Seismic Isolation Retrofit for Major Tall Building

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ABSTRACT :

The main building of the Aichi Prefectural Government, designated as a national registered cultural asset, and is also an important facility as a disaster prevention base in case of a disaster. Investigations and diagnoses conducted until 2002 revealed that the main building was lacking in seismic performance. In selecting a seismic retrofit method, it is necessary to analyze the characteristics of the main building, including its functions and value as a cultural asset, and carefully compare and examine methods. However, there has been no report about in-depth comparisons and examination of seismic retrofit methods. Additionally, the main building is located in a district requiring measures for disaster prevention in the giant Tokai and Tonankai Earthquakes that are said to occur in the near future. Although these giant earthquakes are expected to produce long-continued earthquake motions with amplified earthquake motion long-period components and cause damage to buildings of long-period structures, such as skyscrapers and base-isolated buildings, much consideration has not been given to this issue.
In 2003, we selected seismic retrofit as the optimum work method in consequence of scrutiny of the main building's characteristics and careful and objective comparisons and examination of methods in cooperation with academic experts. In 2004, we and experts jointly examined the main building using simulated earthquake motions created from the latest knowledge and data, which makes the main building a highly earthquake-resisting structure. This paper is a report of what we examined and designed in cooperation with these academic experts.

KEYWORDS: Seismic retrofit, Cultural assets, Base isolation, Simulated earthquake motion

1. SUMMARY OF THE MAIN BUILDING

Location: Within site at 3-chome, Sannomaru, Naka-ku, Nagoya; application: government facility; date of completion: March 1938; building area: 4,666 m^2; total floor area: 28,314 m^2; number of floors: 6 floors, 1 basement, 1 penthouse; eaves height: approx. 26 m; structure: steel encased reinforcement concrete & spread foundation; original design: Maintenance Section, Aichi Prefecture; original contractor: Toda-Gumi Co., Ltd.

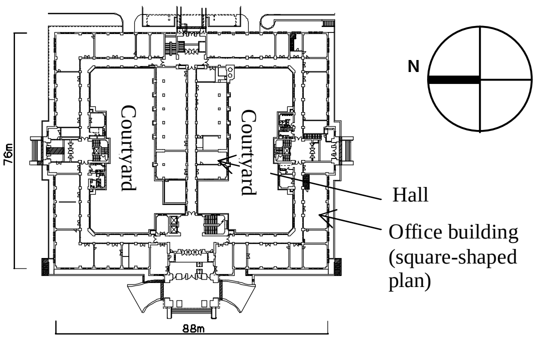


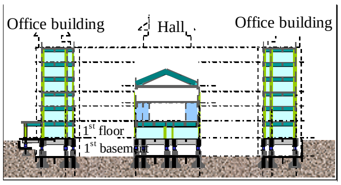
Figure 1 1st floor plan (before seismic retrofit)

2. SELECTION OF SEISMIC RETROFIT WORK METHOD

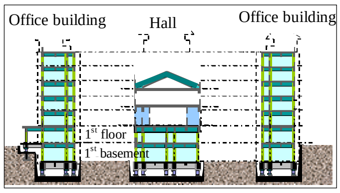
In selecting a seismic retrofit work method, we compared and discussed plural (five) plans in depth. To consider and discuss each plan from various aspects, a technical committee joined by academic experts in design and structure was organized. These plans were compared and discussed in connection with the following six evaluation items taking into account the characteristics of the main building: ① earthquake performance; ② effects on operations during seismic retrofit work; ③ effects on operations after seismic retrofit work; ④ effects on the registered cultural asset; ⑤ the term of seismic retrofit work; and ⑥ total project cost. The plans were evaluated and rated for each of the six evaluation items and given weight determined according to the degree of their importance with the consent of the committee. The selection of a work method was based on the total score of the points with regard to the six evaluation items.

2.1 Outline of Seismic Retrofit Work Methods

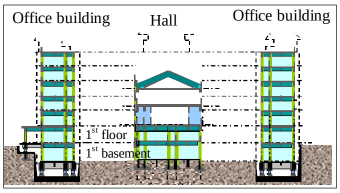
Plans A to E shown below were the seismic retrofit work methods compared and discussed. Plan A is a capital seismic plan with seismic isolation members placed on the capitals on the first basement. Plan B is a base seismic isolation plan. Plan C is a partial seismic isolation plan in which only the hall, which is shorter than the main building, located in the center of the courtyard, and part of the eastern side of the office building connected to it, is subject to seismic strengthening and the other portions are base-isolated. Plan D is a seismic strengthening plan using additional thicker earthquake-resisting walls and an additional seismic frame in the courtyard so that the appearance of the main building will not be affected. Plan E is a seismic strengthening plan (with expanded floors) based on Plan D, which uses the additional seismic frame in the courtyard to expand floors. Figure 2 shows a conceptual diagram of each plan.



