Shear Wall Design

Avalon Bay Communities
Photo credit: Arden Photography

Portions Based On:

By: R. Terry Malone, PE, SE
Senior Technical Director
Architectural & Engineering Solutions
terrym@woodworks.org
928-775-9119

Copyright McGraw-Hill, ICC
This presentation will provide an in-depth look at shear wall designs for low-rise and mid-rise buildings, including those with rectangular, skewed and offset plans. This presentation is intended for structural engineers.

Mid-rise Codes and Standards

WoodWorks
Learning Objectives

Topics:

• Discuss the different types of shear walls commonly used in low-rise and mid-rise structures.

• Discuss complete load paths and the detailing required to maintain lateral load paths to shear walls.

• Review shear wall code requirements.

• Review a new method for force transfer around an opening
Presentation Topics

- Shear Wall Types
  - Shear wall Anchorage
  - SDPWS Code Requirements
  - Complete Load Paths
  - Offset Shear Walls and Relevant ASCE Requirements
  - Mid-rise Multi-story Stacked Shear Walls
Shear Wall Configurations

Segmented or braced Walls (IBC/IRC) (No openings)

Perforated Walls

Force Transfer Around Openings Walls
Segmented Wall Types - Standard & Sloped

- Shearing joint as occurs
- Anchor bolts or nailing
- Hold down anchor
- Chord or Strut

Segmented Shear Walls

<table>
<thead>
<tr>
<th>Resist. mom. Arm 1</th>
<th>Resist. mom. Arm 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>v(plf)</td>
<td>v(plf)</td>
</tr>
<tr>
<td>L bearing</td>
<td>L bearing</td>
</tr>
<tr>
<td>C.L. bearing</td>
<td>C.L. bearing</td>
</tr>
<tr>
<td>T stud + CL</td>
<td>T stud + CL</td>
</tr>
<tr>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>A.B.</td>
<td>A.B.</td>
</tr>
<tr>
<td>b</td>
<td>b</td>
</tr>
</tbody>
</table>

\[ \sum M = 0 \]

Diaphragm shear

- Fv
- Fr1
- Fr2
Dead Load Distribution
Preference & Engineering Judgement

Rigid Body

Short Walls

Semi-Rigid Body

Long Walls

This section in bearing

This section Supported by the first floor bearing width

45

60

b/2
Allowable Aspect Ratios & Adjustment Factors

AWC SDPWS Table 4.3.4-Maximum shear wall dimension ratios

<table>
<thead>
<tr>
<th>Type</th>
<th>Maximum height-width ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood structural panels – Unblocked</td>
<td>2:1</td>
</tr>
<tr>
<td>Wood structural panels – Blocked</td>
<td>3.5:1</td>
</tr>
<tr>
<td>Particleboard – Blocked</td>
<td>2:1</td>
</tr>
<tr>
<td>Diagonal sheathing, conventional</td>
<td>2:1</td>
</tr>
<tr>
<td>Gypsum board</td>
<td>2:1(1)</td>
</tr>
<tr>
<td>Portland Cement Plaster</td>
<td>2:1 (1)</td>
</tr>
<tr>
<td>Structural Fiberboard</td>
<td>3.5:1</td>
</tr>
</tbody>
</table>

Footnotes
1. Walls having aspect ratios exceeding 1.5:1 shall be blocked shear walls.

4.3.4.2
For wood structural panel shear walls with aspect ratios (h/b) greater than 2:1, the nominal shear capacity shall be multiplied by the Aspect Ratio Factor (WSP) =1.25-0.125\( h/b \).

For structural fiberboard shear walls with aspect ratios (h/b) greater than 1:1, the nominal shear capacity shall be multiplied by the Aspect Ratio Factor (fiberboard) =1.09-0.09 \( h/b \).
Segmented Shear Wall Deflection and Stiffness

Traditional 4 term deflection equation

\[ \Delta_{SW} = \frac{8vh^3}{EAb} + \frac{vh}{G_v t_v} + 0.75he_n + \frac{h\Delta_a}{b} \]  

C4.3.2-1

SDPWS combines

Bending
Shear
Nail slip
Rod elongation (Wall rotation)

SDPWS 3 term deflection equation

\[ \Delta_{SW} = \frac{8vh^3}{EAb} + \frac{vh}{1000G_a} + \frac{h\Delta_a}{b} \]  

4.3-1

Bending
Vertical elongation
- Device elongation
- Rod elongation

Apparent shear stiffness
- Nail slip
- Panel shear deformation

Deflection of unblocked segmented shear wall

- Use Eq.4.3-1 with \( v/C_{ub} \) per 4.3.2.2 and Table 4.3.3.2

\[ \Delta_{SW} = \frac{8\left(\frac{v}{C_{ub}}\right)h^3}{EAB} + \frac{\left(\frac{v}{C_{ub}}\right)h}{1000G_a} + \frac{h}{b} \Delta_a \]

- Max. height unblocked=16 feet

Wall stiffness \( k = \frac{F}{\Delta} \)
Segmented Shear Wall Deflection

- SDPWS linear 3 term equation
- Traditional 4 term equation
- Identical at 1.4 ASD

Load, plf vs. Displacement, inches

ASD unit shear
Perforated Shear Walls - Empirical Design

- Header sections do not have to comply with aspect ratios.
- Intermediate uplift anchorage is required at each full height panel locations... "in addition to..." per section 4.3.6.4.2.1.
- Reference examples
  - APA Diaph-and-SW Construction Guide
  - AWC-Perforated Shear Wall Design

Collector per SDPWS section 4.3.5.3 (Full length of wall)

Hold downs at Ends per section 4.3.6.4.2

Top and bottom of wall cannot be Stepped or sloped

All full hgt. sections must meet the aspect ratio requirements of section 4.3.4.1.

Common sheathing joint locations

Use other methods

Typical boundary member

Openings are allowed at end of wall but cannot be part of wall

Intermediate uplift anchorage is required at each full height panel locations... "in addition to..." per section 4.3.6.4.2.1.
Allowable Perforated Shear Wall Aspect Ratios

- Sections exceeding 3.5:1 aspect ratio shall not be considered a part of the wall.
- The aspect ratio limitations of Table 4.3.4 shall apply.
- \( V_n \leq 1740 \text{ plf seismic-WSP 1 side} \)
- \( V_n \leq 2435 \text{ plf wind-WSP 1 side} \)
- \( V_n \leq 2435 \text{ plf wind-WSP 2 sides} \)
- A full height pier section shall be located at each end of the wall.
- Where a horizontal offset occurs, portions on each side of the offset shall be considered as separate perforated walls.
- Collectors for shear transfer shall be provided through the full length of the wall.
- Uniform top-of-wall and bottom-of-wall plate lines. Other conditions require other methods.
- Maximum wall height \( \leq 20' \).
Empirically determined shear resistance reduction factors, \( C_0 \) – based on maximum opening height and percentage of full height wall segments.

\[
V_{\text{allow}} = (v_{\text{Tabular}}) \times (C_0) \times \sum L_i
\]

Where:

\[
C_0 = \left( \frac{r}{3 - 2r} \right) \frac{L_{\text{tot}}}{\Sigma L_i}
\]

Per SDPWS Table 4.3.3.5

\[
r = \frac{1}{1 + \frac{A_0}{h \Sigma L_i}}
\]

Sheathing area ratio

\( A_0 = \) total area of openings

Maximum Shear @ full hgt. sect.

\[
v_{\max} = \frac{V}{C_0 \Sigma L_i}
\]

Hold down at ends

\[
T = C = \frac{Vh}{C_0 \Sigma L_i}
\]

At full-hgt. segments

\[
v_{\max} = T_{\text{int}} = \frac{V}{C_0 \Sigma L_i}
\]

AWC Section 4.3.6.1.3

Each end of each segment shall be designed for the compression force \( C \).

Sugiyama Method-Reduced shear capacity is multiplied by the full length of the wall.

