Council on Tall Buildings and Urban Habitat Korea

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

International Journal of High-Rise Buildings
June 2026, Vol 15, No 2, 85-93
https://doi.org/10.21022/IJHRB.2026.15.2.85

Structural Design and Erection of Super Tall Building: Global Business Center (Seongsu)

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Abstract The Global Business Center (GBC) Seongsu was planned as a 540m super tall building with 110 stories and 9 basement floors, located in Seongsu-dong, Seoul, Korea. In order to realize a supertall building with a slenderness ratio of 4.73, a plan to achieve maximum lateral stiffness was required. Also, all congent alternatives were studied for the floor structure and connections to optimize the structural quantity and efficiency taking into account the usability of the site shape. This paper introduces considerations regarding the placement of stiffness elements on the outer perimeter to maximize lateral stiffness, the placement of steel beams and alternatives to optimize floor weight, and also the erection and installation sequence of mega-braces and belt trusses.

Keywords: supertall building structure, erection sequence for mega-braces and trusses

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1. Introduction

The Global Business Center (GBC) Seongsu was planned to the 540m super tall building, located in Seongsu-dong, Seoul, Korea. The tower consists of office spaces mainly, with other amenity spaces such as cafeteria and museum. At the base of the tower, there are convention/conference facility, health club and four levels of parking space in the basement.

The client of this project is Hyundai Motor Group, a global automotive company in Korea, the building was intended to serve as the headquarters and a landmark tower for the company. This building was not constructed because the client purchased a new site for the project in Samsung-dong, at the end of the completion of design development phase. Arup N.Y and CSSE performed the structural design with KPF N.Y and Baum architect, Seoul.

2. Structural Description

The tower is planned to be 540m high, which has 110 stories on the ground and 9 stories below the ground, and the slenderness ratio of the tower is 4.73, thus it is very important to achieve the proper lateral stiffness of the



Figure 1. A view of the site and Global Business Center Seongsu.

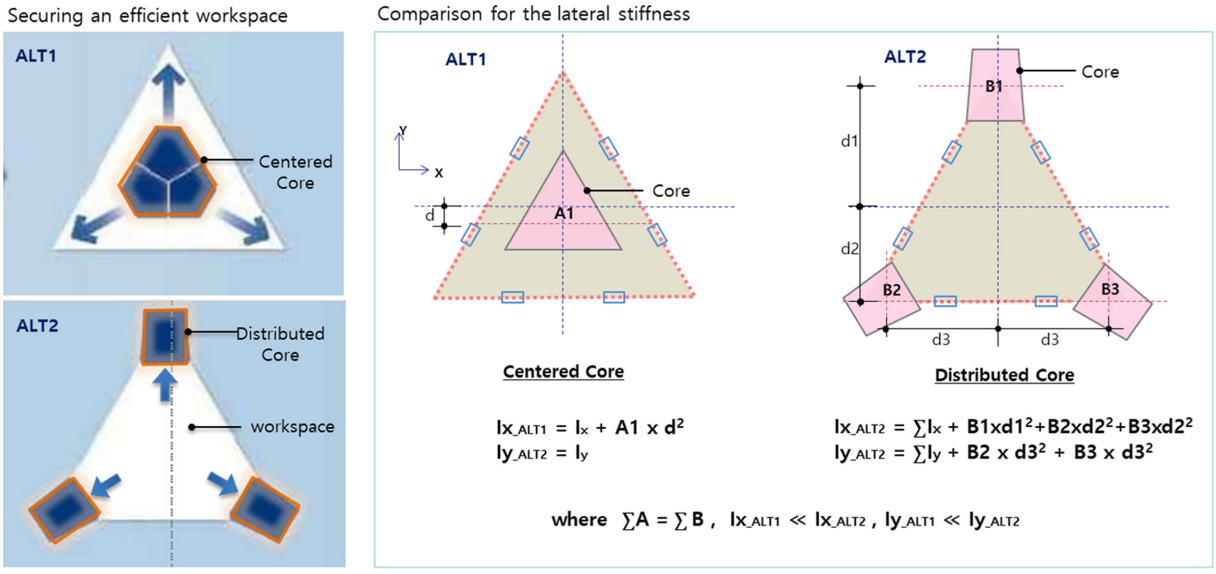


Figure 2. The Core Arrangement Study.

structure to resist lateral load. To maximize lateral stiffness, the three core wall zones, which are the major stiffness elements, were planned to be distributed along the outermost edge of the triangular shaped building plan.

