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Comparison studies on structural codes focusing on story drift limit - Case study on the Philippines and Japan -

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Abstract

The authors have been working on comparison study on seismic design codes to grasp required levels of performance, and the difference and characteristics of codes. Since seismic design 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. They choose a simple design of RC structures of five stories without shear walls. They find that there exists a significant difference in story drift limit in the two codes. The rational design, based on strength alone, of a moment-resisting frame which meets requirements by load combination of the Philippine code does not satisfy the limit of story drift. Therefore, they try to reduce the story drift by increasing dimension of columns and beams, enlarging thickness of slabs and using concrete of high strength. A design which satisfies the story drift limit is compared with a design based on Japanese code. Pushover analysis is applied to three designs to analyze behavior focusing on the story drift. The analysis shows the story drift calculated based on the provisions of the Philippine code is far large than that by the pushover analysis. The authors conclude RC structures in the Philippines are recommended to have shear walls to rationally satisfy the story drift limit and the provisions in the Philippine code to calculate story drift for moment-resisting frames needs further discussion.

Keywords: structural codes, comparison studies, story drift limit, Japan, the Philippines

1. Introduction

Most of earthquake prone countries have seismic design codes. The authors have been working on comparison study on seismic design codes to grasp required levels of performance against earthquakes, and the difference and characteristics of codes. Since seismic design 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 to Uniform Building Code UBC-1997 whereas that of Japan is rather unique in the world. 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 designs earthquake loads and story drift limit. Therefore, pushover analysis is applied to the structural designs on the Philippine code and Japanese one to analyze behavior of the structures to grasp characteristics of the codes.

2. Framework of comparison study

2.1 Outline of Case Study Building

Case Study Building shown below is selected from buildings which are usually found in both countries with simple and regular configuration for simple and clear analysis. 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 to analyze the buildings by pushover analysis.

- Location: capital city area in each of the Philippines and Japan
- Soil profile: usual type in the location (Japan: Category 2, the Philippines: S_D)
- Structural type: reinforced concrete 5-story building, moment-resisting frame
- Configuration: symmetric in two directions with 4 spans of equal length

  story height: 2.86m in all the stories

  total height of buildings: 14.5m
- Occupancy: houses (residential)

