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Authors:	Jong Soo Kim, CS Structural Engineering Duck Won Jo, CS Structural Engineering Eun Gyu Choi, CS Structural Engineering
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Challenges in Structural Design of Bumeo W-project

Jong Soo Kim†, Duck Won Jo, and Eun Gyu Choi

CS Structural Engineering, Seoul, Korea

Abstract

W-Project is 60-story mixed-use residential building complex project in Daegu, the third biggest city in South Korea. There are lots explorable items to be solved to secure structural safety and meet the serviceability requirements. This paper describes what kind of structural system is optimized based on the architectural requirements and structural components design and the grade of concrete strength altered on floors. The defining process of lateral resisting system of outrigger compared to the core ratio of typical plan is illustrated in detail.

Keywords: High-rise Building, Lateral Load System, Outngger System, Coupling Beam, Interaction Force

1. Introduction

W-Project is the multi-complex with four units of 60-story building. South Korea is not categorized as a strong seismic zone, but it is located in the middle of seismic zone and in the passage of typhoon from Pacific Ocean. In this paper, structural system for residential high-rise building is addressed considering architectural requirements and construction cost.

Table 1. Summary of W-Project

Project	W-Project (Daegu Bumeo Mixed-Use Development Project)
Location	Daegu, South Korea
Occupancy	Residential Complex
Size	GFA: 330,612 m^2, B4/60F
Height	190.65 m

Figure 1. Bird's Eye View.

†Corresponding author: Jong Soo Kim
Tel: +82-2-3497-7800
E-mail: jskim@csse.kr

2. Material Strength

Using higher strength material could make structural members slender and it can improve the axial capacity of vertical members. The feasibility studies are conducted in terms of various combinations of material strength. We considered whether if the high strength materials could be supplied instantly on the site as ordered by constructor for the specific area. Therefore, the concrete strength is used up to 60 MPa and the rebar strength is used up to 600 MPa. Fig. 2 shows concrete strength of 28 days at each floor zone.

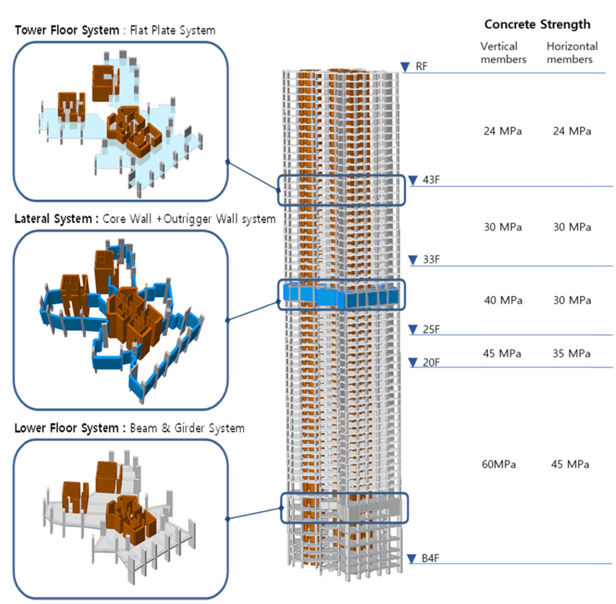


Figure 2. Tower Structural System and Concrete Strength of Vertical and Horizontal Members.

3. Gravity Load System

To choose gravity load resisting system for high-rise buildings, the floor height is the first consideration in some issues. Flat Plate Slab system is chosen to reduce the story height and for constructability, however it gives less lateral stiffness to the structure. For W-Project, thickness 250 mm of Flat Plate Slab system is applied and shear reinforcing bars are added to resist punching shear around the columns. Fig. 3 shows the Flat Plate Slab of the typical floor.

RC Beam & Girder and Flat Plate Slab Systems are selected for the gravity load resisting of podium area. The direct cost of RC Beam & Girder System is slightly higher than Flat Slab System. Besides construction cost, Flat Slab System reduces the floor height. To reduce the floor height of basement can save excavation cost of basement area consisting mostly hard rock strata. It is a summary of structural systems for W-Project as below. The basement floors are designed by 250 mm thickness flat slab with drops around column zone as shown on Fig. 4.

