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Structure Engineering of W-Project in Busan Yonghoman
釜山永湖湾W项目结构工程

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Abstract

W-Project is 70-story mixed-use residential building complex project in Busan, 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. Soft soil tends to amplify earthquake load on a structure, so dealing with earthquake load was one of the biggest challenge for 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. The wind tunnel test is conducted to assess various affect on structure due to strong wind load to check the serviceability requirements.

Keywords: Yonghoman Mixed-Use Development Project, W project, Outrigger, Belt Wall

摘要

W-项目是预计在韩国第一大港口城市釜山建设的超高层商住综合园体项目。本建筑物拥有可眺望海景的优越地理条件，但与此同时也有许多结构问题需要解决。

其中该建筑物地基属于填土地基，因此确保建筑物地基承载力满足设计要求为第一要务，其次要解决由填土地基所产生的地震波增加而引起的结构问题。另外，本建筑物位于直接受台风影响的海边，因此不仅要确保抗风结构体系的安全性，还要满足住户的使用要求。为了检验建筑物在上述制约条件下能否满足居住环境的要求，既而进行了各种风洞试验和非线性结构分析。

关键词: 永湖湾商住综合开发项目，W项目，伸臂结构，带状墙

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 (see Figure 1).

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

前言

W-项目是建设在韩国釜山市的超高层商住综合建筑，由4个69层规模的建筑物所组成。该建筑物是拥有可眺望海景和广安大桥的超高层建筑，拥有着优越的地理条件。韩国虽然不是一个多地震国家，但是每年都有许多台风过境。特别釜山是直接受台风影响的地区，因此要求位于釜山的超高层建筑与其他韩国地区相比需要拥有更好的抗风结构体系，既而保证建筑物正常、安全的使用。本论文主要针对居住用超高层建筑物的结构体系选定，以及结构体系的施工性与施工费用等进行了论述。(见图1)

- 项目名 : Busan Yonghoman Mixed-Use Development Project
- 位置 : 韩国釜山市
- 用途 : 商住综合建筑
- 规模 : 490,481㎡, B6/69F
- 高度 :246.4m

Tower Structure System

To choose gravity load resisting system for high-rise buildings, the floor height is the 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, a Flat Plate System of 250mm thickness is applied and shear reinforcings are added to resist punching shear around the columns.

To resist the lateral loads, a 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 a core wall, the thickness of the core wall should be 2,500mm. To give enough lateral stiffness of the structure, an outrigger system with an outrigger wall and belt wall is applied on the 30th and 57th story of each building. The lateral resisting system will be handled on the next part of this paper (see Figure 2).

After comparing the construction cost of each floor system, reinforced concrete beam-and-girder and flat-slab systems were selected to provide gravity-load resistance in the podium area. 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. Reducing the floor height for the basement can save excavation cost. Below is a summary of structural systems for W-Project. Flat Slab System is

Figure 1. Bird’s Eye View.
图1 俯瞰图

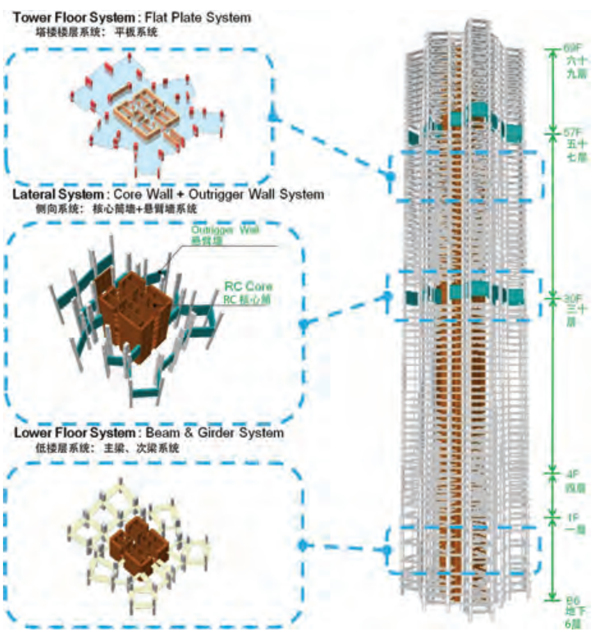


Figure 2. Tower Structural System.
图2 塔楼结构体系

超高层结构体系

选定超高层建筑的重力结构时，能减小层高的结构体系是首选。无梁楼板结构体系的抗弯刚度虽小，但是该结构体系在减小层高和缩短施工时间方面具有优势，因此被广泛应用于建筑物设计。W-项目的板厚为250mm，为了满足柱子的受冲切承载力的安全性，既而对柱子采取了配置加强钢筋的构造措施。

