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TORANOMON HILLS
- Super High-Rise Building on Urban Highway -

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Abstract

TORANOMON HILLS is the main building of a large-scale re-development project located in the center of Tokyo. This high-rise building has a height of 247 m and 52 floors above ground, 5 floors below ground, and 62 m × 80 m in plan. It is used as hotel, residential facilities, offices, shops and conference facilities. The super structure is mainly a rigid steel frame with response-control devices, using concrete-filled steel tube columns. The underground section is a mixed structure composed of steel, steel-reinforced concrete and reinforced concrete framings. The piled-raft foundation type is used. The remarkable feature of this high-rise building is that the motorway runs through the basements of the building, which makes it stand just above the motorway. This condition is an important factor of the building design. The plan shape is designed to fit along the curve of the motorway. Special columns at the corners are required to avoid placing columns in the motorway. This special column is a single inclined column in the lower floors that branches into two columns in the mid-floors to suit the column location in the upper floors. The cast steel joint is used for the branching point of each special column to securely transfer the stress.

Keywords: Highrise buildings, Response-control devices, Structure-switching truss, Road culvert structure and underground, Damping devices

1. Introduction

TORANOMON HILLS - Shimbashi / Toranomon Re-development Project, Zone III" is a large-scale urban re-development project proposed for the Toranomon area of Tokyo. A notable feature of this project is that the planned Loop Road No. 2 will cross east to west through the development site and under a completed super high-rise building with a height of 247 m.(Refer to Figs. 1 and 2)

The planned building is to be erected on a site of about 17,000 m^2, and it has 52 floors above ground and five below ground with a total floor area of about 244,000 m^2. As a multi use building, the parking lot takes up the floors below ground, shops and a conference facility occupy floors 1 to 5 of the lower level, and the offices are in the floors 6 to 35 of the medium-rise section. The 36th floor is totally reserved for the use of a space truss for a different arrangement of columns from the 37th floor and above. In the high-rise section, residential facilities are located from the 37th to the 46th floors, while a hotel occupies the 47th floor and above.

Most of the re-development zone is occupied by the super high-rise building and the underground section where a tunnel for the Loop Road No. 2 passes. A 3-story commercial building is located at the site, and a large freestanding eave that protrudes from the 2nd floor of the high-rise building overhangs the plaza beside the high-rise building.

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2. Outline of Building and Structure

"The aboveground section of the super high-rise building is mainly a rigid steel frame structure (using concrete-filled steel tube columns) with response control devices attached, and the commercial building and large eave are also steel frame structures.

The underground section is a mixed structure composed of steel, steel-reinforced concrete, and reinforced con-

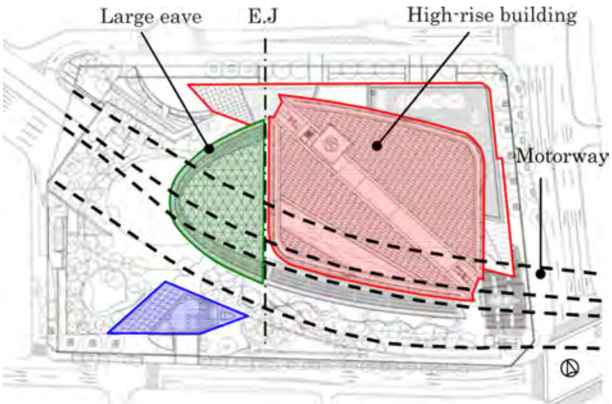

Figure 1. Floor Framing of Standard Floors.

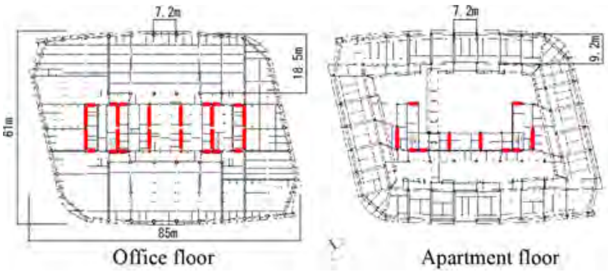

Figure 2. Arrangement of Various Structures.