As seen in the Figures, assuming the core area A1 is same as the sum of core area B1~B3, since bending stiffness is proportional to the square of the distance from the stiffness center, a much greater lateral stiffness can be achieved when core wall is distributed along the perimeter of the building plan. By dispersing the core walls in this way, the architectural layout efficiency of the internal workspace was also significantly improved. The three core walls are designed to effectively withstand lateral forces by connecting them with mega braces and belt trusses to ensure integrated behavior. The building was divided into eight zones based on height, with each mega

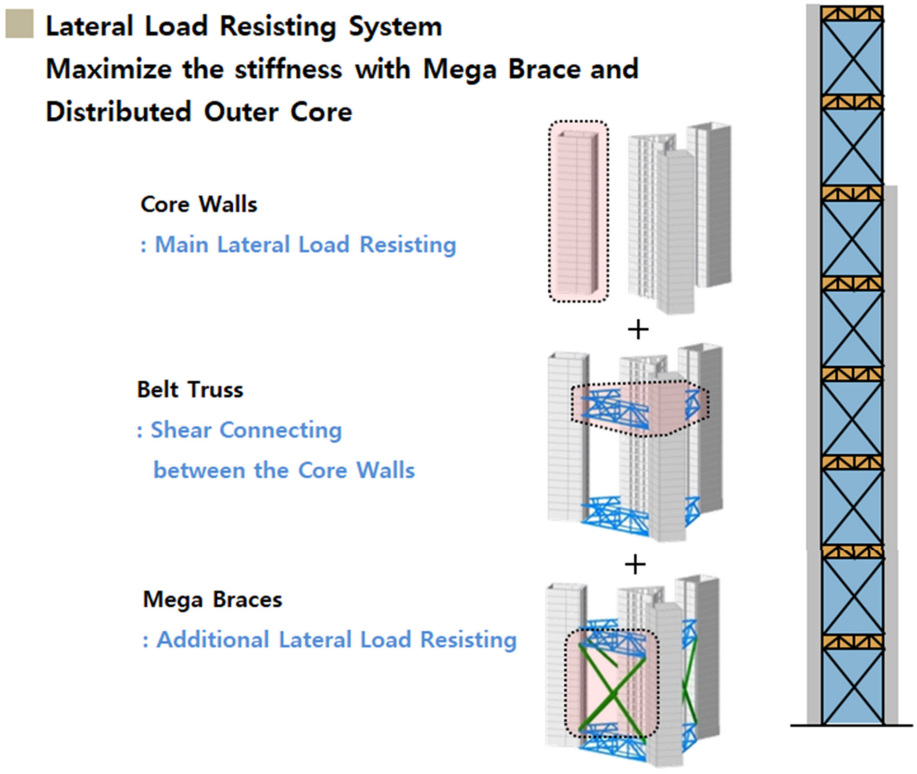


Figure 3. Lateral Load Resisting System.

brace and belt truss serving as the boundary, as seen in the Figure 3.

3. Structural Materials

As shown in the Figure 4, the material strength was applied separately for each zone.

Considering the stress level, a maximum of 80 MPa was applied to the concrete design strength, and for the steel member, SM420(TMC) yielding strength Fy=420 MPa was planned for the lower part of the building, where large member forces occur.

4. Gravity Load resisting system

The accumulated weight of a high-rise structure is inevitably very large and optimizing the weight of the typical floors has a significant impact on the overall structural plan, therefore, a detailed review of the typical floor structure is essential. Accordingly, the spacing of steel beams and the resulting slab thickness was reviewed to optimize the structural quantity, and not only the structural quantity but also the vibration performance of the floor structure were reviewed as well.

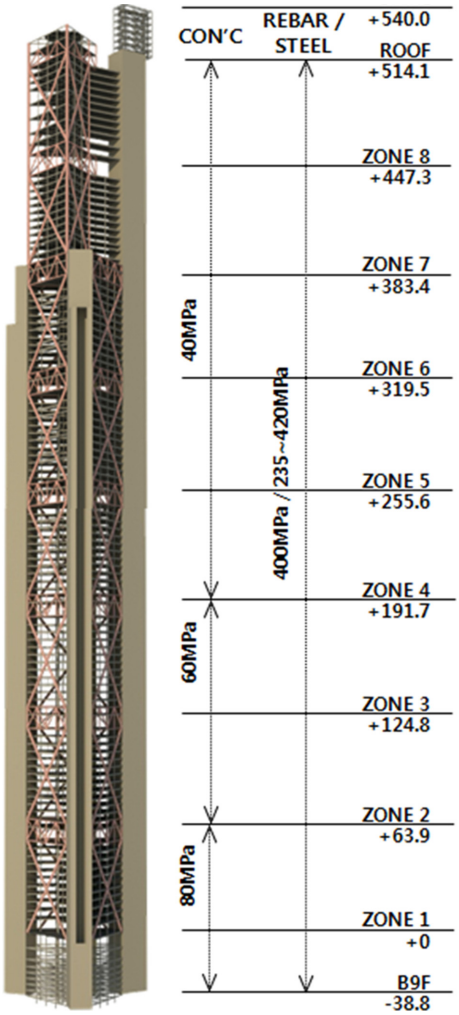


Figure 4. Structural Material Strength layout.

The table in Figure 5 summarizes the floor structural system. The basic option is consists of 135 mm-thick metal deck slabs supported by H500 × 200 beams with 2.625 m spacing, derived by dividing the typical column span of 10.5 m by 4. Alternatively, the beam spacing may be increased to 3.5 m with 150 mm, obtained by dividing the same column spacing by 3.

