EARTHQUAKE DISASTER PREVENTION AND REQUIRED PERFORMANCE OF RAILWAY FACILITIES IN JAPAN

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Abstract

Railways have an important role as a social infrastructure. In Japan, structures of railway facilities have the performance not to collapse at the time of maximum considered earthquake. However, structures are deformed and they are permitted to partly plasticize in some cases due to earthquake ground motion. On the other hand, the system that detects the occurrence of an earthquake as soon as possible and stops the running train is adopted. It is safe to ensure that these function effectively.

In recent years, railways are not only transportation system but also rapidly expanding functions as living infrastructures, such as combined use and information bases of stations. In addition, stations are also important in responding to people having trouble of returning home just after a disaster happens. As seen in the Great East Japan Earthquake, after a large-scale disaster, since trains do not operate as usual at least temporarily, a large number of people stagnate around the station. And stations are being set up where it is possible to stay until the stagnant people move to temporary stay facilities. Large-scale terminal stations itself must have functions as temporary stay facilities that accept people as disaster prevention centers in the surrounding area. Therefore, railway facilities must be planned based not only on the safety at the time of disasters, but also on the subsequent availability.

Here, examples of securing seismic performance with continuous use as railway facilities for a high-rise building and a historic building are introduced.

Introduction

In recent years, railways are not only having role as a social infrastructures but also rapidly expanding functions as living infrastructures, such as combined use and information bases of stations in Japan. Especially in the metropolitan area development demand is high at railway stations and their vicinity with high potential. While preparing for Nankai Trough Earthquake and Tokyo Metropolitan Earthquake is an urgent task, safety measures corresponding to versatile use must be promoted in parallel at stations where functions are accumulated. In addition, continuity of the urban function after disasters is required together with safety of facilities at the time of earthquakes.

In order to ensure safety of trains and passengers at the time of earthquakes, continuous efforts have been made to control train operations quickly (intangible measures), strengthen the seismic performance of the structures (tangible measures), and maintain functions after disasters.

Measures for emergency stop of trains

In Japan, safety of railway is assured by stopping trains promptly at the time of major earthquake. Figure 1 shows outline of earthquake detection system. Seismometers installed along railway tracks capture motion of ground. Based on the data, it is judged whether or not to stop or decelerate trains. This is called “judgment of operation restriction”. Among them, there is a method of performing operation restriction on trains within a certain section when the earthquake ground motion exceeds a predetermined threshold value. This is called "judgment method using earthquake motion index value". For high-speed trains like Shinkansen, it is necessary to make a decision to stop trains faster. And the system that detects primary wave (P-wave) arriving before principal motion (S-wave) of earthquake has been adopted. This is called "judgment method using presumed earthquake characteristics". As shown in Figure 2, earthquake specifications (epicenter, magnitude) are estimated from data of observed P-waves for several seconds, and warnings are output toward the predicted influence range. For Shinkansen, seismometers are installed at 135 locations along railway lines, coast and inland as shown in Figure 3.

On the other hand, it is also important to shorten the stopping distance of trains. The system which trains stop by stopping power transmission to catenary wire when rail line seismometers detect an earthquake has been adopted for Shinkansen. Conventionally, ATC (Automatic Train Control) devices on trains detected stopping power transmission to catenary wires and operated emergency brake, but power failure detection devices are newly provided. As a result, the time required for operation of emergency brake is shortened by about 1 second.

Cooperation with observation networks other than railway has also been strengthened in order to speed up and improve reliability for detection of earthquakes. Method to utilize the JMA (Japan Metrological Agency) 's earthquake early warning information in parallel is introduced, and studies are also begun on methods of utilizing ocean bottom seismometers and underground seismometers information.

