Background

1. ASCE/SEI 41-13 prescribes nonlinear Modeling Parameters (MP) and Acceptance Criteria (AC) for various structural components
2. For columns MP and AC are given as limiting plastic rotations
3. MP are used to build analytical models of structures for seismic evaluation
4. AC provide deformation limits below which member performance is deemed acceptable
5. MP and AC are given in tables for various column conditions (depending on behavior) and key parameters

<table>
<thead>
<tr>
<th>Q/Qy</th>
<th>1.0</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak deformation</td>
<td>θy</td>
<td>θ</td>
<td>or D</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Motivation

1. Current MP were selected conservatively
2. MP for different elements (beams, columns, joints, …) selected with varying conservatism

ASCE/SEI 41-13 Generic Backbone Curve

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Motivation

- AC were selected as fractions of MP

\[ a_1, \text{Large cov} \]
\[ a_2, \text{Low cov} \]

**Table 10-8. Modeling Parameters and Numerical Acceptance Criteria for Nonlinear Procedures—Reinforced Concrete Columns**

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Modeling Parameters</th>
<th>Acceptance Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plastic Rotations</td>
<td>Angle (radians)</td>
</tr>
<tr>
<td></td>
<td>Residual Strength</td>
<td>Ratio</td>
</tr>
<tr>
<td></td>
<td>Plastic Rotations</td>
<td>Angle (radians)</td>
</tr>
<tr>
<td></td>
<td>Performance Level</td>
<td>IO</td>
</tr>
</tbody>
</table>

\[ a, b, c \leq 0.1 \]
\[ a, b, c \\
\[ a, b, c \\
\[ a, b, c \leq 0.1 \]
\[ a, b, c = 0.002 0.027 0.034 0.2 0.005 0.027 0.034 \]

Motivation

- AC generate varying probabilities of exceedance across structural members treated in ASCE/SEI 41-13

Objectives

1. Re-evaluate MP for concrete columns to achieve a median estimate
2. Use new extended database with close to 500 column tests
3. Treat circular columns
4. Explore cyclic damage effects
5. Adjust AC based on new MP
   - Consistency should be incorporated in AC not MP
   - Select AC at percentiles of MP to achieve consistent probability of exceedance across all members

MP for RC columns - Dataset

- Extended database with close to 500 column tests

MP for RC columns - Dataset

- Data in form of lateral force-deformation plots
MP for RC columns – Data Extraction

- **Target:**
  1. plastic rotations at initiations of loss of lateral strength (MP\(a\))
  2. plastic rotations at initiations of loss of axial strength (MP\(b\))

- **Needed:**
  1. Drift at elastic limit \(\Delta y\)
     \[ \frac{V_{\text{max}}}{0.7 V_{\text{max}}} \]

MP for RC columns – Parameters

- Most influential parameters were found to be:
  - Axial load ratio
  - Transverse reinforcement ratio
  - \(\frac{V_y}{V_o}\)

Calculating \(\frac{V_y}{V_o}\):

\(V_y\) is the shear associated with the yield moment strength of a column

- Different from \(V_p\) that utilizes 1.25\(f_y\) for plastic moment strength
- Longitudinal bars will only reach 1.25\(f_y\) in well-confined columns

\[
\frac{V_y}{V_o} = \Phi \left( \frac{A_t f_y}{M/V_d} \right) \left( 1 - \frac{A_t f_y}{A_p f_y} \right) 0.8 a
\]

\(a = \frac{\Delta_{y,0.8} - \Delta y}{L}\)

\(\Phi\) is taken as 1.0 for \(s/d \leq 0.75\), zero for \(s/d \geq 1.0\), and linearly interpolated between the two values of \(s/d\).

