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Structural Design of Lotte World Shenyang, China

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Abstract Located in Shenyang, China this is 60th story building consisting of the lower part office and upper part hotel. The rectangular concrete core is located at center of building. The wall and the steel outrigger on the middle of part are characterized to resist the lateral stiffness of the tower.

Keywords Perimeter Girder, Outrigger Truss, Rigidity Ratio, Stiffness Ratio, RC Frame-Core-Tube

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1. Introduction

1.1. Project Description

• Located in Shenyang, China, Lotteworld Shenyang Project is a modern leisure-sports-type commercial facility that houses a super indoor amusement park, a large shopping center, a super luxury hotel, and an office.

• Mainly comprising a commercial facilities(Land Mark Tower, OFFICE, OFFICETEL and a HOTEL), facilities (department stores and retail outlets), and a residential section, its architectural design was executed by Junglim Architecture Co., Ltd. The structural design of its commercial facilities (Land Mark Tower, OFFICE, OFFICETEL and a HOTEL) was executed by CS Structural Engineering Inc.

1.2. Structural Description

• The Structural outlines of the Land Mark Tower, OFFICE, OFFICETEL and HOTEL, among the commercial facilities, are as follows.

1.3. Structural system of Land Mark Tower

• The Land Mark Tower is 264.6 m high(exception globular shape sculpture). It has 60 stories on the ground and four stories below the ground. It houses offices, hotels, a lobby, restaurants, observation, machine rooms, and consists primarily of hotels and offices.

• High-rise buildings have structurally substantial impact on serviceability, workability, and economic efficiency in selecting a gravity and lateral system. CS Structural



Figure 1. Lotteworld Shenyang view

Table 1. Structural outlines of commercial facilities.

Main use	Work facilities, Neighborhood facilities
Scale	B4F ~ 60F
Height of typical floor	4.1 m (Office) 3.6 m (Hotel)
Building height	
Module	12.5 m × 9.0 m
Structural system	Reinforced Con'c(RC)
Floor system	Post-tension slab with perimeter Girder System
Slab system	Post tension Slab
Lateral resisting system	RC Frame- core-tube + outrigger structure
Foundation type	MAT foundation (PILE)
Feature	

Engineering Inc. examined and compared a wide range of alternative systems applicable to the Land Mark Tower, which led it to the suggestion of the ultimate structural system.

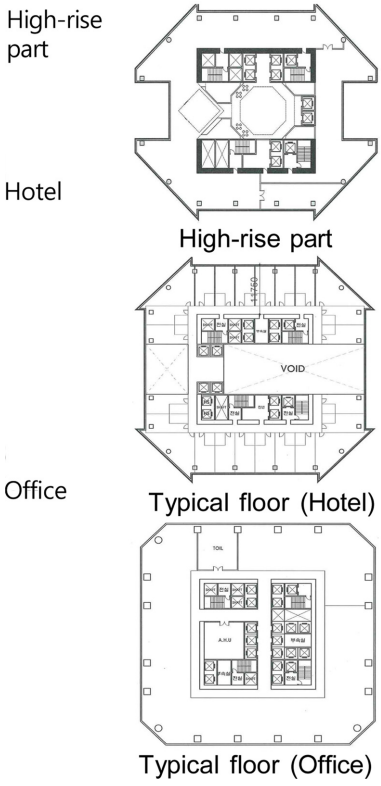


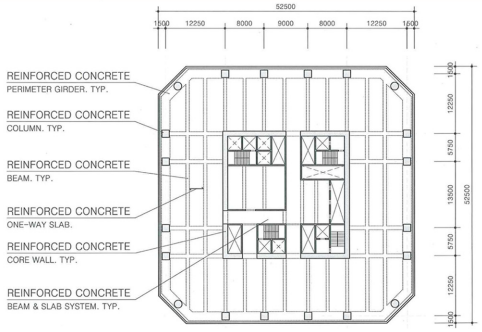
Figure 2. The Land Mark Tower's three-dimensional image and the main building floor plan.

Table 1. Gravity system section by story

RC_Beam & Girder System (Basement, Observation, Restaurant etc.)

• Applied floor
B4F~3F, 56F~RF

• Applied reason
- It was proposed that the underground part is possible for structural design due to various floor-level differences and has flexibility for the architectural plans.
- For the observation and restaurants section on the 54th story and higher, the application of the Beam & Girder System was proposed, as it can restrain the two cores caused by the decrease in the span and the excessive open areas in the hotel section.

