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PERFORMANCE OF SEISMICALLY ISOLATED BUILDINGS IN JAPAN

-Observed records and vibration perception by people in buildings with seismic isolation -

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ABSTRACT

As a country very prone to earthquakes, Japan's long history is marked by disastrous earthquakes. Seismic isolation has the ability to mitigate the seismic force on structures. From the many recent earthquakes in Japan, people are beginning to become aware of the benefits of seismic isolation systems. Remarkable performance of systems has been shown during these earthquakes. The seismic isolation system has begun to be accepted into our society in order to maintain structural safety and functionality during, and after earthquakes. The positive effects are shown by seismograph records and analyses of them. However, until recently there were no reports related to vibration perception by people who experienced shaking during earthquakes in buildings which have seismic isolation systems. It is necessary for structural engineers to know the experiences of the occupants. This report presents data regarding human perception of vibration by the occupants whom the authors interviewed or sent questionnaires, and the acceleration records of seismographs.

1. Introduction

1.1 Profile of Seismically Isolated Buildings

The number of seismically isolated buildings has been increasing dramatically, since the 1995 Great Hanshin-Awaji Disaster. Very recently the number of detached houses with seismic isolation has been increasing also. This expansion is due to the influence of frequent occurrences of earthquakes on the Japanese archipelago. Figure 1.1 shows construction of buildings with seismic isolation. The first seismically isolated building was built in 1983. After the Hyogo-ken Nanbu Earthquake in 1995, construction of such buildings increased dramatically. Half of them are condominiums. Remarkably, almost all hospitals which have been built have seismic isolation systems recently.

Around 5,000 elastomeric isolators have been produced annually by manufacturers since 1996. Elastomeric bearings are classified as NRB (natural rubber bearing), LRB (natural rubber bearing with lead plug) and HDR (high damping rubber bearing). Natural rubber bearings are the

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most commonly used ones in seismic isolation systems.

Design criteria for seismically isolated buildings are mainly in the range of base shear coefficients; they are 0.15. Recently, a coefficient of 0.125 was introduced. As for the input velocity level in the design, a level of 50 cm/s is almost always used, but recently, on demand of clients, a level of 75 cm/s was introduced. Analytical models for the time history response analysis method are chosen as bilinear models of restoring force characteristics of seismic isolation layer. Restoring force characteristics of elastomeric isolators are used in designing before strain-hardening which occurs from 250% of shear distortion (γ) of them. Response displacements and horizontal clearances of a 50 cm/s level in all buildings are approximately 30 cm and 50 cm on average, respectively. For recently manufactured elastomeric isolators, the maximum diameter is up to 1,600 mm, which makes the clearances wider.

Generally, seismic isolation ratios comparing the period of the seismic isolation layer with the period of the superstructure fixed at the base are more than 5. Equivalent fundamental periods of seismically isolated buildings are more than 3 seconds. The periods have gradually gotten longer. Story drifts of superstructures in Japan are mostly over 1/300. A few structures have story drifts of less than that; these are steel structures.

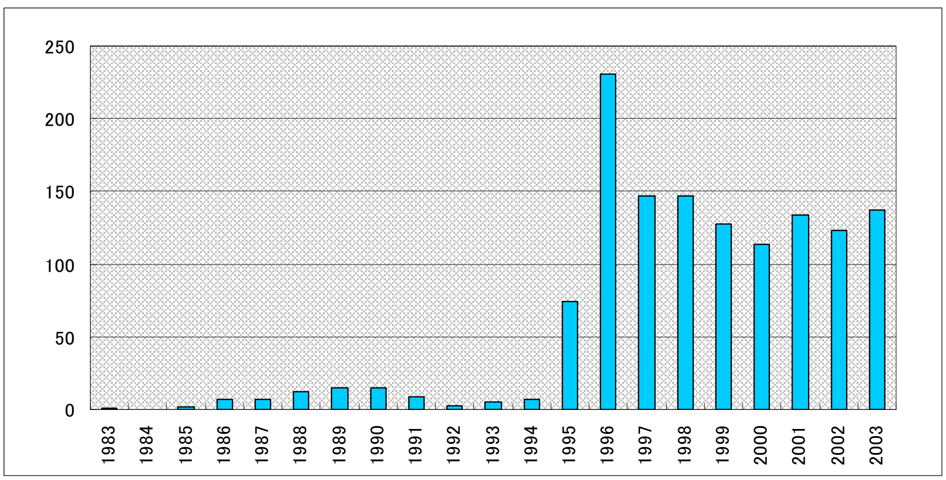


Figure 1.1 Chronology in number of seismically isolated buildings.[1)]

