



SEISMIC ISOLATION RETROFIT IN JAPAN

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SUMMARY

Seismic isolation technology is very effective to retrofit existing buildings while they are in service. In Japan, more than 17 existing buildings has been executed or under planning of retrofit work up to the end of March 1999. Those buildings are historical buildings including temples, government buildings, school buildings and so on. Among them, two middle-rise reinforced concrete buildings are reported in this paper as the first completion of retrofit by seismic isolation method in Japan. These buildings are used as the personnel-training center of Taisei Corporation that is one of the leading construction companies in Japan. One is a 16 storied building, where 22 columns on the 8th story were cut at their mid-height and LRB's (lead rubber bearings) were installed. Retrofit isolation at this height must be the first in the world. Due to the reduction of seismic force by isolation, strengthening of the structure above isolators has come to be unnecessary and that of the structure below isolators also has been mitigated. Elevator, staircase, piping and walls on the isolation floor are schemed so as to follow the large story drift in case of earthquakes. The other building is 7 storied and supported on piles, where base isolation method was adopted. After cutting off the head of piles, rubber and sliding isolators were installed in parallel. This hybrid isolation system is called "TASS (Taisei Shake Suppression) system" and of high performance. Strengthening of the super structure has come to be unnecessary.

INTRODUCTION

In the 1995 Hanshin-Awaji Great Earthquake Disaster severe damage concentrated on buildings designed by old code which was effective before 1981. To prevent the recurrence of such kind of damage on existing buildings, "Law on the Promotion of Seismic Repair of Buildings" was enforced on December 25th 1995. Owners of disqualified existing buildings over a certain scale are encouraged to do the seismic diagnosis and repair.

There are several conventional methods of strengthening existing buildings; addition of reinforced concrete shear walls or steel bracing, thickening existing walls, shear reinforcement of columns by jacketing reinforced concrete, steel plate or carbon fiber sheet. These methods are effective to increase strength and stiffness of buildings. However their construction is mostly done inside the building, which burdens the users or residents of the buildings inconvenience to some extent.

To avoid such disturbance on daily life, exterior strengthening method or seismic isolation retrofit are preferred these days. Construction work can be done outside the building or in limited area, which enables the undisturbed or less disturbed usage of the buildings.

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OUTLINE OF THE RETROFIT BUILDINGS

The two retrofit buildings are used as the personnel-training center of Taisei Corporation. The site is located in the central part of Japan on the Pacific coast, where earthquakes of Richter magnitude 7 to 8 are worried to occur in the near future. Layout of buildings is shown in Figure 1. Main building is a 16 storied steel encased reinforced concrete building with 7 and 2 storied reinforced concrete portion, whose height is 49m. It is built on direct foundation whose level is partially varied along slope of the ground. East building is a 7 storied reinforced concrete building supported on reinforced concrete piles of 30cm diameter and 6m length. The total floor area is 15,658 . They were built in 1964 and more than 30 years have passed since then. Whole view of the buildings is shown in Figure 2.

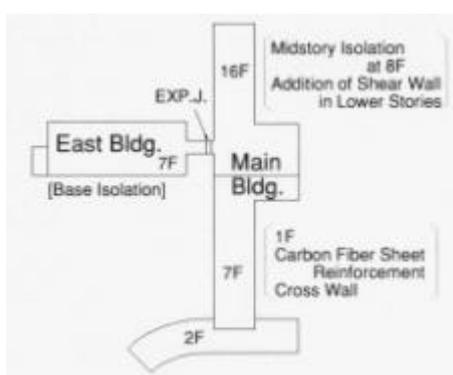


Figure 1 Layout of buildings



Figure 2 Whole view

Diagnosis was conducted along the standard published by Japan Building Disaster Prevention Association. The results revealed that the earthquake resistant capability of these buildings was "doubtful". Most of the stories was estimated to have around or less than half of the required seismic index for structures.

