STRUCTURAL DESIGN OF THE SEISMIC RESPONSE CONTROLLED BUILDINGS WITH ROBUSTNESS

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2011 East Japan Earthquake

The expected height of tsunami in its original design was 6m (20'), but actual maximum height was about 14m (47').
Redundancy or Robustness to Disaster

We can’t know or imagine unexpected events exactly, but engineers should speculate all possible events.

Major Earthquake
Stormy Wind
Heavy Rain, Heavy Snow
Tsunami, Flood, High Tide
Volcano Explosion and Falling Ash
Fire or Explosion

Structures should have more redundancy or robustness to such disasters.
Possible Countermeasures to achieve robustness

Robustness:
The potential performance of building to deviation or uncertainty of the design loads, building properties and so on.

<table>
<thead>
<tr>
<th>Uncertainty Factor</th>
<th>Possible Countermeasures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading</td>
<td>Giving some allowance or margin to design load</td>
</tr>
<tr>
<td>Material Property</td>
<td>Taking the deviation of material properties into account, especially properties of isolators or dampers of seismically isolated structures.</td>
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<tr>
<td>Seismic Force</td>
<td>Giving redundant load factor for seismic input</td>
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<tr>
<td>Seismic Response</td>
<td>Giving enough damping to the building, such as steel-dampers or oil-dampers</td>
</tr>
<tr>
<td></td>
<td>Giving some allowance or margin to seismic response</td>
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</table>
Possible Countermeasures to achieve robustness

![Diagram of response spectra with low and high damping]

Giving enough damping to buildings can make seismic behavior of the building stable.

![Diagram of buildings with low stiffness or strength and with through wall-columns]

Installing through wall-columns makes the story drift smaller and prevents story collapse.
Itoya Ginza Building

Ginza 2, Chuo-ku, Tokyo, Japan
Structural Framing Plan

Through wall-column

Oil damper

BRB

Square-shape steel pipe:
□-390x500(1’-3·1/2” x1’-8”)
(1~5F:Concrete Filled Tube)

Oil damper

Adjacent property line

8m(27’)

9m(30’)

300mm (1’)

38m(125’)

Structural Outline
Structural Framing Elevation

- **Steel Pipe**: (Ø 267.4 x 26.5)
- **Through wall-column**: BH–2500x400x28x60 ~ BH–1500x400x22x40
- **Oil dampers**: (500kN)
- **Oil dampers**: (1000kN)
- **Rubber Bearings**: (270 x 270mm)
- **X1Frame**: 8m
- **X9Frame**: 9m
- **X15Frame**: 9m
- **55m**
Through column in historical building

Trough column is installed at the center of the Japanese traditional 5-storied Pagoda. It is suspended from upper floors, preventing story collapse of the building.

Clearance gap beneath the bottom of suspended column

Suspended through column
Input Ground Motions

<table>
<thead>
<tr>
<th>WAVE</th>
<th>Level2</th>
<th>Level3</th>
<th>Time</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Max.Acc (m/sec²)</td>
<td>Max.Vel (m/sec)</td>
<td>Max.Acc (m/sec²)</td>
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<tr>
<td>Observed seismic motion</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>El Centro 1940 NS</td>
<td>5.108</td>
<td>0.50</td>
<td>7.662</td>
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<tr>
<td>Taft 1952 EW</td>
<td>4.966</td>
<td>0.50</td>
<td>7.449</td>
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<tr>
<td>Hachinohe 1968 NS</td>
<td>3.333</td>
<td>0.50</td>
<td>5.000</td>
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<tr>
<td>Ground motion based on building code spectrum</td>
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<tr>
<td>Wave1(E)</td>
<td>3.623</td>
<td>0.78</td>
<td>5.435</td>
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<td>Wave2(T)</td>
<td>3.567</td>
<td>0.44</td>
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<tr>
<td>Wave3(H)</td>
<td>3.751</td>
<td>0.63</td>
<td>5.626</td>
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</tbody>
</table>

Acceleration response spectrum (Level2)

Velocity response spectrum (Level2)
Results of non-linear response history analysis

Response story drift angle to Level2(DBE)
Results of non-linear response history analysis

Response story drift angle to Level3(MCE)
Influence of deviations or uncertainties of structural performance

Assuming: Stiffness of the 5th story has half of original one

Response story drift angle to Level3(MCE)
Effect of Through Wall–Column and Oil dampers

- Effect of Oil-dampers
- Effect of Wall-Column

Ground Motion with Building Code Spectrum (Level 2)
S-Building (seismic retrofit)

- **Additionally Installed Frame**
- **Wall-Columns** (T=500mm)
- **Steel-Dampers** (made of Low-Yield-Point Steel)

Dimensions:
- 21.2m (70')
- 32m (105')
- 24m (80')
Wall-column for seismic strengthening

The wall-columns equalize story drift of the building to prevent story collapse.

Steel spandrel beams are installed between building and wall-columns, and between two adjacent wall-columns.
Results of non-linear response history analysis

Before Strengthening

After Strengthening

Response story drift angle to Level2(DBE)
Results of non-linear response history analysis

Response story drift angle to larger seismic input
Summary

- Through wall-columns with damping devices make it possible to secure good earthquake-resistant performance.

- Such system can provide robustness to the larger seismic input or uncertainties of structural performance.