation for the bounds of the peaks of strong ground motion, it is proposed here to use the following expressions

$$\log_{10}\left\{\begin{matrix} a_{max,\,p} \\ v_{max,\,p} \\ d_{max,\,p} \end{matrix}\right\} = ap + bI_{MM} + c + ds + ev + fI_{MM}^2 . \qquad (1)$$

In these equations $a_{max,\,p}$, $v_{max,\,p}$ and $d_{max,\,p}$ represent the approximate bounds on peak acceleration a_{max}, peak velocity v_{max}, and peak displacement d_{max} for a confidence level p. I_{MM} is the Modified Mercalli Intensity ($I \le I_{MM} \le XII$), s represents the site constant (s = 0 for alluvium, s = 1 for intermediate rock sites, and s = 2 for basement rock sites), and v describes the component direction (v = 0 for horizontal and v = 1 for vertical direction). The constants a, b, c, d, e and f may be determined from the regression analysis using the least squares fitting technique. These coefficients have been computed from 187 strong-motion accelerograph records which were recorded during 57 earthquakes in the Western United States for the I_{MM} ranging from IV to VII (Trifunac and Brady, 1975). The method employed to calculate a, b, c, d, e and f is analogous to that of Trifunac (1975) and its discussion will not be repeated here.

The functional form of equations (1) has been selected because of its simplicity for the least squares fitting and because it represents an approximation to a more complete functional dependence of $a_{max,p}$, $v_{max,p}$ and $d_{max,p}$ on the parameters involved. It is not based on any physical laws which may characterize these relationships and is meant to represent only an approximate characterization of possibly complicated scaling laws; these laws depend on many other parameters which are either not known to us at this time or are too complicated to consider with only a marginal number of available data points.

In equation (1) we made an arbitrary yet important assumption which is that I_{MM} is on the linear scale, i.e., that the numerical value to be associated with I_{MM} = VIII, for example, is equal to twice that for I_{MM} = IV and so on. Clearly, there is no direct physical basis to support this assumption and we could have adopted some other non-linear relationship just as well. However, allowing for the non-linear term, fI_{MM}^2, in equation (1) partly eliminates the possible difficulties, since many smooth and monotonic distortions of the numerical scale on which I_{MM} is measured would be reflected in different values of the coefficients b, c and f. Small numerical values of the coefficient f in Table II suggest that the linear assumption for the I_{MM} scale may represent an acceptable working hypothesis.

Studies by Barosh (1969) and Trifunac and Brady (1975) indicate that the approximate numerical functions which would correlate different intensity scales are non-linear. Therefore, using a different intensity scale in place of I_{MM} in an equation similar to (1) would lead to different coefficients b, c and f for the same strong-motion data, while the coefficients a, d and e would, in principle, remain the same.

Two regression analyses have been carried out. In the first one, the regression equations (1) have been assumed to be linear by deleting the coefficient f (Table I). In the second analysis, the parabolic regression analysis was carried out to find whether the amplitude data contains an important second order term in I_{MM} and to see whether the low frequency errors which are present in the low amplitude displacement peaks (Trifunac and Brady, 1975; Trifunac and Lee, 1974) represent a significant factor which should be accounted for.

The estimates of a, b, c, d, e and f in Tables I and II, where only the first two digits should be considered to be significant, indicate the following trends of peak amplitudes studied in this paper. Coefficient "a", which is equal to about 0.9 on the logarithmic scale, shows that the spread of all peak amplitudes is equal to about one order of magnitude on the linear amplitude scale. Coefficient "d" shows that the peaks of acceleration are larger on hard basement rocks (s = 2) by a factor of about 2 on the linear amplitude scale when compared with the corresponding peaks recorded on the alluvium sites (s = 0). On the other hand, the peak displacement bounds $d_{max, p}$ are higher by a factor of about 1.3 when recorded on alluvium sites (s = 0) than when recorded on the hard rock sites (s = 2). The bounds on peak velocities $v_{max, p}$ do not seem to depend on the recording site characteristics in a significant way. For both linear (Table I) and parabolic (Table II) regression analyses the bounds on the vertical peak amplitudes are smaller by a factor ranging from about 2 for $v_{max, p}$ to about 1.5 for $d_{max, p}$. Coefficients b, c and f, of course, change from linear to parabolic regression analyses. These changes are negligible for $v_{max, p}$ and minor for $a_{max, p}$ and $d_{max, p}$. The changes for $a_{max, p}$ show a decreasing trend for amplitudes corresponding to large Modified Mercalli Intensities (f being negative). The changes for $d_{max, p}$, however, show the opposite trend and appear to be influenced by the overestimated peak displacements for small I_{MM}. This, of course, results from the presence of digitization noise in the records of acceleration for small intensities of shaking, which are characterized by low amplitudes of acceleration on the instrumental record and, consequently, by the small signal to noise ratio (Trifunac and Brady, 1975; Trifunac and Lee, 1974). In principle, this noise could be partly eliminated by a special study of each strong-motion record separately. However, such an effort is beyond the scope of this brief paper.

Strong-motion data available at this time (Trifunac and Brady, 1975) is only barely adequate to characterize amplitudes of ground shaking that correspond to the Modified Mercalli Intensities in the range from IV to VIII. Therefore, regression analyses (Tables I and II) based on equations (1) are at best applicable only for that range of intensities, and extrapolations to intensities larger than VIII cannot be justified by presently available data. In spite of this fact, for completeness we calculated the expected bounds on peak accelerations, velocities and displacements by using linear and parabolic versions of equations (1) for Modified Mercalli Intensities III to XII. These results are presented in Tables III through VIII for confidence levels p = 0.1, 0.2, ..., 0.8 and 0.9, site conditions s = 0, 1 and 2, and the horizontal and vertical components of ground motion.

COMPARISON WITH OTHER RELATED STUDIES

The lack of an adequate number of recorded strong motion accelerograms corresponding to the I_{MM} levels larger than about VIII is quite unfortunate, indeed, since it is for this range of Modified Mercalli intensities that motions become seriously damaging and often have to be scaled for earthquake resistant design purposes. There appears to be no reliable way of critically testing the scaling of strong ground motions for these intensities through the use of equations (1) other than by using the amplitudes of strong-motion records that will be accumulated during future earthquakes. In the meantime, however, these questions remain: (a) whether equations (1) with the coefficients determined from presently available data may be extrapolated for I_{MM} greater than VIII and (b) if there is a way of checking, even only roughly, whether such an extrapolation is meaningful at all. In what follows we make a rough test of such extrapolations by using other independent estimates of maximum amplitudes of strong ground motion (Trifunac, 1975) in an attempt to examine the plausibility of equations (1) for the large values of I_{MM}.

The Modified Mercalli Intensity XII represents the largest possible range of shaking amplitudes. Quoting from Wood and Neumann (1931) its description reads:

"Damage total--practically all works of construction damaged greatly or destroyed.

Disturbances in ground great and varied, numerous shearing cracks.

