International Journal of High-Rise Buildings
September 2021, Vol 10, No 3, 193-201
https://doi.org/10.21022/IJHRB.2021.10.3.193

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

Structural Design of Cheongna City Tower

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Abstract

Cheongna City Tower is a 448-meter-high rise observatory tower with 8.7:1 aspect ratio located at central lake park in Incheon Cheongna international city. The tower presents a crystal-shaped image and it becomes invisible when the façade is activated. The tower was planned to be hexagonal, 30-story building with two basements which are composed of mega frame structure using mega column and mega brace. In order to minimize the wind effect, the blow-through area was installed so that the wind can pass through. This observatory tower is an unprecedented project since the whole building is covered by façade for invisibility effect.

Keywords: Crystal image, Invisible, Mega column, Mega brace, Blow-through area, Facade

1. Project Information



Figure 1. Cheongna City Tower.



Figure 2. Site plan.

Location:	Cheongna International City, Incheon, Korea
Uses:	Observatory, Retail
Gross Area:	96,469.03 m^2
Story:	30F / B2 (Building Heights : 448m)
Design:	SMDP, DONGIL / LERA, DONGYANG

2. Design Concept and project progress

Cheongna City Tower was selected to be a crystal shaped image for design concept in Design Idea Competition(2008) and was developed to be more detailed design in architectural competition. The building was covered by façade composed of curtain wall to actualize invisibility and there is no such case where façade covers whole surface area of observatory tower. In structural point of view, façade that covers most surface area would maximize the influence

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[Design Idea Competition, 2008]



[2016 Design]



[2018 Design]



[Current Design]

Figure 3. Design progress.

of wind for high rise building design. Therefore, current design shape reflects on several different efforts to keep up with design concept and engineering design concept for aerodynamic properties that can optimize wind load effect.

3. Plan and elevation

Plan concept has been changed from stages to stages and current design shows hexagonal plan. Varying plan as the story rises is an important factor that directly influences crystal shaped image and wind load reduction. Triangular shaped core has been placed on the central part of the plan and mega column has been planned on the edge.

Even though the height of tower is considered to be high rise (448m), there are only 42-stories (30 Occupancy floor+8 PIT floor+4 PH floor) for whole structure. The typical building equivalent to this height should be around 130~140 floor apartment or 90~100 floor office building. Relatively low self-weight of the building due to small number of stories becomes disadvantage for wind load in addition to disadvantage from façade installation.

4. Structural system

4.1. Structural system progress

Special characteristics of Cheongna City Tower are listed below. Structural system has been changed three times according to economic, and construction wise point of view.

