Council on Tall Buildings and Urban Habitat

CTBUH Research Paper

ctbuh.org/papers

Title: **Challenges in Structural Design of W-Project**

Author: Jong Soo Kim, CS Structural Engineering

Subject: Structural Engineering

Keywords: Belt Wall
Mixed-Use
Outriggers

Publication Date: 2014

Original Publication: International Journal of High-Rise Buildings Volume 3 Number 3

Paper Type:
1. Book chapter/Part chapter
2. **Journal paper**
3. Conference proceeding
4. Unpublished conference paper
5. Magazine article
6. Unpublished

© Council on Tall Buildings and Urban Habitat / Jong Soo Kim

International Journal of High-Rise Buildings
September 2014, Vol 3, No 3, 199-204

International Journal of
High-Rise Buildings
www.ctbuh-korea.org/ijhrb/index.php

Challenges in Structural Design of W-Project

Jong Soo Kim†

CS Structural Engineering, Seoul, Korea

Abstract

W-Project is 70-story mixed-use residential building complex project in Busan, the second biggest city in South Korea. As it is a high rise building complex located at the coast, the residents have great ocean view from the height. Though, there were many difficult challenges to be solved to secure structural safety and meet the serviceability requirements. As it is located on the reclaimed land, securing the foundation bearing capacity on soft soil is the first issue to be solved for the stable structure. W-Project. Busan on the way usual track of typhoon, wind load on structure is also critical for structural safety and serviceability for occupants due to wind vibration. This paper will address process of lateral load resisting structural system of W-Project.

Keywords: Yonghoman mixed-use Development project, W project, Outrigger wall, Belt wall

1. Introduction

W-Project is the multi-complex with four units of 69-story- building. High-rise residential area is planned on each tower for dynamic view looking over the ocean and Gwang-an Bridge. South Korea is not categorized as a strong seismic zone, but it located in the middle of the passage of typhoon from Pacific Ocean. Especially for Busan, as it is located under the direct effect of typhoon, buildings are required to resist greater wind loads than any other places of South Korea. In this paper, structural system for residential high-rise building is addressed considering construction cost and constructability.

2. Tower Structure System

To choose gravity load resisting system for high-rise buildings, the floor height is first consideration in many other issues. Flat Plate System is chosen to reduce floor height and for easy construction, however it gives lesser lateral stiffness to the structure. For W-Project, thickness 250 mm of Flat Plate System is applied and shear reinforcings are added to resist punching shear around the columns.

To resist the lateral loads, core wall and outrigger system are applied for W-Project. The core area for W-Project is about 18% of the floor area. If lateral loads were resisted only by core wall, thickness of core wall should be 2500 mm. To give enough lateral stiffness of the structure, outrigger system with outrigger wall and belt wall is applied on 30th and 57th story of each building. The lateral resisting system will be handled on the next part of this paper.

RC Beam & Girder and Flat Slab Systems are selected for the gravity load resisting of podium area as comparing the construction cost of each floor system. RC Beam & Girder System is 100 USD per square meter, and it is 85 USD for Flat Slab system, which is 15% less than RC Beam & Girder System. Besides construction cost, Flat Slab System reduces the floor height. To reduce the floor height for basement can save excavation cost. It is a sum-

Table 1. Summary of W-Project

Project	W-Project (Busan Yonghoman Mixed-Use Development Project)
Location	Busan, South Korea
Occupancy	Residential Complex
Size	490,481 m^2, B6/69F
Height	246.4m

Figure 1. Bird's Eye View

†Corresponding author: Jong Soo Kim
Tel: +82-2-3497-7800; Fax: +82-31-735-9947
E-mail: jskim@csse.kr

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
Tower Foundation System	RCD Pile system (dia. 2500 mm)

mary of structural systems for W-Project as below.

3. Foundation System

W-Project is located in Yongho Bay which is landfill area. Even though foundation is deep planned on basement 6th floor, the soil condition of the ground is not enough to support 69 story buildings. To support the loads from the high-rise tower above, a pile foundation is required to support about 6,000 kN per pile. The RCD piles with 2500 mm diameter are used with 40~60 MPa high strength concrete.

The geotechnical investigation report showed the layer of the ground changed radically where the tower is located, pile stiffness and supporting capacity of bed rock are needed to be assessed accurately. The pile stiffness could affect the displacement and the design of mat foundation under the super structure. To design the mat foundation, the finite element analysis of ground and pile is conducted and is applied on the mat foundation design (see Fig. 3).

