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Structural Design and Construction of Mega Braced Frame System for Tall Buildings

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Abstract

Recently, two unique high rise buildings have been designed and constructed in Korea. The two buildings, which consist of mega braces and mega columns, are 70-story, 105-story high rise buildings. Through two external structural frame systems, it will be analyzed mechanical and structural characteristic mega column and mega brace system in this report. Particularly, the joint has been studied through the analytical method based on the load transfer mechanism at the point where a mega brace and mega column meets.

Keywords: Tall Building, Mega Column, Mega Brace

1. Introduction

The external structural frame systems are a typical structural system that is used for tall buildings. It is an efficient structure system in high rise buildings along with the internal core. However, since the exoskeleton structural system can generate a relatively large amount of tensile force, various methods have been applied to suppress the tension. In general, the most commonly used structural system is a belt truss method, which reduces the tensile force by transferring all gravity loads to the mega column through the belt truss. However, unlike other high rise building mega brace system, which is being tried in China and other countries, the above two buildings use a structural system that transfers the gravity load through the mega brace, unlike the structural system using the load transfer method using the belt truss.

The two building with the mega column and mega brace system are structurally designed by SOM, Arup and Dongyang Structural Engineers Group. One of them is Parc1, which is currently under construction by POSCO E & C. It is 69 stories and 329 m high. The other is Hyundai Motor's headquarters, the so-called GBC(Global Business Center), which is designed up to SD stage by Skidmore, Owings & Merrill LLP. It is planned to be designed in CD Stage in the 105-stories and 562m high. Two buildings have different mega columns with different shape and material types, and these have different characteristics of mega braces. However, it will be explained by the characteristics of mega brace buildings through two buildings with the similar flow of load path. Through these two building, these have been investigated core type, brace angle, and location of mega column for effective lateral stiffness. Particularly, based on the load transfer mechanism, the joints have been studied by analytical methods at where brace and mega column meets.

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2. The State of Arts of Structure System in Tall Buildings

According to a resource from CTBUH, 75% of tall buildings before 1990 had a frame tube with steel, but after