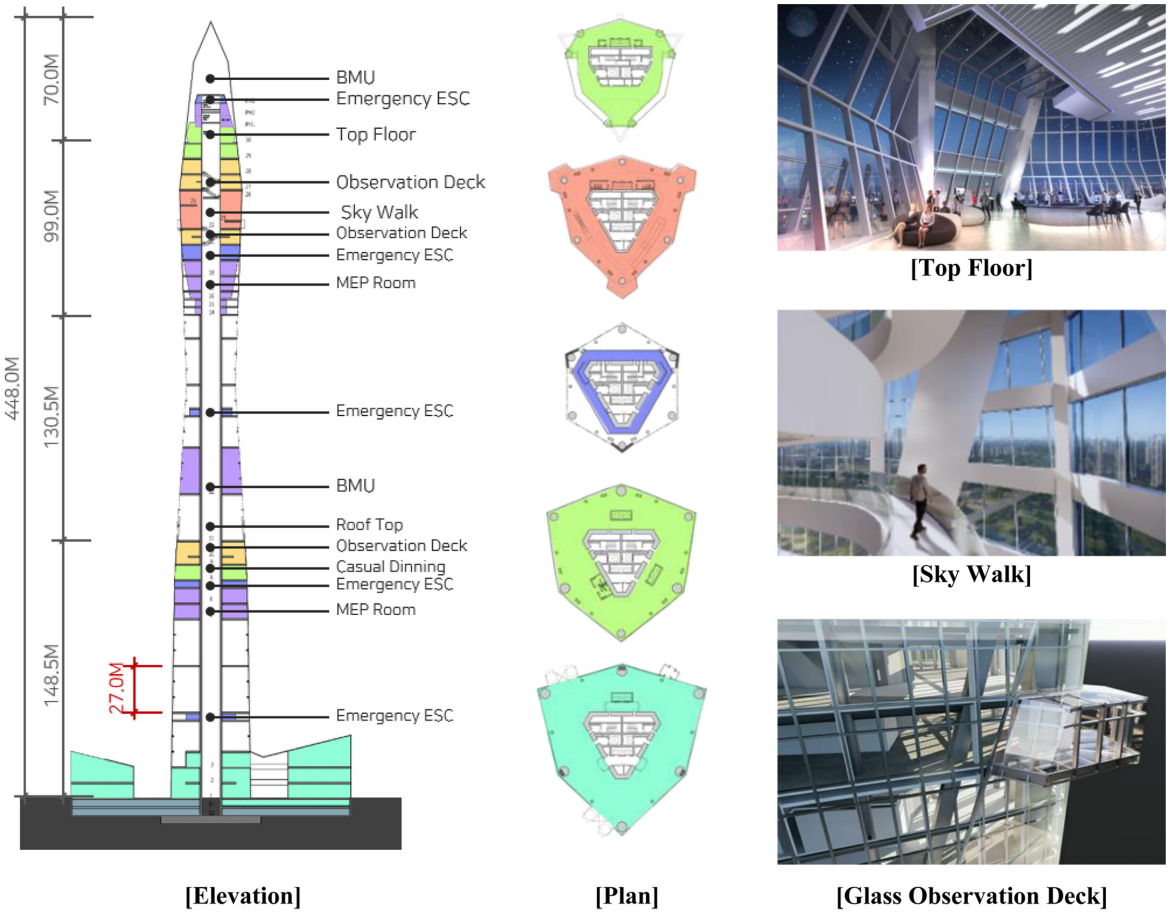


Figure 4. Project plan and elevation.

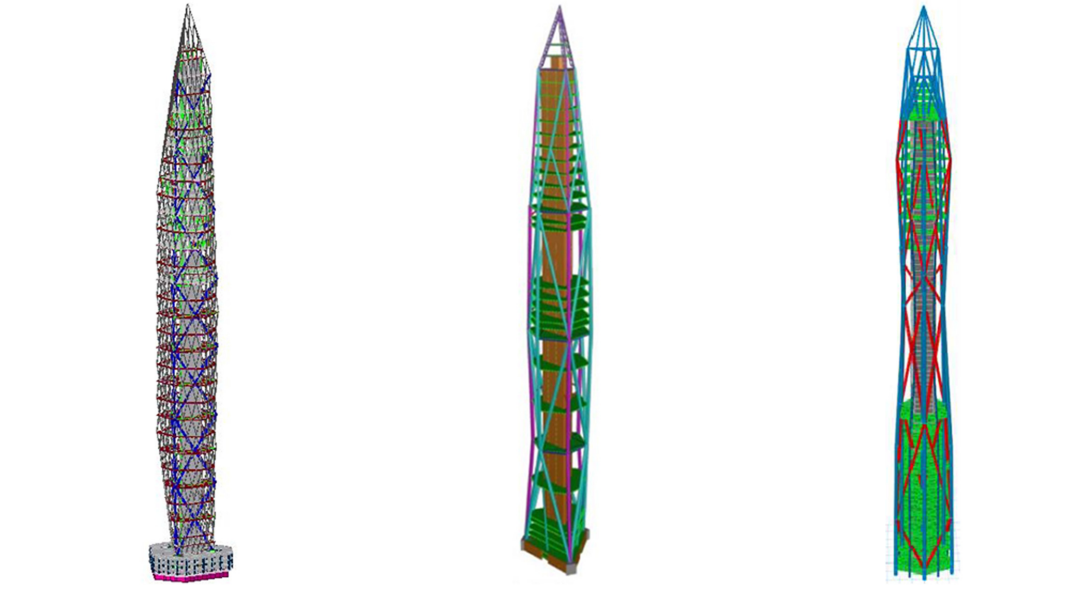


Figure 5. Structural system progress.

