Diaphragm and Shear Wall Design

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Portions Based On:

The Analysis of Irregular Shaped Structures
Diaphragms and Shear Walls

By: R. Terry Malone and Robert W. Rice
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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
Presentation Assumptions

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.
Discontinuous chords
Transverse
Cant.
Mid-rise Multi-family
Lds. Discontinuous struts Longitudinal
Lds. Longitudinal
Discontinuous chords Transverse
No exterior Shear walls
Flexible, semi-rigid, or rigid???
Vertically offset Diaphragms?

Openings in diaphragm

Offsets in the diaphragm and walls

Harrington Recovery Center
Structural engineer: Pujara Wirth Torke, Inc.
Photographer: Curtis Walz
Basic Information

- Boundary Elements
- Complete Load Paths
- Method of Analysis
Strut - receives shears from one side only*.
Collector - receives shears from both sides.

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

![Diagram of diaphragm boundary elements with labeled components: Chord, Strut, Collector, Diaphragm 1 Boundary (typical), Diaphragm 2 Boundary (typical), SW1, SW2, SW3. Note: Interior shear walls require a full depth collector unless a complete alternate load path is 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

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.

Boundary Elements “L” Shaped Buildings-Transverse Loading
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
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).
• 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.)

What does this mean?

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)

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 8:1
4:1 maximum allowed

TD Aspect Ratio Too High

Warping/racking

Over-stressed.
(Notice deformation in transfer diaphragm)
• 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

Typical Section

2x flat blk’g (tight fit)  Tie strap  Potential gaps
WSP sht’g.  Bearing perp. to grain?

Use Z clip to keep blocking level

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

Collector Compression force distribution

Diaphragm unit shear (plf) transfers into blocking

Cont. tie strap over

F(total)=∑F1+F2+F3+F4

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

F1  F2  F3  F4
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

NOTE:
Collector must extend the full depth of the transfer diaphragm
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
Method of Analysis - Method by Edward F. Diekmann

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

V_{net} = +300 - (75) = +225 \, \text{plf}

V_{net} = +225 - (75) = +150 \, \text{plf}

Net shear at the transfer diaphragm:

V_{net} = +300 + (250) = +550 \, \text{plf}

V_{net} = +225 + (250) = +475 \, \text{plf}

Chord force at discontinuity

Analagous to a beam with a concentrated load.

Main chord

Disrupted chord

Collector

Chord

TD1

TD depth

Transfer diaphragm length

Basic Shear Diagram at transfer diaphragm

Subtract from basic shears

Add to basic diaphragm shears

Transfer Diaphragm Shears

Analogous to a beam with a concentrated Load.
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).

Shear left = +550 - 225 = +325 plf
Shear right = +475 - 150 = +325 plf

Collector force = area of shear diagram

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

- Horizontal Offsets
- End offsets
- Large interior Openings
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.

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

**Calcs**

**Sign Convention**

- Support R = 12500 lb
- Support RR = 12500 lb
- Discontinuous diaphragm chord
- A/R = 2.5:1
- F2B = 7142.9 lb
- M2B ft.-lb
- 12500 lb
- F2B
- ∑ M = 0
- ∑ M = 0
- Free body for F2B
- A/R = 2.5:1
- SW 1
- SW 2
- 200 plf
- 15'
- 35'
- 50'
- 7500 lb
- 3500 lb
- 25'
Transfer Diaphragm and Net Diaphragm Shear

Basic shear diagram

$$v = 150 - (107.1) = +42.9 \text{ plf}$$ (Net resulting shear)

$$v = 70 - (107.1) = -37.1 \text{ plf}$$ (Net resulting shear)

TD shear diagram

$$v = \frac{7142.9(15)}{50(20)} = -107.1 \text{ plf}$$

$$v = \frac{7142.9(35)}{50(20)} = +250 \text{ plf}$$

Net resulting shear

12500 lb

$$v = 150 + (250) = +400 \text{ plf}$$

(Net resulting shear)

Can be > 3x basic shear

Legend

375 plf Basic diaphragm shear

(240 plf) Transfer diaphragm shears

=xxx plf Net shears (basic shear +/- TD shears)
Longitudinal Chord Force Diagrams

Calcs

Sign Convention

Support

F = 7200 lb

SW 1

F = 7142.9 lb

Diaph. C.L.

