Using FEMA P695 to Interpret ASCE 41 Seismic Performance of Special Moment Frames

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Outline

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Results
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Motivation

2009
Research Required to Support Full Implementation of Performance-Based Seismic Design

**Critical need** to benchmark “first-generation” PBSD

2010
Perspectives on ASCE 41 for Seismic Rehabilitation of Buildings

74% voted for calibration/comparison between ASCE 41 and ASCE 7

If a building is designed (ASCE 7) and built today and then assessed (ASCE 41) tomorrow, would it need to be retrofitted?

Today

Tomorrow
Results indicated new building designs were **not performing well** per ASCE 41.

**BUT**, do these buildings **meet** the intent of the new building code?

\[ P(C \mid MCE) \leq 10\% ? \]
Motivation (3)

| Building | Design Approach | Nonlinear Static Procedure | | | Nonlinear Dynamic Procedure |
|----------|----------------|-----------------------------|| | | |
| | | RBS connection | Column | Panel Zone | RBS connection | Column | Panel Zone |
| 4-Story | ELF | Pass | Pass | Pass | Pass | Pass | Pass |
| | RSA | × | Pass | Pass | × | Pass | Pass |
| 8-Story | ELF | Pass | × | Pass | × | × | Pass |
| | RSA | Pass | × | Pass | × | × | × |

**Motivation (3)**

- **Nonlinear:**
  - NDP median
  - NDP mean
  - NDP 84th
  - NDP mean + σ
  - NSP

- **Linear:**
  - LSP
  - LDP

**DCR_{ij} = Max of left and right connection**

[Diagram showing floor ID vs. DCR_{ij} for different scenarios]

[Diagram showing Imperial Valley Delta (sf = 2.4)]
Approach

3D model (Perform-3D)
- ASCE 41 “default” backbone curves
- Limited cyclic degradation (captured via $\Delta K$)

2D model (OpenSees)
- IMK hinge properties
- Lignos and Krawinkler (2011) and NIST GCR 17-917-46v2 (2017)
Quantification of Building Seismic Performance Factors

Approach (2)

collapse ≡ 12.5 %

OpenSees models
Results

4-story

ELF

RSA

8-story

ELF

RSA

< 1%

5%

3%

19%
## Discussion

Recall ASCE41 assessment results

<table>
<thead>
<tr>
<th>Building</th>
<th>Design Approach</th>
<th>Nonlinear Static Procedure</th>
<th>Nonlinear Dynamic Procedure</th>
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<tbody>
<tr>
<td></td>
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<td>RBS connection</td>
<td>Column</td>
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<td>4-Story</td>
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</tbody>
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Why the difference? (besides component vs. system level assessment)
Discussion (2)

Differences between P3D model and OpenSees model from a subassembly perspective

(a) Perform-3D Model

- Column Plastic Hinge
- Beam Plastic Hinge
- Reduced Beam Moment of Inertia
- 2.5x End Zone Stiffness

(b) OpenSees Model

- Column Plastic Hinge
- Beam Plastic Hinge
- Reduced Beam Moment of Inertia
- Panel Zone

Reduced Beam Moment of Inertia:
- $a = 121$ mm
- $b = 406$ mm
- $c = 57$ mm
Discussion (3)

Total Displacement = Elastic Displacement + Inelastic Displacement + Panel Zone Displacement

(a) (b) (c) (d)

Perform-3D and OpenSees

Base Shear (kN) vs. Drift Ratio

-600 -400 -200 0 200 400 600

-0.1 -0.05 0 0.05 0.1
Sensitivity Study

Vary modal damping: ~0, 1, 2, and 3%

Modify nonlinear hinges
  ◦ Elastic-plastic
  ◦ Vary backbone curve parameters +/- σ
  ◦ Capture effects of composite slab using recommendations from ATC 114 (NIST GCR 17-917-46v2)
  ◦ Predictive equations vs calibrated to experimental results (Gilton and Uang, 2002)
Sensitivity Study (2)

Baseline

ep2

ep3

composite slab

zeta = 2 %

zeta = 1 %

zeta ~ 0%

minus 30 %

panel zone
Conclusions

A suite of code-designed steel moment frames failed to pass an ASCE 41 assessment

A FEMA P695 influenced IDA indicates
  ◦ 3 out of 4 of the buildings meet the intent of the building code
  ◦ 8-story RSA frame is OK assuming 20% is acceptable for a single building

How do the nonlinear modeling choices effect results?
  ◦ Assumed damping (~small influence)
  ◦ Simplified model (~larger influence for this case)
  ◦ Composite slab (~larger influence -> P(C|MCE) reduced by almost 2)
  ◦ +/-30% change in backbone (~small influence)

Final thought: some improvements have been in ASCE 41-17, but there is still room for more.
Thanks, questions?

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