Performance of Seismically Isolated Buildings at March 11, 2011, Tohoku Earthquake

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The State of the Art of Seismically Isolated Buildings in Japan

Seismic Isolation Techniques has been widely adopted in Japan since the 1995 Great Hanshin-Awaji Earthquake Disaster which caused over 6,400 deaths and 100,000 buildings totally collapsed. From the statistics until the end of 2010, in total over 2,800 buildings are seismically isolated. Also, the number of detached houses equipped with seismic isolation has reached over 4,800, so total number is around 7,000. In recent disastrous earthquakes in Japan, seismic isolation buildings have shown excellent performance and are recognized as promising techniques for sustainable buildings against earthquakes.

As one of the working commissions in CIB (International Council for Research and Innovation in Building and Construction), the Commission W114 (Earthquake Engineering and Buildings) was established in November 2006 and the JSSI (Japan Society of Seismic Isolation) became headquarter of the Commission. One of the missions of W114 is to disseminate seismic isolation technique and enhance its application to buildings.

This paper summarizes the state of the art of application of seismically isolated buildings ((hereinafter referred to as SI buildings) in Japan and its performance in recent earthquakes. Especially survey results of SI buildings after the Great East Japan (Tohoku) Earthquake on March 11, 2011 is described in detail. From the damage survey, it was found that super-structures of SI buildings suffered almost no damage even under strong shaking with JMA (Japan Metrological Agency) intensity 6 plus. It verifies the excellent performance of SI buildings. However, in some buildings, damage was observed at the expansion joints. It seems that parts of expansion joints were not well operated due to the large displacement of SI floor during earthquake. Moderate damage to seismic dampers such as lead dampers and steel dampers was observed.

Keywords: Seismically Isolated Buildings, 2011 Tohoku Earthquake, Earthquake damage

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1. Profile of Seismically Isolated Buildings in Japan

The number of seismically isolated buildings increased after the 1995 Hyogo-ken Nanbu (Kobe) earthquake. Half of the buildings are condominiums and 15% of the buildings are hospitals. Figure 1 shows the latest statistics of seismically isolated buildings except detached houses from the JSSI (Japan Society of Seismic Isolation) database. Detached houses are the seismically isolated wooden private houses increased tremendously after year 2000 as shown in Figure 2 when the new regulation was issued to approve not the individual design of houses but the manufacture of the specific type of construction to streamline the inspection process.

