Structural Design of the Museum Cone

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1=cable net shell 2=horizontal steel ring 3=laminated safety glass 4=stainless steel fittings

Abstract

The Museum Cone is the entrance of the Mori Art Museum located in front of the 54 stories Mori Tower in Tokyo, Japan. The Museum Cone consists of three main elements. First, a GFRC-clad 30m high steel structure called "funnel" contains passenger elevators and provides the primary vertical support for the building. Second is 20m high steel and glass facade operates on the principle of the "cable net shell" a single layer of diagonal net consists of galvanized cables acts in tension, stabilizing twelve horizontal steel rings in compression which hold the elliptical conical form of the facade. And third is an exterior "glass façade" of 10+10mm laminated tempered safety glass point-supported by the stainless steel fittings at the four corners, and they are ceramic fritted dot-pattern, overlapping each other to provide a rain screen.

We aimed to express the lightness/strength of the steel with the transparency of the glass in order to create a unique space as a powerful presence at the bottom of the tower as well as the symbol of the museum.

Introduction – project background

One of the largest re-development projects in the history of Tokyo, Japan called "Roppongi Hills" has been finally open in April 2003 after 18 years of tremendous efforts and works done by the biggest Japanese developer Mori Building Co., Ltd.

The entire area is 11.6ha, site area = 89,400m2, total floor area = 759,700m2, including 4 residential buildings, 2 office towers, cinema complex, hotel, TV broadcasting headquarter, shopping center, public arena and the Mori Museum in the Mori Arts Center.

The Museum Cone is the main organizing element in the design and circulation of the Museum, which corresponds to a major axis of symmetry of the Mori Tower.

It allows visitors arriving from any of four levels - the traditional Japanese Garden at B2F, retails at B1F, vehicular drop off at 1F, and the main plaza at 2F - to ascend to 3F and cross the glass clad Bridge to enter the dedicated

Figure 1

Roppongi hills – night view from Mouri Garden

museum lobby in the base of the Tower and take the high speed elevator to reach the Mori Art Museum and the Tokyo City View (observation deck).

For an unprecedented space

Gluckman Mayner Architects(hereafter GMA) who were the architects for the museum made the Museum Cone an elliptical conical shape as the symbol of cultural component that represents different appearance from the adjacent commercial buildings.

Our role as structural designers was to propose a peculiar and unique light-weight structure and glass façade in order to make the Museum Cone an iconic element on the landscape of Roppongi Hills.

Various types of structural system were proposed and discussed during the design phase, and in the end GMA proposed cable trusses that are radially located at the perimeter and spanning from top to bottom to support translucent glass façade.

But we were thinking that we should take advantage of the nature of the elliptical conical shape as a shell. Our final scheme that consists of steel rings and a single layer of cable net is to

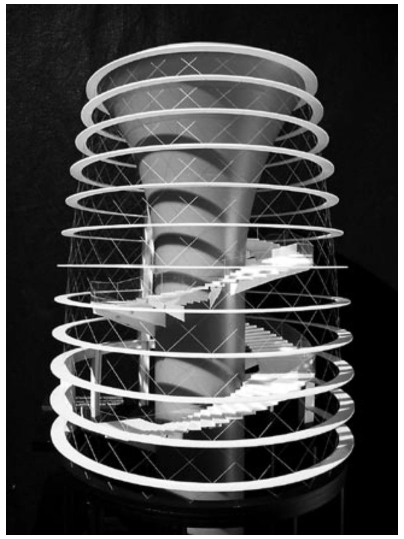

Figure 2

Structural model final design

Figure 3

Museum Cone from the roof of TV Asahi headquarters

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create the powerful horizontal line of the structure with transparent glass façade to give the visitors an excellent view of the garden from the inside.

Structural design of the Museum Cone – cable net shell

Figure 4 shows the main elements of the museum cone and how each element relates each other.

At its center, the "funnel" contains passenger elevators and provides the primary vertical support for the building. The spiral stairs are gently coiling around and supported by brackets from columns of the funnel.

Regarding the load transferring path of the structure, the main compression loads imposed by the cable net are resolved into the top of funnel. The cable net shell and the funnel work compositely to maintain its stability and resist external forces such as the strongest wind load from the Mori Tower behind due to its own shell effect.

Figure 5 shows that various types of structural analyses and performance or structural testing.

