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Different Magnitude-Epicentral Intensity Relations and Estimation of Maximum Ground Acceleration

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SYNOPSIS For an earthquake of magnitude 7.0 or larger, different published relations between magnitude, M, and epicentral intensity, I_o, yield I_o values which may differ from each other by as much as one intensity unit or more. This implies an uncertainty of a factor of about 2 in the estimation of maximum ground acceleration. New empirical relations between M and I_o are derived using the revised estimates of I_o for several earthquakes. Suitability of some of the commonly used M - I_o relations for the estimation of maximum ground acceleration is examined by deriving acceleration-distance curves for different magnitude earthquakes (viz., 5.6, 6.6 and 7.6), using an intensity attenuation relation for the San Andreas attenuation province. The intensity to acceleration conversion is accomplished by using the relation published by Trifunac and Brady (1975). These acceleration-distance curves are compared with several recent acceleration attenuation studies for the western United States. It is found that the use of M - I_o relation derived in this study yields satisfactory acceleration-distance curves for different magnitudes.

INTRODUCTION

For a seismic design of structures, it is a common practice to estimate the maximum credible earthquake for a particular fault or tectonic structure by using different considerations, such as, magnitude versus fault length relationship. The design acceleration at a site for a possible occurrence of such an earthquake may be derived by using a suitable magnitude-epicentral (or fault) distance-acceleration relation. However, because of the paucity of strong motion records from earthquakes in most parts of the world, a regional attenuation relation directly in terms of magnitude and acceleration is usually not available. An alternative procedure is to study the attenuation of intensities with distance. The maximum credible earthquake for a particular tectonic structure may be described in terms of epicentral intensity, I_o, using an appropriate M - I_o relation. The maximum ground acceleration at a site may be computed from the intensity attenuated at the site by using a suitable intensity-acceleration relation.

Several authors have published empirical relations between magnitude and epicentral intensity. Some of these relations are given below:

$M = 1 + (2/3)\, I_o$ Gutenberg and Richter (1956) (1)

$M = 2.1 + (1/2)\, I_o$ Krinitzsky and Chang (1975) (2)

$M_L = 1.93 + 0.51\, I_o$ Murphy and O'Brien (1978) (3)

where M_L is local magnitude. For the entire magnitude range of interest in earthquake engineering, equation (3) yields I_o values almost identical (about 0.2 unit larger) to that given by equation (2). Therefore, equation (3) will not be considered for further discussion in this paper.

At a magnitude of 7.0, the epicentral intensities calculated from equations (1) to (3) differ from each other by as much as 1.0 intensity unit. This difference is quite significant from the earthquake engineering point of view. For example, consider the following recently published relations between maximum ground acceleration, a (cm/sec^2), and Modified Mercalli intensity, I.

$\log a = 0.014 + 0.30\, I$ Trifunac and Brady (1975) (4)

$\log a = \beta + 0.24\, I$ Murphy and O'Brien (1978) (5)

$\beta = 0.29$ western U.S.

$\beta = 0.26$ when data from western U.S., southern Europe, Japan and New Guinea were combined

$\log a = -0.340 + 0.313\, I$ Bolt (1978b) (6)

It is easy to see from equations (4) to (6) that a change of one unit in intensity corresponds to a change in maximum ground acceleration by a factor of about 2.

It is important to note that in the derivation of equations (1) to (3), the maximum observed or mapped intensities were equated to the epicentral intensities for different earthquakes, and that the I_o values used were restricted to integral or bi-integral values, such as VII - VIII. Recently, the author (Chandra, 1979) studied the attenuation of intensities in the United States and, as part of that study, obtained improved estimates of epicentral intensities for a number of earthquakes. It was noted that the intensities estimated from the observations of geological effects, such as ground rupture, may be overestimated on the Modified Mercalli scale. Perhaps because of this reason, the M versus I_o relations, derived without a critical evaluation of I_o values, yield unreasonably large I_o values for higher magnitudes and small I_o values for lower magnitudes.