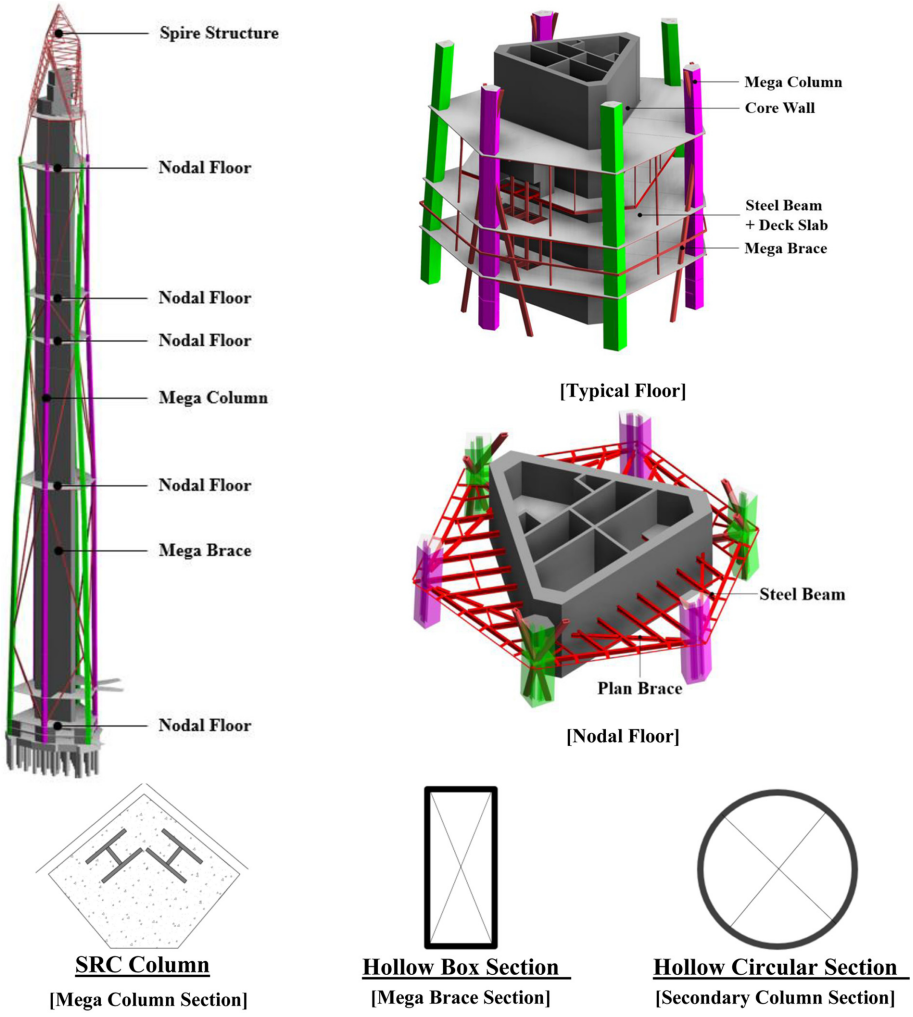


Figure 6. Structural system summary.

