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Comparison Studies on Structural Codes focusing on Effects of Shear Walls –Case Study on the Philippines and Japan –

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

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

The authors have been working on comparison study on structural codes to grasp required levels of performance against earthquakes, and difference and characteristics of codes. Since seismic codes have complicated structures and comprise of various factors and formulas, they take an approach to compare actual structural designs for the same simple architectural designs based on the codes of the Philippines and Japan. Their previous study on structures without shear walls (moment-resisting frames） entitled as "Comparison studies on structural codes focusing on story drift limit –Case study on the Philippines and Japan", shows story drift limit in the Philippine code is strict especially for moment-resisting frames. Therefore engineers usually employ shear walls to rationally satisfy the story drift limit. This paper analyze the same design buildings with shear walls (dual system). The authors design rational designs of RC five-story apartment buildings with shear walls which meet the story drift limit of the codes of the two countries, and apply pushover analysis to both of the designs. The analysis shows shear walls work well both against shear forces and story drift. At the same time they find issues to be further discussed such as 1) evaluation of ductility in structural calculation (***R*** factor in the Philippine code and ***Ds*** in the Japanese code), which is considerably different in the two codes, 2) behavior of "special boundary elements" stipulated in 421.8.6, and 3) comparison of modeling method of shear walls (FEM in the Philippines and equivalent linear members model in Japan). Finally the comparison study is summarized and recommendation on possible improvement of both codes and technical issues to be further discussed is presented.

Keywords: comparison study; structural codes; shear walls, Japan; the Philippines; pushover analysis, boundary element

1. Introduction

Most of earthquake prone countries have seismic codes. The authors have been working on comparison study on seismic codes to grasp required levels of performance against earthquakes, and difference and characteristics of codes. Since seismic codes have complicated structures and comprise of various factors and formulas, they take an approach to compare actual structural designs for the same simple architectural designs (Case Study Building) based on the codes of the Philippines and Japan where the co-authors are conducting practice of structural design. The structural code of the Philippines references Uniform Building Code UBC-1997 whereas that of Japan is rather unique in the world.

At first they choose a simple design of RC structures of five stories without shear walls (moment-resisting frame) for a case study building. They find that assumed ground shaking motion is similar in the two codes, on the other hand there exists a significant difference in calculation of design earthquake loads and story drift limit. Results of comparison study are reported in “Comparison studies on structural codes focusing on story drift limit - Case study on the Philippines and Japan -”, which show story drift limit in the Philippine code is strict especially for moment-resisting frames. Therefore engineers usually employ shear walls to rationally satisfy the story drift limit. This paper analyze the same design buildings with shear walls (dual system). The authors design rational designs of RC five-story apartment buildings with shear walls which meet the story drift limit of the codes of the two countries, and apply pushover analysis to both of the designs. The analysis shows shear walls work well both against shear forces and story drift. At the same time they find issues to be further discussed such as 1) evaluation of ductility in structural calculation (***R*** factor in the Philippine code and ***Ds*** in the Japanese code), which is considerably different in the two codes, 2) behavior of special boundary elements of special reinforced concrete structural walls stipulated in 421.8.6 of the Philippine code, and 3) comparison of modeling method of shear walls (FEM in the Philippines and equivalent linear members model in Japan). Finally the comparison study is summarized and recommendation on possible improvement of both codes and technical issues to be further discussed is presented. .

2. Framework of comparison study

2.1 Outline of Case Study Building

Case Study Building is selected from buildings which are usually found in both countries with simple and regular configuration for easy and clear analysis shown in Figure 1. Structural calculation software, ETABS, is used to design Case Study Buildings based on the Philippine code. SS3 by Union System is used to design buildings on the Japanese code and also to analyze the buildings by pushover analysis.

