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ESTIMATION OF VARIOUS GROUND MOTION PARAMETERS FOR REGIONS OF FEW ACCELERATION DATA

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ABSTRACT

A method of mapping is suggested here for the evaluation of the ground motion parameters for regions with few acceleration observation data. This method assumes that, for a region A of enough acceleration observation data and a region B of few such data, earthquake pairs $(M_A, R_A; M_B, R_B)$ exist in the intensity attenuation curves $I_A(M_A, R_A)$ of region A and $I_B(M_B, R_B)$ of region B so that they give not only the same intensity I but also the same ground motion Y, as given in Eqs (5a) and (5b). Methods of earthquake mapping are suggested to find the earthquake pairs, together with numerical examples. The suggested method has two major advantages over the current ones. Firstly, there is no need to try hard to find a functional relationship among the required parameter Y of ground motion, intensity, and seismological and site parameters, because such a relationship is usually not easy to find for some parameters of ground motion, such as the strength envelope of the ground motion time history.Secondly,any ground motion parameter can be estimated by the method suggested here.

KEYWORDS

attenuation; intensity;ground motion; regions with few data;earthquake pair; minimum distortion mapping; ground motion evaluation; intensity-ground motion conversion.

INTRODUCTION

There are now approximately 10 thousand strong motion observation stations and nearly the same amount of traces of acceleration records of engineering meaning obtained over the whole world ,of which about half are obtained in USA, mostly on the western states;about 1/3 in Japan, with many from distant earthquakes off seashore.Other districts with many records are Mexico, Italy, Canada. The records in China are mostly obtained in Taiwan. There are still a majority of districts in the world where acceleration records are few, so few that no attenuation laws can be deducted from them there.

When design is based on given intensity, it needs only to evaluate the acceleration from a given earthquake intensity. When design response spectrum was introduced in the 1950s-1960s, a standard design response spectrum was scaled by design acceleration, converted from earthquake intensity, and design can be carried out then in the usual manner. After 1970s, design response spectrum, compatible with earthquake and site conditions, was required in the design codes for ordinary structures, and time history for special and important structures. For regions with enough acceleration records, the problem can be easily solved by obtaining some empirical relationships of design ground motion parameters with seismic and site parameters; but for regions with few acceleration records, the problem of evaluating ground motion parameters to match the local seismic and geological and site conditions is difficult to solve. Because the only seismic data exist in such regions are earthquake intensities, the present paper suggests a new method of deriving design earthquake ground motion parameters from macroseismic intensity, without requiring functional relationship among earthquake intensity, ground motion parameters, and seismic and geological or site conditions; the only requirement is that these ground motion parameters should be functions of earthquake and geological or site conditions.

PREVIOUS RESULTS

In regions with enough acceleration records, design ground motion parameters such as response spectrum or its simple substitute, the effective peak acceleration and velocity, are specified directly in the design code. But in many regions, such as the continent of China, such instrumental data are few.Existing earthquake intensity data reveal the effects of seismic and geological background condition on intensity attenuations, and thus possibly on ground motion attenuation. It is then doubtful to take the ground motion attenuation laws of a region with enough acceleration data and directly use them in another region with few such data,simply ignoring the earthquake intensity data in the local region with few acceleration data.Because earthquake intensity data are always easier to collect than acceleration data and they are usually the only data available and related in some way to the ground motion attenuation in regions with few acceleration data.It is then natural to try to derive ground motion from intensity.Early studies in this direction concentrated in finding functional relationship between earthquake intensity and single ground motion parameters (Ambraseys, 1974; Aptikaev,1982;Chang and Franklin,1987;Gutenberg and Richter, 1942;Hershberger,1956). Later studies extended this relationship to multiple ground motion parameters (Liu *et al.*,1982). The results of these early studies seem to show the following feature.They were all trying to find a functional relationship between single or multiple ground motion parameters and earthquake intensity, but in no case with satisfactory answer because the scattering of the relationship was so large (Ambraseys,1974). It has been warned (Hershberger,1956) to be careful not to use this kind of relationship in a simple manner. Though Neumann has pointed out, with numerical data and reasoning, as early as 1950s (Neumann,1954) that the relationship between earthquake intensity and ground acceleration is frequency or distance dependent, but it did not received sufficient considerations.

