Diaphragm and Shear Wall Design

Avalon Bay Communities
Photo credit: Arden Photography

120 Union, San Diego, CA
Togawa Smith Martin

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
Course Description

Intended for structural engineers who would like a deeper understanding of advanced shear wall and diaphragm principles, this presentation will provide an in-depth look at wood-frame shear wall and diaphragm designs commonly used for non-residential and multi-family low-rise and mid-rise buildings, including those with rectangular, offset and open-front plans. Topics will include:

- Basic information and method of analysis
- Diaphragms with horizontal offsets
- Diaphragms with large openings
- Shear wall types and anchorage
- SDPWS and ASCE 7 shear wall code requirements
- Offset shear walls and code requirements
Assumptions:

- Loads to diaphragms and shear walls
  - Strength level or allowable stress design
  - Wind or seismic forces.

- The loads are already factored for the appropriate load combinations.

Code and Standards:
Evolution to Complex Buildings

• Simple structures

• Complex structures

• The method of analysis:
  § Can be used for all construction types.
  § Is straightforward and simple to use. “A rational method of analysis based on simple statics”!
  § Well Documented over several decades

• Today’s presentation focuses on:
  • Developing continuous load paths across areas of discontinuities.
  • Flexible wood sheathed or un-topped steel deck diaphragms.
    Can also be used for semi-rigid or rigid diaphragms.

Wood diaphragms are well suited for these shapes as they can be easily adapted to the building shape and are cost effective.
Mid-rise Multi-family

Discontinuous chords

Transverse

Cant.

Mid-rise Multi-family

Discontinuous struts

Longitudinal

Lds. Discontinuous struts

Longitudinal

Lds.

Discontinuous chords

Transverse

No exterior shear walls

Flexible, semi-rigid, or rigid???
Basic Information

- Boundary Elements
- Complete Load Paths
- Method of Analysis
**Struts, Collectors, and Chords- (my) Terminology**

*Strut*- receives shears from one side only.*

*Collector*- receives shears from both sides.

*[ Drag struts and collectors are synonymous in ASCE7]*

---

**Diaphragm support**

**Chord**

**Strut**

**Collector**

**Chord**

**SW**

**W ( plf)**
Diaphragm Boundary Elements

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
Would you do this?

Failure Modes

Shear failure
Not enough shear capacity

Splitting failure
Bottom section not supported

Alternate load path

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

High stress concentrations at end of the wall

Collector

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
Tearing will occur if collectors are not installed at re-entrant corner.
Basic Information

- Boundary Elements
- Complete Load Paths
- Method of Analysis
Analysis: ASCE7-10 Sections:

- 1.3.1.3.1-Design shall be based on a rational analysis
- 12.10.1-At diaphragm discontinuities such as openings and re-entrant corners, the design shall assure that the dissipation or transfer of edge (chord) forces combined with other forces in the diaphragm is within shear and tension capacity of the diaphragm.

ASCE7-10 Section 1.4-Complete load paths are required including members and their splice connections
Complete Load Paths

SDPWS 4.3.5.1
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).
Basic Information

- Boundary Elements
- Complete Load Paths
- Method of Analysis
The Visual Shear Transfer Method

How to visually show the distribution of shears through the diaphragm

Sheathing element symbol for 1 ft x 1 ft square piece of sheathing in static equilibrium (typ.)

Shears Applied to Sheathing Elements

Transfer shears

Unit shear acting on sheathing element (plf)

Unit shear transferred from the sheathing element into the boundary element (plf)

Shears Transferred Into Boundary Elements
All edges of a diaphragm shall be supported by a boundary element (chord, strut, collector) or other vertical lateral force resisting element (shear wall, frame).

**Shear Distribution Into a Simple Diaphragm**

**The Visual Shear Transfer Method**
Introduction to Transfer Diaphragms and Transfer Areas

**Transfer Diaphragm**

- Sub-diaphragm—don’t confuse w/ sub-diaphragms supporting conc./masonry walls
- Transfers local forces out to primary chords/struts of the main diaphragm. (Based on method, ASCE 7 Section 1.4 and SDPWS 4.1.1)
- Maximum TD Aspect Ratio=4:1 (Similar to main diaph.)

Framing members, blocking, and connections shall extend into the diaphragm a **sufficient distance** to develop the force transferred into the diaphragm. (SDPWS 4.2.1)

What does this mean?

**Collector Length?—My rule of thumb:**

- Check length by dividing discontinuous force by the nailing capacity (other issues need to be considered)
- Length=full depth of transfer the diaphragm, set by A/R
- If L<=30’ o.k. to use strap/blocking, If > 30’ use beam/truss
- Increase TD depth if shears are too high in transfer area
TD Aspect Ratio Too High

TD aspect ratio 8:1
4:1 maximum allowed

Over-stressed.
(Notice deformation in transfer diaphragm)

Warping/racking
• The length of the collector is often determined by dividing the collector force by the diaphragm nailing capacity. (Caution - other issues need to be considered!)
• The collector is often checked for tension only. (Wrong!) Compression forces occur when the loads reverse direction.

Typical callout
Steel tie strap x ga. x width x length with (xx) 10d nails over 2x, 3x or 4x flat blocking. Lap x’-y” onto wall.
Example of Partial Strut/Collector

Potential gaps

Typical Section

Use Z clip to keep blocking level

Bearing perp. to grain?

Alt. 4x blk’g.

Tie strap

WSP sht’g.

2x flat blk’g (tight fit)

Joists

Diaphragm unit shear (plf) transfers into blocking

Strut/collector force diagram

Cont. tie strap over

F1

F2

F3

F4

F(total)=∑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 Compression force distribution
This force must be transferred out to the main chords. A complete load path is required. (ASCE 7 Section 1.4 and SDPWS 4.1.1)

Transfer area without transverse collectors

Transfer Mechanism

Transfer using beam concept
Simple Span Transfer Diaphragm
Analogous to a simple span beam with a concentrated load

Propped Cantilever Transfer Diaphragm
Analogous to a propped cantilever beam with a concentrated load

Simple Span and Propped Cantilever Transfer Diaphragms
No outside force is changing the basic diaphragm shear in this area.

Method of Analysis - Method by Edward F. Diekmann

Chord force at discontinuity

\[ v_{\text{net}} = +300 - (75) = +225 \text{ plf} \]

\[ v_{\text{net}} = +225 - (75) = +150 \text{ plf} \]

Transfer Diaphragm Shears

Analogous to a beam with a concentrated Load.