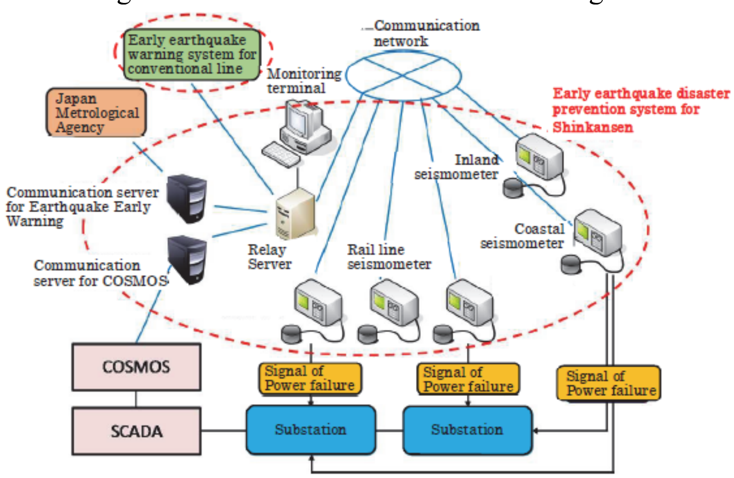


Figure 1 Earthquake detection system

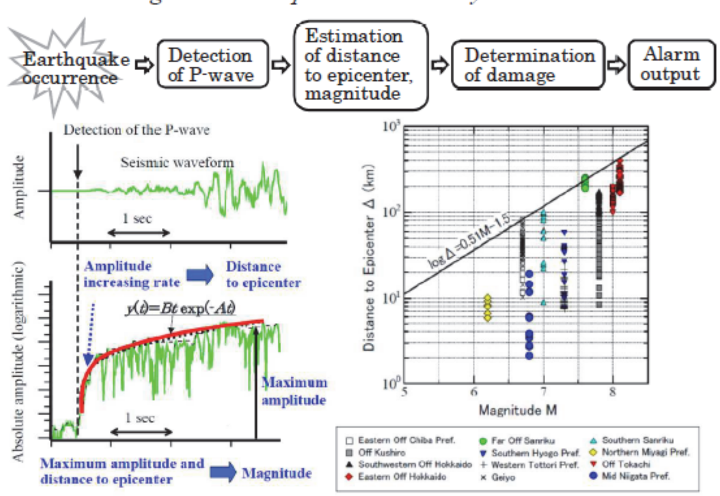


Figure 2 Processing flow of Primary wave alarm [1]

Figure 3 Installation of seismometers [2]

Seismic resistance standard

Over-track buildings are structurally different from ordinary buildings such as high floor height of railway floor, large span and column to pile connection with no footing beam (Figure 4). On the other hand, the function as a shelter that covers the space where trains run is required on railway floor. Even at the time of a major earthquake, railway floor should not be damaged as much as affecting the operation of trains. Therefore, the structure must have great strength and adequate tenacity. Basically, it is desirable that floors of upper layer yield prior to railway floor for absorbing energy. If this can not be satisfied, strength of the railway floor is increased to ensure safety. By combining with the structural features that there are no footing beams, the target performance is set as shown in Table 1.

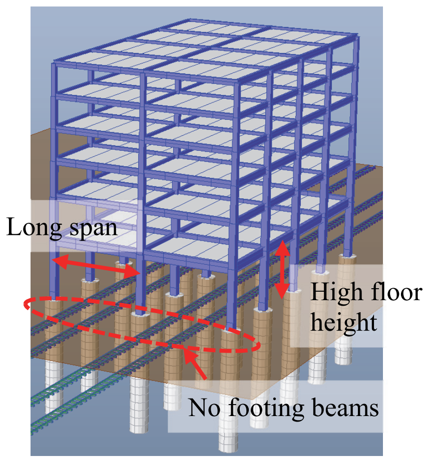


Figure 4 Structural characteristic of over-track buildings

Table 1 Structural characteristic coefficient of each layer in over-track buildings (Value of Ds') 3)

