Wood Diaphragm Analysis and Related Wood Mid-Rise Structure Design Issues

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Course Description

This presentation will focus on complex diaphragm analysis and important engineering considerations related to the lateral design of mid-rise* wood buildings.

Implementation of a well-considered design requires the understanding of diaphragm and shear wall flexibility and their effects on the horizontal distribution of forces through the structure.

Topics:

- Basic information
- Diaphragms with offsets
- Diaphragms with openings
- Lateral design considerations for mid-rise structures

*Definition:
A mid-rise building can be described as something between a high-rise and low-rise structure.
- Between four and ten stories with heights ranging between 35 to 75 feet tall.
Basic Information

• Boundary Elements
• Method of Analysis
**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 7-16 Section 11.2)

**SDPWS 4.3.5.1**

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

**Required for Seismic and wind**

- **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 7-16 Section 12.10.2)

**Note:** Interior shear walls require a full depth collector unless a complete alternate load path is provided.
Shear failure
Not enough shear capacity

Splitting failure
Bottom section not supported

Would you do this?
Failure Modes

Alternate load path

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

Shear Distribution if No Collector

High stress concentrations at end of the wall

Shear Distribution if Continuous Collector

Code does not allow the sheathing to be used to splice or act as boundary elements
Tearing will occur if collectors are not installed at re-entrant corner.
Basic Information

- Boundary Elements
- 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.)

Positive Direction

Transverse Direction (shown)

Shears Applied to Sheathing Elements

Transfer shears

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

Unit shear acting on sheathing 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 \textbf{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, \textbf{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

2'

16'
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.

- 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.

Transfer Diaphragm Members and Elements
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
Method of Analysis - Method by Edward F. Diekmann

Chord force at discontinuity

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

Disrupted chord

Basic Shear Diagram at transfer diaphragm

Transfer Diaphragm Shears
Analogous to a beam with a concentrated Load.

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

Transfer diaphragm length

Method of Analysis

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

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

Basic diaphragm shears

Subtract from basic shears

Add to basic diaphragm shears

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

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

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

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

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

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

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

- Horizontal Offsets
  - End offsets
  - Center 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 7-16 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.

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**Design collector and connections to SW using 25% increase per ASCE 7-16 Section 12.3.3.4. (Grid lines 1 and 4)**

**Design diaphragm connections to SW and struts using 25% increase per ASCE 7-16 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

**Example 1**

- **Diaphragm with Horizontal End Offset**
- **Transverse Loading**

- **Support RL = 12500 lb**
  - **Discontinuous diaphragm chord**
  - **F2B = 7142.9 lb**

- **A.R. = 2.5:1**

- **M2B ft.-lb**

- **F2B = 7142.9 lb**

- **Free body for F2B**

- **Support RR = 12500 lb**

- **TD chords**

- **Support**

- **Collector**

- **Diaphragm chord**

- **C.L.**

- **SW 1**

- **SW 2**

- **w = 200 plf**

- **Diaphragm chord**

- **Collector TD chords**

- **35’**

- **50’**

- **200 plf**

- **12500 lb**

- **Sum \( \Sigma M = 0 \)**

- **F2A**

- **F2B**

- **Sign Convention**

- **A**

- **B**

- **C**

- **1**

- **2**

- **3**

- **4**
Transfer Diaphragm and Net Diaphragm Shear

Basic shear diagram

v = 150 - (107.1) = +42.9 plf (Net resulting shear)

v = 70 - (107.1) = -37.1 plf (Net resulting shear)

v = 150 + (250) = +400 plf (Net resulting shear)
Can be > 3x basic shear

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

12500 lb (Net resulting shear)

Legend

375 plf Basic diaphragm shear
(240 plf) Transfer diaphragm shear
=xxx plf Net shears (basic shear +/- TD shears)
Longitudinal Chord Force Diagrams

Support

F = 7200 lb

F = 7812.5 lb

F = 7142.9 lb

Sign Convention

Calcs
Transverse Collector Force Diagrams

**Sign Convention**

- **Diaph. C.L.**
- **Special nailing**
  - (sum of shears to collector or highest boundary nailing - greater of)

