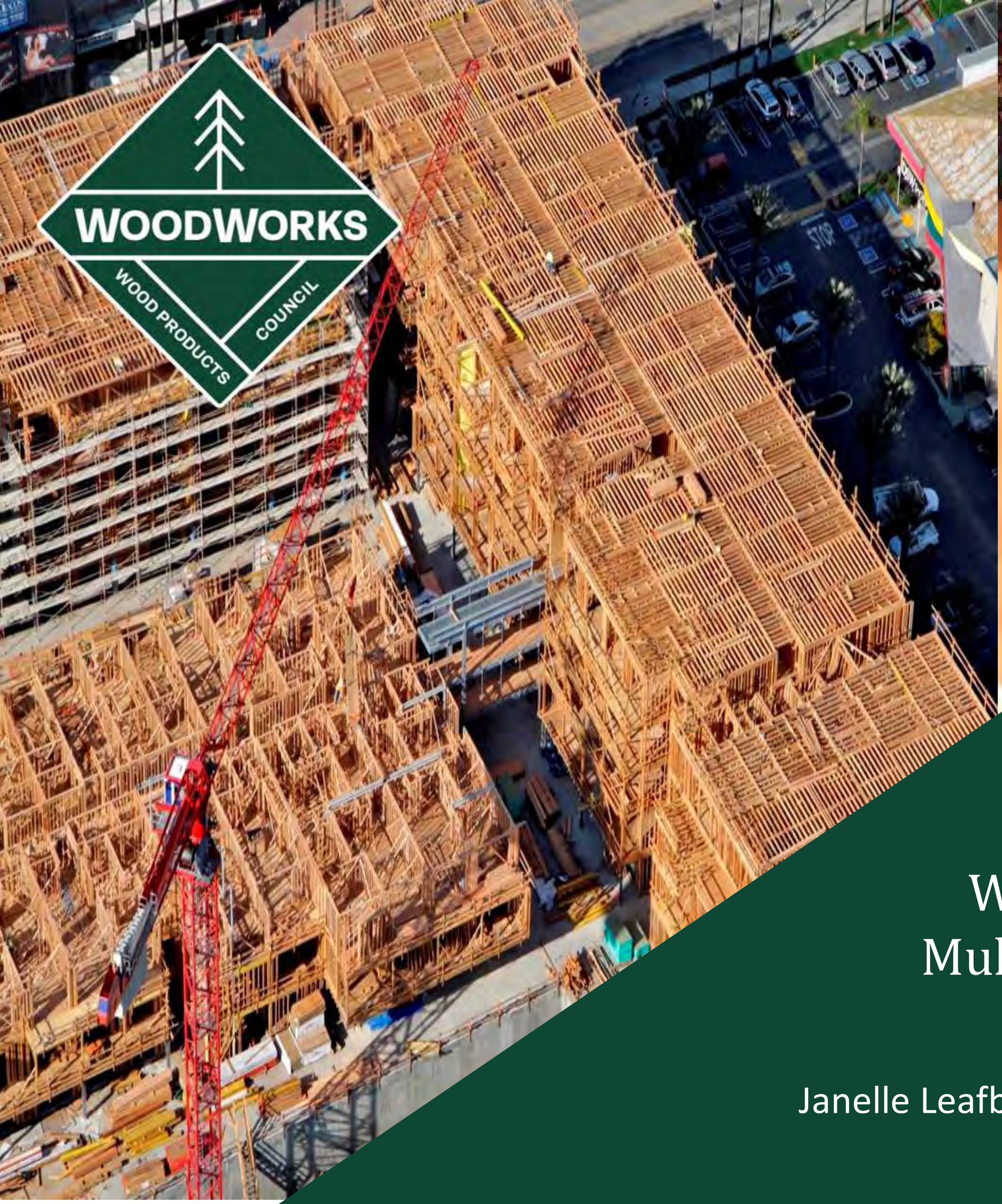

Let’s Talk About Wood: Science, Carbon and Multi-Family Building Design

Presented by
Janelle Leafblad & Chelsea Drenick, WoodWorks
December 16, 2021

MULTI-FAMILY/MIXED-USE | EDUCATION | OFFICE | RETAIL | INDUSTRIAL | CIVIC | INSTITUTIONAL

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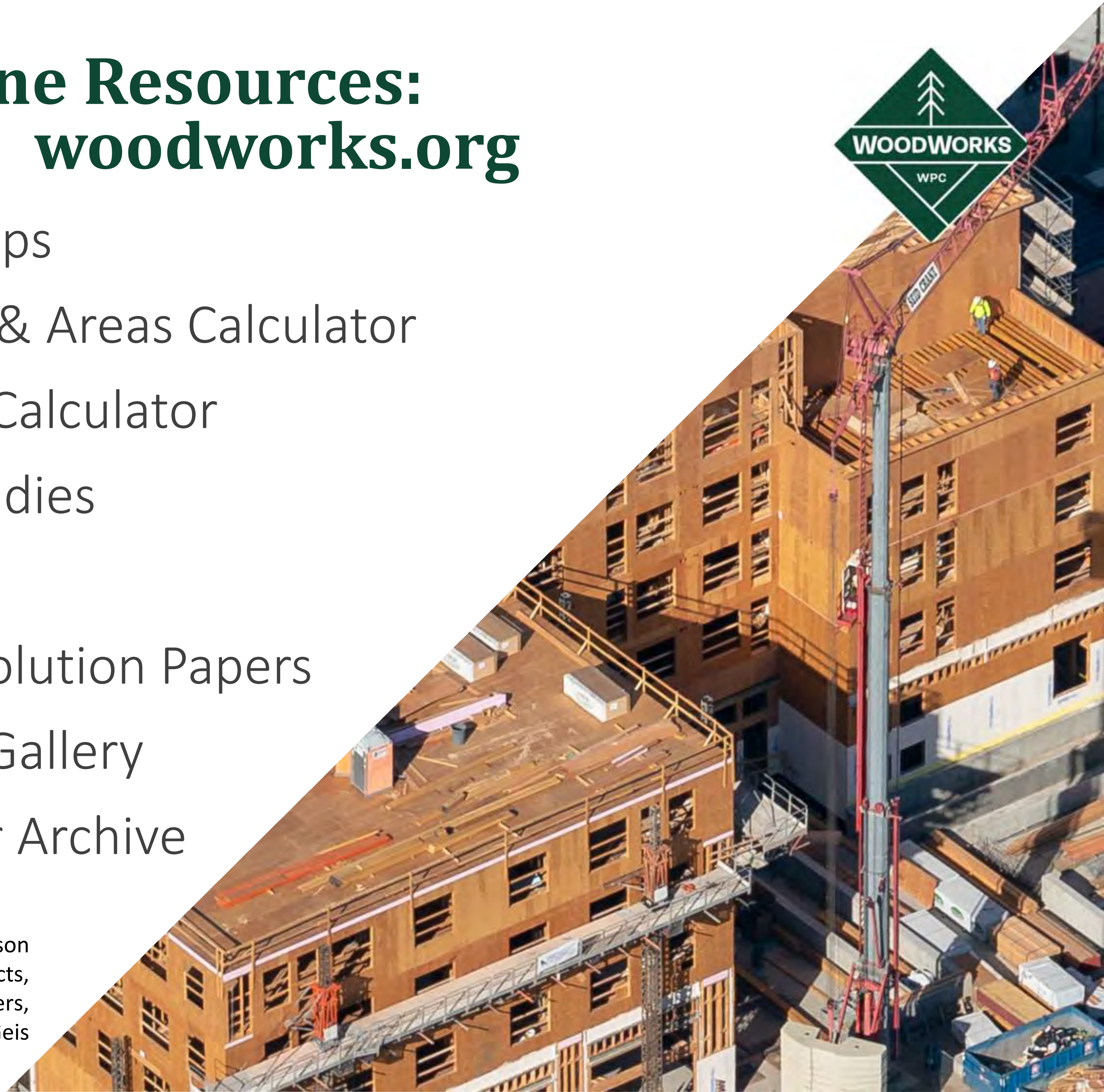

The Gibson
Hummel Architects,
KPFF Consulting Engineers,
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RESOURCES

& UPCOMING EVENTS

New WOOD SOLUTION PAPER

Taking the Guesswork out of Mixed-Use Building Requirements

Mixed-Use Occupancy Design for Low- and Mid-Rise Wood Buildings

Taking the Guesswork out of Mixed-Use Building Requirements

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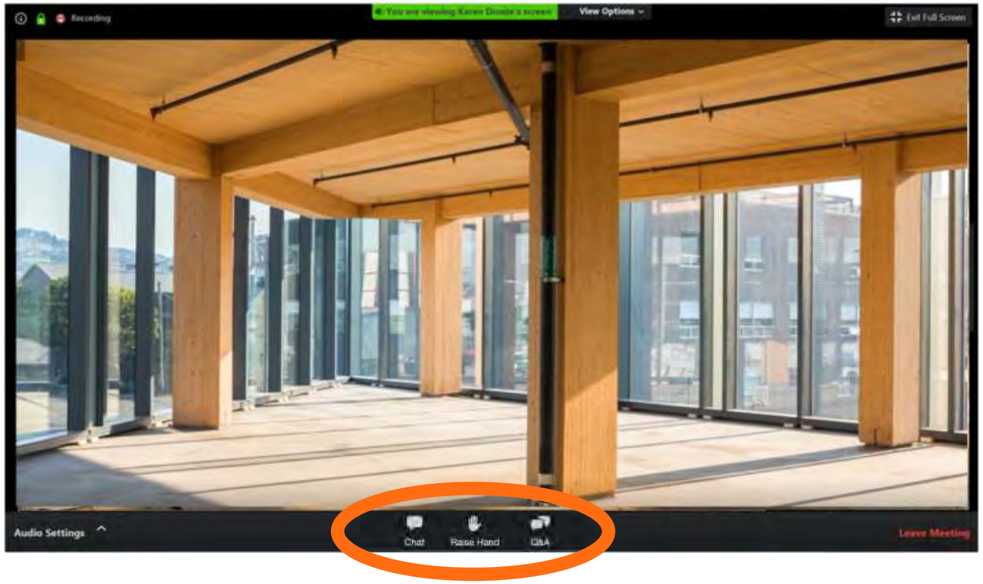
- During today’s event will be sending links, files and other pertinent information through the Chat window, located at the bottom of your screen.
- Submit questions in the Q&A box at the bottom of your screen as they come up in the presentations. We will **get to as many questions as possible.**



Questions? Ask us anything.

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901 East Sixth, Thoughtbarn-Delineate Studio,
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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 will provide a review of wood science as it relates to the structural engineer, including wood's cell structure and moisture interaction properties, followed by a detailed look at wood shrinkage. Discussion will cover available wood species as well as methods of grading and identification for common wood framing material. This course also takes a brief look at the use of wood in construction and highlights some of the positive environmental benefits it can bring to a building. Basic terminology surrounding carbon will be reviewed along with information on carbon sequestration in wood. Key considerations for mid-rise multi-family design will then be reviewed including impacts of construction type, fire ratings, shrinkage design, floor vibration, and exterior wall detailing.

Learning Objectives

1. Review wood's cellular makeup in order to understand carbon storage and how wood and moisture interact.

2. Discuss available wood species as well as methods of grading and identification for common wood framing material.

3. Examine floor-to-exterior wall details for use in wood-frame construction and discuss multi-story wood bearing wall design.

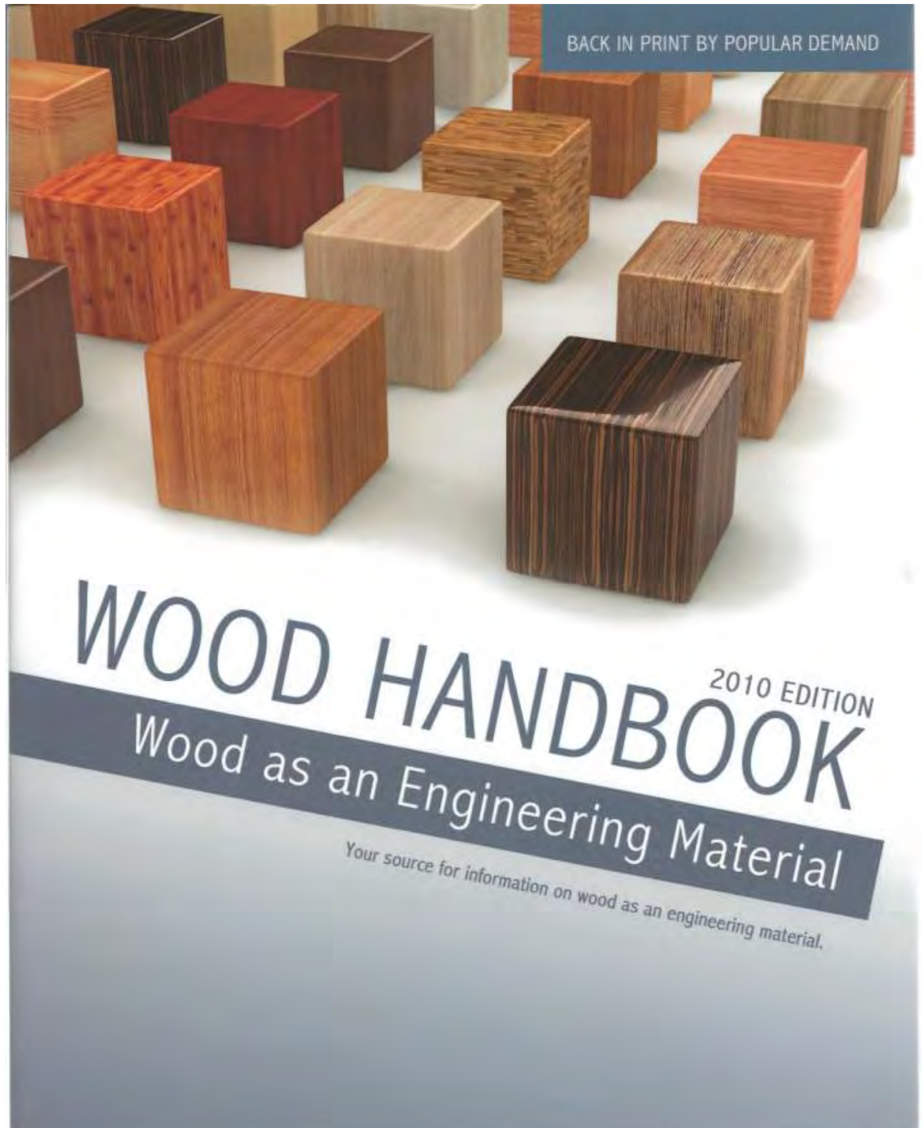
4. Discuss design considerations specific to wood framing such as moisture control and shrinkage accommodation

PRESENTATION OUTLINE

1. WOOD SCIENCE AND GRADING
2. CARBON STORAGE IN WOOD PRODUCTS
3. DESIGN CONSIDERATIONS FOR MID-RISE MULTI-FAMILY CONSTRUCTION

Wood Science

Wood Handbook



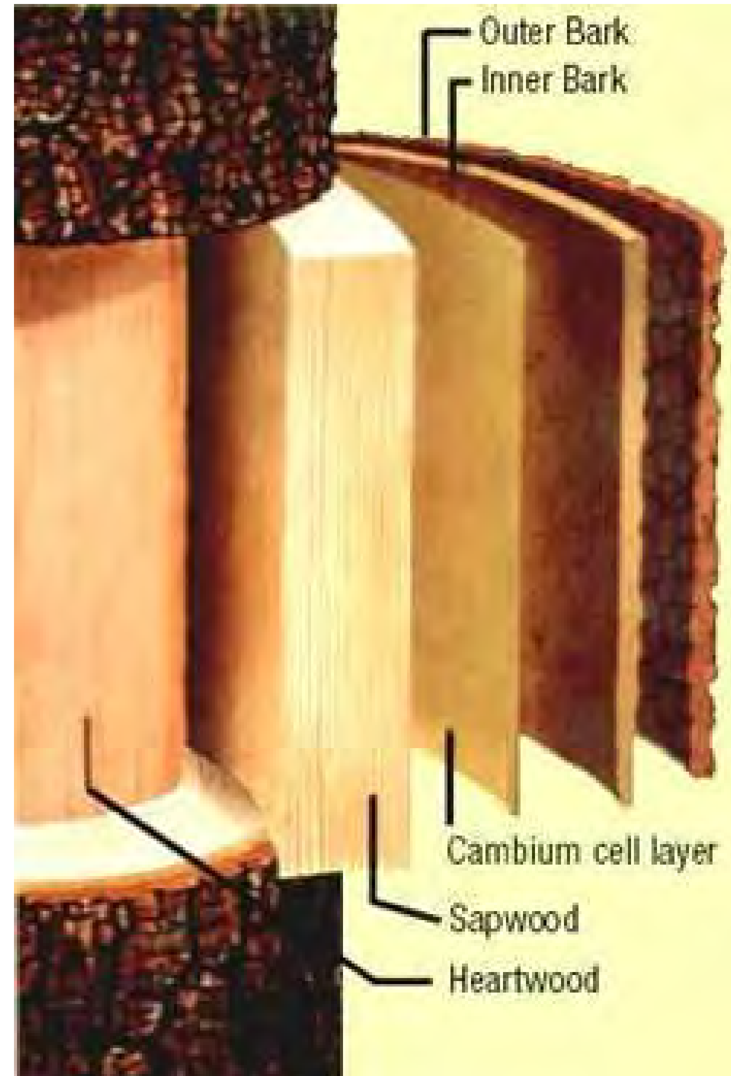
Wood Science: Cell Structure

Wood cell structure has 3 basic functions:

1. Conduction of water from roots to branches, leaves
2. Mechanical support of plant body
3. Storage of biochemicals

Understanding the basic requirements of the wood cell structure as dictated by these 3 functions allows us to understand wood as an engineering and building material.

Relationship of Form and Function



Source: Canadian Wood Council

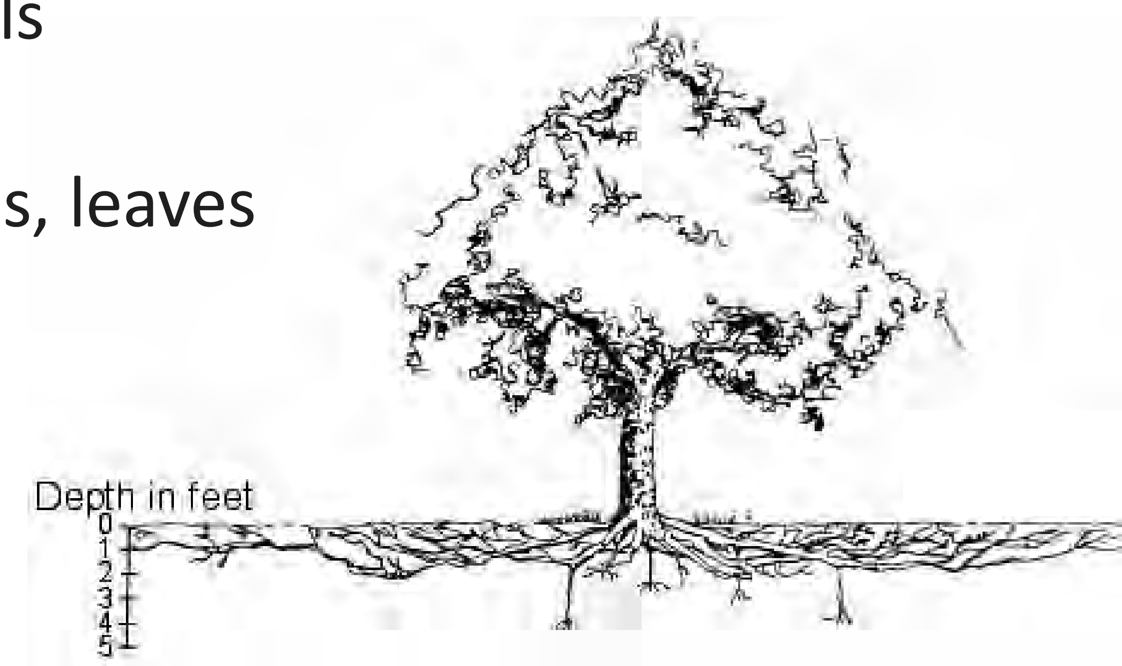
Cell Structure: The Tree

Trees have 2 main components: the **Roots** and the **Shoot**

Roots: Subterranean structure, water and mineral nutrient uptake, mechanical anchoring of shoot, storage of biochemicals

Shoot: Trunk, branches, leaves

Will focus on trunk



Cell Structure: The Trunk

Trunk Cross Section:

A – outer bark (dry dead tissue)

B – inner bark (living tissue)