Using the same beam size, the wider beam spacing reduces the number of beams and results in a savings of approximately 6.3 tons of rebar per floor. However, this alternative requires a thicker slab, leading to increased concrete quantity. The typical floor slabs with increased thickness also contributes to a higher cumulative axial force throughout the building.

Because floor vibration performance is influenced more significantly by mass than by beam depth, the 3.5 m beam-spacing option with thicker slabs demonstrates slightly improved vibration performance compared to the thinner 2.625 m-spacing option. Nevertheless, all alternatives are regarded as satisfying the vibration criteria, as the coefficient of response for most floor areas remains below 6 (AIJ: $V < 5$).

Based on these considerations, the final design adopted the basic option. A detailed camber study is required, taking into account the deflection characteristics of both beams and slabs at each location.

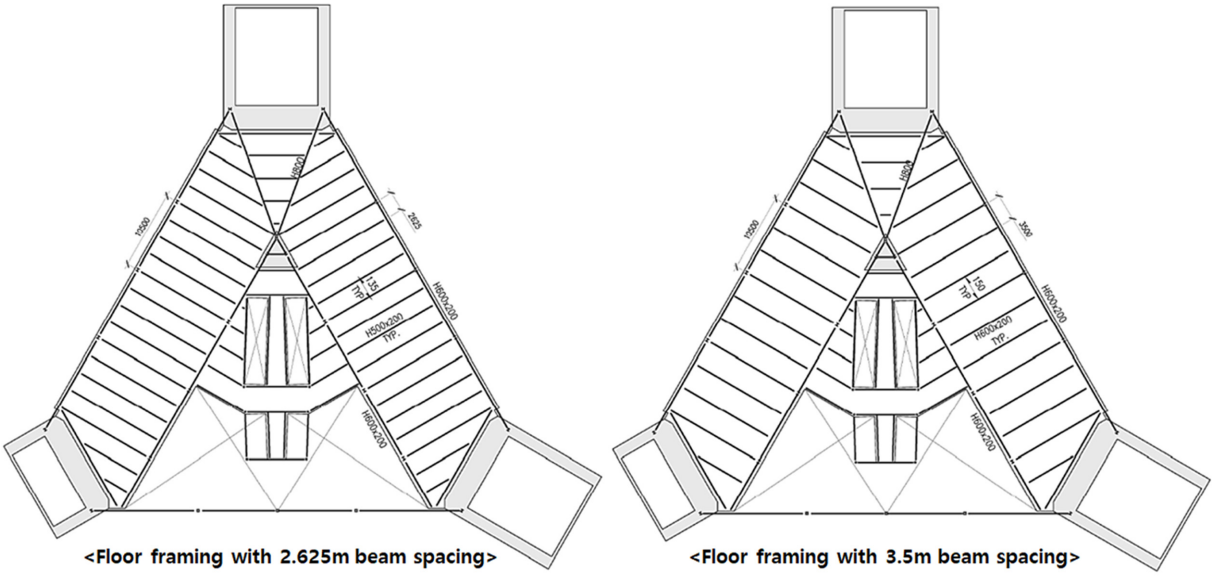
5. Lateral Load Resisting System

The tower's lateral load resistance system consists of a concrete core, steel braces, and belt trusses. These elements are sized to meet all strength requirements while achieving target total and inter-story deflection and displacement criteria. Under 100-year wind load conditions, the maximum deflection at a roof height (512 m) is as Figure 6.

As explained above, the overall stiffness of a building stems from the interaction of braces, belt trusses, and a concrete core. In other words, the amounts of steel members and concrete can be adjusted to achieve a given stiffness objective, and iterative analytical reviews are possible by reducing one if the other is increased.

Concrete and steel members have minimum sizes determined by the required strength, but due to this correlation between the sizes of these two main lateral force resistance elements, various solutions exist. Therefore, the size of the members can be appropriately determined by reviewing the sizes of core and bracing members through iterative analytical review, and the total quantity and price of materials were compared as shown in Figure 7 to find the optimal solution considering the relative cost of each aterial.

The eigenvalue analysis result shows that the periods of the first and second modes are 6.6 to 7.3 seconds, and the



	CURRENT	ALTERNATE	ALTERNATE	ALTERNATE
BEAM SPACING	2.625m	2.625m	3.5m	3.5m
TYP SECONDARY BEAM SERIES**	H500x200	H450x200	H500x200	H600x200
BEAM CAMBER	65mm	65mm	<65mm	<65mm
SLAB THICKNESS	135mm	135mm	150mm	150mm
SPEED DECK	SD 1-85	SD 1-85	SD 3-100	SD 3-100
CAMBER DECK?	NO	NO	YES (=L/200)	YES (=L/200)
MIN FREQUENCY	4.0 Hz	3.5 Hz	3.7 Hz	4.3 Hz
AVERAGE VIBRATION*** ISO, AIJ	R~5.5 V~3.9	R~6.5 V~4.6	R~5.2 V~3.7	R~5.2 V~3.7
FLOOR BEAM TONNAGE	[Base]	-3.6 TONS PER FLOOR	-6.3 TONS PER FLOOR	+8.1 TONS PER FLOOR
REBAR TONNAGE	[Base]	[Base]	+5 TONS PER FLOOR	+5 TONS PER FLOOR
CONCRETE ON DECK	[Base]	[Base]	+25 m^3 PER FLOOR	+25 m^3 PER FLOOR