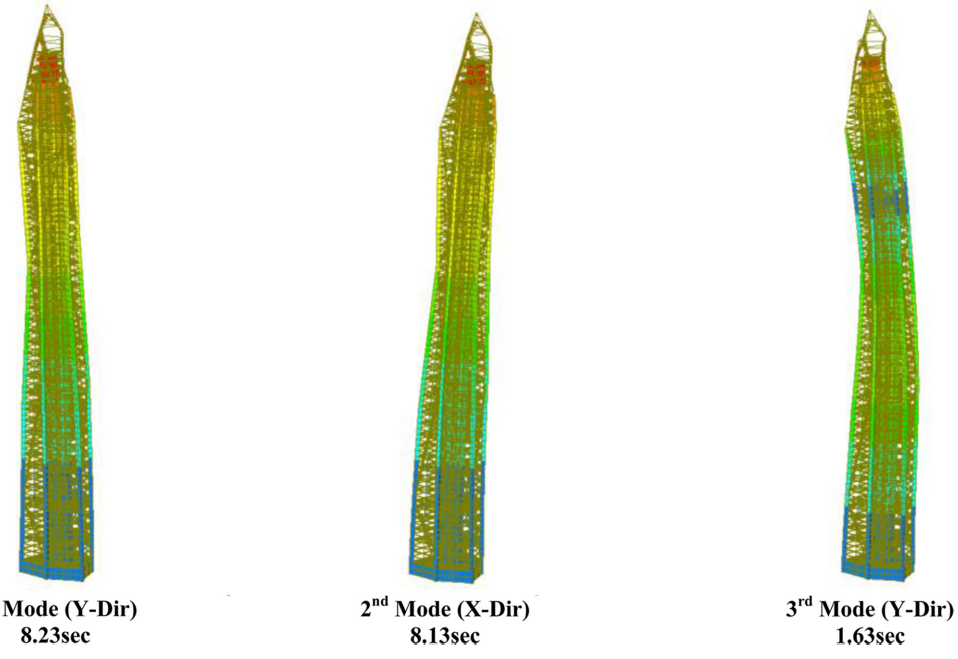


Figure 7. Eigen-value analysis.

- High story height. (Typical Floor: 9.0 m, Max story height : 27.0 m)
- Low building weight
- Additional requirement of façade support
- Separation of Occupancy Zone(Upper Zone) and Non Occupancy Zone (Middle & Lower Zone)

In basic design stage, diagrid system has been changed to mega frame system (Mega Column + Brace) due to exceeding amount of steel frame and connection members. Moreover, Mega Column method has been changed from CFT (Concrete filled tube) to SRC (Steel framed reinforced concrete). Applied method of construction was decided after considering Elevation Design, Member Quantification Planning, Field Welding, Fire Resistance Structure and Construction Precision etc.

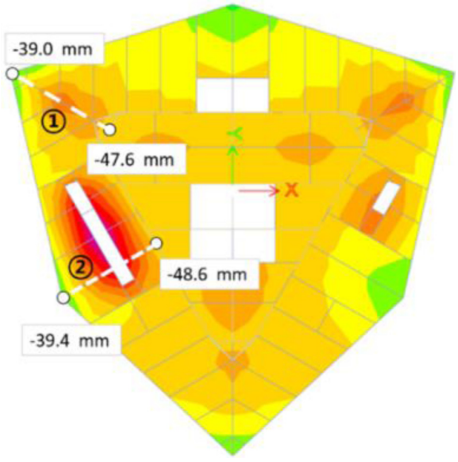
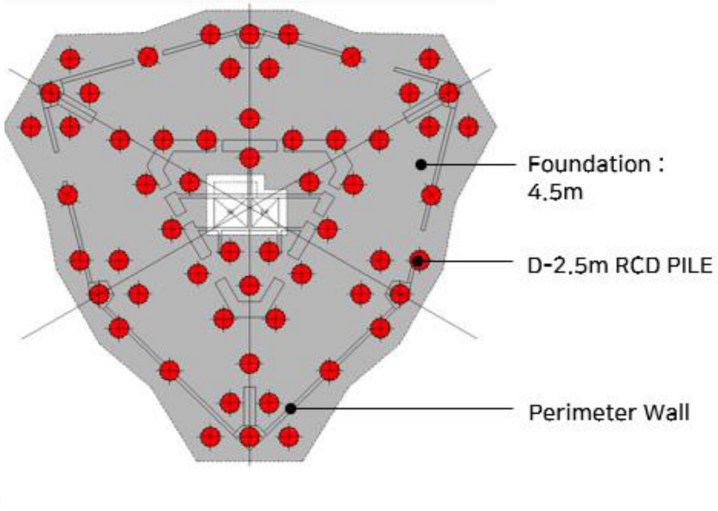
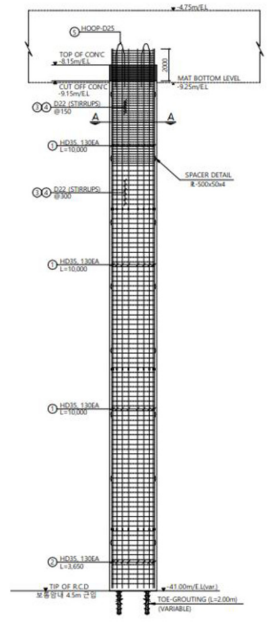
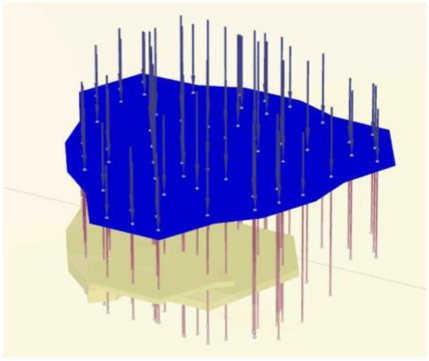


