Diaphragm Basics Using SDPWS

American Wood Council
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SDPWS and IBC

2008 SDPWS is referenced in 2012 IBC
SECTION 2305 GENERAL DESIGN REQUIREMENTS FOR LATERAL FORCE-RESISTING SYSTEMS

2305.1 General. Structures using wood-frame shear walls or wood-frame diaphragms to resist wind, seismic or other lateral loads shall be designed and constructed in accordance with AF&PA SDPWS and the applicable provisions of Sections 2305, 2306 and 2307.
2012 IBC

2306.2 Wood diaphragms. 2306.2.1 Wood-frame structural panel diaphragms. Wood-frame structural panel diaphragms shall be designed and constructed in accordance with AF&PA SDPWS. Where panels are fastened to framing members with staples, requirements and limitations of AF&PA SDPWS shall be met and Wood structural panel diaphragms are permitted to resist horizontal forces using the allowable shear capacities set forth in Table 2306.2.1(1) or 2306.2.1(2). The allowable shear capacities in Tables 2306.2.1(1) and 2306.2.1(2) are permitted to be increased 40 percent for wind design.

2306.2.2 Single diagonally sheathed lumber diaphragms. Single diagonally sheathed lumber diaphragms shall be designed and constructed in accordance with AF&PA SDPWS.

2306.2.3 Double diagonally sheathed lumber diaphragms. Double diagonally sheathed lumber diaphragms shall be designed and constructed in accordance with AF&PA SDPWS.

2306.2.4 Gypsum board diaphragm ceilings. Gypsum board diaphragm ceilings shall be in accordance with Section 2508.5.

Similar changes to 2306.3 for shear walls
Significant Changes to 2012 IBC

SECTION 2307
LOAD AND RESISTANCE FACTOR DESIGN

2307.1 Load and resistance factor design. The structural analysis and construction of wood elements and structures using load and resistance factor design shall be in accordance with AF&PA NDS and AF&PA SDPWS.

2307.1.1 Wood structural panel shear walls. In Seismic Design Category D, E or F, where shear design values exceed 490 pounds per foot (7154 N/m), all framing members receiving edge nailing from abutting panels shall not be less than a single 3-inch (76 mm) nominal member or two 2-inch (51 mm) nominal members fastened together in accordance with AF&PA NDS to transfer the design shear value between framing members. Wood structural panel joint and sill plate nailing shall be staggered at all panel edges. See Sections 4.3.6.1 and 4.3.6.4.3 of AF&PA SDPWS for sill plate size and anchorage requirements.

SECTION 2307
LOAD AND RESISTANCE FACTOR DESIGN

2307.1 Load and resistance factor design. The design and construction of wood elements and structures using load and resistance factor design shall be in accordance with AF&PA NDS and AF&PA SDPWS.
Diaphragm Types

- **Rigid**
  - Diaphragm behaves as a fully rigid body
  - $D_{\text{diaphragm}} < 2D_{\text{shearwalls}}$
  - Inherent and accidental torsion considered in design

- **Flexible**
  - Diaphragm behaves as a series of simple beams
  - $D_{\text{diaphragm}} > 2D_{\text{shearwalls}}$
  - No torsion
  - Tributary loading to vertical resisting elements (shear walls)
Diaphragm Flexibility

- **Idealized as Flexible**
  - Diaphragm load is distributed to shear walls based on tributary area (common for wood frame)

- **Idealized as Rigid**
  - Diaphragm load is distributed to shear walls based on relative wall stiffness

- **Semi-rigid**
  - Diaphragm load is distributed to shear walls based on relative stiffness of shear walls and diaphragm
• Engineered
• Res and Non-Res
• ASD & LRFD
• Efficiencies in designs
• Shear wall provisions
  • Segmented
  • Perforated
  • Force Transfer Around Openings
Chapter 4 - Lateral Force-Resisting Systems