Table 3. Alternative Study of Material Strength

	ALT1	ALT2
Concrete Strength	30~60 MPa	30~80 MPa
Rebar Strength	400~500 MPa	400~600 MPa
Cost	109%	100%

4. Material Strength

Using higher strength material could make structural members more slender and it can increase the axial capacity of vertical members to increase the lateral stiffness of the building. 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 considering the characteristic Busan region. As the ALT.2 has 10% less construction cost than the ALT.1.

Therefore the concrete strength is used up to 80 MPa and

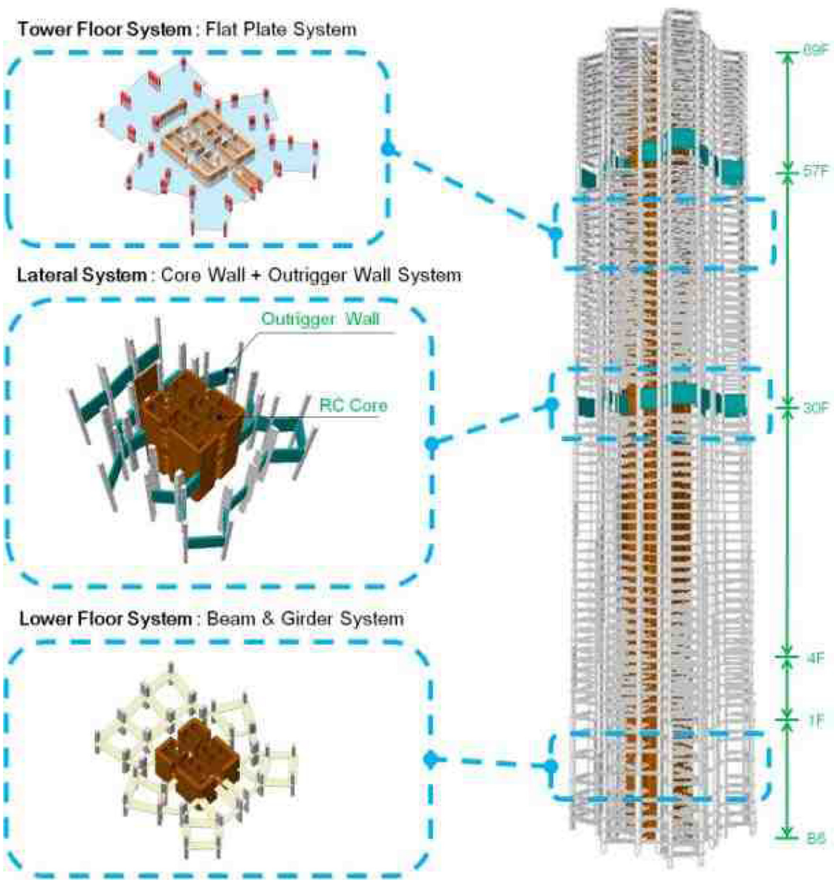
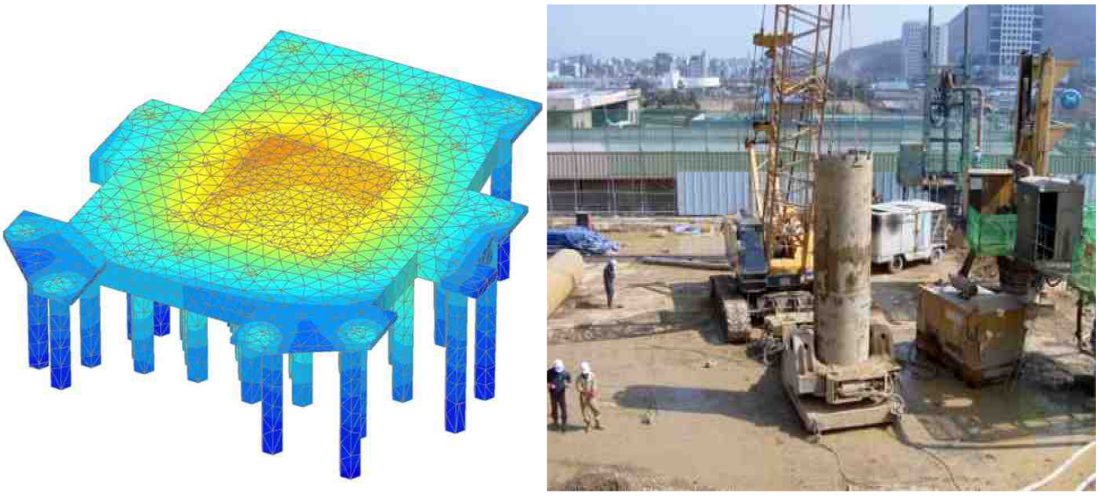
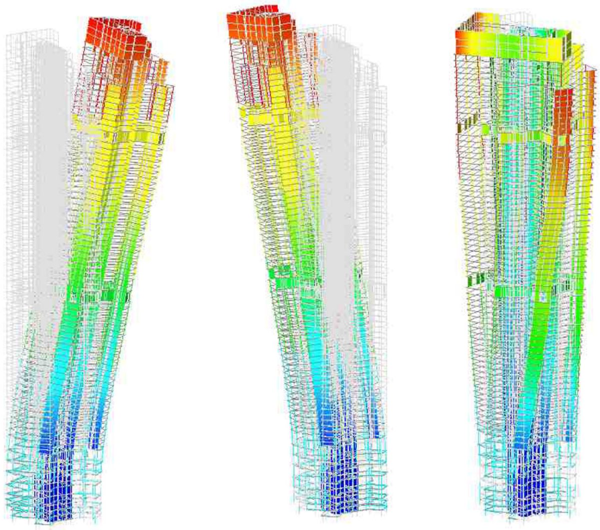