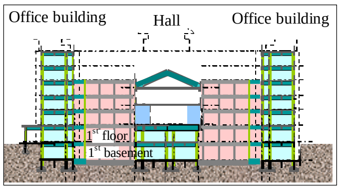
Plan A: Capital seismic isolation plan



Plan B: Base seismic isolation plan



Plan C: Partial seismic isolation plan



Plans D and E: Seismic strengthening plan (Plan E with expanded floors)

Figure 2 Conceptual diagram of each plan

2.2 Seismic Performance

The seismic performance required of the main building is structure class I as defined in the "Comprehensive Seismic Planning Standard for Governmental Facilities and Its Explanation." All of the plans described above fulfill required performance but are different in seismic performance. It has been confirmed that the behavior of the seismic isolation structure in an earthquake is simpler than that of the earthquake-resisting structure, whereas the behavior of earthquake-resisting buildings is complicated and unexpected portions may get damaged. Seismically isolated portions are lower in floor response acceleration than the earthquake-resisting structure and less likely to cause the dropping of nonstructural members and the tumbling of appliances and equipment. So, the plan with the largest number of seismically isolated portions was rated highest.

2.3 Effects on Operations during Seismic Retrofit Work

Since the seismic retrofit work must be carried out in parallel with routine operations, a seismic retrofit work method with minimal hindrance to them is desired. In this project, the weighting factor in evaluation and tallying was set at a minimum value because staff members of the Aichi Prefectural Government, the owner, were the main parties whose operations would be hindered by the seismic retrofit work and the Prefectural Government desired so. Highly evaluated were a plan enabling staff members to remain and work in their offices and requiring fewer substitute facilities during the work, a plan generating less vibration and noise and making passages available during the work, and a plan with small work coverage.

2.4 Effects on Operations after Seismic Retrofit Work

We gave high points to a plan capable of keeping work space equal to or larger than the current space, a plan maintaining the usability and design of the doorways of the main building, and a plan not adversely affecting the external usability of the main building. The seismic strengthening plans were considered undesirable because they would significantly reduce the usability of the main building, for example, the partition of the work space by additional earthquake-resisting walls.
The base isolation plan was highly evaluated in that the original work space could be maintained. The capital seismic isolation plan involved the problem that the rooms and the corridor on the first basement of an earthquake-resisting structure would become narrow as a result of the increased cross sections of the columns.

2.5 Effects on Registered Cultural Asset

The interior and/or exterior of any building designated as a registered cultural asset may be partially modified on condition that the appearance is not considerably changed. Each seismic retrofit work plan can achieve seismic retrofit without violating the regulation on registered cultural assets. On the other hand, there are examples of buildings that were designated as important cultural assets after repair work. Significant modifications, even partially, may eliminate the possibility of being designated as an important cultural asset in the future and are considered improper. So, plans with minimum effects on the appearance were given high points.

2.6 Term of Seismic Retrofit Work

The seismic strengthening plans require a term of work at least 19 months longer than the seismic isolation plans. The term of the seismic strengthening plans can be reduced by reinforcing each floor. In this case, however, the floor of the substitute building will increase, and the economic advantage of these plans will be compromised. For this reason, these plans are assumed to be carried out on Saturdays and Sundays, the Aichi Prefectural Government's regular days off, from the lowest floor in sequence, resulting in a longer term. A comparison among the seismic isolation plans showed that the term of the base seismic isolation plan is about eight months longer than that of the capital seismic isolation plan mainly because in the base seismic isolation plan, the bottom position of the foundation is deeper and the amount of excavated soil increases accordingly and the removal and installation of retaining walls around the dry area is required.

