ATTENUATION OF GROUND MOTION FOR REGIONS WITH NO GROUND MOTION DATA

by

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ABSTRACT

China is a country with a huge amount of intensity data but only a few strong-motion records. The current Chinese Seismic Design Code uses intensity zoning map from intensity attenuation and foreign intensity-acceleration relation to obtain necessary design accelerations. This paper presents authers' suggestion for a change in the Chinese Code by adopting directly ground motion values through ground motion attenuation relations. A brief outline is given at the beginning on the available methods of estimating design accelerations. The suggested method is then explained in three steps: (1) the assumption of a one-to-one correlation of intensity and acceleration is used only for equal epicentral intensity or magnitude; (2) the ground motion attenuation law of a region with given intensity attenuation is derived from the ground motion and intensity attenuation laws of another region; (3) comparisons are given for regions with known ground motion attenuation.

INTRODUCTION

Although there are unsettled problems on what are the ground motion characteristics to be considered in earthquake-resistant design of various structures, some common practice has been followed in most part of the world. Among them, two may be mentioned as follows. Firstly, in design or analysis of structures subjected to earthquake excitation, it is necessary to know an effective or design acceleration for static method, a design response spectrum for pseudo-dynamic method, or an acceleration time-history for dynamic method; and secondly, these ground motion parameters are estimated from information on spatial and temporal characteristics of the regional seismic activity. If y represents ground motion parameters such as design acceleration, velocity, response spectrum, duration, or others, E the earthquake parameters such as magnitude, moment, geometrical and mechanical characteristics of the source, and P the path parameters such as distance from source to site, site condition and directivity, the estimation of earthquake motion requires the attenuation relations

$$y = y(E,P) \quad (1)$$

In order to establish these relations, it is necessary either to have sufficient ground motion data from past earthquakes in the considered region to obtain some empirical relations, or to have enough information of the earthquake source mechanism and wave transmitting media to compute some theoretical relations. The second approach is still in its research stage and not ready for practical use. The first approach is currently used in the Western United States because there exists the best set of strong-motion data of more than 1000 accelerograms accumulated since 1933, including two earthquakes in the 70's with nearly 100 accelerographs triggered for each earhtquake and the highest ground acceleration of 1.74g ever recorded in the world from earthquake.

Since strong earthquakes are rare, the accumulation of strong motion data for a certain region must be a slow process. Strong-motion observation began in 1932 in the United States and it took 50 years to accumulate a set of tolerably sufficient data to cover moderate earthquakes of magnitude 5-7 of shallow focus. Japanese started the observation in 1955 and have accumulated also nearly 1000 accelerograms but with smaller accelerations and less records in one earthquake. A crucial problem is associated then with the first approach, the only approach now practical, in obtaining the necessary relations (1) for regions with no strong-motion data. It is then not possible to follow the first approach by using attenuation relations obtained from local data only.

METHODS AVAILABLE

In seismically active regions with or without sufficient strong-motion data, there are in general many earthquakes and intensity data have been accumulated. In China, for instance, over 140 isoseismal maps have been worked out from dependable historical records and field investigation, with epicentral intensities ranging from VI to XI. It is then natural to try to use them in estimating ground motions in these regions. In fact, even before using ground motion parameters in earthquake-resistant design of structures, acceleration has beeb used as an index to define earthquake intensity, auxilliary to the phenomenal descriptions of earthquake consequences in some earthquake intensity scales.

The Chinese procedure of the estimation of design values of ground motion through intensity (1) is given here as a typical example of this approach. Firstly, the whole country is divided into several regions according to their geological-seismological backgrounds and a seismic risk zoning map is made to provide the location and the most probable magnitude of earthquakes expected in the coming 100 years. Secondly, a set of intensity attenuation relations of different epicentral intensities and a correlation of earthquake magnitude M and epicentral intensity I_0 are obtained from past earthquake data in each region. Considering isoseismals may be elliptical, the attenuation is specified in long and short axes, and the average M-I_0 relation for shallow earthquakes is

$$M = 0.66I_0 + 0.98 \qquad (2)$$

Thirdly, an intensity zoning map is drawn from the earthquake risk map, by considering the epicentral intensity I_0 may occur anywhere within the zone of the corresponding magnitude M in the risk map and by scaling contours of lower intensities away from the epicentral zone according to the attenuation laws. Fourthly, a one-to-one correlation is assumed to exist between intensity and peak acceleration and obtained statistically from earthquake data over the whole world, and then used to give the design acceleration from intensities given in the intensity zoning map.

