Sumitomo Fudosan Roppongi Grand Tower

Mid-story Isolation Building Height of over 200m

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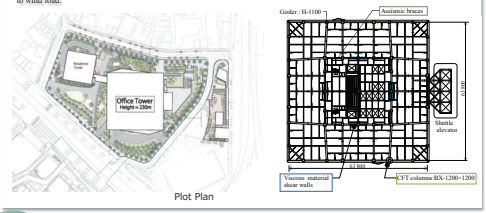
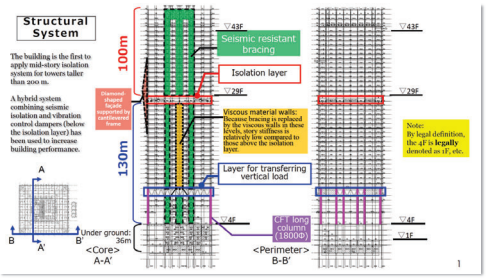
NIKKEN
EXPERIENCE, INTEGRATED

1 Architectural and Structural Scheme Including Seismic isolation

Roppongi Grand Tower is one of the tallest building in the world on the category of the seismic isolation building, have built in 2019 at Tokyo, Japan. The plan shape of the building is approximately 65 m × 65 m with a height of 230 meters. The isolation layer is located between the 25th and 26th floors and comprises of laminated rubber isolators, steel dampers and oil dampers in a point-symmetric arrangement to avoid additional torsional motion.
Steel dampers with a high stiffness are used in Roppongi Grand Tower for suppressing excessive deformation at the isolation layer due to wind load.



Plot Plan



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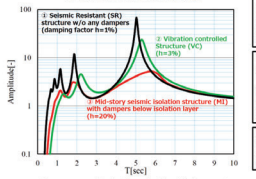
2 Implemented Ideas for Creative Use of SI and ED Technologies due to the Achieved High Seismic Performance

In this building, the criteria were tightened to be 1/125 on the lower part of the isolation layer and 1/180 at the upper part. The performance are quite greater than those of other high-rise building over 200m tall in Japan because those buildings are usually designed with a story drift angle of 1/100 for an "extremely rare earthquake".) In addition, the overall response acceleration of the building is designed to be less than 3.0 m/s². The high seismic performance is achieved at the cost of approximately 3%(including seismic devices, added structural steels, claddings for expansion joints) to the overall cost of the building.

Why does the building use mid-story isolation?

Vibration performance comparison of various structural options



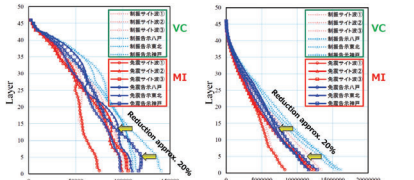
Response amplitude of acceleration/displacement at Roppongi Grand Tower top floor

<Philosophy of seismic resistance in each system >
①SR : Resistant with high stiffness and capacity
②VC : Increase overall damping capacity of building
③MI : Reduction due to extended building fundamental period and concentrated energy absorption in isolation layer
↑This effect is important

The maximum peak of the ③ MI curve is significantly lower than other systems.
The damping ratio calculated from the peak of the system of ② VC is equivalent to 3% of critical.
The damping ratio of ③ MI reaches approx. 20%.
The effect can be applied not only to low or mid-rise buildings, but any tall building.

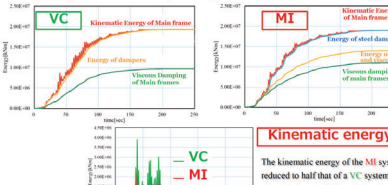
The greatest advantage of MI to tall buildings is that the building response is robust in cases where the building natural periods match the ground motion periods.

Response comparison between VC and MI using time history analysis : story shear force and O.T.M.



➡ MI is approx. 20% lower than VC systems in terms of seismic force and O.T.M.s

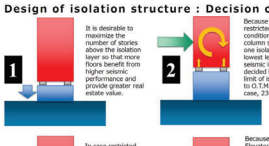
Comparison of responses between VC and MI using time history analysis : Absorbed energy



Kinematic energy

The kinematic energy of the MI system is reduced to half that of a VC system
⇒ equivalent to 30 % reduction in response velocity.