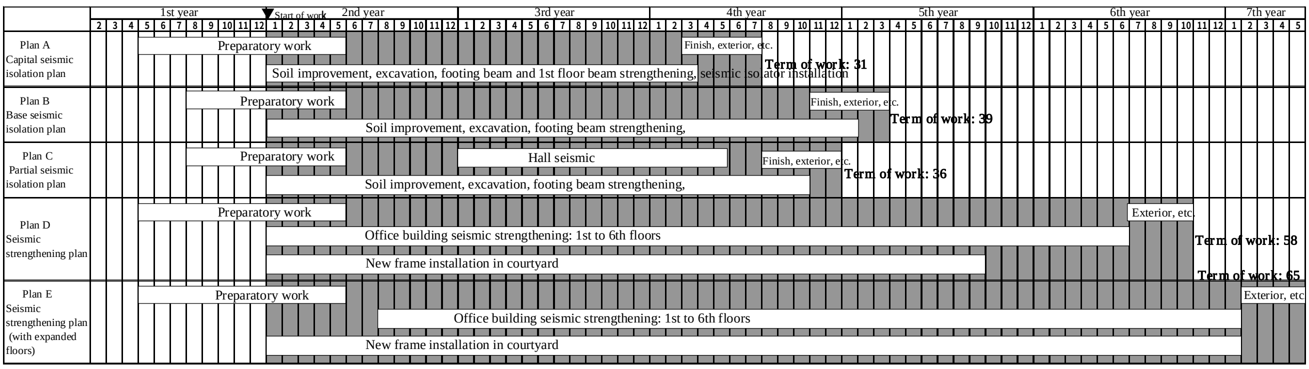


Figure 3 Comparison of terms of work of individual plans

2.7 Total Project Cost

Of the seismic isolation plans (Plans A and B) and the seismic strengthening plan (Plan D), Plan D is the lowest in total project cost. Finish work accounts for a large portion of the total project cost because of finishing required for newly installed earthquake-resisting walls. Additionally, moving and substitute facility expenses are incurred by the locations where new earthquake-resisting walls are installed. With regard to Plan E, the cost of finish work for expanded floors is high, which makes the total cost of this plan higher than that of Plan D. The total cost of the base seismic isolation plan is lower than that of the capital seismic isolation plan. The probable reasons the cost of the capital seismic isolation plan is high are as follows: (1) the skeleton around the seismic isolation members extends not only to the first basement but also to the floor beams of the first floor; (2) the seismic isolation work cost increases in the capital seismic isolation plan requiring a large number of columns and the insertion of a seismic isolation member into each column; (3) almost all of the rooms on the first basement must be refinished; and (4) expenses are incurred by moving to the first floor right above the work floor and by substitute facilities.

Table 1 Overall Evaluation Comparison List

		Seismic isolation work method			
		Plan A: Capital seismic isolation plan	Evaluation Score x Weight	Plan B: Base seismic isolation plan	Evaluation Score x Weight
Seismic performance	Required seismic performance Structure: Class I Nonstructural member: Class A Construction equipment: Class A	The floors above the ground can obtain high seismic performance by a seismic isolator installed on the top of each column on the first basement. However, these seismic isolators may not properly maintain their function due to unexpected behavior of the building in case of an earthquake because the first basement where the seismic isolators are installed is of a seismic isolation structure.	○ 21	Since seismic isolators are installed on the bottom of the foundation, the earthquake acceleration of all floors, including the basement, can be reduced. All of the floors, including the basement, can obtain high seismic performance.	◎ 30
	Necessity of strengthening, including ceiling finish	Unnecessary in principle because earthquake acceleration can be reduced.		Unnecessary in principle because earthquake acceleration can be reduced.	
	Necessity of measures to prevent bookcases, etc. from tumbling	Measures are required for tall racks and bookcases, etc. installed on the floor of the first basement to prevent them from tumbling.		Measures are required for tall racks, etc. to prevent them from tumbling.	
Effects on operations during seismic retrofit work	Feasibility of work with the machine room and the printing office remaining on the first basement	Infeasible. Relocation and substitute facilities are required.	○ 7	Feasible. Although part of the work must be carried out indoors, substitute facilities are not required.	◎ 10
	Feasibility of work with each room remaining on the first basement	Infeasible. Relocation and substitute facilities are required.		Infeasible. Substitute facilities are required because indoor work must be carried out.	
	Feasibility of work with facilities remaining on the floors above the ground	Infeasible in part. Some facilities must be relocated or substitute facilities are required depending on noise or vibration.		Feasible.	
	Noise, vibration, availability of passages, etc.	・The first basement will be seriously affected by vibration or noise. ・The passages to the West Annex and the Aichi Prefectural Assembly will be temporarily closed.		・The first basement will be affected by vibration or noise. ・The passages to the West Annex and the Aichi Prefectural Assembly will be temporarily closed.	
	Scale of temporary work and work excavation, installation of retaining walls	・A wide area, including the courtyard, is covered by the work. ・Part of the periphery of the building (locations of dry areas) must be excavated. ・New retaining walls must be installed in part of the periphery of the building.		・A wide area, including the courtyard, is covered by the work. ・The building in the courtyard must be relocated. ・The entire area surrounding the building must be excavated. ・Retaining walls will be installed all around the building.	
Effects on operations after seismic retrofit work	Availability as in the past or application of rooms	・The space around the reinforced columns on the first basement becomes narrow. ・ Part of the printing office on the first basement must be relocated. ・ Almost all facilities relating to office work are available.	○ 14	The entire building is available as in the past.	◎ 20
	Availability of each entrance and passage to the main building	All entrances and passages are available.		All entrances and passages are available.	
	Availability of corridor to the Aichi Prefectural Assembly	A passage will be available by reconstruction.		A passage will be available by reconstruction.	
	Availability of underground passage to the West Annex	A passage is available.		Although a passage is available, large-scale EXPJ is required halfway.	
	Effects on equipment wiring and piping	・Part of the wiring and piping must be rerouted because of the reinforcement of the columns on the first basement. ・Join flexible piping with joints on the first basement.		Join flexible piping with joints under the foundation (on the floor where seismic isolators are installed).	
	Usage of courtyard	Unchanged from the current situation.		The courtyard will become narrower than the current area because dry areas will be set around the building.	
	Situation of EXPJ, etc.	・An elevator and a staircase to the first basement must be additionally installed. ・EXPJ will be installed between the main building and the West Annex and the Aichi Prefectural Assembly.		・ EXPJ will be installed between the main building and the West Annex and the Aichi Prefectural Assembly.	
Effects on registered cultural asset	Changes to the exterior of the building Degree of effects on the registered cultural asset	・The shape of the columns on the first basement will change. ・The appearance of the courtyard will be affected. ・A notification of changes to registered cultural assets is not necessary.	△ 5	・There is little effect on the appearance of the building. ・A notification of changes to register	◎ 10
Term of work		About 40 months	◎ 10	About 45 months	○ 7
Total project cost (including relocation and temporary work expenses)		8 to 9 billion yen	× 0	6 to 7 billion yen	△ 10
Overall evaluation		△	57	◎	87

