Nakanoshima Festival Tower West


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1. Introduction

This building, together with the adjacent Nakanoshima Festival Tower (mid-story seismic isolation), forms a 200-meter-high twin tower that serves as a landmark in Nakanoshima, Osaka.

To achieve high seismic performance equivalent to that of the adjacent building, the building adopts a lower-level concentrated vibration control structure with high damping efficiency. Because of the large-scale lower-level concentrated vibration control structure, this building was realized by various contrivances, such as the adoption of high-damping oil dampers that exhibit 3 times the damping force of conventional buildings, and the adoption of efficient BigWall frames.

2.Outline of the building

This building is positioned as the second phase of the twin tower project, which is paired with Nakanoshima Festival Tower across Yotsubashi-suji. The building is called "Nakanoshima Festival Tower West" and the entire city block is called "Festival City." (Photo 1)

This building is used as a complex consisting of tenant offices, luxury hotels, cultural exchange facilities, and commercial facilities. Table 1 shows the outline of the building, and Fig. 1 shows the cross-sectional configuration. Commercial and cultural exchange facilities are located on floors 1 to 4, tenant offices are located on floors 6 to 31, and hotels are located on floors 33 to 40. Fig. 2~4 shows the floor plan of the first floor, third floor, and reference floor.

Table 1　Overview of the building

Architects：	Asahi Shimbun Co., Ltd., Takenaka Corporation
Construction site：	3-chome, Nakanoshima, Kita-ku, Osaka City
Use：	Offices, hotels, museums, cultural facilities, Stores, etc.
Site area：	approx. 8,400m^2
Building area：	approx. 6,100m^2
Total floor area：	approx. 150,000m^2
Height：	approx. 200m
Number of floors：	41 stories above ground, 4 stories below ground, 2 stories in a tower

Structure：	Vibration control structure, S/SRC/RC structure
Design supervision：	Nikken Sekkei, structural design cooperation:Takenaka Corporation
Construction：	Takenaka Corporation
Period：	July 2014 to March 2017

Photo1 External view of the building (the building is on the right)

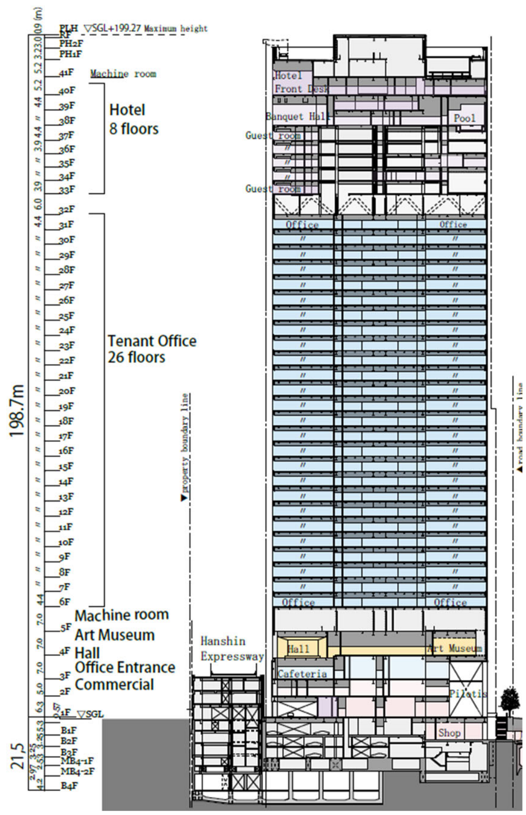
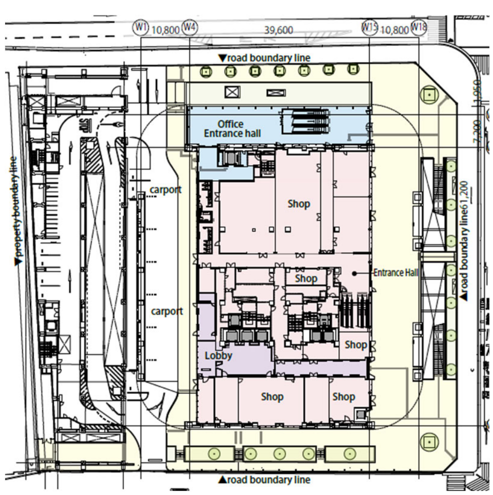