Support

F = 7142.9 lb

F = 7200 lb

F = 7812.5 lb

F = 7812.5 lb

+42.9

-37.1

+357.1 plf net

0 plf

70 plf

250

357

214

42.9

42.9

37.1

37.1

+70

-250

15'

25'

20'

17.5'

357.1 plf

400

320

230 lb

-172.1 lb

10.72'

9.27'

+230 lb

102.9

-37.1

7142.9 lb

Support
Transverse Collector Force Diagrams

F = 6000 lb
(this is not an insignificant force.)

F = 3748.5 lb

F = 3750 lb

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

Diaph. C.L.

Sign Convention

Calcs
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:

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

where
\[ \Delta_B = \int_a^b \frac{mM}{EI_1} \, dx + \int_b^c \frac{mM}{EI_2} \, dx, \text{ and} \]
\[ \Delta_S = \frac{bt}{2GA^2} \left[ \int_a^b \frac{wx}{(b')^2} \, dx + \int_b^c wXdx \right] = \int_0^L \frac{\nu V}{\dot{g}t} \, dx \]

All terms relate to simple span uniformly loaded

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

Cannot use
IBC Eq. 23 – 1
APA equation

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 x 2.5 for unblocked diaphragm
Multiply nail slip by 1.2 if not Structural I plywood
Check the shear capacity of the nailing along the collector

1. 10d @ 4/6/12 B
2. 10d @ 6/6/12 B
3. 10d @ 6/12 UB

**Special nailing along collectors**

Sum of shears to collector or highest boundary nailing - greater of

- Basic shear diagram
- 150 plf
- 214.3 plf
- 357.1 plf
- 70 plf

**Transfer area Boundary (High shear area)**

**Boundary locations**

Diaphragm Nailing Callouts
Example 2-Diaphragm with Horizontal End Offset - Longitudinal Loading
Transfer Diaphragm and Net Diaphragm Shear
Longitudinal and Transverse Collector/Strut Force Diagrams

CHECK: Fstrut  Fchord
Let’s Take a Break
Diaphragm Design

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

- **Section A**: 12' (TD1 A/R=3.73)
- **Section B**: 16'
- **Strut**: Skylight (Enclosed area)
- **Chord**: Uniform shear in walls and in diaph. at grid line 1
- **Diaph. C.L.**: Varies
- **Basic Shear Diagram**: 150'
Resulting Strut, Collector and Chord Force Diagrams if Strut
Example 4 - Intermediate notch at End Wall Without Strut

- SW 1: 6428 lb if strut (-38%)
- SW 2: 8571 lb if strut (+38%)

 Forces in red are from previous example
Transfer diaphragm and net diaphragm shears

1. Basic shear diagram

2. Transfer diaphragm and net diaphragm shears

3. Transfer Forces to Collectors

- **Sign Convention**

- **Sw 1**
  - \( v = 210.7 - (123.7) = +87 \text{ plf} \)
  - \( v = 157.1 - (123.7) = +33.4 \text{ plf} \)

- **Sw 2**
  - \( v = 210.7 + (255.24) = +465.9 \text{ plf} \)
  - \( v = 157.1 + (255.24) = +412.3 \text{ plf} \)

- **Transfer diaphragm and net shears**
  - \( F_{2B} = 5684.4 \)
  - \( F_{2C} = 5584 \)

- **R1B**
  - \( 1855.8 \)
  - \( 1755.4 \)

- **R1D**
  - \( +310.5 \text{ plf} \)

- **R**
  - \( +310.5 \text{ plf} \)
  - \( +157.1 \text{ plf} \)

- **40**
  - \( 93.7 \text{ plf} \)

- **412.3**
  - \( 465.9 \text{ plf} \)

- **255.2**
  - \( 23 \text{ plf} \)

- **33.4**
  - \( 40 \text{ plf} \)

- **Neg.**

- **Pos.**
Longitudinal Chord Force Diagrams

F = 5584 lb

F = 5684 lb

F = 5584 lb

Support

A

B

C

D

R1B

R1D
Traverse Strut/Collector Force Diagrams

SW 1

Vsw=8800 lb
vsw=733.33 plf
vnet=733.3-400=333.33 plf

F=4000

F=4917

F=2271.4

F=1872.2

R₁B=8800

R₁D=6200 lb

SW 2

Vsw=6200 lb
vsw=387.5 plf
vnet=0 plf

F=3469.2

R₁B=6200 lb

Vsw=387.5 plf

SW 3

Net shear diagram
Diaphragm Design

- Horizontal Offsets
- End offsets
- Large interior Openings
Diaphragms With Large Interior Openings

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.

