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A comparison of the seismic provisions of the building codes of Canada and China

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ABSTRACT

This paper compares the earthquake provisions of the National Building Code of Canada (NBCC 1990) with those of the Aseismic Design Building Code of China (ADBCC 1989). Items dealt with in this examination include: seismic zoning and the selection of ground motion parameters; general design approaches followed; analysis of earthquake action; and control of drift.

The presentation should be of interest to designers and code formulation bodies. The NBCC notation is used whenever possible.

1. INTRODUCTION

Over the past few decades significant advances in seismic resistant design have been incorporated in the earthquake codes of many countries. These developments result from research in earthquake engineering, and from the lessons derived from field observations of structures which have experienced major earthquake events. The earthquake design philosophy of Canada and the People's Republic of China (PRC) is the same and both countries have recently revised their earthquake codes. Various provisions in these regulations are compared and discussed in this paper.

2. SEISMIC ZONING AND GROUND MOTION PARAMETERS

Canada and China use their own, but analogous, methods to assess seismic risk and develop seismic zoning maps. These methods incorporate historical records and geological and tectonic information; they are based on a statistical analysis of the earthquakes that have been experienced by the different regions within and adjacent to these countries. Both countries use a probability of exceedence of 10% in 50 years to define zonal ground motion

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parameters and assign this probability level to identify a moderate earthquake.

To consider the influence of earthquake magnitude and epicentral distance on the ground motion spectrum at a given site, the Canadian Code uses both peak horizontal acceleration (PHA) and peak horizontal velocity (PHV) as zoning parameters for design. By using both parameters, the NBCC takes into account information on the frequency content of potential earthquakes.

China has used historical intensity information, together with modern instrument measurements and geological/tectonic conditions, as an indirect parameter for zoning. China's new intensity scale is similar to the modified Mercalli (MM) intensity scale; an approximate relationship between PHA and intensity established for China is:

$$A=10^{(I \lg 2-0.01)} \tag{1}$$

where A= peak horizontal ground acceleration and I=earthquake intensity.

As summarized in Table 1, China's seismic design code, the ADBCC, relates the PHA to its intensity scale for design purposes. This parameter represents only a single ground motion measurement. In order to account for the influence of earthquake magnitude and epicentral distance on the frequency content of the earthquake ground motion, the Engineering Mechanics Institute of the Chinese Academy has statistically analysed the spectra of the main shock and numerous after shocks of the 1976 Tangshang earthquake. The results, which are presented in Fig. 1, show that: (i) the short period oscillations are predominant for nearby, moderate earthquakes and the period corresponding to the peak point of the response spectra is around 0.1 seconds; (ii) the long period oscillations are predominant for large, distant earthquakes and the period corresponding to the peak point of the response spectra is around 1.0 seconds.

The ADBCC refers to a set of characteristic periods on the design spectrum; these are conceptually similar to "predominant periods." The codes stipulates the influence that earthquake magnitude and epicentral distance has on this important parameter (see Fig. 2 and Table 2). For the majority of seismic zones in China, only the influence of nearby earthquakes need be considered. Those zones in which the influence of distant earthquakes must be considered are clearly specified on the Chinese seismic zoning map. The ADBCC also recommends the use of microzoning results (if they are available) and the selection of ground motion records for the design of important structures.

3. GENERAL DESIGN APPROACH OF NBCC AND ADBCC

Various methods for evaluating the seismic response of buildings are suggested in the NBCC and ADBCC. The ADBCC permits an analysis using the base shear method, the elastic modal superposition method, or the nonlinear time-step dynamic method, depending on the type and importance of the structure.

The 1990 NBCC specifies that the minimum lateral seismic force, V, shall be calculated in accordance with the following formula:

$$V=(V_e/R)U \qquad (2)$$

where V_e is an equivalent lateral seismic force representing elastic response. R is a modification factor reflecting the capability of the structural system to dissipate energy through inelastic behaviour (see NBCC 1990). U is a calibration factor (equal to 0.6); it is applied to maintain the design base shear at the same level stipulated in the 1985 edition of the NBCC for buildings with good to excellent capability of resisting seismic loads consistent with the R factors used.

