16th World Conference on Earthquake, 16WCEE 2017
Santiago Chile, January 9th to 13th 2017
Paper N° 770
Registration Code: S- N1463034527

Outline and Features of Japanese Seismic Design Code

T. Narafu[(1)]; Y. Ishiyama[(2)]; R. Ison[(3)], J. Sakuma[(4)], H. Kato[(5)], and S. Kita[(6)]

[(1)] *Senior Advisor, Japan International Cooperation Agency (JICA),Narafu.Tatsuo@jica.go.jp*
[(2)] *Professor Emeritus, Hokkaido University, to-yuji@nifty.com*
[(3)] *Principal, Civil/Structural Engineer, R. S. ISON & Associates, rannie.ison@gmail.com*
[(4)] *Representative, Sakuma Architect's Atelier, setukei_sakuma@ybb.ne.jp*
[(5)] *Engineer, Kajima Corporation, hkato@kajima.com*
[(6)] *Representative, Kita Shigenori Structural Design Office, kitakozo@design.zaq.jp*
…

Abstract

The authors have been working on comparison study on seismic design codes of Japan and the Philippines to grasp required levels of performance against earthquakes, and the difference and characteristics of the codes. The Philippine seismic code (NSCP: National Structural Code of the Philippines 2010) is created referring to Uniform Building Code 1997 (UBC-1997). On the other hand the Japanese code is quite unique and unfamiliar to engineers outside of Japan as it was developed by Japanese engineers and researchers on their own research achievements. This paper explains the outline and features of the Japanese code in comparison with the Philippine code which may be familiar for many readers as UBC-1997 is applied in the United States and widely utilized in many countries.

In this study the authors find that the basic idea, principles and components/items are basically common in the two codes. However there are several significant differences such as verification methods, evaluation of effects of ductility, and kinds of factors used in calculation of seismic loads. This paper reports the outline of the both codes and explain significant differences between them.

Keywords: Comparison study; structural codes; Japan; the Philippines; pushover analysis

1. Introduction

Seismic design codes attract attention of engineers and donor organizations as basic tools to mitigate damage caused by earthquakes. Most of the countries have prepared their own codes. Among them many people are interested in Japanese code as it was proved to be effective by the Great East Japan Earthquake when damage by the shaking motion was limited in spite of the very strong shaking motion in wide area. Japanese seismic code has been developed by Japanese engineers and researchers based on the achievement of the research by their own, and its available information for foreigners, is limited.

Under this condition, this paper shows brief history and the outline of Japanese code and conduct comparison study with the Philippine code which refers to codes of the United States, which may be familiar to many readers. The comparison study clarifies components/items both common and different.

2. Brief history of Japanese seismic design code

2.1 Overview

In 1919, Japan introduced a comprehensive building code (Urban Building Law) covering fire safety, seismic safety, public hygiene, occupancy/function control, building height, setback from site borders and so on. In 1923, the Great Kanto Earthquake hit Tokyo and its surrounding area and killed more than 100 thousand people. In 1924, based on the survey on damage to buildings, the building code introduced seismic design calculation method, which was the first national seismic design method in the world. In 1950 after the World War II, the method was basically succeeded by new legislation of Building Standard Law. After that several significant earthquakes such as Tokachi-oki Earthquake 1968 occurred, and researchers and engineers recognized necessity to improve the seismic design method to consider stronger shaking motion. Under this situation a national research project "Development of New Seismic Deign Method" was conducted. In 1981 Based on achievement of the research project, the seismic design method in the code was drastically revised. The new method requires resilience against response acceleration of 1.0G whereas the former one required 0.2G. At the same time non-linear analyses considering ductility were introduced in evaluating ultimate capacity of structures against lateral force .

2.2 Experience of two mega-disasters

In 1995, another huge disaster hit the 6th largest city of Kobe and its surrounding area and caused heavy damages. Many buildings were severely damages and killed approximately six thousand people. Figure 1 shows numbers of collapsed buildings in categories of year of constructing which corresponding to versions of the building codes in force. It shows that 97% of them are constructed before 1981 when the revised building code was enforced. In other words, the buildings constructed before 1981 are more vulnerable. In 1995, from this lesson the national government enacted a new law to promote retrofitting of the old buildings.

In 2011 the next huge earthquake with Magnitude 9.0 hit east part of Japan and caused very strong shaking motion in wide area. Peak ground acceleration larger than 1.0G was recorded in six prefectures but damage by the shaking motion was limited. The current seismic design method found nothing to be revised in significant points in structural design upon the two mega disasters.