Figure 2. Tower Structural System



(a) Analysis model (b) Construction of RCD pile

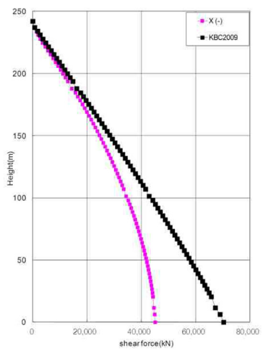
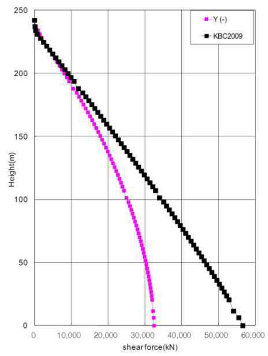
Figure 3. Analysis Model of Foundation



(a) 1st (X-Dir) 6.3 sec (b) 2nd (Y-Dir) 5.4 sec (c) 3rd (Rot-Z) 3.8 sec

Figure 4. Model Analysis

Table 4. Wind Load Evaluation

X - Dir		Y - Dir	
			
KBC200 (CODE)	70,304 kN (100%)	KBC200 (CODE)	70,304 kN (100%)
Wind Tunnel Test	45,036 kN (64%)	Wind Tunnel Test	45,036 kN (64%)

the rebar strength is used up to 600 MPa.

5. Dynamic Performance

Structural design of lateral system for a high-rise building is to achieve sufficient lateral strength and stiffness of the building due to wind loads and seismic loads. The structural dynamic behavior is studied as below; 1st mode (X direction) is 6.3 sec, 2nd mode (Y direction) is 5.4 sec, 3rd mode (Z rotational) is 3.8 sec.

With above results, W-Project shows the less lateral stiffness compares to other high-rise buildings with similar stories. Especially for 1st mode (X direction), natural period is 15% longer than 2nd mode (Y direction). It is resulted from the core shape of W-Project which is having 15 m length in X direction and 20 m length in Y direction having 25% shorter core length in X direction.

6. Wind Load Evaluation

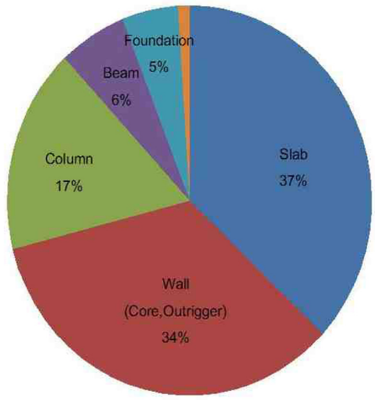
For high-rise buildings in South Korea, wind loads tend to affect more than seismic loads, evaluating wind load is critical to check lateral stiffness of the building. Wind tunnel test was conducted to evaluate accurately wind loads on the structure. The result shows that the base shear force from the test is about 55~65% of the wind load evaluated by the Korean Building Code 2009. 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.

