Comparison of Seismic Fortification Criterion of Eight Asian Countries

Cai Xiaoguang, Bo Jingshan, Sun Youwei, Zhang Jianyi & Zhang Yudong
Institute of Disaster Prevention, Hebei, Sanhe 065201, China

15 WCEE
LISBOA 2012

SUMMARY:
Seismic fortification standard is a national comprehensive reflection of seismic fortification level. In this paper, seismic design code of buildings of Japan, India, Turkey, China and other 4 Asian countries are studied in detail. The seismic fortification criterions of these countries are compared through analyzing the site classification, seismic effective coefficient and design seismic spectral. The results showed that the number of Asian sites category is 3 or 4. Macro description is one of the key indicators in site classification. The level of seismic fortification of Asian countries is different. Example shows that the level of seismic fortification of China and Japan is higher and South Korea and Turkey is lower. When considering site condition impact in design seismic spectrum, it is through adjusting the ground motion intensity and ground motion response spectrum shape in most of the Asian countries building seismic design code. The paper has important reference value in understanding seismic fortification level of the Asian countries.

Key words: Asian countries; seismic fortification level; comparison analysis

1. INTRODUCTION

Asia is earthquake-prone area. In recent years, a series of destructive earthquakes took place, such as Kobe earthquake in Japan, Gujarat earthquake in India, Bam earthquake in Iran and 2008 Wenchuan earthquake. Earthquake disaster caused huge casualties and economic losses to the Asian countries. Building seismic capacity affect the earthquake casualties. Building seismic capacity is decided by the seismic design code of the country at most time. Earthquake casualties and economic losses may different between countries even suffering the same magnitude earthquake because of different building earthquake resistant capability.

In this paper, seismic design code of buildings of eight Asian countries including Japan, India, Turkey, China, Korea, Nepal, Indonesia and Iran are studied in detail. The seismic fortification criterions of these countries are compared through analyzing the site classification, seismic effective coefficient and design seismic spectrum. The results have important reference value in understanding and comparing seismic fortification criterions of Asian countries.

2. SITE CLASSIFICATION

In order to consider the impact of site conditions on ground motion and ground earthquake resistant capability, site is classified in seismic design code of building. Different countries of the site classification are specified in Table 2.1. In the eight countries, there are 4 countries' site divided into three categories and 4 countries' site divided into four categories. Macroscopic description is one of the key indicators in site classification. The macroscopic descriptions include soil hard extent, soil types and formation reason. Soil layer depth is the most commonly used indicator. There are six country using soil layer depth as evaluation indicator. Other indicators include carrying capacity, strength, standard penetration count, wave velocity, relative density. Three countries have adopted one or two classification indicator. Other countries use three or more indicators. Site classification criterion in Asian country codes are shown in Table 2.2.

Table 2.1. Classification numbers and criterion of sites in Asian country codes

Country	Japan	Korea	Turkey	Iran	India	Nepal	Indonesia	China
Classification number	3	4	4	4	3	3	3	4
Classification criterion	Macro description (MD), depth	MD, Depth, Wave Velocity (WV)	MD, Depth WV, SPT, relative density (RD)	MD depth	MD	MD, Depth, WV, SPT, Site vibration period	MD, strength, WV, SPT,	MD, Depth, WV, bearing capacity

Table 2.2. Classification criterion of sites in Asian country codes

2.2.1 Japan, India, Nepal, Indonesia

Site type	Japan	India	Nepal	Indonesia		
				Average shear wave velocity $\bar{v}_s$ (m/s)	Average SPT $\bar{N}$	Average undrained shear strength $\bar{S}_u$ (kPa)
I	Ground consisting mainly of rock mass or hardened gravel beds from the Tertiary Era or earlier	Rock or Hard soil	Rock or Stiff soil sites	$\bar{v}_s \geq 350$	$\bar{N} \geq 50$	$\bar{S}_u \geq 100$
II	Ground types other than Type 1 and Type 3	Medium soil	Medium soil sites. Sites not described as either Type I or Type III	$175 \leq \bar{v}_s < 350$	$15 \leq \bar{N} < 50$	$50 \leq \bar{S}_u < 100$
III	Alluvial layers consisting mainly of humus, mud or similar materials, to a depth of approximately 30 meters or more, marshland or mud sea, etc.	Soft soil	Soft soil sites	$\bar{v}_s < 175$	$\bar{N} < 15$	$\bar{S}_u < 50$
				Or,any soil profile with more than 3m of soft clays with PI>20， wn≥40% and Su<25kPa		

