Reliability of Wood Shearwalls to Natural Hazards Loading

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What is reliability?

The reliability of an item is the probability that it will adequately perform its specified purpose for a specified period of time under specified environmental conditions.

- Leemis, 1995
**Strength-Based Reliability Subject to Wind Load**

CASHEW software to compute ultimate capacity of walls

Suite of twelve walls from APA Panel supplement to AF&PA/ASCE16

Also provides hysteretic parameters

<table>
<thead>
<tr>
<th>Wall I.D.</th>
<th>Sheathing thickness</th>
<th>Ext. sp. mm (in)</th>
<th>$\Delta_{ult}$ mm (in)</th>
<th>$V_{ult}$ kN/m (k/ft)</th>
<th>$\phi V_n$ kN/m (k/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>w01c</td>
<td>9.5mm (3/8&quot;)</td>
<td>152 (6)</td>
<td>41.0 (1.61)</td>
<td>10.8 (0.74)</td>
<td>4.38 (0.30)</td>
</tr>
<tr>
<td>w02c</td>
<td>11mm (7/16&quot;)</td>
<td>102 (4)</td>
<td>43.4 (1.71)</td>
<td>16.1 (1.11)</td>
<td>6.71 (0.46)</td>
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<tr>
<td>w03c</td>
<td>12mm (15/32&quot;)</td>
<td>76 (3)</td>
<td>45.4 (1.79)</td>
<td>20.6 (1.41)</td>
<td>8.61 (0.59)</td>
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<tr>
<td>w04c</td>
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<td>51 (2)</td>
<td>49.5 (1.95)</td>
<td>29.9 (2.10)</td>
<td>11.38 (0.78)</td>
</tr>
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<td>w05c</td>
<td>11mm (7/16&quot;)</td>
<td>152 (6)</td>
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<td>10.8 (0.74)</td>
<td>4.38 (0.30)</td>
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<td>w11c</td>
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<td>51 (2)</td>
<td>47.0 (1.85)</td>
<td>30.6 (2.10)</td>
<td>11.38 (0.78)</td>
</tr>
</tbody>
</table>

1 Shearwall ultimate capacities and displacements were computed using CASHEW (Folz and Filiatrault 2001)

2 Shearwalls were “designed” in accordance with Table 5.4: Factored Shear Resistance for Structural-Use Panel Shear Walls with framing of Douglas-fir, Larch, or Southern Pine for Wind or Seismic Loading (LRFD Structural-Use Panels Supplement).
Shearwall Reliability to Wind Load

Step 1: Set \( W_n = \phi V_n \)

Step 2: Calculate mean as \( \bar{W} = 0.8 \)

Step 3: Set COV

Step 4: Use Method of Moments to get parameters for Type I

Step 5: Calculate failure probability directly from the distribution as:

\[
p_f = \exp \left[ -e^{-\alpha(V_u - u)} \right]
\]

where \( V_u \) is the shearwall strength from CASHEW

This gives us the statistics for the wind load on the wall & the failure probability.
Strength-Based Reliability Subject to Earthquake Load

Spectral scaling used

Analysis tools – CASHEW & SAWS

Maximize seismic mass (AF&PA/ASCE 16)

\[ V_{base} = \gamma C_s mg \]

\[ V_{base} = \phi V_n \]

\[ m = \frac{\phi V_n}{\gamma \cdot C_s \cdot g} \]
## Time Domain Analysis Results

<table>
<thead>
<tr>
<th>Earthquake 1</th>
<th>Wall No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
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<tbody>
<tr>
<td>Cape Mendicino, 1992, Fortuna Boulevard</td>
<td>pga (g)</td>
<td>0.86</td>
<td>25.71</td>
<td>36.82</td>
<td>47.02</td>
<td>73.84</td>
<td>25.75</td>
<td>36.73</td>
<td>46.93</td>
<td>70.14</td>
<td>25.76</td>
<td>38.39</td>
<td>47.15</td>
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<td>Cape Mendicino, 1992, Rio Dell Overpass</td>
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<td>26.05</td>
<td>39.16</td>
<td>47.15</td>
<td>25.71</td>
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<td>Landers, 1992, Desert Hot Springs</td>
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<td>73.97</td>
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<td>26.05</td>
<td>39.00</td>
<td>47.15</td>
<td>26.04</td>
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<td>Landers, 1992, Yermo Fire Station</td>
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<td>26.14</td>
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<td>Loma Prieta, 1989, Hollister Differential</td>
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<tr>
<td>Northridge, 1994, Beverly Hills 14145 Mulhul</td>
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<td>Northridge, 1994, LA – North Faring Road</td>
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<td>73.97</td>
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<td>Northridge, 1994, North Hollywood – Coldwater</td>
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<td>36.87</td>
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<td>73.93</td>
<td>26.19</td>
<td>36.77</td>
<td>47.10</td>
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<td>26.15</td>
<td>39.12</td>
<td>47.15</td>
<td>26.18</td>
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<td>Northridge, 1994, Sunland – Mt Gleason Ave</td>
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<td>73.35</td>
<td>25.88</td>
<td>36.76</td>
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<td>38.92</td>
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<tr>
<td>Superstition Hills, 1987, Brawley</td>
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<td>74.24</td>
<td>26.21</td>
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<td>46.97</td>
<td>71.92</td>
<td>26.16</td>
<td>39.07</td>
<td>47.02</td>
<td>26.19</td>
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<tr>
<td>Superstition Hills, 1987, El Centro Imperial County</td>
<td>0.94</td>
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<td>36.79</td>
<td>47.06</td>
<td>73.57</td>
<td>26.18</td>
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<td>46.97</td>
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<td>26.11</td>
<td>39.19</td>
<td>47.02</td>
<td>26.19</td>
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<td>Superstition Hills, 1987, Plaster City</td>
<td>0.64</td>
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<td>36.90</td>
<td>46.88</td>
<td>73.66</td>
<td>26.16</td>
<td>36.88</td>
<td>47.10</td>
<td>71.88</td>
<td>26.18</td>
<td>39.16</td>
<td>47.15</td>
<td>26.11</td>
</tr>
</tbody>
</table>

