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WOODWORKS
WOOD PRODUCTS COUNCIL

Structural Behavior of Wood Diaphragms
From Rigid to Flexible

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WoodWorks – Wood Products Council

December 10, 2025

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Course Description

When designing light-frame wood buildings, it's essential to consider the flexibility and deflection characteristics of horizontal diaphragms, which can have a critical impact on a structure's performance, safety, and serviceability. This webinar examines how the classification of diaphragms as rigid, flexible, or semi-rigid impacts load distribution and overall building behavior.

Attendees will gain insight into the interaction between diaphragms and vertical shear walls, understanding how diaphragm flexibility and wall layout influence lateral force paths. The presentation will also cover design strategies and detailing methods to increase diaphragm stiffness and reduce deflections when necessary, ensuring code compliance, occupant safety, and long-term building performance.

Learning Objectives

1. Understand how to leverage rigid diaphragm analysis to support architectural goals, such as providing ample daylighting for occupants and open interior layouts.
2. Explore requirements in the International Building Code (IBC) and referenced standards for determining diaphragm flexibility for use with horizontal distribution of seismic and wind loads.
3. Review the impact of the location and stiffness of vertical force-resisting elements (e.g., shear walls) on the distribution of forces within a horizontal diaphragm.
4. Differentiate between rigid, flexible, and semi-rigid diaphragm behavior and understand how each classification impacts lateral load distribution in wood buildings, ensuring structural integrity and safety.

Presentation Overview

- Introduction to Diaphragms & Code Sections
  - Flexible
  - Rigid
  - Semi-rigid
- Irregularities and factors that impact stiffness
- Applying diaphragm and shear wall stiffness in practice
- Resources

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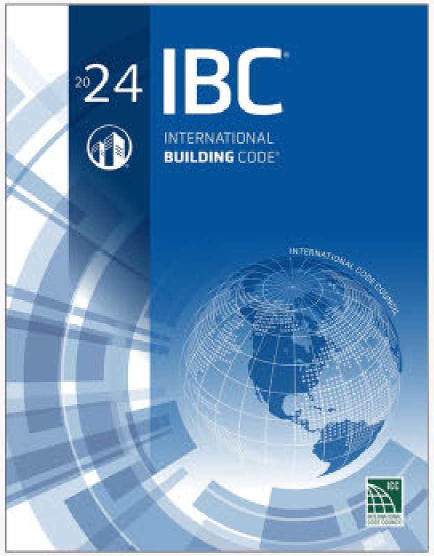
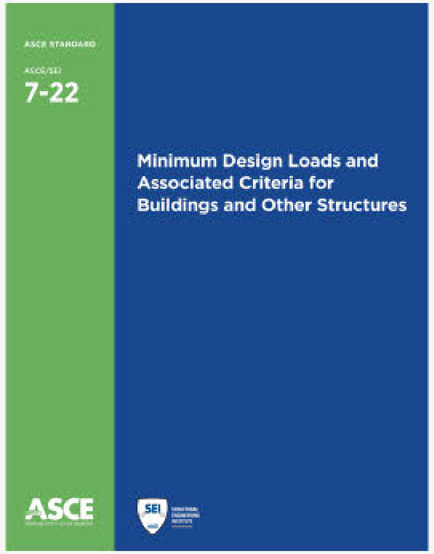
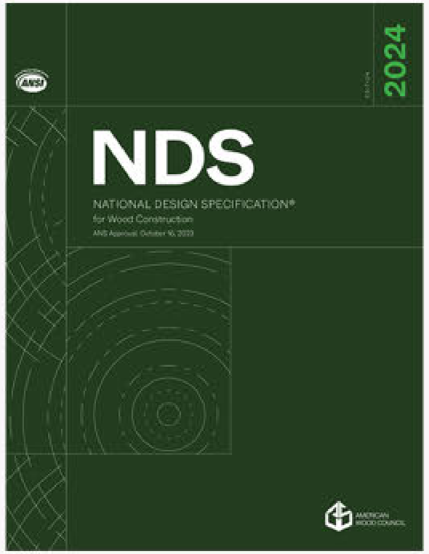
2024 IBC



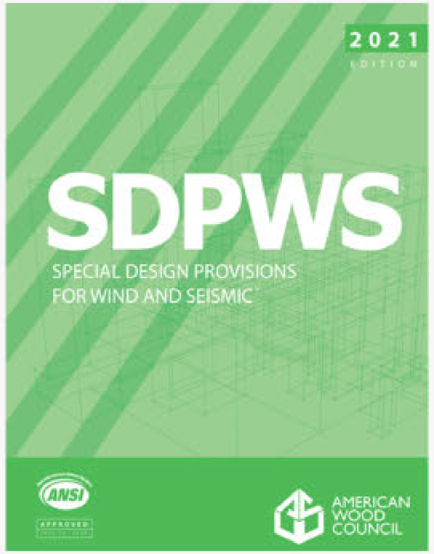
ASCE 7-22
(2022)



2024 NDS

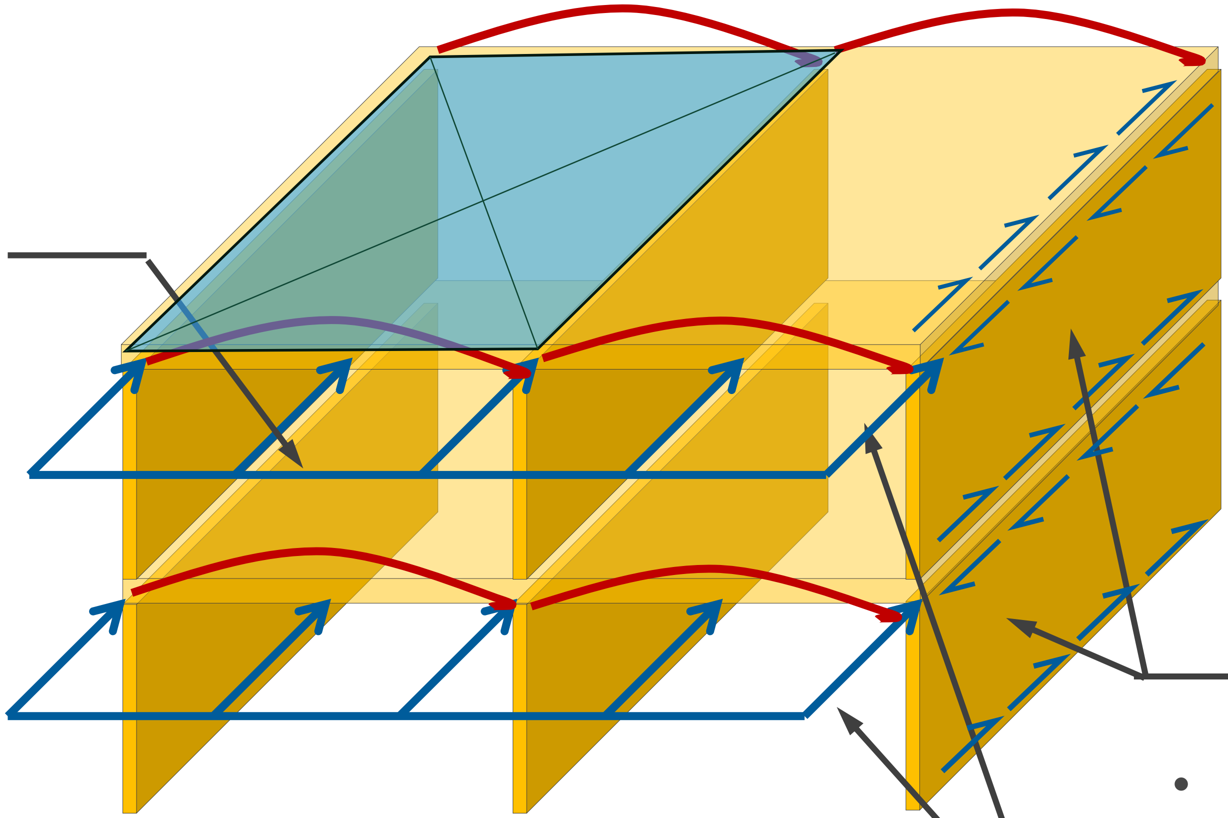


2021 SDPWS



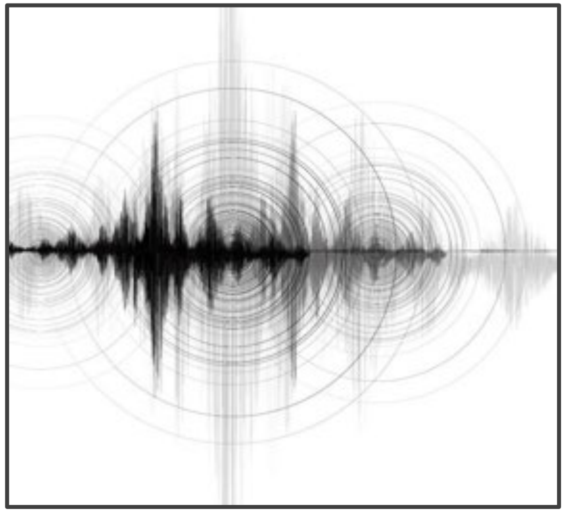
Lateral Forces on Diaphragms

Linear force (plf) on edge and/or area force (psf) on diaphragm



Wind forces

Shear wall, or other vertical elements



Seismic forces

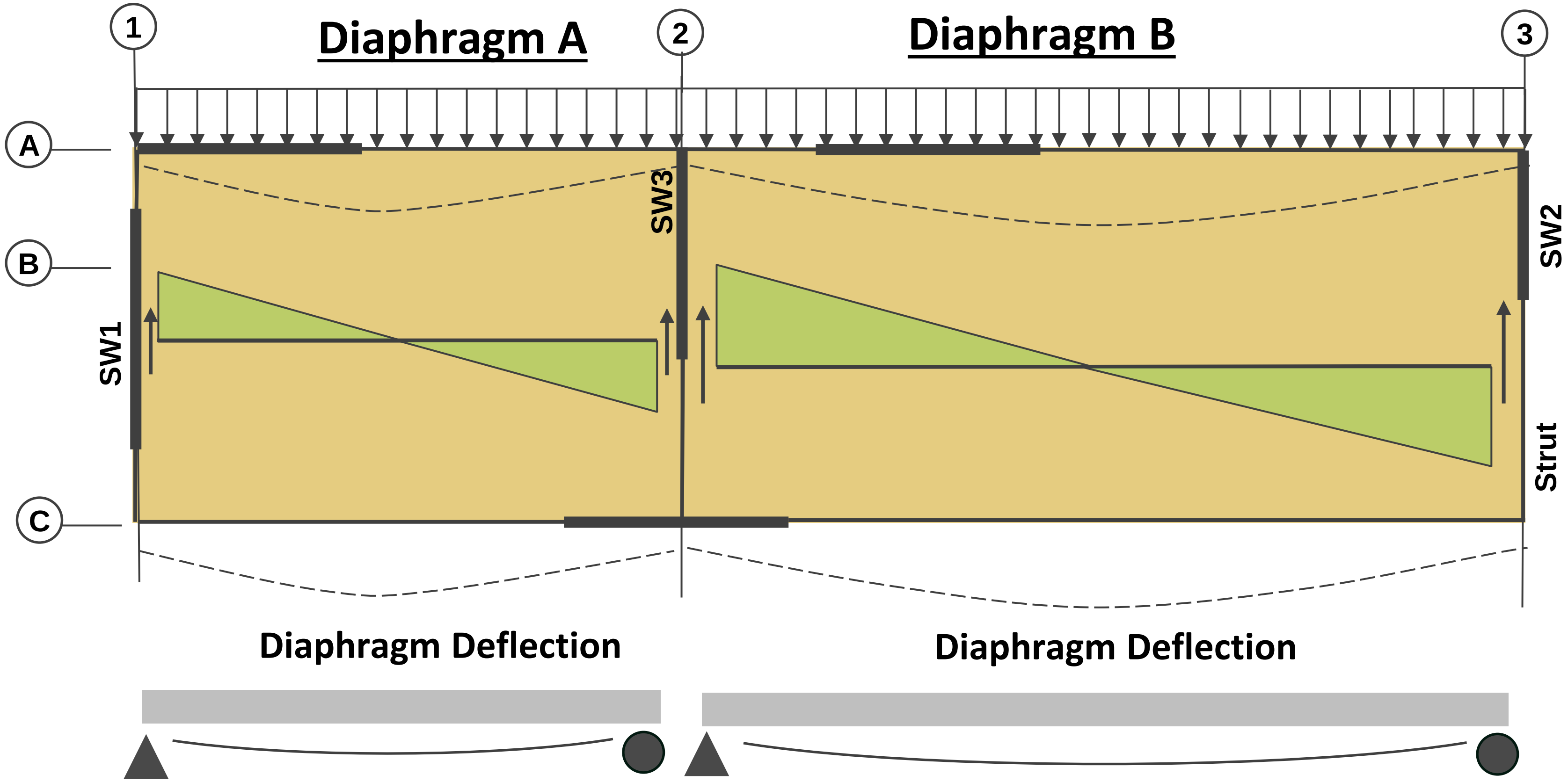
Combine lateral wall loads and (seismic) floor load into equivalent distributed forces

- Seismic forces caused by ground movement and building mass.
- Wind forces caused by windward and leeward wind pressures.

How are the diaphragm force distributed to the vertical elements?

