Wall Design for Out of Plane Wind Loads

October, 2015
Day’s Overview

- Load Path Overview
- Introduction to Codes & Standards
- Diaphragm Design and Detailing
- Shear Wall Design and Detailing
- Prescriptive Design Options for Wood Systems
- Uplift including Combined Shear
- Wall Design
- Multi-Story Considerations
Designing Wood Walls
Wind Load Paths

WIND SURFACE LOADS ON WALLS
Wind Loads

Uniform surface wind loads generally increase with building height.

If wind loads vary with building height, common to use higher wind load over a single story or building.
Wall Design Considerations

- Panels
- Hinges
- L/d Ratio
- Unbraced Length
- Wall Veneer
- Wind only loading C&C
- Design Properties
# Loads into WSP

Wind loads are transferred to wall framing studs through wood structural panels (sheathing).

## TABLE 1a

<table>
<thead>
<tr>
<th>Span Rating&lt;sup&gt;(b)&lt;/sup&gt;</th>
<th>Load Governed By&lt;sup&gt;(c)&lt;/sup&gt;</th>
<th>Perpendicular to Supports Span Center-to-Center of Supports (inches)</th>
<th>Strength Axis&lt;sup&gt;(a)&lt;/sup&gt;</th>
<th>Parallel to Supports Span Center-to-Center of Supports (inches)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>12</td>
<td>16</td>
<td>19.2</td>
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<tr>
<td>24/0</td>
<td>L/360</td>
<td>287</td>
<td>108</td>
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<tr>
<td></td>
<td>L/240</td>
<td>431</td>
<td>162</td>
<td>89</td>
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<td></td>
<td>L/180</td>
<td>574</td>
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<tr>
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<td>Bending</td>
<td>208</td>
<td>117</td>
<td>81</td>
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<tr>
<td></td>
<td>Shear</td>
<td>295</td>
<td>214</td>
<td>175</td>
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<tr>
<td>32/16</td>
<td>L/360</td>
<td>544</td>
<td>205</td>
<td>112</td>
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<tr>
<td></td>
<td>L/240</td>
<td>816</td>
<td>307</td>
<td>168</td>
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<td></td>
<td>L/180</td>
<td>1,088</td>
<td>409</td>
<td>224</td>
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<tr>
<td></td>
<td>Bending</td>
<td>308</td>
<td>173</td>
<td>120</td>
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<tr>
<td></td>
<td>Shear</td>
<td>381</td>
<td>276</td>
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<tr>
<td>40/20</td>
<td>L/360</td>
<td>1,088</td>
<td>409</td>
<td>224</td>
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<td></td>
<td>L/240</td>
<td>1,631</td>
<td>614</td>
<td>336</td>
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<td></td>
<td>L/180</td>
<td>2,175</td>
<td>818</td>
<td>448</td>
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<td>521</td>
<td>293</td>
<td>203</td>
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<td></td>
<td>Shear</td>
<td>467</td>
<td>338</td>
<td>277</td>
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</table>
Which wall is going to withstand high winds?

- L/D < 50
  - 2x6: 22’-11”
  - 2x4: 14’-7”
Gable End Wall Hinge
Gable End Bracing Details

AWC’s Wood Frame Construction Manual

Figure 11. Ceiling Bracing Gable Endwall
Gable End Bracing Details

- Truss Roof framing may require cross bracing details at gable end

Diagram: Cross bracing at gable end with overhang and vertical members of roof trusses. Use two 16d nails or three inch screws where the gable end braces intersect with vertical truss members.
If no openings in gable end wall exist, can design studs to span from floor/foundation to roof (varying stud heights). May require closer stud spacings at taller portions of wall.
Gable End Walls with Openings
Gable End Walls with Openings
- Often gable end walls are locations of large windows
- Horizontally spanning member in plane of wall breaks stud length, provides allowable opening
Determining Unbraced Length

