SEISMIC ISOLATION RETROFIT OF A MEDICAL COMPLEX BY INTEGRATING TWO LARGE-SCALE BUILDINGS

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ABSTRACT :

We developed a methodology of the seismic isolation for retrofitting a group of buildings in one unit using post-tensioned cables, and evaluated their safety and functionary based on the performance based design. We applied this methodology to two large-scale buildings of Hamamatsu Medical Center, which are the first hospital retrofitted by the seismic isolation in Japan. The two buildings are both steel-reinforced concrete frame structures of the nine-story on the ground and the one-story on the underground level. They were constructed in 1973 and 1975, based on the old building code before 1981. In the proposed retrofit scheme, the two buildings were integrated into one structural unit by connecting together at each floor by using post-tensioned cables through slabs. We confirmed that the integration worked well by comparing microtremors of the buildings before and after the integration. Seismic isolation devices were set up mainly in columns of the underground level. We adopted the temporary supporting method using post-tensioned units to install the devices safely and economically (Masuzawa et al., 2004). In the seismic design phase, we first simulated the broadband input earthquake ground motions for a hypothetical M8-class earthquake in the vicinity of the site, using a hybrid method (Hisada, 2000, etc.). Finally, we confirmed the safety and functionary of the medical center by evaluating the seismic performance of the buildings, based on the time history seismic response analysis.

KEYWORDS: Seismic isolation retrofit, Structural integration of buildings, Medical complex, Performance-based design, Site-specific strong ground motion prediction

1. INTRODUCTION

Hamamatsu Medical Center, which consists of five buildings for medical treatment functions with more than six hundred beds, is one of the most important hospitals in the Shizuoka prefecture in Japan. Even though it is expected that the center has to maintain the building function and the emergency medical operation for a large earthquake, the two buildings were designed by the old seismic code and required seismic a retrofitting by seismic diagnosis. As an example of the necessary for retrofitting of old hospitals, the Ojiya hospital in the Ojiya city suffered severe damage during the 2004 Mid Niigata Prefecture earthquake, and could not efficiently continue emergency medical operations. Even though new three buildings of the hospital suffered little damage, most medical functions were lost by the damage of the other three old buildings. It was also required a lot of time to restore and recover the buildings and their functions.

Hamamatsu Medical Center will lose its functions and emergency operations for a major earthquake, because of the damage of the old two buildings. Therefore, it was necessary to retrofit the two adjoining buildings effectively. It was also required not to stop the facilities’ functions during retrofitting and constructing. From such background, we developed a methodology of seismic isolation retrofit by integrating the two buildings into one unit. In this paper, we first explain the details of the structures of the two buildings, and the retrofitting method. Second, we explain the methodology for predicting the site-specific strong ground motions for a M8 Tokai earthquake in a subduction zone under the site. Finally, we evaluate the performance and safety of the retrofitted buildings using on time history response analysis to the assumption earthquake.

2. DESCRIPTION OF THE BUILDINGS OF HAMAMATSU MEDICAL CENTER

Figure 1 shows a bird's-eye view of Hamamatsu Medical Center, and Figure 2 shows the first floor plan and other typical floor plan. The two buildings for the seismic retrofitting are Building No.1 and No.2 in Figure 2. They are both the steel-reinforced concrete frame buildings of the nine-story on the ground and one-story on the underground level. Both buildings have penthouses of three floors on their roofs. Building No.1 and No.2 were completed in 1973 and 1975, respectively. Table 1 shows the description of the two buildings. The plan of the Building No.1 is rotated to about 30 degree from the main axis of the hospital buildings; its length is about 72m with eleven spans, and its width is about 22m with three spans. Building No.2 is almost rectangular with the 50.4m length of eight spans, and with the 22.6m width of three spans.

Figure 1 Bird's-eye view of Hamamatsu Medical Center

Table 1 Description of buildings

Building name	No.1	No.2
Year completed	1973	1975
Building area	2,035m^2	1,532m^2
Total floor area	12,915m^2	10,008m^2
Address	Hamamatsu City, Shizuoka Pref.	
Number of stories	nine-story on the ground and one-story on the underground level	
Structural type	Steel-reinforced concrete structure	
Eaves height	37.10m	
Structural system	Moment-resisting frames with shear wall	
Foundation type	Spread foundation	
Bearing stratum	Silty fine sand	

