PERFORMANCE OF BASE-ISOLATED BUILDINGS UNDER THE 2011 EAST JAPAN EARTHQUAKE

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Introduction

Many buildings in the east area of Japan were strongly shaken under the East Japan Earthquake on March 11, 2011.

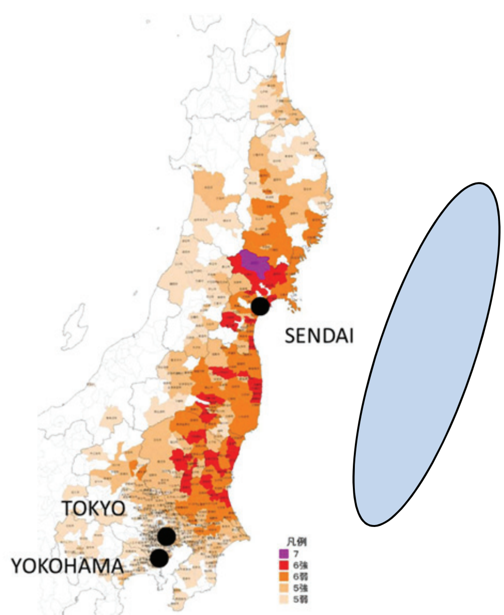
At that time, the number of base-isolated buildings in Japan was 2,600 or more.

Soon after the earthquake, the Japan Society of Seismic Isolation (JSSI) established a research committee to find the actual performance of base-isolated buildings.

The conclusion of the committee's research through 327 base-isolated buildings is as follows.

All base-isolated buildings showed good performance in both extremely shaken area and strongly shaken area. Superstructures were not damaged and nonstructural components were mostly protected.

1. Some damages of finishing material to expansion joints were observed at about 30 % of the base-isolated buildings
2. Cracks of lead damper were observed at a few buildings. Also looseness of bolt fasteners of steel dampers was observed at a few buildings.



1. The Behaviors of Two Base-Isolated Buildings

Earthquake acceleration records were collected from 20 base-isolated buildings. By analyzing them, we recognized that those 20 buildings showed good behaviors of shaking that were reduced effectively. Now we are going to show you two examples.

One is the action of a building built in Yokohama where the earthquake motion was strong (Japanese seismic intensity of 5+).

The other one is the action of a building built in Sendai where the earthquake motion was very strong (Japanese seismic intensity of 6+)

1.1 Building A in Yokohama

Building A is a school which has 7 floors above ground and total floor area is 18,600m^2 total floor areas.

The building is made of steelwork and is seismically isolated at the foundation. Isolation devices are high damping rubber bearing and oil dampers.

The maximum values of acceleration at each floor are shown in table 1. Those value show that the horizontal responses both in x and y direction were reduced by base isolation system.

Table 1.

FL.	**Maximum Acc. (gal)**		
	X	**Y**	**Z**
R	98.5	99.5	103.0
4	59.5	66.0	-
1	50.8	68.2	42.3
B	146.6	86.6	53.9

We estimated the relative displacement between the base and 1st floor by integrating twice the acceleration records. By using this relative displacement and acceleration records, we estimated the restoring force characteristic of the seismic isolation level. The characteristic during 140 to 150 seconds is shown in Fig.1. This figure also shows that the damping system worked effectively. The estimated orbit of this building is shown in Fig.2.

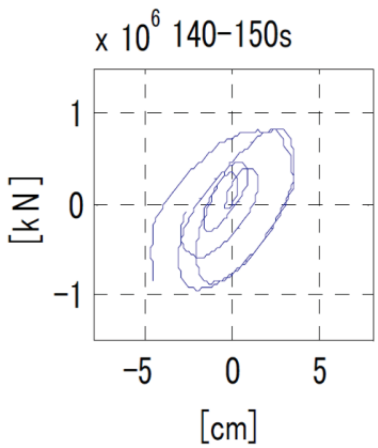


Figure 1. Restoring Force Characteristic(A)

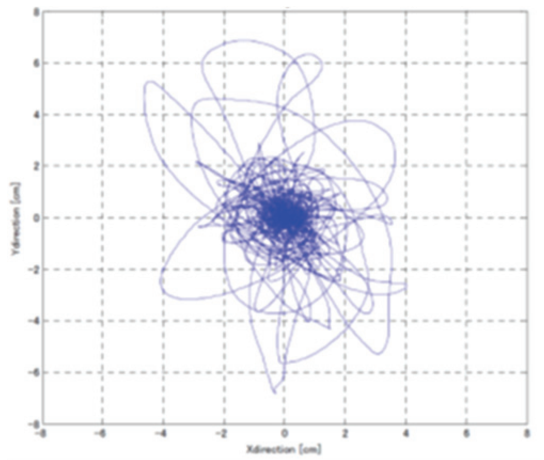


Figure 2. Isolator orbit(A)

1.2 Building B in Sendai

Building B is an office which has 9 floors above ground and 2 floors below ground and the total floor area is 18,000m^2.