The Chinese code expresses the base shear as

$$V=V_{em} \qquad (3)$$

V_{em} is the equivalent lateral force corresponding to the elastic response produced by a "reduced earthquake", which is defined as a minor earthquake by the ADBCC. The minor earthquake and its ground motion parameter are established from the moderate earthquake by the following relationship:

$$\Delta I = I_b - I_c = \lg(1/c)/\lg 2 \qquad (4)$$

In this equation, $c = A_c/A$ is defined as a "structural behaviour factor" (c has the same physical meaning as R); A represents the PHA corresponding to the basic intensity I_b of a moderate earthquake, and A_c the PHA corresponding to the reduced intensity I_c of a minor earthquake. The code specified values of c corresponding to different types of lateral load resisting systems, are listed in Table 3. The decrement of earthquake intensity ΔI can be derived from Eqn (1). Values of ΔI are listed in Table 3 for different structural systems. From the Table we note that the reduced intensity is between 1-2 scales lower than the corresponding basic intensity.

The basic intensity is defined as a moderate earthquake having a probability of exceedance of 10% in 50 years. On a probability density plot of the statistics of Chinese earthquakes, the mean intensity value, I_m, corresponding to frequent events, is about 1.55 scale units lower than the basic intensity I_b. The probability of exceedence in 50 years corresponding to the mean value intensity is approximately 63.2%. The ADBCC defines this I_m as the intensity corresponding to a "minor earthquake" and assumes the PHA of a minor earthquake at about 1/3 of the PHA of a moderate (basic) earthquake; that is $A_m = A/3$. This decreased intensity, or PHA, corresponds to c=0.34 in the Chinese code.

The c factor is introduced to reflect the capability of a structure to dissipate energy during inelastic behaviour. The ductility of various structures (or their elements) can be quite different, so that the factor c can differ from 0.34. To account for this variation, and to consider ductility more carefully, the ADBCC introduces a regulation factor in the design process.

For events which are stronger (and rarer) than the moderate earthquake, the ADBCC defines an earthquake intensity with a probability of exceedence of 2-3% in 50 years as a "major or violent earthquake". Using the ground motion parameters corresponding to this major earthquake (see Table 1), the ADBCC requires an elasto-plastic analysis be undertaken to ensure that the deformations of structures (especially ductile buildings or buildings with weak partitions) are controlled and that collapse does not occur. Based on the probability of exceedence of various intensities, and the economic conditions of China, the ADBCC specifies that PHA of major earthquakes in VII, VIII, and IX intensity zones as 6, 5, and 4 times the PHA corresponding to minor earthquakes for these zones (see Table 1).

In the ADBCC the ground motion parameters corresponding to a minor earthquake are used for cross-section design or checking strengths, and those for a major earthquake are used for checking building drift. The moderate earthquake is used for the detailing of structures.

4. ANALYSIS OF EARTHQUAKE ACTION

Equivalent Lateral Seismic Force and Response Spectra

The main earthquake analysis approaches of both the NBCC and the ADBCC are based upon response spectrum theory. In Eqn (2), which denotes the NBCC provisions for establishing the minimum lateral seismic force V, the equivalent lateral seismic force respresenting elastic response, V_e, is calculated in accordance with the following formula:

$$V_e = v.\ SIFW \qquad (5)$$

v is the zonal velocity ratio, i.e. the specified zonal PHV expressed as a ratio to 1m/s, and S is the seismic response factor for unit value of zonal PHV ratio. Some general comments relating to the foundation factor, F, are offered below. The importance factor of the structure, I, and the gravitational load, W, will not be discussed in this paper. Note that only the PHV is specified explicitly by the NBCC; the PHA is introduced implicitly by means of the seismic response factor S, which depends on the fundamental period of vibration of the building.