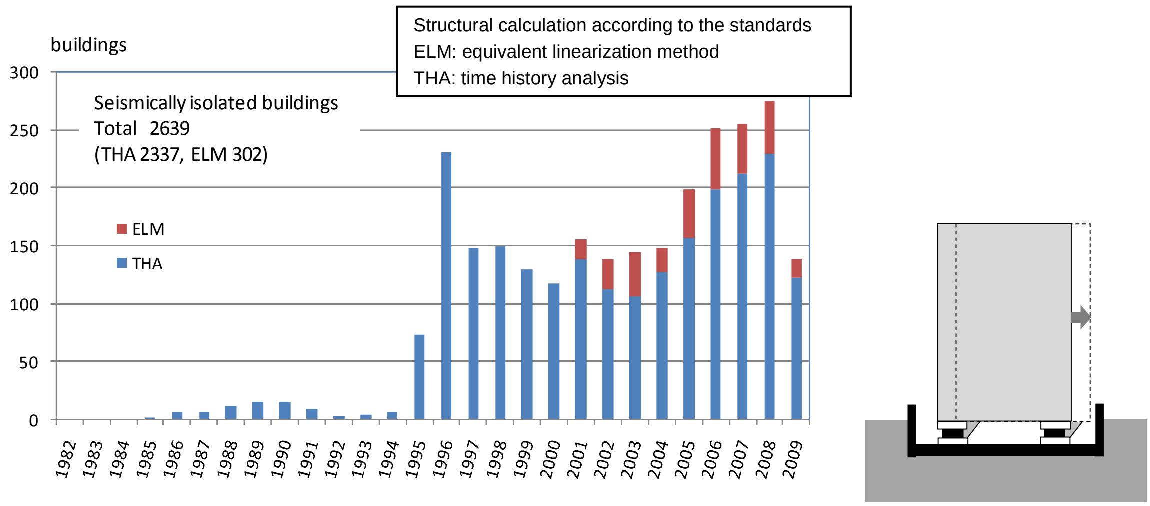

Figure 1: Statistics of seismically isolated buildings except detached houses

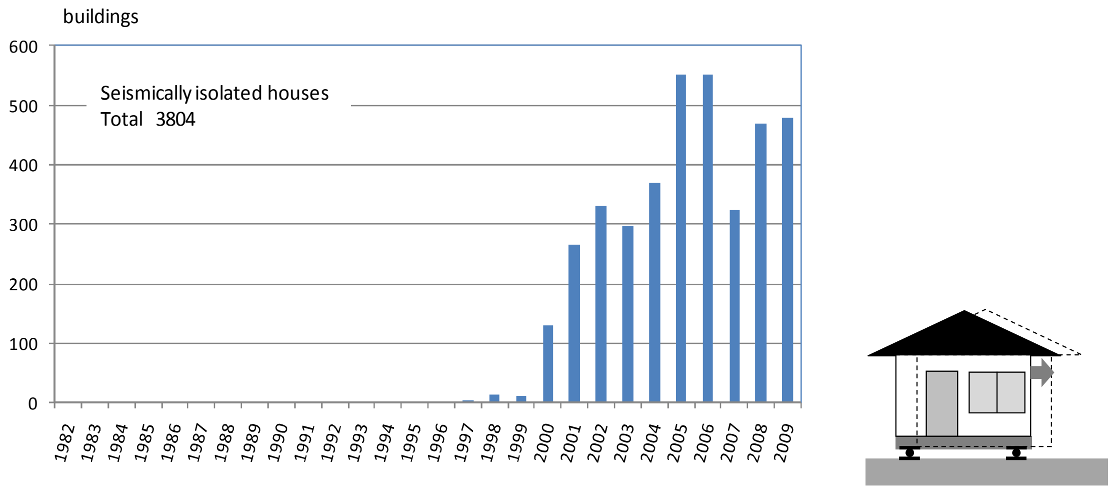

Figure 2: Statistics of seismically isolated detached houses

2. Performance of Seismically Isolated Buildings

Reflecting high consciousness of earthquake risks in Tohoku region, Japan, there are many seismically isolated buildings (hereinafter referred to as SI buildings) have been constructed in those areas. After the 2011 Tohoku Earthquake, an investigation team consisted by the members from NILIM (National Institute of Land, Infrastructure and Management) and BRI

(Building Research Institute) was dispatched to the disaster areas on June 1st and 2nd to examine performance of SI buildings and ask persons in charge of the buildings about the structural damage. In total, 17 SI buildings were investigated. Table 1 shows the list of SI buildings investigated. The list contains the JMA (Japan Meteorological Agency) seismic intensity (from 0 to 7) near the building. Most buildings in the list suffered severe ground motion with the intensity more than JMA 6 lower.

Table 1: List of SI buildings investigated on June 1st and 2nd in 2011

	Usage	Structural type and number of floors	Existence of scratch board	Existence of earthquake record	JMA Seismic Intensity at the nearest observatory
A	Office	SRC, 9F+B2F	○	○	6 lower
B	Warehouse	S, 1F	○		6 lower
C	Condominium	RC, 14F			6 lower
D	Condominium	RC, 12F			6 lower
E	Condominium	RC, 15F	○		6 lower
F	Condominium	RC, 10F			6 lower
G	Hospital	RC, 6F			6 lower
H	Office	RC, 18F +B2F	○	○	6 lower
I	Hotel	RC,12F			6 upper
J	Fire Station	S, 3F			6 upper
K	Hospital	RC, 5F			6 upper
L	Fire Station	RC, 3F	○		6 lower – 6 upper
M	Hospital	S, 6F	○		5 upper
N	Fire Station	RC, 3F	○		5 upper - 6 lower
O	Hospital	RC, 4F			6 lower
P	Hospital	RC, 10F		○	4
Q	Hospital	SRC, 4F	○		5 upper

(SRC: steel reinforced concrete, RC: reinforced concrete, S: steel)

2.1 SI building (A)

The SI building (A) is a reinforced concrete office building with 9-story super-structure and 2-story basement, located in Miyagino-ward in Sendai-city (Figure 3-(a)). The building was retrofitted by using base isolation technique putting isolation devices on the top of columns in B1F. The floor plan has the 26.4 m × 54 m rectangular shape and 44 high-damping rubber bearings (HRBs) are installed. At 2011 Tohoku Earthquake, no furniture was turned over and no structural damage was observed. However, some damage was observed at the cover-panels of fire protection and the expansion joints near the boundary between isolated and non-isolated floors (Figure 3-(b)). It seems that parts of expansion joints were not well operated due to the large displacement of SI floor during earthquake. This building has accelerometers at B2F, 1F and 9F (top floor). Also, there is an accelerometer installed by JMA in the basement of an adjacent building. The maximum acceleration values of these accelerometers at the main shock of 2011 Tohoku Earthquake are listed in Table 2.

(a) Overview of the building (b) Damage to the cover panel

Figure 3: SI Building (A)

Table 2: Maximum acceleration values obtained at 2011 Tohoku Earthquake

Location	Direction		
	Horizontal X(EW) [cm/sec^2]	Horizontal Y(NS) [cm/sec^2]	Vertical Z [cm/sec^2]
Basement of adjacent building	317.9	409.9	251.4
B2F (below SI)	250.8	289.0	234.9
1F (above SI)	143.7	120.5	373.7
9F	169.9	141.7	523.9

2.2 SI building (B)

The SI building (B) is a one-story steel warehouse constructed in 1996, located in Miyagino-ward in Sendai-city (Figure 4-(a)). The building height is 30 m. There are 20 HRBs (with diameter 850 mm) and 4 HRBs (with diameter 800 mm) arranged in the basement with 51.6 m × 31.7 m rectangular shape. Since the building is located near the Sendai-Shiogama bay, Tsunami reached the building and the SI floor was submerged under water. Since this warehouse is a freezer, water entered in the freezer space was frozen after the earthquake. Also it took 16 days to remove the water from the SI floor. No damage to the building was observed. Also, from visual inspection, there was no harmful scratch or inflation of the rubber of HRB, however, severe rust was observed at the steel plates and bolts (Figure 4-(b)).

