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COMPARISON STUDIES ON STRUCTURAL CODES - SEISMIC CODES IN SOUTH EAST ASIA

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Abstract

Many researchers, scientist, engineers and government officials have dedicated to find a design method of seismic resistant structures. Major seismic codes in countries which are located at west part of Ring of Fire are experiencing boost in economy, while facing the risk of huge earthquake at the same time. In this paper, the codes are also compared with international standard then summarize the similarity and difference between codes.

Keywords: Seismic codes, ASEAN countries, ASCE 7, Eurocode 8, ISO 3010, Building Standard Law of Japan

1. Introduction

The construction technology has been developed for many years in its theoretical aspects and accuracy for forecasting behaviors of structures. The development has made clear that the consideration of action induced by earthquake is inevitable for structural design to achieve safe structure against its permanent use, and against strong winds, heavy snows or huge earthquakes as well. Design codes to estimate seismic action for structural design have been studied and developed in many countries. As same as other part of the world, countries in South East Asia have developed seismic codes, especially where the source which may cause huge earthquake are observed.

Because the nature of seismic action is a phenomenon by the law of inertia, the value of seismic action is essentially different from those actions such as permanent load, live load, snow, or wind pressure. The values other than seismic action are regulated based on physical and actual values which represent and act toward structures, and chosen with background of huge amount of data. And the chosen value that describes the amount of action is used directly to analysis of the structure.

But for the case of seismic action for static analysis, the value of seismic intensity itself is not the value used for analysis of the structure. Seismic action for static analysis is estimated based on many items such as base shear factor from predicted maximum ground acceleration at site, soil type of the site, ductility of the structure and methodology of structural analysis.

In this paper, seismic action for static analysis among Eurocode 8, ASCE 7, Japanese Building Standard Law and ISO 3010 are compared in terms of the contents to be considered estimation of seismic action.

2. Seismic codes in South East Asia

South East Asia is a region where the growth of economy is so large for these years. And in meantime, it is a region which consists a part of Ring of Fire, as well as where earthquakes are observed so often in our history. To ensure the safety of the structure against earthquake in this region is essential to guarantee the economical activities of the region.

The seismic codes of countries in South East Asia region, which are researched in this paper, are outlined in Table 1. The order of the country in Table 1 is by GDP per capita high to low except unclear countries which are shown at bottom row.

Table 1 - Seismic codes in South East Asia

Country	**Existence of seismic code**	**current code**	**referenced codes**	**Difference from original**
Singapore	Exist	2013 (1st edition)	Eurocode 8	Applied in a country where maximum acceleration is small
Malaysia	Under development	-	-	Eurocode 8 will be adopted
Thailand	Exist	2009 (1st edition)	ASCE 7-05 (2003 NEHRP)	Spectrum on logarithm expression for marsh soil site
Indonesia	Exist	2012 (3rd edition, 1st edition in 1991)	ASCE 7-10 (2009 NEHRP)	Undefined displacement constant area
Philippines	Exist	2010 (6th edition, 1st edition in 1972)	UBC 1997	Revised importance factor partly
Vietnam	Exist	2006 (1st edition)	Eurocode 8	Subdivided building importance factor
Myanmar	Under development	-	ASCE 7-05	Unclear in detail
Brunei, Laos, Cambodia		survey not completed		

Indonesia and the Philippines, which have experienced huge disasters in cities with large population in their past, have published seismic codes since 1970s. Thailand, Vietnam and Myanmar are the countries where strong seismic sources are found in their territory but not published any of the seismic code until 2000s. Singapore doesn't seem to have strong seismic source in its territory but it has regulated seismic code for important structures on soft soils.

As shown in Table 1, those countries which have sites in seismic prone areas published own seismic codes. However, their codes are mostly the same as original codes which is shown in the 4th column of Table 1 other than conditions unique by the region, such as maximum acceleration or soil condition. It is clear from Table 1 that Eurocode 8 and ASCE 7 are the only two codes used in these countries.

In this paper, seismic action for static analysis is introduced from Eurocode 8 and ASCE 7 as major codes adopted in South East Asia and from Japanese Building Standard Law as a code which succeeded in reducing damage against huge earthquakes, such as Great Hanshin earthquake in 1995, Great East Japan earthquake in 2011 or the 2016 Kumamoto earthquake.

3. Building Standard Law in Japan, Eurocode 8 and ASCE 7

In this chapter, calculation of seismic action for static analysis in each code is introduced. Either code commonly calculate the seismic action of lowest story of the structure (the base shear) and distribute the base shear to upper stories as story shear. And it is also common that each code allows using the calculation method to distribute of base shear to upper stories depending on engineer's decisions. Hence, calculation of base shear of each code is focused using base shear factor C_{B} defined as a factor derived from dividing base shear by weight of the structure.