To achieve the desirable overall stiffness, a pre-tensioning was required in every cable segment by unique installation sequence.

Design of the glass façade

The layout of the glass panels is also very unique. The 25 glass panels are the same size at each ring plate and overlapping each other. The top edges of the 10+10mm laminated tempered glasses are within the width of the ring above and the bottom edges are protruded from the outside edge of the ring. We aimed to express the glass such as a floating light fabric, rather than the glass rests on top of the other. Due to the change of the intensity of the light at the inside and outside, the Museum Cone appears like a green glass shell at the daytime but at the night, the floating ring plates are emerged with the lightings from the funnel.

Design of glass fittings

The "upper glass holder" is hung from the ring above and comes down between the overlapped glasses to hang

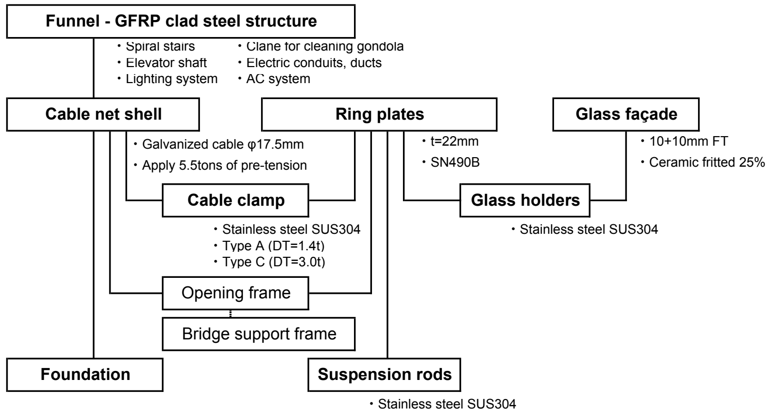

Figure 4

Museum Cone – elements flow

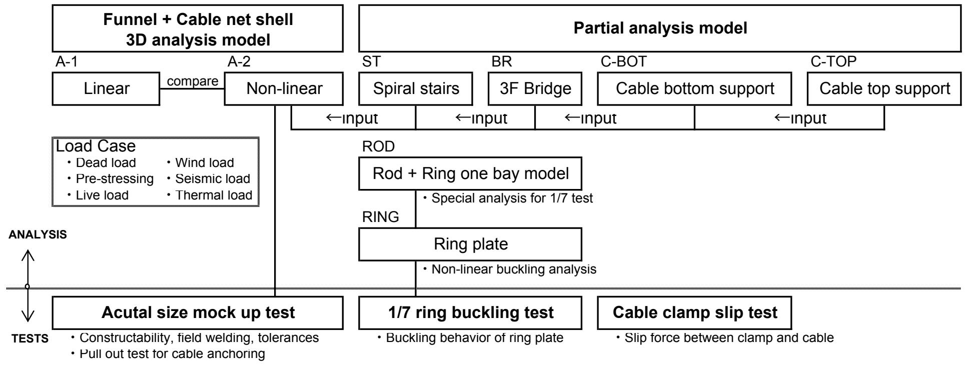

Figure 5

Museum Cone design/calculation flow

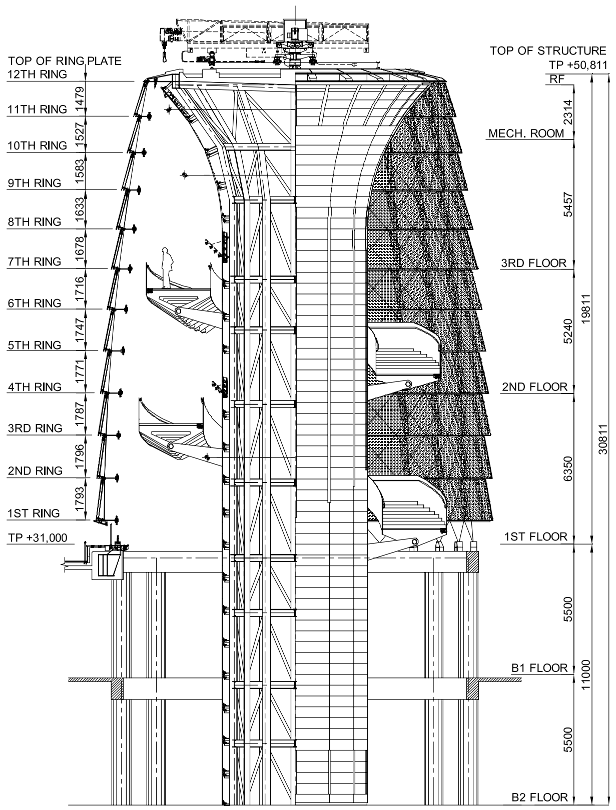

Figure 6

Museum Cone section (Scale 1:300)