*Case Study Building

- Location: capital city area in each of the Philippines and Japan

- Soil profile: usual type in the location (Japan: Category 2, the Philippines: $\boldsymbol{S_D}$)

- Structural type: Reinforced concrete 5-story buildings with shear walls (dual systems)

- Configuration: symmetric in two directions

- Number of spans: 4 spans in each X and Y direction

- Length of spans: 6 m for all the spans

- Story height: 2.86 m in all the stories

-Total height of buildings: 14.5 m

-Occupancy: houses

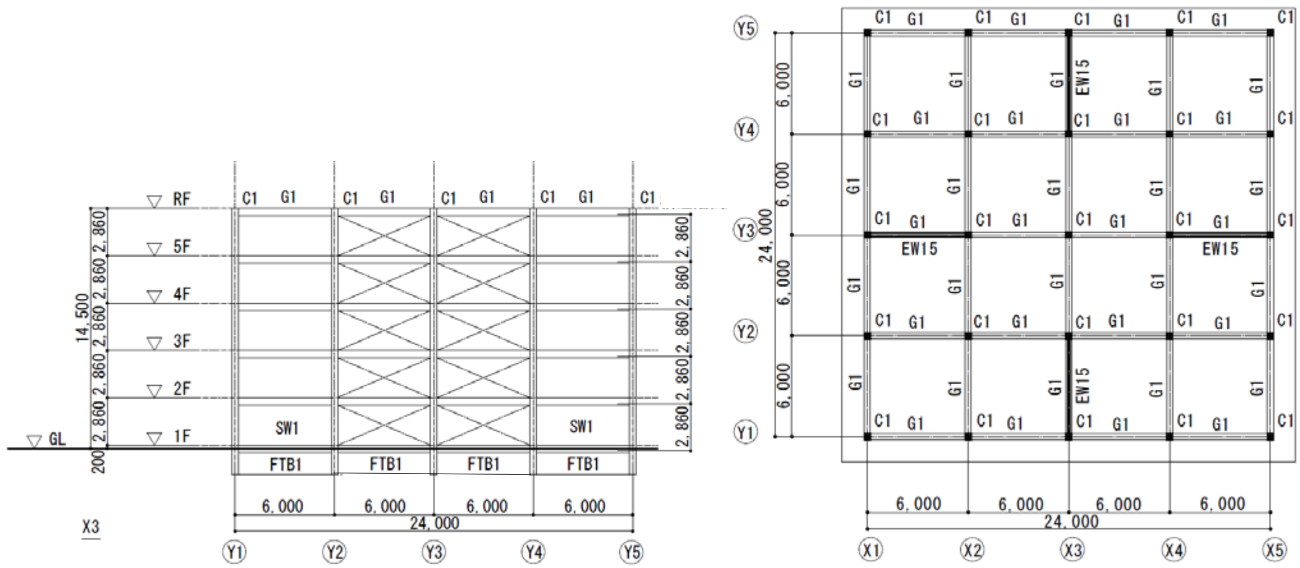

Fig. 1 Plan (left) and elevation (right) of Case Study Building

(two shear walls are installed in each of X and Y direction)

2.2 Overview of procedures of design and analysis

Overview of procedures of design and analysis of buildings is as follows,

1) to design a structure of Case Study Building without shear walls (moment resisting frame) which satisfy requirements by loads and story drift stipulated in the Philippine code (NSCP: National Structural Code of the Philippines) (Case P2). Case P2 is analyzed and reported in "Comparison Studies on Structural Codes focusing on Story Drift Limit - Case study on the Philippines and Japan -", a sister paper of this paper to be presented at 16WCEE

2) to design a structure of a building of the same configuration with shear walls which satisfies requirements of both loads and story drift limit (Case P3)

3) to design a structure of a building of the same configuration with shear walls which satisfies requirements by Japanese code on both loads and story drift limit (Case J2)

4) to compare and analyze Case P2, P3 and J2

2.3 Outline of Case P2 (dual system which satisfies both loads and story drift limit of NSCP)

List of sections of typical structural members of Case P2 is shown in Fig. 2, 3, and 4. Four shear walls are installed at location shown in Fig. 1 and section of the shear walls from ground floor to 4th floor is shown in Fig. 4. Table 1 shows outlines of structural members of Case P2 and P3 and comparison between them. Dimension of structural members of Case P3 is considerably smaller than Case P2 (Comparison E in Table 1) thanks to effect by the shear walls. Table 1 also shows comparison with Japan Case JI, which satisfies requirements of both loads and story drift limit stipulated in Japanese code. Comparison F in Table 1 shows dimension of structural members of Case P3 is smaller than Case J1. Some parts of shear walls adjacent to columns are designed as "special boundary element" to have longitudinal and tie rebar like columns. Length of the special boundary elements from edge of columns is 2,200 mm from ground floor to 4th floor and 1,150 mm above 4th floor. This type of design is not applied in Japan, where shear walls are surrounded by rather large dimension of columns and beams which tightly confine shear walls and modeling of shear walls is quite different which is explained in Section 3.3 2).