In the ADBCC, the horizontal earthquake force corresponding to a single degree of freedom structure is calculated in accordance with the formulae:

$$V_e = KSG \qquad (6)$$

$$\text{or } V_e = \alpha G \qquad (7)$$

In these formulae, G is defined as the "representative gravitational load". K is the ratio of zonal PHA to gravity acceleration. Because these formulae are used to check the strength of a structure in the first stages of the design, K is the value corresponding to a "minor earthquake". The coefficient α is directly used in the ADBCC instead of K and S. α is defined as an earthquake influence coefficient.

$$\alpha = K.S \qquad (8)$$

Although the acceleration ratio, K, varies with zonal intensity, it remains constant for every given intensity. Therefore, the curves of the influence coefficient α are similar to the curves of the response factor S.

The ADBCC stipulates that the earthquake influence coefficient α is determined from Fig. 2 and Table 1, with consideration given to the geology of the site, epicentral distance and the periods of vibration of the structure. The maximum values of α listed in Table 1 are obtained from

$$\alpha_{max} = S_{max}.K \approx 2.25a \qquad (9)$$

The code requires that the minimum values of α shall not be less than $0.2\alpha_{max}$.

The Influence of Sub-soil

The NBCC accounts for soil amplification potential by classifying soil conditions into four types and assigning a foundation factor F to each type (see Eqn (5)). The classification takes into account both the material and depth of the surficial layers. On the other hand, althougth the ADBCC also classifies the subsoil into four types (and also the site), it does not introduce the concept of a foundation factor. Instead, the ADBCC changes the characteristic period of the spectrum to account for the predominant period of the site soil.

Soil-structure interaction is not considered explicitly in the the NBCC and this phenomenon is only dealt with in a perfunctory manner. In the ADBCC, although the analysis of earthquake action is based on the assumption that structures are founded on rigid bases, for the design of high-rise reinforced concrete buildings constructed on type III and IV sites and having concrete box foundations or raft foundations of good rigidity, soil-structure interaction can be accounted for by reducing the resulting earthquake forces by 80-90%, depending on the type of structure and site. The drift calculation of a rigid-based building can also be reduced in this same manner.

Apart from offering some appropriate references outlining the assessment of liquefaction potential of foundation soils, the NBCC does not provide any code provision to handle this important material behaviour. On the other hand, the ADBCC deals with this matter by: (1) specifying a formula to calculate a liquefaction index which is used to assess the potential severity of liquefaction, i.e. to assess depth and scope of liquefaction and the thickness of the liquified soil; (2) suggesting countermeasures depending on the category of importance of buildings and the liquefaction of their subsoils.

5. CONTROL OF DRIFT OF STRUCTURES

Drift and Separation

Deformation limits, which are imposed to minimize non-structural damage and to avoid collapse, often control the design of multi-storey buildings. Many codes require certain deformation criteria to be satisfied which may be more stringent than the traditional strength approach and may therefore govern the earthquake design. The NBCC's stated principles for checking deformation are: (i) The drift obtained from an elastic analysis (using loads given by Eqn 2) shall be multiplied by 3 to give realistic values of anticipated deflections i.e., to account for some plastic deformation in a structural system. (ii) The separation of adjacent structures is required to be 2 times the combined deflection of these structures. (iii) Drift limitations should be established in consideration of acceptable damage to the non-structural components. An inter-storey drift limitation of 0.005 times the storey height is recommended. (iv) The effect of the drift on the vertical load carrying capacity of the lateral force resisting system should also be considered.

The ADBCC requires that the drift be checked not only in consideration of the acceptable damage to the non-structural components, but also to ensure that collapse of the structures is prevented. The check on drift involves two separate calculations:

(1) Evaluation of the elastic drift under the "minor earthquake": The elastic incremental drift or the inter-storey drift of frame-shear wall structures resulting from a minor earthquake shall satisfy

$$\Delta u_e \leq (\theta_e)h \qquad (13)$$

where Δu_e is equal the elastic incremental drift calculated from the α_{max} for minor earthquakes; in this calculation all load factors are taken as 1.00. θ_e is the elastic incremental drift limitation (see Table 4) and h is the storey height.