Landslides, falls of rock of significant character, slumping of river banks, etc., numerous and extensive.

Wrenched loose, tore off, large rock masses.

Fault slips in firm rock, with notable horizontal and vertical offset displacements.

Water channels, surface and underground, disturbed and modified greatly.

Dammed lakes, produced waterfalls, deflected rivers, etc.

Waves seen on ground surfaces (actually seen, probably, in some cases).

Distorted lines of sight and level.

Threw objects upward into the air."

There is some evidence to suggest that shaking at a fault break itself may not always be significantly larger than shaking several miles away and that high-frequency shaking in the immediate vicinity of a fault may depend on the nature of the ground. There are other reports, however, on the extreme violence of shaking close to a fault where the fault trace broke through sound igneous rock (Richter, 1958).

In spite of some possibly important variations in the intensity of shaking at a fault for different ground conditions, it seems reasonable to assume that I_{MM} = XII corresponds to the highest amplitudes of strong ground motion and that, for practical purposes, it occurs at epicentral distance R = 0. Because of the extended source dimensions and only minor attenuation of the wave amplitudes in the immediate near field (Trifunac, 1975), the epicentral distance R = 0 should be interpreted here to represent the immediate source region and not strictly R = 0 only.

Having made these assumptions, it is then possible to suppose that the maximum amplitudes of strong ground shaking implied by equations (1) for I_{MM} = XII should agree with the maximum amplitudes of motion predicted independently by other studies of peak amplitudes in terms of earthquake magnitude and epicentral distance and finally with the independently determined amplitudes estimated from source mechanism studies (Trifunac, 1975). Unfortunately, these independent studies necessarily depend on often too simple assumptions which have been used in derivations of all pertinent results. Consequently, these studies do not offer the most critical test which eventually should be based on the recorded strong ground motion. In the meantime, at least for reasons which relate to internal consistency of all results and definitions employed here and in our previous studies (Trifunac, 1975), it should be required that the maximum peak amplitudes of strong ground motion predicted by the correlations which use earthquake magnitude and those resulting from correlations (1) should agree.

Table IX compares the logarithms of the approximate bounds $a_{max,p}$, $v_{max,p}$ and $d_{max,p}$ computed for p = 0.9 and 0.5 for I_{MM} = XII (using linear and parabolic regression analysis) with the corresponding largest estimates based on previous analyses which were based on earthquake magnitude and source mechanism studies (Trifunac, 1975). It may be seen from this table that the overall amplitudes from these two studies are not inconsistent on the logarithmic scale.

Detailed perusal of data in Table IX shows that the average $a_{max,p}$ amplitudes (i.e., for s = 1) compared for M = 7.5 at R = 0 with those from parabolic regression analysis are not too different. This means that the overall maximum amplitudes predicted by these two methods are not inconsistent. However, comparison of amplitudes for s = 0 and s = 2 site conditions shows opposite trends when the data columns 1 and 2 and 1 and 3 are compared. The amplitudes predicted from the correlations with I_{MM} are higher for s = 2 than for s = 0, while the correlations with earthquake magnitude for R = 0 are higher for s = 0. This inconsistency appears to result from the expected larger scatter of peak amplitudes for s = 0 sites and the approximate manner in which the amplitude attenuation with distance, independent of site conditions and peak amplitudes, has been introduced for the preliminary correlations with earthquake magnitude (Trifunac, 1975). Considering the range of data scatter for magnitude-distance correlations, the trends showing larger $a_{max,p}$ for s = 0 cannot be considered significant. In all probability, future strong-motion data in the immediate near field and more detailed theoretical studies will show that the bounds for $a_{max,p}$ should be larger for s = 2 site conditions.

Similar differences in the trends of the amplitudes $v_{max,p}$ for $s = 0$ versus $s = 2$ site conditions are also indicated by Table IX. Here, correlations with I_{MM} show essentially no site effects, while the correlations of $v_{max,p}$ with earthquake magnitude show more prominent site effects than the correlations for $a_{max,p}$. In general, it is clear that the preliminary scaling laws proposed for the bounds $a_{max,p}$, $v_{max,p}$ and $d_{max,p}$ in terms of earthquake magnitude and epicentral distance tend to amplify peak levels for $s = 0$ relative to $s = 2$ for all $a_{max,p}$, $v_{max,p}$ and $d_{max,p}$.

If it is assumed that the intermediate site conditions ($s = 1$) approximate the average overall amplitudes, then one finds that the logarithms of amplitudes for the columns 1 and 3 for $a_{max,p}$ data in Table IX and for the columns 1 and 2 for $v_{max,p}$ and $d_{max,p}$ data are not too different. We interpret this to mean that the parabolic regression analysis for $a_{max,p}$ and the linear regression analyses for $v_{max,p}$ and $d_{max,p}$ predict overall amplitudes for the largest levels of shaking (I_{MM} = XII) that do not lead to contradiction with other independent estimates of the same largest amplitudes. While it must be emphasized that this result by itself does not justify the validity of equations (1) for I_{MM} > VIII, it suggests that the amplitudes predicted by these equations might not change significantly in the high intensity range when relevant strong-motion data become available.

Coefficient "a" in equation (1), whose numerical value on the logarithmic scale is 0.9 to 1.0, reflects the range of expected peak amplitudes and the uncertainties in this whole approach. Though to some degree this apparently large scatter of peak amplitudes may have been increased by the uncertainties associated with the determinations of I_{MM}, for different earthquakes and by the approximate and descriptive nature of the Modified Mercalli Intensity scale, we believe that the most significant contribution to the large numerical value of this coefficient comes from the great variability in the physical process itself - the earthquake energy release at source. The corresponding coefficient "a" that results from the correlations of $a_{max, p}$, $v_{max, p}$ and $d_{max, p}$ with earthquake magnitude and epicentral distance has numerical values that range on the logarithmic scale from 0.9 to 1.3 (Trifunac, 1975) and is somewhat greater than 0.9 to 1.0 (Tables I and II). This might, of course, mean that the overall quality of the correlations of $a_{max, p}$, $v_{max, p}$ and $d_{max, p}$ with earthquake magnitude and epicentral distance is not as good as the quality of correlations employed in this paper. However, this result can also be considered as an indication that the quality of scaling of strong ground motion by Modified Mercalli Intensity is better than might have been expected.

Finally, it should be pointed out here that we expect coefficient "a" to increase with time as a greater number of records become available. This tendency for a measure of standard deviation to grow with the number of measurements before it reaches its final value is often observed for a broad class of experiments and may be expected in the measurements of a_{max}, v_{max} and d_{max}. This is so because the number of recorded accelerograms, so far, is only barely adequate to indicate some preliminary trends in the scaling laws involved. The total number of recorded accelerograms will have to increase by at least one order of magnitude before empirical models similar to and better than those proposed here can be critically tested and improved.