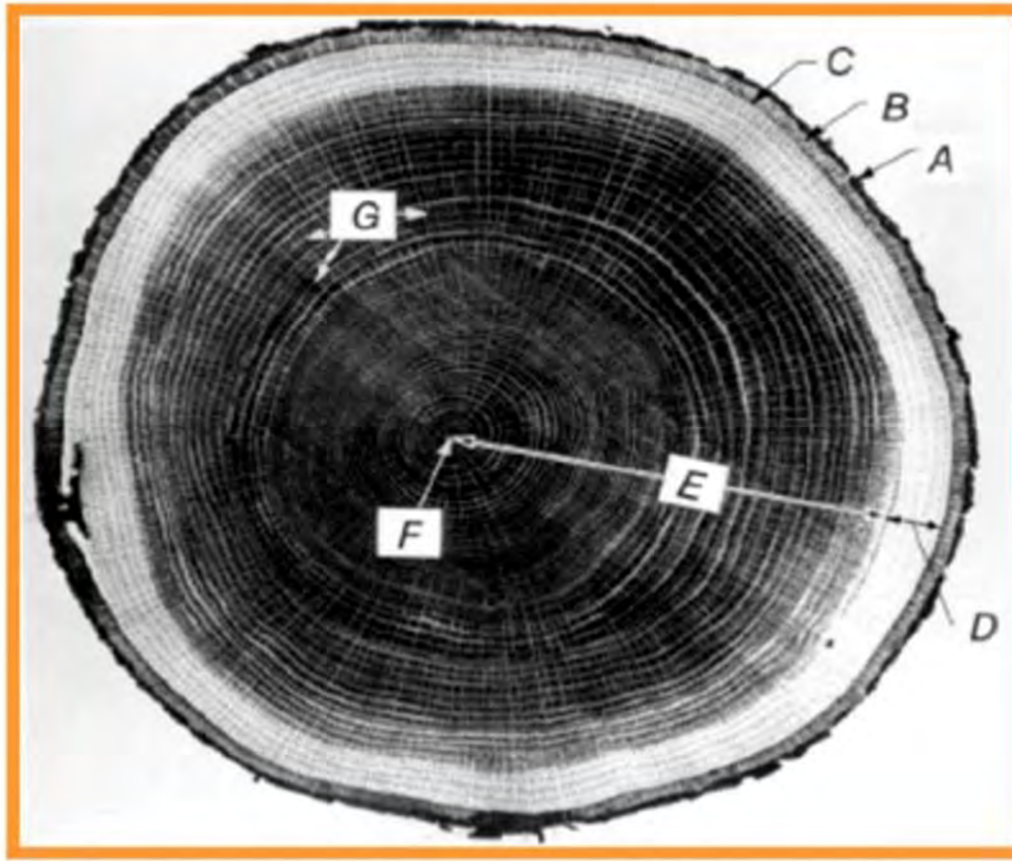
C – cambium (secondary growth cells)

D – sapwood

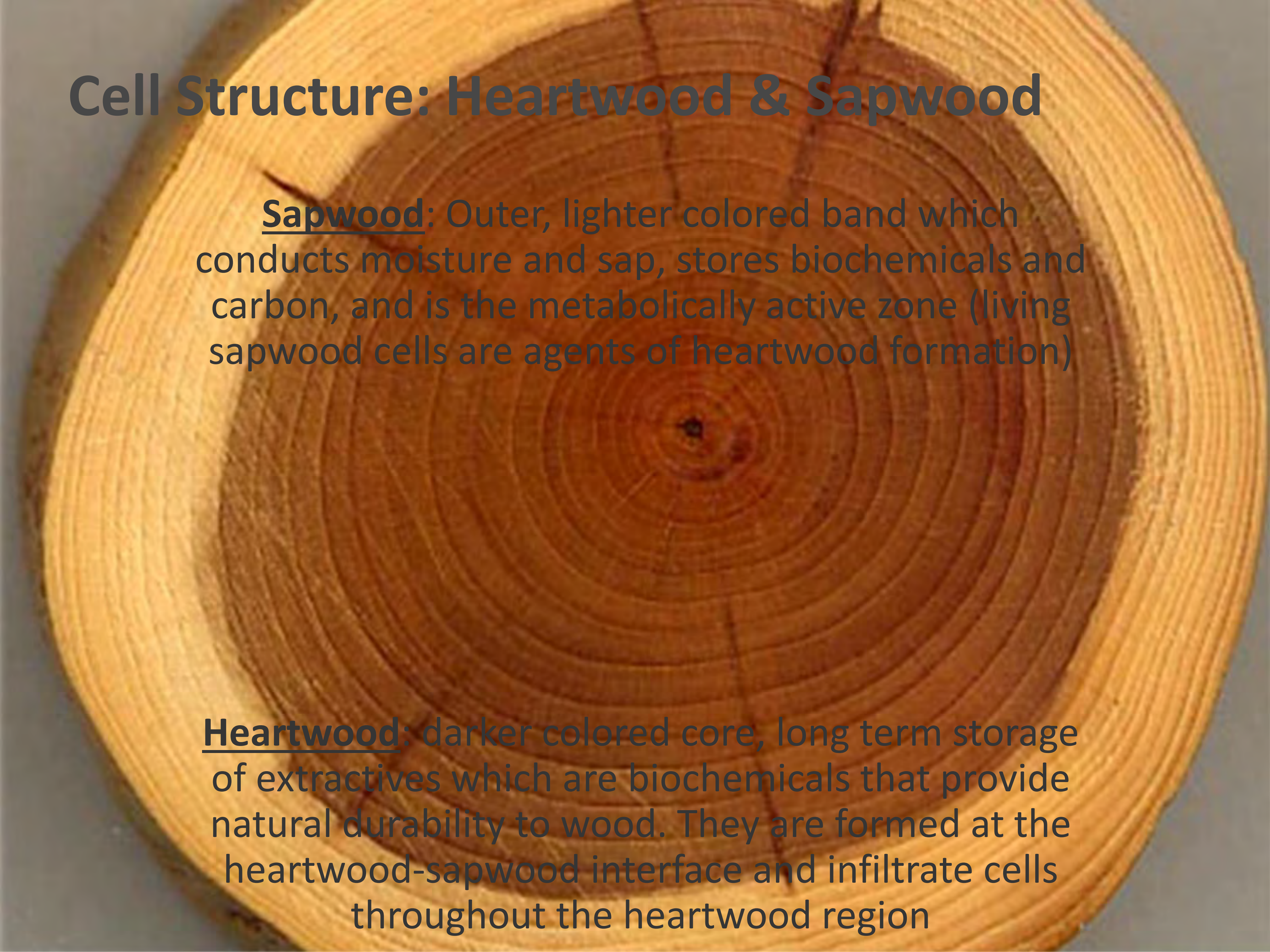
E – heartwood

F – pith

G – wood rays



Source: Wood Handbook, USDA Forest Service

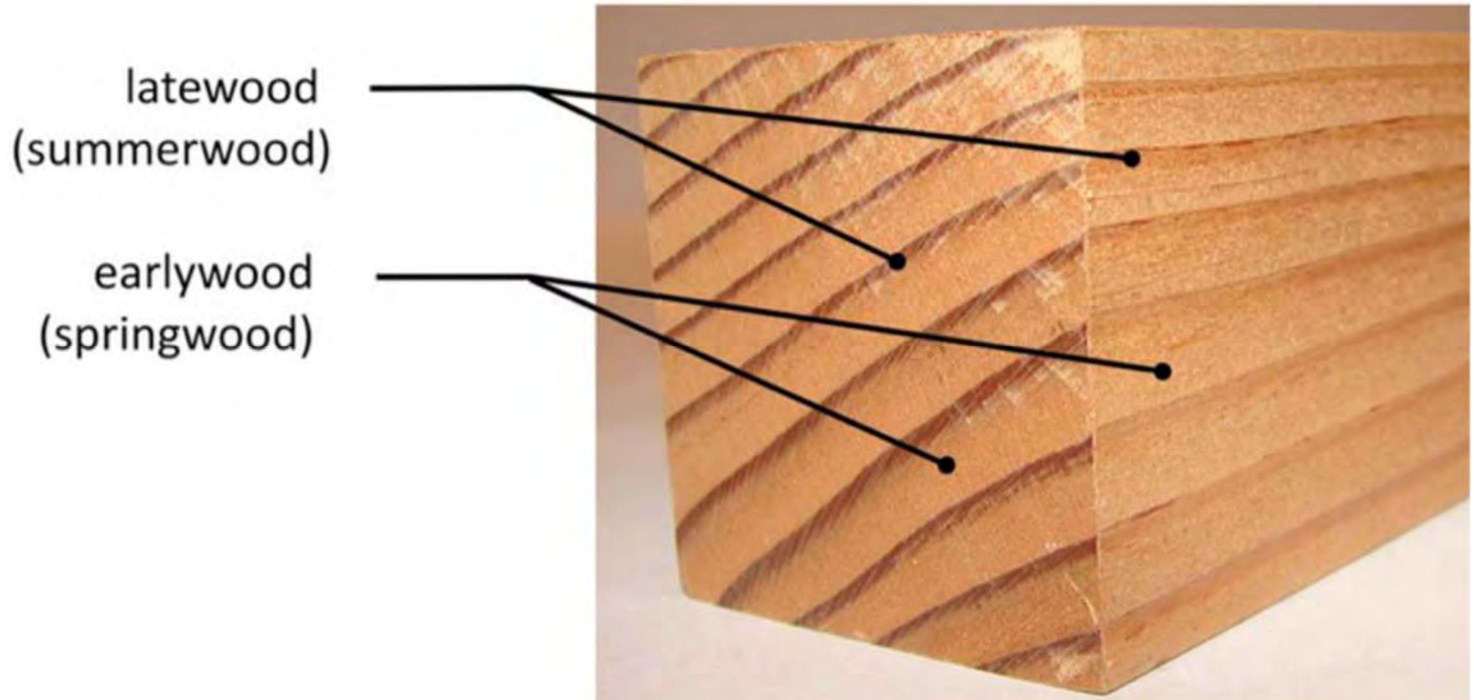


Cell Structure: Heartwood & Sapwood

<u>Sapwood</u>: Outer, lighter colored band which conducts moisture and sap, stores biochemicals and carbon, and is the metabolically active zone (living sapwood cells are agents of heartwood formation)

<u>Heartwood</u>: darker colored core, long term storage of extractives which are biochemicals that provide natural durability to wood. They are formed at the heartwood-sapwood interface and infiltrate cells throughout the heartwood region

Cell Structure: Tree Growth



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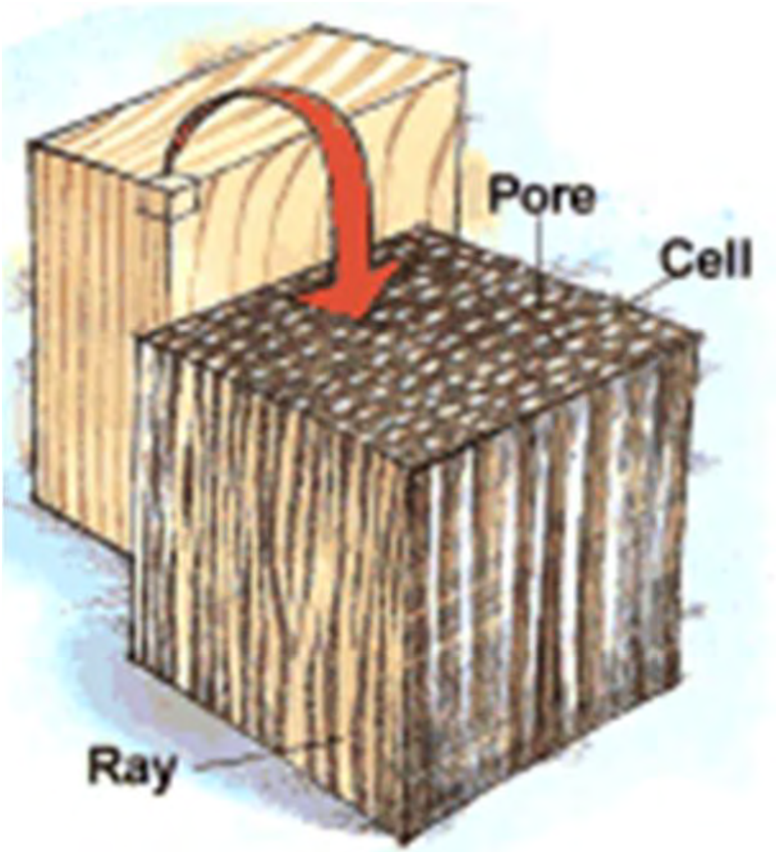
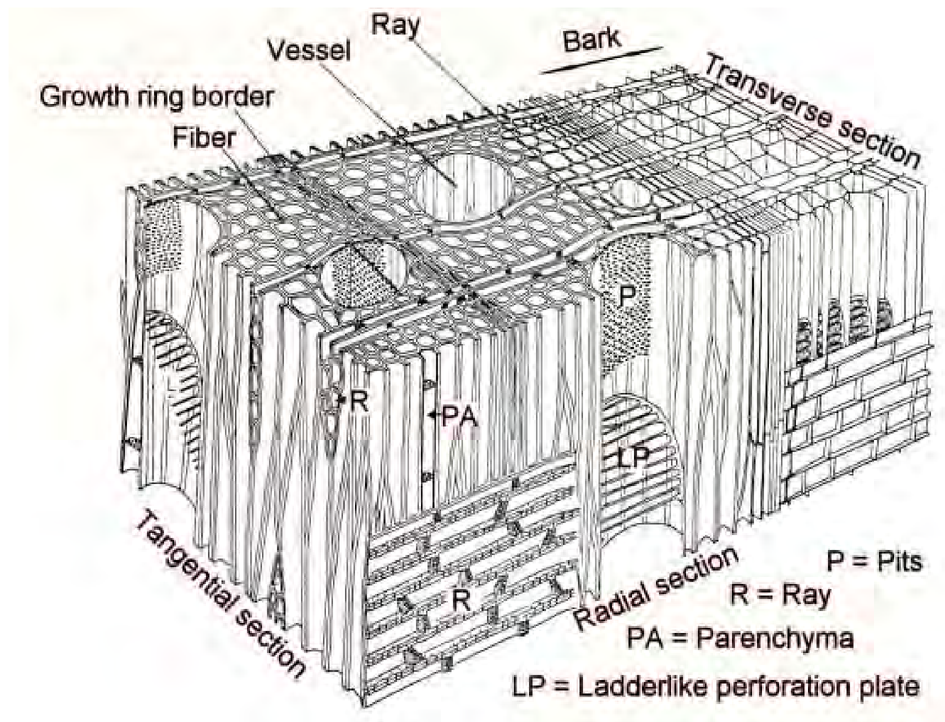
- **Earlywood**: lighter colored, larger portion of growth ring with thinner cell walls (less dense); grows in rainy spring season
- **Latewood**: darker colored, thinner but denser portion of growth ring; grows in dry summer season
- Direct correlation between structural properties and percentage of latewood (more latewood = higher strength)

Cell Structure: Anatomy

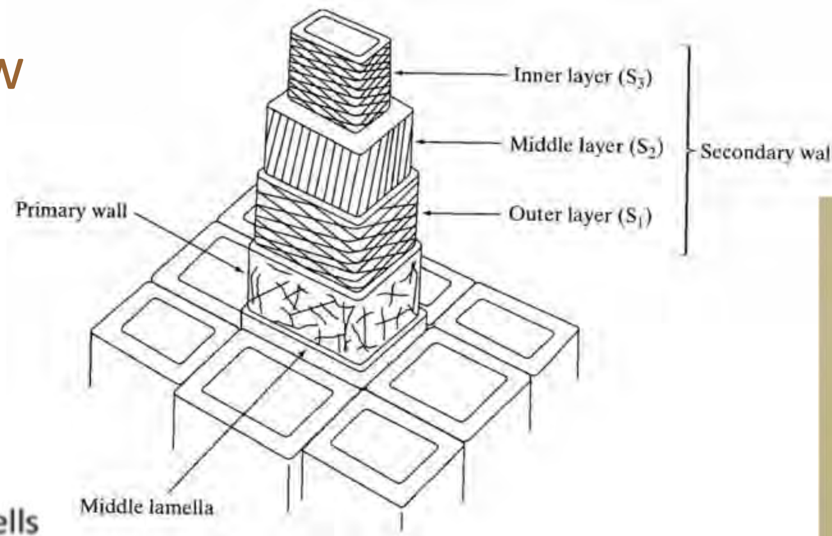


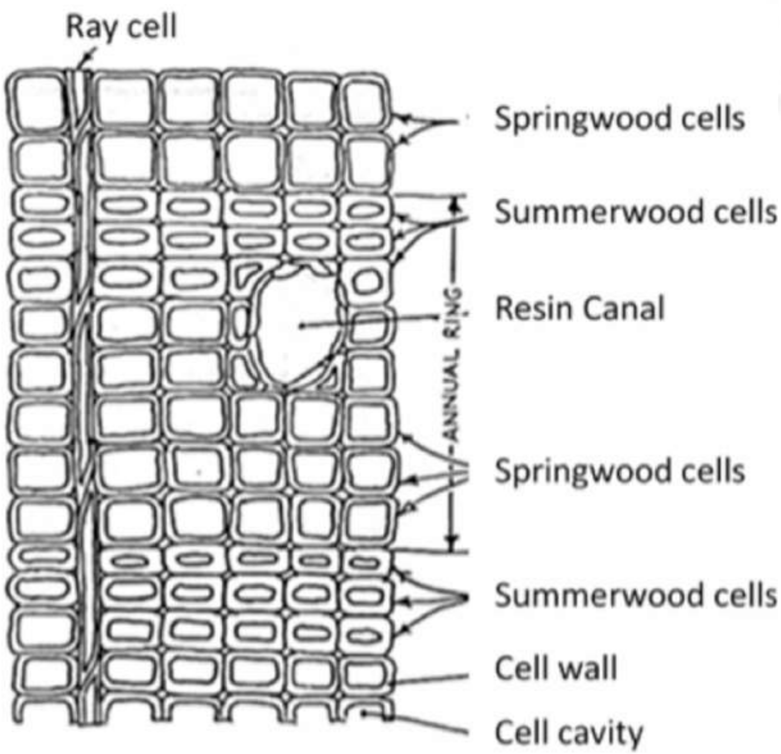
Cell & Ray size, layout and density are all factors that contribute to wood's mechanical properties



Cell Structure: Anatomy

Longitudinal cells allow moisture movement "parallel to grain"





Wood's longitudinal cells are often idealized as a bundle of straws

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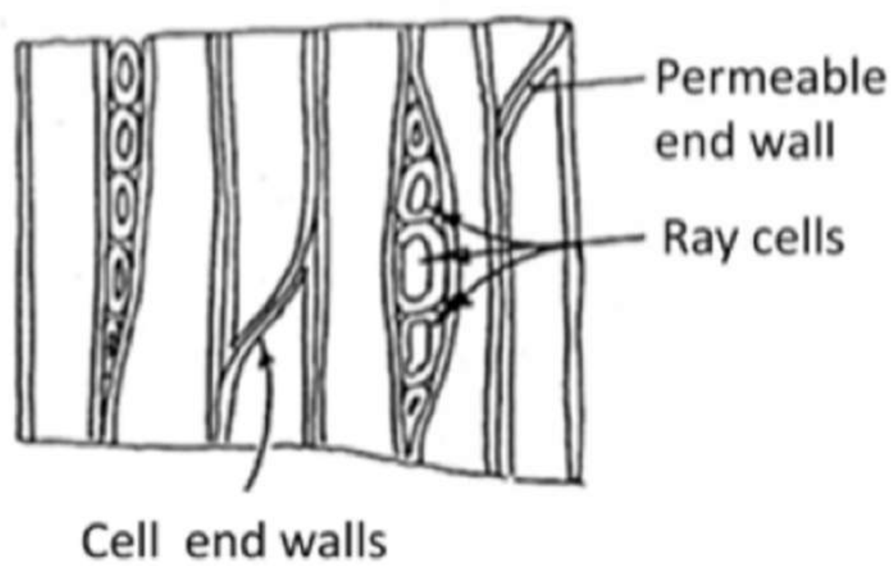
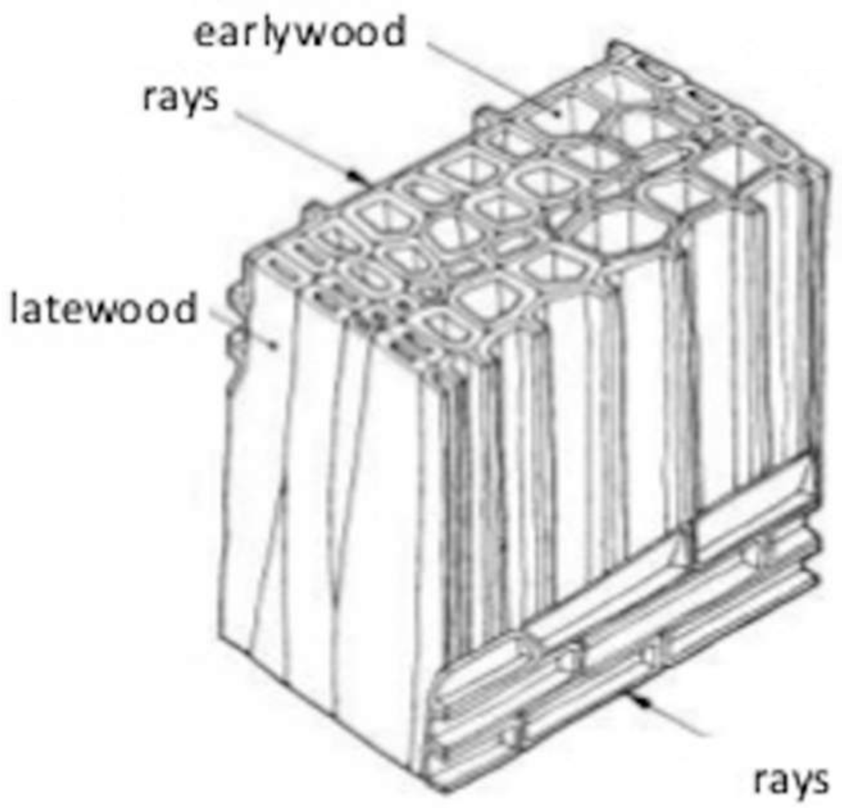
Cell Structure: Anatomy

Rays act as valves to distribute moisture between longitudinal cells





Cell Structure: Interaction with Water

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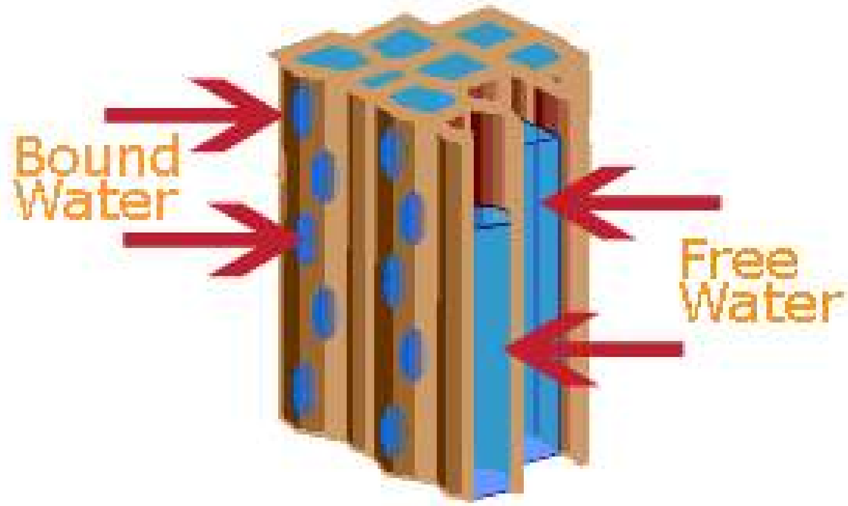


Water exists in wood in two forms: Free Water & Bound Water

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

Cell Structure: Moisture in Wood

Shrinkage begins to occur when wood's moisture content drops below its fiber saturation point (bound water is removed).

