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Full-Scale Tests on Value-Added Performance of 5-Story Building with Various Dampers Commercially Available


*Tokyo Institute of Technology, Yokohama, Japan
**Nikkenn Sekkei Inc., Tokyo, Japan
***Nat.I Res. Inst. for Earth Science and Disaster Prevention, Miki, Hyogo, Japan
Fig. 1  Organizations of E-Defense Steel Projects
Response-Controlled Bldgs.

Building with dampers has never experienced moderate to stronger earthquakes. So, conduct realistic tests using full-scale model, and

- Verify reliability of different damper types & sizes under in- & out-of-plane dispt.s of small to large magnitudes.
- Measure dynamic properties of the realistic building at various vibration levels (ambient, shaker, & shaking table).
- Confirm improved performance of a typical mid-rise steel office bldg. recognized to vibrate too much. Use minor, major, & catastrophic (Kobe) ground motions.
- Attack unresolved problems on design/analysis by means of challenging data measurement schemes.
- Advance numerical simulation techniques.
  → Blind analysis contest
Full-Scale 5-Story Building with Dampers

Seismically Active Wt.: 4,734 kN
Frame Period: 0.74s (x), 0.79s (y)
With Elast. Steel Damper: 0.53s (x), 0.56s (y)
Beam-Column Joints (w.o. & w. Damper)

(A) BEAM-COLUMN-GUSSET CONNECTIONS

(B) BEAM-COLUMN CONNECTIONS

Sample for Deformation Measurement (Oil Damper Case)
Full-Scale 5-Story Specimen

- **Square Section Col.**: BCR295
  - -350 1F: 19,22 (FA), 2～3F: 16,19 (FA), 4～5F: 12 (FB)

- **Damper**: Steel, Viscous, Oil, Visco-Elastic

- **Beam**: SN490B
  - **Undamped Bay (Beam End)**
    - RF: H-400x200x9x12 (FB)
    - 5F: H-400x200x9x16 (FA)
    - 2～4F: H-400x200x9x19 (FA)
  - **Damped Bay (Beam End)**
    - RF: H-400x200x9x12 (FB)
    - 5F: H-400x200x12x16 (FA)
    - 4F: H-400x200x12x16,19 (FA)
    - 3F: H-400x200x12x19,22 (FA)
    - 2F: H-400x200x12x22 (FA)

- **Total Weight**: 580t (Including Foundation Beam)
Major Damper Types Used in Japan

<table>
<thead>
<tr>
<th>Viscous</th>
<th>Oil</th>
<th>Viscoelastic</th>
<th>Steel</th>
<th>Friction</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Viscous Damper" /></td>
<td><img src="image2" alt="Oil Damper" /></td>
<td><img src="image3" alt="Viscoelastic Damper" /></td>
<td><img src="image4" alt="Steel Damper" /></td>
<td><img src="image5" alt="Friction Damper" /></td>
</tr>
<tr>
<td>Shear/Flow Resist. Panel, Box, Cylinder</td>
<td>Flow Resist. Cylinder</td>
<td>Shear Resist. Brace, Panel, etc.</td>
<td>Axial/Shear Yielding Brace, Panel, etc.</td>
<td>Slip Resist. Brace, Panel</td>
</tr>
<tr>
<td>$F = C \cdot \dot{u}^2$</td>
<td>$F = C_1 \cdot \dot{u}$ or $C_2 \cdot \ddot{u}$</td>
<td>$F = K(\omega) \cdot \dot{u} + C(\omega) \cdot \ddot{u}$</td>
<td>$F = K \cdot f(\dot{u})$</td>
<td>$F = K \cdot f(\dot{u})$</td>
</tr>
</tbody>
</table>

**Fig. 4  Five Types of Dampers Considered by JSSI Manual**

Manual by JSSI (Japan Society for Seismic Isolation)  
Deformations of Dampers vs. Added Components

Steel Damper

Viscous Damper

Oil Damper

Viscoelastic Damper

\[ \hat{u}_d = \hat{u}_c + \hat{u}_d' \] (sum of deformation at both side)

\[ \hat{u}_a = \hat{u}_c + \text{stiffness of supporting member} \]
Full-Scale 5-Story Building with Steel Dampers
Instrumentations (Bldg. w. Dampers)

Strain: 1076ch
  Col.: 360ch, Beam: 480ch, Damper: 96ch, Anchor: 8ch,
  Slab Re-bar: 84ch, Slab Surface: 12ch, ALC Panel Bracket: 36ch

Displacement: 171ch
  Damper: 72+12ch, Drift: 35ch, Foundation: 12ch, ALC Panel: 17ch,
  Curtain Wall: 5ch, Partitions: 8ch, Doors: 2ch, Stairs: 8ch