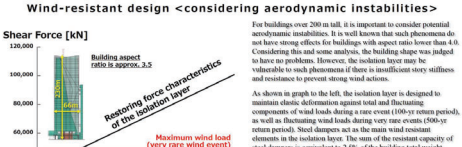
Design of isolation structure : Decision of position of isolation layer



This diagrams describe the process to determine the location of the mid-story isolation layer. Four design factors were considered:
1. Maximization of the numbers of stories above the isolation layer,
2. Vertical support capacity of isolators available in the market,
3. Magnitude of tensile force due to a seismic or strong wind event on the isolators,
4. Integration and coordination with the architectural design.

Considering the above-described factors, the location of the isolation layer was set **just below the Sky Lobby on the 25th (26th denoted in legal) floor.** The elevator frame is designed as a self-standing cantilevered frame rising beyond the isolation layer, and the short decks between the building floor and the elevator frame are connected with flexible joints.

Wind-resistant design <considering aerodynamic instabilities>



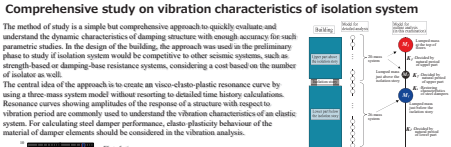
For buildings over 200 m tall, it is important to consider potential aerodynamic instabilities. It is well known that such phenomena do not have strong effects for buildings with aspect ratio lower than 4.0. Considering this and some analysis, the building shape was judged to have no problems. However, the isolation layer may be vulnerable to such phenomena if there is insufficient story stiffness and resistance to prevent strong wind actions.

As shown in graph to the left, the isolation layer is designed to maintain elastic deformation against total and fluctuating components of wind loads during a rare event (100-yr return period), as well as fluctuating wind loads during very rare events (500-yr return period). Steel dampers act as the main wind resistant elements in the isolation layer. The sum of the resistant capacity of steel dampers is equivalent to 2.5% of the building total weight.

In addition, the safety against the phenomenon was verified using modal analysis of wind tunnel experiment data (wind tunnel experiment photos shown below).

Comprehensive study on vibration characteristics of isolation system

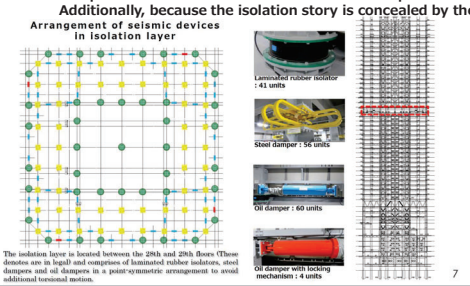
The method of study is a simple but comprehensive approach to quickly evaluate and understand the dynamic characteristics of damping structure with enough accuracy for such parametric studies. In the design of the building, the approach was used in the preliminary phase to study if isolation system would be competitive to other seismic systems, such as strength-based or damping-base resistance systems, considering a cost based on the number of isolator as well.
The central idea of the approach is to create an visco-elasto-plastic resonance curve by using a three-mass system model without resorting to detailed time history calculations. Resonance curves showing amplitudes of the response of a structure with respect to vibration period are commonly used to understand the vibration characteristics of an elastic system. For calculating steel damper performance, elasto-plasticity behaviour of the material of damper elements should be considered in the vibration analysis.



3 Structural Schemes Including Innovative Use of SI and ED to Facilitate Architectural Form and Expression Exceeding Conventional Structural Design.

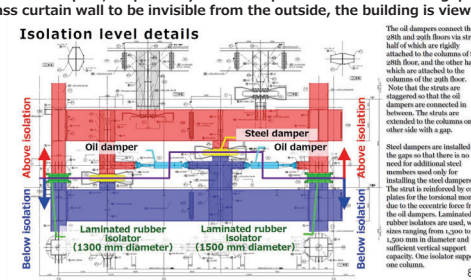
The innovative details are implemented in the building in the isolation story as below. To resistant against wind load and have the building behave as the above high performances, the required dampers should be reached 56 sets in steel dampers and 64 sets oil dampers, respectively. Each dampers are installed in the gaps between the struts from upper structures and bottom structures. Additionally, because the isolation story is concealed by the glass curtain wall to be invisible from the outside, the building is viewed as ordinary high-rise building on the surface.

Arrangement of seismic devices in isolation layer



The isolation layer is located between the 28th and 29th floors (These denotes are in legal) and comprises of laminated rubber isolators, steel dampers and oil dampers in a point-symmetric arrangement to avoid additional torsional motion.