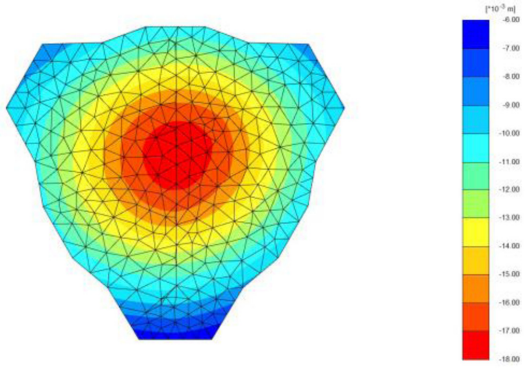
Figure 8. Differential shortening analysis.



[Pile Layout Plan]







Max Displacement	Allowable Displacement	Max Displacement Angle	Allowable Displacement Angle	Check
17.61mm	25.00mm	1/2,300	1/500	OK

Figure 9. Pile layout and foundation settlement check.

4.2. Structural System

4.2.1. Overall Structural System

Triangular RC core wall is located at the center of plan, and SRC mega columns are placed on each six edges. Furthermore, in order to reduce the span of perimeter beam, secondary columns, only supporting floor load, are added between mega columns

4.2.2. Wind Load Resisting System

Mega frame system (Mega column + Mega brace) and RC core wall has been applied for resisting wind load. Mega frame resists around 70% of total wind load, and RC core wall supports the other 30% of wind load.

Mega frame is considered as structurally sound system for uncommon building design like Cheongna City Tower. One of the alternatives would be outrigger system, however, the system cannot secure the structural stiffness because of low building self-weight that might cause high tensile force which will reduce the efficiency of column.

According to eigenvalue analysis result, the modal period for x and y axis is around 8.13~8.23 seconds. Translational weak axis cannot be precisely defined on symmetrical structure because periods are similar to each other. However, relatively high torsional stiffness detected and it is typical characteristic of mega frame structure that places structural members at outermost location.

4.2.3. Foundation

4.5 m mat foundation with 2.5 m-diameter RCD pile have been placed under the structure. The maximum bearing capacity of RCD pile is 83,000kN/EA for com-

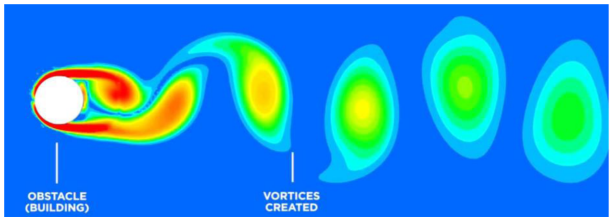


Figure 10. Vortex shedding.



Figure 11. Aero-elastic test, 2018 design.

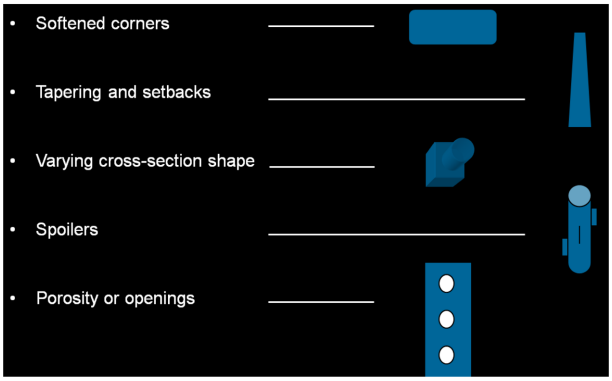


Figure 13. Building shapes strategy for wind load reduction.