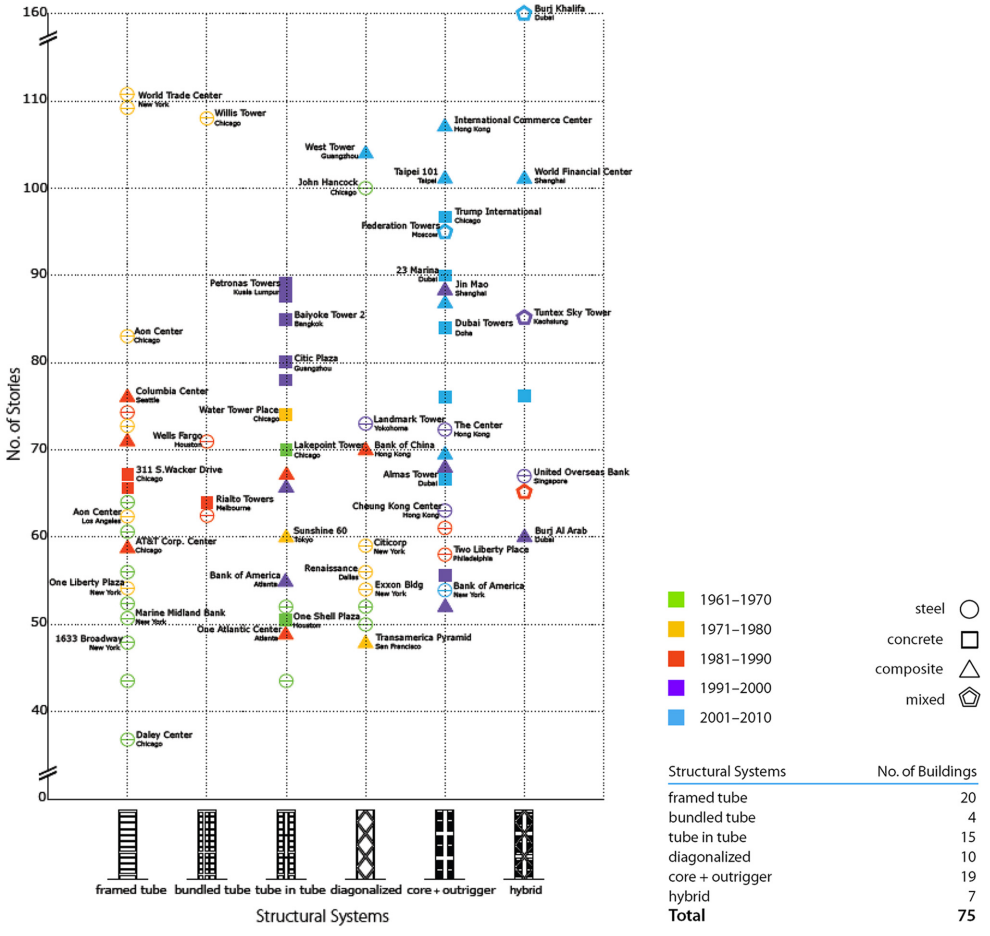


Figure 1. Parc 1. (Rogers Stirk Harbour + Partners)



Figure 2. GBC Tower. (SOM)

2000's 73% of tall buildings are core and outrigger system and 50% are concrete buildings(Figure 3). In Korean tall building history, before 1971, 31 stories were the tallest. And up to the Trade Center in 1987, all of tall buildings in Korea were streel braced frame system. In 2000s, many tall buildings were constructed. The outrigger system was



Structural Systems	No. of Buildings
framed tube	20
bundled tube	4
tube in tube	15
diagonalized	10
core + outrigger	19
hybrid	7
Total	**75**

Figure 3. Classification of the tall buildings by its structural system (CTBUH, 2010)

applied in famous tall buildings including Hyperion I (254m, 69 stories, Seoul), and Northeast Asia Trade Tower (305m, 68 stories, Incheon).

Regarding brace system, the John Hancock Center which was built in 1969 is a braced tube system, but it hasn't be applied well actually. However, recently the braced mega frame system is revived from super tall buildings in China.

3. The Design Parameters of Mega Structure System

3.1. Scheme of mega columns

Mega structure system is in use widely for recent tall building with the advantage of structural efficiency. And, mega column is a basic necessity of mega structure system.

The BRI (Bending Rigidity Index) raised by Taranath is the total moment of inertia of all the building columns about the centroidal axes participating as an integrated system. It is show how the resistance to bending is affected by the arrangement of columns in plan. The ultimate possible bending efficiency, BRI of 100, would manifest in a square building which concentrates all the building columns into four columns (Bungale S. Taranath, 2009).

$$BRI=\sum EI_i=100\times\frac{\sum_i A_i b_i^2}{b^2\sum_i A_i}$$

where: A_i= Axial area of single column, b_i= Column spacing of one outer-frame side

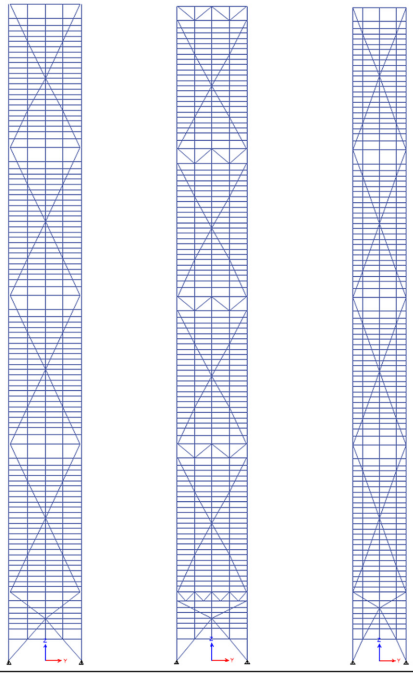
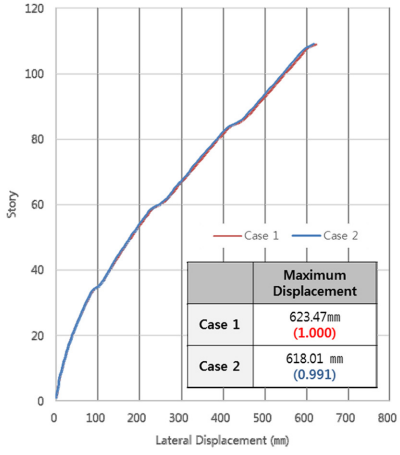
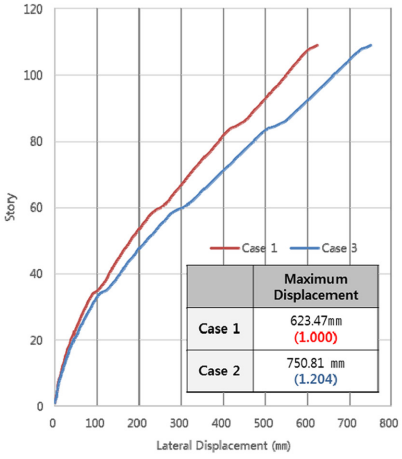
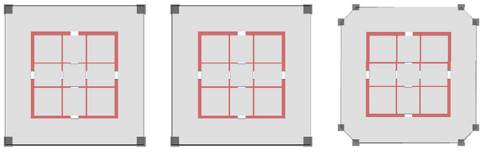
3.2. Belt truss with mega braces

