



Multi-Family Wood Construction: Engineering Mid-Rise Buildings

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Presented by:
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Image: 45 Ashland, Alberice Architecture + Design, Photo: Greg Folkins Photography

WoodWorks | The Wood Products Council

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Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.



Course Description

This presentation is intended for structural engineers who are seeking a full system understanding of unique design considerations associated with 4- to 6-story multi-family wood buildings. Developed in response to growing interest in these projects, this presentation goes beyond code provisions and focuses on the “how-to” associated with their structural design. Topics will include structural design steps, considerations, and detailing best practices related to both gravity and lateral analysis. Shrinkage will be covered in detail, including its cause, effect on structural components, and detailing best practices that minimize and accommodate shrinkage where it occurs. Gravity framing design will be discussed with an emphasis on two commonly overlooked topics: floor vibration and stacked bearing wall loads. Lateral design topics will include diaphragm design and flexibility analysis, shear and overturning force transfer mechanisms, and lateral displacement checks for stacked, multi-story wood-frame structures.

Learning Objectives

1. Discuss wood's shrinkage potential and causes, identify shrinkage effects on structural and non-structural components, and review detailing best practices to minimize the effects of shrinkage
2. Highlight structural implications of utilizing fire retardant-treated wood in exterior wall assemblies of Type III construction.
3. Review floor vibration design checks and associated criteria for residential occupancies in wood-frame construction
4. Explain important lateral engineering issues—such as diaphragm flexibility, shear wall configuration options and design, and load path continuity—that must be considered to successfully design a mid-rise wood structure.

Multi-Story Considerations

- » Mid-Rise Construction Types & Structural Implications
- » Accommodating Wood Shrinkage
- » Gravity Design
- » Lateral Design



Load Path Continuity



Karuna | Holst Architecture

Photo: WoodWorks

Marselle Condos, Seattle, WA

6 stories for Offices,
5 stories for Residential
+ Mezzanine
+ Multi-Story Podium



Emory Point, Dekalb Co., GA



Architects: Cooper Carry & The Preston Partnership
Photo: Josh Meister, courtesy Cooper Carry

Type V Construction

All building elements are any allowed by code:

- » Light-frame wood construction
- » Mass Timber
- » Hybrid

Multi-Family Occupancies (R-1, R-2, R-4):

- » 4 stories
- » 36,000 SF Per Floor
- » 108,000 SF Total Bldg

Assumes V-A Construction, NFPA13 Sprinklers



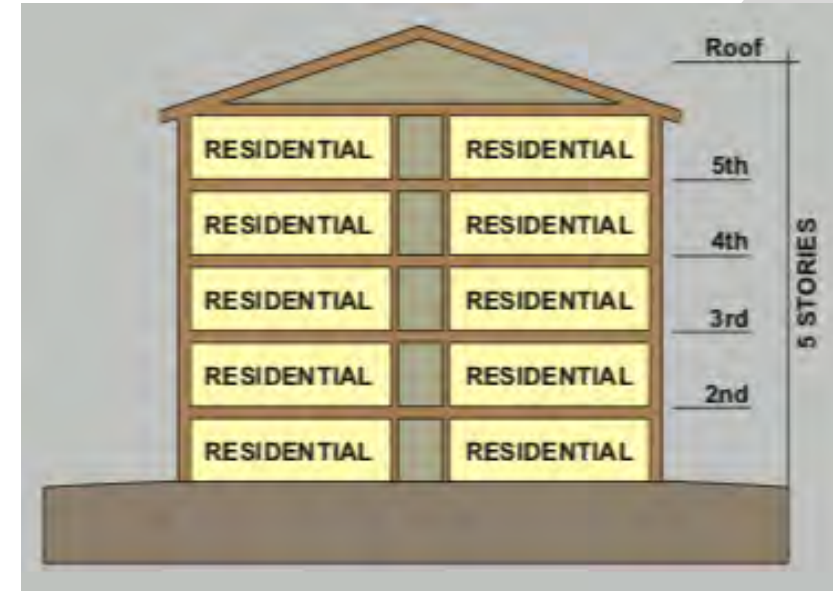
Type III Construction

- » Interior building elements are any allowed by code
- » Exterior walls are fire-retardant treated wood

Multi-Family Occupancies (R-1, R-2, R-4):

- » 5 stories
- » 72,000 SF Per Floor
- » 216,000 SF Total Bldg

Assumes III-A Construction, NFPA13 Sprinklers



Height – 2018 IBC Table 504.3

» IBC 2018: Table 504.3 provides base & increased heights

TABLE 504.3^a
ALLOWABLE BUILDING HEIGHT IN FEET ABOVE GRADE PLANE

OCCUPANCY CLASSIFICATION	TYPE OF CONSTRUCTION									
	SEE FOOTNOTES	TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
		A	B	A	B	A	B	HT	A	B
A, B, E, F, M, S, U	NS ^b	UL	160	65	55	65	55	65	50	40
	S	UL	180	85	75	85	75	85	70	60
R	NS ^{d, h}	UL	160	65	55	65	55	65	50	40
	S13R	60	60	60	60	60	60	60	60	60
	S	UL	180	85	75	85	75	85	70	60

NS = Buildings not equipped throughout with an automatic sprinkler system

S = Buildings equipped throughout with an automatic sprinkler system installed in accordance with Section 903.3.1.1 (NFPA 13)

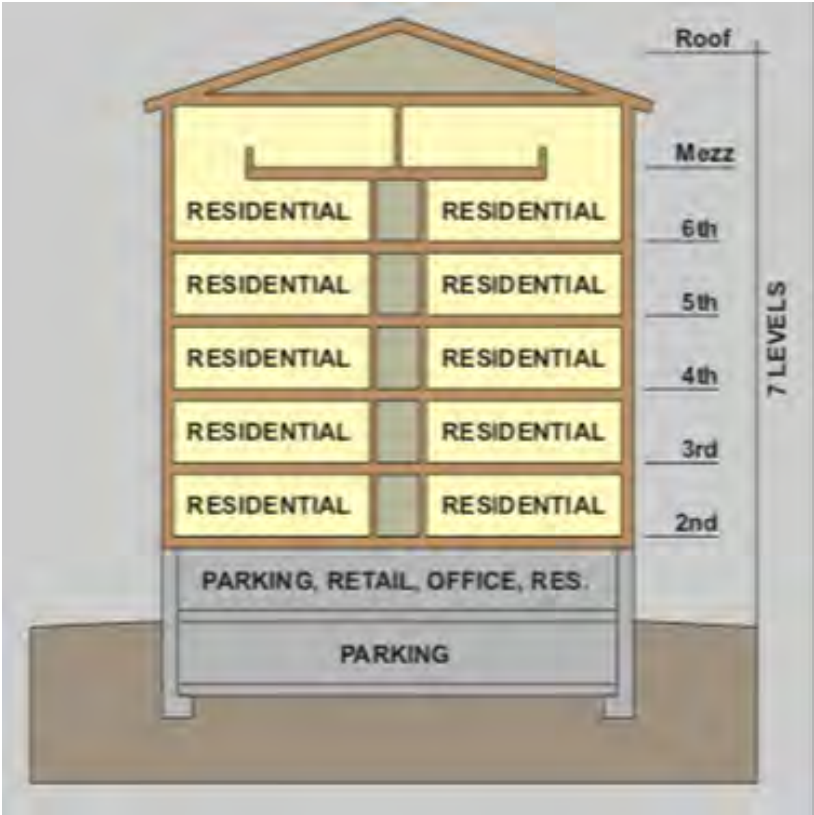
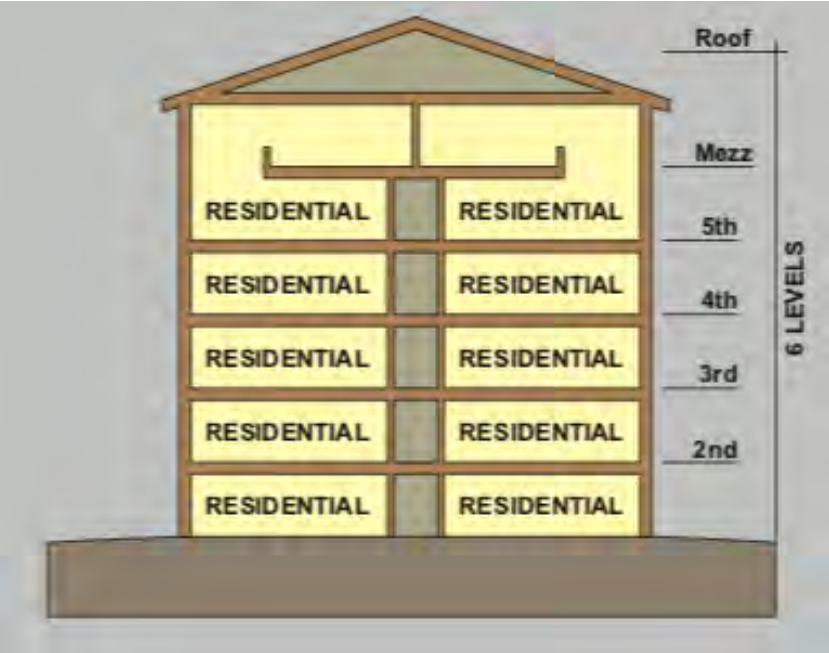
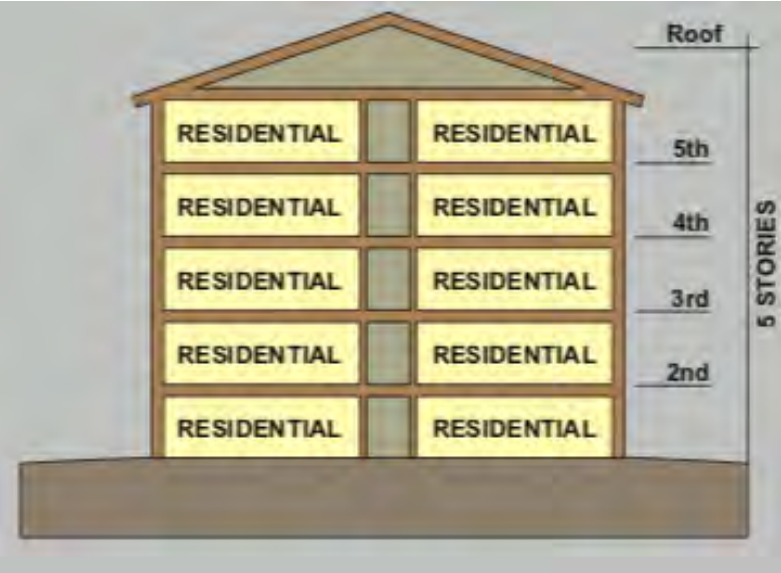
S13R = Buildings equipped throughout with an automatic sprinkler system installed in accordance with Section 903.3.1.2 (NFPA 13R)

S13D (not shown) = Buildings equipped throughout with an automatic sprinkler system installed in accordance with Section 903.3.1.3 (NFPA 13D)

Stories – 2018 IBC Table 504.4

OCCUPANCY CLASSIFICATION	TYPE OF CONSTRUCTION									
	SEE FOOTNOTES	TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
		A	B	A	B	A	B	HT	A	B
A-2	NS	UL	11	3	2	3	2	3	2	1
	S	UL	12	4	3	4	3	4	3	2
A-3	NS	UL	11	3	2	3	2	3	2	1
	S	UL	12	4	3	4	3	4	3	2
B	NS	UL	11	5	3	5	3	5	3	2
	S	UL	12	6	4	6	4	6	4	3
R-1	NS ^{d, h}	UL	11	4	4	4	4	4	3	2
	S13R	4	4						4	3
	S	UL	12	5	5	5	5	5	4	3
R-2	NS ^{d, h}	UL	11	4	4	4	4	4	3	2
	S13R	4	4	4					4	3
	S	UL	12	5	5	5	5	5	4	3
S-1	NS	UL	11	4	2	3	2	4	3	1
	S	UL	12	5	3	4	3	5	4	2

Mid-Rise Construction



Fire Resistance Ratings

Key Differences in Fire Ratings for Construction Types			
	IIIA	IIIB	VA
Exterior wall framing	FRT	FRT	non-FRT
Exterior bearing wall fire rating	2 hr	2 hr	1 hr
Floor assembly fire rating	1 hr	0 hr	1 hr

IBC Tables 601 & 706.4

Note: FRT = Fire Retardant Treated

Type III Exterior Walls – FRT

Type III and IV Construction - IBC Section 602.3:

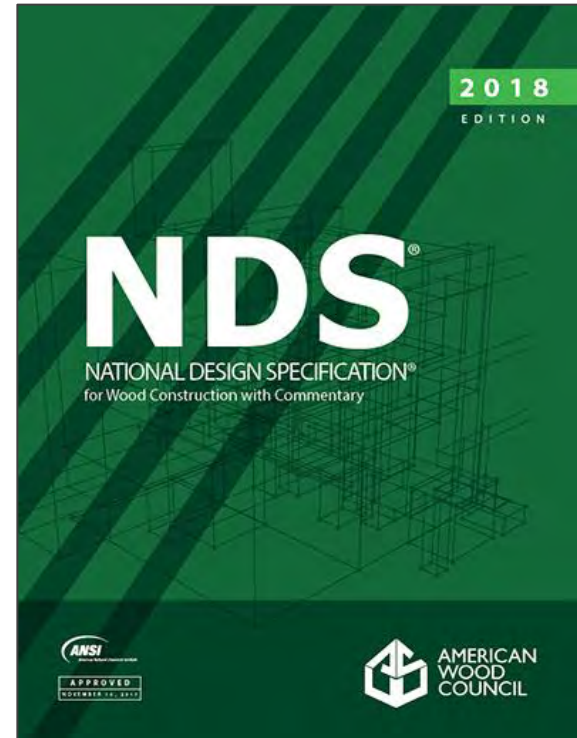
Fire-retardant-treated wood framing complying with Section 2303.2 shall be permitted within exterior wall assemblies of a 2-hour rating or less



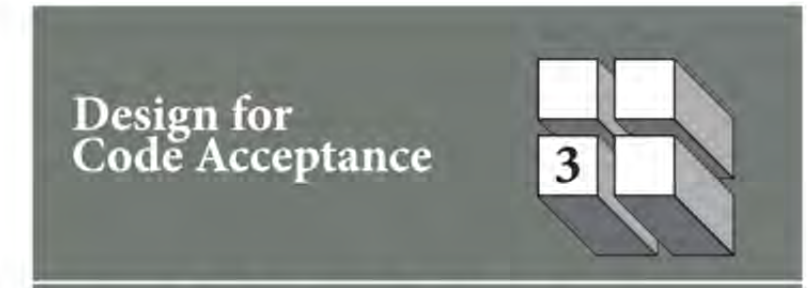
FRT Wood Design Values

NDS 2.3.4 Fire Retardant Treatment

The effects of fire-retardant chemical treatment on strength shall be accounted for in the design. Adjusted design values, including adjusted connection design values, for lumber and structural glued laminated timber pressure-treated with fire retardant chemicals shall be obtained from the company providing the treatment and redrying service.



Exterior Walls – Intersecting Floors



Fire-Resistance-Rated Wood-Frame Wall and Floor/Ceiling Assemblies

Building Code Requirements

For occupancies such as stores, apartments, offices, and other commercial and industrial uses, building codes commonly require floor/ceiling and wall assemblies to be fire-resistance-rated in accordance with

Fire Tested Assemblies

Fire-resistance-rated wood-frame assemblies can be found in a number of sources including the *International Building Code (IBC)*, Underwriters Laboratories *UL's Fire-Resistance Directory*, *Intertek Testing Services*

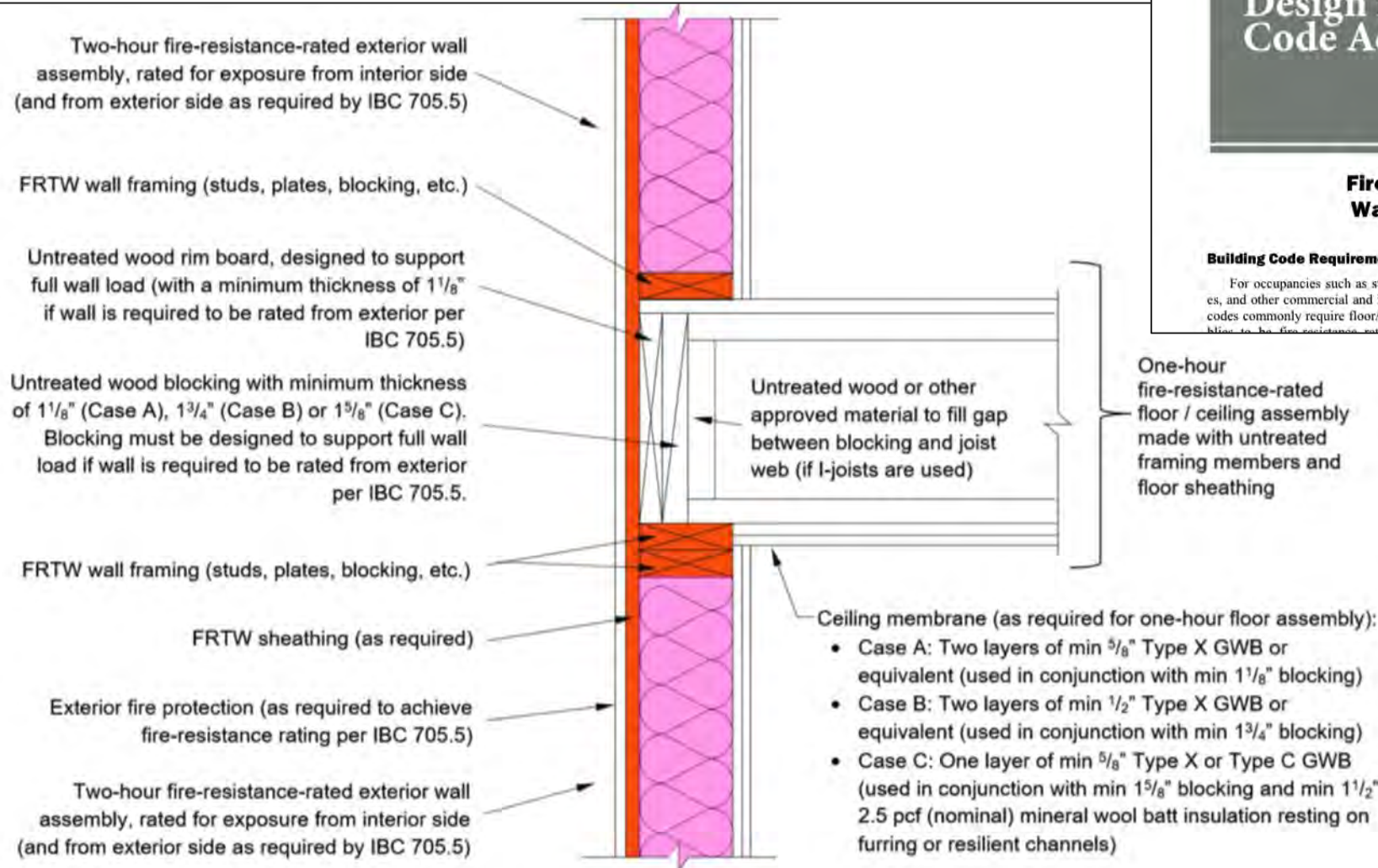


Figure 1A: Example detail for Type III-A exterior wall-floor intersection with rim board and blocking

Shrinkage Resource

Code provisions, detailing options, calculations and more for accommodating differential material movement in wood structures

Free resource at **woodworks.org**

Accommodating Shrinkage in Multi-Story Wood-Frame Structures

Richard McLain, MS, PE, SE, Technical Director, WoodWorks • Doug Steimle, PE, Principal, Schaefer

In wood-frame buildings of three or more stories, cumulative shrinkage can be significant and have an impact on the function and performance of finishes, openings, mechanical/electrical/plumbing (MEP) systems, and structural connections. However, as more designers look to wood-frame construction to improve the cost and sustainability of their mid-rise projects, many have learned that accommodating wood shrinkage is actually very straightforward.