McGuire (1977,1984), Murphy and O'Brien (1977), Hu et al. (1983,1989)and others (Schenk,1990)have studied the relationship among intensity,ground motion (acceleration,velocity or displacement) and seismological parameters (magnitude and distance).This modification is reasonable because earthquake damage and thus intensity may be related to not only one but several ground motion parameters, such as horizontal and vertical acceleration, velocity, relative displacement,response spectrum and also duration of strong motion and they may be considered in some way indirectly by introducing additional parameters. Although such modified relationship reduces the variance of the correlation but the variance is still very large. The studies by Trifunac et al. (Liu *et al.*,1982; Novikova *et al.*,Theodulidis and Papazachos,1992; Trifunac and Lee,1992) are perhaps the most comprehensive; in addition to the parameters mentioned above, they have added also the geological and site parameters and considered the frequency-dependent feature of some ground motion parameters, but the variance remains large. Okada and Kagama (Okada and Kagami,1988) carried out similar studies.

When studying the relationship among intensity,ground motion acceleration and seismic parameter in the past 10 years, Hu and his group emphasize the attenuation curves as a whole instead of individual points.The method (Hu et al.,1989;Hu and Zhang,1983;Tian et al.,1986;Zhou,1992;Zhou,1993) asks for the intensity attenuation curves of two regions,one for a foreign region A with enough acceleration records and another for a local region B, with few acceleration records. The final goal is to find some ground motion attenuation relationships adequate for the local region B. Let the intensity and acceleration attenuation curves of the two regions be

$$I_A = f_A(M,R) \tag{1}$$

$$\lg Y_A = g_A(M,R) \tag{2}$$

$$I_B = f_B(M,R) \tag{3}$$

where Y may be the ground acceleration or velocity or some response spectral ordinate. The Eqs(1) and (2) can be solved simultaneously by eliminating either M or R and a relationship of the following form

$$I_A = F(Y_A, M \quad \text{or} \quad R) \tag{4}$$

is obtained. Eqs(1) and (2) of region A can be plotted in a form shown in Figs.2 and 3.

A new approach of attenuation mapping different from the fore-mentioned one is presented here in some details. The new approach differs from the ordinary ones in the following three aspects. Firstly,the whole attenuation curves are considered as a whole, not as scattered individual points. Secondly, equivalent mapping earthquakes pairs are considered instead of functional relationships between intensity and ground motion parameters, with or without additional seismic and geological and site parameters. And thirdly, consideration of site conditions in attenuation is not a difficult problem here if ground motion on some specific site conditions, such as rock, are required.

A MAPPING APPROACH OF GROUND MOTION EVALUATION FOR REGIONS WITH FEW ACCELERATION DATA

Fundamental Assumption

The fundamental assumption required in the present method is that,when a region B has entirely the same intensity attenuation as another region A,the ground motion attenuations of the two regions are then entirely the same. In case of different intensity attenuations, it is assumed that, for any earthquake (M_A,R_A) in region A, there will be an earthquake (M_B,R_B) in region B, so that the pair of earthquakes will give equal intensity I and ground motion Y in regions A and B,i.e.

$$I_A(M_A,R_A) = I_B(M_B,R_B) \tag{5a}$$

$$Y_A(M_A,R_A) = Y_B(M_B,R_B) \tag{5b}$$

The earthquake pairs are obtained by a mapping approach as given in the next section.