In this paper, new relations between magnitude and epicentral intensity are derived by using the revised I_o

values. The suitability of different $M - I_o$ relations for the estimation of maximum ground acceleration at a site is examined by comparison with the published relations among acceleration, magnitude and distance for the western United States.

MAGNITUDE - EPICENTRAL INTENSITY RELATIONS

Revised estimates of epicentral intensities for several earthquakes in different attenuation provinces of the United States were recently published by the author (Chandra, 1979). The calculated I_o values obtained in connection with the derivation of equations (3), (5), (7) and (9) and presented in Tables 1 to 4 of that paper were used in this study to derive new empirical relations between magnitude and epicentral intensity. For the Kern County earthquake of July 21, 1952, the local magnitude, $M_L = 7.2 \pm 0.2$, recently published by Bolt (1978a), was used. The following relations were obtained by performing a linear least squares regression of I_o on magnitude.

$$I_o = 1.98 + 0.99\, M_L \qquad 5\,1/4 \leq M_L \leq 7.2 \tag{7}$$
$$\sigma_{I_o} = 0.38 \qquad n = 11$$

$$I_o = 3.60 + 0.71\, m_b \qquad 3.7 \leq m_b \leq 6.5 \tag{8}$$
$$\sigma_{I_o} = 0.21 \qquad n = 5$$

$$I_o = 2.90 + 0.80\, M_S \qquad 5.5 \leq M_S \leq 7.1 \tag{9}$$
$$\sigma_{Io} = 0.46 \qquad n = 14$$

$$I_o = 2.91 + 0.82\, M \qquad 3.7 \leq M \leq 7.2 \tag{10}$$
$$\sigma_{I_o} = 0.41 \qquad n = 30$$

where M_L local magnitude
m_b body wave magnitude
M_S surface wave magnitude
M magnitude, when no distinction is made among different types of magnitudes
σ_{I_o} standard error of I_o
n number of earthquakes

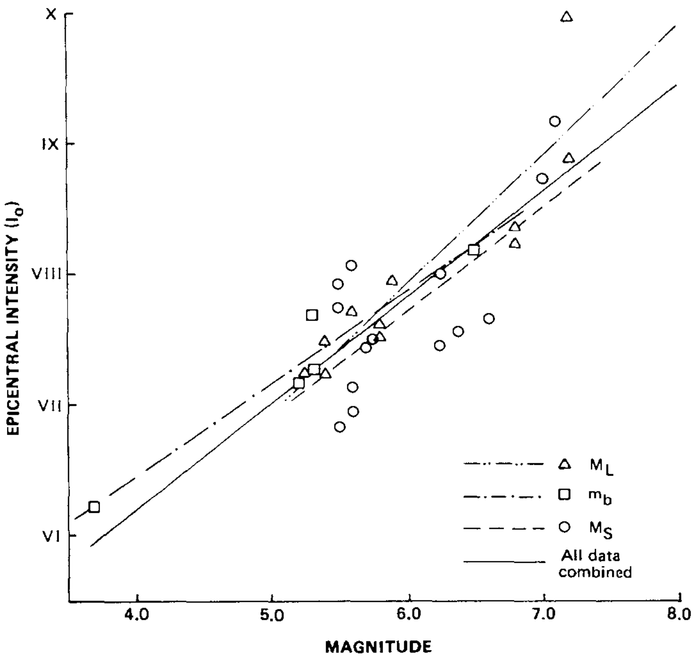

Fig. 1. Magnitude - epicentral intensity relations using data for the United States earthquakes.

The magnitude - epicentral intensity relations given by equations (7) to (10) and the corresponding data points are shown in Figure 1.