Wood is hygroscopic, meaning it has the ability to absorb and release moisture. As this occurs, it also has the potential to change dimensionally. Knowing how and where wood shrinks and swells helps designers detail their buildings to minimize related effects.

Wood shrinkage occurs perpendicular to grain, meaning that a solid sawn wood stud or floor joist will shrink in its cross-section dimensions (width and depth). Longitudinal shrinkage is negligible, meaning the length of a stud or floor joist will essentially remain unchanged. In multi-story buildings, wood shrinkage is therefore concentrated at the wall plates, floor and roof joists, and rim boards. Depending on the materials and details used at floor-to-wall and roof-to-wall intersections, shrinkage in light-frame wood construction can range from 0.05 inches to 0.5 inches per level.

This publication will describe procedures for estimating wood shrinkage and provide detailing options that minimize its effects on building performance.



The Brooklyn Riverside
Jacksonville, Florida
Architect: Dwell Design Studio
Structural Engineer: M2 Structural Engineering

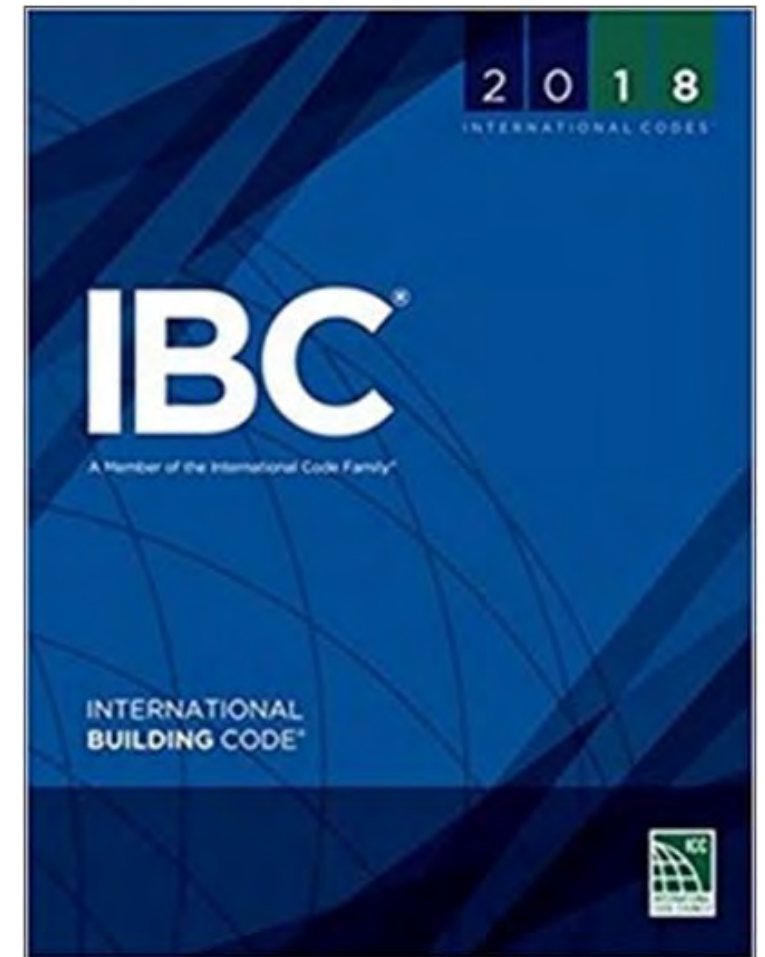
Photo: Pollock Shores, Matrix Residential

a longitudinal cell in the wood. Water can be free water stored in the straw cavity or bound water absorbed by the straw walls. At high moisture contents, water exists in both locations. As the wood dries, the free water is released from the cell cavities before the bound water is released from the cell walls. When wood has no free water and yet the cell wall is still saturated, it is said to be at its fiber saturation

Wood Science & Shrinkage

Shrinkage Code Requirements

2304.3.3 Shrinkage. Wood walls and bearing partitions shall not support more than two floors and a roof unless an analysis satisfactory to the building official shows that shrinkage of the wood framing will not have adverse effects on the structure or any plumbing, electrical or mechanical systems, or other equipment installed therein due to excessive shrinkage or differential movements caused by shrinkage. The analysis shall also show that the roof drainage system and the foregoing systems or equipment will not be adversely affected or, as an alternative, such systems shall be designed to accommodate the differential shrinkage or movements.



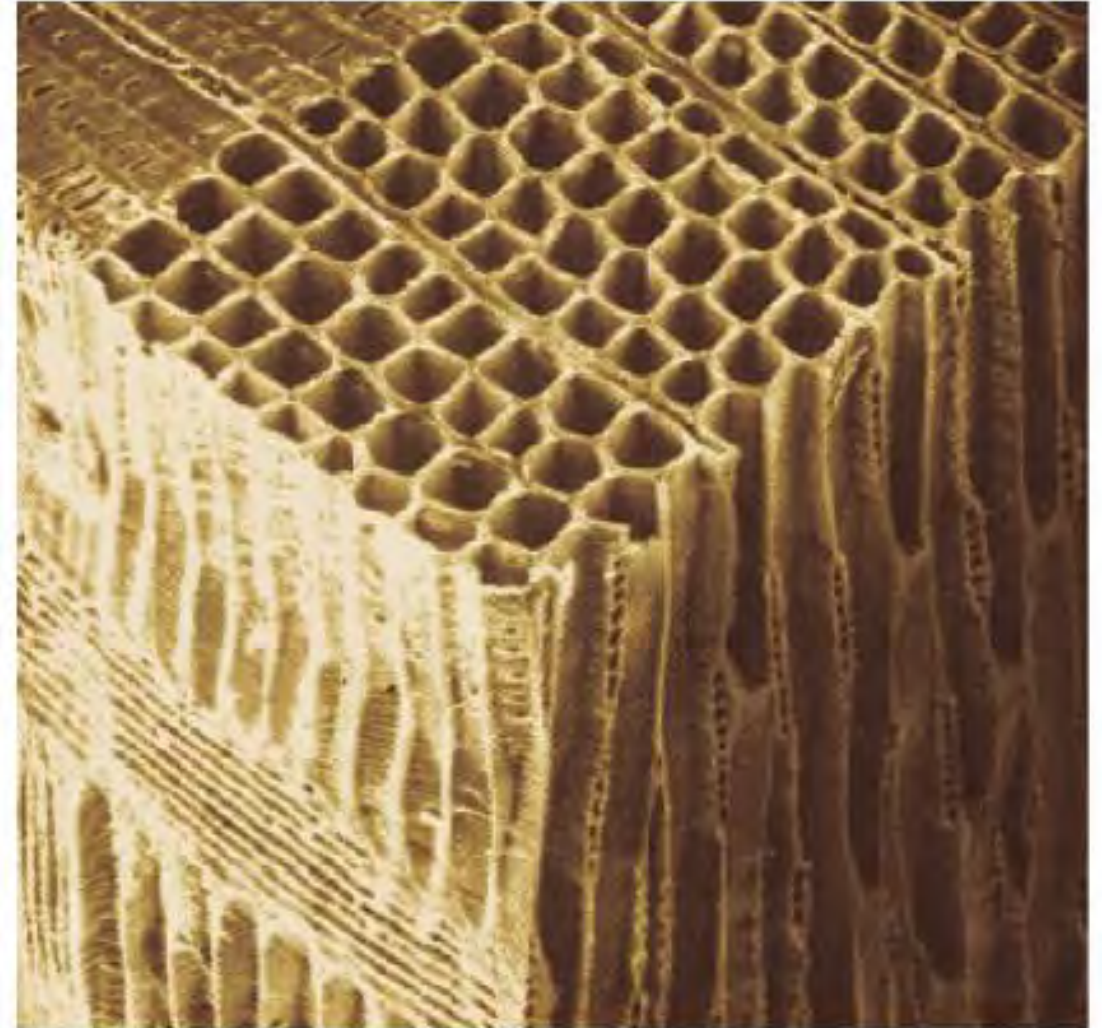
Wood Science – Moisture in Wood

Water exists in wood in two forms:

- » Free Water – water in cell cavity
- » Bound Water – water bound to cell walls

Fiber Saturation Point (FSP):

- » Point at which cell walls are completely saturated but cell cavities are empty (i.e. no free water but still has all its bound water)



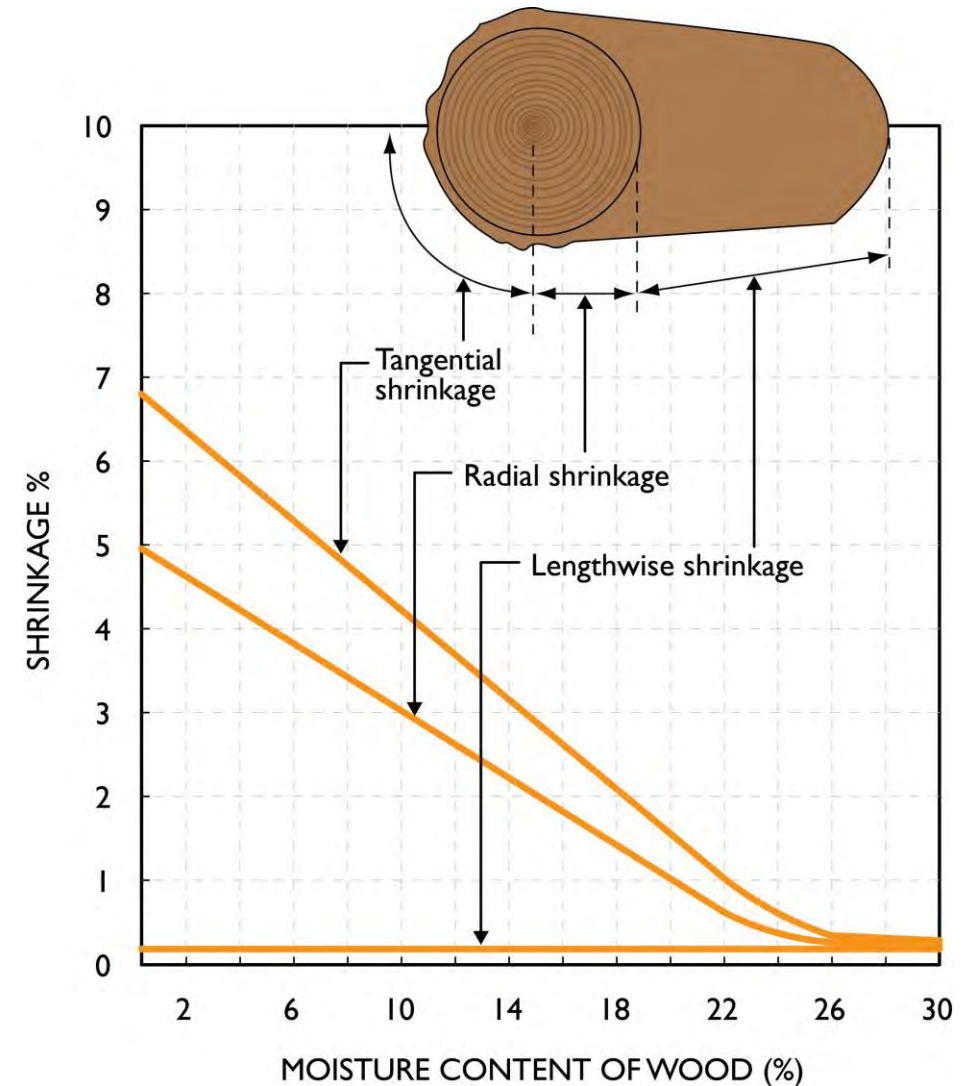
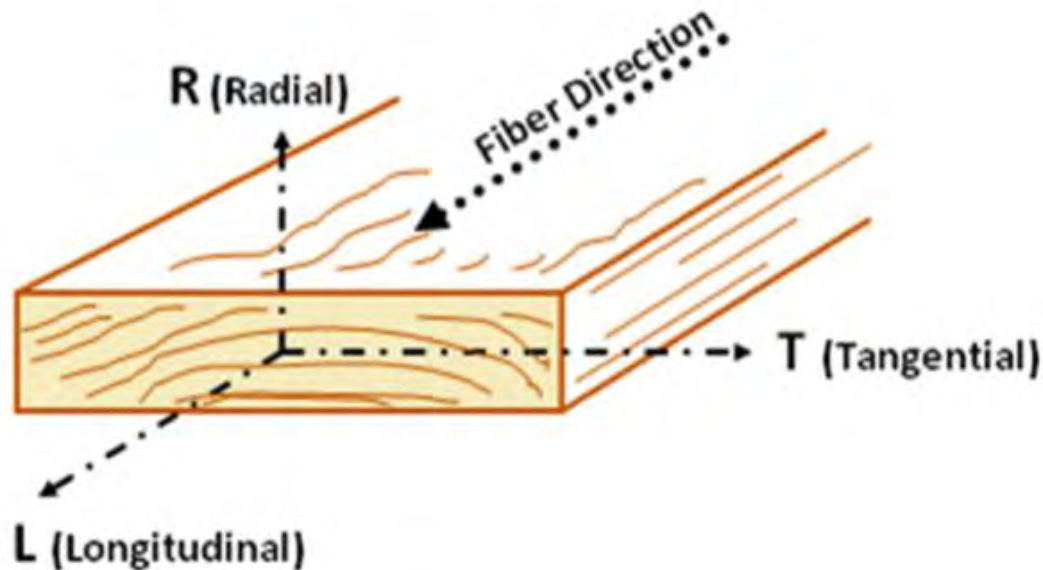
Southern yellow pine cellular makeup

Source: USDA Forest Service Agricultural Handbook (1972)

Wood Science

Wood is orthotropic, meaning it behaves differently in its three orthogonal directions: Longitudinal (L), Radial (R), and Tangential (T)

- » Longitudinal shrinkage is negligible
- » Can assume avg. of radial & tangential or assume all tangential



