PEER
Tall Building Seismic Design Guidelines

Preliminary Design Recommendations & Performance Studies

John Hooper
Principal & Director of Earthquake Engineering
Magnusson Klemencic Associates

SEAW

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Structural Configuration

- Simple arrangement of structural elements
- Clearly defined load paths
- Complicated configurations and geometries complicate behavior—avoid to the extent possible
System Configuration

Changes in Building Stiffness and Mass
System Configuration

Repositioning of Bracing Elements
Multiple Towers on a Common Base

System Configuration
System Configuration

Column Transfers and Offsets
System Configuration

Gravity Induced Shear Forces
Limited Connectivity of Floor Diaphragms
System Configuration

Concentration of Diaphragm Demands
Structural Performance Hierarchy

- Identify zone or elements of nonlinear response
- Establish hierarchy of the nonlinear elements
- Incorporate capacity design concepts as appropriate for remaining elements
- Confirm hierarchy through nonlinear response history analysis
Desirable Modes of nonlinear response include:

- Flexural yielding of beams, slabs and shear walls
- Yielding of diagonal reinforcement in coupling beams
- Tension yielding in steel braces and steel plate shear walls
- Post-buckling compression in steel braces that don’t support gravity
- Tension/compression yielding in BRBs
Wind
Wind
Higher Mode Effects

Significantly Impact Shear and Flexural Demands
Higher Mode Effects

PEERCSSC SAMPLE DESIGN
CORE WALL ONLY BUILDING 1B
June 8, 2009

Service Level Base Shear, Unscaled from ETABS
Vx 4,636 kips
Vy 5,642 kips

Approximate Base Shear
1st mode 2nd mode 3rd mode SRSS
Vx 2.3% 4.1% 2.0% 5.1%
Vy 3.7% 4.8% 1.9% 6.3%

Building Weight
W 84,670 kips

DATA
Service Spectrum, 25 year MRE @ 2.5% Damping
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<th>Period</th>
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Building 1B Modal Data
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Outrigger Elements

Column Demands Due to Outrigger Over Strength
Serviceability Base Shears
The Performance Study

Three Building Systems

- 42-story concrete core wall
  - Building 1 (MKA)
  - Designs A, B, C

- 42-story concrete dual system
  - Building 2 (REI)
  - Designs A, B, C

- 40-story steel buckling restrained braced frame
  - Building 3 (SGH)
  - Designs A, B, C
The Performance Study

Design A

- All provisions followed except height limits
The Performance Study

Design A

- All provisions followed except height limits
- Seismic
  - $S_s = 2.1$, $S_1 = 0.7$
  - Site class C
  - SDC D
- Wind
  - 85 mph, exposure B
The Performance Study

Design B

- Seismic design to disregard all code requirements
- Design verified by nonlinear analysis
- Wind and gravity design to follow code
The Performance Study

Design B

- 2 Design Levels
  - Serviceability
  - MCE

- Serviceability check
  - 25-yr return period
  - response spectrum analysis
  - essentially elastic
  - transient drift ≤ 0.005

- MCE
  - per ASCE 7-05
  - seven ground motion pairs
  - ductile actions
    - mean demands
    - expected materials, $\phi = 1$
  - brittle actions
    - 1.5 x mean demands
    - specified materials, $\phi = 1$
  - transient drift ≤ 0.03

- Minimum base shear
  - waived
  - strength controlled by 25-yr EQ and Wind
The Performance Study

Design C

- Seismic design to disregard all code requirements
- Design verified by nonlinear analysis
- Wind and gravity design to follow code
The Performance Study

Design C

- 2 Design Levels
  - Serviceability
  - MCE

- Serviceability check
  - 43-yr return period
  - response spectrum analysis (or nonlinear analysis)
  - essentially elastic: D/C ≤ 1.5
  - C based on nominal strength & code $\phi$
  - transient drift ≤ 0.005