2.8 Overall Evaluation

The six evaluation items were discussed and given weight in the technical committee. The highest weight was given to seismic performance (weight: 3), and then to total project cost (weight: 2), and effects on operations after seismic retrofit work, effects on the registered cultural asset, effects on operations during seismic retrofit work, and the term of work (weight: 1). The reason weight 3 was given to seismic performance is that it was the objective of this project and considered most important. The total project cost was also an important evaluation item because it would have to be squeezed out of the prefecture ' s tight budget, whereas effects on operations after seismic retrofit work are an evaluation item exerting effects for a long period of time. So, weight 2 was given to these two items. The weight of the other evaluation items was 1. Effects on operations during seismic retrofit work would be burdens on staff members of the Aichi Prefectural Government, but the lowest weight 1 was given to reduce costs with the cooperation of staff members. The weight of effects on the registered cultural asset was also 1. Although this rate seems slightly low in present movements to preserve historical buildings, it was proper for the main building as a registered cultural asset. Of these five plans, the base seismic isolation plan tallied the highest score of 87 points.

A Continuance of Table 1

⑥ Seismic isolation work method + Seismic strengthening		Seismic strengthening				
Plan C: Partial seismic isolation plan	Evaluation Score x Weight	Plan D: Seismic strengthening plan	Evaluation Score x Weight	Plan E: Seismic strengthening plan (with expanded floors)	Evaluation Score x Weight	Weight
The area seismically isolated can secure high seismic performance, and earthquake acceleration can be reduced. Because of seismic strengthening, the building of the Aichi Prefectural Assembly may exhibit unexpected behavior even in an assumed earthquake and consequently fail to completely maintain its functions in some situations.		Although all buildings become an earthquake-resisting structure (wall and column strengthening and frame installation) and secure required seismic strength, they may exhibit unexpected behavior even in an assumed earthquake and consequently fail to completely maintain their functions in some situations.		Although all buildings become an earthquake-resisting structure (wall and column strengthening and frame installation) and secure required seismic strength, they may exhibit unexpected behavior even in an assumed earthquake and consequently fail to completely maintain their functions in some situations.		
Since the earthquake acceleration of the hall cannot be reduced, measures to prevent the ceiling from falling, the strengthening of the roof surface structural frame, and the fixation of equipment and appliances are required.	○ 21	Since the earthquake acceleration of all floors cannot be reduced, measures to prevent the ceiling from falling are required. The hall requires the strengthening of the roof surface structural frame.	△ 15	Since the earthquake acceleration of all floors cannot be reduced, measures to prevent the ceiling from falling and the fixation of equipment and appliances are required. The hall requires the strengthening of the roof surface structural frame.	△ 15	3
Measures are required for tall racks, etc. to prevent them from tumbling. The hall requires measures to prevent all racks, etc. from tumbling.		Measures are required for all racks, etc. to prevent them from tumbling.		Measures are required for all racks, etc. to prevent them from tumbling.		
Feasible. Although part of the work must be carried out indoors, substitute facilities are not required.		The work is infeasible in locations where a reinforcement seismic wall is installed or noise or vibration is a problem. However, it is feasible in other locations.		The work is infeasible in locations where a reinforcement seismic wall is installed or noise or vibration is a problem. However, it is feasible in other locations.		
Infeasible. 2Substitute facilities are required because indoor work must be carried out.		Infeasible. Offices must be relocated and substitute facilities will be required during the work.		Infeasible. Substitute facilities will not be required because offices will be relocated one by one to an extended floor.		
Feasible within the area seismically isolated. Regarding the hall, the work is feasible by installing temporary fences.		Infeasible. Offices must be relocated one by one, and substitute facilities will be required.		Infeasible. Offices must be relocated one by one, and substitute facilities will be required.		