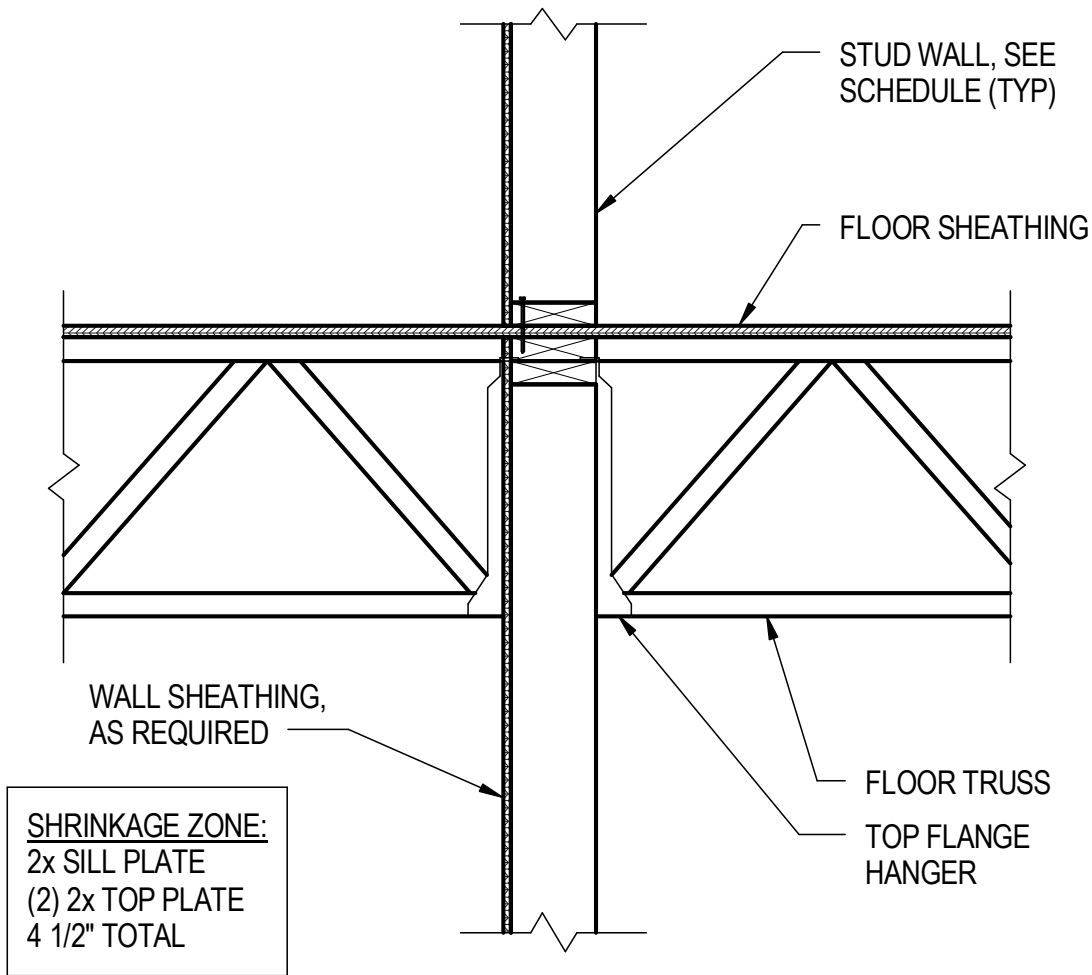
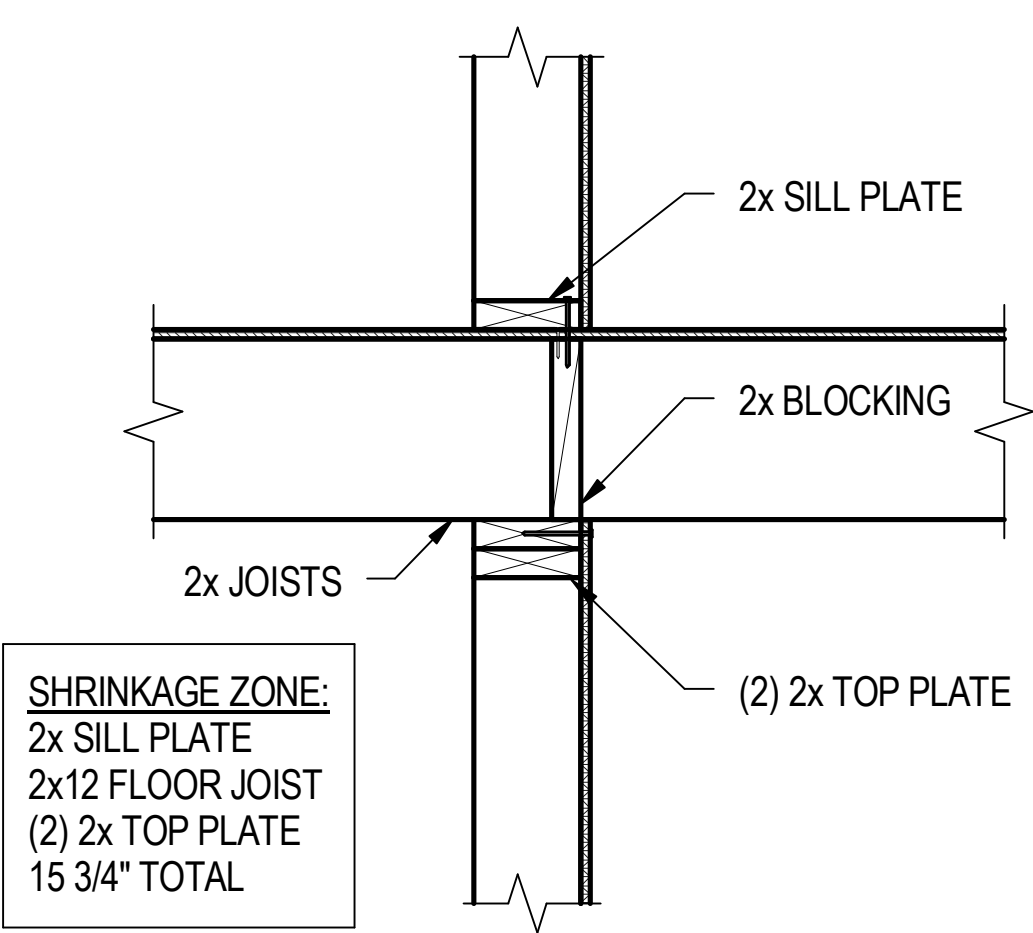
Shrinkage Calculations

Three variables influence amount of shrinkage:

- » Installed moisture content (MC)
- » In-service equilibrium moisture content (EMC)
- » Cumulative thickness of cross-grain wood contributing to shrinkage

Wood species has relatively little impact since most species used in commercial construction have similar shrinkage properties.

Minimizing Shrinkage – Detailing



Minimizing Shrinkage – Detailing



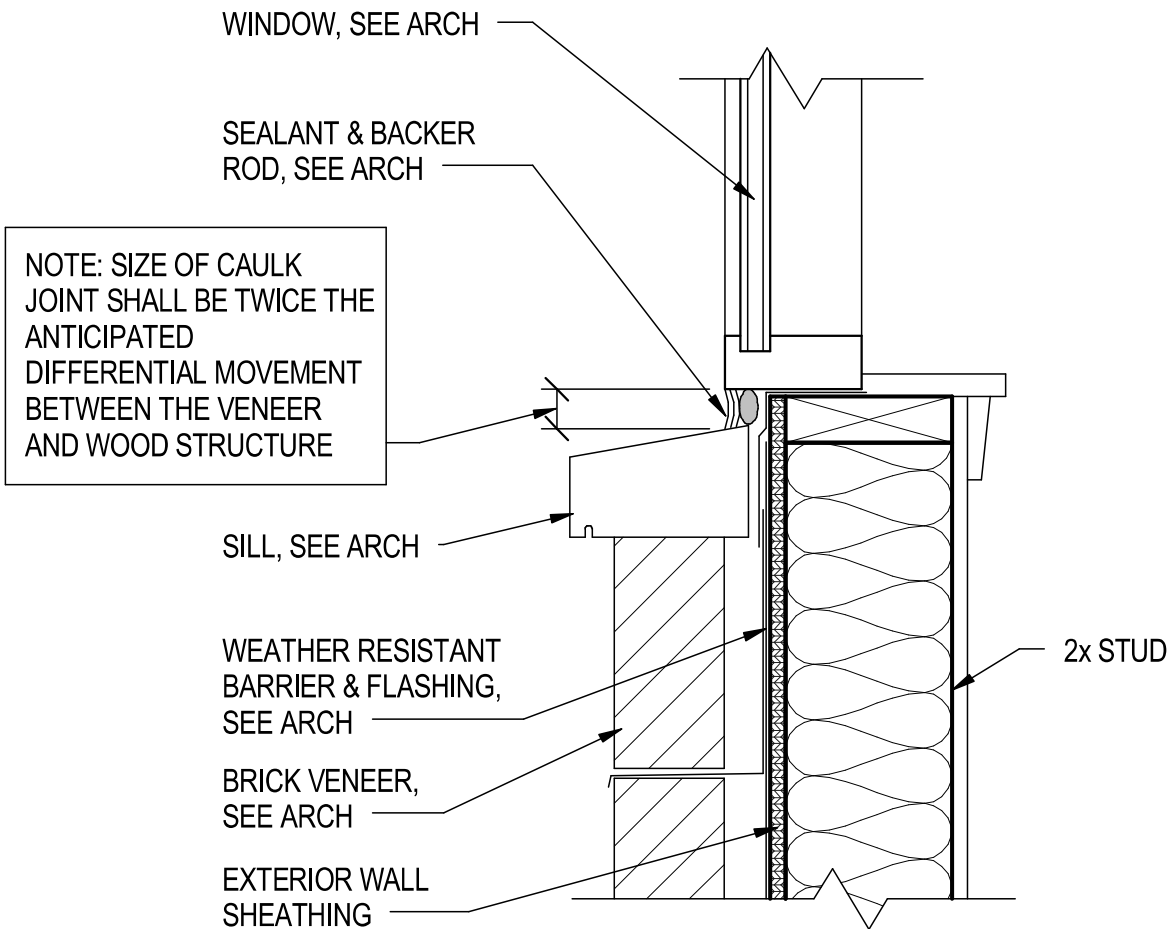
Differential Movement

Need to consider differential movement between wood frame elements and other materials that...

- » Expand due to moisture or thermal changes
- » Do not change with moisture but do change with thermal fluctuations
- » Shrink much less than wood



Differential Movement – Veneer Opening



Differential Movement – Veneer Opening



Image: RDH Building Science

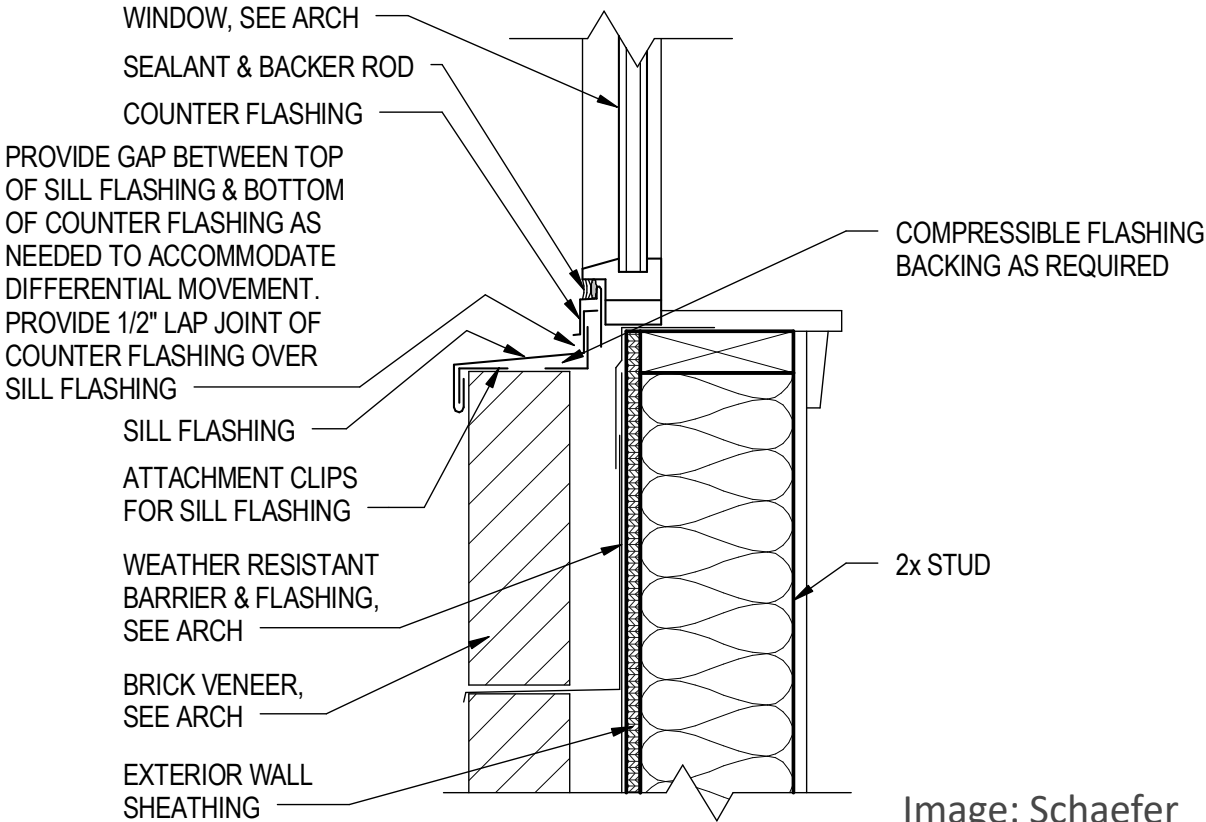


Image: Schaefer

Differential Movement – MEP

Wood framing shrinks, vertical MEP runs remain stationary or expand with thermal fluctuations

Differential movement should be allowed for

Helpful to wait as late as possible after wood framing is erected to install MEP

Note anticipated wood shrinkage at each level on construction documents – MEP contractor should provide methods of accommodating



Differential Movement – MEP

- » Vertically slotted holes in studs allow differential movement
- » Verify structural adequacy of studs

GAP REQUIRED ABOVE & BELOW FOR DIFFERENTIAL MOVEMENT, SEE GENERAL NOTES FOR ANTICIPATED SHRINKAGE OF WOOD STRUCTURE. CONSULT w/ MEP ENGINEER FOR ANTICIPATED MOVEMENT OF CONDUIT OR PIPE

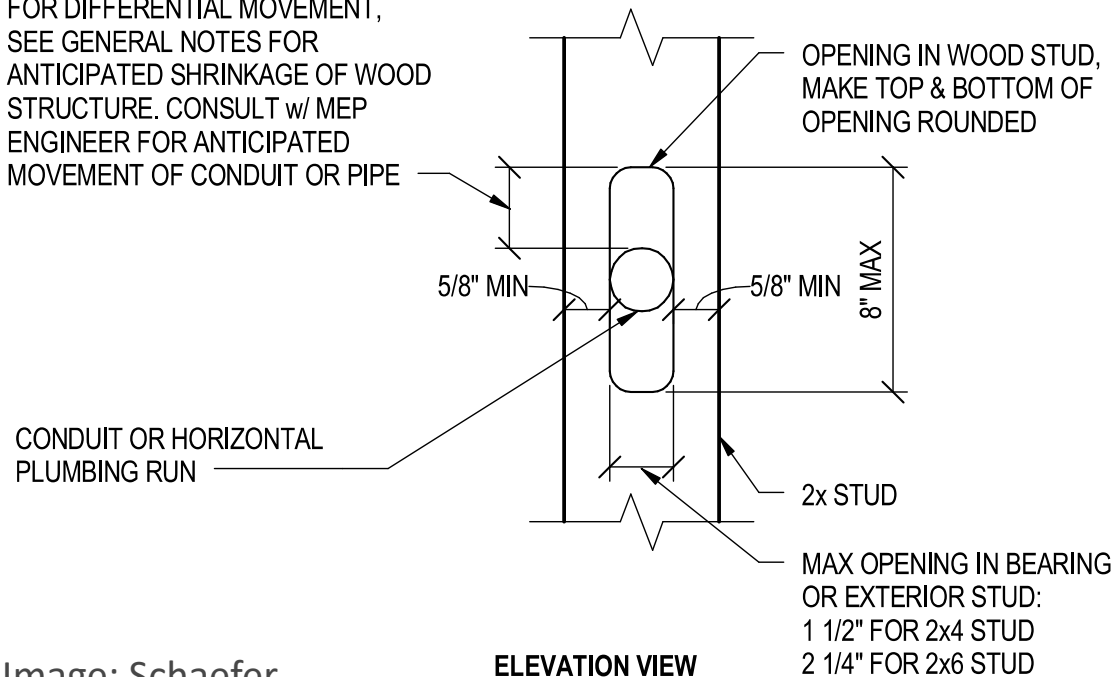


Image: Schaefer



NOTE: ENGINEER SHALL REVIEW LOADING CONDITIONS ON WALL FOR ALLOWABLE SIZE OF PENETRATION

Image: Louisiana-Pacific Corporation

Vertical Stacks – Compensation Devices Installed



A photograph of a wooden building, possibly a cabin or shed, heavily laden with a thick layer of snow and ice. The roof is completely covered, and long icicles hang from the eaves. The building is set against a clear blue sky. The foreground shows a smooth, undisturbed snowdrift. The text 'Gravity Load Design' is overlaid in a bold, black serif font at the bottom center of the image.

Gravity Load Design

Multi-Family Gravity Design

2 Topics Frequently Come Up When Discussing Multi-Story Wood Building Gravity Design

- » Floor Framing Design (Vibration)
- » Wall Design (Stacked Bearing Walls)

Structural Floor Design



Common Wood Floor Assembly:

- LW Concrete Topping
- Acoustical Mat
- Wood Floor Sheathing
- Wood Trusses/I-joists
- Batt Insulation
- Resilient Channel
- Gypsum Ceiling

Structural Floor Design – Vibration

The code is silent on floor vibration criteria and analysis

TABLE 1604.3
DEFLECTION LIMITS^{a, b, c, h, i}

CONSTRUCTION	<i>L</i>	<i>S</i> or <i>W</i> ^f	<i>D + L</i> ^{d, g}
Roof members: ^e			
Supporting plaster or stucco ceiling	<i>l</i> /360	<i>l</i> /360	<i>l</i> /240
Supporting nonplaster ceiling	<i>l</i> /240	<i>l</i> /240	<i>l</i> /180
Not supporting ceiling	<i>l</i> /180	<i>l</i> /180	<i>l</i> /120
Floor members	<i>l</i> /360	—	<i>l</i> /240
Exterior walls and interior partitions:			
With plaster or stucco finishes	—	<i>l</i> /360	—
With other brittle finishes	—	<i>l</i> /240	—
With flexible finishes	—	<i>l</i> /120	—
Farm buildings	—	—	<i>l</i> /180
Greenhouses	—	—	<i>l</i> / 120

Structural Floor Design – Vibration



AMERICAN WOOD COUNCIL

Where can I find criteria for vibration control for wood members?



- Dolan and Woeste developed some information on controlling vibration **published in** *Structural Engineer* **magazine**.
- APA Technical Note called *Minimizing Floor Vibration by Design and Retrofit*
<http://www.apawood.org/SearchResults.aspx?q=E710&tid=1>
- *Wood Design Focus* paper by Dolan and Kalkert called “Overview of Proposed Wood Floor Vibration Design Criteria” (Vol. 5, #3).

Structural Floor Design – Vibration

IS A "SPRING IN YOUR STEP" CAUSING PROBLEMS?

June 2007 » Feature Article



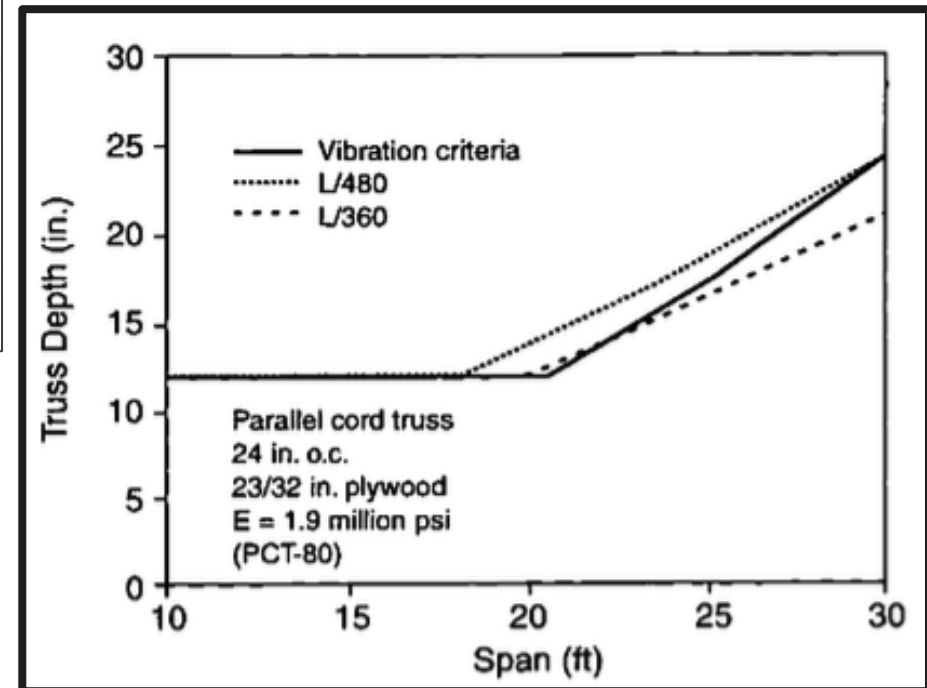
Annoying vibration is probably the most common performance complaint for light-frame wood floors.

