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The Ultra-Modern FKI Tower

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Abstract

A modern and highly-sustainable addition to the skyline of Seoul, South Korea has been completed; the Federation of Korean Industries Headquarters (FKI). The signature saw-toothed exterior wall of the 245-meter tall tower and the contrasting smooth nature of the pipe-shell structured podium "egg" gives this project and site a unique identity in the city.

Keywords: Slender, Saw-toothed, Up-down construction, Plunge-column, Egg, Panelization

1. Introduction

In early 2009 an international design competition was commissioned by the owner of the development, the Federation of Korean Industries, with the hopes of bringing world-class architecture to this fast developing area in Seoul. Thornton Tomasetti was part of the International Design team that was led by Adrian Smith + Gordon Gill Architecture. The program for the development is primarily commercial office, with some conference and public space located in the podium and at the top of the tower. The floor plate of the Class A+ office tower has 12-meter unobstructed lease spans with perimeter columns at 9-meters on center, and generous 4.6 m tall story heights. A series of multi-story atrium spaces for the tenants are located at the corners of the tower in a staggered fashion.

Photograph of Completed Project.

2. Structural System

A key driver in the system selection for the 245-m tall office tower was the regional availability and expertise in the construction of steel and composite-steel buildings. Design wind speeds and the regional wind climate were other key drivers, and in the Korean peninsula are influenced by the coastal climate as well as the potential for typhoons. These conditions have driven local building codes and officials to require structural system designs to resist the effects of wind speeds that equate to approximately 300-year return period events. Given this demand on the structure of the tower a reinforced concrete core was selected to develop the stiffness and weight required to resist the effects of wind overturning loads.

The slenderness of the core however proved to be a challenge in mitigation of wind drift due to the slenderness ratio of the core (20:1 – *height:width*). Augmentation of the reinforced concrete core structure was provided through a 2-story deep steel outrigger and perimeter belt-truss system at the mid-height mechanical zone of the

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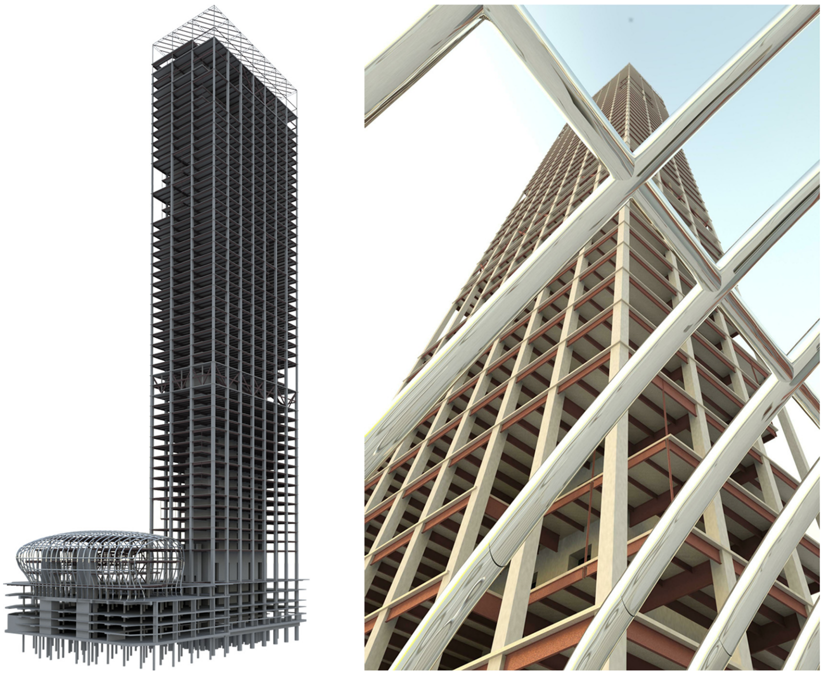