2.2.2 Korea and Iran

Site type	I	II	III	IV
Korea	(a)A rock-like material characterized by a shear-wave velocity not less than 700m/s;(b)Medium-dense to dense or medium-stiff to stiff soil conditions, where soil depth is less than 60m;	A soil profile with predominantly medium-dense to dense or medium-stiff to stiff soil conditions, where the soil depth not less than 60m;	A soil profile containing more than 6m of soft to medium-stiff clay but not more than 12m of soft clay	A soil profile containing more than 12m of soft clay characterized by a shear wave velocity less than 150m/s
Iran	Igneous rocks，hard and stiff sedimentary rocks and massive metamorphic rocks. Conglomerate beds, compact sand and gravel and stiff clay beds up to 60 meters from the bed rock	Loose igneous rocks，friable sedimentary rocks，foliated metamorphic rocks Conglomerate beds, compact sand and gravel and stiff clay beds where the soil thickness exceeds 60 meters from the bed rock	Rocks which have been disintegrated by weathering Beds of gravel and sand with weak cementation and uncemented, unindurated clay where the soil thickness is less than 10 meters from the bed rock	Soft and wet deposites resulted from high level of water table. Grabel and sand beds with weak cementation and uncemented, unindurated clay where the soil thickness exceeds 10 meters from the bed rock

2.2.3 Turkey

Site type		Soil Groups					
Site type	Soil group and topmost layer thickness	Soil Group	Description of soil group	Sand penetr. （N/30）	Relative dense （%）	Unconf. Compres. Strength （kPa）	shear wave velocity (m/s)
I	Group (A) soils Group (B) soils with h1≤15m	(A)	1.Massive volcanic rocks, unweathered sound metamorphic rocks, stiff cemented sedimentary rocks 2.Very dense sand，gravel 3.Hard clay，silty clay	— >50 >32	— 85-100 —	>1000 — >400	>1000 >700 >700
II	Group (B) soils with h1 > 15 m Group (C) soils with h1 ≤ 15 m	(B)	1. Soft volcanic rocks such as tuff and agglomerate, weathered cemented sedimentary rocks with planes of discontinuity 2. Dense sand, gravel 3. Very stiff clay, silty clay	— 30-50 16-32	— 65-85 —	500-1000 — 200-400	700-1000 400-700 300-700
III	Group (C) soils with 15 m < h1 ≤ 50 m Group (D) soils with h1 ≤ 10 m	(C)	1. Highly weathered soft metamorphic rocks and cemented sedimentary rocks with planes of discontinuity 2. Medium dense sand and gravel 3. Stiff clay, silty clay	— 10-30 8-16	— 35-65 —	<500 — 100-200	400-700 200-400 200-300
IV	Group (C) soils with h1 > 50 m Group (D) soils with h1 > 10 m	(D)	1. Soft, deep alluvial layers with high water table 2. Loose sand 3. Soft clay, silty clay	— <10 <8	— <35 —	— — <100	<200 <200 <200

2.2.4 China

Soil Type	Geotechnical description	shear wave velocity of soil layer (m/s)	Overlaying depth of soil profile for site classification （m）			
			I	II	III	IV
Stiff soil	Stable rock，dense detritus	$v_s > 500$	0			
Medium-stiff soil	Medium dense or slightly dense detritus，dense or medium dense gravel, coarse or medium sand，cohesive soil and silt with $f_{ak} \geq 200$	$500 \geq v_s > 250$	<5	≥5		
Medium-soft soil	slightly dense gravel、coarse or medium sand，cohesive soil and silt with $f_{ak} \leq 200$,fill land with $f_{ak} > 130$	$250 \geq v_s > 140$	<3	3~50	>50	
soft soil	Muck and mucky soil，loose sand，new alluvial sediment of cohesive soil and silt, fill land with $f_{ak} \leq 130$	$v_s \leq 140$	<3	3~15	>15~80	>80

3. SEISMIC INFLUENCE COEFFICIENTS

The calculation method for earthquake action on structure is based on response spectrum theory in eight Asian countries seismic design code. According to the base shear method formula $V = \alpha W$, V means base shear, α means seismic influence coefficient, W means structure gravity. Earthquake action value of different countries can be compared by means of comparing the seismic effective coefficient if we take a same building as a model. The calculation of seismic effective coefficient should consider dynamic coefficient β, seismic partition coefficient A, the importance factor I and seismic response reduction factor R. The dynamic coefficient is the ratio of the maximum response of single-particle system under seismic action with the ground acceleration. Seismic partition coefficient is decided by design ground motion. The importance of factor is decided according to the building suffered damage causing casualties, direct and indirect economic losses and social impacts. Seismic response reduction factor reflects the different seismic behavior of structures.

