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# Outline of Structural Design for Kyoto City Hall

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## *Abstract*

Kyoto City Hall is a historic building completed in 1931. The building is not designated as a cultural property (the Japanese government designation for protected/listed buildings), but it’s design was supervised by the famous architect Goichi Takeda. It has significant cultural value and a neat, symmetric building envelope. The façade decoration borrows elements from Islamic architecture.

In the context of recent significant earthquakes in Japan, the seismic resistance of the old city hall, including the main hall, was deemed to be insufficient. Additionally, the city hall sought to expand the usable area. For this reason, a new government building was needed.

It was necessary to solve these issues for the new City Hall. The Main City Hall building, which is a historic landmark, will be maintained, and a new City Hall building will be built adjacent to it.
For this reason, the Main City Hall building will be retrofitted with seismic isolation devices. The new construction will also use seismic isolation. Furthermore, because the site is too small, these old and new buildings have been improved as an integrated seismic isolation structure.
This is the biggest feature of this project (See Fig.1 and Fig.2).

The seismic isolation of the historic building and the newly build are planned to be connected at level B1.
From this seismic isolation level, , two new and old buildings are built like twin towers.
Buildings that integrate historic and new buildings on such a large scale are unparalleled in the world.

Because of this plan, there were many issues to be solved in the design.
The façade design takes care not to damage the landscape (of significant cultural value).
In structural design, the balance between new and old stiffness is an issue.
Because of the seismic isolation structure that integrates both buildings at the B1 level, it was necessary to determine what balance of stiffness to design to. The historic building has extremely high rigidity, whilst the new buildings will have low rigidity, making balance difficult.
As a solution to these problems, the authors explain the design method considering the landscape of the historic building, and the design method of the integrated seismic isolation system.

Fig.1 –Building exterior perspective

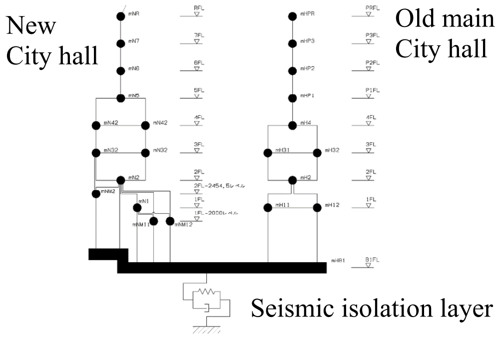



Fig.2 –Structural analysis model conceptual diagram

*Keywords: Historical Building, Heritage Building, Seismic Retrofit, Integrated Seismic Isolation Structure, Twin Tower*

## 1. Introduction

The Kyoto City Government Building is a historic building completed in 1931, currently remaining in active use. It is an important architectural and cultural heritage site and a pride of the local region. However, there are problems with such old buildings, such as lack of earthquake resistance, poor performance and low service levels. Additionally, the building managers bemoaned a lack of office space, having to rent a nearby building to make up for the shortage. This project solves these issues by retrofitting the existing building with a seismic isolation system and constructing a new building. The architects involved in the design are Kyoto City and Nikken Sekkei. The contractor in charge of construction (including that of the main government building) is Taisei J.V., whilst the contractor of the branch government building is Shimizu J.V. At the time of writing, construction is still underway.

## 2. Outline of architectural design

The new government building is divided into two areas by a road. There are two sites: the main government building site, and the branch office site. The plan to renovate the existing Government Building by seismic isolation retrofit, dismantle and replace the existing West and North Government Buildings, and integrate these buildings, is limited in scope to the "Main Government Building Site". The Branch Government Building site is planned as a new structurally independent seismic isolation building. Additionally, a skybridge has been included to connect the third floor of the Main Government Building and the fourth floor of the Branch Government Building. This paper mainly describes the design of the "Main Government Building Site", including the seismic isolation retrofit. Figures 3 and 4 show a perspective view of the building, and Figure 5 shows an overview of the project.