Also, allowing for an error in the independent variable M in the regression analysis, the following relations were obtained under the assumption that the ratio of the standard deviations of the two variables is constant (see also, Bolt, 1978b).

$$I_o = 1.51 + 1.07\, M_L \qquad 5\,1/4 \leq M_L \leq 7.2 \tag{7a}$$
$$\sigma_{I_o} = 0.38 \qquad n = 11$$

$$I_o = 3.45 + 0.74\, m_b \qquad 3.7 \leq m_b \leq 6.5 \tag{8a}$$
$$\sigma_{I_o} = 0.21 \qquad n = 5$$

$$I_o = 2.22 + 0.91\, M_S \qquad 5.5 \leq M_S \leq 7.1 \tag{9a}$$
$$\sigma_{I_o} = 0.47 \qquad n = 14$$

$$I_o = 2.55 + 0.88\, M \qquad 3.7 \leq M \leq 7.2 \tag{10a}$$
$$\sigma_{I_o} = 0.41 \qquad n = 30$$

In deriving equations (7a) through (10a), a standard error of magnitude, $\sigma_M = 0.2$, was assumed.

It is observed that the effect of allowing for a standard error of 0.2 in the independent variable M in the regression analysis is rather small. Over a magnitude range of interest in earthquake engineering, let us say 4.5 - 7.5, the maximum differences in the I_o values computed by using equations (7) and (7a); (8) and (8a); (9) and (9a); and (10) and (10a) are 0.13, 0.08, 0.19 and 0.09, respectively.

Because of a rather small data sample used in the derivation of equations (7) to (10), no attempt was made to investigate the effect of regional dependence on magnitude-epicentral intensity relations. However, it so happened that all the earthquakes used in the derivation of $M_L - I_o$ relation were located in California and Nevada.

SELECTION OF A SUITABLE INTENSITY - ACCELERATION RELATION

Recently, a number of authors have published empirical relations between MM intensity, I, and maximum horizontal ground acceleration, a. Equations (4) to (6) present some of these relations. For the purpose of further discussion in this paper, a suitable acceleration - intensity relation will be selected by considering the data for the San Fernando, California, earthquake of February 9, 1971 (origin time, 14h 00m 41.8s G.M.T., latitude, 34° 24.7' N, longitude, 118° 24.0' W, focal depth, 8.4 km, M_L, 6.4). The San Fernando earthquake is selected because to date it has provided the largest amount of strong motion data.

Chandra (1979) derived the following relation for the attenuation of MM intensities in the San Andreas attenuation province.