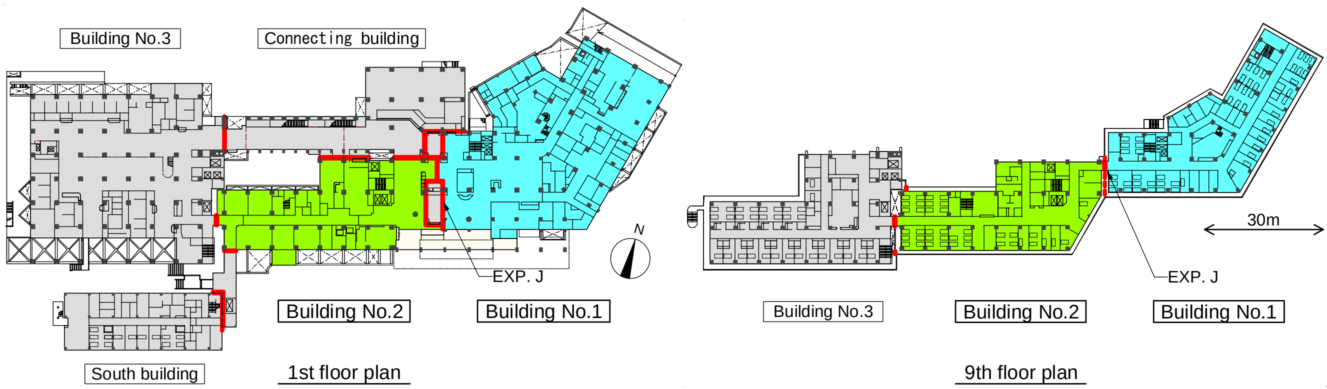


Figure 2 First floor plan (left) and typical floor plan (right)

3. METHODOLOGY OF SEISMIC RETROFIT

3.1. Outline of Seismic Retrofit

Figure 3 shows the framing elevation after it retrofits of the two buildings. In the proposed retrofit scheme, first, the two buildings were connected together at each floor using post-tensioned cables through slabs, and second, they were isolated mainly on the basement floor using eighty-nine seismic isolation devices. Before the construction works, we renewed and moved all the building equipment and facilities from the underground floor to the rooftop, and also moved medical equipment which would disturbed by the construction works. Consequently, we could carry out the construction works not to stop the building function and medical services.

3.2. Integration of The Two Buildings and Microtremor Measurements

Figure 4 shows the detail drawing of the connections of the two buildings for the typical floor. We assume the connections between the existing frames and the newly constructed slabs not to resist against the out-of-plane (bending) of the slabs, because they are connected only with PC cables through the slabs. Accordingly, the connections not only secure the strength in-plane of the slabs, but also do not give unnecessary stresses on the existing frames. We secured the safety against the deflection by the PC strand cables with small adhesion, and by reduction of the prestressing force to 80 percent of the allowable load.
We measured the microtremor before and after the integration of the two buildings. Figure 5 shows comparisons of the predominant directions on the ninth floor during microtremors. The predominant directions of the two buildings were different before the integration, whereas the directions became almost same after the integrations. Therefore, we confirmed that the integration worked effectively.

3.3. Seismic Isolation Retrofit

Figure 6 shows the arrangement of eighty-nine devices; seventy-five were in columns of the underground floor, eight under elevator shafts and six under the entrance base. We used four rectangular natural rubber bearings (diameter 900mm), fifty-one rectangular lead rubber bearings (diameter 900mm), four elastic sliding supports (diameter 300mm), and thirty cross linear bearings (six kinds with a different load limit) for the isolation system. In order to install the devices safely and economically, we used the temporary supporting method based on post-tensioned units (Masuzawa et al., 2004), and confirmed their validity through full-scale experiments. Figure 7 shows the construction process of the temporary supporting system. We used four 3000kN hydraulic lifters on one column, and scheduled less or equal four sets of the temporary supporting systems and the seismic isolation devices as one unit on the construction process. In order to ensure the earthquake resistant performance of 0.2 G even under construction, we installed the temporary steel brace and other earthquake resistant elements.