CONCLUSIONS

The following are the main results and conclusions in the work presented above:

1. For a given Modified Mercalli Intensity level, the range of expected amplitudes of peak acceleration, velocity and displacement is equal to about one order of magnitude.
2. Peak accelerations are on the average larger by a factor equal to about two when recorded on hard rock sites than on alluvium sites for the range of I_{MM} between IV and VIII. Peak velocities essentially do not depend on recording site conditions, while peak displacements are about 30 percent larger on alluvium than on hard basement rocks for the same range of I_{MM}.
3. Logarithms of peak amplitudes of strong shaking that would correspond to the maximum Modified Mercalli Intensity I_{MM} = XII which are extrapolated from the correlations based on the data for IV $\leq I_{MM} \leq$ VIII are not contradicted by other independent estimates of the largest amplitudes of shaking derived from source mechanism studies and correlations with earthquake magnitude.

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Earthquake Engineering Research Laboratory
California Institute of Technology
Pasadena, California 91125

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TABLE I

Linear Regression

$$\log_{10}\begin{Bmatrix} a_{max,p} \\ v_{max,p} \\ d_{max,p} \end{Bmatrix} = ap + bI_{MM} + c + ds + ev$$

	a	b	c	d	e	No. of data points used in regression
acceleration - $a_{max,p}$	0.942	0.293	-0.552	0.142	-0.265	277
velocity - $v_{max,p}$	0.883	0.291	-1.420	0.014	-0.286	277
displacement - $d_{max,p}$	0.913	0.235	-1.369	-0.061	-0.193	277

TABLE II

Parabolic Regression

$$\log_{10}\begin{Bmatrix} a_{max,p} \\ v_{max,p} \\ d_{max,p} \end{Bmatrix} = ap + bI_{MM} + c + ds + ev + fI_{MM}^2$$

	a	b	c	d	e	f	No. of data points used in regression
acceleration - $a_{max,p}$	0.942	0.459	-1.047	0.141	-0.27	-0.014	277
velocity - $v_{max,p}$	0.883	0.288	-1.411	0.014	-0.286	0.000	277
displacement - $d_{max,p}$	0.913	0.006	-0.690	-0.059	-0.186	0.019	277

TABLE III

Logarithms of approximate bounds on vertical and horizontal peak accelerations, $a_{max,p}$, in cm/sec^2, for confidence levels p = 0.1, 0.2, ..., 0.8 and 0.9; site classifications s = 0, 1 and 2 and for Modified Mercalli Intensities III through XII (linear regression)

	p = 0.1		p = 0.2		p = 0.3		p = 0.4		p = 0.5		p = 0.6		p = 0.7		p = 0.8		p = 0.9	
	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.
III-0	0.15	0.42	0.25	0.51	0.34	0.61	0.44	0.70	0.53	0.80	0.63	0.89	0.72	0.98	0.81	1.08	0.91	1.17
III-1	0.30	0.56	0.39	0.66	0.49	0.75	0.58	0.84	0.67	0.94	0.77	1.03	0.86	1.13	0.96	1.22	1.05	1.32
III-2	0.44	0.70	0.53	0.80	0.63	0.89	0.72	0.99	0.82	1.08	0.91	1.18	1.00	1.27	1.10	1.36	1.19	1.46
IV-0	0.45	0.71	0.54	0.81	0.64	0.90	0.73	0.99	0.82	1.09	0.92	1.18	1.01	1.28	1.11	1.37	1.20	1.47
IV-1	0.59	0.85	0.68	0.95	0.78	1.04	0.87	1.14	0.97	1.23	1.06	1.33	1.15	1.42	1.25	1.51	1.34	1.61
IV-2	0.73	1.00	0.83	1.09	0.92	1.19	1.01	1.28	1.11	1.37	1.20	1.47	1.30	1.56	1.39	1.66	1.49	1.75
V-0	0.74	1.00	0.83	1.10	0.93	1.19	1.02	1.29	1.12	1.38	1.21	1.48	1.30	1.57	1.40	1.66	1.49	1.76
V-1	0.88	1.15	0.98	1.24	1.07	1.34	1.16	1.43	1.26	1.52	1.35	1.62	1.45	1.71	1.54	1.81	1.64	1.90
V-2	1.02	1.29	1.12	1.38	1.21	1.48	1.31	1.57	1.40	1.67	1.50	1.76	1.59	1.85	1.68	1.95	1.78	2.04
VI-0	1.03	1.30	1.13	1.39	1.22	1.49	1.31	1.58	1.41	1.67	1.50	1.77	1.60	1.86	1.69	1.96	1.79	2.05
VI-1	1.17	1.44	1.27	1.53	1.36	1.63	1.46	1.72	1.55	1.82	1.65	1.91	1.74	2.00	1.83	2.10	1.93	2.19
VI-2	1.32	1.58	1.41	1.68	1.51	1.77	1.60	1.86	1.69	1.96	1.79	2.05	1.88	2.15	1.98	2.24	2.07	2.34
VII-0	1.32	1.59	1.42	1.68	1.51	1.78	1.61	1.87	1.70	1.97	1.80	2.06	1.89	2.15	1.98	2.25	2.08	2.34
VII-1	1.47	1.73	1.56	1.83	1.66	1.92	1.75	2.01	1.84	2.11	1.94	2.20	2.03	2.30	2.13	2.39	2.22	2.49
VII-2	1.61	1.87	1.70	1.97	1.80	2.06	1.89	2.16	1.99	2.25	2.08	2.35	2.17	2.44	2.27	2.53	2.36	2.63
VIII-0	1.62	1.88	1.71	1.98	1.81	2.07	1.90	2.16	1.99	2.26	2.09	2.35	2.18	2.45	2.28	2.54	2.37	2.64
VIII-1	1.76	2.02	1.85	2.12	1.95	2.21	2.04	2.31	2.14	2.40	2.23	2.50	2.32	2.59	2.42	2.68	2.51	2.78
VIII-2	1.90	2.17	2.00	2.26	2.09	2.36	2.18	2.45	2.28	2.54	2.37	2.64	2.47	2.73	2.56	2.83	2.66	2.92
IX-0	1.91	2.17	2.00	2.27	2.10	2.36	2.19	2.46	2.29	2.55	2.38	2.65	2.47	2.74	2.57	2.83	2.66	2.93
IX-1	2.05	2.32	2.15	2.41	2.24	2.51	2.33	2.60	2.43	2.69	2.52	2.79	2.62	2.88	2.71	2.93	2.81	3.07
IX-2	2.19	2.46	2.29	2.55	2.38	2.65	2.48	2.74	2.57	2.84	2.67	2.93	2.76	3.02	2.85	3.12	2.95	3.21
X-0	2.20	2.47	2.30	2.56	2.39	2.66	2.48	2.75	2.58	2.84	2.67	2.94	2.77	3.03	2.86	3.13	2.96	3.22
X-1	2.34	2.61	2.44	2.70	2.53	2.80	2.63	2.89	2.72	2.99	2.82	3.08	2.91	3.17	3.00	3.27	3.10	3.36
X-2	2.49	2.75	2.58	2.85	2.68	2.94	2.77	3.03	2.86	3.13	2.96	3.22	3.05	3.32	3.15	3.41	3.24	3.51
XI-0	2.49	2.76	2.59	2.85	2.68	2.95	2.78	3.04	2.87	3.14	2.97	3.23	3.06	3.33	3.15	3.42	3.25	3.51
XI-1	2.64	2.90	2.73	3.00	2.83	3.09	2.92	3.18	3.01	3.28	3.11	3.37	3.20	3.47	3.30	3.56	3.39	3.66
XI-2	2.78	3.04	2.87	3.14	2.97	3.23	3.06	3.33	3.16	3.42	3.25	3.52	3.34	3.61	3.44	3.70	3.53	3.80
XII-0	2.79	3.05	2.88	3.15	2.98	3.24	3.07	3.33	3.16	3.43	3.26	3.52	3.35	3.62	3.45	3.71	3.54	3.81
XII-1	2.93	3.19	3.02	3.29	3.12	3.38	3.21	3.48	3.31	3.57	3.40	3.67	3.49	3.76	3.59	3.85	3.68	3.95
XII-2	3.07	3.34	3.17	3.43	3.26	3.53	3.35	3.62	3.45	3.71	3.54	3.81	3.64	3.90	3.73	4.00	3.83	4.09