1.2 Records of Seismographs and Vibration Perception by People

Many records of earthquakes from buildings with seismic isolation have been obtained. The positive effects of seismic isolation buildings are shown by analyses of these records. Regarding design and its advance, and the diffusion of buildings with seismic isolation in the future, it is necessary for structural engineers to know the experiences of the occupants. Actual responses of people and also the acceleration records of seismographs in buildings with seismic isolation in the following two earthquakes will be described. The first one is the 2004 Niigata-Chuetsu Earthquake (magnitude 6.8), Saturday, October 23, 2004, 5:56 pm; and the other is the 2005 Fukuoka West-Offshore Earthquake (magnitude 7.0), Sunday, March 20, 2005, 10:53 am.

2. A Survey of Seismically Isolated Buildings in Niigata Prefecture

The technology committee and committee of public relations at JSSI surveyed the situation of buildings and experiences regarding human perception by the occupants of buildings with seismic isolation during the Niigata-Chuetsu Earthquake.[2)]

2.1 Buildings Surveyed

Table 2.1 shows the buildings surveyed in order of the distance from the epicenter, from nearest to farthest.

Table 2.1 List of the building visited.

Name	Location	Story	Usage	Structure	Substructure	Devices
Building A	Ojiya	5	Health Care	RC	Mat	NRB+ SLD
Building B	Nagaoka	2	Data Center	S	Mat	NRB
Building C	Nagaoka	8	School	RC	Mat	HDR+ SLD
Building D	Niigata	9	Condominium	RC	Piles	NRB

Note: SLD for slider with PTFE

2.2 Ojiya General Hospital Health Care Facility for the Aged (Building A)

The building is RC structure with seismic isolation system (Photograph 2.2). The secretary general of the facility was not in the building at the time of the earthquake, but he did not notice anything different about the building after returning. Nothing fell from shelves, and there was no damage in the building. The next day this building had become a shelter for people from Ojiya hospital facilities which had been damaged. The transformation of seismic isolation layer was around 140mm from a skid trace of the slider with elastomer (Photograph 2.1). The effects of seismic isolation (reduction rate) were 1/4th according to the acceleration ratio of the base to the superstructure, by an installed seismograph.[3)]

Photograph 2.1 Deformed elastomeric isolator.

Photograph 2.2 Health care facility.

2.3 NS Computer Service "Information Center"(Building B)

This building was built as an internet data center in Nagaoka City. It is the first data center with seismic isolation. It was completed on Sept. 1 2004, and business began in October.

The Chief Manager of NS computer service said that they chose a good site in regard to safety for information data center and its occupants, and they adopted the seismic isolation system for it. The structural calculation was according to Notification No. 2009 (equivalent linearized method) of the Ministry of Construction in 2000.

In addition, the server rack of the computer system was attached to the access floor by screws only, in accordance to low response acceleration by adoption of seismic isolation system. The relative displacement of seismic layer in the earthquake was about 80 mm by orbiter, shown in Photograph 2.4. There was no damage. Figure 2.1 shows the records of acceleration at K-NET NIG017 Nagaoka, 2.8 km from this building.

Some of the workers stayed there for a couple of days, using it as a shelter. It is a heavy snowfall area, and structural engineers must design to withstand at least 2.5 m of snow. Well water is used to melt snow in the perimeter zone to provide a secure clearance for the seismic isolation layer. Clearance is secured for the movement of the building (Photograph 2.3). [4)]