APA, IBC, SDPWS Method- Reduced shear capacity is multiplied by the sum of the lengths of the full height sections (slightly more conservative).
Table 4.3.3.5 Shear Capacity Adjustment Factor, \( C_o \)

<table>
<thead>
<tr>
<th>Wall Height, ( h )</th>
<th>Maximum Opening Height</th>
<th>Wall Height, ( h )</th>
<th>Maximum Opening Height</th>
<th>Wall Height, ( h )</th>
<th>Maximum Opening Height</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \frac{h}{3} )</td>
<td>( \frac{h}{2} )</td>
<td>( \frac{2h}{3} )</td>
<td>( \frac{5h}{6} )</td>
<td>( h )</td>
</tr>
<tr>
<td>8' Wall</td>
<td>2'-0&quot;</td>
<td>4'-0&quot;</td>
<td>5'-4&quot;</td>
<td>6'-8&quot;</td>
<td>8'-0&quot;</td>
</tr>
<tr>
<td>10' Wall</td>
<td>3'-4&quot;</td>
<td>5'-0&quot;</td>
<td>6'-8&quot;</td>
<td>8'-0&quot;</td>
<td>10'-0&quot;</td>
</tr>
<tr>
<td>Percent Full-Height Sheathing</td>
<td>Effective Shear Capacity Ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>1.00</td>
<td>0.89</td>
<td>0.69</td>
<td>0.43</td>
<td>0.36</td>
</tr>
<tr>
<td>20%</td>
<td>1.00</td>
<td>0.71</td>
<td>0.59</td>
<td>0.40</td>
<td>0.32</td>
</tr>
<tr>
<td>30%</td>
<td>1.00</td>
<td>0.74</td>
<td>0.56</td>
<td>0.38</td>
<td>0.26</td>
</tr>
<tr>
<td>40%</td>
<td>1.00</td>
<td>0.77</td>
<td>0.53</td>
<td>0.40</td>
<td>0.32</td>
</tr>
<tr>
<td>50%</td>
<td>1.00</td>
<td>0.80</td>
<td>0.57</td>
<td>0.37</td>
<td>0.30</td>
</tr>
<tr>
<td>60%</td>
<td>1.00</td>
<td>0.83</td>
<td>0.60</td>
<td>0.40</td>
<td>0.32</td>
</tr>
<tr>
<td>70%</td>
<td>1.00</td>
<td>0.87</td>
<td>0.63</td>
<td>0.40</td>
<td>0.32</td>
</tr>
<tr>
<td>80%</td>
<td>1.00</td>
<td>0.91</td>
<td>0.67</td>
<td>0.41</td>
<td>0.32</td>
</tr>
<tr>
<td>90%</td>
<td>1.00</td>
<td>0.94</td>
<td>0.71</td>
<td>0.41</td>
<td>0.32</td>
</tr>
<tr>
<td>100%</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

1. The maximum opening height shall be taken as the maximum opening clear height in a perforated shear wall. Where areas above and/or below an opening remain unberthed, the height of each opening shall be defined as the clear height of the opening plus the unberthed area.

2. The sum of the perforated shear wall segment lengths, \( \sum L_i \), divided by the total length of the perforated shear wall.

4.3.4.3
In the design of perforated shear walls, the length of each perforated shear wall segment with an aspect ratio greater than 2:1 shall be multiplied by \( 2b/h \) for the purposes of determining \( L_i \) and \( \sum L_i \). The provisions of Section 4.3.4.2 and the exception to Section 4.3.3.4.1 \( (1.25-0.125h/b) \) shall not apply to perforated shear wall segments.

Where perforated shear walls have WSP on 1 side and GWB on the opposite side, the combined shear capacity shall be in accordance with the provisions of Section 4.3.3.3.2.
Deflection of perforated shear wall

\[ \Delta_{SW} = \frac{8v h^3}{E A b} + \frac{v h}{1000 G_a} + \frac{h \Delta_a}{b} \]  \hspace{1cm} 4.3-1

**Deflection of Perforated Shear Walls:** The deflection of a perforated shear wall shall be calculated in accordance with 4.3.2, where \( v \) in equation 4.3-1 is equal to \( v_{\text{max}} \) obtained in equation 4.3-9 and \( b \) is taken as \( \sum L_i \).
FTAO Shear Walls (See recent Testing-APA Form M410 and T555)

(Diekmann)-Vierendeel Truss/Frame

- Tie straps as required to develop the corner forces into the wall
- Anchor bolts or nails
- 2' min. per SDPWS Section 4.3.5.2 (2008 requirement)
- Many examples ignore gravity loads
- Strut/collector
- Shear panels or blocking

https://www2.strongtie.com/webapps/sitebuiltshearwalldesigner/
https://www.apawood.org/ftao
**Limitations:**

- The aspect ratio limitations of Table 4.3.4 shall apply to the overall wall and the pier sections on each side of the openings.
- Minimum pier width = 2'-0".
- A full height pier section shall be located at each end of the wall.
- Where a horizontal offset occurs, portions on each side of the offset shall be considered as separate FTAO walls.
- Collectors for shear transfer shall be provided through the full length of the wall.

**ATC 7, Diekmann, FPInnovations**

If the sections above, below or on each side of the opening does not meet code aspect ratio limits it should be ignored (not stiff enough).
Force Transfer Methodology – Based on stiffness (FEA analysis)

This slide shows force distribution and location of I.P’s due to sill section not meeting A/R requirements

A/R=2.62 < 3.5 O.K.

A/R=2.63 < 3.5 O.K.

A/R=3 < 3.5 O.K.

A/R=10.5 > 3.5 N.G.

Not to scale
Force Transfer Methodology – Based on stiffness

Example results – double opening with shallow headers

This slide shows force distribution and location of I.P.’s if header section not meeting A/R requirements

Not to scale
Example Cont.

Point of inflection is assumed to occur at mid-length (Typ.)

Gravity loads to wall

F=0 lb

M

V

V

F=0 lb

F=0 lb

F=0 lb

Tie strap/blocking full width

Blocking

Force Transfer Methodology (Diekmann)-Vierendeel Truss/Frame
Units are in lb

Shears and forces determined in previous step.

Resultant Forces on Wall Segments
Example 2 - Blocking and Strapping Partial Width (with uniform load)

4500 lbs.

w = 200 plf

T.D.1

A/R

Transfer diaphragm sections

A/R

Lap as required

T.D.2

A/R

Support

2.67'

3'

6'

2.67'

5.5'

14.5'

A

B

C

D
Partial length straps/anchors
Connected to 1st bay blocking only

APA Wall tests 8 and 9 – M410
Partial length straps/anchors
Connected to 1st bay blocking only

APA Wall tests 8 and 9 – M410

Photo credit APA:

Wall 8 – IMG_1297

Wall 9 – IMG_1667
   100_0018
   100_0021
Advancements in FTAO Shear Wall Analysis

T555
Refine rational design methodologies to match test results

- Used test results from full-scale wall configurations
- Analytical results from a computer model
- Allows asymmetric piers and multiple openings.

https://www.apawood.org/ftao
Example Problem

Calculate O/T forces:

\[ F_{O/T} = \frac{4000(8)}{20} = 1600 \text{ lbs.} \]

(Note: No dead loads)
The deflection of the wall is the average of the deflection of the piers as shown (acting both ways combined) using the 4 term eq.

**Single opening**

\[ \Delta_{Aver} = \frac{(\Delta_{pier 1} + \Delta_{pier 2}) + (\Delta_{pier 1} + \Delta_{pier 2})}{4} \]

- The remainder of the terms are identical to the traditional equation.
- Deflections for a wall with multiple openings is similar.

\[ \Delta_{Aver} = \frac{(\Delta_{pier 1} + \Delta_{pier 2} + \Delta_{pier 3}) + (\Delta_{pier 1} + \Delta_{pier 2} + \Delta_{pier 3})}{6} \]

**Traditional 4 term deflection equation**

\[ \Delta_{SW} = \frac{8vh^3}{EAb} + \frac{vh}{Gvtv} + 0.75he_n + \frac{h\Delta a}{b} \]

Reference APA SR-105
Typical Panel Fastening

- Min. panel thickness = 7/16”
- Sheathing can be applied vertically or horiz.
- Min. fastener spacing = 3” single row, 6” Dbl. row
- All horiz. edges shall be blocked
- Applies to all shear wall types
- Capacity: Table 4.4.1-shear + uplift
  Table 4.4.2-uplift only

\[
V_{ASD} = \frac{V_n}{2}, \quad V_{str} = 0.65V_n
\]
Uplift clips or anchorage shall be on the same side as sheathing.

Increase nailing for uplift on each side.

See Table 4.4.1.6 for maximum anchor bolt spacing.

0.229x3x3 sq. plate washer required.

Splices at Rim Joist or Common Horizontal Member.

Single row of Fasteners

Double row of Fasteners

Nail spacing at common horizontal framing ≥ 3” single row or ≥ 6” double row (4.4.1.7 (1) and Fig. 4H).