SEISMIC ISOLATION RETROFIT AT MID-STORY

Installation of Isolators

Mid-story isolation at the 8th floor was chosen for the main building, as it is partially underground from the 7th floor below. It is difficult to put isolators below the existing foundation stepwise along slope. Mid-height portion of all twenty-two columns of the 8th floor was cut off to install a lead rubber bearing (LRB). Longitudinal section of the main building is shown in Figure 3. Among 22 units of isolator, 4 units are 80cm in diameter and 18 units are 70cm, whose layout in plan is shown in Figure 4.

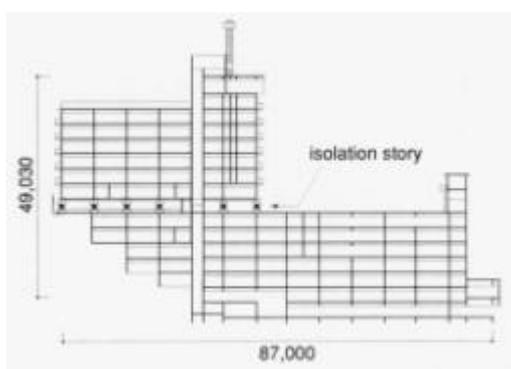


Figure 3 Section of Main Bldg.

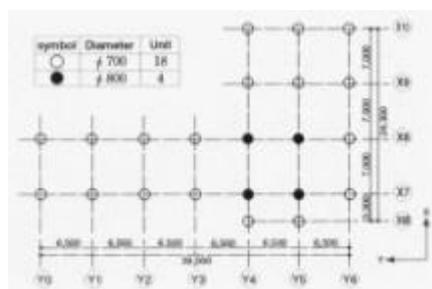


Figure 4 Layout of isolators (Main Bldg.).

Response Characteristics

By changing an old building to a seismically isolated structure, the fundamental period in X direction has been elongated from 0.40sec to 1.18sec in small amplitude and 3.00sec in 100% shear deformation of isolators. In Y direction 0.45sec has been changed to 1.19sec and 2.96sec respectively depending on the amplitude. Two levels of input earthquake motion were considered; level-1 and level-2. Their maximum velocities were 25cm/sec for level-1 and 50cm/sec for level-2. Three kinds of typical observed earthquake record were used for

both levels as well as the synthetic motion taking the probable seismic source around the site into consideration for level-2.

By the preliminary linear response analysis maximum acceleration and shear force of the upper structure above isolators are reduced to 1/5~1/10 of the elastic response of the existing structure (Figure 5). Nonlinear response analysis was done by the 3D model as shown in Figure 6. As seen in Figure 7, no strengthening is necessary in the upper structure. In the lower structure seismic loads are also reduced by large amount. However, to prevent the torsional motion parallel to the slope and to enhance the stability of the lower structure, reinforced concrete shear walls were added in some stories. Also columns on the 1st floor were jacketed by carbon fiber sheet and also strengthened by putting precast concrete cross wall between columns.

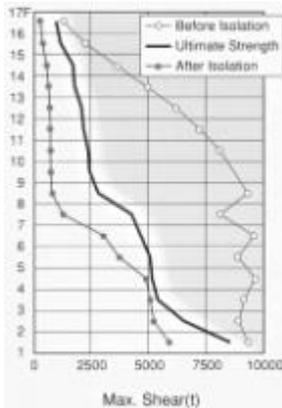


Figure 5 Response reduction

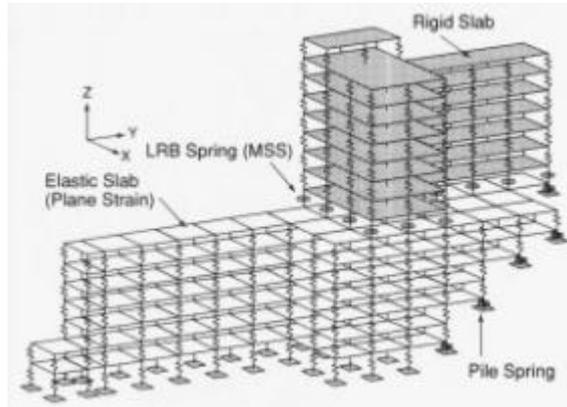


Figure 6 3D model of main bldg.