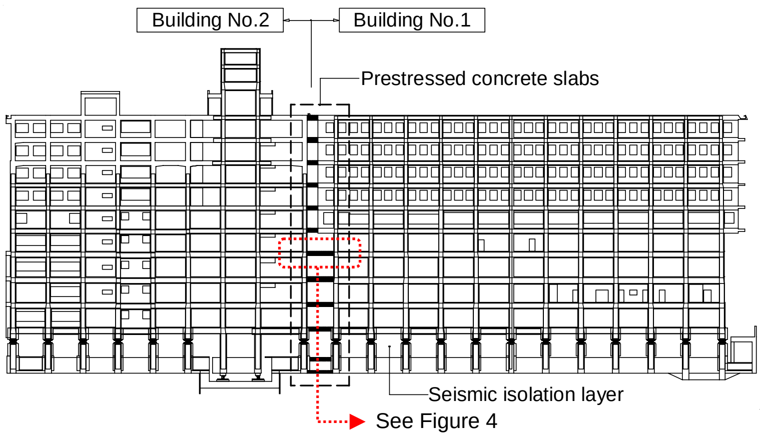


Figure 3 Framing elevation of No.1 and No.2

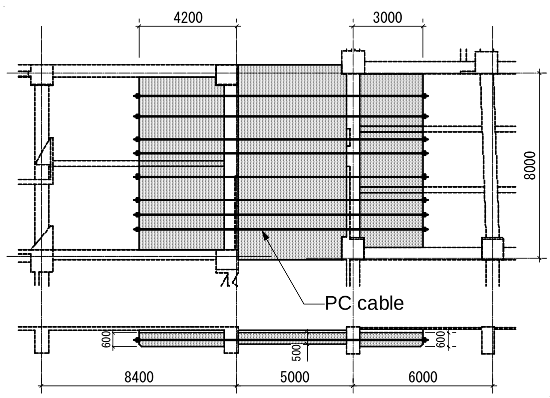
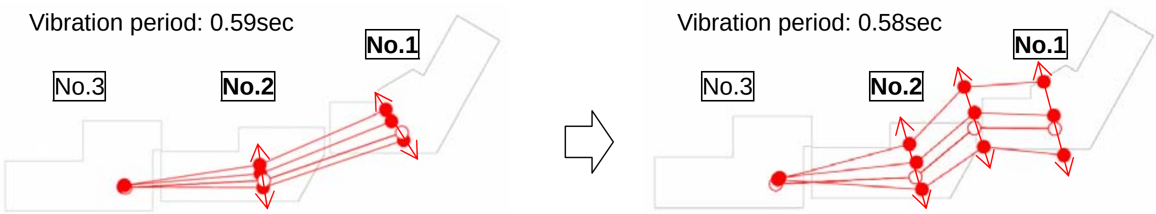


Figure 4 Plan (up) and section (down) of connecting slab



[Before connection] [After connection]

Figure 5 Predominant directions using microtremor before and after connecting No.1 and No.2