Frank Woeste, Ph.D., P.E., and Daniel Dolan, Ph.D., P.E.

Recommendations to minimize annoying wood-floor vibrations:

Annoying vibration is probably the most common performance complaint for light-frame wood floors. The International Code Council's 2006 International Residential Code (IRC) and its 2006 International Building Code (IBC) do not address this issue, yet the engineer-of-record for a project may face the issue at the design stage, or the consulting structural engineer may be engaged to determine the cause of an annoying vibration problem in a dwelling designed and built under the prescriptive provisions of the IRC. While wood floor vibration is not typically a structural safety issue, it deserves attention by the design professional at the design stage because such a problem can be costly or practically impossible to fix.

$$f = 1.57 \sqrt{\frac{386EI}{WL^3}} \quad (\text{Equation 1})$$



Expert Tips

Floor Vibration Analysis in Light-Frame Projects

Covers several methods for analyzing and limiting floor performance for vibration in light-frame wood buildings.

Share 

Vibration of light-frame wood floor construction can be a significant occupant comfort issue. However, achieving acceptable levels of floor vibration is not a code requirement. As such, it is possible to design a code-compliant wood floor structure that produces annoying or unacceptable levels of vibration due to standard foot traffic.

A variety of factors can affect a floor's vibration performance, including:

- Presence of concrete topping or other massing materials
- Thickness/stiffness of floor sheathing
- Stiffness, spacing and span of floor joists/trusses
- Presence, size and spacing of blocking/bridging/strong backs
- Presence of direct-applied ceiling
- Stiffness of joist supporting elements (i.e., beams, bearing walls)
- Presence of partition walls

Several vibration analysis methods have been published, each of which takes into account some or all of these variables.

What constitutes an "acceptable vibration level" is subjective, but level of performance is generally measured by floor frequency. According to [an article by Frank Woeste and Dan Dolan](#), "Occupants are very sensitive to vibrations in the range of 7-10 Hz. In theory, joist designs (or floor system designs) that vibrate well above 7-10 Hz should be judged by the occupants as acceptable simply because they can't feel the higher frequencies. As a general rule, wider joist spacing (24 inches on center versus 12 inches on center) will produce a higher frequency because deeper members, having a greater bending stiffness (EI), will be required to meet building code deflection requirements." However, [studies by FPLInnovations](#) have shown that this approach may be "too simple to differentiate the vibration behavior of the



Wall Design



Exterior Walls – Bearing vs. Nonbearing

Non load-bearing exterior walls may have lower fire resistance rating requirements than bearing walls in certain situations. IBC Chapter 2 defines load bearing walls as:

[BS] WALL, LOAD-BEARING. Any wall meeting either of the following classifications:

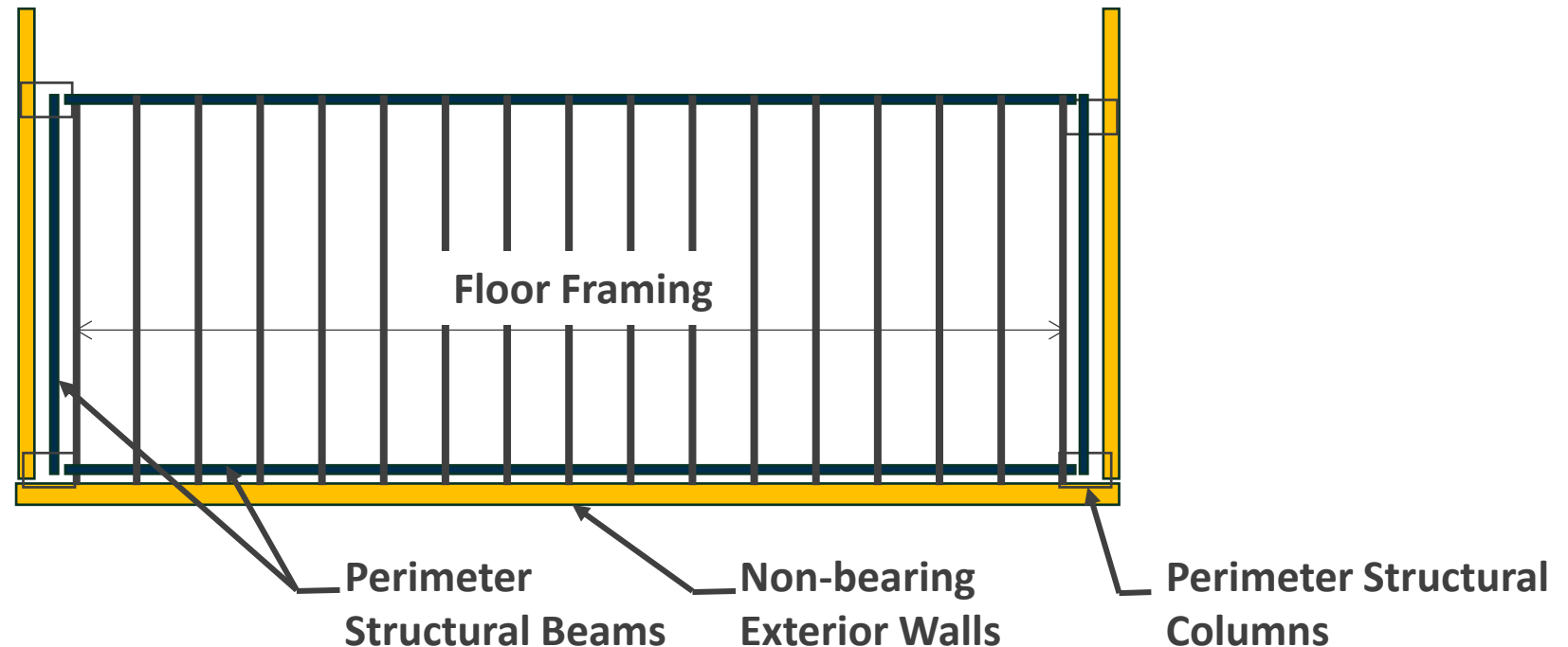
1. Any metal or wood stud wall that supports more than 100 pounds per linear foot (1459 N/m) of vertical load in addition to its own weight.

[BS] WALL, NONLOAD-BEARING. Any wall that is not a *load-bearing wall*.

Exterior Walls – Bearing vs. Nonbearing

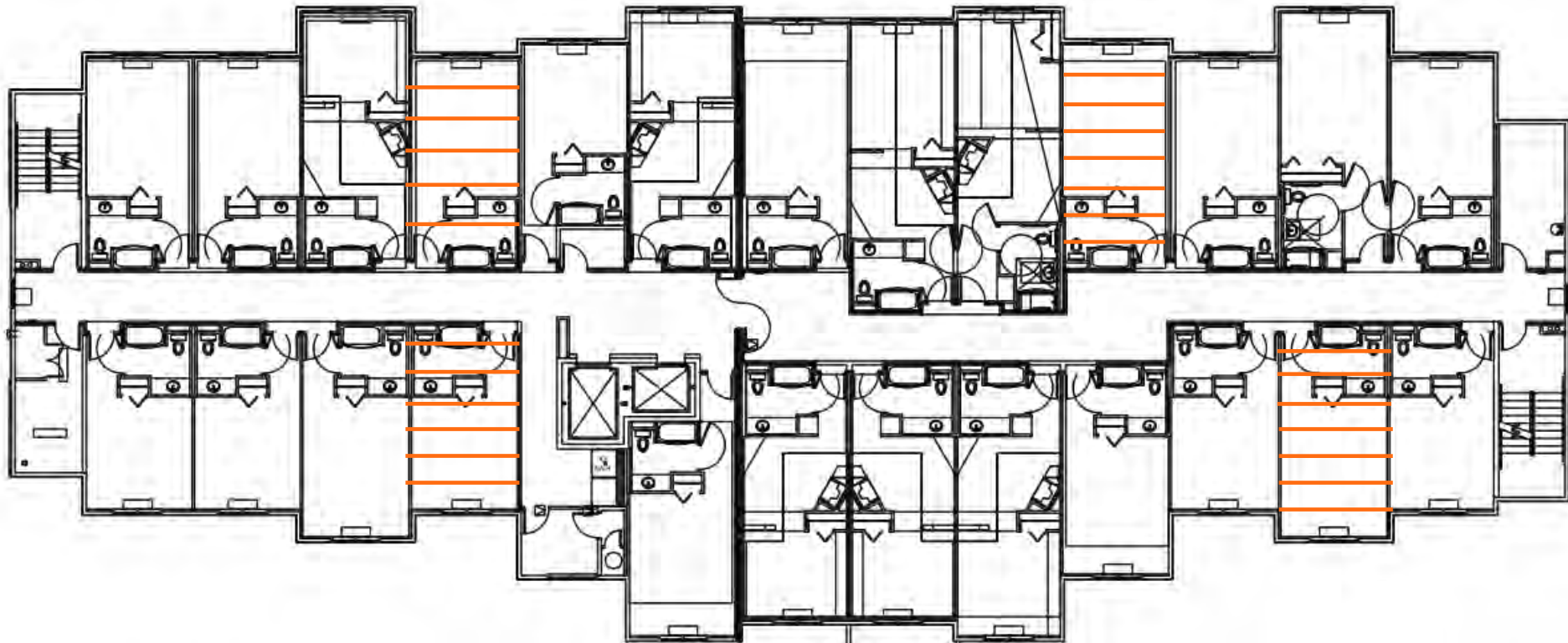
Utilization of structural beams in-board or directly over exterior walls can make walls non-bearing and reduce required fire resistance rating to 1-hr or 0-hr (IBC Table 602)

Note: Beams & Columns will most likely be considered “Primary Structural Frame” & require individual encasement per IBC 704



Exterior Walls – Bearing vs. Nonbearing

If framing parallel to long exterior walls is possible, minimizes area of load bearing exterior walls

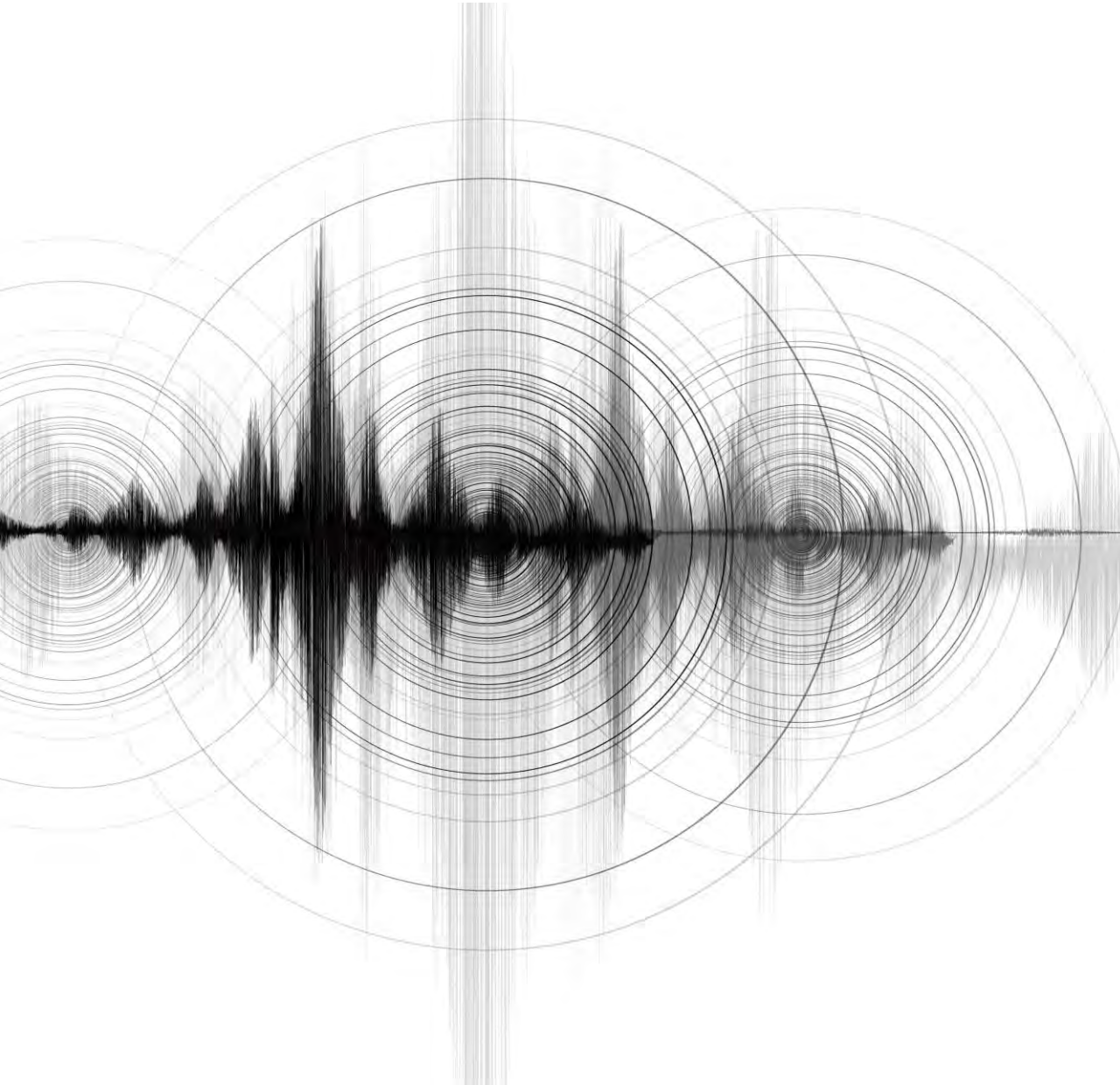


Bearing Wall Studs: Stacking Loads

- » Options for lower level, stacked bearing wall studs:
- » Specify SP or DF plates – up to 40% increase in allowable loads
 $F_c \text{ perp} = 565 \text{ psi to } 625 \text{ psi}$
- » Specify LSL or LVL plates – 75% increase in capacity
- » Decrease stud spacing from 16" o.c. to 12" o.c. – 33% increase in capacity
- » Double studs – 100% increase in capacity
- » Increase the depth of the wall – 2x6 at upper, 2x8 at lower
- » Add interior bearing walls at lower levels



Lateral Load Design





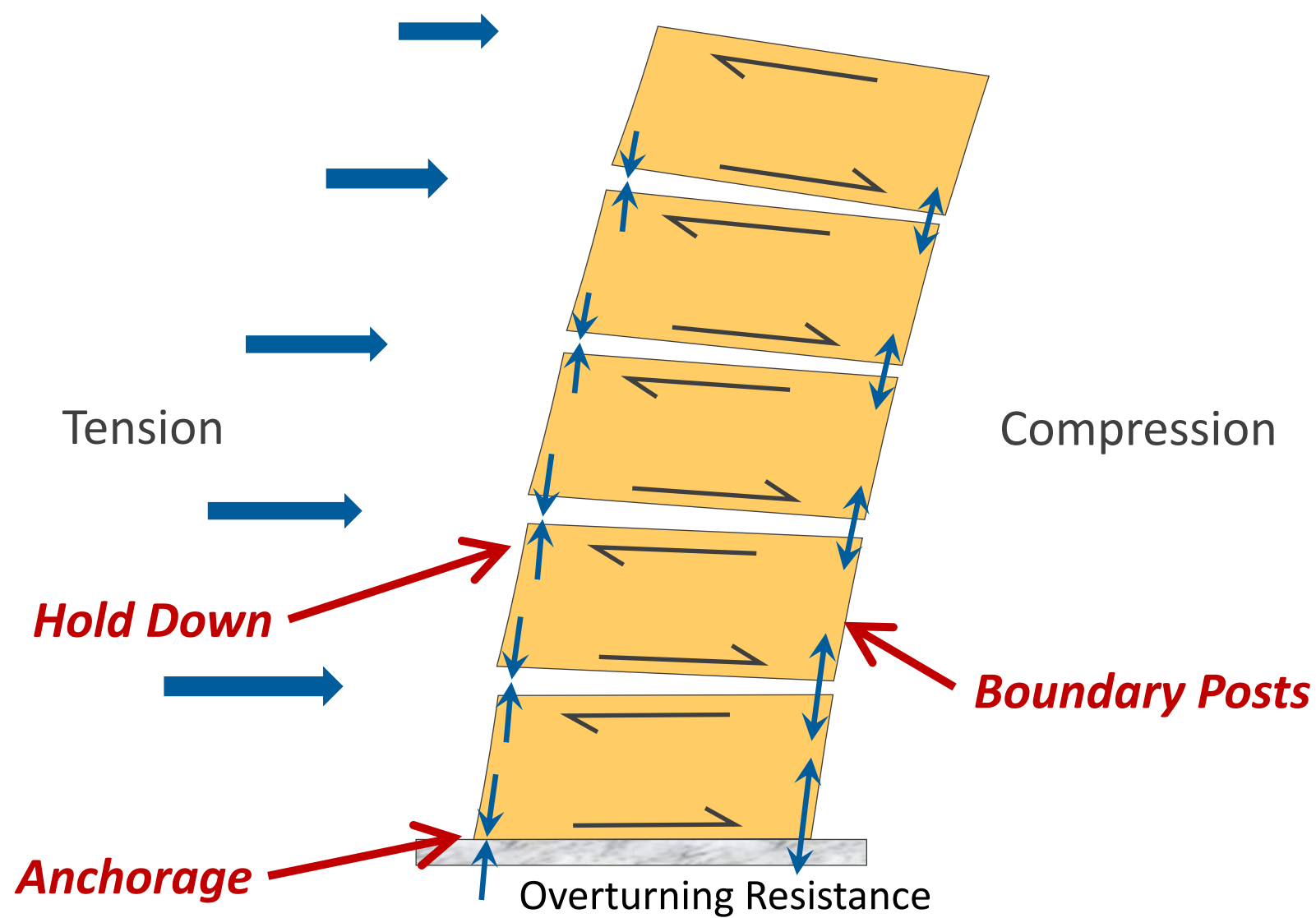
The Bishop / Atlanta, Georgia
Niles Bolton Associates / EM Structural
Photo: Thomas Watkins

Five-Story Light-Frame Wood Structure Over Podium

DESIGN EXAMPLE



Components of Shear Wall Design



Sole Plate Crushing

NDS Commentary C4.2.6: when a joint is made of two wood members and both are loaded perpendicular to grain, the amount of deformation will be approximately 2.5 times that of a metal plate to wood joint.