This one-to-one kind of intensity-acceleration relation assumes a unique relation such as the one in Table 1, no matter it is for intensity at epicenter or far-field, of an earthquake of magnitude 8 or 6, on rock or soft site, in China or in Canada. Although the simplicity of this procedure is attractive, the diagram of the raw data of intensity and acceleration, such as Fig.1 (3), used to obtain the correlation given in Table 1, shows a huge scattering of several tens or even 100 times different accelerations within one intensity grade and the average increase in acceleration is only double for each increment of intensity. Such a wide scattering suggests that intensity is not determined by ground acceleration alone, but jointly by other independent ground motion parameters such as duration and/or spectrum. The low correlation of intensity with any single parameter makes some prominent seismologists and egineers doubt the meaning or the existance of the functional relationship of intensity with only one parameter of ground motion(3,10).

Because of the doubtful correlation of acceleration and intensity, another approach, though not satisfactory, has been used. This third approach uses only ground motion attenuation relations obtained at one region to other regions with no or some judgment-based modifications(9,14). The most commonly used empirical attenuation relations are expressed in ground acceleration or velocity, as functions of earthquake magnitude and distance obtained from data in the Western United States. This approach ignores the effects of regional conditions on attenuation.

A fourth approach of ground motion estimation was introduced and widely used in recent years. This approach uses also ground motion attenuation relations from other regions, but only after some necessary modification from comparisons of intensity attenuation relations of the regions. Nuttli(15) obtained a ground acceleration attenuation relation for the Central United States from those for the Western United States under the assumption of a one-to-one correlation between intensity and ground velocity and Algermissen and Perkins(2) used Nuttli's attenuation relations for the Mid-west and the Eastern United States to draw an acceleration zoning map of the contiguous United States. Bernreuter(5) did the same thing as Nuttli but under the assumption of a one-to-one correlation of intensity VII and ground acceleration and another assumption that the slope of attenuation relation lna vis lnR is constant for small and large earthquakes in the region. Whitman et al(16) pointed out that Algermissen's map of 1976 was taken as a basis to develop the effective acceleration and velocity maps in the model code ATC-3. McGuire(13) prefers the assumption of a one-to-one correlation of intensity and ground velocity because he found that distance R had a strong influence on the relation of intensity-acceleration but not on the relation of intensity-velocity from the California data, but Espinosa(7) found from the San Fernando data that velocity-intensity relation is influenced by distance too, Fig.4.

The latest method of modifying a regional ground motion attenuation relation to count for different geological and seismological conditions is suggested by Battis(4). His method of modification is based on the following three assumptions: (1) Ground motion attenuations can be expressed by some functional relations, for example,

$$\ln a = C_1 + C_2 I_o - \ln(R + R_o) \qquad (3)$$

where C's are constants to be determined and the constant R_o is predetermined; (2) Equal epicentral intensity I_o corresponds always to an acceleration a_o at distance R_o according to a one-to-one correlation of I and a obtained from world-round data;(3) The felt intensity III corresponds to a given acceleration a_f. From these assumptions and a relation a(I), two points on the required acceleration attenuation curve (3) are known as (a_o, R_o) and (a_f, R_f), where epicentral intensity I_o and felt distance R_f are known from the intensity attenuation relation of the region of interest. With two points known, the ground motion attenuation curve (3) is then completely specified for the region of interest. Battis checked his method with the 1971 San Fernando data, Fig.2, and the agreement is good.

