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Structural Design of Mid-Story SI Tall-building with RC Frame Placed on Steel Structure

Tomonobu Isobe[2] and Hideshi Aono[1]

[1]*Design Division, Taisei Corporation, Tokyo 163-0606, Japan*
[2]*Design Division, Hokushinetsu Branch, Taisei Corporation, Niigata 950-8585, Japan*

Abstract

In this paper we introduce Shinagawa HEART, located in Shinagawa district, Tokyo. It is a mixed-use building with residences on the upper floors, offices on the lower floors, and commercial uses on the first and second floors, and is intended to meet the various needs of a building on the border between residential and commercial areas. The upper floors of the building are made of reinforced concrete, while the middle and lower floors are made of steel with CFT columns. First, an overview of the structural plan of the building is presented. Next, the adoption of the middle layer seismic isolation and the switch between the lower steel structure and the upper reinforced concrete structure, which are the features of this building, are explained. Finally, the construction method adopted to achieve the design performance is explained.

Keywords: Structural design, Mid-story SI, Laminated rubber bearing, Oil damper with lock mechanism

1. Introduction

Shinagawa Heart is located near the Konan Exit of Shinagawa Station, an area that is expected to develop further with the opening of the Linear Central Shinkansen Line in the future. In addition, the site is located on the boundary between the office area and the residential area, bordered by the old Avenue called Kaigan-dori on the east side of the site, so we aimed to create a new face of the Shinagawa Station Konan Exit. The building is a high-rise building with a maximum height of approximately 114 meters, with offices in the mid-stories and apartments in the upper sections. To meet the needs of the city, the building consists of a complex of facilities with a nursery school and stores on the lower floors. By creating an open public space, we aimed to create a building that would bring liveliness and enrichment to the city. The exterior design emphasizes vertical pillars extending toward the sky, and the spandrels of the offices and the beams of the residences are repeated in the same rhythm to create a sense of unity while expressing the individuality of each use. The typical floor height is 4.35 m for the office floors and 3.35 m for the residential floors.

In order to secure a large office space on the office floors, the span in the north-south direction (hereinafter referred to as "Y direction") is 20.7 m, and on the residential floors, the span is reduced to 6.9 to 7.2 m. The span in the east-west direction (hereinafter referred to as X direction) is planned to be 7.2 m for both the office and residential floors.

The building is planned as a seismic isolation structure



Figure 1. Exterior of the building.

†Corresponding author: Tomonobu Isobe
Tel: +81-25-247-1197, Fax: +81-25+247-1163
E-mail: isobe@arch.taisei.co.jp

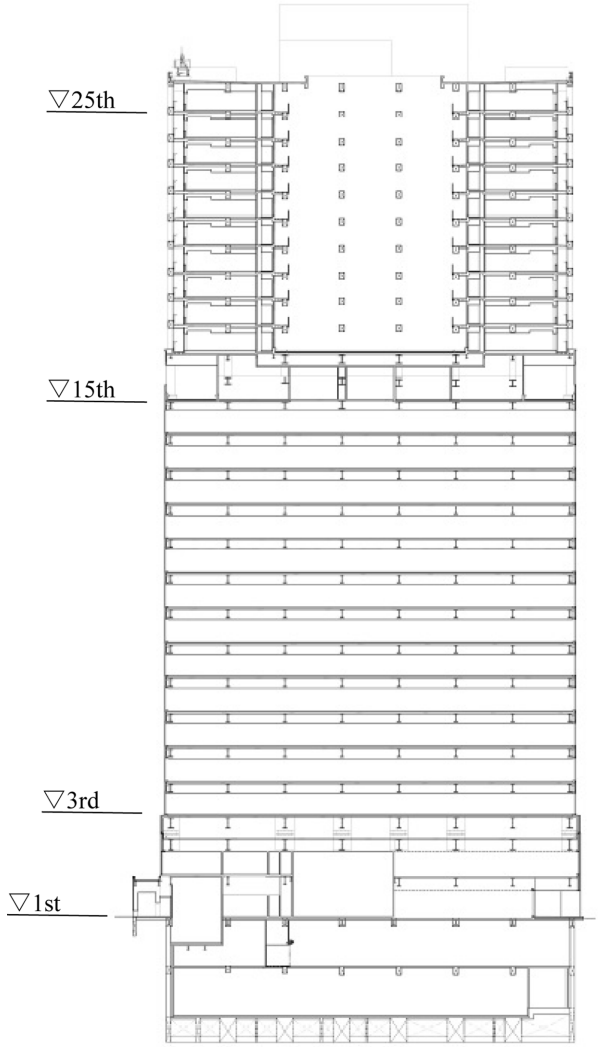


Figure 2. Section view.