- Two most common ways (idealized approach):
  - Idealize as a flexible diaphragm
  - Idealize as a rigid diaphragm
- Other approaches:
  - Calculate the deflections to determine classification
    - Flexible
    - Rigid
    - Semi-rigid
  - Enveloped analysis

Flexible Diaphragm Assumptions

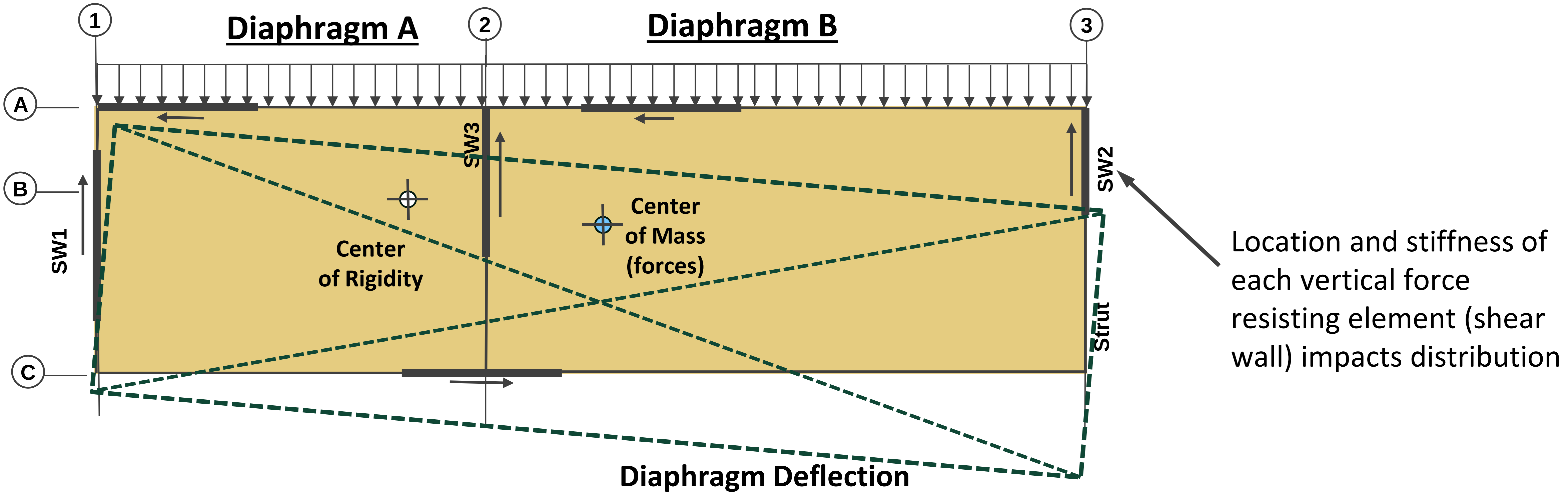


No consideration of wall stiffness to distribute loads

- Each diaphragm span is independent
- Forces distributed to wall lines using a tributary area or simply-supported, single-span “beam” models

It’s just statics… use a free body diagram of the diaphragm

Rigid Diaphragm Assumptions



- Diaphragm idealized as single rigid element with 3 degrees of freedom (lateral displacements, and rotation)
- No consideration of <u>diaphragm</u> stiffness (or shape) to distribute loads

IBC 2021 – Section 1604.4

"…The total lateral force shall be distributed to the various vertical elements of the lateral force-resisting system in proportion to their rigidities, considering the rigidity of the horizontal bracing system or **diaphragm**. Rigid elements assumed not to be a part of the lateral force-resisting system are permitted to be incorporated into buildings provided that their effect on the action of the system is considered and provided for in the design. A diaphragm is rigid for the purpose of distribution of story shear and torsional moment when the lateral deformation of the **diaphragm** is less than or equal to two times the average story drift. Where required by ASCE 7, provisions shall be made for the increased forces induced on resisting elements of the structural system resulting from torsion due to eccentricity between the center of application of the lateral forces and the center of rigidity of the lateral force-resisting system…"

IBC 2024 – Section 1604.4

"…The total lateral force shall be distributed to the various vertical elements of the lateral force-resisting in proportion to their rigidities, considering the rigidity of the horizontal bracing system or **diaphragm**. Rigid elements assumed not to be a part of the lateral force-resisting system are permitted to be incorporated into buildings provided that their effect on the action of the system is considered and provided for in the design. Where a **diaphragm** is not permitted to be idealized as either flexible or rigid in accordance with ASCE 7 or for wood **diaphragms** in accordance with AWC SDPWS, the structure shall be analyzed and designed utilizing one of the following procedures:

1. An envelope analysis of the structure using a flexible and rigid **diaphragm** analysis separately and designing each component for the more severe load condition.
2. A semirigid **diaphragm** analysis and design.

Where required by ASCE 7, provisions shall be made for the increased forces induced on resisting elements of the structural system resulting from torsion due to eccentricity between the center of application of the lateral forces and the center of rigidity of the lateral force-resisting system..."

Stiffness – Seismic vs. Wind

- Seismic
  - ASCE 7-16, 22 Section 12.3.1- Diaphragm flexibility-The structural analysis shall consider the relative stiffnesses of diaphragms and the vertical elements of the seismic force resisting system.
- Wind
  - ASCE 7-16 Section 27.4.5 (Section no longer in ASCE 7-22)- Diaphragm flexibility-The structural analysis shall consider the relative stiffness of diaphragms and vertical elements of the MWFRS. Diaphragm flexibility only mentioned in definitions “Diaphragms” in ASCE 7-22.

ASCE 7-22 Definitions

Chapter 11 Definition (Seismic):

DIAPHRAGM: Roof, floor, or other membrane or bracing system acting to transfer lateral forces to the vertical resisting elements.

Chapter 26 Definition (Wind):

DIAPHRAGM: Roof, floor, or other membrane or bracing system acting to transfer lateral forces to the vertical MWFRS. For analysis under wind loads, diaphragms constructed of untopped steel decks, concrete-filled steel decks, and concrete slabs, each having a span-to-depth ratio of 2 or less, shall be permitted to be idealized as *rigid*. Diaphragms constructed of wood structural panels are permitted to be idealized as *flexible*.

Flexible Diaphragm Condition

SDPWS 2021

4.1.7.1 Flexible Diaphragm
When a diaphragm is idealized as flexible in accordance with ASCE 7, the diaphragm shear forces shall be distributed to the vertical elements of the lateral force-resisting system (LFRS) of the story below based on tributary area.

ASCE 7-22

12.3.1.1 Flexible Diaphragm Condition
Diaphragms constructed of untopped steel decking or wood structural panels are permitted to be **idealized as flexible** if any of the following conditions exist:

…

3. In structures of light-frame construction where all of the following conditions are met:

a) Topping of concrete or similar materials is not placed over wood structural panel diaphragms except for nonstructural topping no greater than 1.5 in. thick, and

b) Each line of vertical elements of the seismic force-resisting system complies with the allowable story drift of Table 12.12-1.

12.3.1.3 Calculated Flexible Diaphragm Condition
Diaphragms not satisfying the conditions of Sections 12.3.1.1 or 12.3.1.2 are permitted to be idealized as flexible provided:

$$\frac{\delta_{MDD}}{\Delta_{ADVE}} > 2 \quad (Eq. 12.3-1)$$

Where δ_{MDD} and Δ_{ADVE} are as shown in Figure 12.3-1. The loading used in this calculation shall be that prescribed in Section 12.8.

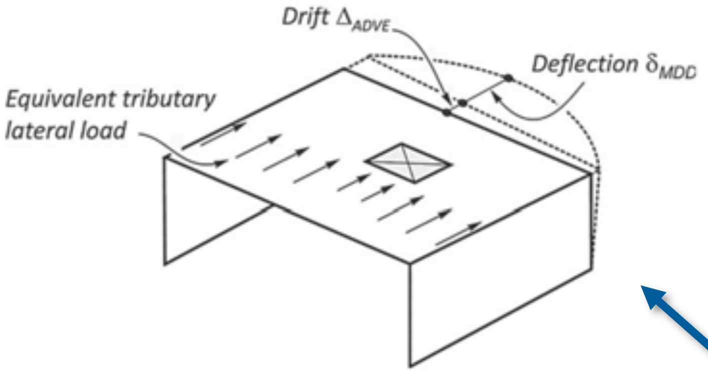


Figure 12.3-1. Flexible diaphragm.

Rigid Diaphragm Condition

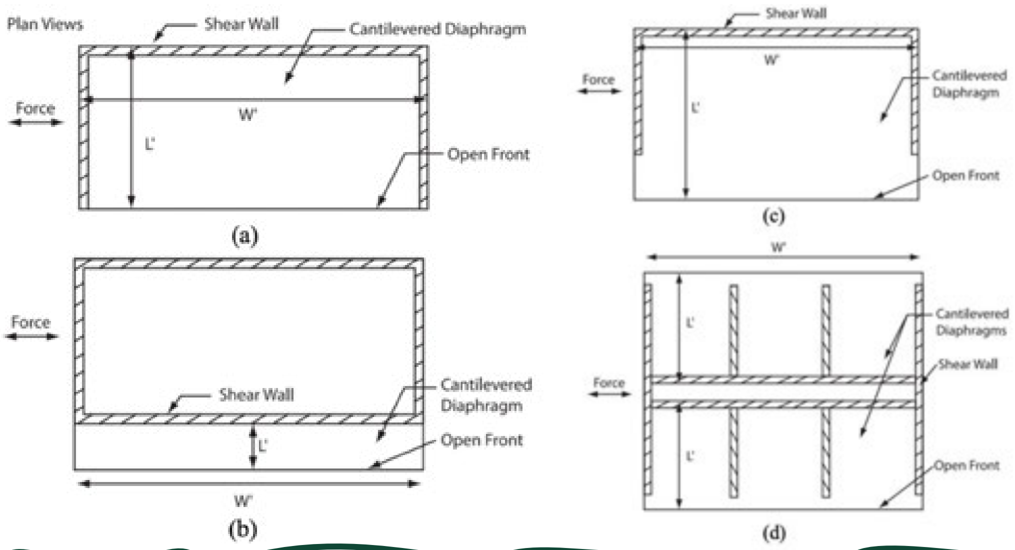
SDPWS 2021

4.1.7.2 Rigid Diaphragm
When a diaphragm is idealized as rigid, the diaphragm shear forces shall be distributed based on the relative lateral stiffness of the vertical elements of the LFRS of this story below. A diaphragm shall be permitted to be idealized as rigid when calculated maximum in-plane deflection of the diaphragm itself under lateral load is less **than or equal to** two times the average deflection of adjoining vertical elements of the associated LFRS of the story below. A cantilever diaphragm shall be permitted to be idealized as rigid when the calculated maximum in-plane deflection of the diaphragm itself under lateral load is **less than or equal to** two times the deflection of adjoining vertical elements of the associated LFRS of the story below used to determine the cantilever length, L’ (See Figure 4A). The calculated deflections required by this section, for diaphragm and adjoining vertical elements of the associated LFRS, shall be determined using an equivalent tributary lateral load.

ASCE 7-22

12.3.1.2 Rigid Diaphragm Condition
Diaphragms of concrete slabs or concrete-filled metal deck with span-to-depth ratios of 3 or less in structures that do not have a Type 2, 3, 4, or 5 Horizontal Structural Irregularity are permitted to be idealized as rigid.

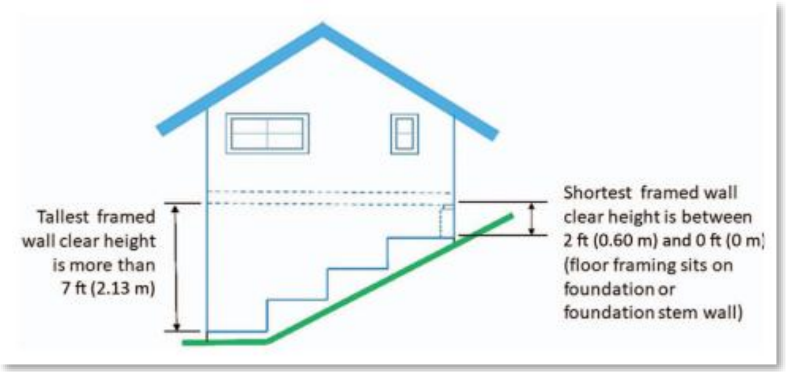
SDPWS Figure 4A: Examples of Open Front Structures



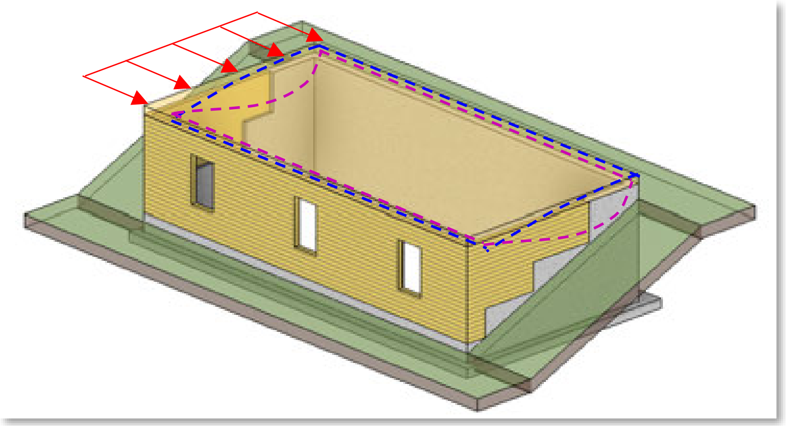
Diaphragms in Hillside Light-Frame Structures

ASCE 7

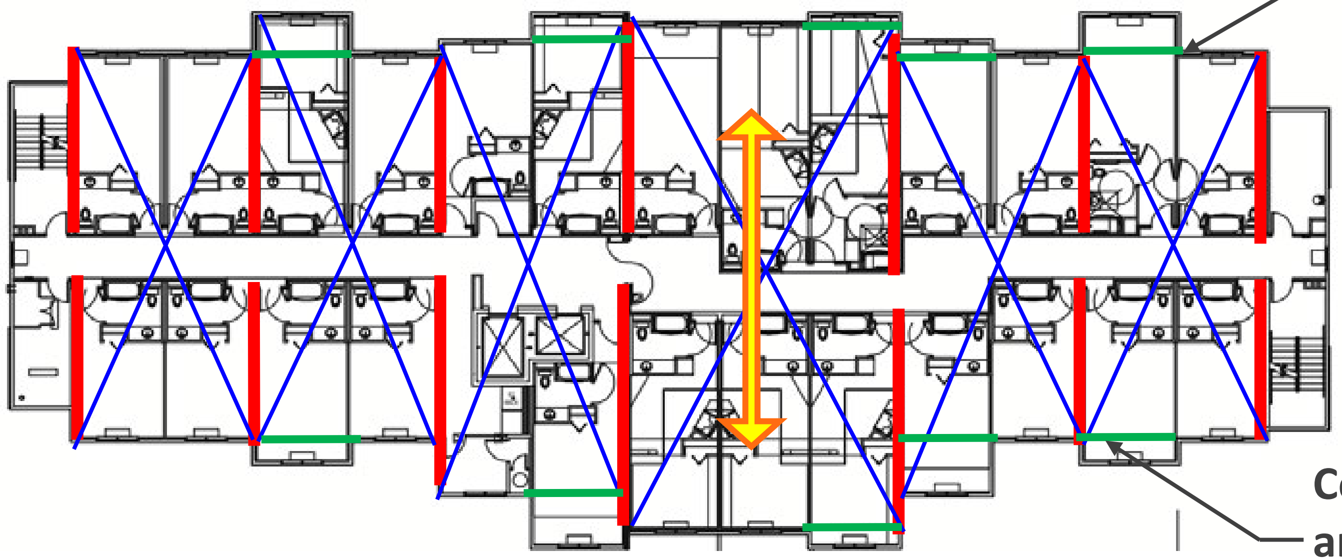
12.3.1.4 Rigid Diaphragm Condition
Diaphragms in hillside structures of light-frame construction shall be modeled as rigid or semirigid when they are seismically braced on one or more sides directly by the foundation or foundation stem wall or by a framed wall with a clear height of 2 ft (0.61 m) or less, and are also seismically braced on other sides by framed walls with any wall having a clear height of more than 7ft(2.13m). Other diaphragms shall be idealized as flexible or rigid in accordance with Sections 12.3.1.1, 12.3.1.2, or 12.3.1.3, or shall be modeled as semirigid.