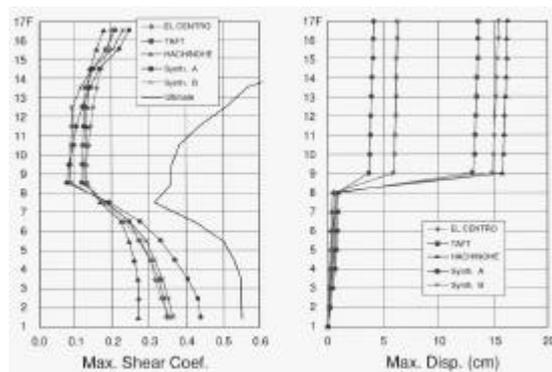


Figure 7 Response of main bldg. (X direction, Y4 axis)

Reform Work

Non-jack method was adopted to support 6,500tf upper structure during cutting and reform 22 columns. As shown in Figure 8 the reform work was done.

It was designed so as to maintain the safety of the building during the reform procedure even in case of earthquake. Due to the transition of vertical load from column to tube and from tube to isolator, about 1mm and 3mm settlement occurred respectively. No harmful differential settlement or cracking of concrete members was observed. Prior to the execution of the work, full-scale model test was done to assure the safety and workability of the method.

Figure 9 is the photos of actual work. As jacks and laborious temporary works were not necessary, the work site was very neat and reliable. Owing to the well-schemed method, the construction time was quite short. The total time was 9 months from August 1996 to April 1997.

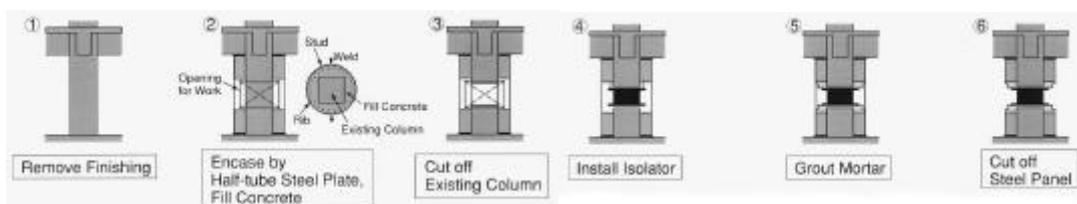


Figure 8 Reform process of mid-story isolation



(1) Remove Finishing



(4) Install Isolator



(2) Encase by Half-tube Steel



(5) Cut off Steel Panel



(3) Cut off Existing Column



(6) Cover for Fire-resistance

Figure 9 Reform work of mid-story isolation

Piping, Elevator and Wall Following Story Drift

Piping, elevator, staircase and walls were schemed so as to be able to move maximum 40cm which is twice as much as the maximum response displacement of the isolation floor. The maximum drift of the isolation story is 7cm for level-1 earthquakes and 18cm for level-2 ones. Pipes were connected by swivel joint (Figure 10) or flexible metal/rubber joint. Deflection-smoothening mechanism (Figure 11) was installed for the elevator to move smoothly even when displaced as much as 20cm in the isolation story. Dislocation of guide mechanism and collision of cage with pit wall can be avoided.

Exterior wall was composed to have horizontal slit with rain barrier and fire-resistant gasket (Figure 12) which is effective up to 10cm relative displacement. Fire-resistant casing of isolator is tubular prefabricated ceramics of 2 hours fire-resistance capability. It is split horizontally to allow lateral sliding motion. For the convenience of inspection of isolator, a small window is prepared.

