9. Response of Seismically Isolated Buildings

9.1 Outline of Surveyed Buildings

Miyagi prefecture and nearby areas have experienced disastrous earthquakes frequently, thus there are many seismically isolated buildings (hereinafter referred to as SI buildings) constructed in those areas. The Joint Survey Team was dispatched on 1st and 2nd June, 2011 to observe performance of SI buildings during the earthquake and asked persons in charge of the buildings about the damage. In total, 16 SI buildings in Miyagi prefecture and one SI building in Yamagata prefecture were surveyed. Table 9.1-1 shows the list of SI buildings surveyed.

Table 9.1-1 List of SI buildings surveyed on 1st and 2nd June, 2011

	Usage	Year of Con-struction	Super-Structure		Isolation Device*2	Existence of Record		JMA Seismic Intensity at the nearest observatory
			Type*1	# of Floors		Displace-ment (scratch)	Accel-eration	
A	Office	2009*3	SRC	9	HRB	○	○	6 lower
B	Warehouse	1996	S	1	HRB	○		6 lower
C	Condominium	2007	RC	14	NRB, LD, USD			6 lower
D	Condominium	2011	RC	12	LRB, USD			6 lower
E	Condominium	2009	RC	15	LRB, ESB	○		6 lower
F	Condominium	2009	RC	10	HRB, ESB			6 lower
G	Hospital	2001	RC	6	LRB, ESB			6 lower
H	Office	1999	RC	18	NRB, ESB	○	○	6 lower
I	Hotel	1998	RC	12	NRB, LD, LSD			6 upper
J	Fire station	2006	S	3	LRB, SB, OD			6 upper
K	Hospital	2002	RC	5	LRB, NRB, OD			6 upper
L	Fire station	2008	RC	3	LRB, ESB, USD	○		6 lower to 6 upper
M	Hospital	2006	S	6	NRB, NRB+USD, USD, ESB	○		5 upper
N	Fire station	2007	RC	3	NRB, ESB, OD	○		5 upper to 6 lower
O	Hospital	2003	RC	4	NRB, LRB, ESB, LSD			6 lower
P	Hospital	2000	RC	10	NRB, LD, LSD		○	4
Q	Hospital	2002	SRC	4	LRB, SB, OD	○		5 upper

*1 SRC: Steel Reinforced Concrete, RC: Reinforced Concrete, S: Steel

*2 NRB: Natural Rubber Bearing, LRB: Lead Rubber Bearing, HRB: High-damping Rubber Bearing, ESB: Elastic Sliding Bearing, SB: Sliding Bearing, LD: Lead Damper, USD: U-Shaped Steel Damper, LSD: Loop-Shaped Steel Damper, OD: Oil Damper (Hereinafter referred to as above abbreviations)

*3 Newly constructed in 1982 and retrofitted by seismic isolation in 2009.

9.2 Behavior of Seismically Isolated Buildings

In this section, 5 SI buildings (A, B, C, L and M in Table 9.1-1) are picked up to describe typical damages and situations under the 2011 Tohoku earthquake (mainly at mainshock).

9.2.1 SI building (A)

(1) Building information

The SI building (A) is a steel reinforced concrete office building with 9-story super-structure and 2-story basement, located in Miyagino ward in Sendai city (Photo 9.2-1). 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 HRBs are installed.

(a) Overview of the building

(b) Sign board to warn about seismic gap

Photo 9.2-1 SI building (A) – SRC office building –

(2) Building performance during the earthquake

Observation results are summarized as follows:

a) According to the person in charge of the building, no furniture was turned over and no structural damage was observed.
b) 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 (Photo 9.2-2). It seems that parts of expansion joints were not well operated due to the large displacement of SI floor during the earthquake.
c) The ground surrounding the building partially subsided around 10 cm.

(a) Damage to the panel

(b) Damage to the expansion joint

Photo 9.2-2 Damage near the boundary between isolated and non-isolated floors

(3) Earthquake motion records

Accelerometers were installed in this building at B2F, 1F and 9F (top floor). A scratch board was also installed in B1F to record the displacement of isolation interface. Furthermore, there is an accelerometer installed by JMA in the basement of an adjacent building. The maximum acceleration values of these accelerometers at the mainshock are listed in Table 9.2-1.