Layer yield order	target floor	Direction without footing beam	Direction with footing beam
Upper floor first	upper	Ds+0.10	Ds+0.10
	railway	1.25(Ds+0.05)	1.25･Ds
Railway floor first	upper	Ds	Ds
	railway	1.5(Ds+0.05)	1.5･Ds

Ds：Value determined by each constituting member

Qun＝Ds'･Fes･Qi

Qun：Necessary ultimate horizontal strength

Fes： Shape characteristic coefficient of each layer

Qi ： Seismic shear force

Planning of high-rise building at terminal station

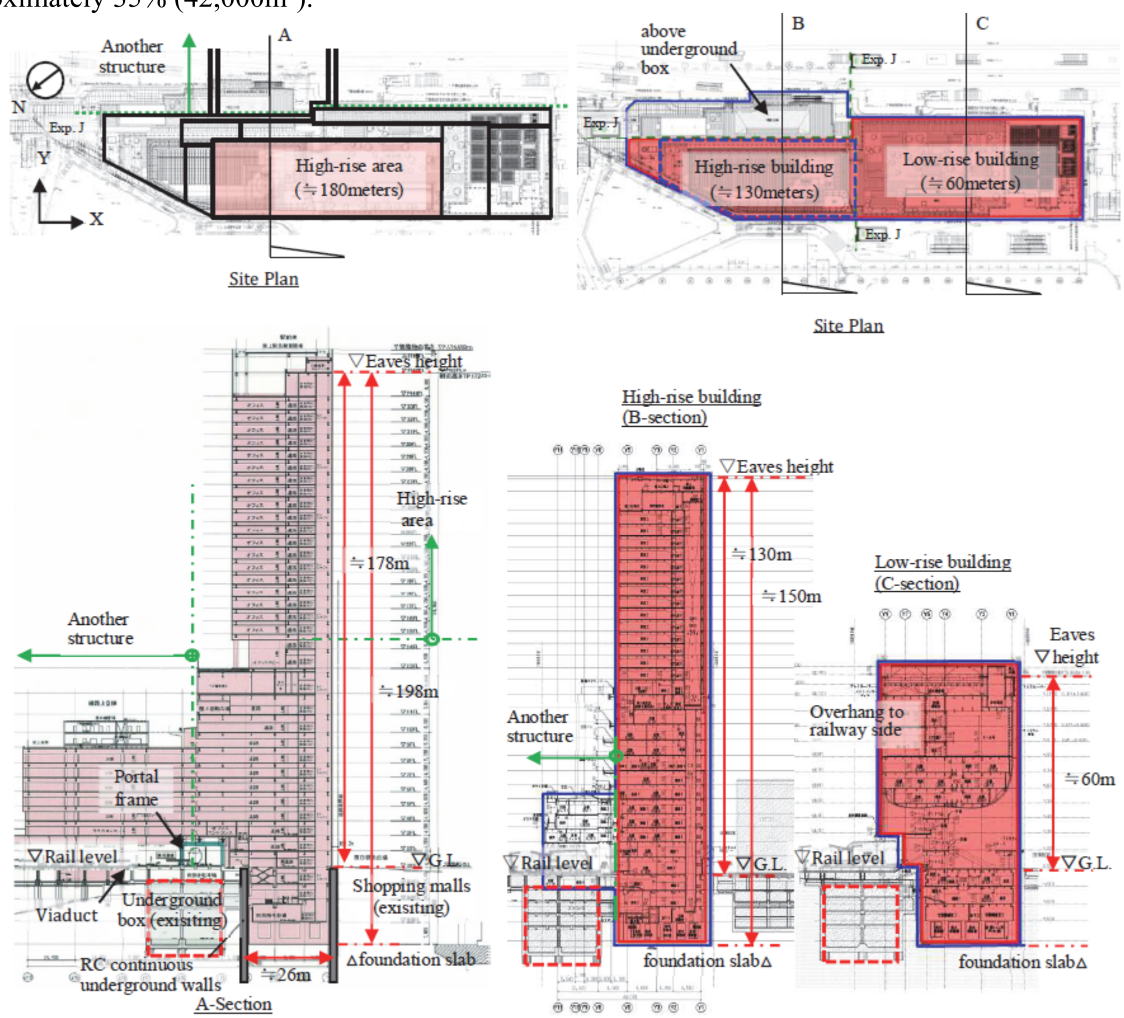
Based on the experiences of the Great East Japan Earthquake, an example will be introduced that reviewed the plan aimed at strengthening earthquake countermeasures.