The model and calculation coefficient are showed in Figure 1 and Table 3.1. The equivalent seismic influence coefficient formula is showed in Table 3.2. After calculation, seismic influence coefficient results are China (0.21), Japan (0.21), India (0.157), Indonesia (0.141), Iran (0.114), Nepal (0.116), South Korea (0.035) and Turkey (0.056). Therefore, the Chinese and Japanese design seismic actions are highest, South Korea and Turkey lowest. So China and Japan seismic fortification level are highest.

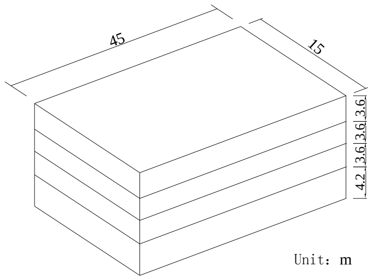

Figure 1. Sketch of Building

Table 3.1. Model calculation coefficient

Structure type	Story	Function	Damping ratio	Design ground motion	Site type
RC	4	School teaching building	5%	The largest of every country	I

Table 3.2. Seismic effective coefficient formulas and numerical results based on different codes

Country	Base shear method	Equivalent seismic influence coefficient formula	Structural natural periods	α results
Japan	$V_i = \alpha_i W_i$	$\alpha_i = A \cdot R_t \cdot S_i \cdot E_0$	$0.0731 h^{3/4}$	0.21
Korea	$V = \alpha W$	$\alpha = \frac{AI\beta}{R}$	$0.07 h^{3/4}$	0.035
Turkey	$V = \alpha W$	$\alpha = \beta(T_1)/R_a(T_1) \geq 0.10AI$	$0.07 h^{3/4}$	0.056
Iran	$V = \alpha W$	$\alpha = \frac{A\beta I}{R}$	0.075 h0.75	0.114
India	$V = \alpha W$	$\alpha = \frac{AI\beta}{2R}$	$0.06 h^{3/4}$	0.157
Nepal	$V = \alpha W$	$\alpha = C(T_i)AIK$	$0.0731 h^{3/4}$	0.116
Indonesia	$V = \alpha W$	$\alpha = \frac{CI}{R}$	$2\pi \sqrt{\frac{\sum_{i=1}^{n} W_i d_i^2}{g \sum_{i=1}^{n} F_i d_i}}$	0.141
China	$V_{EK} = \alpha_1 W_t$	seismic influence coefficient curve	$(0.08 \sim 0.10)N$	0.21

V：the floor horizontal seismic force; α：seismic influence coefficient; W: floor weight; the Wi: weight of the i-th floor; A: earthquake partition coefficient; I: importance factor; R: seismic response reduction coefficient; C：Structural reaction coefficient; β: dynamic coefficient; K: the structure performance coefficient; R_t: Vibration characteristics coefficient; S_i: i floors horizontal shear distribution coefficient; E_0: Standard shear coefficient; *Fi*: equivalent seismic action of the i-th floor; *di*：i-th floor lateral seismic displacements;; g：gravity acceleration; h：Height of building; N：total layer number of Structure.

4. DESIGN SEISMIC RESPONSE SPECTRUM

The design seismic response spectrum can be represents by formula 1 and Figure 2. a_m design ground motion peak acceleration; β_m maximum amplification factor; T_0 first inflection point period values; T_g characteristic period; γ control parameters of descending speed. The impact of site conditions in seismic design is realized by adjusting vibration intensity and ground motion response spectrum shape. Site condition effect has reflected in the most Asian countries' seismic design code of building except Korea. Because there is not design seismic response spectrum content in Korea seismic design code of building. Figure 3 shows response spectrum of design earthquake.