Table 9.2-1 Maximum acceleration values

Location	Direction		
	NS [gal]	EW [gal]	Vertical Z [gal]
Basement of adjacent building	409.9	317.9	251.4
B2F (below SI)	289.0	250.8	234.9
1F (above SI)	120.5	143.7	373.7
9F	141.7	169.9	523.9

From the trace on the scratch board installed on the SI floor (Photo 9.2-3), the maximum displacement was estimated as around 18 cm at the mainshock on 11 March, 2011 and around 10 cm at an aftershock on 7 April, 2011 (Photo 9.2-4).

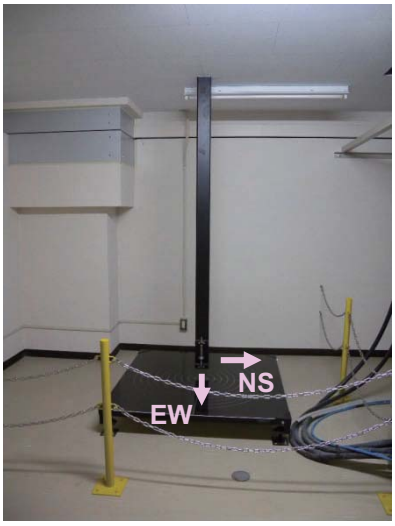
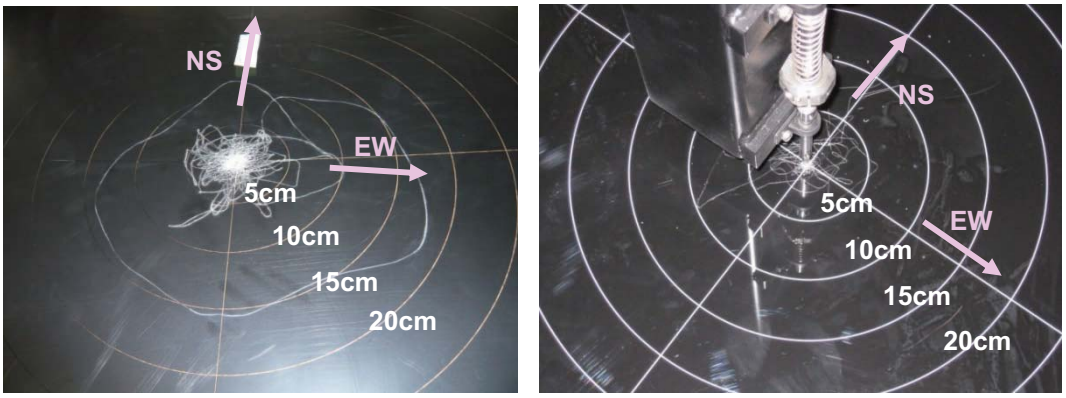


Photo 9.2-3 Scratch board installed on the SI floor



(a) Trace at the mainshock on 11 Mar. (b) Trace at an aftershock on 7 Apr.

Photo 9.2-4 Trace of displacement of SI floor during earthquake

9.2.2 SI building (B)

(1) Building information

The SI building (B) is a one-story steel warehouse constructed in 1996, located in Miyagino ward in Sendai city (Photo 9.2-5). 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.

Photo 9.2-5 SI building (B) – Steel warehouse -

(2) Building performance during the earthquake

Since the building is located near the Sendai-Shiogama bay, tsunami reached the building and the SI floor was submerged under water. The building also suffered the damage to outer walls by the collision of floating debris (Photo 9.2-6). Observation results are summarized as follows:

a) According to the person in charge of the building, other warehouses nearby had trouble of cargo-shift or collapse of stuff by the earthquake. On the contrary, this SI warehouse had no such trouble at all. Since this warehouse is a freezer, tsunami water entered in the freezer space was frozen. It took 16 days to remove the water from the SI floor.

b) Tsunami height was estimated around 4.0 m from the trace of water on the wall (Photo 9.2-7) and damage situation of surrounding buildings (Photo 9.2-8). There was no information about the direction and impact force of tsunami.

c) The ground was excavated in northeast corner of the building around 1.0 m depth, probably because of the water flow from the building at the moment of tsunami (Photo 9.2-9).

d) 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 (Photo 9.2-10).

Photo 9.2-6 Damage due to debris

Photo 9.2-7 Trace of tsunami water

Photo 9.2-8 Tsunami damage to surrounding buildings

Photo 9.2-9 Excavation of ground

Photo 9.2-10 Rust of High-damping rubber bearing

(3) Earthquake motion records

From the trace on the scratch board in the SI floor, the maximum displacement

was estimated as around 21 cm at the mainshock (Photo 9.2-11).