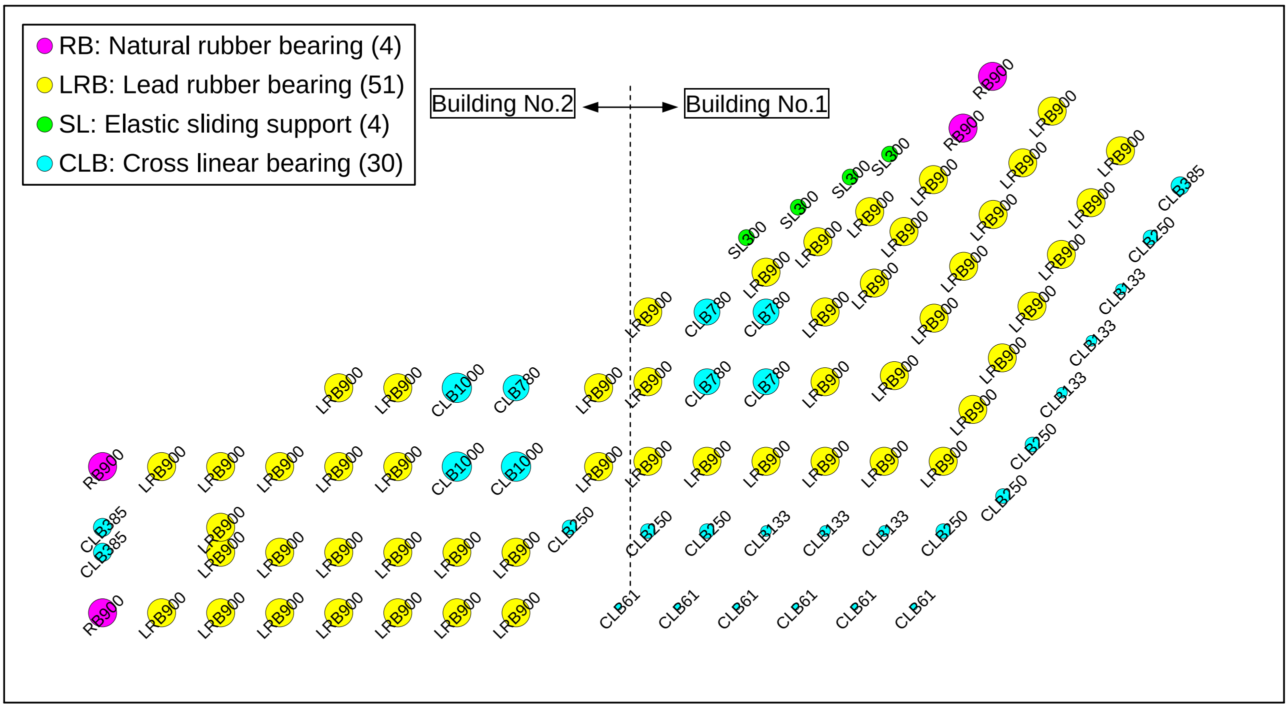


Figure 6 Arrangement of seismic isolation devices

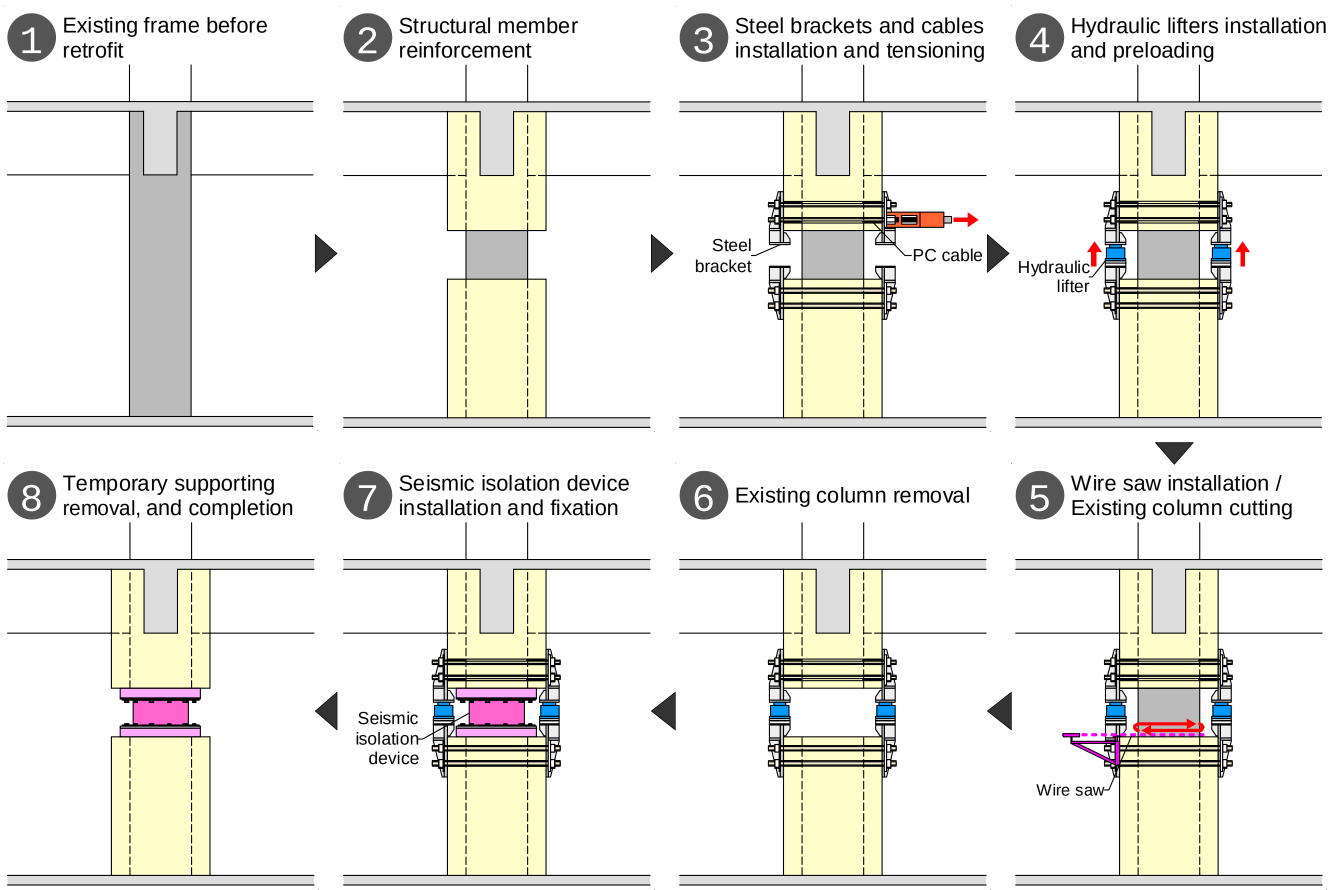


Figure 7 Construction process by the temporary supporting method

4. SIMULATION OF SITE-SPECIFIC STRONG GROUND MOTION

In the seismic design phase, we checked the safety and functionary of the medical center during earthquake by simulating a hypothetical M8-class Tokai earthquake in proximity to the site, which is located in subduction zone of the Suruga trough and estimated the 86% occurrence probability in 30 years. In order to make broadband input earthquake ground motions for the performance based design, we simulated site-specific strong ground motions using a hybrid method (Hisada, 2000, etc.), which combines theoretical and statistical methods at low and high frequencies, respectively. Figure 8 shows the hypothetical Tokai earthquake seismic fault model. The main source parameters and slipping displacements of asperities are shown in Table 2. We made the source model based on the asperity model of the Central Disaster Management Council of the Cabinet Office, Government of Japan. We modeled the deep ground structure by a flat-layered structure model from seismic bedrock (Vs=3000 m/s) to engineering bedrock (Vs=510 m/s) as shown in Table 3. We evaluated the seismic waves at the building basement (8 m in depth and Vs=220 m/s) using the equivalent-linear earthquake response analysis based on an one-dimensional stress-strain relationship. We simulated the input seismic motions by considering the three different hypocenters as shown in Figure 8. Figure 9 shows pseudo velocity response spectra of horizontal components. We selected the seismic wave with the largest amplitude level at effective period of the building after the retrofit (horizontal direction: approx. three seconds, vertical direction: approx. 0.1 seconds). Figure 10 shows the EW components of the acceleration, velocity and displacement, respectively, for Tokai-3 model, which is the severest case. In addition to the site-specific ground motions, we made the synthesized several input ground motions, which are required by the current building code. Table 4 shows the maximum amplitudes of all the earthquake ground motion waveforms used for the time history response analysis.

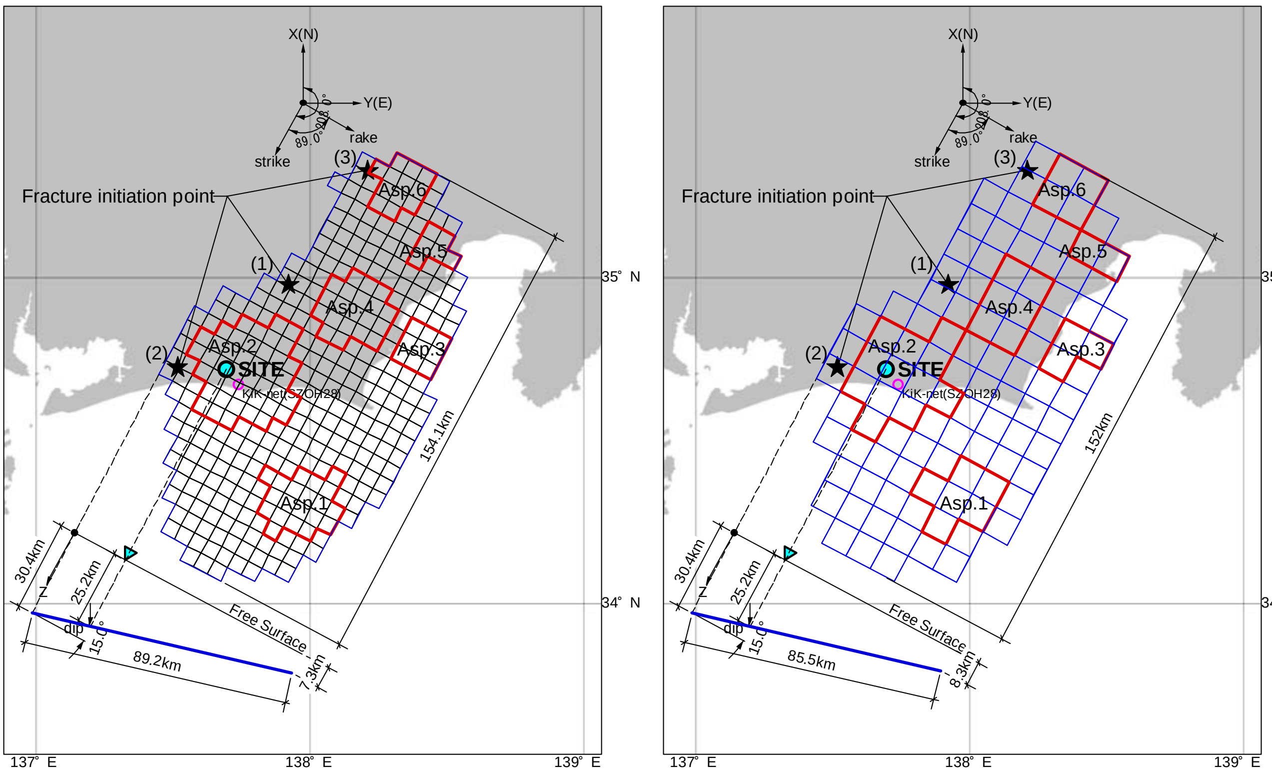


Figure 8 Tokai earthquake seismic fault model used for theoretical method (left) and statistical method (right)