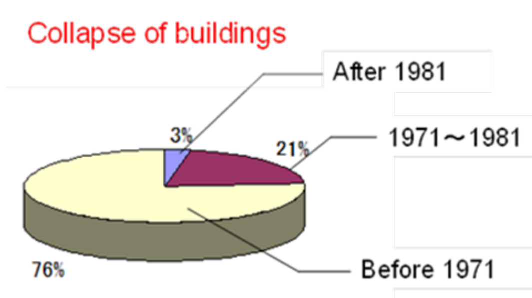


Fig. 1 – Percentage of collapsed houses in categories of year of construction

3. Comparison of the two codes

2.1 Overview of Japanese code

The features of the structural design method based on the Japanese Building Standard Law 1981 could be listed as below.

- two levels of seismicity for structural design

Second stage seismic calculation against severe earthquake ground motion (return period of around 500 years) : to avoid collapse/heavy damage which may threaten life safety (introduced in the revision in 1981)

First stage seismic calculation against moderate earthquake ground motion (return period of several decades): no significant damage in structural members to maintain continuous service

- structural design methods for each structural types such as reinforced concrete (RC), steel structure, wood structure and so on, are prepared

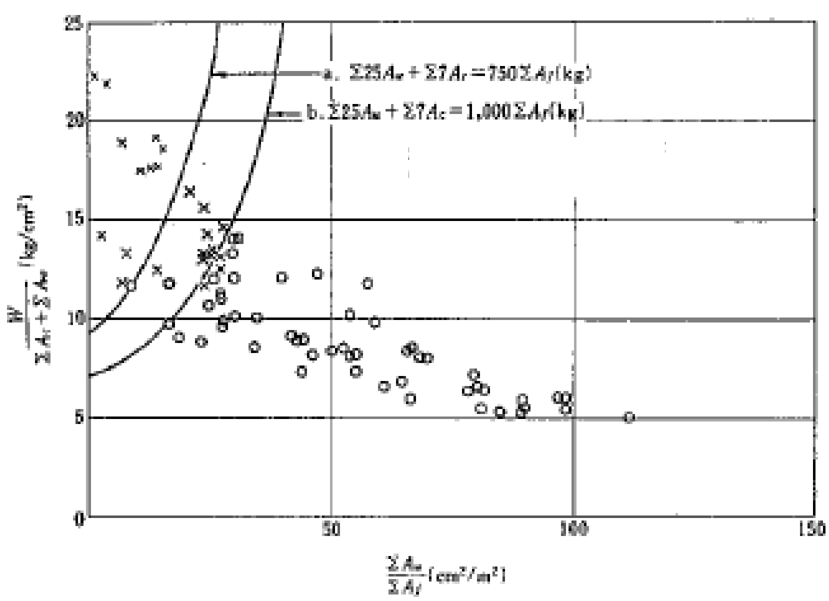
- several seismic calculation methods (called “Seismic Calculation Routes” in the code, explained in following section) are prepared according to structural characteristics of buildings such as height of buildings, resisting system against lateral force (frame, frame with structural walls, or others)

The Japanese code does not have factors to reflect effects/action by seismic sources near construction sites and importance of occupancy of buildings such as hospitals, fire departments and so on.

2.2 Several “Seismic Calculation Routes” in Japanese code for reinforced concrete structure

Several “Seismic Calculation Routes” are prepared in the Japanese code as shown below. Seismic Calculation Route 1, 2-1 and 2-2 are simple methods based on detail survey on affected buildings by Miyagiken-oki Earthquake 1978 by Dr. Toshio Shiga shown in Fig. 2 where relation between total section areas of structural members and degree of damage is clearly related. These simple Routes require First stage seismic calculation and additional requirements on the total section areas of structural members, limits on story drift, eccentricity and story stiffness ration.

Seismic Calculation Route 1: a simple method applied to buildings with many structural walls in height of 20 meters or less



Horizontal axis: $\dfrac{\sum Aw}{\sum Af}$ (cm2/m2)

Vertical axis: $\dfrac{W}{\sum Ac + \sum Aw}$ (kg/cm2)

o: none/slight damage

x: moderate/heavy damage

Aw: section area of shear walls

Ac: section area of columns

Af: floor area of each floor

W: weight (dead load and live load):

Fig. 2 – Results of field survey on damage caused by Miyagiken-oki Earthquake 1978 by Dr. T. Shiga

Seismic Calculation Route 2-1: a simple method applied to buildings with many structural walls in height of 31 meters or less

Seismic Calculation Route 2-2: a simple method applied to buildings with many wing walls (walls attached to columns) in height of 31 meters or less