In mega brace system, generally, building divided to several part by belt truss placed in each part. A beam-column frame of each part transfer gravity load to the belt truss below, which in turn transfer it to the mega columns. It means the mega brace do not resist gravity load and resist lateral loads only. However, without belt truss, mega brace will be connected with floor structures and take all gravity loads at every floor. In this case, an analysis and design shall be performed considering its connection detail.

3.3. Case study about the efficiency of mega structure system

We made 3-modeling to study an effect of a shape and location of mega structures. Basically, they are based on the scheme of GBC Tower. In the lateral stiffness, there is

Table 1. Case study of a shape of mega structure

Case	1	2	3	Lateral Displacement
Elevation				
Type	Mega brace w/o belt truss	Mega brace w/ belt truss	Mega brace w/o belt truss	
Plan				

no difference between Case 1 and 2. However, Case 3 show relatively low stiffness because narrow brace width by 8-columns (Table 1).

4. The design of Parc 1 and GBC tower

4.1. Lateral load sharing ratio with core ratio

The most important thing in a tall building is the size of the core area versus the floor area. For a typical tall building, effective cores account for 25% to 35%. The core ratio of Parc1 is relatively small at 9%, and the core ratio of the Hyundai Motor Company (GBC) is relatively large at 35%. Therefore, in order to resist the lateral load, in the case of Parc1, the required lateral load resistance of the external frame is higher than that of the core (wind load sharing ratio is 85%). In case of the GBC Tower, the frame has a relatively low lateral load ratio (wind load sharing ratio 30%) (Figure 4).

4.2. Efficiency according to location of mega column

In the case of Parc1, as shown in Figure 5, it consists of two columns at each corner and one gravity column at the center, and a total of eight mega columns and four gravity columns. In the case of the GBC, it is made up of one mega column at each corner and is composed of three gravity columns on each side, totally four mega columns and twelve gravity columns. Not only considering the architectural influences but also for the most efficient bending stiffness of the whole building the columns were placed.

Considering BRI, Table 2 shows GBC is more efficient than Parc1. It is difficult to simply compare these indicators.