Fig. 3 –Perspective (view from the south)

Fig. 4 –Perspective (view from the northeast)



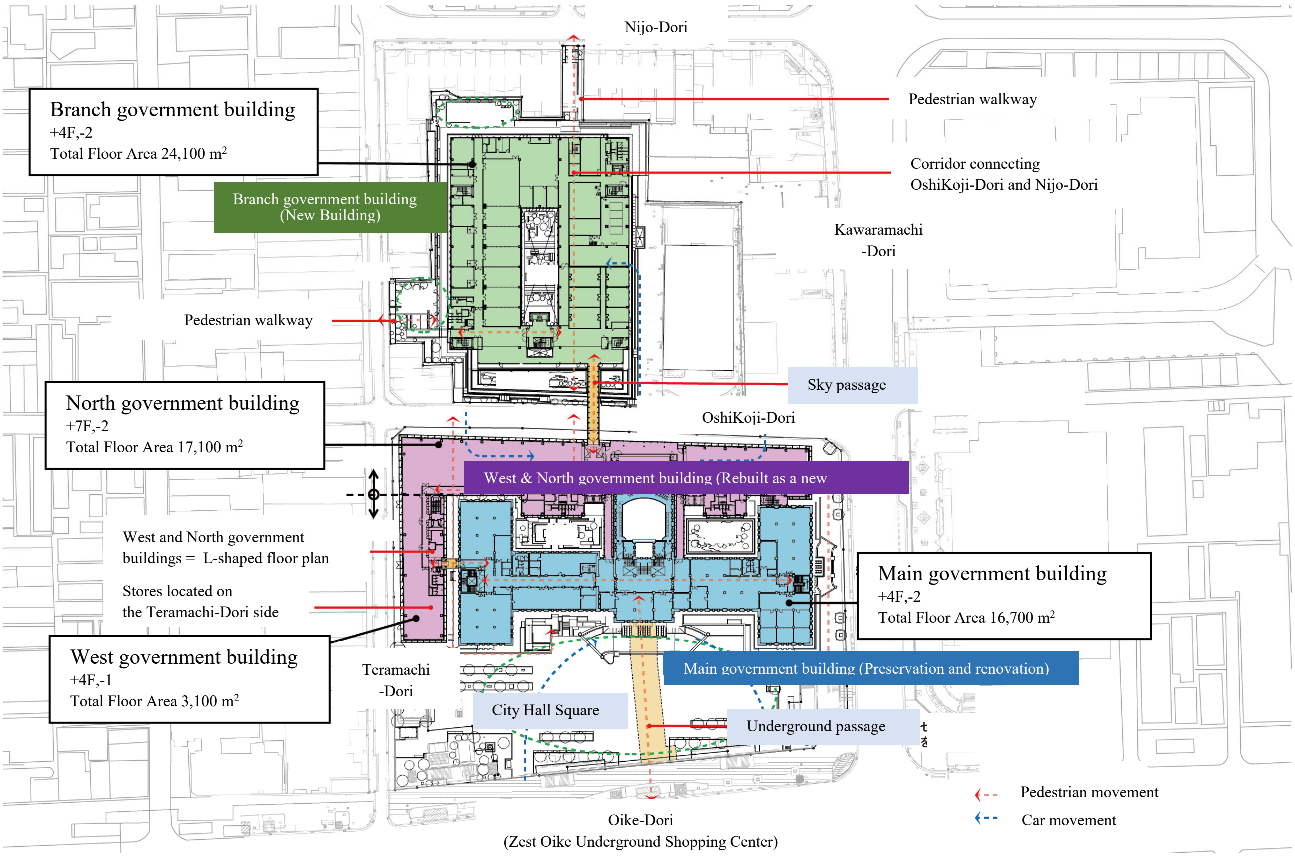



Fig.5 –Masterplan of Kyoto City New Government Buildings

## 3. Outline of structural design

For the main government building site area, the existing main government building will be retrofitted with a seismic isolation system, and the West and North government buildings will be constructed anew. All buildings on this site will be integrated together. This is because the necessary expansion joints are long and expensive when considering a structurally independent solution. Furthermore, in the case of independent seismic isolation buildings, it was thought that the land area could not be used effectively because space for the isolation of each building was required. The newly constructed West & North government buildings are therefore structurally connected with the main building, and have a L-shaped plan. However, in order to provide temporary use of a part of the west side in advance, this part is conveniently referred to as the "West government building". The later construction section is called "North Government Building". The structural design of each building is described below. Figure 6 shows an outline of the structural design.