Table 13. Deformation Adjustment Factor for Bearing Condition

Bearing Condition	Deformation Adjustment Factor
1. Wood-to-wood (both perpendicular to grain)	2.5
2. Wood-to-wood (one parallel to grain and one perpendicular to grain)	1.75
3. Metal-to-wood (wood loaded perpendicular to grain)	1.0

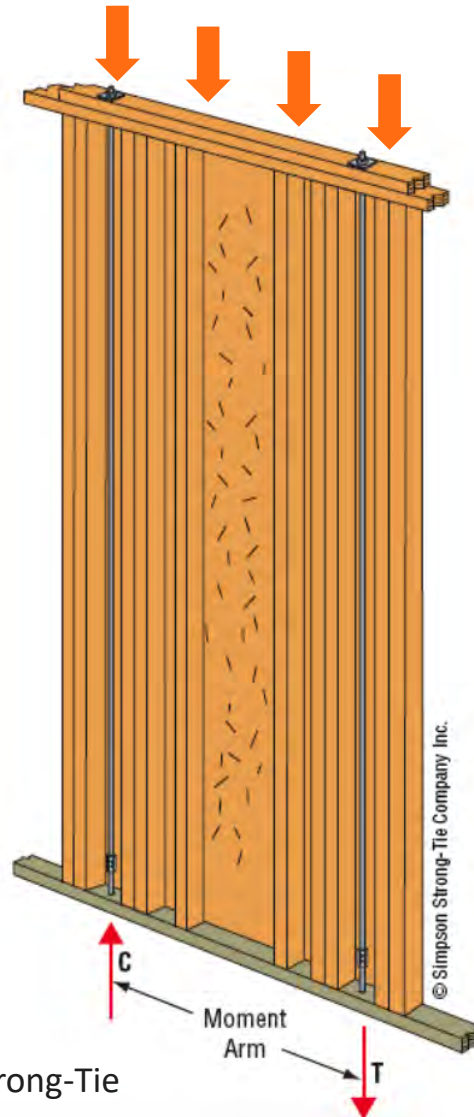
Using Dead Load to Resist Overturning

ASD Load
Combinations of
ASCE 7-16:

$$\underline{0.6D} + 0.6W$$

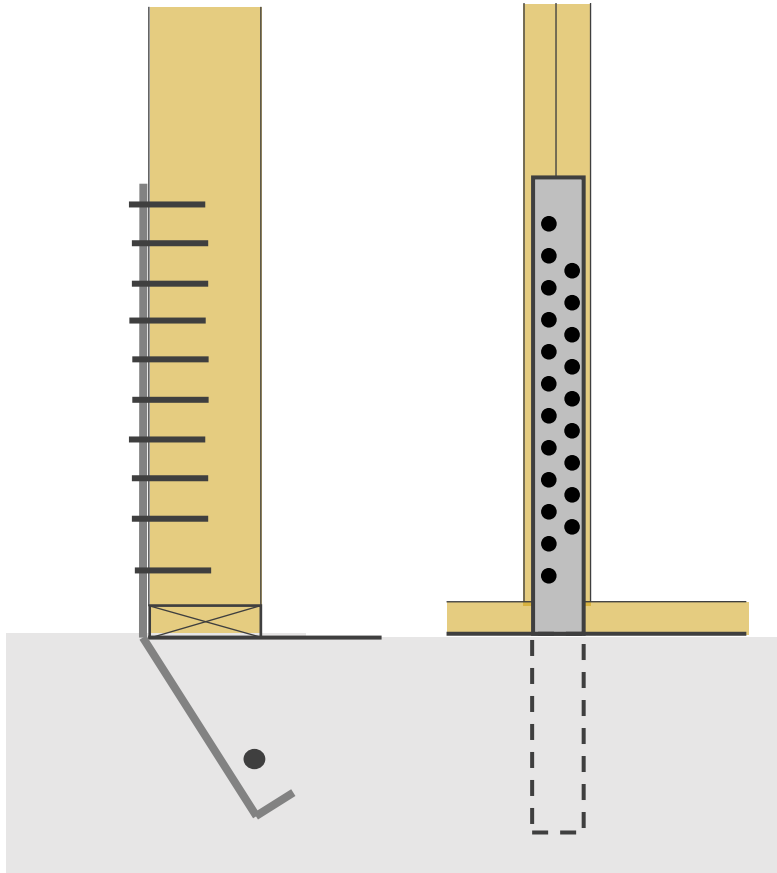
$$\underline{0.6D} - 0.7E_v + 0.7E_h$$

Dead load from above
(wall, floor, roof) can be
used to resist some or all
overturning forces,
depending on magnitude



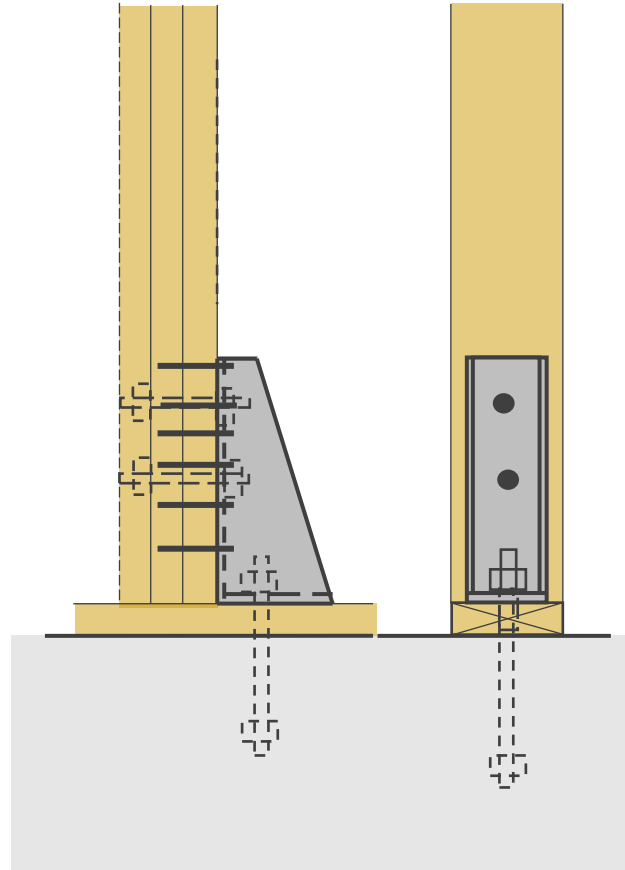
Source: Simpson Strong-Tie

Shear Wall Hold Down Options



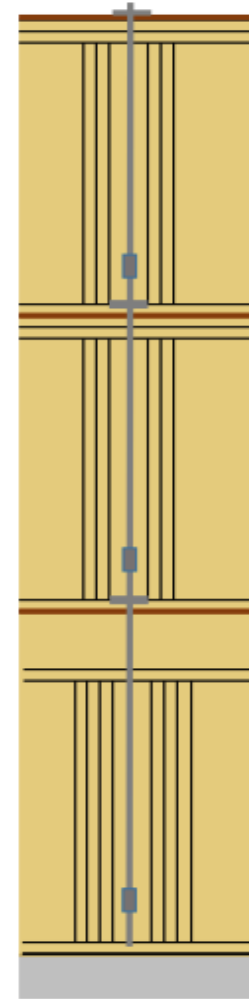
Strap Hold Down

*6+ kip story to
story capacities*



Bucket-Style Hold Down

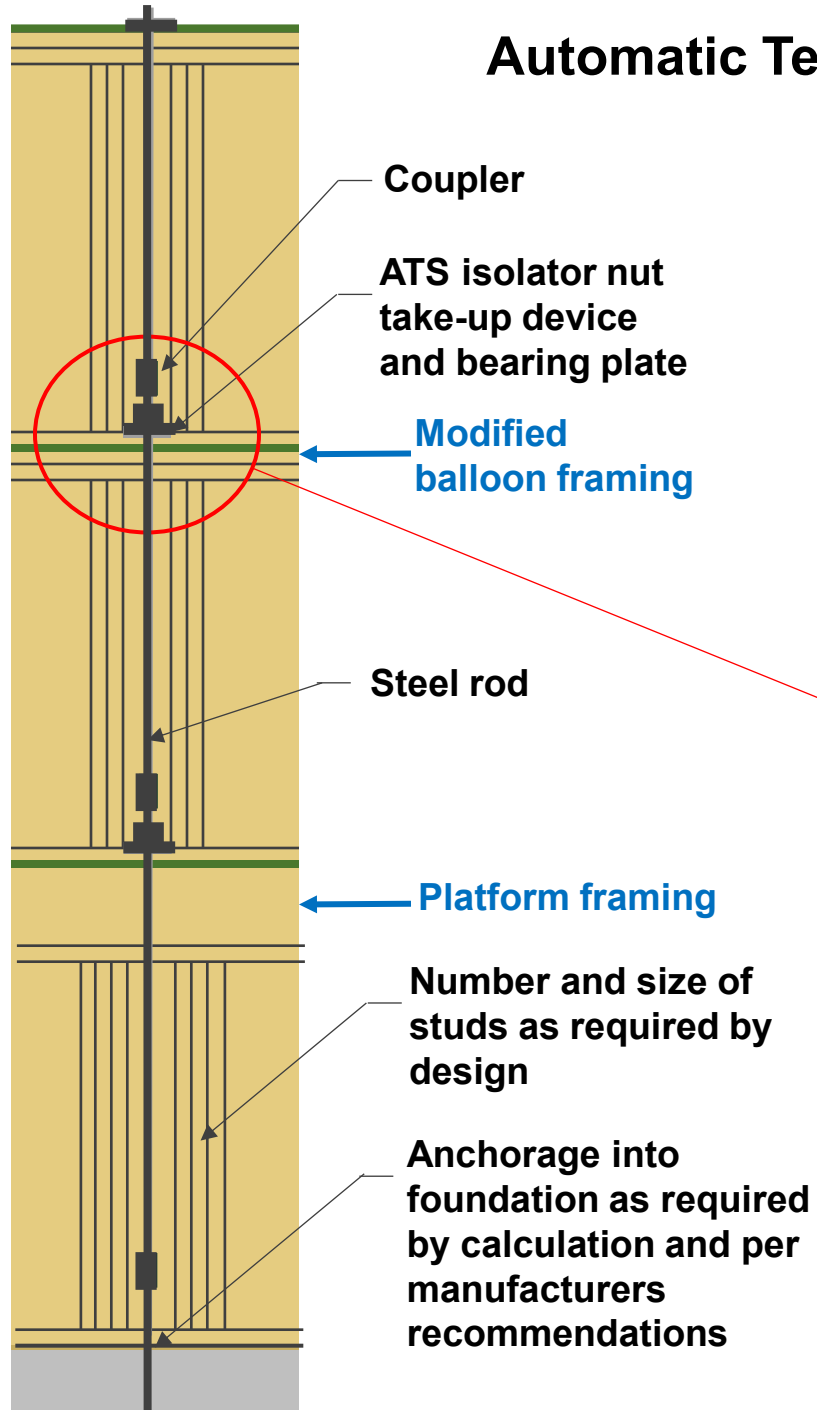
*13+ kip
capacities*



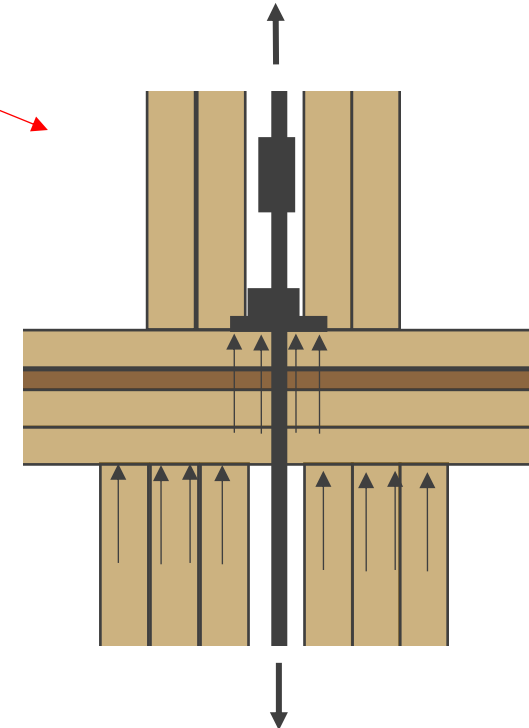
**Continuous Rod
Tie Down Systems**

*100+ kip capacities
20+ kips/level*

Automatic Tensioning Systems/Devices



- 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



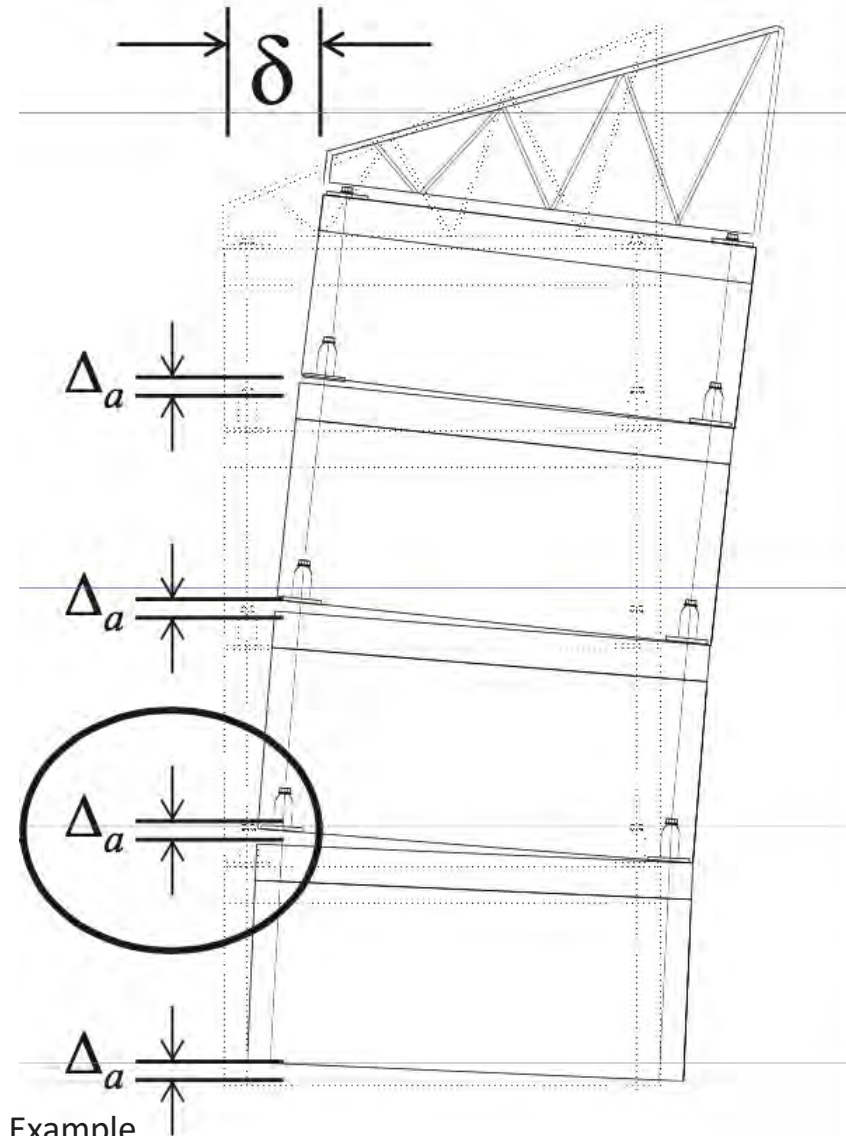
Threaded Rod Tie Down w/o Take Up Device



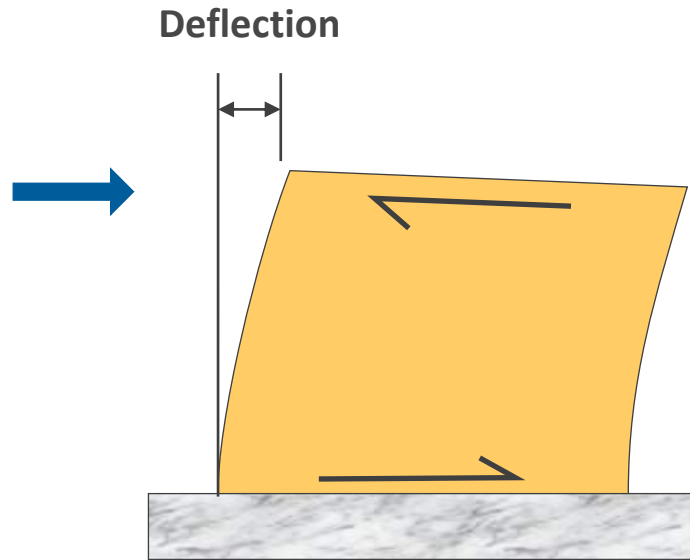
Shear Wall Deformation – System Stretch

Total system stretch includes:

- Rod Elongation
- Take-up device displacement
- Bearing Plate Crushing
- Sole Plate Crushing