- What is the unbraced length, $l_u$?
- Strong & weak axis
Does Gypsum Prevent Weak Axis Buckling

NDS Commentary:
“Experience has shown that any code allowed thickness of gypsum board, hardwood plywood, or other interior finish adequately fastened directly to studs will provide adequate lateral support of the stud across its thickness irrespective of the type or thickness of exterior sheathing and/or finish used.”
Intermediate Wall Stud Blocking
### Calculating Deflection – IBC Table 1604.3

For $\Delta$ of most brittle finishes use $l/240$

For C&C pressures a 30% load reduction is allowed for $\Delta$ only (IBC Table 1604.3 footnote f)

<table>
<thead>
<tr>
<th>CONSTRUCTION</th>
<th>L</th>
<th>S or W</th>
<th>D + L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof members: e</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supporting plaster ceiling</td>
<td>$l/360$</td>
<td>$l/360$</td>
<td>$l/240$</td>
</tr>
<tr>
<td>Supporting nonplaster ceiling</td>
<td>$l/240$</td>
<td>$l/240$</td>
<td>$l/180$</td>
</tr>
<tr>
<td>Not supporting ceiling</td>
<td>$l/180$</td>
<td>$l/180$</td>
<td>$l/120$</td>
</tr>
<tr>
<td>Floor members</td>
<td>$l/360$</td>
<td></td>
<td>$l/240$</td>
</tr>
<tr>
<td>Exterior walls and interior partitions:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With brittle finishes</td>
<td></td>
<td>$l/240$</td>
<td></td>
</tr>
<tr>
<td>With flexible finishes</td>
<td></td>
<td>$l/120$</td>
<td></td>
</tr>
<tr>
<td>Farm buildings</td>
<td></td>
<td></td>
<td>$l/180$</td>
</tr>
<tr>
<td>Greenhouses</td>
<td></td>
<td></td>
<td>$l/120$</td>
</tr>
</tbody>
</table>

f. The wind load is permitted to be taken as 0.42 times the "component and cladding” loads for the purpose of determining deflection limits herein.
Wood Studs with Brick Veneer - Deflection

IBC Table 1604.3: min. wall deflection with brittle finishes = L/240

Brick Industry Association recommends much stricter limits

Structure Magazine May 2008 article, Harold Sprague

BIA Tech Note 28
Example: Large Diamond Retailer

22’ tall wood framed walls.
Assume studs 16” o.c.
130 mph Exposure B
Least Horizontal Dim. = 64 ft.
External Pressure Coefficients – Wall Zones 4 & 5

\[ a = \text{Lesser of:} \]

- 10\% least horizontal dimension (LHD) \( 64' \times 0.1 = 6.4' \)
- \( 0.4h = 0.4 \times 22 = 8.8' \)

But not less than:

- \( 0.04 \times \text{LHD} = 2.6' \) or 3'

\textbf{Use } a = 6.4' \text{ for zone 5}
Effective Wind Area

For wind design, tributary area does not necessarily = effective wind area

Effective Wind Area (EWA) - Two cases:
• Area of building surface contributing to force being considered (tributary area)
• Long and narrow area (wall studs, roof trusses): width of effective area may be taken as 1/3 length; increases effective area, decreases load (per ASCE 7-10 section 26.2 commentary); EWA = \(L^2/3\)
Effective Wind Area Example

Trib. \( A = (22)(1.33) = 29 \text{ ft}^2 \)

EWA = \( \frac{22^2}{3} = 161 \text{ ft}^2 \)
External Pressure Coefficients - Walls

Assume wall studs are 22’ long

EWA = \( h^2/3 \) = 161 ft\(^2\)

Zone 4:

\( GC_{pf} = -0.89 \)
\( GC_{pi} = -0.18 \) (Table 26.11-1)

Zone 5:

\( GC_{pf} = -1.0 \)
Running the numbers – Zone 4

- $GC_{pf}$: 0.89 (Figure 30.4-1)
- $GC_{pi}$: 0.18 (Table 26.11-1)
- $q_h = 0.00256K_z K_{zt} K_d V^2$
  - $K_h$: 0.70 - Table 30.3-1
  - $K_{zt}$: 1.00 - Figure 26.8-1
  - $K_d$: 0.85 - Table 26.6-1
  - $V$: 130 mph
- $q_h = 25.74$ psf
- $p = 25.74$ psf $(0.89+0.18) = 27.54$ psf
- $0.6 W = 0.6(27.54) = 16.52$ psf
Lumber Design Properties

Design Properties from NDS Supplement.