**Type 3 Horizontal Irregularity - SDC D-F** - Diaphragm Discontinuity Irregularity.

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.

Diaphragm shears are not required to be increased 25%.
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
Openings in diaphragm

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.

Location and Magnitude of Shear

Local shears higher

Local shears lower

Basic Shear Diagram

Stairwells
Elevators

Location and Magnitude of Shear

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

Some examples apply load to one side of the diaphragm only.

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

Vierendeel truss action
Shear distribution follows analysis

Shear Distribution in Diaphragm
All sections must meet Code required aspect ratios.

**Aspect Ratio Issues**

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

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).

Easy to visualize if header section is replaced by a wire.
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 Diaph.

Width > 0.15 Ldiaph.

End dist. < 3x width

Detailed analysis required

---

**Diagram Details:**

- Wind Loads Calculation:
  - V = 25120
  - V = 21120
  - V = 19520
  - V = 13920
  - V = 8320
  - V = 6720
  - V = 2720

- Shear Forces:
  - F3A
  - F3D

- Sub-Chord Forces:
  - W = 50 plf

- Diaphragm Forces:
  - W = 200 plf
  - W = 123 plf
  - W = 50 plf

- Diaphragm C.L.

- Detailed analysis required for the design conditions specified.
Free-body of Chord Forces and Segment Forces

The sum of the section shears must match the basic diaphragm shear Values without an opening, $\Sigma V=0$.

$\Sigma V_1 = 10104 + 9416 + 1600 = 21120$ Lb

$\Sigma V_2 = 123 + 20340 + 10104 = 21367$ Lb

$\Sigma V_3 = 5956 + 5956 = 11912$ Lb

$\Sigma V_4 = 5824 + 2496 = 8320$ Lb

$\Sigma V_5 = 7964 + 1600 = 9564$ Lb
Net Shears - Left Transfer Diaphragm

Basic Shear Diagram

T.D.1

418.7 - 361 = +57.7

418.7 + 278.7 = +639.7

418.7 - 44 = +374.7

352 - 361 = -9

352 + 278.7 = +630.7

352 - 44 = +308

6453 lb

7236.6 lb

12810 lb

879.6 lb

Transfer diaphragm shears

Sign convention

Neg.

Pos.

Neg.
**Sign convention**

- **Net Shears-Right Transfer Diaphragm**

Net Shears:
- Right Transfer Diaphragm

**Basic Shear Diagram**

- TD2

Net Shears:
- 45.33 lb
  - vnet = 45.33 - 168.2 = -122.8 plf
  - vnet = 45.33 + 185.7 = +231.02 plf
  - vnet = 45.33 - 60.55 = -15.22 plf

Walls:
- A
- B
- C
- D

Transfer diaphragm shears:
- 4924 lb
- 7076 lb
- 3363 lb
- 1211 lb
- 1600 lb
Collector Force Diagrams - Right Side

2.67' - 2.83'

A

B

C

D

T

C

TD2

F = 7076 lb

F = 3170 lb

F = 4384 lb

F = 4924 lb

F = 2018 lb

F = 1696 lb

1600 lb

2496

5824

297.7

56.15

297.7

51.45

297.7

56.15

297.7

51.45

51.45

51.45

F = 3170 lb

F = 4384 lb

F = 4924 lb

F = 1696 lb

F = 2018 lb

F = 7076 lb

Sign convention
Final Strut/Chord Force Diagrams
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