Seismic Calculation Route 3: a method introducing effects of ductility in seismic structural calculation (usually employ pushover analysis in recent years) applied to buildings in height of 60 meters or less

Ultimate State Analysis: a different type of method based on principles of performance based design

Time History Analysis: another different type of method by dynamic analysis applying several time history vibration data of earthquakes

2.3 Overview of design methods for reinforced concrete structures

In this comparison study, model design of 5-story reinforced concrete buildings is selected for simple and clear comparison analysis. The current seismic design method of Japan prepares several Seismic Calculation Routes according to characteristics of buildings for reinforced concrete structures as explained in the previous section. Seismic Calculation Route 3 is selected as it is a usual route for 5-story moment-resisting frames..

The seismic code of the Philippines (NSCP2010: National Structural Code of the Philippines) is prepared by a private association of structural engineers, ASEP (Association of Structural Engineers of the Philippines), referring to structural codes of the United States namely UBC1997, ASC318, ASCE and so on.

Comparison study on the two codes is conducted. It is found that basic structures of the codes and components which consisting the codes are common which is shown by Figure 3. Table 1 shows key components/items of seismic design methods.

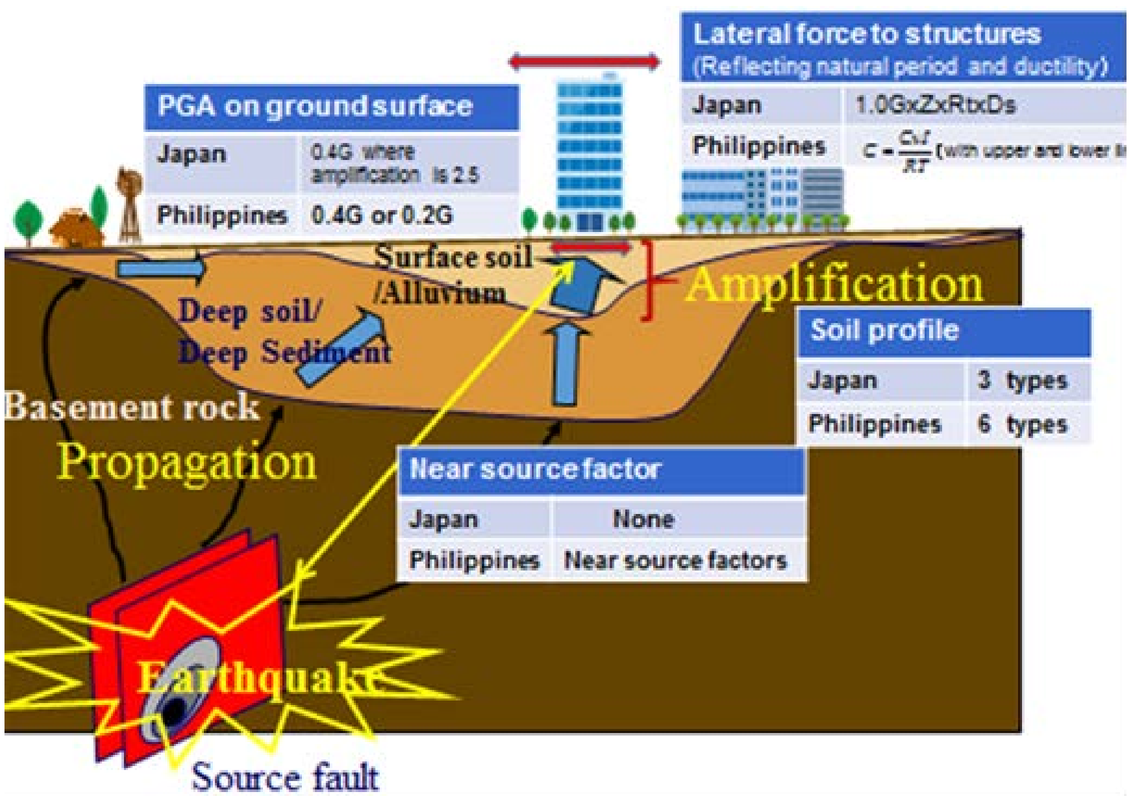


Fig. 3 – Basic structure of seismic design method

Table 1 – Comparison of each of components/items of seismic design methods

Items for structural design	Japan	The Philippines
return period	Around 500 years (not clearly stated)	475 years
Design base shear factor (coefficient)	$C = ZRt\ C_0 D_s$ Z= 1.0	$C = \frac{CvI}{RT}$
Vertical distribution of seismic forces	Ai $A_i = 1 + \left(\frac{1}{\sqrt{\alpha_i}} - \alpha_i\right)\frac{2T}{1+3T}$	Inverted triangle
zone in seismic hazards	coefficient (1.0, 0.9, 0.8, 0.7)	0.4, 0.2
Near source coefficient	none	1.6, 1.2, 1.0
Reflection of ductility (RC)	Ds (0.55 - 0.3)	R factor (3.5- 8.5) (inverted numbers: 0.29 - 0.12)