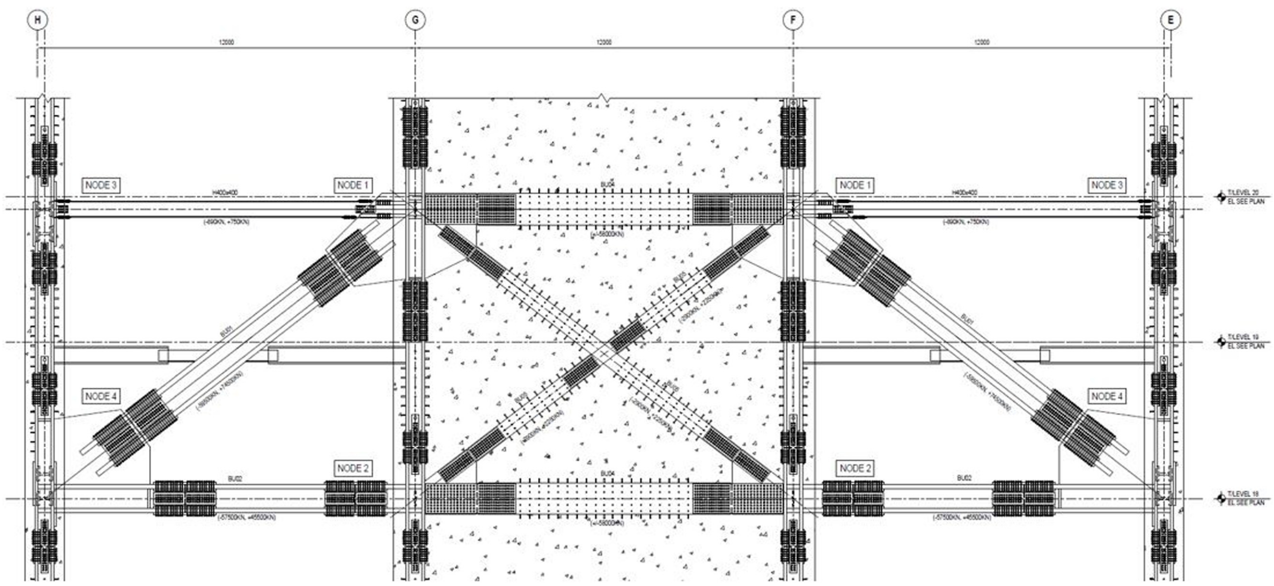
REVIT Building Information Model of Structural Systems.

tower, which engaged the tower perimeter columns. Concrete cylinder compressive strength for the core walls was limited to 60 MPa due to local availability of high-strength concrete. Core flange wall thickness at the base of the tower was 1300 mm and reduced to 500 mm over the tower height.