Main chord

Disrupted chord

Chord

TD1

Collector (TD support)

Collector (TD support)

No outside force is changing the basic diaphragm shear in this area.

Basic Shear Diagram at transfer diaphragm

TD depth

+500 plf

+300 plf

+225 plf

+225 plf

Transfer diaphragm length

LTD

LTD

\[ V_{\text{A}} = \frac{V_A}{D_{TD}}, \text{ Shear} = \frac{V_A}{D_{TD}} \]

\[ V_{\text{C}} = \frac{V_C}{L_{TD}}, \text{ Shear} = \frac{V_C}{D_{TD}} \]

Add to basic diaphragm shears

Subtract from basic shears

No outside force is changing the basic diaphragm shear in this area.

Main chord

TD1

Collector

Collector
Resulting net shear diagram acting on collector

Shear Distribution Into The Collector

- Place the net diaphragm shear on each side of the collector
- Place the transfer shears on each side of the collector
- Sum shears on collector (based upon direction of shears transferred onto collector).

\[
\text{Shear left} = +550 - 225 = +325 \text{ plf}
\]
\[
\text{Shear right} = +475 - 150 = +325 \text{ plf}
\]
- Collector force = area of shear diagram

\[
F_{\text{collector}} = \frac{(325 + 325)(L_{\text{collector}})}{2}
\]
Diaphragms
Diaphragm Design

- Horizontal Offsets
- End offsets
- Large interior Openings
Irregularity Requirements for Diaphragms with Horizontal End Offsets - Seismic

A Type 2 Horizontal Irregularity (Re-entrant corner) exists where both projections > 15% of plan dimension in given direction. SDC D-F

- Triggers Section 12.3.3.4
- Can also trigger a Type 3 Horizontal Irregularity - abrupt discontinuity or variation in stiffness in diaphragm SDC D-F
Irregularity Requirements for Diaphragms with Horizontal End Offsets - Seismic

ASCE 7-10 Section 12.3.3.4 – A 25% increase is required in diaphragm (inertial) design forces \((F_{px})\) for Type 2 or Type 3 horizontal irregularities located in (SDC D-F) for the following elements:

- Connections of diaphragm to vertical elements and collectors (diaphragm supporting elements-TD)
- 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.

---

**Diagram Description:**

- Design collector and connections to SW using 25% increase per ASCE 7-10 Section 12.3.3.4. (Grid lines 1 and 4)
- Design diaphragm connections to SW and struts using 25% increase per ASCE 7-10 Section 12.3.3.4. (Grid lines 1 and 4)
- Diaphragm shears are not required to be increased 25%.

See 12.10.2 & 12.10.2.1 for collectors.
Example 1 - Diaphragm with Horizontal End Offset - Transverse Loading

- **w=200 plf**
- **F2B=7142.9 lb**
- **A/R=2.5:1**
- **12500 lb**
- **Discontinuous diaphragm chord**
- **Support RL=12500 lb**
- **Support RR=12500 lb**
- **Calcs**

**Free body for F2B**

**Sum of Moments = 0**

- **∑M=0**
- **M2B ft.-lb**
- **F2A**
- **F2B**
- **Sign Convention**

**Example 1** - Diaphragm with Horizontal End Offset - Transverse Loading
### Transfer Diaphragm and Net Diaphragm Shear

**Basic shear diagram**

- **SW 1 35’**
  - **v = 150 - (107.1) = +42.9 plf (Net resulting shear)**
  - **v = 70 - (107.1) = -37.1 plf (Net resulting shear)**

**Net change occurs in TD**

- **v = 150 + (250) = +400 plf (Net resulting shear)**
- **v = 70 + (250) = +320 plf (Net resulting shear)**

**Net change occurs in TD**

- **v = 70 + (250) = +320 plf (Net resulting shear)**

**No net change**

**Legend**

- 375 plf: Basic diaphragm shear
- (240 plf): Transfer diaphragm shears
- =xxx plf: Net shears (basic shear +/- TD shears)

**Sign Convention**

- +: Pos.
- -: Neg.

**Diaphragm C.L.**

- 2142.9 lb

**TD shear diagram**

- v = \( \frac{7142.9(15)}{50(20)} \) = -107.1 plf
- v = \( \frac{7142.9(35)}{50(20)} \) = +250 plf

**TD shear diagram**

- 7142.9 lb
- 12500 lb

**No net change**

- 25’
- 20’
- 80’

---

**Calcs**

- **Basic shear diagram**
  - **v = 150 - (107.1) = +42.9 plf (Net resulting shear)**
  - **v = 70 - (107.1) = -37.1 plf (Net resulting shear)**

- **Net change occurs in TD**
  - **v = 150 + (250) = +400 plf (Net resulting shear)**
  - **v = 70 + (250) = +320 plf (Net resulting shear)**

- **No net change**
  - **v = 150 - (107.1) = +42.9 plf (Net resulting shear)**
  - **v = 70 - (107.1) = -37.1 plf (Net resulting shear)**

---

**Sign Convention**

- +: Pos.
- -: Neg.
Transverse Collector Force Diagrams

- **F = 6000 lb**
  - **F = 6000 lb**
  - **F = 3750 lb**
  - **F = 3748.5 lb**

**Special nailing**
(sum of shears to collector or highest boundary nailing - greater of)

- **250 plf net**
- **171.4 plf net**
- **107.1 plf net**

**Sign Convention**

(this is not an insignificant force.)

Diaph. C.L.
Diaphragm Deflection Equations

Equation variables for offset diaphragms
- Varying uniform loads
- Concentrated loads from discontinuous shear walls
- Varying moments of inertia, and sometimes
- Different support conditions

**ATC7**
- Modify the bending and shear portion of the standard rectangular deflection equation to fit the model:

\[ \Delta_{TL} = \Delta_B + \Delta_S + 0.188 L e_n + \frac{\Sigma(\Delta_C \chi)}{2b} \]

where
\[ \Delta_B = \int_a^b \frac{mM}{E I_1} \, dx + \int_b^c \frac{mM}{E I_2} \, dx \]
and
\[ \Delta_S = \frac{bt}{2G A^2} \left[ \int_a^b \frac{wx}{(b')^2} \, dx + \int_b^c wx \, dx \right] = \int_0^L \frac{vV}{\bar{g}t} \, dx \]

SDPWS combines

\[ \Delta_{TL} = \frac{5vL^3}{8EAb} + \frac{vL}{4G_t} + 0.188 L e_n + \frac{\Sigma(\Delta_C \chi)}{2b} \]

**Shear Deflection - USDA Research Note FPL-0210**
- Simplified energy method (Virtual Work).
- The integrations of the equations can be reduced to multiplying the total area of the shear diagram due to the general loading by the ordinate of the shear diagram due to a dummy load applied at the desired point of shear deflection.