Assume 2x8 Douglas Fir-Larch #2 Studs, 16” o.c. Repetitive Member adjustment = 1.25
Size Factor = 1.2
Duration of Load = 1.6
Lumber Design Properties

Note on stud repetitive member factor:
NDS section 4.3.9: $C_R = 1.15$

SDPWS Table 3.1.1.1 allows larger $C_R$ factors for studs in bending, 16” spacing max, interior covered with min. ½” gypsum, exterior covered with min. 3/8” WSP, other fastener requirements

<table>
<thead>
<tr>
<th>Table 3.1.1.1 Wall Stud Repetitive Member Factors</th>
</tr>
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<tbody>
<tr>
<td>Stud Size</td>
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<tr>
<td>2x4</td>
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<tr>
<td>2x6</td>
</tr>
<tr>
<td>2x8</td>
</tr>
<tr>
<td>2x10</td>
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<tr>
<td>2x12</td>
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<table>
<thead>
<tr>
<th>DESIGN PROPERTIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_b$ (psi)</td>
</tr>
<tr>
<td>$C_D$</td>
</tr>
<tr>
<td>$C_R$</td>
</tr>
<tr>
<td>$C_F$</td>
</tr>
<tr>
<td>$E$ (psi)</td>
</tr>
<tr>
<td>$S_x$ (in³)</td>
</tr>
<tr>
<td>$I$ (in⁴)</td>
</tr>
</tbody>
</table>
So is our stud going to work?

Two of the most critical design parameters are bending and deflection.

\[ M_{applied} = \frac{wL^2}{8} = \frac{(16.52 \text{ psf})(1.333 \text{ ft})(22 \text{ ft})^2}{8} = 1333 \text{ ft} \times \text{lb} \]

\[ M_{resistance} = F'_b \times S_x = (900 \text{ psi})(1.6)(1.2)(1.25)(13.1 \text{ in}^3) \left(\frac{1 \text{ ft}}{12 \text{ in}}\right) = 2358 \text{ ft} \times \text{lb} \]

IBC Table 1604.3
footnote f

\[ \Delta_{actual} = \frac{5wL^4}{384EI} = 0.7 \frac{(5)(16.52 \text{ psf})(1.333 \text{ ft})[(22 \text{ ft})\left(\frac{12 \text{ in}}{1 \text{ ft}}\right)]^4}{(384)(1600000 \text{ psi})(47.6 \text{ in}^4)} \left(\frac{1 \text{ ft}}{12 \text{ in}}\right) = 1.07 \text{ in} \]

\[ \Delta_{allowed} = \frac{L}{240} = \frac{(22 \text{ ft})(\frac{12 \text{ in}}{1 \text{ ft}})}{240} = 1.10 \text{ in} \]

\[ M_{applied} < M_{resistance} \quad \Delta_{actual} < \Delta_{allowed} \]

Studs work!
Running the numbers – Zone 5

- \( GC_p : 1.00 \) (Figure 30.4-1)
- \( GC_{pi} : 0.18 \) (Table 26.11-1)
- \( q_h = 0.00256K_zK_{zt}K_dV^2 \)
  - \( K_h : 0.70 \) - Table 30.3-1
  - \( K_{zt} : 1.00 \) - Figure 26.8-1
  - \( K_d : 0.85 \) - Table 26.6-1
  - \( V: 130 \) mph
- \( q_h = 25.74\text{psf} \)
- \( p = 25.74\text{psf}(1.0+0.18) = 30.37\text{psf} \)
- \( 0.6W = 0.6(30.37) = 18.22\text{psf} \)
What about corner zones?