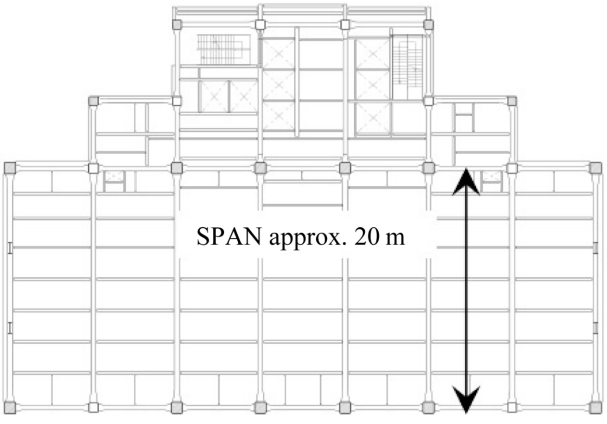


Figure 3. Structual plan for office.

to ensure high structural safety against major earthquakes and to maintain the building functions even after the earthquakes. In order to reduce the flooding risk of the seismic isolation layer, seismic isolation of this building has been installed between the second and third floors. The emergency generator, which can operate 72 hours in the event of a disaster, is installed on the roof where it is never submerged.

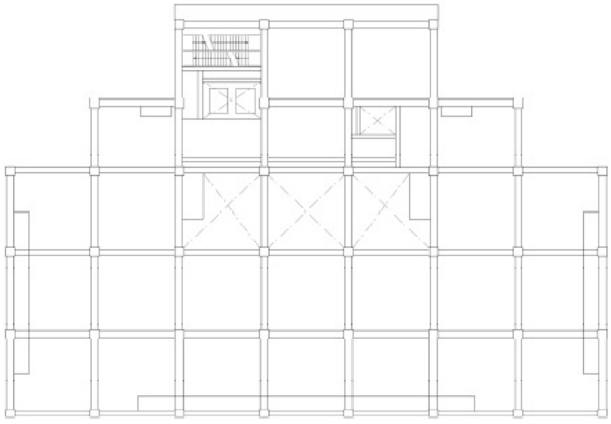


Figure 4. Structual plan for residence

2. Outline of Structural Design

This building has 26-stories above ground with two basement floors. The main use of the building is for offices and apartments. This building has the intermediate seismic isolation floor with a seismic isolation under the third floor. The 1st, 2nd floors below the seismic isolation layer and 3rd to 15th are steel-framed, and from 16th to 25th floors are RC frame. 26 to PH2 are steel-framed. The basement is a combination of RC-encased steel (SRC), RC and steel structures.

Considering the sound insulation and habitability, RC frames are used for residential floors and layered construction system as Precast-RC is adopted. The laminated rubber bearing type isolators are basically placed directly under the columns on the third floor. However, where the columns adjacent to the corner, as the countermeasure against tension force at the corners of the building, the laminated rubber bearings are not placed directly under the columns in order to concentrate the axial force(vertical load) on the corner columns and isolator. On the 15th floor, which is the boundary between the office floors and the residential floors (various rooms with small partitions such as conference rooms and storage rooms are located), a structural transfer floor with a mega truss structure is provided to support the force of the columns which have no isolator under those, and to support the standing columns of the residential floor on the mega truss, which have different spans from the office floors. Sufficient safety margin was given deciding truss members considering the influence of vertical seismic movement. As for the structure of the floors below the seismic isolation layer (hereinafter referred to as the lower structure), vertical braces are placed in a balanced manner in both X and Y directions on the ground floor to increase the