- Wood Diaphragms

Table 4.2.4 Maximum Diaphragm Aspect Ratios
(Horizontal or Sloped Diaphragms)

<table>
<thead>
<tr>
<th>Diaphragm Sheathing Type</th>
<th>Maximum L/W Ratio</th>
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<td>Wood structural panel, blocked</td>
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<td>Single-layer straight lumber sheathing</td>
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<td>Single-layer diagonal lumber sheathing</td>
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<tr>
<td>Double-layer diagonal lumber sheathing</td>
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Chapter 4 – Nominal Design Value

- Wind nominal unit shear capacity \( v_w \)
- IBC allowable stress design value x 2.8
- Seismic nominal unit shear capacity \( v_s \)
  \[ v_s = \frac{v_w}{1.4} \]

### Table 4.2A Nominal Unit Shear Capacities for Wood-Frame Diaphragms

<table>
<thead>
<tr>
<th>Sheathing Grade</th>
<th>Common Nail Size</th>
<th>Minimum Fastener Penetration in Framing (in.)</th>
<th>Minimum Nominal Panel Thickness (in.)</th>
<th>Minimum Nominal Framing Width (in.)</th>
<th>A (SEISMIC)</th>
<th>B (WIND)</th>
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Nominal unit shear values adjusted in accordance with 4.2.3 to determine ASD allowable unit shear capacity and LRFD factored unit resistance.

**ASD unit shear capacity,** $v_s$:

$$v_s = \frac{520 \text{ plf}}{2.0} = 260 \text{ plf}$$

- ASD reduction factor
- Reference nominal value

**LRFD unit shear capacity,** $v_s$:

$$v_s = 520 \text{ plf} \times 0.80 = 416 \text{ plf}$$

- LRFD resistance factor
- Reference nominal value
Adjustment for Framing G

• Reduced nominal unit shear capacities determined by multiplying the tabulated nominal unit shear capacity by the Specific Gravity Adjustment Factor
  • SG Adjustment Factor = [1.0-(0.50-G)] < 1.0

• Example SG Adjustment Factors

<table>
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<tr>
<th>Species Combination</th>
<th>Specific Gravity, G</th>
<th>FACTOR = 1.0 - (0.50 - G)</th>
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<td>Western Woods</td>
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Chapter 4 - Lateral Force-Resisting Systems

• Wood Diaphragms

4.2.2 Deflection

Calculations of diaphragm deflection shall account for bending and shear deflections, fastener deformation, chord splice slip, and other contributing sources of deflection.

The diaphragm deflection, $\delta_{\text{dia}}$, is permitted to be calculated by use of the following equation:

$$\delta_{\text{dia}} = \frac{5vL^3}{8EAW} + \frac{0.25vL}{1000G_a} + \frac{\sum (x\Delta_c)}{2W}$$  \hspace{1cm} (4.2-1)
Deflections (4-term equations)

- Diaphragm

\[ \text{Total} \Delta = \Delta_b + \Delta_v + \Delta_n + \Delta_c \]

\[ \Delta = \frac{5vL^3}{8EAb} + \frac{vL}{4Gt} + 0.188Le_n + \sum \left( \Delta_c X \right) \]

\[ \frac{0.25 v L}{1000Ga} \]

SDPWS – nails unblocked and blocked
Comparison – 3-term vs. 4-term

Shear panel deformation and nail slip

4-term
\[
\frac{vL}{4G_v t_v} + 0.188Le_n
\]

3-term
\[
\frac{0.25vL}{1000G_a}
\]

\(G_v t_v\) = shear stiffness, lb/in. of panel depth.
\(e_n\) = nail slip, in.
\(G_a\) = apparent diaphragm shear stiffness, kips/in.
Questions?