ASCE 7-22, Figure C12.3-1a



Multi-Story Wind and Seismic Design



Offsets create diaphragm chord discontinuities

Aspect ratios visually suggest diaphragms are semi-rigid.

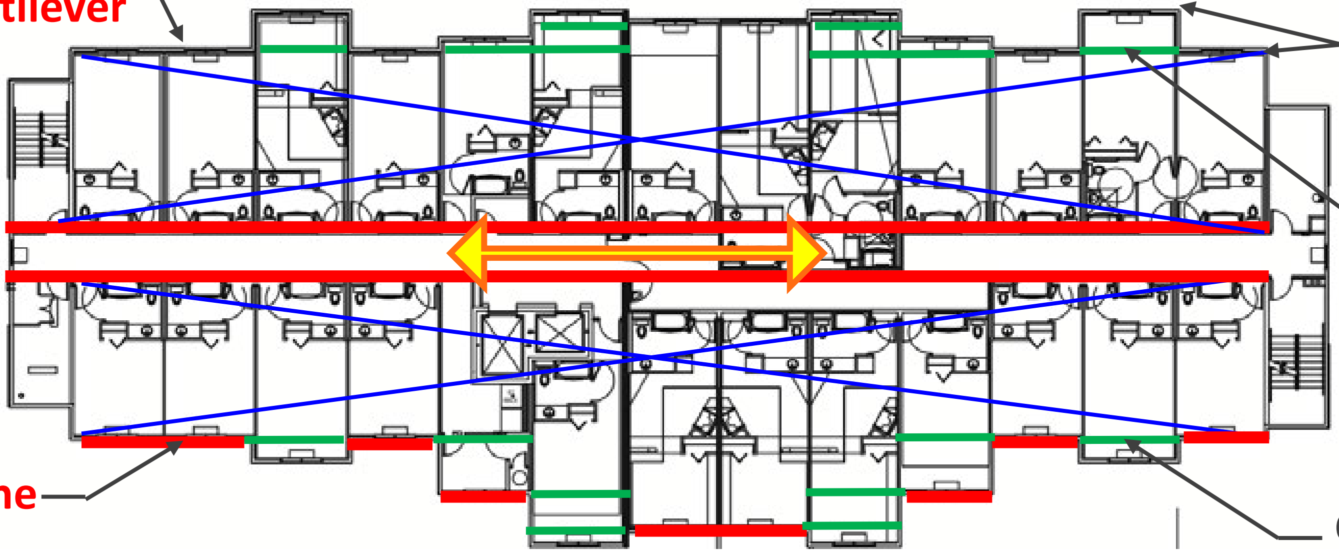
Collectors are required to act as chords and address chord discontinuity

Potential Shear Wall Layouts

Multi-Story Wind and Seismic Design

No SWs this line creates cantilever diaphragm

Drift and diaphragm flexibility check at extreme corners



Collectors are required to act as chords and address chord discontinuity. If no shear walls here, this becomes a cantilever diaphragm.

SWs this line

Collectors are required to connect shear walls across offsets

Potential Shear Wall Layouts

Diaphragm Classification – Seismic Flowchart

Start

Is diaphragm Wood Structural Panels Or untopped steel decking

Yes →

Is **any** of the following true?		
1 & 2 Family Dwelling	Vertical elements one of the following: 1. Steel braced frames 2. Composite steel and concrete braced frames 3. Concrete, masonry, steel shear walls or composite concrete and steel shear walls	Light frame construction where all of the following are met: 1. Topping of concrete or similar material is not placed of wood structural panel diaphragms except for non-structural topping ≤ 1-1/2" thick. 2. Each line of vertical elements of the seismic force-resisting system complies with the allowable story drift of Table 12.12-1.

Yes → **Idealize as flexible**

No →

No → Is diaphragm concrete slab or concrete filled steel deck?

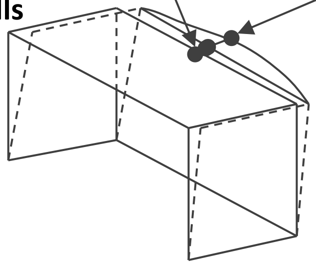
Yes → Is span to depth ratio ≤ 3 and having no horizontal irregularities?

Yes → **Idealize as rigid**

No →

No →

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

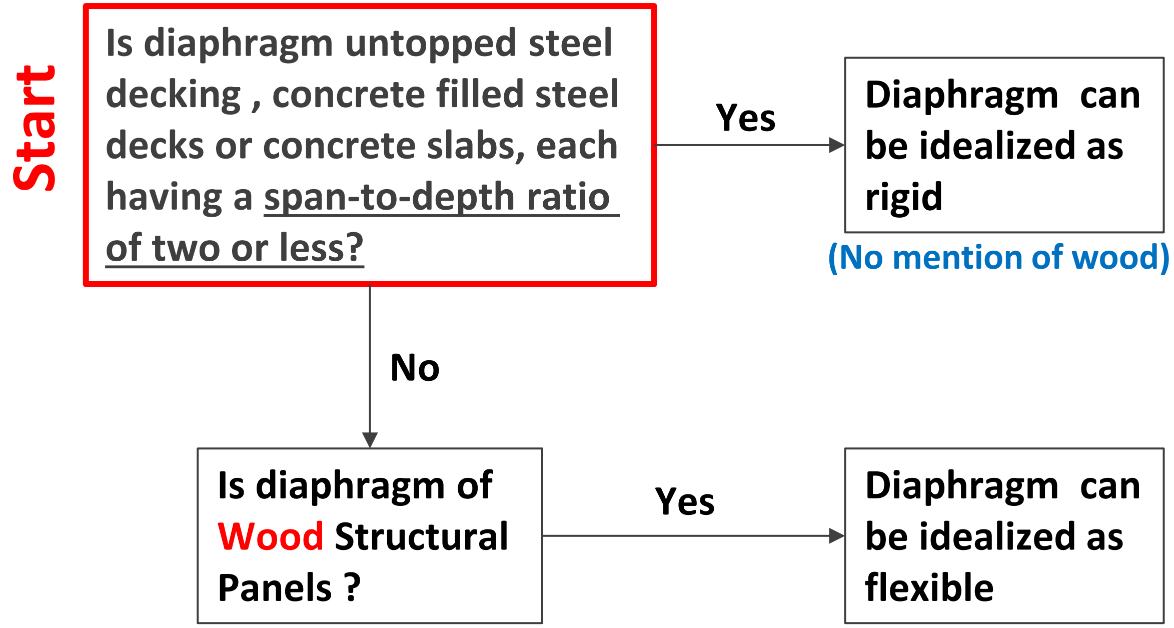


Yes → **Idealize as flexible**

No → **Structural analysis must explicitly include consideration of the stiffness of the diaphragm (i.e. semi-rigid modeling), or calculated as rigid in accordance with 2021 IBC Section 1604.4 or ASCE 7-16, 22 Section 12.3.1.2.**

Envelope method allowed for semi-rigid modelling

Diaphragm Classification – Wind Flowchart



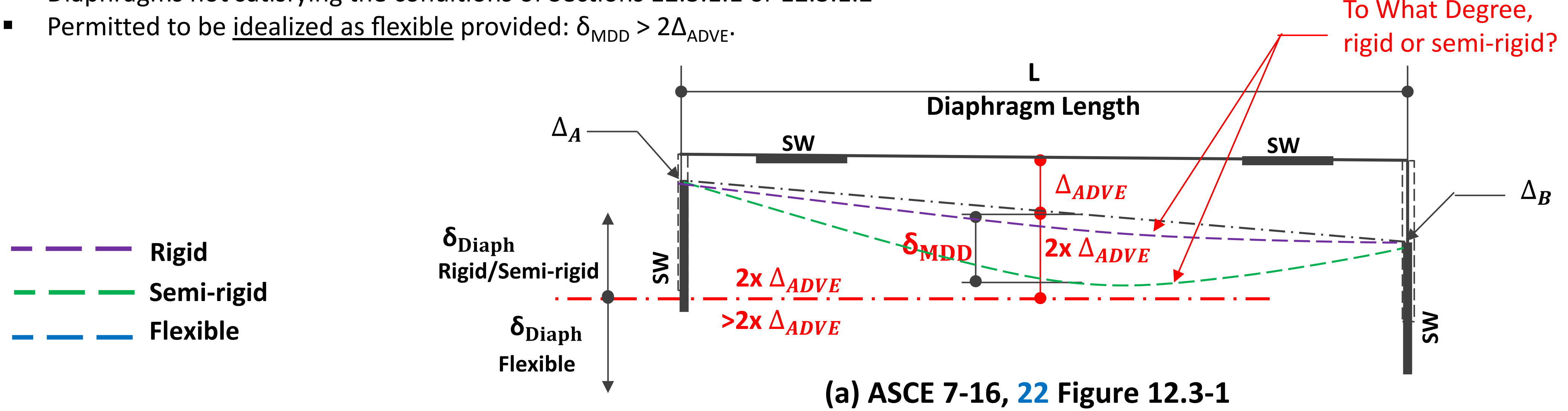
ASCE 7-22, SECTION 26.2

Diaphragm Flexibility – Simple Span

- ASCE 7-16, 22
  - 12.3.1.1 Flexible Diaphragm Condition.
    - Untopped steel decking or wood structural panels
    - Permitted to be <u>idealized as flexible</u> under certain conditions.
  - 12.3.1.2 Rigid Diaphragm Condition.
    - Concrete slabs or concrete-filled metal deck (No mention of wood)
    - Span-to-depth ratios of 3 or less with no horizontal irregularities
    - Permitted to be <u>idealized as rigid.</u>
  - 12.3.1.3 Calculated Flexible Diaphragm Condition. (No calculated Rigid condition)
    - Diaphragms not satisfying the conditions of Sections 12.3.1.1 or 12.3.1.2
    - Permitted to be <u>idealized as flexible</u> provided: $\delta_{MDD} > 2\Delta_{ADVE}$.

- 2021 IBC Section 1604.4:
  - A diaphragm is <u>rigid</u> when $\delta_{MDD} \leq 2\Delta_{ADVE}$

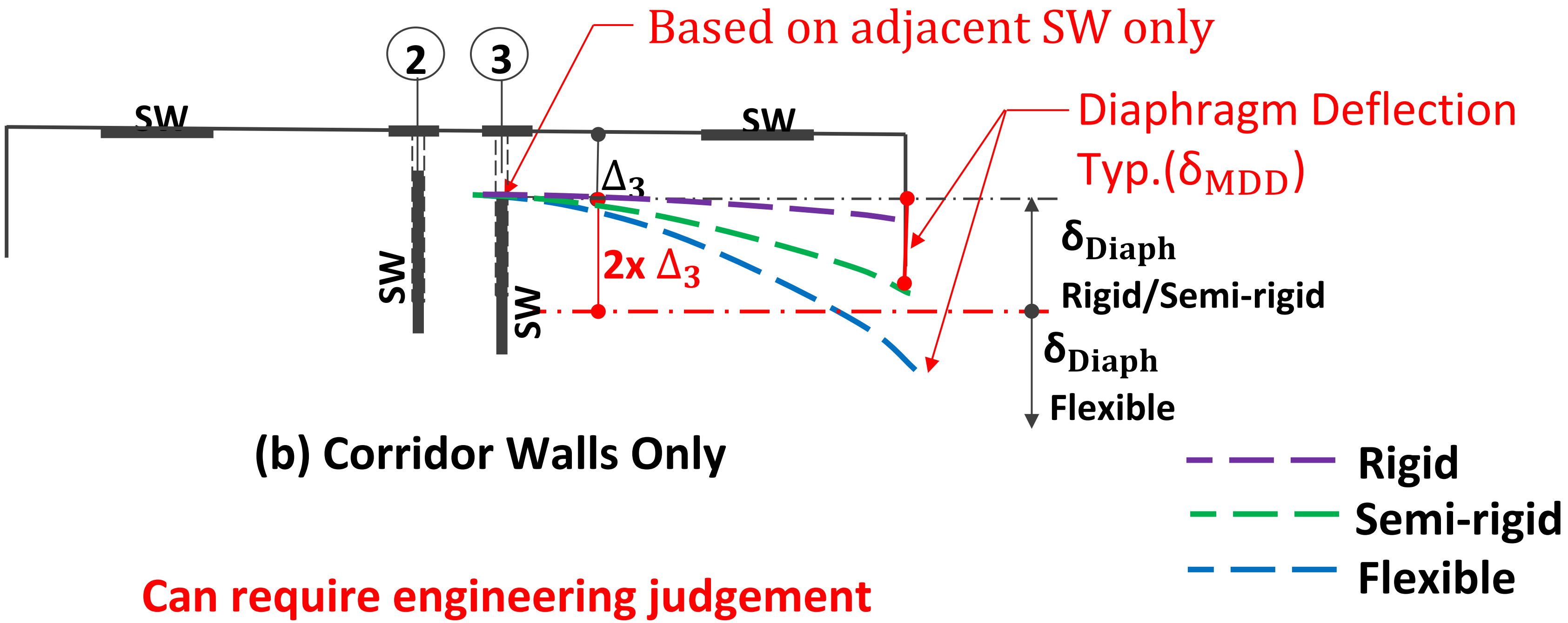
- 2021 SDPWS 4.1.7.2 Horizontal Distribution of Shear
  - <u>Idealize as rigid</u> when <u>computed</u> $\delta_{MDD} \leq 2\Delta_{ADVE}$



(a) ASCE 7-16, 22 Figure 12.3-1

Simple Span Diaphragm

Diaphragm Flexibility – Cantilever



(b) Corridor Walls Only

Can require engineering judgement

SDPWS 4.1.7.2 Rigid Diaphragm

"…A cantilever diaphragm shall be permitted to be idealized as rigid when the calculated maximum in-plane deflection of the diaphragm itself under lateral load is **less than or equal to** two times the deflection of adjoining vertical elements of the associated LFRS of the story below used to determine the cantilever length, L' (See Figure 4A)…"

Diaphragm Classification – Pros & Cons

Flexible	Rigid	Semi-Rigid
Simple distribution based on tributary area	Allows easier determination of building drift	Difficult to model and analyze
Can underestimate forces to long lengths of shear walls, and over-estimate forces to short lengths of shear walls	More conservatively distributes forces to longer lengths of shear walls (i.e. corridors and demising walls)	Need to consider vertical element stiffness in addition to diaphragm stiffness
May not represent diaphragm shear forces correctly	Can over-estimate torsional drift	Option for envelope analysis
	May not represent diaphragm shear forces correctly	

Weigh your options & use your engineering judgement

NOTE: Offsets in diaphragms can also affect the distribution of shear in the diaphragm due to changes in the diaphragm stiffness.

