Welcome to 2008 SDPWS Diaphragm Deflection Design
Copyright Materials

This presentation is protected by US and International Copyright laws. Reproduction, distribution, display and use of the presentation without written permission of the speaker is prohibited.

© American Wood Council 2010
Learning Objectives

At the end of this program, participants will be able to:

1. Calculate wood-frame diaphragm deflection using the 2008 SDPWS.
2. Compare the difference between the 3-term and 4-term deflection equation in the 2008 SDPWS.
3. Analyze individual components of the deflection equations to determine their magnitude of impact on total deflection.
4. Utilize the example deflection calculation in future design work as a model for their own calculations.
Welcome to 2008 SDPWS Diaphragm Deflection Design
Outline

- Code acceptance of 2008 SDPWS
- Diaphragm Deflection Equation
- Diaphragm Deflection Example
Now let’s look at the how model codes implement the Wind & Seismic Standard.
The same tables that specify nominal unit shear capacities also contain values of apparent shear stiffness, \((Ga)\). Re-formatted deflection equations make use of these tabulated values of apparent shear stiffness to simplify deflection calculations and to extend deflection calculations to a variety of sheathing materials and unblocked wood structural panel diaphragms. The SDPWS three-term deflection equations are an algebraic simplification of the four-term equations in the IBC; however, SDPWS provides an option to calculate deflections using other methods such as the four-term equations.

Applies to both floor and roof diaphragms.
The same tables that specify nominal unit shear capacities also contain values of apparent shear stiffness, (Ga). Re-formatted deflection equations make use of these tabulated values of apparent shear stiffness to simplify deflection calculations and to extend deflection calculations to a variety of sheathing materials and unblocked wood structural panel diaphragms. The SDPWS three-term deflection equations are an algebraic simplification of the four-term equations in the IBC; however, SDPWS provides an option to calculate deflections using other methods such as the four-term equations.
Diaphragm Deflection Equation

Bending Chord Deformation Excluding Slip

\[ \frac{5vL^3}{8EAW} \]

- \( v \) = induced unit shear, plf
- \( L \) = diaphragm dimension perpendicular to the direction of the applied force, ft
- \( E \) = modulus of elasticity of diaphragm chords, psi
- \( A \) = area of chord cross-section, in.\(^2\)
- \( W \) = width of diaphragm in direction of applied force, ft
Diaphragm Deflection Equation

Bending Chord Splice Slip

\[ \frac{\sum (x \Delta_c)}{2W} \]

- \( x \) = distance from chord splice to nearest support, ft. For example, a shear wall aligned parallel to the loaded direction of the diaphragm would typically be considered a support.

- \( \Delta_c \) = diaphragm chord splice slip at the induced unit shear, in.

- \( W \) = width of diaphragm in direction of applied force, ft
## Comparison – 3-term vs. 4-term

**Shear panel deformation and nail slip**

<table>
<thead>
<tr>
<th>4-term</th>
<th>3-term</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ \frac{vL}{4G_v t_v} + 0.188Le_n ]</td>
<td>[ \frac{0.25vL}{1000G_a} ]</td>
</tr>
</tbody>
</table>

- \( G_v t_v \) = shear stiffness, lb/in. of panel depth.
- \( G_a \) = apparent diaphragm shear stiffness, kips/in.
- \( e_n \) = nail slip, in.
Tabulated Panel Shear Stiffness $G_a$ values, used to calculate the component of deflection due to shear deformation, replace the need for intermediate calculations that separately account for nail slip and panel shear stiffness. Equation [3] relates $G_a$ to nail slip and panel shear stiffness.