The building is made of steel encased reinforced concrete and is seismically isolated under 1st floor. Lead plug rubber bearing and natural rubber bearing are used for the isolation devices for this building.

The maximum values of acceleration at each floor are shown in table 2. Those value show that the horizontal responses in both x and y direction were reduced by base isolation system.

Table 2.

	Maximum Acc. (gal)		
FL	**X**	**Y**	**Z**
9	169.9	141.7	524.0
1	143.8	120.5	373.7
B2	250.8	289.0	234.9

The characteristic during 75 to 100 seconds is shown in Fig.3. This figure also shows that the damping system worked effectively. The estimated orbit of this building is also shown in Fig.4

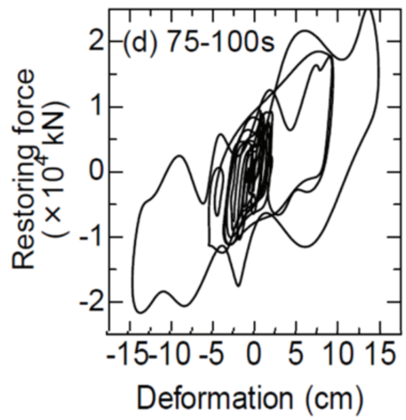


Figure 3. Restoring Force Characteristic(B)

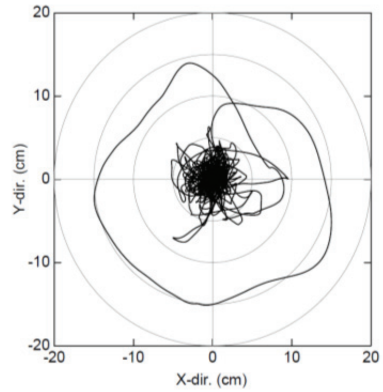


Figure 4. Isolator orbit(B)

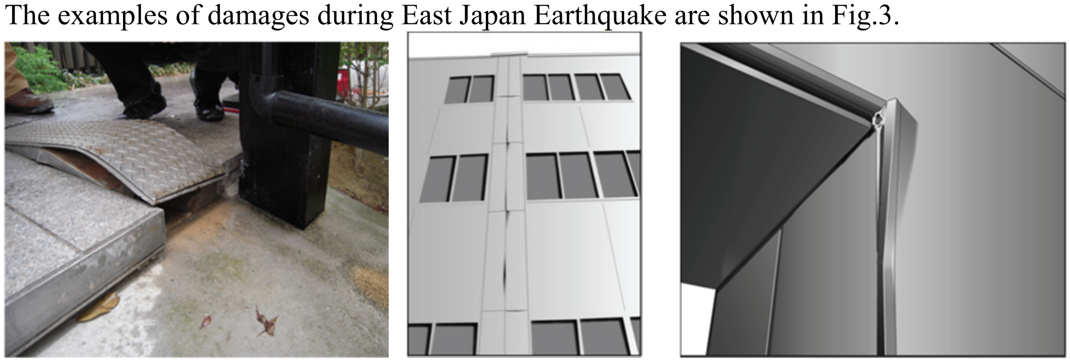
2. Damages of Finishing Material to the Expansion Joints

According to the investigation report of 327 base-isolated buildings, damages of finishing material to expansion joints were observed in 30% of the base-isolated buildings.

2.1 Causes of Damages

Base-isolated building is a building which collects earthquake displacement into the isolation level. Therefore, finishing materials which cover the horizontal and vertical clearance at the isolation level have to follow with the motion. If it could not follow with the motion, the finishing material would be destroyed.

The examples of damages during East Japan Earthquake are shown in Fig.3.



Floor Panel to Post Wall Panel Ceiling Panel to Wall Panel

Figure 5. Examples of damage

According to the survey, damages of finishing material to expansion joints were the result of causes listed below.

1. Insufficient consideration of dynamic and cyclic behavior.
2. Unintended contact with other elements.
3. Lack of strength and deformation capacity.

4. Neglecting unique considerations required for joints during construction.
5. Misunderstandings the required deformation capacity to one direction only.

2.2 Measures against Damages

To prevent similar damages at future earthquake, JSSI has developed the recommendations. The recommendations include method of quality control and maintenance management.