W-项目的抗侧力结构体系为核心筒+伸臂结构体系 (Core Wall+ Outrigger System) 。在标准层，核心筒面积仅占该层总建筑面积的18%，相对于项目的规模来说，核心筒所占面积较少。如果仅用核心筒结构来满足该项目的抗侧力要求，则核心筒抗侧墙厚度需要从原先1000mm增加至2500mm。但从实际出发，墙厚2500mm既不经济也不现实。为了减少抗侧墙的厚度，在第30层和第57层各设制了由伸臂墙和带状墙所组成的伸臂 (Outrigger) 结构体系。后面将进一步论述选定抗侧力结构体系的背景与经济性比较等内容。(见图2)

低层裙房的重力结构体系采用了混凝土框架结构和无梁楼板结构体系。混凝土框架结构每平方米施工费为104,000韩元(100美金)，无梁楼板结构为90,000韩元(85美金)，两种结构体系相差15%左右。无梁楼板结构不仅能减少结构构件的总用量，还能有效的降低层高，使地下结构物在施工当中，能减少挖土量与垂直结构构件的总物量既而节约施工费。在地下结构物当中无梁楼板结构在经济性方面有着明显的优势，但是在解决不规则平面或着存在较大的板高差问题上就有明显的不足。结构设计荷载大且存在很多板高差问题的地上1层至3层采用了混凝土框架柱结构形式，而在地下停车场部分采用了无梁楼板结构形式。在整个低层部重力结构体系当中混凝土框架柱和无梁楼板结构所占总面积的比例基本相等。

- 塔楼抗侧力结构体系: 核心筒+伸臂墙+带状墙
- 塔楼重力结构体系: 无梁楼板结构 (标准板厚: 250mm; 基本模板: 8.0 x 8.0m)
- 低层裙房部重力结构体系: 混凝土框架柱结构+无梁楼板结构
- 高层塔楼部基础结构体系: RCD桩基础

基础结构体系

w-项目所在地永湖湾 (地名，Yonghoman) 的地基属于填土地基。虽然建筑物的基础位于地下6层，但是作为支撑69层规模建筑物的地基，其承载力仍有不足。要想支撑69层规模建筑物的垂直轴向力，需要桩基的设计承载力为6000KN，既直径为2500mm大口径桩基。另外RCD桩基础采用了Fck=40～60MPa的高强度混土使桩基的强度与刚度满足设计要求。

根据地质堪察报告，建筑物高层部基础所在地基其刚度强度有明显地变化，因此我们需要准确的算出桩基的设计承载力与地基承载力特征值。由于桩基的不均匀刚度所引起的地基不均匀沉降，使扩展基础的设计略有不同。为了正确设计基础，采用有限元单元法对地基和桩基进行了结构分析。在设计桩基时的把容许沉降量设定为25mm以下。(见图 3)

材料强度

结构设计当中采用高强度材料，不仅能实现结构物构件的整体轻量化，而且能增加结构物垂直构件的轴向刚度，既而增加建筑物

an economical way to form basement gravity load resisting system like mentioned above, but it is difficult to have a Flat Slab System for a non-moduled plan or downed level area. For the 1st ~3rd floors of the W-project where various level differences are located and resisting a relatively large load than other floors, RC Beam & Girder System is applied. A Flat Slab System is applied to basement parking area. Two different systems are applied to the W-Project podium area considering their structural characteristics, and they share almost the same portion of total floor area.

- Tower Lateral System: RC core wall + outrigger + belt wall
- Tower Gravity System: Flat Plate System (Typical floor slab Thk. 250mm, module 8x8m)
- Podium Gravity System: RC Beam & Girder System, Flat Slab System
- Tower Foundation System: RCD Pile system (dia. 2500mm)

Foundation System

W-Project is located in Yongho Bay which is landfill area. Even though foundation is as deep as the 6th floor of the basement, 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 6,000kN per pile. The RCD piles with 2,500mm diameter are used with 40~60MPa 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. When the pile foundation was designed, the total vertical displacement of piles was limited by less than 25mm (see Figure 3).