Outline of the plan is shown in Figure 5. Initially, several new buildings were scheduled to be built at the station and the surrounding area. Among them, a high-rise building with a height of 180 meters and 33 floors was planned in front of the station. However, width of the building in span direction was narrow, and the aspect ratio was large. In the basement part, there are existing underground shopping malls and box for railways on both sides of the building, and width is also narrow. At the same time, it is necessary to consider at least above the two basement levels are not embedded in the ground. Furthermore, there are large cantilever structures to railway side, which is eccentric in weight. Groundwater level is also high, so the building is under uplift at the time of large earthquake. Therefore, RC continuous underground walls installed to the depth of 27 meters from the foundation base were planned to resist large pull-out force.

On the other hand, it was not completely separated from the adjacent underground box. The box supports a part of the cantilever structures of the high-rise building by roller bearings. For the calculation, reaction force was transmitted only in the vertical direction. This box was designed assuming the extension of a building afterwards, but the assumption was to build on just above the box. This plan was quite different from the initial design conditions. In calculation, it was possible to keep the stress of the box at the time of extension within the range of existing design reserve. However, considering this building shape, it was obvious that in the case when preconditions in calculation are gone a little, larger load was applied to the box located on railway side. It was assumed that the rigidity of continuous underground walls and soils are also uncertain. From the above, it was difficult to satisfy the performance required for the railway facilities, and the plan was reviewed. The part above the underground box was structurally completely separated from the high-rise building, and it was planned to be consistent with the assumption of the original design. The area where the overhang to railway side remains unavoidably is also structurally separated and its height is limited to 60 meters. Target performance is assumed to be equivalent to over-track buildings. As a result, the weight eccentricity of the high-rise building became small. By reducing the height to about 130 meters and 26 floors, the aspect ratio also became 6 or less.

An example of the result of examination of the high-rise building after reviewing the plan is shown in Figure 6, 7. These are time history response analysis results by lumped mass system model. It shows there is sufficient safety at the time of large earthquakes. Although the shape was improved, the building is still under uplift by large seismic force in span direction. But the stretched piles in circumference can resist pull-out force.

Overall, combined with other plan changes, the total floor area of the buildings was reduced by approximately 35% (42,000m^2).