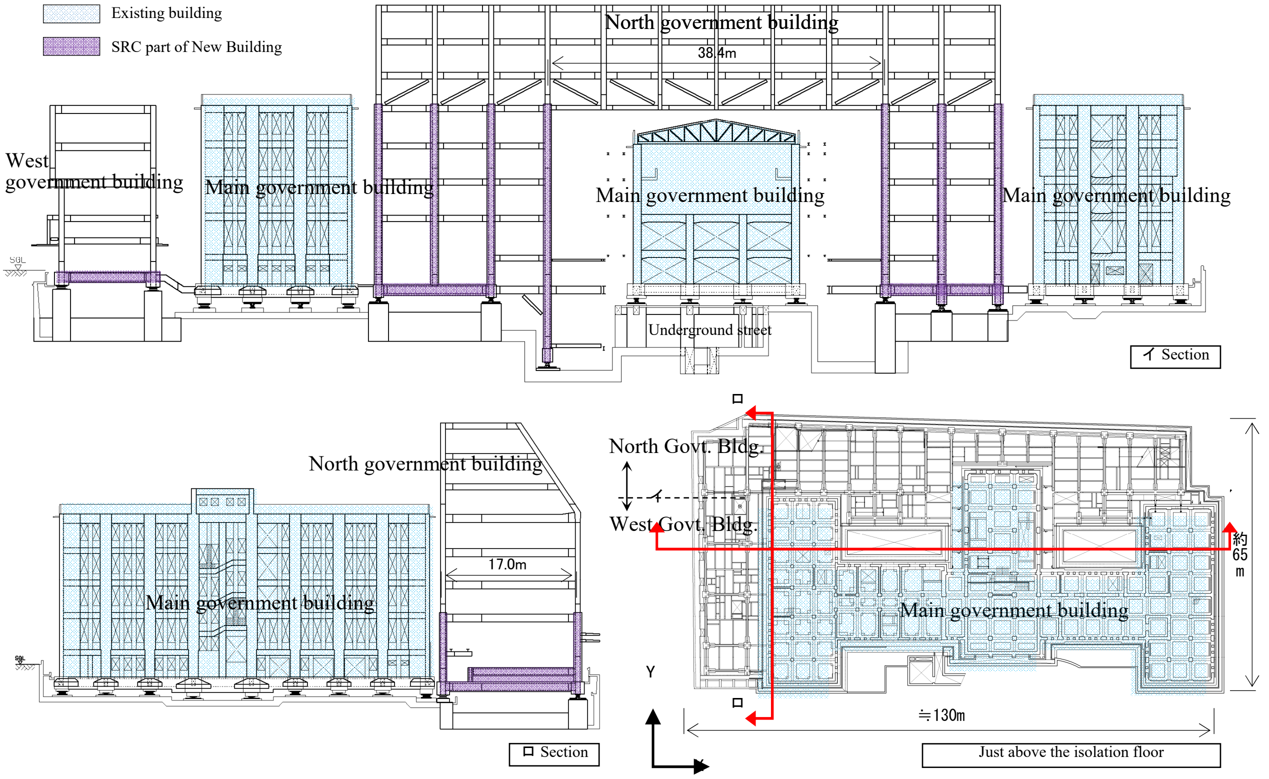



Fig.6 – Outline of structural plan

## 3.1 Main government building

(1) Superstructure

The seismic resistance of the government building was estimated to satisfy seismic regulations at the time of construction. That is to say, the design actions were within the current allowable stress when considering a horizontal seismic coefficient of 0.2. The seismic response value at stage 2 design (ultimate limit verification) was designed so that the base shear coefficient was less than 0.1, so that the horizontal seismic coefficient on the top floor was about 0.2. It was judged that the current allowable stress design could be performed. Figure 7 shows the results of pushover analysis of the main building. Bending yield occurs close to the shear force coefficient (exceeding 0.2), confirming that the estimation was correct. In addition, two "shear failure" points are shown (points ① and ② on Figure 7). However, in the case of ①, since the main structure did not suffer any collapse mechanisms, the timing of ② was judged to be the ultimate lateral capacity for shear failure.

By adopting a seismic isolation scheme, Nikken Sekkei aimed to avoid making the superstructure stiffer. Moreover, per request of the architect/client, it was necessary to remove some earthquake-resistant walls and to construct new ones. There were also a few other notable improvements. By renovating existing girders and other techniques, a new large space has been created in the central hall, a new passage has been created from the newly constructed underground passage, and the historic buildings have been granted new charm.