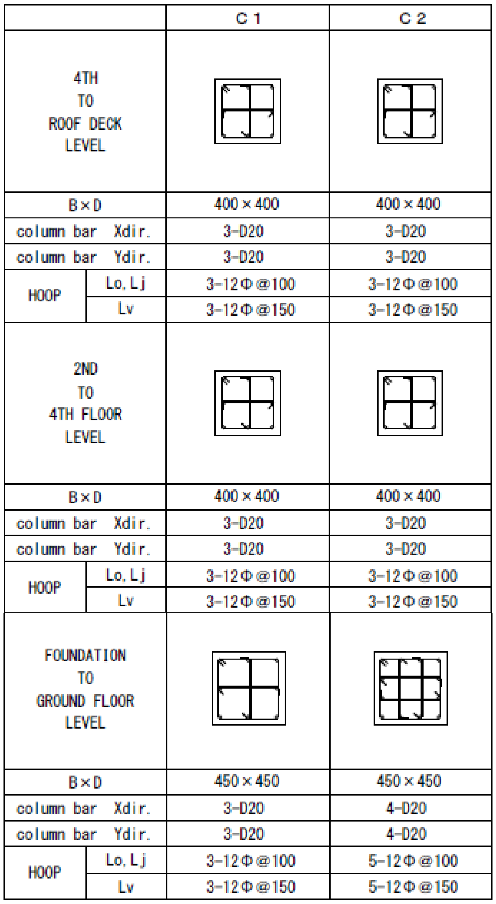

Fig. 2 List of sections of typical columns of Case P2 (dual system which satisfies loads and story drift limit)

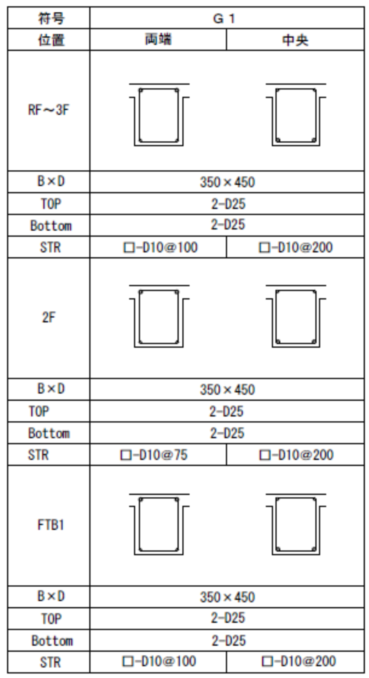

Fig. 3 List of sections of typical beams of Case P2 (dual system which satisfies loads and story drift limit)

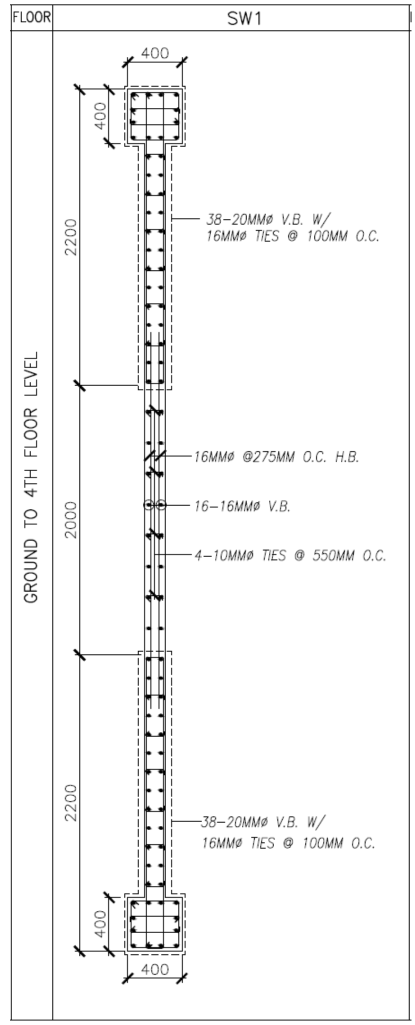

Fig. 4 Sections of typical shear wall and adjacent columns of Case P2 (dual system which satisfies loads and story drift limit)