Fig.1 Cross-sectional plan



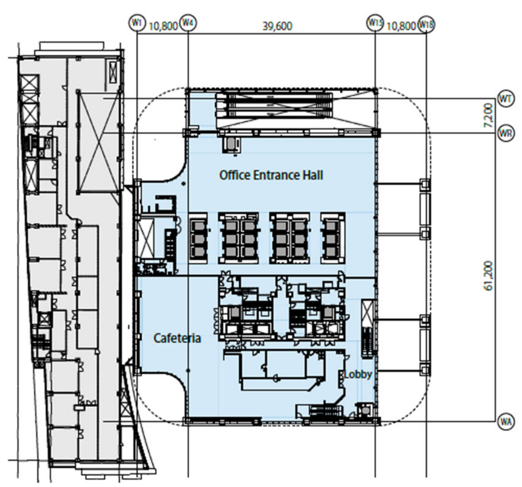


Fig.2 First Floor Plan

Fig.3 Third Floor Plan

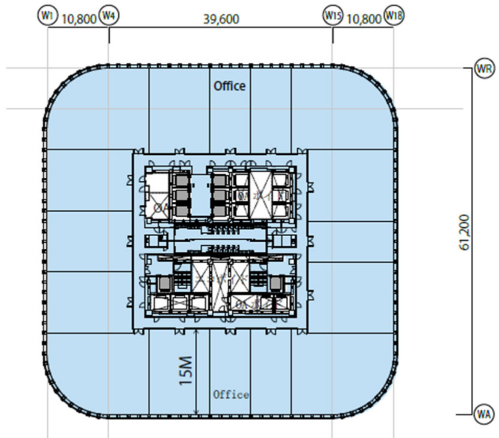


Fig.4 Standard Floor Plan

3.Outline of Structure

3.1 History of Deciding on the Structural Plan

When deciding on the structural plan of this building, the building owner presented the following requirements regarding seismic performance.

‣High seismic resistance equivalent to the Festival Tower

‣Adoption of seismic isolation structure as in the Festival Tower.

Here, equivalent seismic performance was defined as 1) members remaining within the elastic range against Level 2 earthquakes (major earthquake in Japan), and 2) interstory drift angles of each floor being within 1/150 during Level 2 earthquakes, and this was agreed upon with the building owner.

Regarding the adoption of seismic isolation structure, as a various architectural planning and structural analyses, concluded that the installation position (height) of the seismic isolation layer would be lower than that of Festival Tower, and the aspect ratio above the seismic isolation layer would become larger, making it disadvantageous although not impossible to achieve equivalent seismic resistance. In this case, adopting a seismic isolation structure would necessitate, the use of cross linear bearings (CLB) for high tensile strength. And the column positions directly below the seismic isolation members and the structural walls required to ensure large horizontal rigidity, significantly reduced architectural design flexibility.

What we focused on to achieve seismic performance equivalent to Festival Tower was that the exterior large wall surfaces covered with brick of the lower floors (Photo 2).

Through various analytical studies, it was confirmed that the performance equivalent to the Festival Tower can be obtained by adopting a "concentrated vibration damping" structure in which damping members (oil dampers) are placed in the same wall while ensuring sufficient rigidity in the lower floor. This concentrated vibration damping part of the lower floor is called the "Vibration control layer (VC layer) ", and Fig. 5 shows the structural plan concept diagram explained to the building owner in comparison with the seismic isolation of the middle floor of the Festival Tower.