Fiber Saturation Point is generally around MC 30%

$$MC = \frac{W_{wet} - W_{dry}}{W_{dry}} * 100\%$$

Where:

MC = Moisture Content

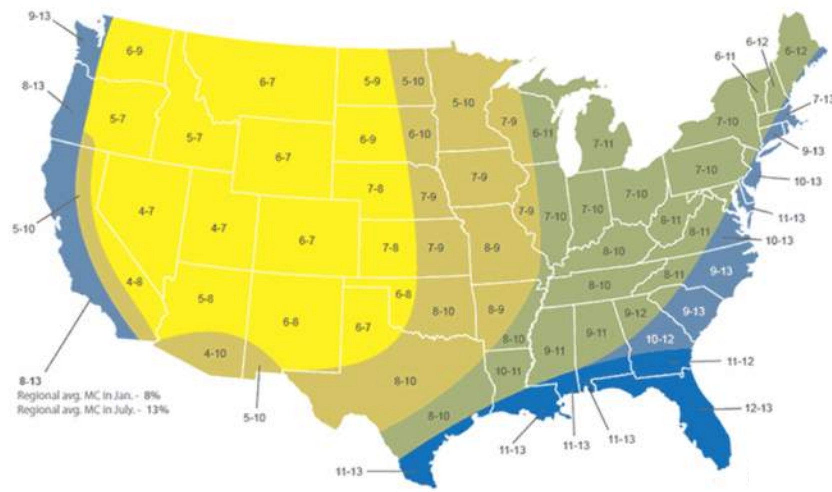
W_{wet} = current weight of wood

W_{dry} = oven dry weight of wood

Wood is a hygroscopic material, meaning it has the ability to gain or lose moisture due to changes in its surrounding environment

Cell Structure: Moisture in Wood

Shrinkage will continue to occur linearly until the wood's equilibrium moisture content (EMC) has been reached.



EMC is the point at which the wood is neither gaining nor losing moisture. However, this is a dynamic equilibrium as it is a function of temperature and relative humidity

Moisture Content of Wood at Various Temperatures and Relative Humidity

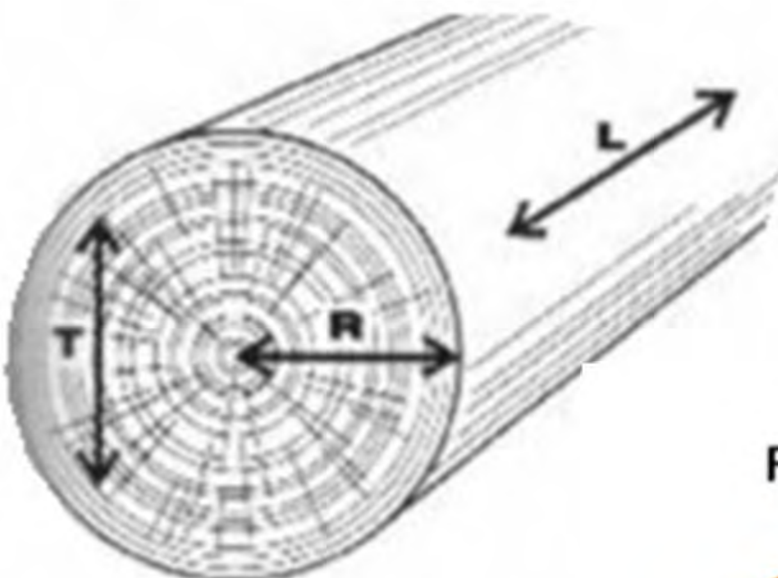
Temperature (F)															
40	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.4	13.5	14.9	16.5	18.5
50	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.4	13.5	14.9	16.5	18.5
60	3.6	4.6	5.4	6.2	7.0	7.8	8.6	9.4	10.2	11.1	12.1	13.3	14.6	16.2	18.2
70	3.5	4.5	5.4	6.2	6.9	7.7	8.5	9.2	10.1	11.0	12.0	13.1	14.4	16.0	17.9
80	3.5	4.4	5.3	6.1	6.8	7.6	8.3	9.1	9.9	10.8	11.7	12.9	14.2	15.7	17.7
90	3.4	4.3	5.1	5.9	6.7	7.4	8.1	8.9	9.7	10.5	11.5	12.6	13.9	15.4	17.3
	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
Relative Humidity (percent)															

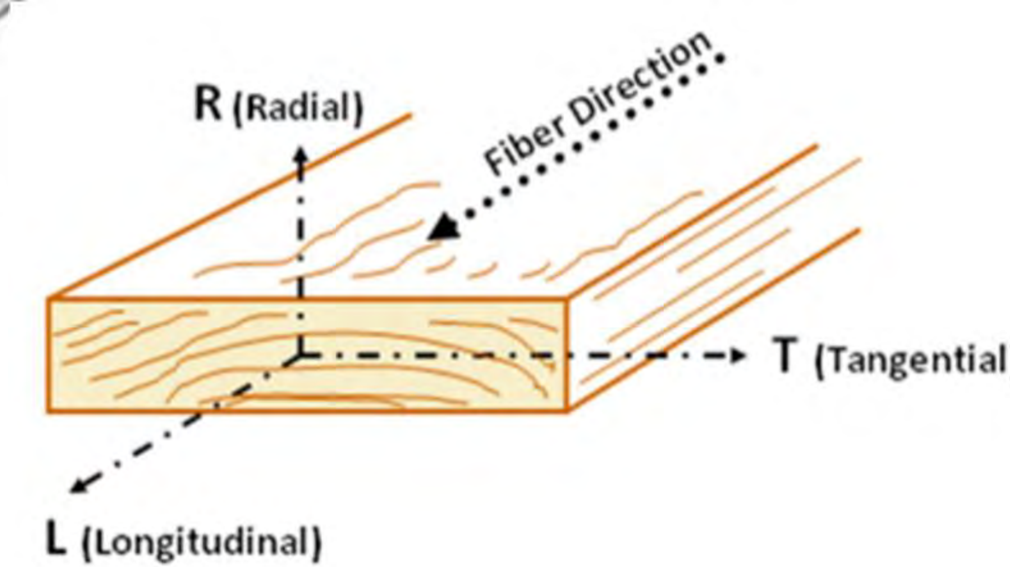
Source: Wood Handbook, USDA Forest Service

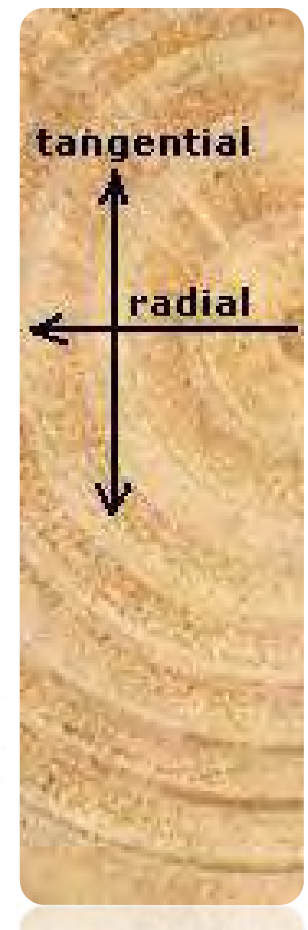
Cell Structure: Shrinkage

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

This is a direct result of the arrangement of wood cells



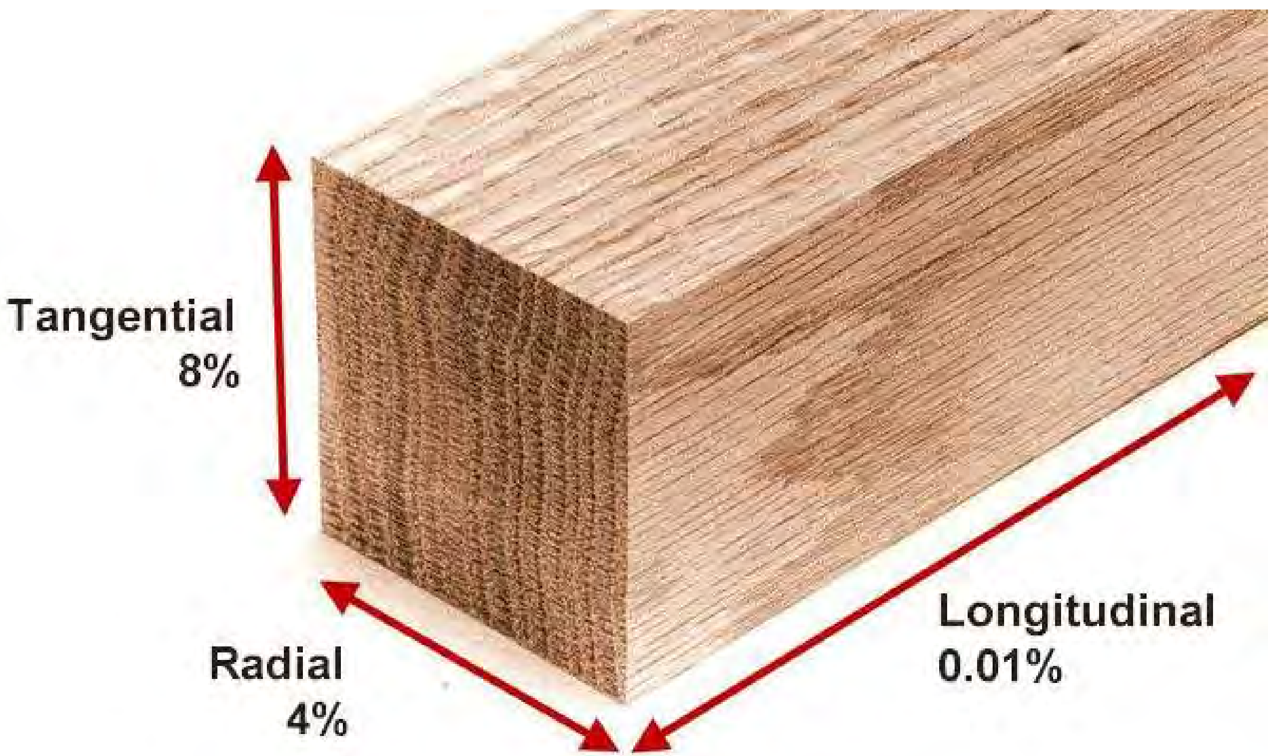




Cell Structure: Shrinkage

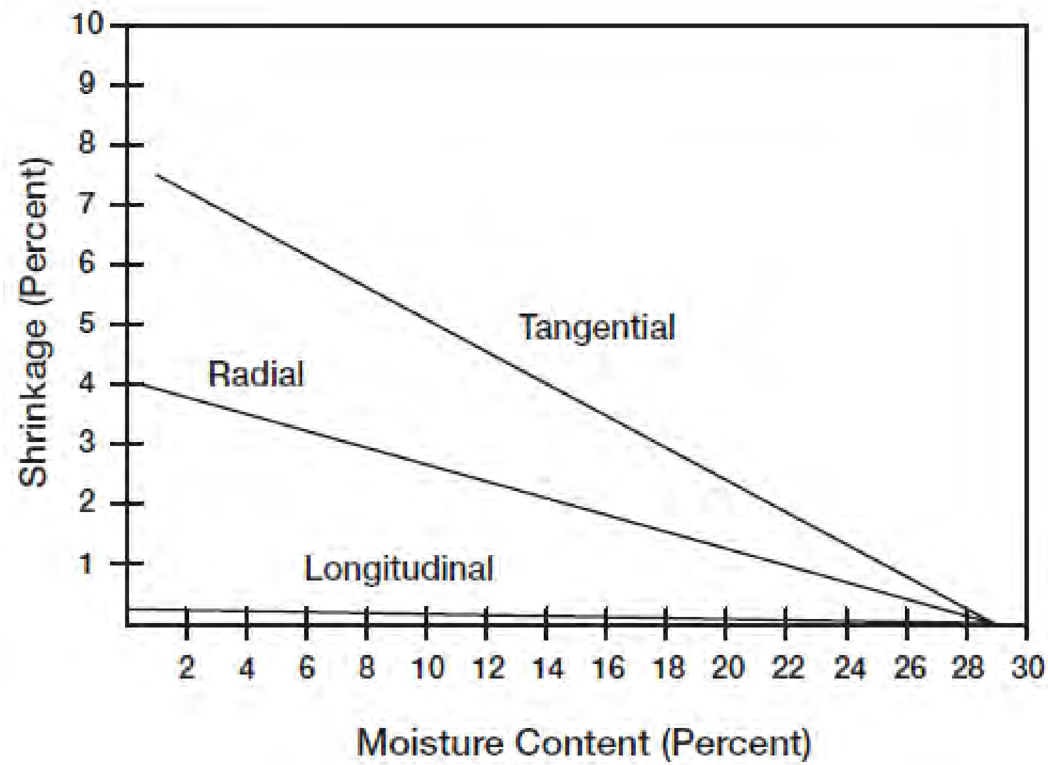
Shrinkage behavior and amount varies in each of the three orthogonal directions:

- **Longitudinal**
- **Radial**
- **Tangential**



Cell Structure: Shrinkage

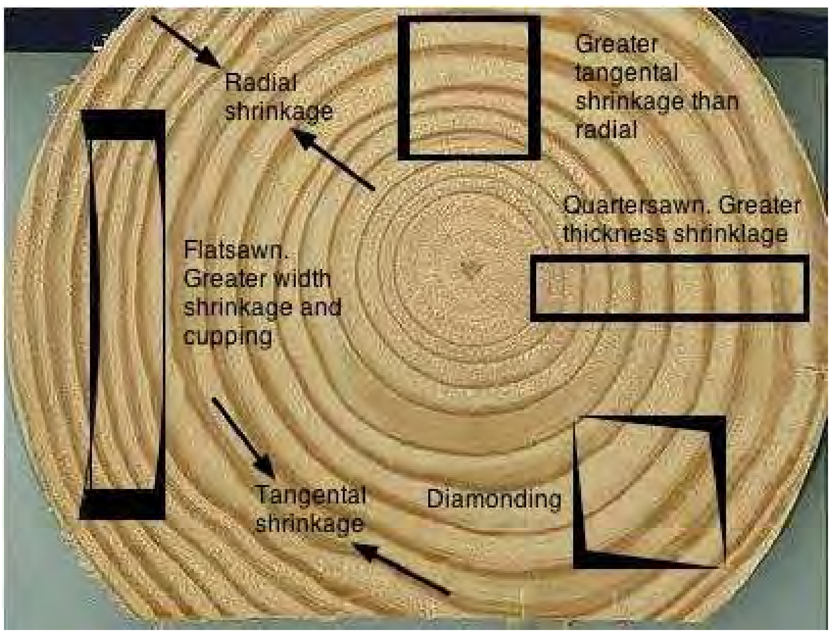
- **Longitudinal Shrinkage**: Least amount of shrinkage by far, typically neglected (wood cells shortening in length)
- **Radial Shrinkage**: Shrinkage across growth rings, wood cell walls change thickness
- **Tangential Shrinkage**: Shrinkage along (tangential to) growth rings, twice as much as radial, wood cell walls change thickness

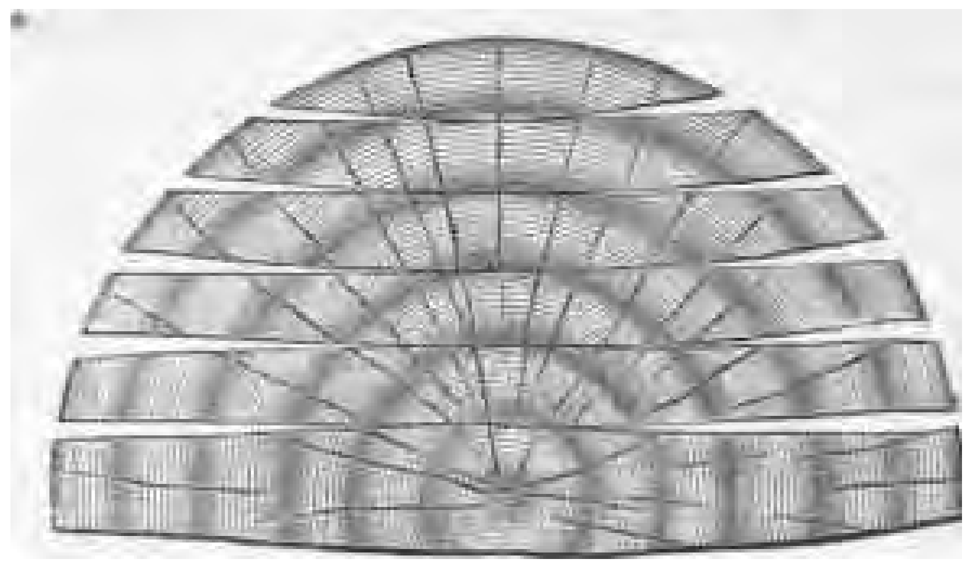


Cell Structure: Shrinkage

The difference in radial and tangential shrinkage can result in unequal shrinkage in a given member, depending on cut and grain orientation

Proper drying techniques, detailing, and specification account for this





Wood Species & Grading: Necessity

Structural wood used in construction can vary in species and grade. This affects:

- Mechanical properties (strength)
- Decay resistance
- Visual appearance

Photo: Vanwoody.com

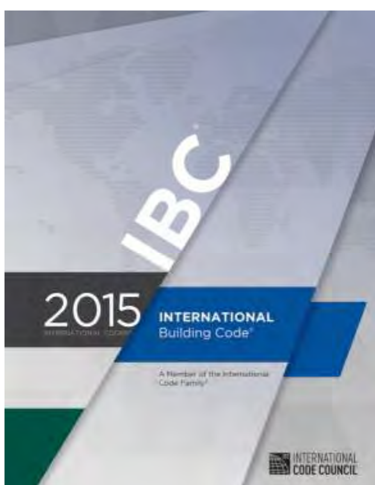
Understanding species & grading provides framework for proper design & specification

The Bullitt Center Photo: John Stamets

Wood Species & Grading: Building Code

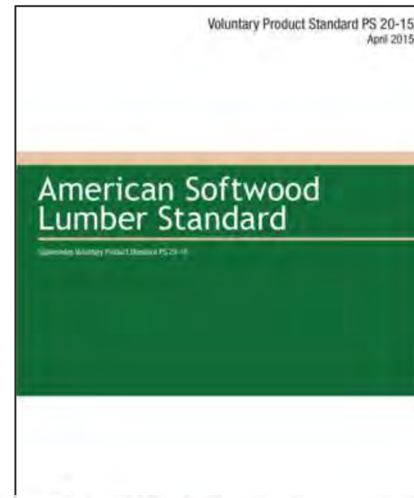
IBC **2303.1.1 Sawn Lumber**

Sawn lumber used for load-supporting purposes…shall be identified by the grade mark of a lumber grading or inspection agency that has been approved by an accreditation body that complies with DOC PS 20 or equivalent. Grading practices and identification shall comply with rules published by an agency approved in accordance with the procedures of DOC PS 20 or equivalent procedures.