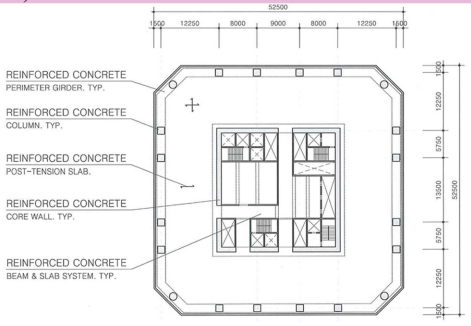


- Perimeter girder : 1000X900
- Slab : THK.150
- Beam & Girder : 700X750 / 1000X750

RC_Post-Tension Slab with Perimeter Girder System (Office)

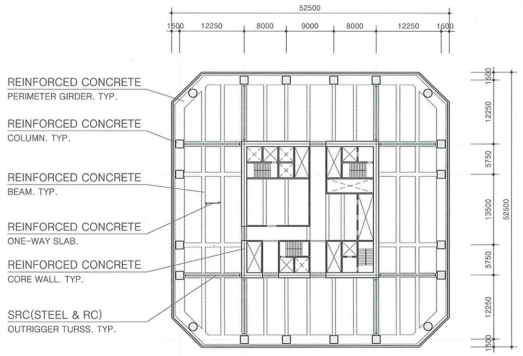
• Applied floor
4F~29F, 32F~55F

• Applied reason
- For typical floors, a flat plate was chosen due to its excellent workability, and post-tension was applied to control the deflection caused by the long-term span.
- Because of the 12.5m long-term span, the slab thickness was set at 250mm.



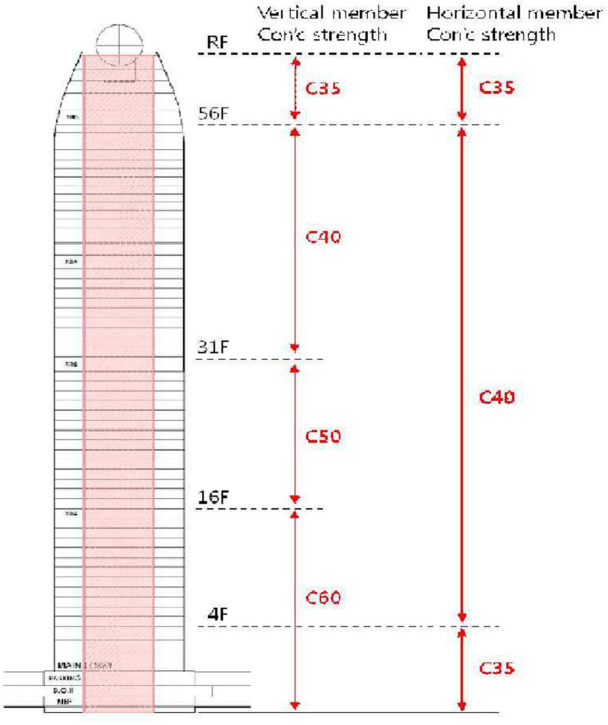
- Perimeter girder : 1800X600
- Slab : THK.250

Table 1. Continued.

RC_Beam & Girder System + Outrigger Truss System (Mechanical)	
• Applied floor 30F, 31F • Applied reason - RC_Post tension Slab couldn't apply in the outrigger floor due to interference of truss. - The slab thickness is applied to 400mm for securing integrity between outrigger truss and slab.	 - Perimeter girder : 1200X1000 - Slab : THK.400 - Beam & Girder : 1000X750 / 700X750 - Outrigger truss : 700X1200 (SRC, H-800x500x60x60)