- **Wall**
- **Shear wall chord**
- **Sheathing joint as occurs**
- **2x blocking as required at joints.**
- **Anchor bolts or nailing**
- **Hold down anchor**
- **tstuds**
- **Resist. mom. Arm 1**
- **C.L. bearing**
- **Resist. mom. Arm 2**
- **C.L. bearing**
- **L bearing**
- **Chord or Strut**
- **Chord or Strut**
- **Diaphragm shear**
- **Fv**
- **Fr1**
- **Fr2**
- **Sum \( M = 0 \)**
- **2x blocking as required at joints.**
- **Anchor bolts or nailing**
- **Hold down anchor**
- **tstuds**
- **Resist. mom. Arm 1**
- **C.L. bearing**
- **Resist. mom. Arm 2**
- **C.L. bearing**
- **L bearing**
- **Chord or Strut**
- **Chord or Strut**
- **Diaphragm shear**
- **Fv**
- **Fr1**
- **Fr2**
- **Sum \( M = 0 \)**

### Formula

\[
\sum M = 0
\]
Dead Load Distribution
Preference & Engineering Judgement

- Rigid Body
- Short Walls
- Semi-Rigid Body
- Long Walls

This section Supported by the first floor bearing width
This section in bearing

b/2
### 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) = 1.25-0.125 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

\[ \Delta_{SW} = \frac{8vh^3}{EAb} + \frac{vh}{Gvt_v} + 0.75h\varepsilon_n + \frac{h\Delta_a}{b} \]  

SDPWS combines

- Bending
- Nail slip
- Rod elongation (Wall rotation)

SDPWS 3 term deflection equation

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

- 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
Segmented Shear Wall Deflection

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

Load, plf vs. 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.

Perforated Shear Walls- Empirical Design

Common sheathing joint locations

Collector per SDPWS section 4.3.5.3 (Full length of wall)

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

Wall segment

Opening

Use other methods

Hold downs at Ends per section 4.3.6.4.2

Top and bottom of wall cannot be Stepped or sloped

Typical boundary member

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
Allowable Perforated Shear Wall Aspect Ratios

(a) Perforated Shear Wall

Limitations:

- The aspect ratio limitations of Table 4.3.4 shall apply.
- 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.

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

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

$A_0 = \text{total area of openings}$

Maximum Shear @ full hgt. sect.

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

Hold down at ends

$$T = C = \frac{V h}{C_0 \Sigma L_i}$$

At full-hgt. segments

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

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</th>
<th>$h/3$</th>
<th>$h/2$</th>
<th>$2h/3$</th>
<th>$5h/6$</th>
<th>$h$</th>
</tr>
</thead>
<tbody>
<tr>
<td>8' Wall</td>
<td></td>
<td>2'-6&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></td>
<td>3'-4&quot;</td>
<td>5'-0&quot;</td>
<td>6'-8&quot;</td>
<td>8'-4&quot;</td>
<td>10'-0&quot;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Percent Full-Height Sheathing</th>
<th>$h/3$</th>
<th>$h/2$</th>
<th>$2h/3$</th>
<th>$5h/6$</th>
<th>$h$</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>1.00</td>
<td>0.97</td>
<td>0.91</td>
<td>0.87</td>
<td>0.83</td>
</tr>
<tr>
<td>20%</td>
<td>1.00</td>
<td>0.97</td>
<td>0.91</td>
<td>0.87</td>
<td>0.83</td>
</tr>
<tr>
<td>30%</td>
<td>1.00</td>
<td>0.97</td>
<td>0.91</td>
<td>0.87</td>
<td>0.83</td>
</tr>
<tr>
<td>40%</td>
<td>1.00</td>
<td>0.97</td>
<td>0.91</td>
<td>0.87</td>
<td>0.83</td>
</tr>
<tr>
<td>50%</td>
<td>1.00</td>
<td>0.97</td>
<td>0.91</td>
<td>0.87</td>
<td>0.83</td>
</tr>
<tr>
<td>60%</td>
<td>1.00</td>
<td>0.97</td>
<td>0.91</td>
<td>0.87</td>
<td>0.83</td>
</tr>
<tr>
<td>70%</td>
<td>1.00</td>
<td>0.97</td>
<td>0.91</td>
<td>0.87</td>
<td>0.83</td>
</tr>
<tr>
<td>80%</td>
<td>1.00</td>
<td>0.97</td>
<td>0.91</td>
<td>0.87</td>
<td>0.83</td>
</tr>
<tr>
<td>90%</td>
<td>1.00</td>
<td>0.97</td>
<td>0.91</td>
<td>0.87</td>
<td>0.83</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 areas.