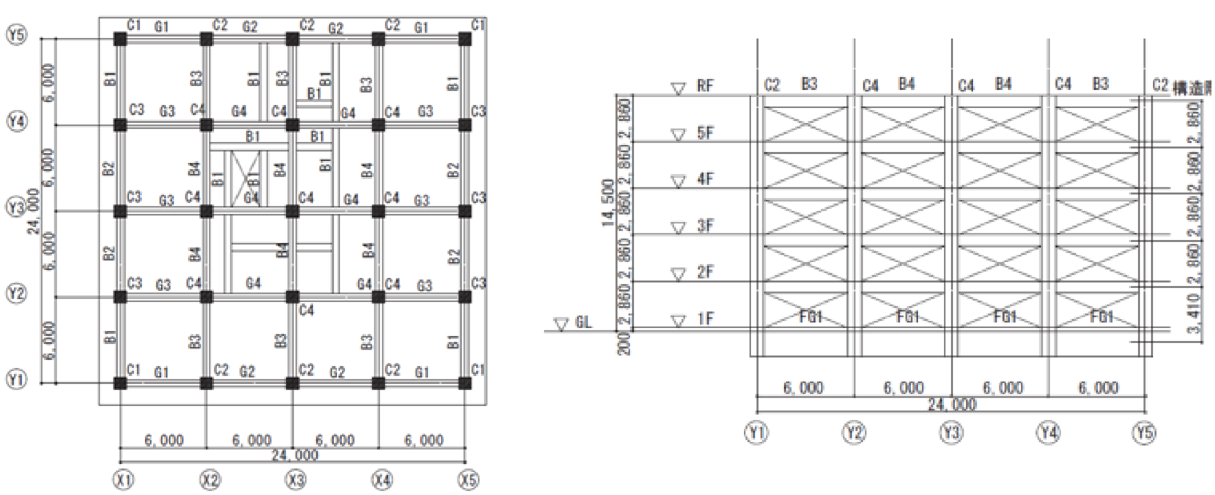

Fig. 1 Plan (left) and elevation (right) of Case Study Building

2.2 Overview of designing and analyzing procedurs

Overview of designing and analyzing procedures is as follows,

1) to design a structure of a Case Study Building which satisfies the requirements by loads stipulated in the Philippine code (NSCP: National Structural Code of the Philippines), strength capacity compliant, but compliance with story drift limit not verified (Case P1)

2) to revise Case P1 to satisfy both strength capacity and story drift limit (Case P2)

3) to design a structure of a Case Study Building which satisfy requirements by loads stipulated in the Japanese code (Building Standard Law and its relevant ordinances and regulations) (Case J1), which simultaneously satisfies story drift limit

4) to compare and analyze Case P1, P2 and J1

3. Overview of procedures of structural design based on Japanese code

The Japanese code prepares several "seismic design calculation route" such as Route 1, Route 2 and Route 3. For this study, Route 3 is applied which are usually used for buildings like Case Study Buildings of 5-story moment-resisting frames. The procedures are characterized in comparison with the Philippine code in 1) design base shear is applied to verify lateral strength of the structure calculated by analysis such as pushover analysis (Fig. 2), whereas that of the Philippine code is applied to verify critical point of appearance of plastic hinges, 2) factors to calculate the design base shear in Japanese code (***Ds***, equivalent to inverted number of ***R*** factor in the Philippine code) is decided based of analysis of failure mechanism of the building (Fig. 3), whereas ***R*** factors are given in a table of NSCP in the Philippines.

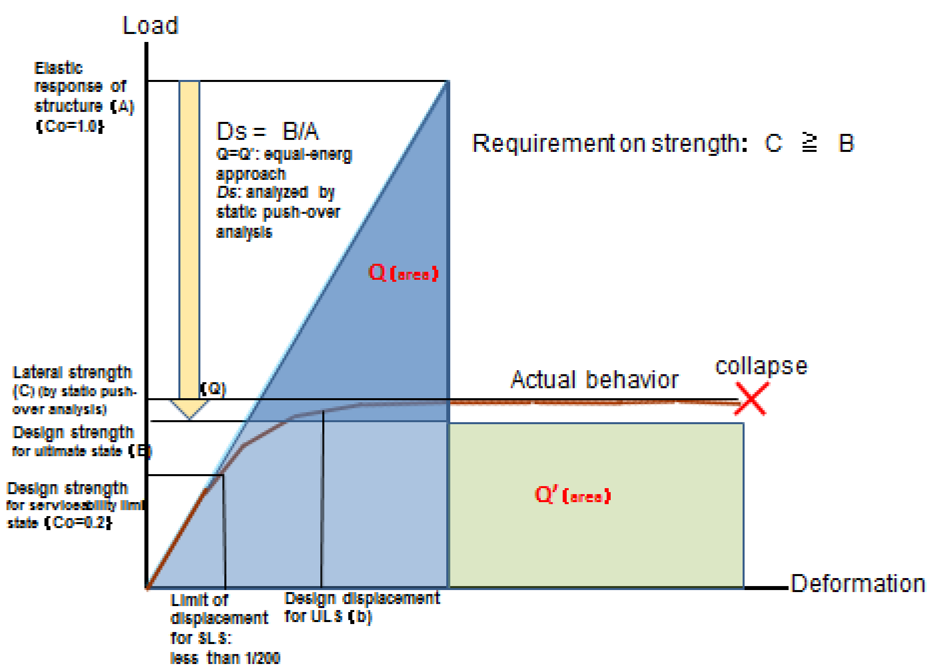

Fig. 2 Conceptual model of structural design of Seismic Calculation Route 3 on Japanese code

