Researches about the conversion relationships among the parameters of ground motions in the seismic design codes of China, America and Europe

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SUMMARY:
By the comparison between the seismic design codes of China and America and Europe about the site classification and the seismic hazard characteristics, this paper determines the coincidence relations of the site classifications among the three codes, presents the conversion relationships between the parameters of ground motions in China Code and that in the other Codes, and the parameter values of ground motions of Chinese seismic zones in the forms of America Code and Europe Code

Keywords: seismic design; site classification; seismic hazard characteristics; parameters of ground motions.

1. INSTRUCTIONS

Now almost every country had its own engineering design criterion, but there were many differences among those criteria with respect to the design ideas, the design concepts, the design requirements and so on. So, for the Chinese enterprises which prepare participating in international competition, the principle problem is how to learn, understand and apply a fire-new technical criterion. By the comparison between the seismic design codes of China and America and Europe about the site classification and the seismic hazard characteristics, this paper presents the conversion relationships between the parameters of ground motions in China Code and that in the other Codes. It was wished to have some helps to understand and apply the seismic design codes of America and Europe

2. SITE CLASSIFICATION

The seismic design codes of worldwide had considered the site effects on the design earthquake in different degrees, that is, to classify the site in accordance with its seismic responses, and adopt different design earthquake for different site classi*fication. The China code, Code for seismic design of buildings* GB 50011-2001*, the America code, 2003 International Building Code*(IBC-2003) and SEI/ASCE 7-02 *Minimum Design Loads for Buildings and Other Structures(*ASCE7-02), and the Eurocode 8: *Design of structures for earthquake resistance. Part 1: General rules, seismic actions and rules for buildings*(EN 1998-1:2004) had all presented the methods for site classification (seen Table 1~3), and adopted different design response spectra for different site. In the same code, there were obvious differences in the heights (α_{max} or S_{DS}) and the widths (T_g or T_s) of the flat phases of the design response spectra. In additional, these differences also exist between the different codes. These facts indicated that the site classes have important impacts on the determining of the seismic actions on the structures.

2.1 The China Code GB50011-2001

The China code GB50011-2001 specified that the site class of building structures shall be classified according to the equivalent shear-wave velocity of soil and the site overlying depth as guideline.

The site overlaying depth shall be determined in according to the following provisions:

1. In generally, the overlaying depth shall be determined according to the distance from the ground surface to a soil-layer level, which any profile under such level of soil having the shear-wave velocity more than 500m/s.

2. For a soil layer, which depth lower than 5 m underground and the shear-wave velocity is more than 2.5 times of that in above this soil layer and is not less than 400m/s, then the overlaying thickness may be adopted the distance from the ground surface to this layer.

3. The lone-stone and lenticular-soil with a shear-wave velocity greater than 500m/s shall be deemed the same as surrounding soil profile.

4. The hard volcanic inter-bedded rock in the soil profile shall be deemed as rigid body and its thickness shall be deducted from the overlaying thickness.

The equivalent shear-wave velocity of the soil profile shall be calculated according to the following equation:

$$v_{se} = d_0 / t \quad (1)$$

$$t = \sum_{i=1}^{n} (d_i / v_{si}) \quad (2)$$

Where, v_{se} is equivalent shear wave velocity, in m/s; d_0 is the calculated depth, in m, and it shall be taken as the minor of both the overlaying thickness and 20m; t is the transmission time of the shear-wave from the ground surface to the calculated depth; d_i is the thickness of the *i-th* soil layer within the range of calculated depth, in m; v_i is the shear-wave velocity of the *i-th* soil layer within the calculated depth, in m/s; and n is number of soil layers within the range of calculated depth.

The construction sites shall be classified as one of four site classes defined in **Table 1** depend on the equivalent shear-wave velocity and the overlaying depth of soil profile. Only the values of the reliable shear-wave velocity and/or the overlaying depth are near to the dividing line of the listed site values in Table 1, the design characteristic period value shall be permitted to determine by the interpolation method in calculating the seismic action.