2. The sum of the perforated shear wall segment lengths, $L_i$, 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.
Perforated Shear Wall Deflection

Deflection of perforated shear wall

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

4.3-1

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 \( v_{max} \) 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

Many examples ignore gravity loads

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

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).

Allowable Shear Wall Aspect Ratios For FTAO Shear Walls
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

Example results – double opening with shallow headers

Not to scale
Example Cont.

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

Gravity loads to wall

Tie strap/blocking full width

Force Transfer Methodology (Diekmann) - Vierendeel Truss/Frame
Free-body of Upper Half and Upper Left Section
Resultant Forces on Wall Segments

Units are in lb

Shears and forces determined in previous step.
Example 2 - Blocking and Strapping Partial Width (with uniform load)

4500 lbs.
w=200 plf

Transfer diaphragm sections

Lap as required

A/R

T.D. 1

T.D. 2

Support

Support

Support

Support

2.67'

2.67'

3'

6'

5.5'

14.5'

w=200 plf

A/R

A/R

A/R

A/R

w=200 plf
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
Pier Section Forces and Loads

Sign convention

Transfer diaphragm shears

Support

Support

Basic Shear Diagram From Gravity Loads

4243.1 lbs.

4243.1 lbs.

4243.1 lbs.

Neg.

Neg.

Neg.

Neg.

Pos.

Pos.

Pos.

Pos.

1937.1

1975.8

w=200 plf

T.D.2

3.6

2.83'

2.67'

F

F

F

F

1551.7

1591.4

3676.6

1591.4

1975.8

v3

v3.6

v4

Summing

Summing

Summing

Summing

Summing
Transfer Diaphragm Shears and Net Shears

**Sign convention**
- **Transfer diaphragm shears**
  - 3143.1 lbs (3449.23 plf)
  - 3677.1 lbs (4243.1 lbs. +471.46 plf)

**Net Shears**
- 1937.1 lbs
- 1551.7 lbs
- 281.1 lbs
- 2020.6 lbs
- 1975.8 lbs
- 1591.4 lbs
- 408.57 lbs

**Formulae**
- \( v = \frac{281.1}{2.67} \) = 105.3 plf
- \( v = \frac{1656}{2.67} \) = 620.2 plf
- \( v = \frac{2020.6}{2.67} \) = -756.8 plf

**Basic Shear Diagram**
- Summing
- \( v_{net} = 349.23 - 105.38 = +243.93 \) plf
- \( v_{net} = 349.23 + 620.2 = +969.45 \) plf
- \( v_{net} = 349.23 - 756.8 = -407.55 \) plf

**Transfer diaphragm shears**
- 281.1 lbs
- 105.3 lbs
- 1937.1 lbs
Horizontal Collector Forces

- $F = 1975.8 \text{ lbs.}$
- $F = 1937.1 \text{ lbs.}$
- $F = 3676.6 \text{ lbs.}$

Sign convention:

- $4243.1 \text{ lbs.}$
Vertical Collector Forces

Sign convention

Summing

F=4243.1 lbs.
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
What happens when different depths?

Multi-story walls? Tall shear walls?
• 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

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

• The remainder of the terms are identical to the traditional equation.

• Deflections for a wall with multiple openings is similar.

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

Traditional 4 term deflection equation

\[ \Delta_{SW} = \frac{8v h^3}{E A b} + \frac{v h}{G v t v} + 0.75 h e_n + \frac{h \Delta a}{b} \]
Let’s Take a 10 Minute Break
**Combined Shear and Uplift Shear Walls** - **WSP-APA SR-101C**

**Typical Panel Fastening**

- **Field nailing**: 12” o.c.
- **Edge nailing**
- **Straps are required at edges of an opening to transfer uplift forces**

**Single row of Fasteners**

- 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

**Double row of Fasteners**

- V_{ASD} = Vn/2, V_{str} = 0.65Vn
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.
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)

Diaphragm rotates

Wall warps and translates

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

Wall stiffness (SW1 & longit. walls)

Structure is stable
Circular Shear Walls

No Circular Shear Wall Testing

WSP thickness depends on radius

Diaphragm support

Effective width

TD1

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

16” o.c. typ.