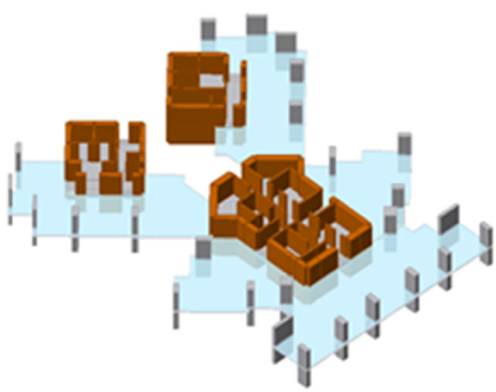


Figure 3. Flat Plate Slab of Typical Floor.

Table 2. Structural System

Tower Lateral System	RC Core Wall + Outrigger + Belt Wall
Tower Gravity System	Flat Plate System (THK. 250 mm)
Podium Gravity System	RC Beam & Girder System, Flat Slab System

4. Lateral Load System

4.1. The Selection of Lateral Load Resisting System

The lateral stiffness and characteristic are evaluated through four steps by structural system and members.

1) Core wall only
2) Core wall with reinforced coupled beam
3) Core wall with coupled beam, outrigger and belt wall
4) Core wall with coupled beam, outrigger and belt wall plus adopting the out of plane stiffness of typical floor slab

The natural period of core wall only is 8.21 seconds and the result stiffness of reinforced coupled beams is assumed by 50 percentage cracked section. The effective stiffness of flat slab is counted by 20 percentage for cracked section. Fig. 5 reveals what extend of the effectiveness to resisting lateral loads according to four steps of structural system is.

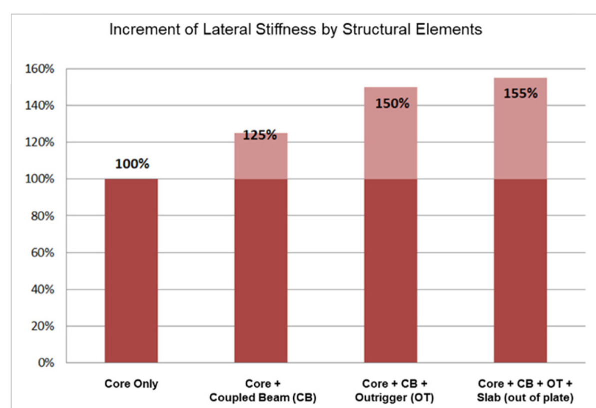


Figure 5. Lateral Stiffness Increment by Structural Elements.

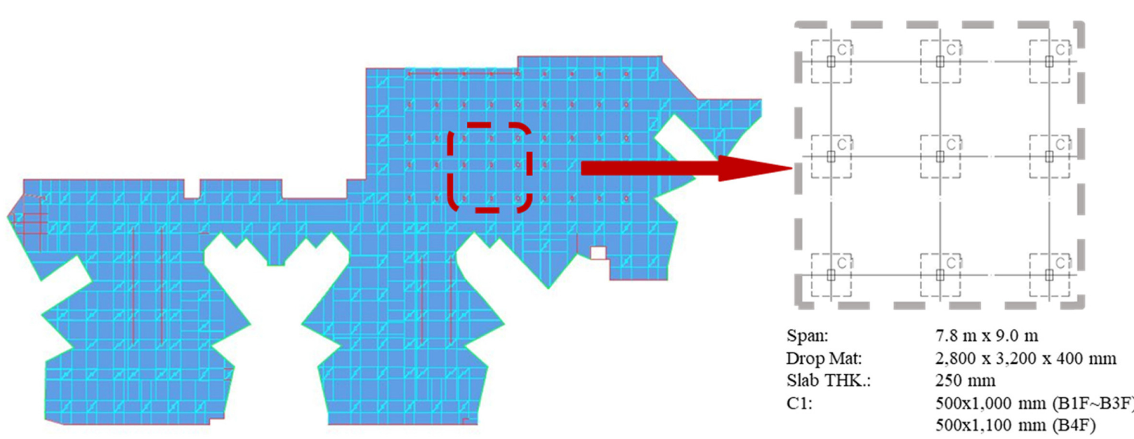


Figure 4. Flat Plate Slab of Basement Floor.