Table 1 The site classification of China code GB50011-2001

Equivalent shear-wave velocity (m/s)	Site			
	I	II	III	IV
	Overlaying depth of soil profile for site classification, in m			
v_{se}>500	0			
500≥v_{se}>250	<5	≥5		
250≥v_{se}>140	<3	3~50	>50	
v_{se}≤140	<3	3~15	>15~80	>80

2.2 The America Code IBC-2003

In the America code IBC-2003, the site classes were defined in **Table 2**. Where site-specific data are not available to a depth of 100 feet (30 480 mm), appropriate soil properties are permitted to be estimated by the registered design professional preparing the soils report based on known geologic conditions.

Table 2 The site classification of America code IBC-2003

Site Class	Soil profile name	Average properties in top 100 feet		
		Soil shear wave velocity $\bar{v}_s$ (ft/s)	standard penetration resistance, N	soil undrained shear strength, s_u(psf)
A_{US}	Hard rock	$\bar{v}_s > 5{,}000$		
B_{US}	Rock	$2{,}500 < \bar{v}_s \le 5{,}000$		
C_{US}	Very dense soil and soft rock	$1{,}200 < \bar{v}_s \le 2{,}500$	N>50	$S_u>2{,}000$
D_{US}	Stiff soil profile	$600 \le \bar{v}_s \le 1{,}200$	15≤N≤50	$1{,}000 \le S_u \le 2{,}000$
E_{US}	Soft soil profile	$\bar{v}_s < 600$	N<15	$S_u<1{,}000$

2.3 The Europe Code EN 1998-1:2004

In the Europe Code EN 1998-1: 2004, in order to consider the influence of local ground conditions and deep geology on the seismic action, the site shall be classified as Ground types A_{EN}, B_{EN}, C_{EN}, D_{EN}, or E_{EN}, described by the stratigraphic profiles and parameters given in **Table 3**.

Table 3 The site classification of Europe code EN 1998-1: 2004

Ground type	Description of stratigraphic profile	Parameters		
		$v_{s,30}$ (m/s)	N_{SPT} (blows/30cm)	c_u (kPa)
A_{EN}	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.	> 800		
B_{EN}	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of meters in thickness, characterized by a gradual increase of mechanical properties with depth.	360 – 800	> 50	> 250
C_{EN}	Deep deposits of dense or medium dense sand, gravel or stiff clay with thickness from several tens to many hundreds of meters.	180 – 360	15 - 50	70 - 250
D_{EN}	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.	< 180	< 15	< 70
E_{EN}	A soil profile consisting of a surface alluvium layer with v_s values of type C_{EN} or D_{EN} and thickness varying between about 5 m and 20 m, underlain by stiffer material with v_s > 800 m/s.			

2.4 The relationships between the site classes of the three Codes

All the parameters of ground motion for seismic design in the three codes were presented in the basis of site reference, for example, in China, the reference is site class II; in America, the reference is site class B_{US}; and in Europe, the reference is ground type $A_{EN;}$ furthermore, there were a lot of differences between the site references of the three codes. So, if we want to give the conversion relationships among the parameters of ground motions in the seismic design codes of China, America and Europe, we must know the relationships between the site classes of the three codes clearly, especially the relationships of the site references. It can be found out from the site classifications of the three codes that there were obvious differences between the three classifications with respect on the number of parameters, calculated depth, confirming of the rock top and so on.

For the sake of convenient for comparison, we ignore the differences of the confirming of the rock top and the methods for the menstruations of the shear-wave velocities in the three codes, and extend the calculated depth of China code from 20 meters to 30 meters. And according to the principle of maintaining the site classes, we re-estimate the equivalent shear-wave velocity of site class II in China code. The assumptions used in the calculations were as follows:

1. The shear-wave velocity of the soil layers below the overlaying were taken as 500 m/s;

2. When the overlaying depth of soil profile, d_{ov}, was greater than 20 meters, the shear-wave velocity of the soil layers which depths were between 20 meters and d_{ov} were taken as $1.3v_{20}$;