No Horizontal Sheathing Joint Over Studs.
Uplift clips or anchorage shall be on same side as sheathing

- Blocking to resist shear, stud nailing to resist uplift

See Table 4.4.1.6 for maximum anchor bolt spacing

0.229x3x3 sq. plate washer required

Splices at Studs w/ Blocking

Increase nailing for uplift ea. side

≥ 3” Spacing

3/4”

Single row of Fasteners

2x blocking

Sheathing splice plate, same thk. and face grain orientation as sheathing

Section If resisting both shear and uplift

Horizontal Sheathing Joint Over Studs
Angled/Skewed Shear Walls

No Angled/Skewed Shear Wall Testing

Shear walls are parallel to applied loads

Acts like open front diaphragm (SDPWS 4.2.5.2)

Not all shear walls are parallel to applied loads
Diaphragm with Angle Shear Wall-Horizontal
Type 5 Irregularity Transverse Loading

Structure is stable

P-delta problem. Wall deflects too much out-of-plane, which causes rotation in the diaphragm (Acts like open front diaphragm-shifts forces to side walls)
Circular Shear Walls

No Circular Shear Wall Testing

WSP thickness depends on radius

Effective width

Diaphragm support

Cantilever section

Effective width

Diaphragm support

Hold down

Hold down
Mid-Ply Shear Walls

- **Mid-ply walls:**
  - Carry high shear demand
  - Reduce torsional effects

- **Test Results:**
  - Mid-ply walls 2.4 to 2.8 x stiffer than standard shear walls monotonic loading.
  - Mid-ply walls 1.8 to 2.2 x stiffer than standard shear walls cyclic loading.
  - Better energy dissipaters, 3 to 5x better than standard shear walls
Typical Mid-Ply Shear Walls

Fasteners are in double shear

1 Layer WSP w / GWB

3 Layer WSP

16” o.c. typ.
CLT Shear Walls

- Significant ductility if boundary conditions allow rocking of the wall.
- ELF Seismic performance Factors; R, Omega, Cd. *(under development)*
- (CLT handbook provides values considered to be conservative, R=2)
- Suggested values have ranged between 2 to 4.3
Prescriptive / Proprietary Portal Frames

IBC 2308.9.3.2
Prescriptive Code Portal Frames

Truss Walls

Proprietary Portal Frames

Truss Frames

Hybrid Wood/Steel Proprietary Systems
Presentation Topics

- Shear Wall Types
- Shear wall Anchorage
- SDPWS Code Requirements
- Complete Load Paths
- Offset Shear Walls and Relevant ASCE Requirements
- Mid-rise Multi-story Stacked Shear Walls
Hold Down Anchors Systems

Standard Hold Down (Bucket Style)

Strap Hold Down

Continuous Rod

Automatic Tensioning System
ATS
Bucket Style Hold Downs

Typical Hold Down Details at Foundation
Standard (discrete) Hold Downs

1. **Bolts, nails or screws per manufacturer**
2. **Minimum wood member thickness**
3. **Number of studs as required by design.**
4. **Raise 3” for every ¼” offset from H.D. centerline (Manufacturers instructions) for misplaced anchors**
5. **Approved coupler**
6. **Self positioning hold down. Install per manufacturer’s instruction**
7. **Install anchor per manufacturer’s instruction**
8. **Top of brg. plate**
9. **Preservative treated barrier may be required**
10. **Opt. supplied manufacturers anchor**
11. **18” max.**
12. **3” to 5”**
13. **1½” max.**
14. **5° max.**
Multiple Hold Downs at Corners

Source: DartDesignInc.com

Source: strongtie.com
Hold downs installed at an angle.

Large knots

Field Installation Issues
Field Installation Issues

Hold down misplaced. Sheathing is removed.

Courtesy of Willdan Engineering
Strap to be installed plumb and tight to studs. Fill all holes.

Possible foundation corner location

½” min. at foundation corner

#4 rebar. Extend 2 x Le each way beyond strap. Bend 90° at corner.

3” to 5”
Field Installation Issues

Loose anchor strap-stabbed into foundation-no vibration

Too close to vent opening
Slack in hold down strap (bent) Often stabbed into foundation without vibration.

Field Installation Issues
Field Installation Issues

Slack in strap (bent) due to vertical shrinkage of framing.

Nail after shrinkage occurs.

Loose bolted connection due to vertical shrinkage of framing. Tighten after shrinkage.

Typical Hold Down Details at Floor
Standard (discrete) Hold Downs
Continuous Rod Tie Downs with Shrinkage Compensation Devices

Automatic Tensioning Systems/Devises

Source: strongtie.com
Automatic Tensioning Systems/Devises

- Restraints are required at roof and each floor level to get best results
- Software programs are available for design
- Must be installed per manufacturers recommendations

- Number and size of studs as required by design
- Anchorage into foundation as required by calculation and per manufacturers recommendations
Automatic Tensioning Systems/Devises

Legend

- 2 kips
- 4 kips
- 7 kips
- 13.5 kips
- 27 kips
- (27 kips) Full hgt.
- 14 kips

- Tied off at roof only
  - Lack of redundancy
  - Increased costs
  - Increased drift
  - Single device must accommodate shrinkage at all floors

- Tied off at roof and all floors
  - Accommodates shrinkage at each floor
  - Greater redundancy
  - Reduced drift
  - Lower costs (Can be subjective)

Tied off at each floor

Skipped floor

Tied off at each floor
Let’s Take a 10 Minute Break
Presentation Topics

• Shear Wall Types
• Shear wall Anchorage
• **SDPWS Code Requirements**
• Complete Load Paths
• Offset Shear Walls and Relevant ASCE Requirements
• Mid-rise Multi-story Stacked Shear Walls
Allowable values shown in tables are nominal shear values

**Design values:**

- LRFD (Strength) = 0.8 x Vn
- ASD = Vn/2

2015 SDPWS
# Shear Wall Capacity-Wood Based Panels

## Blocked

### Table 4.3A Nominal Unit Shear Capacities for Wood-Framed Shear Walls

<table>
<thead>
<tr>
<th>Sheathing Material</th>
<th>Minimum Nominal Panel Thickness (in.)</th>
<th>Minimum Fastener Penetration In Framing Member or Blocking (in.)</th>
<th>Fastener Type &amp; Size</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood Based Panels</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4/5</td>
<td>5/16</td>
<td>1-1/4</td>
<td>Nail (common or Galvanized box) 6d</td>
<td>OSB PLY</td>
<td>Panel Edge Fastener Spacing (in.)</td>
</tr>
<tr>
<td></td>
<td>3/8</td>
<td>1-3/8</td>
<td>8d</td>
<td>OSB PLY</td>
<td>Panel Edge Fastener Spacing (in.)</td>
</tr>
<tr>
<td></td>
<td>7/16</td>
<td>1-3/8</td>
<td>10d</td>
<td>OSB PLY</td>
<td>Panel Edge Fastener Spacing (in.)</td>
</tr>
<tr>
<td></td>
<td>15/32</td>
<td>1-1/2</td>
<td></td>
<td>OSB PLY</td>
<td>Panel Edge Fastener Spacing (in.)</td>
</tr>
</tbody>
</table>

Use Table 4.3B for WSP over 1/2” or 5/8” GWB or Gyp-sheathing Board
Use Table 4.3C for Gypsum and Portland Cement Plaster
Use Table 4.3D for Lumber Shear Walls

*40% Increase based on reducing the load factor from 2.8, which was originally used to develop shear capacities down to 2.0 for wind resistance. (2006 IBC commentary)
**Unblocked**

Table 4.3.3.3.2  Unblocked Shear Wall Adjustment Factor, \( C_{ub} \)

<table>
<thead>
<tr>
<th>Supported Edges</th>
<th>Intermediate Framing</th>
<th>Stud Spacing (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>1.0</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
<td>0.8</td>
</tr>
</tbody>
</table>

\[ v_{ub} = v_b \cdot C_{ub} \quad \text{Eq. 4.3-2} \]

\( v_{ub} = \) Nominal unit shear value for unblocked shear wall

\( v_b = \) Use nominal shear values from Table 4.3A for blocked WSP shear walls with stud spacing at 24” o.c. and 6” o.c nailing
Summing Shear Capacities-4.3.3.3

- **Vallow=2x**

- **Same material, construction and same capacities** (can double $G_a$)

$$V_{allow} = 2x$$

- **Dissimilar materials**

$$V_{allow} = \text{largest, greater of}.$$  
  *(Exception-for wind, add capacities)*

- **Vallow=2x smaller or largest, greater of.**

  - **VS1**
  - **VS2**

**Same material, construction on both sides, different capacities-Seismic**

The shear wall deflection shall be calculated using the combined apparent shear wall shear stiffness, $G_{ac}$ and the combined nominal unit shear capacity, $v_{sc}$, using the following equations:

$$v_{sc} = K_{min}G_{ac}$$  
Combined apparent shear wall shear capacity (seismic)

$$G_{ac} = G_{a1} + G_{a2}$$

$$K_{min} = \frac{v_{S1}}{G_{a1}} \text{ or } \frac{v_{S2}}{G_{a2}}$$  
Minimum of

Where:

- $G_{ac}$= Combined apparent shear wall shear stiffness
- $G_{a1}$= Apparent shear wall shear stiffness side 1 ($G_{a2}$ side 2)-from SDPW Tables 4A-4D
- $v_{S1}$=Nominal unit shear capacity of side 1 ($v_{S2}$ side 2)

$$V_{sc} = \text{combined nominal unit shear capacity seismic}$$
$$V_{wc} = \text{combined nominal unit shear capacity wind}$$
$$v_{S1} = \text{Nominal unit shear capacity of side 1 (vS2 side 2)}$$
When two layers of WSP sheathing are applied to the same side of a conventional wood-frame wall, the shear capacity for a single-sided shear wall of the same sheathing-type, thickness, and attachment may be doubled provided that the wall assembly meets all of the following requirements:

- Panel joints between layers shall be staggered
- Framing members located where two panels abut shall be a minimum of 3 x framing.
- Special sheathing attachment requirements
- Special retrofit construction requirements
- Double 2x end studs, if used, shall be stitch-nailed together based on the uplift capacity of the double-sheathed shear wall.
Shear Wall A/R Adjustment Factors-SDPWS Section 4.3.4

Segmented SW

Capacity Adjustments - Wind and seismic

- WSP’s with A/R > 2:1 multiply \( V_n \times (1.25-0.125\frac{h}{b}) \) per Section 4.3.4.2.
- Struct. Fiberboard with A/R > 1:1 multiply \( V_n \times (1.09-0.09\frac{h}{b}) \) per Section 4.3.4.2.

Justification - Based on tests:

- Accounts for reduced unit shear capacity in high aspect ratio walls due to loss of stiffness as A/R increases.

- Segments with an aspect ratio > 2:1 shall be multiplied by \( 2\frac{b}{h} \) for the purposes of determining \( L_i \) and \( \sum L_i \). The provisions of Section 4.3.4.2 and the exceptions to Section 4.3.3.4.1 (equal deflection) shall not apply to perforated shear wall segments.
Distribution of lateral forces to In-line Shear Walls

Section 4.3.4.2-Limitation of section
- All walls are of same materials and construction
- Shear distribution to individual SW’s shall provide same calculated deflection in each shear wall (Default Method) per 2015 SDPWS)

Exception:
1. Where $V_n$ of all WSP shear walls having $A/R>2:1$ are multiplied by $2b/h$, shear distribution to individual full-height wall segments is permitted to be taken as proportional to design shear capacities of individual full height wall segments. (Traditional Method-by length)

Where multiplied by $2b/h$ the $V_n$ need not be reduced additionally by Aspect Ratio Factor (WSP) = $1.25 - 0.125h/b$ per Section 4.3.4.2.

2. Where $V_n \times 0.1 + 0.9b/h$ of all structural fiberboard shear walls with $A/R>1:1$, shear distribution to individual full-height wall segments shall be permitted to be taken as proportional to design shear capacities. (Traditional Method-by length)

Where multiplied by $V_n \times 0.1 + 0.9b/h$, the nominal shear capacities need not be reduced additionally by Section 4.3.4.2
Distribution of lateral forces to In-line Shear Walls

Section 4.3.3.4-Limitation of section
- All walls are of same materials and construction

Method 1-Simplified Approach
   Traditional Method

Example Calculation per Commentary
(assumes same unit shear capacity)

SW1 and SW2
- Find nominal shear capacity
- Check aspect ratio-adjust per SDPWS 4.3.4.1 exception
- Aspect ratios > 2:1 use reduction factor \( \frac{2b}{h} \) (further reductions in 4.3.4.2 are not required)
- Convert to ASD unit shear capacity
- Sum design strengths = \( v_{sw1} \times b_1 + v_{sw2} \times b_2 \) for line strength
- Will produce similar results to equal deflection method
Distribution of lateral forces to In-line Shear Walls

Method 2 - Equal Deflection

Example Calculation per Commentary (assumes same unit shear capacity)

Method of Analysis

SW1 and SW2

- Find nominal unit shear capacity
- Check aspect ratio - adjust per SDPWS 4.3.4.2
- Aspect ratios > 2:1 use reduction factor 1.25-0.125h/b per 4.3.4.2
- Determine Ga and EA values
- Determine ASD unit shear capacity
- Calculate deflection of larger SW (SW2)

- Determine unit shear in smaller SW (SW1) that will produce same deflection

\[ v_{sw1} = \frac{\Delta_{sw2}}{\frac{8h^3}{EAb_{sw1}} + \frac{h}{1000G_a} + \frac{h^2}{kb_{sw1}}} \]

- Sum design strengths
  \[ = v_{sw1} \times b_1 + v_{sw2} \times b_2 \]

Diagram:

- ASD strength and deflection of shear wall line
- ASD strength and deflection of SW1
- ASD strength and deflection of SW2
- ASD strength and deflection of SW2 at SW2 defl. limit
- ASD strength of SW1 Per SDPWS 4.3.4.2
- Reserve capacity
4.3.7.1 - 3x Stud: Requirements:

3x’s at adjoining panels required when:

- Nails are spaced 2” o.c.
- 10d nails are spaced 3” o.c. and have penetration >1.5”
- Nominal unit shear capacity on either side of shear wall > 700 plf (SDC D-F)

4.3.6.3.1 Adhesives:
Adhesive attachment of shear wall sheathing shall not be used alone, or in combination with mechanical fasteners.

Exception: Approved adhesive attachment systems shall be permitted for wind and seismic design in Seismic Design Categories A, B, and C where \( R = 1.5 \) and \( \Omega_o = 2.5 \), unless other values are approved. Not permitted in SDC D.
Footnote:
6. Where panels are applied on both faces of a shear wall and nail spacing is less than 6" on center on either side, panel joints shall be offset to fall on different framing members. Alternatively, the width of the nailed face of framing members shall be 3" nominal or greater at adjoining panel edges and nails at all panel edges shall be staggered.
4.3.6.4.3 Anchor Bolts:
- Foundation anchor bolts shall have a steel plate washer under each nut.
- Minimum size - 0.229”x3”x3” in.
- The hole in the plate washer - Diagonally slotted, width of up to 3/16” larger than the bolt diameter, and a slot length not to exceed 1-3/4” is permitted if standard cut washer is provided between the nut and the plate.
- The plate washer shall extend to within 1/2" of the edge of the bottom plate on the side(s) with sheathing.
- Required where sheathing nominal unit shear capacity is greater than 400 plf for wind or seismic. (i.e. 200 plf ASD, 320 plf LRFD)
Standard cut washers

- Permitted to be used where anchor bolts are designed to resist shear only and the following requirements are met:
  a) The shear wall is designed segmented wall with required uplift anchorage at shear wall ends sized to resist overturning neglecting DL stabilizing moment.
  b) Shear wall aspect ratio, h:b, does not exceed 2:1.
  c) The nominal unit shear capacity of the shear wall does not exceed 980 plf for seismic or 1370 plf for wind.
Presentation Topics

• Shear Wall Types
• Shear wall Anchorage
• SDPWS Code Requirements
• Complete Load Paths
• Offset Shear Walls and Relevant ASCE Requirements
• Mid-rise Multi-story Stacked Shear Walls
Detailing for Continuous Load Paths

Simple Load Paths

Continuous Stacked In-line Load Paths

Photo: Terry Malone
Detailing for Continuous Load Paths

Complicated Load Paths

Dis-continuous Load Paths
Type 4 Vertical Irregularity, in-plane offset

ASCE 7-10 12.3.3.3 Elements supporting discontinuous walls SDC B-F

ASCE 7-10 12.3.3.4 25% increase in Fpx SDC D-F (connections)
In-plane Offset Segmented Shear Walls

Boundary nailing should be installed at each 2x stud at hold down and each plate.

Compr. blocks required at all H.D. locations.

Blk’g. or rim joist.

Analyze this Section as a transfer diaph. or transfer wall.

Anchor bolts or nails.

Hold down (Option 2 -only).

Nail shtg to each 2x stud.

Type 4 Vertical Irregularity, in-plane offset.

ASCE 7-10 12.3.3.3 Elements supporting discontinuous walls SDC B-F.

ASCE 7-10 12.3.3.4 25% increase in Fpx SDC D-F (connections).
Examples of Drag Struts, Collectors and chords at Exterior Boundaries
Roof sheathing

Shear panel

Double top plate used as strut / collector or chord.

Examples of Drag Struts, Collectors and chords at Exterior Boundaries

Flat strap and blocking used as strut / collector or chord.