Photo 9.2-11 Trace of displacement of the SI floor on the scratch board

9.2.3 SI building (C)

(1) Building information

The SI building (C) is a 14-story reinforced concrete building used for condominium, located in Miyagino ward in Sendai city (Photo 9.2-12). The building has U-shaped plan and corners of the building are separated by expansion joints. There are 24 NRBs, 8 LDs and 13 USDs installed in the SI floor.

(a) Overview of the building (b) Sign board to warn about seismic gap

Photo 9.2-12 SI building (C) – RC condominium building –

(2) Building performance during the earthquake

Observation results are summarized as follows:

a) According to the person in charge of the building, no furniture was turned over and no structural damage was observed inside of rooms. However, the damage to the expansion joint was observed.

b) Drop of the ceramic tiles on outer wall (Photo 9.2-13) and shear crack on the wall in

the first floor parking space (Photo 9.2-14) were observed. The subsidence of ground around 10 cm was observed around the building.

c) No damage was found to RBs by visual inspection (Photo 9.2-15), however, paint of USDs was peeled off (Photo 9.2-16) and many cracks were found on LDs (Photo 9.2-17).

Photo 9.2-13 Drop of ceramic tiles

Photo 9.2-14 Shear crack on the wall

Photo 9.2-15 Natural rubber bearing

Photo 9.2-16 U-shaped steel damper

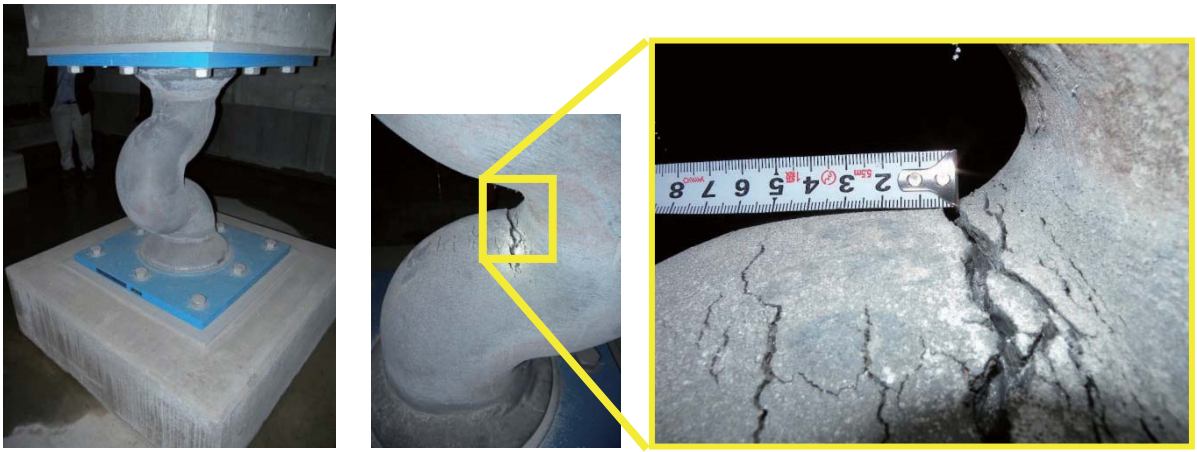


Photo 9.2-17 Lead damper and cracks on the surface

9.2.4 SI building (L)

(1) Building information

The SI building (L) is a 3-story reinforced concrete building used for fire station, located in Tome city (Photo 9.2-18). The following SI devices are installed in the basement with L-shaped plan; 61 m in the east-west direction and 58 m in the north-south direction:

- 34 LRBs (6 with diameter 650 mm and 28 with diameter 700 mm)
- 11 ESBs (6 with diameter 500 mm and 5 with diameter 600 mm)
- 8 USDs

(a) Overview of the building

(b) Sign board to warn about seismic gap

Photo 9.2-18 SI building (L) – RC fire station building –

(2) Building performance during the earthquake

Observation results are summarized as follows:

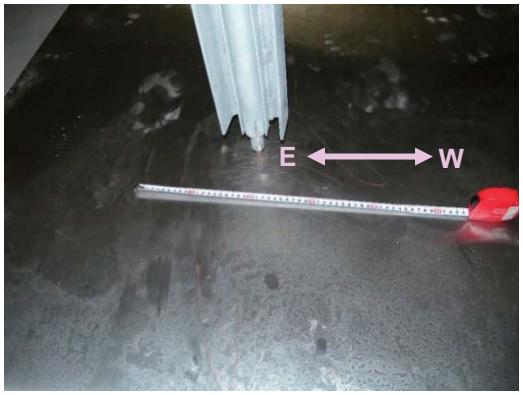
a) According to the person in charge of the building, no furniture was turned over and no structural damage was observed.
b) Because of the movement of the SI floor during the earthquake, the bolts of steel dampers became loose and the paint on the dampers was peeled off widely. Furthermore, a large amount of residual deformation of steel was remained (Photo 9.2-19).