3.1 Building Standard Law in Japan

In Building Standard Law in Japan (BSL), base shear factor C_{B} against ultimate limit state is calculated by the equation as shown below.

$$C_{\mathrm{B}} = D_{\mathrm{S}}\, Z\, R_{\mathrm{t}}\, C_0 \tag{1}$$

where;

D_{S} : Structural property factor (calculated based on ductility of the structure)

Z : Regional factor

R_{t} : Vibration property factor

C_0 : Standard shear coefficient (1.0)

The regional factor Z is used as a reduction factor of the standard seismic action, which is regulated for Tokyo in accordance with region of the site. The vibration property factor R_{t} is expressed as a function of natural period T and three functions are given in accordance with soil category.

The structural property factor D_{S} expresses the ductility of the structure, and D_{S} is derived by totaling the amount of graded structural members which are ranked in 4 grades based on characteristic condition under ultimate state. In general, the value of D_{S} has been chosen more dependent on decision by engineer in the past, however, thanks for the development of personal computers, D_{S} is chosen based on push-over analysis these days.

The base shear factor C_{B} expressed as functions of natural period T are shown below;

$$C_B(T) = D_S\ Z \qquad : T < T_C \qquad (2)$$

$$C_B(T) = D_S\ Z \left\{1 - 0.2\left(\frac{T}{T_C} - 1\right)^2\right\} \qquad : T_C \le T < 2T_C \qquad (3)$$

$$C_B(T) = D_S\ Z \left(\frac{1.6\,T_C}{T}\right) \qquad : 2T_C \le T \qquad (4)$$

where,

T : First mode natural period for design

T_c : Soil property factor (0.4 for hard soil, 0.6 for medium soil, 0.8 for soft soil)

T_c is a period providing the corner point from acceleration constant range to velocity constant range.

The equation (2) corresponds to acceleration constant range and equation (4) corresponds to velocity constant range. The equation (3) which is period between T_c and 2 T_c is provided to avoid sudden change even for a slight change of the period near the corner point (See Figure 1).

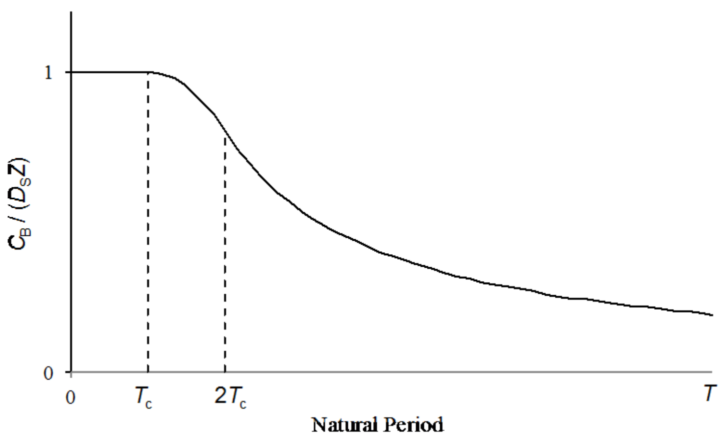

Figure 1 - Base shear factor C_B of BSL

3.2 Eurocode 8

Eurocode 8 is a seismic code included in series of Eurocode and used mainly in Europe but also in Singapore, Vietnam and expected to be used in Malaysia. The use in Singapore is acknowledged by CEN, and SPRING published national annex for Singapore, while the use in Vietnam is a translation of Eurocode 8 to Vietnamese language.

The base shear factor C_B in Eurocode 8 can be expressed as shown below.

$$C_{\mathrm{B}}(T) = a_{\mathrm{g}} S \left[\frac{2}{3} + \frac{T}{T_{\mathrm{B}}} \left(\frac{2.5}{q} - \frac{2}{3} \right) \right] \qquad : 0 \leq T \leq T_{\mathrm{B}} \tag{5}$$

$$C_{\mathrm{B}}(T) = \frac{2.5 a_{\mathrm{g}} S}{q} \qquad : T_{\mathrm{B}} \leq T \leq T_{\mathrm{C}} \tag{6}$$

$$C_{\mathrm{B}}(T) = \frac{2.5 a_{\mathrm{g}} S}{q} \left(\frac{T_{\mathrm{C}}}{T} \right) \text{ and } C_{\mathrm{B}}(T) \geq \beta a_{\mathrm{g}} \qquad : T_{\mathrm{C}} \leq T \leq T_{\mathrm{D}} \tag{7}$$

$$C_{\mathrm{B}}(T) = \frac{2.5 a_{\mathrm{g}} S}{q} \left(\frac{T_{\mathrm{C}} T_{\mathrm{D}}}{T^2} \right) \text{ and } C_{\mathrm{B}}(T) \geq \beta a_{\mathrm{g}} \qquad : T_{\mathrm{D}} \leq T \tag{8}$$

where

T : natural period of a linear single degree of freedom system

a_{g} : design ground acceleration on type A (Rock) ground

S : Soil factor

q :behaviour factor based on ductility of the structure

β : lower bound factor for the horizontal design spectrum. $\beta = 0.2$ is recommended.