Non-SW  SW  Non-SW  SW  Non-SW  SW  Non-SW  SW  Non-SW  SW  Non-SW  SW  Non-SW

All shear is transferred into top plates, then into SW

Strut/collector

All shear is transferred flat strap and blocking, then into SW

Non-Strut/collector

Non-SW
Complete Load Path to Foundation
Roof at Different Elevations - Chord Forces

- Soil pressure
- Diaphragm shear g. elevation
- Parapet (typ.)
- Vert. Step in diaph.
- Transfer area
- Shear Wall (transfer wall)
- Collector
- Chord
- Tie strap
- No shear wall perpendicular to this wall at step

Chord force
T

If strut action

F_o/t

Foundation
Blocking not full height.
No diaph. Shr. Transfer (boundary nailing?).
Truss top chords in cross-grain bending.

NEW: See 2015 IBC Figures 2308.6.7.2(1) and 2308.6.7.2(2) for possible solutions
Insulation

Screened vent

Typical shear panel

Boundary nailing

Middle 3rd available for vent holes-No continuous vents

2015 IBC Figure 2308.6.7.2(1)

2x blocking

Insulation

2x blocking

2x vertical nailer

2x framing all 4 sides

2x blocking

Truss

Insulation

2x blocking

A

Typical shear panel

A

Venting Options
Insulation

Screened vent holes

Typical shear panel

2x framing all 4 sides

Boundary nailing

Outriggers per manuf. instructions

Baffle

Baffle as required

2x blocking w/ vent holes

2x blocking

2x rafter

Insulation

Insulation

Typical Solid Blocking

Screened vent holes

2x vertical nailer E.S.

Insulation

Truss

B Typical shear panel
Let’s Take a 10 Minute Break
Diaphragm Boundary Elements and Interior Shear Walls

Fundamental Principles:
A shear wall is a location where diaphragm forces are resisted (supported), and therefore defines a diaphragm boundary location.

Note: All edges of a diaphragm shall be supported by a boundary element. (ASCE 7-10 Section 11.2)

SDPWS 4.3.5.1

3. Collectors for shear transfer to individual full-height wall segments shall be provided.

• Diaphragm Boundary Elements:
  • Chords, drag struts, collectors, Shear walls, frames
  • Boundary member locations:
    • Diaphragm and shear wall perimeters
    • Interior openings
    • Areas of discontinuity
    • Re-entrant corners.

• Diaphragm and shear wall sheathing shall not be used to act as or splice boundary elements. (SDPWS 4.1.4)

• Collector elements shall be provided that are capable of transferring forces originating in other portions of the structure to the element providing resistance to those forces. (ASCE 7-10 Section 12.10.2)

Required for Seismic and wind

1 2 3

A
B
C

Diaphragm 1
Diaphragm 2

Diaphragm 1 Boundary (typical)
Diaphragm 2 Boundary (typical)

Chord
Chord

Strut
SW1
SW2
SW3

Note: Interior shear walls require a full depth collector unless a complete alternate load path is provided.
Would you do this?

Failure Modes

- Shear failure
  - Not enough shear capacity

- Splitting failure
  - Bottom section not supported

Alternate load path
Note:
Diaphragm sections act as notched beams (shear distribution-diagonal tension or compression)

High stress concentrations at end of the wall

Code does not allow the sheathing to be used to splice or act as boundary elements

Shear Distribution if No Collector

Shear Distribution if Continuous Collector
Diaphragm Boundary Elements and Interior Shear Walls

**Fundamental Principles:**
A shear wall is a location where diaphragm forces are resisted (supported), and therefore defines a diaphragm boundary location.

**Note:** All edges of a diaphragm shall be supported by a boundary element. (ASCE 7-10 Section 11.2)

Let's take a look at load paths to the shear wall at grid line 2.

**Diaphragm Boundary Elements:**
- Chords, drag struts, collectors, Shear walls, frames
- Boundary member locations:
  - Diaphragm and shear wall perimeters
  - Interior openings
  - Areas of discontinuity
  - Re-entrant corners.

**Required for Seismic and wind**

**Note:** Interior shear walls require a full depth collector unless a complete alternate load path is provided.

Let’s take a look at load paths to the shear wall at grid line 2.
Typical Collector Framing and Connection Parallel to Shear Wall

- Special sheathing nailing required, usually 8d or 10d at 6” o.c. or 4” o.c.
- Strut/truss (Call out out force)
- End nailed w/2-16d.
- This connection often has less capacity than the shears applied (e.g. nail capacity failure problem)
- Cont. 2x plate w/ 16d at calculated Spacing (cross-grain or end nail failure problem)
- Optional Shth’g.
- Strut/truss
- 2x flat cross blk’g. at 24” o.c. w/2 or 4-16d to plate
- 16d at calculated spacing (truss to flat blk’g.)
- Cross-grain if truss deflects
- Configuration A
  - Lateral distribution
- Configuration B
  - Horizontal and vertical distribution
- Configuration C
  - Strut/truss (multiple if required)
  - Shear clips
  - Shear clips
- Detail elevation on drawings

**Lateral distribution**

\[ V \]

\[ \frac{L}{2} \quad \frac{L}{2} \]

\[ a \quad b \]
Typical Collector Framing and Connections - Roof Framing Perpendicular to Shear Wall

- **Roof trusses @ 24” o.c.**
- **GWB ceiling buckling**
- **No shear panels installed or detailed.**
- **Typical interior Shear wall or braced wall**
- **Collector / strut is missing**
- **Trusses rotate because there is nothing present to resist the lateral forces, and the lateral load is not transferred into the wall.**
- **Roof diaphragm force to wall**

Corridor Shear Wall Line
Corridor Shear Wall with Shear Panels and Collector Added

Continuous drag strut or collector is required

Shear panels vary in detailing from designer to designer (mini-shear walls). Add member at end of wall as required.

Note: When designing the shear wall, the forces from the shear panels above must be transposed to the shear wall below.

Ceiling
Trusses also brace wall

Tie straps at end of wall as required.

Framing Perpendicular to Wall
The shear panels shown are 24” wide by 6’-0” high. The framing could easily be 16” wide by 15’-0” high or greater.

Wood shear panels between trusses

Shear panel ratios 3:1

Does not appear to have vertical blocking at truss (no shear transfer for vertical shear force).

Photo-Typical Shear Panels

Courtesy of Willdan Engineering
Side members nailed to truss chords by side grain nailing, full height.

Top and bottom members nailed to truss chords by end grain nailing-2 16d.

Panel edge buckling.

Blk’g. top and bottom only.

Option 1:
Top and bottom members nailed to truss chords by end grain nailing-2 16d.

Option 2:
Side members nailed to truss chords by side grain nailing-2 16d.
Side frm’g. members added.

Option 3:
Side members nailed to truss chords by side grain nailing, full height.
Add vertical nailing member in truss.

Typical Shear Panel Detailing.
Roof sheathing

Roof trusses

Steel strap

Shear panels per detail 3

Hold down straps as required

2x, 3x, or 4x flat blocking

Continuous ledger at corridor

Shear wall

Collector Framing Option 1
Example of Partial Strut/Collector

2x flat blk’g (tight fit)

WSP sht’g.

Potential gaps

Bearing perp. to grain?

Alt. 4x blk’g.

Tie strap

Joists

Use Z clip to keep blocking level

Note: If open web joists, continuous 2x members can be nailed to blocking to take compression forces.

Typical Section

Strut/collector force diagram

F(total) = \sum F1 + F2 + F3 + F4

For compression, blocking acts as mini strut/collector and transfers (accumulates) forces into the next block.

No gaps allowed. Diaphragm sheathing is not allowed to transfer strut/collector tension or compression forces.

Collector force distribution
Corridor Wall Line?

- Collector/strut
- Fully sheathed?
- Shear panel or truss rotation blocking
These connections are part of the complete load path

Section A

Collector Framing Option 2
(Assuming the collector does not fall at a truss joint)
Section A

Collector Framing Option 3
(Assuming the collector does not fall at a truss joint)

- Roof sheathing
- Roof trusses
- Shear panels per detail 3
- Hold down straps as required
- Shear wall
- 2x blocking w/ shear clips (as req’d.)
- Single or multiple continuous drag members
- Special strut nailing full length
- Blocking with nails and/or shear clips (as req’d.)
- Connections for shear transfer
- Edge nailing each 2x
- Horizontal strap is required across joint if 2x members can not be cont.
- Connections for shear transfer
- Shear clips as required
- Collector Framing Option 3 (Assuming the collector does not fall at a truss joint)
Roof sheathing

Roof trusses

Shear panels per detail 3

Shear wall

Edge nailing each 2x

Horizontal strap is required across joint if 2x members can not be continuous

Drag strut or collector

Special nailing (drag shear plus basic diaphragm shear)

Collector Framing Option 4
(If the collector falls at a truss joint)
Presentation Topics

• Shear Wall Types
• Shear wall Anchorage
• SDPWS Code Requirements
• Complete Load Paths
• Offset Shear Walls and Relevant ASCE Requirements
• Mid-rise Multi-story Stacked Shear Walls
Mid-rise Multi-family

Discontinuous chords

Transverse

Cant.