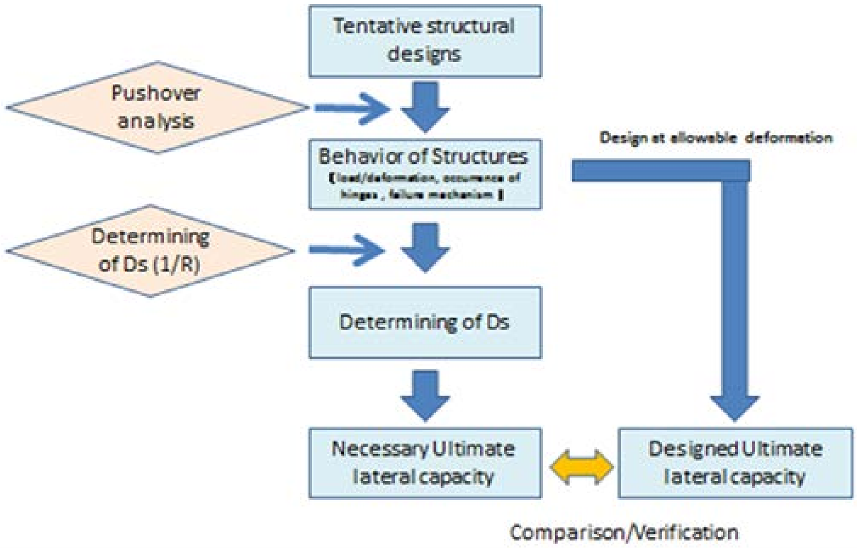

Fig. 3 Flow of structural design procedures of Seismic Calculation Route 3 on Japanese code

The story drift limit under the design seismic shear force for serviceability limit state shall not exceed 1/200 (.005) of the story height. The value can be increased to 1/120 (.0083) in case non-structural elements are designed not to have severe damage when the story drift becomes large.

4. Overview of the structural design based on the Philippine code

The National Structural Code of the Philippines (NSCP) provides the design procedures and basis for design of buildings. The earthquake provisions of the code are largely adapted from the Uniform Building Code, UBC 1997. Faults location are based on the studies performed and fault mapping by the Philippine Institute of Seismology and Volcanology (PHIVOLCS). The seismic design base shear is influenced by the location or the nearness of the building to the fault source, the soil-type, the building type and and the magnitude of the ground motion for the design level earthquake.

The structural members are designed for the maximum effects of the combination of factored dead, live and earthquake loading conditions as determined by elastic analysis.

The structures are analyzed using cracked sections or reduced moment of inertia. Typical cracked sections used in the analysis are $.35I_g$ (I_g = moment of inertia of the gross concrete section) for beams and $.7I_g$ for columns and walls as required by the NSCP 410.12.3 provisions.

Aside from providing the strength capacity requirements of the structural members, the building is required to comply with story drift limitations in NSCP 208.5.9.2. The story drift is computed using the maximum inelastic response displacement, $\triangle_{M,}$ which is the displacement when the design basis ground motion is applied to the structure.

$$\triangle_M = 0.7R\triangle_S \tag{1}$$

$\triangle_S$ or the design level response displacement results from code-prescribed seismic force and ***R*** or the response modification factor is based on the structural lateral system. In the case of this study, ***R*** is taken to be ***8.5*** for the special moment resisting space frame. $\triangle_S$ is obtained at different story levels based on a static, elastic analysis. For structures with a fundamental period, ***T***, less than 0.7 seconds, the calculated story drift,$\triangle_{M,}$ shall not exceed .025 times the story height, 1/40. While for structures with ***T*** > 0.7 seconds, the calculated story drift shall not exceed .020 times the story height or 1/50.