*DESIGN LOADS: 0.8kPa SDL + 3.5kPa LL

**GIRDERS (PRIMARIES) ARE DEEPER THAN TYPICAL SECONDARY BEAMS

***FOR 95% OF FLOOR AREA

Figure 5. Summary for floor structure study.

period of the torsional mode is approximately 3.2 seconds. This indicates that it exhibits relatively greater stiffness compared to other towers of similar height located in areas with similar wind speeds and seismic activity, which is due to the very rigid structure with a concrete core placed on the exterior of the tower.

High compressive forces are generated in the tower's mega braces due to wind loads, gravity loads, and additional loads incurred during the construction process due to the shortening effect of concrete core-walls. The differential shrinkage between the concrete and the steel members, the axial force of the mega brace increases significantly. As a solution, concrete-filled tubes (CFT) were selected as the most efficient cross-section for the mega brace design. As seen in the the comparison of CFT and steel box section table in Figure 9 below, with CFT section the steel quantity can be optimized effectively.

The tower is laterally restrained at the foundation level 40 m below ground level, and accordingly, the seismic soil class was considered to be Class A. Consequently,

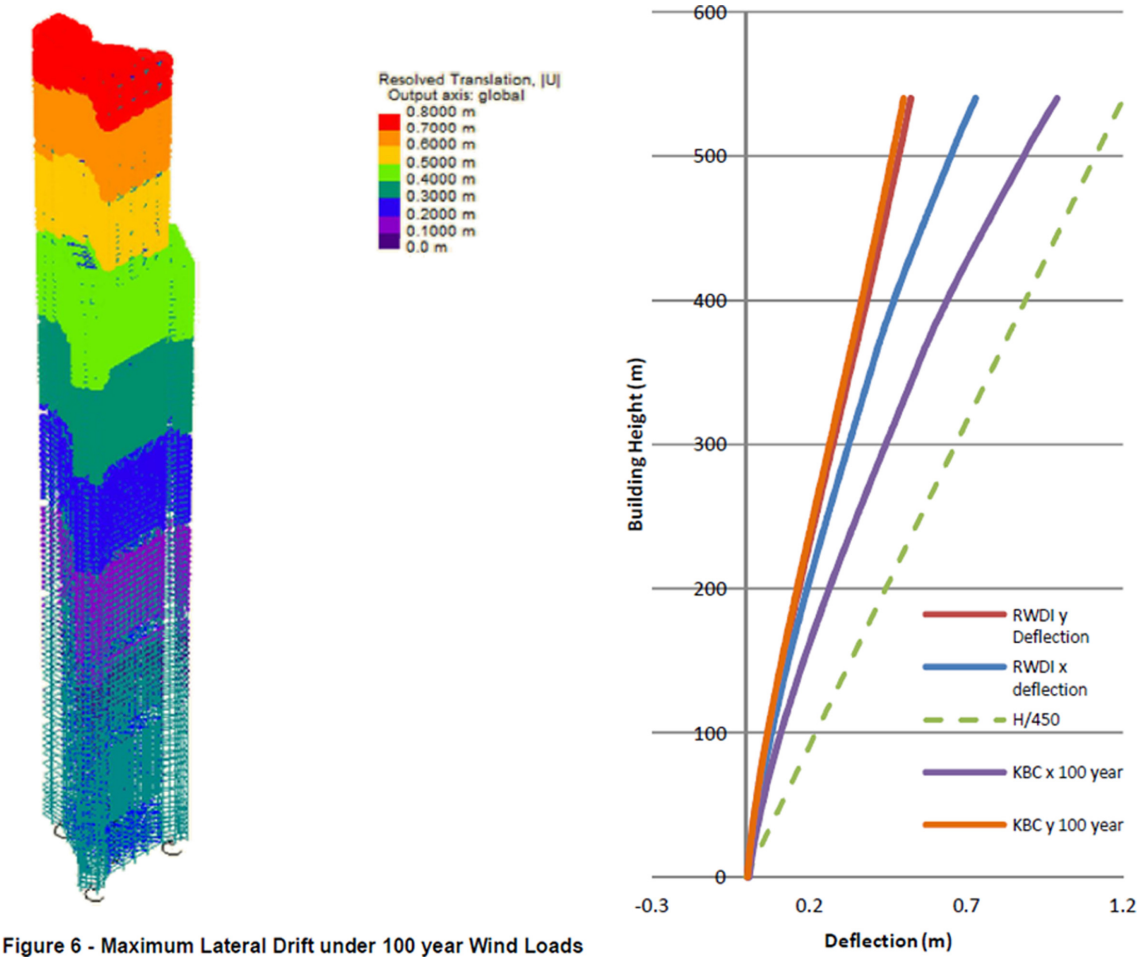


Figure 6. Drift and Displacement due to the Wind Load.