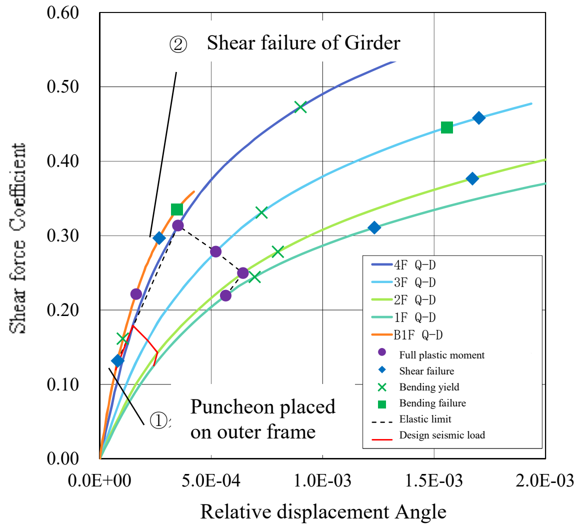



Fig.7 – Pushover analysis of Main Government Bldg.（X-Direction）

(2) Structure of Seismic isolation layer

The retrofitting is based on the base seismic isolation method, in which the floor beams on level B1 are reinforced and a seismic isolation layer is provided underneath. The construction procedure of the seismic isolation retrofit is slightly different between the "Existing phase 1 construction" – where the foundation footing is located below the existing foundation girders – and the "Existing phase 2 construction", where the footing is located at almost the same level as the existing foundation beam. However, in all cases, a method was adopted in which a temporary steel pipe pile was pressed in with a jack using the weight of the upper building as a reaction force. Figure 8 shows an outline of the seismic isolation retrofit construction procedure.

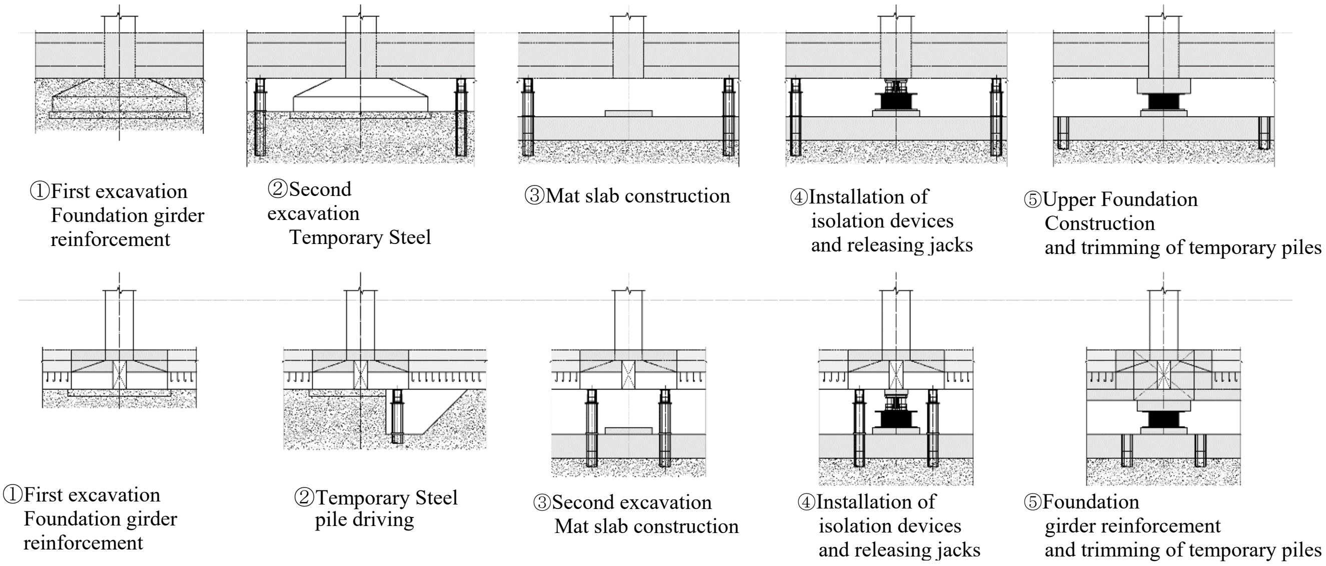



Fig.8 – Construction procedure (Upper: Original phase 1, Lower: Original phase 2)



### 3.2 West and north government buildings

The west and north government buildings were planned to be primarily steel structures (partly SRC). The lower floor pillars including the pillars of the lower floor of the North Government building, mainly the lower two floors, are made of SRC, whilst the others are made of steel. The main cross-sections are cold-formed steel pipes 600 mm square, circular steel pipes with a diameter φ of 600 mm (inclined columns), and girders 700-1000 mm in depth. The cross section of the SRC column sections is 900 cm square, whilst the height of the girders is 1200 mm (the height of the internal steel frame is 900 mm). The seismic isolation layer will be installed at the capital of the second basement floor. Floor level B1 of the main, west and north government buildings will have an integrated structure. In order to secure a large floor area, the north government building has a large area that straddles over the upper part of the hall of the main government building. For this part, a large span of 38.4 m has been realized by a truss frame structure. It also features a frame with a slanted northern column to avoid height restrictions.