T_{B}, T_{C}, T_{D} : Corner periods of spectrum

The base shear factor C_{B} is composed by ground acceleration at site, soil condition at site, and ductility of the structure itself. T_{B}, T_{C}, T_{D} and S are determined by soil category. The equation (5) connects the ground motion and the maximum acceleration, equation (6) corresponds to acceleration constant range, equation (7) corresponds to velocity constant range and equation (8) corresponds to displacement constant range of the spectrum (see Figure 2).

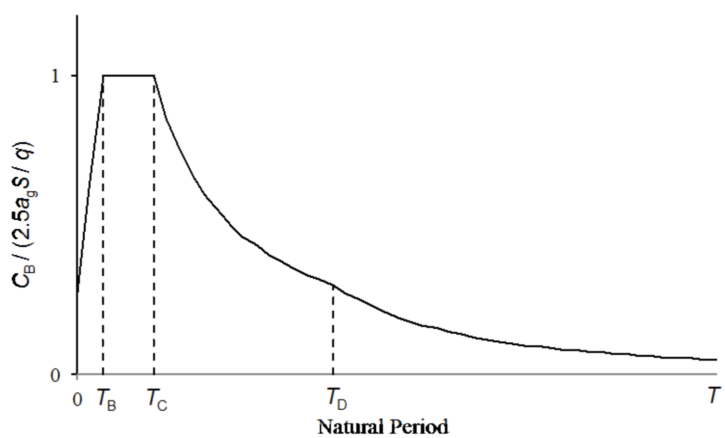

Figure 2 - Base shear factor C_{B} of Eurocode 8

The value of modification factor based on ductility q is determined by the design codes of each structural material. Design method in detail differs corresponding to the value of q.

3.3 ASCE 7

ASCE 7 is a code titled "Minimum Design Loads for Buildings and Structures". ASCE 7 is updated mostly within every 5 years. The code also includes standards of basic loads other than earthquake load and load combinations. The chapters related to seismic design have much in common with provisions by NEHRP (National Earthquake Hazards Reduction Program).

In Thailand, the seismic regulation is based on 2005 edition of ASCE 7. In Indonesia, the seismic code is similar to 2010 edition. And in Myanmar, the seismic code is under development based on 2005 edition of ASCE 7.

The base shear factor C_B of ASCE 7 expressed as function of natural period T is as shown below.

$$C_B(T) = S_{DS}\left(0.4 + 0.6\frac{T}{T_0}\right) \quad : 0 < T \le T_0 \tag{9}$$

$$C_B(T) = \frac{S_{DS}}{R} I_e \quad : T_0 < T \le T_S \tag{10}$$

$$C_B(T) = \frac{S_{D1}}{T\ R} I_e \quad : T_S < T \le T_L \tag{11}$$

$$C_B(T) = \frac{S_{D1} T_L}{T^2\ R} I_e \quad : T_L < T \tag{12}$$

where

S_{DS} : design, 5% damped, spectral response acceleration parameter at short periods

$$S_{DS} = \frac{2}{3} F_a\ S_S \tag{13}$$

S_{D1} : design, 5% damped, spectral response acceleration parameter at a period of 1 second

$$S_{D1} = \frac{2}{3} F_v\ S_1 \tag{14}$$

T : the fundamental period of the building

$$T_0 = 0.2\frac{S_{D1}}{S_{DS}}$$

$$T_S = \frac{S_{D1}}{S_{DS}}$$

T_L: long-period transition period

I_e : the importance factor

S_S : mapped MCE_R, 5% damped, spectral response acceleration parameter at short periods

S_1 : mapped MCE_R, 5% damped, spectral response acceleration parameter at a period of 1 second

F_a : short-period site coefficient (at 0.2 s-period)

F_v : long-period site coefficient (at 1.0 s-period)

The base shear factor C_B is composed by ground acceleration at site, soil condition at site, and ductility of the structure. The equation (9) corresponds to acceleration constant range, equation (10) corresponds to velocity constant range and equation (11) corresponds to displacement constant range of the spectrum (see Figure 3).