CASE 1

		C 1	C 2
4TH TO ROOF DECK LEVEL			
B×D		450×450	450×450
column bar Xdir.		3-D25	3-D25
column bar Ydir.		3-D25	3-D25
HOOP	Lo, Lj	3-12Φ@100	3-12Φ@100
	Lv	3-12Φ@150	3-12Φ@150
2ND TO 4TH FLOOR LEVEL			
B×D		500×500	500×500
column bar Xdir.		3-D25	4-D25
column bar Ydir.		3-D25	5-D25
HOOP	Lo, Lj	3-12Φ@100	3-12Φ@100
	Lv	3-12Φ@150	3-12Φ@150
FOUNDATION TO 2ND FLOOR LEVEL			
B×D		500×500	500×500
column bar Xdir.		5-D25	6-D25
column bar Ydir.		5-D25	7-D25
HOOP	Lo, Lj	3-12Φ@100	3-12Φ@100
	Lv	3-12Φ@150	3-12Φ@150

	G 1 (FTB1)		
	LEFT SURPPORT	MIDSPAN	RIGHT SURPPORT
RF			
B×h	300×500		
TOP	2-D25		
Bottom	2-D25		
STP	□-D10@75	□-D10@200	□-D10@75
3~5F			
B×h	300×500		
TOP	5-D25	2-D25	5-D25
Bottom	3-D25	2-D25	3-D25
STP	□-D10@100	□-D10@200	□-D10@100
2F			
B×h	300×500		
TOP	6-D25	2-D25	6-D25
Bottom	4-D25	2-D25	4-D25
STP	□-D10@100	□-D10@200	□-D10@100
FOOTING			
B×h	300×500		
TOP	5-D25	2-D25	5-D25
Bottom	5-D25	2-D25	5-D25
STP	□-D10@100	□-D10@200	□-D10@100