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 high strength material is actively applied in various high-rise construction sites in spite of increasing the cost of material recently in South Korea. But to secure supply status and to qualify the materials on site, they need to be checked by constructors and inspectors. The supply status of high strength material can affect the construction schedule and cost. The feasibility studies are conducted in terms of various combinations of material strength. The characteristics of the Busan region were taken into consideration when looking at the possibility of the high strength materials being supplied directly on site as ordered by the constructor. The ALT.2 shows having 10% less construction cost than the ALT.1. Therefore the concrete strength is used up to 80MPa and the rebar strength is used up to 600MPa (see Table 1).

Dynamic Performance

The Structural design of lateral system for a high-rise building is to achieve sufficient lateral strength and stiffness of the building due

的整体抗侧力刚度，有利于结构物的稳定。在韩国，价格增长比例没有比材料的强度增加比例大，因此结构设计者在确保材料品质与材料供给要求下，在超高层建筑物设计当中积极采用高强度的材料能使结构设计更加实用化与经济化。在超高层建筑物建设当中所需材料总量是非常庞大的，因此如果出现高强度材料供给不足，将会出现延误工期等施工方面的问题。W项目以釜山地区能供给的材料为基准，进行了材料强度的经济性比较分析。分析结果显示方案2所采用的高强度混凝土给设计会带来10%的经济效益。因此本项目采用最高混凝土强度为80Mpa(混凝土设计强度)，最高钢筋强度为600Mpa(钢筋设计强度)。(见表1)

结构的动态表现

高层建筑物的抗侧力结构体系对风荷载和地震荷载都应该进行充足的刚度与强度设计。本建筑物的水平地震作用力小于水平风荷载作用力。另外建筑物所在地的地基属于软弱地基，因此对地震波有增幅的作用使水平地震作用力有所增加。综上所述，本建筑物的抗侧力结构体系充分满足了各向水平荷载作用下的刚度与强度要求。

建筑物为了要满足风荷载作用下的抗侧力刚度，在以100年再现周期为基准的风荷载作用下，使最大水平位移限制在H/500以内。除此之外，风加速度不仅用AIJ(日本标准)与ISO两项标准进行了验证，而且居住者的舒适度满意思指数也都得到了保障。

为了满足地震作用下结构物的抗侧力刚度与强度，使建筑物拥有充分的塑性变形能力，采用了特殊抗震墙结构体系与相应的构造要求。建筑物第1振型 (X-方向) 周期为6.3秒，第二振型 (Y-方向) 周期为5.4秒，而第一次出现扭转的第3振型周期为3.8秒。(见图4)

从动态分析结果可知，本建筑物抗侧力刚度相比于其它拥有相似

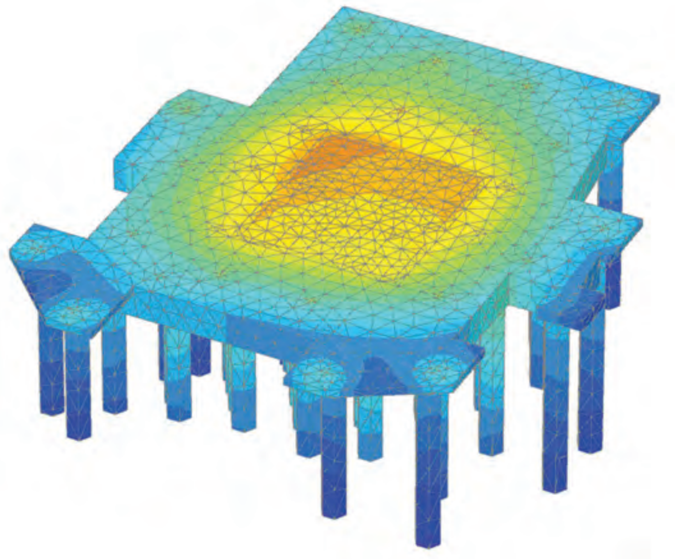


Figure 3. Analysis Model of Foundation
图3 地基分析模型

	ALT1 视图1	ALT2 视图2
Concrete Strength 混凝土强度	30~60 MPa	30~80 MPa
Rebar Strength 钢筋强度	400~500 MPa	400~600 MPa
Cost 造价	109%	100%

Table 1. Alternative Study of Material Strength.
表1 材料强度方案比较表

to wind loads and seismic loads. The wind base shear is higher than seismic loads in this structure. Furthermore if the super structures are placed in the soft ground, the seismic loads of these can be increased due to ground seismic amplification effect. As a result, we considered securing the lateral strength and stiffness for lateral loads on the design of the building.