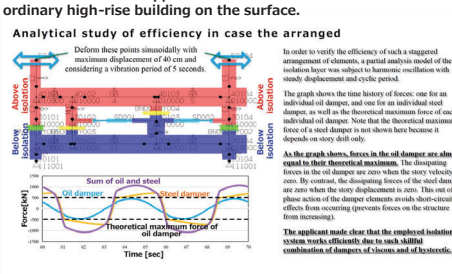
Isolation level details



The oil dampers connect the 28th and 29th floors via struts, half of which are rigidly attached to the columns of the 28th floor, and the other half of which are attached to the columns of the 29th floor. Note that the struts are staggered so that the oil dampers are connected in between. The struts are extended to the columns on the other side with a gap.

Steel dampers are installed in the gaps so that there is no need for additional steel members used only for installing the steel dampers. The strut is reinforced by cover plates for the torsional moment due to the eccentric force from the oil dampers. Laminated rubber isolators are used, with sizes ranging from 1,300 to 1,500 mm in diameter and sufficient vertical support capacity. One isolator supports one column.

Analytical study of efficiency in case the arranged



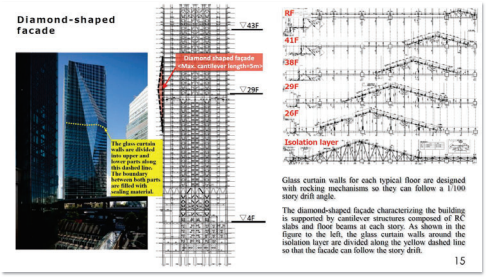
In order to verify the efficiency of such a staggered arrangement of elements, a partial analysis model of the isolation layer was subject to harmonic oscillation with steady displacement and cyclic period.

The graph shows the time history of forces: one for an individual oil damper, and one for an individual steel damper, as well as the theoretical maximum force of each individual oil damper. Note that the theoretical maximum force of a steel damper is not shown here because it depends on story drift only.

As the graph shows, forces in the oil damper are almost equal to their theoretical maximum. The dissipating forces in the oil damper are zero when the story velocity is zero. By contrast, the dissipating forces of the steel dampers are zero when the story displacement is zero. This out of phase action of the damper elements avoids short-circuiting effects from occurring (prevents forces on the structure from increasing).

The applicant made clear that the employed isolation system works efficiently due to such skillful combination of dampers of viscous and of hysteretic.

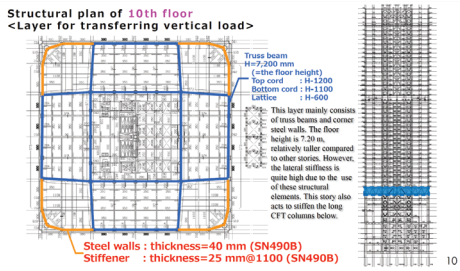
Diamond-shaped facade



Glass curtain walls for each typical floor are designed with rocking mechanisms so they can follow a 1/100 story drift angle.

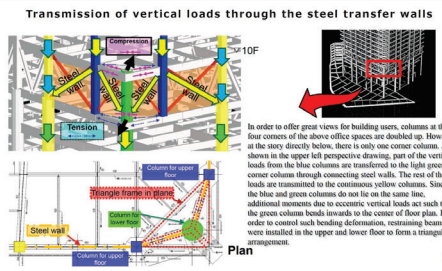
The diamond-shaped façade characterizing the building is supported by cantilever structures composed of RC slabs and floor beams at each story. As shown in the figure to the left, the glass curtain walls around the isolation layer are divided along the yellow dashed line so that the facade can follow the story drift.

Structural plan of 10th floor <Layer for transferring vertical load>



This layer mainly consists of truss beams and corner steel walls. The floor height is 7.20 m, relatively taller compared to other stories. However, the lateral stiffness is quite high due to the use of these structural elements. This story also acts to stiffen the long CFT columns below.

Transmission of vertical loads through the steel transfer walls



In order to offer great views for building users, columns at the four corners of the above office spaces are doubled up. However, at the story directly below, there is only one corner column. As shown in the upper left perspective drawing, part of the vertical loads from the blue columns are transferred to the light green corner column through connecting steel walls. The rest of the loads are transmitted to the continuous yellow columns. Since the blue and green columns do not lie on the same line, additional moments due to eccentric vertical loads act such that the green column bends inwards to the center of floor plan. In order to control such bending deformation, restraining beams were installed in the upper and lower floor to form a triangular arrangement.