NOTE: Multiply deflection \( \times \) 2.5 for unblocked diaphragm
Multiply nail slip by 1.2 if not Structural I plywood

- Bending deflection
- Shear deflection
- Nail slip Adjusted for non-uniform nailing (ATC-7/APA)
- Chord slip

**Standard deflection equation for simple span, rectangular, rigid supports, fully blocked, uniformly loaded, constant cross section** \( \Delta \) at C.L.)
Check the shear capacity of the nailing along the collector

Special nailing along collectors
Sum of shears to collector or highest boundary nailing - greater of

Transfer area Boundary (High shear area)

Boundary locations

Diaphragm Nailing Callouts
Example 2 - Diaphragm with Horizontal End Offset - Longitudinal Loading

Diaphragm 1

Diaphragm 2

Transfer diaphragm TD1

Collector and TD chords

Drag strut

Discontinuous Drag strut

Chord

200 pflf

35'

40 pflf

50'

160 pflf

200 pflf

Discontinuous Drag strut

Collector

Diaphragm 1

Diaphragm 2

Example 2 - Diaphragm with Horizontal End Offset - Longitudinal Loading
Transfer Diaphragm and Net Diaphragm Shear

\[ V_{\text{net}} = V_{\text{sw}} - V_{\text{diaph}} \]
Longitudinal and Transverse Collector/Strut Force Diagrams
Let’s Take a Break
Diaphragm Design

- Horizontal Offsets
- End offsets
- Large interior Openings
End Openings

Does not meet A/R (Envelope)
Example 3- Intermediate Horizontal Offset at End Wall With Strut

Basic Shear Diagram

Uniform shear in walls and in diaph. at grid line 1

Sw 1

Sw 3

A

B

C

D

Strut

18' Skylight (Enclosed area)

Chord

Collector

Collector

Collector

Section A

Section B

Section A

Section B

10' 12'

15'

16'

150'

10'

12'

16'

15'

56'

w1 plf (WW)

w plf

w2 plf (LW)

w plf

w2 plf (LW)

w plf

Varies

TD1

A/R=3.73

w plf

Chord

Chord

Chord

Collector

Collector

Collector

F2C

V3B

F2B

V3A

SUM SHEARS

Collector

Collector

Collector

F2B

V3A

V3B

F2C

R1

Section A

Section A

Section B

Section B

A

B

C

D

4

1

2

3

w2 plf (LW)

w1 plf (WW)

150'→

Diaph. C.L.
Resulting Strut, Collector and Chord Force Diagrams if Strut
Example 4 - Intermediate notch at End Wall **Without Strut**

**SW 1**
- 6428 lb
- Open area
- 12'
- R1B = 8800 lb (V = 400 plf)
- 10'

**SW 2**
- 8571 lb
- 16'
- R1D = 6200 lb (V = 387.5 plf)

**SW 3**
- W = 200 plf
- 18'

**Basic Shear Diagram**
- Shear varies
- Diaphragm at grid line 2
- R = 15000 lb
- Forces in red are from previous example
Basic shear diagram

Transfer diaphragm and net diaphragm shears

Transfer diaphragm and net diaphragm shears

Transfer Forces to Collectors

Sign Convention

v = 210.7 - (123.7)

v = 157.1 - (123.7)

v = 210.7 + (255.24)

v = 157.1 + (255.24)

v = 210.7 - (117)

v = 157.19 - (117)

v = 210.7 + (123.7)

v = 157.1 + (123.7)

F_{2B} = 5684.4

F_{2C} = 5584

1855.8

1755.4

412.3

93.7

Transfer diaphragm shears

Transfer diaphragm and net diaphragm shears

v = 210.7 + (255.24) = +465.9 plf

v = 157.1 + (255.24) = +412.3 plf

Transfer diaphragm and net diaphragm shears

v = 210.7 - (117) = +93.7 plf

v = 210.7 - (123.7) = +87 plf

v = 157.1 - (123.7) = +33.4 plf

v = 157.19 - (117) = +40 plf

R_{1B}

R_{1D}

R_{1B}

R_{1D}
Longitudinal Chord Force Diagrams

- **SW 1**
  - Point 1: 400 lb, 340.5 ft, 87°
  - Point 2: 387.5 lb, 340.5 ft, 93.7°
- **SW 2**
  - Point 1: 400 lb, 310.5 ft, 40°
  - Point 2: 387.5 lb, 310.5 ft, 40°
- **SW 3**
  - Support at point D

**Notes:**
- Forces in pounds (lb)
- Distances in feet (ft)
- Angles in degrees (°)
 Traverse Strut/Collector Force Diagrams

Net shear diagram

\[ V_{sw} = 8800 \text{ lb} \]
\[ v_{sw} = 733.33 \text{ plf} \]
\[ v_{net} = 733.3 - 400 = 333.33 \text{ plf} \]

\[ V_{sw} = 6200 \text{ lb} \]
\[ v_{sw} = 387.5 \text{ plf} \]
\[ v_{net} = 0 \text{ plf} \]

\[ R_{1B} = 8800 \text{ lb} \]
\[ R_{1D} = 6200 \text{ lb} \]
Analysis Option 1-Analyze as Diaphragm with Intermediate Offset
Analysis Option 2 - Analyzing as separate diaphragms

Assumes small diaphragms are supported off of main diaphragm
Analysis Option 3 - Ignoring lower diaphragm sections
(Not recommended)

Values Options 1 and 2

A/R = 6:1 > 4:1, \( \therefore \) N.G.

F_{chord} = 18000 lb

Still must make a connection

Assumes main diaphragm takes all of the load.
Lower diaphragms are ignored.

12000 lb

W = 200 plf

Basic Shear Diagram

F = 16000 lb

Chord

\[ F_{chord} = 18000 \text{ lb} \]
Using partial sections ????
(Not recommended)

Aspect ratios all diaphragms 4:1 max.

No exterior Shear walls

Unshaded areas ride off of main designated diaph.'s

Cont. collector required (full depth of diaph.).