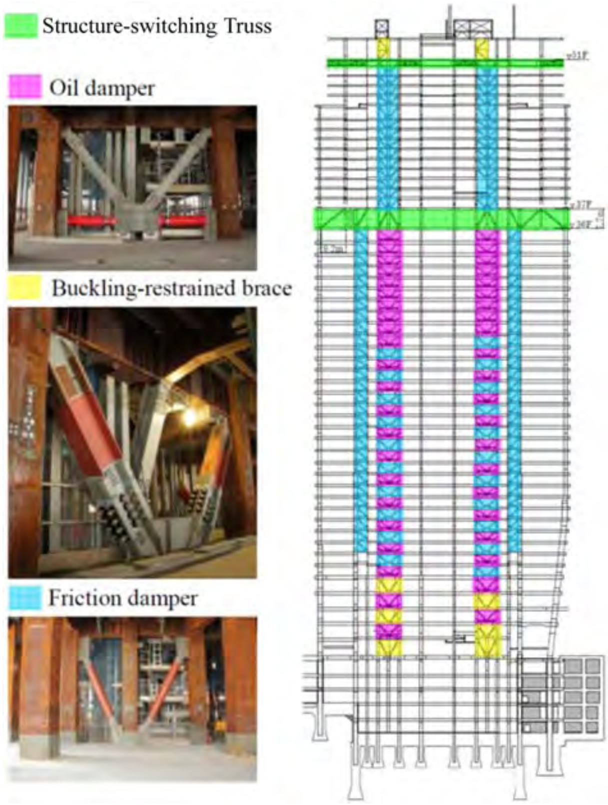

Figure 3. Arrangement of Response-control Devices and Structure-switching Truss.

crete framings. The podium structure (artificial ground) on the Loop Road tunnel consists of 1 m-thick precast slabs. The inverted construction method was adopted for the foundation construction in order to reduce the construction term. Cast-in-place piles were used to form a piled raft foundation in which the piles and spread foundation bear loads respectively according to their rigidity.

3. Response-Control Structure

A response-control structure was selected for the super structure, with 85 m × 61 m in plan, and the response-control devices are positioned in different sections of the center core. A mega-frame, that covers from the 1st story to the 51st story, is created in order to effectively suppress bending deformation of the entire building. A combination of inclined roofing and shifted roof tops to form a distinctive roof frame is adopted and all the structures are linked employing response-control devices (Fig. 3). A combination of three kinds of response-control devices is used: oil dampers (516), buckling-restraint braces (448) and friction dampers (620). A response-control mechanism, that takes advantage of this kind of combined use, can successfully secure high seismic resistance by reducing the inter-story drift ratio during an earthquake to 1.5-more times less than that of common high-rise buildings. (Refer to Fig. 3)

Photo 1. Perspective Drawing.

4. Connection for Tilted Column-Crossed Section

The tilted column system is adopted for the northwest, southeast and southwest corners of the building for the following reasons: columns can not be positioned above the area covering the Loop Road No. 2; and the building corners must be finished with sharply acute angles for aesthetic purposes. This is done from the 8th to the 13th floors, two tilted columns on each upper floor intersect and combine to form a single column on the floor below. Cast steel connections, weighing about 20 tons each (max crane lifting weight), are adopted where the columns intersect so that the stress carried by the two upper columns can be securely transferred to the single column below. (Photo 2)

Photo 2. Cast steel connection for peripheral tilted column-crossed section.

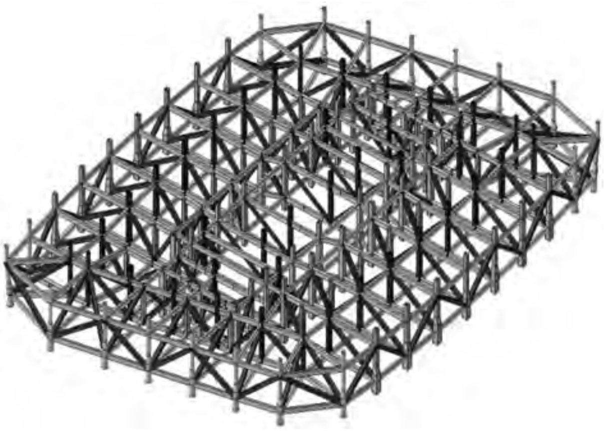

Figure 4. Structural Frame for 36floor.

5. Structure-Switching Truss

The building is arranged in a doughnut shape without changing the outer building design at the top of the 37th floor. (Fig. 3)

To be able to do this columns located at 9m from the outer column are used (see Fig. 4), and these are supported by the structure switching floor trusses of 7.7 m height at level 36.

These space trusses are disposed over the entire area of the floor in two directions.

The girders height of the 36 and 37 floors is h = 1000. The truss diagonal members have H- 600~800 height and 600 width , and a reinforced cover plate on both sides to increase the axial stiffness.

The column connection has a complex shape formed by five diagonal members that are arranged on the floor 36 Northeast and southeast corners. The details are examined for the assembly, welding and inspection procedure of the column connection previous to the production (Fig. 5).