TABLE IV

Logarithms of approximate bounds on vertical and horizontal peak velocities, $v_{max, p}$, in cm/sec, for confidence levels p = 0.1, 0.2, ..., 0.8 and 0.9; site classifications s = 0, 1 and 2 and for Modified Mercalli Intensities III through XII (linear regression)

	p = 0.1		p = 0.2		p = 0.3		p = 0.4		p = 0.5		p = 0.6		p = 0.7		p = 0.8		p = 0.9	
	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.
III-0	-0.74	-0.46	-0.66	-0.37	-0.57	-0.28	-0.48	-0.19	-0.39	-0.10	-0.30	-0.02	-0.21	0.07	-0.13	0.16	-0.04	0.25
III-1	-0.73	-0.44	-0.64	-0.36	-0.55	-0.27	-0.47	-0.18	-0.38	-0.09	-0.29	-0.00	-0.20	0.09	-0.11	0.17	-0.02	0.26
III-2	-0.72	-0.43	-0.63	-0.34	-0.54	-0.25	-0.45	-0.17	-0.36	-0.08	-0.28	0.01	-0.19	0.10	-0.10	0.19	-0.01	0.28
IV-0	-0.45	-0.17	-0.36	-0.08	-0.28	0.01	-0.19	0.10	-0.10	0.19	-0.01	0.27	0.08	0.36	0.17	0.45	0.25	0.54
IV-1	-0.44	-0.15	-0.35	-0.06	-0.26	0.02	-0.17	0.11	-0.09	0.20	0.00	0.29	0.09	0.38	0.18	0.46	0.27	0.55
IV-2	-0.43	-0.14	-0.34	-0.05	-0.25	0.04	-0.16	0.13	-0.07	0.21	0.02	0.30	0.10	0.39	0.19	0.48	0.28	0.57
V-0	-0.16	0.12	-0.07	0.21	0.02	0.30	0.10	0.39	0.19	0.48	0.28	0.57	0.37	0.65	0.46	0.74	0.54	0.83
V-1	-0.15	0.14	-0.06	0.23	0.03	0.31	0.12	0.40	0.21	0.49	0.29	0.58	0.38	0.67	0.47	0.76	0.56	0.84
V-2	-0.13	0.15	-0.05	0.24	0.04	0.33	0.13	0.42	0.22	0.50	0.31	0.59	0.40	0.68	0.48	0.77	0.57	0.86
VI-0	0.13	0.42	0.22	0.50	0.31	0.59	0.39	0.68	0.48	0.77	0.57	0.86	0.66	0.95	0.75	1.03	0.84	1.12
VI-1	0.14	0.43	0.23	0.52	0.32	0.61	0.41	0.69	0.50	0.78	0.58	0.87	0.67	0.96	0.76	1.05	0.85	1.14
VI-2	0.16	0.44	0.25	0.53	0.33	0.62	0.42	0.71	0.51	0.80	0.60	0.88	0.69	0.97	0.78	1.06	0.86	1.15
VII-0	0.42	0.71	0.51	0.80	0.60	0.88	0.69	0.97	0.77	1.06	0.86	1.15	0.95	1.24	1.04	1.33	1.13	1.41
VII-1	0.43	0.72	0.52	0.81	0.61	0.90	0.70	0.99	0.79	1.07	0.88	1.16	0.96	1.25	1.05	1.34	1.14	1.43
VII-2	0.45	0.73	0.54	0.82	0.62	0.91	0.71	1.00	0.80	1.09	0.89	1.18	0.98	1.26	1.07	1.35	1.15	1.44
VIII-0	0.71	1.00	0.80	1.09	0.89	1.18	0.98	1.26	1.07	1.35	1.15	1.44	1.24	1.53	1.33	1.62	1.42	1.70
VIII-1	0.73	1.01	0.81	1.10	0.90	1.19	0.99	1.28	1.08	1.37	1.17	1.45	1.26	1.54	1.34	1.63	1.43	1.72
VIII-2	0.74	1.03	0.83	1.11	0.92	1.20	1.00	1.29	1.09	1.38	1.18	1.47	1.27	1.56	1.36	1.64	1.45	1.73
IX-0	1.00	1.29	1.09	1.38	1.18	1.47	1.27	1.55	1.36	1.64	1.45	1.73	1.53	1.82	1.62	1.91	1.71	2.00
IX-1	1.02	1.30	1.11	1.39	1.19	1.48	1.28	1.57	1.37	1.66	1.46	1.74	1.55	1.83	1.64	1.92	1.72	2.01
IX-2	1.03	1.32	1.12	1.41	1.21	1.49	1.30	1.58	1.38	1.67	1.47	1.76	1.56	1.85	1.65	1.94	1.74	2.02
X-0	1.30	1.58	1.38	1.67	1.47	1.76	1.56	1.85	1.65	1.93	1.74	2.02	1.82	2.11	1.91	2.20	2.00	2.29
X-1	1.31	1.59	1.40	1.68	1.49	1.77	1.57	1.86	1.66	1.95	1.75	2.04	1.84	2.12	1.93	2.21	2.02	2.30
X-2	1.32	1.61	1.41	1.70	1.50	1.79	1.59	1.87	1.68	1.96	1.76	2.05	1.85	2.14	1.94	2.23	2.03	2.31
XI-0	1.59	1.87	1.67	1.96	1.76	2.05	1.85	2.14	1.94	2.23	2.03	2.31	2.12	2.40	2.20	2.49	2.29	2.58
XI-1	1.60	1.89	1.69	1.97	1.78	2.06	1.86	2.15	1.95	2.24	2.04	2.33	2.13	2.42	2.22	2.50	2.31	2.59
XI-2	1.61	1.90	1.70	1.99	1.79	2.08	1.88	2.16	1.97	2.25	2.06	2.34	2.14	2.43	2.23	2.52	2.32	2.61
XII-0	1.88	2.16	1.97	2.25	2.05	2.34	2.14	2.43	2.23	2.52	2.32	2.61	2.41	2.69	2.50	2.78	2.58	2.87
XII-1	1.89	2.18	1.98	2.27	2.07	2.35	2.16	2.44	2.24	2.53	2.33	2.62	2.42	2.71	2.51	2.80	2.60	2.88
XII-2	1.90	2.19	1.99	2.28	2.08	2.37	2.17	2.46	2.26	2.54	2.35	2.63	2.43	2.72	2.52	2.81	2.61	2.90

