Updates to the ASCE 41 Standard for Nonlinear Modeling of Light-Frame Wood Walls for Performance-Based Earthquake Engineering

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Outline

• Introduction
• Past Performance
• Recommendations for Numerical Modeling
• Illustrative case study
• Conclusions
• Acknowledgments
Introduction

- **Wood shear walls**: primary elements of SFRS in virtually all light-frame wood buildings.

- **Assembly of components**:
  - Lumber sheathing (e.g. 2x4 or 2x6)
    - Straight or diagonal boards
    - Plaster
    - Gypsum wallboard
    - Plywood or OSB
  - Fasteners (typically nails)
  - Hold down devices

Photo credit: Bahmani and van de Lindt (2014)
Past Performance

• Light-frame wood buildings: historically good seismic performance with regards to life safety
  – High relative strength to weight ratio
• Damage associated with:
  – Soft story mechanism
• Significant economic losses:
  – Damage to sheathing layers (exterior stucco, gypsum wall board-GWB)
Damage to SFRS: wood shear walls
- Nail withdrawal, pull-through or tear out
- Splitting of the sill plate around anchor bolts
- Excessive uplift or rocking when anchorage fails or overturning restraint is inadequate.

Damage to finishes:
- GWB or other finishes

Past Performance

Corner nail pulling through and tearing out

Sheathing rotating
Numerical Modeling of Wood Shear Walls

- Nonlinear analysis is a widely used tool for evaluating the seismic performance of new and retrofit designs of existing buildings.
- **Nonlinear analysis** is included in *performance-based seismic design and assessment methodologies*:
  - Design code analysis for new building structures (ASCE 7)
  - Response evaluation analysis and retrofit of existing buildings (ASCE 41)
  - Collapse evaluation analysis of building systems (FEMA P695)
  - Probabilistic assessment of seismic performance and possible economic losses of buildings (FEMA P58)
Numerical Modeling of Wood Shear Walls

- Numerical modeling challenges based on experimental studies:
  - Generalized F-Δ models (used in the past for OSB or plywood) → NOT good fit for other sheathing materials
  - Refined combination rules needed for walls sheathed with layers of different materials
  - Commercial software: DO NOT provide representative hysteretic models

- To address the challenges:
  - Extensive synthesis of experimental backbone curve data developed
    - Includes: wood planks, drywall, stucco, plywood, gypsum and wood siding materials
  - Development of simplified force-displacement backbone curve based on hysteretic response parameters
Synthesis of backbone curves:

- Statistically computed values (mean/average, maximum, minimum, standard deviation and COV) of shear resistance at different drift ratios.
- Variations due to: differences in loading protocols, boundary conditions, nailing size and schedule.

Data contribution by K. Cobeen and P. Line
ASCE 41 vs. Experimental Response

- **ASCE 41 Backbone Curve:**
  - Accounts for *strength degradation* and *residual strength*
  - Defined in terms of elastic and plastic regions
  - **Does not account for hysteretic response** parameters
    - Parameters (e.g. $\Delta y$, $\Delta u$, c, d and e) $\rightarrow$ based on judgement of engineers and researchers
Numerical Modeling Recommendations

- **Modeling Recommendations:**
  - *Detailed modeling* of sheathing and fasteners using the 10-parameter CUREE model
    - Hysteretic properties of the CUREE model based on sheathing and connector databases
    - Used in user-defined software
  - *Multi-linear backbone curve* accounting for *residual strength* used in user-defined hysteresis of software
    - Parameters used to define its shape → based on 10-parameter CUREE model
Numerical Modeling Recommendations

- **Multi-linear backbone curve**
  - Few of *hysteretic parameters of the CUREE* hysteretic model adopted ($F_o$, $k_o$, $r_1$, $r_2$ and $\delta_u$)
  - *Residual strength and displacements* as a factor of the ultimate displacement ($\Delta_{u,max}$) based on a number of reversed-cyclic tests and shake table testing that demonstrated that drift levels of 6-7% are achievable
    - For WSP (wood structural panels): $\gamma = 1.4-1.5$
    - Wood panels other than WSP: $\gamma = 1.2-1.5$ ($1.2-1.5\Delta_{u,max}$)

Multi-linear Backbone Curve

- Proposed backbone curve envelope compared to average synthesis data
Multi-linear Backbone Curve

- Proposed backbone curve envelope compared to average synthesis data

Wood structural panels (1:1)
• Design Characteristics:
  – 5-story building archetype located in San Francisco
    • Designed per ASCE/SEI 7-10
    • Seismic Design Category D (S_{DS}=1.206 and S_{D1}=0.692)
    • Risk Category II
    • R-factor= 6.5, \( \Omega_o \) =3.0 and \( C_d \) =4.0.
    • Total height of 50 feet to the roof
    • 12,000 square feet of living area per floor
    • Shear walls: 15/32 Structural I sheathing with 10d common nails
    • 2x4 sill plate used at the base of the wood frame shear walls
Illustrative Case Study