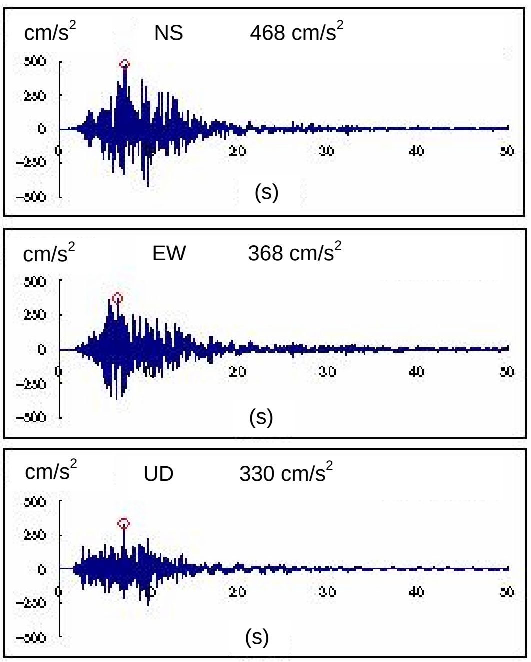
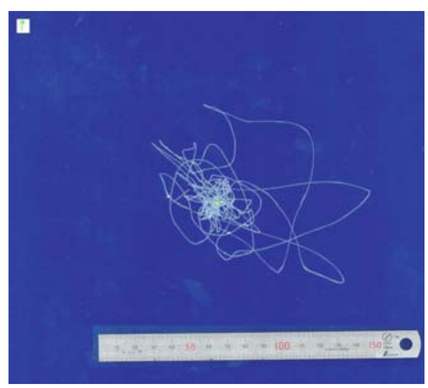


Figure 2.1 Record of acceleration.

Photograph 2.3 NS computer



Photograph 2.4 Orbiter maximum displacement 80 mm.

2.4 Hokuriku Vocational School (Building C)

The structure of this building is RC with high damping rubber bearings. The chairperson of the board of directors and the executive director said that there was nobody in the school at the time of the earthquake. The next day, they found nothing unusual in the building; nothing fell and none of the furniture or household articles had fallen. They experienced many aftershocks in this building which they said felt like riding a boat (Photograph 2.5).

They are very satisfied with the seismic isolation system in their building. About 200 mm displacement of seismic isolation layer was measured shown as Figure 2.2. The effect of seismic isolation is shown as one-fourth reduction by an installed seismograph installed in the seismic isolation layer as shown in Figure 2.3, 2.4 and Table 2.2. [5)]

Photograph 2.5 Hokuriku Vocational School.

Table 2.2 Observed acceleration.

Time	Magnitude	Floor	Maximum (cm/s²)		
			EW	NS	UD
Oct. 23 17:56	6.8	8FL	162.4	122.4	179.8
		1FL	141.3	116.4	143.1
		B1FL	238.8	188.7	150.2
Oct. 23 18:03	6.3	8FL	90.1	85.2	228.2
		1FL	87.7	77.1	181.0
		B1FL	228.3	180.0	125.8
Oct. 23 18:34	6.5	8FL	68.6	74.3	139.6
		1FL	73.1	62.1	78.9
		B1FL	97.4	135.8	72.2

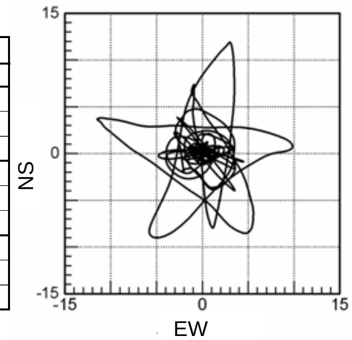


Figure 2.2 Trace of the movement.

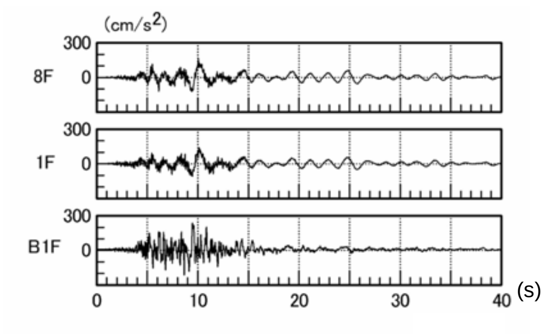


Figure 2.3 Record of acceleration (EW).

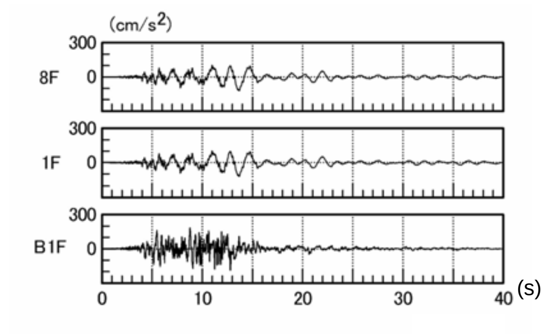


Figure 2.4 Record of acceleration (NS).