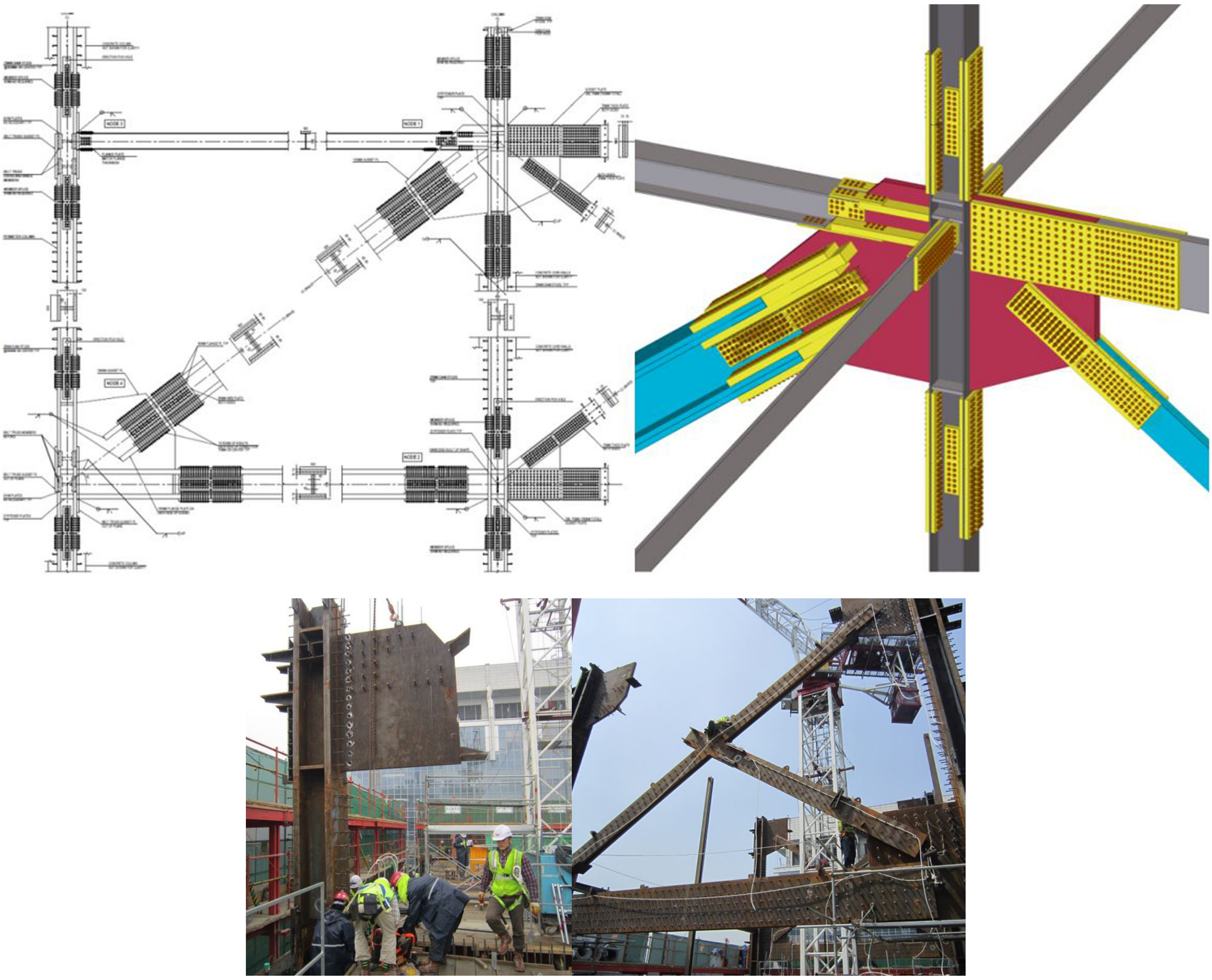
The structural system of the floor is a composite steel framed system that utilized a local Korean composite metal deck, Ferro deck, topped with normal-weight concrete. The ferro deck system is prefabricated with reinforcement welded to the metal deck. All steel material for rolled shapes and plates was in accordance with KS SM400 or KS SM490.

3. Wind Tunnel Testing Program

Wind-induced lateral forces for design of FKI tower governed over seismic forces, which is typical for this