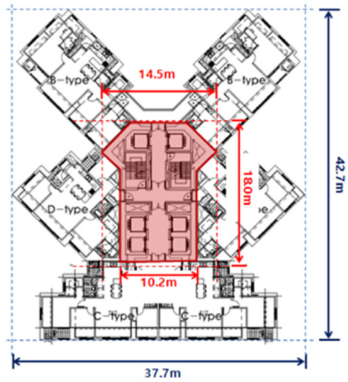
	Building and Core Size	
Plan		
Building Size	Longer Side	42.7 m
	Shorter Side	37.7 m
Core Size	Longer Side	18.0 m
	Shorter Side	10.2 m
Core Slenderness Ratio	Longer Side	10.56
	Shorter Side	18.63

Figure 6. Typical Floor (ALT2).

4.2. Lateral Load Resisting of Outrigger System

The ratio of core floor area to typical plan is about 20% as shown on Fig. 6. Stiffness of longitudinal direction (Y) is much stronger than short direction (X) due to the different widths of core. The slenderness ratio of core is 18.63 (X) and 10.65 (Y) but the wind force to x-direction is far bigger than y-direction. For strengthening stiffness along x-direction the fin walls extended from core wall are considered for all floors as shown in Fig. 7 (ALT-1) and the lateral stiffness of x-direction is increased about 15% from original structure. However, when considering the material quantity and constructability of core preceding construction, fin wall construction process could make some disadvantages on site. Therefore, ALT-2 with extended core width in x-direction and outrigger without the fin wall on the typical floor is finally adopted as shown on Fig. 7 considering constructability and architectural advantages.

4.3. Comparison of Wind Load and Seismic Load

For high-rise buildings in South Korea, wind loads tend to affect the design more than seismic loads, therefore evaluating wind load is critical to check lateral stiffness of the building. Wind tunnel test was conducted to check accurately the effect of wind loads on the structure. The result shows that the base shear force from the test is about 55~65% of the shear force from evaluating by the Korean Building Code 2016. For W-project tower structure, 80% of the wind load evaluated by the design code is applied as it is restricted for wind tunnel test not to exceed 80% of code value. Fig. 8 compares the design wind and seismic load. As you can see in Fig. 8, wind load governs the tower design. The seismic load in ultimate condition is 56% to X-direction and 72% to Y-direction compared with wind load.

4.4 Boundary Condition of Support at Basement

The core wall is resisting to the lateral load acting as the cantilever motion supported by the basement floor shown as Fig. 9. The basement area is enclosed by the rigid basement wall as shown in Fig. 10. The big negative

