SEISMIC DESIGN RESPONSE SPECTRA CONSIDERING INTENSITY, EPICENTRAL DISTANCE AND SITE CONDITION

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SUMMARY

In this paper, intensities below 9 have been subdivided according to epicentral distance in order to consider the influence of magnitude, epicentral distance on shape of response spectrum, if intensity is taken as a main parameter of ground motion in seismic design. On the basis of statistical analysis of response spectra for free field ground motion recorded by accelerographs for different intensities and epicentral distances, design spectra are classified in accordance with probable combination of generalized intensity subdivided according to epicentral distance and site condition in this paper. Standard spectra are suggested for seismic design.

INTRODUCTION

Significant effects of site conditions on the shape of response spectrum are known from many investigations, thus set of site-dependent design response spectra has been specified in a considerable number of seismic design codes as a basis of earthquake resistant design. But site condition is by no means the only factor which controls the shape of response spectra. In fact, some near-field strong motion records on soft alluvium have been obtained in Luton area of Taiwan and the corresponding response spectra seem to be quite different from the average one on very loose soil given in Ref.1.

As the number of strong ground motion records increases frequency content of different bands of response spectra was firstly treated as a function of magnitude and hypocentral distance by McGuire (Ref.2). Similar results were obtained by Yongnian Zhou based on strong ground motion records, both of the mainshock and after shocks in the 1976 Tangshan earthquake as shown in Fig.1 (Ref.7).

In recent years, the site condition was introduced by Trifunac & Anderson, Shannon & Wilson / Agbabian Associates (SW/AA) and Katayama into such statistical analysis for response spectra (Refs. 3-5). They acquired undoubtedly more advanced results when compared with those who considered site condition as the only effecting factor of spectral shape or ignored it at all. Since earthquake intensity and its corresponding peak ground acceleration (PGA) represent severity of ground motion, they play a more important role than magnitude in earthquake resistant design, it seems to be reasonable to use earthquake intensity but not magnitude in design. Furthermore, we will discuss in this paper the relationship between magnitude, intensity and epicentral distance, the method of site classification and finally propose a seismic design

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response spectra considering intensity, epicentral distance and site condition.

SUBDIVISION OF INTENSITY ACCORDING TO EPICENTRAL DISTANCE

It is known that the destructive action of strong ground motion may be represented by its strength or severity, spectrum shape and duration which all depend on earthquake magnitude,hypocentral distance and site condition. However, in many seismic codes, the design level of ground motion is represented by earthquake intensity. The corresponding average PGA's for different earthquake intensities were given by Trifunac & Brady as follows: VII - 0.125g, VIII - 0.25g, IX - 0.5g, X - 1.0g (Ref.6).

Since a certain earthquake intensity may be produced by earthquakes of different magnitudes and epicentral distances, as a result, the destructiveness of earthquakes of a certain intensity may be quite different. In fact, in an earthquake of minor or medium magnitudes, e.g. magnitude 5.5, near the source, and in an earthquake of magnitude 8 far from the source, e.g. a hundred kilometers away, intensities at these two locations might be the same, say VII, in latter, damage to tall buildings and other structures with long natural period far away from source are more severe than that of the same kind of buildings located near source, but vice versa for low rigid buildings with short natural period. It is known that intensity scale chiefly gives subjective description of human response and associated damage to buildings in earthquakes. If we try to use earthquake intensity to represent the level of severity and spectral characteristics of strong ground motion, it may be necessary to subdivide a certain intensity according to different magnitudes or epicentral distances.

Based on statistical analysis of isoseismals of historical earthquakes in China, we obtain the two following empirical formulas

$$I = 0.92 + 1.63M - 3.49 \log_{10} R \qquad (1)$$

and

$$I_0 = 0.24 + 1.26 M \qquad (2)$$

where
I - seismic intensity at specified distance,
M - magnitude,
I_0- epicentral intensity,
R - epicentral distance in K M.

From Eq.(1) and (2) several intensity belts interested in engineering practice are plotted in a plane of rectangular coordinates M and $\log_{10} R$ as shown in Fig.2. The equi-intensity belts in Fig.2 represent the attenuation law of intensity in other form which assists to distinguish the effect of various M or R. In Fig.2 the belt of intensity 7 is subdivided into three smaller regions with different magnitude and epicentral distance. Boundaries of these smaller regions lie at 15 and 50 kilometers, respectively. The entire belt of intensity 8 is subdivided into two regions with boundary at a distance of 25 k M. The equi-intensity belts of intensity 9 and above are no longer subdivided bacause the epicentral distance is short.