(2) Evaluation of elasto-plastic drift under major earthquakes: The elasto-plastic deformations of soft stories or weak portions of structures shall be checked with respect to "major earthquakes". To distinguish the weak storey, a yielding strength coefficient is used. The yielding strength coefficient of a storey is the ratio between the storey shear force carrying capacity V_y and the storey shear force V_e imposed by a major earthquake:

$$\xi_y = V_y/V_e \qquad (14)$$

V_y is evaluated from the specific shear strength and the actual reinforcement of the structural members involved and V_e is determined by elastic analysis under the action of a major earthquake.

The elasto-plastic incremental drift of a soft storey or a weak portion of a structure resulting from a major earthquake should satisfy

$$\Delta u_p \leq (\theta_p)h \qquad (15)$$

where Δu_p is the elasto-plastic incremental drift. The ADBCC has suggested a practical method for calculating Δu_p. θ_p is the elasto-plastic incremental drift limitation (see Table 5). The ADBCC also allows some conditions under which this limitation may be increased.

TABLE 1 DESIGN PHA AND α_{max} IN ADBCC

Level of Earthquake	Probability of Exceedance in 50 Years	K and α_{max} For Various Intensities					
		Ratio of PHA to gravity acceleration K			Earthquake Influence Coefficient α_{max}		
		VII	VIII	IX	VII	VIII	IX
minor, frequent event	63.2 %	0.04	0.08	0.16	0.08	0.16	0.32
moderate (zonal) event	10.0 %	0.125	0.25	0.50	0.23	0.45	0.90
major, rare event	2 ~ 3 %	0.25	0.40	0.65	0.50	0.90	1.40

• The earthquake influence coefficient is the product of the ratio of PHA to gravity acceleration K by the maximum magnification factor of the response spectrum; see section 3 of this paper.

*The Chinese earthquake intensity scale is similar to the Modified Mercalli scale. In this Table VII, VIII, IX are Chinese intensity scales.

Table 2 Characteristic Period of Site Soil

Distance from Epicenter	Category of Site Soil			
	I	II	III	IV
nearby	0.20	0.30	0.40	0.65
distant	0.25	0.40	0.55	0.85

Table 3 Structure Influence Factor C and Intensity Decrement ΔI

Type of Lateral Load Resisting System		C	ΔI
Ductile moment-resisting frame	steel	0.25	2.0°
	R.C.	0.30	1.74°
R.C. moment-resisting frame with R.C. wall		0.30~0.35	1.74°~1.51°
R.C. Wall		0.35~0.40	1.51°~1.32°
Unreinforced masonry		0.45	1.15°
Hinged Bents	steel column	0.30	1.74°
	R.C. column	0.35	1.51°
	masonry column	0.45	1.32°
Chimneys, water-tank towers, tall but flexible structures	steel	0.35	1.51°
	R.C.	0.40	1.32°
	masonry	0.50	1.00°
Timber structures		0.25	2.00°

Table 5 Elasto-Plastic Incremental Drift Limitation

Type of Structure	θ_p
Bent of single storey workshop with reinforced concrete columns	1/30
Frame and infilled frame	1/50
Frame of ground storey under upper masonry storeys	1/70

Table 4 Elastic Incremental Drift Limitation

Type of Structure	Condition	θ_e
Frame	incorporation of infilled walls	1/550
	interaction not considered	1/450
Frame-Shear Wall	higher standard decorated public buildings	1/800
	other common buildings	1/650