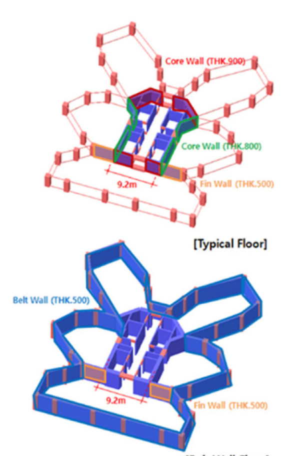
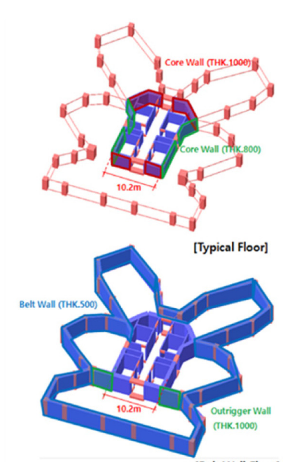
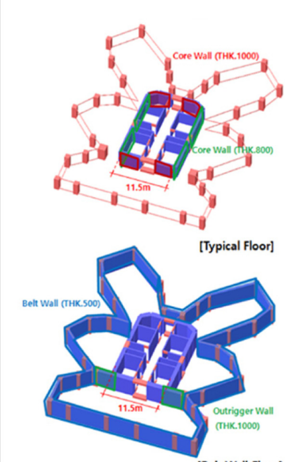
	ALT1 (Core + Belt Wall + Fin Wall)	ALT2 (w/o Fin Wall- Core Type 1)	ALT3 (w/o Fin Wall- Core Type 2)
Shape & Size			
Period	X-dir.: 5.67sec. (1st) / Y-dir.: 4.48sec. (2nd)	X-dir.: 5.97sec. (1st) / Y-dir.: 4.47sec. (2nd)	X-dir.: 5.97sec. (1st) / Y-dir.: 4.52sec. (2nd)

Figure 7. Alternative Study of Outrigger Floor.

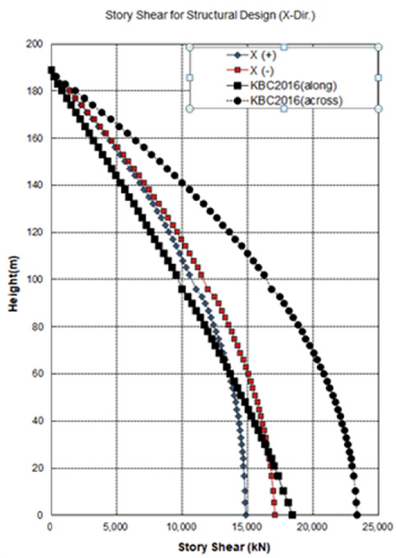
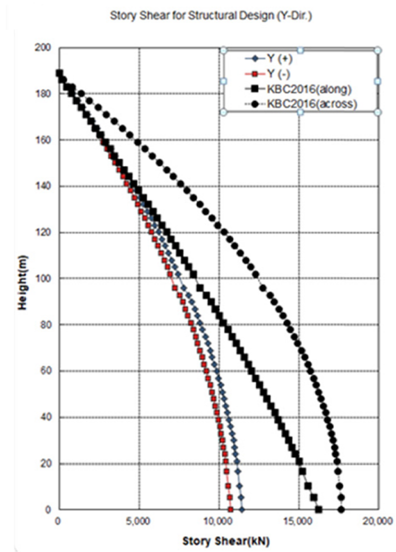
X – dir.		Y – dir.	
			
Wind Load (1.3W)	27,743kN (100%)	Wind Load (1.3W)	21,484kN (100%)
Seismic Load (E)	15,570kN (56%)	Seismic Load (E)	15,570kN (72%)

Figure 8. Comparison of Wind and Seismic Load.