Mid-rise Multi-family

Discontinuous struts

Longitudinal

Lds.

Discontinuous chords

Transverse

Flexible, semi-rigid, or rigid???
Out-of-Plane Offset Shear Walls
Assumed to act in the Same Line of Resistance

Offset walls are often assumed to act in the same line of lateral-force-resistance.

Calculations are seldom provided showing how the walls are interconnected to act as a unit, or to verify that a complete lateral load path has been provided.

Collectors are required to be installed to transfer the disrupted forces across the offsets.

Where offset walls occur in the wall line, the shear walls on each side of the offset should be considered as separate shear walls and should be tied together by force transfer around the offset (in the plane of the diaphragm).

Check for Type 2 horizontal irregularity
Re-entrant corner irregularity
Tying Shear Walls Across the Corridor or a Large Diaphragm

SDPWS 4.3.5.1

3. Collectors for shear transfer to individual full-height wall segments shall be provided.

Where offset walls occur in the wall line, the shear walls on each side of the offset should be considered as separate shear walls and should be tied together by force transfer around the offset (in the plane of the diaphragm).

Must follow engineering mechanics and all force diagrams must close to zero or be resolved by other methods.
3. Collectors for shear transfer to individual full-height wall segments shall be provided.

SDPWS 4.3.5.1

Tying Shear Walls Across the Corridor

Special nailing of the sheathing to the collector is required the full length of the collector (typ.)

Common Transverse Wall Layouts
Layout 1-Full length walls aligned

\[ \text{R}_L = \text{R}_R = 200 \left( \frac{78}{2} \right) = 7800 \text{ #} \]
\[ \text{v}_R = \frac{7800}{50} = 156 \text{ plf} \]

\[ \text{v}_{SW} = 454.55 \text{ plf} \]
\[ \text{v}_{Net} = 54.55 \text{ plf} \]

\[ \text{R}_L = \text{R}_R = 200 \left( \frac{122}{2} \right) = 12200 \text{ #} \]
\[ \text{v}_R = \frac{12200}{50} = 244 \text{ plf} \]

\[ \text{Sum} = 20000 \text{ #} \]
\[ \text{Sum} = 40000 \text{ #} = 200 \text{ plf}(200’) \]
Example 1-Offset Shear Walls -Layout 6

Case 1-Full length offset walls

- Full length offset walls

- Example 1 - Offset Shear Walls

- Layout 6

Diagram:

- Diaphragm 1
- Diaphragm 2
- SW1
- SW2
- SW3
- SW4

- Transfer Area

- RL=RR=112(78/2)=4368 #
- VR=4368/28=156 plf
- RL=RR=88(122/2)=5368 #
- VR=5368/22=244 plf
- RL=RR=88(82/2)=3608 #
- VR=3608/22=164 plf
- RL=RR=112(118/2)=6608 #
- VR=6608/28=236 plf

- W=200 plf

- Sum=7976 #
- Sum=20048 #
- Sum=11976 #

- Transfer Area

- RL=RR=24(4/2)=48 #
- VR=48/6=8 plf
- RL=RR=88(122/2)=5368 #
- VR=5368/22=244 plf
- RL=RR=112(78/2)=4368 #
- VR=4368/28=156 plf
- RL=RR=88(82/2)=3608 #
- VR=3608/22=164 plf
- RL=RR=112(118/2)=6608 #
- VR=6608/28=236 plf

- Sum=40000 #
- =200 plf(200')
Case 1 - Smaller resulting forces at corridor

Total load to grid lines 2 & 3

\[ R_{23} = 4368 + 3608 + 48 + 5368 + 6608 + 48 = 20048 \text{ # O.K.} \]

L\text{SW} = 22 + 22 = 44'
V\text{SW} = 20048 #
\[ v_{\text{SW}} = \frac{20048}{44} = 455.64 \text{ plf} \]
\[ v_{\text{net SW1}} = 455.64 - 156 - 244 = 55.64 \text{ plf} \]
\[ v_{\text{net SW2}} = 455.64 - 164 - 236 = 55.64 \text{ plf} \]
Checks, they should be equal

SW1
\[ F_{2\text{AB}} = 55.64(22) = 1224 \text{ #} \]
\[ F_{2\text{BC}} = (156 + 8)6 = 984 \text{ #} \]
\[ F_{2\text{C}} = 1224 - 984 = 240 \text{ #} \]

SW2
\[ F_{3\text{CD}} = 55.64(22) = 1224 \text{ #} \]
\[ F_{3\text{CB}} = (236 + 8)6 = 1464 \text{ #} \]
\[ F_{3\text{B}} = 1224 - 1464 = -240 \text{ #} \]
FB\text{23} = FC\text{23} = 240(4)/6 = 160 #

Sum = 20048 #
All forces in lb., all shears in plf

O.K.
Case 2—Full length plus partial length offset shear walls

Diaphragm 1:
- SW1:
  - $R_L = R_R = \frac{112 \times 78}{2} = 4368 \#$
  - $v_R = \frac{4368}{28} = 156 \text{ plf}$
- SW2:
  - $R_L = R_R = \frac{88 \times 82}{2} = 3608 \#$
  - $v_R = \frac{3608}{22} = 164 \text{ plf}$
- SW4:
  - $R_L = R_R = \frac{112 \times 82}{2} = 4368 \#$
  - $v_R = \frac{4368}{22} = 164 \text{ plf}$

Diaphragm 2:
- SW3:
  - $R_L = R_R = \frac{88 \times 122}{2} = 5368 \#$
  - $v_R = \frac{5368}{22} = 244 \text{ plf}$
- SW2:
  - $R_L = R_R = \frac{112 \times 118}{2} = 6608 \#$
  - $v_R = \frac{6608}{22} = 236 \text{ plf}$

Transfer Area:
- $R_L = R_R = \frac{24 \times 4}{2} = 48 \#$
- $v_R = \frac{48}{6} = 8 \text{ plf}$

Sum:
- Case 2 = 7976 #
- Full length = 20048 #
- Full length + partial length offset = 11976 #

Transfer Area:
- $R_L = R_R = 50 \#$
- $v_R = \frac{50}{200} = 0.25 \text{ plf}$
Case 2 - Larger resulting forces at corridor

Total load to grid lines 2 & 3

R_{23} = 4368 + 3608 + 48 + 5368 + 6608 + 48 = 20048 \text{ # O.K.}

L_{SW} = 22 + 12 = 34'
V_{SW} = 20048 \text{ #}
v_{SW} = \frac{20048}{34} = 589.65 \text{ plf}

v_{net \, SW1} = 589.65 - 156 - 244 = 189.65 \text{ plf}

v_{net \, SW2} = 589.65 - 164 - 236 = 189.65 \text{ plf} \text{ Checks, they should be equal}

SW1
F_{2AB} = 189.65(22) = 4172.24 \text{ #}
F_{2BC} = (156 + 8)6 = 984 \text{ #}
F_{2C} = 4172.24 - 984 = 3188.24 \text{ #}

SW2
F_{SW2} = 189.65(12) = 2275.76 \text{ #}
F_{SW2 \, to \, 3B} = (236 + 8)6 + (236 + 164)10 = 5464 \text{ #}
F_{3B} = 2275.76 - 5464 = -3188.24 \text{ #}

F_{B23} = F_{C23} = \frac{3188.24(4)}{6} = 2125.49 \text{ #}

Shear at transfer area = 3188.24/6 + 8 = 539.37 \text{ plf}

All forces in lb., all shears in plf
Case 3 - Smaller resulting forces at corridor

Total load to grid lines 2 & 3

\[ R_{23} = 4368 + 3608 + 48 + 5368 + 6608 + 48 = 20048 \text{ # O.K.} \]

\[ LSW = 12 + 10 = 22' \]
\[ VSW = 20048 \text{ #} \]
\[ v_{SW} = \frac{20048}{22} = 911.27 \text{ plf} \]

\[ v_{net} SW1 = 911.27 - 156 - 244 = 511.27 \text{ plf} \]
\[ v_{net} SW2 = 911.27 - 164 - 236 = 511.27 \text{ plf} \]

Checks, they should be equal

\[ SW1 \]
\[ FSW1 = 511.27(10) = 5112.7 \text{ #} \]
\[ FSW1 \text{ to 2B} = (156 + 244)12 = 4800 \text{ #} \]
\[ F2B = (156 + 8)6 = 984 \text{ #} \]
\[ F2C = 5112.7 - 4800 - 984 = -671.3 \text{ #} \]

\[ SW2 \]
\[ FSW2 = 511.27(12) = 6135.24 \text{ #} \]
\[ FSW2 \text{ to 3C} = (236 + 8)6 + (236 + 164)10 = 5464 \text{ #} \]
\[ F3B = 6135.24 - 5464 = 671.24 \text{ #} \]

\[ FB23 = FC23 = \frac{671.3(4)}{6} = 120 \text{ #} \]

Shear at transfer area = 671.3/6 + 8 = 119.9 plf

All forces in lb., all shears in plf

O.K.
Potential buckling problem w/ supporting columns and beams

The deflection equation must be adjusted to account for the uniformly distributed load plus the transfer force.