- MCE
  - per ASCE 7-05
  - seven ground motion pairs
  - ductile actions
    - mean demands
    - expected materials, $\phi = 1$
  - brittle actions
    - 1.5 x mean demands
    - expected materials, $\phi$ per code
  - transient story drifts
    - mean ≤ 0.03
    - max ≤ 0.045
  - residual story drifts
    - mean ≤ 0.01
    - max ≤ 0.015

- Minimum base shear
  - waived
  - strength controlled by 43-yr EQ and Wind

Seismic Design Guidelines for Tall Buildings

Developed by the Pacific Earthquake Engineering Research Center (PEER) as part of the Tall Buildings Initiative

PEER 2010
Building 1 Example—Information

- Located in Los Angeles
- 42-Story Residential Building
- 410 ft Tall
- 108 ft X 107 ft Plan Dimensions
- Core Wall System
- Approximate Period: 5 Sec
Tower and Core Wall Isometric
Tower Plan
Design B & C Seismic Hazard Spectra

PEER TBI, CSSC Spectra

- (1) MCE Spectra, Site Specific
- (6) Service Spectrum, 25 year MRI @ 2.5% Damping
- (7) Service Spectrum, 43 year MRI @ 2.5% Damping

42% increase through period range of interest
Design B & C—Serviceability Model

- 3-D Model using ETABS
- Elastic RSA
- Model Included Slab Outriggers
# Summary of Results—Code & Serviceability

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<tr>
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<th>Design A</th>
<th>Design B</th>
<th>Design C</th>
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<tr>
<td><strong>Code/Service EQ</strong></td>
<td>$V_x = 4,581$</td>
<td>$V_x = 5,013$</td>
<td>$V_x = 6,686$</td>
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<td><strong>Base Shear (kips)</strong></td>
<td>$V_y = 4,581$</td>
<td>$V_y = 6,018$</td>
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<td><strong>Service EQ</strong></td>
<td>$M_y = 587,000$</td>
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<td><strong>Overturning Moment (kip-ft)</strong></td>
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<td>$M_x = 921,000$</td>
<td>$M_x = 1,371,000$</td>
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<td><strong>Wall thicknesses</strong></td>
<td>Grade – Lvl 25 = 24 in (E-W) and 32 in (N-S)</td>
<td>Grade – Lvl 13 = 28 in (E-W) and 36 in (N-S)</td>
<td>Grade – Lvl 13 = 32 in (E-W) and 36 in (N-S)</td>
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<tr>
<td></td>
<td>Lvl 25 – Roof = 21 in</td>
<td>Lvl 13 – Lvl 31 = 24 in</td>
<td>Lvl 13 – Lvl 31 = 24 in</td>
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<tr>
<td></td>
<td>Lvl 31 – Roof = 21 in</td>
<td>Lvl 31 – Roof = 21 in</td>
<td>Lvl 31 – Roof = 21 in</td>
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<td><strong>Periods (sec)</strong></td>
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<td>(ETABS)</td>
<td>(PERFORM)</td>
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</table>
Coupling Beam Reinforcement

- Design A
- Design B
- Design C
Vertical Wall Reinforcement

Design A
Design B
Design C
Design B & C—MCE Model

- 3-D model using CSI Perform-3D
  - Modeled as inelastic:
    - Coupling beams
    - Core wall flexural behavior
    - “Slab-beams”
  - Modeled as elastic:
    - Core wall shear behavior
    - Diaphragm slabs
    - Columns
    - Basement walls
- Model extended to mat
Design B Coupling Beam Rotations
Design C Coupling Beam Rotations
Design B Story Drifts
Design C Story Drifts
Core wall shear is the governing design parameter & governs wall thickness

Serviceability Design governed over Wind Design for Design B & C

Walls thicker for Design C vs. Design B vs. Design A

Serviceability Demands of Design C > Design B > Design A
Building 1 Observations

- Coupling Beam Reinforcement for Design C < Design B ~ Design A
- Vertical Wall Reinforcement for Design C > Design B > Design A
- Design C Results in Greater Strong Pier—Weak Coupling Beam Performance than Design A & B