(a) Initial (b) After change

Figure 5 Planning of a high-rise building

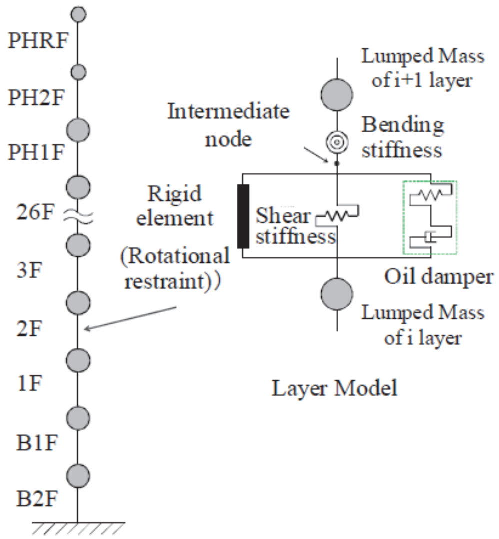


Figure 6 Analytical Model

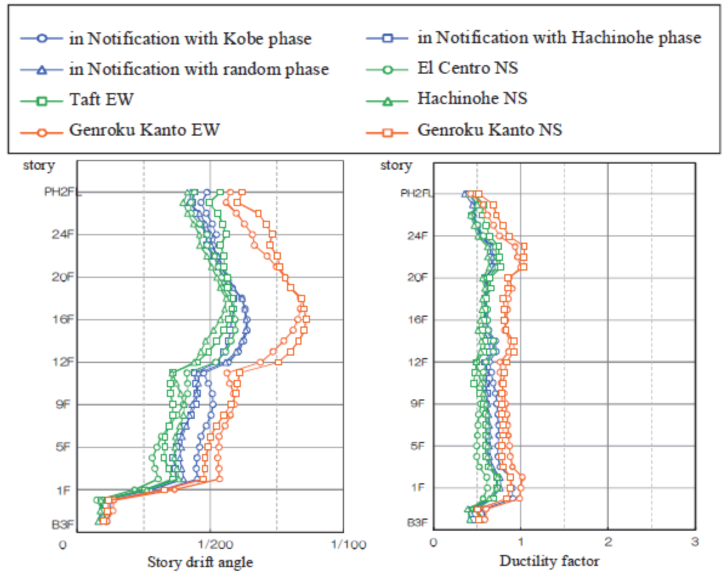


Figure 7 Seismic response (Level 2 earthquake)

In this plan, measures to keep the function of the building after disaster are also under consideration. After an earthquake, the station confirmed to be safe will be used as a temporary stay place. Restrooms and public phones will be released, and information such as earthquake disaster situation and driving situation will be provided (Figure 8). In addition, this is a plan at the terminal station that has more than 400,000 passengers a day on average, and support for people having trouble returning home is essential. Public spaces in the building will be released to stagnant people staying temporary or having trouble returning home, and emergency power supply and stockpiling of food are also included in this plan.

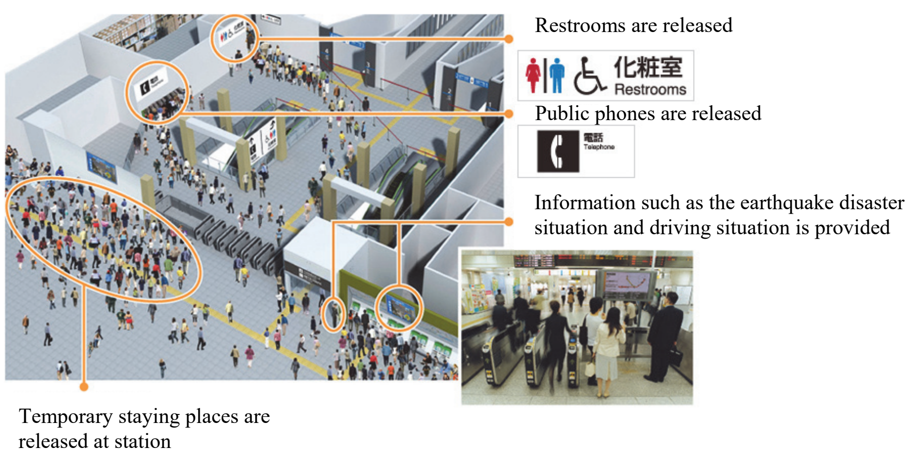


Figure 8 Image of temporary staying place in the station [2)]

Earthquake disaster prevention of a historic station building

Tokyo station Marunouchi building is designated as an important cultural property of the country by its cultural value (Figure 9). The roof and the inside were burnt down due to the air raid at the end of World War 2nd. It has been used for about 60 years as a form of emergency reconstruction, but a plan was made to reproduce the original appearance, leaving historic buildings in the future as far as possible. [4)]

Structural system of this building consists of brick walls containing steel members inside. The structural steel frames comprise the columns of I-section steel installed at 2-m intervals onto the foundation and the channel girders provided on both sides of each column. Structural bricks (thickness corresponding to 2and a halfbricks for exterior walls and to 2 bricks for interior walls) were piled up around the steel structural frames which had been erected in advance as shown in Figure 10.

