THE USE OF INTENSITY DATA IN SEISMIC-HAZARD ANALYSIS

by

R. K. McGuire[I]

SYNOPSIS

Relations between peak ground-motion parameters and Modified Mercalli (M.M.) intensity, based on strong-motion data obtained in California, are presented. Peak ground acceleration and displacement, when related to M.M. intensity, are found to depend also on source to site distance, whereas velocity does not. Several alternate methods of deriving design ground-motion values for the Eastern United States, where only intensity data are available, are discussed and illustrated. The predicted ground velocity for an event of given size and distance in the Eastern United States is the same whether strong ground motion as a function of intensity is assumed to be similar to California, or whether high intensities at long distances in the East are assumed to result from lower levels of shaking but longer durations. Design levels of acceleration and displacement, however, do depend on which hypothesis is assumed.

RELATIONSHIP BETWEEN M.M. INTENSITY AND GROUND-MOTION PARAMETERS

To examine the relationship between M.M. intensity and the peak values of certain parameters of strong ground motion, 68 strong-motion records (136 horizontal components) from California were examined for which intensity, magnitude, and distance data were available (3). The records were divided into "soft" and "medium" sites according to the classification assigned by Trifunac and Brady (6). (Not enough records were available from "hard" sites to allow a meaningful analysis.) The distribution of data according to magnitude, distance, site intensity, and geologic classification is shown in Figure 1. Several available records obtained close to fault rupture were not used, as the purpose was to develop medium- and far-field relationships for use in the Central and Eastern United States, as will be discussed.

Many regression analyses were performed on the data, using various combinations of magnitude, epicentral distance, and site intensity as the independent variables. The dependent variables used were peak horizontal ground acceleration, velocity, and displacement. A summary of the regression coefficients and standard errors of estimate are shown in Table 1 for the soft soil data and in Table 2 for the medium soil data. In the regression equation for $\ln a_g = f(M,\Delta)$, coefficient c_3 of the log distance term is about -.9 for both sets of data. If the variable R+25 is substituted for Δ in the regression analysis, where R is hypocentral distance, the typical coefficient obtained is -1.7, comparable to that

---

[I] Structural Engineer, U.S. Geological Survey, Denver, Colorado, USA

reported by others (1). The equations obtained for $\ln a_g = f(I_s)$, $\ln v_g = f(I_s)$, and $\ln d_g = f(I_s)$ generally predict accelerations, velocities, and displacements close to those reported elsewhere (6) for intensities V to VII when the mean of a lognormally distributed variable (e.g. ground acceleration a_g) is expressed correctly in terms of the mean and variance of the corresponding normally distributed variable (e.g. $\ln a_g$); for example,

$$E[a_g] = \exp\left\{E[\ln a_g] + \frac{1}{2}\sigma^2_{\ln a_g}\right\} \qquad (1)$$

where E indicates expection and σ indicates standard deviation. As a result of these comparisons, the data set of Figure 1 is considered to be typical of those generally used to derive attenuation equations and intensity-ground motion parameter relations.

Several conclusions are immediate from Tables 1 and 2. First, peak ground acceleration, when related to site intensity, is also a function of epicentral distance; the regression $\ln a_g = f(I_s, \Delta)$ reduces the standard deviation of residuals by about 7 percent from the regression $\ln a_g = f(I_s)$. The coefficient c_3 of $\ln \Delta$ is significantly negative, implying that, for a given site intensity, ground acceleration decreases with increasing distance from the event. This effect was recognized long ago by Neumann (4) and more recently by other investigators; at large epicentral distances, higher-than-expected intensities for low ground accelerations are often attributed to long duration of strong shaking. Ground velocity v_g, on the other hand, when related to site intensity, can be considered independent of distance. The coefficient c_3 of $\ln \Delta$ in the regression $\ln v_g = f(I_s, \Delta)$ is not significantly different from zero, and the dispersion of residuals is not reduced from the regression $\ln v_g = f(I_s)$. This reinforces the conclusion often expressed (e.g. 5) that peak ground velocity is the best measure of M.M. intensity. The regression for ground displacement d_g, $\ln d_g = f(I_s, \Delta)$, shows an increase of displacement with distance for a given I_s, although the coefficient c_3 is significant only at the 90 percent level. As a result of these regressions, it is suggested that distance be taken into account when relating acceleration and displacement to site intensity, but that ground velocity be considered a function of site intensity alone.

The regression analyses reported in Tables 1 and 2 indicate different results for the soft soil sites from those for the medium soil sites. These differences are, in general, significant at the 95 percent level for velocity and displacement but not for acceleration. Conclusions regarding which soil type implies higher values of ground acceleration, velocity, or displacement depend in general on the intensity, distance, and/or magnitude of interest.