Fig. 4 List of sections of typical columns (left) and beams (right) of Case P1

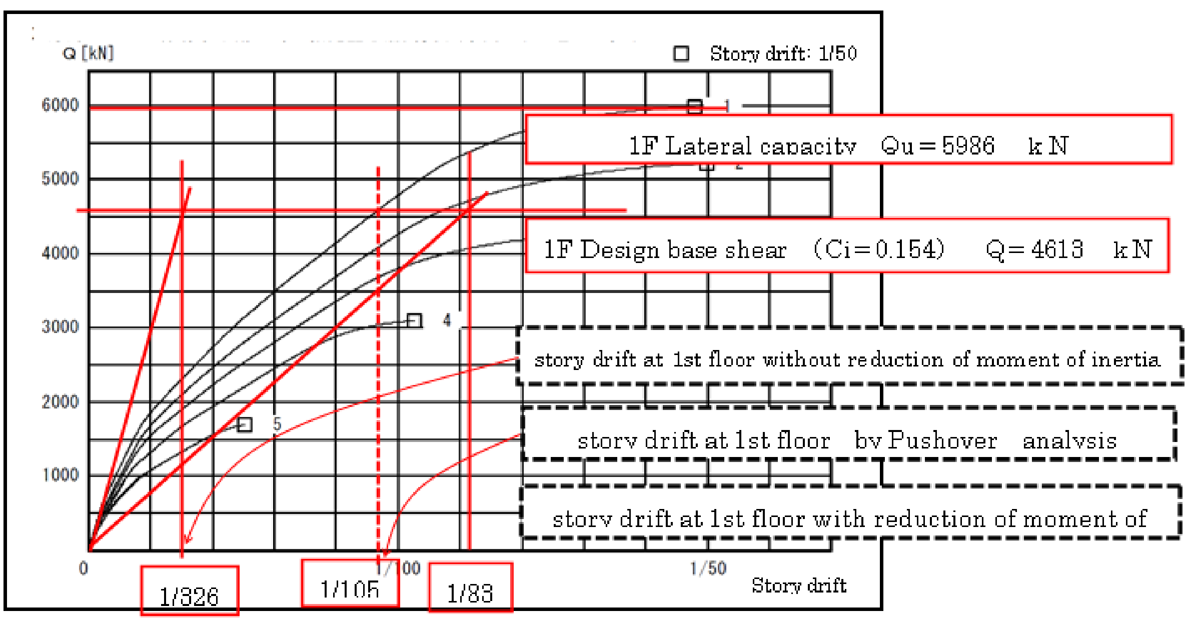

Fig. 5 Result of Pushover Analysis on Case P1

4.1 Design of Case P1

List of sections of typical structural members is shown in Fig. 4. The result of pushover analysis is shown in Fig. 5. The story drift at 1st floor is calculated to be 1/326, and 1/83 when I (moment of inertia) is reduced according to provision of the NSCP. (Story drift from the pushover analysis is also shown in Fig. 5 as 1/105.)

Maximum inelastic response displacement $\triangle_M$ is calculated based on NSCP to be around 1/14 ($\triangle_M$ = 0.7R$\triangle_S$= 0.7x8.5x1/83), which is far larger than the story drift limit of 1/50 for the building with period ***T***, greater than 0.7s.

4.2 Design of Case P2 (Revision procedures in order to meet story drift limit)

Revision of Case P1 to satisfy the story drift limit is conducted. The revision procedures are summarized as below and shown in Table 1. Case 1E satisfies the story drift limit. Case 1E is to be referred as Case P2 hereinafter, meaning Case 2 of the Philippines. Case 1F is a case to seek possibility to reduce dimension of beams but it is unsuccessful. Also cases 2A, 2B and 2C are cases to try to reduce dimension of columns, but again, unsuccessful. List of sections of typical structural members of Case P2 is shown in Fig. 6.

1) from Case P1 to Case 1A:

   to enlarge dimension of structural members of Case P1 such as from 500x500mm to 800x800mm in columns, from 300x500mm to 600x500mm in beams

2) from Case 1A to Case 1B:

   to increase concrete strength from 21 N/mm^2 to 35 N/mm^2

3) from Case 1B to Case 1C:

   to increase thickness of slabs from 135mm to 200mm and concrete strength from 35 N/mm^2 to 42 N/mm^2

4) from Case 1C to 1D:

   to increase dimension of beam from 600x500mm to 800x500mm

5) from 1D to 1E:

   to increase thickness of slabs from 200mm to 225mm

Table 1 – Procedures of revision of Case P1 in order to satisfy story drift limit

<table>
<tr><td>Cases</td><td>1A</td><td>1B</td><td>1C</td><td>1D</td><td>1E</td><td>1F</td><td>2A</td><td>2B</td><td>2C</td></tr>
<tr><td>column dimension(mm)</td><td colspan="6">800 x 800</td><td colspan="3">700 x 700</td></tr>
<tr><td>beam dimension (mm)</td><td colspan="3">600 x 500</td><td colspan="2">800 x 500</td><td>600 x 500</td><td colspan="2">600 x 500</td><td>800 x 500</td></tr>
<tr><td>slab thickness (mm)</td><td colspan="2">135</td><td colspan="2">200</td><td colspan="2">225</td><td>135</td><td>200</td><td>225</td></tr>
<tr><td>concrete strength (fc) (N/mm^2)</td><td>21</td><td>35</td><td colspan="4">42</td><td>21</td><td colspan="2">42</td></tr>
</table>

4.3 Design of Case J1

Structural design to meet requirements of Japanese code (hereinafter referred to Case J1 meaning Case 1 of Japan) is shown in Fig. 7. Case J1 is designed to satisfy requirements on loads on Japanese code, which also satisfy story drift limit stipulated in the code (1/200 or less when seismic load is 0.2g without considering cracks in concrete).