3. When the value of v_{20} was less than 140m/s, the low limit of v_{20} was taken as 70m/s.

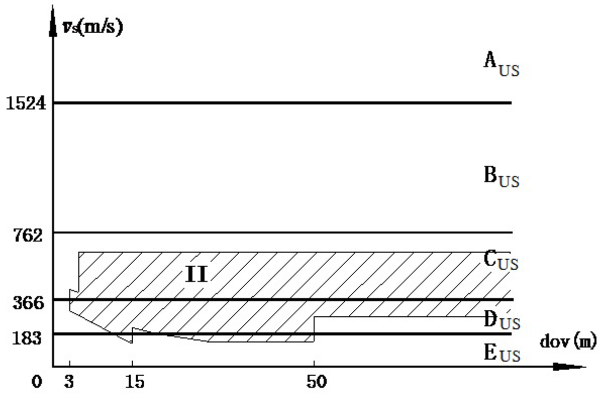


Figure 1. The site classes in IBC-2003

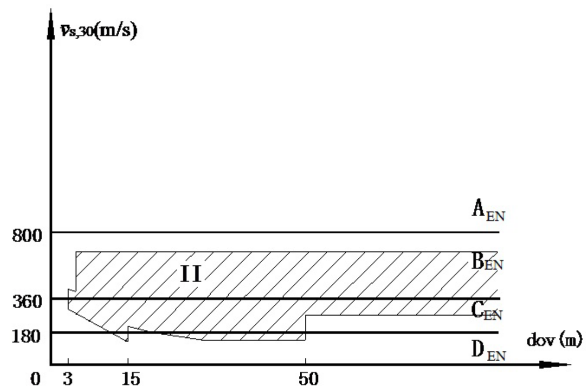


Figure 2. The ground types in EN 1998-1:2004

The site classifications of *IBC*-2003 and ground types of *EN* 1998-1:2004 were shown in **Figure 1** and **Figure 2**, respectively, and in which the shaded areas were the conversion scopes of the site class II of China code GB 5001-2001. It can be seen from the two figures that:

1. the site class II of China code was corresponding to the site class C_{US} or D_{US} of America code and the ground type B_{EN} or C_{EN} of Europe code approximately;

2. the ground type A_{EN} of Europe code was corresponding to the site class A_{US} and B_{US} of America code, and the ground type B_{EN}, C_{EN} and D_{EN} in *EN* 1998-1:2004 were corresponding to the site class C_{US}, D_{US} and E_{US} in *IBC-2003*, respectively.

3. SEISMIC HAZARD CHARACTERISTICS

The probability levels of the fortification earthquakes used in the China, America and Europe code were different, for example, in China, the probability of exceedance of the fortification earthquake was 10% in 50 years; in America, the 2% in 50 years ground motions were selected as the maximum considered earthquake ground motions; and in Europe, the design seismic action for the no-collapse requirement was expressed in terms of the reference seismic action with a reference probability of exceedance, 10% in 50 years. So, we must find out the relationships between the ground motions with different probabilities of exceedance or return periods in order to convert the parameters of ground motions among the seismic design codes in China, America and Europe.