Note it is 1.4 x unit shear “capacity” vs. “induced unit shear”
## Comparison – 3-term vs. 4-term

### Table C4.2.2A  Shear Stiffness, G_t, (lb/in. of depth), for Wood Structural Panels

<table>
<thead>
<tr>
<th>Span Rating</th>
<th>Nominal Panel Thickness (in.)</th>
<th>Structural Sheathing</th>
<th>Structural I</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Plywood 3-ply</td>
<td>OSB 3-ply</td>
</tr>
<tr>
<td>24/0</td>
<td>3/8&quot;</td>
<td>25,000</td>
<td>32,500</td>
</tr>
<tr>
<td>24/16</td>
<td>7/16</td>
<td>27,000</td>
<td>35,000</td>
</tr>
<tr>
<td>32/16</td>
<td>15/32</td>
<td>27,000</td>
<td>35,000</td>
</tr>
<tr>
<td>40/20</td>
<td>19/32</td>
<td>28,500</td>
<td>37,000</td>
</tr>
<tr>
<td>48/24</td>
<td>23/32</td>
<td>31,000</td>
<td>40,500</td>
</tr>
</tbody>
</table>

### Shear Stiffness, G_t, (lb/in. of depth), for Other Sheathing Materials

<table>
<thead>
<tr>
<th>Sheathing Material</th>
<th>Minimum Nominal Panel Thickness (in.)</th>
<th>G_t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plywood siding</td>
<td>5/16 &amp; 3/8</td>
<td>25,000</td>
</tr>
<tr>
<td>Particleboard</td>
<td>1/2</td>
<td>28,000</td>
</tr>
<tr>
<td></td>
<td>5/8</td>
<td>28,500</td>
</tr>
<tr>
<td>Structural fiberboard</td>
<td>1/2 &amp; 25/32</td>
<td>25,000</td>
</tr>
<tr>
<td>Gypsum board</td>
<td>1/2 &amp; 5/8</td>
<td>40,000</td>
</tr>
<tr>
<td>Lumber</td>
<td>All</td>
<td>23,000</td>
</tr>
</tbody>
</table>
Question: What nail spacing do you use to calculate $e_n$? Diaphragm boundary edge nailing or interior panel edge nail spacing?

Answer: Use the interior panel edge nail spacing, not the diaphragm boundary nail spacing, to calculate $G_a$. If you look at the test data summary in Table C4.4.2E, it matches up reasonably well with this approach.
Comparison – 3-term vs. 4-term

**EXAMPLE C4.2.2-1 Derive \( G_b \) in SDPWS Table 4.2A**

Derive \( G_b \) in SDPWS Table 4.2A for a blocked wood structural panel diaphragm constructed as follows:

- **Sheathing grade**: Structural I (OSB)
- **Sheathing layup**: Case 1
- **Nail size**: 6d common (0.113" diameter, 2" length)
- **Minimum nominal panel thickness**: 5/16 in.
- **Boundary and panel edge nail spacing**: 6 in.
- **Minimum width of nailed face**: 2x nominal

### Panel shear stiffness:

\[ G_{st} = 77,500 \text{ lb/in. of panel depth} \]

### Nail load/dip at 1.4 \( V_{ASID} \):

\[ V_n = \text{fastener load (lb/nail)} \]

\[ V_{ASID} = 1.4 \times 1.4 \times 1.4 \times e_n \]

\[ e_n = \frac{(V_n \times 0.05)}{5} \]

\[ e_n = 0.0191 \text{ in.} \]

### Calculate \( G_j \):

\[ G_j = \frac{1.4 \times V_{ASID}}{G_{st} + 0.75e_n} \]  \hspace{1cm} (C4.2.2-3)

### Nominal unit shear capacity for seismic, \( V_s \):

\[ V_s = 370 \text{ p/lf} \]

### Allowable unit shear capacity for seismic:

\[ V_{ASID} = 370 \text{ p/lf} \times 1.15 = 185 \text{ p/lf} \]
Tests of blocked and unblocked diaphragms (4) are compared in Table C4.2.2E for diaphragms constructed as follows:

• Sheathing material = Sheathing Grade, 3/8" minimum nominal panel thickness
• Nail size = 8d common (0.131” diameter, 2½” length)
• Diaphragm length, L = 24 ft
• Diaphragm width, W = 24 ft
• Panel edge nail spacing = 6 in.
• Boundary nail spacing = 6 in. o.c. at boundary parallel to load (4 in. o.c. at boundary perpendicular to load for walls A and B)

Calculated deflections at 1.4 x $v_0$(ASD) closely match test data for blocked and unblocked diaphragms.
Identical values of calculated deflection are given by the three-term and four-
term deflection equations at 1.4 times the ASD unit shear value (or, strength
level force), as shown in Figure 1, for a wood structural panel shear wall. For
the case shown, the maximum difference in calculated deflection is 0.045
inch. This small difference is not a significant factor in design; however,
users should be aware that calculated deflection values will be different
except at 1.4 times the ASD unit shear value.