Elements requiring over-strength load combinations

ASCE 7 Table 12.3-1
Type 4 horizontal irregularity: out-of-plane offset discontinuity in the LFRS load path

ASCE 7 Table 12.3-2
Type 4 vertical irregularity: in-plane offset discontinuity in the LFRS (if no H.D. at A.25)

See Section 12.10.1.1 (transfer forces)

Relevant Irregularities Per ASCE 7-10
Horizontal Irregularities Table 12.3-1 and Vertical Irregularities Table 12.3-2
Type 4 Horizontal & Vertical Offset Irregularity - Seismic

Type 4 horizontal irregularity-Out-of-plane offset irregularity occurs where there is a discontinuity in lateral force resistance load path. Out-of-plane offset of at least one of the vertical lateral force resisting elements.

Type 4 vertical irregularity-In-plane discontinuity in vertical lateral force resisting element occurs where there is an offset of vertical seismic force resisting element resulting in overturning demands on a beam, column, truss, wall or slab.

- **ASCE 7-10 Section 12.3.3.3 (SDC B-F)**
  Elements supporting discontinuous walls or frames.

- **ASCE 7-10 Section 12.3.3.4 (SDC D-F)**
  Increases in force due to irregularity
ASCE 7-10 Section 12.3.3.3 (SDC B-F)
Elements supporting discont. Walls or frames:

- Beams, columns, slabs, walls or trusses.
- Requires over-strength factor of Section 12.4.3

Also see 12.10.2.1 SDC C-F for collector requirements.

Type 4 Vertical Irregularity SDC D-F
(Interior collector similar)
ASCE 7-10 Section 12.3.3.4 (SDC D-F) - Type 4 Horizontal and Type 4 vertical irregularity requires a 25% increase in the diaphragm (inertial) design forces determined from 12.10.1.1 \( (F_{px}) \) for the following elements:

- Connections of **diaphragm** to vertical elements and collectors.
- Collectors and their connections to vertical elements.

**Exception:** Forces using the seismic load effects including the over-strength factor of Section 12.4.3 need not be increased.

Type 4 Horizontal Irregularity - Seismic
ASCE 7-10 Section 12.3.3.4 (SDC D-F)

- Type 2 Horizontal Re-entrant corner Irregularity
- Type 3 Diaphragm discontinuity irregularity
- Type 4 horizontal or vertical irregularity:

Requires a 25% increase in the diaphragm design forces \((F_{px})\) determined from 12.10.1.1 for the following elements:

- Connections of diaphragm to vertical elements and collectors.

Type 2 Horiz., Type 3 Horiz., and Type 4 Vert. & Horiz. Irregularity SDC D-F

(Interior collector similar)
Type 2 Horiz., Type 3 Horiz., and Type 4 Vert. & Horiz. Irregularity

ASCE 7-10 Section 12.3.3.4 (SDC D-F)

- Type 2 Horizontal Re-entrant corner irregularity
- Type 3 Diaphragm discontinuity irregularity
- Type 4 horizontal or vertical irregularity:

Requires a 25% increase in the diaphragm design forces \((F_{px})\) determined from 12.10.1.1 for the following elements:

- Connections of diaphragm to vertical elements and collectors.
- Collectors and their connections, including their connections to vertical elements.

Collector

Shear Wall

Blocking or shear panels

Continuous member

Strut

Alt. Collector/strut Connection

(Interior collector similar)
Struts and Collectors - Seismic

Struts / collectors and their connections shall be designed in accordance with ASCE 7-10 sections:

12.10.2 SDC B - Collectors can be designed \textit{w/o} over-strength but not if they support discontinuous walls or frames.

12.10.2.1 SDC C thru F - Collectors and their connections, including connections to the vertical resisting elements require the over-strength factor of Section 12.4.3, except as noted:

\textbf{Shall be the maximum of:}

- \( \Omega_o F_x \) - Forces determined by ELF Section 12.8 or Modal Response Spectrum Analysis procedure 12.9
- \( \Omega_o F_{px} \) - Forces determined by Diaphragm Design Forces \((F_{px})\), Eq. 12.10-1 or

\[ F_{px \, \text{min}} = 0.2S_{DS}I_e w_{px} \] - Lower bound seismic diaphragm design forces determined by Eq. 12.10-2 \((F_{px\,\text{min}})\) using the Seismic Load Combinations of section 12.4.2.3 \((w/o \text{ over-strength})\)-do not require the over-strength factor.

\[ F_{px \, \text{max}} = 0.4S_{DS}I_e w_{px} \] - Upper bound seismic diaphragm design forces determined by Eq. 12.10-2 \((F_{px\,\text{max}})\) using the Seismic Load Combinations of section 12.4.2.3 \((w/o \text{ over-strength})\)-do not require the over-strength factor.

\textbf{Exception:}

1. In structures (or portions of structures) \textit{braced entirely by light framed shear walls}, collector elements and their connections, including connections to vertical elements need only be designed to resist forces using the standard seismic force load combinations of Section 12.4.2.3 with forces determined in accordance with Section 12.10.1.1 (Diaphragm inertial Design Forces, \(F_{px}\)).
Wall element is designed for standard load combinations of ASCE 7-10 Sections 2.3 or 2.4.

Shear wall hold downs are designed for standard load combinations of Sections 2.3 or 2.4.

Wall designed for over-strength per ASCE 7-10 Section 12.3.3.3 (SDC B-F) and/or 12.3.3.4 (SDC D-F)

Assuming no hold down

ASCE 7 Table 12.3-2-Type 4 vertical irregularity- In-plane offset discontinuity in the LFRS


See struts and collectors

Shear wall system at grid line 1
In-plane Offset of Wall
Wall element is designed for standard load combinations of ASCE 7-10 Sections 2.3 or 2.4.

Shear wall hold downs and connections are designed for standard load combinations of ASCE 7-10 Sections 2.3 or 2.4.

Footings and connections are not required to be designed for over-strength.

Collector and columns shall be designed in accordance with ASCE 7-10 section: 12.3.3.3

Elements supporting discontinuous walls or frames require over-strength Factor of Section 12.4.3.

Connection is designed for standard load combinations of Sections 2.3 or 2.4.

See struts and collectors

ASCE 7 Table 12.3-1-Type 4 horizontal irregularity- out of-plane offset discontinuity in the LFRS

Shear wall system at grid line 2
Out-of-Plane Offset
Wall element, hold downs, and connections are designed for standard load combinations of ASCE 7-10 Sections 2.3 or 2.4.

Connections are designed for standard load combinations of Sections 2.3 or 2.4.

Footings and connections are not required to be designed for over-strength.

Collector and columns shall be designed in accordance with ASCE 7-10 section: 12.3.3.3

Elements supporting discontinuous walls or frames require over-strength factor of Section 12.4.3.

ASCE 7 Table 12.3-2-Type 4 vertical irregularity- In-plane offset discontinuity in the LFRS

See struts and collectors

Shear wall system at grid line 3-In-plane Offset
Discontinuous Shear wall system at **Podium Slab**

Wall element, hold downs, and connections are designed for standard load combinations of ASCE 7-10 Sections 2.3 or 2.4.

Connections are designed for standard load combinations of Sections 2.3 or 2.4.

Seismic reactions from the flexible upper portion shall be amplified by the ratio

$$\frac{R_{Upper \ portion}}{\rho} > 1.0$$

for connections embedded into slab (does not apply to gravity reactions).