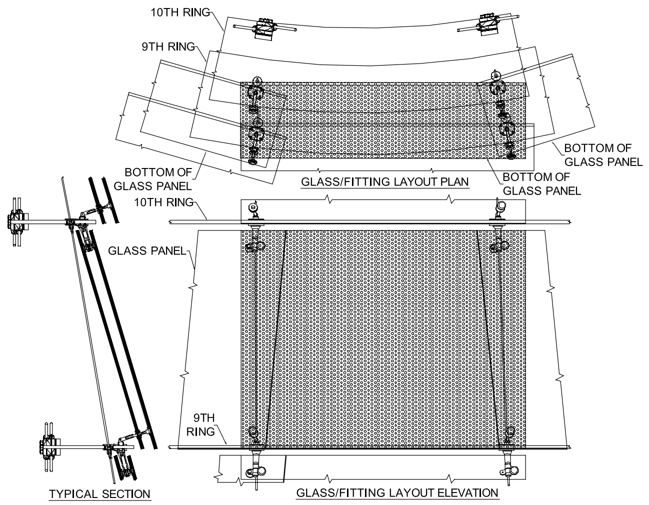

Figure 7

Typical glass layout and typical section (Scale 1:50)

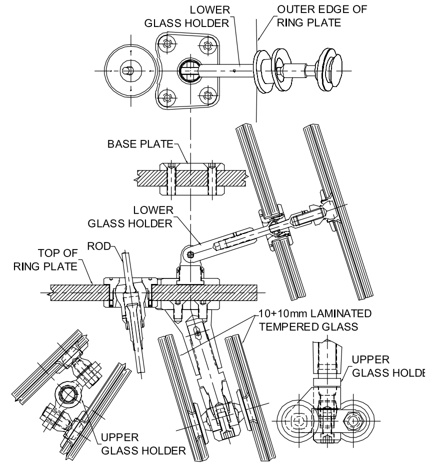

Figure 8

Glass holder details (Scale 1:10)

both with integrated point support fittings (Figure 8, 9).

The "lower glass holder" is horizontal strut for the glasses connected to the ring with articulated "double hinge mechanism" detail to avoid some local twisting effects at the supporting holes and accommodate differential movements among two laminated glasses and ring (Figure 8, 9).

In order to emphasize the continuity of the horizontal rings, we designed all the stainless steel fittings as minimum number and smallest as possible. Due to the elliptical conical form of the façade, it was required to fully understand variations of angle and position changes of each element for a typical fitting detail to adjust and accommodate construction tolerance and movements caused by specified load conditions. Finally we have achieved our desirable shapes with required structural performance that was verified through partial structural tests.

Experiment 1 – steel ring buckling test

Because of the thinness of the horizontal ring plates compared with the width, the buckling test was examined in parallel to the analyses. Due to the convex conical shape, inward forces are generated at the connection points between the cables and the ring plates and they are transferred and resolved into the ring plates as compression forces.

The behavior of the ring plates in the test was similar to one in the analyses and we confirmed we would achieve our desirable safety factor against the buckling in required loading conditions. [1], [2]

Figure 9

Upper/Lower glass holders

Figure 10

Unassembled fitting pieces

Figure 11
Ring buckling test device

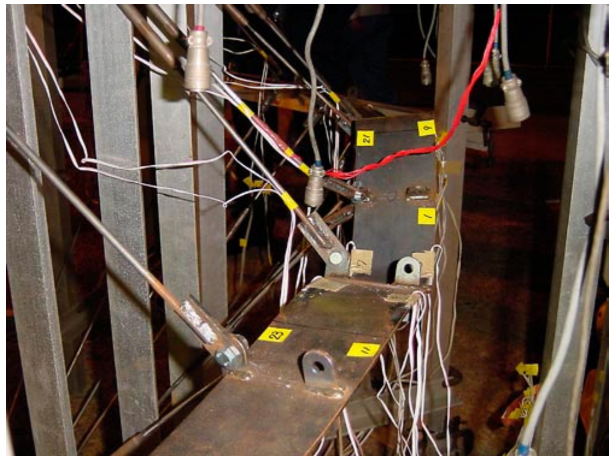

Figure 12
Buckled ring plate – applied three times heavier design force

Experiment 2 – Mock up

We completed the actual size mock up test to review constructability, field welding, cable tensioning sequence, lighting adjustments, water spray tests, and cleaning method.