Table 1 – Outline and comparison of structural members of Cases which satisfy requirements of each of codes

Items		Philippine Case 2 (A) (momentg resisting	Philippine Case 3 (B) (dual system)	Japan Case 1 (C)	Comparison	
					Comparison E (B/A)	Comparison F (B/C)
columns	dimension (mm)	800x800	400x400	750x750	—	—
	section areas (mm2)	640,000	160,000	562,500	0.25	0.28
beams	dimension (mm)	800x500	350x450	40x70	—	—
	section areas (mm2)	400,000	157,500	280,000	0.39	0.56
shear walls	outline	none	2 shear walls each in X and Y direction, thickness: 150mm	none	—	—
slabs	thickness (mm)	225	135	210	0.6	0.64
concrete	strength(N/mm2)	42	21	24	0.5	0.88

3. Comparison and analysis of Cases of P2, P3 and J1

3.1 Analysis on Case P3 by pushover analysis

Pushover analysis is applied to Case P3 and result is shown in Fig. 5 and 6. Story drift calculated according to provisions in NSCP is shown in red vertical lines in Fig. 5. Story drift at 1st floor is 1/1748 when reduction of inertia moment in not applied and 1/1314 when reduction is applied, both of which are far smaller than Case P2, which is 1/326 when reduction is not applied and 1/83 when reduction is applied shown in Fig. 7. This proves shear walls work well to reduce story drift. Attention should be paid to relation of the drift calculated based on the code and result of pushover analysis. In Case P3, story drift by pushover analysis is around 1/700, whereas story drift calculated based on the code is far less such as 1/1748 and 1/1314. In Case P2, story drift by pushover analysis is 1/105 whereas calculation based on the code are 1/326 and 1/83. This issue will be discussed in section 4.3 2) B. Fig. 6 shows crush of concrete in a column adjacent to shear wall occurs when load becomes large, which is deemed to be one of vulnerable types of failure.

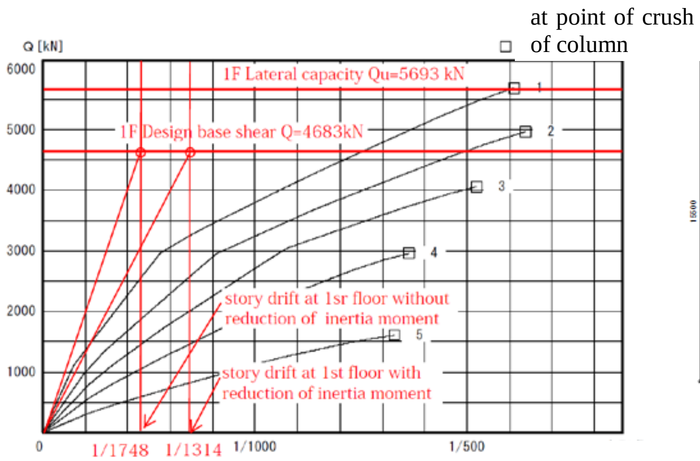

Fig. 5 Result of Pushover analysis on Case P3 Load/deformation curve of 1st floor (uppermost curve) to 5th floor (lowest)

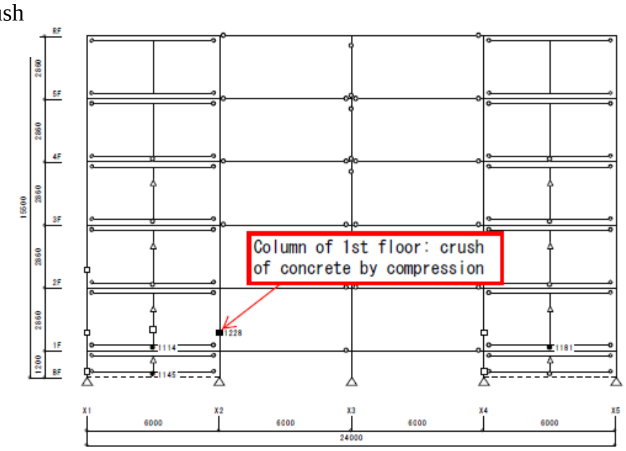

Fig.6 Result of Pushover analysis on Case P3 Crush of concrete of a column adjacent to a shear wall occurs at indicated point