(3) Earthquake motion records

According to the scratch board in the SI floor, the maximum displacement was estimated as around 40 cm northward (Photo 9.2-20). The displacement was also confirmed from the trace of scratch found at the expansion joint outside of the building.

(a) Peeling off of paint (2) Deformation of steel

Photo 9.2-19 Deformation of U-shaped steel damper



(a) Around 40 cm northward (b) Around 15 cm eastward and 22 cm westward

Photo 9.2-20 Trace of displacement of the SI floor on the scratch board

9.2.5 SI building (M)

(1) Building information

The SI building (M) is a 6-story steel building with one story basement used for hospital, located in Ishinomaki city (Photo 9.2-21). 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 NRBs with diameter 1000 mm
- 16 NRBs with diameter 1000 mm with USD
- 74 ESBs (30 with 400 mm diameter, 25 with 600 mm diameter, 11 with 800 mm diameter and 8 with 900 mm diameter)

(2) Building performance during the earthquake

Observation results are summarized as follows:

a) According to the person in charge of the building, up-down shaking happened together with horizontal shaking during the 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. Above the 4th floor, PC monitors were turned over.

b) In the penthouse, anti-vibration rubber of a power generator was moved and the bottom part of a water tank was broken.

c) Because of the movement of the SI floor during the earthquake, the bolts of the steel dampers became loose and the paint on the dampers was peeled off (Photo 9.2-22).

d) The ground around the building subsided around 20 cm.

(a) Overview of the building

(b) Sign board to warn about seismic gap

Photo 9.2-21 SI building (M) – Steel hospital building –

(3) Earthquake motion records

From the trace on the scratch board in the SI floor, the maximum displacement was estimated as around 25 cm westward (Photo 9.2-23). The displacement was also confirmed from the trace of displacement of the ESB (Photo 9.2-24).

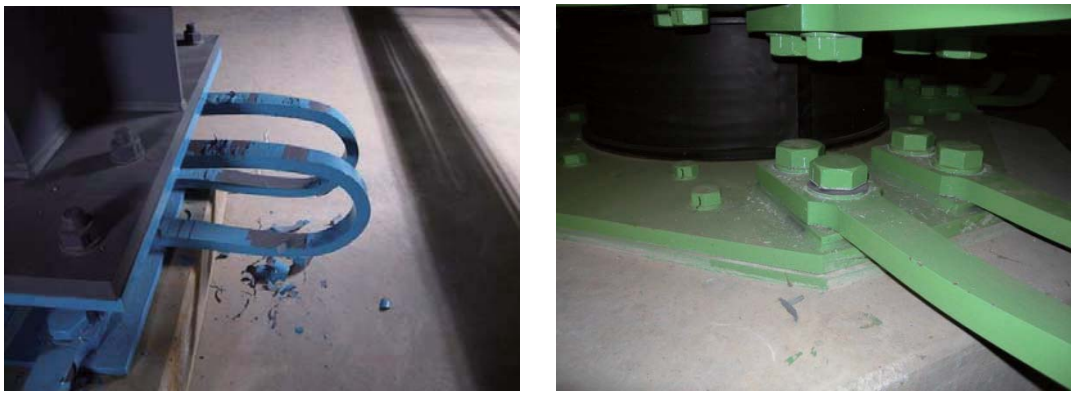


Photo 9.2-22 Peeling off of paint and loose of the bolts of U-shaped steel dampers

Photo 9.2-23 Trace of displacement of the SI floor on the scratch board

Photo 9.2-24 Trace of displacement of elastic sliding bearing

9.3 Results of Survey

Investigation results of 16 SI buildings in Miyagi prefecture and one SI building in Yamagata prefecture are summarized as follows:

a) Super-structures of the SI buildings suffered almost no damage even under strong shaking with JMA intensity 6 upper. It verifies the performance of the SI buildings.

b) There are 8 buildings with scratch boards to measure displacement of the SI floor.

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

c) 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 the SI floor during the earthquake.

d) Subsidence of ground around the building was observed in some buildings.

e) Many cracks were found in lead dampers. A number of cracks might be increased by aftershocks.

f) Peeling off of paint was observed widely for U-shaped steel dampers. In some cases, residual deformation of steel remained.