･The first basement is affected by vibration or noise. ･The passage to the West Annex must be temporarily closed.	○ 7	･Work noise or vibration will be conducted to the entire building (by the work or relocation).	× 0	･Although work noise or vibration seriously affects the entire building (by the work or relocation), it can be reduced by implementing it on days off.	△ 5	1
･Temporary partition of the floors, including the first basement of the hall, is required. ･A wide area, including the courtyard, is covered by the work. ･The building in the courtyard must be relocated. ･The entire area surrounding the building to be seismically isolated must be excavated. ･Retaining walls must be installed all around the building to be seismically isolated.		･Temporary partition of the floors, including the first basement of the hall, is required. ･A wide area, including the courtyard, is covered by the work. ･Excavation is required to install a new frame in the courtyard.		･Temporary partition of the floors, including the first basement of the hall, is required. ･A wide area, including the courtyard, is covered by the work. ･Excavation is required to install a new frame in the courtyard.		
･The area to be seismically is available as in the past. ･The use of the six section rooms connecting the seismically isolated area and the area not seismically isolated will be restricted.		･Compartmented office space will be created by earthquake-resisting walls. ･Daylighting from the courtyard will be restricted, and the available area will become narrow due to reinforcing earthquake-resisting walls.		･Small partitioned rooms will increase. ･Compartmented office space will be created by earthquake-resisting walls. ･Daylighting from the courtyard will be restricted, and the available area will become narrow due to reinforcing earthquake-resisting walls.		
All entrances and passages are available.		All entrances and passages are available.		All entrances and passages are available.		
Unchanged from the current situation.		Unchanged from the current situation.		Unchanged from the current situation.		
Although a passage is available, large-scale EXPJ is required halfway.	△ 10	Unchanged from the current situation.	× 0	Unchanged from the current situation.	△ 10	2
･Join flexible piping with joints under the foundation. ･All flexible piping to the Aichi Prefectural Assembly not seismically isolated must be connected with joints.		Wiring or piping interfering with any reinforcing earthquake-resisting wall must be rerouted.		Wiring or piping interfering with any reinforcing earthquake-resisting wall must be rerouted.		
The courtyard will become narrower than the current area because dry areas will be set around the building.		The courtyard will become considerably narrow due to a new structural frame in it.		The courtyard will become considerably narrow due to a new structural frame in it.		
･EXPJ will be installed in the space between the main building and the West Annex.		Unchanged from the current situation.		Unchanged from the current situation.		
･Large-scale EXPJ in the space connected to the hall not seismically isolated will affect the appearance of the main building.	△ 5	･The courtyard will significantly change and affect the appearance of the main building. ･A notification of changes to registered cultural assets is not necessary.	× 0	･The courtyard will significantly change and affect the appearance of the main building. ･A notification of changes to registered cultural assets is not necessary.	× 0	1
Abut 40 months	◎ 10	About 65 months	× 0	About 70 months	× 0	1
5 to 6 billion yen	○ 14	5 to 6 billion yen	○ 14	4 to 5 billion yen	◎ 20	2
○	67	△	29	△	50	

Points of subitems: ◎: 10, ○: 7, △: 5, ×: 0

3. OUTLINE OF BASIC DESIGN

The creation of simulated earthquake motions based on up-to-date knowledge and data is a special field beyond the capabilities of designers. Nearby national and municipal buildings were also planning seismic isolation retrofit when the seismic retrofit of the main building of the Aichi Prefectural Government was under planning. So, the owner of the seismic retrofit project, the designer, and academic experts agreed to jointly create simulated earthquake motions of this district for design at the owner’s expense, as the academic experts proposed. The resultant simulated earthquake motions created with the aid of the empirical Green’s function were “Sannnomaru Simulated Motions,” which were used as simulated earthquake motions for design. The adopted criteria are shown in Table 2. The most prominent feature of these criteria is that high earthquake performance against earthquake motions beyond level 2 can be ensured by seismic retrofit although these criteria are almost equal to those generally used for level 2 input.

