PEER/SSC Tall Building Design

Case study #2

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Acknowledgments:

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Yangbo Chen
Erzen Hoda
Maria Bravo
Kathy Lee
Building Description

Location:

- Downtown Los Angeles, CA.

Use:

- 42 Story Hotel / residential with 4 parking levels below ground

Story heights:

- 10.5 ft. typical
- 13.6 ft. from ground floor to 2nd
- 11.5 ft. at roof
Building Description

Slab Construction:

- 10 in. thick at parking
- 12 in. thick at ground floor
- 8 in. thick post-tensioned typical
- 10 in. thick at roof

Seismic Weight:

- 102,000 kips (Above ground floor)
Design Program

- Building 2
  - Building 2A
    - Code design
      - IBC 2006
        - ASCE 7-05
        - ACI 318-08
  - Building 2B
    - LATBSDC 2008
      - Service Level
        - 25 years return period
      - Collapse Prevention
        - 2,475 years return period
## Stiffness Modifiers

<table>
<thead>
<tr>
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Typical Plan View at Ground Floor and Below
Typical Plan View at 2\textsuperscript{nd} Floor and Above
Code Design

Building 2A
Building 2A Shear Wall properties

Shear wall thickness and concrete strength

- **t = 18”**
  - $f’c = 5,000$ psi

- **t = 24”**
  - $f’c = 6,000$ psi
Building 2A Frame Properties

Frames A & F
Interior & Corner columns
36” x 36”

Frame column concrete strength

- f’c = 5,000 psi
- 15th
- f’c = 6,000 psi
- 10th
- f’c = 8,000 psi
- Ground
- f’c = 10,000 psi
Building 2A Frame Properties

Frame column concrete strength

- $f_c = 5,000$ psi
- $f_c = 6,000$ psi
- $f_c = 8,000$ psi
- $f_c = 10,000$ psi

Interior columns at gridline C.5
- 46” x 46” from Ground to 10th
- 42” x 42” from 10th to 25th
- 36” x 36” from 25th to Roof
Building 2A Periods and Base Shear

Site specific design response spectra

**Periods:**

\[ T_1 = 5.50 \text{ sec.} \]
\[ T_2 = 4.97 \text{ sec.} \]
\[ T_3 = 2.98 \text{ sec.} \]

**Design base shear:**

\[ V_B = 0.043 \text{ W} \]
Design Ductility

**V_{b, min} = 0.043 W**

**V_{b, site specific} = 0.112 W**

**Period = 5.5 sec**

**R = 2.6**

\[ C_s = \frac{S_{DS}}{(R/I)} \]

\[ C_{s, Max} = \frac{S_{D1}}{T(R/I)} \]

\[ C_{s, Min} = 0.44S_{DS}I \]
Building 2A Static Shear Distribution
Building 2A Inter-story Drifts

Maximum inter-story drift allowed
0.020 \( h_n \)
Service Level and Collapse Prevention Design
Building 2B
Exceptions from LATBSDC

1. Service level check is for an earthquake event of 25 year return period with 2.5% viscous damping.

3. Up to 20% of the elements with ductile actions are allowed to reach 150% of their capacity under the serviceability check.

5. The minimum base shear specified by the LATBSDC (2008) is waived.

7. Strengths for ductile actions at service level are calculated using strength reduction factors per ACI 318-08.
Shear Wall Concrete Strength and Thickness Comparison

**Code Design**
- **t = 18"**
  - \( f'c = 5,000 \text{ psi} \)
- **t = 24"**
  - \( f'c = 6,000 \text{ psi} \)

**Performance Design**
- **t = 16"**
  - \( f'c = 5,000 \text{ psi} \)
- **t = 18"**
  - \( f'c = 6,000 \text{ psi} \)
- **t = 24"**
  - \( f'c = 8,000 \text{ psi} \)
Corner Column Concrete Strength and Size Comparison

**Code Design**

- $f'c = 5,000$ psi
- 36” x 36”
- $f'c = 6,000$ psi
- 15th
- $f'c = 8,000$ psi
- 10th
- $f'c = 10,000$ psi
- Ground