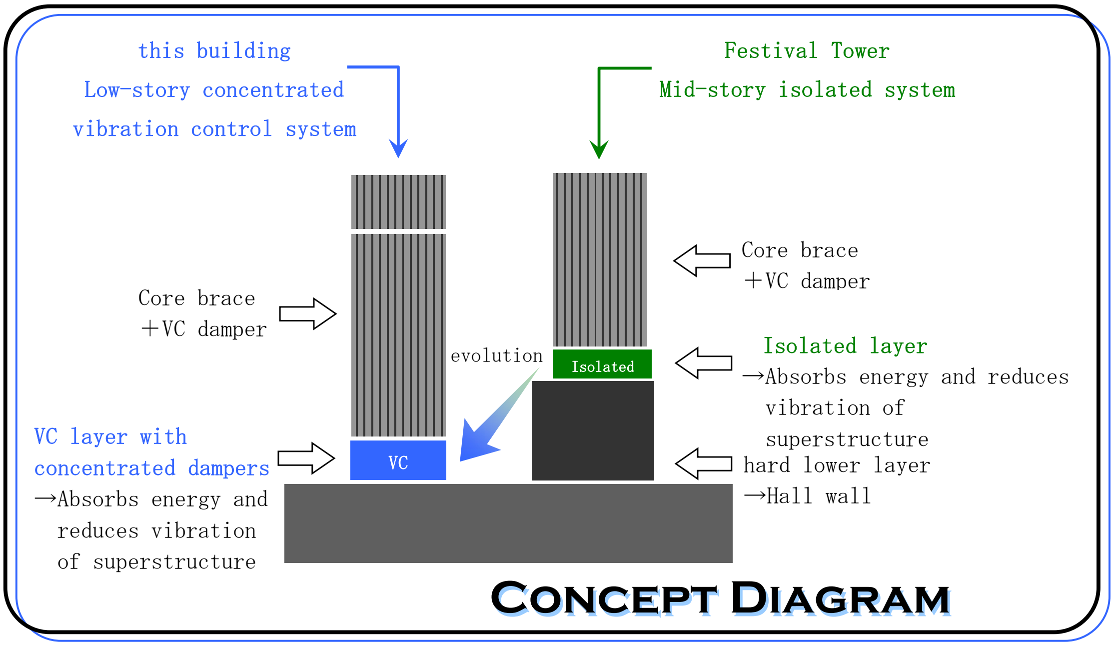


Fig.5 Structural plan concept

Photo 2 Low-rise external view

3.2 Structural outline

The earthquake resistance criteria of this building are as described in the preceding paragraph. For Level 2 earthquakes, the elastic range of members and the deformation angle between layers are within 1/150. Fig. 6 shows the frame perspective, Fig. 7 shows the framing elevation, and Figs. 8 and 9 show the third floor and standard floor plan.

This building is a steel structure, and as shown in Fig. 6, the span of the outer columns varies according to the building use. The span of the outer columns is 7.2 m to 18.0 m for floors 1st to 4th, 3.6 m for floors 6th to 31st, and 4.5 m for floors above the 33rd floor. The fifth and 32nd floors, which are the switching floors, are both machine rooms, and the column span is adjusted on the outer circumference portion of the truss, and the bending deformation of the core is suppressed by the truss connecting the core and the outer circumference portion. The structural plan is described below from the upper floor to the bottom floor.

The hotel floor, which is the top floor, secures horizontal rigidity with the perimeter structure consisting of H-shaped steel columns and beams at a pitch of 4.5 m, and the moment resisting frames with earthquake-resistant braces at the core.