2.4 Comparison of key items between Japan and the Philippines

Figure 4 shows hazard maps of each country. It shows four zones in Japan and two in the Philippines. Figure 5 shows relation between natural period of structures and response coefficient. In Japan, influence of soil profiles is also described in this figure. Figure 6 shows vertical distribution of lateral force. The Japanese formula reflects characteristics of structures in vibration.

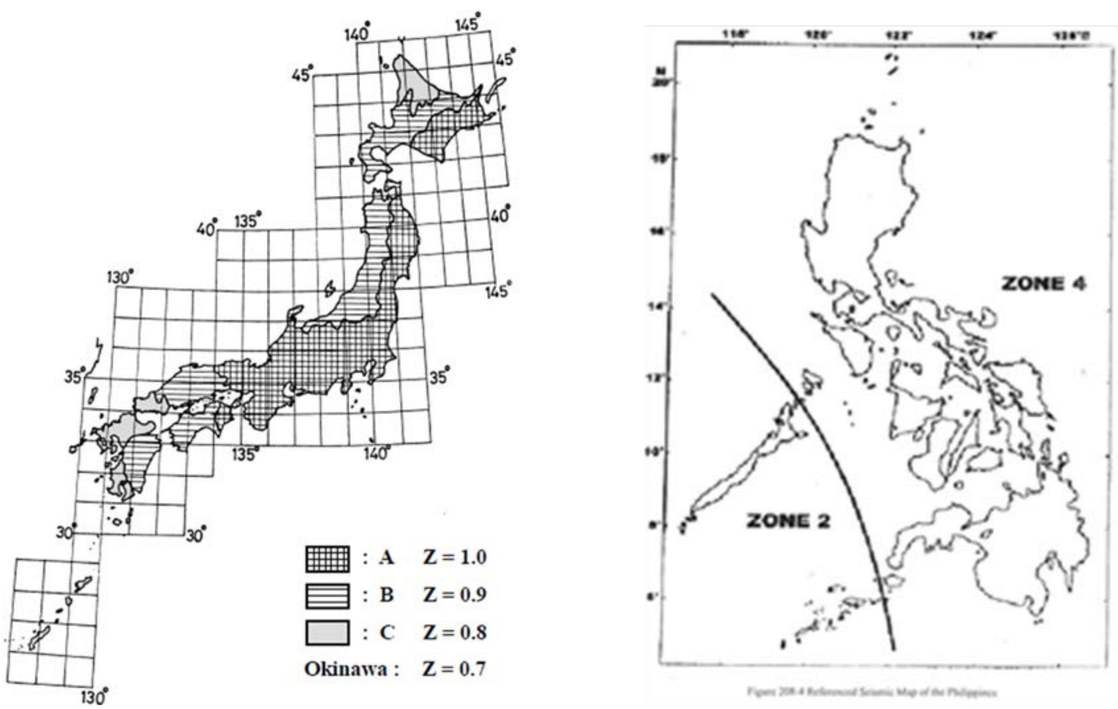


Fig. 4 – Seismic hazard maps (left: Japan, right: the Philippines)