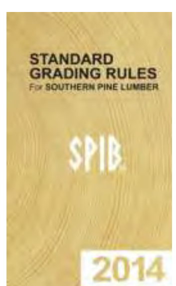
Referenced Standard & Grading Rules

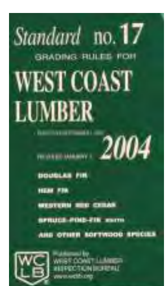
DOC PS 20: U.S. Department of Commerce Voluntary Product Standard PS 20-15 (American Softwood Lumber Standard)



Grading rules established by 7 agencies:

- National Lumber Grades Authority (Canada)
- Northeastern Lumber Manufacturers Association
- Northern Softwood Lumber Bureau
- Redwood Inspection Service
- Southern Pine Inspection Bureau
- West Coast Lumber Inspection Bureau
- Western Wood Products Association





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E-Mail: alsc@alsc.org

March 2015
(this list supersedes all previous lists)

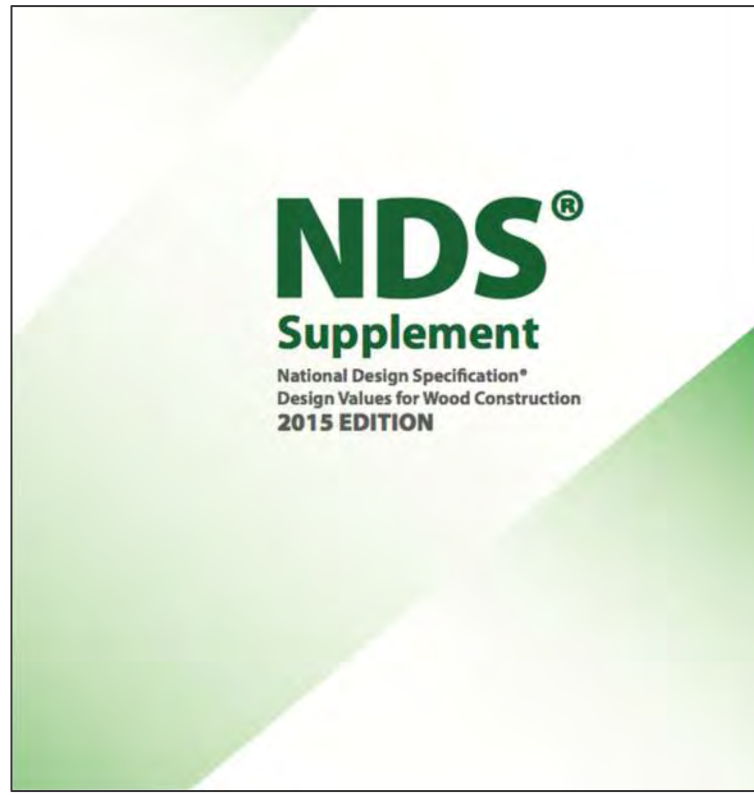
The following rules have been certified as conforming to the American Softwood Lumber Standard, PS20, by the Board of Review of the American Lumber Standard Committee

1. Standard Grading Rules for Northeastern Lumber; published by the Northeastern Lumber Manufacturers Association (NeLMA), 272 Tuttle Road, P.O. Box 87A, Cumberland Center, ME 04021; phone 207.829.6901; fax 207.829.4293
2. Standard Grading Rules; published by the Northern Softwood Lumber Bureau (NSLB), 272 Tuttle Road, P.O. Box 87A, Cumberland Center, ME 04021; phone 207.829.6901; fax 207.829.4293
3. Standard Specifications for Grades of California Redwood Lumber; published by the Redwood Inspection Service (RIS), 818 Grayson Road, Suite 201, Pleasant Hill, CA 94523-2693; phone 925.935.1499; fax 925.935.1496
4. Standard Grading Rules for Southern Pine Lumber; published by the Southern Pine Inspection Bureau (SPIB), 4709 Scenic Highway, Pensacola, FL 32504; phone 850.434.2611; fax 850.433.5594
5. Standard Grading Rules for West Coast Lumber; published by the West Coast Lumber Inspection Bureau (WCLIB), Box 23145, Portland, OR 97281-3145; phone 503.639.0651; fax 503.684.8928
6. Western Lumber Grading Rules; published by the Western Wood Products Association (WWPA), 1500 SW First Avenue, Suite 870, Portland, OR 97204-2122; phone 503.224.3930; fax 503.224.3934
7. Standard Grading Rules for Canadian Lumber; published by the National Lumber Grades Authority (NLGA), Suite 105, 13401-108th Avenue, Surrey, BC V3T 5T3; phone 604.584.2393; fax 604.584.2890

Reference Design Values - NDS

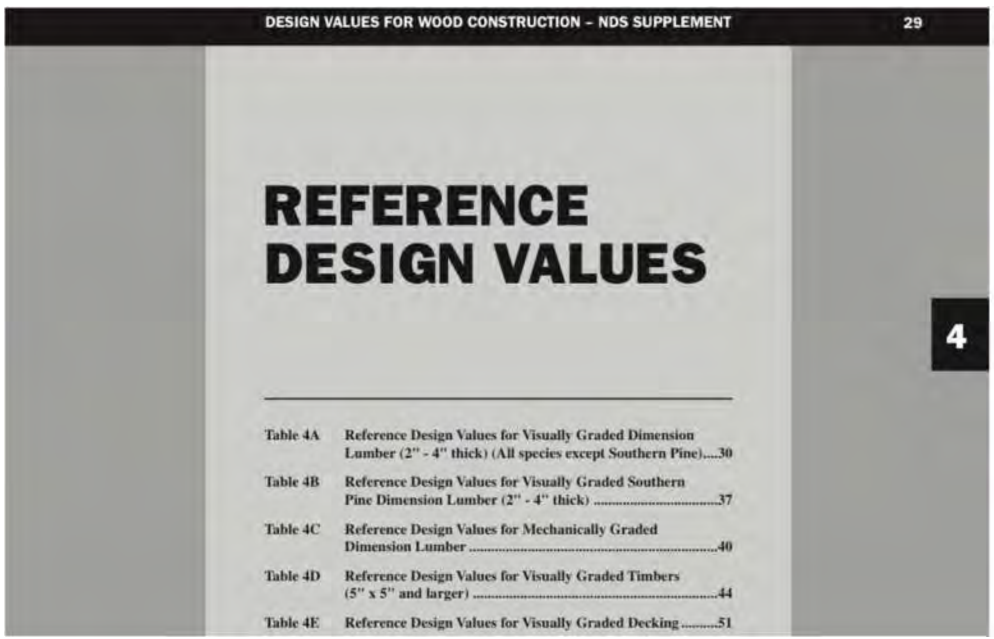
Reference design values for lumber – given in Chapter 4 of AWC's NDS Supplement – are generated using the 7 sets of recognized grading rules as well as by using the provisions in one or more of the following:

- ASTM D1990: Standard Practice for Establishing Allowable Properties for Visually-Graded Dimension Lumber from In-Grade Tests of Full-Size Specimens
- ASTM D245: Standard Practice for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber
- ASTM D2555: Standard Practice for Establishing Clear Wood Strength Values



Reference Design Values

Reference Design Values: The quantifiable mechanical properties that are associated with each identifiable commercial grade of wood


DESIGN VALUES FOR WOOD CONSTRUCTION – NDS SUPPLEMENT 29

REFERENCE DESIGN VALUES

4

Reference Design Values	
F_b	Bending stress
F_v	Shear stress
F_t	Tension stress
F_c	Compression stress
F_{cT}	Compression stress perpendicular to grain
E/E_{min}	Modulus of elasticity

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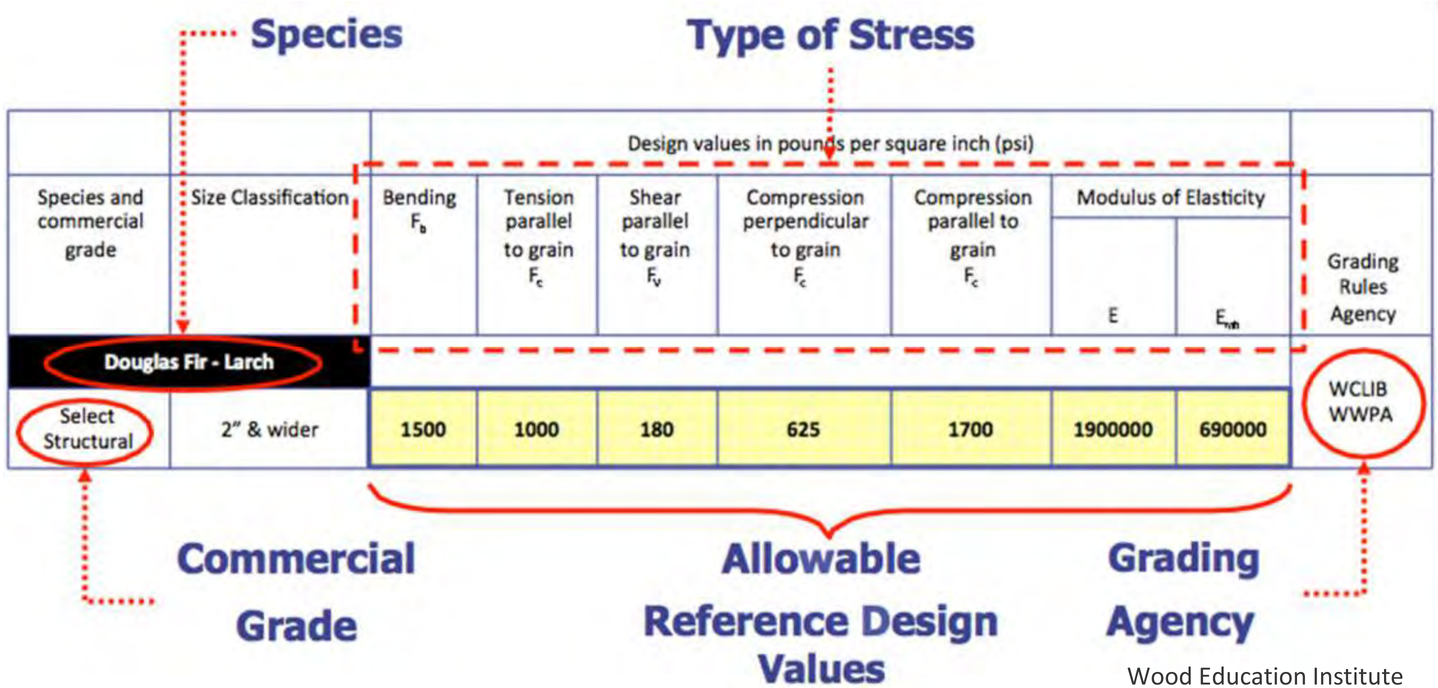
Reference Design Values

Reference Design Values in NDS are given based on four main variables:

- Grading Method
- Species Group
- Commercial Grade
- Size Classification



		Design values in pounds per square inch (psi)							
Species and commercial grade	Size Classification	Bending F_b	Tension parallel to grain F_c	Shear parallel to grain F_v	Compression perpendicular to grain F_c	Compression parallel to grain F_c	Modulus of Elasticity E	Modulus of Elasticity E_{min}	Grading Rules Agency
Douglas Fir - Larch									
Select Structural	2" & wider	1500	1000	180	625	1700	1900000	690000	WCLIB WWPA

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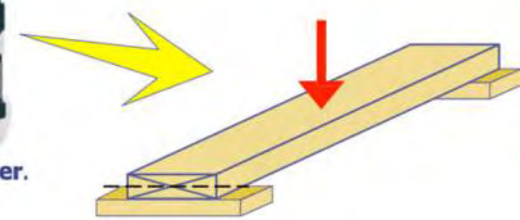
Reference Design Values: Grading Methods

Grading: The process of categorizing wood members into groups that have common material properties.

Grading methods:

- Visually Graded Lumber (VGL)
  - Grade is determined by visual inspection using the guidelines of the applicable grading rules
- Machine Stress Rated (MSR)
  - Automated, nondestructive method of grading in which the modulus of elasticity of a member is determined through an applied bending load
- Machine Evaluated Lumber (MEL)
  - Automated, nondestructive method of grading in which MSR lumber undergoes radiographic inspection to measure density



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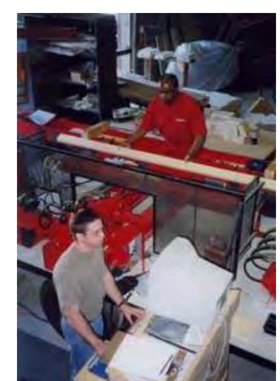


Notes:

NDS groups MSR & MEL into "Mechanically Graded Dimension Lumber"

MSR & MEL only apply to dimension lumber 2" thick

Reference Design Values: Species

Over 100 sawn lumber species are available and in use as structural members in construction

These species are grouped into 50 species combinations in NDS Supplement, Chapter 2, based similarities in mechanical properties

Note that Southern Pine reference design values are separate in Table 4B, all others are in Table 4A

Species or Species Combination	Species That May Be Included in Combination	Grading Rules Agencies	Design Values Provided in Tables
Douglas Fir-Larch	Douglas Fir Western Larch	WCLIB WWPA	4A, 4C, 4D, 4E
Douglas Fir-Larch (North)	Douglas Fir Western Larch	NLGA	4A, 4C, 4D, 4E
Douglas Fir-South		WWPA	4A, 4C, 4D, 4E
Eastern Hemlock		NELMA NSLB	4D
Eastern Hemlock-Balsam Fir	Balsam Fir Eastern Hemlock Tamarack	NELMA	4A
Eastern Hemlock-Tamarack	Eastern Hemlock Tamarack	NELMA NSLB	4A, 4D, 4E
Eastern Hemlock-Tamarack (North)	Eastern Hemlock Tamarack	NLGA	4D, 4E

Reference Design Values: Commercial Grade

Commercial Grade: A function of the member's use and quality as defined in the Grading Rules

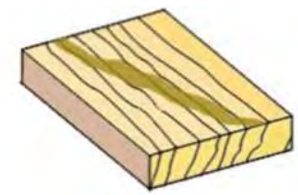
- Select Structural
- Dense No. 1
- No. 1
- No. 2
- No. 3
- Stud
- Construction
- Standard
- Utility

Reference Design Values: Commercial Grade

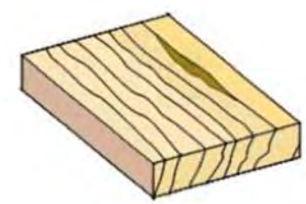
Grading Rules define parameters for quality for various growth characteristics such as:

- Checks
- Knots
- Pitch & Pitch Streaks
- Pockets
- Shake
- Slope of Grain
- Stain
- Unsound Wood
- Wane
- Warp

PITCH & PITCH STREAKS: An accumulation of resinous material. If the material leaves well defined line, it is called a pitch streak.



POCKET: Well defined opening between the annual growth rings, usually contains pitch or bark.



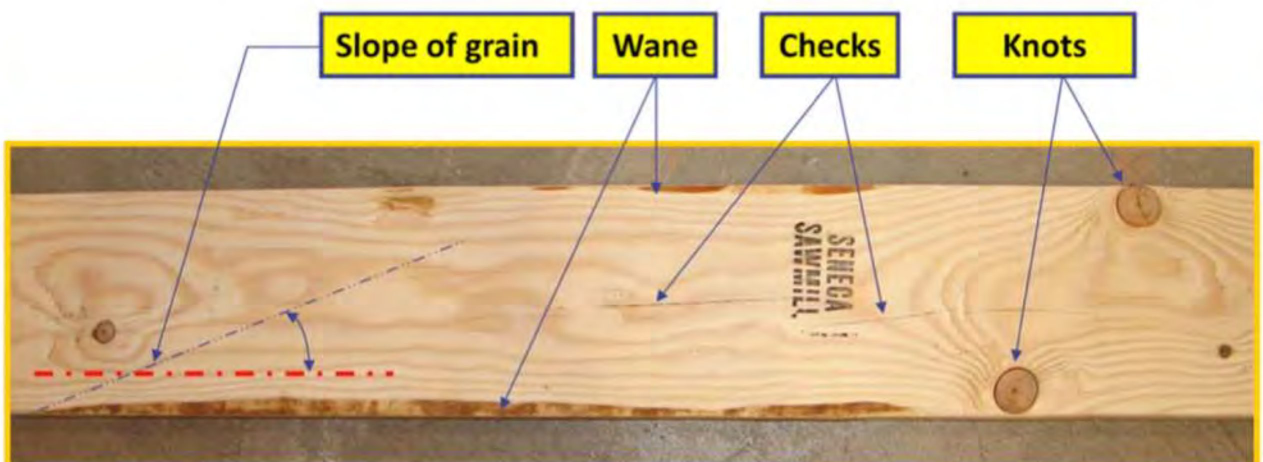
SHAKE: Separation of grain between the growth rings, often extending along the board's face and sometimes below its surface.

Wood Education Institute

Reference Design Values: Commercial Grade

Partial List of Grading Limitations				
Structural Light Framing – 2″ to 4″ thick, 2″ to 4″ wide Structural Joists and Plank – 2″ to 4″ thick, 5″ and wider				
	Lumber Grade			
Characteristic	**Select Structural**	**No. 1**	**No. 2**	**No. 3**
Checks	Not limited	Not limited	Not limited	Not limited
Knots (largest allowed knot on the wide face edge)	%″/2″ nom %″/4″ nom	½″/2″ nom 1″/4″ nom	%″/2″ nom 1¼″/4″ nom	¾″/2″ nom 1¾″/4″ nom
Manufacture	E	E	F	F
Shake	2 ft. long	2 ft. long	2 ft. long	1/3 the length
Slope of grain	1 in 12	1 in 10	1 in 8	1 in 4
Splits	Width of piece	Width of piece	1.5 x Width of piece	1/6 the length of piece

Standard 17 Grading Rules for West Coast Lumber 2004
Wood Education Institute

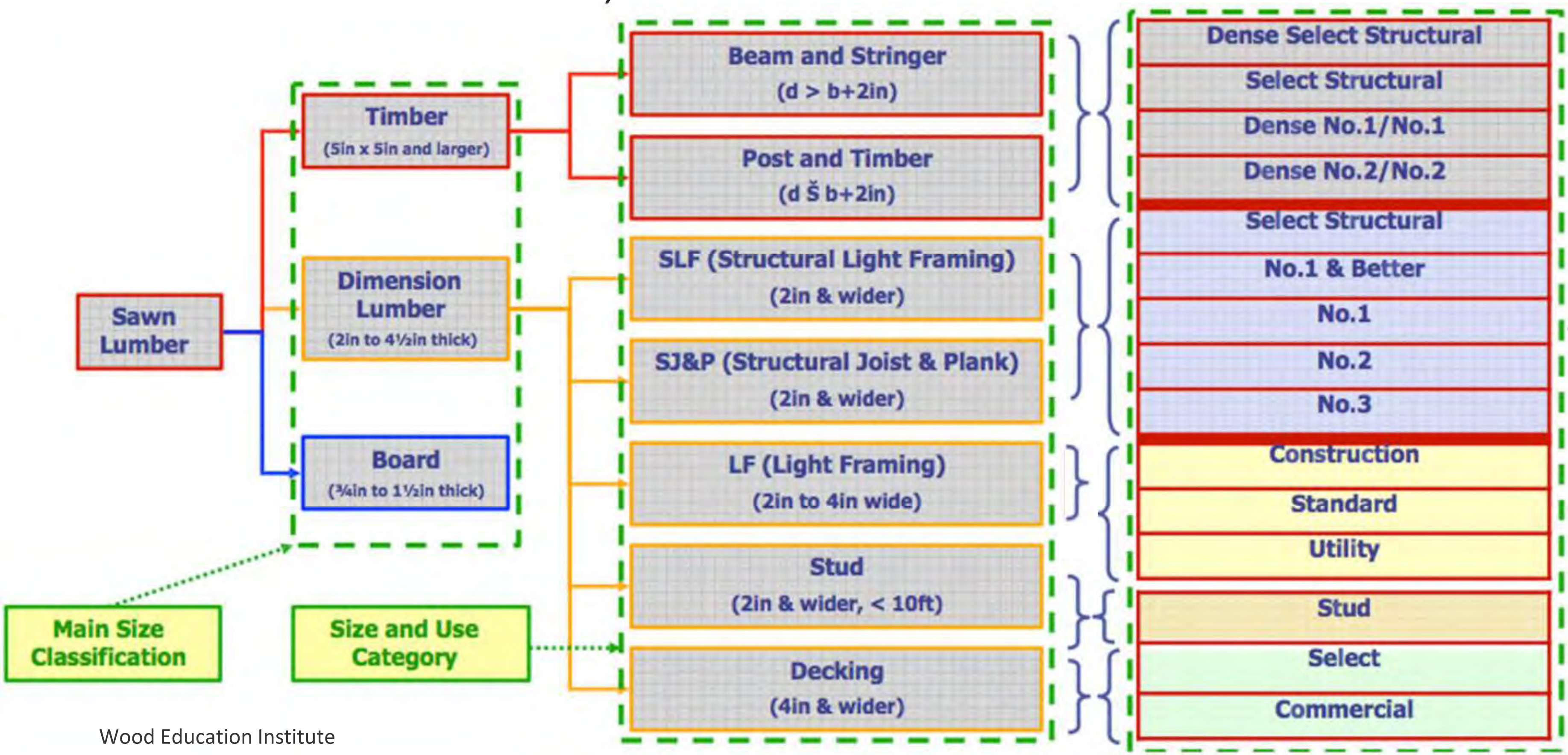


Wood Education Institute

Reference Design Values: Size Classification

Three size classifications: **Dimension**, **Timber**, & **Boards**

- **Dimension:** 2”-4” thick, 2” wide & wider
- **Timber:** 5”x5” & larger
- **Board:** 1” thick & thicker, 2” wide & wider