There is a distinction between the “induced shear” used in the three or four
term deflection equation and the “unit shear capacity” that is used to
calculate $G_a$ in the SDPWS Commentary. If the designer chooses to use
“induced shear” to calculate $G_a$, s/he should come up with the same result as
s/he would get using the 4-term equation. In the figure, note the difference
which is less than 1/16” for this example. If someone says it is “extremely
conservative” to use “capacity” to calculate $G_a$, that really depends on the
diaphragm capacity vs. the load and further, the magnitude of difference is
well within the construction tolerances out there.
Diaphragm deflection example in 2008 SDPWS Commentary
Calculate mid-span deflection for the blocked wood structural panel diaphragm shown. The diaphragm chord splice is sized using allowable stress design loads from seismic while deflection due to seismic is based on strength design loads in accordance with *ASCE 7.*
Diaphragm apparent shear stiffness, $G_a = 14$ kips/in. (*SDPWS Table 4.2A*)
Diaphragm allowable unit shear capacity for seismic, $v_s$ (ASD) = 255 plf (*SDPWS Table 4.2A*)

### Diaphragm Capacity

*SDPWS Table 4.2A*

<table>
<thead>
<tr>
<th>Sheathing Grade</th>
<th>Common Nail Size</th>
<th>Minimum Fastener</th>
<th>Minimum Nominal Panel</th>
<th>Minimum Nominal Width of Nailed Face</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Penetration in Framing Member or Blocking (ln.)</td>
<td>Thickness (ln.)</td>
<td>at Adjoining Panel Edges and Boundaries (ln.)</td>
</tr>
<tr>
<td>Structural I</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>
<tr>
<td>Sheathing and Single-Floor</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>

Nominal/2.0
Part 1 - Calculate the number of 16d common nails in the chord splice

Diaphragm chord:
Two 2x6 No. 2 DFL
E = 1,600,000 psi
G = 0.50

For each chord, one top plate is designed to resist induced axial force (tension or compression) while the second top plate is designed as a splice plate (see Figure). The connection at the chord splice consists of 16d common nails (0.162” diameter x 3-1/2” length).
Part 1 - Calculate the number of 16d common nails in the chord splice

The allowable design value for a single 16d common nail in a face-nailed connection is: $Z'_{ASD} = 226$ lb. Based on moment at the joint, calculate 12 nails required.
Part 1 - Calculate the number of 16d common nails in the chord splice

Designers should consider whether a single maximum chord force at mid-span of the diaphragm should be used to determine the number of fasteners in each splice joint since the actual location of joints may not be known. The number of 16d common nails based on the maximum chord force at mid-span of the diaphragm is 14 nails.
Mid-Span Deflection

Part 2 – Calculate mid-span deflection

Use 3-term equation

\[ \delta_{\text{dia}} = \frac{5vL^3}{8EA} + \frac{0.25vL}{1000G_a} + \frac{\sum(x\Delta_c)}{2W} \]

Part 2 - Calculated mid-span deflection
Term 1. Deflection due to bending and chord deformation (excluding chord splice slip):

\[ \nu = 1.4 \times 255 \text{ plf}, \text{ induced unit shear due to strength level seismic load} \]

\[ E = 1,600,000 \text{ psi}, \text{ modulus of elasticity of the 2x6 chord member ignoring effects of chord splice slip. The effect of chord splice slip on chord deformation is addressed in deflection equation Term 3.} \]

\[ A = 8.25 \text{ in.}^2, \text{ cross sectional area of one 2x6 top plate designed to resist axial forces.} \]
Term 1. Deflection due to bending and chord deformation (excluding chord splice slip):

\[ v = 1.4 \times 255 \text{ plf} \], induced unit shear due to strength level seismic load