### 3.3 Design of Seismic isolation

The seismic isolation devices used in the seismic isolation plan are as follows. (See Figure 9)
・Natural rubber isolator (φ=900 mm)
・Lead rubber bearing isolator (φ=900 mm)
・Elastic Sliding device
・Uniaxial Roller device
The stable performance of the linear motion uniaxial roller device was evaluated and used frequently. On the other hand, since the uniaxial roller has a high device height, an elastic sliding device with low device height is used in certain areas. The primary natural period of the seismic isolation layer is 5.77 seconds for the isolators only, and 4.36 seconds for the equivalent period at Stage 2 design. The ratio of the damper strength to the upper structure mass is about 2.9%. The main and west government buildings will temporarily become a single seismic isolation structure during construction, until the construction is complete. In other words, during construction the seismic isolation members are planned to work for each individual building too.



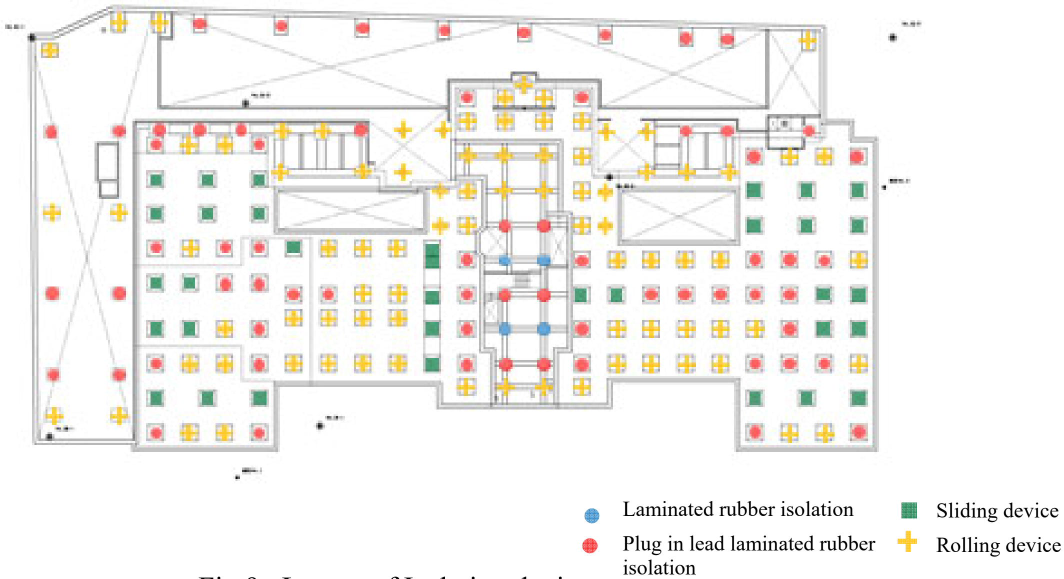



Fig.9 –Layout of Isolation device

## 3.4 Foundation structure

The foundation structure is a reinforced concrete spread footing foundation. The site has a high groundwater level, normally around GL-4.5m. For this reason, the lowest foundation level of the government building was planned to be shallower than the groundwater level. The main government building area has a 700 mm thick mat slab type foundation. Immediately below the seismic isolation supports, a 2.5 m square "capital" is installed to increase the thickness. The supporting plate thickness is 200 to 500 mm. In addition, a connection to the underground mall on the south side of the site is planned from the central basement of the building. The west and north government buildings were solid foundations with foundation beams and pressure-resistant mat slab. For the works below the groundwater level, drainage works by deep well recharge wells have been planned. Figure 10 shows the model of the substructure used for the FEM analysis.