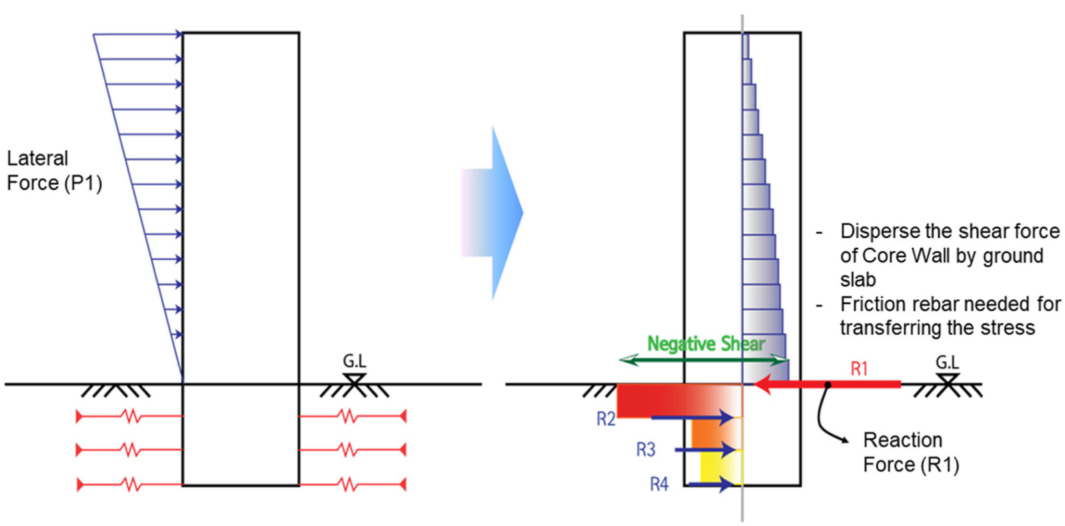


Figure 9. Boundary Condition of Core Wall and Shear Force Diagram.

shear developing from the diaphragm rigidity of basement floors is designed to be resolved by the axial force in-plane tension or compression of slab.

5. Structural Component Design

5.1 Coupling Beam

Core wall is divided by openings for corridors' hall and mechanical purposed openings situated on uncoupled walls as shown in Fig. 11. Coupling beams acting on major component to resist the lateral forces resulting shear force are essential to strengthen it for the stiffness of core wall. The effective stiffness is adopted to $0.5I_g$ counting cracks of members on ultimate limit state load. The big shear force arising from the lateral forces is designed by providing steel members as shown on Fig. 12.

5.2 Foundation

Mat foundations are supported directly on the sound bed rocks for the towers and isolated footings are designed for podium part. The thickness of mat varied from 2,500 mm to 3,000 mm using shear reinforcing bars for minimizing depth of footing. Foundations are depicted on Fig. 13.

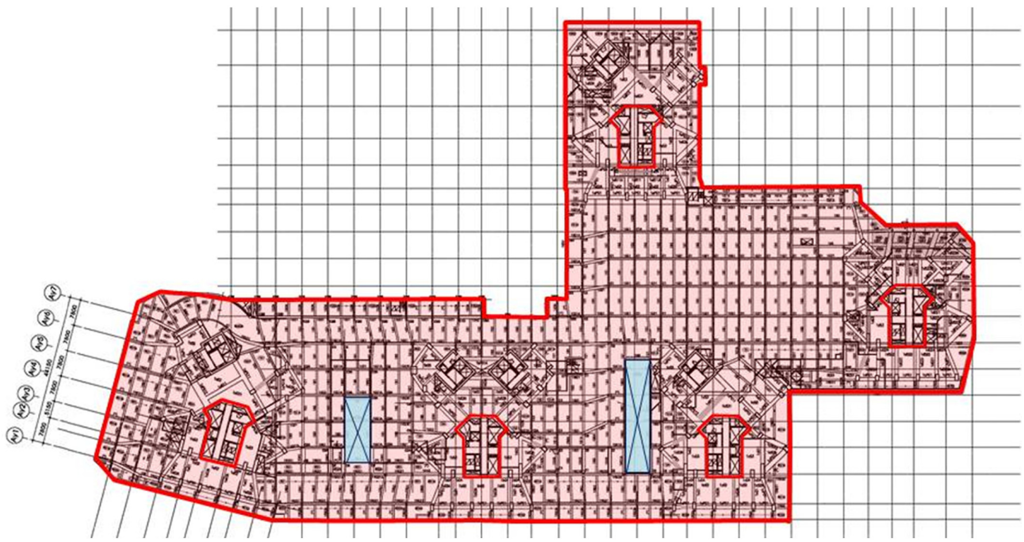


Figure 10. Ground Floor Framing Plan.

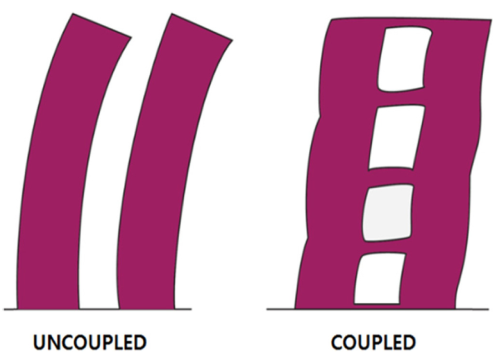


Figure 11. Coupled and Uncoupled Core Wall.