There are design ground motion parameters of Asian countries in Table 4.1. There are 6 earthquake partitions in Indonesia. The parameter is given in table 4 corresponding to the earthquake zone Ⅵ which is highest zone of seismic intensity. Design earthquake in China's seismic design code of buildings divided into three groups. The parameters of characteristic period in table 4.1 correspond to the first group. K_a means the ratio of the peak ground motion between different site kinds to site-class 1 (bedrock). K_β means the ratio of response spectrum platform amplification factor between different site kinds to site-class 1 (bedrock).

$$S_a(T)=\begin{cases} a_m + a_m(\beta_m - 1.0)\dfrac{T}{T_0} & 0.0 < T \le T_0 \\ a_m\beta_m & T_0 < T \le T_g \\ a_m\beta_m\left(\dfrac{T_g}{T}\right)^{\gamma} & T_g < T \le T_m \end{cases} \qquad (1)$$

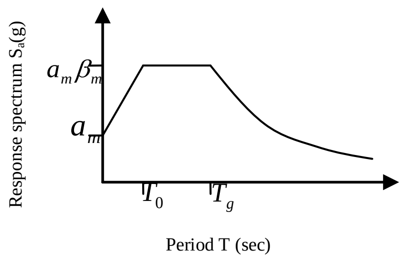

Figure 2. Response spectrum of design earthquake

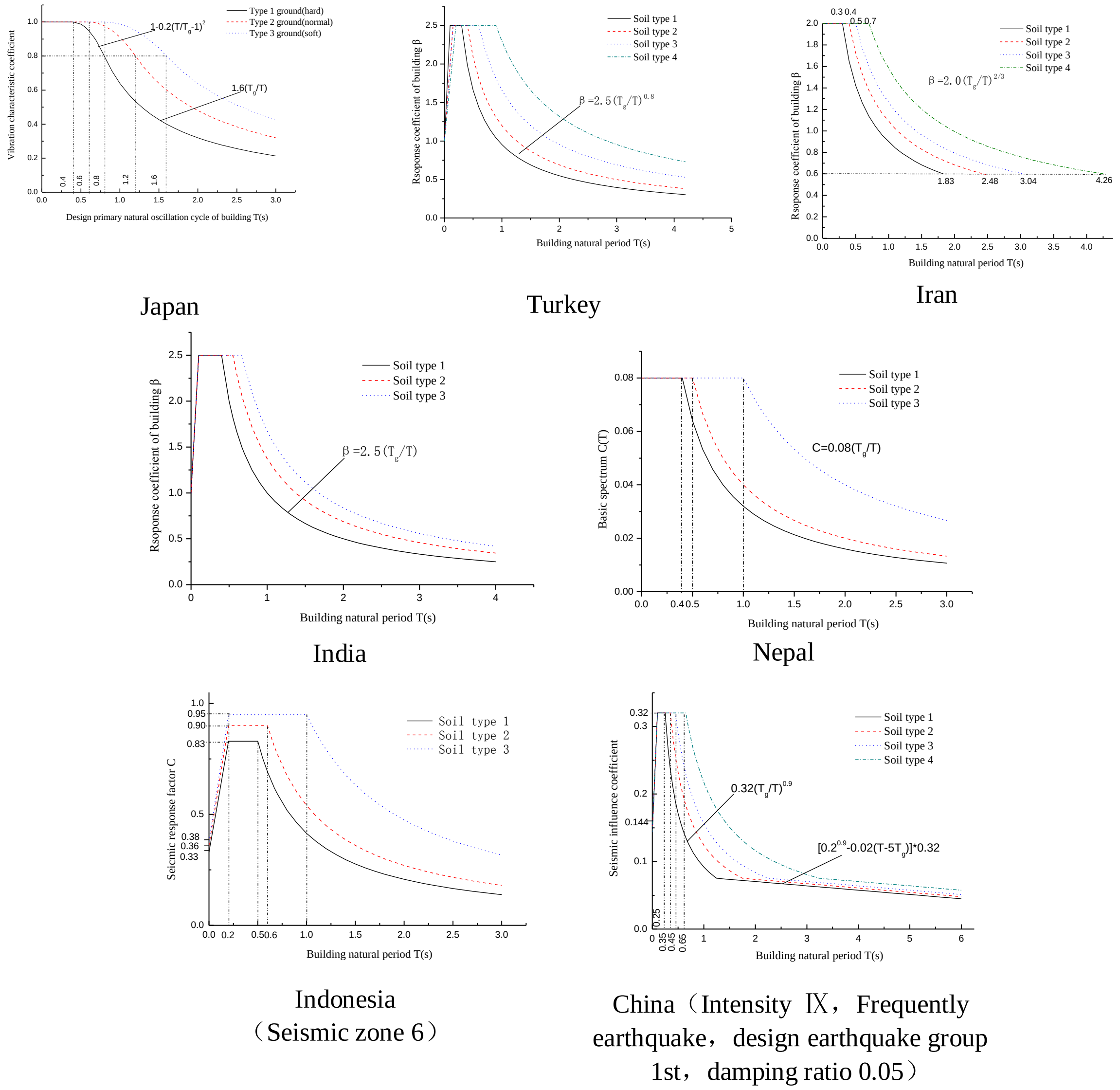

Figure 3. Response spectrum of design earthquake

Table 4.1 show that there are some similarities and differences between Asian countries, which as follows:

1) Every countries use T_g to reflect the amplification effect of soft site to low frequency seismic motion. The value of T_g of the site-class 1 is 0.25-0.5 seconds. The value of T_g of the soft site is 0.65-1.0 seconds.