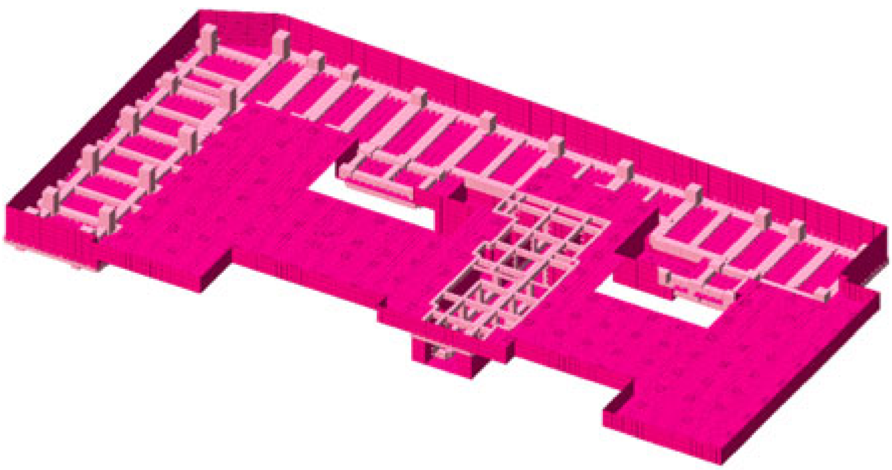


Fig.10 –FEM model of structure below the isolation devices



# 4 Structural design criteria

## 4.1 Structural design criteria for seismic loads

As a disaster prevention base facility, criteria were set with the goal of maintaining the function of the building even during an ultimate limit (2nd stage design) rare earthquake. Table 1 shows the design criteria for the seismic loads. To satisfy the superstructure criterion, the beams and columns were designed to remain within the elastic limit strength and the wall was within the short-term allowable stress. Here, the elastic limit strength is defined as the point in time when a plastic hinge is first formed on a member or a point in time when shear fracture occurs. It is indicated by a dashed line in Figure 7. At that time, round steel was used for the reinforcing steel, and the adhesive stress exceeded the short-term allowable stress for a Stage 1 design seismic load on some girders. However, the member stress was within the bending crack moments. It was confirmed that no harmful damage occurred, and it was judged that the condition of the building during such an event was within criteria. In addition, outer studs are included in the frame rigidity and the lateral strength, but have a strong decorative pillar character. These are members that do not collapse even if they lose the horizontal resistance and the vertical support ability, and are regarded as non-structural members.

Table 1 – Criteria of Seismic design

| Assumed seismic ground motion | | Stage 1 Design (Elastic Limit Verification)<br>Medium- or small-scale earthquake | Stage 2 Design (Ultimate Limit Verification)<br>Large earthquake |
|---|---|---|---|
| Upper structure | | Maximum story deformation angle<br>・1/750 rad or less (Main)<br>・1/300 rad or less (West・North)<br>・1/400 rad or less (Branch)<br>Stress of structural members<br>・Equal to or lower than allowable stress for temporary loading<br>・Equal to or lower than bearing capacity<br>(Main／Puncheon placed on outer flame) | Maximum story deformation angle<br>・1/500 rad or less (Main)<br>・1/200 rad or less (West・North)<br>・1/200 rad or less (Branch)<br>Stress of structural members<br>・Main Govt. Bldg.<br>Column & Girder：Equal to or lower than Elastic limit<br>Wall ：Equal to or lower than allowable stress for temporary loading<br>Puncheon：Equal to or lower than bearing capacity<br>・West・North・Branch Govt. Bldg.<br>Equal to or lower than allowable stress for temporary loading |
| Isolation devices | Shear strain | Equal to or lower than Performance Guaranteed deformation<br>Max shear strain 250% or less (450 mm or less) | |
| | Contact pressure * | 2 times or less of Standard surface pressures & Standard loads | |
| | Pulling force * | Does not occur | Laminate rubber isolation<br>・Equal to or lower than allowable pulling force<br>(Pulling pressure 1 N/mm²or less)<br>Rolling device<br>・Equal to or lower than Limit capacity for pulling |
| | Device performance variation | — | Considered |
| Clearance for seismic isolation | | Horizontal direction<br>・700 mm (Main・West・North buildings)<br>・650 mm (Branch building)<br>Vertical direction<br>・50 mm | |
| Structure below isolation device | | Stress of structural members<br>・Equal to or lower than allowable stress for temporary loading | |

* When examining contact pressure and pulling force, 45° & 135° direction loads were considered、35% change in weight



# 5 Outline of time history response analysis

## 5.1 Analysis model

The time history response analysis model was a 24-mass equivalent shear model in which the vibration degrees of freedom were set at the representative nodes of each rigid floor. Figure 11 shows the analysis model diagram. Of the total lumped mass points, 10 masses represent the upper structure of the main government building, 13 masses represent the upper structure of the west and north government buildings, and the remaining mass represents the floor immediately above the seismic isolation layer (where the two buildings are integrated). Each rigid floor includes two degrees of freedom for translation and one [-1]degree of freedom for torsion. For the shear spring of the upper structure of this government building, the moment frames and walls were modeled separately. The hysteresis rule was evaluated using a Takeda model for the moment frames and a tri-linear type oriented to the origin for the walls. The west and north government buildings were modeled with linear behavior and initial rigidity. The western and northern government buildings have particularly rigid floors and stairwells. Furthermore, the bridge-like passage connecting the rigid floors was modeled as an axial spring and a bending-shear spring. The seismic isolation layer was replaced with a linear or bi-linear shear spring for each seismic isolation device, and modeled at each respective position.