SITE CLASSIFICATION

In order to determine the extent to which the geological condition of a site may effect the earthquake ground motion recorded at a site, the first problem we encountered is how to classify the soil condition of a site.

In view of wave propagation theory the recorded ground motions may be affected by subsurface materials that extend to a depth that might be compared to the wave length of input motion. According to this requirement, we should obtain detailed geological data from several hundred meters to a few kilometers deep. However, for most sites of engineering interest, only limited geological information of shallow layers is known which can be used in site classification. Thus, we are forced to make classification based on properties of subsurface materials of depth within tens of meter. For that reason, sites are classified in a manner similar to that suggested by SW/AA(Ref.4).

Class I - rock or rock-like ground with overburden thickness less then 7M

Class II - intermediate deposit, the depth of which to rock-like ground ranges from 7-80 M.

Class III- deep soil deposit, the depth of which to rock-like ground is greater than 80 M.

In order to identify the rock-like ground, a relative criterion is suggested as follows: if the S-wave velocity of the lower stratum is up to two times larger than that of the upper stratum, the former is defined as the rock-like ground. Otherwise, if the S-wave velocity of the subsurface stratum is as large as 500 m/sec or greater, it will be also taken as the rock-like ground although the S-wave velocity ratio between two neighboring layers is less than two.

DESIGN SPECTRA DEPENDING ON INTENSITY, EPICENTRAL DISTANCE AND SITE CONDITION

Considering practical possibility provided by available data and convenience in the application to seismic design, it is reasonable to classify the normalized response spectra according to seismic intensity, epicentral distance and site condition and then carry out statistical analysis. For this reason, the available acceleration records are classified and normalized acceleration response spectra are deduced into 5 groups according to similarity of their shapes, as shown in Table 1. The records used in Table 1 mostly come from USA and Japan, several records come from China and other countries. All these records are grouped in Table 2 from different aspects. The figures listed in Table 1 represents the number of group of similar spectral shapes for the given intensity, epicentral distance and class of sites.

Since a certain intensity has been subdivided into a few smaller regions corresponding to different epicentral distance, it is apparent that PGA's must be specified for these regions. Therefore the average peak acceleration of each region has been calculated and shown in Table 3. It can be seen from Table 3 that the average value of peak ground acceleration caused by distant earthquakes is less than that caused by near ones even though intensities are identical. Examining the data in Table 3, it is also found that the influence of site condition on PGA is not so significant as that of epicentral distance, although there is an indication that decrease of PGA in deep soft deposits, for example, class III site is likely occurred when compared with bedrock or stiff ground. It is interesting to point out that the average PGA's of various site conditions for regions of intensity 7_b and 8_a are very close to the results obtained by Trifunac and Brady in Ref.6, as mentioned previously.

Number of records used in each case in Table 3 has been indicated by figures in brackets. In Table 3 blanks without figures show no records are available in classification. In such case, we only have to deduce the category from tendency presented by the figures in Table 1 as shown by numbers in round brackets. It can be seen from Fig.3 that the spectral shapes of five types are obviously different from each other and the distant major earthquakes and deep deposits tend to produce ground motion with enhanced long-period content, thus, have a greater effect on long-period structures; on the other hand, the near minor earthquakes and shallow deposits of stiff soil result in predominately short period contents which will be harmful to short period structures. The general conclusion mentioned above is agreement with damage to buildings and structures observed during earthquakes.

PROPOSED DESIGN SPECTRA

For covenience of application to seismic design, some simplified spectrum shapes having several smoothed portions are proposed to approximate the average ones shows in Fig.4. These are the normalized acceleration response spectra in Fig.4. Response spectrum shapes of each type can be determined from the data in Table 1 and the spectra in Fig.4 according to intensity, epicentral distance and site condition at a specified site.

Since the acceleration response spectra for design purpose may be defined as product of PGA and spectrum shape, the logical procedure is to multiply the spectrum shape selected from Fig.4 and Table 1 by the corresponding PGA in Table 3 as a design criterion. However, data in Table 3 are too dispersive for the sake of direct application. In view of the scatter range and traditional design experience, the total average of PGA in the bottom row of Table 3 are suggested as standard levels in this paper.