Shear Wall Deflection



SDPWS 2015 Eq 4.3-1

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

SDPWS 2015 Eq. C4.3.2-1

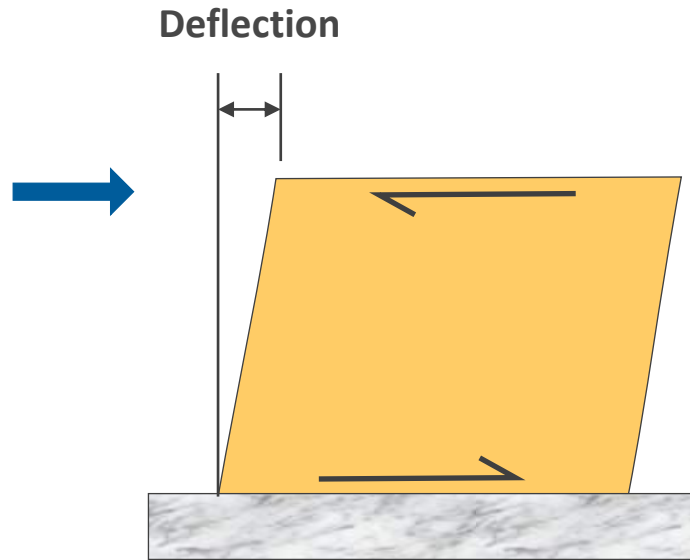
$$\delta_{sw} = \frac{8vh^3}{EAb} + \frac{vh}{G_v t_v} + 0.75he_n + \frac{h}{b}\Delta_a$$

IBC 2000 to 2015 Eq. 23-2

$$\Delta = \frac{8vh^3}{EAb} + \frac{vh}{Gt} + 0.75he_n + d_a \frac{h}{b}$$

Bending of boundary elements

Shear Wall Deflection



SDPWS 2015 Eq 4.3-1

$$\delta_{sw} = \frac{8vh^3}{EAb} + \boxed{\frac{vh}{1000G_a}} + \frac{h\Delta_a}{b}$$

SDPWS 2015 Eq. C4.3.2-1

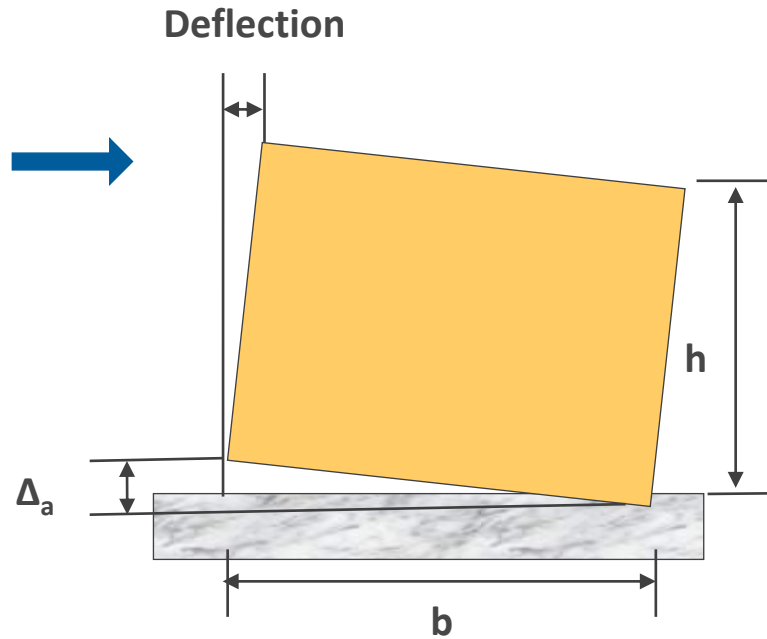
$$\delta_{sw} = \frac{8vh^3}{EAb} + \boxed{\frac{vh}{G_v t_v} + 0.75he_n} + \frac{h}{b}\Delta_a$$

IBC 2000 to 2015 Eq. 23-2

$$\Delta = \frac{8vh^3}{EAb} + \boxed{\frac{vh}{Gt} + 0.75he_n} + d_a \frac{h}{b}$$

**Shear Deformation of Sheathing Panels
&
Slip of nails @ panel to panel connections**

Shear Wall Deflection



SDPWS 2015 Eq 4.3-1

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

SDPWS 2015 Eq. C4.3.2-1

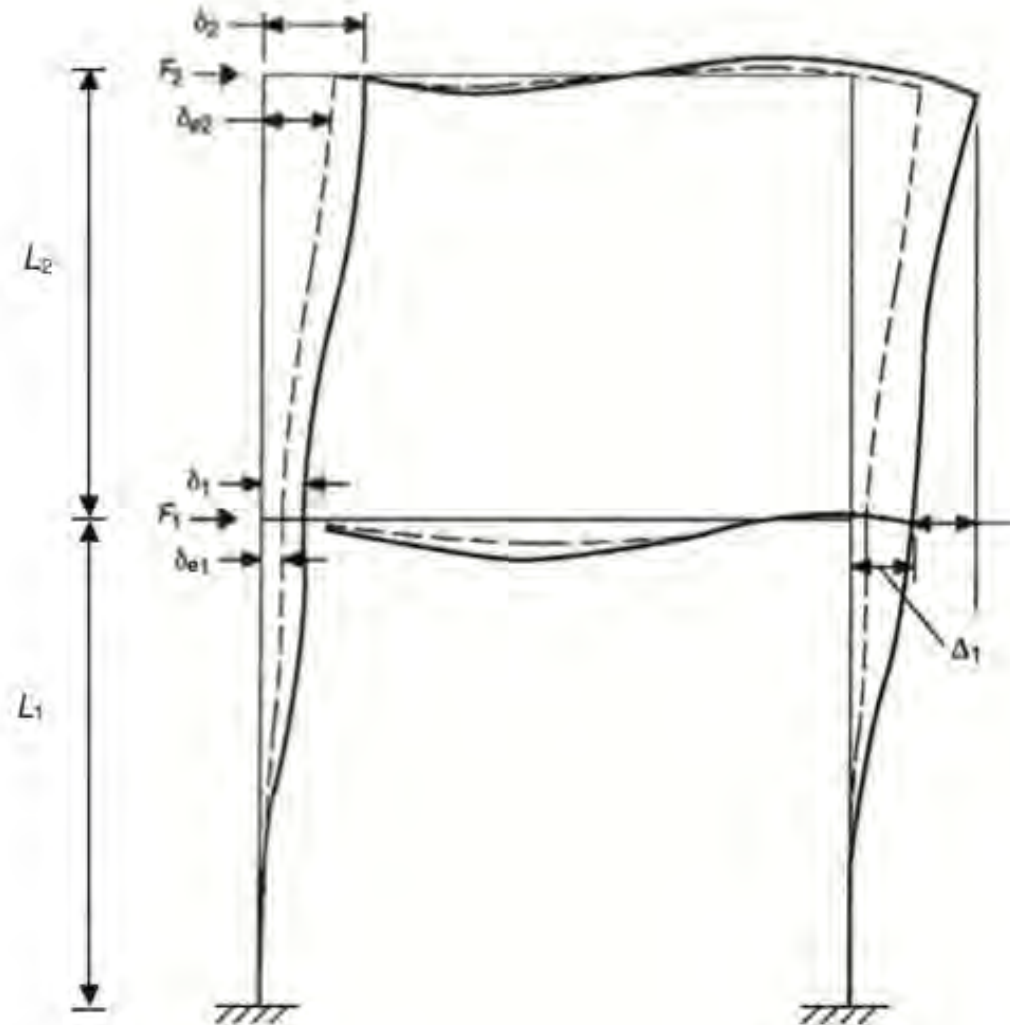
$$\delta_{sw} = \frac{8vh^3}{EAb} + \frac{vh}{G_v t_v} + 0.75he_n + \frac{h}{b}\Delta_a$$

IBC 2000 to 2015 Eq. 23-2

$$\Delta = \frac{8vh^3}{EAb} + \frac{vh}{Gt} + 0.75he_n + d_a \frac{h}{b}$$

Rigid Body Rotation

Seismic Story Drift



Story Level 2

- F_2 = strength-level design earthquake force
- δ_{e2} = elastic displacement computed under strength-level design earthquake forces
- δ_2 = $C_d \delta_{e2}/I_E$ = amplified displacement
- Δ_2 = $(\delta_{e2} - \delta_{e1}) C_d / I_E \leq \Delta_a$ (Table 12.12-1)

Story Level 1

- F_1 = strength-level design earthquake force
- δ_{e1} = elastic displacement computed under strength-level design earthquake forces
- δ_1 = $C_d \delta_{e1}/I_E$ = amplified displacement
- Δ_1 = $\delta_1 \leq \Delta_a$ (Table 12.12-1)

- Δ_i = Story Drift
- Δ_i/L_i = Story Drift Ratio
- δ_2 = Total Displacement

FIGURE 12.8-2 Story Drift Determination

Shear Wall Deflection Criteria – Wind

Unlike seismic, no code information exists on deflection/drift criteria of structures due to wind loads

Serviceability check to minimize damage to cladding and nonstructural walls

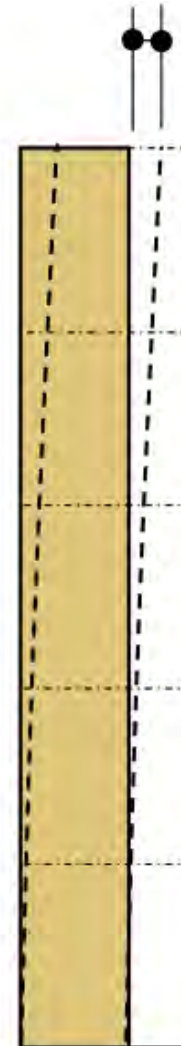
ASCE 7-16:

C.2.2 Drift of Walls and Frames. Lateral deflection or drift of structures and deformation of horizontal diaphragms and bracing systems due to wind effects shall not impair the serviceability of the structure.

What wind force should be used?

What drift criteria should be applied?

Allowable = ?



Shear Wall Deflection Criteria – Wind

Wind Forces

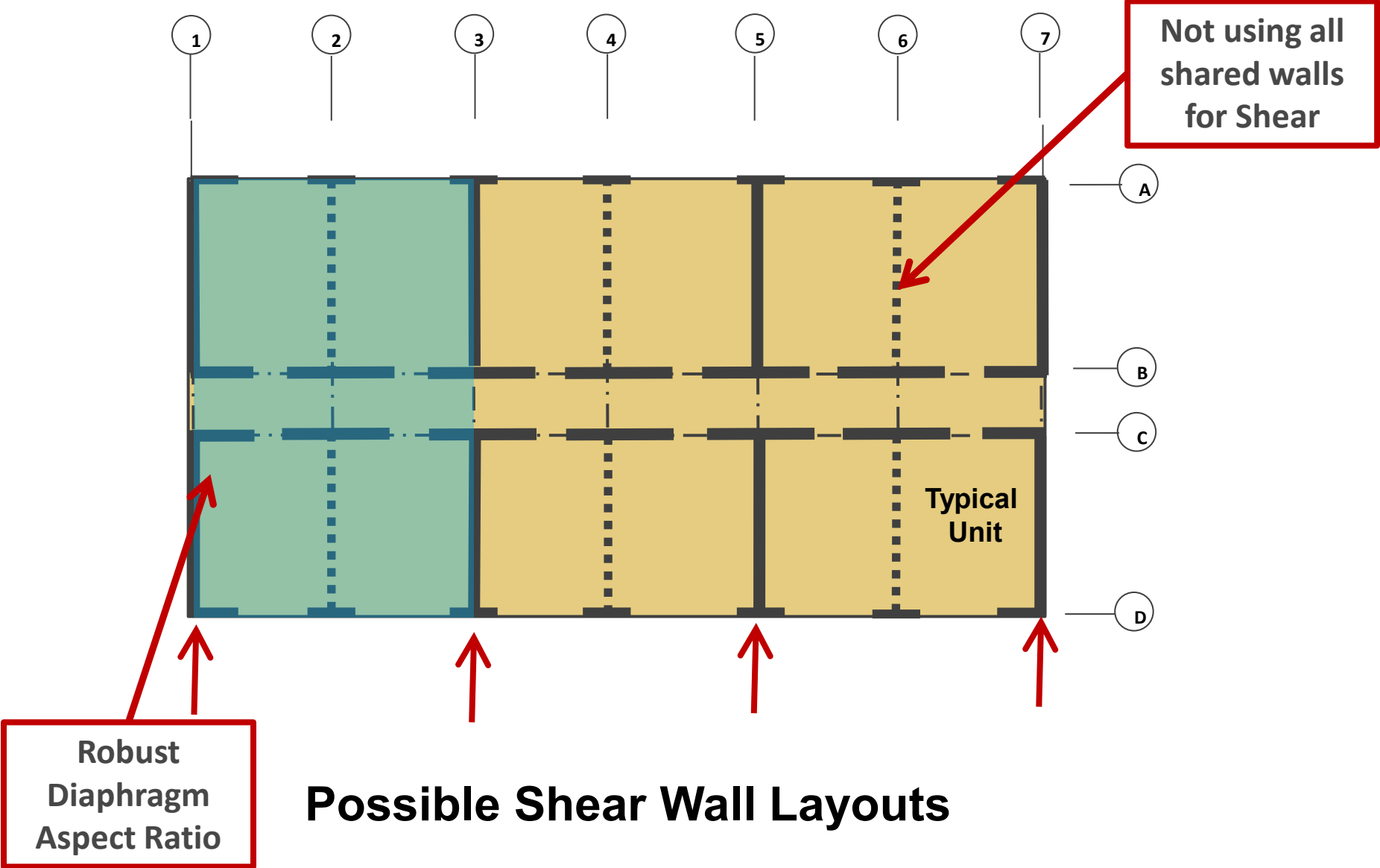
Consensus is that ASD design level forces are too conservative for building/frame drift check due to wind

- Commentary to ASCE 7-16 Appendix C suggests that some recommend using 10 year return period wind forces:
 - ~ 70% of 700 return period wind (ultimate wind speed for risk category II buildings)
- Others (AISC Design Guide 3) recommend using 75% of 50 year return period forces

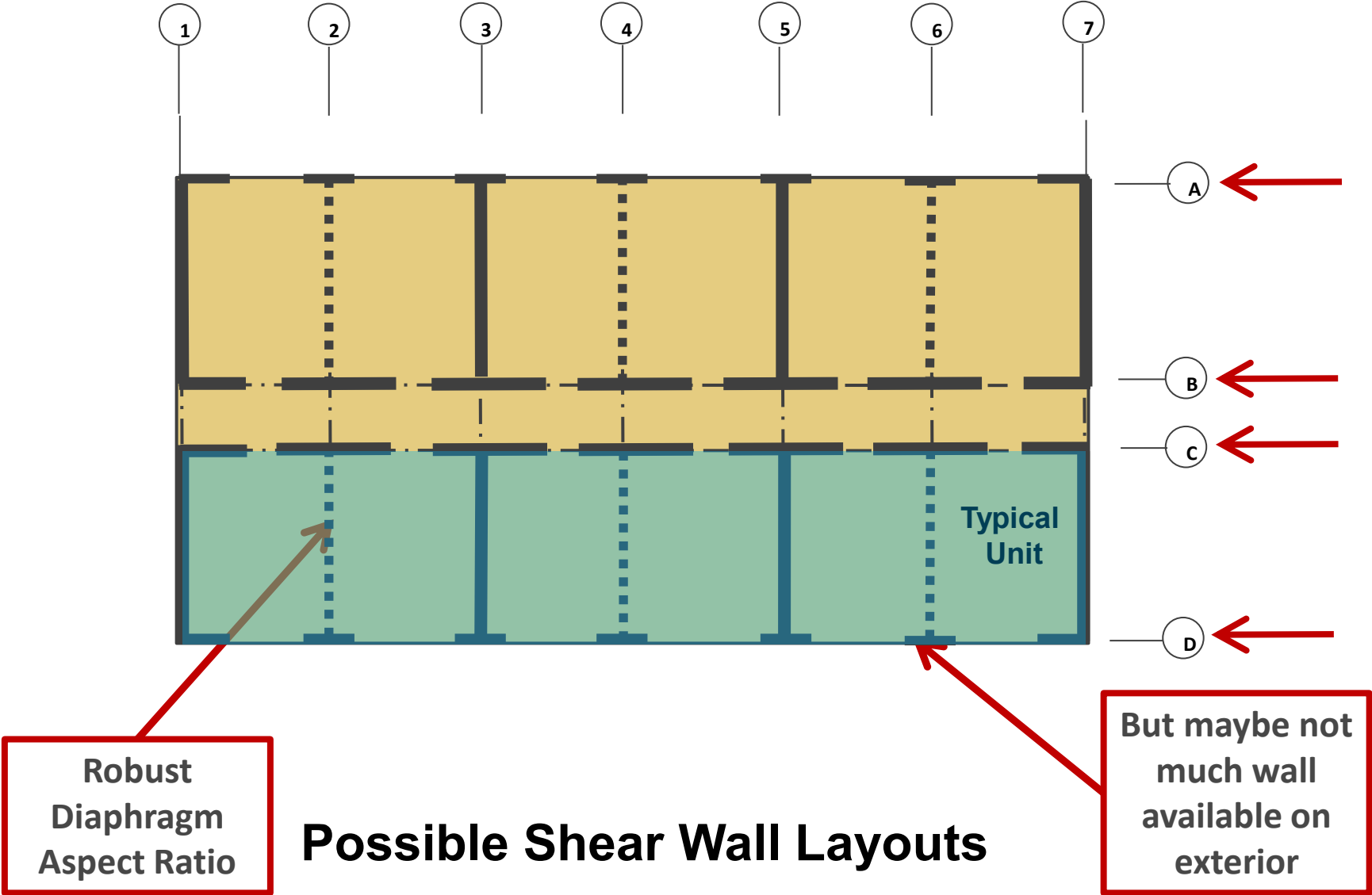
Drift Criteria

Can vary widely with brittleness of finishes but generally recommendations are in the range of $H/240$ to $H/600$

Diaphragm Modeling Methods



Diaphragm Modeling Methods



Rigid or Flexible Diaphragm?