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info@awc.org

AMERICAN WOOD COUNCIL
Diaphragm Design for Non-Residential and Multi-Family Buildings

Bryan Readling, PE
Senior Engineer, APA
Wood Structural Panels are by definition either Plywood or OSB (2302 & R202)
Wood Structural Panels come in two grades: Structural I, and Sheathing.
Wood Diaphragms:

- Design Concepts
- Deflection Calculations
- Design Values
Diaphragm Design: Load Effects

Load, $w$:

Load, $w$: $\triangleleft$

$x$ $L$

Shear, $V$:

$V = w \left( \frac{L}{2} - x \right)$

Moment, $M$:

$M = \frac{wx}{2} \left( L - x \right)$
Horizontal Diaphragms

WIND

Compression

Reaction

ROOF DIAPHRAGM

Tension

Reaction

Plan View
Diaphragm Design: Loads

Designed like a wide flange beam:
- Flanges ~ diaphragm chords or collector carry moment
- Web ~ wood panels and framing carry shear
Wood Shear Wall and Diaphragms Design

- Function of: fastener’s size, spacing and panel thickness
- Values in Tables all building codes
- Alternately, capacities can be calculated by principles of mechanics
### Table 4.2C Nominal Unit Shear Capacities for Wood-Frame Diaphragms

<table>
<thead>
<tr>
<th>Sheathing Grade</th>
<th>Common Nail Size</th>
<th>Minimum Fastener Penetration in Framing (in.)</th>
<th>Minimum Nominal Panel Thickness (in.)</th>
<th>Minimum Nominal Width of Nailed Face at Supported Edges and Boundaries (ft)</th>
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#### A: SEISMIC

6 in. Nail Spacing at diaphragm boundaries and supported panel edges

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<th>Common Nail Size</th>
<th>Minimum Fastener Penetration in Framing (in.)</th>
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#### B: WIND

6 in. Nail Spacing at diaphragm boundaries and supported panel edges

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<th>Minimum Nominal Panel Thickness (in.)</th>
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<td>670</td>
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<td></td>
</tr>
</tbody>
</table>
The allowable shear capacities have been increased by 40% for wind load resistance.
40% Increase for Wind - Justification

- Confidence in code wind load accuracy is high

- The current shear wall and diaphragm tables are based on a 2.8 min. safety factor and it was agreed that a 2.0 safety factor is adequate, thus a 40% increase in tabulated values
### Table 4.2B Nominal Unit Shear Capacities for Wood-Frame Diaphragms

#### Unblocked Wood Structural Panel Diaphragms

<table>
<thead>
<tr>
<th>Sheathing Grade</th>
<th>Common Nail Size</th>
<th>Minimum Fastener Penetration in Framing (in.)</th>
<th>Minimum Nominal Panel Thickness (in.)</th>
<th>Minimum Nominal Framing Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural 1</td>
<td>6d</td>
<td>1-1/4</td>
<td>5/16</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>8d</td>
<td>1-3/8</td>
<td>3/8</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>10d</td>
<td>1-1/2</td>
<td>15/32</td>
<td>2</td>
</tr>
</tbody>
</table>

#### A - SEISMIC

<table>
<thead>
<tr>
<th>v_s (plf)</th>
<th>G_a (kips/in.)</th>
<th>v_s (plf)</th>
<th>G_a (kips/in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>330</td>
<td>9.0</td>
<td>250</td>
<td>6.0</td>
</tr>
<tr>
<td>370</td>
<td>7.0</td>
<td>280</td>
<td>4.5</td>
</tr>
<tr>
<td>480</td>
<td>8.5</td>
<td>360</td>
<td>6.0</td>
</tr>
<tr>
<td>530</td>
<td>7.5</td>
<td>400</td>
<td>5.0</td>
</tr>
<tr>
<td>570</td>
<td>14.0</td>
<td>430</td>
<td>9.5</td>
</tr>
<tr>
<td>640</td>
<td>12.0</td>
<td>480</td>
<td>8.0</td>
</tr>
</tbody>
</table>