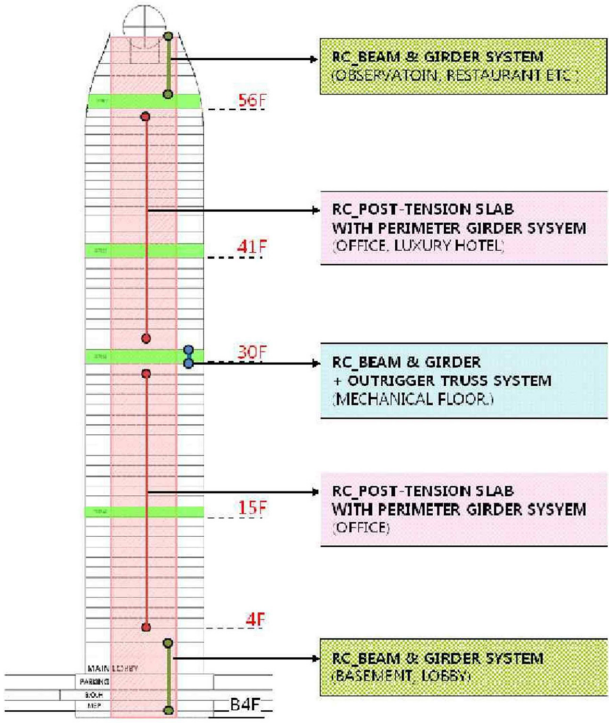
2. Structural Materials

2.1. Story zoning for concrete stregth



3. Structural System

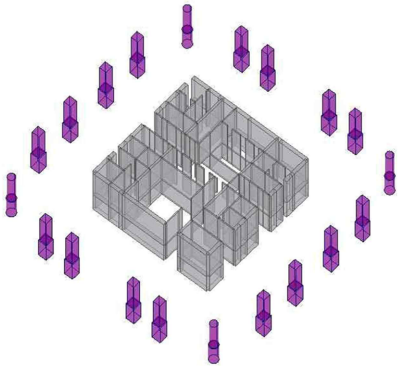
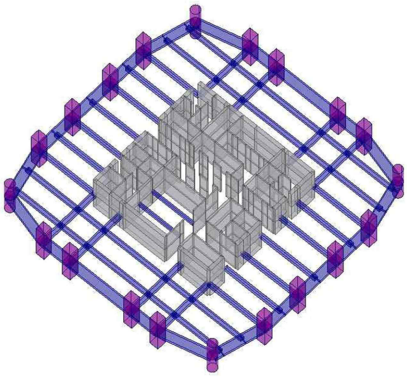
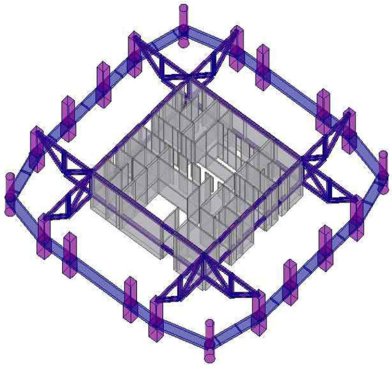
3.1. Grevity resisting system



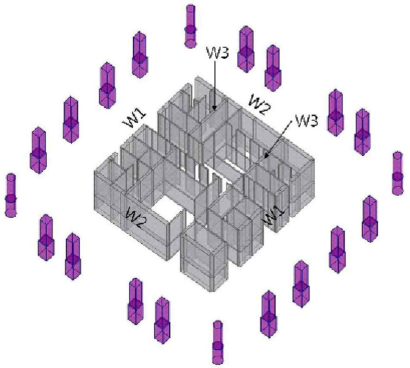
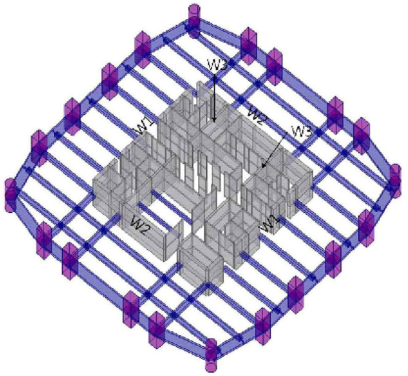
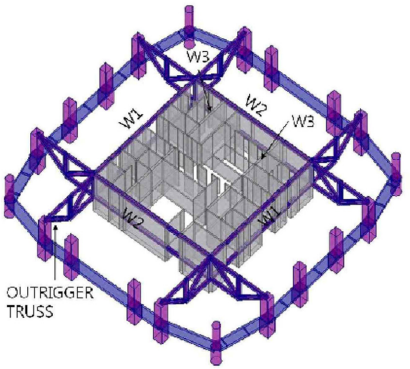
3.2. Lateral Load System