Mapping Criteria

Mapping can also be interpreted as a transformation of the coordinate system (M,R). Suppose the attenuation curves of regions A and B are plotted separately on two sheets in identical coordinates, with one on an ordinary white paper and another on a transparent rubber, which may be deformed in any way necessary. When over lapped, the look like those shown in Fig.1. Mapping may then be imagined as a process to distort the transparent rubber so that one set of attenuation curves are entirely coincided on the other with the coordinate axes also coincided but the scales of the axes on the transparent sheet changed. The coincided points, P on the attenuation curve for region A and Q on the attenuation curve for region B, form then a mapping earthquake pair. Point P should be read on the coordinate of the undistorted white paper and the point B on that of the distorted transparent rubber, and they give the same intensity value.

There are different ways of distorting the transparent sheet, or different mapping criteria, and thus different results of mapping. Fig.1 shows four of them.

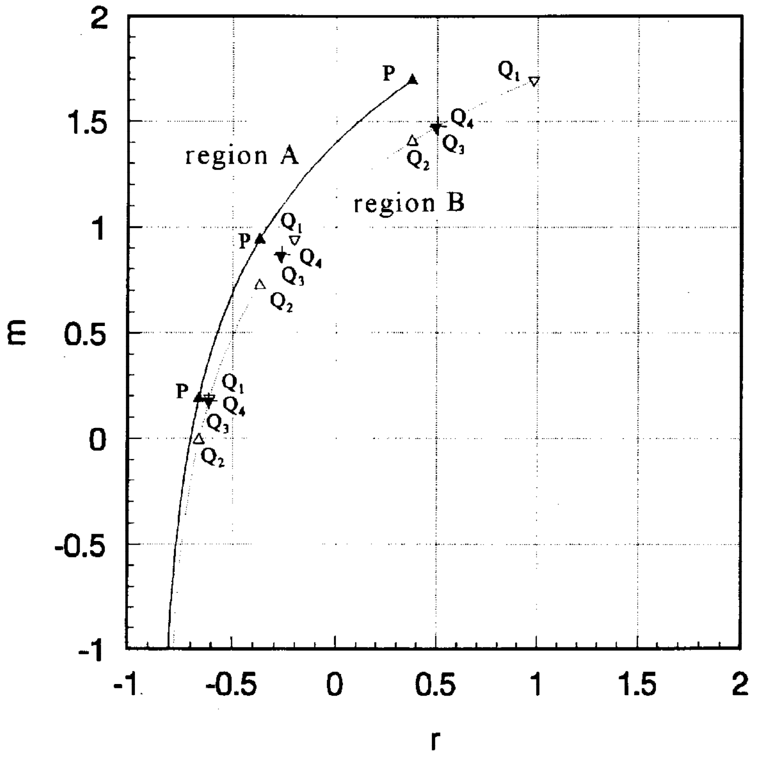

Fig.1 Mapping Criteria of the Attenuation Curves .(PQ_1 equal M or IR criterion, with $M_A = M_B$; PQ_2 equal R or IM criterion, with $R_A = R_B$; PQ_3 minimum distortion criterion, with shortest distance PQ; PQ_4 reversible minimum distortion criterion, with shortest distance PQ, but giving the same pairs P and Q when mapping from P to Q or from Q to P.)

The fourth criterion requires the same angle between the straight line PQ and the tangents of the attenuation curves at points P and Q separately. No matter which mapping criterion is used, it adds an additional restraint on the relationship among M_A, M_B, R_A and R_B. For example, the first and second criteria require respectively $M_A = M_B$ and $R_A = R_B$; and the addition restraint may be written in a general form as follows

$$H(M_A, M_B) = I(M_A, M_B, R_A, R_B) \tag{6}$$

Solving Eqs(5) and (6) simultaneously, the mapping transformation between the earthquake pair may be obtained and written in a general form as follows

$$M_A = h_1(M_B, R_B) \tag{7a}$$

$$R_A = h_2(M_B, R_B) \tag{7b}$$

When using the last two criteria, the variables M and R should be normalized and the following way of normalization is used here

$$m = \frac{(M - \overline{M})}{\sigma_M} \tag{8a}$$

$$r = \frac{(R - \overline{R})}{\sigma_R} \tag{8b}$$

where $M - \overline{M}, \sigma_M, R - \overline{R}, \sigma_R$ are respectively the mean and standard error of the numerical values of M and R used.