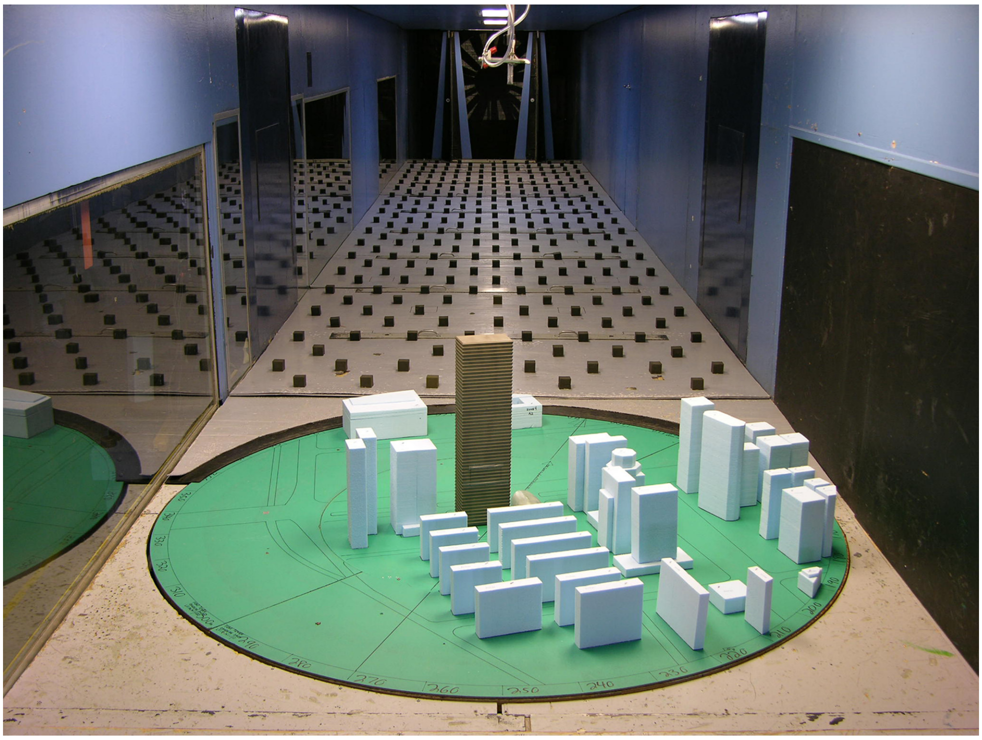
Section through Tower Outrigger System.

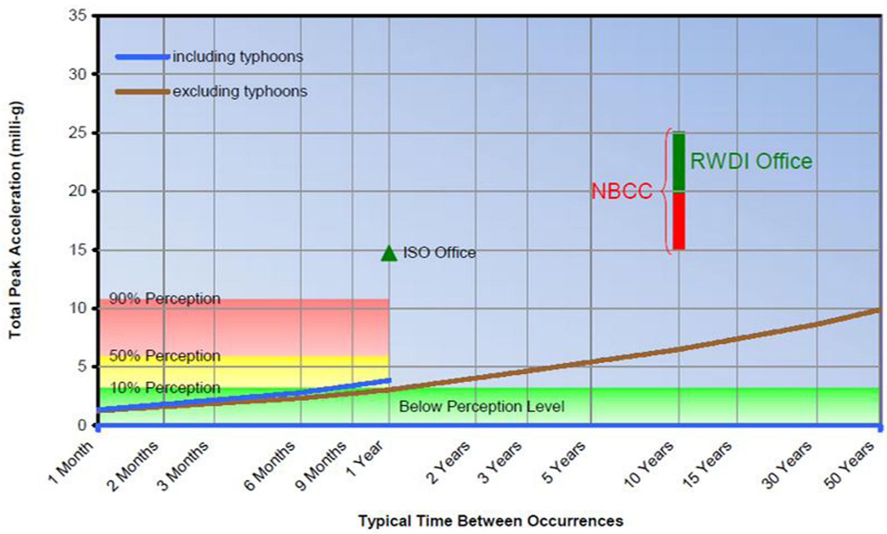


Outrigger Connections.

Ferro Deck System Installation.

region but is highly dependent on site soil conditions. The FKI project site is located on the island of Yeouido which is surrounded by the Han River. Soil conditions at the surface are poor with primarily fill material and sandy-clays.