Light Frame Wood Diaphragms often default to Flexible Diaphragms

Code Basis: ASCE 7-16 26.2 Definitions (Wind)

Diaphragms constructed of wood structural panels are permitted to be idealized as flexible

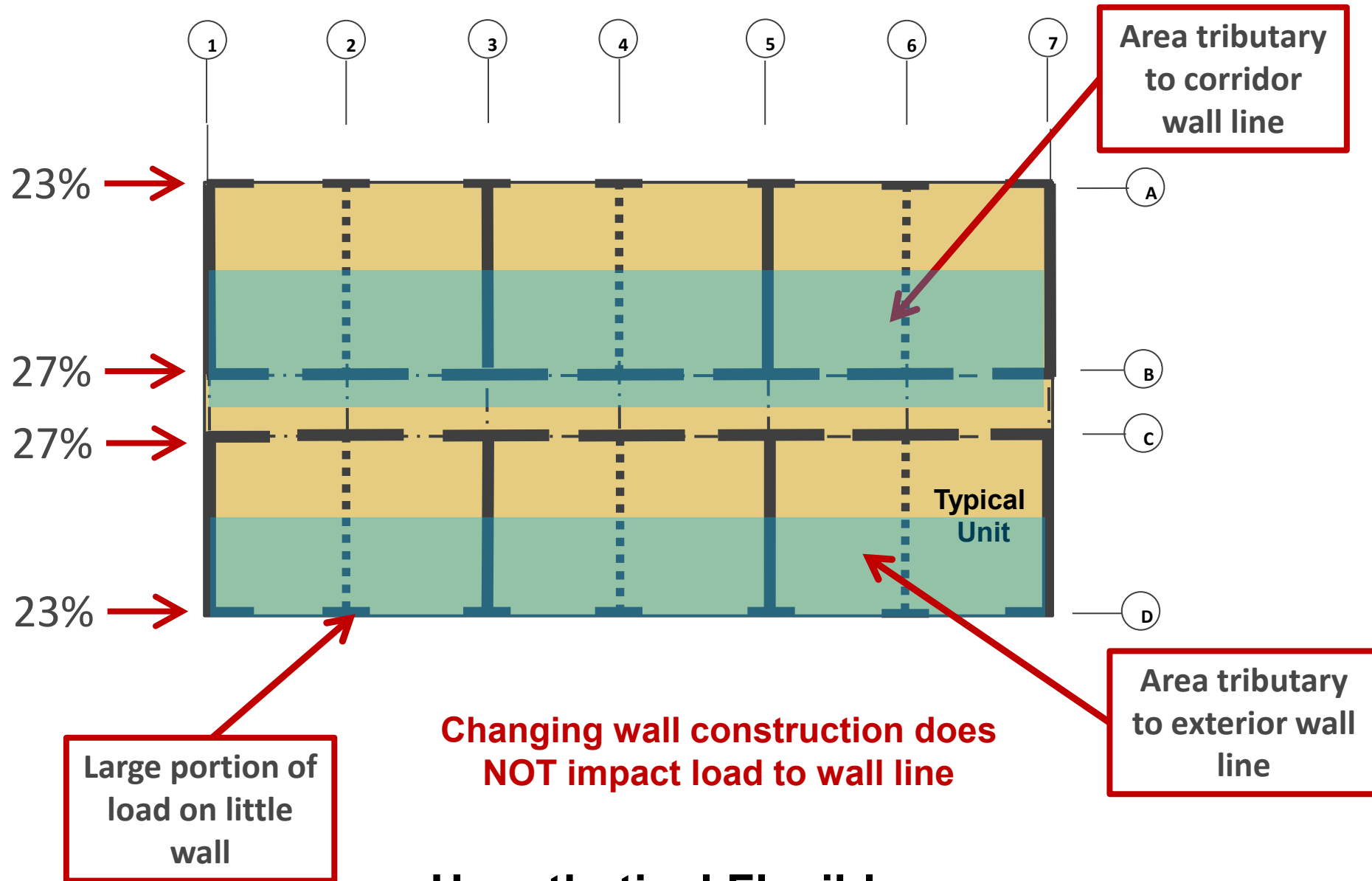
Code Basis: ASCE 7-16 12.3.1.1 (Seismic)

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

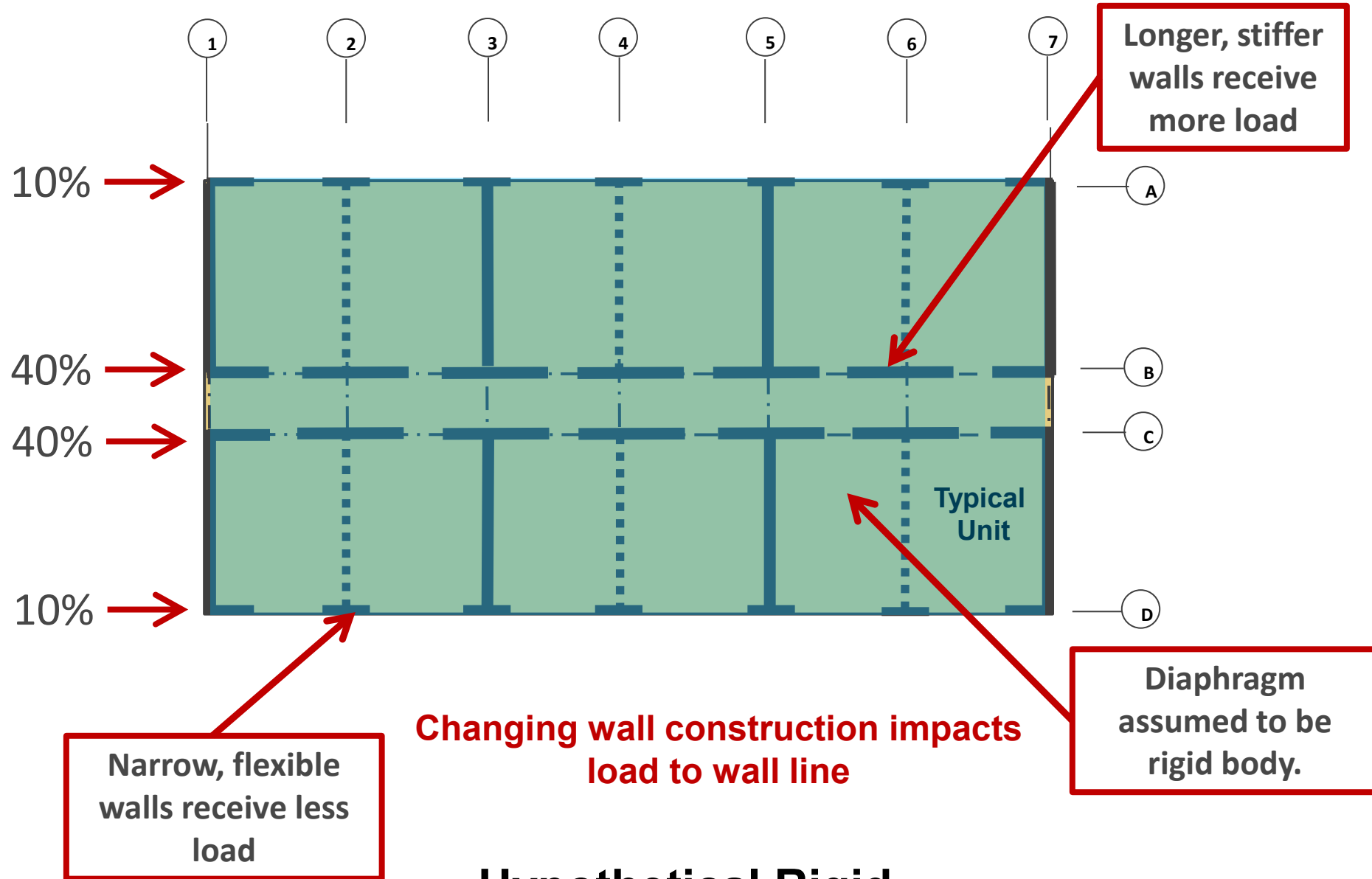
[...]

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

- 1. Topping of concrete or similar materials is not placed over wood structural panel diaphragms except for nonstructural topping no greater than 1 1/2 in. thick.*
- 2. Each line of vertical elements of the seismic force resisting system complies with the allowable story drift of Table 12.12-1..*



Hypothetical Flexible Diaphragm Distribution



Hypothetical Rigid Diaphragm Distribution

Can a Rigid Diaphragm be Justified?

» ASCE 7-16 12.3.1.3 (Seismic)

[Diaphragms] are permitted to be idealized as **flexible** where the computed maximum **in-plane deflection of the diaphragm under lateral load is more than two times the average story drift of adjoining vertical elements** of the seismic force-resisting system of the associated story under equivalent tributary lateral load as shown in Fig. 12.3-1.

» IBC 2012 Chapter 2 Definition (Wind & Seismic)

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**.

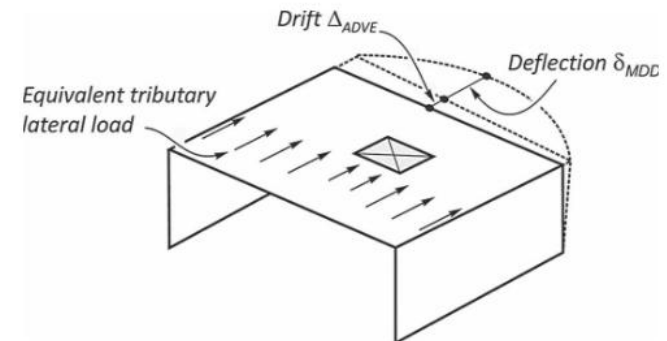


Figure 12.3-1. Flexible diaphragm.

Source: ASCE 7-16

Rigid Diaphragm Analysis

Some Advantages of Rigid Diaphragm

- » More load (plf) to longer interior/corridor walls
- » Less load (plf) to narrow walls where overturning restraint is tougher
- » Can tune loads to walls and wall lines by changing stiffness of walls

Some Disadvantages of Rigid Diaphragm

- » Considerations of torsional loading necessary
- » More complicated calculations to distribute load to shear walls
- » May underestimate “real” loads to narrow exterior walls
- » Justification of rigid assumption

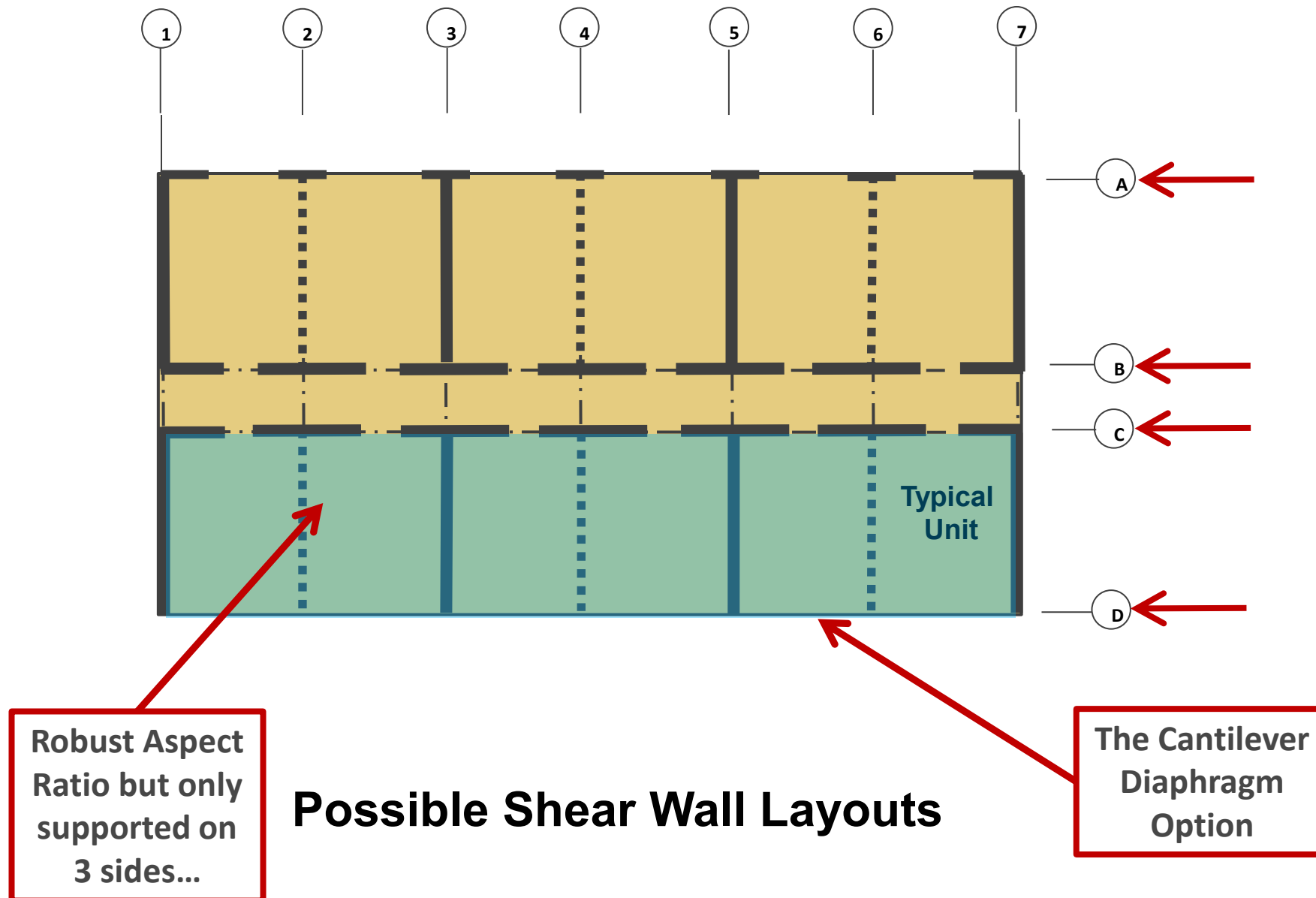
Two More Diaphragm Approaches

Semi-Rigid Diaphragm Analysis

- » Neither idealized flexible nor idealized rigid
- » Explicit modeling of diaphragm deformations with shear wall deformations to distribute lateral loads
- » Not easy

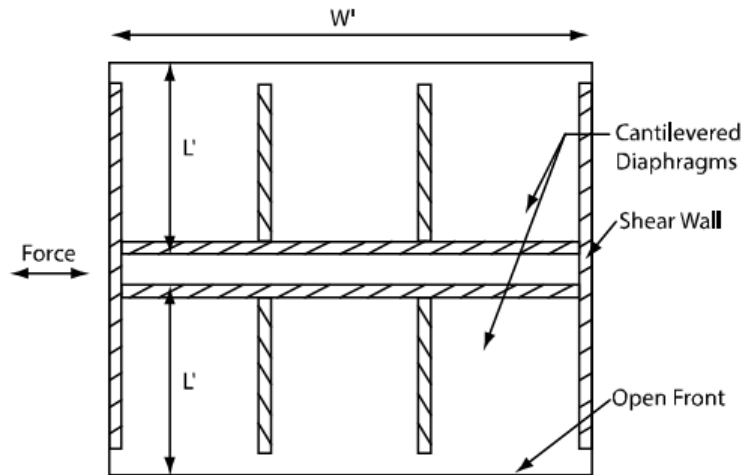
Enveloping Method

- » Idealized as BOTH flexible and rigid.
- » Individual components designed for worst case from each approach
- » Been around a while, officially recognized in the 2015 SDPWS



Open Front Structure & Cantilevered Diaphragms in SDPWS 2015

Cantilevered Diaphragm



SDPWS 4.2.5.2

- $L'/W' \leq \mathbf{1.5}$
- When torsionally irregular
 $L'/W' \leq 1$, one story
 $\leq 2/3$, multi-story
- $L' \leq \mathbf{35}$ ft

Provided diaphragms modelled as rigid or semi-rigid and for seismic, the story drift at each edge of the structure within allowable story drift of ASCE 7. Story drifts include torsion and accidental torsional loads and deformations of the diaphragm.

Exception: If $L' \leq 6$ ft , section doesn't apply.

Seismic Design – Podium Projects

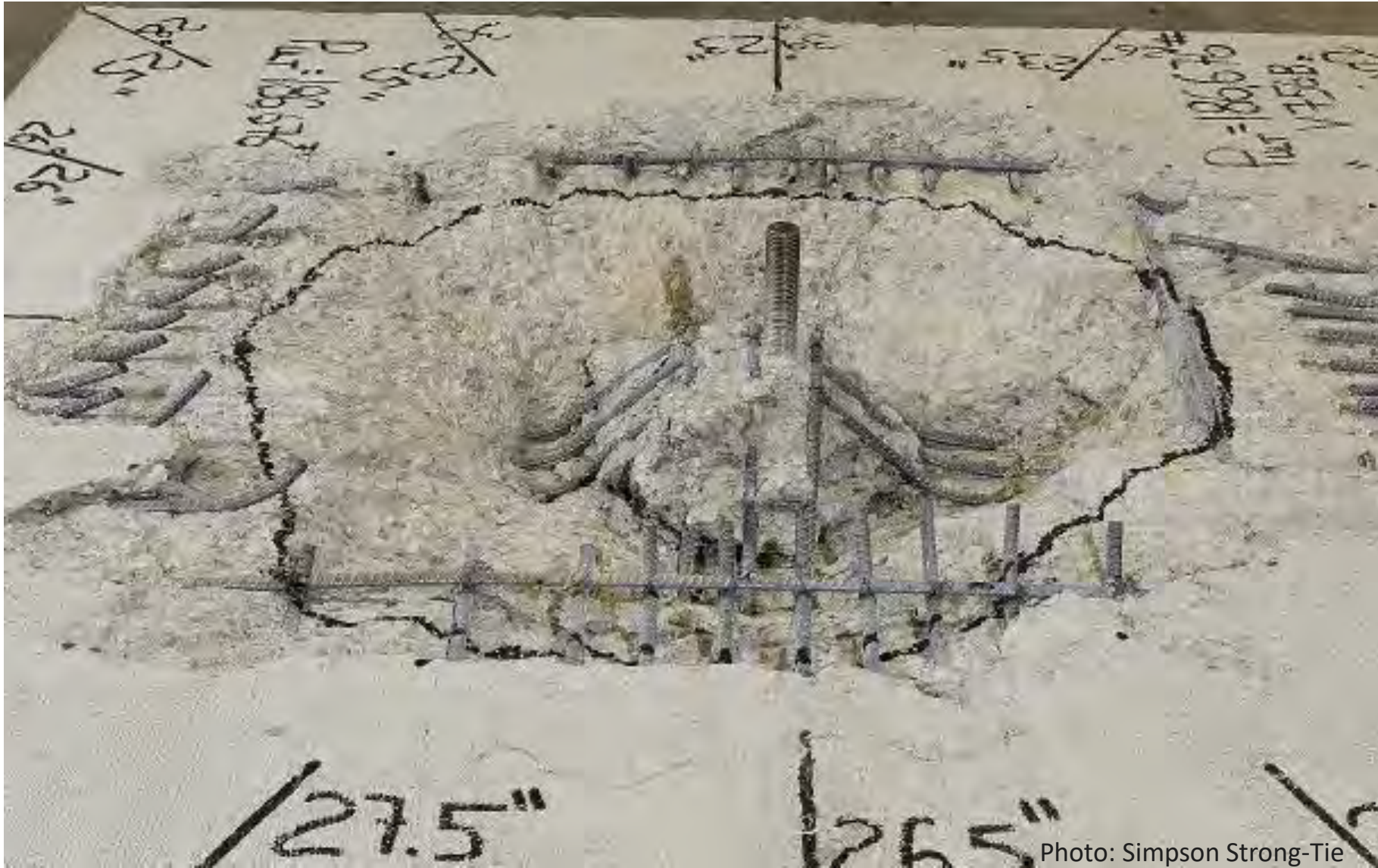
ASCE 7-10 Section 12.2.3.2 permits seismic analysis of structure above and below podium separately under certain conditions.