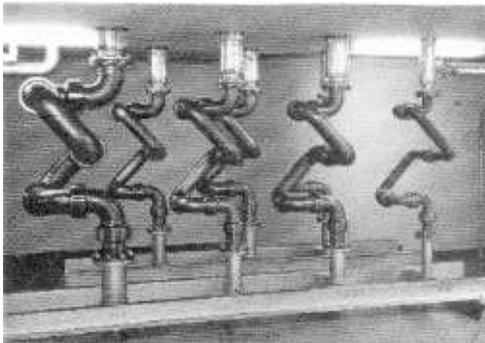


Figure 10 Swivel joint

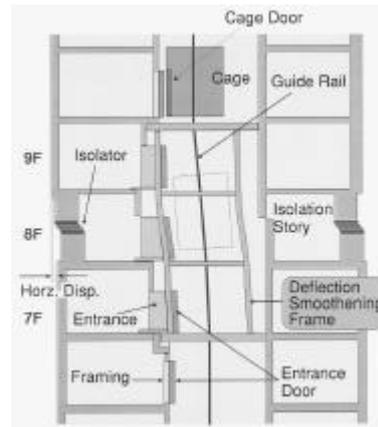


Figure 11 Deflection following elevator

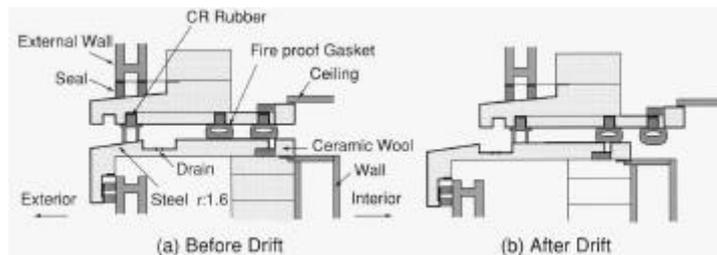


Figure 12 External wall with horizontal slit

BASE ISOLATION RETROFIT

Hybrid Isolation System

Base isolation was adopted for the east building which is supported by piles on flat ground. Piles were cut at their head to install rubber and sliding isolators. Figure 13 is the longitudinal section of the east building. Figure 14 is the layout of isolators; 7 units of sliders and 13 units of rubber bearings. In this case "Hybrid TASS system" was used, which is the combination of rubber bearings and sliding bearings in parallel. This system is superior to the conventional rubber bearing system, as more elongation of equivalent natural period and more absorption of response energy can be realized.

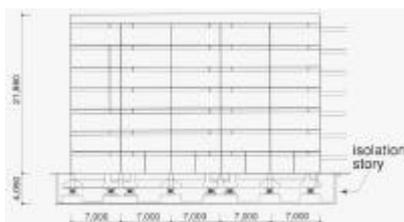


Figure 13 Section of east bldg

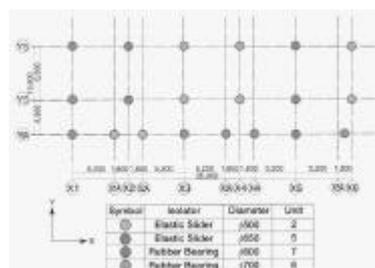


Figure 14 Layout of isolators

Response Characteristics

The fundamental period in X direction has been changed from 0.51sec to 1.43sec before sliding and 4.07sec after sliding. That in Y direction has become from 0.24sec to 1.38sec before sliding and 4.05sec after sliding. Nonlinear response analysis was conducted, whose results are shown in Figure 15 in terms of maximum shear coefficient and displacement.

As the seismic response is reduced enough by the rubber-slider hybrid isolation system of high performance, strengthening of the upper structure is not necessary.

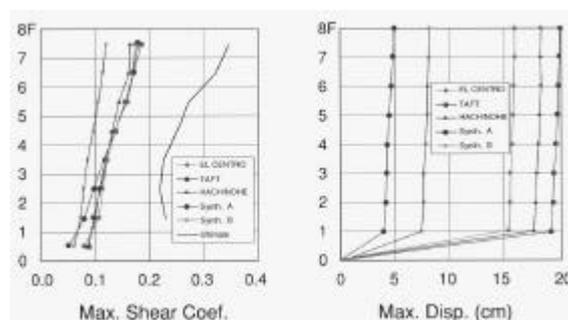


Figure 15 Maximum response of east bldg.