2.5 Condominium on the South side of Niigata Station (Building D)

The structure is a steel composite reinforced concrete building that is a condominium of fifty-three units in Niigata City, all of which are rented (Photograph 2.6).

Residents of two units replied that they were not aware that their building was installed with a seismic isolation system and they were surprised that other buildings had shaken so much.

Photograph 2.6 Condominium.

3. Seismically Isolated Buildings in Fukuoka City

Previous to this earthquake, the most recent one of significance in Fukuoka area was in 1898. Response displacements of most buildings were less than the equivalency of a 50 cm/s level, but nothing fell down or moved in buildings with seismic isolation. Slight damage was found to be caused by defective work. There are thirteen seismically isolated buildings in the city. Nine of them are listed in Table 3.1.[6)]

Table 3.1 List of buildings with seismic isolation in Fukuoka City.

Name	Location	Story	Usage	Structure	Substructure	Devices
Building A	Hakata	4	Dormitory	RC	Mat	HDR
Building B	Minami	14	Condominium	RC	Piles	NRB
Building C	Minami	14	Condominium	RC	Piles	LRB
Building D	Minami	12	Condominium	RC	Piles	LRB
Building E	Minami	6	Condominium	RC	Piles	HDR
Building F	Chuo	7	Office	RC	Piles	HDR
Building G	Chuo	9	Office	SRC	Piles	NRB
Building H	Higashi	11	Hospital	SRC, S	Mat	NRB
Building I	Chuo	13	Hotel	RC	Piles	NRB

Note: SLD for slider with PTFE

3.1 Buildings Surveyed

***Building A*:**

The manager of the building was right at the front entrance at the time of the earthquake. He thought that movement was from a nearby JR freight line. Nothing fell from shelves.

***Building B - E*:**

These buildings are located in the same housing complex. The transformation of the seismic isolation layer was small because of the distance from the epicenter. A resident who lives on the eighth floor of the building felt almost no movement.

***Building F*:**

The building is in the vicinity of the Kego Fault. Photograph 3.1 shows the appearance of the building after the earthquake. The entrance step was partially damaged because of insufficient vertical clearance in Photograph 3.2. Conventional structures suffered damages in this area. In addition, the orbit was traced on the iron plate at the corner of the service entrance of the building (Photograph 3.3).

The north and south component was greater than east-to-west. The maximum response displacement of the seismic isolation layer reached about 300 mm.

A seismograph was installed in this building; acceleration indicated 203 gal of NS component at 65 m below ground, 489 gal at base, and 234 gal at the top floor of the building.

Photograph 3.3 Trace of the movement.

Photograph 3.1 Appearance of Building F.

Photograph 3.2 Damage around the entrance.

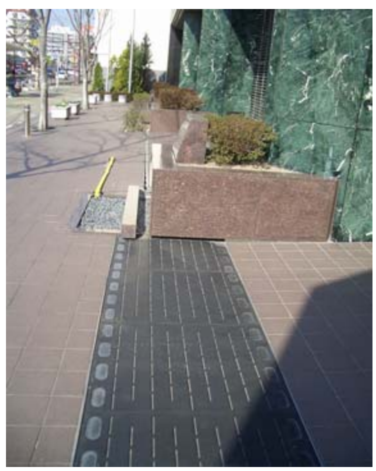
***Building G*:**

Appearance of the building is shown in Photograph 3.4. The seismograph recorded a maximum acceleration in the base of 146 gal, but 71 gal at R floor and 45 gal at the first floor in the east-west direction.

Photograph 3.5 of the entrance shows that curb stones had moved about 150 mm to the south. It is a good correspondence that the observed displacement was 145 mm shown as Figure 3.1. Acceleration of the superstructure was reduced to one-half to one-third in Figure 3.2 and Table 3.2.

The clerk of this building said that nothing fell from shelves and his perception of vibration was very small in the office on the top floor.[7)]

Photograph 3.4 Appearance of Building G.



Photograph 3.5 Entrance approach.

Table 3.2 Observed acceleration.