Regression analysis results

- Rectangular columns
  \(a = 0.042 - 0.043 \cdot \frac{P}{A_p f_y} + 0.63\frac{V}{V_o} - 0.023 \geq 0.0\) (out)

- Circular columns (spirals or hoops)
  \(a = 0.06 - 0.058 \cdot \frac{P}{A_p f_y} + 1.3\frac{V}{V_o} - 0.037 \geq 0.0\) (out)

Values of \(a\) at parameter boundaries

<table>
<thead>
<tr>
<th>Axial Load Ratio</th>
<th>0.005</th>
<th>0.01</th>
<th>0.0175</th>
<th>0.03</th>
<th>0.05</th>
<th>0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.005</td>
<td>0.0005</td>
<td>2.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.01</td>
<td>0.0005</td>
<td>0.2</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0175</td>
<td>0.0005</td>
<td>2.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.03</td>
<td>0.0005</td>
<td>2.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.05</td>
<td>0.0005</td>
<td>2.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td>0.0005</td>
<td>2.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
MP for RC columns – a

- Analysis of fit

- Median estimate achieved
- Improved fit for circular columns

MP for RC columns – a

- Analysis of fit

MP for RC columns – a

- Analysis of fit

- Little bias with respect to a/d
- Little bias with respect to tie hooks

MP for RC columns – b

- Behavioral model

- Due to the scarcity of columns tested to axial collapse a behavioral model is selected instead of a regression-based model

- Simplified Elwood-Moehle axial failure model

\[ \Delta = \frac{0.5}{S + \frac{1}{2\sqrt{\sigma}} \left( \frac{\sigma}{\mu} \right)} \]

Drift ratio at axial failure

MP for RC columns – b

- Analysis of fit
MP for RC columns – b

- Analysis of fit
  - Including a loading protocol factor of 0.5 on the drift at axial failure for columns tested under 6 load cycle per drift level or biaxially

<table>
<thead>
<tr>
<th>Model</th>
<th>Average Measured/Calculated drift ratio at axial failure</th>
<th>Standard Deviation</th>
<th>Coefficient of Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASCE 41-06 Suppl. 1</td>
<td>1.97</td>
<td>0.93</td>
<td>0.47</td>
</tr>
<tr>
<td>Elwood-Moehle</td>
<td>0.97</td>
<td>0.44</td>
<td>0.46</td>
</tr>
<tr>
<td>Simplified Elwood – Moehle with loading factor</td>
<td>1.13</td>
<td>0.38</td>
<td>0.33</td>
</tr>
</tbody>
</table>

ASCE 41-13 versus Proposed MP

- MP a
  - Shift to median estimates for rectangular columns results in slightly larger estimates
  - Large changes for spirally reinforced circular columns that have significantly larger deformation capacity

<table>
<thead>
<tr>
<th>Criteria</th>
<th>IO</th>
<th>10% of MP a</th>
<th>25th percentile of MP a</th>
<th>50% of MP a</th>
<th>75th percentile of MP a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular</td>
<td></td>
<td>0.1 aR</td>
<td>0.30 aR</td>
<td>0.71 aR</td>
<td>0.60 aR</td>
</tr>
<tr>
<td>Circular</td>
<td></td>
<td>0.1 aC</td>
<td>0.30 aC</td>
<td>0.65 aC</td>
<td>0.40 aC</td>
</tr>
</tbody>
</table>

Acceptance Criteria

- AC defined as percentiles of MP a and b
  - Fixed probability of exceeding a threshold behavior defined by MP a and b

<table>
<thead>
<tr>
<th>Criteria</th>
<th>10% of MP a</th>
<th>25th percentile of MP a</th>
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</tr>
</tbody>
</table>

Summary

1. MP estimated at median → “best” estimate analyses
2. New relations for MP a and b are proposed
3. Circular columns with spirals are treated separately
   - Significantly higher deformation capacities than rectangular columns
4. MP a defined through regression models
5. MP b defined through behavioral model due to scarcity of data
6. AC criteria are proposed as percentile values of MP estimates
   - Fixed probability of exceeding damage state defined by MP

- Larger b parameter for most columns