The recommendations emphasize the importance of setting up appropriate target performance of finishing material to expansion joints at the design stage and to carry out and maintain the actual performance after construction.

The following items have to be acknowledged before setting up the target performance of finishing material.

1. Fatal damage must be prevented.
   Even if the maximum displacement occurs,
   1) People must not be injured.
   2) There must not be any serious trouble in the case of refuge or help is needed.
   3) Continuous use of building must be possible.

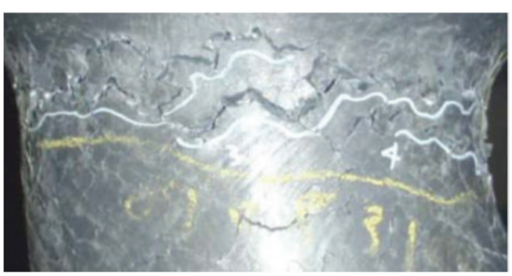
2. Allowable damage should be considered and confirmed.
   A damage of finishing material to expansion joint may be allowable unless it is not a fatal damage. However, if damage occurs, it has to be repaired, hence cost performance should also be considered. In order to study cost performance, allowable damage in each part has to be set up.

3. Damages of Dampers

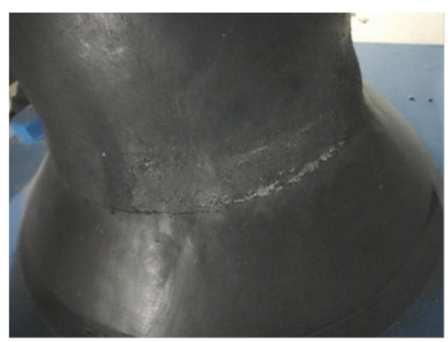
According to the investigation most of isolation and damping devices worked well. However some troubles i.e., crack of lead dampers and looseness of bolt fasteners of steel dampers were observed.

3.1 Crack of Lead Dampers

Some cracked lead dampers were found in Sendai and Yokohama. Examples are shown in Fig.6.



(cracked depth) 30mm



(cracked depth) 7mm.

Figure 6. Crack of lead dampers

The possibility of cracking in lead dampers was reported a few years ago by the manufacturer. The manufacturer had reported that repetition of small strain for many times might cause the crack. The East Japan Earthquake was a huge earthquake and the earthquake motion continued for a long time. Also the aftershocks continued many times. Therefore, such repetition of ground motion is assumed to be the cause of cracks of lead dampers.

When such crack occurred, to know the residual capacity of the lead damper is an important subject. According to our study, the residual capacity can be presumed as follows.

$$a = 1 - \frac{p}{r}$$

a : residual energy ratio to initial energy

p : cracked depth

r : radius of lead dumper

The coating method for preventing crack is now under research.

3.2 Damage of Bolt Fasteners of Steel Dampers

The paint coat was peeled off and bolt fasteners were loosened in some steel dampers. (Fig.7)

Suggestions for improving the painting and bolt tightening method have been made.

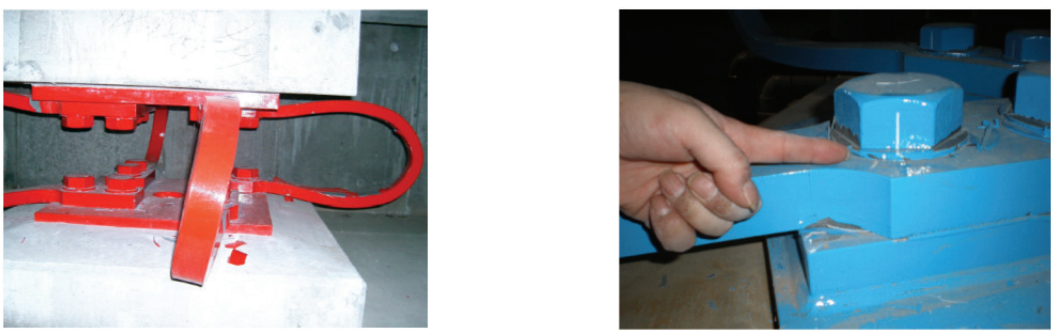


Figure 7. Damage of bolt fasteners of steel dampers

Conclusion

Under the 2011 East Japan Earthquake, base-isolated buildings functioned properly to suppress the shake of building and prevented structural damage.

However, some damage of finishing material to expansion joints and dampers occurred.

Although those damages may be minor obstacles to safety, it can not be neglected from a total building safety.

In order to prevent such damages, it is important to set up the performance objectives concretely. And to design, to build and to maintain the performance objectives are even more important.

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