As the windward area of X direction of the tower is

Table 5. Volume of Structural Members

	Concrete		Form		Rebar	
	m^3	%	m^2	%	ton	%
Foundation	6033	9.5	608	0.2	818	8.8
Column	10110	15.8	38115	14.8	2010	21.5
Beam	3484	5.5	7779	3.0	1075	11.5
Slab	25145	39	107490	41.6	2673	28.8
Wall	18854	29.5	101484	39.3	2688	28.8
Stair	428	0.7	2905	1.1	59	0.6
SUM	64054	100.0	258381	100.0	9323	100.0

Graph



larger than Y direction, wind load in X direction is greater than Y direction about 25%. The dynamic performance analysis above, tower structure has the less lateral stiffness in X direction than Y direction. Considering both the wind load value and the lateral stiffness, achieving the proper lateral stiffness in X direction of the tower structure was the key issue in the design process.

Table 6. Lateral Stiffness of Structural members

	Lateral Stiffness	
	X - Dir	Y - Dir
Core Wall + Lintel Beam	56%	61%
Outrigger + Belt Wall	41%	34%
Moment Frame (Column + Slab)	3%	5%

7. Lateral System

Slab is holding the biggest portion (37%) of the tower structure from the construction cost table categorized by member types. Moment frame; combination of column and slab; of the tower is 54% of total construction cost, but it only shows less than 5% of the lateral stiffness. But the walls (core wall, outrigger wall, belt wall) show more than 95% of the lateral stiffness of the tower with only 34% of construction cost. Especially for outrigger wall and belt wall, these are not the major part of wall elements, but 34~41% of lateral stiffness comes from them. The outrigger system is the most efficient lateral system in W-Project lateral system.

8. Alternative Study of Outrigger System

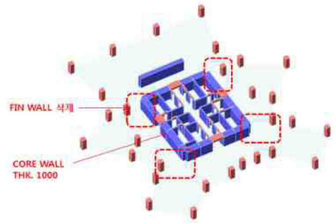
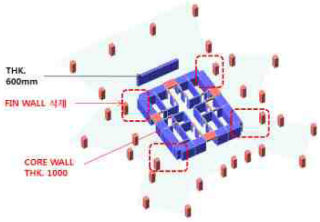
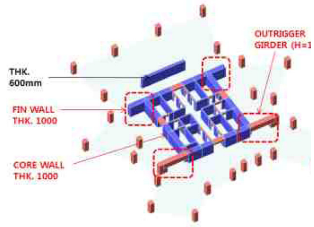
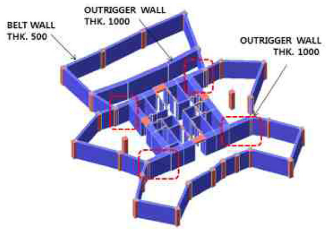
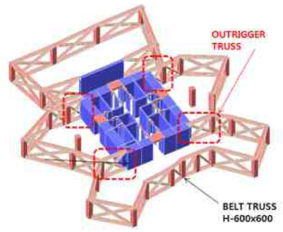
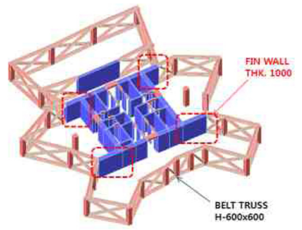
The Outrigger is located in two different floors - 30th and 57th story. The lateral stiffness increases about 10% more when the outrigger is located in two places than only one place. For about 70-story high-rise buildings, lateral stiffness is not changing dramatically due to the number of outrigger places. But as the refuge area and the mechanical floor are required by the architectural plan, two outriggers are placed in different floors.

The outrigger wall could be formed in various systems, but RC wall is checked as first option because W-Project is RC structure. The ALT. 1 shows outrigger wall of RC wall. Thickness 1000 mm of outrigger wall is placed in X direction to have sufficient the lateral stiffness in X direction and thickness 500~1000 mm of belt wall is placed around the perimeter. The structural behavior of outrigger and belt wall is not similar to typical shear walls and massive amount of stress will flow in these walls. Dense reinforcing in walls could delay construction time of outrigger wall. Some of these walls might be required to pour lately considering column shortening. The construction schedule for W-Project is not planned yet as it is still under the design phase, the construction of outrigger floor in high-rise building takes 30~45 days to construct otherwise it takes only 4 days for typical floor. Therefore the construction time for outrigger floor is critical for determining whole construction schedule.