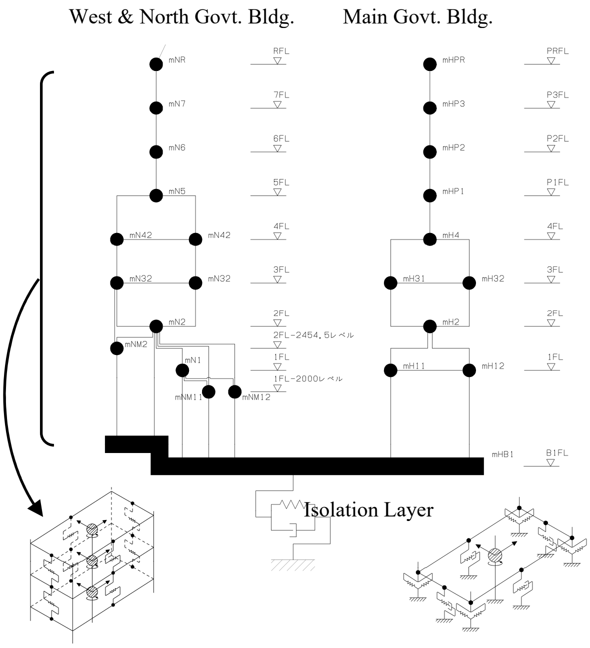



Fig.11– Analysis Model for Time history analysis



## 5.2 Input ground motions for design

Table 2 shows a list of input ground motions for design. Figure 12 shows the pseudo velocity response spectra of the Stage 2 design ground motion. Site waves were adopted for two different types of epicenters. One is an earthquake caused by the Hanaore fault near the site. For the Hanaore Fault earthquake, the authors decided to use the waves created by Kyoto City as damage assumptions[1],[2]. The Nankai Trough Earthquake uses the design simulation ground motion generation method developed by Nikken Sekkei[3]. The Nankai Trough earthquake was a small ground motion with a long distance from the epicenter to the site.

## 5 .3 Time history response analysis result

Figures 13 (a) to 13 (c) show the time history response analysis results. The maximum response of the government building is 0.11 in base shear coefficient, which is in line with the original design policy. On the other hand, the maximum response of the west and north government buildings, especially in the Y direction where the frame rigidity is low, has a base shear coefficient of 0.19, which is larger than that of a general seismic isolation building. As a property of a twin tower-like buildings integrated with a seismic isolation layer like this case, the response of the seismic isolation layer during an earthquake is dominated by the effect of the heavier buildings. Regarding this case, the upper structural mass ratio of the main government building and each of the west and north government buildings is about 3: 1, and the influence of the main government building is therefore dominant. As a result, it is not possible to achieve efficient seismic isolation at the West and North Government Buildings as compared to the case of a single seismic isolation building.

Table 2 – Assumed seismic ground motion for design

| Assumed seismic ground motion | Level1 | | Level2 | |
|---|---|---|---|---|
| Maximum value of ground motion | Acceleration ($mm/sec^2$) | Velocity (mm/sec) | Acceleration ($mm/sec^2$) | Velocity (mm/sec) |
| Simulated motion (Hachinohe) | 713 | 105 | 3563 | 523 |
| Simulated motion (Tohoku Univ.) | 586 | 106 | 2930 | 529 |
| Simulated motion (Kobe) | 762 | 109 | 3812 | 546 |
| EL CENTRO NS | 2555 | 250 | 5110 | 500 |
| TAFT EW | 2485 | 250 | 4970K Obe | 500 |
| HACHINOHE EW | 1195 | 250 | 2390 | 500 |
| Kyoto Hanaore Fault NS | — | — | 4002 | 290 |
| Kyoto Hanaore Fault EW | — | — | 8978 | 642 |
| Nankai Trough 1 | — | — | 3359 | 271 |
| Nankai Trough 2 | — | — | 3228 | 261 |
| Nankai Trough 3 | — | — | 3292 | 344 |