$$I(R) - I_o = 2.014 - 0.00659\, R - 2.014 \log (R + 10) \tag{11}$$

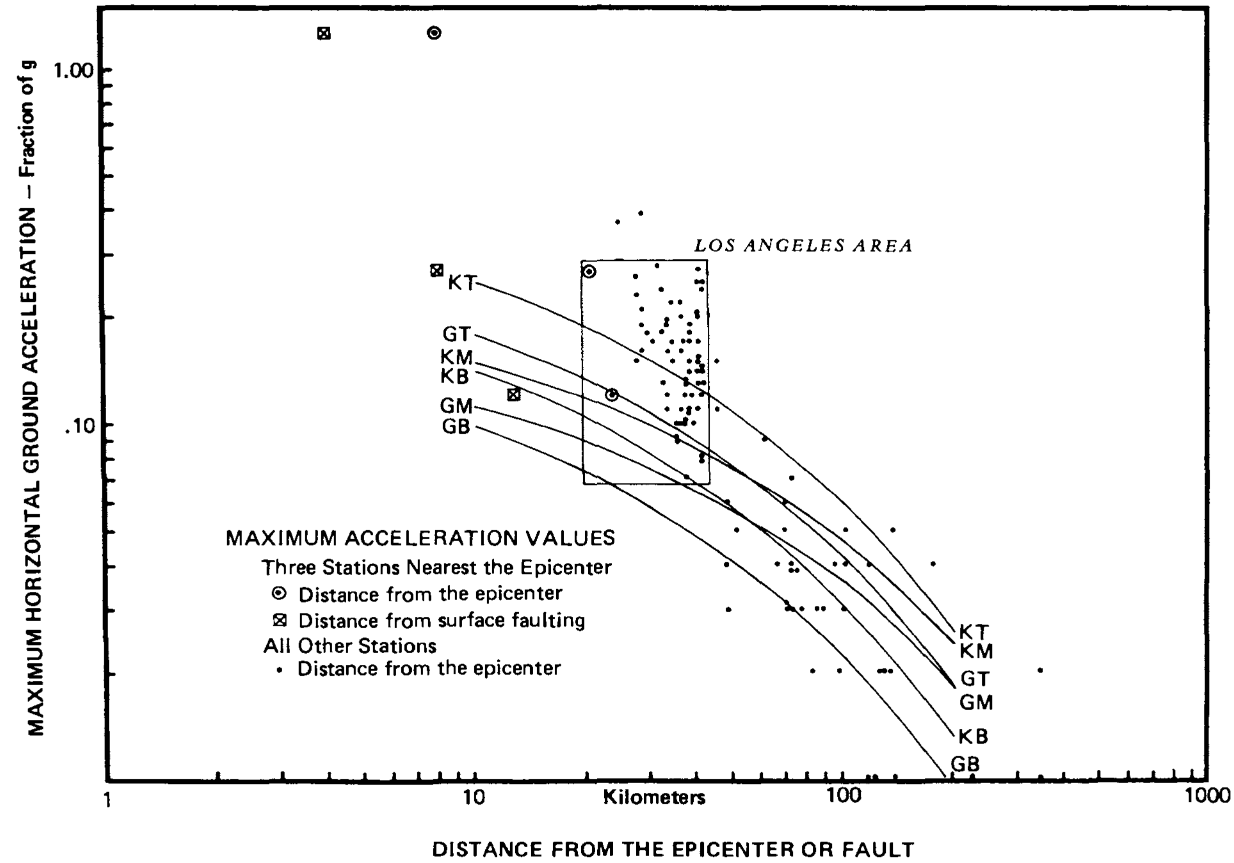

Fig. 2. A comparison of acceleration - distance data for the San Fernando, California earthquake of February 9, 1971 with the computed acceleration attenuation curves. The acceleration-distance curves were derived by using the intensity attenuation relation for the San Andreas attenuation province (Chandra, 1979). Epicentral intensities for a magnitude 6.4 earthquake were calculated by using M - I_0 relations, and accelerations at different distances were calculated from corresponding intensities by using acceleration-intensity relations. The curves are labeled by two letter symbols. The first letter identifies the M - I_0 relation used (G - Gutenberg and Richter, 1956; K - Krinitzsky and Chang, 1975) and the second letter identifies the log a - I relation used (T - Trifunac and Brady, 1975; M - Murphy and O'Brien, 1978; B - Bolt, 1978b). It is observed that the acceleration-distance curves (KT and GT) derived by using acceleration-intensity relation of Trifunac and Brady (1975) agree better with the observed data for the San Fernando earthquake than the curves derived by using other acceleration-intensity relations.

TABLE 1.

RMS Deviation of Maximum Horizontal Ground Acceleration - Fraction of g

log a - I relations	M - I_0 relations		
	Gutenberg & Richter (1956) eq. (1)	Krinitzsky & Chang (1975) eq. (2)	This Study eq. (7)
Trifunac & Brady (1975) eq. (4)	0.013	0.012	0.013
Murphy & O'Brien (1978) eq. (5)	0.015	0.013	0.014
Bolt (1978b) eq. (6)	0.016	0.014	0.015

where I(R) is intensity at a distance R km from the epicenter.