Transfer area

Diaphragm 1

Diaphragm 2

Diaphragm 3

1 2 3 4

Sw

Sw

Sw

Sw

Non-shear wall

Shear wall
Diaphragm Design

- Horizontal Offsets
- End offsets
- Large interior Openings
ASCE 7-10 Section 12.3.3.4 (SDC D-F) - Horizontal irregularity Type 3 requires a 25% increase in the diaphragm design forces determined from 12.10.1.1 (Fpx) for the following elements:

- Connections of diaphragm to vertical elements and collectors (diaphragm supporting elements).
- 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.

- Use of over-strength forces is not commonly considered to be triggered for boundary elements at diaphragm openings. However, the 25% increase does apply.

**Diaphragms With Large Interior Openings**

ASCE 7-10 Section 12.3.3.4 (SDC D-F) - Diaphragm Discontinuity Irregularity.

Diaphragm discontinuity irregularity exists where there is an abrupt discontinuity or variation in stiffness, including a cut-out or open area greater than 50% gross enclosed diaphragm area, or a change in effective diaphragm stiffness of more than 50% from one story to the next.
Common Openings In Diaphragms

- Roof pop-up section with opening below
- Skylight or atrium opening
- Clerestory windows
- End opening
- Stairwell access to roof
- Optional strut
Harrington Recovery Center
Structural engineer: Pujara Wirth Torke, Inc.
Photographer: Curtis Walz
IBC 2305.1.1
Openings in shear panels that materially effect their strength shall be fully detailed on the plans and shall have their edges adequately reinforced to transfer all shear stresses.

FPInnovations
Design example: Designing for openings in wood diaphragm

It is strongly recommended that analysis for a diaphragm with an opening should be carried out except where all four of the following items are satisfied:

a. Depth no greater than 15% of diaphragm depth;
b. Length no greater than 15% of diaphragm length;
c. Distance from diaphragm edge to the nearest opening edge is a minimum of 3 times the larger opening dimension;
d. The diaphragm portion between opening and diaphragm edge satisfies the maximum aspect ratio requirement. (all sides of the opening)

Most openings of any significant size should be checked.

Affect of Size and location in Diaphragm
Displacement and Local Forces

Vierendeel truss action

Some examples apply load to one side of the diaphragm only

Local forces

Chord forces are assumed to be zero at these locations due to contraflexure (inflection points). M=0

Vierendeel truss action
Shear Distribution in Diaphragm

Shear distribution follows analysis

Shear Distribution in Diaphragm
Easy to visualize if header section is replaced by a wire.

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).

Transfer diaphragms are required if the opening size affects the shear or tension capacity of the diaphragm.

All sections must meet Code required aspect ratios.
Typical method of analysis (APA Report 138), ATC-7, and FPInnovations

1. Calculate the chord forces at grid lines 2, 3, and 4 using FBD’s.
2. Determine the basic diaphragm shears without an opening.
3. Determine the diaphragm shears with an opening.
4. Break the sections above and below the opening into elements as shown.
5. Determine the local forces at each corner of each segment by FBD’s.
6. Determine the net resulting shears and forces (+/-) by combing the shears with and without an opening using a table.

Using the visual shear transfer method

1. Determine shear (V4) at grid line 4.
2. Break the sections above and below the opening into elements as shown.
3. Calculate the chord force at grid line 3.
4. Starting at grid line 4 and moving to the left, sum forces at each corner of each segment to determine the local forces, by FBD’s.
5. Calculate all chord, collector forces, and transfer diaphragm shears and forces using the visual shear transfer method.

Opening Analysis-Diekmann method
**Example 5 - Pop-up Roof Section**

A/R main diaphragm and upper section = 3.33:1
A/R TD1 = TD2 = 3.0:1  o.k.

Wind Loads (ASD)
- Main
  - W = 200 plf
- At opening
  - Ww = 123 plf
  - Lw = 77 plf
- At pop-up (20 psf)
  - Ww = 50 plf
  - Lw = 30 plf

FPInnovations:
- Hgt. > 0.15 \( d_{Diaph} \)
- Width > 0.15 \( L_{diaph} \)
- End dist. < 3x width
- Detailed analysis required

Basic Shear Diaphragm With Opening (plf)
The sum of the section shears must match the basic diaphragm shear values without an opening, $\Sigma V=0$.

Free-body of Chord Forces and Segment Forces
Transfer diaphragm shears

Net Shears - Left Transfer Diaphragm

Sign convention

Basic Shear Diagram

418.7 - 361 = +57.7
418.7 + 278.7 = +639.7
418.7 - 44 = +374.7

352 + 278.7 = +630.7
352 - 361 = -9
352 - 44 = +308

1600 lb
6453 lb
879.6 lb
7236.6 lb
12810 lb
784.6 lb
369.9 lb

W

A

B

C

D

T.D.1
Net Shears-Right Transfer Diaphragm

Sign convention

Transfer diaphragm shears

Basic Shear Diagram
Collector Force Diagrams - Left Side

Sign convention:

- Positive force (upward): +
- Negative force (downward): -

 Forces and Values:

- A: 57.7 lb to 697.3 lb
- B: 9 lb to 630.7 lb
- C: F = 12800 lb
- D: F = 9524 lb
- E: F = 6453 lb
- TD1: F = 1476 lb
- F: 697.3 lb to 308 lb
- T: 630.7 lb to 308 lb

Total Forces:

- 697.3 lb to 347.7 lb
- 630.7 lb to 308 lb

Note: The diagram shows the forces acting on the collector and their directions according to the sign convention.
Typical Review and Response

EOR Questions

- Traditionally residential (single-family and duplexes) have not been designed with strapping and transfer diaphragms.
- Are straps required at stair openings or offsets in the exterior walls?
- What is a justified approach to these diaphragms based on contractor expectations and time allotted in our engineering fee to analyze?
- Would you provide blocking with a tension strap at the locations that I have shown in red on a plan like this? If yes:
  - Do you calculate your transfer diaphragms?
  - Do you provide a nominal length of strapping and blocking or know intuitively it will work based on your experience? Or,
  - Do you simply provide a standard distance of strapping but don’t attempt to calculate?
- Are you ever okay with not providing the straps and blocking in projects like this?
- Do you like flat 2x blocking or full depth joist blocking?

• The justification in this case, IRC R301.2.2.2.5(4) opening > 12’ Seismic irregularity SDC C, Ds, D would require an engineered design, but not for wind.
Hint

(Can’t get directly involved with calculations)
Shear Walls
Shear Wall Design

- Shear Wall Types
  - Shear wall Anchorage
  - SDPWS Code Requirements
  - Complete Load Paths
  - ASCE 7 Offset Shear Wall Requirements
  - Offset 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

2x blocking as required at joints.