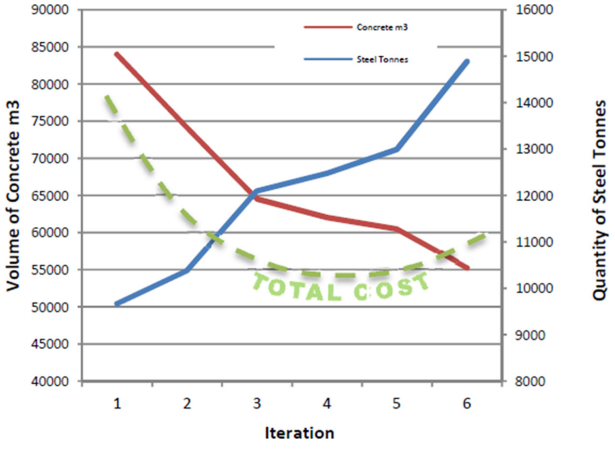


Figure 7. Material Optimization.

the seismic design category was changed from 'D' to 'B', eliminating the need to apply ductile detail design instead of relying on the lateral restraint of the surrounding soil. To meet this requirement, the structural model was restrained only at the foundation level, and the surrounding soil was ignored. Additionally, a soil-structure interaction model was executed by modeling both the ground and the surrounding soil. Ignoring the surrounding soil is generally a conservative approach, because it ignores additional restraint forces exerted by the soil. However, the impact of ground on the tower structure itself must be considered. Therefore, in the analysis model, the influence of the surrounding soil was represented as a series of springs installed on each floor, which corresponds to the ground stiffness evaluated in a separate analysis. Seismic effects were incorporated into the main model using multimode response spectrum analysis.

As a result, since the base shear force for seismic loads is only a tiny fraction of the wind load, the tower will exhibit essentially elastic behavior at the design seismic level. Even if the R factor is adjusted to 1.0 (i.e., even without ensuring ductile behavior), the increased seismic force is very small compared to the wind load. Therefore, the resulting seismic force does not affect the design of the main structural members. As a result of reviewing the seismic displacement considering this elastic behavior, it was found that the seismic displacement is within the recommended allowable range.

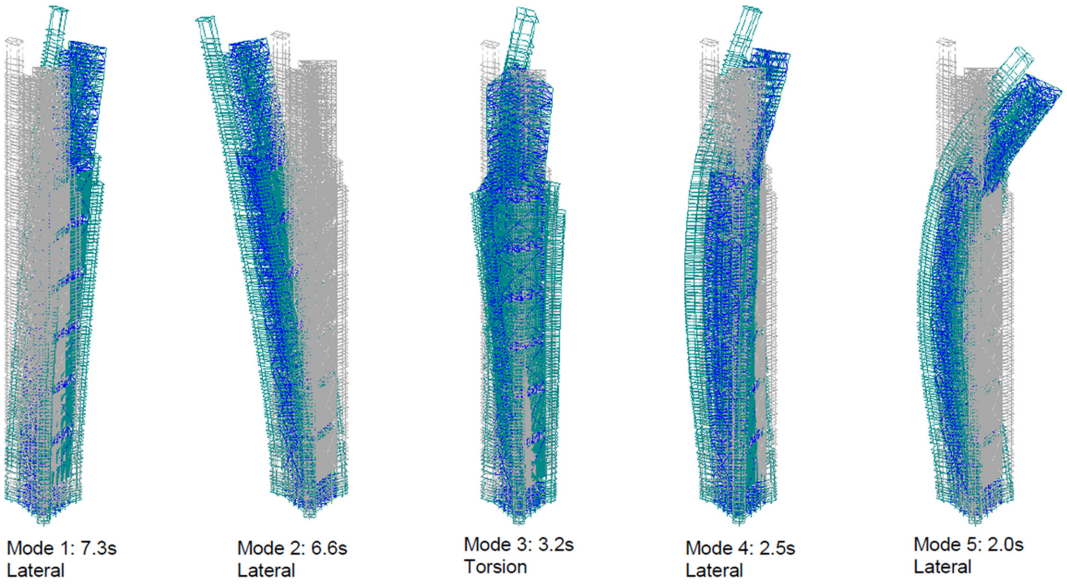
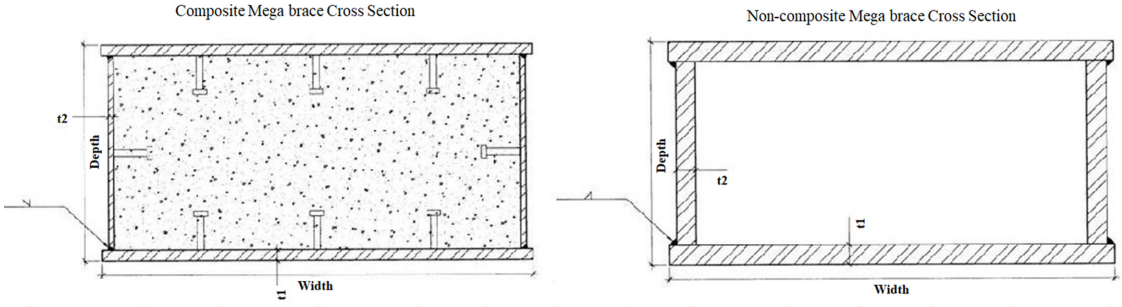