Fasteners are in double shear

ATS system
Prescriptive / Proprietary Portal Frames

IBC 2308.9.3.2 Proprietary Portal Frames

For SI: 1 foot = 304.8 mm; 1 inch = 25.4 mm; 1 pound = 4.448 N.

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

Source: strongtie.com

Truss Frames

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
Typical Hold Down Details at Foundation

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
- 18” max.
- 1 ½” max.
- Opt. supplied manufacturer's anchor
- Preservative treated barrier may be required
- 3” to 5”
- 5° max.
- Standard (discrete) Hold Downs
Multiple Hold Downs at Corners
Field Installation Issues

Hold downs installed at an angle

Large knots

Courtesy of Willdan Engineering
Hold down misplaced. Sheathing is removed.

Field Installation Issues

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.
Field Installation Issues

Loose anchor strap-stabbed into foundation-no vibration

Too close to vent opening
Field Installation Issues

Slack in hold down strap (bent)
Often stabbed into foundation without vibration.
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

• xx kips Tied off at each floor
• (xx kips) Tied off at roof only

Tied off at each floor
Skipped floor

2 kips

4 kips

7 kips

14 kips
(27 kips) Full hgt.

13.5 kips

27 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 roof only

Legend

xx kips Tied off at each floor
(xx kips) Tied off at roof only
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
### Table 4.3A Nominal Unit Shear Capacities for Wood-Framed Shear Walls

*Wood Based Panels*

<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 Seismic</th>
<th>B Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Panel Edge Fastener Spacing (in.)</td>
<td>Panel Edge Fastener Spacing (in.)</td>
<td></td>
</tr>
<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>4,5 Structural</td>
<td>5/16</td>
<td>1-1/4</td>
<td>6d</td>
<td>Vs (plf) (kips/in.)</td>
<td>6</td>
</tr>
<tr>
<td>Panes</td>
<td></td>
<td></td>
<td>OSB PLY</td>
<td>400 13 10</td>
<td>600 18 13</td>
</tr>
<tr>
<td>3/8</td>
<td></td>
<td></td>
<td>OSB PLY</td>
<td>460 19 14</td>
<td>720 24 17</td>
</tr>
<tr>
<td>Nail (common or</td>
<td></td>
<td></td>
<td>OSB PLY</td>
<td>510 16 13</td>
<td>790 21 16</td>
</tr>
<tr>
<td>Galvanized box)</td>
<td></td>
<td></td>
<td>OSB PLY</td>
<td>560 14 11</td>
<td>860 18 14</td>
</tr>
<tr>
<td>15/32</td>
<td></td>
<td></td>
<td>OSB PLY</td>
<td>680 22 16</td>
<td>1020 29 20</td>
</tr>
<tr>
<td>1-1/2</td>
<td></td>
<td></td>
<td>OSB PLY</td>
<td></td>
<td></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

*Increased 40%*

*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>

$v_{ub} = v_b C_{ub}$  \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 $G_a$)

- $V_{allow} = 2x$
- $V_{S1}$
- $V_{S2}$

Dissimilar materials

- $V_{allow} = 2x$ smaller or largest, greater of.
  (Exception-for wind, add capacities)

Vallow = largest (Not cumulative)

$V_{S1}$
$V_{S2}$

Dissimilar materials

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:

$$v_{sc} = K_{\text{min}} G_{ac}$$

Combined apparent shear wall shear capacity (seismic)

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

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

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} = $ combined nominal unit shear capacity seismic

$V_{wc} = $ combined nominal unit shear capacity wind

$v_{S1}$ = Nominal unit shear capacity of side 1 ($v_{S2}$ 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.
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)

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

- Sum design strengths = \( v_{SW1} \times b_1 + v_{SW2} \times b_2 \) 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.
Square plate washers prevent cross grain bending-splitting of sill plate.

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.
Lunch
Information Overload

Deer in Headlight
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

Photo: Terry Malone
Detailing for Continuous Load Paths

Complicated Load Paths

Discontinuous Load Paths
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
- Anchor bolts or nails
- Hold Down (option 1) No irreg.