#### B - WIND

<table>
<thead>
<tr>
<th>v_w (plf)</th>
<th>v_w (plf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>460</td>
<td>350</td>
</tr>
<tr>
<td>520</td>
<td>390</td>
</tr>
<tr>
<td>670</td>
<td>505</td>
</tr>
<tr>
<td>740</td>
<td>560</td>
</tr>
<tr>
<td>800</td>
<td>600</td>
</tr>
<tr>
<td>895</td>
<td>670</td>
</tr>
</tbody>
</table>
4.2.3 Unit Shear Capacities

The nominal unit shear capacities for seismic design are provided in Column A of Tables 4.2A, 4.2B, and 4.2C; and for wind design in Column B of Tables 4.2A, 4.2B, and 4.2C. The ASD allowable unit shear capacity shall be determined by dividing the nominal unit shear capacity by the ASD reduction factor of 2.0. No further increases shall be permitted. The LRFD factored unit resistance shall be determined by multiplying the nominal unit shear capacity by a resistance factor, $\phi_D$, of 0.80.
Wind Design Key Points

For wind design, shear wall and diaphragm deflections are probably not needed

- E.g. the SDPWS doesn’t even list $G_a$ for wind
Unblocked Diaphragm
Blocked Diaphragm
Diaphragm Buckling Failure

Diaphragm Shear Strength Failure
APA Research Reports 138 and 154

- Shear wall history
- Diaphragm history
Load Path Components

3. Diaphragm

Lateral load from wind or seismic
Diaphragm

- Horizontal or slopped system acting to transmit lateral forces to the vertical-resisting elements (IBC Sec. 1602.1)
From Diaphragm to Shear Walls

Diaphragm reaction goes to shear walls
Idealizing and Simplifying Complicated Structures

- Sloped roofs
- Offset roof planes
- T-, L-shaped and other odd
- Drag struts
- Flexible v. rigid diaphragm
Sloped Roofs

Idealize sloped wood roof diaphragms as if they are flat
Curved Diaphragms

Idealize it as flat
Offset Roof Planes

Offset roof planes

Treat as two separate diaphragms
Each with their own chords
Offset Roof Planes

Offset roof planes

Provide lateral force resistance (shear walls) at diaphragm boundaries
Offset Roof Planes

Roof framing must keep diaphragm in plane

Load on diaphragms may be different due to different heights

- Proportion load rationally
Collector

- A horizontal diaphragm element parallel and in line with the applied force that collects and transfers diaphragm shear forces to the vertical elements of the lateral-force-resisting system and/or distributes forces within the diaphragm.

(IBC Sec. 2302.1)
A collector works just like a post collects load from beam and transfers it to the foundation

A collector collects load from the diaphragm and transfers it to the shear wall
Shear Walls, Drag Struts

8 ft

v = 100 lb/ft

1,600 lb

v = 300 lb/ft

32 ft

Collector

v = 300 lb/ft

8 ft
Offset Diaphragms

Example - Complex Diaphragm

Pre-recorded Webinar at www.woodworks/education/online-seminars/
Framing Parallel to Strut Forces

Collector Strap
Framing Perpendicular to Strut Forces

Collector Strap
Flexible, Rigid and Semi-Rigid Diaphragms

- **Flexible**
  - Diaphragm load is distributed to shear walls by tributary area

- **Rigid**
  - Diaphragm load is distributed to shear walls by wall stiffness and torsion

- **Semi-rigid**
  - Between flexible and rigid, dependent on stiffness
Diaphragm (Plan View)
Flexible Diaphragm

$\Delta_{sw}$

Flexible \(0.25wL\)

Flexible \(0.50wL\)

Flexible \(0.25wL\)

$\Delta_{di}$

$L/2$

$L/2$
Rigid - All Walls Identical

Δ_{sw} \uparrow \downarrow

Rigid (no Torsion)