TABLE V

Logarithms of approximate bounds on vertical and horizontal peak displacements, $d_{max, p}$, in cm, for confidence levels p = 0.1, 0.2, ..., 0.8 and 0.9; site classifications s = 0, 1 and 2 and for Modified Mercalli Intensities III through XII (linear regression)

	p = 0.1		p = 0.2		p = 0.3		p = 0.4		p = 0.5		p = 0.6		p = 0.7		p = 0.8		p = 0.9	
	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.
III-0	-0.77	-0.57	-0.68	-0.48	-0.58	-0.39	-0.49	-0.30	-0.40	-0.21	-0.31	-0.12	-0.22	-0.03	-0.13	0.06	-0.04	0.16
III-1	-0.83	-0.64	-0.74	-0.54	-0.65	-0.45	-0.55	-0.36	-0.46	-0.27	-0.37	-0.18	-0.28	-0.09	-0.19	0.00	-0.10	0.09
III-2	-0.89	-0.70	-0.80	-0.61	-0.71	-0.51	-0.62	-0.42	-0.52	-0.33	-0.43	-0.24	-0.34	-0.15	-0.25	-0.06	-0.16	0.03
IV-0	-0.53	-0.34	-0.44	-0.25	-0.35	-0.16	-0.26	-0.07	-0.17	0.03	-0.08	0.12	0.02	0.21	0.11	0.30	0.20	0.39
IV-1	-0.59	-0.40	-0.50	-0.31	-0.41	-0.22	-0.32	-0.13	-0.23	-0.04	-0.14	0.06	-0.05	0.15	0.05	0.24	0.14	0.33
IV-2	-0.66	-0.46	-0.56	-0.37	-0.47	-0.28	-0.38	-0.19	-0.29	-0.10	-0.20	-0.01	-0.11	0.09	-0.02	0.18	0.07	0.27
V-0	-0.30	-0.10	-0.21	-0.01	-0.12	0.08	-0.02	0.17	0.07	0.26	0.16	0.35	0.25	0.44	0.34	0.53	0.43	0.63
V-1	-0.36	-0.17	-0.27	-0.07	-0.18	0.02	-0.09	0.11	0.01	0.20	0.10	0.29	0.19	0.38	0.28	0.47	0.37	0.56
V-2	-0.42	-0.23	-0.33	-0.14	-0.24	-0.05	-0.15	0.05	-0.06	0.14	0.04	0.23	0.13	0.32	0.22	0.41	0.31	0.50
VI-0	-0.06	0.13	0.03	0.22	0.12	0.31	0.21	0.40	0.30	0.49	0.39	0.59	0.48	0.68	0.58	0.77	0.67	0.86
VI-1	-0.12	0.07	-0.03	0.16	0.06	0.25	0.15	0.34	0.24	0.43	0.33	0.52	0.42	0.62	0.51	0.71	0.61	0.80
VI-2	-0.19	0.01	-0.09	0.10	-0.00	0.19	0.09	0.28	0.18	0.37	0.27	0.46	0.36	0.55	0.45	0.65	0.54	0.74
VII-0	0.17	0.36	0.26	0.46	0.35	0.55	0.45	0.64	0.54	0.73	0.63	0.82	0.72	0.91	0.81	1.00	0.90	1.09
VII-1	0.11	0.30	0.20	0.39	0.29	0.49	0.38	0.58	0.48	0.67	0.57	0.76	0.66	0.85	0.75	0.94	0.84	1.03
VII-2	0.05	0.24	0.14	0.33	0.23	0.42	0.32	0.52	0.41	0.61	0.51	0.70	0.60	0.79	0.69	0.88	0.78	0.97
VIII-0	0.41	0.60	0.50	0.69	0.59	0.78	0.68	0.87	0.77	0.96	0.86	1.06	0.95	1.15	1.04	1.24	1.14	1.33
VIII-1	0.34	0.54	0.44	0.63	0.53	0.72	0.62	0.81	0.71	0.90	0.80	0.99	0.89	1.09	0.98	1.18	1.07	1.27
VIII-2	0.28	0.48	0.37	0.57	0.47	0.66	0.56	0.75	0.65	0.84	0.74	0.93	0.83	1.02	0.92	1.12	1.01	1.21
IX-0	0.64	0.83	0.73	0.92	0.82	1.02	0.91	1.11	1.01	1.20	1.10	1.29	1.19	1.38	1.28	1.47	1.37	1.56
IX-1	0.58	0.77	0.67	0.86	0.76	0.95	0.85	1.05	0.94	1.14	1.04	1.23	1.13	1.32	1.22	1.41	1.31	1.50
IX-2	0.52	0.71	0.61	0.80	0.70	0.89	0.79	0.98	0.88	1.08	0.97	1.17	1.07	1.26	1.16	1.35	1.25	1.44
X-0	0.88	1.07	0.97	1.16	1.06	1.25	1.15	1.34	1.24	1.43	1.33	1.52	1.42	1.62	1.51	1.71	1.61	1.80
X-1	0.81	1.01	0.91	1.10	1.00	1.19	1.09	1.28	1.18	1.37	1.27	1.46	1.36	1.55	1.45	1.65	1.54	1.74
X-2	0.75	0.95	0.84	1.04	0.94	1.13	1.03	1.22	1.12	1.31	1.21	1.40	1.30	1.49	1.39	1.58	1.48	1.68
XI-0	1.11	1.30	1.20	1.39	1.29	1.49	1.38	1.58	1.48	1.67	1.57	1.76	1.66	1.85	1.75	1.94	1.84	2.03
XI-1	1.05	1.24	1.14	1.33	1.23	1.42	1.32	1.52	1.41	1.61	1.50	1.70	1.60	1.79	1.69	1.88	1.78	1.97
XI-2	0.99	1.18	1.08	1.27	1.17	1.36	1.26	1.45	1.35	1.55	1.44	1.64	1.53	1.73	1.63	1.82	1.72	1.91
XII-0	1.34	1.54	1.44	1.63	1.53	1.72	1.62	1.81	1.71	1.90	1.80	1.99	1.89	2.09	1.98	2.18	2.07	2.27
XII-1	1.28	1.48	1.37	1.57	1.47	1.66	1.56	1.75	1.65	1.84	1.74	1.93	1.83	2.02	1.92	2.12	2.01	2.21
XII-2	1.22	1.41	1.31	1.51	1.40	1.60	1.50	1.69	1.59	1.78	1.68	1.87	1.77	1.96	1.86	2.05	1.95	2.15