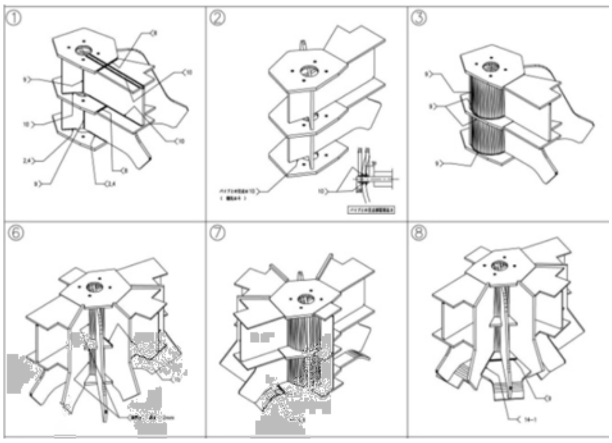

Figure 5. Column connection.

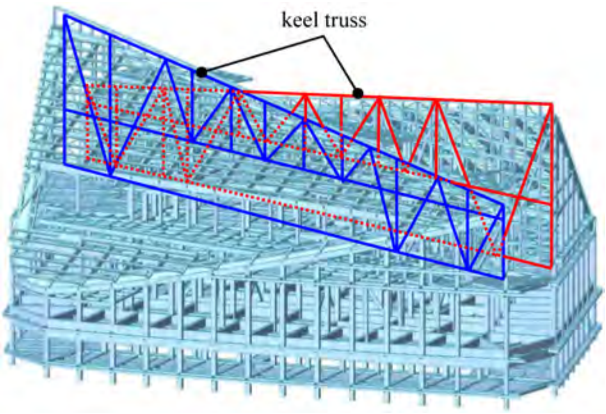

Figure 6. Inclined roofing.

6. Inclined Roofing

The top of the building is a major feature on the building exterior design. The sloping roofs follow the east-west direction and have triangular pyramids shifted shapes.

Two keel trusses connected by tie members are used to effectively transmit the roof forces to the building. The roof largest diagonal member at the top is 30 m. The size of the diagonal member is H -800 × 400, and has reinforced cover plates on both sides to increase the in-plane stiffness.

7. Countermeasures against Road Vibration

The running underground, Loop Road No. 2, connects the east side of the building at the second-basement level with an underground tunnel installed outside the development site, and then resurfaces on the west side of the site. The road runs through a tunnel-shaped culvert structure that was built independently of the building structure. In order to avoid any effect of road traffic vibration to the building, the building structure is insulated from the cul-

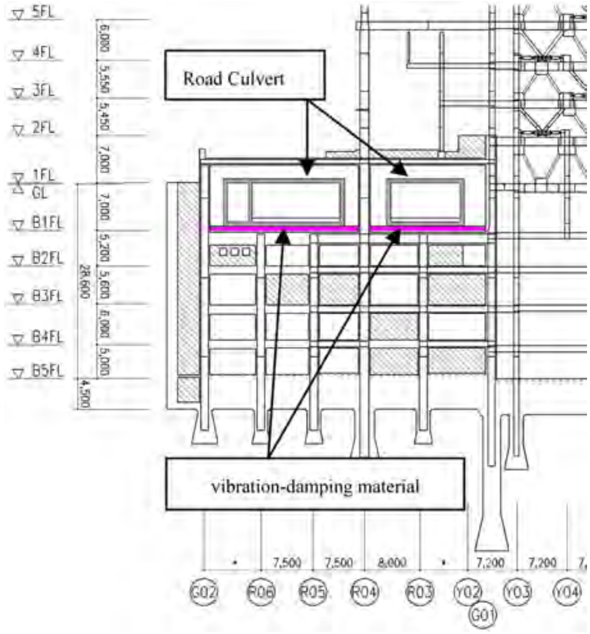

Figure 7. Road Culvert Structure and Underground Building Structure.