The ALT. 2 shows outrigger and belt wall could be formed with steel truss system. This option would save construction time of outrigger floor than RC wall as steel system does not require curing time. It also could be used manage mixed construction method because of column shortening action. But the lifting equipment are essential to be prepared to erect heavy steel trusses up to the high location for this option. The construction work might become much simpler with this option but construction cost would be higher and the lateral stiffness is not enough when it is compared with RC wall. As W-project tower structure does not have enough lateral stiffness, small stiffness difference could affect the overall serviceability level of the tower. The ALT. 2 is not qualified option to meet the serviceability limit of the tower.

To solve constructional problems while having enough the lateral stiffness, placing RC fin wall in every floor is

Table 7. Alternative Study of Outrigger System

	ALT 1	ALT 2	ALT 3
Typical Floor			
Outrigger Floor			
Fin Wall	X	X	O
Outrigger Wall	RC Wall	Steel Truss	RC Wall
Belt Wall	RC Wall	Steel Truss	Steel Truss
Lateral Stiffness	100%	87%	125%
Construction Cost (Only Outrigger)	100%	250%	330%

adopted as the ALT. 3. Having RC fin wall is very powerful to increase the lateral stiffness to have about 40% more lateral stiffness in X direction. The ALT. 3 can be the most reasonable solution among all the options.

9. Construction Outrigger Wall and Beltwall

Due to massive shear forces on the outrigger wall, the reinforcing inside the outrigger wall is very complicated than usual shear walls. The reinforcing inside the outrigger wall is decided due to the horizontal shear force from the lateral loads and the vertical shear force from differential settlement (see Fig. 5). Placing delay joint could be helpful to reduce vertical shear force, but it requires complicated detail work on construction site (see Fig. 6). To improve the constructability, minimizing the number of delay joint is required. Delay joint is placed only on the outrigger wall as the shear force on the outrigger wall is much greater than the belt wall. Also the outrigger wall is located inside the building; it does not cause construction time delay.

10. Health Monitoring System

As there are many residents living in high-rise buildings, problems in structural system might be resulted into a serious happening. It is very important to secure safety

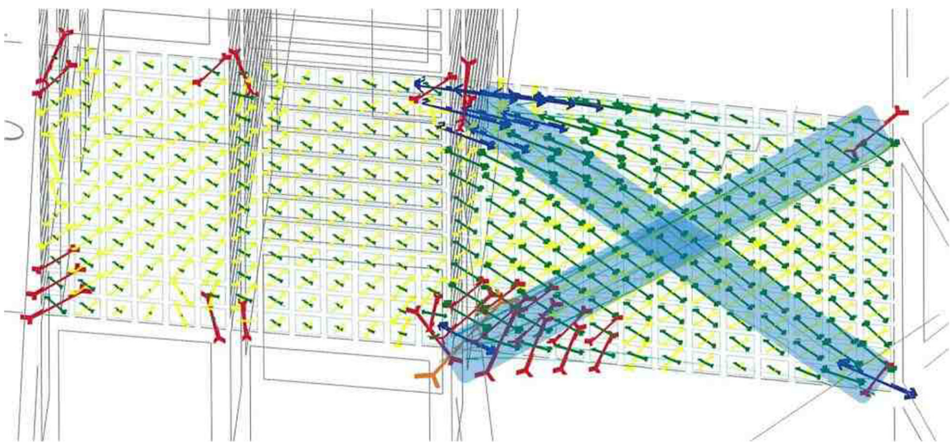


Figure 5. Analysis of Outrigger

Figure 6. Construction of Outrigger Wall

of the structure all the time through the whole life cycle of the building. To secure safety of resident in high-rise building, Health Monitoring System is applied for W-Project.

With various sensors attached on structure, supervisors can monitor the real time behavior of the structure due to any other impacts from the outside. Monitored results can be checked and used to compare the current status of the structure with the designed status to evaluate safety and integrity of the structure in real time. Supervisor can alarm residents when structural behavior is considered to be abnormal. Monitored results also can be used to verify various assumptions and theoretical approaches made during the design process.

11. Conclusion

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