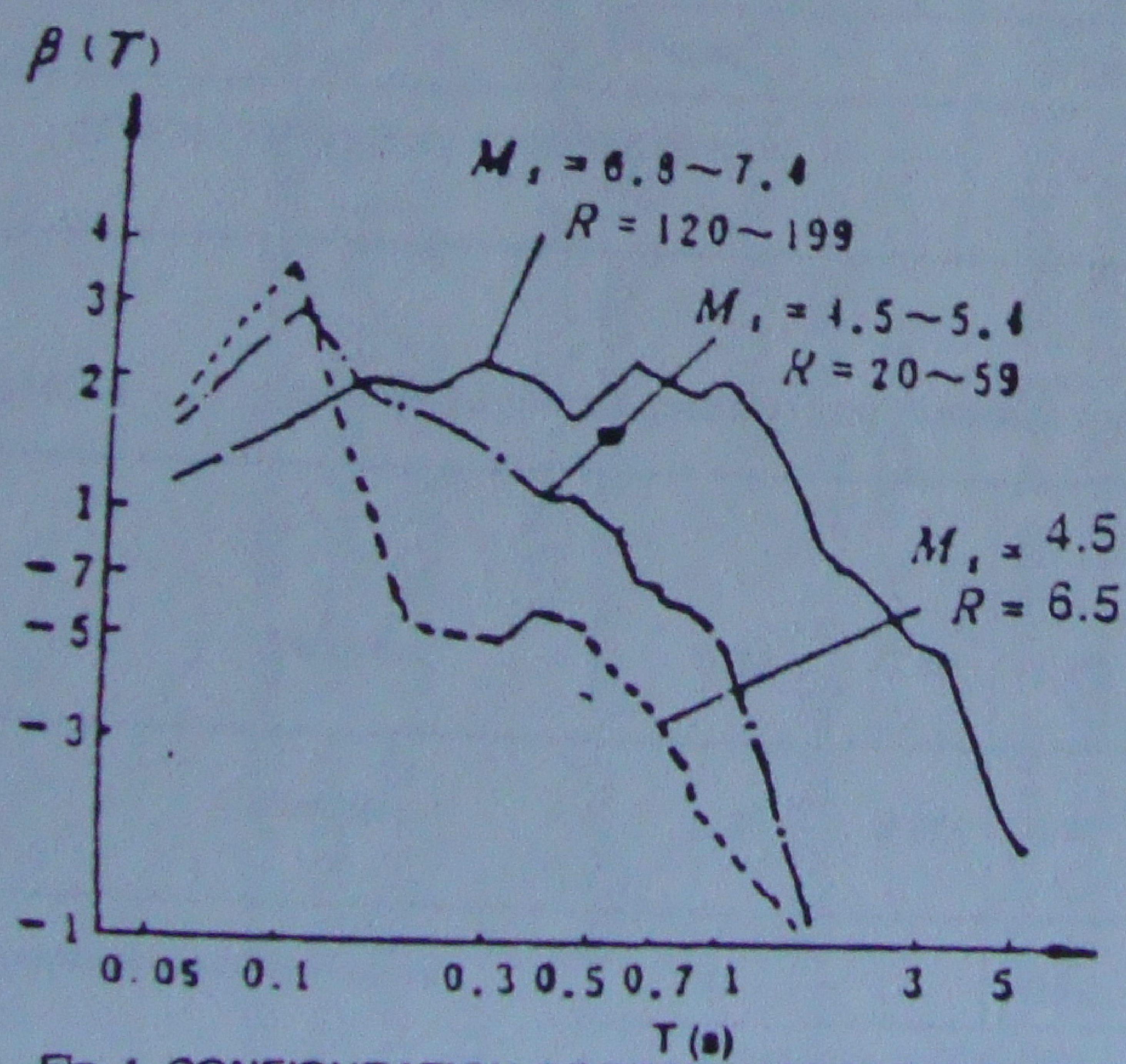

Fig. 1 CONFIGURATION OF RESPONSE SPECTRA FOR VARIOUS EARTHQUAKE MAGNITUDES AND EPICENTRAL DISTANCES

Ms–Magnitude; R–Distance from