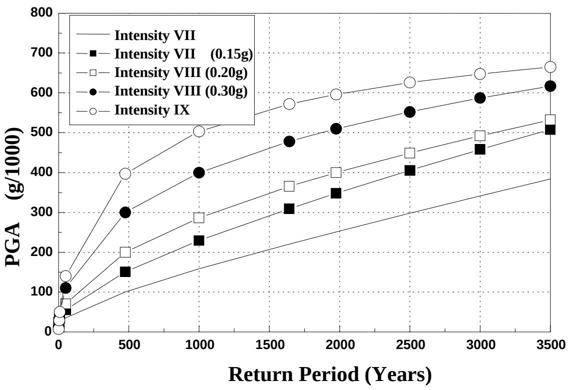
3.1. The China Code GB 50011-2001

The fortification principle with three level ground motions was adopted in China code *GB 50011-2001*. The three level ground motions were frequent earthquake, basic intensity earthquake and rare earthquake, that is, the so-called little earthquake, moderate earthquake and great earthquake, with the probabilities of exceedance of 63.2%, 10% and 2~3% in 50 years or the return periods of about 50 years, 475 years and 2475~1642years, respectively(Wang Yayong, 2006). The intensities or the peak accelerations of ground motions corresponding to the moderate earthquake were presented by the seismic intensity zonation map or seismic ground motion parameter zonation map. And then, taking the intensity I of moderate earthquake as the benchmark, we defined the intensity of little earthquake as I-1.55, and the intensity of great earthquake as I+1.0. In fact, such definitions were only the average results of the seismic hazard analysis for some cities according to the 1977 edition *Seismic Intensity Zonation Map of China*, and different from the average results of every edition seismic intensity zonation maps after the year of 1977. Furthermore, according to the seismic hazard analysis, the relationship of the seismic intensities or the peak accelerations of seismic ground motions with different return periods was not constant but variational with zone. For a certain site or a special region, if we define the little earthquake and great earthquake by the probability of exceedance or return period, the intensity differences of the little earthquake and great earthquake to moderate earthquake were generally unequal to -1.55 and 1.0; if we define the little earthquake and great earthquake by the intensity differences of the little earthquake and great earthquake to moderate earthquake with -1.55 and 1.0, the return period of little earthquake and great earthquake were generally unequal to 50 years and 1975years(Zhou Xiyuan,2002). Actually, from the statistic analysis for the results of seismic hazard analysis of 7,000 regions of China made by Gao Mengtan in 1992, the intensity differences of the great earthquake to moderate earthquake were less than 1.0 at large, and with distinct regionality.

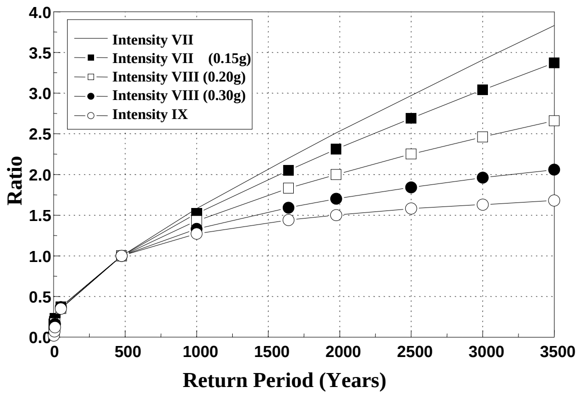
In order to keep the continuity of seismic design code, GB50011-2001 still used the definitions by intensity differences. For the sake of convenient for engineering application, GB50011-2001 presented the peak accelerations of ground motions corresponding to seismic fortification intensities. In GB50011-2001, for the regions with same basic seismic intensity, the relationship of the peak accelerations of ground motions or seismic intensity to return period was unique, that is, the seismic hazard characteristic or the seismic hazard curve was invariable. According to the definitions for little earthquake and great earthquake used in China code and the assumptions as following, we can approximately determine the seismic hazard curves for each seismic intensity region. As shown in the **Figure 3**, it was the seismic hazard curves of different intensity regions in China, and **Table 4** gives the ratios of the peak accelerations of seismic ground motions with other return periods to that of ground motions with return period of 475 years, that is, the return period modification factors γ_{CN}. It can be seen from the **Figure 3** and **Table 4** that with the increasing of the basic intensity (or the peak accelerations of basic seismic ground motions), the seismic hazard curves tend to flat, and the return period modification factors γ_{CN} decline gradually.