TABLE VI

Logarithms of approximate bounds on vertical and horizontal peak accelerations, $a_{max,p}$, in cm/sec^2, for confidence levels p = 0.1, 0.2, ..., 0.8 and 0.9; site classifications s = 0, 1 and 2 and for Modified Mercalli Intensities III through XII (parabolic regression)

	p = 0.1		p = 0.2		p = 0.3		p = 0.4		p = 0.5		p = 0.6		p = 0.7		p = 0.8		p = 0.9	
	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.
III-0	0.03	0.30	0.13	0.40	0.22	0.49	0.31	0.59	0.41	0.68	0.50	0.77	0.60	0.87	0.69	0.96	0.79	1.06
III-1	0.17	0.44	0.27	0.54	0.36	0.63	0.46	0.73	0.55	0.82	0.64	0.91	0.74	1.01	0.83	1.10	0.93	1.20
III-2	0.31	0.58	0.41	0.68	0.50	0.77	0.60	0.87	0.69	0.96	0.78	1.06	0.88	1.15	0.97	1.24	1.07	1.34
IV-0	0.4C	0.67	0.49	0.76	0.58	0.86	0.68	0.95	0.77	1.04	0.87	1.14	0.96	1.23	1.06	1.33	1.15	1.42
IV-1	0.54	0.81	0.63	0.90	0.73	1.00	0.82	1.09	0.91	1.18	1.01	1.28	1.10	1.37	1.20	1.47	1.29	1.56
IV-2	0.68	0.95	0.77	1.04	0.87	1.14	0.96	1.23	1.05	1.32	1.15	1.42	1.24	1.51	1.34	1.61	1.43	1.70
V-0	0.73	1.00	0.83	1.10	0.92	1.19	1.02	1.29	1.11	1.38	1.20	1.47	1.30	1.57	1.39	1.66	1.49	1.76
V-1	0.87	1.14	0.97	1.24	1.06	1.33	1.16	1.43	1.25	1.52	1.35	1.62	1.44	1.71	1.53	1.80	1.63	1.90
V-2	1.01	1.29	1.11	1.38	1.20	1.47	1.30	1.57	1.39	1.66	1.49	1.76	1.58	1.85	1.67	1.94	1.77	2.04
VI-0	1.04	1.31	1.14	1.41	1.23	1.50	1.33	1.60	1.42	1.69	1.51	1.78	1.61	1.88	1.70	1.97	1.80	2.07
VI-1	1.18	1.45	1.28	1.55	1.37	1.64	1.47	1.74	1.56	1.83	1.66	1.93	1.75	2.02	1.84	2.11	1.94	2.21
VI-2	1.32	1.60	1.42	1.69	1.51	1.78	1.61	1.88	1.70	1.97	1.80	2.07	1.89	2.16	1.98	2.25	2.08	2.35
VII-0	1.33	1.60	1.42	1.69	1.51	1.78	1.61	1.88	1.70	1.97	1.80	2.07	1.89	2.16	1.99	2.26	2.08	2.35
VII-1	1.47	1.74	1.56	1.83	1.66	1.93	1.75	2.02	1.84	2.11	1.94	2.21	2.03	2.30	2.13	2.40	2.22	2.49
VII-2	1.61	1.88	1.70	1.97	1.80	2.07	1.89	2.16	1.98	2.25	2.08	2.35	2.17	2.44	2.27	2.54	2.36	2.63
VIII-0	1.58	1.85	1.68	1.95	1.77	2.04	1.86	2.13	1.96	2.23	2.05	2.32	2.15	2.42	2.24	2.51	2.34	2.61
VIII-1	1.72	1.99	1.82	2.09	1.91	2.18	2.01	2.28	2.10	2.37	2.19	2.46	2.29	2.56	2.38	2.65	2.48	2.75
VIII-2	1.86	2.13	1.96	2.23	2.05	2.32	2.15	2.42	2.24	2.51	2.33	2.60	2.43	2.70	2.52	2.79	2.62	2.89
IX-0	1.81	2.08	1.90	2.18	2.00	2.27	2.09	2.36	2.19	2.46	2.28	2.55	2.38	2.65	2.47	2.74	2.56	2.83
IX-1	1.95	2.22	2.05	2.32	2.14	2.41	2.23	2.50	2.33	2.60	2.42	2.69	2.52	2.79	2.61	2.88	2.70	2.98
IX-2	2.09	2.36	2.19	2.46	2.28	2.55	2.37	2.64	2.47	2.74	2.56	2.83	2.66	2.93	2.75	3.02	2.85	3.12
X-0	2.01	2.28	2.11	2.38	2.20	2.47	2.29	2.57	2.39	2.66	2.48	2.75	2.58	2.85	2.67	2.94	2.77	3.04
X-1	2.15	2.42	2.25	2.52	2.34	2.61	2.44	2.71	2.53	2.80	2.62	2.89	2.72	2.99	2.81	3.08	2.91	3.18
X-2	2.29	2.56	2.39	2.66	2.48	2.75	2.58	2.85	2.67	2.94	2.76	3.03	2.86	3.13	2.95	3.22	3.05	3.32
XI-0	2.19	2.46	2.28	2.55	2.37	2.65	2.47	2.74	2.56	2.83	2.66	2.93	2.75	3.02	2.85	3.12	2.94	3.21
XI-1	2.33	2.60	2.42	2.69	2.52	2.79	2.61	2.88	2.70	2.97	2.80	3.07	2.89	3.16	2.99	3.26	3.08	3.35
XI-2	2.47	2.74	2.56	2.83	2.66	2.93	2.75	3.02	2.84	3.12	2.94	3.21	3.03	3.30	3.13	3.40	3.22	3.49
XII-0	2.33	2.60	2.43	2.70	2.52	2.79	2.62	2.89	2.71	2.98	2.80	3.08	2.90	3.17	2.99	3.26	3.09	3.36
XII-1	2.47	2.74	2.57	2.84	2.66	2.93	2.76	3.03	2.85	3.12	2.95	3.22	3.04	3.31	3.13	3.40	3.23	3.50
XII-2	2.62	2.89	2.71	2.98	2.80	3.07	2.90	3.17	2.99	3.26	3.09	3.36	3.18	3.45	3.27	3.54	3.37	3.64