(a) Overview of the building (b) Damage to the cover panel

Figure 4: SI Building (B)

2.3 SI building (C)

The SI building (C) is a 14-story reinforced concrete building used for condominium, located in Miyagino-ward in Sendai-city (Figure 5-(a)). The building has the U-shape plan and the corners of the building are separated by expansion joints. There are 24 NRBs, 8 Lead dampers, and 13 U-shape steel dampers installed in the SI floor. According to the owner of the building, no furniture was turned over and no structural damage was observed inside of rooms after the earthquake. Also no damage was found to NRBs by visual inspection; however, paint of U-shape dampers was peeled off (Figure 5-(b)) and many cracks were found on Lead dampers (Figure 5-(c)).

(a) Overview of the building

(b) U-shape steel damper

(c) Lead damper and crack on the surface

Figure 5: SI Building (C)

2.4 SI building (L)

The SI building (L) is a 3-story reinforced concrete building used for firehouse, located in Tome-city (Figure 6-(a)). The following SI devices are installed in the basement with L-shape plan; 61 m in the East-West direction and 58 m in the North-South direction: 34 lead rubber bearings (LRB) (6 with diameter 650 mm and 28 with diameter 700 mm) , 11 elastic-sliding bearings (6 with diameter 500 mm and 5 with diameter 600 mm), and 8 U-shape steel dampers. a) According to the person in charge of the building, no furniture was turned over and no structural damage was observed. However, because of the movement of SI floor during earthquake, the bolts of steel dampers became loose and the paint on the dampers was peeled off widely. Also a large amount of residual deformation of steel was remained (Figure 6-(b)).

(a) Overview of the building

(b) Deformation of steel damper

Figure 6: SI Building (L)

2.5 SI building (M)

The SI building (M) is a 6 story steel building with one story basement used for hospital, located in Ishinomaki-city (Figure 7-(a)). Lower part of the building up to second story has the 100 m × 100 m square plan and higher part has 100 m × 25 m plan.

The following SI devices are installed in the basement: 6 natural rubber bearings (NRB) with diameter 1000 mm, 16 laminated rubber bearings with diameter 1000 mm with U shape steel dampers, 16 U shape steel dampers, 74 elastic sliding dampers (30 with 400 mm diameter, 25 with 600 mm diameter, 11 with 800 mm diameter and 8 with 900 mm diameter). According to the person in charge of the building, up-down shaking happened together with horizontal shaking during earthquake. On the 6th floor, contents inside of the rooms such as refrigerators and shelves were moved or turned over, and the fire protection steel door moved to open and hit against the ceiling by vertical shaking causing the damage to the lamp covers. From the trace on the scratch board in the SI floor, the maximum displacement was estimated around 25 cm in the West direction. This displacement was also confirmed from the trace of movement of the sliding bearing (Figure 7-(b)). The bolts of steel dampers became loose and the paint on the dampers was peeled off widely (Figure 7-(c) and (d)).

(a) Overview of the building

(b) Trace of movement of sliding damper

(c) Overview of the building

(d) Trace of movement of sliding damper

Figure 7: SI Building (M)

3. Conclusion

In Japan, construction of seismically isolated buildings is increasing rapidly. The superior performance of seismic isolation has become clear every time experiencing a large earthquake. However, since the seismic isolation techniques is still a new technology, it is necessary to consider the benefits of technology from various perspectives.

From the investigation of 17 seismically isolated buildings located in the disaster area of the 2011 Tohoku Earthquake, the following points were revealed:

1) Super-structures of all seismically isolated buildings suffered almost no damage even under strong shaking with JMA intensity 6 plus. It verifies the excellent performance of seismically isolated buildings.

2) In most cases, the maximum displacement has been estimated around 20 cm. There was one case with the maximum displacement estimated over 40 cm.

3) On the other hand there is no damage to super-structure; damage was observed at the expansion joints. It seems that parts of expansion joints were not well operated due to the large displacement of seismically isolated floor during earthquake.

4) Also damage was seen in the seismic isolation devices. Many cracks were found in lead dampers that might be increased by the aftershocks. Loose of the bolts and peeling off the paint was observed widely for U-shape steel dampers. In some cases, residual deformation of steel was remained.

From the survey results, it can be seen that the safety and function of the building was ensured after the earthquake by adopting seismic isolation technology. On the other hand, damage to non-structural members and damper devices was widely seen. It is necessary to pay more attention to these points when seismic isolation technology is employed.

Also, it was confirmed that some steel dampers experienced plastic deformation during the earthquake; however, it is unclear how much of plastic deformation capacity is left. Therefore, it is required to install a sensor in seismically isolated floor to measure the amount of deformation.

Reference

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