*ASCE 7* requires that seismic story drift be determined using strength level design loads; therefore, induced unit shears and chord forces used in terms 1, 2, and 3 of the deflection equation are calculated using strength level design loads. Strength level design loads can be estimated by multiplying the allowable stress design seismic loads, shown in Figure C4.2.2-3a, by 1.4.
Term 1. Deflection due to bending and chord deformation (excluding chord splice slip):

\[ \delta_{\text{dis(bending, chords)}} = \frac{5vL^3}{8EAW} \]

\[ = \frac{5(1.4 \times 255 \text{ plf})(48 \text{ ft})^3}{8(1,600,000 \text{ psi})(8.25 \text{ in.}^2)(24 \text{ ft})} \]

\[ = 0.078 \text{ in.} \]

Effect of chord splice slip on chord deformation addressed in deflection equation Term 3

A spliced chord member has an “effective” stiffness (EA) due to the splice slip that occurs throughout the chord. In this example, and for typical applications of Equation C4.2.2-2, the effect of the spliced chord on midspan deflection is addressed by independently considering deflection from: a) chord deformation due to elongation or shortening assuming a continuous chord member per deflection equation Term 1, and b) deformations due to chord splice slip at chord joints per deflection equation Term 3.
Term 1. Deflection due to bending and chord deformation (excluding chord splice slip):

A = 8.25 in.$^2$, cross sectional area of one 2x6 top plate designed to resist axial forces.

For each chord, one top plate is designed to resist induced axial force (tension or compression) while the second top plate is designed as a splice plate. Note that this is engineering judgment. Doubling the cross sectional area will change the result to 0.04”.

\[
\delta_{d(bending,\ chs)} = \frac{5vL^3}{8EAW}
\]

\[
= \frac{5(1.4 \times 255 \text{ plf})(48 \text{ ft})^3}{8(1,600,000 \text{ psi})(8.25 \text{ in.}^2)(24 \text{ ft})}
\]

\[
= 0.078 \text{ in.}
\]
Term 2. Deflection due to shear, panel shear, and nail slip

\[
\delta_{\text{dia}}(\text{panel shear+nail slip}) = \frac{0.25vL}{1000Ga} \\
= \frac{0.25(1.4 \times 255 \text{ plf})(48 \text{ ft})}{1000(14 \text{ kips/in.})} \\
= 0.306 \text{ in.}
\]

\(G_a = 14 \text{ kips/in.}, \) apparent shear stiffness  
\((SDPWS \ Table \ 4.2A)\)

Term 2. Deflection due to shear, panel shear, and nail slip
Term 3. Deflection due to bending and chord splice slip

\[ \delta_{\text{dia (chord splice slip)}} = \frac{\sum (x \Delta_c)}{2W} \]

\( x = 16 \text{ ft}, \) distance from the joint to the nearest support. Each joint is located 16 ft from the nearest support.
Mid-Span Deflection

Term 3. Deflection due to bending and chord splice slip

\[ \delta_{\text{dia}(\text{chord splice slip})} = \frac{\sum (x_i \Delta_c)}{2W} \]

\[ \Delta_c = \text{Joint deformation (in.) due to chord splice slip in each joint.} \]

Term 3. Deflection due to bending and chord splice slip

\[ \Delta_c = \frac{2(T \text{ or } C)}{\gamma n} \]

\[ \Delta_c = \text{Joint deformation (in.) due to chord splice slip in each joint.} \]
Term 3. Deflection due to bending and chord splice slip

\[ \Delta_c = \frac{2(T \text{ or } C)}{\gamma n} \]

\[ (T \text{ or } C) = \frac{(1.4 \times 65,280 \text{ ft-lb})}{24 \text{ ft}} = 3,808 \text{ lb} \]

\[ \gamma = 11,737 \text{ lb/in./nail}, \text{ load slip modulus for dowel type fasteners per NDS 10.3.6:} \]

\[ \gamma = 180,000 \text{ D}^{1.5} \]
Mid-Span Deflection

Term 3. Deflection due to bending and chord splice slip

\[ \Delta_c = \frac{2 (T \text{ or } C)}{\gamma n} \]

\[ = \frac{2 (3,808 \text{ lb})}{11,737 \text{ lb/ in. }/\text{ nail (12 nails)}} \]

\[ = 0.054 \text{ in.} \]