TABLE VII

Logarithms of approximate bounds on vertical and horizontal peak velocities, $v_{max, p}$, in cm/sec for confidence levels p = 0.1, 0.2, ..., 0.8 and 0.9; site classifications s = 0, 1 and 2 and for Modified Mercalli Intensities III through XII (parabolic regression)

	p = 0.1		p = 0.2		p = 0.3		p = 0.4		p = 0.5		p = 0.6		p = 0.7		p = 0.8		p = 0.9	
	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.
III-0	-0.74	-0.46	-0.65	-0.37	-0.57	-0.28	-0.48	-0.19	-0.39	-0.10	-0.30	-0.01	-0.21	0.07	-0.12	0.16	-0.04	0.25
III-1	-0.73	-0.44	-0.64	-0.35	-0.55	-0.27	-0.46	-0.18	-0.38	-0.09	-0.29	-0.00	-0.20	0.09	-0.11	0.18	-0.02	0.26
III-2	-0.71	-0.43	-0.63	-0.34	-0.54	-0.25	-0.45	-0.16	-0.36	-0.08	-0.27	0.01	-0.18	0.10	-0.10	0.19	-0.01	0.28
IV-0	-0.45	-0.17	-0.36	-0.08	-0.28	0.01	-0.19	0.10	-0.10	0.19	-0.01	0.28	0.08	0.36	0.17	0.45	0.25	0.54
IV-1	-0.44	-0.15	-0.35	-0.06	-0.26	0.02	-0.17	0.11	-0.09	0.20	0.00	0.29	0.09	0.38	0.18	0.47	0.27	0.55
IV-2	-0.42	-0.14	-0.34	-0.05	-0.25	0.04	-0.16	0.13	-0.07	0.21	0.02	0.30	0.11	0.39	0.19	0.48	0.28	0.57
V-0	-0.16	0.12	-0.07	0.21	0.02	0.30	0.10	0.39	0.19	0.48	0.28	0.57	0.37	0.65	0.46	0.74	0.54	0.83
V-1	-0.15	0.14	-0.06	0.23	0.03	0.31	0.12	0.40	0.21	0.49	0.29	0.58	0.38	0.67	0.47	0.76	0.56	0.84
V-2	-0.13	0.15	-0.05	0.24	0.04	0.33	0.13	0.42	0.22	0.51	0.31	0.59	0.40	0.68	0.48	0.77	0.57	0.86
VI-0	0.13	0.42	0.22	0.50	0.31	0.59	0.39	0.68	0.48	0.77	0.57	0.86	0.66	0.95	0.75	1.03	0.84	1.12
VI-1	0.14	0.43	0.23	0.52	0.32	0.61	0.41	0.69	0.50	0.78	0.58	0.87	0.67	0.96	0.76	1.05	0.85	1.14
VI-2	0.16	0.44	0.25	0.53	0.33	0.62	0.42	0.71	0.51	0.80	0.60	0.88	0.69	0.97	0.77	1.06	0.86	1.15
VII-0	0.42	0.71	0.51	0.80	0.60	0.88	0.69	0.97	0.77	1.06	0.86	1.15	0.95	1.24	1.04	1.33	1.13	1.41
VII-1	0.43	0.72	0.52	0.81	0.61	0.90	0.70	0.99	0.79	1.07	0.88	1.16	0.96	1.25	1.05	1.34	1.14	1.43
VII-2	0.45	0.73	0.54	0.82	0.62	0.91	0.71	1.00	0.80	1.09	0.89	1.18	0.98	1.26	1.07	1.35	1.15	1.44
VIII-0	0.71	1.00	0.80	1.09	0.89	1.18	0.98	1.26	1.07	1.35	1.15	1.44	1.24	1.53	1.33	1.62	1.42	1.71
VIII-1	0.73	1.01	0.82	1.10	0.90	1.19	0.99	1.28	1.08	1.37	1.17	1.45	1.26	1.54	1.34	1.63	1.43	1.72
VIII-2	0.74	1.03	0.83	1.11	0.92	1.20	1.01	1.29	1.09	1.38	1.18	1.47	1.27	1.56	1.36	1.64	1.45	1.73
IX-0	1.01	1.29	1.09	1.38	1.18	1.47	1.27	1.56	1.36	1.64	1.45	1.73	1.54	1.82	1.62	1.91	1.71	2.00
IX-1	1.02	1.31	1.11	1.39	1.20	1.48	1.28	1.57	1.37	1.66	1.46	1.75	1.55	1.84	1.64	1.92	1.73	2.01
IX-2	1.03	1.32	1.12	1.41	1.21	1.50	1.30	1.58	1.39	1.67	1.47	1.76	1.56	1.85	1.65	1.94	1.74	2.03
X-0	1.30	1.58	1.39	1.67	1.48	1.76	1.56	1.85	1.65	1.94	1.74	2.03	1.83	2.11	1.92	2.20	2.01	2.29
X-1	1.31	1.60	1.40	1.69	1.49	1.77	1.58	1.86	1.67	1.95	1.75	2.04	1.84	2.13	1.93	2.22	2.02	2.30
X-2	1.33	1.61	1.41	1.70	1.50	1.79	1.59	1.88	1.68	1.97	1.77	2.05	1.86	2.14	1.94	2.23	2.03	2.32
XI-0	1.59	1.88	1.68	1.97	1.77	2.05	1.86	2.14	1.95	2.23	2.03	2.32	2.12	2.41	2.21	2.50	2.30	2.58
XI-1	1.61	1.89	1.69	1.98	1.78	2.07	1.87	2.16	1.96	2.25	2.05	2.33	2.14	2.42	2.22	2.51	2.31	2.60
XI-2	1.62	1.91	1.71	1.99	1.80	2.08	1.88	2.17	1.97	2.26	2.06	2.35	2.15	2.44	2.24	2.52	2.33	2.61
XII-0	1.89	2.17	1.97	2.26	2.06	2.35	2.15	2.44	2.24	2.53	2.33	2.61	2.42	2.70	2.50	2.79	2.59	2.88
XII-1	1.90	2.19	1.99	2.27	2.08	2.36	2.16	2.45	2.25	2.54	2.34	2.63	2.43	2.72	2.52	2.80	2.61	2.89
XII-2	1.91	2.20	2.00	2.29	2.09	2.38	2.18	2.46	2.27	2.55	2.35	2.64	2.44	2.73	2.53	2.82	2.62	2.91