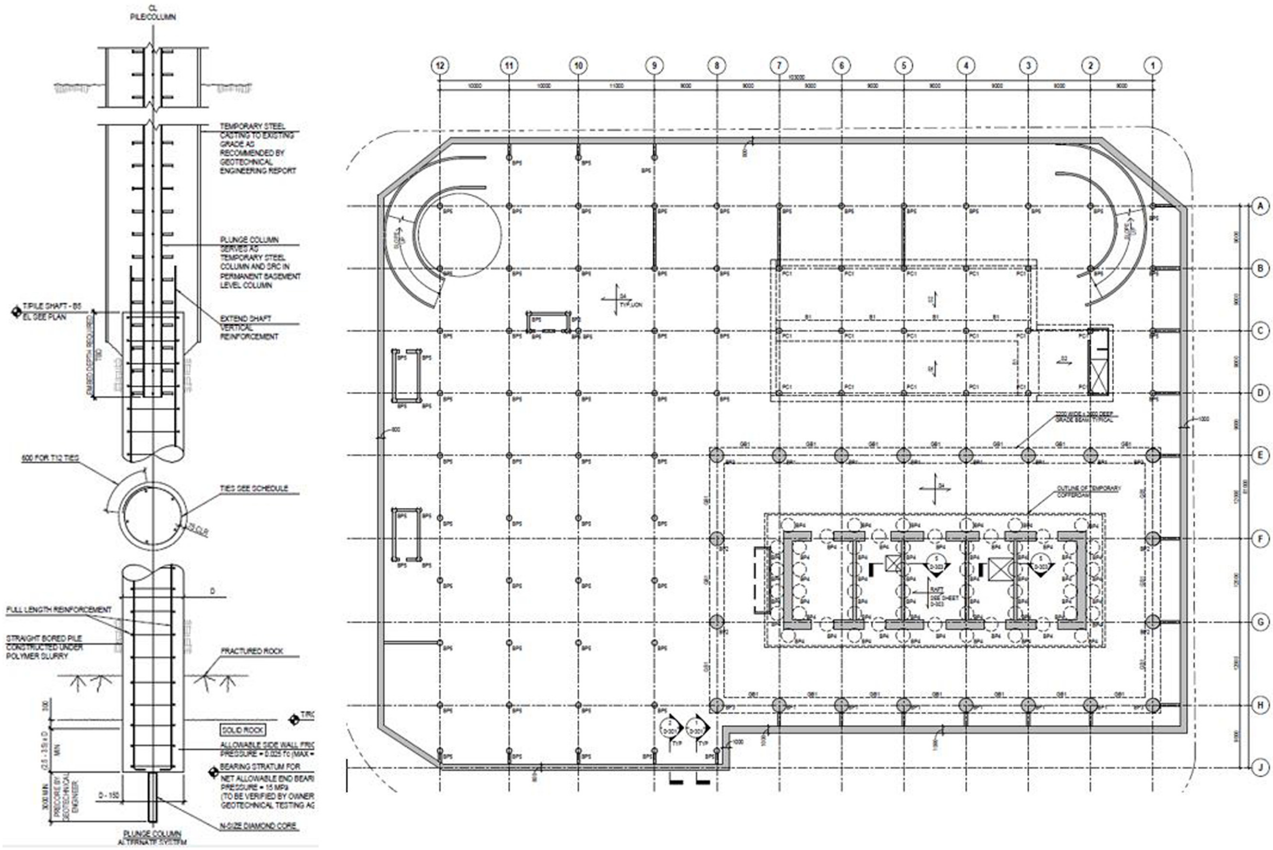
High-Frequency Force Balance Test Conducted at RWDI.

However, hard high-quality rock is relatively shallow at a depth of approximately 35 m from grade.