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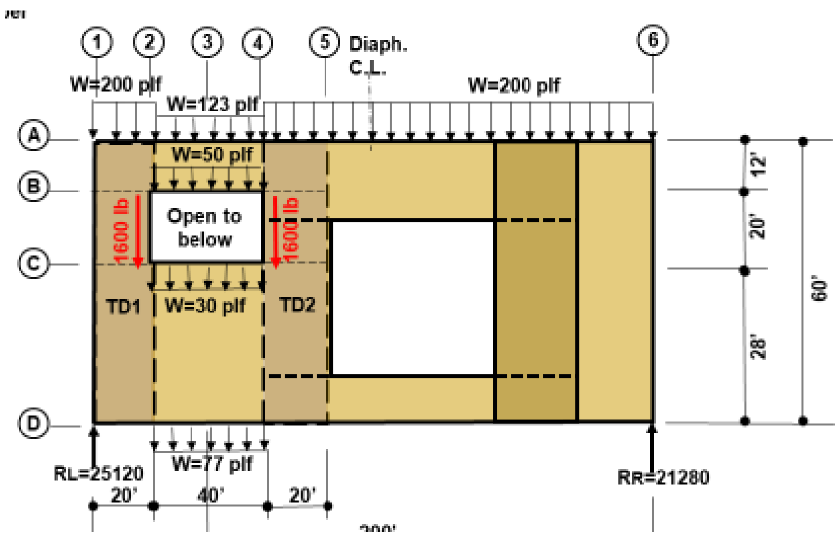
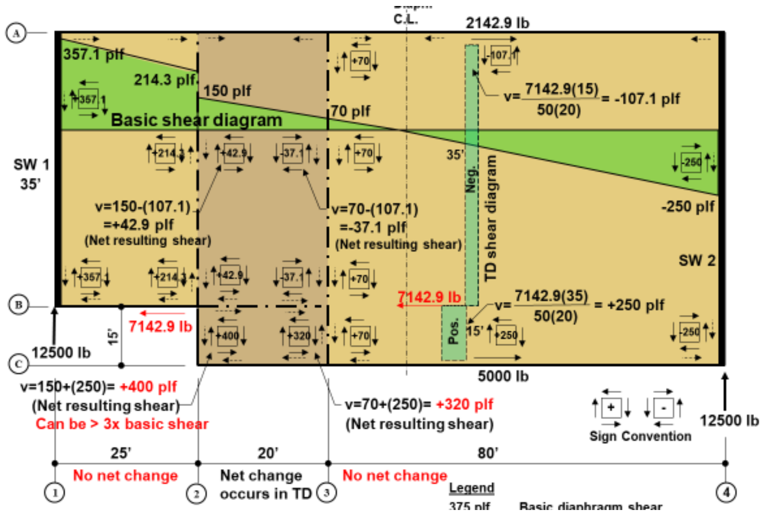
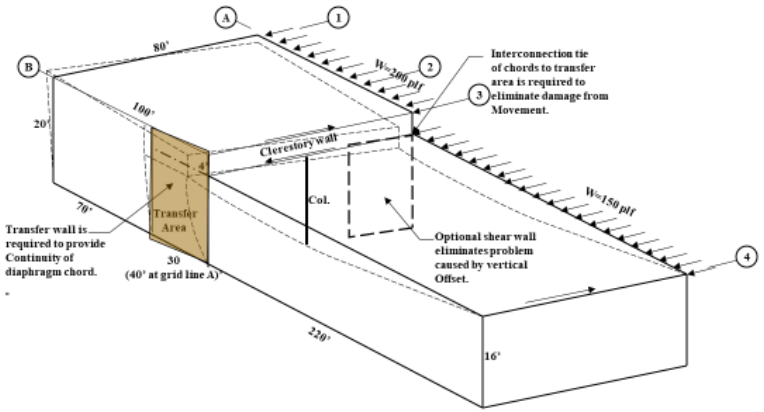
Conditions Affecting Diaphragm Stiffness



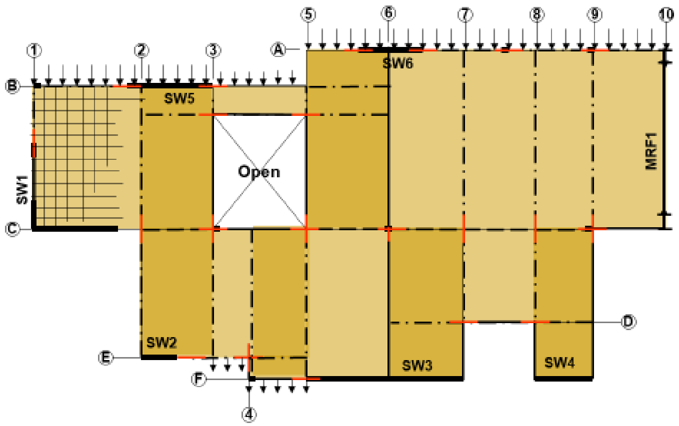
Diaphragms with Openings



Horizontally Offset Diaphragms

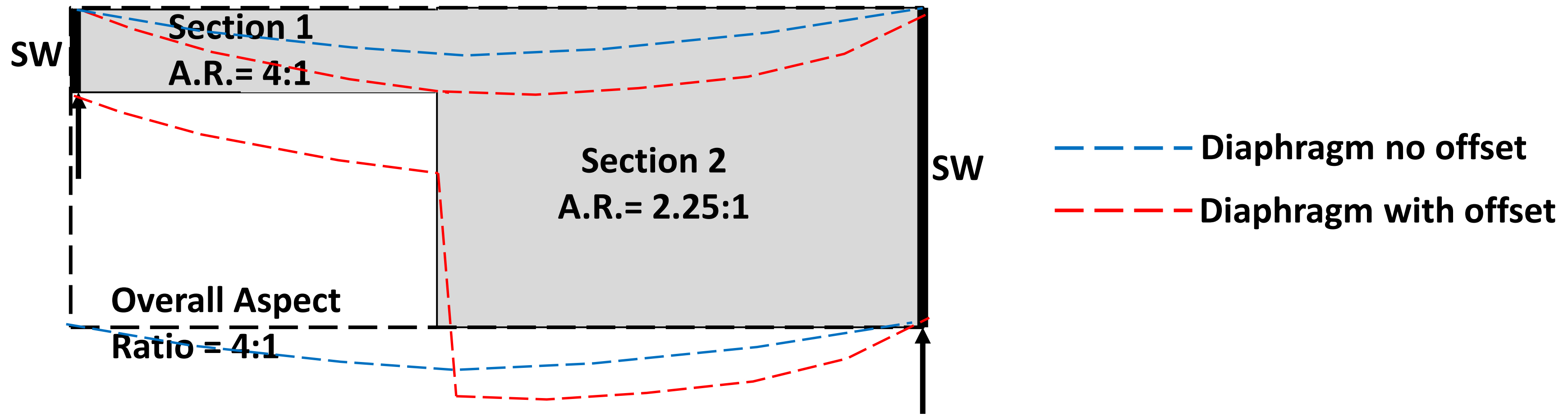


Vertically Offset Diaphragms



Irregular Shaped Diaphragms

Aspect Ratios for Irregular Shaped Diaphragms



Unacceptable Layout

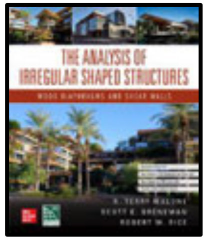
4.2.2 Maximum Diaphragm Aspect Ratios

Diaphragm Sheathing Type	Maximum L/W Ratio
Wood structural panel, unblocked	3:1
Wood structural panel, blocked	4:1
Single-layer straight lumber sheathing	2:1
Single-layer diagonal lumber sheathing	3:1
Double-layer diagonal lumber sheathing	4:1

Courtesy, American Wood Council, Leesburg, VA.

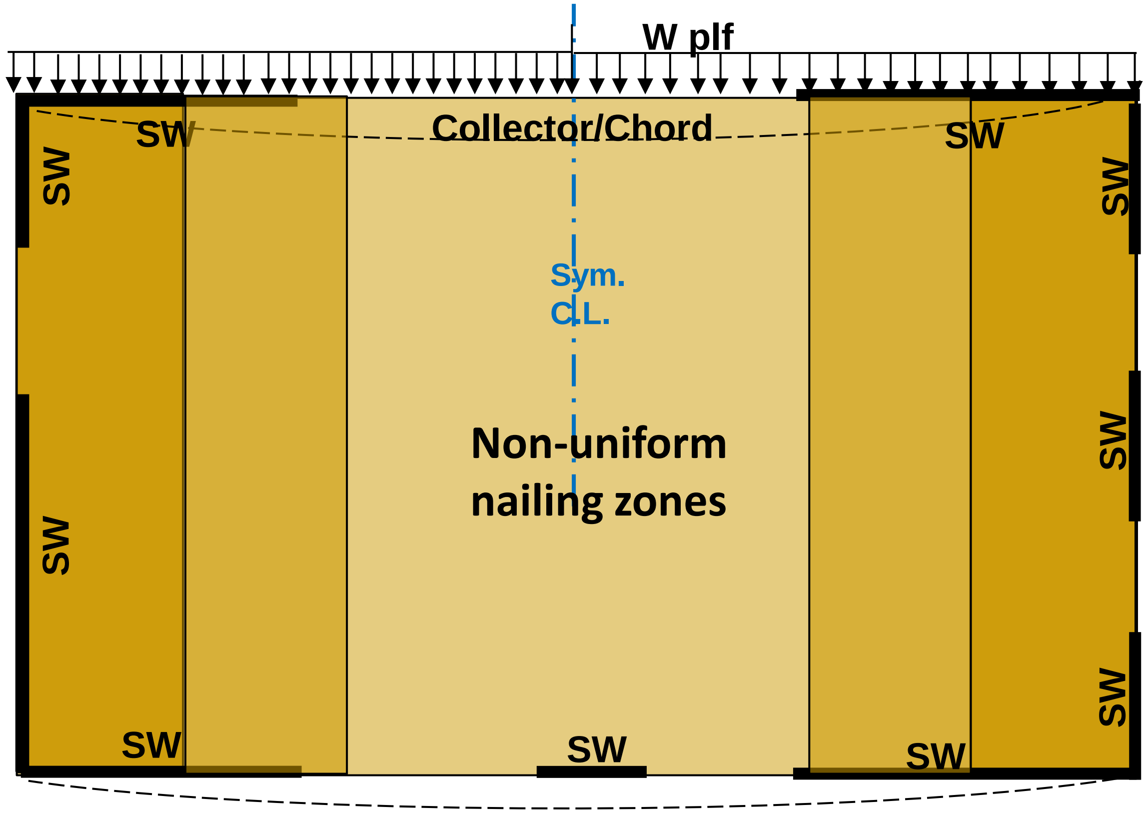
SDPWS Table 4.2.2
Maximum Diaphragm Aspect Ratios (Horizontal or sloped diaphragms)

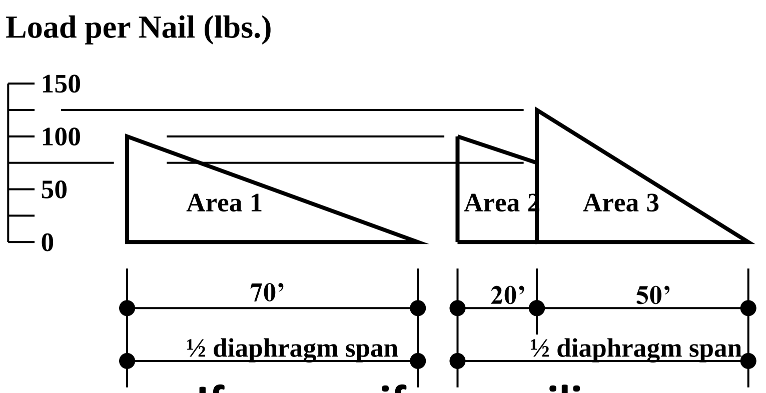
Excerpts from the
2nd Edition, 2022



Terry Malone, PE, SE
Scott Breneman, PhD, PE, SE
Robert Rice, CBO

Blocked/Unblocked Diaphragm Combinations





If non-uniform nailing:

- **Modified nail slip constant = 0.188(Vn')/Vn .**
- **SDPWS 3-term equation and tables have an apparent shear stiffness value, Ga, for blocked and unblocked (seismic), However, no guidance for mixing blocked and unblocked portions of the diaphragm.**

Deflection Equations-Simply Supported Rectangular Diaphragm

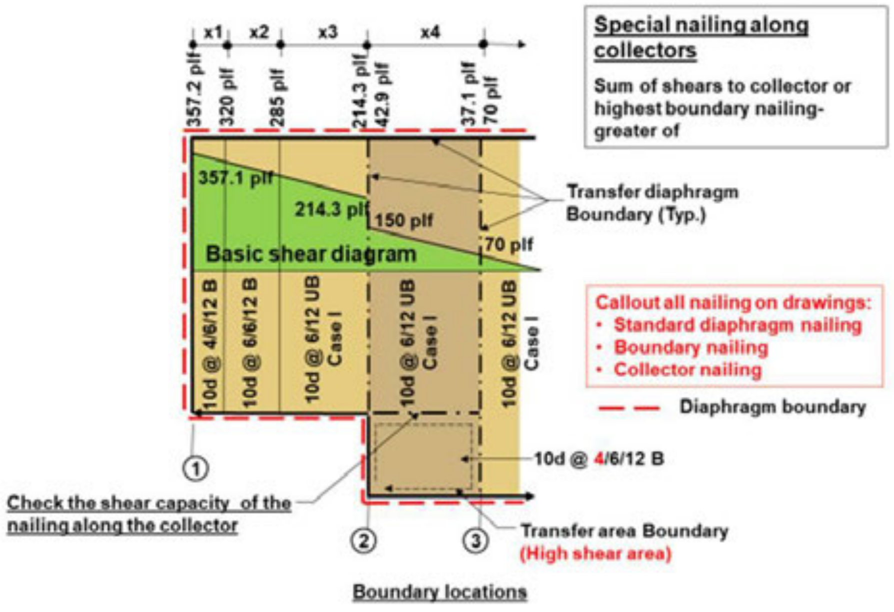
$$\delta_{Diaph\ Unif} = \frac{3v_{max}L'^3}{EAW'} + \frac{0.5v_{max}L'}{1000G_a} + \frac{\Sigma A_C X_C}{W'} \qquad \text{3-term eq.}$$

$$\delta_{\mathrm{Diaph\ Unif}} = \frac{3vL'^3}{EAW'} + \frac{0.5vL'}{Gvtv} + 0.376\,L'\,e_n + \frac{\Sigma x\Delta_C}{W'} \qquad \text{4-term eq.}$$

Both equations are based on:

- **Uniform load full length of diaphragm.**
- **Uniform nailing and nail size full length of diaphragm.**
- **Blocking full length of diaphragm.**

Blocked/Unblocked Diaphragm Examples



Diaphragm Nailing Callouts

Offsets or large openings will increase shears in the diaphragm.