For the stiffness of wind loads, the vertical displacement is limited within H/500 as 100yrs return period. The acceleration of wind is checked in accordance with AIJ code (Japanese code) and ISO, in order to ensure the comfortable index of occupants. For the strength and stiffness of seismic loads, the special shear wall system and the details are applied on the seismic design so that the ductility of structure secure in the core wall.

The structural dynamic behavior is studied as below; 1st mode (X direction) is 6.3 sec, 2nd mode (Y direction) is 5.4sec, 3rd mode (Z rotational) is 3.8 sec. (see Figure 4).

With above results, W-Project shows the less lateral stiffness compares to other high-rise buildings with similar stories. Especially for the 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 15m length in X direction and 20m length in Y direction having 25% shorter core length in X direction.

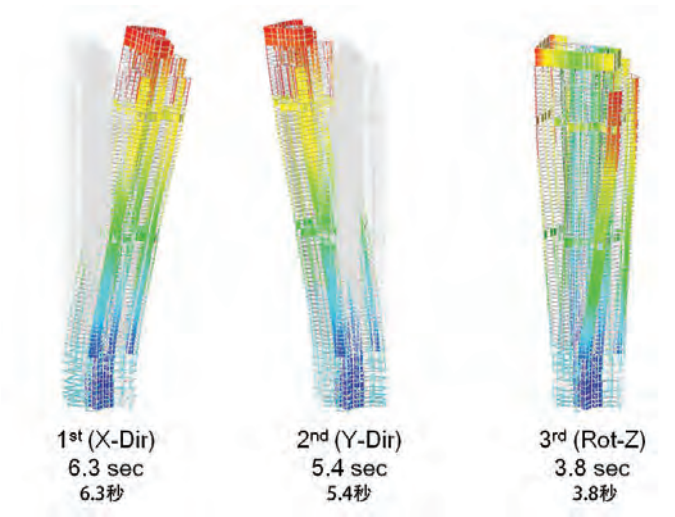


Figure 4. Modal Analysis
图4 模型分析

高度，且受相似大小的风荷载和地震荷载建筑物的抗侧力刚度略显偏低。这是因为本建筑物核心筒面积所占比例过低造成的。特别是向Y方向变形的第2振型周期比往X方向变形的第1振型周期长15%。这是因为X方向核心筒抗侧墙长度为15m，比20m的Y方向核心筒抗侧墙长度短25%造成的。但建筑物整体扭转为第3振型且周期比较小，所以本建筑物整体趋于稳定。

Wind Load Evalution

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. A 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 a wind tunnel test not to exceed 80% of code value (see Table 2).

As the windward area of X direction of the tower is larger than Y direction, wind load in X direction is greater than Y direction by about 25%. The dynamic performance analysis above shows the tower structure has 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.

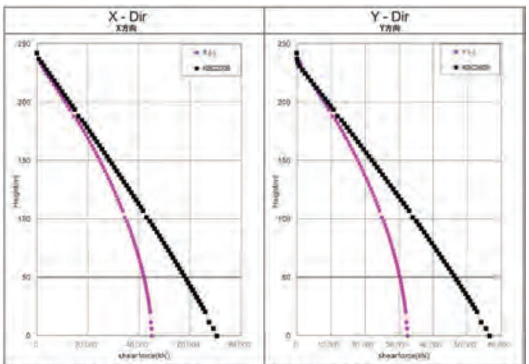
风荷载评估

韩国超高层建筑物的水平风荷载相比于水平地震荷载要大，因此在选定结构物的抗侧力结构体系时如何准确评价风荷载大小将变得十分重要与关键。此项目为了准确评价风荷载大小进行了风洞试验。从试验得到的风荷载大小为按规范 (KBC 2009) 计算出的基本风荷载大小的55～65%。但韩国规范KBC 2009里有明文规定由风洞试验实测的风荷载大小不得小于规范规定的基本风荷载的80%，所以本项目以规范风荷载的80%设为结构物的设计风荷载。(见表2)

本建筑物的X 方向迎风面比Y方向迎风面要宽，因此X方向的风荷载比Y方向风荷载大25%左右。从建筑物的动态分析结果可知，本建筑物的X方向抗侧力刚度比Y方向抗侧力刚度略显不足。因此在选定结构物抗侧力结构体系时，应把设计重点放在选定X方向抗侧力结构体系上。

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 the outrigger wall and the 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 the W-Project lateral system (see Table 3 and 4).