Constant of 2 used in numerator to account for slip in nailed splices on each side of joint

Term 3. Deflection due to bending and chord splice slip

Constant of 2 used in numerator to account for slip in nailed splices on each side of joint
Term 3. Deflection due to bending and chord splice slip

tension chord slip calculation
Term 3. Deflection due to bending and chord splice slip

Compression chord and total slip calculation

\[ \delta_{dia(\text{compression chord splice slip})} = 0.036 \text{ in.} \]

Total deflection due to chord splice slip is:

\[ \delta_{dia(\text{chord splice slip})} = 0.036 \text{ in.} + 0.036 \text{ in.} = 0.072 \text{ in.} \]

Assume compression chord butt joints have a gap that exceeds the splice slip, so tension chord slip also used for compression chord

Term 3. Deflection due to bending and chord splice slip
Total mid-span deflection

Summing deflection components from deflection equation Term 1, Term 2, and Term 3 results in total diaphragm mid-span deflection of 0.456".
Frequently Asked Questions

Q: How do pneumatic nails affect diaphragm capacity?

A: International Staple, Nail, and Tool Association (ISANTA)
  • ICC ES ESR-1539 - Power-Driven Staples and Nails for Use in All Types of Building Construction
  • www.isanta.org
Tighter limits for brick are for moisture control.
Frequently Asked Questions

Q: Is diaphragm deflection cumulative with shear wall deflection?

A: Yes. Shear walls supporting a horizontal diaphragm would also be evaluated for deflection. Cumulative deflection would then be calculated to determine the maximum anticipated movement to compare with allowables.
Frequently Asked Questions

Q: Are there provisions to calculate the deflection for a diaphragm that is only partially blocked (i.e. at ends only) or is it proper to base the deflection on the entire diaphragm being unblocked?

A: There are no provisions for a partially blocked diaphragm. Suggest calculating for both a blocked and unblocked diaphragm to determine magnitude of difference and use engineering judgment.
Frequently Asked Questions

Q: When the nailing pattern in a horizontal diaphragm varies instead of being uniform, how is deflection calculated?

A: One approach is to modify the nail-slip constant in the 4-term equation in proportion to the average load on each nail with non-uniform nailing compared to the average load with uniform nailing. APA’s Diaphragm and Shear Wall Design and Construction Guide (L350) provides an example: www.apawood.org.
Frequently Asked Questions

Q: Is there any benefit if wood structural panels are glued to the assembly?

A: We are not aware of any added benefit with respect to diaphragm deflection.
Frequently Asked Questions

Q: Is there a multiplier to use for a long-term consideration due to possible enlargement of nail holes or is that all included in the nail slip deflection calculations?

A: Testing done to verify diaphragm deflection calculations is based on full reverse cyclic loads, so the effects of nail hole enlargement has been addressed.
Frequently Asked Questions

Q: For large diaphragm, what adjustments to deflection equations need to be made to obtain inelastic diaphragm deflection?

A: ASCE 7 Minimum Design Loads for Buildings and Other Structures, Section 12.8.6 includes an amplification factor $C_d$ which is used for story drift and seismic gaps.
Questions?

- www.awc.org
  - Online eCourses
  - FAQ's
  - Helpdesk

Contact Information

The American Wood Council is ready to assist with technical inquiries regarding the publications it produces. **Please understand that AWC does not provide engineering consulting services outside the bounds of the standards it develops.** However, it does provide a Design Professional Member database that is searchable by area of expertise and geographic location. Any questions not specifically relating to AWC technical issues should be relayed to the general phone line below. *Also, for efficiency, email is preferred.*

AWC Staff

Phones

- General: (202) 463-2766
- Helpdesk: (202) 463-4713 (please see above in bold before calling)
- General FAX: (202) 463-2791
- Publications: (800) 890-7732
- Publications FAX: (608) 232-9354

Email

- Publications: publications@awc.org
- Education: education@awc.org
- Technical: info@awc.org