Zhou (1992,1995) introduced first the idea of mapping earthquake between two intensity attenuation curves; he considered the case of attenuation expressed in straight lines and the reversible minimum distortion criterion can be achieved by requiring points P and Q symmetrically located to the bisecting line of the intersection angle of the two straight lines of attenuation.

Ground Motion Attenuation Relations for Regions with Few Acceleration Data

The first important step, earthquake mapping, of the method suggested in the present paper is explained above. The second step is then to find the ground motion attenuation relations for region B with few acceleration data.

If the ground motion attenuation curves of region A are plotted together with the intensity attenuation curves of region A on the same white paper, the ground motion attenuation curves of region B can easily be obtained in one of the following ways: (1) by reading the ground motion attenuation curves of region A according to the distorted coordinates M_B and R_B on the transparent rubber sheet; or (2) by introducing the mapping earthquake pairs transformation , Eqs(7a) and (7b), into the ground motion attenuation curves, Eq.(2), for region A. This comes directly from the fundamental assumption, as expressed by Eqs (5a) and (5b). These two key steps of the present method may be illustrated in the following two flow diagrams

$$P(M_A, R_A) \rightarrow [\text{Eq.}(5a)] \rightarrow Q(M_B, R_B)$$

$$Y_A(M_A, R_A) \rightarrow [\text{Eq.}(5b)] \rightarrow Y_B(M_B, R_B)$$

Example

The attenuation curves for the western United States (region A) and for the northern China (region B) are considered here as an example. The intensity attenuation curves of these two regions are respectively

$$I_A = 3.524 + 1.047M - 2.559\lg(R + 10) \tag{9}$$

$$I_B = 2.340 + 1.292M - 2.763\lg(R + 7) \tag{10}$$

Fig.2 shows the intensity attenuation curves of Regions A and B, and numerals 1, 2, 3 and 4 refer respectively to the mapping criteria 1, 2, 3 and 4 when mapping by distorting the coordinates (M,R) of the region B. It is seen that the difference between criteria 3 and 4 is always small and the differences of those between criteria 2,3 and are is small when two sets of attenuation curves are nearly parallel to the R axis; and the differences of those between criteria 1,3 and 4 are small when two sets of attenuation curves are nearly parallel to the M axis.