Table 4 The ratios γCN of the peak accelerations of seismic ground motions with other return periods to that of the 475-year return period ground motions

Return Period (Year)	Ratios (γ_{CN})				
	Intensity VII (0.10g)	Intensity VII （0.15g）	Intensity VIII （0.20g）	Intensity VIII （0.30g）	Intensity IX
50	0.35	0.37	0.35	0.37	0.35
475	1.00	1.00	1.00	1.00	1.00
1975	2.51	2.31	2.00	1.70	1.50
2500	2.97	2.69	2.25	1.84	1.58



(a) the relationship between peak accelerations of seismic ground motions and return periods



(b) the normalization relationship between peak accelerations of seismic ground motions and return periods

Figure 3. The seismic hazard curves of different intensity regions in China

3.2 The America Code IBC-2003

Before the year of 2000, the seismic ground motions with probability of exceedance, 10% in 50years, were always used as the design earthquake in the *Uniform Building Code* of America. But some research results (see *Kennedy et al*. 1994; *Cornell*, 1994 and *Ellingwood,* 1994) indicated that if a structure is subjected to a ground motion 1.5 times the design earthquake, the structure should have a low likelihood of collapse, however, when the ground motions are greater than 1.5 times the design earthquake, the probability of structural collapse will increase rapidly. So, the concept of seismic margin which was equal to 1.5 times the design earthquake was presented in the *1997 Edition NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures.* On the other hand, due to the differences of the seismic structures and the earthquake source mechanisms, the relationships between peak accelerations of seismic ground motions and returns periods have regional differences as shown in **Figure 4** and **Table 5**. It can be observed in the figure that the difference between the 10% in 50 years ground motion and the 2% in 50 years ground motion in the western United States is typically less than the difference between these two probabilities in less active seismic areas such as those in the central and eastern United States. For example in Los Angeles and San Francisco, California, the ratio (hereinafter named the return period modification factors γ_{US}) between the 0.2 second spectral acceleration for the 2% in 50 years and the 10% in 50 years is about 1.5; whereas in other parts of the United States the ratio varies from 2.0 to 5.0 and more in some areas. Differences such as these raised a question that a same design level based on 10% in 50 years ground motions for the entire United States would result in not the same levels of seismic safety for structures in all regions. In order to provide a uniform level of safety across the country against collapse in the maximum considered earthquake, 1997 *NEHRP* provisions and 2000 *International Building Code* (IBC) defined the 2500-year return period earthquake (2% probability of exceedance in 50 years) as the seismic margin, that is, the maximum considered earthquake (MCE), and determined the design earthquake equal to two-third (the reciprocal of 1.5) of MCE (see Leyendecker, E.V 2000).

Table 5. Ratio γ_{US} of spectral acceleration at 0.2 seconds for 2%-50yrs to 10% - 50yrs

City name	Ratio γ_{US}
Los Angeles	1.7
San Francisco	1.7
New York City	3.3
Charleston	5.0
Memphis	5.1

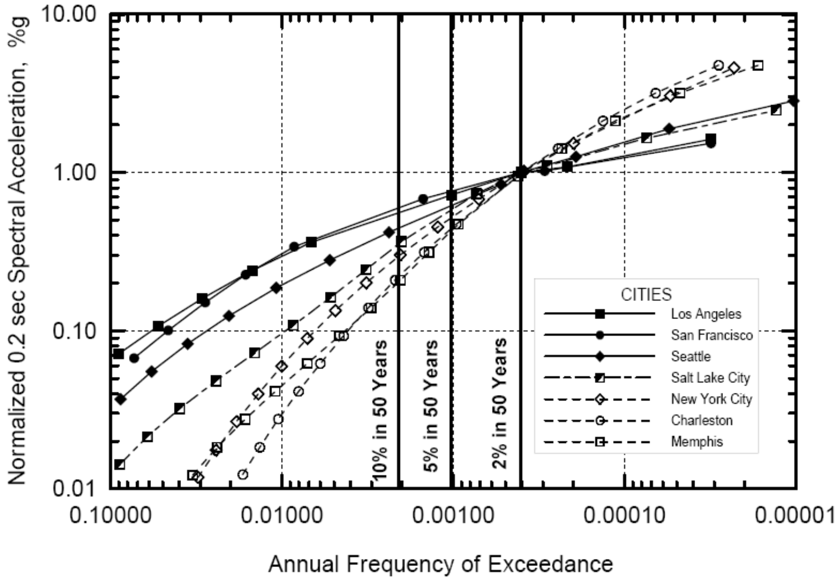


Figure 4. Normalized hazard curves for some cities of USA **(**Leyendecker et al, 2000)

3.3 The Europe Code EN 1998-1:2004

Two fortification levels were employed in the Europe code EN 1998-1:2004*,* that is, subjected to the design seismic action with 475-year-return period, the structure shall have no local or global collapse; subjected to the frequent earthquake with 95-year-return period, the structure shall have no occurrence of damage and the associated limitations of use, the costs of which would be disproportionately high in comparison with the costs of the structure itself. The design earthquake and the frequent earthquake were mainly presented by the National Authorities, and may be founded in the National Annex.