1) RC Core wall only
2) RC Core wall with tube structure
3) RC Core wall with tube plus outrigger Structure

Table 3. Comparison of seismic force resistance systems

Division	Structure system	Important matter
RC Seismic-wall structure	 - The space frame resists the vertical load. - The shear wall supports the lateral load.	- The core walls are designed about resistant to lateral force only.
RC Frame-core-tube structure	 - The ductility moment resisting frame that bears the lateral load is combined with the shear wall.	- Seismic details to secure ductility against seismic loads should be applied to the moment frame.
RC Frame-core-tube + outrigger structure	 - It is a very efficient system for securing lateral rigidity due to the interaction between the columns and the cores. - It is desirable to minimize the use of the outrigger, as its difficulty of construction .	- The core-column differential deflection that generates stress should be considered.

3.3. Summary of seismic force resistance system

Division		RC Seismic-wall structure				RC Frame-core-tube structure				RC Frame-core-tube + outrigger structure			
Shape													
Core wall size		W1 : THK. 1500 W2 : THK. 1500 W3 : THK. 400 Inner wall : THK. 200				W1 : THK. 1000 W2 : THK. 1000 W3 : THK. 400 Inner wall : THK. 200				W1 : THK. 700 W2 : THK. 700 W3 : THK. 400 Inner wall : THK. 200			
Outrigger truss		-				-				H-700x500x60x60			
Con'c strength		Vertical member	- B4F ~ 15F : C60 - 16F ~ 30F : C50 - 31F ~ 55F : C40 - 56F ~ RF : C35			Vertical member	- B4F ~ 15F : C60 - 16F ~ 30F : C50 - 31F ~ 55F : C40 - 56F ~ RF : C35			Vertical member	- B4F ~ 15F : C60 - 16F ~ 30F : C50 - 31F ~ 55F : C40 - 56F ~ RF : C35		
		Horizontal member	- B3F ~ 55F : C40 - 56F ~ RF : C35			Horizontal member	- Whole story : C30			Horizontal member	- B3F ~ 55F : C40 - 56F ~ RF : C35		
Eigenvalue result (Period, sec)		MODE 1	TRAN-X, T=8.261			MODE 1	TRAN-X, T=7.316			MODE 1	TRAN-X, T=7.521		
		MODE 2	TRAN-Y, T=7.051			MODE 2	TRAN-Y, T=6.292			MODE 2	TRAN-Y, T=6.703		
		MODE 3	ROT.-Z, T=4.757			MODE 3	ROT.-Z, T=4.047			MODE 3	ROT.-Z, T=4.624		
Check of lateral disp.	Classification	Division		Disp. ratio	Limits ratio	Result	Division		Disp. ratio	Limits ratio	Result	Division		Disp. ratio	Limits ratio	Result
	Lateral disp. due to seismic load	Frequently earthquake (1/1000)	X-dir	0.00117	0.001	N.G	Frequently earthquake (1/800)	X-dir	0.00098	0.00125	O.K	Frequently earthquake (1/800)	X-dir	0.00109	0.00125	O.K
			Y-dir	0.00112	0.001	N.G		Y-dir	0.00106	0.00125	O.K		Y-dir	0.00111	0.00125	O.K
		Rarely earthquake (1/120)	X-dir	0.01067	0.0083	N.G	Rarely earthquake (1/100)	X-dir	0.00825	0.01	O.K	Rarely earthquake (1/100)	X-dir	0.0083	0.01	O.K
			Y-dir	0.00408	0.0083	O.K		Y-dir	0.00688	0.01	O.K		Y-dir	0.0070	0.01	O.K
	Lateral disp. due to wind load	X-dir (H/500)		158.8 mm	528.8 mm	O.K	X-dir (H/500)		172.4 mm	528.8 mm	O.K	X-dir (H/500)		222.6 mm	528.8 mm	O.K
		Y-dir (H/500)		153.4 mm	528.8 mm	O.K	Y-dir (H/500)		181.8 mm	528.8 mm	O.K	Y-dir (H/500)		221.8 mm	528.8 mm	O.K
Stiffness ratio		97%					100%					109%				
Proposal of CSSE		The examination of the alternatives showed that the constructability in relation to the outrigger installation appeared to be poor, but the serviceability and economic efficiency seemed excellent. After a comprehensive review, the **RC Frame-core-tube + outrigger structure** was proposed.														

