Effect of Column-to-Beam Strength Ratio on Seismic Performance of RC Moment Frames

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Outline

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2. Objectives
3. Methodology
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Introduction - ACI 318

• American Concrete Institute Building Code Requirements for Structural Concrete (ACI 318)
  – Intent is to ensure survival to occupants during design-basis loading
  – Provisions concerning column-to-beam strength ratio are meant to reduce the likelihood of yielding in columns (or the formation of a story mechanism)

• ACI-ASCE Committee 352
  – Makes recommendations concerning design of RC joints
Introduction - ACI 318

<table>
<thead>
<tr>
<th>Publication</th>
<th>Min. Ratio</th>
<th>Location</th>
<th>Member Strength Description</th>
<th>Incl. Slab</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACI 318-71</td>
<td>1.0</td>
<td>Joint Principal Planes</td>
<td>Moment Strength</td>
<td>?</td>
</tr>
<tr>
<td>ACI 318-83</td>
<td>1.2</td>
<td>Joint Center</td>
<td>Design Flexural Strength</td>
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<tr>
<td>ACI-ASCE 352-85</td>
<td>1.4</td>
<td>Joint</td>
<td>Nominal Moment Strength</td>
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<tr>
<td>ACI-ASCE 352-91</td>
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<td>Joint</td>
<td>Nominal Moment Strength</td>
<td>Yes</td>
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<tr>
<td>ACI 318-99</td>
<td>1.2</td>
<td>Joint Faces</td>
<td>Nominal Flexural Strength</td>
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</tbody>
</table>

- Therefore, existing RC frame structures have minimum strength ratios from 0.67 to 1.2
- Codes in other countries (New Zealand, Mexico) require higher ratios (1.5 to 2.0)
**Introduction - PBEE**

- Method of design for earthquake resistance in which engineer chooses structural response to various magnitudes of seismic load
- Desired response specified in terms of maximum acceptable probabilities of exceeding different limit states
- One typical limit state is Life Safety
- One typical level of seismic load is Design-Basis
Introduction - PBEE

- FEMA 273 definitions:
  - LS = “building remains stable and has significant reserve capacity; hazardous non-structural damage is controlled”
  - Design-Basis Seismic Event:
    - 67% of mapped “maximum considered earthquake” intensity
    - approximately 10% probability of exceedence in 50 years (475-year return period) in California
**Objectives**

- Two objectives:
  - Examine possibility of varying strength ratio to control seismic performance of two RC frame buildings
  - Evaluate current ACI 318 required minimum ratio

- In order to simultaneously complete the two objectives, consider performance with respect to LS limit state under Design-Basis loading
Methodology

Identify Study Buildings

Vary Strength Ratio

Create Numerical Models

Use Suite of Earthquakes as Input

Find Demand Inter-Story Drifts

Represent Demands Probabilistically

Describe Story LS Capacity in terms of Inter-Story Drift

Find Deterministic Story LS Capacities

Determine P(D>LS) for Each Building
Study Buildings

Plan View

- 0.9 m (3 ft.)
- 9 m (30 ft.) (typ.)
- 15 x 45 cm (6 x 18 in.) joist (typ.)
- Frame modeled
Study Buildings

- Multiple versions of each building created, each with a different strength ratio (six ratios, from 0.8 to 2.4)
- Beams and columns throughout each version given same cross-section
- Original beam dimensions and reinforcement preserved
- Column strength varied to achieve strength ratios by:
  - Varying gross dimensions
  - Varying reinforcement ratio
- If neglect reinforcement, stiffness ~ gross dimensions
**Study Buildings**

- Four sets of results:
  - 3-story, constant column-to-beam stiffness ratio
  - 3-story, varied column-to-beam stiffness ratio
  - 6-story, constant column-to-beam stiffness ratio
  - 6-story, varied column-to-beam stiffness ratio

- Each set is collection of data from six models (each with a different strength ratio) of one building
**Results - Numerical Modeling**