**Ultimate strength from CASHEW**

**Seismic demands**
CDF of Reliability Indices

CDF representation assumes 12 wall portfolio is representative of all wood shearwalls.
Drift-Based Reliability Subject to Earthquake Load

Polynomial backbone hysteresis model used (van de Lindt & Walz, 2003 JSE)

- Number of shear wall tests for input data
- Number of ground accelerations

Number of time domain analyses: \( m \times n \)

Fit peak response to extreme value distributions

Calculate reliability index,

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2004 Conference on Wood-frame Housing Durability and Disaster Issues
Relative effect of Hysteresis variability

\[ P_{\text{exceedance}} = 0.23 \]
Damage-Based Seismic Reliability Concept

Selection of Damage Model

Identification of Critical Model Parameters

Testing and/or Data Procurement For Parameters Calibration

Fastener Parameters

Cyclic Analysis to get Equivalent SDOF System

Earthquake Ground Motion Suite

Time Domain Analysis of Wood frame Structure

Maximum Allowable Seismic masses from Design Code

Damage prediction to structure using Calibrated model

Damage – Based Reliability Estimate
Test Program - Dynamic Displacement

Twelve 8 x 8ft (2.44 x 2.44m) walls tested

Exterior panel spacing varied, i.e. 3, 4, and 6”.

Dynamic Displacement (DD) - 6 walls total

Couple scaled ground acceleration with structural model.

Use nonlinear response as DD input signal to actuator.
Illustrative Model Calibration

\[ D = \frac{\Delta_m}{\Delta_u} + \frac{\psi}{F_y \Delta_u} \int dE = 1.0 \]
## Defining “Performance”

<table>
<thead>
<tr>
<th>Performance Descriptor</th>
<th>Performance Description</th>
<th>Intended Type of Limit State</th>
<th>Indicator During Test(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corner nail pullout</td>
<td>Corner nail pulls out beyond load carrying capacity.</td>
<td>Serviceability / Overload</td>
<td>Observation</td>
</tr>
<tr>
<td>Splitting of bottom plate</td>
<td>1/16 in (1.6mm)</td>
<td>Safety / Serviceability</td>
<td>LVDT No. 4</td>
</tr>
<tr>
<td>Out-of-plane sheathing movement at mid-height</td>
<td>1/16 in (3.2mm)</td>
<td>Safety</td>
<td>LVDT No. 2</td>
</tr>
<tr>
<td>Bottom of sheathing detaches</td>
<td>1/8 in (1.6mm)</td>
<td>Collapse</td>
<td>LVDT No. 3</td>
</tr>
</tbody>
</table>

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Making the Model
Mechanistic

Linear regression to get damage/structural parameters as a function of exterior panel nail spacing

\[ D = \frac{\Delta^m}{\Delta_u} + \frac{\psi}{F_y \Delta_u} \int dE \]

Maximum displacement and absorbed hysteretic energy are found through dynamic analysis.
Mechanistic Damage Model

Only function of nail spacing, \( s \)

Requires only nonlinear time domain simulation

From E.Q. Simulation

\[
D = \frac{\Delta m}{a_{\Delta u} s + b_{\Delta u}} + \int dE
\]

\[
= \frac{a_{\varphi} s + b_{\varphi}}{(a_{Fey} s + b_{Fey})(a_{\Delta u} s + b_{\Delta u})}
\]
Example Calculation: Damage-Based Seismic Reliability

Compare to FEMA collapse-prevention - 3% transient drift
Compare to ultimate strength-based reliability

Difference here could be used to back calibrate basic structural behaviors, i.e. performance, to ensure FEMA drift provisions are met.

Damage limit state E reached

3% Drift
In Summary…

These are all methods to calculate reliability of wood shearwalls to lateral load with applications ranging from:

LRFD calibration  Emerging PBSD

Damage-limiting design philosophies
Thank you!

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