3.3.1. Lateral rigidity ratio according to lateral resisting member

Freq.	Only Core	Only Core + Perimeter Girder	Only Core + Perimeter Girder + Outrigger truss
1 mode	8.21	7.66	6.93
2 mode	7.60	7.06	6.33
3 mode	4.44	4.23	4.13
Stiffness ratio	71.2	82.8	100

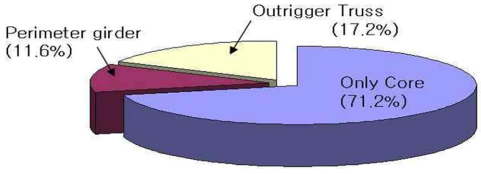


Figure 5. Division ratio of lateral rigidity.

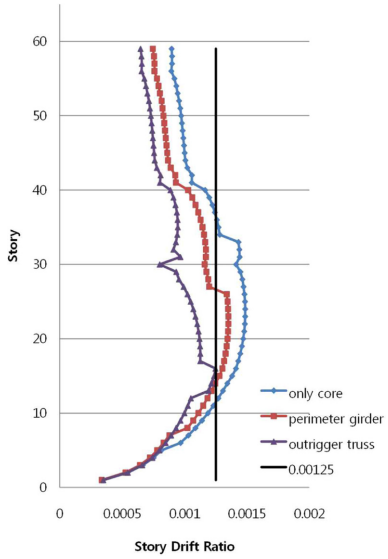
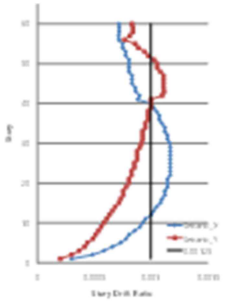
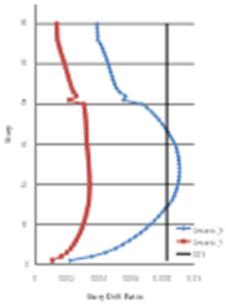
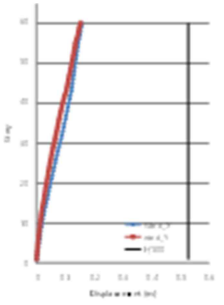
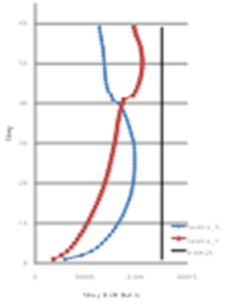
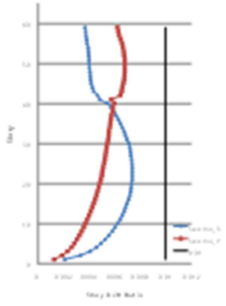
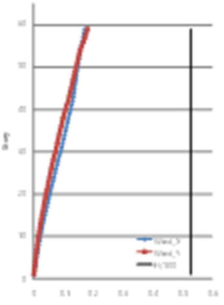
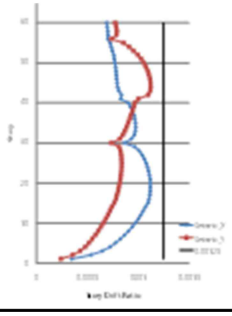
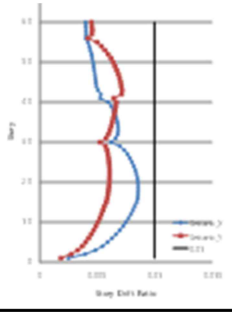
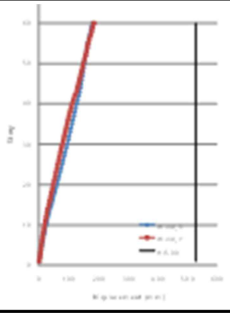


Figure 6. Rigidity evaluation (Frequently earthquake).