Figure 9 Original Construction (1914)

To advance the plan, for the current demanded standard of seismic performance, it was necessary to reinforce existing brick walls by additional such as reinforced concrete wall with considerable quantity. To prevent the reduction of the architectural value of the original, therefore, isolation system was adopted, since it requires little additional structural reinforcement (Figure 11). It is also possible to improve the safety of the building by this system. This system was achieved by placing the existing upper structure on temporary supports (underpinning), adding an underground part by inversed placing method, and to install seismic isolators between the brick structure.

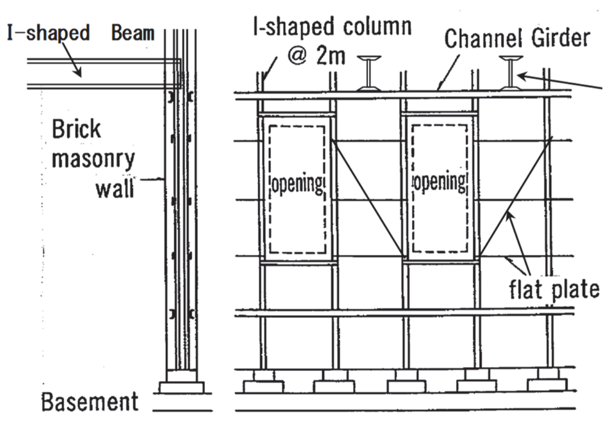


Figure10 Typical Steel Structure Frame

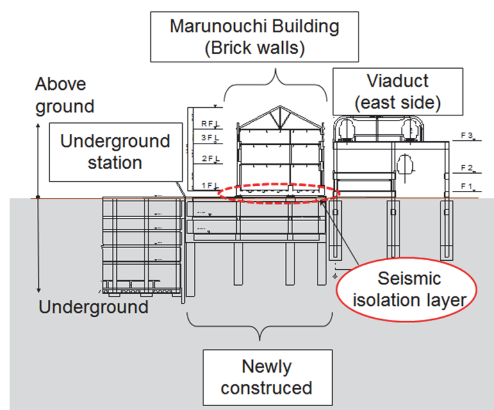


Figure 11 Location

In moderate earthquakes, cracks do not occur on the brick wall, and in the largest possible earthquake, cracks are allowed to occur on the brick walls, but the target earthquake resistance performance is set so that the building can be used without major repair.

As many as 352 seismic rubber isolators were installed between existing superstructure and newly constructed substructure. Total weight of the superstructure is about 700,000kN, and seismic isolation system used for such a huge building is largest in Japan. In order to avoid the crash of the building with the neighbouring viaduct, 158 oil dampers were used to enlarge the damping power so as to suppress lateral deformation at the time of earthquake (Figure 12). It is possible to hold the seismic isolation layer deformation to about 12 cm even at the time of large earthquake. In order to verify safety of this building, which has total length of 335m, special analysis, such as lateral torsional vibration and phase difference of seismic wave analysis were required in addition to normal analysis (Figure 13-15).