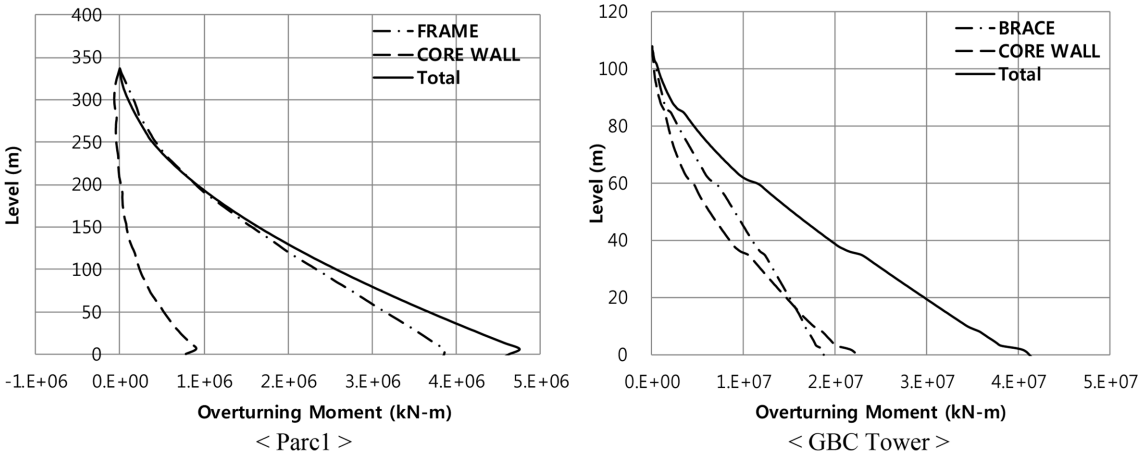


Figure 4. Overturning Moment Comparison.

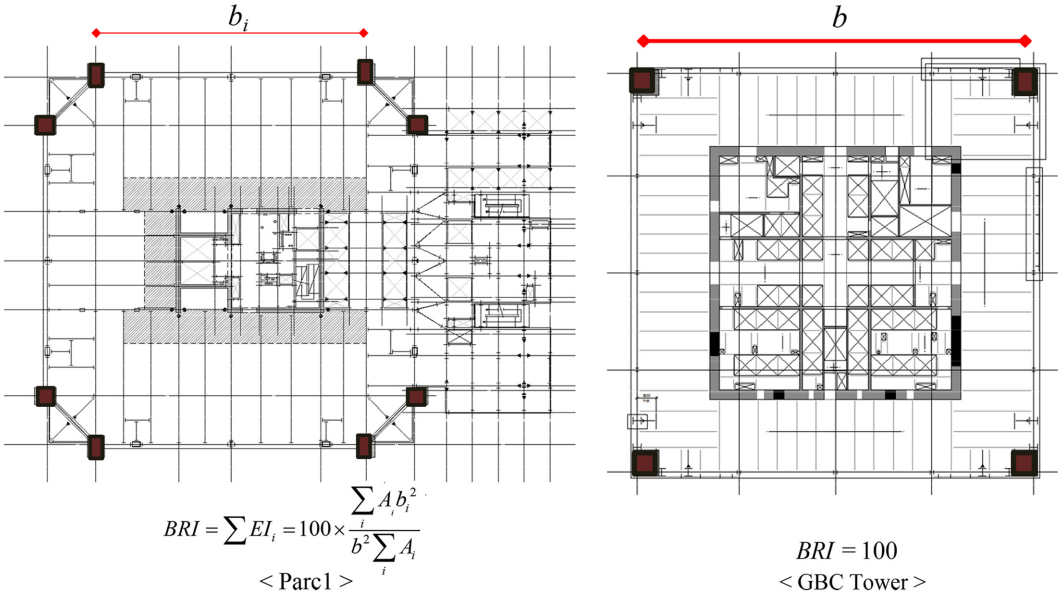


Figure 5. BRI (Bending Rigidity Index) review.

Table 2. Calculated BRI

	Column Size (mm)	b (m)	b_i (m)	BRI
GBC Tower	3000x3000	58.9	58.9	100
Parc1	2000x2500	42.4	31.5	77.6

As mentioned in previous chapter, since the lateral contribution of the exoskeleton is small, the GBC can be applied to four mega columns. However, in the case of Parc1, it is difficult to control the tensile force generated at the mega column because the lateral contribution ratio of the external structures is high. Therefore, it is more structurally economical to increase BRI than to reduce the flexural stiffness generated at the mega column.