Reference Design Values: Examples

Grading Method

Table 4A Reference Design Values for Visually Graded Dimension Lumber (2" - 4" thick)[1,2,3]

Species and commercial grade	Size classification	Design values in pounds per square inch (psi)							Specific Gravity[4]	Grading Rules Agency
		Bending	Tension parallel to grain	Shear parallel to grain	Compression perpendicular to grain	Compression parallel to grain	Modulus of Elasticity			
		F_b	F_t	F_v	$F_{c\perp}$	F_c	E	E_{min}	G	
DOUGLAS FIR-LARCH										
Select Structural	2" & wider	1,500	1,000	180	625	1,700	1,900,000	690,000	0.50	WCLIB WWPA
No. 1 & Btr		1,200	800	180	625	1,550	1,800,000	660,000		
No. 1		1,000	675	180	625	1,500	1,700,000	620,000		
No. 2		900	575	180	625	1,350	1,600,000	580,000		
No. 3		525	325	180	625	775	1,400,000	510,000		
Stud	2" & wider	700	450	180	625	850	1,400,000	510,000		
Construction	2" - 4" wide	1,000	650	180	625	1,650	1,500,000	550,000		
Standard		575	375	180	625	1,400	1,400,000	510,000		
Utility		275	175	180	625	900	1,300,000	470,000		

Species

Commercial Grade

Size Classification

Note: NDS splits Dimension & Timber into separate Reference Design Tables, no structural properties given to Boards

Tables also indicate Grading Rules followed

Reference Design Values: Examples

Grading Method

Table 4C Reference Design Values for Mechanically Graded Dimension Lumber[1,2,3]

USE WITH TABLE 4C ADJUSTMENT FACTORS

Commercial grade	Size classification	Design values in pounds per square inch (psi)					Grading Rules Agency
		Bending	Tension parallel to grain	Compression parallel to grain	Modulus of Elasticity		
		F_b	F_t	F_c	E	E_{min}	
MACHINE STRESS RATED (MSR) LUMBER							
750f-1.4E	2" and less in thickness 2" and wider	750	425	925	1,400,000	710,000	SPIB
850f-1.4E		850	475	975	1,400,000	710,000	SPIB
900f-1.0E		900	350	1,050	1,000,000	510,000	WCLIB, WWPA, NELMA, NSLB
975f-1.6E		975	550	1,450	1,600,000	810,000	SPIB
1050f-1.2E		1,050	450	1,225	1,200,000	610,000	SPIB
1050f-1.6E		1,050	575	1,500	1,600,000	810,000	SPIB
1200f-1.2E		1,200	600	1,400	1,200,000	610,000	NLGA, WCLIB, WWPA, NELMA, NSLB
1200f-1.3E		1,200	600	1,400	1,300,000	660,000	SPIB
1200f-1.6E		1,200	650	1,550	1,600,000	810,000	SPIB
1250f-1.4E		1,250	800	1,475	1,400,000	710,000	WCLIB
1250f-1.6E		1,250	725	1,600	1,600,000	810,000	SPIB
1350f-1.3E		1,350	750	1,600	1,300,000	660,000	NLGA, WCLIB, WWPA, NELMA, NSLB

Size Classification

Tables also indicate Grading Rules followed

Commercial Grade

Reference Design Values: Examples

Grading Method

Table 4C Reference Design Values for Mechanically Graded Dimension Lumber[1,2,3]

Commercial grade	Size classification	Design values in pounds per square inch (psi)					Grading Rules Agency
		Bending	Tension parallel to grain	Compression parallel to grain	Modulus of Elasticity		
		F_b	F_t	F_c	E	E_{min}	
MACHINE EVALUATED LUMBER (MEL)							
M-5		900	500	1,050	1,100,000	510,000	SPIB
M-6		1,100	600	1,300	1,000,000	470,000	SPIB
M-7		1,200	650	1,400	1,100,000	510,000	SPIB
M-8		1,300	700	1,500	1,300,000	610,000	SPIB
M-9		1,400	800	1,600	1,400,000	650,000	SPIB
M-10	2" and less in thickness	1,400	800	1,600	1,200,000	560,000	NLGA, SPIB
M-11		1,550	850	1,675	1,500,000	700,000	NLGA, SPIB
M-12	2" and wider	1,600	850	1,675	1,600,000	750,000	NLGA, SPIB
M-13		1,600	950	1,675	1,400,000	650,000	NLGA, SPIB

Commercial Grade & Species

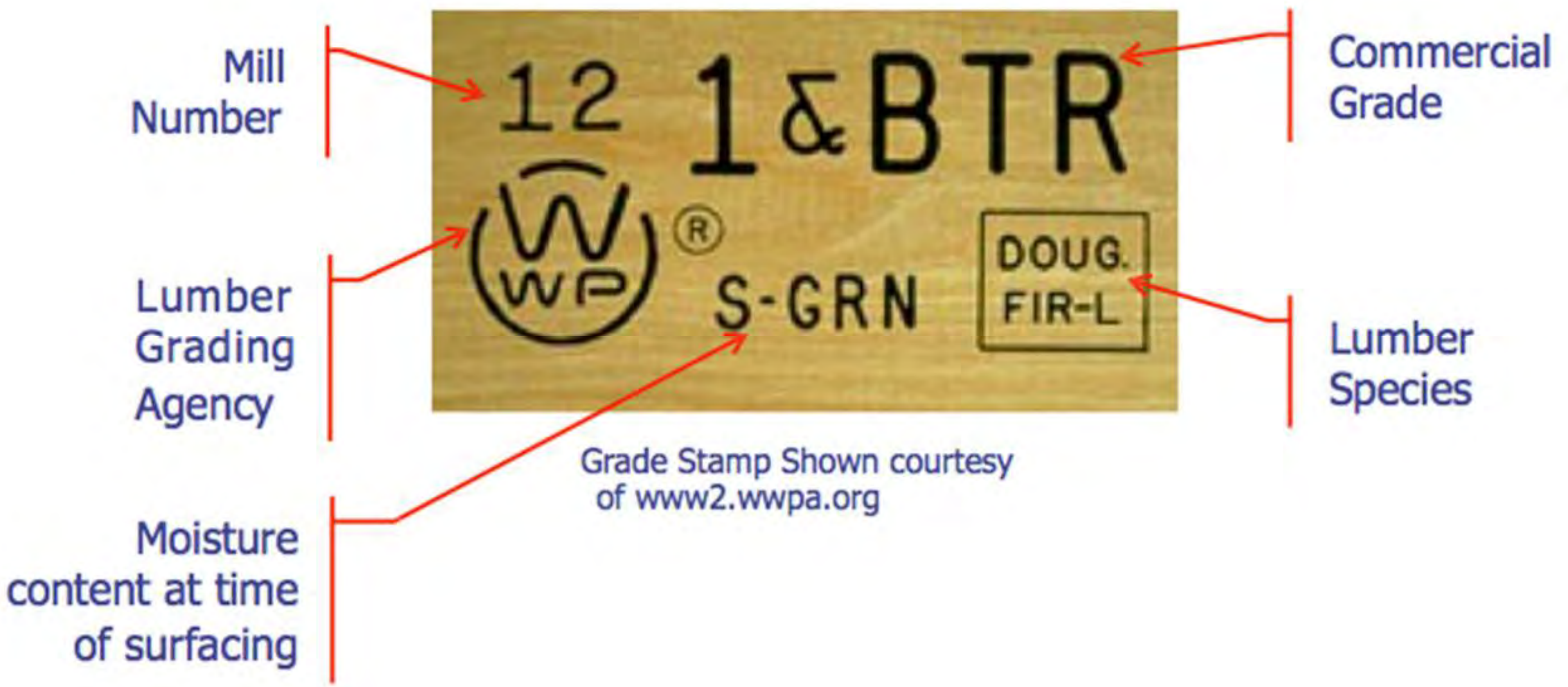
Size Classification

Tables also indicate Grading Rules followed

Identification Stamps

Stamp applied directly to a member that includes pertinent information (e.g. Lumber grading agency, species, grade, etc.)

Required per IBC 2303.1.1



Example VGL Stamp

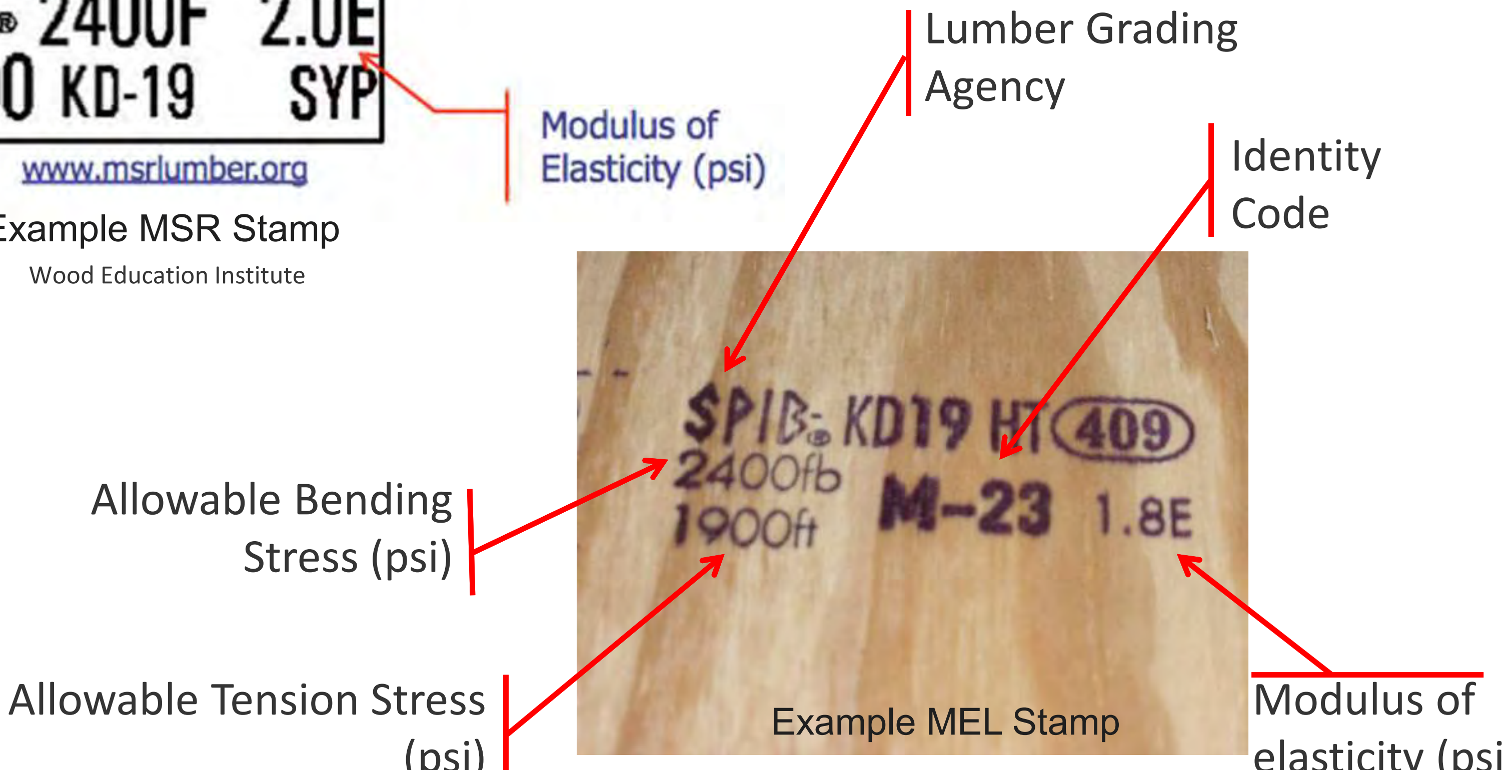
Wood Education Institute

Identification Stamps

Examples of Identification Stamps for Mechanically Graded Lumber

Example MSR Stamp

Wood Education Institute



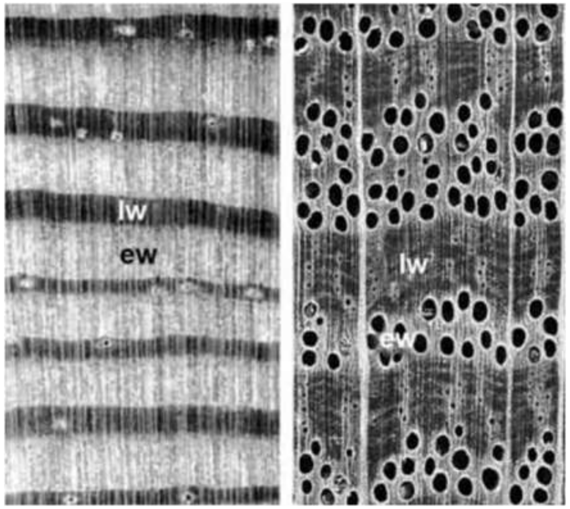
Example MEL Stamp

Specific Gravity

Specific Gravity (SG), or density, is the weight or mass of wood divided by the volume of the specimen at a given moisture content

- Density generally expressed in lbs/ft^3; SG generally expressed as a decimal (0.50) which is a comparison to the SG of water (SG = 1.0)
- Function of cell wall thickness, growth rate
- Generally, higher SG translates to higher structural properties
- Given in NDS Chapter 11

Density comparison: earlywood (ew) to latewood (lw)



Source: Wood Handbook, USDA Forest Service

Table 11.3.3A Assigned Specific Gravities

Species Combination	Specific[1] Gravity, G
Alaska Cedar	0.47
Alaska Hemlock	0.46
Alaska Spruce	0.41
Alaska Yellow Cedar	0.46
Aspen	0.39
Balsam Fir	0.36
Beech-Birch-Hickory	0.71
Coast Sitka Spruce	0.39
Cottonwood	0.41
Douglas Fir-Larch	0.50
Douglas Fir-Larch (North)	0.49
Douglas Fir-South	0.46
Eastern Hemlock	0.41
Eastern Hemlock-Balsam Fir	0.36
Eastern Hemlock-Tamarack	0.41
Eastern Hemlock-Tamarack (North)	0.47
Eastern Softwoods	0.36
Eastern Spruce	0.41

Species Combinations of MSR and MEL Lumber	Specific[1] Gravity, G
Douglas Fir-Larch	
E=1,900,000 psi and lower grades of MSR	0.50
E=2,000,000 psi grades of MSR	0.51
E=2,100,000 psi grades of MSR	0.52
E=2,200,000 psi grades of MSR	0.53
E=2,300,000 psi grades of MSR	0.54
E=2,400,000 psi grades of MSR	0.55
Douglas Fir-Larch (North)	
E=1,900,000 psi and lower grades of MSR and MEL	0.49
E=2,000,000 psi to 2,200,000 psi grades of MSR and MEL	0.53
E=2,300,000 psi and higher grades of MSR and MEL	0.57
Douglas Fir-Larch (South)	
E=1,000,000 psi and higher grades of MSR	0.46
Engelmann Spruce-Lodgepole Pine	
E=1,400,000 psi and lower grades of MSR	0.38
E=1,500,000 psi and higher grades of MSR	0.46
Hem-Fir	
E=1,500,000 psi and lower grades of MSR	0.43

Naturally Durable Species

Some wood species, due to their composition and cell structure, are naturally resistant to insect damage and moisture or decay

- IBC 2304.12 provides requirements

Douglas-Fir

Western Red Cedar

Jwlumber.com

Naturally Decay Resistant Species

Natural Durability of North American Softwoods		
Species	**Predominant in the Tree**	**Heartwood Durability**
Western Red Cedar	Heartwood	Durable
Eastern White Cedar	Heartwood	Durable
Yellow Cedar	Heartwood	Durable
Redwood	Heartwood	Durable
Douglas Fir	Heartwood	Moderately Durable
Southern Pine	Sapwood	Moderately Durable
Western Larch	Heartwood	Moderately Durable
Tamarack (E. Larch)	Heartwood	Moderately Durable
Western Hemlock	Heartwood	Slightly Durable
Eastern Hemlock	Heartwood	Slightly Durable
White Spruce	Heartwood	Slightly Durable

Source: Canadian Wood Council

Species: Treating Wood

Some wood species are easier to treat than others. The cell structure determines how permeable the wood is to chemicals

Pressure-treated Douglas-fir

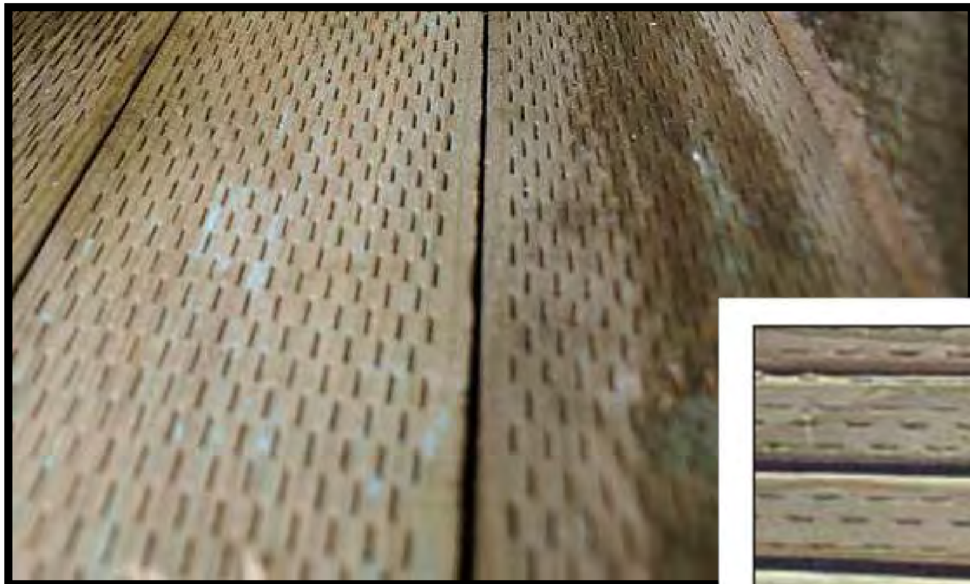
Pressure-treated Southern Pine

Photo from University of Tennessee Forest Products Extension

Fire retardant-treated wood

Species: Treating Wood

Incising is a method to increase chemical penetration



Incising is an aid in securing deeper and more uniform penetration of preservatives in western softwood species such as Douglas-fir, Hem-Fir and Spruce-Pine-Fir.