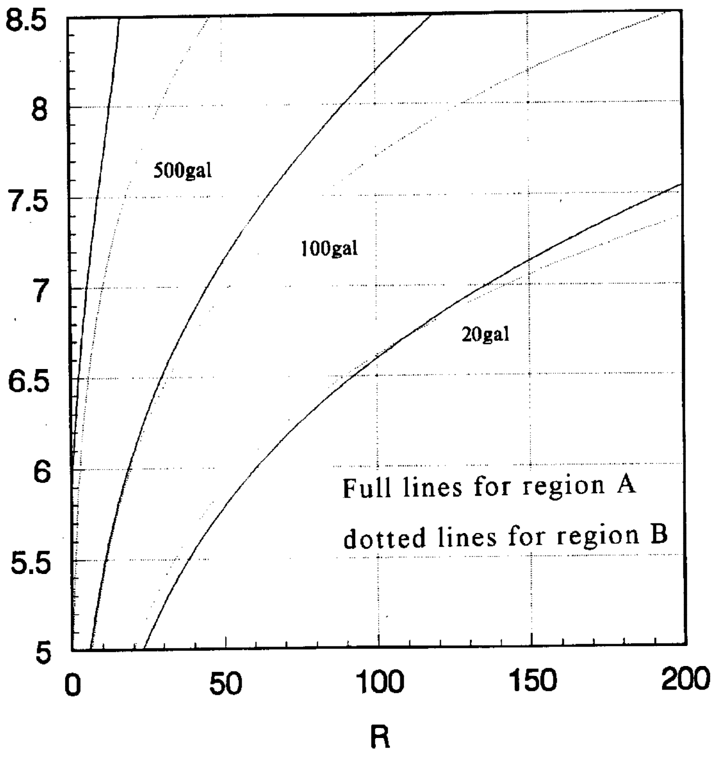

Fig.2 Earthquake Mapping of Intensity Curves of Regions A and B

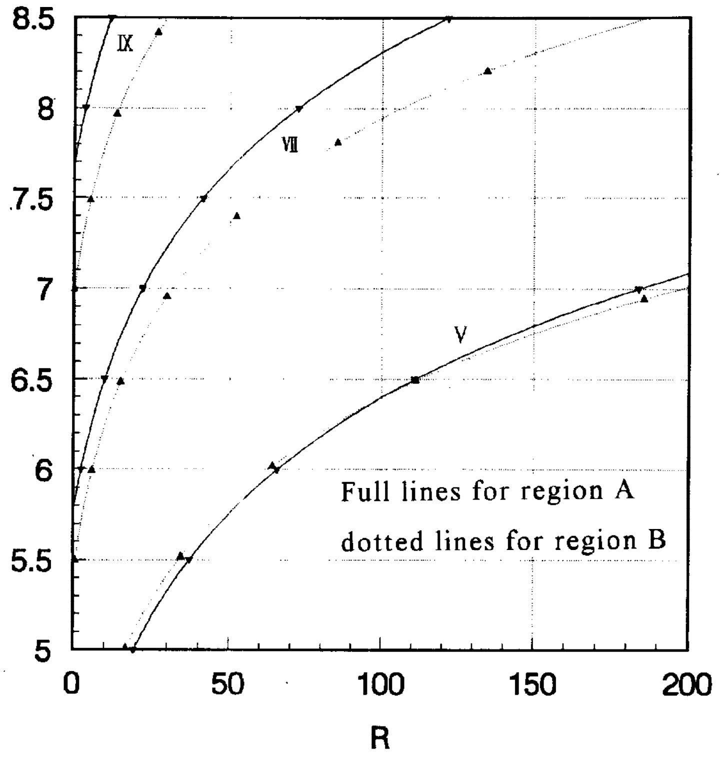

Fig.3 Acceleration Attenuation Curves of Region A and B

If the ground acceleration attenuation curve on the rock sites of the western United States is given by the following nonlinear form

$$\lg Y_A = -0.935 + 1.241M - 0.046M^2 - 1.904\lg(R + 0.3268e^{0.6135M}) \qquad (11)$$

the ground acceleration attenuation curve on the rock sites of the northern China is then derived on the basis of the reversible minimum distortion criterion and expressed as follows

$$\lg Y_B = -0.830 + 1.105M - 0.022M^2 - 2.038\lg(R + 0.0873e^{0.8005M}) \qquad (12)$$

The analytical formula of Eq.(12) is obtained by regression of the numerical acceleration data obtained by introducing the mapping earthquake $Q(M_B,R_B)$ into the acceleration attenuation curves of Eq.(11) as indicated by the second step Eq.(5b). The derived acceleration attenuation curves for the northern China are plotted together with those of the western United States in Fig.3. Similar attenuation curves for any other ground motion parameters on any site condition for region B may be derived in the same manner if the attenuation curves of that parameter on the same site condition can be obtained in region A.

ADVANTAGES OF THE SUGGESTED METHOD

The suggested method has the following 3 advantages over the ordinary methods. (1) It does not ask for any direct relationships between intensity and ground motion,which are usually not easy to find. (2) Any ground motion parameter can be estimated by the suggested method, for example, even for the rising time of the strength enveloping function of the acceleration time history and the response spectrum ordinate at some long period. (3). Site conditions are much easier to deal with in the present method. When using other methods, the site condition becomes a difficult problem because it is required to specify the site condition for ground motion attenuation but it is always difficult to specify it for intensity attenuation.In the suggested method, because equivalent earthquakes are derived and the site conditions can be considered easily if there are enough acceleration data can be obtained and a ground motion attenuation relationship can thus be derived in some region A.

The reliability of the suggested method should be tested.

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