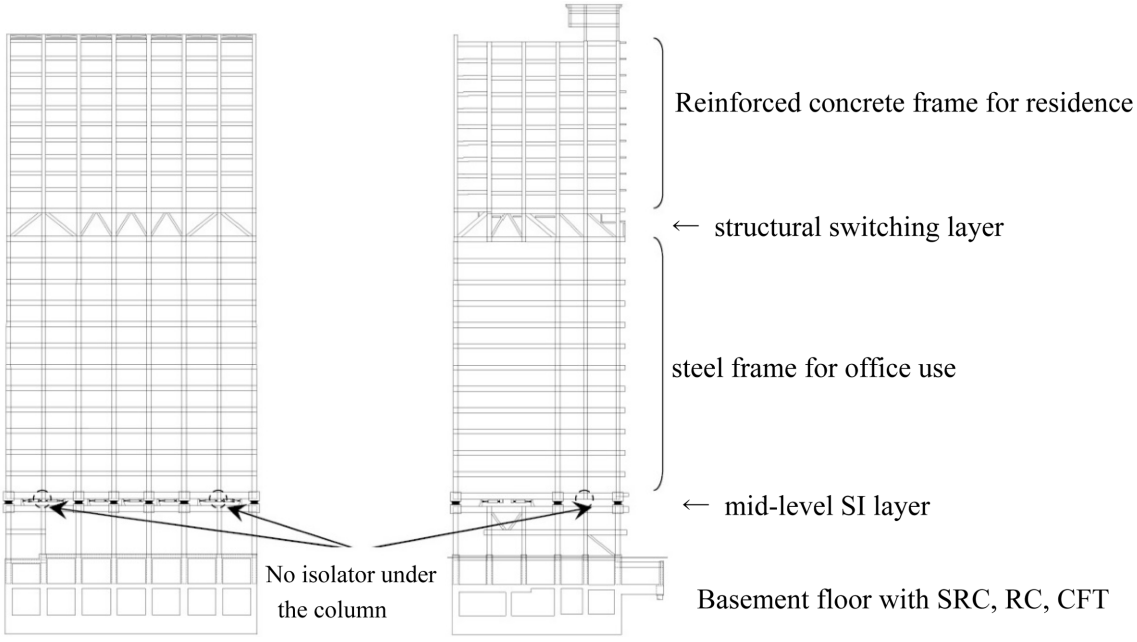


Figure 5. Structural framework drawing.

stiffness of the story and improve the seismic isolation effect of the upper structure. In addition to the braces, the basement floor has exterior basement walls and interior seismic walls.

The main features of the structural design are as follows.

- The structure of the 3rd to 14th floors, which is used for offices, is adopting steel-frame system to achieve large spaces and large-span structures.
- The CFT (concrete filled tube) is adopted for the columns to secure higher rigidity and bearing capacity.
- The typical beam depth is 1000 mm on the office floors. The columns are 800 × 800 mm on the standard office floors and 800 × 800 mm to 1000 × 1000 mm on the lower floors.
- The typical beams depths of the upper residential floors are 700 mm to 950 mm, and the size of columns are 800 mm × 800 mm.
- The 15th floor is used as transfer floor with mega truss to support the upper residential floors safely.
- For the seismic isolation layer, vertical braces are appropriately provided to ensure necessary stiffness as the seismic isolation layer.
- The basement of the building is basically made as SRC, and partially CFT columns are adopted to improve the building space.
- The foundation is mainly the direct foundation on sand gravel layer, and piles are used where the bottom level of the raft is higher.
- The laminated rubber bearing type isolators are adopted. In addition, provided oil dampers absorb energy and contribute to make the displacement of isolators within the reasonable value.
- As the measure for the induced wind vibration, some of the oil dampers are equipped with a locking mechanism, which ensures the comfortability of occupants under normal wind conditions. The oil dampers with locking mechanism are controlled depending on wind speed.
- For column-beam joint, field-welded joint (butt-weld) is adopted for flanges and bolted joint (friction grip type) for web.
- At the field welding portion of steel flange, the width of flange is horizontally enlarged (horizontal haunch) to prevent the excessive stress and strain.
- Precast construction method shall be adopted for the RC residential floors. RC columns shall be made as full precast members, and the beams, and floor slabs shall be made as half precast members, and the upper concrete shall be cast in place.
- As for the joint of beam and column, full precast members are along the perimeter, and cast-in-place concrete is used for the interior joints.
- The elevator support frame is planned to suspend from the 3rd floor, which secure the continuity of ELV operation and recoverability under earthquakes.