Figure 8. Dynamic Behavior of the Tower.



Location	Zone	Width(mm)	Depth(mm)	Composite Megabrace Cross Section					Non-composite Megabrace Cross Section			
				t1(mm)	t2(mm)	Conc' grount f'c(MPa)	Steel Fy(MPa)	Weight of Steel (ton/m)	t1(mm)	t2(mm)	Steel Fy(MPa)	Weight of Steel (ton/m)
South	Z8	1600	600	30	25	40	325	0.96	45	25	325	1.32
South	Z7	1600	600	30	25	40	325	0.96	45	25	325	1.32
South	Z6	1600	800	35	25	60	325	1.16	45	35	325	1.51
South	Z5	1600	800	40	25	60	325	1.28	70	45	325	2.21
South	Z4	1600	800	40	30	70	325	1.34	80	65	325	2.65
South	Z3	1600	800	50	30	70	420	1.58	70	70	440	2.47
South	Z2	1600	800	50	30	70	420	1.58	70	70	440	2.47
South	Z1	1600	800	60	40	70	420	1.92	80	80	440	2.80
East/West	Z8	1600	450	30	25	40	325	0.90	45	25	325	1.26
East/West	Z6	1600	800	30	25	60	325	1.04	50	35	325	1.63
East/West	Z5	1600	800	35	25	60	325	1.16	70	60	325	2.36
East/West	Z4	1600	800	35	25	70	325	1.16	75	60	325	2.48
East/West	Z3	1600	800	50	30	70	325	1.58	85	70	325	2.81
East/West	Z2	1600	800	50	30	70	325	1.58	85	70	325	2.81
East/West	Z1	1600	800	60	45	70	420	1.97	85	75	420	2.86

Figure 9. Section Study for Mega-brace member.

6. Shortening Analysis

As with all reinforced concrete structures, the tower will be subject to the effects of creep and shrinkage. This causes the concrete elements of the tower to shorten over time, which leads to slight changes to the elevation of