In estimating the ground motion, the first approach uses the intensity attenuation data, ignores the ground motion attenuation data, and assumes a one-to-one correlation of intensity vis ground motion parameter (acceleration or velocity) holds everywhere; the second approach depends only on theoretical attenuation relations; the third approach uses only ground motion data, ignores intensity data, and assumes the same ground motion attenuation laws hold everywhere; the fourth approach uses limited information of both intensity and ground motion attenuation relations, for example, only the slope or data near two ends of the attenuation curves. The present paper follows the general principle of the fourth approach and suggests a method that uses all information on both the intensity and ground motion attenuations, but adopts a strong limitation on the assumption of intensity-acceleration correlation. This method is being suggested for use in modifying the current Chinese Seismic Design Code (11,12).

THE METHOD SUGGESTED

Given the intensity attenuation laws $I^A(I_o,R)$ and $I^B(I_o,R)$ of region A of interest and region B for comparison respectively and the ground motion attenuation law $a^B(I_o,R)$ of region B, the problem is to find the ground motion attenuation law $a^A(I_o,R)$ at region A. The suggested method assumes that the relation between intensity I and ground motion parameter a is one-to-one only when epicentral intensities are the same. This assumption leads to a method as shown in Fig.3.

The differences between the suggested method and the Battis' are: (1) the suggested method uses all information of the three given curves I^A, I^B, and a^B, while the Battis' uses only I_o, ao, R_f and af; (2) consequently, the resultant curve a^A of two methods will be similar only near R_o and R_f; and (3) the resultant curve a^A by the suggested method will be closely related to the details of the given attenuation curves but that by the Battis' to the assumed geometry of Eq.(3).

The difference between the suggested method and the first approach is simple but great. Although both methods assume some functional relationship between intensity and ground motion parameter, the first method uses it with no restriction and thus consider it a unique or one-to-one function, but the suggested method uses it under a strong limitation of equal epicentral intensity and thus allows a multi-valued function between intensity and ground motion parameter. This limitation is considered necessary and possible.

There are many reasons for the huge scatter of the intensity -acceleration or velocity relation as shown in Fig.1, but the widely different combinations of factors such as magnitude,distance and site condition in one intensity category is believed to be an important one. These factors have strong influence on ground motion through changes in duration, spectrum and other properties, which are all important in structural response and thus intensity. Fig.4(7,13) shows clearly that, in addition to acceleration, there are other factors affecting intensity. It is well known that, for same intensity, ground motion in near-field of small earthquake, say M=5, has a larger peak acceleration, a shorter duration of 5-10 sec. and a spectrum richer in high-frequency components and ground motion in far-field of large earthquake, say M=8, has a smaller peak acceleration, a longer duration of 30-40 sec. and a spectrum richer in low-frequency components. Fig.5(12) shows one set of evidence from records of the 1976 Tangshan earthquake and its aftershocks. Under the same epicentral intensity, for one site intensity the variations of duration and spectrum will be limited to much narrower ranges and thus much better predictions of the considered parameter of ground motion. It is therefore necessary to impose **this** limitation on the intensity-ground motion parameter relation.

It is also possible now to have adequately sufficient data to introduce this requirement. Fig.6 shows three sets of intensity and acceleration attenuation curves for magnitudes 5.9-6.1, 6.5-6.7 and 7.2-7.4, or epicentral intensities VII, VIII and IX respectively from the Western United States, Japan and Yugoslavia. With additional data currently available, it is possible to interpolate intermediate curves and extrapolate curves upto perhaps M=5.5 and 8.

For practical use, the magnitude and epicentral intensity are interchangeable for earthquakes of comparable focal depth. For most part of China, focal depth is usually in a narrow range of 10-30 km, which is comparable to the Western United States. The average relation between magnitude M and epicentral intensity I_o in the States is $M=2I_o/3+1$, which is practically identical to Eq.2, the Chinese case.

COMPARISON OF RESULTS

In order to check the applicability of the suggested method, data given in Fig.6 are used. The ground motion attenuation data of the Japanese earthquakes are considered unknown at first, then estimated by the suggested method from other pairs of curves, and the estimated results finally compared with the actual ones. Results are given in Table 2, together with results of estimations by using average attenuation curves given by Espinosa(7), McGuire (13) and Eguchi(6). The results by using directly the one-to-one correlation of intensity-acceleration given in Table 1 according to the current method used in China are also shown in the table. It is clear from the comparison that the suggested method gives good results.