3.3.2. Comparison of displacement and story drift ratio due to lateral loads

Division	Story drift graph due to seismic load		Lateral disp. graph due to wind load
	Frequently earthquake	Rarely earthquake	
RC Seismic-wall structure			
RC Frame-core-tube structure			
RC Frame-core-tube + outrigger structure			

3.3.3. Comparison of rigidity ratio to vertical variation of core wall thickness

· The core wall is a vertical member, with greater axial force and shear force at the lower parts of the wall than at the upper parts. Accordingly, when designing with identically thick core walls for all floors, the wall thickness are mostly determined with the stress of the lower parts, and it cannot be economically designed for the upper walls. Accordingly, modification of the wall thickness through appropriate grouping is necessary for an economical design, except for when it is impossible due to architectural (a lot-solid area) and workability reasons (re-installation of the form), modification of the wall thickness through appropriate grouping is necessary for an economical design.

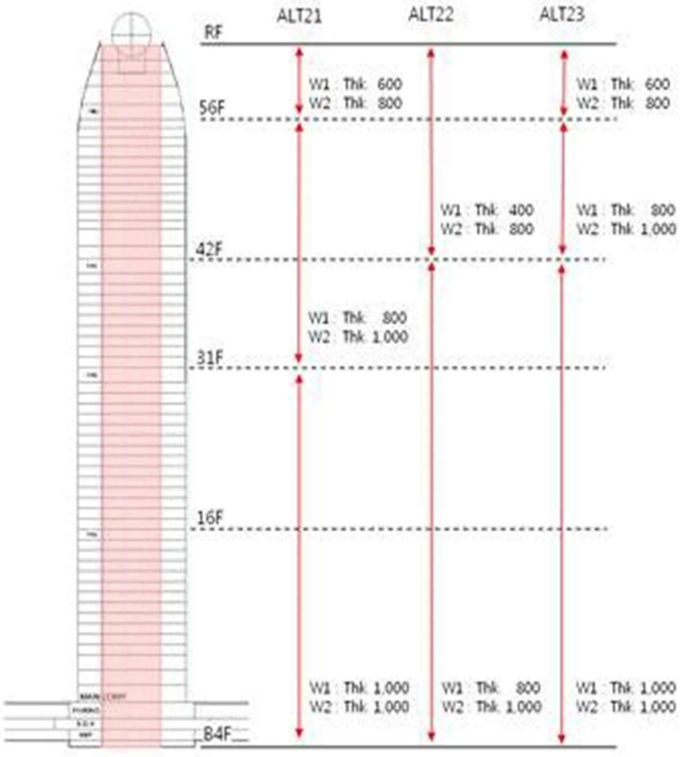


Figure 7. Grouping by ALT.

Table 4. Comparison of stiffness ratio by the vertical variation of core wall thicknes

Division		ALT 0	ALT 21	ALT 22	ALT 23
Lateral displacement	X-dir (mm)	182.1	182.8	187.6	182.3
	Stiffness ratio (%)	100	99.6	97.1	99.9
	Y-dir (mm)	199.5	201.0	215.9	200.3
	Stiffness ratio (%)	100	99.2	92.4	99.6

3.3.4. Comparison of rigidity ratio to story outrigger

• An efficient outrigger should be installed to increase lateral rigidity capacity of a high-rise building. Outrigger installation location is limited to machine rooms. Thus, the following floors were compared: 15F, 30F, 41F, and 56F.

• For the outrigger in the SD stage, the installation of a steel truss with excellent workability was planned. The truss was fixed at 6 m deep, in line with the initial architectural plan. As shown in Fig 8, the installation of an outrigger truss with efficient workability was pursued.

• The truss size in relation to the location of the outrigger installation in this study was H-700x 70x50x50, and the optimal size of the outrigger will be examined in the future.

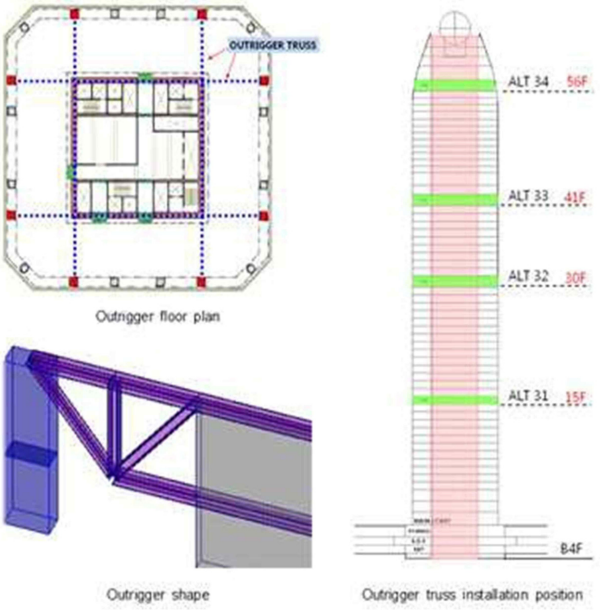


Figure 8. Location of the outrigger truss installation and shape.