.333wL

.333wL

.333wL

L/2

L/2
Flexible v. Rigid

Stiffness: $2K$

Flexible: $0.25wL$

Rigid (no Torsion): $0.40wL$

$K$

-.50wL

-.20wL

-.25wL

-.40wL

L/2

L/2
Prescribed Rigid Wood Diaphragms (SDPWS)

- Open front
- Cantilevered diaphragms

Torsionally irregular
Rigid Analysis

- **Direct Shear:**
  - Force proportioned based on stiffness ($k$)

- **Torsional Shear:**
  - Force proportioned by
  - $M = F \times e$
  - $J = \sum k d_x^2 + \sum k d_y^2$
  - $k = $ stiffness wall
  - $d = $ distance from center of rigidity

- Examples in Breyer et al.
Flexible, Rigid or Semi-Rigid

Which do you have?

- Prescribed flexible
- Calculated flexible
- Prescribed rigid
- Else, “semi-rigid”
Prescribed Flexible Diaphragm

In many cases wood diaphragms are permitted to be idealized as flexible

ASCE 7-10 Sec. 26.2: Diaphragms constructed of wood structural panels are permitted to be idealized as flexible.
Calculated Flexible Diaphragm

ASCE 7-10 Sec. 12.3.1.3

Diaphragms are permitted to be idealized as flexible when:

- The diaphragm deflection is more than two times the average story drift of adjoining shear walls

\[ \Delta_{\text{DIAPHRAGM}} \geq 2 \times \Delta \]
Calculated Flexible Diaphragm

The longer the diaphragm the more likely it is to calculate as flexible
Calculating Shear Wall and Diaphragm Deflection

**Importance**
- Rigid v. flexible diaphragm
- Drift limit
- Building separation
Deflections (4-term eqn’s)

- Shear Wall (IBC §2305.3.2)
  \[ \Delta = \frac{8vht^3}{EAb} + \frac{vh}{G_{tv}} + 0.75he_n + \frac{h}{d_a} \]

- Diaphragm (IBC §2305.2.2)
  \[ \Delta = \frac{5vL^3}{8EAb} + \frac{vL}{4G_{tv}} + 0.188Le_n + \frac{\sum (\Delta cX)}{2b} \]

APA L350 (www.apawood.org) has comprehensive listing of input parameters and examples
Deflection (3-term eqn.)

- **Diaphragm (SDPWS §4.2.2)**

\[
\Delta = \frac{5\nu L^3}{8EAW} + \frac{0.25\nu L}{1000G_a} + \sum \frac{(\Delta cX)}{2W}
\]

- \(G_a\) values for blocked and unblocked diaphragms
Diaphragms and Shear Walls

- Deflection of Unblocked Diaphragms is 2.5 times the deflection of blocked diaphragm.

- If framing members are spaced more than 24”o.c., testing indicates further deflection increase of about 20%, or 3 times the deflection of a comparable blocked diaphragm. (This is based on limited testing of the diaphragm by APA)
Prescribed Rigid Wood Diaphragms (SDPWS 4.2.5.2)
Prescribed Rigid Wood Diaphragms (SDPWS 4.2.5.2)

- **Open front**

- **Cantilevered diaphragms**
Semi-Rigid Diaphragm

• Diaphragm flexibility - ASCE 7 Sec. 12.3.1

• Unless it can be idealized as flexible or rigid, then:
  • The structural analysis shall consider the relative stiffness of diaphragms and shear walls
Semi-Rigid Diaphragm

- Semi-rigid results in force distribution somewhere between rigid and flexible.
- Thus, an envelope approach can be used where the both rigid and flexible models are used and the highest forces from each are selected.
Assuming the diaphragm is flexible is always allowed, except for the open front and cantilever case where rigid is prescribed.
Shear Transfer from Roof Diaphragm - to Shearwall
Force Transfer from Diaphragm to Shearwall
APA Publications and Website

Free APA publications

www.APAnwood.org

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