Image: Western Wood Preservers Institute

Species: Treating Wood

Treatability of North American Softwoods			
Tree	Permeability Sapwood	Permeability Heartwood	Predominant in the Tree
Douglas Fir	2	4	Heartwood
Western Hemlock	2	3	Heartwood
Eastern Hemlock	2	4	Heartwood
White Spruce	2	3-4	Heartwood
Southern Pine	1	3	Sapwood

Source: Canadian Wood Council

1 – Permeable
2 – Moderately Impermeable
3 – Impermeable
4 – Extremely Impermeable

Sapwood generally more permeable for accepting treatment

Common species used for FRT:

Douglas-fir	Spruce-pine-fir
Redwood	Spruce
White pine	Ponderosa Pine
Hem-fir	Western red cedar
Southern pine	White fir
Red pine	Western hemlock

Architecturally Exposed Species & Grades

Some structural wood framing components are left exposed and integrated with the architectural features of the building. These applications often require a unique criteria for allowable visible wood characteristics. The species and grade selection are key

- Common species include: Douglas-Fir, Hemlock
- Common grades: No. 1 & Better, Select Structural
- Glulam has options for "Architectural Grade"

Indian Mountain Student Arts & Innovation Center
Photo: Robert Benson Photography

Jackson Hole Airport
Photo: Matthew Millman Photography/Tim Griffith Photography

Softwood vs. Hardwood

- Almost all structural wood used in construction is softwood
- Names do not refer to mechanical properties or density. Some softwoods (e.g. Douglas-Fir) are harder (denser) than hardwoods (e.g. balsa)

Wood Education Institute

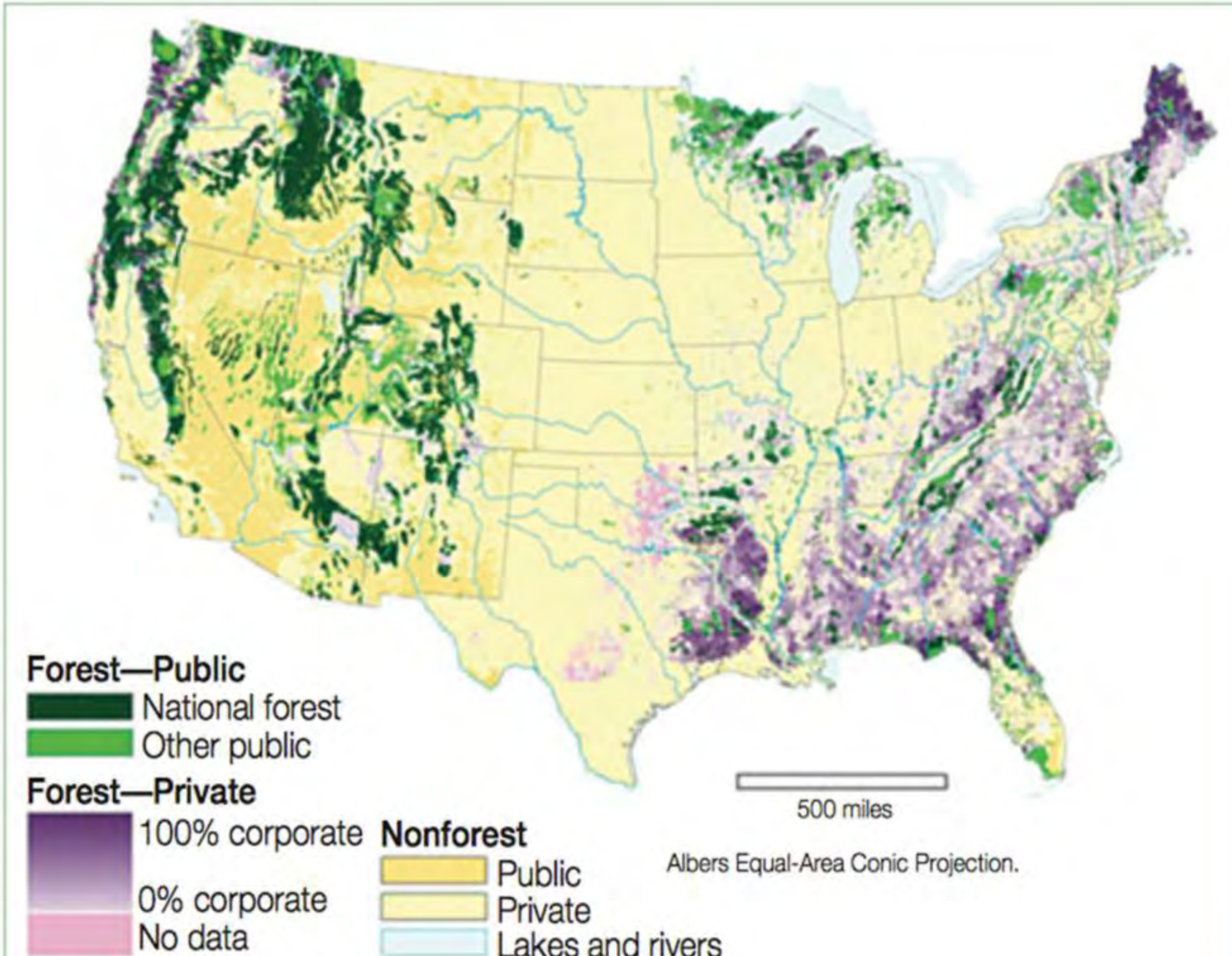
Wood Education Institute

Softwood Trees

Hardwood Trees

Source: Wood Handbook, USDA Forest Service

Geographic Impacts: Growing Regions

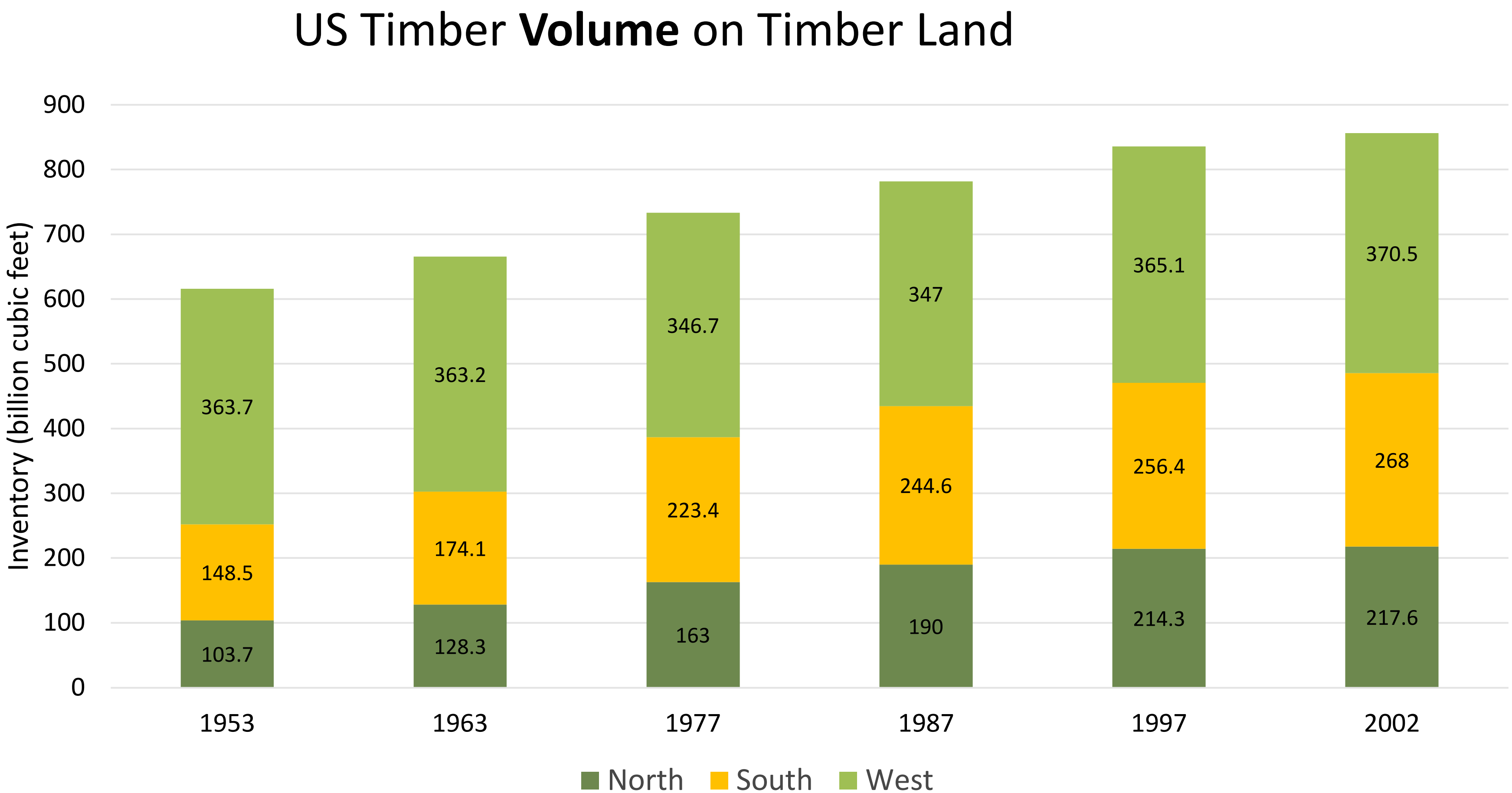


[a] Corporate land includes land held by timber investment management companies and real estate investment trusts.

Source: USDA Forest Service, Forest Inventory and Analysis

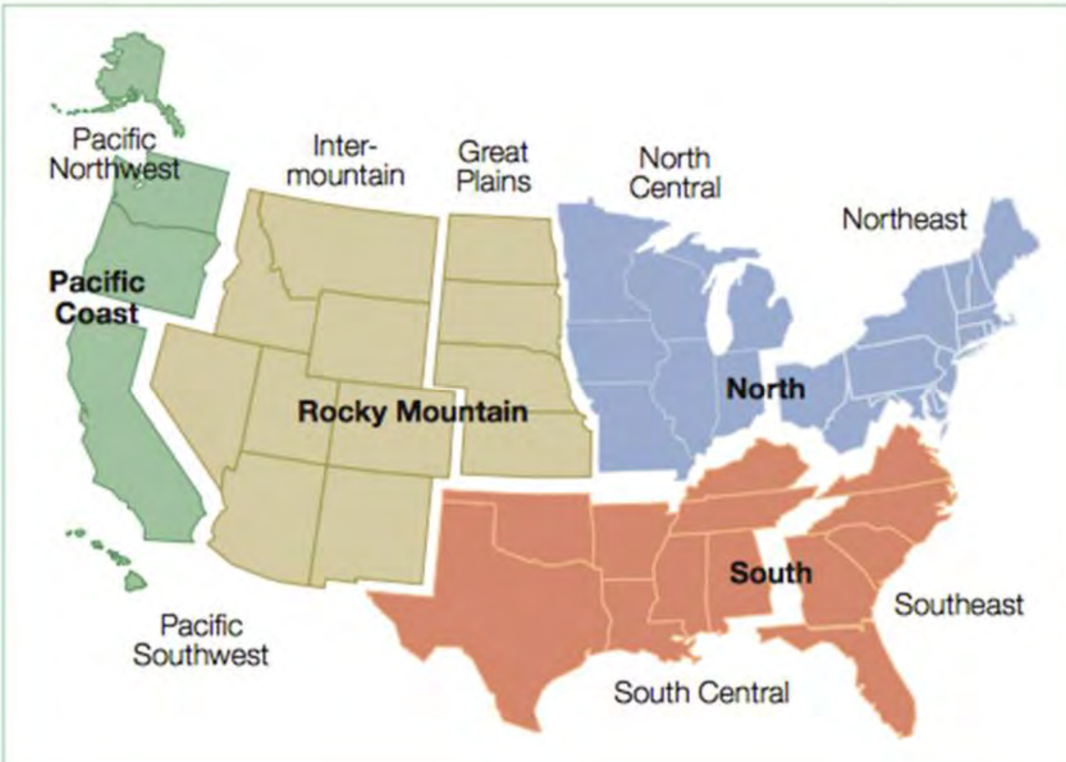
Source: USDA-Forest Service, Future of America's Forests and Rangelands: Forest Service 2010 Resources Planning Act Assessment

Geographic Impacts: Growing Regions



Source: USDA-Forest Service, US Forest Resource Facts and Historical Trends FS-801. (2004).

Geographic Impacts: Growing Regions



Source: USDA-Forest Service, Future of America's Forests and Rangelands: Forest Service 2010 Resources Planning Act Assessment

Predominant Softwood Species by Region

<u>South</u>:
- Southern Pine

<u>North</u>:
- Mixed pine
- Spruce-fir

<u>Rocky Mountain</u>:
- Juniper
- Fir-spruce-hemlock
- Douglas-fir

<u>Pacific Coast</u>:
- Douglas-fir
- Ponderosa Pine

Geographic Impacts: Use & Availability

Growing Regions have a large impact on the available species of framing lumber in an area

Common framing lumber species by region

- **West**: Douglas-fir, hem-fir, redwood
- **Northeast**: Spruce-pine-fir, hemlock
- **South**: Spruce-pine-fir

Some species are available in areas beyond their growing region for certain characteristics (e.g. douglas-fir for its aesthetics, southern pine for its treatability)

Local availability, transportation costs, structural requirements, and aesthetic properties all play a role

Douglas-Fir Growing Regions

Eastern White Pine Growing Regions

Source: USGS, Digital Representations of Tree Species Range Maps


CLIMATE

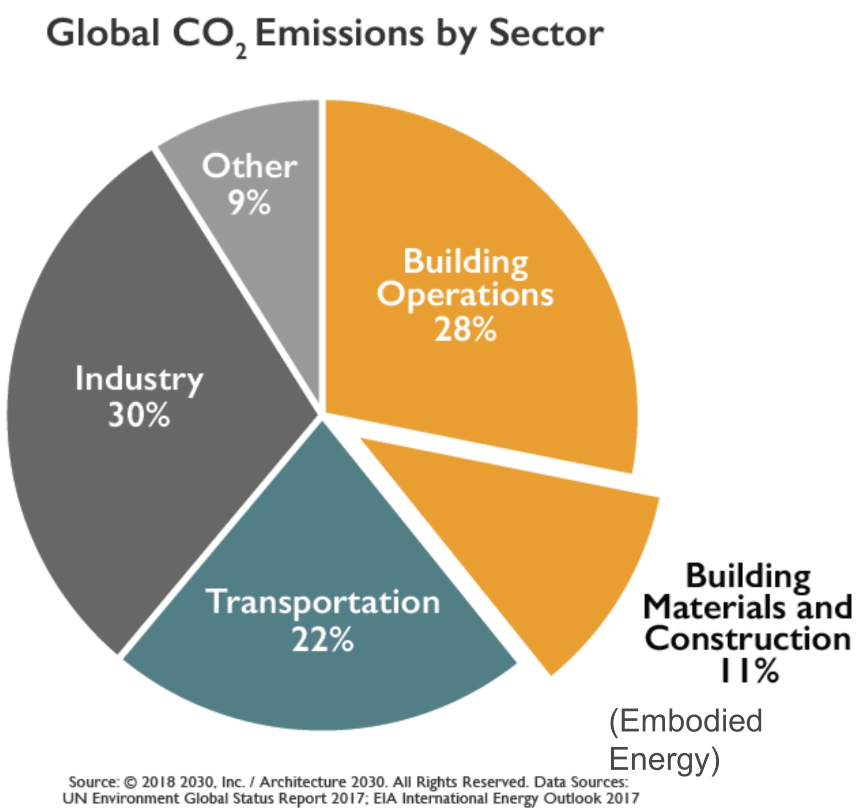
Global Population Increase

2050 = 9.9
billion people

2020 = 7.8
billion people

Source: www.prb.org

New Buildings & Greenhouse Gases



Buildings generate nearly **40%** of annual global greenhouse gas emissions (*building operations + embodied energy*)

Embodied energy: **11%**

Concrete, iron, steel **~9%**

Image: Architecture 2030

US Climate Policy

In the absence of strong Federal Policy, states and municipalities have adopted their own regulations

- CA: Buy Clean California – first US law to address embodied carbon in construction materials
  - GWP must not exceed set limits
  - Currently targets structural steel, steel rebar, glass, and mineral wool

Federal Policy is advancing under the Biden Administration:

- Rejoining the Paris Agreement
- Several first-week executive actions aimed at advancing zero-carbon technologies, increasing reforestation and carbon sequestration

Measuring Greenhouse Gases

Global Warming Potential (GWP) was developed to allow comparisons of the global warming impacts of different gases. Specifically, it is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2). The time period usually used for GWP's is 100 years. (EPA)

	GWP
Carbon Dioxide (CO_2)	1
Methane (CH_4)	28-36
Nitrous Oxide (N_2O)	265-298
Fluorinated Gases	Thousands to Tens of Thousands

Carbon Dioxide Equivalents (CO_{2eq}) = International standard practice is to express greenhouse gases in terms of CO_2 equivalents

Carbon vs CO_2

+ 2 *

= 44 CO_2

1 ton Carbon ≠ 1 ton CO_2

1 ton Carbon = (44/12=) **3.67 tons CO_2**

Carbon Terms

- **Embodied Carbon**: Carbon emissions associated with the entire life cycle of the building including harvesting, mining, manufacturing, transporting, installing, maintaining, decommissioning, and disposing/reuse of a material or product
- **Operational Carbon**: Carbon emissions associated with operating a building including power, heat, and cooling

Image: Boston Society for Architecture

Embodied Carbon

- Primarily related to **manufacturing of materials**
- More significant than many people realize, has been **historically overlooked**
- Big upfront GHG “cost” - which makes it a **good near-term target** for climate change mitigation

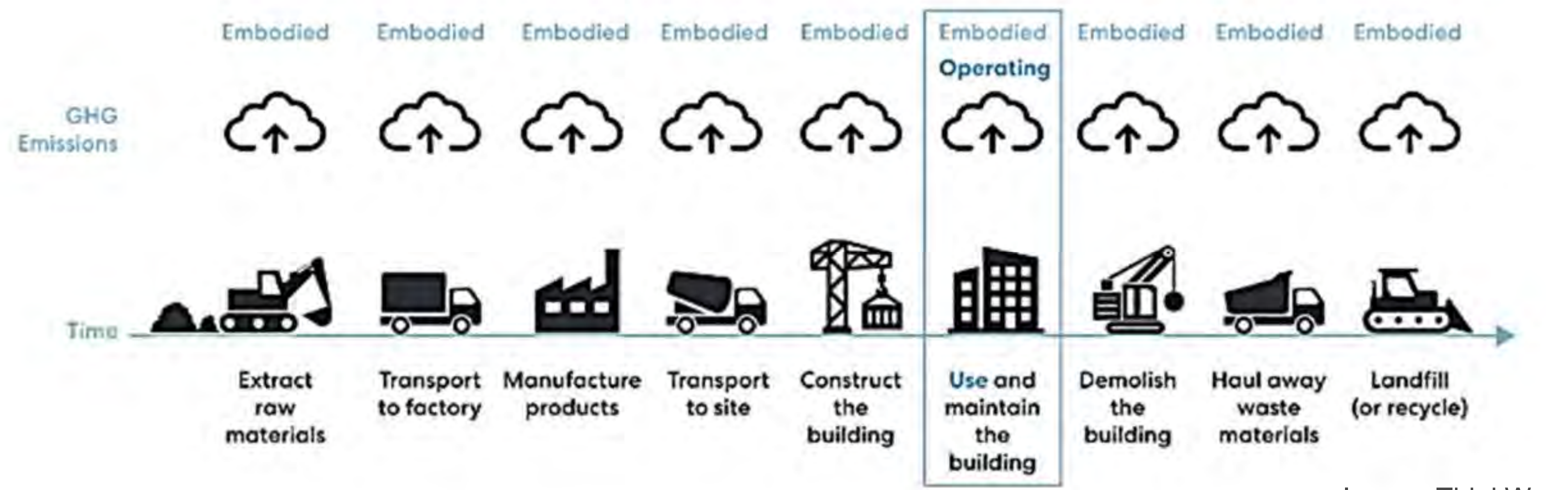


Image: ThinkWood

Embodied vs. Operational Energy

Traditional Non-Wood Building

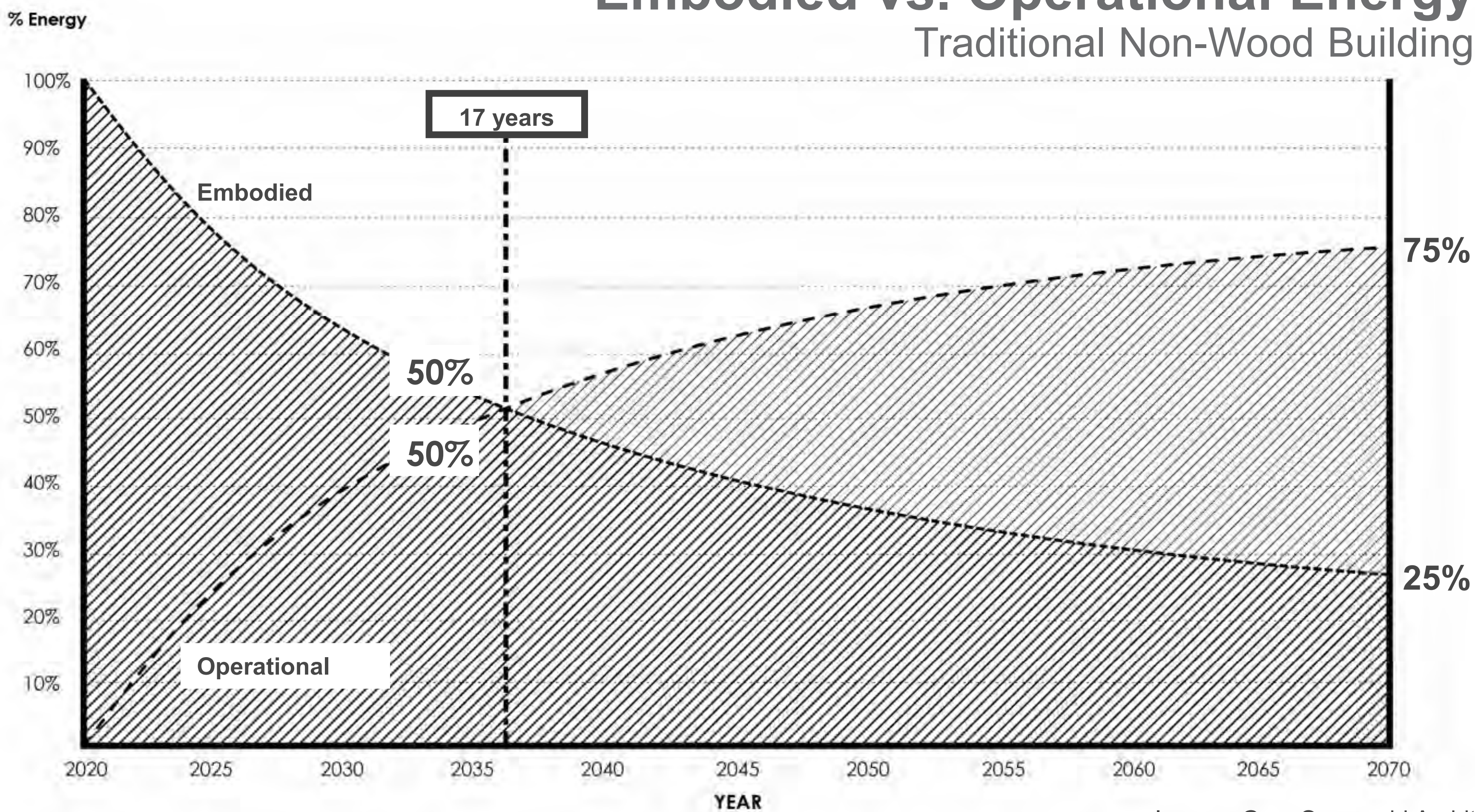


Image: Gray Organschi Architecture

Embodied Energy vs Embodied Carbon

Embodied Energy:

Amount of energy used to:

- Extract, harvest, mine resources
- Process and assemble materials
- Transport products
- Construct building
- Maintain and repair building
- Deconstruct building and dispose or recycle materials

Embodied Carbon:

Carbon emissions resulting from:

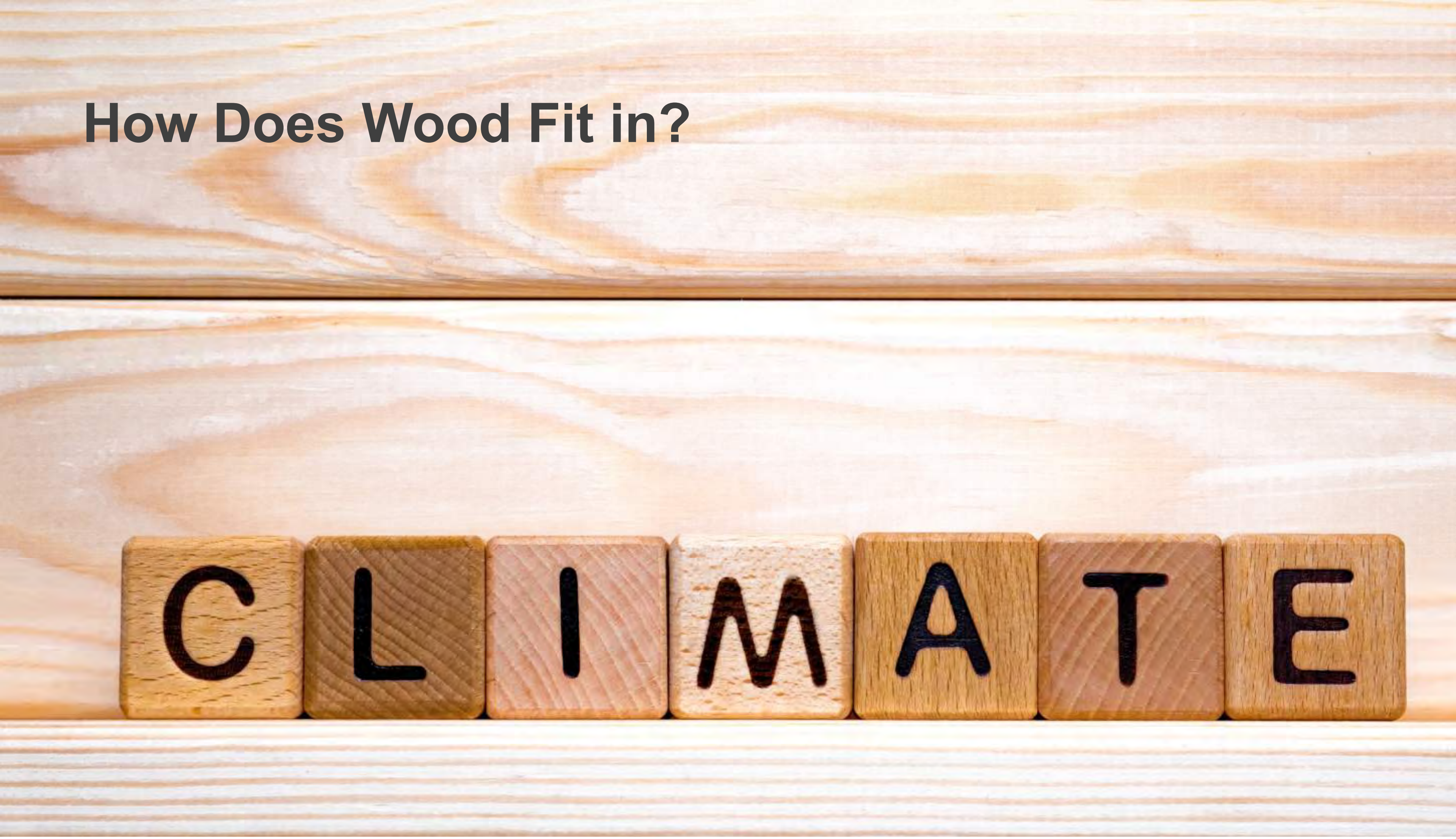
- Combustion of fuels to generate embodied energy
- Chemical reactions

Carbon emissions may be offset by:

- Carbon sequestration during growth or manufacturing*

* Sequestered carbon may be included in embodied carbon calculation or considered separately.

How Does Wood Fit in?



Carbon Benefits of Wood

- **Less energy intensive** to manufacture than steel or concrete
- **Less fossil fuel consumed** during manufacture
- **Avoid process emissions**
- Carbon **storage in forests** and **promote forest health**
- Extended carbon **storage in products**

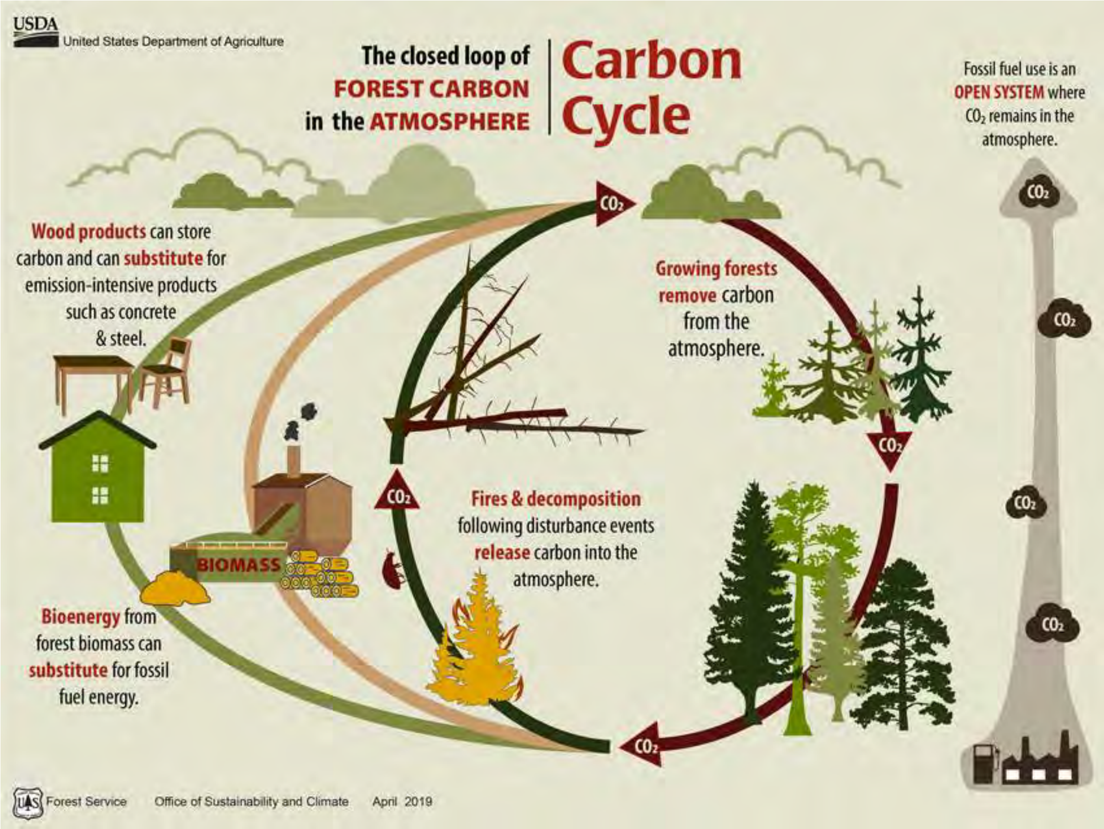


Image: USDA US Forest Service

More Carbon Terms

Carbon Sequestration: The process by which CO_2 is **removed** from the atmosphere and deposited in solid or liquid form in oceans, living organisms, or land.

Carbon Storage: Carbon is **stored as a solid** in the form of plant material: roots, trunks, branches, stems, and leaves. It can continue to be stored in **wood building materials**.

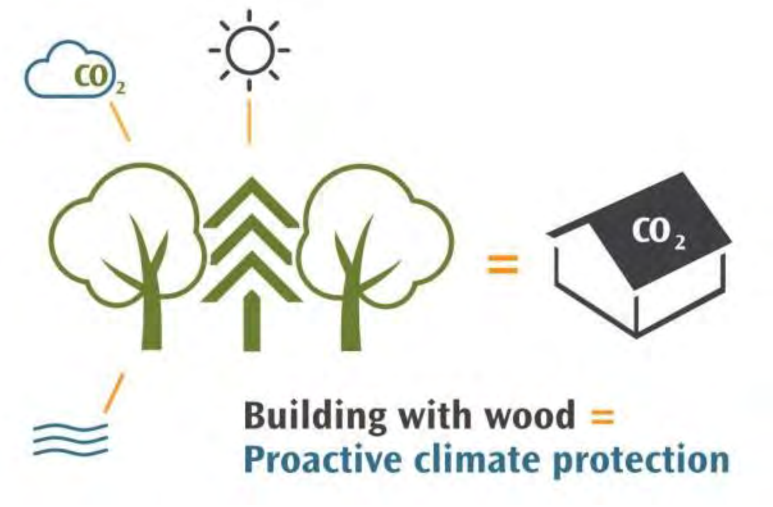


Image: Dovetail Partners, Inc.

Carbon Storage

Wood ≈ 50% Carbon (dry weight)

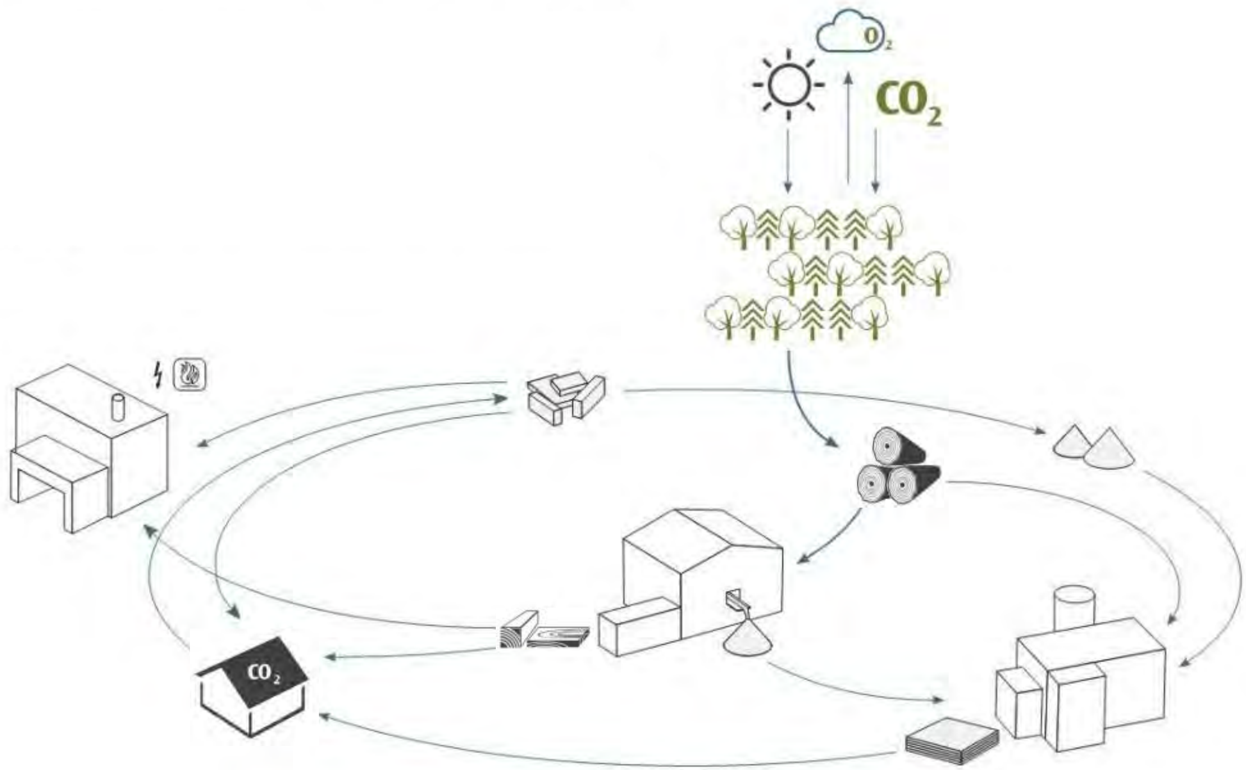
Long-Term Positive Effects

		Energy effect	Carbon effect	Value-added effect
	**Forest**	Stores solar energy	Removes C from Atmosphere	**Increases forest value;** supplies wood
	**Timber**	Often local, short transit	C in raw material	**Strengthens rural economies**
	**Lumber**	**Low embodied energy**	**Stores C**; replaces materials w/ greater C impact	Supports energy independence; strengthens US Forestry
	**Wood structure**	**Low thermal conductivity** & bridging	**Stores C**; reduces insulation / GHG emissions	**Cost effective** & provides **biophilic environment**
	**Modernization, refurbishment, urban densification**	**Lightweight** & easy to transport	**More C storage**	Increasing use of prefab; saves resources & retains value
	**Demo, recycling, energy recovery**	Low energy recycling or emissions neutral energy recovery	Extended C fixation due to recycling	**Innovative solutions for circular economy**

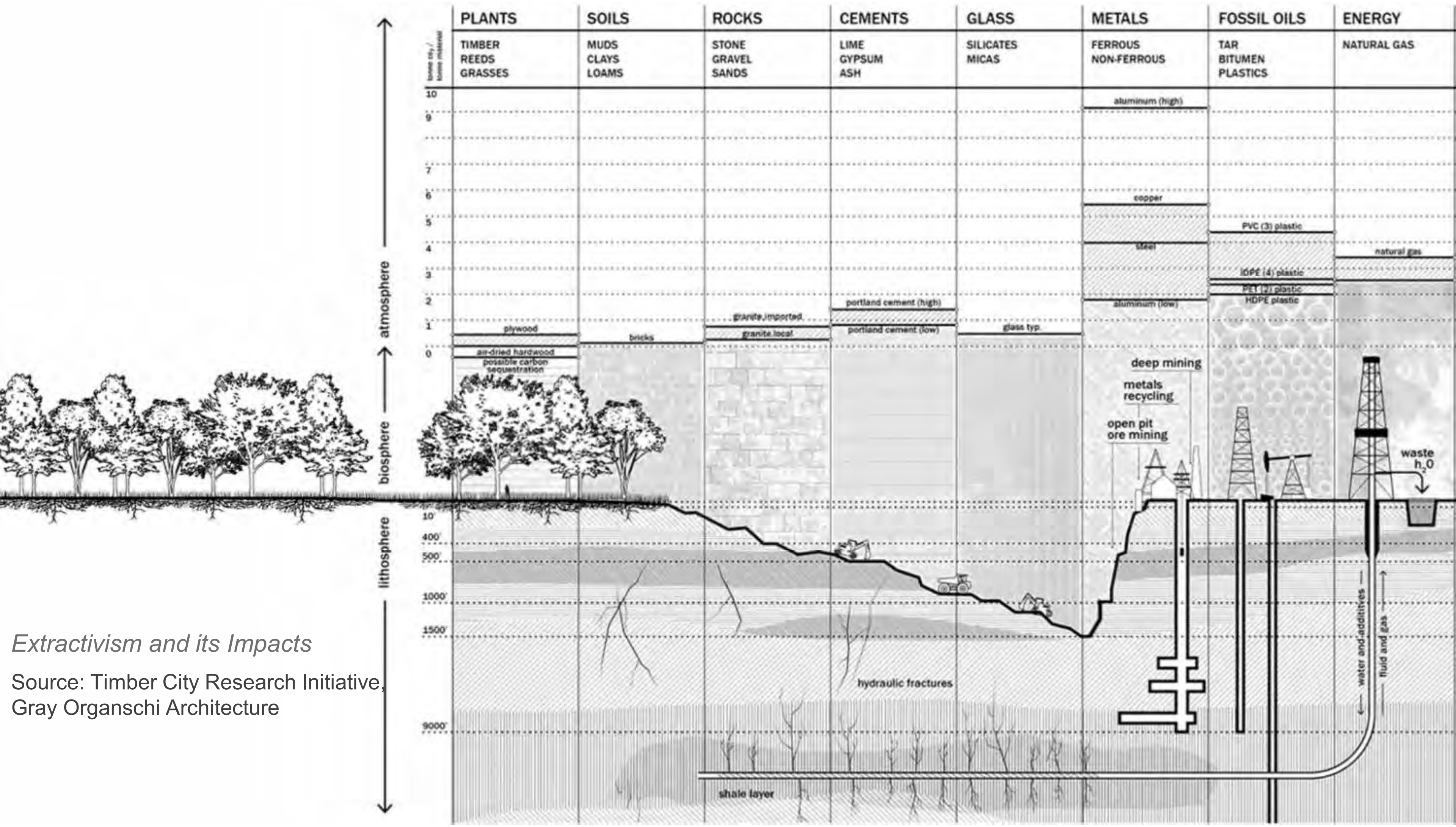
Source: Building with Wood – Proactive Climate Protection, Dovetail Partners, Inc.

Carbon Cycle

Renewable Resource | Carbon Sequestration



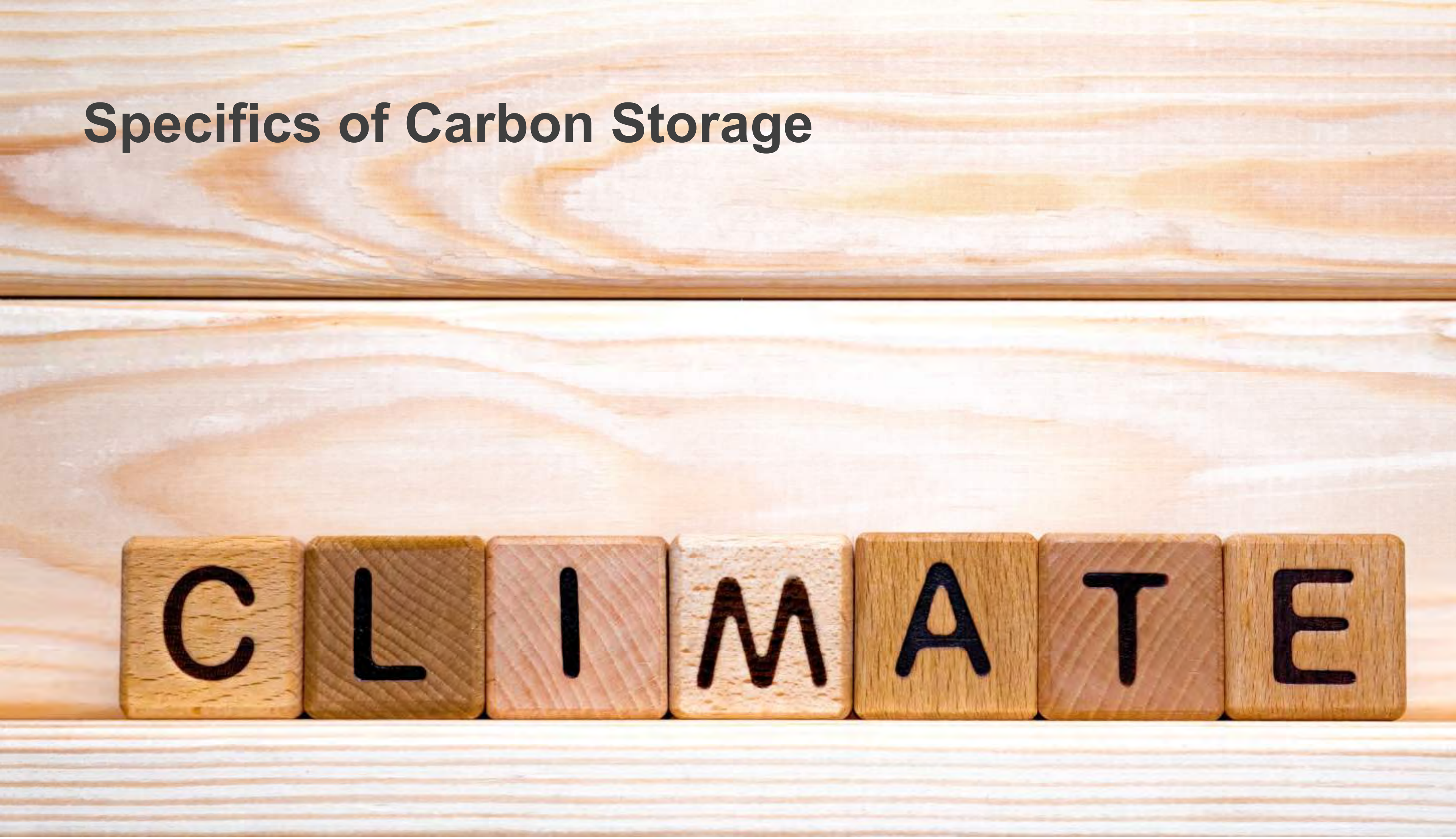
Source: Building with Wood – Proactive Climate Protection, Dovetail Partners, Inc.



Extractivism and its Impacts

Source: Timber City Research Initiative, Gray Organschi Architecture

Specifics of Carbon Storage



Where is Carbon Stored?