• 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)
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.

**Section A**

Type 4 vert. irreg. SDC B-F

**Section B**

Type 4 vert. irreg. SDC B-F

**Section C**

Nail shtg to each 2x stud

(Option 2)

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

Hold down (Option 2 -only)

Hold down (Typical)

- **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
Examples of Drag Struts, Collectors and chords at Exterior Boundaries

- Roof sheathing
- Shear panel
- Double top plate used as strut / collector or chord.
- Strut/collector
- All shear is transferred into top plates, then into SW
- Flat strap and blocking used as strut / collector or chord.
- Strut/collector
- All shear is transferred flat strap and blocking, then into SW
- Non-Strut/collector
- Non-SW
- SW
- Non-SW
- Non-SW
- SW
- Non-SW
- Non-SW
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
2015 IBC Figure 2308.6.7.2(1)

Boundary nailing

Middle 3rd available for vent holes - No continuous vents

2x blocking

Insulation

2x blocking

2015 IBC Figure 2308.6.7.2(2)

Venting Options

A

2x vertical nailer

Screened vent

2x framing all 4 sides

Truss

Typical shear panel

A
Insulation
Screened vent holes

Boundary nailing
2x framing all 4 sides

Outriggers per manuf. instructions

Venting Options

Baffle as required

2x vertical nailer E.S.

Truss

Typical Solid Blocking

Typical shear panel
Shear Wall Design

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

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)

Potential buckling problem w/ supporting columns and beams

Elements requiring over-strength load combinations
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

![Diagram](image-url)

- **Diaphragm**
- **Strut**
- **Chord**
- **Collector**
- **Shear wall**
- **Cantilever?**

Shear wall is not continuous to foundation. Type 4 horizontal and vertical irregularity.
ASCE 7-10 Section 12.3.3.3 \(\text{(SDC B-F)}\)

Elements supporting discont. Walls or frames:

**Type 4 Vertical Irregularity SDC D-F**

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.

Continuous member

Blocking or shear panels

Strut

2
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.

- 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 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)

Shear wall anchorage is designed for standard load combinations of Sections 2.3 or 2.4.

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

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.

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.

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

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.

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 (F\text{px}), Eq. 12.10-1 or

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

\[ F_{px\max} = 0.4S_{DSI_e}w_{px} \] - Upper bound seismic diaphragm design forces determined by Eq. 12.10-2 (F\text{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\text{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)

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

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

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]
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

Diaphragm 1

Diaphragm 2

$W = 200 \text{ plf}$

$\text{R}_L = \text{R}_R = 200 \left( \frac{78}{2} \right) = 7800 \#$

$\text{v}_R = \frac{7800}{50} = 156 \text{ plf}$

$\text{R}_L = \text{R}_R = 200 \left( \frac{122}{2} \right) = 12200 \#$

$\text{v}_R = \frac{12200}{50} = 244 \text{ plf}$

$\text{Sum} = 20000 \#$

$\text{Sum} = 40000 \#$

$= 200 \text{ plf}(200')$

$v_{SW} = 454.55 \text{ plf}$

$v_{Net} = 54.55 \text{ plf}$

Full length walls aligned
layout 2 - full length offset walls

\[ R_L = R_R = 112 \times \frac{78}{2} = 4368 \text{ plf} \]
\[ v_L = v_R = 4368/28 = 156 \text{ plf} \]

\[ R_L = R_R = 88 \times \frac{122}{2} = 5368 \text{ plf} \]
\[ v_L = v_R = 5368/22 = 244 \text{ plf} \]

\[ R_L = R_R = 112 \times \frac{118}{2} = 6608 \text{ plf} \]
\[ v_L = v_R = 6608/28 = 236 \text{ plf} \]

Transfer Area

\[ R_L = R_R = 24 \times \frac{4}{2} = 48 \text{ plf} \]
\[ v_L = v_R = 48/6 = 8 \text{ plf} \]

\[ R_L = R_R = 24 \times \frac{28}{2} = 3608 \text{ plf} \]
\[ v_L = v_R = 3608/22 = 164 \text{ plf} \]

\[ R_L = R_R = 24 \times \frac{6}{2} = 48 \text{ plf} \]
\[ v_L = v_R = 48/6 = 8 \text{ plf} \]