Elements supporting discontinuous walls or frames require over-strength factor of Section 12.4.3. Collector, columns, Podium slabs and beam shall be designed using the over-strength factor of ASCE 7-10 section 12.3.3.3
Struts and Collectors

Possible struts:
- Truss or rim joist over wall
- Double top plate
- Beam/header
Struts / collectors and their connections shall be designed in accordance with ASCE 7-10 sections:

12.10.2 SDC B - Collectors can be designed w/o over-strength
but not if they support discontinuous walls or frames.

12.10.2.1 SDC C thru F - Collectors and their connections, including connections to the vertical resisting elements require the over-strength factor of Section 12.4.3, except as noted:

** SHALL be the maximum of:**

\[ \Omega_F F_x \quad \text{ - Forces determined by ELF Section 12.8 or Modal Response Spectrum Analysis procedure 12.9} \]

\[ \Omega_o F_{px} \quad \text{ - Forces determined by Diaphragm Design Forces (Fpx), Eq. 12.10-1 or} \]

\[ F_{px \min} = 0.2 S_{DS} I_e w_{px} \quad \text{ - Lower bound seismic diaphragm design forces determined by Eq. 12.10-2 (Fpx\text{min}) using the Seismic Load Combinations of section 12.4.2.3 (w/o over-strength)-do not require the over-strength factor.} \]

\[ F_{px \max} = 0.4 S_{DS} I_e w_{px} \quad \text{ - Upper bound seismic diaphragm design forces determined by Eq. 12.10-2 (Fpx\text{max}) using the Seismic Load Combinations of section 12.4.2.3 (w/o over-strength)-do not require the over-strength factor.} \]

**Exception:**

1. In structures (or portions of structures) braced entirely by light framed shear walls, collector elements and their connections, including connections to vertical elements need only be designed to resist forces using the standard seismic force load combinations of Section 12.4.2.3 with forces determined in accordance with Section 12.10.1.1 (Diaphragm inertial Design Forces, \( F_{px} \)).
In-plane Offset Shear Walls
Example 5-In-plane Offset Segmented Shear Wall -with Gravity Loads

Sections do not comply with the required aspect ratio for a perforated or FTO shear wall.

ASCE 7 Table 12.3-2-Type 4 vertical irreg.- in-plane discontinuity in the LFRS if no hold down at B.

12.3.3.3 & 12.3.3.4
SDC B-F  SDC D-F
Ends of wall panels do not line up. Requires special nailing of sheathing into stud below.

Nailing found in field was 12” o.c.

Requires same number of studs above and below with boundary nailing each stud.

Solid blocking required

No hold-down below

Hold down

Photo-In-plane Offset Segmented Shear Walls
Diaphragm with Horizontal End Offset
Longitudinal Loading-Out-of-plane offset Shear Walls

Drag strut

Chord

TD1

Offset SW

SW 2

Drag strut

Collector

Drag strut

SW 3

Drag strut

SW 4

Support

Pos. direction

Drag strut is discontinuous
**Total Shear to Shear Walls (Assumed)**

\[ V_{sw2} = \frac{wL}{2} = \frac{200(50)}{2} = 5000 \text{ lb}, \quad v_{sw2} = \frac{5000}{10} = 500 \text{ plf} \]

\[ V_{sw1}, \, sw3, \, sw4 = \frac{wL}{2} = \frac{200(50)}{2} = 5000 \text{ lb}, \quad v_{sw} = \frac{5000}{8+8+15} = 161.3 \text{ plf} \]

Determine Force transferred Into Transfer Diaphragm

**Basic Diaphragm Shears and Transfer Diaphragm Shear**
Adjusted Longitudinal Strut Force Diagrams (8% increase to B/C)

[Amount shifted to B/C depends on the offset to span ratio of the transfer diaphragm]
Presentation Topics

- Shear Wall Types
- Shear wall Anchorage
- SDPWS Code Requirements
- Complete Load Paths
- Offset Shear Walls and Relevant ASCE Requirements
- **Mid-rise Multi-story Stacked Shear Walls**
Current Examples of Shear Wall Multi-story Effects and Mid-rise Analysis

Current Examples of Mid-rise Analysis-Traditional Method

• Thompson Method-Woodworks Website
  Webinar [http://www.woodworks.org/education/online-seminars/](http://www.woodworks.org/education/online-seminars/)


Current Examples of Mid-rise Analysis-Mechanics Based Approach

• Shiotani/Hohbach Method-Woodworks Slide archive

• FPInnovations-Website NEW
  ”Seismic Analysis of Wood-Frame Buildings on Concrete Podium”, Newfield

• 2016 WCTE: A Comparative Analysis of Three Methods Used For Calculating Deflections For Multi-storey Wood Shear Walls: Grant Newfield, Jasmine B. Wang

• FPInnovations-Website
  ”A Mechanics-Based Approach for Determining Deflections of Stacked Multi-Storey Wood-Based Shear Walls”, Newfield

• Design Example: ”Design of Stacked Multi-Storey Wood-Based Shear Walls Using a Mechanics-Based Approach ”, Canadian Wood Council

• APEGBC Technical & Practice Bulletin   Revised April 8, 2015
  “5 and 6 Storey Wood Frame Residential Building Projects (Mid-Rise)”-Based on FPInnovations Mechanics Based Approach
New Research and Analytical methods-Tall Shear Walls

Currently not addressed or required by code: Engineering preference and/or judgement

Testing shows that the traditional deflection equation is less accurate for walls with aspect ratios higher than 2:1. (Dolan)

- Current research suggests that the traditional method of shear wall analysis might be more appropriate for low-rise structures.

- Multi-story walls greater than 3 stories should:
  - Consider flexure and wall rotation.
  - Rotation and moment from walls above and wall rotation effects from walls below.

Allowable story drift for traditional and tall shear walls is checked floor to floor.

Total displ. of Tall Wall. More flexible.

A/R=3.5:1 flr.-flr.

A/R=2:1 flr.-flr.

Acting as a continuous wall

Total displ. of

Floor to floor A/R’s and Stiffness of Shear Walls

\[ \frac{\sum M_i H_i^2}{2(EI)_i} + \frac{\sum V_i (H^3)}{3(EI)_i} \]
Tall Wall Deflection $\Delta_i = \frac{\sum M_i H_i^2}{2(EI)_i} + \frac{\sum V_i H_i^3}{3(EI)_i} + \frac{V_i H_i}{c_{v,i} v_i} + 0.75H_i e_{n,i} + \frac{H_i}{L_i} d_{a,i} + H_i \sum_{i=1}^{k} \left( \frac{M_i H_i}{(EI)_i} + \frac{V_i H_i^2}{2(EI)_i} \right) + H_i \sum_{j=1}^{k-1} \frac{d_{a,j}}{L_j}$

Note:
Increased wall flexibility can increase the period of the building, lowering the seismic force demands.
Rigid or spring support? 

Exterior shear walls 

Rigid support or partial support 

Rigid or spring support? 

Seismic Loads 

Support 

Wind Loads as applicable 

Support 

Unit with Exterior Wall 

Unit without Exterior Wall 

If flexible diaphragm 

Condition A 

Full support (SW rigid) 

Condition B 

Partial support (Decreasing SW stiffness) 

Corridor only SW 

Condition C 

No SW support 

Varying Degrees of Stiffness Effects of Exterior Walls
Load distribution to corridor SW’s
Load distribution to exterior SW’s
Load distribution based on flexible diaphragm
Seismic Design Example of a Cantilever Wood Diaphragm

R. Terry Malone, P.E., S.E., Senior Technical Director
Scott Breneman, PHD, PE, SE, Senior Technical Director

• Overview
• Relevant ASCE 7-16 and 2015 SDPWS Code Requirements
  1. Diaphragm Flexibility-Seismic
  2. Open Front Diaphragms
  3. Torsional Irregularities
  4. Redundancy
  5. Diaphragm Design Forces
• Basic Information
• Lateral Load Calculations
  1. Calculate Seismic Forces
  2. Rigid Diaphragm Analysis
  3. Shear Wall Deflections
Reference Materials

• The Analysis of Irregular Shaped Structures: Diaphragms and Shear Walls-Malone, Rice-Book published by McGraw-Hill, ICC

• Woodworks Presentation Slide Archives-Workshop-Advanced Diaphragm Analysis


• SEAOC Seismic Design Manual, Volume 2

• Woodworks-The Analysis of Irregular Shaped Diaphragms (paper). Complete Example with narrative and calculations.


Information on Website

• Webinar Archive- Offset Diaphragms -Part 1
• Webinar Archive- Offset Shear Walls-Part 2
• Slide Archive-Workshop-Advanced Diaphragm Analysis
• Slide Archive-Offset Diaphragms and Shear Walls

• Webinar Archive- Lateral Design Considerations for Mid-rise Structures-Stacked multi-story shear walls (MBA)
Method of Analysis and Webinar References

Offset Diaphragms

Offset Shear Walls

Diaphragms Openings

Example Results

Information on Website
Presentation Slide Archives, Workshops, White papers, research reports
QUESTIONS?

This concludes Our Workshop Presentation on Advanced Diaphragm Analysis

WoodWorks

R. Terry Malone, P.E., S.E.
Senior Technical Director
WoodWorks.org

Contact Information:
terrym@woodworks.org
928-775-9119
Time for Lunch