**Calcs**

- $F = 6000 \text{ lb}$
  - (this is not an insignificant force.)
- $F = 3748.5 \text{ lb}$
- $F = 3750 \text{ lb}$
  - $250 \text{ plf net}$

**Dimensions**

- SW 1
- SW 2
- 15'
- 25'
- 20'
- 80'

**Annotations**

- $+357.15$
- $+214.3$
- $+42.9$
- $-37.1$
- $+70$
- $171.4 \text{ plf net}$
- $107.1 \text{ plf net}$
- $400$
- $320$
Example 2 - Diaphragm with Horizontal End Offset - Longitudinal Loading

- Diaphragm 1
- Diaphragm 2
- Collector and TD chords
- Collector
- Transfer diaphragm TD1
- Drag strut
- Discontinuous Drag strut
- Drag strut
- 200 plf
- 160 plf
- 200 plf
- 40 plf
- SW 1
- SW 2
- 25'
- 20'
- 15'
- 50'
- Chord
- 80'
- 15'
- 5'
- SW 1
- SW 2
- Collector and TD chords
- Collector and TD chords
- Diaphragm 1
- Diaphragm 2
- Discontinuous Drag strut
- Pos. direction
- +
- -
Transfer Diaphragm and Net Diaphragm Shear
Longitudinal and Transverse Collector/Strut Force Diagrams
• Horizontal Offsets
• End offsets
• Center Offsets
• Large interior Openings

Diaphragm Design

Does not meet A.R. (Envelope)
Example 4 - Intermediate notch at End Wall **Without Strut**

**SW 1**
- Section A
  - Chord
  - TD1
    - A.R. = 3.73
  - Collector

**SW 2**
- Section B
  - Chord
  - Collector
  - Collector

**SW 3**
- Section A
  - Collector
  - Collector

**Open area**
- R₁B = 8800 lb
- (v = 400 plf)

**Chord**
- 8800 lb
- +6200 lb
- 15000 lb

**Section B**
- R₁D = 6200 lb
- (V = 387.5 plf)

**Collector**
- F₂B = 5684.4 lb
- F₂C = 5584 lb

**R = 15000 lb**

**V = 8800 lb**

**Basic Shear Diagram**
- +310.5 plf
- +210.7 plf
- +157.1 plf

**Sum Shears**
- R = 15000 lb
Transfer diaphragm and net diaphragm shears

Basic shear diagram

Transfer diaphragm and net diaphragm shears

V = 210.7 - (123.7) = +87 plf

V = 157.1 - (123.7) = +33.4 plf

V = 210.7 + (255.24) = +465.9 plf

V = 157.1 + (255.24) = +412.3 plf

V = 210.7 - (117) = +93.7 plf

V = 210.7 - (123.7) = +87 plf

V = 157.19 - (117) = +40 plf

Transfer diaphragm
net shears

F2B = 5684.4

F2C = 5584

Transfer Forces
to Collectors

Sign Convention
Diaphragm Design

- Horizontal Offsets
- End offsets
- **Center Offsets**
- Large interior Openings
Analysis Option 1-Analyze as Diaphragm with Intermediate Offset
Diaphragm Design

• Horizontal Offsets
• End offsets
• Center Offsets
• Large interior Openings
ASCE 7-16 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.

**Type 3 Horizontal Irregularity - 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.
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.
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). \( M=0 \).
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.
### Opening Analysis - Diekmann method vs. VSTM

**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.
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)
Free-body of Chord Forces and Segment Forces
Net Shears - Left Transfer Diaphragm

Basic Shear Diagram

Transfer diaphragm shears

Sign convention

**Sign convention**

Transfer diaphragm shears

**Net Shears-Right Transfer Diaphragm**

- $v_{net} = 112 - 168.2 = -56.2 \text{ plf}$
- $v_{net} = 112 + 185.7 = +297.7 \text{ plf}$
- $v_{net} = 112 - 60.55 = +51.45 \text{ plf}$
- $v_{net} = 45.33 - 168.2 = -122.8 \text{ plf}$
- $v_{net} = 45.33 + 185.7 = +231.02 \text{ plf}$
- $v_{net} = 45.33 - 60.55 = -15.22 \text{ plf}$