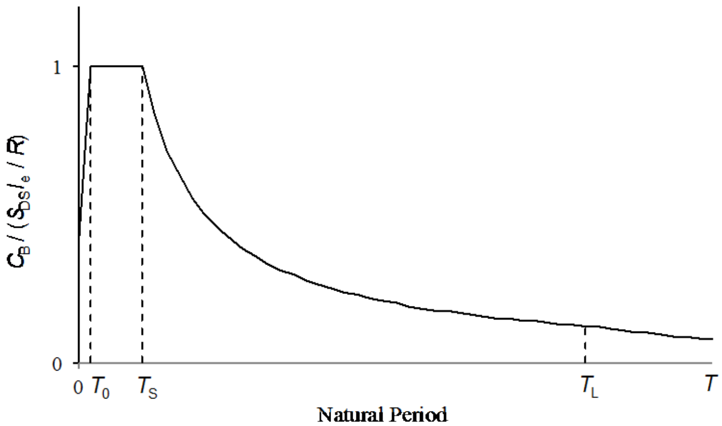

Figure 3 - Base shear factor C_B of ASCE 7

4. Correlation with ISO 3010

4.1 Outline of ISO 3010

As introduced in the previous chapter, the factors given to estimate seismic action for static analysis varies among the codes. However, the basic concept of them are in similar in terms of composing the seismic action by ground acceleration, natural period of the structure, soil category at site and ductility of the structure.

In the activity of ISO, a variety of international standards has been developed in aim of harmonizing national standards in each country. ISO 3010 is the international standard for seismic actions on structures which the first edition was published in 1998. The latest and the third edition is expected to be published in year 2016. In ISO 3010, two limit states, Ultimate Limit State (ULS) and Serviceability Limit State (SLS), are defined and the base shear factor $C_{E,u}$ for ULS may be written as shown below.

$$C_{E,u} = \gamma_{E,u}\ k_Z\ k_{E,u}\ k_S\ k_D\ k_R \tag{15}$$

where

$\gamma_{E,u}$ is the load factor as related to reliability of the structure for ULS;

k_Z is the seismic hazard zoning factor to be specified in the national code or other national documents;

$k_{E,u}$ is the representative value of earthquake ground motion intensity for ULS to be specified in the national code or other national documents by considering the seismicity;

k_S is the ratio of the earthquake ground motion intensity considering the effect of soil conditions to the earthquake ground motion intensity for the reference site condition;

k_D is the structural design factor to be specified for various structural systems according to their ductility, acceptable deformation, restoring force characteristics, and overstrength;

k_R is the ordinate of the normalized design response spectrum, as a function of the fundamental natural period of the structure considering the effect of soil conditions and damping property of the structure ;

4.2 Correlation of ISO 3010 and seismic codes

As the ISO 3010 requiring to consider the factors as introduced in equation (14), the correspondence of code is shown in Table 2.

The right most column of Table 2 describes if the factor is determined by site conditions or by structural system of which is the objective of the engineer.

Table 2 -Factors in ISO 3010

ISO 3010	BSL	Eurocode 8	ASCE 7	Factor dependent to
k_Z	Z	Considered in a_g	S_S, S_1	site condition
$k_{E,u}$	1.0	Considered in a_g	S_{DS}, S_{D1}	site condition
k_S	Considered in R_t	S	F_a, F_v	site condition
k_D	D_S	q	R	structural condition
k_R	Considered in R_t	Considered by each equation	Considered by each equation	structural condition

And also it is common that base shear factor C_B for all codes can be described, as function of natural period T, which describes characteristics of structural system.

From the Table 2, it is obvious that each item which ISO 3010 requires is considered in each code.

5. Conclusion

The seismic codes of countries in South East Asia is summarized and found that only Eurocode 8 and ASCE 7 are used, with almost no change from original. Correlation of base shear factor C_B between ISO 3010 and BSL, Eurocode 8 and ASCE 7 is clarified.

In spite of shown similarity in this paper, the difference between codes may be described as in attitude to involve the evolution of techniques in actual design in practical field. The examples are such as, the consideration of stiffness reduction when estimating natural period of structure, if the code put priority to static analysis or dynamic analysis, if the code written considering plane model analysis or space model analysis, if the model shall include the foundation or soil, if each floor should be considered as elastic diaphragm or rigid body, etc. Some of these items are very essential in terms of code for structural calculation. Seismic code shall also need to be conforming logically to the design verification of section which is the post routine of structural analysis.

And the most important task is that not only in technically immature countries such as in South East Asian countries but also in Japan, lack of deep understanding of the code or the given method not only by structural engineers but also by the stakeholders in the society are causing damage which become clear each time when an earthquake occurs.

To catch up recent technologies in standard as well as spreading the concept which might be hardly seen from the sentence of codes are the issues to be solved before the next earthquake cause another casualties.

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