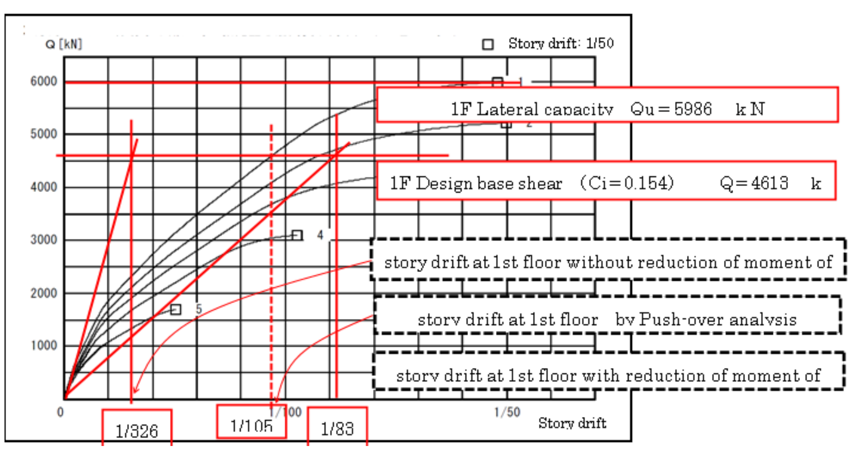

Fig. 7 Result of Pushover analysis on Case P2

Load/deformation curve of 1st floor (uppermost curve) to 5th floor (lowest)

3.2 Comparison of Case P3 with Case J2 (design which satisfies Japanese code)

A structural design with shear walls which satisfies requirements by Japanese code is conducted by revising Case P3. The design is called Case J2 in this paper. List of sections of typical structural members of Case J2 are shown in Fig. 8 and 9. Comparison of Case P3 and J2 (both have shear walls and satisfy requirements of codes of each of the countries) is shown in Table 2. Comparison G in Table 2 indicates section of P3 is smaller than J2 especially in columns. The special boundary element of P3 has rebar similar to columns and is assumed to bear axial force just like columns. In Case 2J dimension of columns adjacent to shear walls (C2 in Fig.8) is larger than other columns (C1 in Fig.8) because Japanese design policy on shear walls is that shear walls should be tightly confined by rather rigid columns and beam so as that distribution of shear stress in shear walls becomes more even and effectiveness of shear walls is increased.