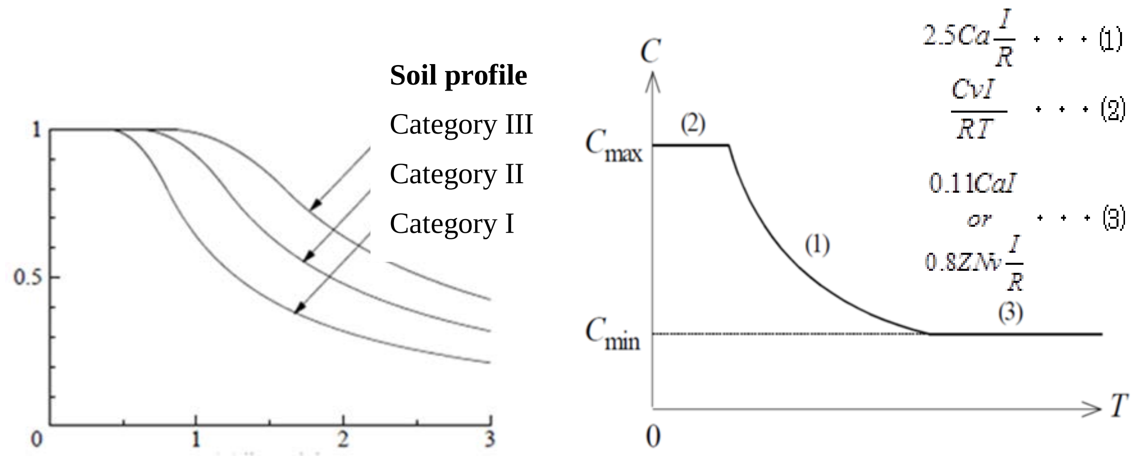


Fig. 5 – Elastic response coefficient and natural periods of structures

(left: Japan, right: the Philippines)

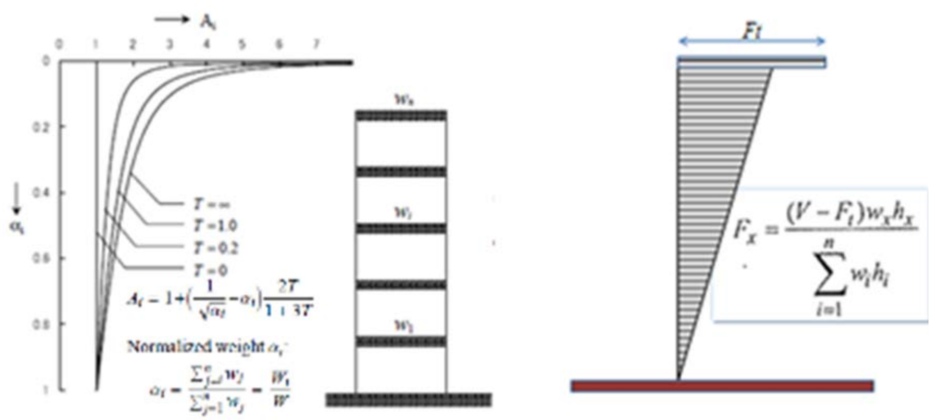


Fig. 6 – Vertical distribution of lateral forces by earthquakes

(left: Japan, right: the Philippines)

2.5 Comparison of key items on RC buildings

Table 2 shows values on several important items for seismic designs of 5-story RC housing buildings of short natural periods (moment resisting-frames) located in the capital city areas in both countries. It indicates target seismicity such as return periods, and ground acceleration is similar. On the other hand the base shear factors (elastic response coefficient) become larger in the Philippines especially when Near-source factors or Importance factors for occupancy are applied. The effect by ductility is larger in the Philippines (lateral force for seismic design could be reduced from elastic response base shear in a large degree) even though the values calculated with the ductility factors are applied in different ways, which are explained in detail in the next chapter.

2.6 Comparison of design base shear in relation with natural period of buildings

The both codes stipulate simple calculation formulas for natural periods of buildings mainly in accordance to height of buildings. The calculated results by both codes are shown in Fig. 7, which shows natural periods by Philippine code is longer compared with those by the Japanese. Fig. 8 shows relation between natural periods and elastic response base shear coefficient in case of 5-story RC housing buildings (Near Source Factor is applied in Philippine buildings). It indicates the elastic response base shear coefficient based on the Philippine code is larger. However natural periods based on Philippine code is larger as shown in Fig. 8 left. Fig. 8 right is similar figure as Fig. 8 left, but horizontal axis is height of buildings instead of natural period. It clarifies elastic response on the Philippine code is smaller in case of higher buildings especially in case of applying the detailed calculation method for natural periods.

Table 2 – Key items for seismic design for 5-story RC buildings located in Capital city areas in Japan and the Philippines

Components	Tokyo, Japan	Metro Manila, the Philippines			
		near source*		not near source	
		important facilities**	usual	important facilities**	usual
Ground acceleration	0.4G	0.4G			
Return period (years)	500	475			
Amplification by elastic response	2.5 (assumed)	2.5			
Seismic zone factor	1.0	1.0			
Influence by soil profile	1.0	1.1			
Effects by near sources	none	1.2		1.0	
Importance factor by occupancy	none	1.5	1.0	1.5	1.0
Base shear factor	1.0	1.98	1.32	1.65	1.1
Effect by ductility of structures	0.3 (Ds)	0.118 (1/R)			
Necessary ultimate lateral capacity	0.3	—	—	—	—
Design base shear	—	0.23	0.16	0.19	0.13