Example 5, 2006 SEAOC Seismic Design Manual, Volume 2

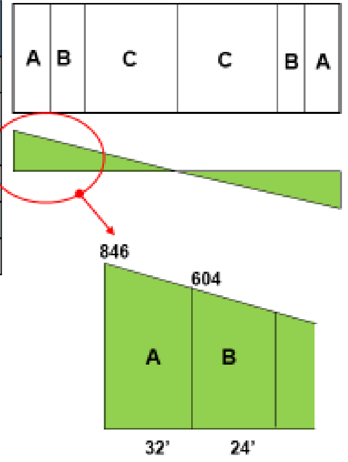
Another method based on virtual work principles is presented in SEAOC's 2006 IBC Structural/Seismic Design Manual (SEAOC, 2006). This method creates a table format computing average shears over respective diaphragm lengths.

$$\Delta_{shear} = \Sigma \frac{0.5 v_{i\ ave} L_i}{1000 G_{ai}}$$ Virtual work Eq.

Where:
Vi=the average diaphragm shear within each shear stiffness zone.
Li=the length of each stiffness zone measured perpendicular to the loading.
Gai=the apparent shear stiffness of each shear stiffness zone being considered.

Zone	Vi left	Vi right	Vi ave	Li	Ga	$\frac{0.5 v_{i\ ave} L_i}{1000 G_{ai}}$
A	846	604	725	32'	20	0.58"
B	604	423	514	24	15	0.41"
C	423	0	212	56	24	0.25"
C	0	423	212	56	24	0.25"
B	423	604	514	24	15	0.41"
A	604	846	725	32	20	0.58"
						2.48"

Web shear plus nail slip deflection



1. If 3-term equation, Ga from Table 4.2C must be used for unblocked diaphragm areas.
2. If 4-term equation, unblocked area deflection of diaphragm might have to be increased per TT-064 for Zone C. (e.g., 2.5x or 3.0x)

(Far too big)
4-15

Virtual work can be used to solve for the shear deflection in zones of different shear stiffness. Also refer to ATC-7 for examples.

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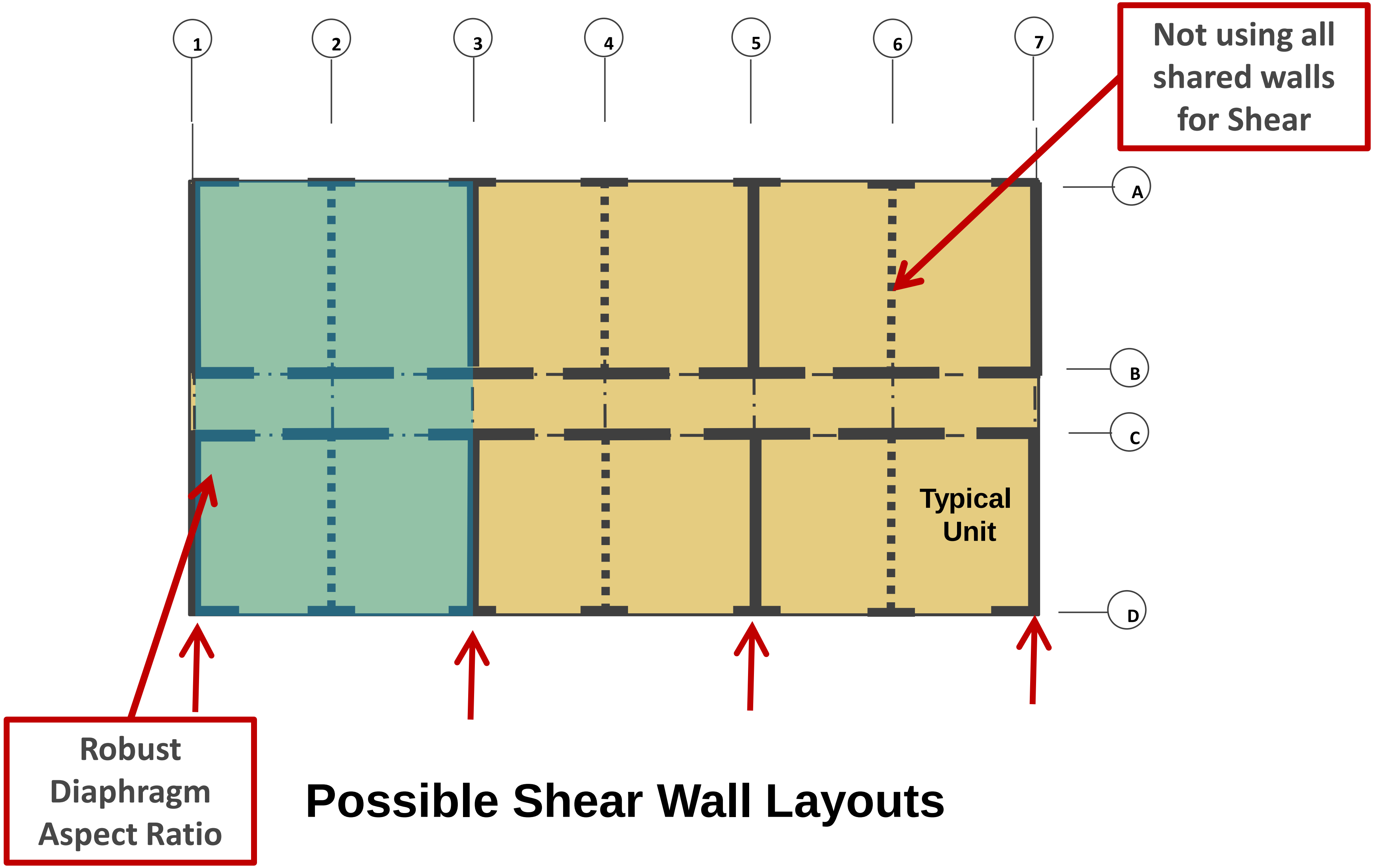
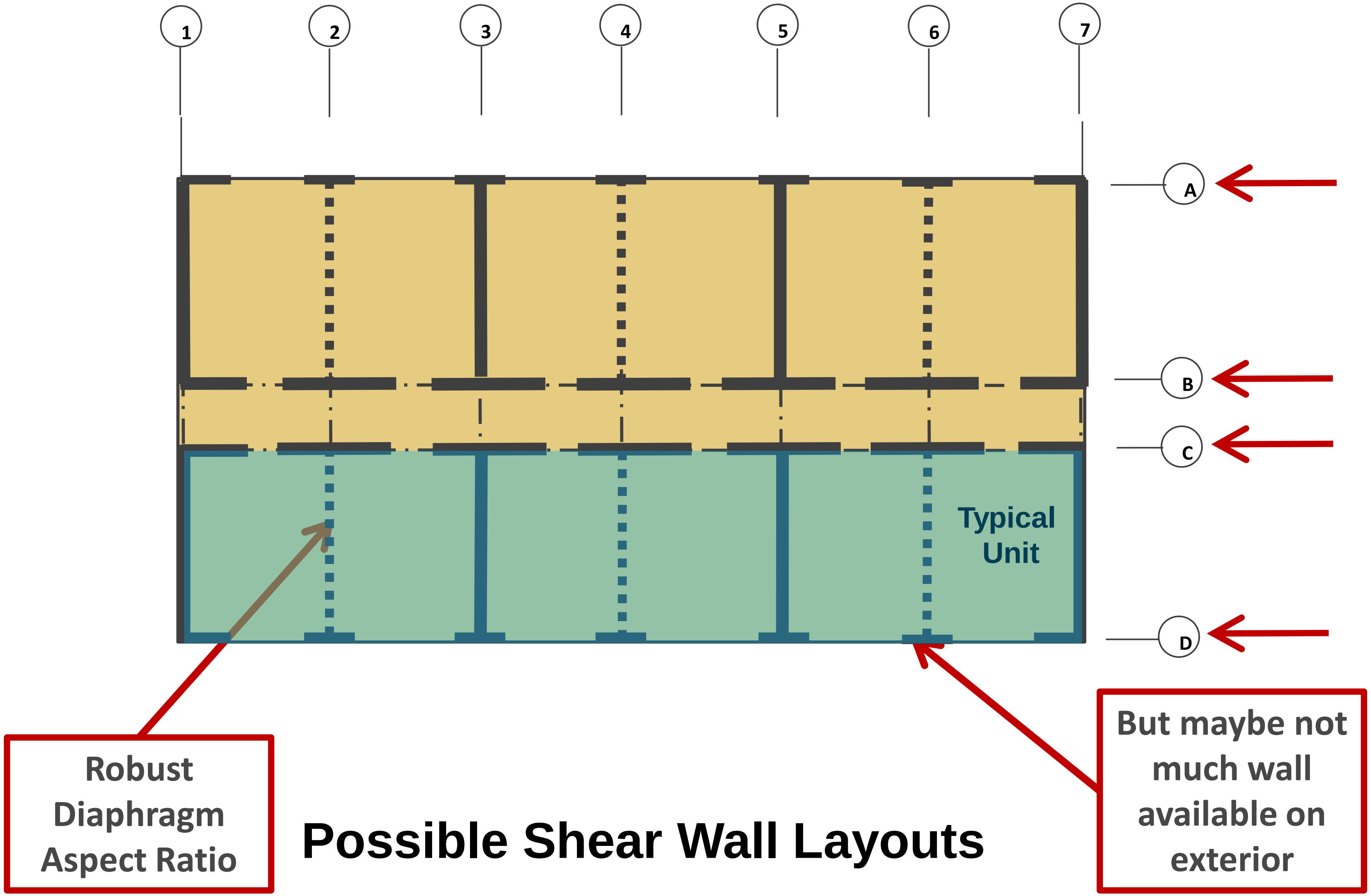
Multi-Story Lateral Design