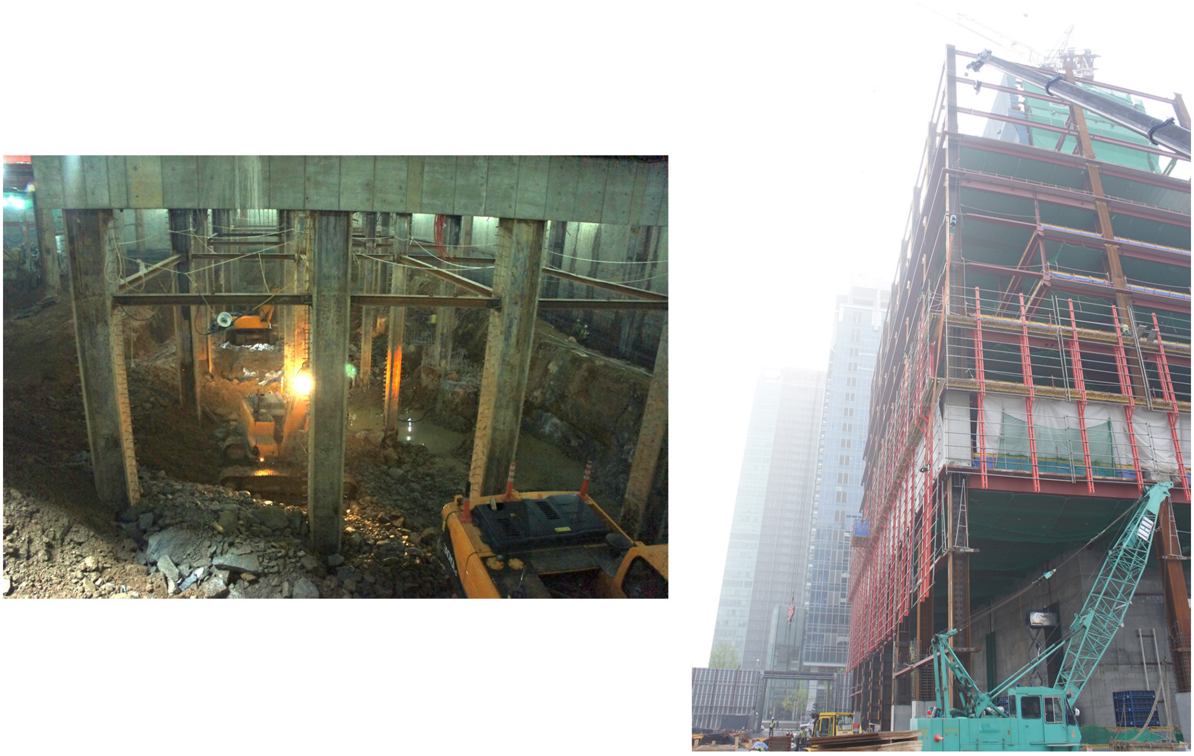
Rowan Williams Davies & Irwin Inc. (RWDI) was commissioned to evaluate the local wind climate and conduct both a high-frequency force balance and high-frequency pressure integration wind tunnel test of the tower and the podium egg structures. These tests were utilized to better evaluate the wind loads induced on both the tower and podium structures, as well as evaluate the tower motions (accelerations and torsional velocities) that occupants experience in wind events. Testing confirmed the structure was well behaved and would be very comfortable for its occupants, with its predicted motions well below the ISO's threshold on perceptibility, and with the furrowed exterior architectural expression greatly improving the prismatic tower's aerodynamic behavior.

4. Up-Down Construction

The project site is surrounded on all four sides by roadways directly adjacent to the property lines. Adjacent sites contain existing mid-rise and high-rise towers that

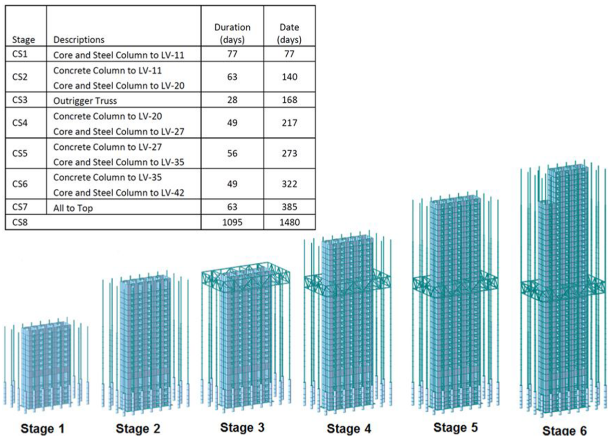


Basement Plan and Plunge-Column Detail.