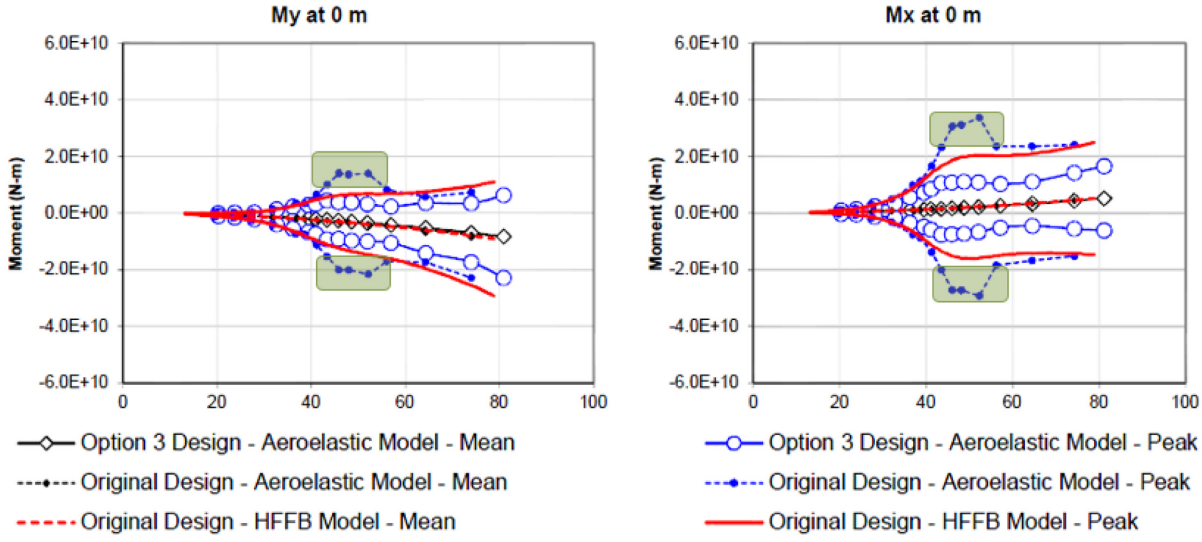


Figure 12. Aero-elastic test result, 2018 design.

pression and 19,000kN/EA for tension. Precise settlement value has been evaluated by using foundation settlement check. (See below)

During pile design process, core wall foundation area is mostly governed by compression and mega column foundation area is mostly governed by tension.

800 mm thickness perimeter wall has been installed underground to support shear force and foundation stress

