Performance of High-rise Buildings and Seismically Isolated Buildings at the 2011 Great East Japan Earthquake

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Topics
1. The 2011 Great East Japan Earthquake
2. Performance of high-rise buildings
3. Performance of seismically isolated buildings

2011 Great East Japan Earthquake

Casualties  Source: National Police Agency, as of 22 December 2011

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Deaths</td>
<td>15,843</td>
</tr>
<tr>
<td>Missing</td>
<td>3,469</td>
</tr>
<tr>
<td>Injured</td>
<td>5,890</td>
</tr>
</tbody>
</table>

More than 95% by Tsunami

Other factors (not official source)
- 0 building collapse
- 5 falling down of ceiling panels
- 3 falling down of bridge
- 3 falling down of outer wall
- 25 land slide
- ...

Next M=9.0 earthquake may hit south part of Japan

2. Performance of high-rise buildings
Strong motion observations for buildings by BRI

We obtained data at 54 stations (from Hokkaido to West Japan)

Earthquake observation of High-rise buildings

Max. Acc. 259 gal
Max. Acc. 299 gal
Max. Acc. 346 gal
Max. Acc. 379 gal
Max. Acc. 129 gal
Max. Acc. 99 gal

Shaking of high-rise buildings in Tokyo at the 2011 Great East Japan Earthquake

High-rise office building in Osaka

Max. Acc. 3 m
Max. Acc. 259 gal
Max. Acc. 346 gal
Max. Acc. 299 gal
Max. Acc. 129 gal
Max. Acc. 99 gal

3m movement by BRI shaking table

High-rise office building in Osaka

Max. Acc. 3 m
Max. Acc. 259 gal
Max. Acc. 346 gal
Max. Acc. 299 gal
Max. Acc. 129 gal
Max. Acc. 99 gal
Vibration characteristics of Steel high-rise building

- T=2.0 sec
- h=2%
- 163 gal

(from BRI strong motion observation)

Vibration characteristics of RC high-rise building

- T=1.9 sec
- T=2.5 sec
- h=6%
- 87 gal

(from BRI strong motion observation)

High-rise building with dampers

Steel building, 54 stories, 216m, constructed in 1979, Tokyo

- 288 Oil dampers

(from TAISEI cooperation)

Effects of the Countermeasure

- Damping Ratio (Transverse direction)
  - Without Damper: 1.3 %  - Niigata Chuetsu Earthquake, 2004
  - With Dampers: 0.7 %  - Great East Japan Earthquake, 2011

Maximum Displacement (Roof level of transverse direction)

- Without Damper: 110 cm
- With Dampers: 84.5 cm  - 22% Reduction

Roof Level Displacement of Transverse Direction (Analysis)

(from TAISEI cooperation)

List of 17 SI buildings investigated by BRI and NILIM

<table>
<thead>
<tr>
<th>Usage</th>
<th>Structural type and number of floors</th>
<th>Existence of scratch board</th>
<th>Existence of earthquake record</th>
<th>JMA Intensity near the building</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Office</td>
<td>8F + B2F</td>
<td>○</td>
<td>5 minus</td>
</tr>
<tr>
<td>B</td>
<td>Warehouse</td>
<td>9F, 3F</td>
<td>○</td>
<td>6 minus</td>
</tr>
<tr>
<td>C</td>
<td>Condominium</td>
<td>12F, 13F</td>
<td>○</td>
<td>6 minus</td>
</tr>
<tr>
<td>D</td>
<td>Condominium</td>
<td>11F, 12F</td>
<td>○</td>
<td>6 minus</td>
</tr>
<tr>
<td>E</td>
<td>Condominium</td>
<td>10F, 11F</td>
<td>○</td>
<td>6 minus</td>
</tr>
<tr>
<td>F</td>
<td>Condominium</td>
<td>9F, 10F</td>
<td>○</td>
<td>6 minus</td>
</tr>
<tr>
<td>G</td>
<td>Hospital</td>
<td>8F, 9F</td>
<td>○</td>
<td>6 minus</td>
</tr>
<tr>
<td>H</td>
<td>Office</td>
<td>13F - B2F</td>
<td>○</td>
<td>9 minus</td>
</tr>
<tr>
<td>I</td>
<td>Hotel</td>
<td>12F, 13F</td>
<td>○</td>
<td>6 plus</td>
</tr>
<tr>
<td>J</td>
<td>Condominium</td>
<td>6F, 7F</td>
<td>○</td>
<td>6 plus</td>
</tr>
<tr>
<td>K</td>
<td>Hospital</td>
<td>5F, 6F</td>
<td>○</td>
<td>6 plus</td>
</tr>
<tr>
<td>L</td>
<td>Firehouse</td>
<td>5F, 6F</td>
<td>○</td>
<td>6 minus - 7 plus</td>
</tr>
<tr>
<td>M</td>
<td>Hospital</td>
<td>4F, 5F</td>
<td>○</td>
<td>8 plus</td>
</tr>
<tr>
<td>N</td>
<td>Firehouse</td>
<td>3F, 4F</td>
<td>○</td>
<td>5 plus - 6 minus</td>
</tr>
<tr>
<td>O</td>
<td>Hospital</td>
<td>3F, 4F</td>
<td>○</td>
<td>6 minus</td>
</tr>
<tr>
<td>P</td>
<td>Hospital</td>
<td>5F, 6F</td>
<td>○</td>
<td>6 plus</td>
</tr>
<tr>
<td>Q</td>
<td>Hospital</td>
<td>4F, 5F</td>
<td>○</td>
<td>5 plus</td>
</tr>
</tbody>
</table>