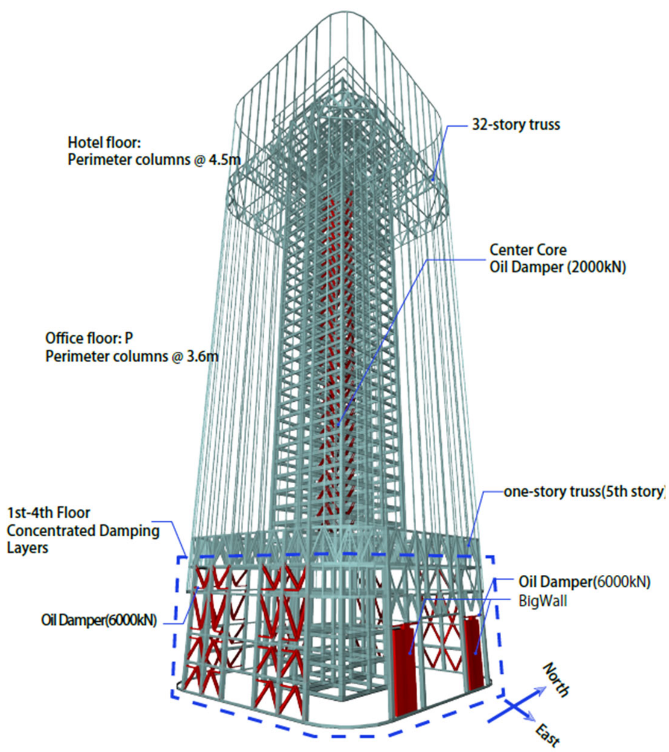


Fig.6 Frame Perth

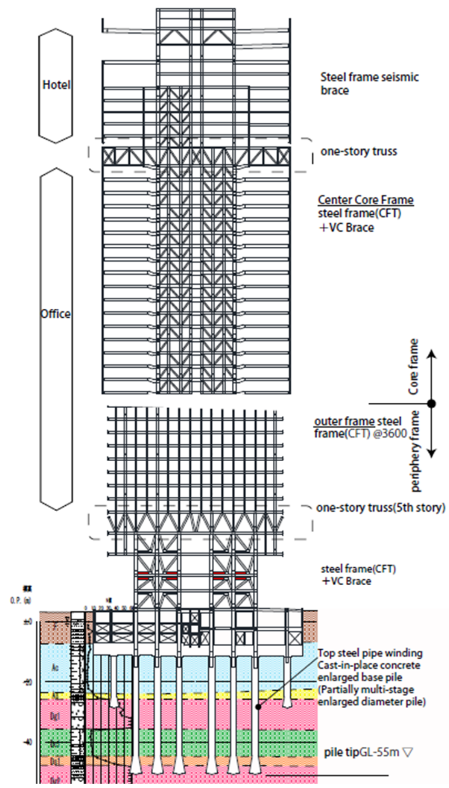


Fig.7 Frame Elevation

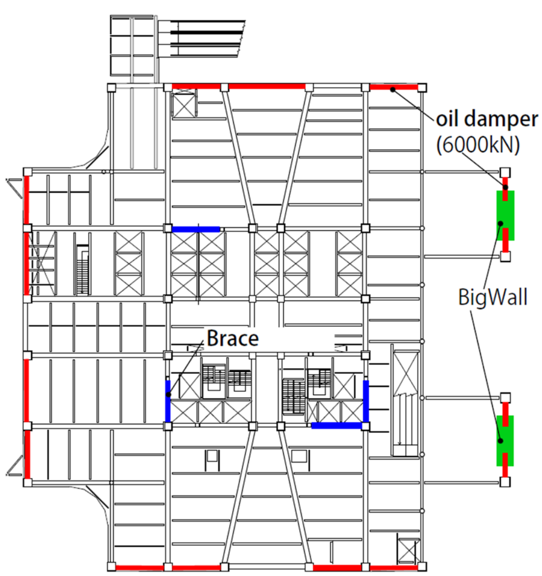


Fig.8 Third-floor plan

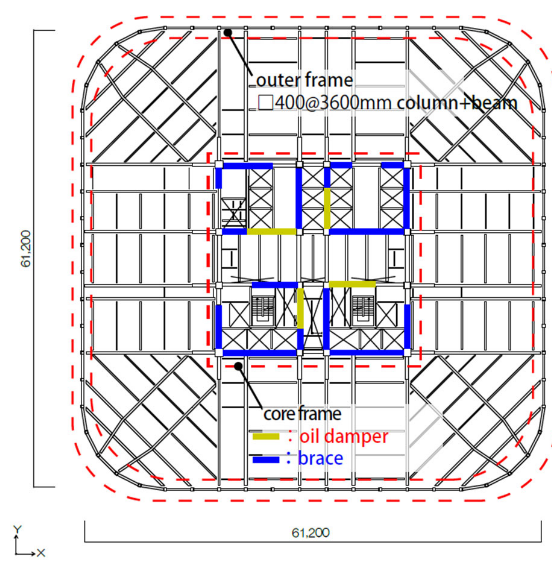


Fig.9 Standard floor plan

The standard floor (Fig. 9) secures horizontal rigidity with the perimeter structure (perimeter tube frame) consisting of 400 square CFT columns and H-shaped steel beams at a pitch of 3.6 m, and the moment resisting frames with earthquake-resistant and damping braces at the core (center core frame). The perimeter tube frame has about 15% of horizontal force sharing ratio and the center core frame has about 85% of horizontal force sharing ratio.

The lower floor (Fig. 8) has moment resisting frames with earthquake-resistant braces and high-damping oil dampers at the periphery, and the columns are CFT columns (550 N grade steel +Fc90 concrete).

The steel materials use 490 N grade steel and 550 N grade steel. The maximum size of the columns is 1300 mm square, and the maximum thickness is 80 mm.

The substructures are made by SRC columns (partially S columns) and steel beams, and it is moment resisting frames with earthquake-resistant walls with underground external walls and earthquake-resistant walls installed in various places.