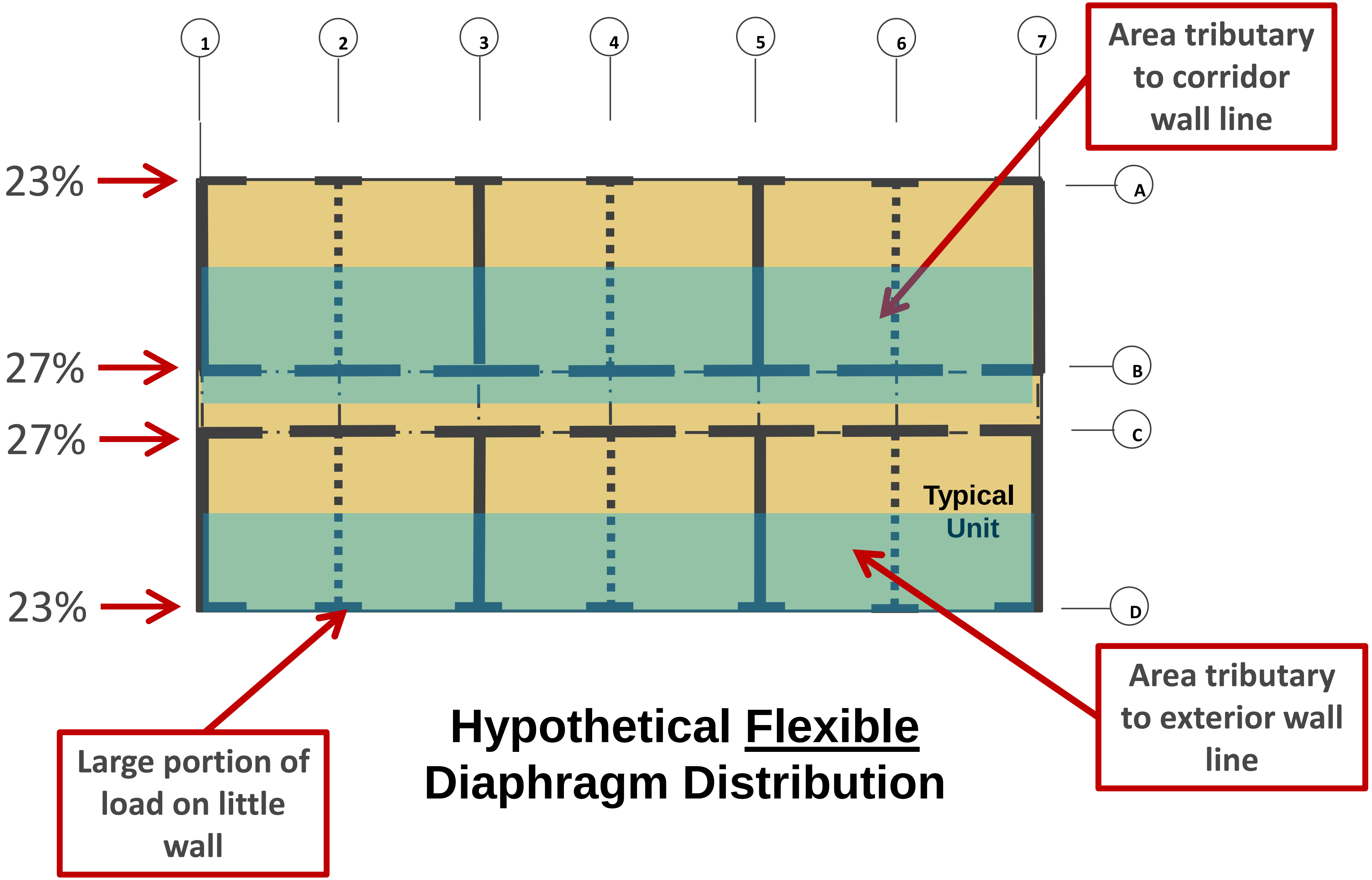


Possible Shear Wall Layouts

Multi-Story Lateral Design

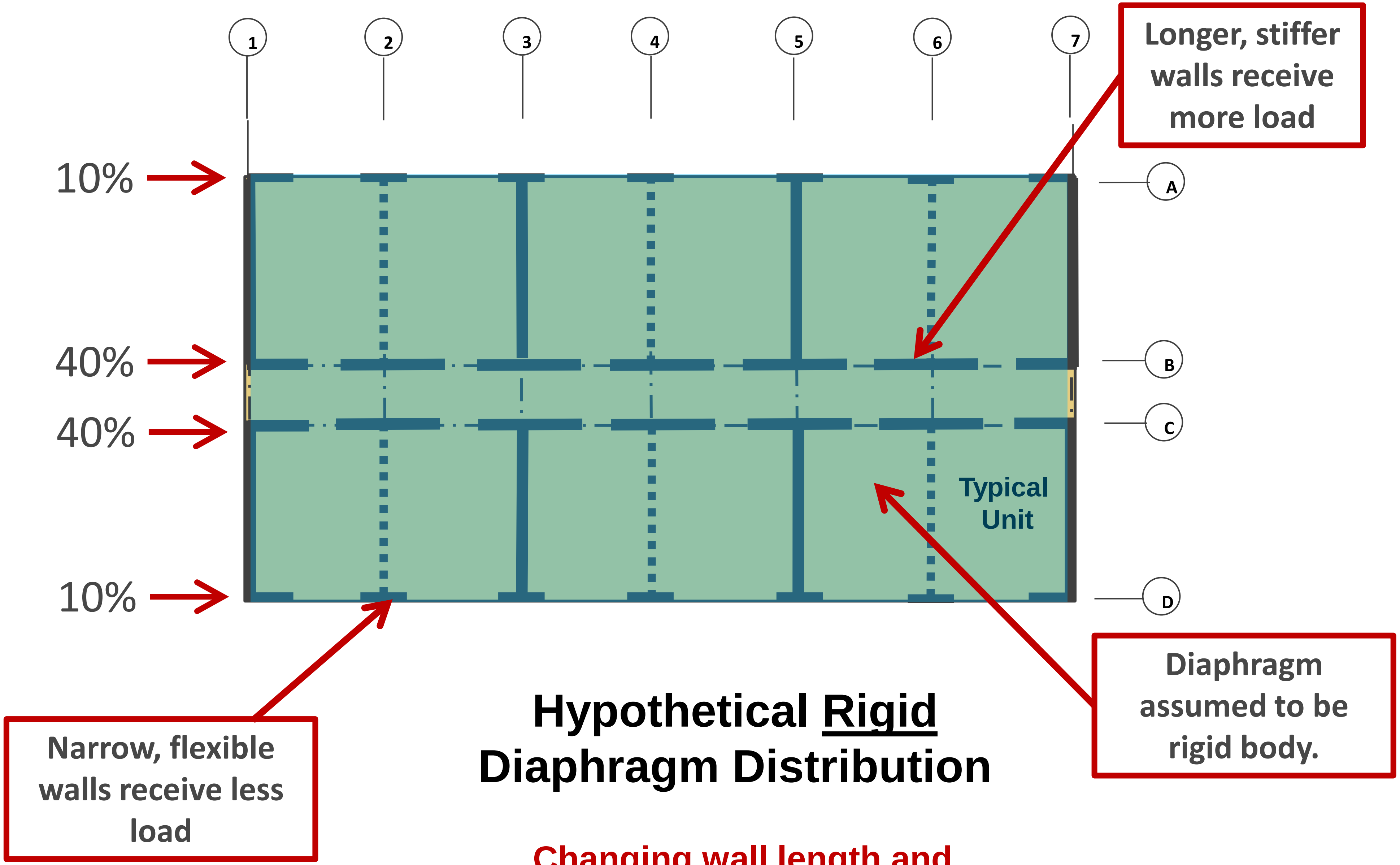


Possible Shear Wall Layouts



Hypothetical Flexible Diaphragm Distribution

Changing wall construction does NOT impact load to wall line



Hypothetical <u>Rigid</u> Diaphragm Distribution

Changing wall length and construction does impacts load to wall line

Two More Diaphragm Approaches

Semi-Rigid Diaphragm Analysis

» Neither idealized flexible nor idealized rigid

» Explicit modeling of diaphragm deformations with shear wall deformations to distribute lateral loads

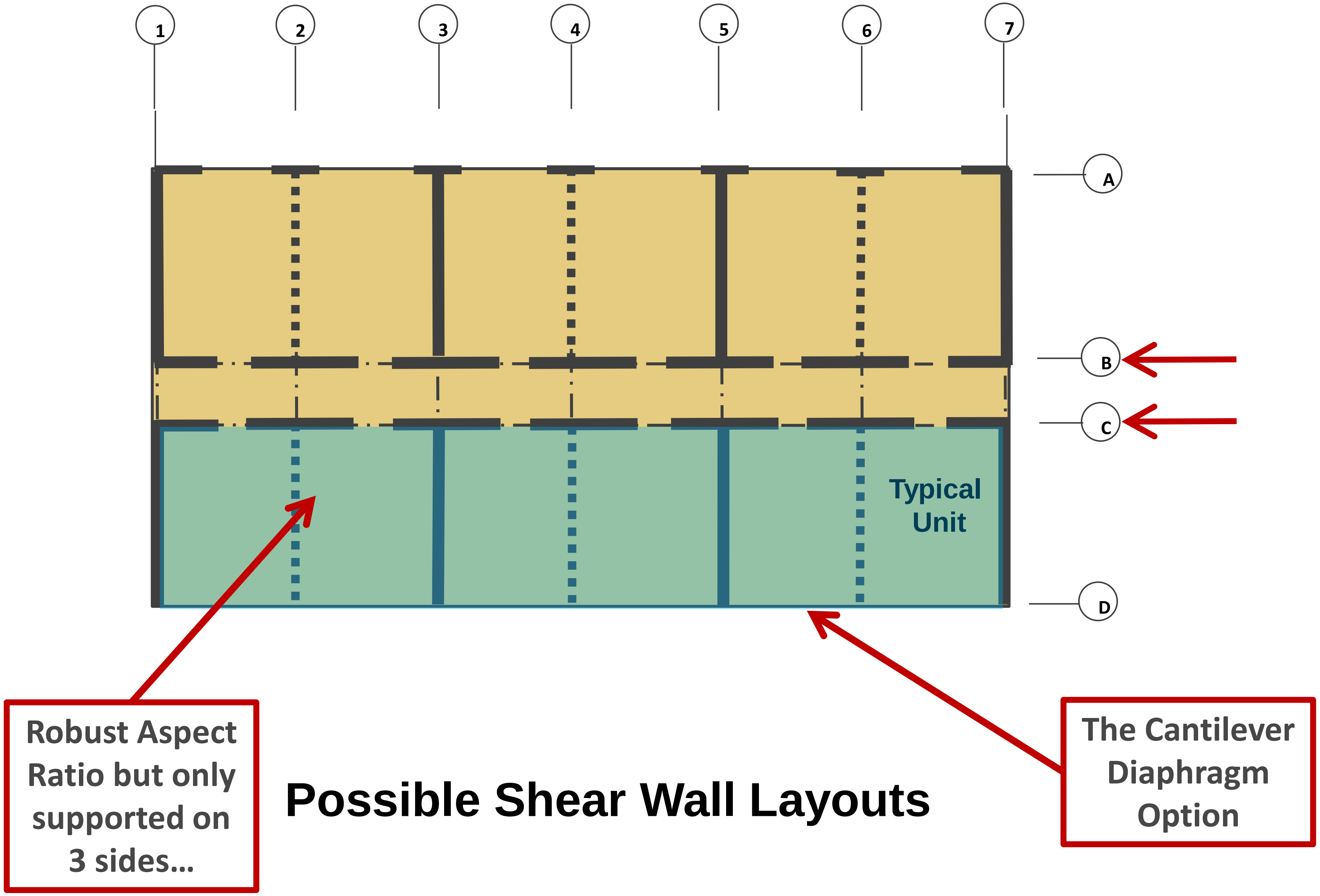
» Not quick or easy

Enveloping Method

» Idealized as BOTH flexible and rigid.

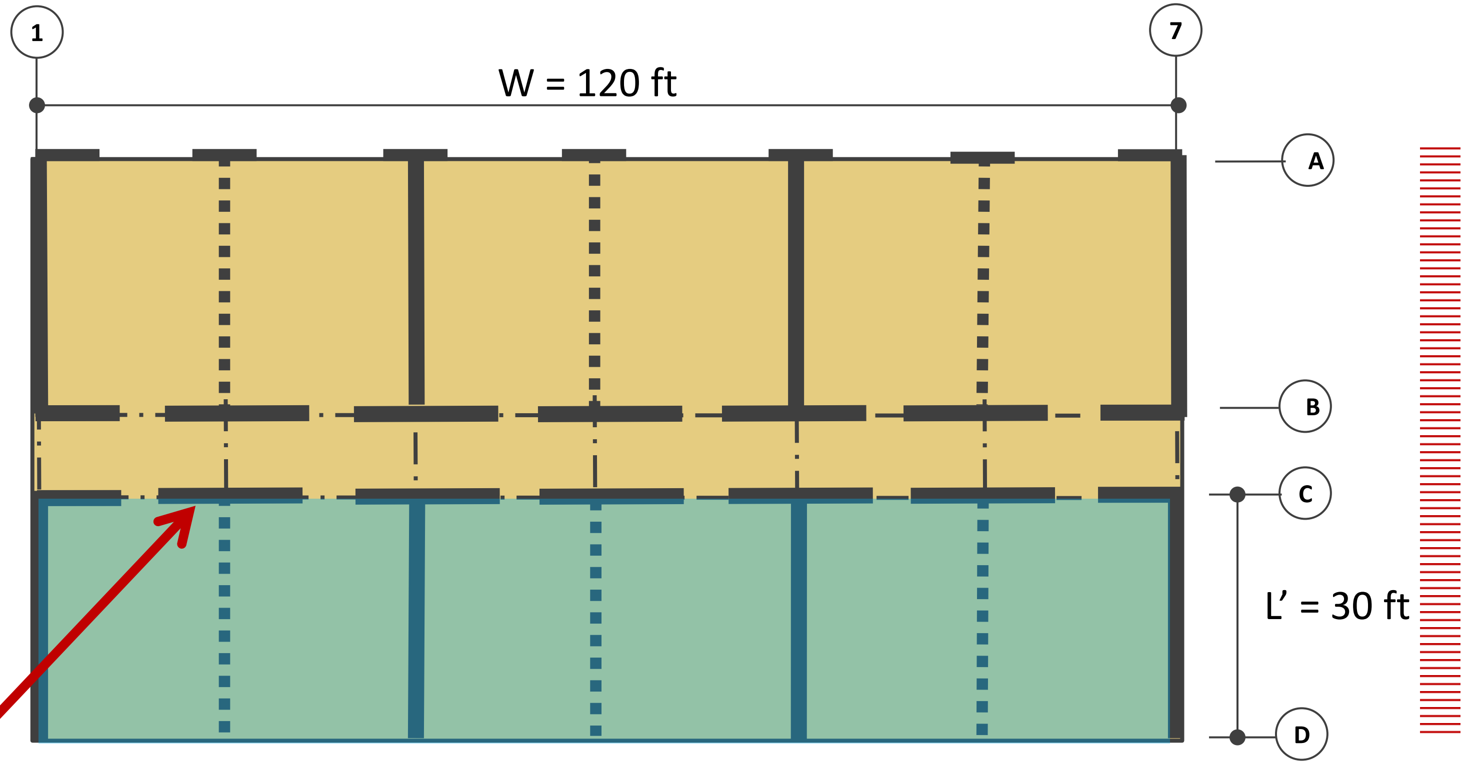
» Individual components designed for worst case from each approach

» Recognized in the SDPWS as alternative to semi-rigid



Possible Shear Wall Layouts

Simple example with a few numbers



w = 10 psf
ASD Seismic

ASD design diaphragm
shear at support line
v = 10 psf (30 ft) = 300 plf

Use 19/32" OSB Sheathing with 10d at 6" o.c. each way in 2" Doug-Fir Larch or Southern Pine framing

Table 4.2A Nominal Unit Shear Capacities for Sheathed Wood-Frame Diaphragms

Blocked Wood Structural Panel Diaphragms[1,2,3,4,6]