For a magnitude 6.4 earthquake, equations (1), (2) and (7) yield I_o values of 8.10 8.60 and 8.32, respectively. Curves for the fall-off of acceleration with distance were derived by using equation (11) in which I(R) was substituted by log a from equations (4) to (6). In equation (5) $\beta = 0.29$ was assumed. Thus, by using three different M- I_o relations and three log a - I relations, a set of nine acceleration versus distance curves were derived. The acceleration - distance data for the San Fernando earthquake of February 9, 1971, published by Maley and Cloud (1971), are shown in Figure 2. Six of the calculated acceleration - distance curves are also plotted in Figure 2. To avoid a crowd of too many curves on Figure 2, it was considered sufficient to plot curves corresponding to I_o values of 8.1 and 8.6. In order to quantitatively determine which of the various curves fit the observed data the best, a root mean square (RMS) deviation, defined by

$$\text{RMS deviation} = \frac{1}{N}\sqrt{\sum_{i=1}^{N}\left({}^{a}oi - {}^{a}ci\right)^2} \qquad (12)$$

was calculated, for data in the distance range 10 km - 200 km, for each case. ${}^{a}oi$ and ${}^{a}ci$ are the observed and calculated accelerations, respectively, at the i^{th} point. N is the number of data points. The RMS deviations are summarized in Table 1.

From Table 1 and also from a visual examination of Figure 2, it is observed that the acceleration - distance curves computed by using acceleration - intensity relation derived by Trifunac and Brady (1975), equation (4), agree better with the observed data for the San Fernando earthquake than the curves derived by using equation (5) or (6).

AN APPRAISAL OF DIFFERENT M - I_o RELATIONS

In this section, suitability of different M - I_o relations, viz. equations (1), (2) and (7), for the estimation of maximum ground acceleration is examined by deriving acceleration - distance curves for different magnitude earthquakes, using the intensity attenuation equation (11) for the San Andreas attenuation province. The intensities are converted to acceleration by using equation (4). The acceleration - distance curves thus derived for magnitudes 5.6, 6.6 and 7.6 are shown in Figures 3, 4 and 5, respectively. Recently published acceleration attenuation relations by Schnabel and Seed (1973), Donovan (1973) and Trifunac (1976) are also plotted in Figures 3 to 5. The curves TO and T2 were derived for a confidence level of 0.5 using the equations presented by Trifunac (1976). These figures also show 70% prediction intervals, derived by Boore et al. (1978), for data set for appropriate magnitude classes (5.0 - 5.7, 6.0 - 6.4 and 7.1 - 7.6) and small structures.

For an earthquake of magnitude 5.6, I_o is computed to be 6.9 using Gutenberg and Richter's (1956) relation and 7.0 using Krinitzsky and Chang's (1975) relation. In view of the closeness of the two I_o values, an acceleration-distance curve derived for I_o of 6.9 is shown in Figure 3 and is labeled G, K. It is noted that both curves, C and G, K, occur within 70% prediction interval of Boore et al. (1978) drawn for distances less than 30 km. However, the curve C occurs closer to the mean. It is also observed that for distances less than about 50 km, curve C is in better agreement with the attenuation curves derived by other investigators (S, TO, T2 and D) than the curve G, K. Beyond 50 km, the curve G, K is closer to the curves S, TO and T2. The curve C is relatively close to the curve D throughout the distance range shown.