		C 1	C 2
4TH TO ROOF DECK LEVEL			
B×D		800×800	800×800
column bar	Xdir.	7-D20	7-D20
column bar	Ydir.	7-D20	7-D20
HOOP	Lo, Lj	5-12Φ@100	5-12Φ@100
	Lv	5-12Φ@150	5-12Φ@150
2ND TO 4TH FLOOR LEVEL			
B×D		800×800	800×800
column bar	Xdir.	7-D20	7-D20
column bar	Ydir.	7-D20	7-D20
HOOP	Lo, Lj	5-12Φ@100	5-12Φ@100
	Lv	5-12Φ@150	5-12Φ@150
FOUNDATION TO 2ND FLOOR LEVEL			
B×D		800×800	800×800
column bar	Xdir.	7-D20	7-D20
column bar	Ydir.	7-D20	7-D20
HOOP	Lo, Lj	5-12Φ@100	5-12Φ@100
	Lv	5-12Φ@150	5-12Φ@150

	G 1		
	LEFT SURPPORT	MIDSPAN	RIGHT SURPPORT
RF			
B×h	800×500		
TOP	3-D25		
Bottom	3-D25		
STP	□-D10@100	□-D10@200	□-D10@100
3~5F			
B×h	800×500		
TOP	4-D25	3-D25	4-D25
Bottom	3-D25	3-D25	3-D25
STP	□-D10@75	□-D10@200	□-D10@75
2F			
B×h	800×500		
TOP	5-D25	3-D25	5-D25
Bottom	3-D25	3-D25	3-D25
STP	□-D10@75	□-D10@200	□-D10@75
FOOTING			
B×h	800×500		
TOP	5-D25	3-D25	5-D25
Bottom	3-D25	3-D25	3-D25
STP	□-D10@75	□-D10@200	□-D10@75

Fig. 6 List of sections of typical columns (left) and beams (right) of Case P2 (Case 1E in Table 1)

5. Comparison and analysis of three Cases of P1, P2 and J1

5.1 Comparison of Case P1 and P2

Comparison of Case P1, P2 and J1 is shown in Table 3. Comparison D in Table 3 shows comparison between P1 (not satisfying the story drift limit) and P2 (satisfying the story drift limit) in the Philippines in case of moment-resisting frames. It indicates dimensions (section areas) of columns and beams need to be much larger in order to satisfy the story drift limit such as 2.56 times for columns and 2.67 times for beams.

5.2 Comparison of Case P2 and J1

Case P2 and J1 are designed under similar conditions as shown in Table 3. Both of them are designed to satisfy both the requirements on loads and story drift limit. Comparison E in Table 3 indicates the dimensions of structural members in the Philippines are larger than those of Japan.

Table 2 – Comparison of conditions for design for Case P2 and J1

Components	J1: Tokyo, Japan	P2: Metropolitan Manila, the Philippines
Ground acceleration	0.4G	0.4G
Return period (years)	about 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
Importance factor by occupancy	none	1
Base shear factor	1.0	1.32
Effect by ductility of structures	0.3（Ds）	0.118（1/R）
Necessary ultimate lateral capacity	0.3	—
Design base shear	—	0.156