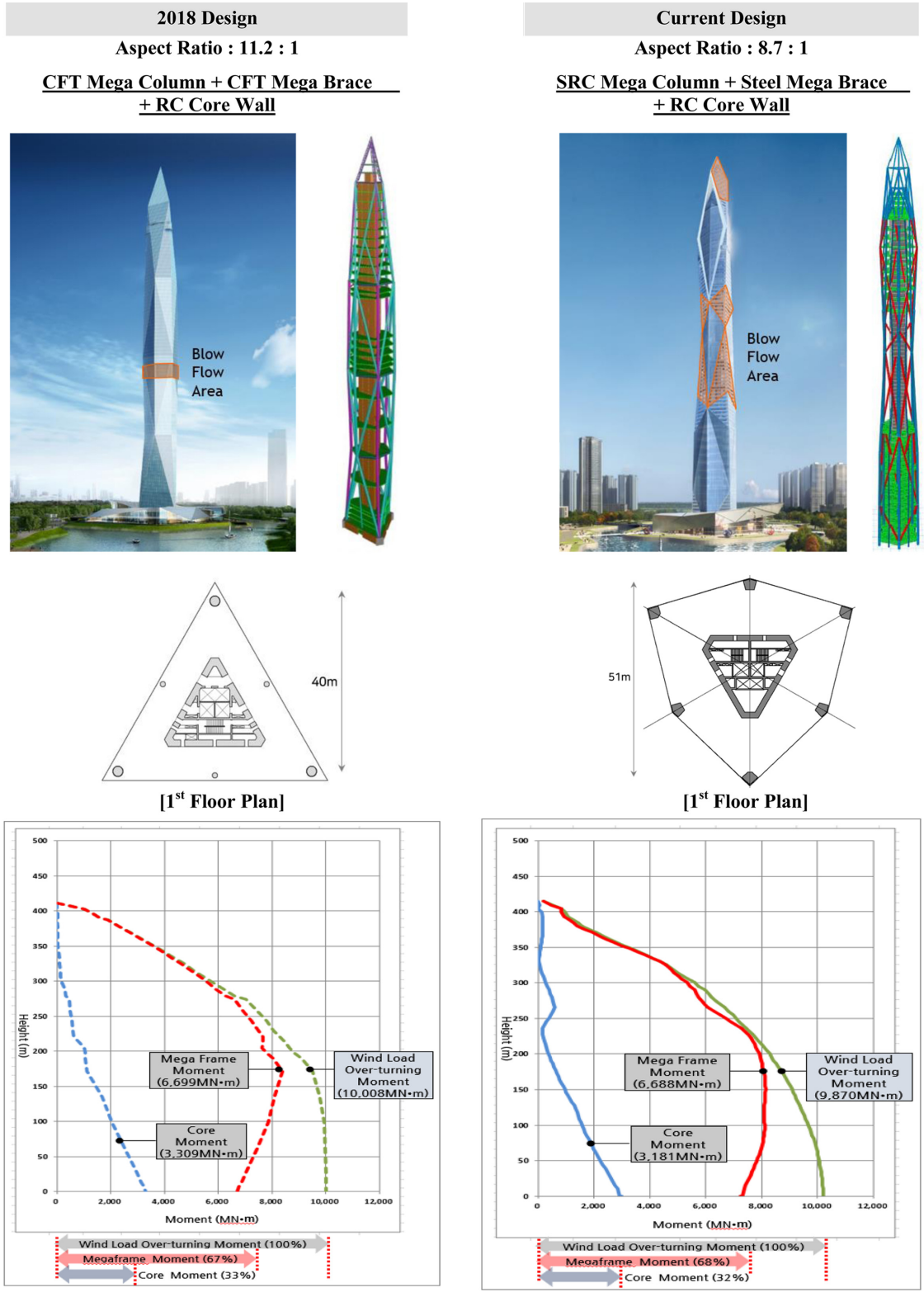


Figure 14. Design revision comparison.

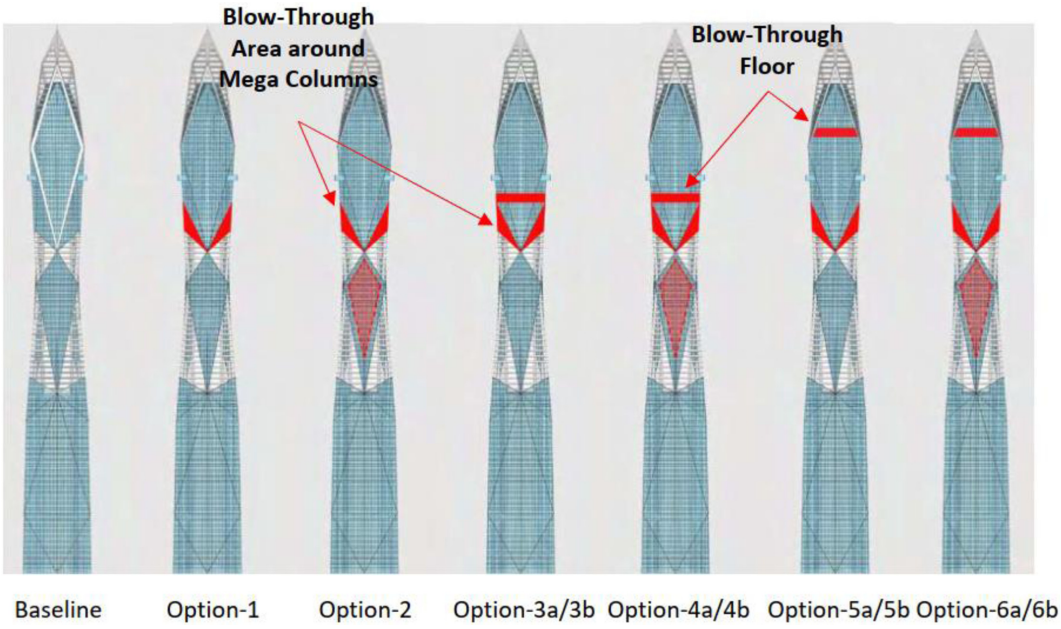


Figure 15. Design options for wind tunnel test.

transferred from upper mega brace.