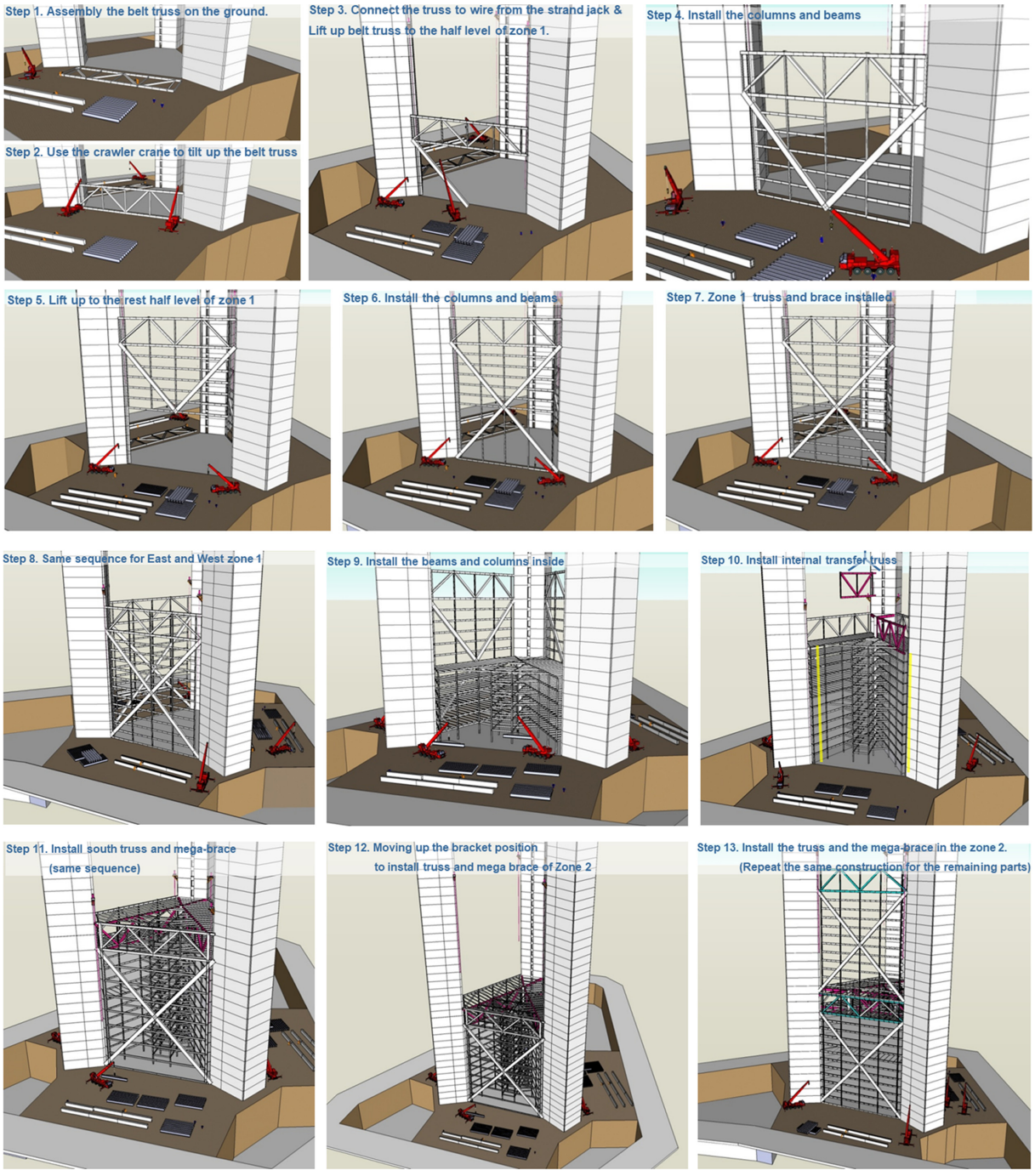


Figure 10. Study for erection sequence.

each floor, and the redistribution of loads where there are other load paths that shorten less. To control this, it is necessary to plan so that the stress generated in the vertical concrete members occurs as uniformly as possible. By adding the central concrete core, some load redistributed through the transfer trusses, and thus allows the stress to be more uniform. Additionally, due to the bracing pattern extending to the ground, a portion of the load applied to the core is transferred to the mega-brace members as the concrete shrinks.

It should be noted that the rate of observed shortening is greatest immediately after a unit of concrete is set in place and cured. Over time, these shortening effects diminish. As a result, a substantial percentage of the core shortening will occur while the tower is under construction. The construction sequencing should therefore leave as much delay as reasonable between pouring the concrete and welding the mega-braces in place.

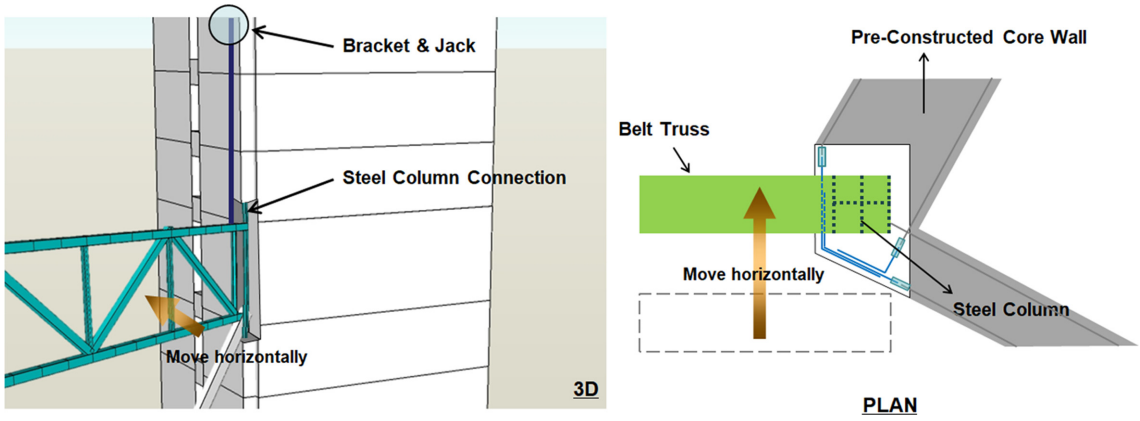


Figure 11. ALT1 for truss connection. (core wall block-out type)

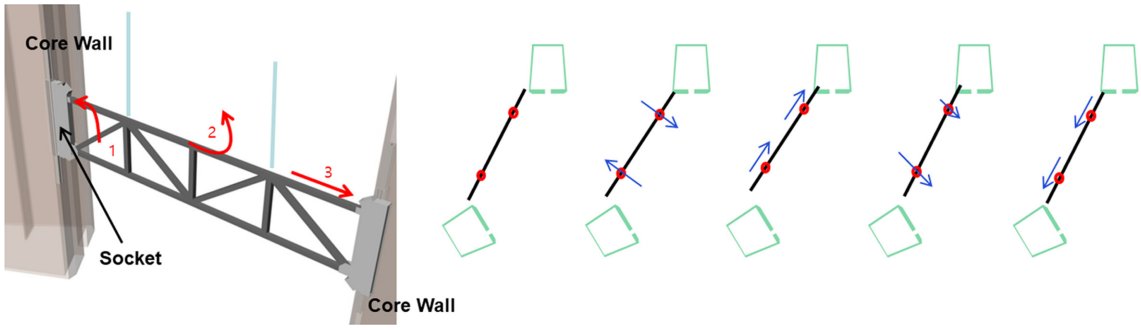


Figure 12. ALT2 for truss connection. (socket type)