Sheathing Grade	Common Nail Size[5] Length (in.) x Shank diameter (in.) x Head diameter (in.)	Minimum Nail Bearing Length in Framing Member or Blocking, ℓ_m (in.)	Minimum Nominal Panel Thickness (in.)	Minimum Nominal Width of Nailed Face at Adjoining Panel Edges and Boundaries (in.)	Nail Spacing (in.) at diaphragm boundaries (all cases), at continuous panel edges parallel to load (Cases 3 & 4), and at all panel edges (Cases 5 & 6)											
					6			4			2-1/2			2		
					Nail Spacing (in.) at other panel edges (Cases 1,2,3, & 4)											
					6			6			4			3		
					v_n (plf)	G_a (kips/in.)		v_n (plf)	G_a (kips/in.)		v_n (plf)	G_a (kips/in.)		v_n (plf)	G_a (kips/in.)	
						OSB	PLY		OSB	PLY		OSB	PLY		OSB	PLY
Sheathing and Single-Floor	6d (2 x 0.113 x 0.266)	1-1/4	5/16	2	475	15	10	630	9.0	7.0	940	13	9.5	1065	21	13
				3	530	12	9.0	700	7.0	6.0	1065	10	8.0	1205	17	12
			3/8	2	520	13	9.5	700	7.0	6.0	1050	10	8.0	1175	18	12
				3	590	10	8.0	785	5.5	5.0	1175	8.5	7.0	1330	14	10
	8d (2-1/2 x 0.131 x 0.281)	1-3/8	3/8	2	670	15	11	895	9.5	7.5	1345	13	9.5	1525	21	13
				3	755	12	9.5	1010	7.5	6.0	1510	11	8.5	1710	18	12
			7/16	2	715	14	10	950	8.5	7.0	1415	12	9.5	1610	20	13
				3	800	11	9.0	1065	7.0	6.0	1595	10	8.0	1805	17	12
			15/32	2	755	13	9.5	1010	7.5	6.5	1485	11	8.5	1680	19	13
				3	840	10	8.5	1120	6.0	5.5	1680	9.0	7.5	1890	15	11
	10d (3 x 0.148 x 0.312)	1-1/2	15/32	2	810	25	15	1080	15	11	1610	21	14	1835	33	18
				3	910	21	14	1205	12	9.5	1820	17	12	2060	28	16
			19/32	2	895	21	14	1190	13	9.5	1790	18	12	2045	28	17
				3	1010	17	12	1345	10	8.0	2015	14	11	2295	24	15

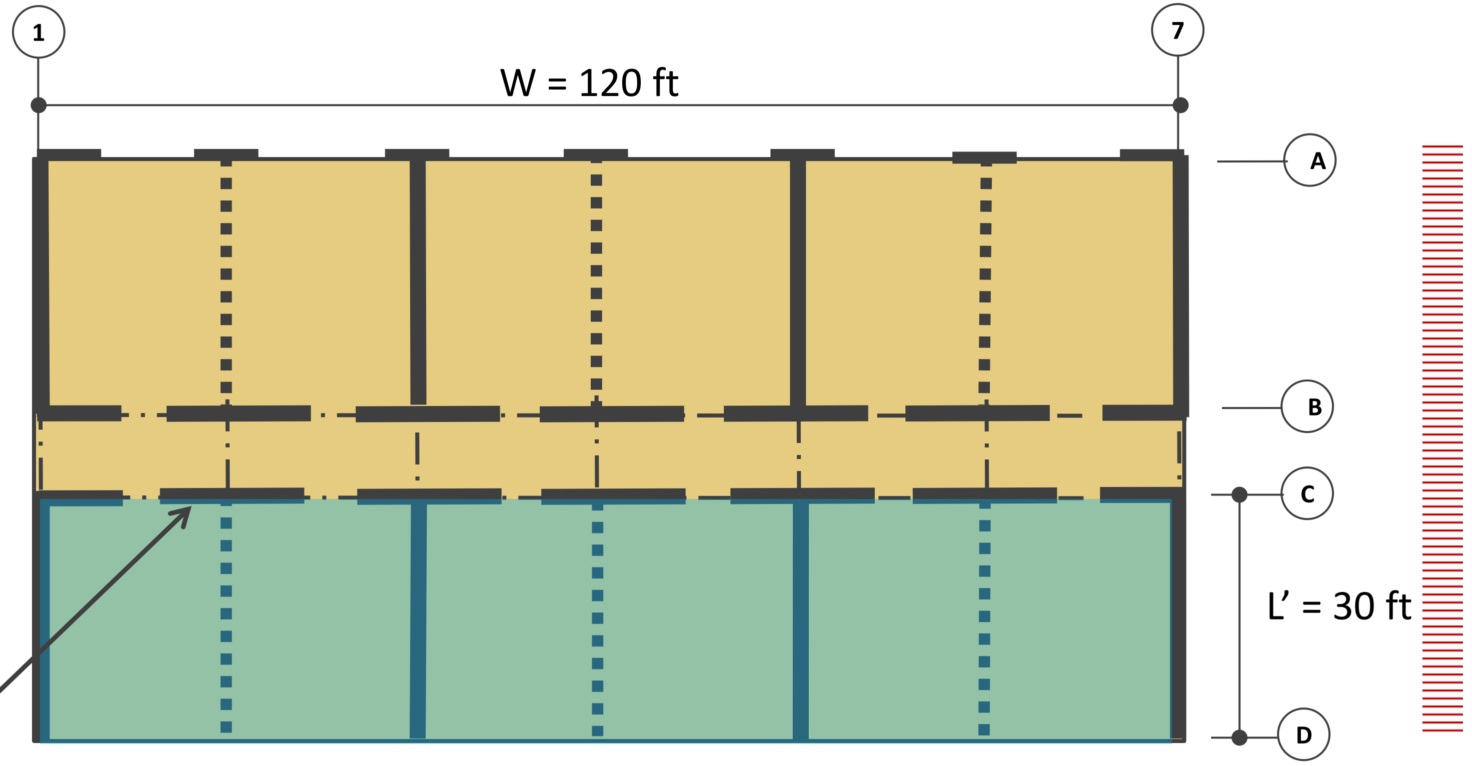
Shear capacity check

v_n =895 plf

ASD Seismic Capacity = 895 plf / 2.8 = 319 plf > 300 plf

Strength Sufficient

2.8 per SDPWS 2021 4.1.4



w = 10 psf
ASD Seismic

ASD design diaphragm
shear at support line
v = 10 psf (30 ft) = 300 plf

Flexible diaphragm assumption not valid per SDPWS 4.2.6
Does this diaphragm qualify at a Rigid Diaphragm? Check at LRFD level forces

$$\delta_{dia,cant} = \frac{3vL'^3}{EAW'} + \frac{0.5vL'}{1000G_a} + \frac{\Sigma(x'\Delta_C)}{W'} = 0.33\ in$$

Shear Wall design:
15/32” OSB Sheathing with 10d at 6” o.c.
on DF or SP framing near 100% Capacity

$$\delta_{wall} = \frac{8vh^3}{EAb} + \frac{vh}{1000G_a} + \frac{h}{b}\Delta_a = 0.16\ in$$

$$\mathbf{0.33\ in > 2\ (0.16) = 0.32\ in}$$

Does not qualify as Rigid!!
(it’s close)

How to stiffen a diaphragm: More nails?

Table 4.2A Nominal Unit Shear Capacities for Sheathed Wood-Frame Diaphragms

Blocked Wood Structural Panel Diaphragms[1,2,3,4,6]

Sheathing Grade	Common Nail Size[5] Length (in.) x Shank diameter (in.) x Head diameter (in.)	Minimum Nail Bearing Length in Framing Member or Blocking, ℓ_m (in.)	Minimum Nominal Panel Thickness (in.)	Minimum Nominal Width of Nailed Face at Adjoining Panel Edges and Boundaries (in.)	Nail Spacing (in.) at diaphragm boundaries (all cases), at continuous panel edges parallel to load (Cases 3 & 4), and at all panel edges (Cases 5 & 6): 6			4			2-1/2			2		
					Nail Spacing (in.) at other panel edges (Cases 1,2,3, & 4): 6			6			4			3		
					v_n (plf)	G_a (kips/in.) OSB	PLY	v_n (plf)	G_a (kips/in.) OSB	PLY	v_n (plf)	G_a (kips/in.) OSB	PLY	v_n (plf)	G_a (kips/in.) OSB	PLY
[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sheathing and Single-Floor	6d (2 x 0.113 x 0.266)	1-1/4	5/16	2	475	15	10	630	9.0	7.0	940	13	9.5	1065	21	13
				3	530	12	9.0	700	7.0	6.0	1065	10	8.0	1205	17	12
			3/8	2	520	13	9.5	700	7.0	6.0	1050	10	8.0	1175	18	12
				3	590	10	8.0	785	5.5	5.0	1175	8.5	7.0	1330	14	10
	8d (2-1/2 x 0.131 x 0.281)	1-3/8	3/8	2	670	15	11	895	9.5	7.5	1345	13	9.5	1525	21	13
				3	755	12	9.5	1010	7.5	6.0	1510	11	8.5	1710	18	12
			7/16	2	715	14	10	950	8.5	7.0	1415	12	9.5	1610	20	13
				3	800	11	9.0	1065	7.0	6.0	1595	10	8.0	1805	17	12
			15/32	2	755	13	9.5	1010	7.5	6.5	1485	11	8.5	1680	19	13
				3	840	10	8.5	1120	6.0	5.5	1680	9.0	7.5	1890	15	11
	10d (3 x 0.148 x 0.312)	1-1/2	15/32	2	810	25	15	1080	15	11	1610	21	14	1835	33	18
				3	910	21	14	1205	12	9.5	1820	17	12	2060	28	16
			19/32	2	895	21	[illegible]	[illegible]	13	[illegible]	[illegible]	18	12	[illegible]	28	17
				3	1010	17	12	1345	10	8.0	2015	14	11	2295	24	15

Same framing with more nails <u>often does not increase</u> stiffness G_a, so often not helpful

How to stiffen a diaphragm: Plywood vs OSB?

Table 4.2A Nominal Unit Shear Capacities for Sheathed Wood-Frame Diaphragms

Blocked Wood Structural Panel Diaphragms[1,2,3,4,6]

Sheathing Grade	Common Nail Size[5] Length (in.) x Shank diameter (in.) x Head diameter (in.)	Minimum Nail Bearing Length in Framing Member or Blocking, ℓ_m (in.)	Minimum Nominal Panel Thickness (in.)	Minimum Nominal Width of Nailed Face at Adjoining Panel Edges and Boundaries (in.)	Nail Spacing (in.) at diaphragm boundaries (all cases), at continuous panel edges parallel to load (Cases 3 & 4), and at all panel edges (Cases 5 & 6)											
					6			4			2-1/2			2		
					Nail Spacing (in.) at other panel edges (Cases 1,2,3, & 4)											
					6			6			4			3		
					v_n (plf)	G_a (kips/in.)		v_n (plf)	G_a (kips/in.)		v_n (plf)	G_a (kips/in.)		v_n (plf)	G_a (kips/in.)	
						OSB	PLY		OSB	PLY		OSB	PLY		OSB	PLY
Sheathing and Single-Floor	6d (2 x 0.113 x 0.266)	1-1/4	5/16	2	475	15	10	630	9.0	7.0	940	13	9.5	1065	21	13
				3	530	12	9.0	700	7.0	6.0	1065	10	8.0	1205	17	12
			3/8	2	520	13	9.5	700	7.0	6.0	1050	10	8.0	1175	18	12
				3	590	10	8.0	785	5.5	5.0	1175	8.5	7.0	1330	14	10
	8d (2-1/2 x 0.131 x 0.281)	1-3/8	3/8	2	670	15	11	895	9.5	7.5	1345	13	9.5	1525	21	13
				3	755	12	9.5	1010	7.5	6.0	1510	11	8.5	1710	18	12
			7/16	2	715	14	10	950	8.5	7.0	1415	12	9.5	1610	20	13
				3	800	11	9.0	1065	7.0	6.0	1595	10	8.0	1805	17	12
			15/32	2	755	13	9.5	1010	7.5	6.5	1485	11	8.5	1680	19	13
				3	840	10	8.5	1120	6.0	5.5	1680	9.0	7.5	1890	15	11
	10d (3 x 0.148 x 0.312)	1-1/2	15/32	2	810	25	15	1080	15	11	1610	21	14	1835	33	18
				3	910	21	14	1205	12	9.5	1820	17	12	2060	28	16
			19/32	2	895	21	14	1190	13	9.5	1790	18	12	2045	28	17
				3	1010	17	12	1345	10	8.0	2015	14	11	2295	24	15

Same framing with same nailing, plywood has lower stiffness than OSB, so higher deflection

How to Soften a Shear Wall: Plywood vs OSB?

Table 4.3A Nominal Unit Shear Capacities for Sheathed Wood-Frame Shear Walls [1,3,6]

Wood-based Panels [4]

Sheathing Material	Minimum Nominal Panel Thickness (in.)	Minimum Nail Bearing Length in Framing Member or Blocking, ℓ_m (in.)	Nail Type & Size [9] Length (in.) x Shank diameter (in.) x Head diameter (in.)	Panel Edge Nail Spacing (in.)											
				6			4			3			2		
				v_n (plf)	G_a (kips/in.)		v_n (plf)	G_a (kips/in.)		v_n (plf)	G_a (kips/in.)		v_n (plf)	G_a (kips/in.)	
					OSB	PLY		OSB	PLY		OSB	PLY		OSB	PLY
Wood Structural Panels - Sheathing [4,5]	5/16	1-1/4	6d common nail (2 x 0.113 x 0.266) [8]	505	13	9.5	755	18	12	980	24	14	1260	37	18
	3/8			560	11	8.5	840	15	11	1090	20	13	1430	32	17
	3/8 [2]	1-3/8	8d common nail (2-1/2 x 0.131 x 0.281) [8]	615	17	12	895	25	15	1150	31	17	1485	45	20
	7/16 [2]			670	15	11	980	22	14	1260	28	17	1640	42	21
	15/32			730	13	10	1065	19	13	1370	25	15	1790	39	20
	15/32	1-1/2	10d common nail (3 x 0.148 x 0.312) [8,10]	870	22	14	1290	30	17	1680	37	19	2155	52	23
	19/32			950	19	13	1430	26	16	1860	33	18	2435	48	22

Same framing with same nailing, plywood has lower stiffness than OSB, so higher deflection

