Uncertainties in Small-Displacement-Based Algorithms for Simulating Structural Collapse

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Motivation

Current State-of-Practice on Using Small-Displacement-Based Software Packages to Perform Nonlinear Dynamic Analysis of Structural Collapse:

- **Computer Model**
- **Black Box**
  - Software S1
  - Software S2
  - Software S3
- **Outputs**
- **Input**

Graph showing time (s) vs. displacement with data points for Software S1, S2, and S3.
Uncertainties among Software Packages

(1) Software packages use different numerical algorithms for the nonlinear dynamic calculations.

(2) Software packages make different assumptions on how to handle geometric nonlinearity and material nonlinearity.

(3) Analytical theory is not available to address the coupling effect between geometric nonlinearity and material nonlinearity.

What we know:

(1) Software packages produce consistent results for performing linear response history analysis.

(2) Software packages produce reasonably consistent results for performing geometric nonlinear response history analysis.

(3) Software packages produce somewhat consistent results for performing material nonlinear response history analysis.

(4) Software packages produce inconsistent results for performing nonlinear response history analysis with both material and geometric nonlinearities.
Analysis

Investigate Different Geometric Stiffness Formulations
(1) P-Delta Stiffness PD (Small Displacement)
(2) Corotation CR (Small Displacement)
(3) Stability Functions SF (Small Displacement)
(4) Large Displacement LD (Finite Element)

Material Nonlinearity
(1) Elastic-Perfectly-Plastic
(2) Panel Zone Not Modeled

Damping
(1) 0.25 Mass Proportional
(2) Compute Modal Damping

Loading
(1) Gravity First Applied on All Columns
(2) Use 7 Earthquakes Scaling Up to Near-Collapse and Collapse
Results

EQ1 (Kobe)

Near Collapse

2.0 × Kobe

Collapse

2.2 × Kobe

EQ4 (Imp1)

2.8 × Imp1

3.0 × Imp1

EQ5 (Nis2)

2.8 × Nis2

3.0 × Nis2
(1) Dynamic solvers produce consistent responses among small displacement algorithms.

(2) Uncertainties occur due to coupling between material nonlinearity with geometric nonlinearity.

<table>
<thead>
<tr>
<th>EQ</th>
<th>LD</th>
<th>PD</th>
<th>% Diff</th>
<th>CR</th>
<th>% Diff</th>
<th>SF</th>
<th>% Diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 × Kobe</td>
<td>1.340</td>
<td>1.344</td>
<td>0.3 %</td>
<td>1.494</td>
<td>11.5 %</td>
<td>1.357</td>
<td>1.3 %</td>
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<tr>
<td>1.8 × Sylm</td>
<td>0.771</td>
<td>0.771</td>
<td>0.0 %</td>
<td>0.768</td>
<td>0.4 %</td>
<td>0.771</td>
<td>0.0 %</td>
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<tr>
<td>3.5 × Mulh</td>
<td>1.104</td>
<td>1.002</td>
<td>9.2 %</td>
<td>0.972</td>
<td>11.9 %</td>
<td>0.943</td>
<td>14.6 %</td>
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<tr>
<td>2.8 × Imp1</td>
<td>0.582</td>
<td>0.607</td>
<td>4.4 %</td>
<td>0.545</td>
<td>6.2 %</td>
<td>0.551</td>
<td>5.3 %</td>
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<tr>
<td>2.8 × Nis2</td>
<td>0.524</td>
<td>0.439</td>
<td>16.3 %</td>
<td>0.623</td>
<td>19.0 %</td>
<td>0.592</td>
<td>12.9 %</td>
</tr>
<tr>
<td>1.7 × Koca</td>
<td>1.104</td>
<td>1.002</td>
<td>9.2 %</td>
<td>0.972</td>
<td>11.9 %</td>
<td>0.943</td>
<td>14.6 %</td>
</tr>
<tr>
<td>3.0 × Loma</td>
<td>1.170</td>
<td>1.312</td>
<td>12.2 %</td>
<td>1.358</td>
<td>16.2 %</td>
<td>1.393</td>
<td>19.1 %</td>
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**Maximum Displacement at Near Collapse**

<table>
<thead>
<tr>
<th>Mean</th>
<th>PD</th>
<th>7.4%</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR</td>
<td>11.0%</td>
<td></td>
</tr>
<tr>
<td>SF</td>
<td>9.7%</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Standard Deviation</th>
<th>PD</th>
<th>5.6%</th>
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</thead>
<tbody>
<tr>
<td>CR</td>
<td>5.7%</td>
<td></td>
</tr>
<tr>
<td>SF</td>
<td>6.9%</td>
<td></td>
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</tbody>
</table>

Near Collapse

<table>
<thead>
<tr>
<th>EQ</th>
<th>LD</th>
<th>PD</th>
<th>% Diff</th>
<th>CR</th>
<th>% Diff</th>
<th>SF</th>
<th>% Diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2 × Kobe</td>
<td>1.728</td>
<td>∞</td>
<td>×</td>
<td>∞</td>
<td>×</td>
<td>1.683</td>
<td>2.6 %</td>
</tr>
<tr>
<td>1.9 × Sylm</td>
<td>∞</td>
<td>∞</td>
<td>√</td>
<td>∞</td>
<td>√</td>
<td>∞</td>
<td>√</td>
</tr>
<tr>
<td>3.8 × Mulh</td>
<td>1.192</td>
<td>1.115</td>
<td>3.4 %</td>
<td>∞</td>
<td>×</td>
<td>0.993</td>
<td>16.7 %</td>
</tr>
<tr>
<td>3.0 × Imp1</td>
<td>0.582</td>
<td>∞</td>
<td>×</td>
<td>∞</td>
<td>×</td>
<td>0.549</td>
<td>5.7 %</td>
</tr>
<tr>
<td>3.0 × Nis2</td>
<td>∞</td>
<td>∞</td>
<td>√</td>
<td>∞</td>
<td>√</td>
<td>∞</td>
<td>√</td>
</tr>
<tr>
<td>1.8 × Koca</td>
<td>1.006</td>
<td>∞</td>
<td>×</td>
<td>∞</td>
<td>×</td>
<td>∞</td>
<td>×</td>
</tr>
<tr>
<td>3.2 × Loma</td>
<td>1.294</td>
<td>1.448</td>
<td>11.9 %</td>
<td>∞</td>
<td>×</td>
<td>1.497</td>
<td>15.6 %</td>
</tr>
</tbody>
</table>

Collapse

**Mean**

- PD: 7.4%
- CR: 11.0%
- SF: 9.7%

**Standard Deviation**

- PD: 5.6%
- CR: 5.7%
- SF: 6.9%
Come see my Poster!

Today Poster Session:

- **Time**: 5:15 – 7:00 pm
- **Room**: Pasadena (Exhibit Hall)
- **Poster location**: Number 087