Up-Down Construction: Milling under Core and Tower Progress above Grade.

Erection Column System.



Stage	Descriptions	Duration (days)	Date (days)
CS1	Core and Steel Column to LV-11	77	77
CS2	Concrete Column to LV-11 Core and Steel Column to LV-20	63	140
CS3	Outrigger Truss	28	168
CS4	Concrete Column to LV-20 Core and Steel Column to LV-27	49	217
CS5	Concrete Column to LV-27 Core and Steel Column to LV-35	56	273
CS6	Concrete Column to LV-35 Core and Steel Column to LV-42	49	322
CS7	All to Top	63	385
CS8		1095	1480

Midas Gen FEM Construction Stages/Sequence

were also susceptible to additional settlements due to potential temporary basement excavation conditions on our site. A permutation of Top-Down construction, called "Up-Down" construction was utilized for the construction of the basement structure on our site to mitigate this risk, as well as to reduce the overall construction schedule.

In the Up-Down construction process perimeter slurry walls were installed first. Next reinforced concrete bored pile foundations were drilled from grade at each podium and tower column location, as well as directly under the tower core. Reinforced concrete bored piles under the tower columns and tower core were 2.5 meters in diameter and socketed into the local hard-rock formation. During the concreting of these pile foundations a steel "plunge-column" was inserted, and then centered/plumbed in the hole. These steel columns extended to grade and were fully encased in concrete.

After this step construction of the first basement level began with excavation of the first below-grade level, followed directly by exposing of the steel columns in the piles and installing a composite-steel framed floor system at grade. From this point forward construction of the tower and podium commenced both up and down simultaneously. In the tower foot print, the core walls were cast around the steel plunge columns in the piles directly below the core starting from grade, going both up and down simultaneously as well. This process was repeated until the lowest level of the basement structure is completed. Prior to casting of the lowest segment of tower walls a 3-meter-thick reinforced concrete raft was poured directly under the tower core linking the adjacent bored piles.

5. Erection Columns

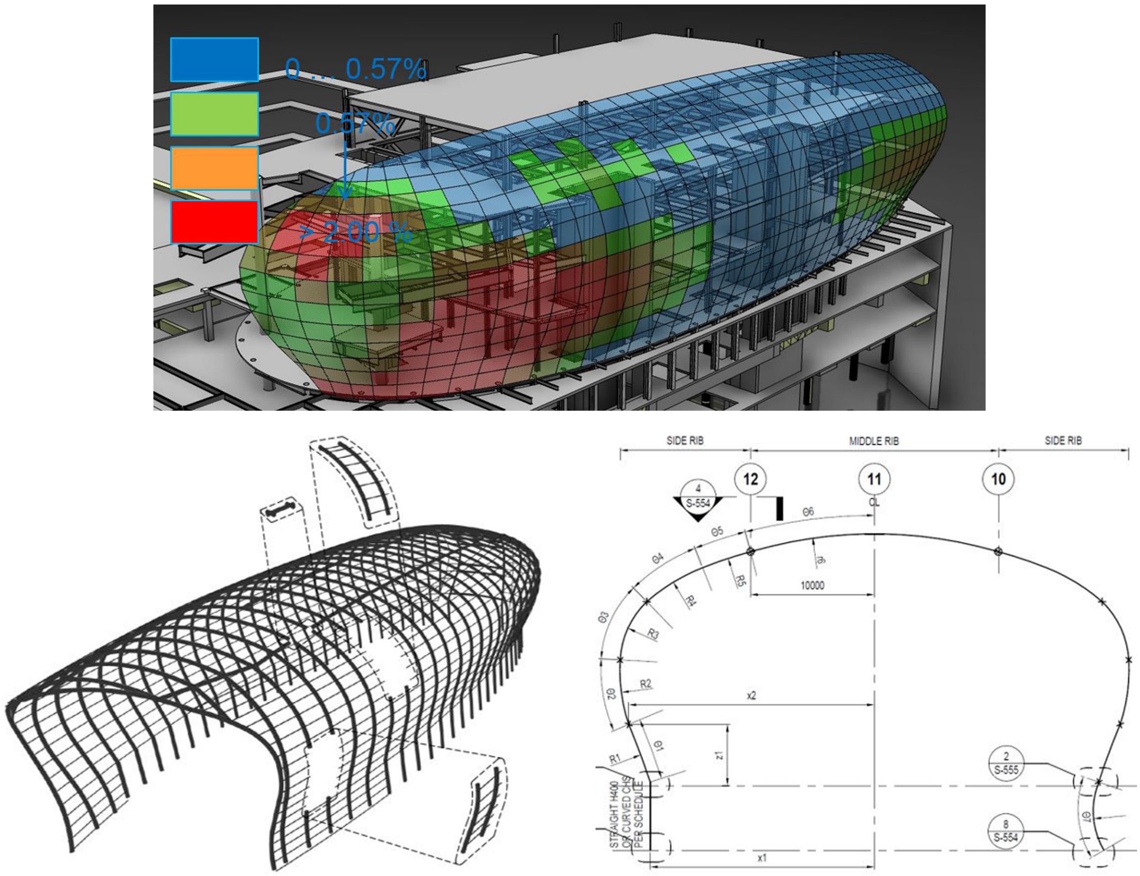
A key part of the system's constructability was the utilization of the embedded steel shapes in the perimeter composite columns below the outrigger system, and the smaller erection columns above. This concept removed the