4.3. Angle and module of mega brace

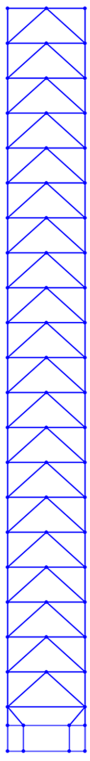
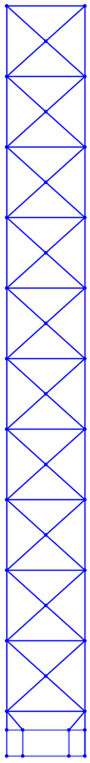
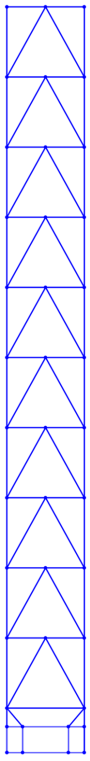
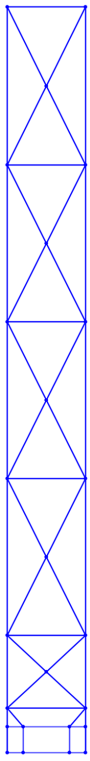
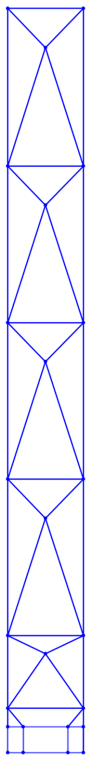
The angle of the braces is a very important factor for the lateral resistance. The brace module can be determined by the angle of the braces, which greatly affects the lateral stiffness of the building. In order to evaluate the effect of lateral stiffness according to the angle, various types of brace shapes were examined to the GBC tower. Its result is showing in Table 3.

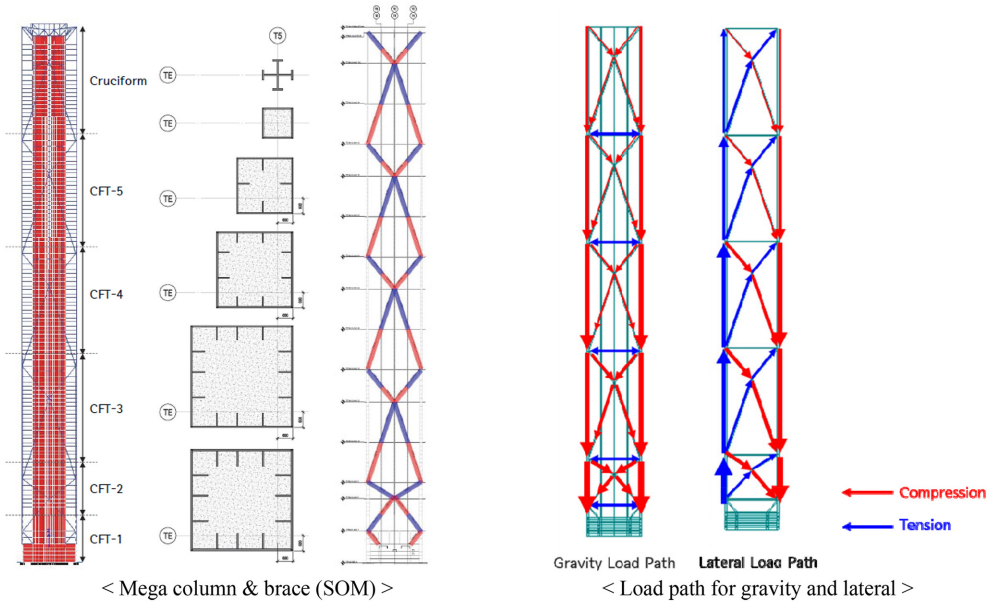
The lateral stiffness was evaluated based on basic wind load in Seoul. The basic wind load in Seoul is evaluated with a 27m/s wind speed based on that the average wind speed of 100-year return period is 10 minutes. The lateral displacement was evaluated based on H/500 basically considering in Korea and the lateral stiffness and amount of brace were evaluated based on this result. The angle of the brace was evaluated most effectively when it was kept between 35° and 70°, and the brace module of the building was decided according to this shape. The high-waisted brace of the GBC Tower is applied based on Stromberg et al, and as a result, the high-waist is most effective for the GBC building (Stromberg, Lauren L, 2012).

