PEER
Tall Building Seismic Design Guidelines

Case Studies Performance Assessment

Jack P. Moehle
Pacific Earthquake Engineering Research Center
University of California, Berkeley

SEAW
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TBI thanks

- **Sponsors**
  - CSSC – F. Turner, A. Sadre, D. McCarthy
  - CalEMA
  - City of LA
  - Pankow Foundation

- **TBI Guidelines Development Team**

- **Designers**
  - MKA – A. Fry, B. Morgen, J. Hooper, R. Klemencic
  - REI – T. Ghodsi, J.S. Flores Ruiz, R. Englekirk, C. Massie, Y. Chen, E. Hoda, M. Bravo, K. Lee
  - SGH – A. Dutta, R. Hamburger

- **Analysts**
  - URS/SCEC – P. Somerville
  - UCB/UBC – T. Yang, J. Moehle, Y. Bozorgnia
  - UCLA – J. Wallace, Z. Tuna
  - UCI – F. Zareian, P. Zhong, P. Jones

- **Loss Studies**
  - ATC 58 – R. Hamburger, J. Hooper, P. Morris, T. Yang, J. Moehle
  - RMS – N. Shome, M. Rahnana, P. Seneviratna; H. Aslani
1.5Km, Puente Hills
7.3Km, Hollywood
8.8Km, Raymond
11.5Km, Santa Monica
24.5Km, Elsinore
40.0Km, Sierra Madre (San Fernando)
56Km, San Andreas (Cucamonga)
Record selection and scaling

- All the usual challenges for tall buildings
  - Long fundamental period
  - Multiple contributing periods
- ... and more
  - Three different buildings
  - Interest in extreme hazard (> 2500-year return period)
Response Spectra SLE25 (25 year)
Response Spectra SLE43 (43 year)
Response Spectra DBE (475 year)

Matched Spectra for TBI (DBE, 3 & 0.1, 7 & 0.6)

(Sa(T)/g [5% critical damping])

Period (T)

0.2T1

1.5T1

Target Spectrum
Median Spectrum
Indv. Spectrum
Response Spectra MCE (2475 year)
Response Spectra OVE (4975 year)

7 unscaled pairs are from simulated motions (URS/SCEC)
Response Spectra OVE (4975 year)
Building Design and Modeling

Three Building Systems

1. 42-story reinforced concrete core wall
2. 40-story steel special moment-frame
3. Performance-based design guideline for tall buildings
42-Story Concrete Core Wall

Building Design Comparison

1A: Code

24”  24”

$T_{1EW} = 5.2$ sec

1B: PBEE

28”  28”

$T_{1EW} = 4.8$ sec

1C: PBEE+

32”  32”

$T_{1EW} = 4.6$ sec
42-Story Concrete Core Wall
Building Design and Modeling

Three Building Systems

- 42-story reinforced concrete core wall
- 42-story reinforced concrete dual system
- 40-story steel special moment-frame
42-Story Concrete Dual System

Corner Column Concrete Strength and Size Comparison

Code Design

- $f'_c = 5,000 \text{ psi}$
- 36" x 36"
- 15th
- $f'_c = 6,000 \text{ psi}$
- 10th
- $f'_c = 8,000 \text{ psi}$
- Ground
- $f'_c = 10,000 \text{ psi}$

Performance Design

- 30th
- 36" x 36"
- 36th
- $f'_c = 5,000 \text{ psi}$
- 22nd
- 42" x 42"
- 18th
- $f'_c = 6,000 \text{ psi}$
- 10th
- 46" x 46"
- 3rd
- $f'_c = 8,000 \text{ psi}$
- 3rd
- $f'_c = 10,000 \text{ psi}$
Building 2B – Inter-story drifts in H1 direction
Building Design and Modeling

Three Building Systems

- 42-story reinforced concrete core wall
- 42-story reinforced concrete dual system
- 40-story steel special moment-frame
40-Story Buckling Restrained B.F.