**Basic Shear Diagram**

- 4924 lb
- 7076 lb
- 1211 lb
- 1600 lb
- 4924 lb
Chord Force Diagrams

- Chord 1: 57.67 lb
- Chord 2: 784.6 lb
- Chord 3: 496.3 lb
- Chord 4: 496.3 lb
- Chord 5: 208 lb

- Average: 640.5 lb

- Chord 6: 56.2 lb
- Chord 7: 122.8 lb
- Chord 8: 45.33 lb

- Average: 352.2 lb

- Chord 9: 18858 lb
- Chord 10: 18876 lb
- Chord 11: 18550 lb

- Average: 89.5 lb

- Closes to zero
Let’s Take a Break
Lateral Design Considerations for Mid-Rise Structures

- Design Considerations
- Complete Load Paths
- Diaphragm Flexibility
- Horizontal Distribution of Shears
- Mid-rise: Exterior Shear Walls vs. Open-front
Design Considerations

Methods of analysis for low-rise and mid-rise structures are currently evolving as more complex building geometries are becoming more prevalent. Building shapes and footprints are driving the design procedures for all lateral resisting systems and materials.

Design requirements:

- **IBC1604.4- Analysis:**
  - Method of analysis shall take into account equilibrium, general stability, geometric compatibility, and both short- and long term material properties.
  - Shall be based on rational analysis in accordance with well established principals of mechanics. Analysis shall provide complete load paths.

Considerations:

- Make sure that you have complete continuous lateral load paths.
- Address vertical / horizontal irregularities.
- **Investigate diaphragm and shear wall flexibility/stiffness.**
- Consider the multi-story effects on shear wall stiffness.
- Check the effects of offset diaphragms and shear walls.
- Verify the horizontal distribution of forces within the diaphragm and to the shear walls.
Lateral Design Considerations for Mid-Rise Structures

- Design Considerations
- Complete Load Paths
- Diaphragm Flexibility
- Horizontal Distribution of Shears
- Mid-rise: Exterior Shear Walls vs. Open Front
SDPWS 4.3.5.1

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

Analysis: ASCE7-16 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.

ASCE7-16 Section 1.4-Complete load paths are required including members and their splice connections
Lateral Design Considerations for Mid-Rise Structures

- Design Considerations
- Complete Load Paths
- Diaphragm Flexibility
- Tall Shear Walls-Flexibility
- Horizontal Distribution of Shears
- Mid-rise: Exterior Shear Walls vs. Open Front
ASCE7-10 Section 12.3 Diaphragm Flexibility Seismic

Section 12.3.1- The structural analysis shall consider the relative stiffnesses of diaphragms and the vertical elements of the lateral force resisting system.

12.3.1.1- Is any of the following true?

<table>
<thead>
<tr>
<th>1 &amp; 2 family Dwelling</th>
<th>Vertical elements one of the following:</th>
<th>Light framed construction where all of the following are met:</th>
</tr>
</thead>
</table>
| 1. Steel braced frames
2. Composite steel and concrete braced frames
3. Concrete, masonry, steel SW or composite concrete and steel shear walls. | | 1. Topping of concrete or similar material is not placed over wood structural panel diaphragms except for non-structural topping not greater than 1 ½” thick.
2. Each line of vertical elements of the seismic force-resisting system complies with the allowable story drift of Table 12.12-1. |

Is diaphragm untopped steel decking or Wood Structural Panels

Yes

Is diaphragm concrete slab or concrete filled steel deck?

Yes

Idealize as flexible

No

Is span to depth ratio ≤ 3 and having no horizontal irregularities?

Yes

Yes

Idealize as flexible

No

Yes

Maximum diaphragm deflection

Is maximum diaphragm deflection (MDD) >2x average story drift of vertical elements, using the Equivalent Force Procedure of Section 12.8?