epicenter; β–PHA magnification factor

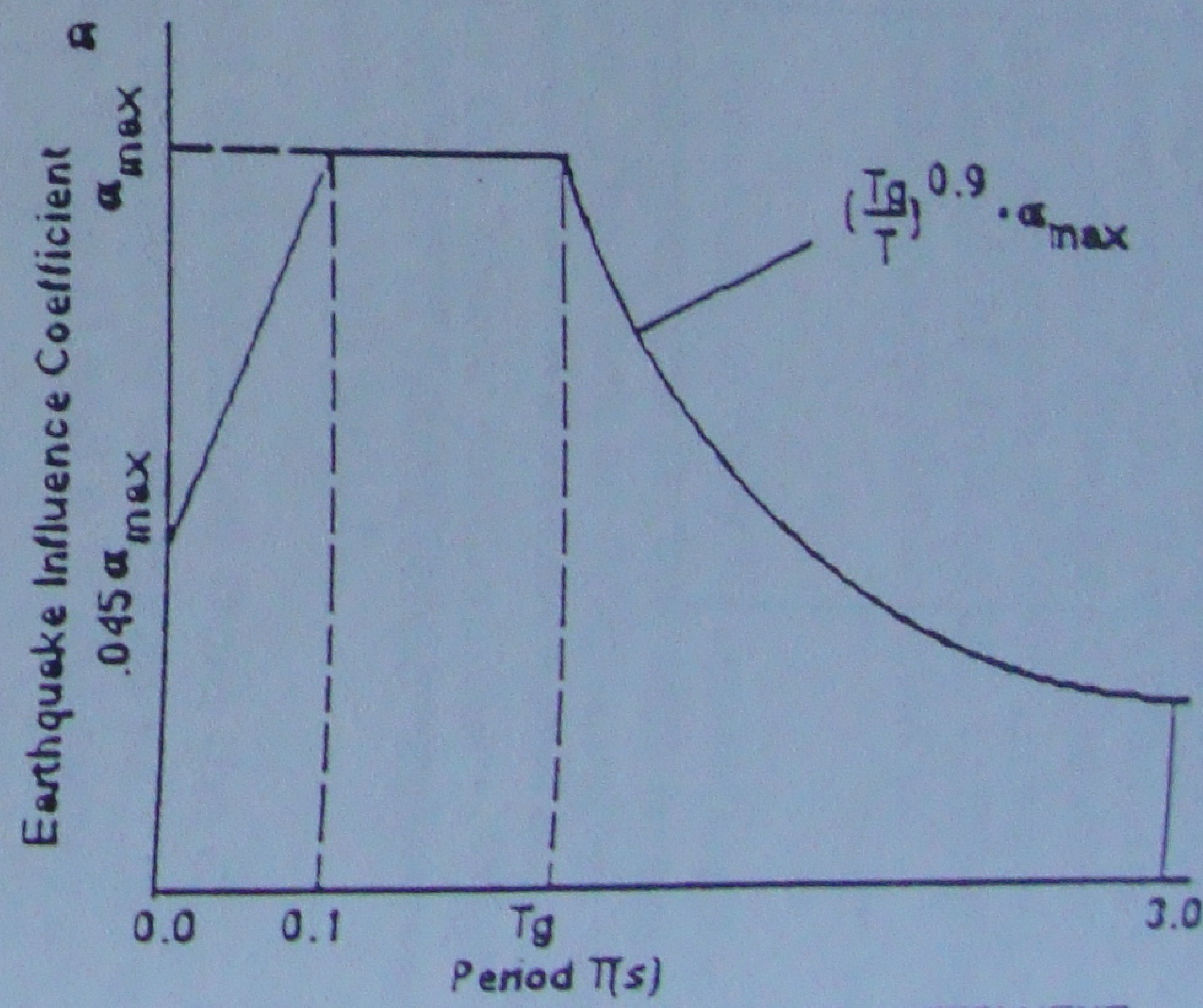

Fig. 2 SEISMIC RESPONSE INFLUENCE COEFFICIENT (ADBCC)

Tg—Characteristic Period (see Table 2)