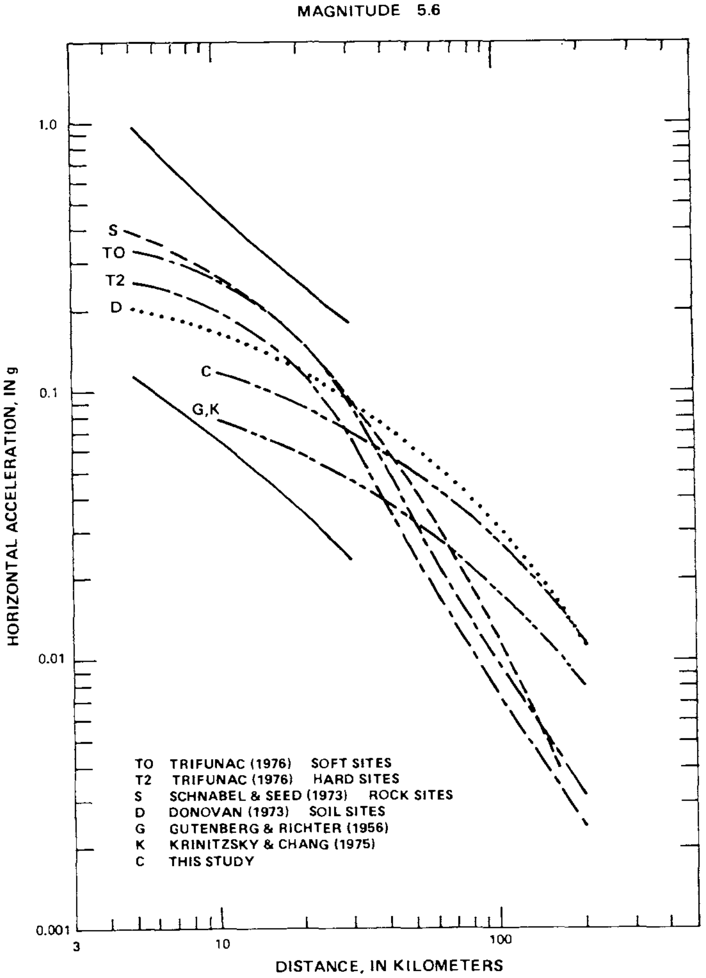

Fig. 3. Comparison of calculated acceleration attenuation curves for a magnitude 5.6 earthquake, obtained by using different M - I_o relations, with some of the published acceleration-distance relations. The curves labeled G, K, and C were derived by using M - I_o relations of Gutenberg and Richter (1956), Krinitzsky and Chang (1975), and this paper (equation 7), respectively. Solid lines show 70% prediction interval for data set for magnitude class 5.0 - 5.7 and small structures, from Boore et al., (1978).

For an earthquake of magnitude 6.6, I_o is computed to be 8.51 using equation (7) and 8.40 using equation (1). An acceleration curve derived for I_o of 8.51 is shown in Figure 4 and is labeled C, G. It is observed that the curve C, G occurs within 70% prediction interval of Boore et al. (1978) over the distance range (15-55 km) shown. The curve K occurs within 70% prediction interval for distances less than about 40 km and exceeds this interval at larger distances. The curve K is generally in better agreement than the curve C, G, with the curves TO, T2 and S for distances less than about 40 km, although the curve C, G is in better agreement with the curves TO, T2 and S at larger distances. The curve C, G