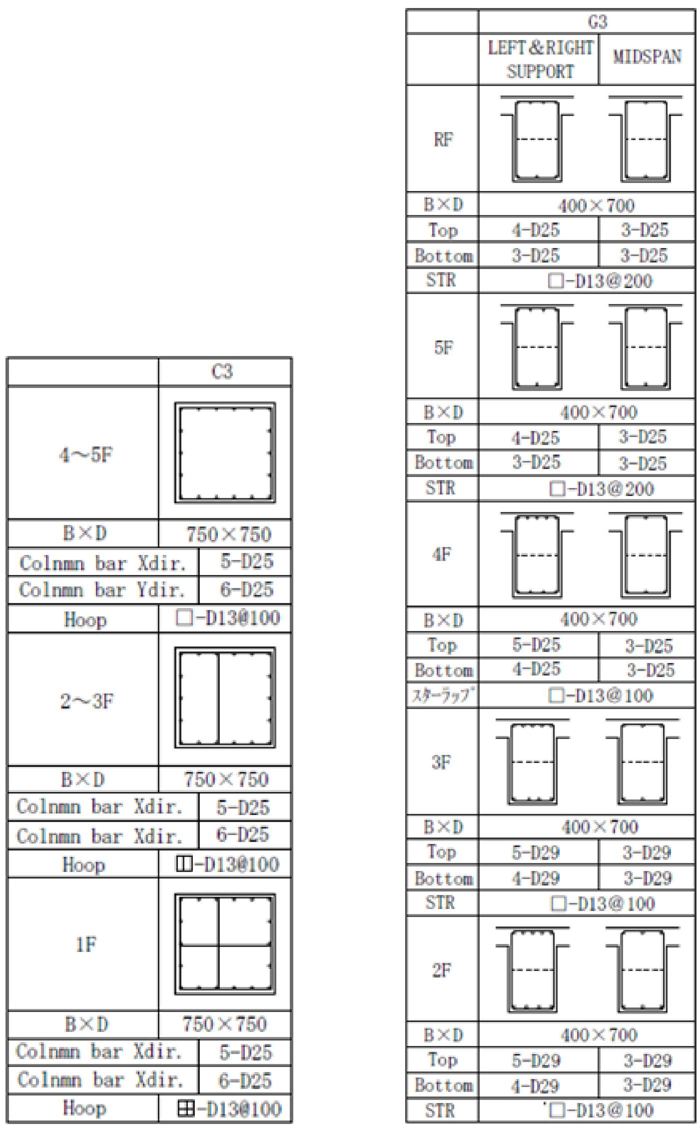

Fig. 7 List of sections of typical columns (left) and beams (right) of Case J1

Table 3 – Comparison of Case P1, P2 and J1

Items		Case P1（A）（not meeting story drift requirements）	Case P2（B）（meeting story drift requirements）	Case J1（C）	comparison	
					D=B/A	E=B/C
columns	dimension(mm)	500x500	800x800	750x750	—	—
	area (mm2)	250,000	640,000	562,500	2.56	1.14
beams	dimension (mm)	300x500	800x500	400x700	—	—
	area (mm2)	150,000	400,000	280,000	2.67	1.43
slabs	thickness (mm)	135	225	210	1.67	1.07
concrete strength fc (N/mm2)		21	42	24	2	1.75

6. Consideration and proposal on the next step study

6.1 Consideration on several key issues

In case of moment-resisting frame on the Philippine code, the story drift limit is a dominant factor/requirement to determine the dimensions of structural members. It is found that with the reduction of gross moment of inertia, ***Ig***, and using cracked sections in accordance to the requirements of the Philippine code provision NSCP 410.12.3, the story drift becomes quite large from 1/326 to 1/83. Maximum inelastic response displacement $\triangle_M$ calculated based on NSCP 208.5.9.2 is around 1/14, which is far larger compared with 1/105, the drift calculated using pushover analysis by the Japanese code. Since story drift is critical for the safety of the structure and calculation of it is an influential issue in structural design, this should be further investigated.

Evaluation of the effect of ductility differs much between two codes. As is shown in Table 2, design earthquake load becomes 0.118 times of the base shear on the Philippine code and 0.3 times on Japanese code, even though application methods in designing are different in two codes. Evaluation of effects of ductility is one of key issues in recent structural design and more detailed discussion/study is recommended on the big difference between two codes.

6.2 Proposal on the next step study

Enlarging structural members to control drift will amount to uneconomical design and reduction in usable space. The usual practice of structural design in the Philippines employs shear walls to reduce story drift to avoid large dimensions of structural members such as in Case P2 when subjected to design level earthquake. Therefore, comparison study on this type of structures using shear walls (Dual Systems) is recommended for the next step study.

7. References

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