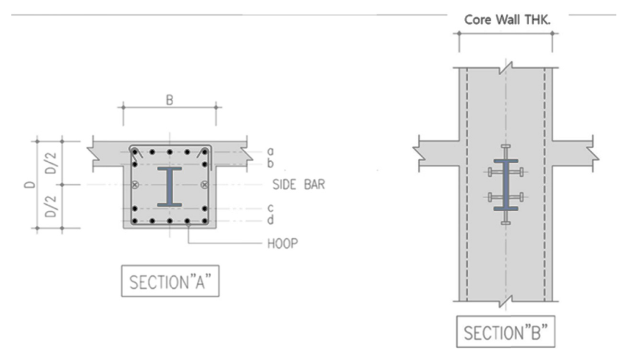


Figure 12. Coupled Beam Section.

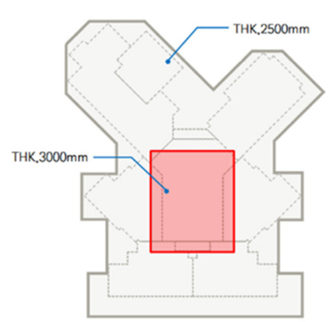
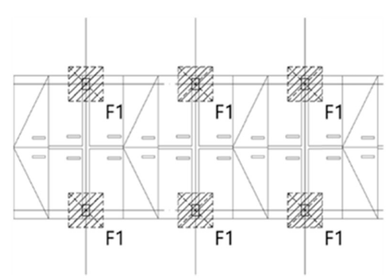
	High-rise Building	Low-rise Building
Foundation Plan		
Foundation System	Mat Foundation / Shallow Foundation	Isolated Foundation / Shallow Foundation
Size (THK.)	THK. 2,500~3,000 mm	2,200 x 2,800 x 900 mm
Bearing Capacity	F_a=2,500 kN/m^2	F_a=1,500 kN/m^2

Figure 13. Foundation System.

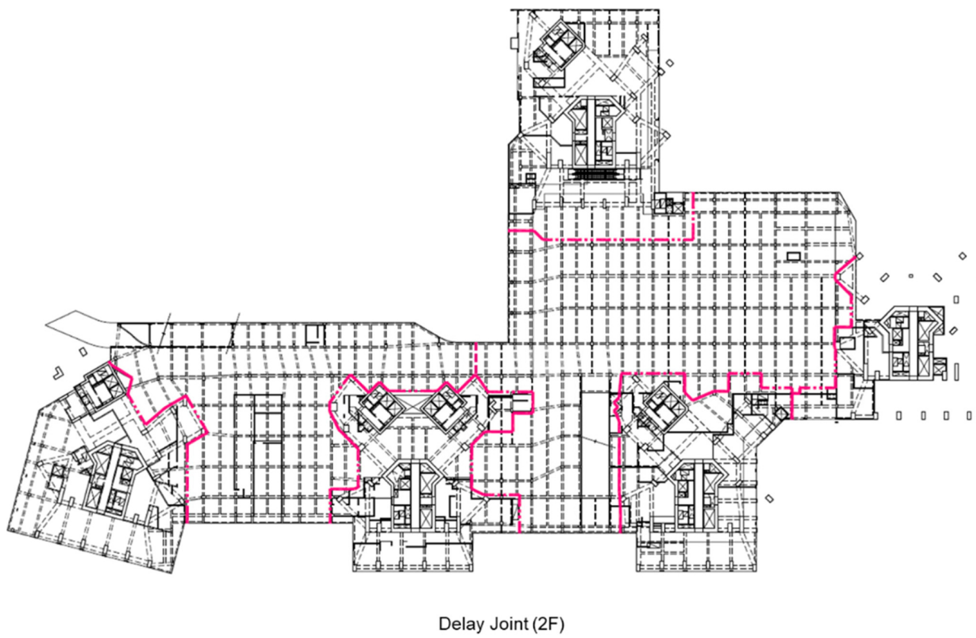


Figure 14. Delay Joint Arrangement.