The foundation is a pile draft foundation. The top steel pipe reinforced cast-in-place concrete beveled piles expanded base diameters of 2000 and 2500 are provided directly under each column. And partially multi-belled cast in place concrete piles, are used with depths of about 1FL-33m and -55 m, in which provide high axial force.

3.3 Outline of Response Analysis Results

Fig. 10 shows the maximum story drift angle during a Level 2 earthquake. It is confirmed that the story drift angle is 1/150 or less for each floor and that the members are in the elastic range. The response acceleration of this structure is equivalent to that of the base seismic isolation structure. Fig. 11 shows the energy time history during the same Level 2 earthquake. By comparing with the internal viscous damping, the damping of this building is about 3 times larger than the internal viscous damping of a general building (stiffness proportional first order 2%).

In addition to the Level 2 earthquake, the safety of the building has been confirmed by examining the extremely earthquake "Uemachi fault wave (Level 3B) proposed by JSCA Kansai and others". In the same way, we have also examined the seismic wave of the Nankai Trough, which is a long-period earthquake.

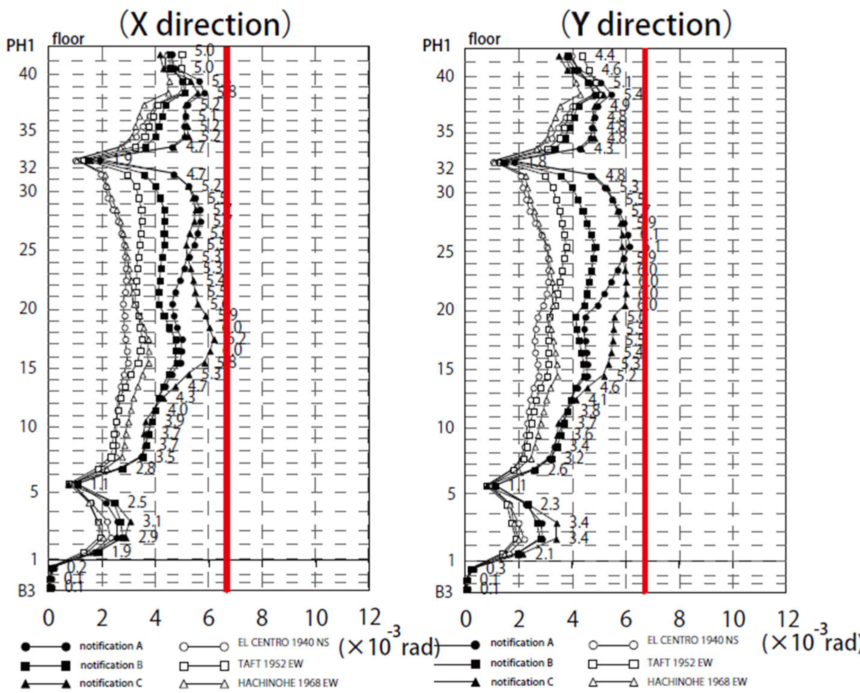


Fig.10 Response analysis results (story drift angle at level 2 earthquakes)