And meanwhile, EN 1998-1:2004 presented a reduction factor *v* to take into account the determination of the frequent earthquake from the design earthquake. The value of the reduction factor *v* may also depend on the importance class of the building. The values to be ascribed to *v* for use in a country may be found in its National Annex. Different values of *v* may be defined for the various seismic zones of a country, depending on the seismic hazard conditions and on the protection of property objective. The recommended values of *v* are 0.4 for importance classes III and IV and *v* = 0.5 for importance classes I and II.

The EN 1998-1:2004 also presented recommended seismic hazard curve, that is, the annual rate of exceedance, $H(a_{gR})$, of the reference peak ground acceleration a_{gR} may be taken to vary with a_{gR} as following equation:

$$H(a_{gR}) = k_o(a_{gR})^{-k} \tag{3}$$

with the value of the exponent *k* depending on seismicity, but being generally of the order of 3.

4. CONVERSION BETWEEN THE PARAMETERS OF GROUND MOTIONS IN CHINA AND AMERICA CODES

4.1 The parameters for China cities in terms of that in America code

For a certain city in China, the basic intensity earthquake and the design earthquake group can be found in *Seismic ground motion parameter zonation map of China* GB18306-2001 and *Code for seismic design of buildings* GB50011-2001. So, the parameters of ground motions for the city in terms of that in America code IBC-2003 can be determined by the following equations.

$$S_s = 2.5\gamma_{CN} A_{cc} / F_a \tag{4}$$

$$S_1 = 2.5\gamma_{CN} T_g A_{cc} / F_v \tag{5}$$

Where S_s and S_1 are the mapped maximum considered earthquake spectral response acceleration at short period and 1-second period for site class B_{US} in IBC-2003, respectively. F_a and F_v are the acceleration-related and velocity-related soil factors, respectively, for a site class C_{US} or D_{US} in IBC-2003 that was corresponding to site class II in China code. A_{cc} Is the basic peak acceleration of ground motion corresponding to the basic intensity earthquake in China code; T_g is the design characteristic period of ground motion of site class II in China code, and γ_{CN} is the return period modification factor, determined from Table 6 by the return period as 2500 years.

Applying the calculation methods above can give the parameters of ground motions for each intensity region in China code in terms of that in America code IBC-2003, as shown in **Table 8,9**.

Table 8 the spectral response acceleration for intensity regions of China (II_C) (Unit :g)

Parameter	Intensity VII (0.10g)	Intensity VII (0.15g)	Intensity VIII (0.20g)	Intensity VIII (0.30g)	Intensity IX (0.40g)
S_s	0.65	1.01	1.13	1.38	1.58
S_1(1st Group)	0.16	0.22	0.25	0.33	0.39
S_1(2nd Group)	0.18	0.26	0.30	0.39	0.48
S_1(3rd Group)	0.21	0.30	0.35	0.46	0.55

Note: II_C indicates that the site class II in China code is corresponding to site class C_{US} in America code.

Table 9 the spectral response acceleration for intensity regions of China (II_D) (Unit :g)

Parameter	Intensity VII (0.10g)	Intensity VII (0.15g)	Intensity VIII (0.20g)	Intensity VIII (0.30g)	Intensity IX (0.40g)
S_s	0.55	0.89	1.04	1.38	1.58
S_1(1st Group)	0.11	0.17	0.20	0.26	0.31
S_1(2nd Group)	0.13	0.20	0.23	0.31	0.40
S_1(3rd Group)	0.15	0.24	0.28	0.38	0.46

Note: II_D indicates that the site class II in China code is corresponding to site class D_{US} in America code.