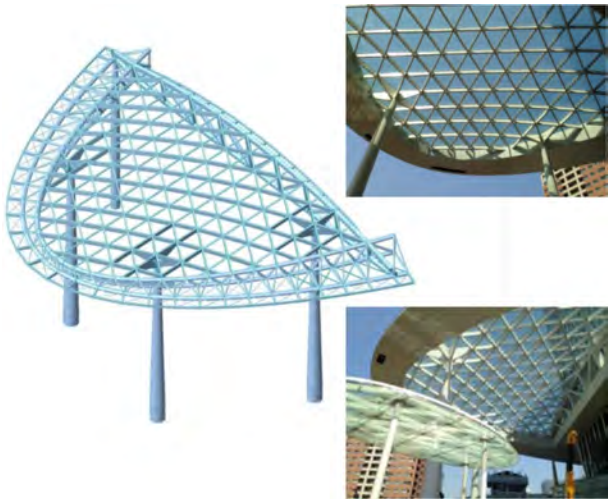

Figure 8. Structural Frame for Large Eave.

vert structure by sandwiching a vibration-damping material (polyurethane elastomer) between the culvert bottom slab lower section and the building structure (Fig. 7).

8. Large Eave

A large freestanding eave is installed on the plaza at the West side of the building (Fig 2). It has skylights with outer dimensions of about 57 m × 32 m. It stands at a height of about 22 m above the podium structure and has an oval shape (Fig. 9). The inner frame section adopts a single layer frame and is composed of skylight glass. The

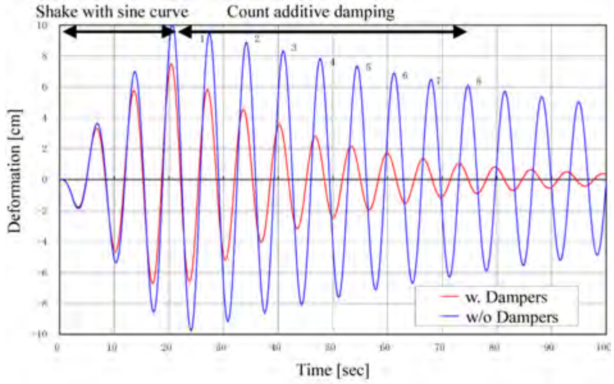

Figure 9. Results of the free vibration response.

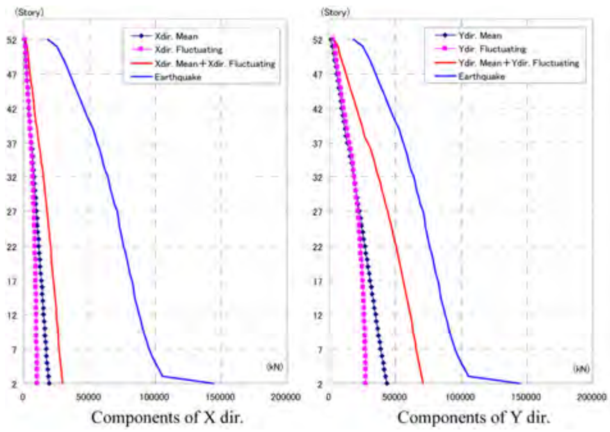

Figure 10. Story shear force by wind load. [Maximum for Y dir. 35°].

frame is designed as a space truss composed mainly of steel pipes in order to carry the inner frame and to maintain its own high rigidity.

9. Evaluation of the Wind Load Considering the Additional Damping Effect of the Viscous Damper

The modal analysis on the frequency domain is performed for the building using its structural properties and the wind force obtained by the wind-force experiment. The 1st mode is the Y axis direction with 6.80 seconds period. The 2nd mode is the torsion direction with 6.69 seconds period. The 3rd mode is the X axis direction with 6.18 seconds period.

Two dynamic analysis models are performed to estimate the additional damping effect of the viscous dampers.

The building model without oil dampers and the model with oil dampers were carried out to estimate the additional damping effect of the oil dampers. The damping of the building is considered as 1% stiffness-proportional damping. 21 seconds long SIN wave vibration (the period:

7 seconds <≒ the natural period>) applied to the two models as it causes similar deformation results to the wind load for a return period of 1 year (wind velocity of 17 m/s). The additional damping effect of the oil dampers was estimated comparing the free damped vibration responses of these two models.

The result of the free vibration responses measured at the top of the building models is shown in Fig. 10. It was found from the results that the additional damping of the oil dampers are 0.5% in the X axis direction and 2.0% in the Y axis direction.

Fig. 10 shows the story shear force distribution(Y axis direction) evaluated for a very rare case of wind load. The ratio of the story shear force due to the wind load against the one due to earthquakes is maximum 70%. It can be concluded that the wind load can be reduced about 20% when considering the additional damping effect of the oil dampers.

10. Conclusions

- An important factor of the building design is that the motorway runs through the basements.
- A combined response-control mechanism was successfully used as it secured a high seismic resistance of the building.
- Special columns connections have been used in the design.
- Special countermeasures against the road vibration have been used.
- Additional damping effects for wind loads have been studied and checked.