Results of regression analyses of the type $\ln p = f(M, \Delta)$ are included in Tables 1 and 2 to indicate the dispersion of residuals associated with the usual regression equations. Regressions of the form $\ln p = f(M, \Delta, I_s)$ do not further reduce dispersion significantly and have the disadvantage that I_s is not independent of M and Δ.

The regression equations of Tables 1 and 2 may be used in several ways to derive design values of strong ground motion for areas such as the Central and Eastern United States where only historical intensity reports are available. It is assumed that the attenuation of intensity with distance is available in the form

$$I_S = d_1+I_e+d_3 \ln \Delta \quad , \qquad (2)$$

where I_e is epicentral intensity, Δ is epicentral distance, and d_1 and d_3 are obtained from regression analysis using intensity reports. Values of 3.08 and -1.34 for d_1 and d_3, respectively, are applicable to the Eastern United States (2) with a standard deviation σ_I of 1.2 intensity units. One theory (labeled here "Hypothesis A") suggests that the low attenuation of intensities in the Eastern United States is caused simply by small damping of all frequencies of the motion; hence, typical values of peak ground-motion parameters for a given intensity in the Eastern United States would be similar to those in Califonia for the same intensity. Under Hypothesis A, to calculate design accelerations, one would substitute Equation (2) into the relations $\ln a_g = f(I_S)$ from Tables 1 and 2 to obtain design values of $\ln a_g$ as a function of I_e and Δ. A second theory, Hypothesis B, suggests that the peak motion parameters behave similarly to those in California with respect to I_S and Δ, so that damage at large epicentral distances is associated with (for instance) low levels of acceleration but long duration of shaking. Accordingly, Equation (2) would be substituted into $\ln a_g = f(I_S, \Delta)$. Note that this realistically implies a change in relative frequency content of strong motion with distance; under Hypothesis A, only a very weak change of frequency content with distance is obtained, resulting from the difference in coefficients c_4 relating log acceleration, velocity, and displacement to site intensity. For a given site intensity, there is no change in frequency content with epicentral distance under Hypothesis A.

The predicted logarithms of acceleration for these two hypotheses are shown in Figure 2 for an event of I_e = X. Note that Equation (1) should be used to predict accelerations from the logarithms. The variance of residuals can be computed as $\sigma^2_{\ln a_g} + c_4^2\sigma_I^2 + 2\rho c_4\sigma_I\sigma_{\ln a_g}$, where $\sigma_{\ln a_g}$ is the standard deviation of log accelerations from Tables 1 and 2, and ρ is the correlation coefficient between errors in site intensity (Equation 2) and log acceleration (Tables 1 and 2). The value for ρ is typically -0.1 from California data; hence, the standard deviation of residuals predicted by these methods is typically large, equal to 1 or more.

It is important to note that the peak ground velocities predicted by the two hypotheses are identical, because ground velocities, when related to site intensities, are not dependent on epicentral distance for the California data examined. For ground displacements, Hypothesis B yields larger expected values than A, except at short distances; this result is in direct contrast to the comparison for ground acceleration.

CONCLUSIONS

From the intensity-ground motion parameter relations presented here, it is evident that peak ground acceleration and displacement, when related to M.M. intensity of the motion, are dependent on the distance from the event. This is not true of ground velocity, however. Several hypotheses can be suggested which, in conjunction with an intensity attenuation equation for the Eastern United States, will limit the expected accelerations and displacements in that region for a design event defined by an epicentral M.M. intensity and distance. The peak ground velocities predicted by the two hypotheses are identical, suggesting that this parameter might be most useful for quantitative description of ground motion in areas where strong-motion records are not available.

BIBLIOGRAPHY

1. Donovan, N. C., "A Statistical Evaluation of Strong Motion Data Including the February 9, 1971, San Fernando Earthquake," Proceedings, Fifth World Conference on Earthquake Engineering, Rome, pp. 1252-1261, 1974.

2. McGuire, R. K., "Methodology for Incorporating Parameter Uncertainties into Seismic Hazard Analysis for Low Risk Design Intensities," Proceedings, Int. Sym. on Earthquake Struc. Eng., St. Louis, Aug. 1976.

3. McGuire, R. K., and Barnhard, J. A., "Magnitude, Distance and Intensity Data for C.I.T. Strong Motion Records," submitted to U.S. Geological Survey Jour. Research, June 1976.

4. Neumann, Frank, Earthquake Intensity and Related Ground Motion, Univ. of Washington Press, Seattle, 77 p., 1954.

5. Nuttli, O. W., "The Mississippi Valley Earthquake of 1811 and 1812: Intensities, Ground Motion, and Magnitudes," Seismol. Soc. America Bull., v. 63, No. 1, pp. 227-248, Feb. 1973.