3. Design of the Seismic Isolation Layer

The adoption of the seismic isolation system consists of a combination of laminated rubber bearings and oil dampers that do not cause residual deformation after an earthquake, is intended that the misalignment of external cladding will not happen in the seismic isolation layer after earthquakes. In addition, locking mechanism is added on some of the oil dampers considering the comfort

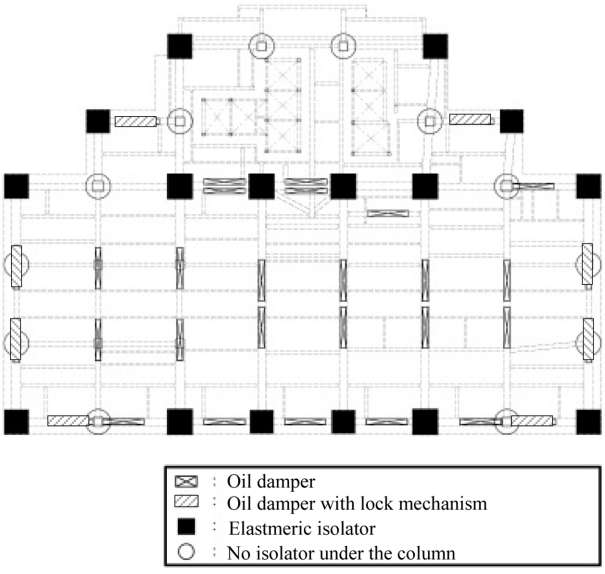


Figure 6. Seismic isolator layout.

ability under the vibration by wind shaking. Figure 6 shows the layout of the seismic isolation devices. The elastomeric isolator is the square type that fits well in the corner of the building, which sizes □-1300 to 1500 are arranged depending on the weight balance. The steel column and base plate of the seismic isolations were directly connected to improve construction ability. Since the accuracy of the steel construction directly affects the accuracy of the seismic isolation, special care was paid to the accuracy control by facing treatment to the bearing base plate. The eccentricity ratio of the base isolation layer is less than 1%, and the natural period of the seismic isolation layer is about 5 seconds. The assumed design clearance was set as 600 mm in consideration of the maximum response displacement (considering the margin: seismic motion of 1.5 times the level 2 notified wave by law).

4. Seismic Response Analysis

Figure 7 shows the results of the Level 2(the earthquake of 500-year return period) seismic response analysis considering the tolerance of the physical isolators performance. The seismic response analysis was conducted for the three observed waves and the three notified waves, and it was confirmed that the maximum response values for each wave satisfied the target seismic performance for Level2. The maximum deformation of the seismic isolation layer was 36 cm, and the maximum story drift angle was less than 1/260. In addition to the above study, we confirmed the safety of the building against seismic motion of 1.5 times the level 2 notified wave.

The energy consumed by the seismic isolation layer is about 60 to 90% of the total input energy, and it can be judged that the seismic isolation effect is being demonstrated.

The strain energy of the structure above isolation layer seems to be consumed by upper RC structure as the form of stiffness degrading of RC members due to being cracked. However, since the value is 3.2% at the most, structural safety can be judged this is less than minor damage.