Reform Work

Figures 16 and 17 show the work procedure of base isolation retrofit. As there is an open courtyard in front of the building and also the 1st floor level of the east building is elevated as high as the 2nd floor level of the main building, excavation was done laterally from the front side more easily.

The maximum relative displacement between the upper structure and ground was calculated to be 11cm for level-1 earthquakes and 19cm for level-2 ones. Piping which connects outside and inside of the building was so schemed as to be able to follow up to 40cm displacement by using flexible metal or rubber joints.

PROJECTS OF SEISMIC ISOLATION RETROFIT IN JAPAN

Until the end of March 1999, seventeen seismic isolation retrofit projects have passed the check of the committee of Building Center of Japan, most of them have been completed or under construction. They are historical buildings including temples, government offices, school buildings and so on as shown in Table 1.

Figure 18 is the government office of Toshima-Ward of Tokyo. It is now under construction of seismic isolation retrofit putting rubber and sliding isolators below the existing foundation. The building is used as usual by officials and citizens even during the construction work.

Figure 19 is the school building of Nihon University, where mid-story isolation is applied at the top of the columns of basement floor. Also in this case the building is used for research and education uninterrupted during construction work.

In both cases isolation retrofit was adopted through assessing its superiority to other counter measures like conventional strengthening method on the point of cost-performance and uninterrupted use of the buildings during construction work.

CONCLUSIONS

Seismic isolation retrofit in base or mid-story has advantages over the conventional strengthening method as follows.

- 1) It is effective for reform buildings while they are in use as usual, because the work area can be limited or outside of the building.
- 2) Construction cost is cheaper than the conventional strengthening method in the case of middle-rise buildings; e.g. around 10 storied or more. Taking temporary move to other place during construction work inside the building into consideration, and also from the view point of life cycle cost reflecting the seismic performance, cost benefit increases.

3) Seismic performance is excellent not only to secure structural safety but also for the preservation of function and properties.

4) Scarce deformation of the isolated structure is suitable to keep structural integrity even in case of reinforced concrete, whereas conventional method or response control method are difficult to avoid some degree of damage.

On the contrary attention should be paid on the following items due to the large displacement as much as scores of centimeter during severe earthquakes.

1) Clearance to the neighboring structure requires around 40cm.

2) In the case of base isolation the distance to the border of site requires 1~2m excluding work space, as there should be dry area and retaining wall.

3) In the case of mid-story isolation, repair and space are necessary for piping, staircase, elevator and escalator to follow the large displacement of the isolation story.

The retrofit work herein described was done safely and reliably almost without jacks and temporary support. Noise was also measured at various points during construction work to choose suitable method and device. These experiences can be reflected on the future project of this type.

