Current Assessment Approaches

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Outline

- Background
- Early assessment and rehabilitation approaches
- Current assessment and rehabilitation approaches
- Improved simplified analysis methods
Seismic assessment/upgrading through mid-1990s (FEMA 178)

- Checklist to identify critical deficiencies
- Minimum strength requirement

\[ V \approx \frac{3}{4} \left( \frac{ZICS}{R} W \right) \]
Seismic assessment/upgrading since mid-1990s (FEMA 273)

- Checklist to identify critical deficiencies
- Detailed requirements for condition assessment
- Performance approach
  - Performance objectives
  - Seismic hazard characterization
  - Nonlinear, displacement-based analysis
  - Detailed acceptance criteria
## Performance objectives

<table>
<thead>
<tr>
<th>Design Shaking Level</th>
<th>Building Performance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequent (50%/50yr)</td>
<td>a</td>
</tr>
<tr>
<td>Occasional (20%/50yr)</td>
<td>b</td>
</tr>
<tr>
<td>Rare (~10%/50yr)</td>
<td>c</td>
</tr>
<tr>
<td>MCE (~2%/50yr)</td>
<td>d</td>
</tr>
</tbody>
</table>

The table shows the performance objectives for different seismic shaking levels and building performance levels. The shaded area indicates the most commonly selected performance objective.
Performance objectives

Damage Threshold

Collapse Onset

Base Shear

IO
LS
CP

Deformation

FEMA 356 Levels

Rare
(10%/50yr)

MCE
(~2%/50yr)

Dead Load

Live Load

Force

FEMA 356 Levels
Seismic hazard

\[ S_a = \frac{S_{xs}}{B_s} \]

Spectral response accel., \( S_a \)

\[ 0.4S_{xs} \]

Period, sec

1.0

0.2
Design response spectra

*general approach (shown) or site-specific*

\[ S_a = \frac{S_{xs}}{B_s} \]

Spectral response accel., \( S_a \)

0.4\( S_{xs} \)

\( S_{x1}/B_1 \)

Period, sec

0.2

1.0
Nonlinear analysis model/upgrading concept
Modeling, analysis, and acceptance

Component Model ⇄ Global Model

Force ⇄ Deformation

Acceptance Criteria ⇄ Component Tests

Global Model

EQ effect

Global displacement, \( \delta \)

Component Model

Life Safety limit
Foundation modeling

(a) Foundation deformations

High forces cause shear wall damage

Small displacements protect frame from damage

Stiff/Strong Foundation

Δ small

(b) Modified input

• “slab” averaging
• embedment
• damping

Flexible/Weak Foundation

Foundation yielding and rocking protects shear wall

Δ large

Large displacements cause frame damage
Free field motion

Site plan

$FFM_A \neq FFM_B$

Comartin
Foundation input motion

Site plan

Building footprint

$FFM_A$

$FFM_B$
Slab averaging

**Graph:**
- **Title:** Simplified Model
- **Legend:**
  - $b_e = 65$ ft
  - $b_e = 130$ ft
  - $b_e = 200$ ft
  - $b_e = 330$ ft
Embedment effect

Building

Ground surface

Input ground motion

Period (s)

Foundation/Free-Field RRS

\(e = 30\) ft

\(V_s = 2500\) ft/s

\(V_s = 1200\) ft/s

\(V_s = 600\) ft/s

FEMA 440
Foundation (radiation) damping

Ground surface

Building

Some energy is dissipated
Displacement demand –

*Equivalent linearization (formerly capacity-spectrum)*

General concept shown below. See FEMA 440 for details.
Displacement demand –

**Coefficient method**

\[ \delta_t = C_0 C_1 C_2 C_3 S_a \frac{T_e^2}{4\pi^2} g \]

- **Elastic roof displacement**

**Coefficient definitions**:

- \( C_0 \) = converts SDOF spectral displacement to MDOF roof displacement

- \( C_1 \) = amplification for nonlinear response of bilinear system

\[ C_1 = 1 + \frac{R - 1}{a T^2} \]

- \( C_2 \) = amplification for pinched hysteresis, stiffness degradation, and strength deterioration

\[ C_2 = 1 + \frac{1}{800 \left(\frac{R - 1}{T}\right)^2} \]

- \( C_3 \) = amplification due to dynamic P–Δ effects

\[ C_3 = \text{amplification due to dynamic P–Δ effects} \]

replaced by minimum strength requirement

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*FEMA 440*
Two types of strength degradation

- Strength loss *between* cycles
- Strength loss *during* cycles

Cyclic strength degradation

In-cycle strength degradation
Two types of strength degradation

Displacement, in.

Time, sec

Force

Displacement

Force

Displacement

Michael Scott, PEER, 2003
Test observations

(a) 1985 Chile record
(b) 1995 Kobe record

Shin, PEER, 2005
Strength, strength degradation, and instability

FEMA 440 recommends maximum value for $R$ as function of $\alpha_e$.