5. Design of the Switching Section

As mentioned above, the structural type of this building is switched at the transfer level (15th floor). The columns are switched from CFT columns to RC columns on the 16th floor. The shape of the switchover area is shown as Fig. 8. This switching section is considered to be a type of "RC columns + steel beams", although the lower columns on lower story are CFT columns. This column-beam joint seems to be categorized as "F-6 type", which is illustrated

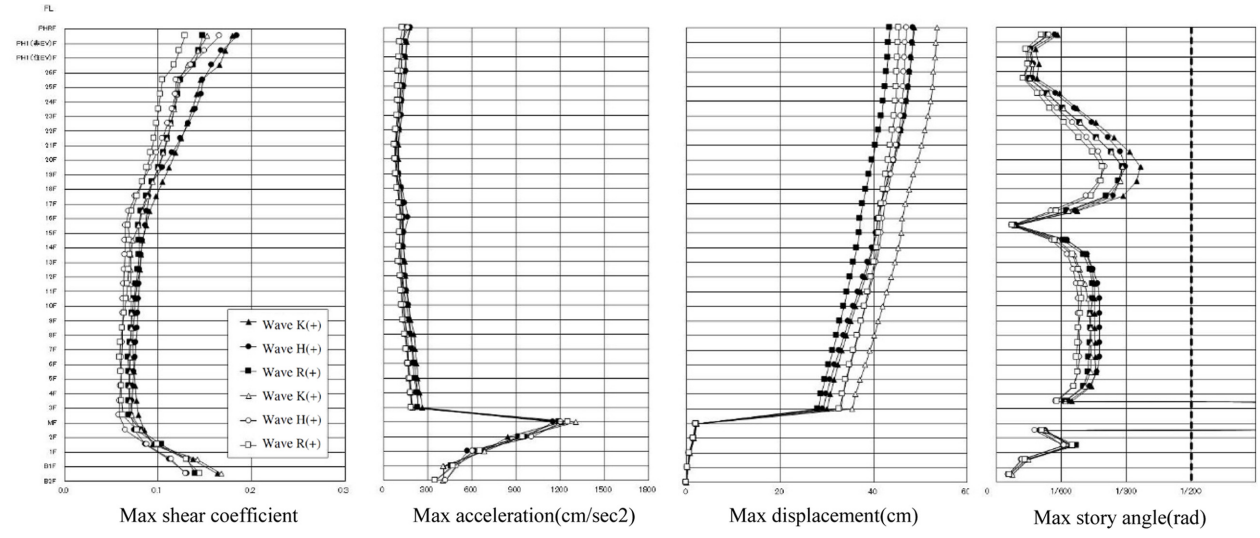


Figure 7. Result of seismic response. (Level2 notified wave by law)