Seismic isolation design is represented by the following three features: 1) consideration is given to long-period earthquake motions expected to occur in a giant earthquake; 2) column-to-column intervals are small, up to four columns are collectively supported by a single seismic isolation member as a seismic design approach to the cultural asset with many columns for the purpose of a long-period structure, and cost reduction is achievable by reducing seismic isolation members; and 3) the 日-shaped plane building is designed to exhibit behavior as a seismically isolated, integral building. To be specific, regarding 1), rolling seismic isolation members are also used, and large-diameter isolators with high deformation performance are adopted to ensure both a long-period structure and high deformation performance. Features 2) and 3), as shown in Figures 4 and 5, enable the main building to maintain integral behavior by installing a 日-shaped, solid Vierendeel girder along the plane courtyard, and can reduce seismic isolation members by girder-supporting the existing columns from these Vierendeel girders.

Table 2 Seismic isolation design criteria

			Level 1	Level 2	Review of safety allowance	Reference motion
Earthquake motion for review			Level 2 Simulated motion × 1/2	Level 2 Simulated motion Sannomaru Simulated M. /Tokai and Tonankai Sannomaru Simulated M./North of Mt. Sanage Sannomaru Simulated M./Ise Bay	Lebel 2Simulated motion×1.5 *1	Sannomaru Simulated Motion/ estimated concealed fault JMA Kobe (original seismic motion) *2
Upper structure	Strength		Within short-period permissible stress		Within 1.1 times of elastic limit strength *3	
	Story deformation		1/1000	1/500	1/500	1/500
Seismic isolation member	Shear strain		Within 250%		Within 275%	Within 300%
	Tensile stress		No	No	Within permissible tensile stress	
	Fluctuation	LRB	Kd±15%、Qd±25%			Not considered.
		Rolling support	-40%〜+100%			Not considered.
		Damper	±15%			Not considered.
Foundation structure			Within short-period permissible stress		Within short-period permissible stress	Within elastic limit strength
Load bearing capacity of ground			Within short-period bearing capacity		Within short-period bearing capacity	
Liquefaction			No The FL value of each story is 1 or over per meter of the floors checked for liquefaction whose GL is about 12 to 14 meters.		The average FL value of the stories checked for liquefaction whose GL is about 12 to 14 meters is 1 or over.	

Level 2: Extremely rare earthquake motion

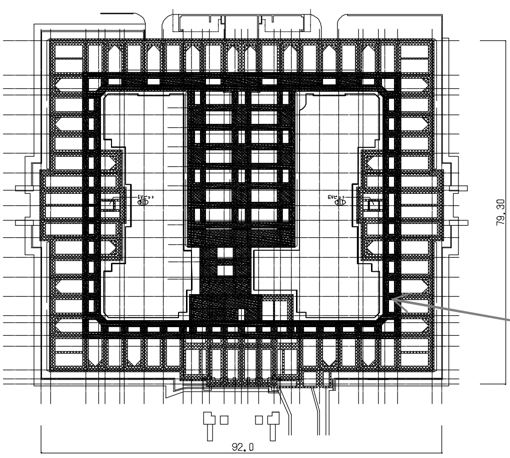
Review of safety allowance: Earthquake motion for seismic performance which a facility must have as a disaster prevention base in the district concerned

As earthquake motions representing local characteristics, (level 2) anticipated Tokai and Tonankai Earthquake EW, anticipated Ise Bay Earthquake EW, anticipated Mt. Sanage Earthquake EW, and (level 3:Safety allowance) estimated concealed fault (central lower end of destruction start point asperity) ES out of the “Nagoya Sannomaru Simulated Motions” recommended by the Chubu Regional Bureau of the Ministry of Land, Infrastructure, and Transport are used.

*1: Use an input motion obtained by multiplying the Level 2 Simulated motion in the position of the bottom of the foundation by 1.5 times.

*2: With regard to the original seismic motion input of JMA Kobe, the criteria shown under Level 2 shall be fulfilled.

*3: In a review of safety allowance, strength shall be within 1.1 times of elastic limit strength when a fluctuation is taken into account.



日-shaped, solid Vierendeel girder (The footing beams in the filled area are laid in a ladder pattern and form a large 日-shaped frame.)

Figure 4 Framing plan of footing beams (日-shaped Vierendeel girder)

The upper structure of the building was modeled with an equivalent shear spring with each floor set as a mass point. For the seismically isolated stories, laminated rubber isolators containing a lead plug, rolling supports, and lead dampers were represented by a bilinear model and integrated into a single spring. The damping of the upper structure was of a rigidity proportional type, and the damping constant was set at 2% to the 1st natural frequency. The primary period of the analysis model under equivalent rigidity corresponding to level 2 displacement was 3.91 seconds in both east-west and north-south directions, longer than the relatively long predominant period of 3 seconds of Sannomaru Simulated Motion/Tokai and Tonankai. Table 3 lists the input earthquake motions used for the response analyses, and Figure 6 shows the response spectra. Figure 7 shows some of the results of the earthquake response analyses. They fulfill the criteria set as targets for analysis results.