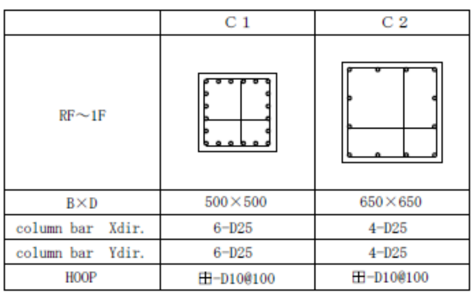

Fig. 8 List of sections of typical columns of Case J2

C1: usual columns C2: columns adjacent to shear walls

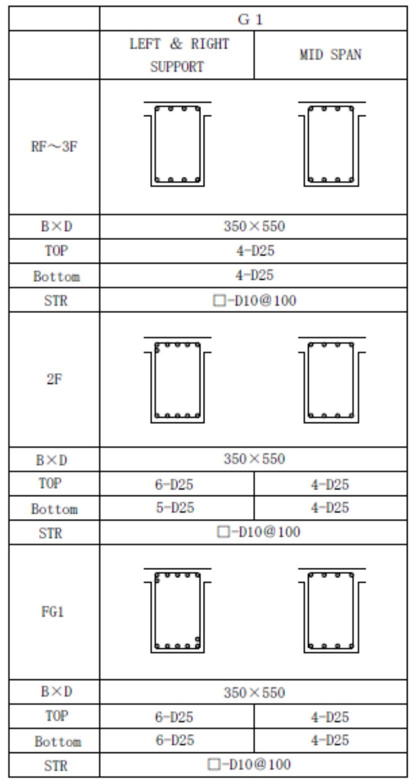

Fig. 9 P List of sections of typical beams of Case J2

Table 2 – Outline and comparison of structural members of Case P3 and J2

Items		Philippine Case 3 (B) (dual system)	Japan Case 2 (D)	Comparison Comparison G (B/D)
columns	dimension (mm)	400x400	500x500	—
			650 x 650	—
	section areas (mm2)	160,000	250,000	0.64
			422,500	0.38
beams	dimension (mm)	350x450	350x550	—
	section areas (mm2)	157,500	192,500	0.81
shear walls	outline	2 shear walls each in X and Y direction, thickness: 150mm	2 shear walls each in X and Y direction, thickness: 150mm	—
slabs	thickness (mm)	135	135	1.0
concrete	strength (N/mm2)	21	21	1.0

3.3 Discussion on key issues on comparison of Case P3 and J2

1) Evaluation of effect of ductility in calculation of design seismic loads

Both of the codes allow to reduce design seismic loads from elastic response shear force considering effect of ductility. In the Philippines, design seismic load is calculated by dividing elastic response seismic loads by ***R*** Factor. In Japan, design seismic load is calculated by multiplying with ***Ds***. In the Philippines the same **R** Fctor should be used when shear walls are installed. On the other hand in Japan, larger ***Ds*** should be used when shear walls are installed considering behavior of total structure would be changed by shear walls.

2) Analytical modeling methods of shear walls

In the Philippines, shear walls are analyzed with FEM (Finite Element Method) shown in Fig. 10. In Japan most of structural calculation softwares employ modeling method shown in Fig. 11. In the modeling, all the structural members are modeled to be linear members. Shear walls are also modeled to be linear member which have very large capacity against lateral force. The shear walls are designed to be supported by rigid beams, ends of which are connected to columns with pin connection in order not to transfer moments at connection. In the model, columns are connected to beams with pin connection in order not to bear lateral force. In other words, shear force is born only by shear walls in the model.

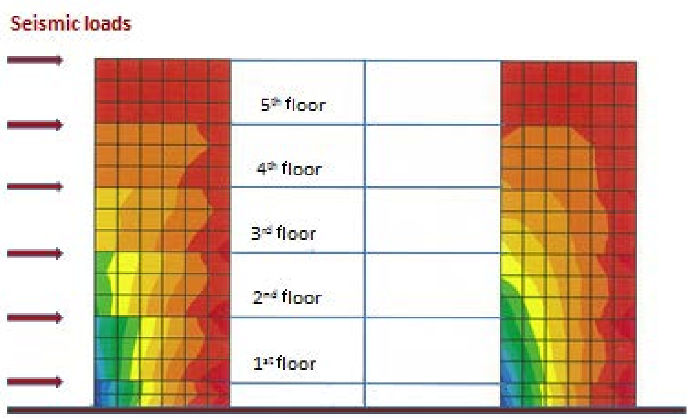

Fig. 10 Analysis of shear walls of Case P3 by FEM (Finite Element Method)