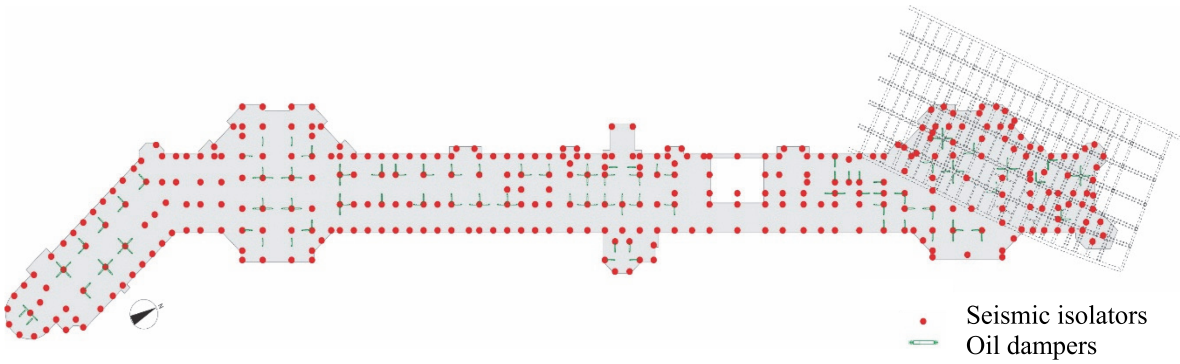


Figure 12 Layout of seismic isolation system

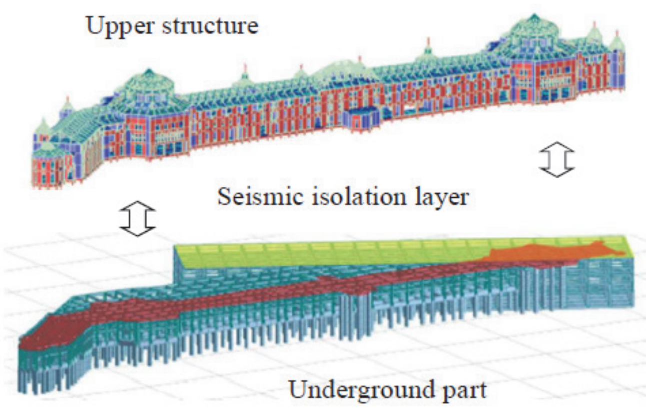


Figure 13 Structural model

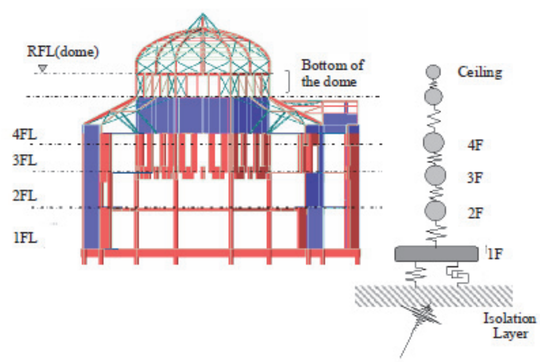


Figure 14 Lumped mass system model

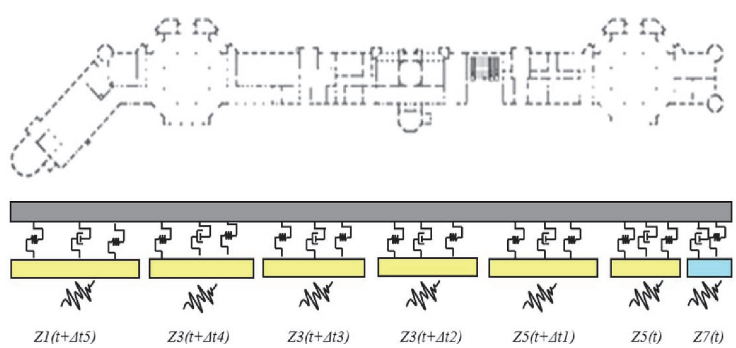


Figure 15 Model for lateral torsional vibration and phase difference of seismic wave analysis

It was very difficult to adopt isolation system without the temporary closedown of the passage to the underground station. The large staircase with three escalators made it hard to solve this problem more. Therefore the system which can go through this building without using seismic isolation floor at all times was devised. For this system, in the central part of the building, passing to the underground concourse was enabled, without encountered at the boundary. By using the multi-layered plates system, upper structure can be able to integrate structure without separating from the central part of the building (Figure 16).