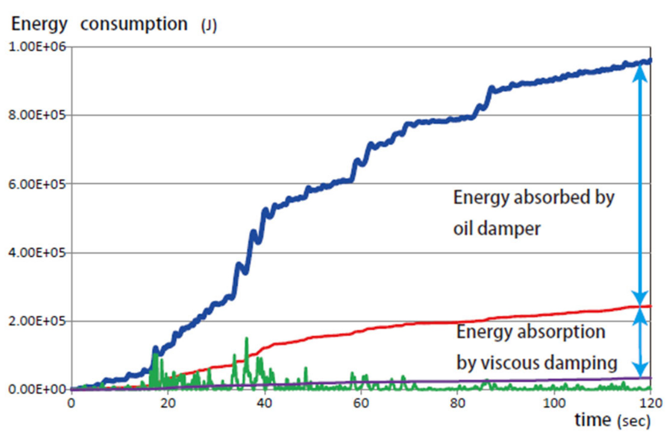


Figure 11 Time history of energy(level 2)

4. Low-stories concentrated damping system and the outline of surrounding structure

4.1 Effect of low-story concentrated damping system

Fig. 12 shows a comparison of the response maximum story drift angle between the first and fourth floors with and without damping layers. The seismic response of the upper floors is also improved by the concentrated damping of the lower floors.

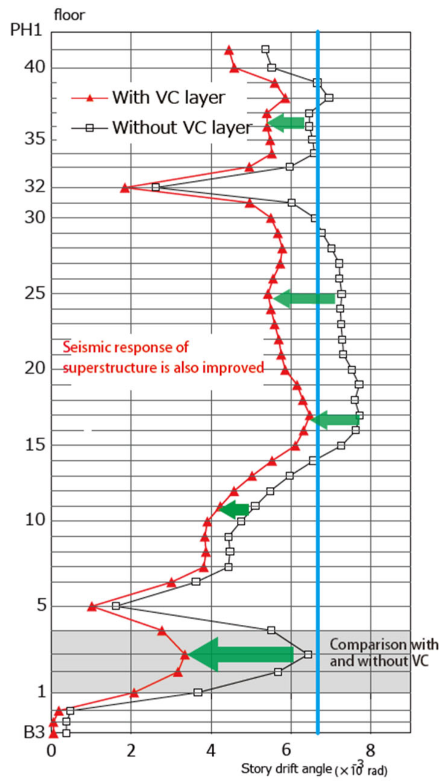


Fig. 12 Effect of concentrated damping layers

4.2 High damping oil damper (Thigh POD)

A high damping oil damper (Thigh POD), which has a 3 times maximum damping force that of a general oil damper (which is 2000kN of the maximum damping force), was adopted to provide maximum damping performance in a limited area to realize the low-stories concentrated damping system.

Fig. 13 shows a conceptual diagram of a high damping oil damper. Three 2000 kN dampers arranged in series work simultaneously via a common piston rod. And a maximum damping force of 6000 kN is exerted by this system.

Fig. 14 shows a comparison of a typical oil damper with a maximum damping force of 2000 kN and a high damping oil damper on the same scale. By making the diameter larger than conventional oil dampers, the length is less than three times that of standard ones, allowing for more rational placement compared to installing multiple general oil dampers.