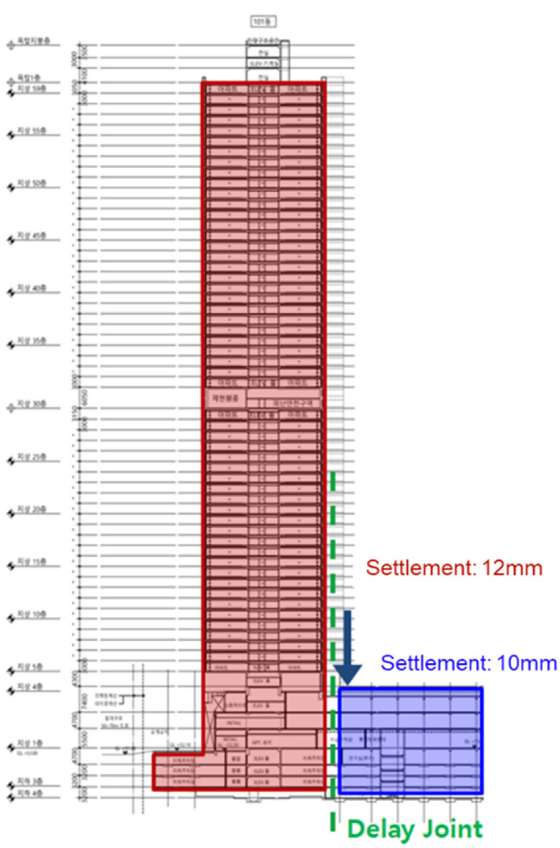


Figure 15. Vertical Settlement.

5.3 Separation Joints

The joint planning is fulfilled for about 150 m length by 100 m width structure including 4 towers of 60-story. The shrinkage and expansion are conditions checked for temperature changes and concrete curing. The basement area of structure covered with 1.0 m thickness of soil is not necessary to check the thermal effect. Delay joint provided as Fig. 14 would be effective horizontally separating between towers and parking basement floors and vertically as Fig. 15 allowing 2.0 mm the differential settlement.

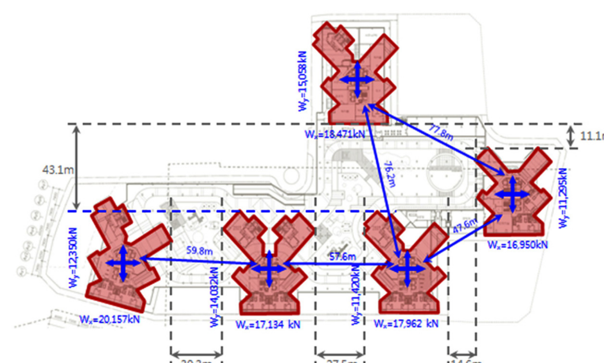


Figure 16. Interaction Diagram on The Podium.

5.4 Interaction Force due to Earthquake

The interaction force among towers due to seismic load would be added on the 4th floor of podium area. 20,157 kN are counted to slab area reinforcing added to the nominal reinforcing of slabs and beams. Fig. 16 depicts the interaction diagram on the podium.

6. Conclusions

To live a tall building has some disadvantages for comfortable living aspect to complication of vertical transportation and stability. However, the residents in a tall building could have attractive merits such as a great view and convenient facilities even though they have some disadvantages. For this reason, high-rise structures are expected to be expanded in the future considering to population density of South Korea.

The legislation caused by earthquakes that occurred in recent years on the southern part of Korea peninsular is intensifying to secure the stability to structures. Engineers are having their best to develop its proper structure system to cover requirements from architects and developers. It is anticipating that the articles from material to how define structural system are helpful further to encourage the better structural solutions.

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