Bldg. 3A
$T_{1NS} = 5.3$ sec

Bldg. 3B
$T_{1NS} = 6.5$ sec

Bldg. 3C
$T_{1NS} = 5.7$ sec
<table>
<thead>
<tr>
<th>Return Period</th>
<th>GM set</th>
<th>E-W</th>
<th>N-S</th>
</tr>
</thead>
<tbody>
<tr>
<td>4975 (years)</td>
<td>OVE</td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
</tr>
<tr>
<td>2475 (years)</td>
<td>MCE</td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
</tr>
<tr>
<td>475 (years)</td>
<td>DBE</td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
</tr>
<tr>
<td>43 (years)</td>
<td>SLE43</td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
</tr>
<tr>
<td>25 (years)</td>
<td>SLE25</td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
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</tbody>
</table>

**Building 3A**

MAXIMUM IDR
<table>
<thead>
<tr>
<th>Return Period</th>
<th>GM set</th>
<th>E-W</th>
<th>N-S</th>
</tr>
</thead>
<tbody>
<tr>
<td>4975 (years)</td>
<td>OVE</td>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
</tr>
<tr>
<td>2475 (years)</td>
<td>MCE</td>
<td><img src="image3.png" alt="Graph" /></td>
<td><img src="image4.png" alt="Graph" /></td>
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<tr>
<td>475 (years)</td>
<td>DBE</td>
<td><img src="image5.png" alt="Graph" /></td>
<td><img src="image6.png" alt="Graph" /></td>
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<tr>
<td>43 (years)</td>
<td>SLE43</td>
<td><img src="image7.png" alt="Graph" /></td>
<td><img src="image8.png" alt="Graph" /></td>
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<tr>
<td>25 (years)</td>
<td>SLE25</td>
<td><img src="image9.png" alt="Graph" /></td>
<td><img src="image10.png" alt="Graph" /></td>
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</tbody>
</table>

MAXIMUM IDR

Building 3B

- N-S
- E-W

median

%16th and 84th

Individual earthquake
Return Period | GM set | E-W | N-S
---|---|---|---
4975 (years) | OVE | ![Graph](image) | ![Graph](image)
2475 (years) | MCE | ![Graph](image) | ![Graph](image)
475 (years) | DBE | ![Graph](image) | ![Graph](image)
43 (years) | SLE43 | ![Graph](image) | ![Graph](image)
25 (years) | SLE25 | ![Graph](image) | ![Graph](image)

MAXIMUM IDR

Building 3C

N-S | E-W
---|---
median
%16th and %84th
Individual earthquake
Cost and Benefit Studies

- Construction Costs
  - Detailed building take-offs

- Loss Calculations
  - Generic approach
    - Conventional loss assessment based on inter-story drift and floor acceleration results
    - Similar components in all buildings.
  - Detailed ATC 58 approach
    - Detailed building inventories
    - Detailed losses based on ATC 58 fragilities and consequence functions
## Construction costs (under review)

<table>
<thead>
<tr>
<th>Design</th>
<th>Building 1</th>
<th>Building 2</th>
<th>Building 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$223M</td>
<td>$237M</td>
<td>$355M</td>
</tr>
<tr>
<td>B</td>
<td>$222M</td>
<td>$237M</td>
<td>$340M</td>
</tr>
<tr>
<td>C</td>
<td>$227M</td>
<td>$237M</td>
<td>$345M</td>
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</tbody>
</table>

Source: Davis Langdon
Losses of Different PEER Tall Buildings

- Core Wall: Design 1A
- Core Wall: Design 1B
- Core Wall: Design 1C
- Dual System: Design 2A
- Dual System: Design 2B
- BRB: Design 3A
- BRB: Design 3B
- BRB: Design 3C

After: Nilesh Shome
ATC 58 repair costs

EDP = story drift

Hazard level
- 5/50
- 10/50
- 50/50

Total Cost

Unit Cost, $

C_i

Q_i

Probability

y_0

y_1

y_2

y_3

EDP = story drift

0

1

2

3

4

5

6

0.0

0.5

1.0

0.0

1.0

y_0

y_1

y_2

y_3
Core Wall – Building 1C – 25yrs
Core Wall – Building 1C – 43yrs
Core Wall – Building 1C – 2475yrs
Core Wall – Building 1A
Core Wall Losses