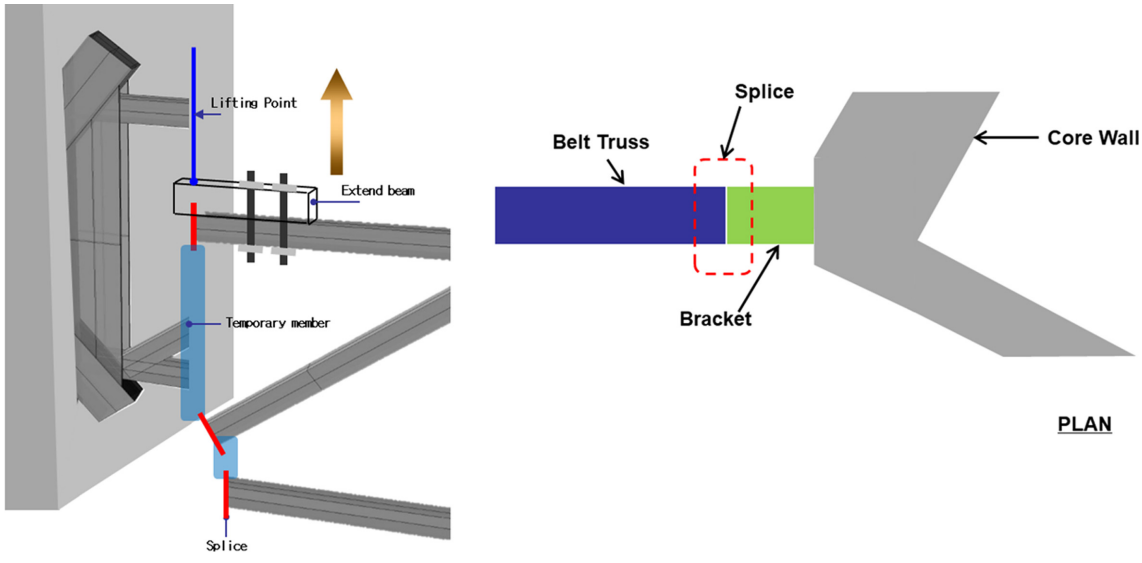


Figure 13. ALT3 for truss connection (splice type)

7. Erection Sequence

To realize super high-rise structures, it is crucial to conduct a structural analysis considering constructability beforehand. The following content examines the general construction sequence and the concepts of connections for mega brace and truss steel members.

Basically, after pre-constructing a certain portion of the core walls, the steel members can be installed by ground-assembling each zone and then lifting them using wire and strand jacks. The plan involves lifting the members at a certain distance from the building, moving them to their original connection points, and then joining and fastening them. Several alternatives regarding the details of the joints

have also been presented to ensure construction convenience and safety.

The following alternatives in Figure 11~13 were considered for the details of the connections of the steel trusses.

ALT1 is core wall block-out type, which is a method of post-constructing concrete at the corner location of the core wall after connecting the trusses. To apply this method, the strand jack must be capable of horizontal movement, and the construction process may be complex due to the rebar placement in the post-construction concrete walls.

ALT 2 refers to a method of inserting the truss into a pre-assembled socket, where the member is lifted and rotated slightly to insert the ends one by one. The strand jack must be capable of horizontal movement and rotation, and requires precise displacement control.

ALT 3 is a method in which the belt truss is lifted and the joints of the end members are connected to truss end joints that are pre-constructed and embedded in the core wall. This method requires the installation of temporary members for lifting, and since the truss ends are embedded in the core wall and constructed in advance, the lifting weight of the truss members can be reduced.

8. Closing Remarks

As a structural engineer, having the opportunity to design a supertall building exceeding 100 stories is truly a rare and fortunate experience. It also represents a significant professional milestone—one that required the collective expertise of our entire organization, as well as the successful navigation of numerous technical and practical challenges.

CSSE began the design process in 2009, when the client, Hyundai Motors, initiated plans to develop the Global Business Center (GBC) as a landmark project in Seongsu-dong, along the Han River in Seoul. However, after two years of design work, the project was suspended when Hyundai Motors decided to relocate the development to a new site in Samseong-dong, Seoul.

Despite this change, we believed that the knowledge and design data accumulated over those two years were far too valuable to remain internal. Therefore, we have chosen to share our work through this conference.

In addition to the material presented today, we have further resources, including detailed drawings. Should you have any questions regarding the design, please feel free to contact us, and we will be happy to respond at a later time.