* cases when Near Source Factors are amplified for locations very near to seismic source
** cases when Seismic Important Factors are amplified for essential facilities

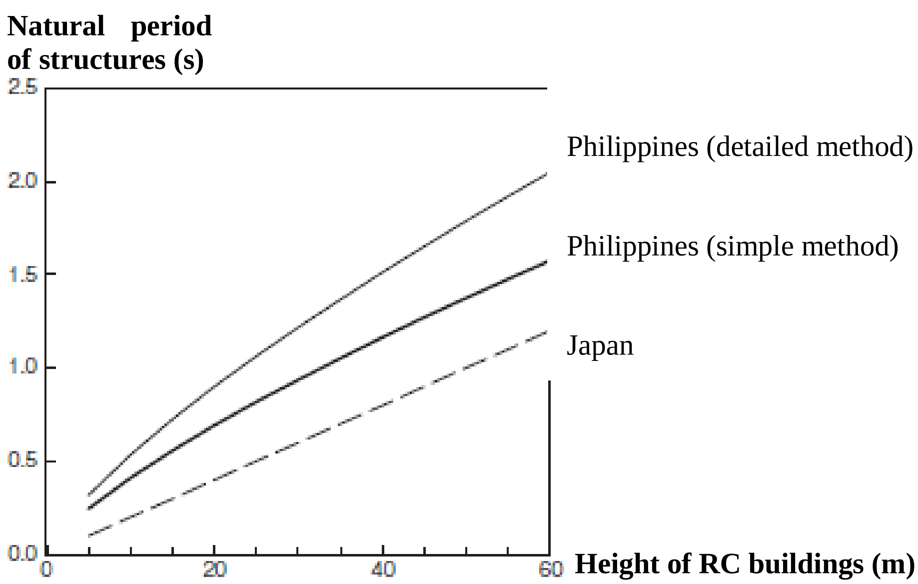


Fig. 7 – Relation between height of RC buildings and natural periods based on the formulas in the codes

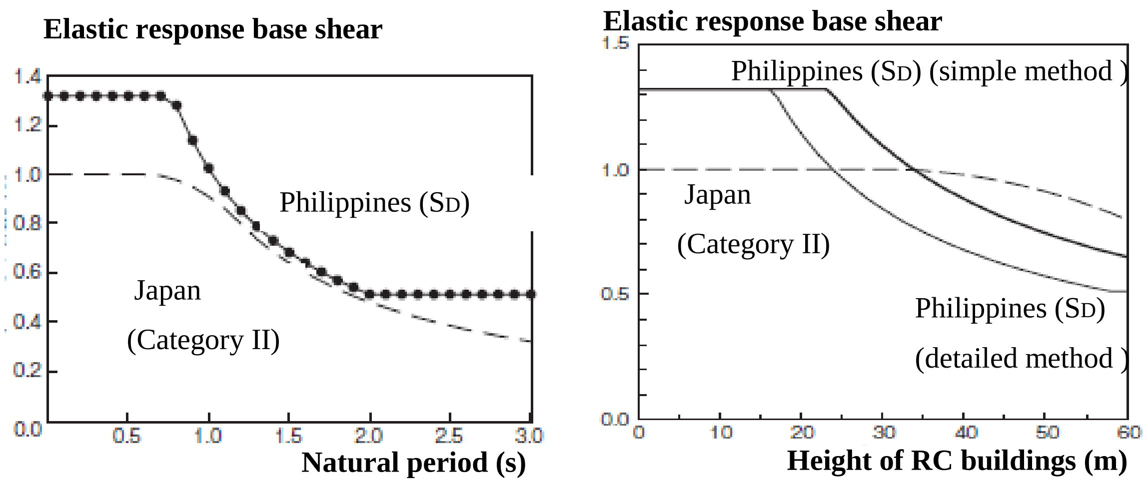


Fig. 8 – Elastic response base shear coefficient in accordance to natural periods (left) and to height of buildings (right) based of the codes

2.7 Overview of Seismic Calculation Route 3 on Japanese building code

Figure 9 shows conceptual image of Seismic Calculation Route 3 for RC buildings and Figure 10, its design procedures. It is quite important that the Route 3 applies non-linear analysis such as pushover analysis to verify resilience of structures against lateral force whereas corresponding design method in the Philippines (static analysis) applies linear analysis. The idea of pushover analysis is shown in Figure 11. It reproduces non-linear behavior of structures exposed to large lateral force beyond critical point of yielding of rebar and provide important information on occurrence of failures (position, time history, types (shear, compression or tensile) and so on), balance of stiffness and strength among structural members, and final failure mechanism. All are quite significant information to make structural designs to be rational and well-balanced. Nowadays it is usual practice in Japan to apply this analysis method for structural design thanks to availability of practical calculation soft wares. The calculated values (defined as Necessary Ultimate Lateral Capacity in the Japanese code (see Table 2. The notation in Figure 9 is “Design capacity for ultimate state” Q_B) are used to verify whether maximum lateral strength of the structure (Q_C in Figure 9) is larger than this.