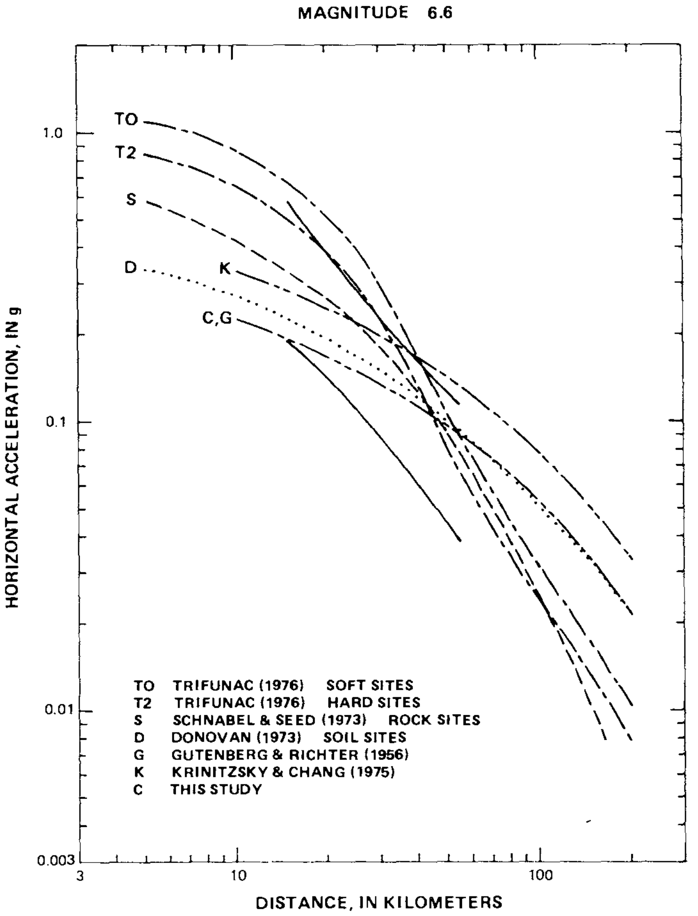

Fig. 4. Comparison of calculated acceleration attenuation curves for a magnitude 6.6 earthquake, obtained by using different M - I_0 relations, with some of the published acceleration-distance relations. The curves labeled G, K, and C were derived by using M - I_0 relations of Gutenberg and Richter (1956), Krinitzsky and Chang (1975), and this paper (equation 7), respectively. Solid lines show 70% prediction interval for data set for magnitude class 6.0 - 6.4 and small structures, from Boore et al. (1978).

is generally in good agreement with the curve D throughout the distance range considered, although the difference tends to increase toward smaller distances.

Different acceleration-distance curves for a magnitude 7.6 earthquake are presented in Figure 5. It is observed that the curve C agrees fairly well with the curves S and D. The deviation of the curves TO and T2 from the curve C is smaller than it is from either of the curves K or G, although the agreement can not be described as good. The curve C occurs within the 70% prediction interval of Boore et al. (1978) in the distance range, 40-85 km. The curve G occurs within this interval in the distance range, 40-60 km. The curve K exceeds the 70% prediction interval throughout the entire distance range (40-150 km) shown. In general, the agreement of the curve G with the various published attenuation curves is poor over most of the distance range considered. The curve K shows no agreement with the published attenuation curves.

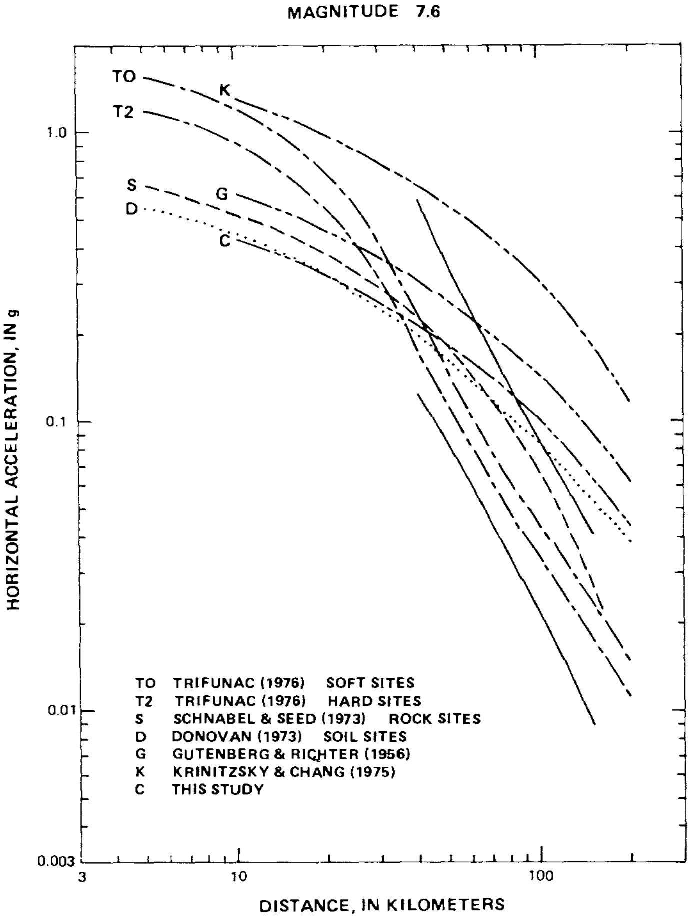

Fig. 5. Comparison of calculated acceleration attenuation curves for a magnitude 7.6 earthquake, obtained by using different M - I_0 relations, with some of the published acceleration - distance relations. The curves labeled G, K, and C were derived by using M - I_0 relations of Gutenberg and Richter (1956), Krinitzsky and Chang (1975), and this paper (equation 7), respectively. Solid lines show 70% prediction interval for data set for magnitude class 7.1 - 7.6 and small structures, from Boore et al. (1978).