4.4. Load Transfer of mega brace

An important factor in the exoskeleton building is the bending stiffness of the entire building as described in the preceding sections. In this case, since a high tensile force is generated in the mega column, it is necessary to concentrate gravity load as much as possible on the mega column. Therefore, a load should be transferred to the mega column by adding a belt truss and a load transfer member in the brace module.

Table 3. Brace module case study in GBC

Brace Shape					
Case	A	B	C	D	E
Angle (°)	42.4	42.4	61.3	63.9	71.9
Lateral Stiffness	**0.63**	0.82	0.74	**1.02**	1.00
Volume of Member	0.96	1.22	**0.83**	**1.03**	1.00



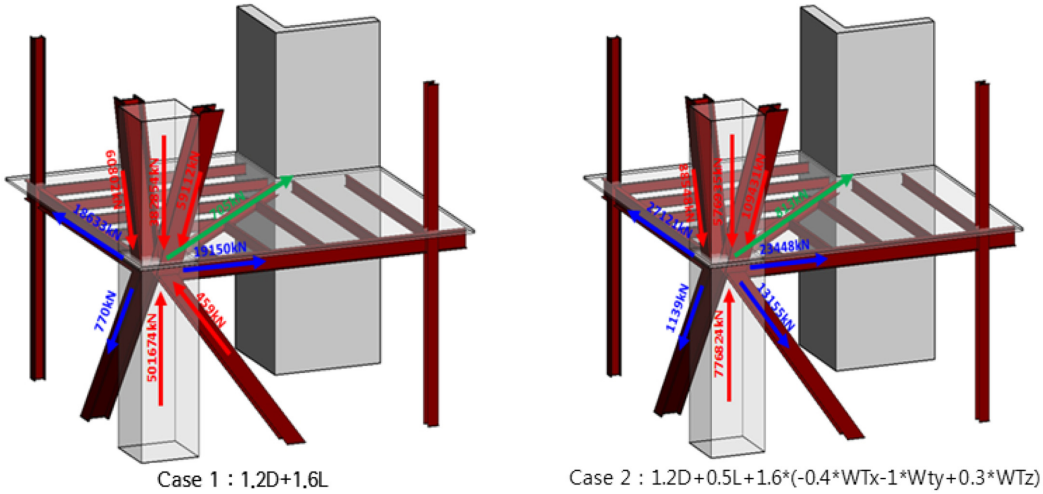
< Mega column & brace (SOM) > < Load path for gravity and lateral >

Figure 6. Load path of GBC Tower.

The braces usually resist the lateral force only, but in the case of Parc1 and GBC, the entire load is transferred to the mega column through the mega braces. (Figure 6) In order to transmit the vertical load, the mega braces must have sufficiently high bending stiffness and axial stiffness. However, since when the gravity load and the lateral load are transmitted through the mega brace, a high tensile force is generated at the end of each module, it should be essentially reviewed. In the case of GBC building, the generated tensile force is 27,121kN, so that the dimension of the member is H-900×1200×80×80 to resist enough tensile force. (Figure 7)

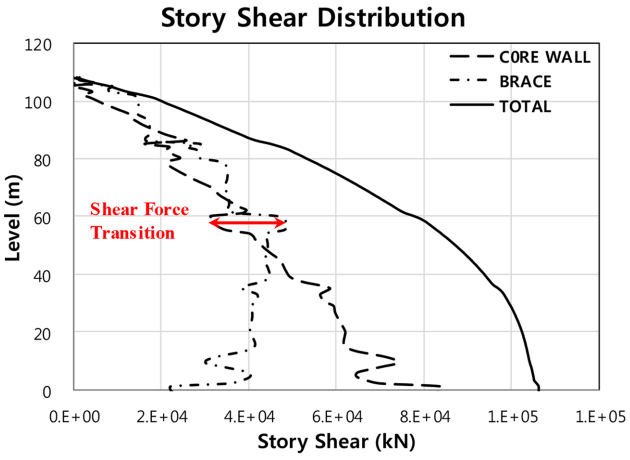
Where the column and brace nodes meet, the load transitions due to the difference in stiffness with the core. Since the shear force is transmitted through the slab, the horizontal load and the vertical load transfer in the mega brace building are very important factors.