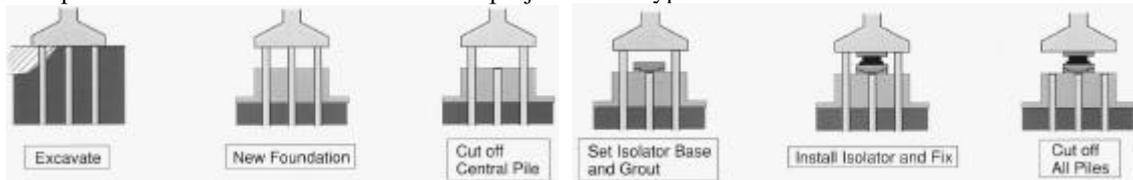


Figure 16 Reform process of base isolation retrofit

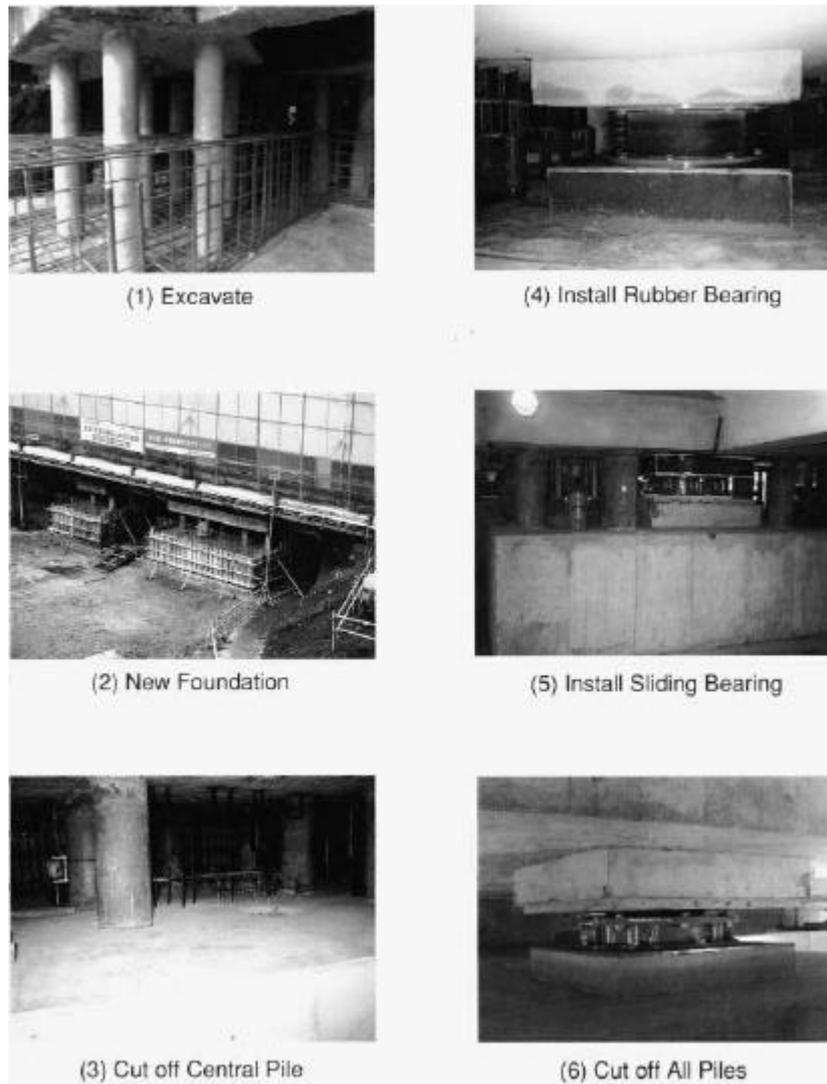


Figure 17 Reform work of base isolation retrofit

Table 1 Seismic Isolation Retrofit Projects in Japan

	PROJECT NAME	STRUCTURE /STORY	TOTAL AREA (COMPLETED ON
1	National Museum of Western Art	RC/B1+3F	4,354	1998.03
2	Obihiro Branch of Honganji Temple	RC/B1+1F	1,173	1997.11
3	Training Center of Taisei-East	RC/7F	3,153	1997.04
4	Training Center of Taisei-Main	SRC/B2+14F	12,505	1997.04
5	Lecture Hall of a Religious Group	S/1F	907	1997.12
6	Company Apartment of Kajima	RC/5F	1,686	1998.06
7	School Building of Chubu University	RC/5F	1,964	1997.10
8	Government Office of Toshima Ward, Tokyo	RC/B1+4F	13,058	2000.06
9	Chapel of Rikkyo University	Brick/1F	505	1999.02
10	Head Office of Tekken Construction Company	SRC/B1+11F	8,304	1999.09
11	National Diet Library-Ueno Branch	Brick+RC/B1+7F	6,590	
12	Living Quarters of Rinkouji Temple	RC/3F	434	1999.06
13	School Building of Nihon University	RC/B1+4F	3,061	1999.08
14	Central Hall of Osaka City	S+Brick/B1+3F	8,000	
15	Kudan Post Office and Dormitory	RC+SRC/10F	7,696	1999.11
16	Government Office of Hakone Town	RC/4F	3,529	
17	School Building of Tokyo Domestic Science College	RC/B1+4F	4,273	



Figure 18 Base isolation retrofit of a government building (Toshima-Ward, Tokyo)



Figure 19 Mid-story isolation retrofit of a school building (Nihon University)

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