• Design characteristics (cont’d)

<table>
<thead>
<tr>
<th>Roof</th>
<th>Component</th>
<th>Weight</th>
<th>Floor</th>
<th>Component</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Roofing material</td>
<td>0.24kPa</td>
<td></td>
<td>Flooring material</td>
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<tr>
<td></td>
<td>Wood roof sheathing</td>
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<td>Wood sheathing</td>
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<td></td>
<td>Roof trusses and blocking</td>
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<td>Joists and blocking</td>
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<td>Insulation and sprinklers</td>
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<td>Ceiling and miscellaneous</td>
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<tr>
<td></td>
<td>Ceiling and miscellaneous</td>
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<td></td>
<td>Beams</td>
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<tr>
<td></td>
<td>Beams</td>
<td>0.048kPa</td>
<td></td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Floor/Level</th>
<th>Wall length</th>
<th>Wall Sheathed 1 or 2 sides</th>
<th>Fastener edge spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>8.8m (29.0ft)</td>
<td>2</td>
<td>50.8mm (2in) o.c.</td>
</tr>
<tr>
<td>3</td>
<td>8.8m (29.0ft)</td>
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<td>50.8mm (2in) o.c.</td>
</tr>
<tr>
<td>4</td>
<td>8.8m (29.0ft)</td>
<td>2</td>
<td>50.8mm (2in) o.c.</td>
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<tr>
<td>5</td>
<td>8.8m (29.0ft)</td>
<td>1</td>
<td>50.8mm (2in) o.c.</td>
</tr>
<tr>
<td>Roof</td>
<td>8.8m (29.0ft)</td>
<td>1</td>
<td>152.4mm (6in) o.c.</td>
</tr>
</tbody>
</table>
Illustrative Case Study

• Numerical Modeling of 5-story building
  – Modeled in RUAMOKO 2D software
  – **Wood shear walls**: modeled with inelastic horizontal springs and anchored to a rigid foundation
  – **Exterior & interior wall finishes**: modeled with zero-length horizontal springs in parallel with springs representing the wood shear walls
    • FEMA P807 material combination rules:
      – Interior walls: 100% wood and 50% gypsum
      – Exterior walls: 100% wood, 50% gypsum and 50% stucco
  – Inelastic horizontal springs for WSPs, interior and exterior wall finishes modeled accounting (i) the ASCE 41 and (ii) the proposed force-displacement curve parameters
    • Following loading & unloading paths per Wayne-Stewart model
  – **Wood roof diaphragms**: modeled with horizontal hysteretic springs (Wayne-Stewart hysteretic model)
Illustrative Case Study

- IDAs performed under FEMA P695 Far Field ground motion ensemble
  - **IM**: spectral acceleration at the fundamental period of the building system
  - **EDP**: story drift ratio
  - Damping ratio = 3% of critical
  - **Performance levels considered**: Immediate Occupancy (IO), Life Safety (LF) & Collapse Prevention (CP)
Illustrative Case Study

- Results comparison

**Wood shear wall modeling consideration**

<table>
<thead>
<tr>
<th>Performance level</th>
<th>Fragility parameters (lognormal distribution)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median ($m_R$)</td>
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<tr>
<td><strong>ASCE 41</strong></td>
<td></td>
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<tr>
<td>IO</td>
<td>-0.27</td>
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<tr>
<td>LS</td>
<td>0.23</td>
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<tr>
<td>CP</td>
<td>0.49</td>
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<tr>
<td><strong>Proposed envelope curve</strong></td>
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<tr>
<td>IO</td>
<td>0.14</td>
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<tr>
<td>LS</td>
<td>0.53</td>
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<tr>
<td>CP</td>
<td>0.81</td>
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</tbody>
</table>

**Diagram:**
- IM = Sa (T_1) (g)
- P(EDP>LS)
- ASCE 41
- Proposed envelope curve
- IO: Drift LS=1%
- LS: Drift LS=2%
- CP: Drift LS=6%
Conclusions

• A multi-linear backbone curve accounting for residual strength was introduced for wood shear walls
  – Proposed curved based on 10-parameter CUREE model & extensive data synthesis
  – Applied to model nonlinear response for a 5-story building & compared to response achieved using the ASCE 41-13 backbone envelope curve
  – Improved (more representative) seismic response for IO, LF and CP performance levels achieved compared to ASCE 41 backbone envelope curve
Acknowledgments

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Thank you!

Questions?

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