Anchor bolts or nailing Hold down anchor

Chord or Strut

Diaphragm shear $V_v = \sum M = 0$

Wall DL

Wall chords

Sheathing joint as occurs

Segmented Shear Walls

$V_v = \sum M = 0$
## Allowable Aspect Ratios & Adjustment Factors

AWC SDPWS Table 4.3.4-Maximum shear wall dimension ratios-Wind and seismic

<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) = 1.25-0.125h/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

$$\Delta_{SW} = \frac{8vh^3}{EAb} + \frac{vh}{G_v t_v} + 0.75 h e_n + \frac{h \Delta_a}{b}$$  C4.3.2-1

- Bending
- 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

Displacement, inches
Intermediate uplift anchorage is required at each full height panel locations... *in addition to...* per section 4.3.6.4.2.1.

Header sections do not have to comply with aspect ratios.

Hold downs at Ends per section 4.3.6.4.2

Top and bottom of wall cannot be Stepped or sloped

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

Reference examples
- APA Diaph-and-SW Construction Guide
- AWC-Perforated Shear Wall Design

All full hgt. sections must meet the aspect ratio requirements of section 4.3.4.1.
Allowable Perforated Shear Wall Aspect Ratios

- Sections exceeding 3.5:1 aspect ratio shall not be considered a part of the wall.
- \( V_n \leq 1740 \text{ plf seismic-WSP 1 side} \)
- \( V_n \leq 2435 \text{ plf wind-WSP 1 side} \)
- \( V_n \leq 2435 \text{ plf wind-WSP 2 sides} \)
- 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.

$$V_{allow} = (V_{tabular}) \times (C_0) \times \sum L_i$$

Where:

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

$C_0$ = Sheathing

$A_0$ = 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

$$v_{max} = T_{int} = \frac{V}{C_0 \Sigma L_i}$$

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 $^1$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>h/3</td>
</tr>
<tr>
<td>8’ Wall</td>
<td>2’-8”</td>
</tr>
<tr>
<td>10’ Wall</td>
<td>3’-4”</td>
</tr>
<tr>
<td>Percent Full-Height Sheathing $^2$</td>
<td>Effective Shear Capacity Ratio</td>
</tr>
<tr>
<td>10%</td>
<td>1.00</td>
</tr>
<tr>
<td>20%</td>
<td>1.00</td>
</tr>
<tr>
<td>30%</td>
<td>1.00</td>
</tr>
<tr>
<td>40%</td>
<td>1.00</td>
</tr>
<tr>
<td>50%</td>
<td>1.00</td>
</tr>
<tr>
<td>60%</td>
<td>1.00</td>
</tr>
<tr>
<td>70%</td>
<td>1.00</td>
</tr>
<tr>
<td>80%</td>
<td>1.00</td>
</tr>
<tr>
<td>90%</td>
<td>1.00</td>
</tr>
<tr>
<td>100%</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的概念 frame and/or below an opening remain unframed, the height of each opening shall be defined as the clear height of the opening plus the unframed 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.
4.3.2.1 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 $\sum L_i$. 

$$\Delta_{SW} = \frac{8v_{\text{max}}h^3}{EAD} + \frac{v_{\text{max}}h}{1000G_a} + h\frac{\Delta_a}{b}$$  \hspace{1cm} 4.3-1

---

**Apparent shear stiffness**
- Nail slip
- Panel shear deformation

**Vertical elongation**
- Strap nail slip
- Device elongation
- Rod elongation

**Open’g**

**Wall segment**

**Max. opening height**

**Hdr**

**L_i** (typ)
FTAQ Shear Walls (See recent Testing-APA Form M410 and T555)

(TDiekmann)-Vierendeel Truss/Frame

Shear panels or blocking

4500 lb

(Typical boundary Member)

w=200 plf

Many examples ignore gravity loads

Cont. Rim joist

Anchor bolts or nails

2' min. per SDPWS

Section 4.3.5.2 (2008 requirement)

Typical boundary member

Tie straps as required to develop the corner forces into the wall

https://www2.strongtie.com/webapps/sitebuiltshearwalldesigner/
https://www.apawood.org/ftao
Allowable Shear Wall Aspect Ratios For FTAO Shear Walls

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.

Note: Not shown as having to comply w/ A/R

ATC 7, Diekmann, FPIInnovations
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.

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

Force Transfer Methodology (Diekmann)-Vierendeel Truss/Frame
Free-body of Upper Half and Upper Left Section
Shears and forces determined in previous step.

Units are in lb

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

4500 lbs.

A/R

Lap as required

Transfer diaphragm sections

w=200 plf

Support

2.67'

2.67'

3'

6'

14.5'

2.67'

5.5'

9'

3'

4'

2'

B

C

D

A

T.D.1

T.D.2

A/R

A/R

A/R

A/R
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
Transfer diaphragm shears

Sign convention

Basic Shear Diagram From Gravity Loads

4243.1 lbs.

4243.1 lbs.

Pos.

Neg.

Support

Support

A

B

C

D

F

F

1975.8

w=200 plf

1937.1

3676.6

1591.4

1551.7

3.6

2.83'

2.67'

T.D.2

Neg.
Transfer Diaphragm Shears and Net Shears
Horizontal Collector Forces

\[ F = 1975.8 \text{ lbs.} \]

\[ F = 1937.1 \text{ lbs.} \]

\[ F = 3676.6 \text{ lbs.} \]

4243.1 lbs.
**Vertical Collector Forces**

- **F=0 lbs.** at points 3 and 4.
- **F=1103.5 lbs.**
- **F=2774.4 lbs.**
- **F=210.54 lbs.**
- **F=2270.3 lbs.**
- **F=4243.1 lbs.**

**Sign convention**

- Positive force is upward.
- Negative force is downward.

**Key points**

- **3**
- **4**
- **A**
- **B**
- **C**
- **D**

**Dimensions**

- **2.67'**
Advancements in FTAO Shear Wall Analysis

(See recent Testing-APA Form M410)

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
Multi-story walls?  
Tall shear walls? 

What happens when different depths?
• 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

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

Reference APA T555
Let’s Take a 10 Minute Break
Combined Shear and Uplift Shear Walls-WSP-APA SR-101C

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
  
  \[ V_{ASD} = \frac{V_n}{2}, \quad V_{str} = 0.65V_n \]
Angled/Skewed Shear Walls

No Angled/Skewed Shear Wall Testing

Shear walls are parallel to applied loads

Diaphragm support
Stable
Diaphragm support

Acts like open front diaphragm (SDPWS 4.2.5.2)

Shear walls are parallel to applied loads

Diaphragm support
Unstable
Diaphragm support

Not all shear walls are parallel to applied loads
Structure is stable

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

Wall stiffness (SW1 & longit. walls)

Concentric steel braced frame or shear walls both sides of the building-resist rotational forces.