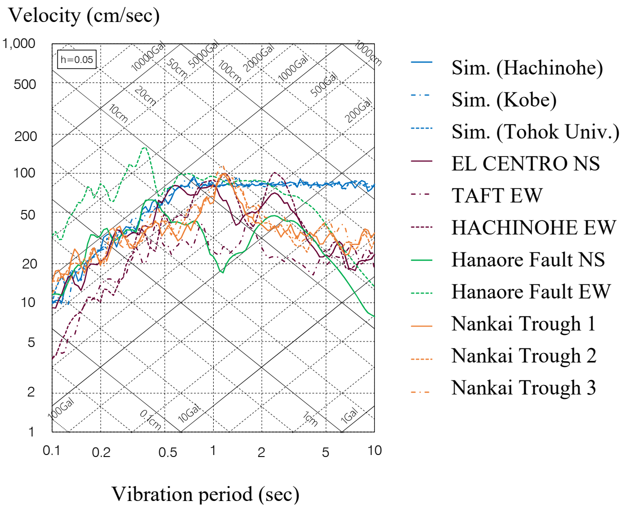
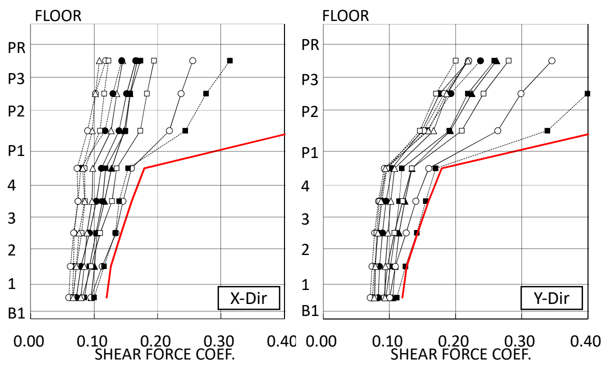


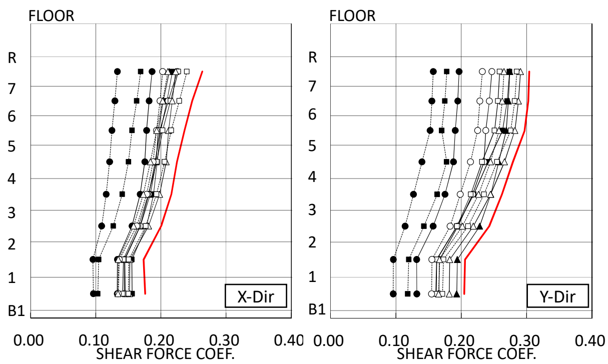

Fig.12–response spectrum / Level2 (h=0.05)



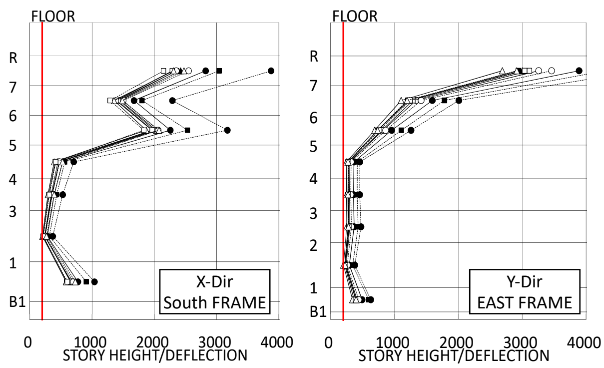
 




(a) Main Govt.bidg. / Maximum shear force coefficient




(b) West & North Govt. Bldg. / Maximum shear force coefficient




(c) West & North Govt. Bldg. / Reciprocal of Maximum story deformation angle of outer Flame

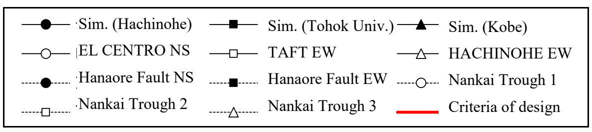



Fig.13– Result of timehistory analysis



## 6. Conclusion

This paper has described the design of a large-scale building with unprecedented seismic isolation retrofitting and new construction.
The main government building benefits from seismic isolation renovation, whilst the West & North government buildings are newly built and also include a seismic isolation system integrated into the main building.
In particular, in the seismic isolation design, a long-period seismic isolation design was used to reduce the reinforcement of the Main government building, which is a historic building, and the new and old buildings were designed to be well-balanced while taking into account the effect on the northwestern government building.
In addition, the main building removes the girders and provides a large atrium space to add new charm to the historic building.
We hope that our experience will be helpful in designing similar buildings.

## 7. References

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