TABLE VIII

Logarithms of approximate bounds on vertical and horizontal peak displacements $d_{max,p}$, in cm, for confidence levels p = 0.1, 0.2,..., 0.8 and 0.9; site classifications s = 0, 1 and 2 and for Modified Mercalli Intensities III through XII (parabolic regression)

	p = 0.1		p = 0.2		p = 0.3		p = 0.4		p = 0.5		p = 0.6		p = 0.7		p = 0.8		p = 0.9	
	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.	vert.	horiz.
III-0	-0.60	-0.41	-0.51	-0.32	-0.42	-0.23	-0.33	-0.14	-0.23	-0.05	-0.14	0.04	-0.05	0.13	0.04	0.23	0.13	0.32
III-1	-0.66	-0.47	-0.57	-0.38	-0.48	-0.29	-0.38	-0.20	-0.29	-0.11	-0.20	-0.02	-0.11	0.08	-0.02	0.17	0.07	0.26
III-2	-0.72	-0.53	-0.63	-0.44	-0.53	-0.35	-0.44	-0.26	-0.35	-0.17	-0.26	-0.08	-0.17	0.02	-0.08	0.11	0.01	0.20
IV-0	-0.46	-0.28	-0.37	-0.19	-0.28	-0.09	-0.19	-0.00	-0.10	0.09	-0.01	0.18	0.08	0.27	0.18	0.36	0.27	0.45
IV-1	-0.52	-0.34	-0.43	-0.24	-0.34	-0.15	-0.25	0.06	-0.16	0.03	0.07	0.12	0.03	0.21	0.12	0.30	0.21	0.39
IV-2	-0.58	-0.40	-0.49	-0.30	-0.40	-0.21	-0.31	-0.12	-0.22	-0.03	-0.12	0.06	-0.03	0.15	0.06	0.24	0.15	0.33
V-0	-0.29	-0.10	-0.20	-0.01	-0.11	0.08	-0.02	0.17	0.08	0.26	0.17	0.35	0.26	0.44	0.35	0.54	0.44	0.63
V-1	-0.35	-0.16	-0.26	-0.07	-0.17	0.02	-0.07	0.11	0.02	0.20	0.11	0.29	0.20	0.38	0.29	0.48	0.38	0.57
V-2	-0.41	-0.22	-0.32	-0.13	-0.23	-0.04	-0.13	0.05	-0.04	0.14	0.05	0.23	0.14	0.33	0.23	0.42	0.32	0.51
VI-0	-0.08	0.11	0.01	0.20	0.10	0.29	0.19	0.38	0.29	0.47	0.38	0.56	0.47	0.65	0.56	0.75	0.65	0.84
VI-1	-0.14	0.05	-0.05	0.14	0.04	0.23	0.14	0.32	0.23	0.41	0.32	0.50	0.41	0.60	0.50	0.69	0.59	0.78
VI-2	-0.20	-0.01	-0.11	0.08	-0.01	0.17	0.08	0.26	0.17	0.35	0.26	0.45	0.35	0.54	0.44	0.63	0.53	0.72
VII-0	0.17	0.36	0.26	0.45	0.35	0.54	0.44	0.63	0.53	0.72	0.63	0.81	0.72	0.90	0.81	0.99	0.90	1.09
VII-1	0.11	0.30	0.20	0.39	0.29	0.48	0.38	0.57	0.48	0.66	0.57	0.75	0.66	0.84	0.75	0.93	0.84	1.03
VII-2	0.05	0.24	0.14	0.33	0.23	0.42	0.32	0.51	0.42	0.60	0.51	0.69	0.60	0.78	0.69	0.88	0.78	0.97
VIII-0	0.45	0.64	0.55	0.73	0.64	0.82	0.73	0.91	0.82	1.01	0.91	1.10	1.00	1.19	1.09	1.28	1.18	1.37
VIII-1	0.40	0.58	0.49	0.67	0.58	0.76	0.67	0.86	0.76	0.95	0.85	1.04	0.94	1.13	1.03	1.22	1.13	1.31
VIII-2	0.34	0.52	0.43	0.61	0.52	0.70	0.61	0.80	0.70	0.89	0.79	0.98	0.88	1.07	0.98	1.16	1.07	1.25
IX-0	0.78	0.96	0.87	1.05	0.96	1.15	1.05	1.24	1.14	1.33	1.23	1.42	1.32	1.51	1.42	1.60	1.51	1.69
IX-1	0.72	0.90	0.81	0.99	0.90	1.09	0.99	1.18	1.08	1.27	1.17	1.36	1.27	1.45	1.36	1.54	1.45	1.63
IX-2	0.66	0.84	0.75	0.94	0.84	1.03	0.93	1.12	1.02	1.21	1.12	1.30	1.21	1.39	1.30	1.48	1.39	1.57
X-0	1.14	1.32	1.23	1.41	1.32	1.50	1.41	1.60	1.50	1.69	1.59	1.78	1.68	1.87	1.78	1.96	1.87	2.05
X-1	1.08	1.26	1.17	1.35	1.26	1.45	1.35	1.54	1.44	1.63	1.53	1.72	1.62	1.81	1.72	1.90	1.81	1.99
X-2	1.02	1.20	1.11	1.30	1.20	1.39	1.29	1.48	1.38	1.57	1.47	1.66	1.57	1.75	1.66	1.84	1.75	1.93
XI-0	1.53	1.72	1.62	1.81	1.72	1.90	1.81	1.99	1.90	2.08	1.99	2.18	2.08	2.27	2.17	2.36	2.26	2.45
XI-1	1.47	1.66	1.57	1.75	1.66	1.84	1.75	1.93	1.84	2.03	1.93	2.12	2.02	2.21	2.11	2.30	2.20	2.39
XI-2	1.42	1.60	1.51	1.69	1.60	1.78	1.69	1.87	1.78	1.97	1.87	2.06	1.96	2.15	2.05	2.24	2.15	2.33
XII-0	1.97	2.15	2.06	2.24	2.15	2.34	2.24	2.43	2.33	2.52	2.42	2.61	2.51	2.70	2.61	2.79	2.70	2.88
XII-1	1.91	2.09	2.00	2.19	2.09	2.28	2.18	2.37	2.27	2.46	2.36	2.55	2.46	2.64	2.55	2.73	2.64	2.82
XII-2	1.85	2.04	1.94	2.13	2.03	2.22	2.12	2.31	2.21	2.40	2.31	2.49	2.40	2.58	2.49	2.67	2.58	2.77

TABLE IX

Comparison of the logarithms of approximate bounds on horizontal peak accelerations, $a_{max,p}$, velocities, $v_{max,p}$ and displacements, $d_{max,p}$ derived in this study from linear and parabolic regression analyses for I_{MM} = XII with the independent estimates of the same quantities for a magnitude M = 7.5 earthquake and for epicentral distance R = 0*

		acceleration			velocity			displacement		
Confidence level p	Site Class. s	M=7.5* R=0	I_{MM} = XII linear regress.	I_{MM} = XII parabolic regress.	M=7.5* R=0	I_{MM} = XII linear regress.	I_{MM} = XII parabolic regress.	M=7.5* R=0	I_{MM} = XII linear regress.	I_{MM} = XII parabolic regress.
		1	2	3	1	2	3	1	2	3
p = 0.9	0	3.65	3.81	3.36	2.85	2.87	2.88	2.58	2.27	2.88
	1	3.59	3.95	3.50	2.72	2.88	2.89	2.37	2.21	2.82
	2	3.53	4.09	3.64	2.58	2.90	2.91	2.17	2.15	2.77
p = 0.5	0	3.29	3.43	2.98	2.42	2.52	2.53	2.06	1.90	2.52
	1	3.23	3.57	3.12	2.29	2.53	2.54	1.86	1.84	2.46
	2	3.17	3.71	3.26	2.15	2.54	2.55	1.65	1.78	2.40

*Trifunac (1975).