KBC2009(CODE)	70,304kN(100%)	KBC2009(CODE)	56,574kN(100%)
Wind Tunnel Test	45,036kN(64%)	Wind Tunnel Test	32,475kN(57%)

Table 2. Wind Load Evaluation.
表2 风荷载评估

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 (see Table 5).

The outrigger wall could be formed in various systems, but the RC wall is checked as the first option because the W-Project is an RC structure. The ALT. 1 shows an outrigger wall of RC wall. The 1,000mm thickness of the outrigger wall is placed in X direction to have sufficient lateral stiffness in X direction and the 500~1000mm thickness of the 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 the outrigger wall. Some of these walls might be required to pour lately considering column shortening. The construction schedule for the W-Project is not planned yet as it is still under the design phase. The construction of the 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 the outrigger floor is critical for determining whole construction schedule.

The ALT. 2 shows the outrigger and belt wall could be formed with steel truss system. This option would save construction time of the outrigger floor than the RC wall as steel system does not require curing time. It could also be used to manage mixed construction method because of the column shortening action. But it is essential that the lifting equipment is 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 the W-project tower structure does not have enough lateral stiffness, a small stiffness difference could affect the overall serviceability level of the tower. The ALT. 2 is not a qualified option to meet the serviceability limit of the tower.

To solve constructional problems while having enough lateral stiffness, placing an RC fin wall in every floor is adopted as the ALT. 3. Having an RC fin wall is very powerful to increase the lateral stiffness by about 40% in X direction. The ALT. 3 can be the most reasonable solution among all the options.

The architectural plan should be put first before other considerations for residential usage building. The ALT. 3 is not a possible option because it is almost completing the design phase. It is difficult to change the location of the bearing wall considering residential usage.

As a result, the ALT. 1 is chosen for good lateral stiffness and lower construction cost. As the ALT. 1 has poor constructability as mentioned above, solutions will be made during design process to minimize difficulties in construction.

Construction Outrigger Wall and Beltwall

Due to massive shear forces on the outrigger wall, the reinforcing inside the outrigger wall is more 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

	Concrete 混凝土		Form		Rebar 钢筋		Graph
	m³	%	m²	%	ton	%	
Foundation	6033	9.5	608	0.2	818	8.8	
Column 柱	10110	15.8	38115	14.8	2010	21.5	
Beam 梁	3484	5.5	7779	3.0	1075	11.5	
Slab 楼板	25145	39	107490	41.6	2673	28.8	
Wall 墙	18854	29.5	101484	39.3	2688	28.8	
Stair 楼梯	428	0.7	2905	1.1	59	0.6	
SUM	64054	100.0	258381	100.0	9323	100.0	

Table 3. Volume of Structural Members.
表3 各结构构件体积比较表

	Lateral Stiffness 侧向刚度	
	X - Dir X方向	Y - Dir Y方向
Core Wall + Lintel Beam 核心筒墙+水平横楣梁	56 %	61 %
Outrigger + Belt Wall 悬臂梁+带状墙	41 %	34 %
Moment Frame (Column + Slab) 抗弯钢架（柱+楼板）	3 %	5 %

Table 4. Lateral Stiffness of Structural Members.
表4 各结构构件抗侧力刚度比较表

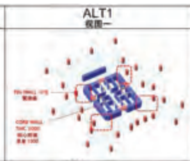
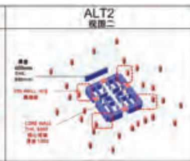
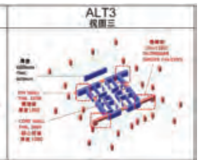
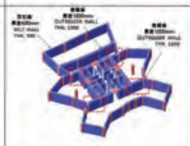
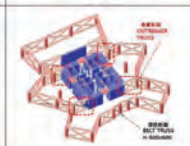
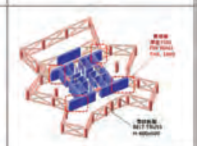
	ALT1	ALT2	ALT3
Typical Floor 标准层			
Outrigger Floor 悬臂层			
Fin Wall 翼缘墙	X	X	○
Outrigger Wall 悬臂墙	RC Wall RC墙	Steel Truss 钢桁架	RC Wall RC墙
Belt Wall 带状墙	RC Wall RC墙	Steel Truss 钢桁架	Steel Truss RC墙
Lateral Stiffness 侧向刚度	100%	87%	125%
Construction Cost (Only Outrigger) 施工造价（仅悬臂）	100%	250%	330%