5. Wind Load Design

5.1. Vortex-Induced Oscillations

Vortex-Induced Oscillations is a phenomenon caused by unstable winds; when the wind speed reaches a certain speed, the behavior of wind flow becomes unpredictable. Even though the building does not move, the structure transmits energy to the structure to generate random vibration. This instability of wind is caused by the wind generated by the structure itself.

Aero-elastic wind test was performed for 2018 design and the result confirms negative damping caused by strong amplification of Vortex-Induced Oscillations. The design changed to current design after the aero-elastic wind test.

5.2. Wind load design

As mentioned above, Cheongna City Tower is a rare case of high-rise observatory tower with fully covered façade on entire tower surface. Also, light self-weight of the building becomes disadvantage for wind load. To effectively reduce the wind load, it is important to reflect aerodynamic properties of building shape for analysis.

Cheongna City Tower is tapering shaped building that



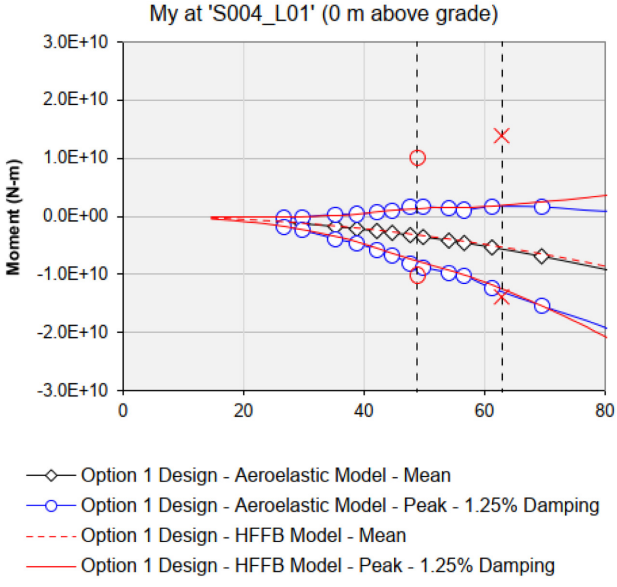


Figure 16. Aero-elastic test, current design.

has different plan for each floor and the most effective blow-through area has been designated to satisfy certain design. Blow-through area was also installed for 2018 design that had negative damping effect. For 2018 design, Blow-through area was very effective for high frequency force balance test but critical defects were detected from aero-elastic test due to Vortex-Induced Oscillations.

Design change has been conducted to resolve negative damping problem revealed during 2018 design aero-elastic test. Design change was difficult before 2018 design aero-elastic test because it was essential to maintain design concept. However, the wind load problem was coming to the surface and the design change becomes inevitable to solve problems from aero-elastic test.

The main design variations are shown next page. The primary purpose of design change was to resolve wind problem by applying aerodynamic reinforcement and improving structural efficiency maintaining crystal shaped image at the same time.

- Blow-through area expansion
- Reinforcement of tapering shape along building elevation
- Improvement of structural efficiency by changing plan

Original triangular plan with three mega columns has been changed to hexagonal plan with six mega columns. By changing plan, aspect ratio has been reduced from 11.2:1 to 8.7:1, and section secondary moment of plan has been improved around 40%.The most decisive solution for wind load issue, Blow-through area has been determined by performing wind tunnel test for many possible alternative architectural plans. Aero-elastic test has been performed for the final design output and confirmed that negative damping problem occurred in 2018 design was solved.

Conclusions

The design of the Cheongna City Tower began in 2008 Design Idea Competition and has been ongoing. It is a world-class high-rise observatory tower with whole surface covered with façade. During the design process, many different trial and errors lead us to discover a rare case of wind load that causes negative damping effect, and solved the problem by changing architectural and structural plan maintaining original concept of the project. Dong Yang has been involved in the project since the design in 2018, the design in 2018 was carried out with Arup in Hong Kong, and the design is currently collaborating with LERA in New York. This project reminds us the importance of wind loads for skyscrapers. There have been so much efforts to counter unprecedented wind cases that results in change of whole design. The most important thing in the wind resistance design of a super tall buildings is the aerodynamic shape design (ex. softened corners, tapering, setbacks, varing cross-section shape, spoilers and openings) of the building and proper structural stiffness. And if necessary, the application of a damper to secure additional damping can be considered. In the end, Cheongna City Tower will become symbolical landmark of Cheongna International City.

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