**Performance Design**

- 36” x 36”
- 30th
- $f'c = 5,000$ psi
- 22nd
- 42” x 42”
- 18th
- $f'c = 6,000$ psi
- 10th
- 46” x 46”
- 3rd
- $f'c = 8,000$ psi
- $f'c = 10,000$ psi
Response Spectrum Analysis for Service Level Earthquake Building 2B
Service Level Acceptance Criteria

- Gravity load combinations per IBC 2006

- Earthquake actions at service level per
  \[ D_L + 0.25L_L \pm E_{\text{service}} \]
Building 2B Service Level Periods and Base Shear

2.5% damped service level site specific response spectra

**Periods:**

\[ T_1 = 4.13 \text{ sec.} \]
\[ T_2 = 3.81 \text{ sec.} \]
\[ T_3 = 2.21 \text{ sec.} \]

**Base Shear:**

\[ V_{Bx} = 0.043 \text{ W} \]
\[ V_{By} = 0.047 \text{ W} \]
## Strength of Elements at Service Level

### Ductile actions:

- Expected material properties
  - $\phi$ per code

### Brittle actions:

- Specified material properties
  - $\phi$ per code

### CAUTION:

- Specified material properties
  - $\phi$ per code
- Could result in the same design as that prescribed by code
# Classification of Actions

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Inter-story Drifts at Service Level

Overall drift allowed at service level

$0.005 \, h_n$
Modal Analysis Peak Shear at Service Level on X Direction
Pier 1 Service Level Peak Shear on X Direction

\[ \phi 10 A_{cw} \sqrt{f'c} \]
Coupling Beam Shear Demand at Service Level

150% $\phi V_{N\text{expected}}$

20% of elements
Frames 2 & 5 Beam Moment Demand at Service Level

Corner Beam-Column Joint

Interior Beam-Column Joint

Positive Moments

Negative Moments

20% of elements

150% $\phi M_{\text{N expected}}$
Step by Step Time-History Non-Linear Analyses at MCE Level
Building 2B
# Collapse Prevention MCE Level Acceptance Criteria

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<td>Linear</td>
<td>Hinge rotation $&lt; 0.025$ rad</td>
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</tr>
</thead>
<tbody>
<tr>
<td>Reinforced Concrete Frame Beam</td>
<td>Plastic hinge rotation Beam</td>
<td>Ductile</td>
<td>Non-linear</td>
<td>Hinge rotation &lt; 0.045 rad</td>
</tr>
<tr>
<td></td>
<td>Shear</td>
<td>Brittle</td>
<td>Linear</td>
<td>N.A.</td>
</tr>
<tr>
<td>Reinforced Concrete Frame Column</td>
<td>Axial-Flexure interaction</td>
<td>Ductile</td>
<td>Non-linear</td>
<td>Axial compression &lt; 0.40 $f'c_{esp}$ Ag</td>
</tr>
<tr>
<td></td>
<td>Shear</td>
<td>Brittle</td>
<td>Linear</td>
<td>Hinge rotation &lt; 0.025 rad</td>
</tr>
<tr>
<td>Reinforced Concrete Shear walls</td>
<td>Axial-Flexure interaction</td>
<td>Ductile</td>
<td>Non-linear</td>
<td>Concrete compression strain &lt; 0.015</td>
</tr>
<tr>
<td></td>
<td>Shear</td>
<td>Brittle</td>
<td>Linear</td>
<td>Reinforcing rebar tension strain &lt; 0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Axial compression force &lt; 0.35$f'c_{esp}$ Ag</td>
</tr>
<tr>
<td>Reinforced concrete coupling beams</td>
<td>Shear</td>
<td>Ductile</td>
<td>Non-linear</td>
<td>0.06 rad chord rotation</td>
</tr>
</tbody>
</table>
Element Properties for Non-Linear Model

Expected material properties
φ of 1

Demand Actions at MCE Level

**Ductile actions:**
Average of 7 records

**Brittle actions:**
Average of 7 records times 1.5

Element Capacity at MCE Level

Expected material properties
φ equals 1

Specified material properties
φ equals 1
Building 2B MCE Periods and Average Base Shear