Wall

G_a = 22 OSB

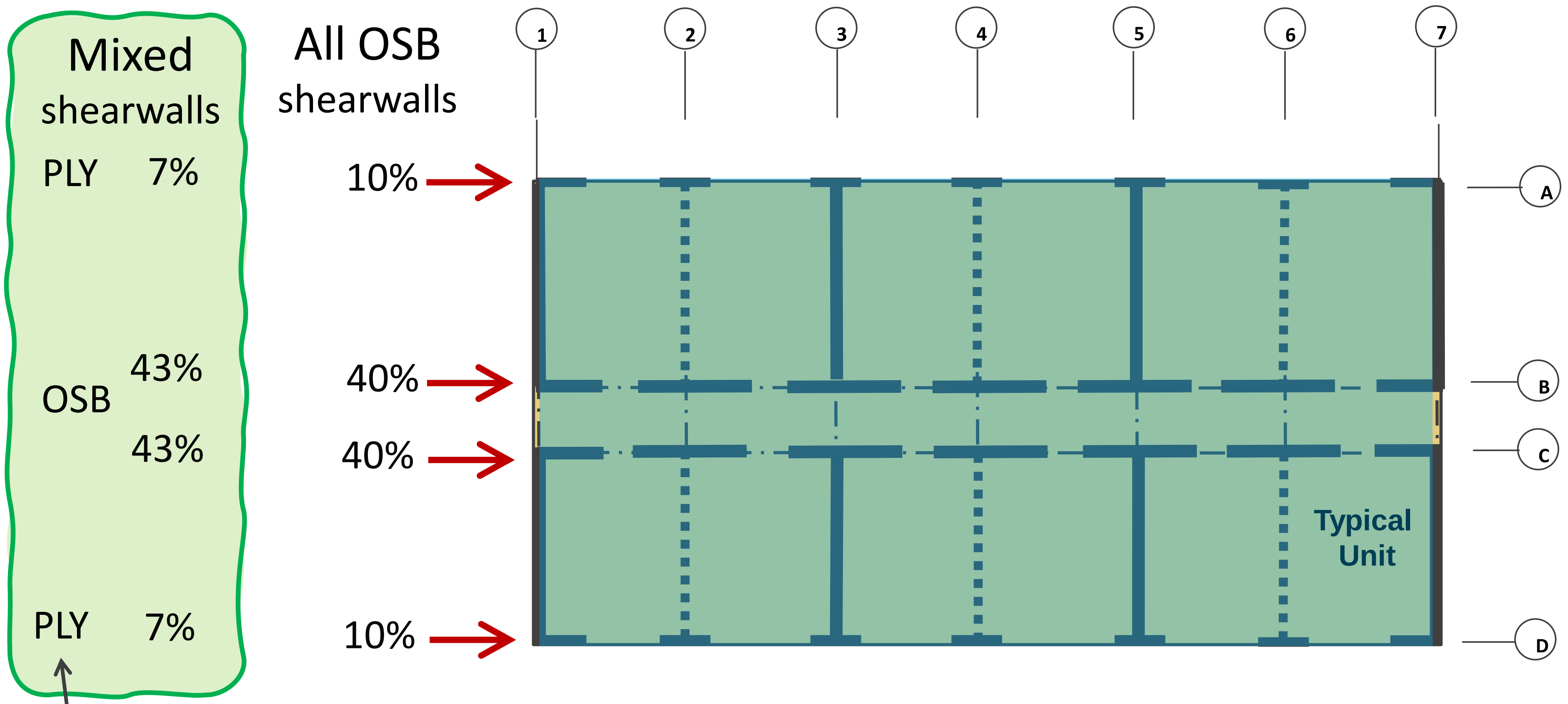
G_a = 14 PLY

$$\delta_{dia,cant} = \frac{3vL'^3}{EAW'} + \frac{0.5vL'}{1000G_a} + \frac{\Sigma(x'\Delta_C)}{W'} = 0.33\ in$$

$$\delta_{wall} = \frac{8vh^3}{EAb} + \frac{vh}{1000G_a} + \frac{h}{b}\Delta_a = 0.25\ in$$

$$0.33\ in < 2\ (0.25) = 0.50\ in$$

Diaphragm Does Qualify as Rigid!!



FRT Plywood on exterior of Type III building?

Hypothetical Rigid Diaphragm Distribution

Changing type of sheathing can impact force distribution in RDA

How to stiffen a diaphragm: Different Calculations?

SDPWS Eq. 4.2-2 (3-term equation)

$$\delta_{dia,cant} = \frac{3vL'^3}{EAW'} + \frac{0.5vL'}{1000G_a} + \frac{\Sigma(x'\Delta_C)}{W'} = 0.33\ in$$

4-term equation for uniformly loaded cantilever diaphragm:

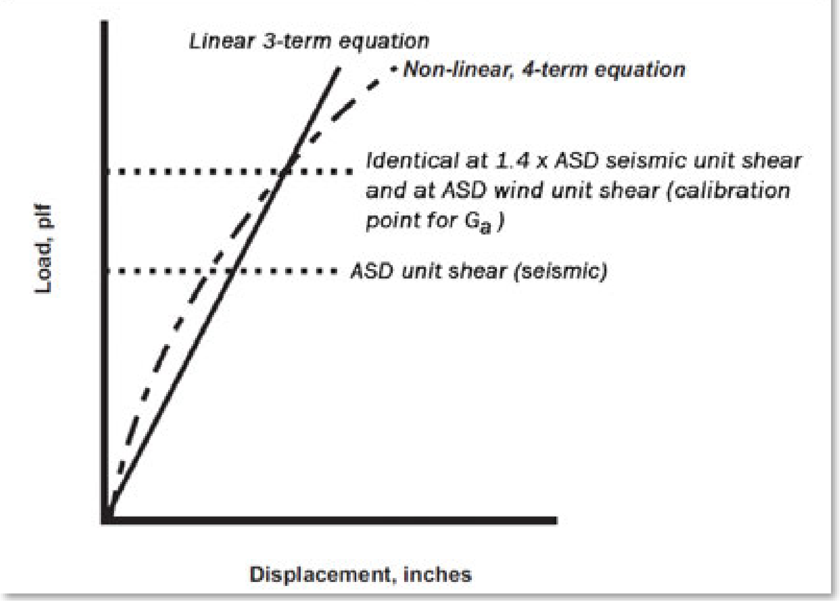
$$\delta_{dia,cant,4} = \frac{3vL'^3}{EAW'} + \frac{vL'}{2G_v t_v} + 0.375L'e_n + \frac{\Sigma(x'\Delta_C)}{W'} = 0.27\ in$$

$$\delta_{dia} < 2\,\delta_{wall}\ ?$$

$$0.27\ in < 2\ (0.16\ in) = 0.32\ in$$

Diaphragm Qualifies as Rigid?

Figure C4.3.4 Comparison of 4-Term and 3-Term Deflection Equations



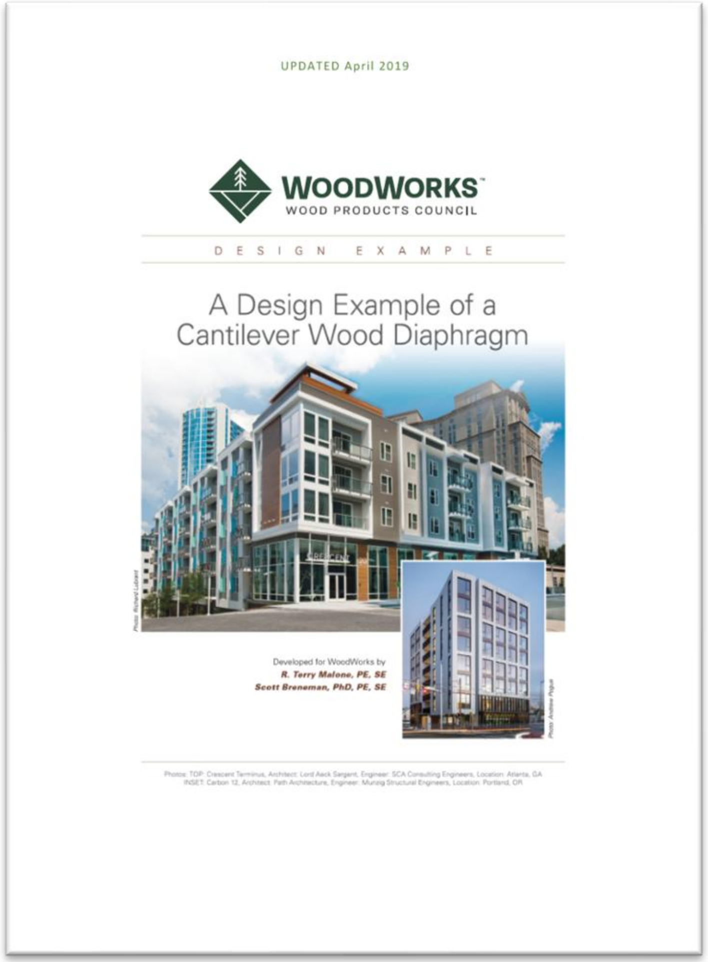
3-term deflection equations are stiffness values based on nail slip at LRFD capacity.

Calculated deflections at lower demands result in 4-term equation value less than 3-term equation value.

Presentation Overview

- Introduction to Diaphragms & Code Sections
  - Flexible
  - Rigid
  - Semi-rigid
- Irregularities and factors that impact stiffness
- Applying diaphragm and shear wall stiffness in practice
- Resources

Design Example of a Cantilever Wood Diaphragm



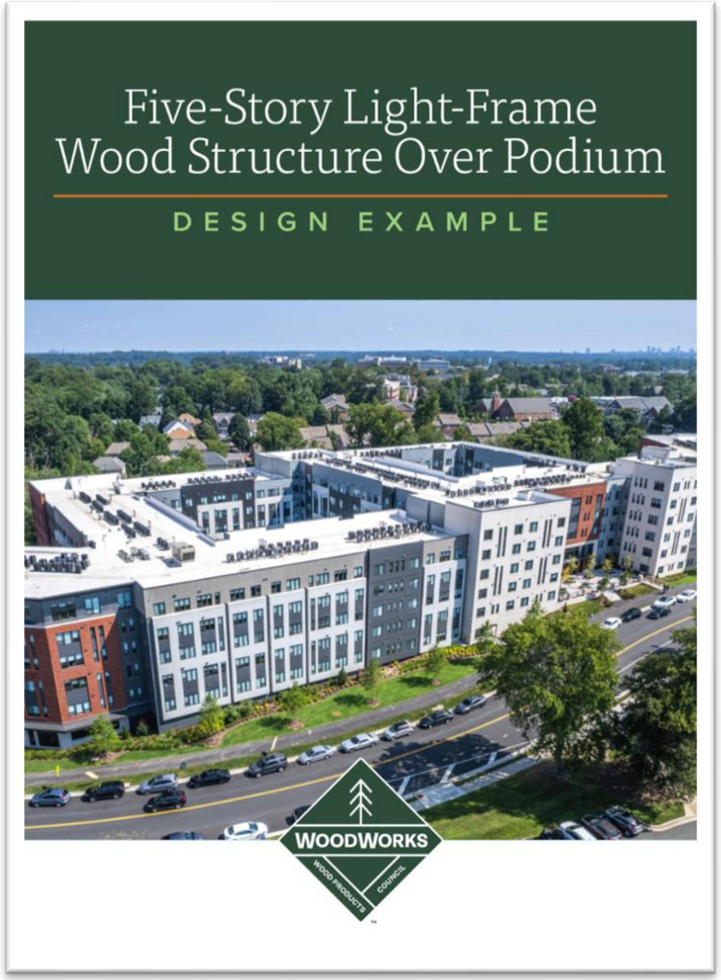
Covers diaphragm classification as rigid by calculation, rigid diaphragm analysis calculations, 3-term vs 4-term deflection calculations of diaphragms and shear walls, torsional irregularities, story drift checks, etc.

https://www.woodworks.org/resources/design-example-of-a-cantilever-wood-diaphragm/

Design Example: Five-Story Wood-Frame Over Podium

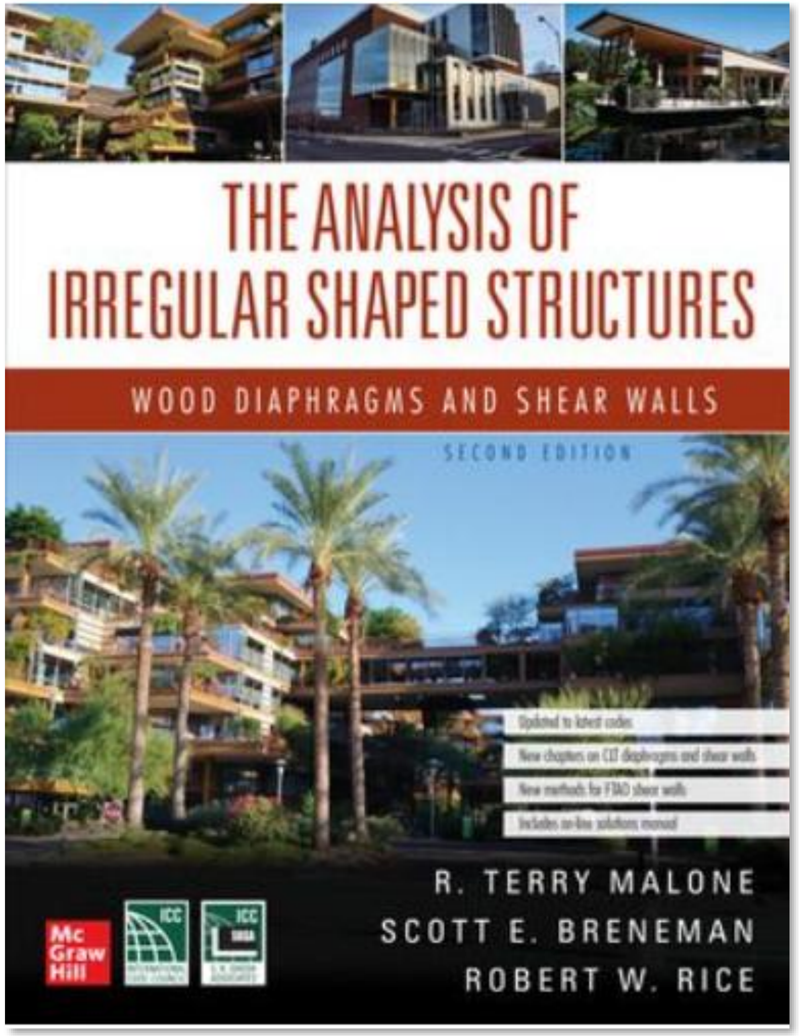
Covers lateral design approaches, seismic emphasis, 2-stage analysis,

Shrinkage considerations, Type III detailing, gravity detailing, etc.



https://www.woodworks.org/resources/five-story-wood-frame-structure-over-podium-slab/

Detailed book on wood diaphragm and shear walls



500+ pages of discussion and worked examples, many of complicated real world irregularly-shaped wood buildings.

NEHRP Technical Brief No. 10

National Earthquake Hazards Reduction Program (NEHRP). Free resources with comprehensive information that can be applied beyond seismic design


NEHRP Seismic Design Technical Brief No. 10

Seismic Design of Wood Light-Frame Structural Diaphragm Systems

A Guide for Practicing Engineers

Kelly E. Cobeen
J. Daniel Dolan
Douglas Thompson
John W. van de Lindt

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

QUESTIONS?

This concludes The American Institute of Architects Continuing Education Systems Course

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