In the last part of this paper we will briefly discuss the problem associated with zoning of seismic intensity or PGA. In the new classification, addition of epicentral distance for intensity 8 and 7 is required. That can be done by using the map of distribution of earthquake causative areas, which is usually used as a basis in intensity zoning, and intensity attenuation similar to that shown in Fig.2. Furthermore, it is obvious that for some special areas which are expected to encounter more than two earthquakes of the same intensity but different epicentral distances, envelop of response spectra corresponding to various sources should be used and then taken as standard design spectrum for the sake of safety.

CONCLUDING REMARKS

There are three stages in the development of application of standard response spectra in seismic design codes. At first, a uniform design spectrum was adopted and the other factors were taken into account by using regional seismic coefficient or intensity. Later, groups of response spectra were taken to consider the effect of site condition. The recent tendency is to take different response spectra as design criteria based on source mechanism, transmission path and local site condition. But it would be long enough to aim at the target bacause of little information about source area,from which seismic energy is emerged,and geological structure along the path of energy propagation. However, detailed statistical analysis in which the response spectra and other parameters of strong ground motion have been treated as functions of magnitude, focal distance and site condition has been done by several investigators, and results of analysis can be used certainly in seismic design for special engineering project. But, for ordinary buildings and structures which are large in number the chief parameter used in seismic design is PGA or intensity rather than magnitude and epicentral distance. In such a case, how to consider the effect of magnitude and epicentral distance reasonably is well worth to study. Recently, it is suggested by the tentative provisions ATC-3 of U.S.A. to use coefficient A_v, an equivalent acceleration related to peak velocity, and corresponding zoning map to represent the influence of magnitude and epicentral distance in addition to the effective peak acceleration A_a, which also has its zoning map. In this paper, the authors propose another possible approach to consider the influence of magnitude and epicentral distance on response spectrum shape and only one zoning map of generalized intensities subdivided by different epicentral distances is needed. Although what we discuss in the paper is chiefly the case of using intensity as a representative of severity of strong ground motion, the principle and the procedure used in this paper are available for other strong motion parameters such as peak ground acceleration, Arias intensity etc.

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REFERENCES

1. C.H. Loh etc. (1982). Engineering Analyses of SMART 1 Array Accelerograms, EESD, Vol.10. PP.575-591.
2. R.K.McGuire (1974). Seismic Structure Response Risk Analysis, Incorporating Peak Response Regressions on Earthquake Magnitude and Distance, Report No. R74-51, MIT, Cambridge, Mass.
3. M.D.Trifunac and J.G.Anderson (1977). Preliminary Empirical Models for Scaling Absolute Acceleration Spectra, Report No.CE 77-03, USC.
4. Shanon & Wilson/Agbabian Associates (1979). Statistical Analysis of Earthquake Ground Motion, NUREG/CR-1175.
5. T.Katayama (1982). An Engineering Prediction Model of Acceleration Response Spectra and Its Application to Seismic Hazard Mapping, EESD, Vol.10. PP. 149-163.
6. M.D.Trifunac and A.G.Brady (1975). On the Correlation of Seismic Intensity Scales with the Peaks of Recorded Strong Ground Motion, BSSA, Vol, 65, No.1 PP.139-162.
7. Personal Communication.

TABLE 1 CLASSIFICATION of SPECTRAL SHAPES

Intensity / Distance / Class of sites	7			8		9
	a	b	c	a	b	
	short	intermediate	long	short	intermediate	
I	1	2	(3)	2	3	3
II	2	3	4	3	4	(4)
III	3	4	5	4	5	(5)

TABLE 2 CLASSIFICATION of ACCELERATION RECORDS

Country	No.	Magnitude Range				PGA Range (gal)				
		4.5–5.5	5.5–6.5	6.5–7.5	7.5–7.9	≥30	≥50	≥100	≥200	≥500
USA	165	16	131	6	12	165	155	115	29	2
Japan	51	1	13	35	2	50	47	23	9	
China	4		1	3		4	4	4	3	
others	26		9	14	3	24	21	20	15	5
Total No.	246	17	154	58	17	243	227	162	56	7