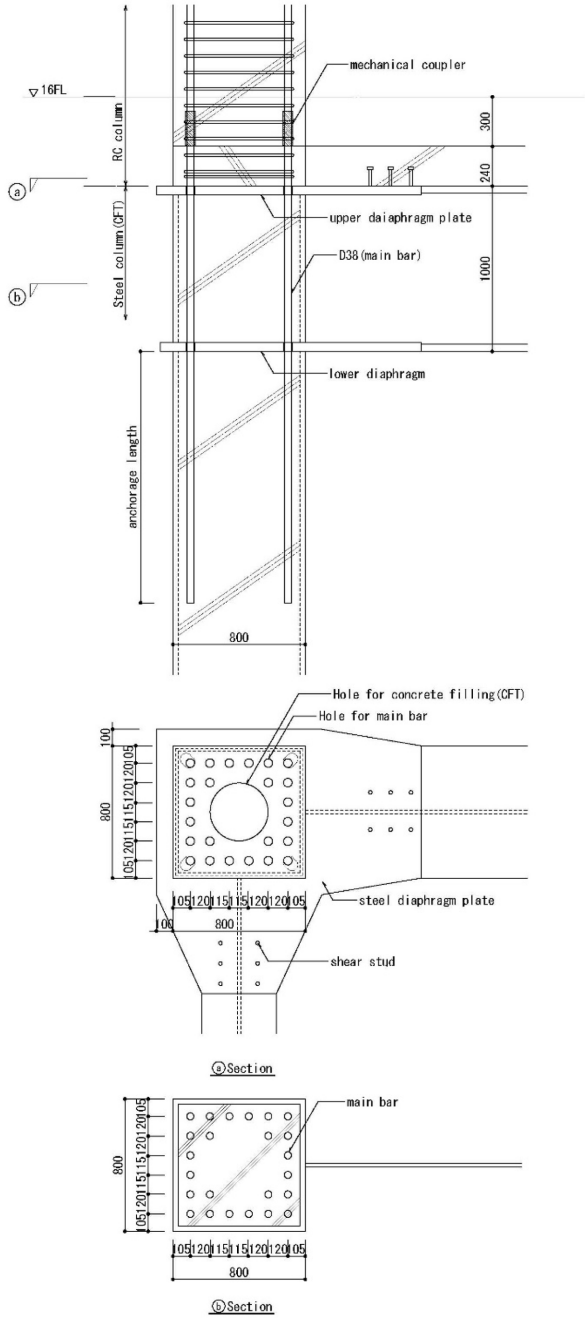


Figure 8. Switching section detail.

in the "Design and construction of mixed structure composed of reinforced concrete columns and steel beams" (AIJ, hereinafter referred to as the "Guidelines for Mixed Structures"). This guideline says it is important to confirm the following points to ensure structural safety.

- No shear failure happens at the column-beam joint
- Top and bottom Of column connected to joint never cause bearing failure against compression force
- Main bars of column never cause bonding failure with in the joint.
- No yielding of anchor bars or steel diaphragms In addition, since the lower floor columns of the building are CFT columns, the following points are also checked.
- Column shear force can be securely transferred to the joint.
- Appropriate anchorage of the main bars of RC column to lower CFT column.

Since the steel frame, reinforcing bars, and filled concrete are interrelated, careful approach was necessary about the detailed process of the construction of this part. Therefore, a mock-up was made prior to the actual construction to confirm the insertion method of the steel bars and the filling ability of the concrete.

6. Fixing the Seismic Isolation Layer During Construction

As mentioned above, the columns which have no isolators under the those are planned to be supported (suspended) from the mega trusses on the structural transfer floor. Therefore, it was planned to install hydraulic jacks under the columns to support them until the election of structural transfer floor was completed. Fig. 9 shows the installed jacks. During construction, the load on the jacks and the vertical deformation were continuously checked at all times. The loads are confirmed to be within the allowable limit, and the vertical deformation needs to be checked to make sure that the vertical relative deformation with the adjacent seismic isolation bearing does not exceed 1/2000 of the span. If it exceeds this value, jacking up or down is necessary to keep it less than 1/2000. If the seismic isolation layer moves due to the earthquake during the period of installing of jacks, it may fall down. Therefore, during the period, the horizontal deformation of the seismic isolation layer is fixed by installing horizontal restraint element using damper brackets and horizontally restraining it by bolting the damper brackets to the upper floor beams. Fig.10 shows the provision of horizontal restraint element on the seismic isolation layer.



Figure 9. Situation of hydraulic jack.

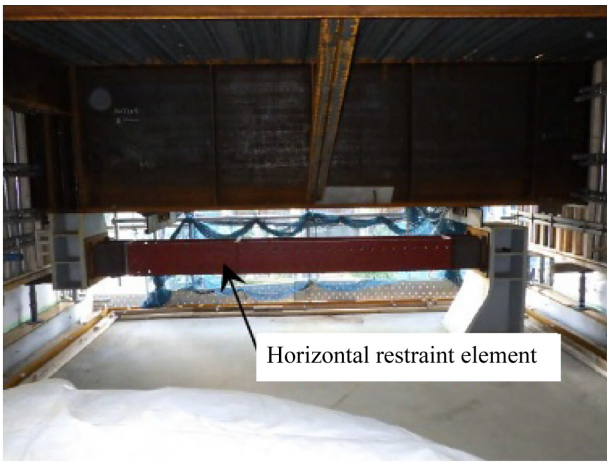


Figure 10. Situation of horizontal restraint.

7. Conclusion

This building was designed as the complex facility with commercial and office uses in the lower to middle floors and residential uses in the upper floors, which is not so common. By adopting a structural system in which the lower floors are steel-frame and the upper floors are RC, and by adding a seismic isolation layer on the middle floors, we determined that we could create a building with a high level of safety and functionality. This report is introducing only about the design and construction plan, but we would like to make efforts to accumulate experiences so that this project can be a good example of the building type that can meet with various needs.

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