Diaphragm rotates

Wall warps and translates

Top of wall braces

Large deflection

C.L. SW support

Diaphragm with Angle Shear Wall-Horizontal

Type 5 Irregularity Transverse Loading

Structure is stable
Circular Shear Walls

No Circular Shear Wall Testing

WSP thickness depends on radius

Diaphragm support

Effective width

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 under monotonic loading.
- Mid-ply walls 1.8 to 2.2 x stiffer than standard shear walls under cyclic loading.
- Better energy dissipaters, 3 to 5x better than standard shear walls.
Typical Mid-Ply Shear Walls

Fasteners are in double shear

WSP

WSP

WSP

16” o.c. typ.

GWB

WSP

GWB

w / GWB

3 Layer WSP

1 Layer WSP

ATS system

w / GWB
Prescriptive / Proprietary Portal Frames

IBC 2308.9.3.2
Prescriptive Code Portal Frames

Proprietary Portal Frames

Figure 2308.9.3.2 Alternate Braced Wall Panel Adjacent to a Door or Window Opening

Truss Frames

Source: strongtie.com

Truss Walls

Hybrid Wood/Steel Proprietary Systems
Shear Wall Design

- Shear Wall Types
- Shear wall Anchorage
- SDPWS Code Requirements
- Complete Load Paths
- ASCE 7 Offset Shear Wall Requirements
- Offset Shear Walls
Hold Down Anchors Systems

Standard Hold Down (Bucket Style)

Strap Hold Down

Continuous Rod
Automatic Tensioning System
ATS
Bucket Style Hold Downs

Minimum wood member thickness

Number of studs as required by design.

Raise 3” for every ¼” offset from H.D. centerline (Manufacturers instructions) for misplaced anchors

Approved coupler

Self positioning hold down. Install per manufacturer’s instruction

Install anchor per manufacturer’s instruction

Top of brg. plate

Bolts, nails or screws per manufacturer

C.L.

18” max.

1 1/2” max.

Preservative treated barrier may be required

3” to 5”

Opt. supplied manufacturers anchor

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

Source: DartDesignInc.com

Source: strongtie.com
Field Installation Issues

Hold downs installed at an angle

Large knots

Courtesy of Willdan Engineering
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.

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

½” min. at foundation corner

Possible foundation corner location
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
Tied off at each floor

Tied off at roof only

Skipped floor

Legend

xx kips         Tied off at each floor

(27 kips)     Tied off at roof only

Tied off at roof and all floors

• Accommodates shrinkage at each floor
• Greater redundancy
• Reduced drift
• Lower costs (Can be subjective)

Lack of redundancy
• Increased costs
• Increased drift
• Single device must accommodate shrinkage at all floors
Shear Wall Design

- Shear Wall Types
- Shear wall Anchorage
- **SDPWS Code Requirements**
- Complete Load Paths
- ASCE 7 Offset Shear Wall Requirements
- Offset Shear Walls
Allowable values shown in tables are nominal shear values

**Design values:**
- LRFD (Strength) = 0.8 x Vn
- ASD = Vn/2
# 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>Panel Edge Fastener Spacing (in.)</th>
<th>Panel Edge Fastener Spacing (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Based Panels</td>
<td>5/16</td>
<td>1-1/4</td>
<td>Nail (common or Galvanized box) 6d</td>
<td>OSB PLY</td>
<td>OSB PLY</td>
</tr>
<tr>
<td></td>
<td>3/8</td>
<td>1-3/8</td>
<td>8d</td>
<td>460 19 14 17</td>
<td>920 30 20 19</td>
</tr>
<tr>
<td></td>
<td>7/16</td>
<td></td>
<td></td>
<td>720 24 17</td>
<td>1220 43 24</td>
</tr>
<tr>
<td></td>
<td>15/32</td>
<td></td>
<td></td>
<td>510 16 13</td>
<td>1340 40 24</td>
</tr>
<tr>
<td></td>
<td>15/32</td>
<td>1-1/2</td>
<td>10d</td>
<td>560 14 11</td>
<td>1460 37 23</td>
</tr>
<tr>
<td></td>
<td>15/32</td>
<td></td>
<td></td>
<td>680 22 16</td>
<td>1740 51 28</td>
</tr>
</tbody>
</table>

### Use Table 4.3B for WSP over ½” 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>

$v_{ub} = v_b \cdot C_{ub}$ \hspace{1cm} 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**

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

\[ V_{\text{allow}} = 2x \]

\[ V_{\text{S1}} \quad V_{\text{S2}} \quad V_{\text{sc or Vwc}} \]

**Dissimilar materials**

\[ V_{\text{allow}} = 2 \times \text{smaller or largest, greater of.} \]

(Except for wind, add capacities)

\[ V_{\text{S1}} \quad V_{\text{S2}} \quad V_{\text{sc or Vwc}} \]

**Dissimilar materials (Not cumulative)**

\[ V_{\text{S1}} \quad V_{\text{S2}} \quad V_{\text{sc or Vwc}} \]

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:

\[ v_{SC} = K_{\text{min}} G_{ac} \quad \text{Combined apparent shear wall shear capacity (seismic)} \]

\[ G_{ac} = G_{a1} + G_{a2} \]

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

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)

\[ V_{sc} = \text{combined nominal unit shear capacity seismic} \]

\[ V_{wc} = \text{combined nominal unit shear capacity wind} \]

\[ v_{S1} = \text{Nominal unit shear capacity of side 1 (} v_{S2} \text{ side 2)} \]
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

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.

\[ \Delta_{wall} \]

Equal wall deflection

Summing is allowed

Same materials in same wall line

Section 4.3.3.4 does not apply

Dissimilar materials in same wall line
Distribution of lateral forces to In-line Shear Walls

Method 1 - Simplified Approach

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

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

\[ v_{SW1} = \frac{\Delta_{SW2}}{8h^3} + \frac{h}{EAb_{SW1}} + \frac{h^2}{1000G_a + kb_{SW1}} \]

• Sum design strengths = vsw1 x b1 + vsw2 x b2 for line strength
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.
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.
Shear Wall Design

- Shear Wall Types
- Shear wall Anchorage
- SDPWS Code Requirements
- Complete Load Paths
- ASCE 7 Offset Shear Wall Requirements
- Offset Shear Walls
Detailing for Continuous Load Paths

Continuous Stacked In-line Load Paths

Simple Load Paths

Photo: Terry Malone
Detailing for Continuous Load Paths

Complicated Load Paths

Discontinuous Load Paths

Photo: Terry Malone
Architect: Holst Architecture
Structural: Froelich Engineers

Karuna at One North, Portland, Oregon

Photo: Andrew Pogue
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

Section A

Section B

Section C

Hold Down (option 1)

No irreg.