Sum = 7976 #

Sum = 20048 #

Sum = 40000 #

= 200 plf (200')

Sum = 11976 #
Total load to grid lines 2 & 3

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

\[
L_{SW} = 22 + 22 = 44' \quad \quad V_{SW} = 20048 \text{ #} \quad \quad v_{SW} = 20048/44 = 455.64 \text{ plf}
\]

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

\[
v_{net \ SW2} = v_{SW} - 164 - 236 = 55.64 \text{ plf} \quad \text{Checks, they should be equal}
\]

\[
F_{2AB} = v_{net \ SW1} \times 22 = 1224 \text{ #}
\]

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

\[
F_{2C} = F_{2AB} - F_{2BC} = 240 \text{ #}
\]

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

\[
O.K.
\]

\[
Shear \ at \ transfer \ area = 240/6 + 8 = 48 \text{ plf}
\]
Layout 3 - Full length plus partial length offset shear walls

- Diaphragm 1
  - Diaphram 1
  - SW1
  - SW2
  - SW4
  - Transfer Area
  - $R_L = R_R = 112(78/2) = 4368 \text{ plf}$
  - $V_L = V_R = 4368/28 = 156 \text{ plf}$
  - $R_L = R_R = 88(82/2) = 3608 \text{ plf}$
  - $V_R = 3608/22 = 164 \text{ plf}$

- Diaphragm 2
  - Diaphram 2
  - SW3
  - SW2
  - SW4
  - Transfer Area
  - $R_L = R_R = 112(118/2) = 6608 \text{ plf}$
  - $V_R = 6608/28 = 236 \text{ plf}$

- Full length plus partial length offset shear walls

- Sum = 7976 #
- Sum = 20048 #
- Sum = 40000 # = 200 plf (200')
Total load to grid lines 2 & 3

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

\[ L_{SW} = 22 + 12 = 34' \]

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

\[ v_{SW} = \frac{20048}{34} = 589.65 \text{ plf} \]

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

\[ v_{\text{net SW2}} = 589.65 - 164 - 236 = 189.65 \text{ plf} \]

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

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

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

Shear at transfer area = 3188.24/6 + 8 = 539.37 plf

All forces in lb., all shears in plf
Layout 4 - Partial length offset shear walls

Diaphragm 1

R_L = R_R = 112(78/2) = 4368 #

v_R = 4368/28 = 156 plf

W = 200 plf

SW1

R_L = R_R = 24(4/2) = 48 #

v_L = v_R = 48/2 = 8 plf

Diaphragm 2

R_L = R_R = 88(122/2) = 5368 #

v_R = 5368/28 = 244 plf

Transfer Area

v_R = 24(4/2) = 48 #

v_L = 48/6 = 8 plf

R_L = R_R = 112(118/2) = 6608 #

v_R = 6608/28 = 236 plf

Sum = 7976 #

Sum = 20048 #

Sum = 11976 #

Layout 4 - Partial length offset shear walls
Total load to grid lines 2 & 3

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

\[ L_{SW} = 12 + 10 = 22' \]

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

\[ v_{SW} = \frac{20048}{22} = 911.27 \text{ plf} \]

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

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

Checks, they should be equal

\[ SW_1 \]

\[ F_{SW1} = 511.27(10) = 5112.7 \text{ #} \]

\[ F_{SW1} \text{ to } 2B = (156 + 244)12 = 4800 \text{ #} \]

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

\[ F_{2C} = 5112.7 - 4800 - 984 = -671.3 \text{ #} \]

\[ SW_2 \]

\[ F_{SW2} = 511.27(12) = 6135.24 \text{ #} \]

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

\[ F_{3B} = 6135.24 - 5464 = 671.24 \text{ #} \]

\[ F_{B23} = F_{C23} = 671.3(4)/6 = 120 \text{ #} \]

Shear at transfer area = 671.3/6 + 8 = 119.9 plf
Seismic Design Example of a Cantilever Wood Diaphragm

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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

- 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

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

This concludes Our Workshop Presentation on Advanced Diaphragm Analysis

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