Taken together the information presented in Figures 3 to 5, it may be concluded that in general, for the magnitude range 5.6 - 7.6, the acceleration-distance curves derived from the intensity attenuation consideration, using the M - I_0 relation presented in this paper provide a more satisfactory agreement with the acceleration attenuation published by various investigators, than the curves derived by using M - I_0 relations of Gutenberg and Richter (1956) or Krinitzsky and Chang (1975).

CONCLUSIONS

For earthquakes of large magnitude, greater than about 7.0, and also for moderate earthquakes, magnitude less than about 5.5, various published M - I_0 relations yield substantially different I_0 values. When these I_0 values are used for the estimation of design acceleration at a site, large differences in computed accelerations, unacceptable from an earthquake engineering point of view, are obtained. The M_L - I_o relation presented in this paper, when used in conjunction with the San Andreas province intensity attenuation (Chandra, 1979) and intensity - acceleration relation of Trifunac and Brady (1975), yields satisfactory agreement with the western U.S. acceleration-distance relations published by various investigators.

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REFERENCES

Bolt, B.A. (1978a). The Local Magnitude M_L of the Kern County Earthquake of July 21, 1952, Letter to the Editor, Bull. Seism. Soc. Am., 68, 513-515.

Bolt, B.A. (1978b). Fallacies in Current Ground Motion Prediction, Proc., 2nd International Conference on Microzonation for Safer Construction - Research and Application, vol. II, 617-633.

Boore, D.M., W.B. Joyner, A.A. Oliver III, and R.A. Page (1978). Estimation of Ground Motion Parameters, U.S. Geol. Surv. Circular 795, 43 pp.

Chandra, U. (1979). Attenuation of Intensities in the United States, Bull. Seism. Soc. Am., 69, 2003-2024.

Donovan, N.C. (1973). A Statistical Evaluation of Strong Motion Data Including the February 9, 1971 San Fernando Earthquake, Proc., 5th World Conference on Earthquake Engineering, Rome, Italy, vol. 1, 1252-1261.

Gutenberg, B. and C.F. Richter (1956). Earthquake Magnitude, Intensity, Energy, and Acceleration, Bull. Seism. Soc. Am., 46, 105-145.

Krinitzsky, E.L. and F.K. Chang (1975). State-of-the-Art for Assessing Earthquake Hazards in the United States, Report 7, Specifying Peak Motions for Design Earthquakes, Miscellaneous Paper S-73-1, U.S. Army Engineer, Waterways Experiment Station, Vicksburg, MS.

Maley, R.P. and W.K. Cloud (1973). Strong-Motion Accelerograph Records, in San Fernando, California, Earthquake of February 9, 1971; Vol. 3, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 325-348.

Murphy, J.R. and L.J. O'Brien (1978). Analysis of a Worldwide Strong Motion Data Sample to Develop an Improved Correlation Between Peak Acceleration, Seismic Intensity and Other Physical Parameters, a Report Prepared for U.S. Nuclear Regulatory Commission, NUREG - 0402.

Schnabel, P.B. and H.B. Seed (1973). Accelerations in Rock for Earthquakes in the Western United States, Bull. Seism. Soc. Am., 63, 501-516.

Trifunac, M.D. (1976). Preliminary Analysis of the Peaks of Strong Earthquake Ground Motion -- Dependence of Peaks on Earthquake Magnitude, Epicentral Distance, and Recording Site Conditions, Bull. Seism. Soc. Am., 66, 189-219.

Trifunac, M.D. and A.G. Brady (1975). On the Correlation of Seismic Intensity Scales with the Peaks of Recorded Strong Ground Motion, Bull. Seism. Soc. Am., 65, 139-162.