3. Performance of seismically isolated buildings
SI building (A)

Local government office (retrofitted by SI)

Sign board to warn about seismic gap

Damage near the boundary between isolated and non-isolated floors
(from BRI & NILIM report)

SI building (A)

Accelerometers at B2F, 1F and 9F (top floor).

<table>
<thead>
<tr>
<th>Location</th>
<th>Horizontal X(EW) [gal]</th>
<th>Horizontal Y(NS) [gal]</th>
<th>Vertical Z [gal]</th>
</tr>
</thead>
<tbody>
<tr>
<td>B2F (below SI)</td>
<td>250.6</td>
<td>289.8</td>
<td>234.9</td>
</tr>
<tr>
<td>1F (above SI)</td>
<td>143.7</td>
<td>120.5</td>
<td>373.7</td>
</tr>
<tr>
<td>9F</td>
<td>169.9</td>
<td>141.7</td>
<td>523.9</td>
</tr>
</tbody>
</table>

40 HRBs are installed

Scratch board
Main Shock on 3/11 18cm
Aftershock on 4/7 10cm
(from BRI & NILIM report)

SI building (B)

Warehouse building

Tsunami damage

Excavation of ground by Tsunami
(from BRI & NILIM report)

SI building (B)

21cm

(4m)

(from BRI & NILIM report)

SI building (B)

24 HRBs

(from BRI & NILIM report)

SI building (C)

Condominium

NRB Steel damper

Lead damper

(from BRI & NILIM report)
SI building (C)

SI building (L)

SI building (L)

SI building (M)

Fire station

34 LRB

11 elastic sliding bearing

8 steel damper

40cm in the North direction

18cm

20cm

30cm

40cm

Deformation of steel

Hospital

6 NRB (no photo)

16 steel damper + NRB

16 steel damper

74 elastic sliding bearing

(from BRI & NILIM report)
Peeling off of paint
(from BRI & NILIM report)

Loose of bolts
(from BRI & NILIM report)

Chisui-kan (3D isolation system) in Tokyo
Structural design by Kozo Keikaku Engineering
(from Kozo Keikaku Eng.)

Isolator for horizontal movement
Air damper for vertical movement
How to control rocking movement?
(from Kozo Keikaku Eng.)

Conclusions
- Both high-rise buildings and seismically isolated buildings performed quite well during the 2011 Great East Japan Earthquake, almost no damage to structural element.
- However, high-rise buildings experienced large shaking even the building located more than 700km far from epicenter due to long period ground motion. It caused the damage to ceiling panels and elevator facilities.
- For seismically isolated buildings, damage was observed at the expansion joints. Also, many cracks on lead dampers and peeling off of the paint and residual deformation of steel dampers were observed.
First Announcement

Venue: Tohoku University, Kawasaki Campus, Sendai, Japan
Date: 24-27 September, 2013

Program (draft)
- 9:04: Opening ceremony, Keynote lectures
- 9:05: Technical sessions, Reception
- 9:25: Technical sessions, Technical tour
- 9:27: Optional tour for visiting Tsunami disaster area