MCE target response spectra

**Periods:**

\[ T_1 = 4.93 \text{ sec.} \]
\[ T_2 = 4.50 \text{ sec.} \]
\[ T_3 = 2.78 \text{ sec.} \]

**Base Shear:**

\[ V_{Bx} = 0.154 \text{ W} \]
\[ V_{By} = 0.190 \text{ W} \]
MCE Records Adjusted to Match Target Response Spectra
Peak Story Shear at MCE Level
Inter-story Drifts at MCE Level on X direction

Maximum inter-story drift allowed at MCE level

0.030 \( h_n \)
Pier 1 MCE Average Shear on X Direction

\[ 10A_{cw}\sqrt{f'c} \]
Maximum compression strain allowed for confined concrete

$$\varepsilon_u = 0.015 \text{ in/in}$$

Maximum compression strain allowed for unconfined concrete

$$\varepsilon_u = 0.003 \text{ in/in}$$
Coupling Beam Rotation at MCE Level

Maximum Coupling Beam rotation allowed
\[ \theta_u = 0.06 \text{ rad} \]
Corner Column Peak Shear on X Direction at MCE Level

\[ 8A_c \sqrt{f'c} \]
Corner Column Peak Compression at MCE Level

$0.4 f'c_{\text{exp}} A_g$
Frame A Peak Beam Rotation at MCE Level

\[ \theta_u = 0.045 \text{ rad} \]
Period and Base Shear Comparison

**Code design periods**

\[ T_1 = 5.5 \text{ sec.} \]
\[ T_2 = 4.97 \text{ sec.} \]
\[ T_3 = 2.98 \text{ sec.} \]

**Service level periods**

\[ T_1 = 4.13 \text{ sec.} \]
\[ T_2 = 3.81 \text{ sec.} \]
\[ T_3 = 2.21 \text{ sec.} \]

**MCE level periods**

\[ T_1 = 4.93 \text{ sec.} \]
\[ T_2 = 4.50 \text{ sec.} \]
\[ T_3 = 2.78 \text{ sec.} \]

**Base Shear:**

- **Code design periods**
  \[ V_{Bx} = 0.043 \text{ W} \]
  \[ V_{By} = 0.043 \text{ W} \]

- **Service level periods**
  \[ V_{Bx} = 0.043 \text{ W} \]
  \[ V_{By} = 0.047 \text{ W} \]

- **MCE level periods**
  \[ V_{Bx} = 0.154 \text{ W} \]
  \[ V_{By} = 0.190 \text{ W} \]
Lateral Restrain Provided by Soil Below Ground Floor

Landers Yermo maximum shear on X direction

\[ V_{Bx} = 11.1\% \]

\[ V_{Bx} = 13.5\% \]

20% increase
Lateral Restrain Provided by Soil Below Ground Floor

Loma Prieta Gilroy maximum shear on X direction

$V_{Bx} = 10.7\%$

$V_{Bx} = 15.4\%$

44\%$ increase
Corner Column Axial Load Comparison

Code design column at seismic base:
36”x 36” column
f’c = 8,000 psi

Non-linear design column at seismic base:
46”x 46” column
f’c = 10,000 psi

178% increase
Code Maximum Axial Load

\[ \phi P_{n,\text{max}} = 0.8\phi \left[0.85f'c(A_g - A_{st}) + f_y A_{st}\right] \quad \text{Eq. 10-2 ACI 318-08} \]
Frame Beam Longitudinal Reinforcing Comparison

**Code design:**

- 4#9 T&B

**Performance design:**

- 4#9 T&B
Coupling Beam Diagonal Reinforcing Comparison

**Code design:**

- 4#10
- 6#10
- 8#11
- 10#11

**Performance design:**

- 4#9
- 4#11
- 6#10

32nd
21st
10th
MCE Pseudo-velocity Response Spectra Comparison

At 1 second:
- Code = 57 in/sec
- Site Specific PEER = 47 in/sec
- Downtown 1 & 2 = 70 in/sec
- Westwood = 84 in/sec

At 5 seconds:
- Code = 57 in/sec
- Site Specific PEER = 43 in/sec
- Downtown 2 = 50 in/sec
- Westwood = 61 in/sec
The Englekirk Companies

Questions?