As shown in Figure 8, the load transfer can be seen at the end of the brace module. In the GBC tower, relatively large load transitions occur (10,100kN) as the stiffness of the core is large, and relatively small load transitions occur (3,000kN) because the stiffness of the core is small in Parc1. However, in order to transfer the load, there are two methods to increase the in-plane force of the slab and to generate a load path by applying internal steel horizontal braces. Therefore, for tall buildings with the mega brace system, it is necessary to establish a structural plan considering these load paths, and various horizontal structure systems

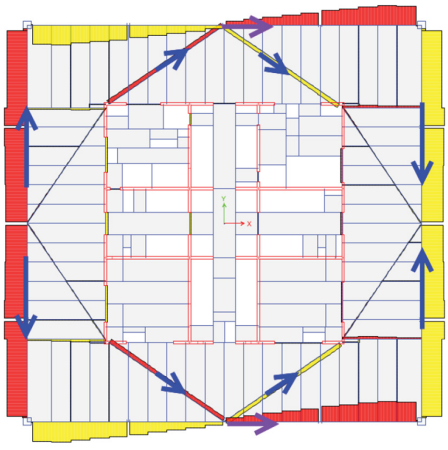


Case 1 : 1.2D+1.6L Case 2 : 1.2D+0.5L+1.6*(-0.4*WTx-1*Wty+0.3*WTz)

Figure 7. Load component at a joint in GBC Tower.

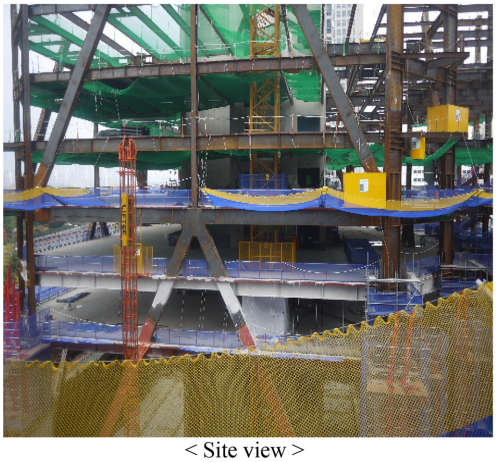


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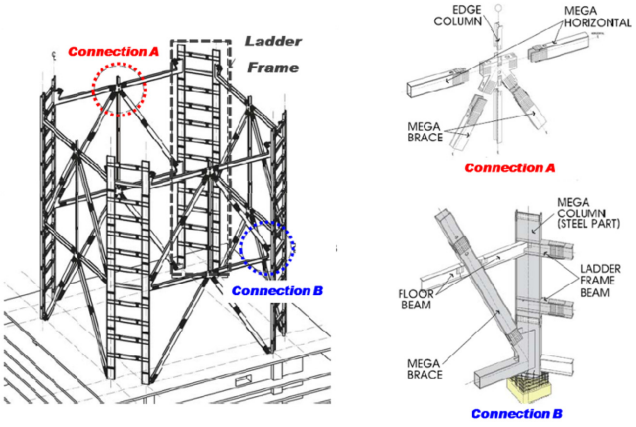


< Bracing system of plan (SOM) >

Figure 8. Shear force transition in GBC Tower



< Site view >



< Bracing system and joint (Arup) >

Figure 9. Brace system in Parc1.

should be applied according to the generated loads.

Since the mega brace is a diagonal member that transmits both the lateral force and the gravity load, the joint is very important. Therefore, the joint must have enough stiffness. The mega column of Parc1 is the SRC structure, and the diagonal member to be bonded is steel brace. (Figure 9) In addition, the GBC tower is a steel brace and the CFT mega column, the two types of joints are as follows. Shear stud was applied to the joint to transfer the load to the concrete sufficiently.

5. Conclusions

To apply the mega column and mega brace system to tall buildings, the structural engineer must consider both plan and elevation plans. Therefore, it is necessary to plan the structural system considering the overall size of the core, the arrangement of the columns, and the angle of the braces, and then design all from the vertical and horizontal load paths to the joints based on the structural planning. In this paper, the characteristics of the exoskeleton building have been described through two tall buildings with the mega brace system to be constructed in Seoul, Korea.

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