Table 2 Main source parameter and slipping displacement of each asperity

Strike	Dip	Length	Width	Upper depth	Slip	Rupture vel.
208°	15°	154.14 km	89.25 km	7.28 km	89°	2.7 km/s
Asperity 1	Asperity 2	Asperity 3	Asperity 4	Asperity 5	Asperity 6	back ground
4.8	6.93	3.35	4.84	2.78	3.9	1.78

Table 3 Deep ground structure model

Layer No.	Depth m	Thickness m	Density g/cm3	Vp m/sec	Vs m/sec	Reference origin
1	50～200	150	2.1	2020	510	KiK-net observation point (SZOH28)
2	200～840	640	2.3	2280	840	KiK-net observation point (SZOH28)
3	840～900	60	2.5	2870	1280	KiK-net observation point (SZOH28)
4	900～1000	100	2.5	4140	1840	KiK-net observation point (SZOH28)
5	1000～1900	900	2.5	4600	2500	Central Disaster Management Council
6	1900～		2.6	5300	3000	Central Disaster Management Council

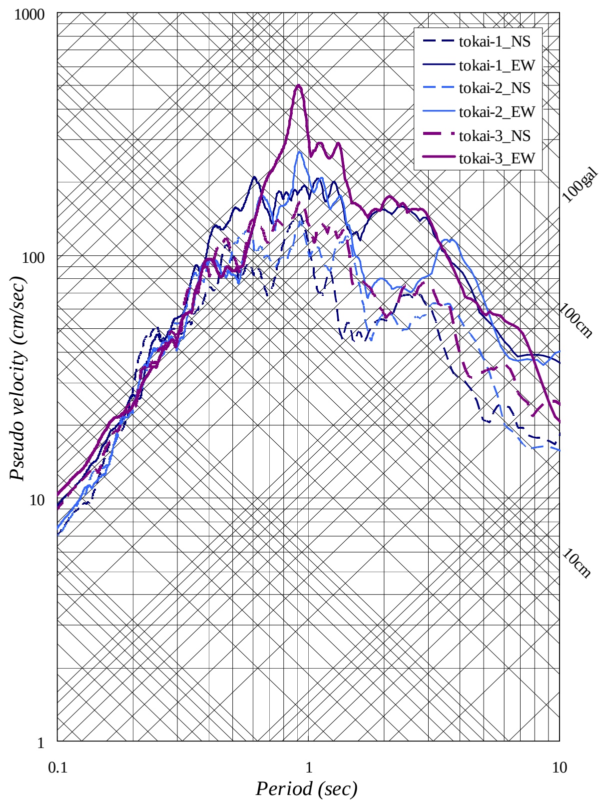


Figure 9 Velocity response spectra of simulated waves

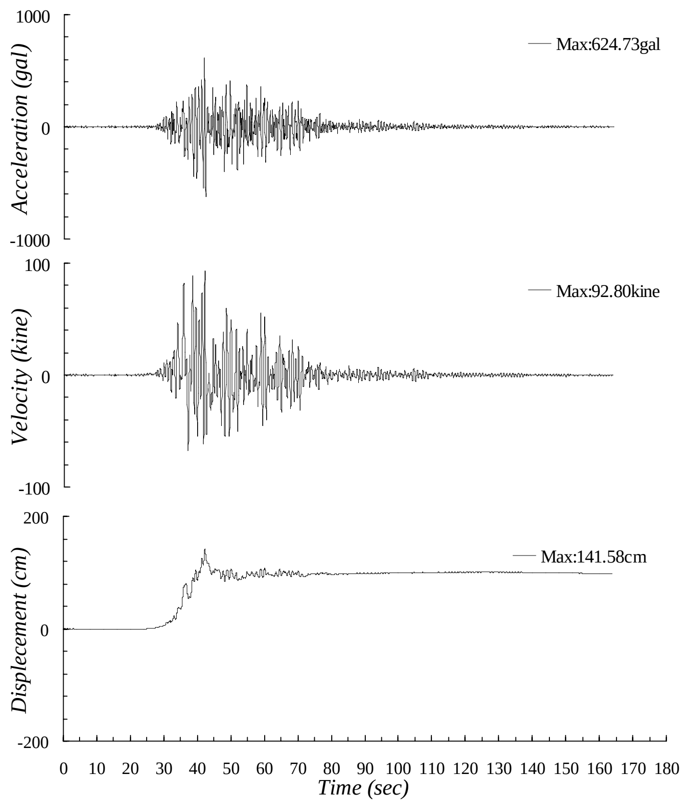


Figure 10 Simulated waves for Tokai-3_EW

Table 4 Maximum amplitudes of the earthquake ground motion waveforms used for the response analysis (the names of ground motions based on the building code show phase characteristic model)