Another important difference is determining procedures of the factors on ductility. As shown in Figure 10, the values of *Ds* in Japanese code are determined on results of analysis of each of the designs whereas it is given in the table in accordance to structural types in the code in the Philippines.

3. Conclusion

The comparison study reveals the structural codes of Japan and the Philippines are similar in

a) the basic components/items of the codes and the structure composed of them

b) the seismicity for structural design in the capital city areas

On the other hand, they are different in

c) Seismic Calculation Route 3 on the Japanese code usually applies pushover analysis to verify safety by reproducing failure procedures of structures whereas the static analysis on the Philippine code, linear analysis

d) the expected effects by ductility is larger in the Philippine code

e) the elastic response base shear coefficients become larger especially when Near-source factor and/or Importance factor is applied in the Philippines

Further detail comparison study is recommended to understand better and obtain implication to improve design methods of both countries to be more appropriate and practical.

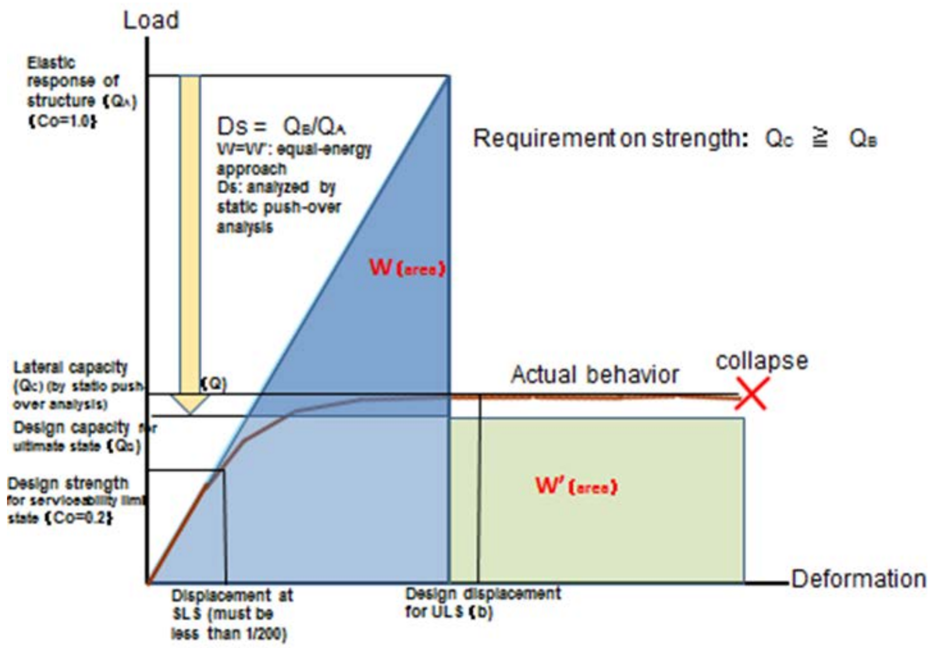


Fig. 9 – Conceptual image of Seismic Calculation Route 3 on Japanese code for RC buildings