Beneficial as upper portion (wood) typ. has $R = 6.5$ and lower portion (concrete/steel) typ. has $R < 6.5$.
This inverse analysis only allowed per this special provision

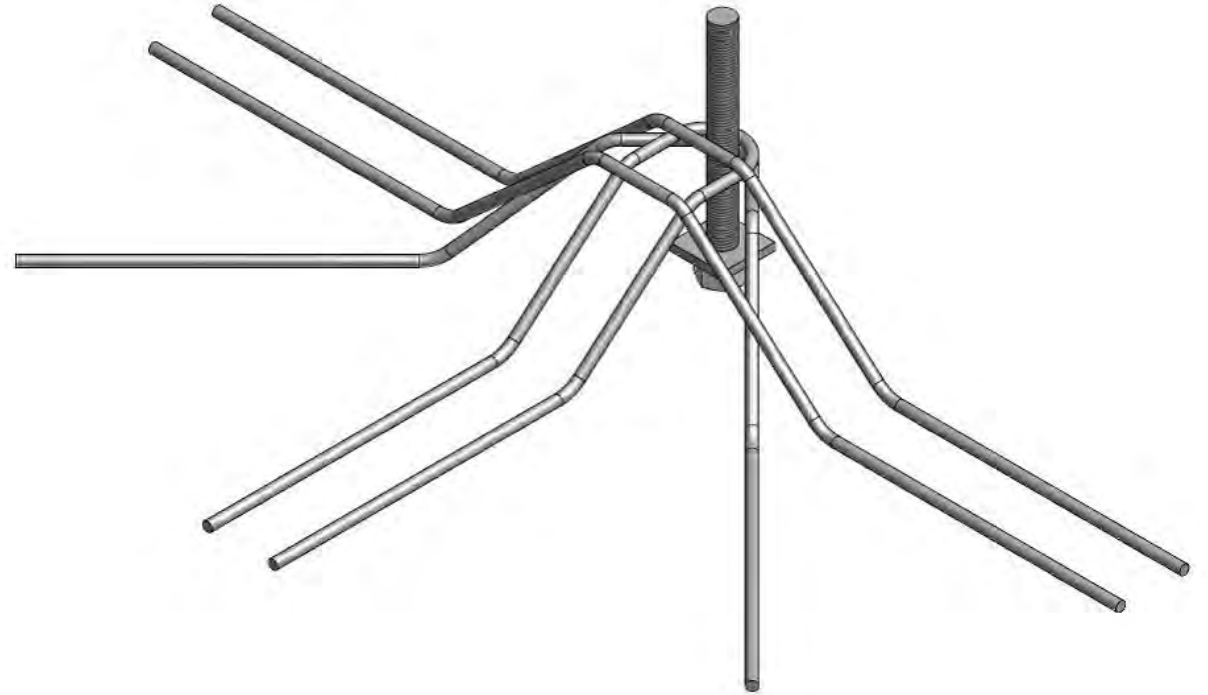
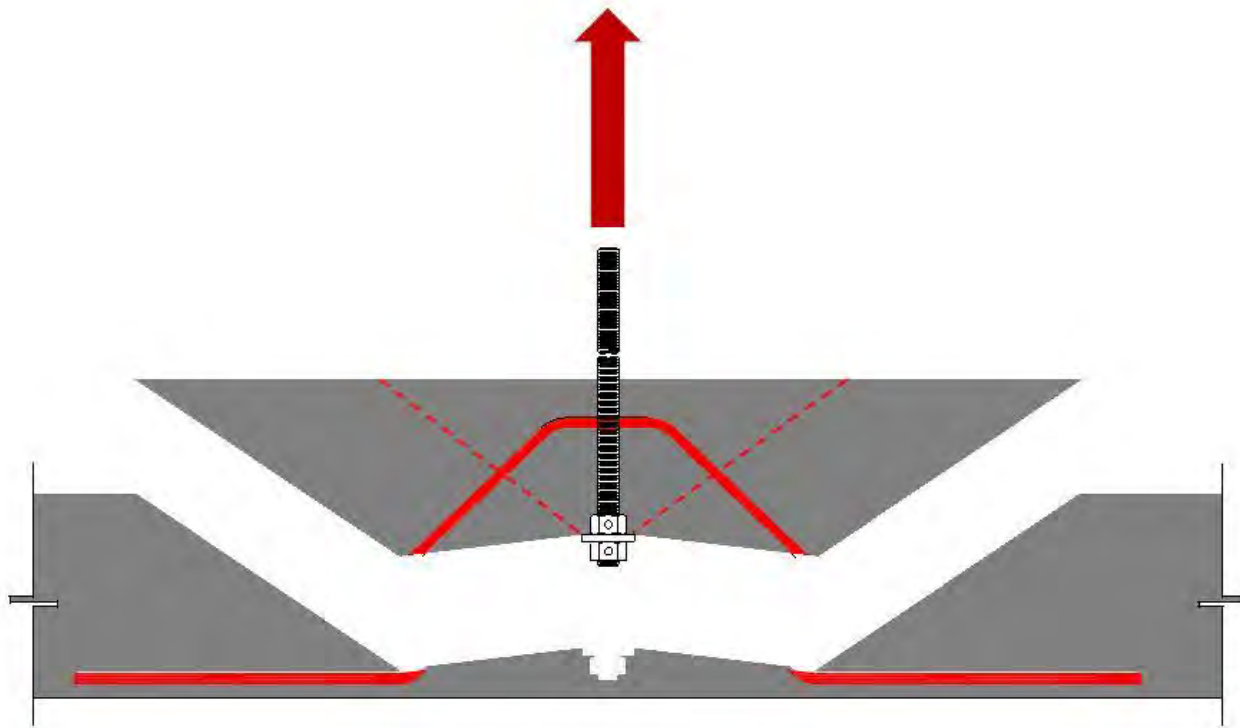
12.2.3.2 Two-Stage Analysis Procedure. A two-stage equivalent lateral force procedure is permitted to be used for structures having a flexible upper portion above a rigid lower portion, provided the design of the structure complies with all of the following:

- a. The stiffness of the lower portion shall be at least 10 times the stiffness of the upper portion.
- b. The period of the entire structure shall not be greater than 1.1 times the period of the upper portion considered as a separate structure supported at the transition from the upper to the lower portion.
- c. The upper portion shall be designed as a separate structure using the appropriate values of R and ρ .
- d. The lower portion shall be designed as a separate structure using the appropriate values of R and ρ . The reactions from the upper portion shall be those determined from the analysis of the upper portion amplified by the ratio of the R/ρ of the upper portion over R/ρ of the lower portion. This ratio shall not be less than 1.0.
- e. The upper portion is analyzed with the equivalent lateral force or modal response spectrum procedure, and the lower portion is analyzed with the equivalent lateral force procedure.

Tie Down Attachment to Concrete



Tie Down Bolt with Washer



Embedded Steel Plates – Weld on Rods

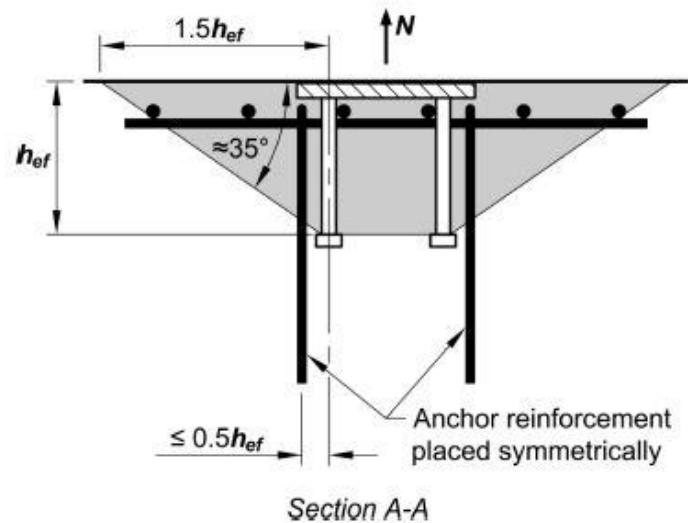
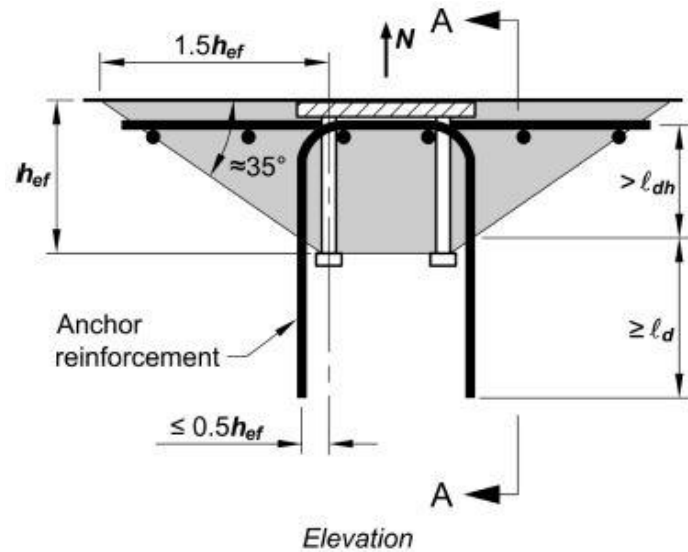


Fig. RD.5.2.9—Anchor reinforcement for tension.

Tie Down Anchors – Through Podium



Offset Shear Wall Overturning Resistance

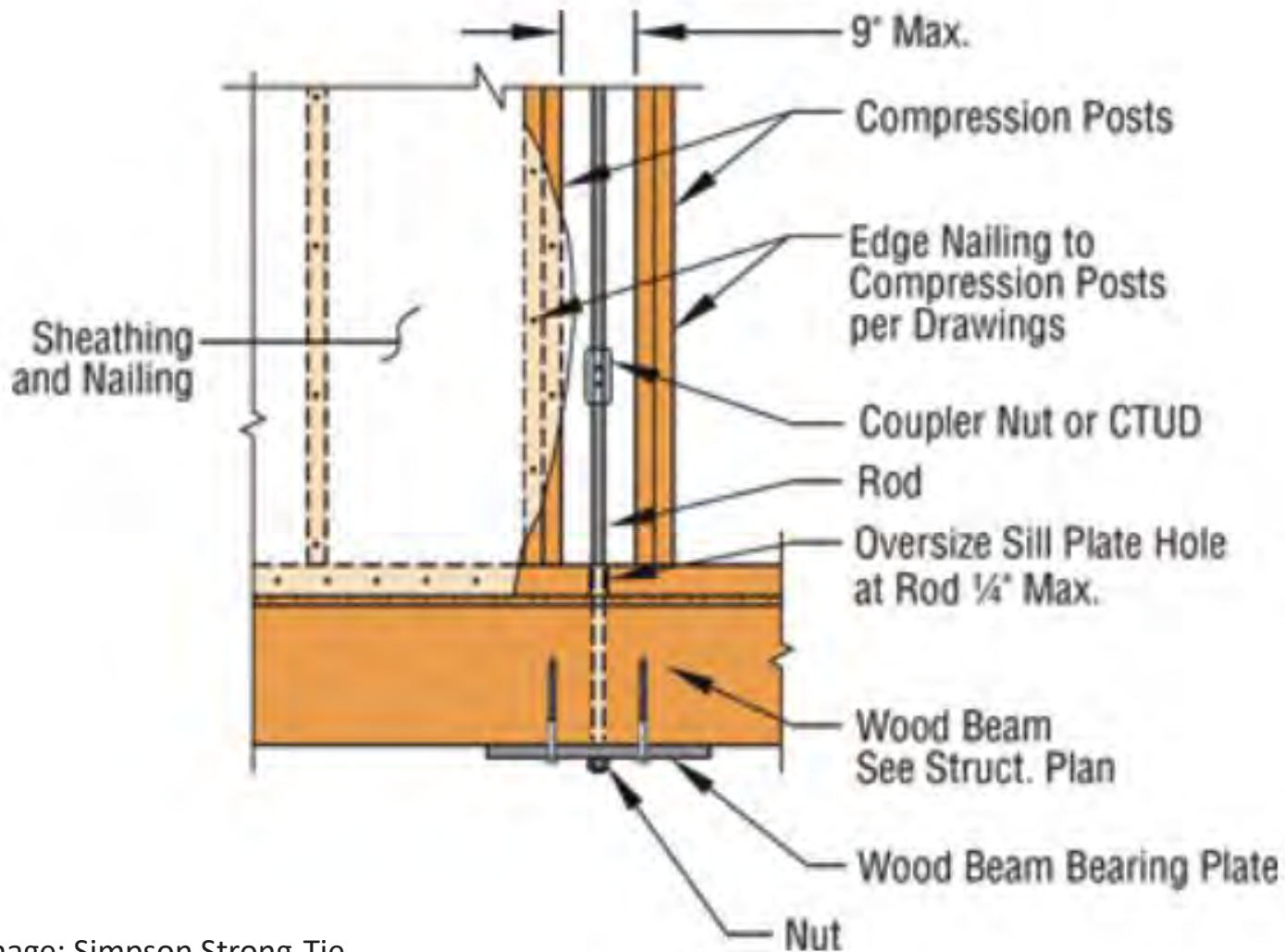


Image: Simpson Strong-Tie

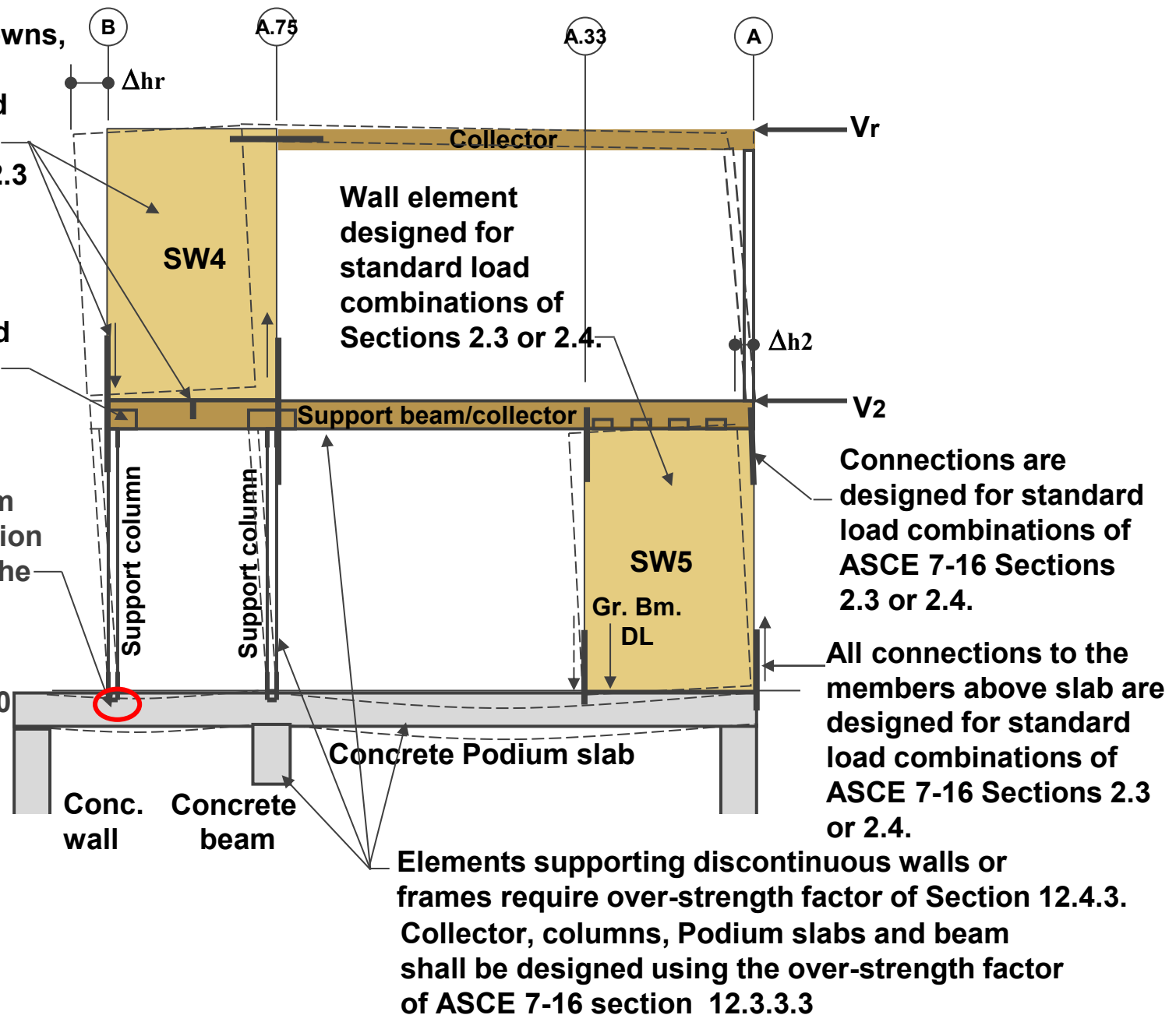
Wall element, hold downs, and connections are designed for standard load combinations of ASCE 7-16 Sections 2.3 or 2.4.

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

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

$$\frac{\frac{R}{\rho}_{Upper\ portion}}{\frac{R}{\rho}_{Lower\ portion}} > 1.0$$

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



Discontinuous Shear wall system at Podium Slab

Recap: Multi-Story Considerations

- » Mid-Rise Construction Types & Structural Implications
- » Accommodating Wood Shrinkage
- » Gravity Design
- » Lateral Design



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Questions? Ask me anything.



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Please take our survey!



901 East Sixth, Thoughtbarn-Delineate Studio, Leap!Structures, photo Casey Dunn