		Acceleration (cm/s^2)	Velocity (cm/s)	Displacement (cm)
Site-specific ground motions	Tokai-3_EW	624.73	92.80	141.58
	Tokai-3_UD	215.82	26.57	26.98
Building code (very rare level)	Random	635.16	75.62	22.85
	El centro_NS	657.77	76.98	26.76
	Taft_EW	717.09	75.19	27.16
	Hachinohe_NS	630.75	98.75	24.37

5. EVALUATION OF SEISMIC PERFORMANCE OF THE BUILDING

5.1. Outline of Performance-Based Seismic Design

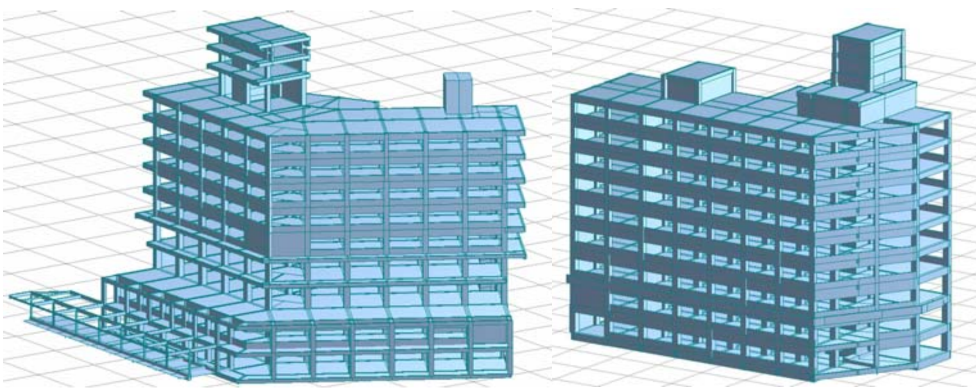
In order to secure the seismic safety and functionality of the building after the retrofit, we carried out the time history seismic response analysis. First, we constructed the three-dimensional frame model as shows in Figure 11. We confirmed that the theoretical vibration modes were nearly equal to those of the microtremor measurements. Then, using the static load incremental method considering the inelasticity of the structural frame, we analyzed each building and estimated the stress and deflection of component elements, the axial force of the seismic isolation devices and the ductility of each layer, etc. Next, we made the seismic response analysis model based on static analytical results, and carried out the time history seismic response analysis. Figure 12 shows the analysis model. We made the parallel multi-lumped mass model by concentrating the masses on each floor location. We confirmed that the response results satisfied the seismic performance targets for both the upper structure and the seismic isolation layer

5.2. Seismic Performance Targets

Table 5 shows the earthquake performance targets used in our response analyses. We used I=1.25 as for the importance factor for the buildings. We set the story drift angle for the main frames of the buildings to be 1/250 radian or less. We assumed that the structural members were less than the shear failure with the yield hinges in some boundary girders. We also assumed that the criterion of the seismic isolation devices was within the safety deformation level, and the under structure was less than the allowable stresses.

5.3. Results of Evaluation

We evaluated the seismic performance of the retrofitted building based on static and dynamic analyses. Figure 13 shows the time history response analysis results of the upper structure and the seismic isolation layer after the seismic retrofit. The results confirmed all the target values were satisfied. In addition, we secured the functionality of the building and securing medical operations after the earthquake, because the floor response acceleration roughly becomes 300gal or less.