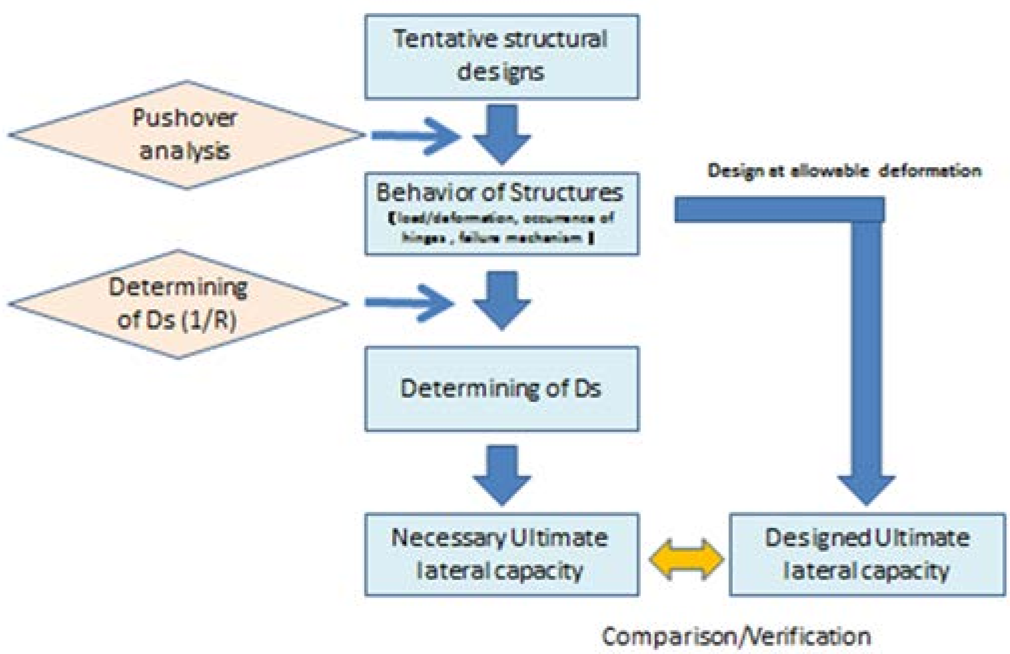
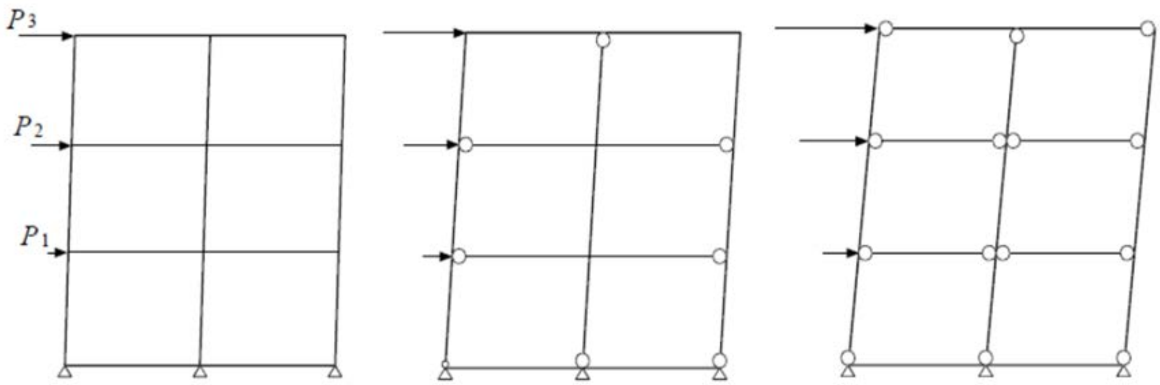


Fig. 10 – Design procedures of Seismic Calculation Route 3 on Japanese code for RC buildings



a) elastic range (no failures) b) occurrence of failures (o: plastic hinges) c) final failure mechanism

Fig. 11– Conceptual image of Push-over analysis
(analysis by gradual increase of lateral force from left)

4. Acknowledgements

This paper is based on discussion at a subcommittee on earthquake disaster management under CIB Committee in Architectural Institute of Japan (AIJ) and contribution of the members namely K. Shibanuma, R. Okamoto, M. Seki, T. Shimizu, H. Hosaka, S. Matsuzaki, A. Morita, M. Araki, H. Nakamura and K. Sakoda. The authors owe much to JICA Philippine Office for support on comparison work and video conference facilities for discussions in remote venues in Japan and the Philippines.

5. References

[1] Building Standard Law of Japan, http://law.e-gov.go.jp/htmldata/S25/S25HO201.html

[2] The National Building Code of the Philippines with its Implementing Rules and Regulations, Philippine Law Gazette

[3] National Structural Code of the Philippines Volume 1: Buildings, Towers and Other Vertical Structures,(2010) Association of Structural Engineers of the Philippines

[4] Tatsuo NARAFU, Yuji ISHIYAMA, Hideya KATO, Ryunosuke OKAMOTO, Toyokazu SHIMIZU, Mamoru JOH. Kazushi SHIRAKAWA, Shizuko MATSUZAKI, Matsutaro SEKI, Hiroto HOSAKA, Shigenori KITA, Keiko Sakoda KANEDA (2015) "Basic Study on Comparison of Structural Codes of the Philippines and Japan Part 1- Part 9", Proceedings of Annual Conference of Architectural Institute of Japan (AIJ)