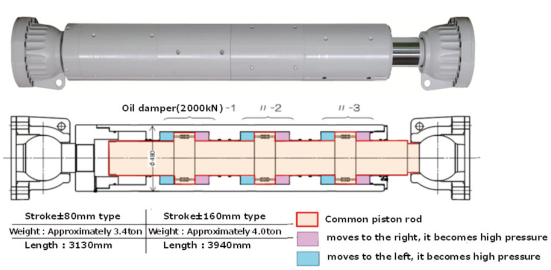


Fig.13 Concept of high damping oil damper

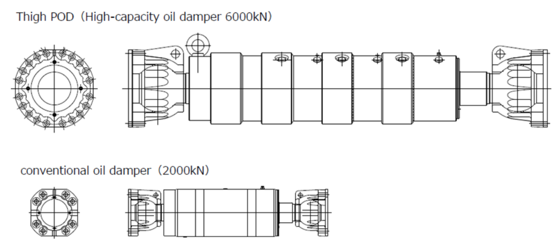


Fig.14 Comparison of the Oil Damper Size

4.3 Bigwall Structure

The BigWall structure is a frame installed on the east side of the concentrated vibration control section in the lower floors (Figure 15). As shown in the 3rd floor plan (Figure 4), this section has an atrium interior, and it was determined that utilizing large self-supporting walls to take advantage of the inter-story deformation (velocity) across three floors would be more efficient than installing braced frameworks with vibration control dampers on typical columns and floor beams at each level.

The effectiveness of this BigWall frame is verified through absorbed energy. Figure 16 shows a comparison between the absorbed energy of oil dampers installed in the east-side BigWall frame during Level 2 seismic motion and the absorbed energy of oil dampers for four stories on the west-side. By concentrating interstory deformation across three stories, the energy absorption efficiency per damper becomes more than four times higher, demonstrating the high efficiency of the BigWall frame. It has been confirmed that there are no safety issues with the dampers regarding interstory velocity.

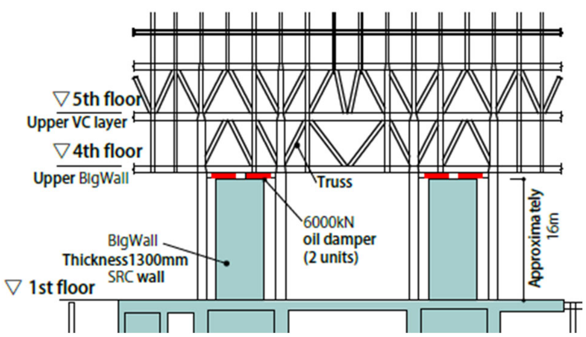


Fig.15 Big Wall structure

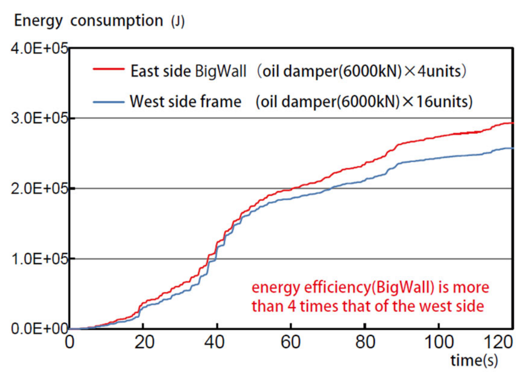


Fig.16 Comparison of the Absorbed Energy of the BigWall Structure

4.4 The stiffness balance of the east and west sides of the lower part.

In the preceding paragraph, it was shown that the energy absorption efficiency of the east-side with the BigWall structure was higher than that of the west-side. On the other hand, if the rigidity of the east-side is extremely low compared with that of the west-side, there is a possibility of twist due to eccentricity. Therefore, as shown in Fig. 15, the east-side of the fourth floor, which is directly above the BigWall structure, is a truss structure to ensure the rigidity balance.

Fig. 17 shows the deformation of the east-side and the west-side under seismic loading for Y-direction design. The deformation of the fourth floor is affected by the small rigidity of the east-side, but the deformation of the fifth floor is almost the same on the east-side and the west-side because of the truss structure. It can be confirmed that the difference in the structure type of the east and west sides of the low-rise section does not adversely affect the stiffness balance of the building.