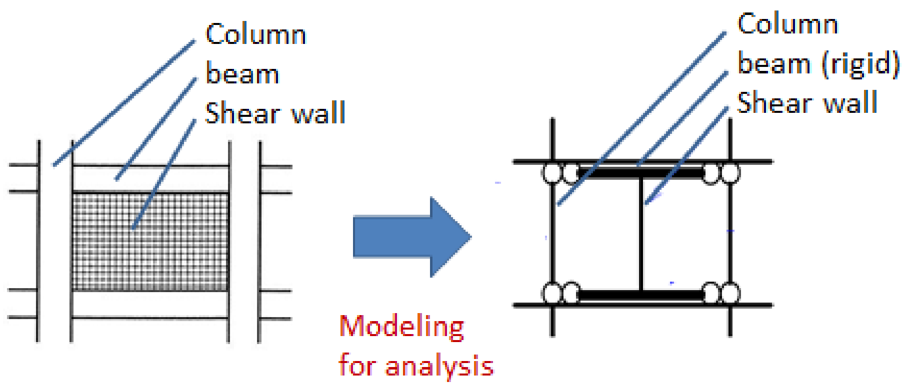

Fig. 11 Modeling method used in structural calculation softwares in Japan

4. Summary of comparison study and recommendation

4.1 Summary of comparison study

All the procedures of this comparison study including report by "Comparison studies on structural codes focusing on story drift limit - Case study on the Philippines and Japan -" could be summarized as follows,

1) Structural design of 5-story RC housing with a same configuration is conducted based on the Philippine code and Japanese code

2) Assumed ground acceleration in the Philippines is larger by 10% because of evaluation of effect of soil condition. In case of the Philippines, the code has specific factor (Near Source Factor) to reflect seismic source near construction sites. In metro Manila area there exists a large active fault and ground acceleration must be amplified by 1.2 when construction site located within 5 km from the large seismic source (case of maximum value). Therefore the assumed ground acceleration is 1.32 times larger compared with that of Tokyo in this study.

3) To calculate design seismic load, the Philippine code allows to apply 8.5 for ***R*** Factor and design seismic load is calculated to be 1.32/8.5=0.155. In Japan, design seismic load is decided using ***Ds*** values in a table in accordance with analysis of structure and structural members, which is 0.3 for ductile moment resisting frame.

4) Ductile moment resisting frames are designed based on the Philippine code and Japanese code. In the Philippines, moment resisting frame needs to have large dimension of structural members in order to meet story drift limit (Case P2).

5) Dual system structure (frame with shear walls. Case P3) is designed based on the Philippine code, which satisfies story drift limit in reasonable manner and usually employed by Philippine engineers. The dimension of structural members is smaller than both of the moment-resisting frame base the Philippine code (Case P2) and the one based on Japanese code (Case J2). However the result of pushover analysis shows Case P3 would fail in crush of concrete of columns adjacent to shear walls when load becomes larger than the design seismic load.

6) Reasons of the smaller dimension of Case P3 than J2 is considered 1) the design seismic load in Manila is smaller thanks to larger reduction by ***R*** Factor than that of Tokyo, even though assumed ground acceleration in Manila is larger than in Tokyo, 2) the special boundary elements are expected to support axial force and could contribute to reduce axial force for columns.

7) In both countries, adoption of shear walls could reduce dimension of structural members. However there exists significant difference on evaluation of effects of ductility for dual systems. In the Philippines same ***R*** Factor with moment-resisting frame could be applied to dual systems as far as frames have same detailing whereas in Japan larger ***Ds*** must be applied based on analysis of behavior of structure with shear walls.

4.2 Summary of comparison of the codes

There are many differences between Philippine code and Japanese one. Among them those listed below are ones which have strong influence to actual structural design.

1) Philippine code has Near Source Factor and Importance Factor according to types of occupancy which Japanese code does not. When those are applied, assumed ground acceleration would be considerably larger in the Philippines as assumed basic ground acceleration is similar in both countries.

2) Evaluation of effect of ductility is larger in the Philippines (comparison between ***R*** Factor and ***1/Ds***), which allows larger reduction in calculation of design seismic loads from elastic response shear forces.

3) In structural analysis on Philippine code, effects of cracks in concrete of structural member must be considered, which makes calculated story drift larger, whereas effects of cracks are not considered in Japan. This issue seems to influence to calculation methods of natural periods of structures.

4) Application methods of design seismic loads are different. In the Philippines it is applied to design dimension of structural members by linear analysis so as to stresses are within material strength at all points of the structural members. In Japan it is used to verify the maximum lateral strength (defined as "Ultimate

Lateral Capacity" in the Japanese code) calculated in non-linear analysis (usually pushover analysis in recent years).

5) In the Philippines, shear walls and slabs are analyzed by FEM. In Japan, shear walls are modeled to be a combination of linear members and slabs are assumed to be rigid.