1984 Morgan Hill, California Earthquake
Gilroy #3, Sewage Treatment Plant, Comp. 0°

$\Delta i/\Delta e$

$T = 1.0s$

$\alpha_e = -0.21$

$\alpha_e = -0.06$
Construction of load-displacement relation
Construction of load-displacement relation

\[ \alpha_e = \alpha_{P-\Delta} + \lambda(\alpha_2 - \alpha_{P-\Delta}) \]

\[ \lambda = 0.8 \text{ for near-field motions} \]

\[ = 0.2 \text{ otherwise} \]
Minimum strength

\[ R_{\text{max}} = \frac{\Delta d}{\Delta y} + \frac{|\alpha_e|^{-t}}{4} \]

\[ \alpha_e = \alpha_{P-\Delta} + \lambda (\alpha_2 - \alpha_{P-\Delta}) \]

\[ t = 1 + 0.15 \ln T \]
Modeling, analysis, and acceptance

Component Model

Global Model

Force

Life Safety limit

Deformation

Acceptance Criteria

Component Tests
Component strength
(example, column shear strength)

\[ V_n = V_c + V_s \]

\[ V_c = k \left( \frac{1}{M/Vd} \right) \left( 6\sqrt{f'_c} \sqrt{1 + \frac{P}{6\sqrt{f'_c A_g}}} \right)^{0.8A} \]

\[ V_s = k \frac{A_{sw} f_y d}{s} \]

Displacement Ductility

\[ k \]

\[ 0 \quad 0.2 \quad 0.4 \quad 0.6 \quad 0.8 \quad 1 \quad 1.2 \]

\[ 0 \quad 2 \quad 4 \quad 6 \quad 8 \quad 10 \]
Component deformation capacity
(example, columns controlled by flexure)
## Component deformation capacity

*(example, columns controlled by flexure)*

### Table 6-3: Modeling Parameters and Numerical Acceptance Criteria for Nonlinear Procedures—Reinforced Concrete Columns

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Plastic Rotation Angle, radians</th>
<th>Residual Strength Ratio</th>
<th>Acceptance Criteria&lt;sup&gt;4&lt;/sup&gt;</th>
<th>Performance Level</th>
<th>Component Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>♦</td>
<td>♦</td>
<td>Primary</td>
</tr>
<tr>
<td>♦ ≤ 0.1</td>
<td>♦ C</td>
<td>♦ ≤ 3</td>
<td>♦ 0.03</td>
<td>♦ 0.005</td>
<td>LS</td>
</tr>
<tr>
<td>≤ 0.1</td>
<td>♦ C</td>
<td>♦ ≤ 6</td>
<td>♦ 0.016</td>
<td>♦ 0.005</td>
<td>LS</td>
</tr>
<tr>
<td>≥ 0.4</td>
<td>♦ C</td>
<td>♦ ≤ 3</td>
<td>♦ 0.015</td>
<td>♦ 0.003</td>
<td>LS</td>
</tr>
<tr>
<td>≥ 0.4</td>
<td>♦ C</td>
<td>♦ ≤ 6</td>
<td>♦ 0.012</td>
<td>♦ 0.003</td>
<td>LS</td>
</tr>
<tr>
<td>≤ 0.1</td>
<td>♦ NC</td>
<td>♦ ≤ 3</td>
<td>♦ 0.006</td>
<td>♦ 0.005</td>
<td>LS</td>
</tr>
<tr>
<td>≤ 0.1</td>
<td>♦ NC</td>
<td>♦ ≤ 6</td>
<td>♦ 0.005</td>
<td>♦ 0.005</td>
<td>LS</td>
</tr>
<tr>
<td>≥ 0.4</td>
<td>♦ NC</td>
<td>♦ ≤ 3</td>
<td>♦ 0.003</td>
<td>♦ 0.002</td>
<td>LS</td>
</tr>
<tr>
<td>≥ 0.4</td>
<td>♦ NC</td>
<td>♦ ≤ 6</td>
<td>♦ 0.002</td>
<td>♦ 0.002</td>
<td>LS</td>
</tr>
</tbody>
</table>

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*FEMA 356*
Some shortcomings

*insufficient data, deterministic procedures*

Sezen, 2004
Some shortcomings

*static versus dynamic response*

8-story wall — 2 %

9-story frame — 2 %
Some shortcomings
- Component-based

When the first component gets to LS performance level, the whole building is defined to be at that level.
Some shortcomings
results can be sensitive to assumptions

Stiff/Strong Foundation

- High forces cause shear wall damage
- Small displacements protect frame from damage

Flexible/Weak Foundation

- Foundation yielding and rocking protects shear wall
- Large displacements cause frame damage

Some shortcomings results can be sensitive to assumptions.
Example: Escondido Village Midrises

- 1961-64 construction
- 8 stories tall
- Vertical system
  - columns
  - bearing walls
- Lateral system
  - walls controlled by flexure
- Foundation
  - spread footings
- Deficiencies
  - shear-critical columns
  - inadequate boundary steel in walls
  - punching at slab-column connection
Typical Floor Plan

Concrete shear walls

Concrete columns

Comartin
Structural analysis and retrofit approach

Base Shear (kips) vs. Roof displacement (in.)

- Capacity curve before retrofit
- Capacity curve after retrofit
- Column shear failures
- Floor beam shear failures
- Shear wall boundary splice failure

Various upgrading measures
Boundary Steel
Column Collars and Fiber Wrap
Older RC building performance ratings - a case study
Current Assessment Approaches

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