No

Average drift of walls

Envelope Method

Allowed for semi-rigid modelling

Structural analysis must explicitly include consideration of the stiffness of the diaphragm (i.e. semi-rigid modeling), or calculated as rigid in accordance with 2018 IBC Section 1604.4 or ASCE 7-16 Section 12.3.1.2.
ASCE7-16, Sections 26.2 and 27.4.5 Diaphragm Flexibility

Wind

Start

Is diaphragm untopped steel decking, concrete filled steel decks or concrete slabs, each having a span-to-depth ratio of two or less?

Yes

Diaphragm can be idealized as rigid

No

Is diaphragm of Wood Structural Panels?

Yes

Diaphragm can be idealized as flexible

No

Is diaphragm untopped steel decking, concrete filled steel decks or concrete slabs, each having a span-to-depth ratio greater than two?

Yes

Justify by Calculation as flexible, semi-rigid or rigid per 2015 IBC Section 1604.4 or ASCE 7-10 Section 12.3.1.3.

No

• ASCE 7-16 Section 27.4.5-Diaphragm flexibility-The structural analysis shall consider the stiffness of diaphragms and vertical elements of the MWFRS

Open-Front-Wind

• Recommend Following SDPWS 4.2.5.2 (not required by code):
  1. Considered good engineering practice
  2. Diaphragm should meet semi-rigid or rigid stiffness requirements
  3. Show that the resulting drift at the edges of the structure can be tolerated.
Determination of Cantilever Diaphragm Flexibility (Question 3):

Use the drift of adjacent wall line supporting the Cantilever

(a) ASCE 7-16 Figure 12.3-1

Allows additional diaphragm flexibility to be classified as semi-rigid or rigid if adjacent wall method used (not average).

(b) Corridor Walls Only

Preferred Method – Simplifies Check
(c) Back Span Diaphragm
SDPWS Figure 4A Case (b)

(d) Diaphragm flexibility Shear Wall One Side
Lateral Design Considerations for Mid-Rise Structures

- Design Considerations
- Complete Load Paths
- Diaphragm Flexibility
- Horizontal Distribution of Shears
- Mid-rise: Exterior Shear Walls vs. Open Front
Distribution of shear to vertical resisting elements shall be based on analysis where the diaphragm is modeled as:

- **Idealized as flexible**-based on tributary area.
  - Can under-estimate forces distributed to the corridor walls (long walls) and over-estimate forces distributed to the exterior walls (short walls)
  - Can inaccurately estimate diaphragm shear forces

- **Idealized as rigid**-Distribution based on relative lateral stiffnesses of vertical-resisting elements of the story below.
  - More conservatively distributes lateral forces to corridor, exterior and party walls
  - Allows easier determination of building drift
  - Can over-estimate torsional drift
  - Can also inaccurately estimate diaphragm shear forces

- **Modelled as semi-rigid.**
  - Not idealized as rigid or flexible
  - Distributed to the vertical resisting elements based on the relative stiffnesses of the diaphragm and the vertical resisting elements accounting for both shear and flexural deformations.
  - In lieu of a semi-rigid diaphragm analysis, it shall be permitted to use an enveloped analysis.

Note:
Offsets in diaphragms can also affect the distribution of shear in the diaphragm due to changes in the diaphragm stiffness.
Single Story - Longitudinal Loads - A.R.=1.5:1 (8" wall)

M1-5 M1-6 M1-7 ... - Member Graph
Load Case: Dead loads

Bending increases at start of offset

A.R. 1.5:1 wall
A.R. 2:1 wall
A.R. 3.5:1 wall
Ext. SW
Full cantilever

Disp. y (in.)
Shear y (K)
Moment z (K-ft)

Base Line=0

51.13 k
46.4 k
43.21 k

7.66
4.47
0.674
8.95
80.48

414.2 k
526.55 k
692.1 k

Distance From Start (ft)
Determine Diaphragm and TD Nailing, and Chord Forces

Sym. C.L.