Fig.2 shows the comparison used by Battis. Results obtained from the suggested method by using the Japanese attenuation pairs as reference to estimate the ground acceleration attenuation for the 1971 San Fernando earthquake are also shown in the figure, together with that directly obtained from acceleration-intensity correlation. It is also clear that the suggested method gives good result and better than that by the current method in China.

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Table 1 Intensity-Acceleration Relation

Intensity I	V	VI	VII	VIII	IX	X
Acceleration a(cm/s^2)	31	63	125	250	500	1000

TABLE 2 COMPARISON OF RESULTS OF GROUND ACCELERATION ESTIMATION

REGION OF INTEREST					REGION OF REFERENCE								NOTE
JAPAN EQK NO.	M	R km	MMI	A_{max}/g	IMPERIAL VALLEY 1979	SAN FERNANDO 1971	COYOTE LAKE 1979	MONTE NEGRO 1979	ESPINOSA 1977	McGUIRE 1977	EGUCHI 1980	MMI	
877	6.7	18	7	0.23	0.26	0.22			0.24	0.15	0.10	.13	
		25	7	.20	.20	.17			.18	.12	.07	.13	
		53	6	.09	.12	.10			.09	.09	.05	.06	*
		70	6	.06	.09	.06			.07	.09	.04	.06	*
763	6.7	86	7	0.14	0.20	0.19			0.20	0.13	0.08	.13	
		102	6	.11	.15	.13			.14	.11	.06	.06	
		128	6	.07	.08	.05			.05	.08	.04	.06	
898	6.1	82	6	0.11			0.095		0.06	0.10	0.06	.06	*
		108	6	.06			.095		.06	.10	.06	.06	*
		153	5	.04			.06		.04	.06	.04	.03	*
789	7.4	80	8	0.30				0.26	1.01**	0.27	0.15	.25	
		100	8	.26				.23	.81	.23	.12	.25	
		115	8	.22				.20	.66	.21	.10	.25	
		158	7	.11				.06	.21	.15	.06	.13	*
		164	7	.10				.07	.18	.14	.06	.13	*
		185	7	.04				.04	.13	.13	.05	.13	*

* Attenuation considered separately in long and short axes

** Espinosa's acceleration is too high for M > 7

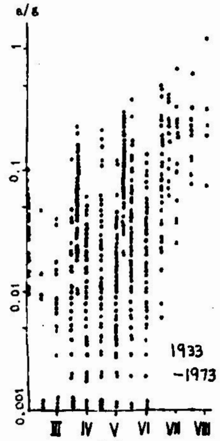

FIG.1
INTENSITY-ACCELERATION DATA
(AFTER AMBRASEYS)