Hold down (Typical)

Anchor bolts or nails

Anchor bolts or nails

Nail shtg to each 2x stud

Header/collector

Tie strap

Header/collector

Tie strap

Type 4 vert. irreg. SDC B-F

Shear transfer Conn.

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 (option 2)

Section A
Type 4 vert. irreg. SDC B-F

Section B
Type 4 vert. irreg. SDC B-F

Section C

Header/collector

Shear transfer Conn.

Collector

Hold down (Typical)

Nail shtg to each 2x stud

Alt. Config.

Hold down (Option 2 -only)

Tie strap

Anchor bolts or nails

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

- Floor or roof sheathing
- Blocking or continuous rim joist
- Continuous rim joist, beam or special truss can be used as strut / collector or chord.
- Double top plate can be used as strut / collector or chord.
- Splice at all joints in boundary element

Possible perforated or FTAO shear wall

Direction of Load

Segmented shear wall
Examples of Drag Struts, Collectors and chords at Exterior Boundaries
Diaphragm sh'tg. elevation

Parapet (typ.)

Transfer area

Vert. Step in diaph.

Diaphragm sh’tg. elevation

Chord, force

T

T

Soil pressure

Chord force

Fo/t

Fo/t

Foundation

Complete Load Path to Foundation

Roof at Different Elevations-Chord Forces

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

Cross grain bending at gang-nail plate
Assumed bearing of block against truss chord

NEW: See 2015 IBC Figures 2308.6.7.2(1) and 2308.6.7.2(2) for possible solutions
**Venting Options**

- **A** Typical Solid Blocking
  - Boundary nailing
  - Baffle as required
  - 2x blocking w/ vent holes
  - Insulation

- **B** Typical shear panel
  - Boundary nailing
  - Outriggers per manuf. instructions
  - Baffle
  - 2x vertical nailer E.S.
  - Screened vent holes
  - 2x rafter
  - 2x framing all 4 sides
  - Insulation
  - Truss
Tie strap force (sum areas of shears)

**Strut/collector Force Diagram**

- Compression
- Tension

**Option 1**
- Bolted angles
- Tube or pipe (optional sleeve)
- Edge nailing each stud
- Tie-strap as required (Alt.-Simpson CTS218)

**Option 2**
- Proprietary connections

Wall required to be braced out-of-plane continuously by floor framing or cross-blocking (full length)

Net shear at wall (shear wall shear minus diaphragm shear)

Steel Column Close to Wall Width

Figure 1
Plumbing Pipe Close to Wall Width

Wall required to be braced out-of-plane continuously by floor framing or cross-blocking (full length)

Shear wall

Simpson CTS218

PVC plumbing pipe

Clr. = SW deflection plus 1/4” +/- (both sides)

Edge nailing each stud

Strut/SW connection across top or side of wall

Figure 2
Discontinuous Shear Wall Top Plate

Figure 3

Wall required to be braced out-of-plane continuously by floor framing or cross-blocking (full length)

Edge nailing each stud

Stitch-nail studs together = O/T

Full bearing

Tie strap on top or side

Stitch-nail studs together

Full bearing

Tie strap on top or side

Party/ Plumbing wall

Discontinuous Shear Wall Top Plate

Plumbing at Party Wall
Shear Wall Design

- Shear Wall Types
- Shear wall Anchorage
- SDPWS Code Requirements
- Complete Load Paths
- ASCE 7 Offset Shear Wall Requirements
- Offset Shear Walls
ASCE 7 Offset Shear Wall Wall Requirements

Out-of-plane Offsets

In-plane Offsets
Potential buckling problem w/ supporting columns and beams

ASCE 7 Table 12.3-2
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

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

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

Diaphragm

Shear wall is not continuous to foundation. Type 4 horizontal and vertical irregularity

Strut

Chord

Collector

SW above or No SW

Cantilever?
ASCE 7-10 Section 12.3.3.3 (SDC B-F)
Elements supporting discont. Walls or frames:

Applies to:
• 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
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 (Fpx) 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.

- Diaphragm shears are not required to be increased 25%.
- The transfer force (SW3) in SDC D-F must be increased by rho, per 12.10.1.1.

See 12.10.2 & 12.10.2.1 for collectors.

Type 4 Horizontal Irregularity - Seismic
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.

Blocking or shear panels

Continuous member

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

(Interior collector similar)
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.

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

(Interior collector similar)
Column elements are designed for standard load combinations 2.3 or 2.4.
Connections are designed for standard load combinations 2.3 or 2.4.

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)

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.

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

See struts and collectors

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.

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

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
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 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:

\[ \Omega_o F_x \] - 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 (Fpx), Eq. 12.10-1 or

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

\[ F_{px \ max} = 0.4 S_{DS} I_e w_{px} \] - Upper bound seismic diaphragm design forces determined by Eq. 12.10-2 (F_{px \ 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}).
Shear Wall Design

- Shear Wall Types
- Shear wall Anchorage
- SDPWS Code Requirements
- Complete Load Paths
- ASCE 7 Offset Shear Wall Requirements
- Offset Shear Walls
Out-of-Plane Offset Shear Walls

- 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
Diaphragm with Horizontal End Offset
Longitudinal Loading—Out-of-plane offset Shear Walls

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

Vsw2 = \( \frac{wL}{2} = \frac{200(50)}{2} = 5000 \text{ lb} \), \( vsw2 = \frac{5000}{10} = 500 \text{ plf} \)

Vsw1, sw3, sw4 = \( \frac{wL}{2} = \frac{200(50)}{2} = 5000 \text{ lb} \), \( vsw = \frac{5000}{(8+8+15)} = 161.3 \text{ plf} \)

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]
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.
Layout 1 - Full length walls aligned

\[ W = 200 \text{ plf} \]

\[ R_L = R_R = 200 \left( \frac{78}{2} \right) = 7800 \# \]
\[ v_R = \frac{7800}{50} = 156 \text{ plf} \]

\[ v_{SW1} = 454.55 \text{ plf} \]
\[ v_{Net} = 54.55 \text{ plf} \]

\[ R_L = R_R = 200 \left( \frac{122}{2} \right) = 12200 \# \]
\[ v_R = \frac{12200}{50} = 244 \text{ plf} \]

\[ \text{Sum} = 20000 \# \]

\[ \text{Sum} = 40000 \# = 200 \text{ plf}(200') \]
Layout 2 - Full length offset walls