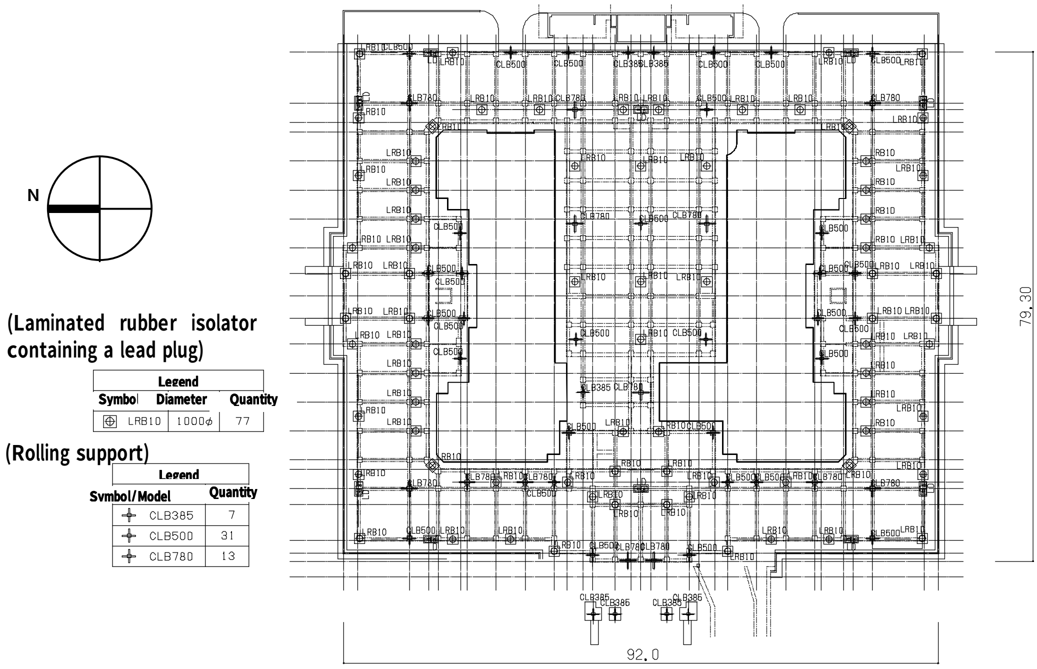


Figure 5 Layout of seismic isolation members

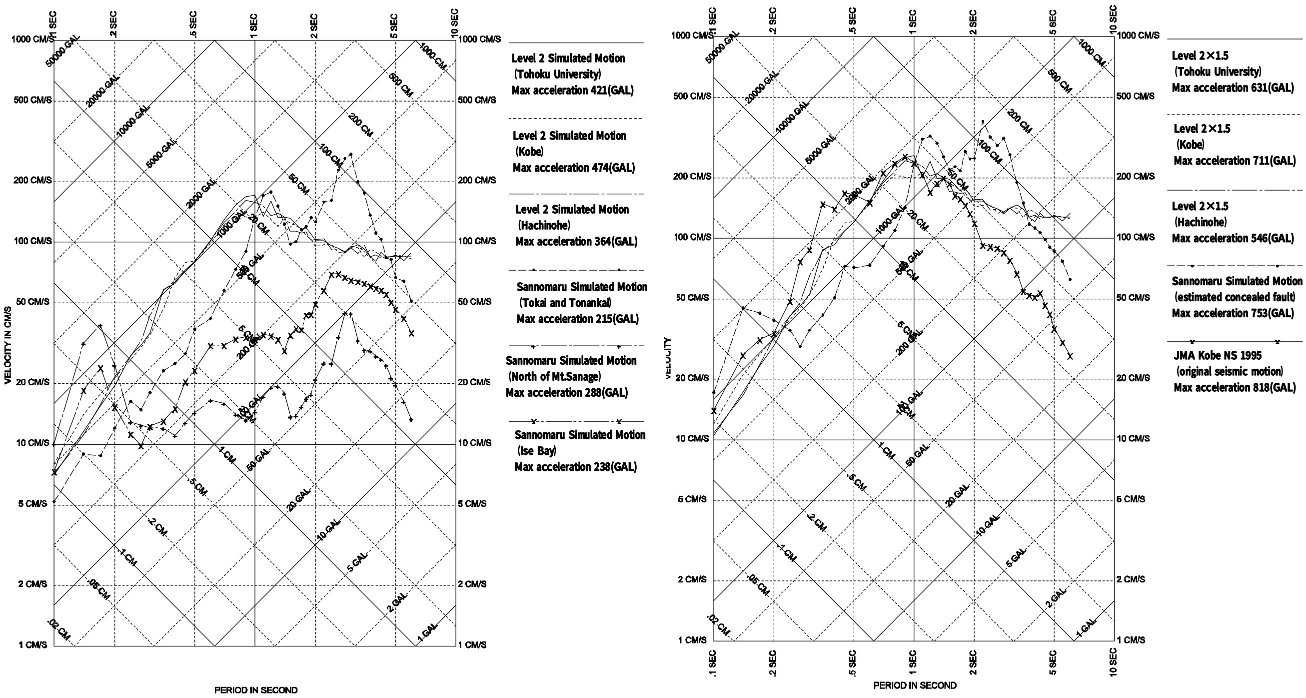


Figure 6 Response spectra of input earthquake motions adopted

Table 3 List of input earthquake motions adopted

Earthquake motion for review		Maximum acceleration (cm/s^2)	Maximum speed (cm/s)
Level 2	Level 2 Simulated Motion/Tohoku University	421	65.6
	Level 2 Simulated Motion /Hachinohe	364	64.5
	Level 2 Simulated Motion /Kobe	474	71.0
	Sannomaru Simulated Motion/Tokai and Tonankai	215	62.4
	Sannomaru Simulated Motion /North of Mt. Sanage	288	17.0
	Sannomaru Simulated Motion /Ise Bay	238	33.6
Review of Safety allowance	Level 2 × 1.5/Tohoku University	631	98.3
	Level 2 ×1.5/Hachinohe	546	96.7
	Level 2 ×1.5/Kobe	711	106.5
Reference motion	Sannomaru Simulated Motion/Estimated concealed fault	753	89.4
	JMA Kobe (Original seismic motion)	818	90.9

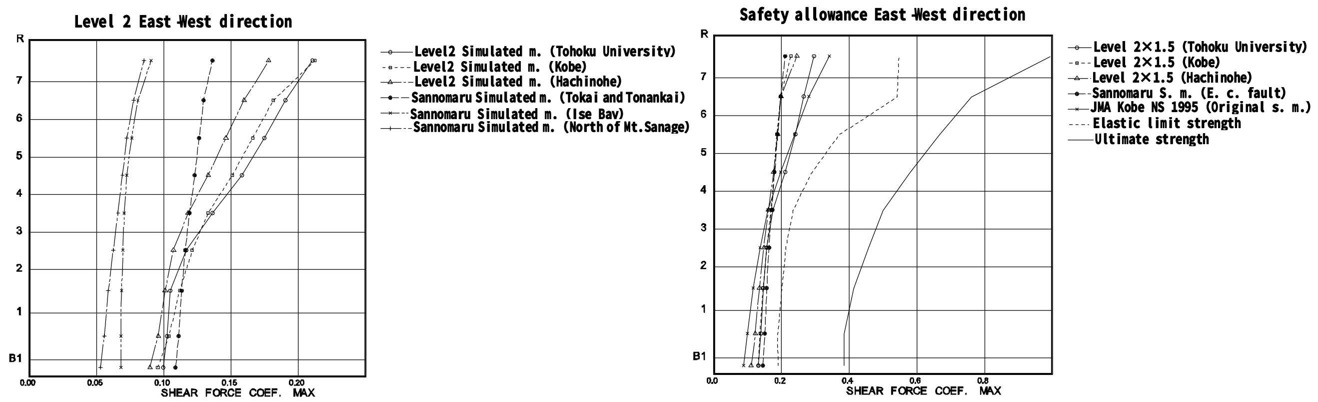


Figure 7 Results of earthquake response analyses

4. CONCLUSION

After in-depth, objective comparisons and examination of the selected seismic retrofit work methods for the main building of the Aichi Prefectrural Government, we reached the conclusion that the base isolation plan was most desirable. In planning the basic design for base isolation, simulated earthquake motions based on the latest knowledge and data were used as waveforms for review, and the building is being given higher seismic performance than new seismically isolated buildings thanks to various design approaches and ideas. At present, the seismic retrofit work is smoothly carried out by Toda Corporation, the contractor responsible for working design and execution, and almost half of the project has been completed. Finally, we would like to express our heartfelt thanks to Professor Mutsuaki Sasaki at Hosei University (then professor at Nagoya University), Professor Toshikatsu Ichinose at the Nagoya Institute of Technology, Professor Nobuo Fukuwa at Nagoya University, Professor Katsuhiro Kawata at the Nagoya Institute of Technology (then assistant professor), Mr. Masanori Iiba, director of the Structural Research Group, the Building Research Institute (then director of the Institute), and responsible staff members of the Public Building Construction and Maintenance Division of the Aichi Prefectural Government for the valuable comments and advice we received in the technical committee.

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