Delayed Outrigger Connection.

perimeter column rebar fixing and formwork from the critical path, as 10 stories of floor framing could be constructed prior to casting of the concrete for these elements.

6. Vertical Shortening

A comprehensive staged construction analysis model of the tower was conducted in Midas Gen to consider both the loading during construction and estimate the vertical shortening of the reinforced concrete core, considering the time-dependent creep and shrinkage properties of the concrete. This analysis was utilized to both inform the contractor of elevational compensation requirements to maintain level floors, and determine the optimal time to fully connect the outrigger during construction of the tower. The analysis results indicated a significant benefit to delaying the connection until after the complete casting of the reinforced concrete core, as the load in the outrigger due to the initial vertical shortening of the core was mitigated and the predictability of the core shortening was



Panelization and Structural Form.

Construction of Pipe-Formed Shell Structural of Ornamental Egg.

improved, minimizing the risk of over compensation.

7. The Ornamental Egg

In a contrasting, yet modern expression to the tower, a classical oriental egg shape comes to life in the podium of the FKI headquarters. The structure of this podium required careful attention to not only the geometric rationalization and optimization of the pipe-shell structure, but also the minimization of Insulated Glass Unit (IGU) panel diversity in order to keep costs under control. Step 1 was to optimize the form of these pipes to allow for flat-mounted IGU panels to be installed without damaging their sealed joints, minimizing the number of panel sizes

Ornamental Egg Podium Structure.

and panels that require hot-bent glass.

The structure of the pipe shell was then rationalized such that the pipe geometry was definable by circular arcs tangent at their intersection and broken into prefabricated sections as Step 2. All connections of the architecturally exposed steel pipes were welded and ground smooth prior to inspection and final painting.

The ultra-modern FKI tower has been a welcomed addition of Class A+ office space in Yeouido, and has helped transform the skyline in Seoul's ever developing financial district.

<u>Project Team</u>:

Owner: The Federation of Korean Industries

Contractor: Hyundai Construction

International Architect: Adrian Smith + Gordon Gill Architecture

International Structural Engineer: Thornton Tomasetti

International Facade Engineering Consultant: Thornton Tomasetti

Local Architect: Chang-jo Architects

Local Structural Engineer: Dongyang Structural Engineers