Table 5. Alternative Study of Outrigger System.
表5 伸臂结构方案分析表

抗侧向力结构体系

从建筑物各构件物施工费的比较来看，楼板所占比例最高，达总施工费的37%。由柱与无梁楼板所组成的框架结构的构件总物量占建筑物总物量的54%，但其所占抗侧力刚度仅为总抗侧力刚度的5%。相反仅占据总施工费34% 的抗侧墙(核心筒墙+伸臂墙+带状墙Core wall, Outrigger wall, Belt wall) 其所占抗侧力刚度为总抗侧力刚度的95%。其中由伸臂墙和带状墙 (Outrigger wall, Belt wall) 所组成的结构体系所占物量为总抗侧墙的一小部分，但是将抗侧力刚度提高了34～41%。下面一起考察一下相对于物量增加刚度增强效率更高更好的伸臂 (Outrigger) 结构体系。 (见表3, 表4)

伸臂结构设计方案

伸臂结构 (Outrigger) 体系占两层楼，设置于第30层和第57层。伸臂结构占两层楼与占一层楼时相比，抗侧力刚度的差距为10%。在70层规模的建筑物上，虽然伸臂结构体系所占楼层数对抗侧力刚度的影响不大，但在建筑规化设计当中，要求在建筑物的中间层设置机械室和避难层，为了符合建筑要求，将两伸臂结构体系设置在不同楼层。 (见表5)

本建筑物是钢筋混凝土建筑，因此在选定伸臂结构材料时应先考虑混凝土墙。如前分析，方案1将着眼于本建筑物的X方向抗侧力刚度设计，因此不仅在X方向设置厚度为1000mm的伸臂墙，而且还在建筑物外层设置了厚度为500～1000mm的带状墙 (Belt Wall) force from differential settlement (see Figure 5). Placing a delay joint could be helpful to reduce vertical shear force, but it requires complicated detail work on construction site (see Figure 6). To improve the constructability, minimizing the number of delay joints is required. A 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.

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

With various sensors attached on structure, the manager can monitor the real time behavior of the structure due to any other impacts from the outside. Monitored results can be checked by the maintenance manager 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. And a part of sensors is supposed to be managed by government such as the seismic accelerometers and wind anemometers.

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.

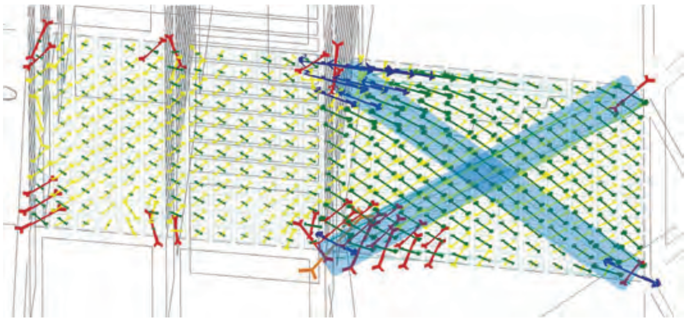


Figure 5. Analysis of Outrigger.
图5 伸臂结构分析

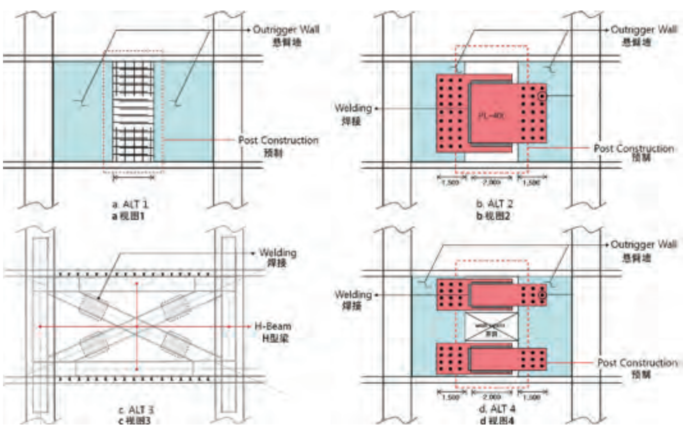


Figure 6. Alternative of Delay Joint of Outrigger Wall For Construction
图6 伸臂墙后浇缝的设置方案与构造要求。