6. Trifunac, M. D., and Brady, A. G., "On the Correlation of Seismic Intensity Scales with the Peaks of Recorded Strong Motion," Seismol. Soc. America Bull., v. 65, No. 1, pp. 139-162, Feb. 1975.

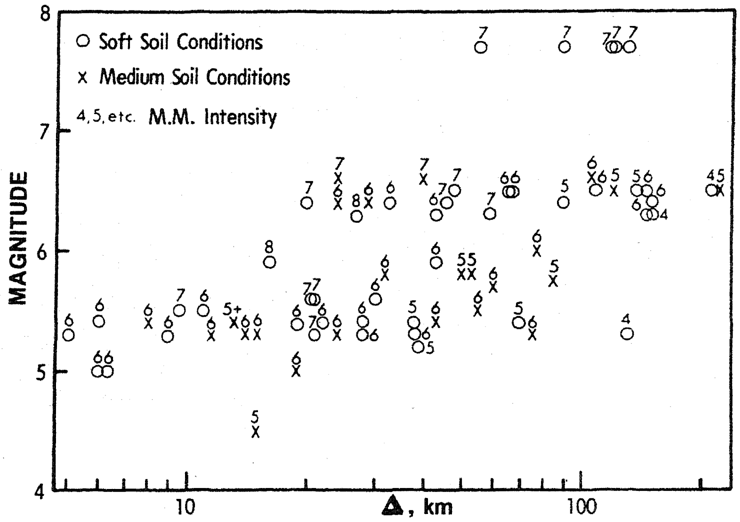

Fig. 1
MAGNITUDE, DISTANCE, INTENSITY, AND SOIL CONDITIONS OF RECORDS

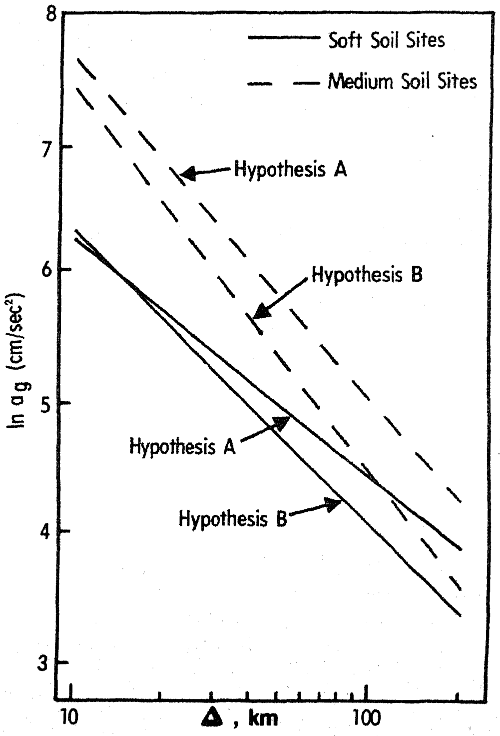

Fig. 2
ATTENUATION OF LOG ACCELERATION WITH DISTANCE FOR INTENSITY X EVENT, FOR DIFFERENT SOILS

TABLE 1

REGRESSION COEFFICIENTS FOR SOFT SITES

$$\ln p = C_1 + C_2 M + C_3 \ln \Delta + C_4 I_s$$

	C_1	C_2	C_3	C_4	$\sigma_{\ln p}$
$\ln a_g$	.271	x	x	.601	.781
(peak ground acceleration)	2.01	x	-.313	.506	.723
cm/sec^2	1.81	.904	-.901	x	.696
$\ln v_g$	-1.51	x	x	.543	.770
(peak ground velocity)	-1.11	x	-.072	.521	.771
cm/sec	-1.58	.997	-.710	x	.715
$\ln d_g$	-1.47	x	x	.415	.791
(peak ground displacement)	-2.35	x	.157	.463	.780
cm	-2.67	.863	-.398	x	.746

TABLE 2

REGRESSION COEFFICIENTS FOR MEDIUM SITES

$$\ln p = C_1 + C_2 M + C_3 \ln \Delta + C_4 I_s$$

	C_1	C_2	C_3	C_4	$\sigma_{\ln p}$
$\ln a_g$	-.831	x	x	.851	.753
(peak ground acceleration)	1.45	x	-.359	.680	.703
cm/sec^2	1.47	1.01	-.884	x	.619
$\ln v_g$	-4.02	x	x	.952	.751
(peak ground velocity)	-3.61	x	-.064	.923	.758
cm/sec	-3.61	1.37	-.776	x	.605
$\ln d_g$	-4.68	x	x	.899	.664
(peak ground displacement)	-5.75	x	.168	.979	.658
cm	-4.81	1.25	-.509	x	.581