6) Philippine code adopts design method of special boundary element for shear walls which are expected to support axial force like columns. Japanese code does not have similar one.

4.3 Recommendation

Detail analysis and discussion on possible revision of the codes and discussion on key technical issues is recommended as follows.

1) Possible revision of codes

A. Philippine code (NSCP: National Structural Code of the Philippines)

a. Application of Pushover analysis for important buildings

Understanding on ultimate state (what kind of failures occur in which positions when load go beyond design seismic loads) provides significant inputs for more resilient design. In Philippine code, structural design is conducted at a point of design seismic load and safety/resilience of structures beyond the design load relies on specification requirements such as hoops and ties without simulating the behavior. In this study the pushover analysis on Case 3P shows it would have a vulnerable type of failure of crush of concrete in columns when load becomes larger beyond the design load. Important buildings such as bases for rescue and response activities, hospitals, police stations, and fire department are expected to function even after a large scale earthquake. Therefore it is recommended to apply pushover analysis to understand ultimate state for improvement of design to be more resilient by avoiding vulnerable types of failures.

b. Introduction of verification of serviceability limit state for specific buildings

In Philippine code structural design is conducted at a point of design seismic load to be resilient against large scale earthquakes. This procedure assures safety of people at a large scale earthquake but not functioning/usage of the building after the earthquake. (Technical requirements by the code allow structural members to fail and need repair works for functioning) Therefore buildings exposed to moderate earthquakes and required to be used without repair works such as public buildings which are expected to be utilize as emergency shelters are recommended to be applied with "serviceability limit state" verification in addition to current "ultimate state limit". This is recommended in ISO 3010 "Basis for design of structures — Seismic actions on structures". Japanese code introduces it as "First stage seismic calculation against moderate earthquake ground motion (return period of several decades)".

B.Japanese code (Building Standard Law and relevant orders)

a. Introduction of a new seismic calculation route in linear analysis for simple and small buildings

Japanese code requires non-linear analysis for most of buildings (linear analysis such as seismic calculation route 1, 2-1, and 2-2 is prepared but application is limited to small and certain types of buildings with many structural walls). For simple and regular types of buildings, complicated non-linear analysis is not always necessary and introduction of a new seismic calculation route on linear analysis is recommended to be discussed. The new route would be more practical and user-friendly especially when various different conditions and combination of loads (earthquakes, typhoons, tsunami, etc.) needs to be considered.

2) Discussion of key technical issues

Several key technical issues which are different in two codes and influence much in structural designs are identified. It is recommended to review technical background of each code, analyze causes of difference and discuss on possible improvement. It should be noted that structural codes must discussed as a whole and accuracy only from view point of scientific knowledge does not necessarily improve the code in practical points of view.

A. Calculation of loads

a. Calculation methods of natural periods

Both codes prepare simple calculation methods of natural periods and differ considerably from each other. Calculated values of natural periods influence much on elastic response seismic loads. Difference should be analyzed and evaluated considering effects to total procedures of structural design.

b. Evaluation of effects of ductility

This issue is one of the most influential ones which causes difference in actual designs between in the Philippines and Japan. Also it is the most important idea for current structural design policy to secure safety of people with failures in structural members.

B.Modeling and structural analysis

a. Reduction of rigidity (consideration of cracks in concrete)

This issue influences to calculation of story drift and natural period. Regarding story drift the method of reduction of inertia moment results big difference in story drift between moment-resting frame and dual system which can be seen in Fig. 5 and 7. It has difficult aspects that rigidity of structure changes during shaking motion and needs to be discussed from every relevant view point.

b. Modeling of shear walls and slabs

Shear walls and slabs are analyzed by FEM in the Philippines. In Japan shear walls are modeled to be combination of linear member and slabs to be rigid. Japanese modeling method is rather unique and based on design practice in Japan. Discussion should be made considering this fact.

C.Designing of structural members considering story drift

Story drift is another critical issue which directly influences safety of structure by inviting dangerous damage such as total collapse. It may also cause serious damage to rigid non-structural members. This issue is more significant in the Philippines as it is not directly analyzed but calculated by simple formulas provided in the code. Criteria for story drift limits also should be importnatr topics to be discussed.

5. Acknowledgements

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