Longitudinal Loading
Force Distribution Due to Diaphragm/SW stiffness

Exterior shear walls

Seismic Loads

Support

Unit with Exterior Wall

Full support (SW rigid)

Partial support (Decreasing SW stiffness)

No support

Rigid or spring Support ??

Flexible

Semi-rigid

Rigid

If rectangular diaphragm

A

B

C

D

TD1

TD2

Condition A

Flexible diaphragm

Condition B

Loads shift

Condition C

Full cantilever, no exterior wall support

No significant exterior wall support. Conserv. to design as cantilever

Most load goes to corridor walls. Check Diaph./SW stiffness, use RDA to design diaphragm

Can be idealized as flexible diaphragm

Consider SW multi-story effects

Traditional SW Vs. MBA SW

FTAO?
Lateral Design Considerations for Mid-Rise Structures

- Design Considerations
- Complete Load Paths
- Diaphragm Flexibility
- Horizontal Distribution of Shears
- **Mid-rise: Exterior Shear Walls vs. Open Front**
- Flexible analysis
- Rigid analysis
- Semi-rigid (Envelope)

Longitudinal-Allowed to be idealized as flexible, provided exterior shear walls exist and is in compliance with ASCE 7-10 Section 12.3.1.1 (c). If calculations show that the story drift at a line of lateral force resistance exceeds the allowable limit, flexible diaphragm behavior cannot be used.
Non-open front

- ASCE 7-16 Section 12.3.1.1- (c), Light framed construction, meeting all conditions:
  - Longitudinal-Typically permitted to be idealized as flexible, provided exterior shear walls of adequate stiffness exist. However, diaphragm can be semi-rigid, rigid or open front, even if exterior walls exist.
  - Transverse-Traditionally assumed to be flexible diaphragm.
  - If token or questionable wall stiffness occurs at the exterior wall line, consider using semi-rigid analysis using the envelope method-(conservative), or semi-rigid, or idealize as rigid.

Open Front Structures:

- SDPWS 4.2.5.2:
  - Loading parallel to open side - Model as semi-rigid, which shall include shear and bending deformation of the diaphragm, or it can be idealized as rigid.
  - Loading perpendicular to open side (Transverse)-traditionally assumed to be flexible.
  - Drift at edges of the structure ≤ the ASCE 7 allowable story drift when subject to seismic design forces including torsion, and accidental torsion (strength, multiplied by Cd). No set drift requirements required for wind (Drift can be tolerated).
Seismic Design Example of a Cantilever Wood Diaphragm
A workshop

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Calculated Example

Carbon 12, Portland, OR  
PATH Architecture

120 Union, San Diego, CA  
Togawa Smith Martin
Questions

1. When does a loss in stiffness in the exterior walls cause an open-front diaphragm condition?

2. What is the deflection equation for open-front/cantilever diaphragms?

3. How is diaphragm flexibility defined for open-front/cantilever diaphragms vs. ASCE 7-16, Figure 12.3-1?

4. What are the available methods of distributing torsional forces into the diaphragm?

5. Do shear walls located along diaphragm chord lines affect the diaphragm chord forces?

6. Will the in-plane lateral forces of the exterior walls located at the ends of the cantilever increase chord forces, or is it acceptable to include these as part of the PSF lateral load?

7. How are torsional irregularities determined and addressed for open-front/cantilever diaphragms?
• The Analysis of Irregular Shaped Structures: Diaphragms and Shear Walls-Malone, Rice-Book published by McGraw-Hill, ICC

• Woodworks Presentation Slide Archives-Workshop-Advanced Diaphragm Analysis


• SEAOC Seismic Design Manual, Volume 2


• Woodworks-Guidelines for the Seismic Design of an Open-Front Wood Diaphragm (paper). Complete Example

• Five-Story Wood-frame Structure Over Podium Slab (paper). Complete Example-Traditional Shear Walls
Method of Analysis and Webinar References

Offset Diaphragms

Offset Shear Walls

Diaphragms Openings

Example Results

Information on Website
Presentation Slide Archives, Workshops, White papers, research reports
This concludes Woodworks Presentation:

Questions?

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THANK YOU