\[ M_{\text{applied}} = \frac{wL^2}{8} = \frac{(18.22 \text{ psf})(1.333 \text{ ft})(22 \text{ ft})^2}{8} = 1469 \text{ ft} * \text{ lb} \]

\[ M_{\text{resistance}} = F'_b * S_x = (900 \text{ psi})(1.6)(1.2)(1.25)(13.1 \text{ in}^3) \left(\frac{1 \text{ ft}}{12 \text{ in}}\right) = 2358 \text{ ft} * \text{ lb} \]

\[ M_{\text{applied}} < M_{\text{resistance}} \]

IBC Table 1604.3
footnote f

\[ \Delta_{\text{actual}} = \frac{5wL^4}{384EI} = 0.7 \frac{(5)(18.22 \text{ psf})(1.333 \text{ ft})[(22 \text{ ft}) \left(\frac{12 \text{ in}}{1 \text{ ft}}\right)]^4}{(384)(1600000 \text{ psi})(47.6 \text{ in}^4)} \left(\frac{1 \text{ ft}}{12 \text{ in}}\right) = 1.18 \text{ in} \]

\[ \Delta_{\text{allowed}} = \frac{L}{240} = \frac{(22 \text{ ft}) \left(\frac{12 \text{ in}}{1 \text{ ft}}\right)}{240} = 1.10 \text{ in} \]

\[ \Delta_{\text{actual}} > \Delta_{\text{allowed}} \]

Deflection check no good – solution: reduce loads on each stud
12” Stud Spacing

Since stud depth cannot be increased consider reducing stud spacing to 12” in all Zone 5 areas:

\[ M_{\text{applied}} = \frac{wL^2}{8} = \frac{(18.22 \text{ psf})(1 \text{ ft})(22 \text{ ft})^2}{8} = 1102 \text{ ft} \times \text{lb} \]

\[ M_{\text{resistance}} = F'_{b} \times S_{x} = (900 \text{ psi})(1.6)(1.2)(1.25)(13.1 \text{ in}^3) \left(\frac{1 \text{ ft}}{12 \text{ in}}\right) = 2358 \text{ ft} \times \text{lb} \]

IBC Table 1604.3 footnote f

\[ \Delta_{\text{actual}} = \frac{5wL^4}{384EI} = 0.7 \frac{(5)(18.22 \text{ psf})(1 \text{ ft})[(22 \text{ ft})\left(\frac{12 \text{ in}}{1 \text{ ft}}\right)]^4}{(384)(1600000 \text{ psi})(47.6 \text{ in}^4)} \left(\frac{1 \text{ ft}}{12 \text{ in}}\right) = 0.88 \text{ in} \]

\[ \Delta_{\text{allowed}} = \frac{L}{240} = \frac{(22 \text{ ft})\left(\frac{12 \text{ in}}{1 \text{ ft}}\right)}{240} = 1.10 \text{ in} \quad M_{\text{applied}} < M_{\text{resistance}} \quad \Delta_{\text{actual}} < \Delta_{\text{allowed}} \]

Studs work! – Use 2x8 @ 16” o.c. typical, use 2x8 @ 12” o.c. in corners (Zone 5 areas)
Wall Design Considerations

For tall walls while it is less likely for combined bending and axial to control

- Main Wind Force Loads may be utilized
- Load combinations (ASCE 7 Chpt 2)
  - for:
    - wind + dead or
    - dead + 0.75 live + 0.75 roof live (or snow)

AWC Paper discusses this topic:

Wall Stud Design Aid

Western Wood Products Association (WWPA) Design Suite:
Questions?

Visit www.woodworks.org for more educational materials, case studies, design examples, a project gallery, and more