4. Foundation system

• In accordance with the Report on the Ground Investigation of Lotteworld Shenyang China, since the site's geological strata consist of sand and gravel, which make it impossible to secure its soil-bearing capacity.

• The foundation in this project is based on sand and gravel the allowable maximum soil stress is about 400kN/m^2.Consideringselfweightofstructure,pilefoundationwouldbedesigned.

• The detailed base referenced to 沈阳乐天项目 岩土工程勘察报告(初步勘查, 辽宁省建筑设 计研究院岩土工程公司，2009.12.22.)".

• In Land Mark Tower, the foundation of the column and core is designed mat foundation considering large axial forces. Foundation of THK.3,500 is used due to pile arrangement, moment and shear force.

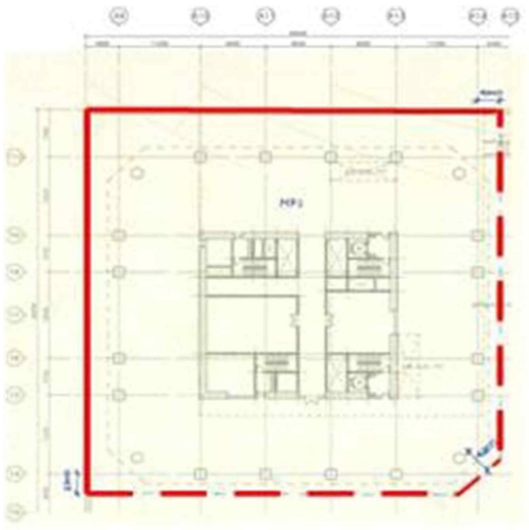


Figure 9. Foundation plan of Land Mark Tower.

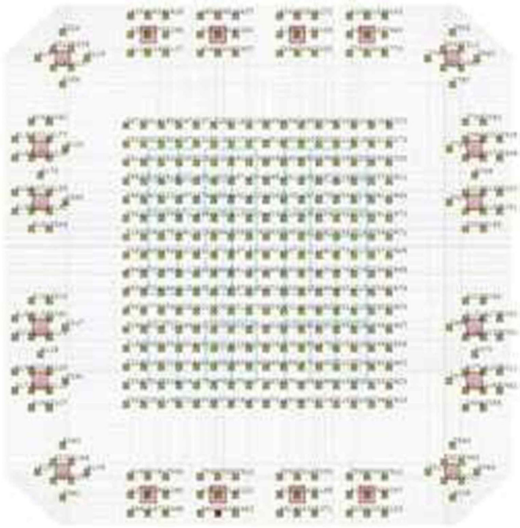


Figure 9. Pile arrangement and reaction foundation tower part.

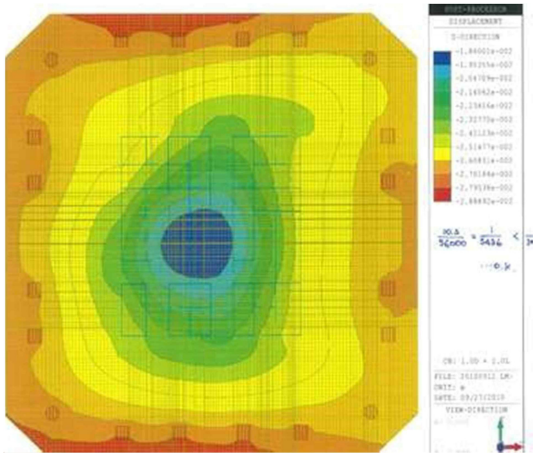


Figure 10. Foundation deflection check of Land Mark Tower.

5. Lessons Learned

To define the lateral load system in the heavy seismic zone, the stiffness ratio of the center concrete core and the outrigger truss on the middle floor are characterized to each component design.

6. Conclusion

The gravity system is selected to post tension slab with perimeter girder for constructability and story height.

The varied thickness of the central core and the steel outrigger truss on the middle floor are the most effective lateral resisting system of the tower.

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