2) Most countries do not consider the impact of site conditions to a_m except Indonesia. So the K_a value is 1.0-2.0 in the seismic design code of Indonesia.

3) The value of β_m is 2.0-2.5. Most Asian countries take 2.5.

4) The value of T_0 is 0.0-0.2 seconds.

5) The value of γ is 0.67-1.0 seconds.

Table 4.1 Parameters of response spectrum of design earthquake in different codes

Country	Site-class	K_a	T_0 （sec）	T_g (sec)	β_m	K_β	γ
Japan（2001）	I（II III）	1.0	0.0	0.4（0.6 0.8）	Absolute response spectrum platform value	1.0	Fig.3
Turkey（1998）	I（II III IV）	1.0	0.10（0.15 0.15 0.2）	0.30（0.4 0.6 0.9）	2.5	1.0	0.8
Iran（1998）	I（II III IV）	1.0	0.0	0.3（0.4 0.5 0.7）	2.0	1.0	2/3
India（2002）	I（II III）	1.0	0.1	0.4（0.55 0.67）	2.5	1.0	1.0
Nepal（1995）	I（II III）	1.0	0.0	0.4（0.55 1.0）	Absolute response spectrum platform value	1.0	1.0
Indonesia（2002）	I（II III）	1.0（1.08 1.14）	0.2	0.5（0.6 1.0）	2.5	1.0	1.0
China（2008）	I（II III IV）	1.0	0.1	0.25 （0.35 0.45 0.65）	2.25	1.0	0.9

5. CONCLUSIONS

In this paper, seismic design code of buildings of eight Asian countries including Japan, India, Turkey, China, Korea, Nepal, Indonesia and Iran are studied in detail. The seismic fortification criterions of these countries are compared through analyzing the site classification, seismic influence coefficient and design seismic spectrum.

(1) The number of site classification in Asian countries' seismic design code is 3 to 4. The macro description is one of the key indicators in site Classification.

(2) The calculation of seismic influence coefficient should consider dynamic coefficient, seismic partition coefficient, the importance factor and seismic response reduction factor. The example shows that the highest horizontal seismic actions are in China and Japan. So the seismic fortification level is high in China and Japan. Seismic fortification level is low in Turkey and Korea.

(3)Response spectrum theory is used in seismic design of buildings in most Asian countries except the Republic of Korea. When considering the influence of site condition on response spectrum, it is achieved by adjusting the intensity of ground motion and response spectrum shape.

ACKNOWLEDGMENT

The present study was based upon work supported by University teacher research funds of China Earthquake Administration 2009(No.20090110), Special funds for basic research of the National University (No. ZY20110102), Earthquake Engineering and Engineering Vibration Laboratory Fund, Institute of Engineering Mechanics (No.2009A04).

REFERENCES

Building code for structural regulations(1988). Korea, Ministry of construction and transportation, 1-18.

Criteria for earthquake design of structures -Part 1 general provisions and buildings(2001).India, IS 1893-2002 Indian standard, 1-35.

Earthquake resistant design for buildings(2001). Japan, Ministry of Land, Infrastructure and Transport, 82-102.

GB 50011-2010, Code for seismic design of buildings(2010).Beijing: China Architecture & Building Press, 1-41

Hu Yuxian(2006). Earthquake engineering. Earthquake Press, 469-523.

Iranian code for seismic resistant design of buildings(1988).Iran, Building and housing research center, 1-49.

Li Xiaojun, Peng Qing, Liu Wenzhong(2011).Consideration of site effects for determination of design earthquake ground motion parameters. *World Information on Earthquake Engineering*, 17:4,34-41.

NBC105 Nepal national building code, Seismic design of buildings in Nepal(1995). Nepal, Ministry of housing and physical planning, 1-31.

SNI-02-1726-2002, Seismic resistance design standard for buildings(2002). Indonesia, Ministry of public work, 1-25.

Specification for structures to be built in disaster areas(1998). Turkey, Ministry of public works and settlement, 1-32.