Floor	Maximum (cm/s²)		
	NS	EW	UD
RFL	101.5	70.7	214.2
1FL	66.0	45.4	119.8
Base	110.5	146.2	168.4
Ratio	0.60	0.31	0.71

Note: Ratio = 1FL / Base

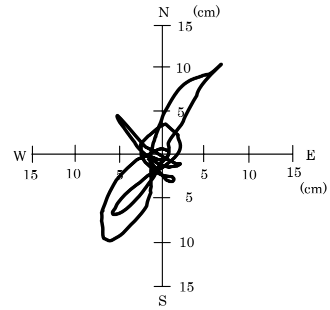


Figure 3.1 Trace of the movement.

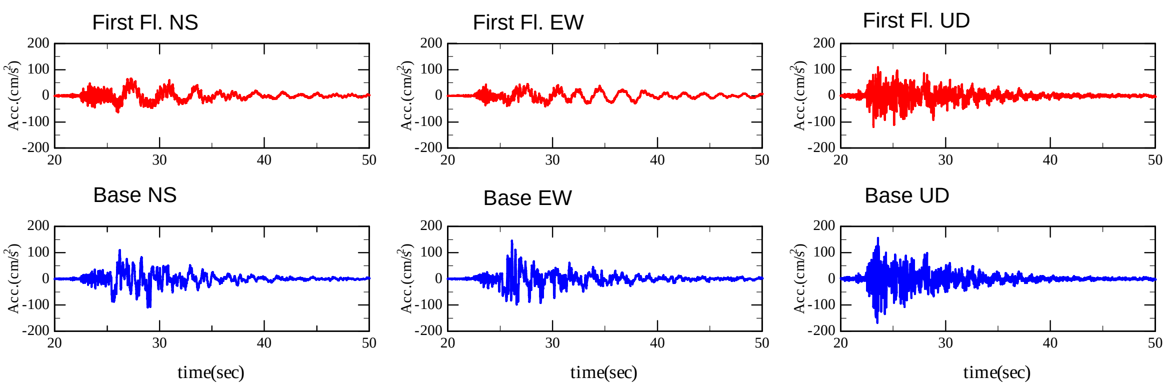


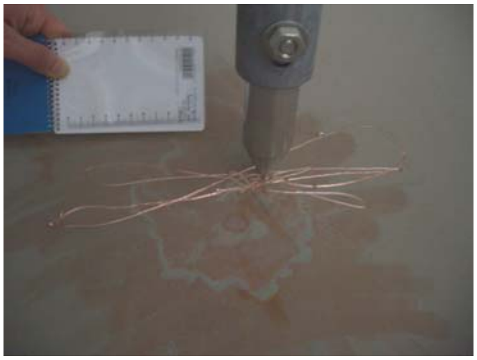
Figure 3.2 Record of acceleration.

***Building H*:**

Photograph 3.6 shows the building appearance of a large-scale hospital. The entrance bridge of the south side of the hospital has expansion joints, but the handrail part of it did not work well as shown in Photograph 3.7.

An inpatient on the sixth floor said that he had a perception of vibration, but that nothing fell down or moved.
Wall cracks occurred in adjacent conventional structures. Photograph 3.8 shows the trace with an orbiter installed in the seismic isolation layer.
As for the displacement of the seismic isolation layer,
the north-south axis is bigger than the east-west one;
it was about 150 mm. A repetition of almost 2 cycles was traced at the maximum.

Photograph 3.6 Appearance of the hospital.



Photograph 3.7 Expansion joint of the bridge. Photograph 3.8 Orbit in seismic isolation layer.

***Building I*:**

This building is located about 600m from the fault. The building appearance after the earthquake is in Photograph 3.9. As for the trace in the seismic isolation layer, transformation was estimated at about 100 to120 mm in the north-south direction, and about 70 mm east-to-west.

According to a hotel clerk, his perception was that the vibration was slow during the earthquake. There were ten guests there at the time of the earthquake, but they did not express any fear about shaking of the building. The elevators stopped for about five minutes, but resumed automatically, and nothing fell down or moved. There was no residual deformation in the seismic isolation devices according to the plumb-bobs in Photograph 3.10.

Photograph 3.9 Appearance of the hotel Photograph 3.10 Devices of the hotel

Conclusions

The effects of seismic isolation, and the satisfaction and dissatisfaction of occupants have been verified by this survey. Structural engineers should know the abovementioned experiences of the people, and they should design buildings with seismic isolation on the performance based concept. In spite of the benefits of seismic isolation systems, very few people know what they are. More dissemination, explanation and expansion of public relations must be carried out.

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