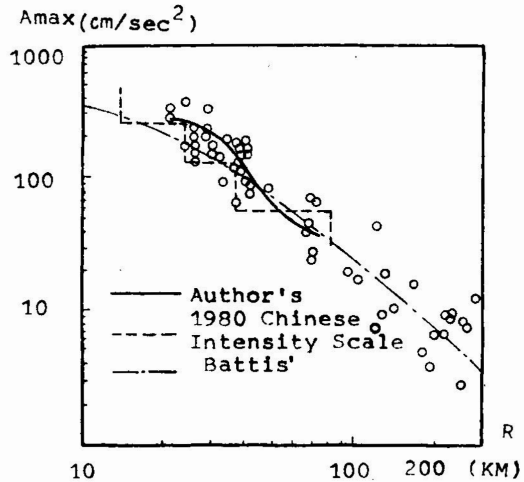

FIG.2 COMPARISON OF VARIOUS METHODS OF GROUND MOTION ESTIMATION

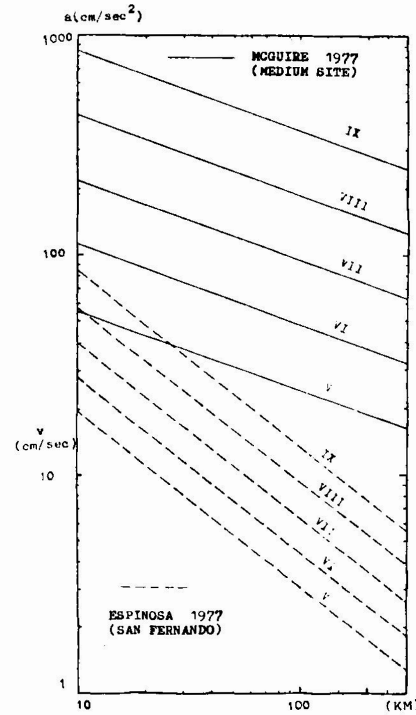

FIG.4 DISTANCE AS A FACTOR INFLUENCING INTENSITY

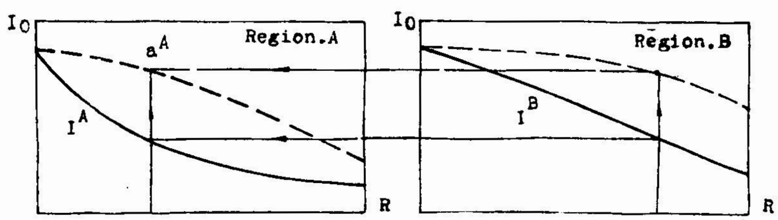

FIG.3 PROCEDURE OF THE SUGGESTED METHOD

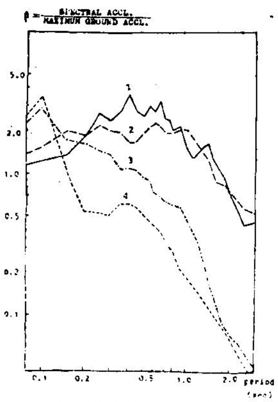

FIG.5 SPECTRA OF GROUND MOTION FROM TANGSHAN EARTHQUAKES

1---M_s=7.5--7.9 D=120--[illegible] km
2--- 6.8--7.4 120--[illegible]
3--- 4.5--5.3 20-- [illegible]
4--- 4.5 6.5

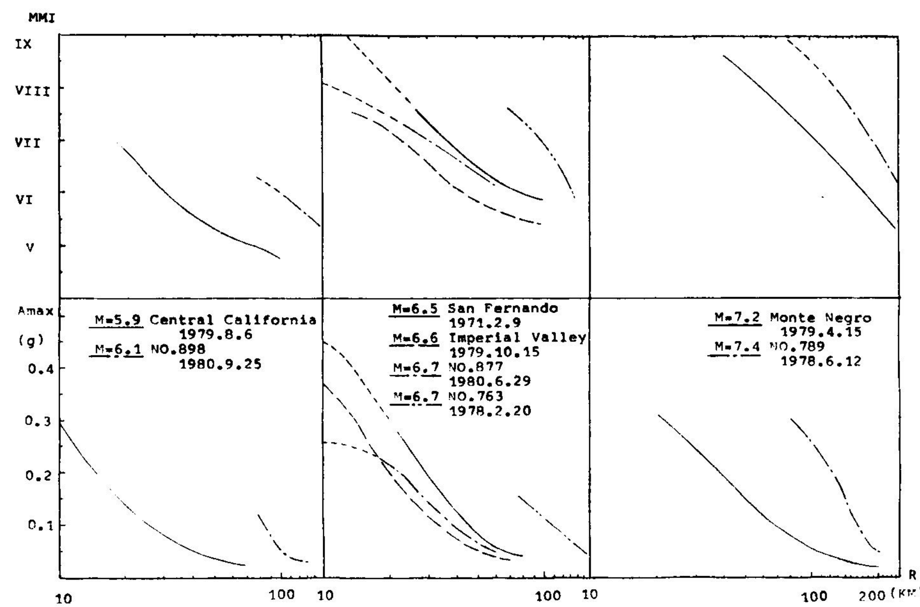

FIG.6 TYPICAL ATTENUATION CURVES