TABLE 3 AVERAGE PGA and NUMBER of RECORDS

Intensity / Distance / Class of Sites	7			8		9
	a	b	c	a	b	
	short	intermediate	long	short	intermediate	
I	209 (10)	171 (14)		560 (2)	238 (3)	876 (4)
II	166 (31)	126 (92)	115 (19)	262 (6)	206 (15)	
III	162 (8)	120 (20)	55 (12)	172 (6)	169 (4)	
I-III	174 (49)	130 (126)	92 (31)	266 (14)	203 (22)	
Total average	135 (206)			228 (36)		
Suggested values	150	125	100	250	200	400

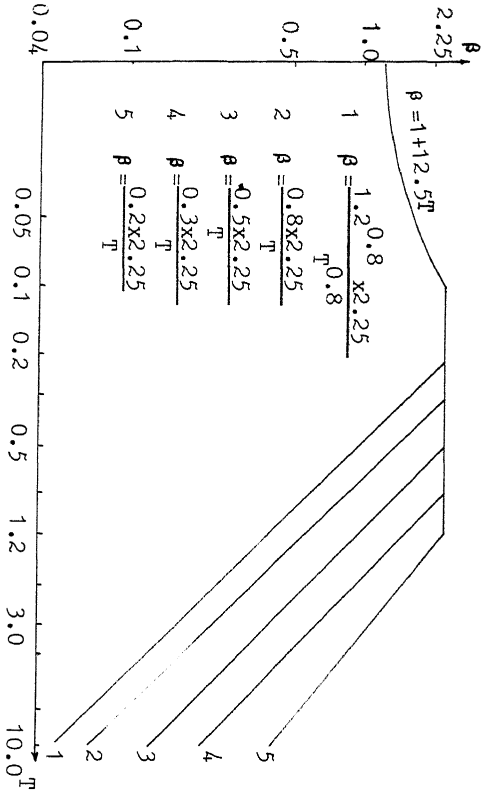

Fig.4

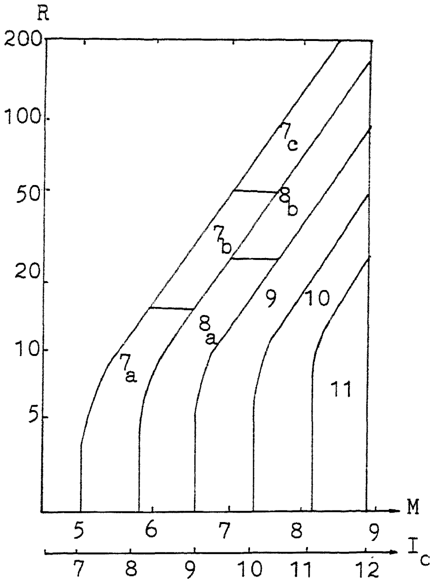

Fig.2

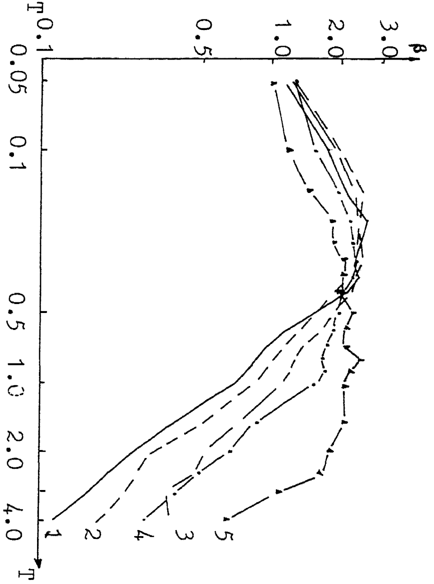

Fig.3

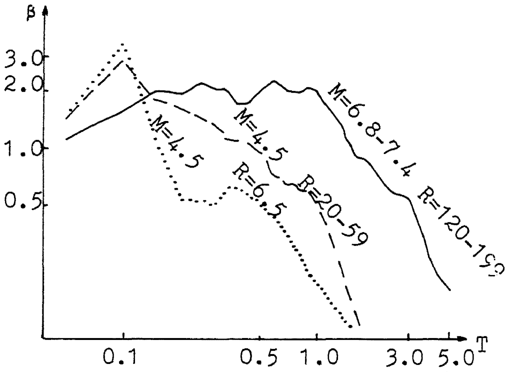

Fig.1