。伸臂墙 (Outrigger Wall) 和带状墙 (Belt Wall) 的受力状态与一般抗侧墙有所不同，因为在伸臂墙与带状墙设置层会发生高度的应力集中现象，因此此层墙体需要非常高的配筋率来满足设计承载力。

另外，因考虑混凝土柱缩短现象 (Column Shortening)，会有一部分区域采用后施工方法，为此会产生工期延缓现象。本项目现如今仍处于结构设计阶段，因此现阶段还没有详细的施工计划，但是根据以往的经验，伸臂结构层所需的施工期一般为30～45天。如果考虑一般结构体系施工一层的所需时间为4天左右时，伸臂结构层的施工会给整体工程日期带来严重的延缓现象。

为了解决工程延期问题，考虑用钢桁架的伸臂墙和带状墙的方案2。方案2组装无需经过养护等阶段所以能大幅度缩短伸臂层的施工时间，而且由混凝土柱缩短现象产生的后施工问题也可以用简单的构造措施来解决。虽然为了将比重较大的钢材应用于高层部位，而必需进一步考虑钢材的起重方案，但是从施工角度来看，方案2是最简单易行的设计方案。

但是本方案不仅有施工费比混凝土结构方案高出许多的问题，而且有抗侧力刚度下降的问题。特别是在本建筑物的抗侧力刚度十分不充分的状态下，13%抗侧力刚度的差异就已经否决了方案2的可行性。

最后，为了解决施工和刚度问题，既而推出了全层增加钢筋混凝土翼墙的方案。钢筋混凝土翼墙是能确保不充足的X方向抗侧力刚度的有效结构措施，在设置翼墙后X方向的抗侧力刚度提高了40%。方案3是十分合理的结构方案，但是唯一缺点要多设立一些原先建筑规划之外的抗侧墙。本项目属于住宅楼，因此设计时优先考虑建筑面积和建筑平面的构成，因此方案3没有通过。

最终选定抗侧力刚度较好、施工费较低的方案1作为设计方案。如前所述，方案1在施工上有许多不利因素，因此在设计阶段考虑降低不利因素是非常有必要的。

伸臂墙和带状墙的施工

因结构体系的原因，伸臂墙和带状墙会产生剪力集中现象，因此伸臂墙和带状墙的配筋比一般抗侧墙要复杂得多。伸臂墙和带状墙的水平方向配筋受到水平剪力的影响，而垂直方向的纵筋配筋跟不均匀沉降所引起的垂直剪力有关。(见图5) 建筑后浇缝 (Delay Joint) 能有效地降低由不均匀沉降所引起的垂直剪力，但对其构造有详细的要求。(见图6) 为了提高施工的可行性，将后浇缝的设置数量降至最低是非常有必要的。因此，仅当伸臂墙上的剪力远大于带状墙的时候才在伸臂墙上布置后浇缝。同时，由于伸臂墙位于建筑的内部，因此后浇缝的施工可以与建筑外墙同时进行，而不必担心拖长施工时间。

健康监控系统

超高层建筑物是人口密集的建筑物，当建筑物产生问题时会引起较大范围的人员伤亡。因此，时刻维持建筑物的安全状态是十分重要与必要的。W项目采用了健康监控系统 (Health Monitoring System)。

建筑物里安装了风向风速仪、和地震加速度计等检测系统，对建筑物进行动态结构分析，并且可以实时判断建筑物的动态状态是否在设计允许范围内。

若发现建筑物的异常动态，业主可及时应对确保建筑物使用者的人身安全。地震加速度计和风向风速仪等部分传感器的管理预计

Conclusion

To live in a tall building has some disadvantages from 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.

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将由政府负责。另外，根据建筑物的实际状态可以判断是否与设计时考虑的状态相同，从而验证建筑物结构设计的合理性与实用性。

结 论

从垂直动线的复杂性和稳定性等层面上看，超高层建筑物可能在用户的居住生活便利性上并不占优势，但是高层建筑拥有的绝佳景观和更多的生活便利设施是吸引消费者的主要魅力。在这样的优势下，考虑到韩国人口密度高的特殊性，今后超高层建筑将呈现逐渐增多的趋势。

致谢

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