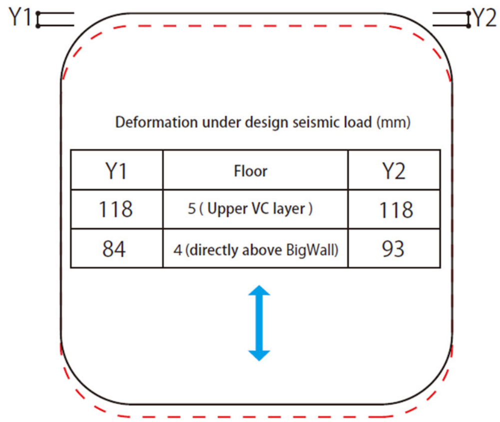


Fig.17 Deformation under design seismic load in Y-direction

5.Structural designs of non-structural members

○ Exterior support material for the hotel floor atrium

As shown in Photo 3, the hotel lobby on the 40th floor has a large atrium with a panoramic view of the southwest direction in Nakanoshima from a height of about 200 m.

To minimize the view, cut by the exterior materials, the mullion, which is about 19 m high and receives the curtain wall, uses a 180*250 mm box-shaped cross-section material, as shown in Figure 18, to ensure the necessary rigidity and resistance in the in-plane and out-of-plane directions.

Each mullion is transversely connected by a tie rod to prevent the variation of the mullion spacing due to windstorms on the arc-shaped exterior wall and to ensure the same deformation during in-plane earthquakes.

The tie rod is attached to a threaded steel pin, and by adjusting the length with screws and rotating the pin, workability including arc-shaped exterior wall is considered.

This horizontal connecting member was aligned with the sash mullion, and by keeping the connecting hardware within the mullion width, it achieved a finish as if there were no elements other than the mullion and transom. The corner welding of the mullion was finished with negative within a range that does not compromise structural strength, and by using putty repair, it achieved a finish resembling extremely thick flat steel.


Photo 3 Hotel floor atrium

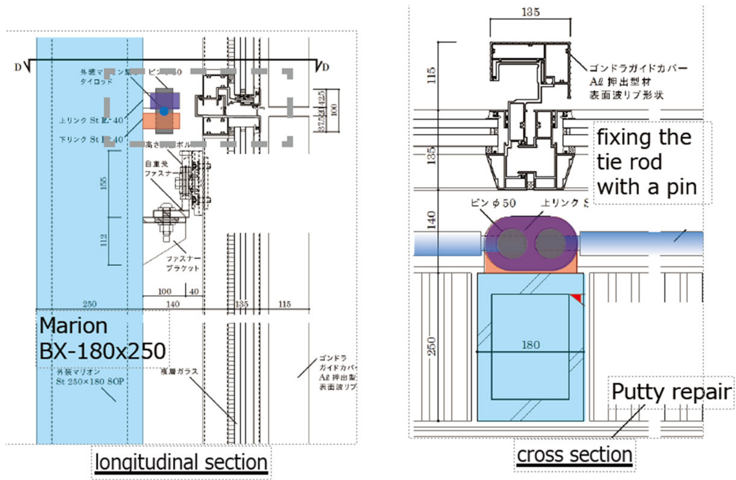


Figure 18 Detailed view of mullions and lateral joiners

6.Summary

This building was completed in March 2017 with the cooperation of the architect, builder and design supervisor. I hear that both the tenant office and hotel are very well received. With the completion of the Twin Towers, it can be said that a large "town" with 12000 people staying on both sides of Yotsubashi-suji, one of the main streets in Osaka, has been completed in Nakanoshima, and I think that it has great social significance.

One of the foundations supporting "town" is safety. In the case of Nakanoshima Festival Tower West, the low floor concentrated vibration damping structure has been adopted to ensure the same high seismic safety as that of the adjacent building in accordance with the architectural plan.

The structural plan of the adjacent Nakanoshima Festival Tower, which adopts the mid-story seismic isolation structure, is described in detail in MENSHIN No. 78 (2012.11). It would be appreciated if you could refer to the difference in the structural plan between this building and the twin tower, which has achieved the same seismic performance under different structural plans.