[Building No.1] [Building No.2]

Figure 11 Three-dimensional frame model

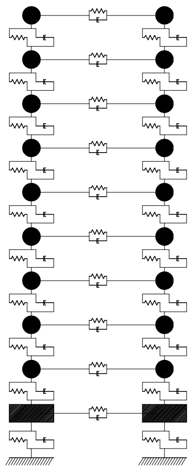


Figure 12 seismic response analysis model

Table 5 Earthquake performance targets for the Site-specific ground motions and building code (very rare level)

Earthquake performance target	Upper structure	- within elastic strength level of each layer - below 1/312.5 (=1/250/1.25) of story drift angle
	Seismic isolation layer	- within the safety deformation level (below 473.2mm (=591.6/1.25) for the rubber bearings) - within the allowable tensile stress level (below 0.8N/mm^2 (=1/1.25) for the rubber bearings)
	Foundation structure	- within the allowable stress level

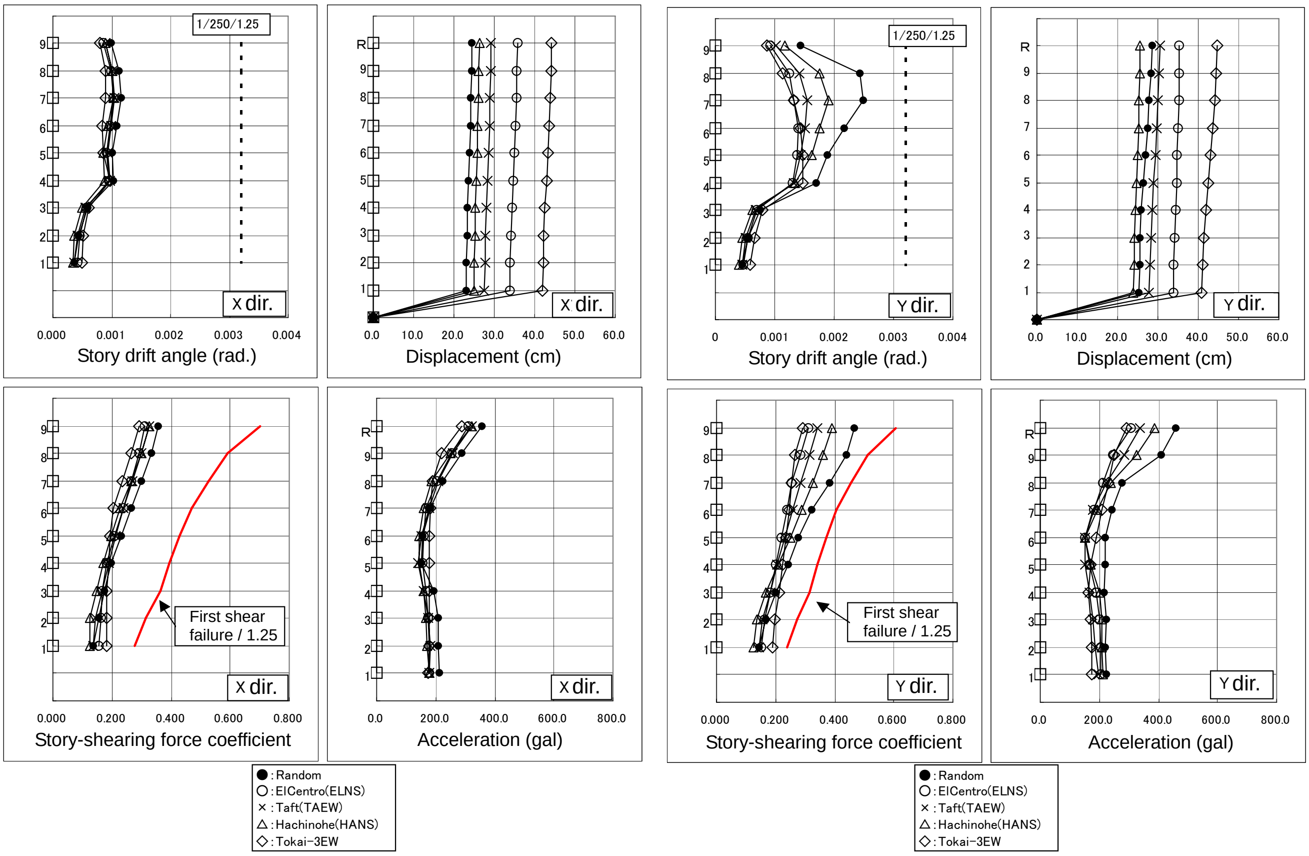


Figure 13 Time history response analysis results of the upper structure and the seismic isolation layer (stiffness of seismic isolation layer: hard case)

6. SUMMARY

We developed a methodology of the seismic isolation for retrofitting a group of buildings in one unit using post-tensioned cables, and applied it to Hamamatsu Medical Center. We showed the details of the methodology for integrating the two buildings using cables, and for retrofitting those buildings. We also evaluated their safety and functionary based on the performance based design by simulating realistic strong ground motions from a Tokai earthquake. Finally, we evaluated the effectiveness of the retrofitting for maintaining the building function and the emergency medical operation for a large earthquake using the time history response.

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