4.2 The parameters for America cities in terms of that in China code

For a given city in United States, the maximum considered earthquake spectral response acceleration at short period S_s and 1-second period S_1can be determined in accordance with the provisions of IBC-2003 and SEI/ASCE 7-02, and the corresponding parameters of ground motions in GB50011-2001 can be derived from Equation (6).

$$A_{cc} = \frac{F_a S_s}{2.5\gamma_{US}} \qquad T_g = \frac{F_v S_1}{F_a S_s} \tag{6}$$

When the basic peak acceleration A_{cc} of ground motion with 475-year return period for site class II was calculated by the equation (6), the intensity region which shall be consistent with China code for a certain America city can be determined according to the provisions of GB50011-2001, and furthermore, the parameter α_{max} for seismic design of buildings may be defined (seen **Table 10)**.

Table 10 the parameters of seismic ground motions for some America cities in terms of that in China code

City	II_C			II_D		
	Calculating results		Intensity & design earthquake group	Calculating results		Intensity & design earthquake group
	A_{cc} (g)	T_g (s)		A_{cc} (g)	T_g (s)	
Los Angeles	0.471	0.65	Intensity IX 3rd group	0.471	0.75	Intensity IX 3rd group
San Francisco	0.353	0.77	Intensity VIII(0.30g) 3rd group	0.353	0.89	Intensity VIII(0.30g) 3rd group
Memphis	0.078	0.45	Intensity VI 3rd group	0.086	0.49	Intensity VI 3rd group

Note: II_C indicates that the site class II in China code is corresponding to site class C_{US} in America code.
II_D indicates that the site class II in China code is corresponding to site class D_{US} in America code.

5. CONVERSION BETWEEN THE PARAMETERS OF GROUND MOTIONS IN CHINA AND EUROPE CODES

Because the same probability level of 10% in 50 years was adopted in China and Europe code for seismic ground motion parameter zonation, the seismic design ground motion parameters in the two codes can be directly used for each other without the conversion for return period. But, due to the differences of the reference site, the site effects must be considered carefully.

For a given city in China, the parameters of ground motions in terms of that in Europe code *EN*1998-1:2004 can be determined by the following equation.

$$a_g = A_{cc} / S \tag{7}$$

For a certain city in Europe, the corresponding design ground motion parameters of the China code GB50011-2001 can be determined by equation (8).

$$A_{cc} = S \cdot a_g \;, \quad T_g = T_c \tag{8}$$

Where a_g is the peak acceleration of the seismic design ground motions for ground type A_{EN} in EN1998-1:2004. S is the soil factor for ground type B_{EN} or C_{EN} in EN1998-1:2004 that was corresponding to site class II in China code. A_{cc} is the basic peak acceleration of ground motion corresponding to the basic intensity earthquake in China code.

6 . CONCLUSIONS

By the comparison between the seismic design codes of China and America and Europe about the site classification and the seismic hazard characteristics, this paper presents the conversion relationships between the parameters of ground motions in China Code and that in America Code and Europe Code, and simultaneously, with the following conclusions:

(1) The site class II of China code was corresponding to the site class C_{US} or D_{US} of America code and the ground type B_{EN} or C_{EN} of Europe code approximately.

(2) The ground type A_{EN} of Europe code was corresponding to the site class A_{US} and B_{US} of America code, and the ground type B_{EN}, C_{EN} and D_{EN} in EN 1998-1:2004 were corresponding to the site class C_{US}, D_{US} and E_{US} in IBC-2003, respectively.

(3) The probability levels of the fortification earthquakes used in the China, America and Europe code were different, so the special attention shall be given to the relationships between the ground motions with different probabilities of exceedance or return periods, that is, the seismic hazard characteristics, when the America code or Europe code was used in China.

(4) The parameters for China cities in terms of that in America code and Europe code can be determined by the Equation (4), (5) and (7).

(5) The parameters for America cities and Europe cities in terms of that in China code can be determined by Equation (6) and Equation (8), respectively.

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