- **IDASS**
  - Inelastic Damage Analysis of Structural Systems
  - Two-dimensional dynamic and static analysis program
- Only one frame modeled (involves assumption of rigid diaphragms and no torsion)
- Members modeled by specified trilinear moment-curvature behavior and hysteretic parameters
Results - Earthquakes

- Suite of earthquake ground motions with 20 earthquake time histories
- Return period = 475 years
- Only horizontal accelerations
- Representative of Los Angeles region
- Developed by Woodward-Clyde Federal Services for SAC project
Results - Demands

- Found using inelastic time-history dynamic analyses in IDASS
- Defined as maximum inter-story drift during an earthquake, as a percentage of story height
- Determined for each story under each earthquake time history
- Represented by best-fit lognormal probability density functions
## Results - Demands

% Change in Mean Demands as Increased Strength Ratio from 0.8 to 2.4

<table>
<thead>
<tr>
<th></th>
<th>Story No.</th>
<th>Constant Stiffness</th>
<th>Varied Stiffness</th>
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</thead>
<tbody>
<tr>
<td><strong>Three-Story</strong></td>
<td>1</td>
<td>-49%</td>
<td>-56%</td>
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<tr>
<td></td>
<td>2</td>
<td>-26%</td>
<td>-33%</td>
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<tr>
<td></td>
<td>3</td>
<td>101%</td>
<td>173%</td>
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<tr>
<td><strong>Six-Story</strong></td>
<td>1</td>
<td>-52%</td>
<td>-63%</td>
</tr>
<tr>
<td></td>
<td>2</td>
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<td>-50%</td>
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<tr>
<td></td>
<td>3</td>
<td>-8%</td>
<td>-20%</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>46%</td>
<td>78%</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>161%</td>
<td>183%</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>277%</td>
<td>313%</td>
</tr>
</tbody>
</table>
Results - Capacities

- Deterministic story capacities found using non-linear monotonic pushover analyses in IDASS
- Story LS capacity = inter-story drift at which column-sidesway mechanism forced
  - Consistent with ACI (deter loss of life by minimizing risk of story mechanisms)
  - Consistent with FEMA 273 (structure surpasses LS when it no longer has significant reserve capacity)
Results - Capacities

Pushover Method
Results - Capacities

- Story Shear / Bldg Wt
- Story Drift (%)

LS Limit State Capacity

$f (\text{section } \mu, \text{ PYS, } P-\Delta)$
Results - Capacities

1st Story, Const Col-to-Bm Stiff, 3-Story Bldg
Results - Capacities

Inter-Story Drift (%)

Story Shear / Bldg Wt.

0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5

1st Story, Varied Col-to-Bm Stiff, 3-Story Bldg
Results - $P(D>LS)$

- $P(D>LS)$ for each story
- $P(D>LS)$ on system level
  - Whole building considered to exceed LS limit state if at least one story did so
  - First order bounds used to approximate probability of this union of events
Results - $P(D > LS)$

3-Story Building

- Constant Col-to-Bm Stiffness
- Varied Col-to-Bm Stiffness
Results - $P(D>LS)$

6-Story Building

- Constant Col-to-Bm Stiffness
- Varied Col-to-Bm Stiffness
Conclusions - Demands

• As $M_{col}/M_{beam}$ increased:
  - Demands placed on lower stories decreased, while those placed on upper stories increased
  - Demands became more evenly distributed throughout building

• Demands changed more as strength ratio increased for varied stiffness investigations
Conclusions - Capacities

• As $M_{col}/M_{beam}$ increased:
  – Yielding occurred in more areas before story mechanism formed
  – Therefore, story LS capacities increased

• Capacities increased more with strength ratio for constant stiffness investigations
Conclusions - $P(D > LS)$

- Increasing strength ratio:
  - resulted in improved performance
  - was most effective within a certain range of ratios
  - was more effective for the constant stiffness investigations than for the varied stiffness investigations
Conclusions - ACI 318

- For all cases, with strength ratio of 1.2, probability of forming story mechanism under Design-Basis loading = 90 to 95%

- More appropriate ACI 318 code minimum might be about 2.0