Each glass panel is directly attached to the structural steel through stainless steel fitting, which required a very tight construction tolerance. On checking through the test, we confirmed that our specified tolerance would be suitable, and our proposed construction sequence was adequate and realistic.

Construction – cable tension installation sequence

The cable element is stabilized and exhibits its performance only when it is in appropriate tension. Each diagonal cable of the museum cone is tracing the conical spiral 3D curve by the connection of the designated location at each ring. It was so obvious we can't pull the cable either at the one top end or bottom by a jack system.

Our solution of this problem is a use of the geometry. First backer plates were welded to the rings and set the inner clamps and cables together with certain distance from the final position. And outer and mid clamps and four long slip-critical M19 bolts were pre-set. Two teams of workers symmetrically located from the center of the funnel, started to tighten the nuts with a planned procedure, and then cables are pulling toward rings like pulling a bow to apply required tensile forces to the cables without using a jack system.

Figure 13
Actual size mock up

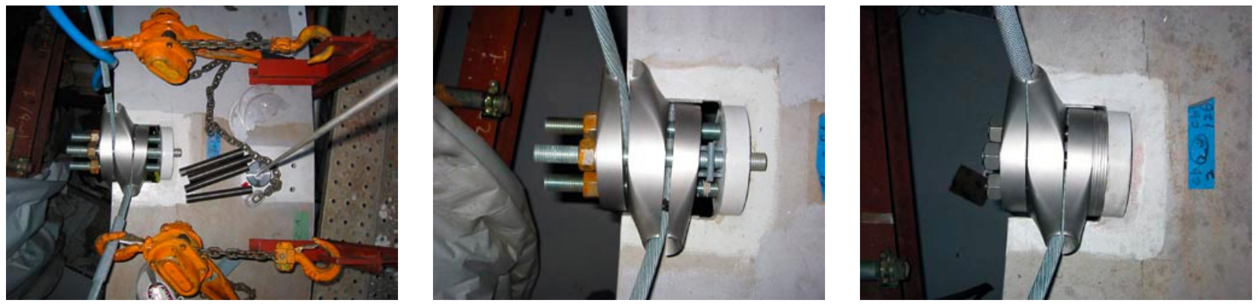

Figure 14
Cable clamp

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Construction – glass installation

The glass panels were installed from the top to the bottom, the perimeter edge of each ring was pre-cambered based on the advanced analyses. So all the rings were leveled after all the glasses were installed completely.

Figure 15
Cable tensioning

Figure 16
Glass installation

Figure 17
Erection sequence

Summary

From the structural design point of view, we have the powerful vertical line of the funnel and conversely horizontal lines by parallel ring plates. We are satisfied with expressing floating plates like Saturn's ring in addition to the thinness of the cables.

We could develop the minimum number and size of glass fitting and its system to dedicate to the transparency of the glass.

As result of two significant mock up tests, we have convinced that our structure would remain intact under factored design forces as we planned, and we had a clear vision how to construct this delicate structure with pre-tensioning the cable net.

As the structural designer/engineer, who has considered our role, task and responsibility, we hope that people feel the Museum cone serve pragmatic functions and safety as well as experience of structural art.

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References

[1] Nito, Fujikawa, Ishizuka, Tsuchihashi, Wakui, Funaoka, Ishida, Kamisawa: Buckling Examination of the Glass Support Structure (Oval Steel Ring) for ROPPONGHI HILLS "Museum Cone" (Part 1 Buckling Test)

[2] Nito, Fujikawa, Ishizuka, Tsuchihashi, Wakui, Funaoka, Ishida, Kamisawa: Buckling Examination of the Glass Support Structure (Oval Steel Ring) for ROPPONGHI HILLS "Museum Cone" (Part 2 Analyses of the Buckling Strength), Summaries of Technical Papers of Annual Meeting 2002, Architectural Institute of Japan

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