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

Transfer Area
- Transfer Area

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

SW1
- SW2
- SW3
- SW4

Sum = 7976 #

Sum = 20048 #

Sum = 11976 #

Sum = 40000 #

= 200 plf (200')
Total load to grid lines 2 & 3

\[ R_{23} = 4368 + 3608 + 5368 + 6608 + 2(48) = 20048 \text{ # O.K.} \]

\[ L_{SW} = 22 + 22 = 44' \]

\[ V_{SW} = 20048 \text{ #} \]

\[ v_{SW} = \frac{20048}{44} = 455.64 \text{ plf} \]

\[ v_{net\,SW1} = 455.64 - 156 - 244 = 55.64 \text{ plf} \]

\[ v_{net\,SW2} = 455.64 - 164 - 236 = 55.64 \text{ plf} \]

Checks, they should be equal

SW1

\[ F_{2AB} = 55.64(22) = 1224 \text{ #} \]

\[ F_{2BC} = (156+8)(6) = 984 \text{ #} \]

\[ F_{2C} = 1224 - 984 = 240 \text{ #} \]

O.K.

SW2

\[ F_{3CD} = 55.64(22) = 1224 \text{ #} \]

\[ F_{3CB} = (236+8)(6) = 1464 \text{ #} \]

\[ F_{3B} = 1224 - 1464 = -240 \text{ #} \]

\[ F_{B23} = F_{C23} = 240(4)/6 = 160 \text{ #} \]

Shear at transfer area = 240/6 + 8 = 48 plf
Layout 3 - Full length plus partial length offset shear walls
Total load to grid lines 2 & 3

R_{23} = 4368 + 3608 + 5368 + 6608 + 2(48) = 20048 \# \; \text{O.K.}

L_{SW} = 22 + 12 = 34'

V_{SW} = 20048 \#

v_{SW} = 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 \#

F_{2BC} = (156 + 8)6 = 984 \#

F_{2C} = 4172.24 - 984 = 3188.24 \#

SW2

F_{SW2} = 189.65(12) = 2275.76 \#

F_{SW2\; to\; 3B} = (236 + 8)6 + (236 + 164)10 = 5464 \#

F_{3B} = 2275.76 - 5464 = -3188.24 \#

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

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

All forces in lb., all shears in plf

Sum = 20048 \#
Layout 4 - Partial length offset shear walls

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

Transfer Area

\[ R_L = R_R = 112 \frac{(78/2)}{2} = 4368 \, \text{plf} \]
\[ V_L = V_R = 4368/28 = 156 \, \text{plf} \]

\[ R_L = R_R = 88(122/2) = 5368 \, \text{plf} \]
\[ V_L = V_R = 5368/28 = 244 \, \text{plf} \]

\[ R_L = R_R = 88(82/2) = 3608 \, \text{plf} \]
\[ V_L = V_R = 3608/22 = 164 \, \text{plf} \]

\[ R_L = R_R = 112(118/2) = 6608 \, \text{plf} \]
\[ V_L = V_R = 6608/28 = 236 \, \text{plf} \]

\[ R_L = R_R = 24(4/2) = 48 \, \text{plf} \]
\[ V_L = V_R = 48/6 = 8 \, \text{plf} \]
Total load to grid lines 2 & 3

R23=4368+3608+48+5368+6608+48=20048 #  O.K.

LSW=12+10=22'
VSW=20048 #
vSW=20048/22=911.27 plf

vnet SW1=911.27-156-244=511.27 plf
vnet SW2=911.27-164-236=511.27 plf  Checks, they should be equal

SW1
FSW1=511.27(10)=5112.7 #
FSW1 to 2B=(156+244)12=4800 #
F2BC=(156+8)6=984 #
F2C=5112.7-4800-984=-671.3 #

SW2
FSW2=511.27(12)=6135.24 #
FSW2 to 3B=(236+8)6+(236+164)10=5464 #
F3B=6135.24-5464=671.24 #

FB23=FC23=671.3(4)/6=120 #

Shear at transfer area=671.3/6+8=119.9 plf
Layout 2 - Full length offset walls Double walls

24000 3rd floor - roof forces

W = 200 plf

Diaphragm 1

R_L = R_R = 106.98(26/2) = 1390.7 #

V_R = 1390.7/46 = 30.23 plf

Diaphragm 2

R_L = R_R = 93(34/2) = 1395 #

V_R = 1395/40 = 34.88 plf

Transfer Area

R_L = R_R = 14(4/2) = 28 #

V_R = 28/6 = 4.67 plf

2nd floor diaphragm loads

Sum = 2785.7 #

Sum = 30027.4 #

Sum = 3185.7 #
Total load to grid lines 2 & 3

24000 3rd-Roof
V=2400/80=300 plf

\[ \Sigma V = 1390.7 + 1581 + 1395 + 1604.7 + 4(14) + 24000 = 30027.4 \] #
Lsw = 2(40+40) = 160', sheathing 1 side only
Vsw = 30027.4 #
\[ v_{SW} = \frac{30027.4}{160} = 187.67 \text{ plf per wall} \]

V_net SW1 = 2(187.67) - 300 - 30.23 - 39.53 = 5.58 plf

V_net SW2 = 2(187.67) - 300 - 34.88 - 34.88 = 5.58 plf

Checks, they should be equal

Shear at transfer area = 14(2)/6 = 4.66 plf

SW1
F2AB = 5.58(40) = 223.2 #
F2BC = (30.23 + 4.66)6 = 209.4 #
F2C = 223.4 - 209.4 = 14 #

SW2
F3CD = 5.58(40) = 223.4 #
F3CB = (34.88 + 4.66)6 = 237.2 #
F3B = 223.4 - 237.2 = -13.84 say -14 #

FB23 = FC23 = 14(4)/6 = 9.3 # insignificant

Almost negligible. No need to calculate.
Reason forces are small, short width of unit to unit.
Are you there yet?

Information Overload

Deer in Headlight
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
Diaphragm and Shear Wall Flexibility Issues
Reference Materials

- 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

FTAO Shear Walls

Mid-rise Design Considerations

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

This concludes Our Workshop Presentation on Advanced Diaphragm Analysis

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

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