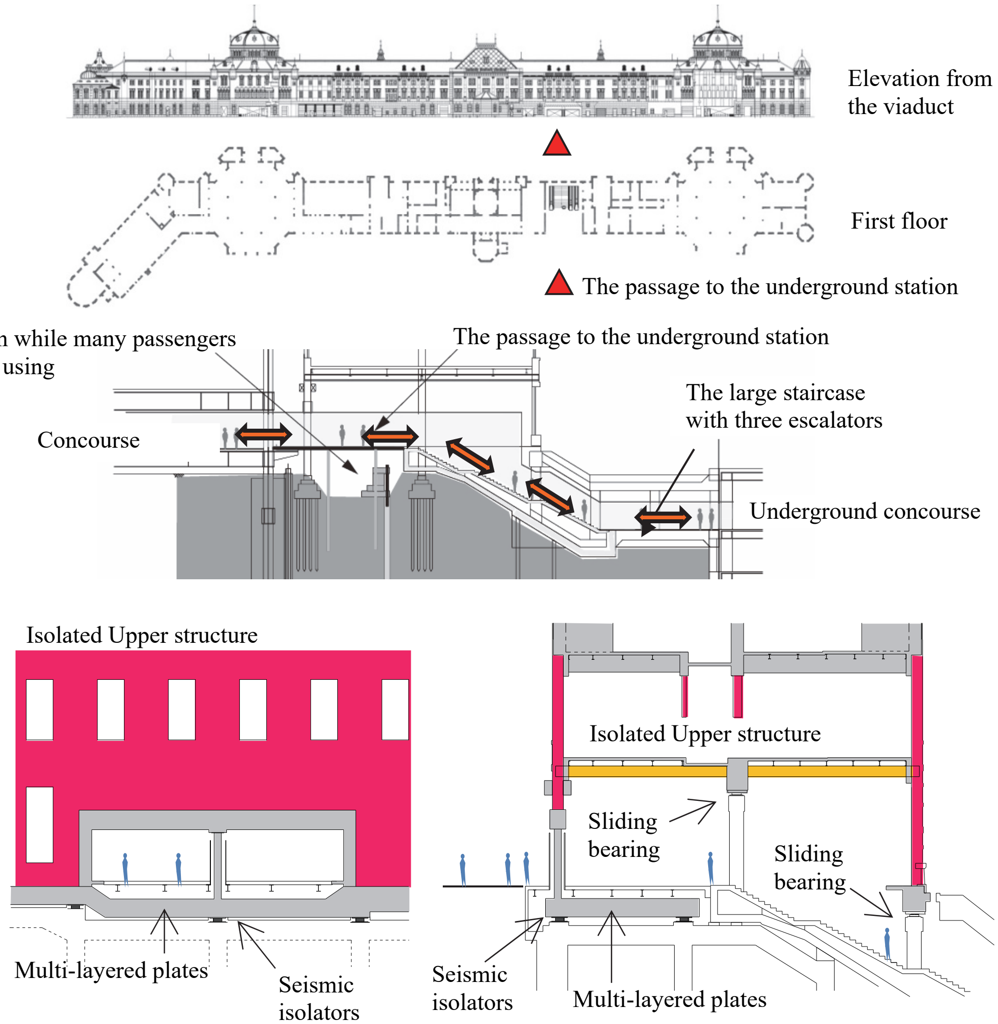


Figure 16 Solution of seismic isolation system for passenger traffic

Conclusion

In this paper, recent trends of earthquake countermeasures in buildings of railway facilities in Japan were mainly described. Natural disasters such as earthquakes can sometimes exceed the level assumed in advance. It is very important to incorporate specific requirements regarding safety and restorability in the design conditions as much as possible with this in mind. Although the examples introduced here are the results considered as optimal under the respective conditions, it is desirable to observe these processes and develop more rational methods through further technical innovation.

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