Accelerations: 88ch
  Floor: 72ch, 1F Tower: 4ch, ALC Panel: 12ch

Synchronization: 3ch

Total: 1338ch (1447ch After Removing Dampers)
## Test Schedule

<table>
<thead>
<tr>
<th>Date</th>
<th>Damper</th>
<th>Largest Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/27 (Fri.)</td>
<td>Steel</td>
<td>Preliminary (elastic)</td>
</tr>
<tr>
<td>3/2 (Mon.)</td>
<td>Steel</td>
<td>JR-Takatori 40%</td>
</tr>
<tr>
<td>3/5 (Thurs.)</td>
<td>Steel</td>
<td>JR-Takatori 100%</td>
</tr>
<tr>
<td>3/11 (Wed.)</td>
<td>Viscous</td>
<td>JR-Takatori 40%</td>
</tr>
<tr>
<td>3/12 (Thurs.)</td>
<td>Viscous</td>
<td>JR-Takatori 100%</td>
</tr>
<tr>
<td>3/18 (Wed.)</td>
<td>Oil</td>
<td>JR-Takatori 40%</td>
</tr>
<tr>
<td>3/19 (Thurs.)</td>
<td>Oil</td>
<td>JR-Takatori 100%</td>
</tr>
<tr>
<td>3/26 (Thurs.)</td>
<td>Viscoselastic</td>
<td>JR-Takatori 40%</td>
</tr>
<tr>
<td>3/27 (Fri.)</td>
<td>Viscoselastic</td>
<td>JR-Takatori 100%</td>
</tr>
<tr>
<td>4/6 (Mon.)</td>
<td>No Damper</td>
<td>JR-Takatori 40%</td>
</tr>
<tr>
<td>4/7 (Tues.)</td>
<td>Np Damper</td>
<td>JR-Takatori 70%</td>
</tr>
</tbody>
</table>
Video Presentation

Full-Scale Passively-Controlled Building:

Vibration Generator Tests

March to April, 2009
Video Presentation

Full-Scale Passively-Controlled Building: Shake Table Tests
(Steel, Viscous, Oil, and Viscoelastic Dampers)

March to April, 2009
Contrasting Example (1)

Frame without Dampers:

Ceiling Failure

April, 2009
Contrasting Example (2)

Seismic Collapse Test of Full-Scale 4-Story Steel MRF

September 27, 2007
JR-Takatori 100% (Collapse)
Full-Scale 5-Story Building with Dampers

Seismically Active Wt.: 4,734 kN
Frame Period: 0.74s (x), 0.79s (y)
With Elast. Steel Damper: 0.53s (x), 0.56s (y)
Story Shear (with Seel Dampers, Takatori 100%, X-Dir.)

5th story

3rd story

1st story

Calculated from inertia forces
Calculated from member forces

(kN)
Hysteresis Curves of Dampers (Seel Dampers, 1st Story)

X-Dir. (D1)

Y-Dir. (D3)

Takatori 15%

Takatori 50%

Takatori 100%
Hysteresis Curves of Dampers (Oil Dampers, 1st Story)

X-Dir. (D1)

Y-Dir. (D3)

Takatori 15%

Takatori 50%

Takatori 100%

D1

D2

D3
Hysteresis Curve of Dampers (Viscous Dampers, 1st Story)

X-Dir. (D1)

Y-Dir. (D3)

Takatori 15%

Takatori 50%

Takatori 100%
Hysteresis Curves of Dampers (Visco-Elastic Dampers, 1st Story)

Takatori 15%

Takatori 50%

Takatori 100%

X-Dir. (D1)

Y-Dir. (D3)
Hysteresis Curves of System (with Steel Dampers)

- Takatori 50% (X)
- Takatori 100% (X)
- Takatori 50% (Y)
- Takatori 100% (Y)

5th story

3rd story

1st story
Maximum Responses (Steel Damper Case vs. No-Damper Case)

Takatori 50%

Takatori 100%

*Values for Takatori 100% (No-Damper Case) are extrapolated as 2 times those for Takatori 50%.
Maximum Responses (with VE. Damper)

**Takatori 50%**

*Values for Takatori 100% (No-Damper Case) are extrapolated as 2 times those for Takatori 50%.*
On-Going Blind Analysis Contest for Steel Damper Case and Viscous Damper Case
Full-Scale Tests of Passively-Controlled 5-Story Steel Building Using E-Defense Shake Table Part 2: Preliminary Analysis Results

Analysis Results (Damper Force – Damper Stroke)

1st story for Y-Dir.

Takatori 100%

Steel

Viscous

Oil

Viscoelastic

Test

Analysis
Conclusions and Future Studies

The bldg. with all 4 damper types performed well under design basis & catastrophic earthqs. Since frame members remained mostly elastic and dampers modeled by clear mathematical equations, analysis was more accurate.

Using test data, design & analysis will be verified and improved, including focused studies on the six challenging issues listed earlier in this presentation.

Cases of frame member yielding, and ultimate state must be studied by applying even stronger quakes to the building. The study should be combined with testing of each major components of the building.