Harvested Wood Pools

- Harvested Wood Products
- Solid Waste Disposal Sites

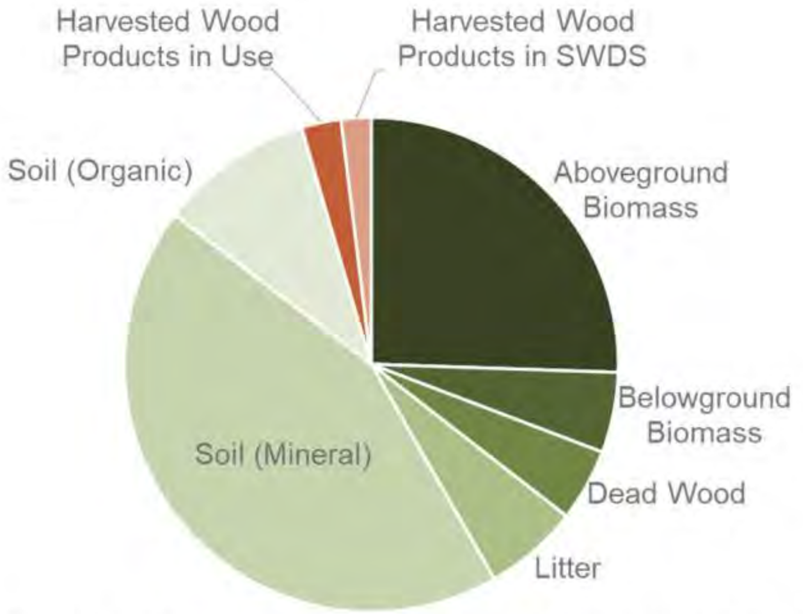
Forest Pools

- Aboveground Biomass
- Belowground Biomass
- Dead Wood
- Litter or Forest Floor
- Soil Organic Carbon

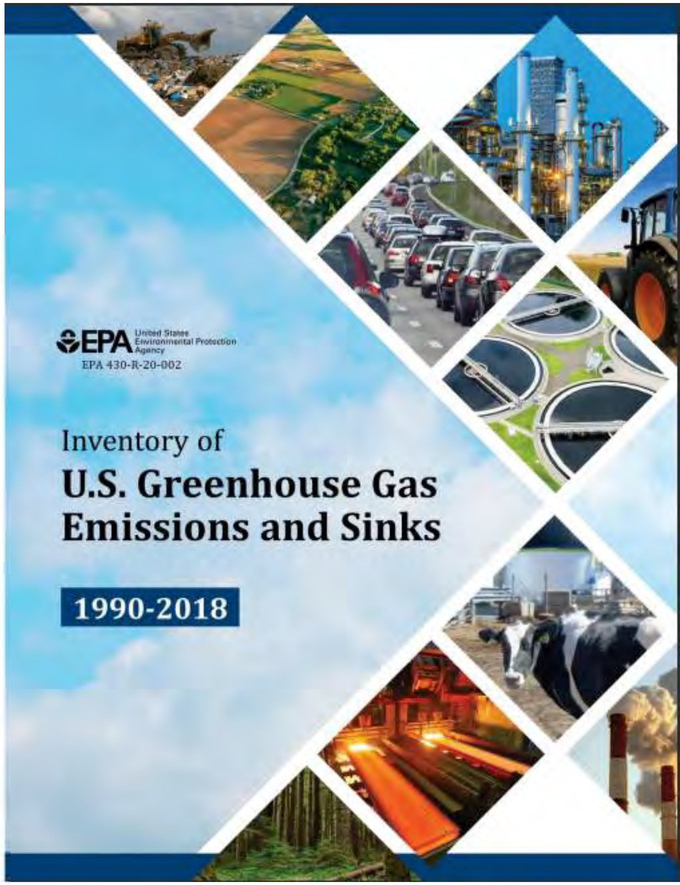
Source: https://usaforests.org/

Carbon Storage in Harvested Wood Products

As of 2019, the carbon stock for Harvested **Wood Products in Use** in the conterminous 48 states is estimated at **1,521 Million Metric Tons**.



Carbon Stocks in Forest Land and Harvested Wood Pools, 2019



https://www.epa.gov/sites/production/files/2020-04/documents/us-ghg-inventory-2020-main-text.pdf

Table 6-12: Forest Area (1,000 ha) and C Stocks in *Forest Land Remaining Forest Land* and Harvested Wood Pools (MMT C)

	1990	2005	2015	2016	2017	2018	2019
Forest Area (1,000 ha)	***279,748***	***279,749***	***280,041***	***280,041***	***279,893***	***279,787***	***279,682***
Carbon Pools (MMT C)							
Forest Ecosystem	**51,527**	**53,886**	**55,431**	**55,592**	**55,746**	**55,897**	**56,051**
Aboveground Biomass	11,833	13,484	14,561	14,672	14,780	14,884	14,989
Belowground Biomass	2,350	2,734	2,982	3,008	3,033	3,056	3,081
Dead Wood	2,120	2,454	2,683	2,707	2,731	2,753	2,777
Litter	3,662	3,647	3,638	3,639	3,639	3,640	3,641
Soil (Mineral)	25,636	25,639	25,640	25,640	25,637	25,637	25,638
Soil (Organic)	5,927	5,929	5,927	5,927	5,926	5,926	5,926
Harvested Wood	**1,895**	**2,353**	**2,567**	**2,591**	**2,616**	**2,642**	**2,669**
Products in Use	1,249	1,447	1,490	1,497	1,505	1,513	1,521
SWDS	646	906	1,076	1,094	1,112	1,129	1,148
Total C Stock	**53,423**	**56,239**	**57,998**	**58,183**	**58,362**	**58,539**	**58,720**

Notes: Forest area and C stock estimates include all *Forest Land Remaining Forest Land* in the conterminous 48 states

https://www.epa.gov/sites/production/files/2020-04/documents/us-ghg-inventory-2020-main-text.pdf

Harvested Wood Products

- **Solid sawn** wood products have the lowest level of embodied energy.
- Wood products requiring more processing steps (for example, plywood, engineered wood products, flake-based products) require more energy to produce but still require **significantly less energy** than their non-wood counterparts.

Image: Weyerhaeuser

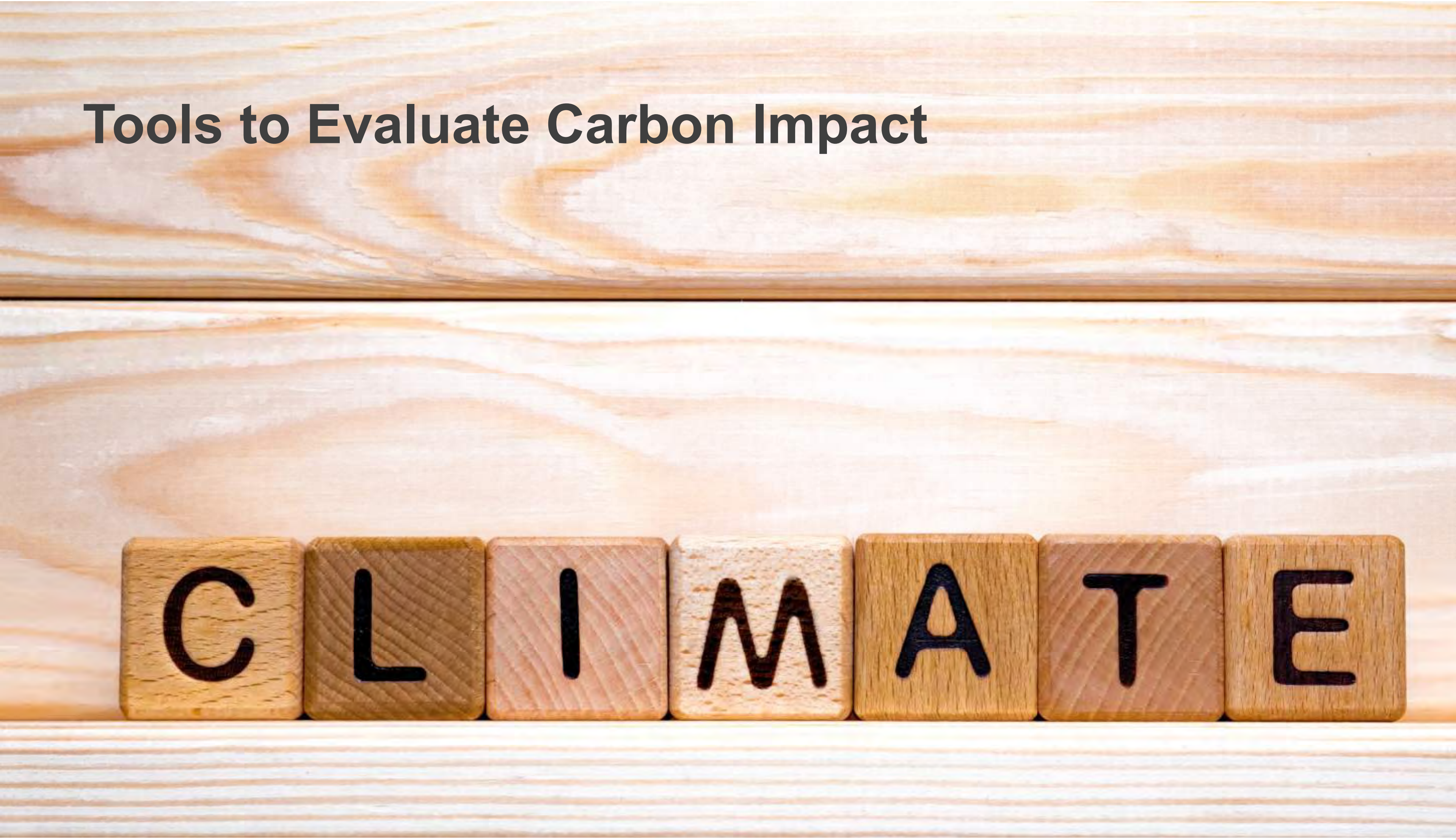
Image: LP Building Solutions

Image: Structurecraft

Image: Georgia-Pacific

Source: USFPL Wood Handbook; Wood as a Sustainable Building Material

Tools to Evaluate Carbon Impact



Whole Building Life Cycle Analysis (WBLCA)

"Evaluation of the inputs, outputs, and potential environmental impacts… throughout its life cycle"

- WBLCA covers all stages in the life cycle of a building and its components
- Several tools available; various methodologies
- https://www.thinkwood.com/education/calculate-wood-carbon-footprint
- https://www.thinkwood.com/blog/understanding-the-role-of-embodied-carbon-in-climate-smart-buildings

WoodWorks Carbon Calculator

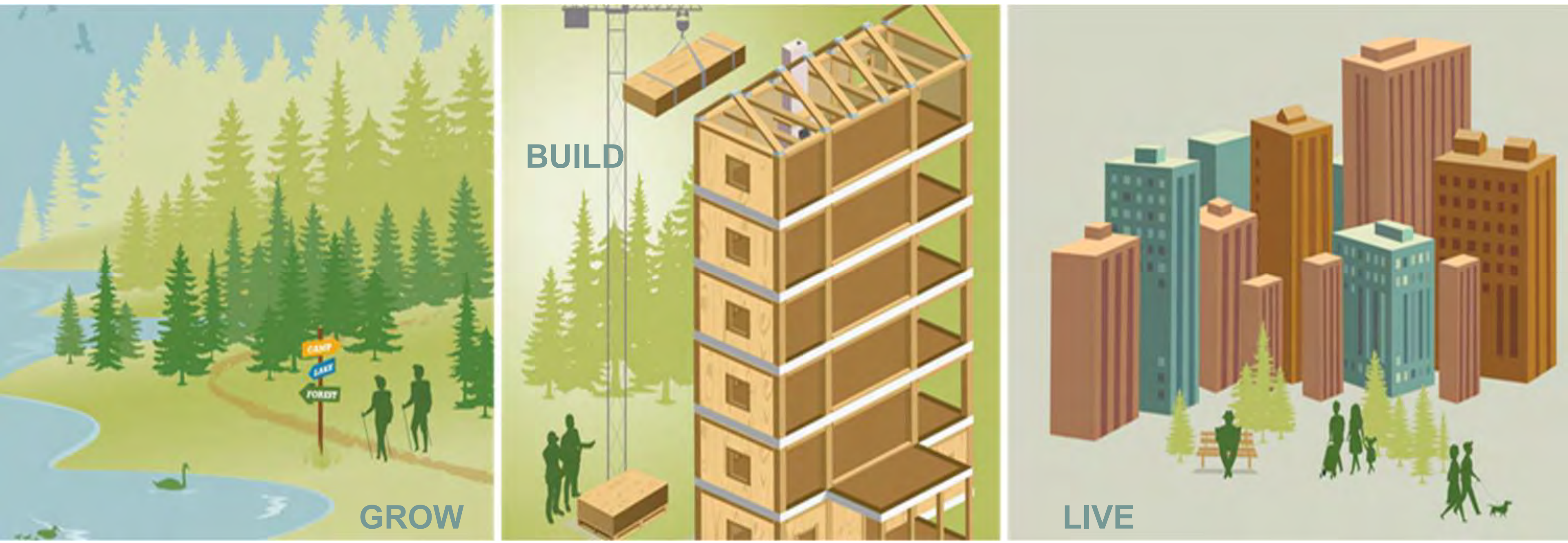
- Available at **woodworks.org**
- Estimates total wood mass in a building
- Relays **estimated** carbon impacts:
    - Amount of **carbon stored** in wood
    - Amount of **greenhouse gas emissions avoided** by choosing wood over a non-wood material

WoodWorks™
WOOD PRODUCTS COUNCIL

http://www.woodworks.org/carbon-calculator-download-form/

Forest to Cities

A Systemic Solution in Action



www.ForesttoCities.org

Multi-Story Considerations

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

Marselle Condos, Seattle, WA

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

Type V Construction

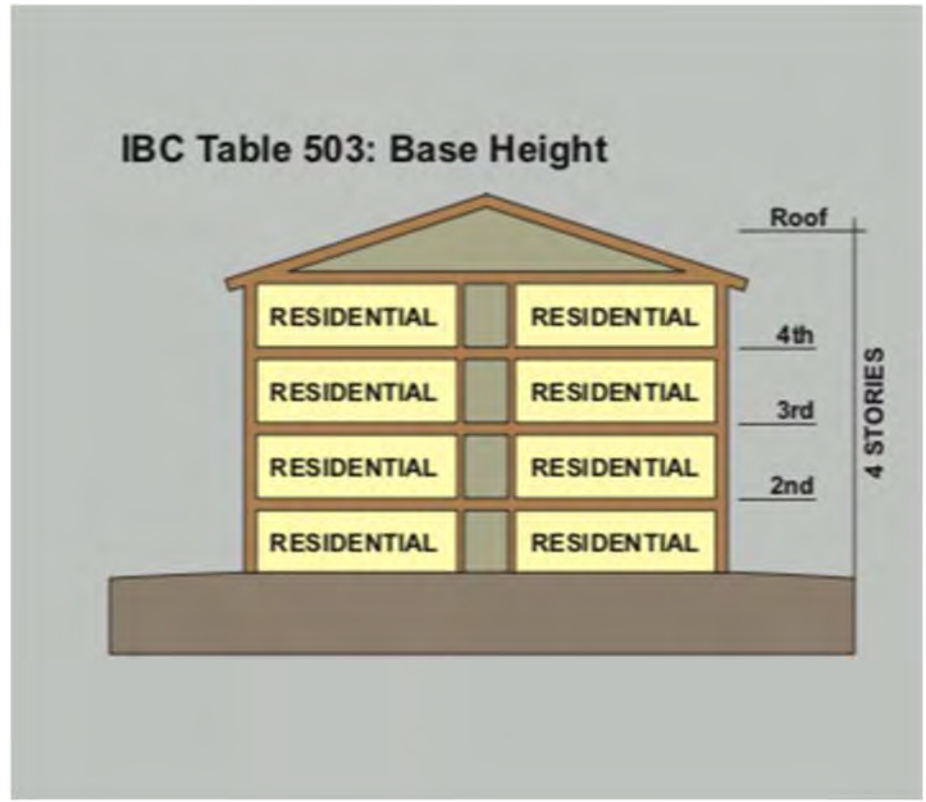
All building elements are any allowed by code:

- Light-frame wood construction
- Mass Timber
- Hybrid

Multi-Family Occupancies:

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

Assumes VA Construction, NFPA13 Sprinklers



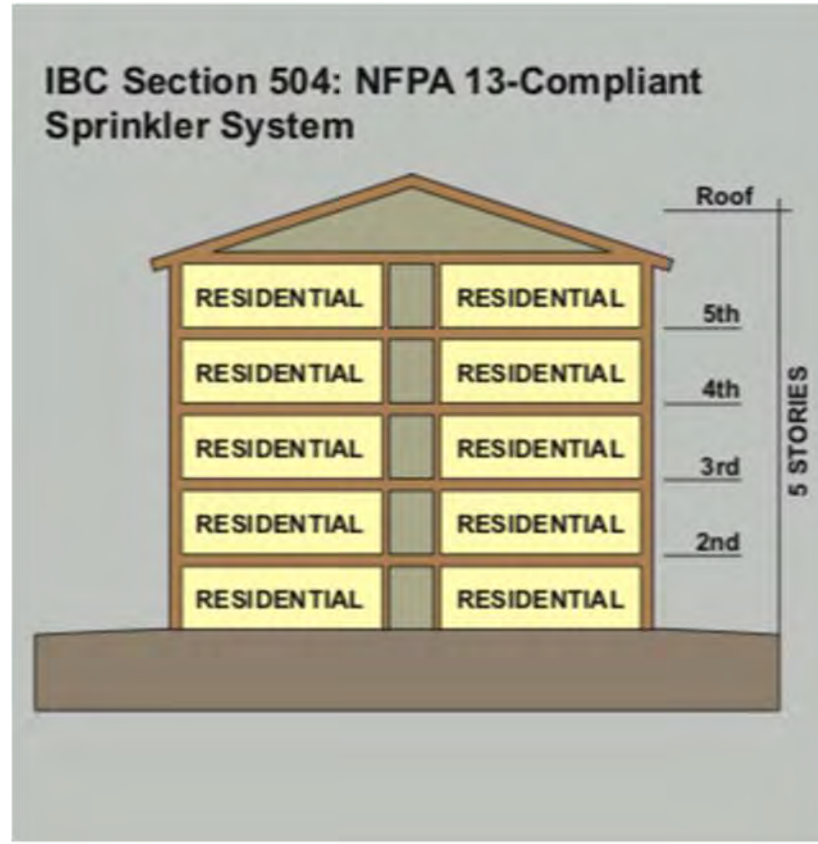
Type III Construction

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

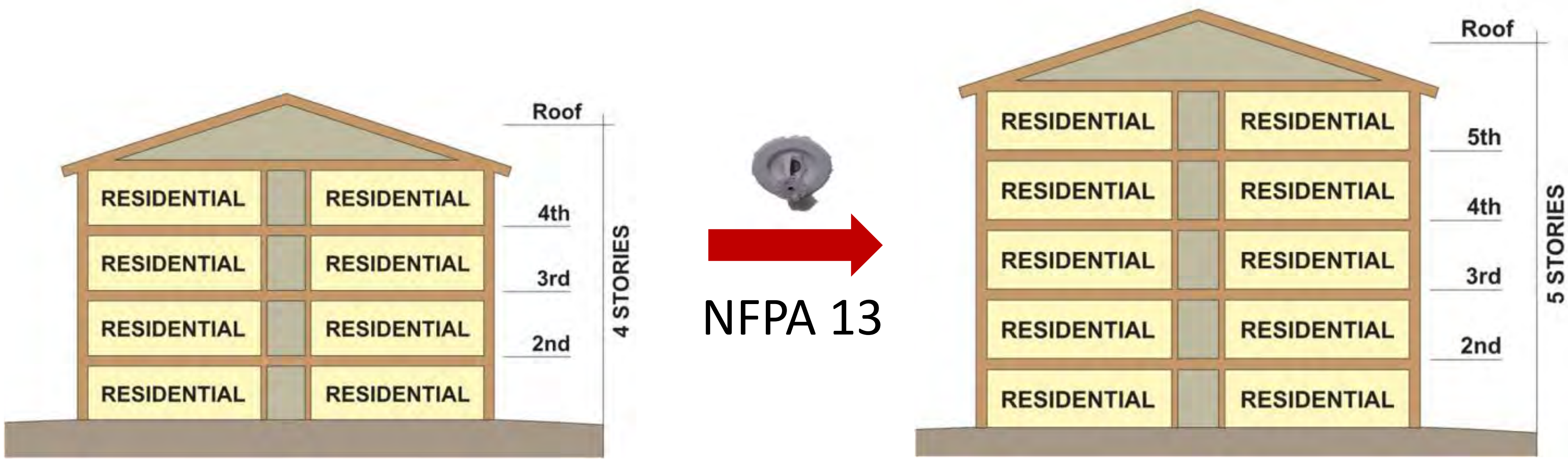
Multi-Family Occupancies:

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

Assumes IIIA Construction, NFPA13 Sprinklers



IBC Building Size Limits



Without Sprinklers

With Sprinklers

With NFPA Sprinklers, IBC gives an allowable Heights and Area Increase

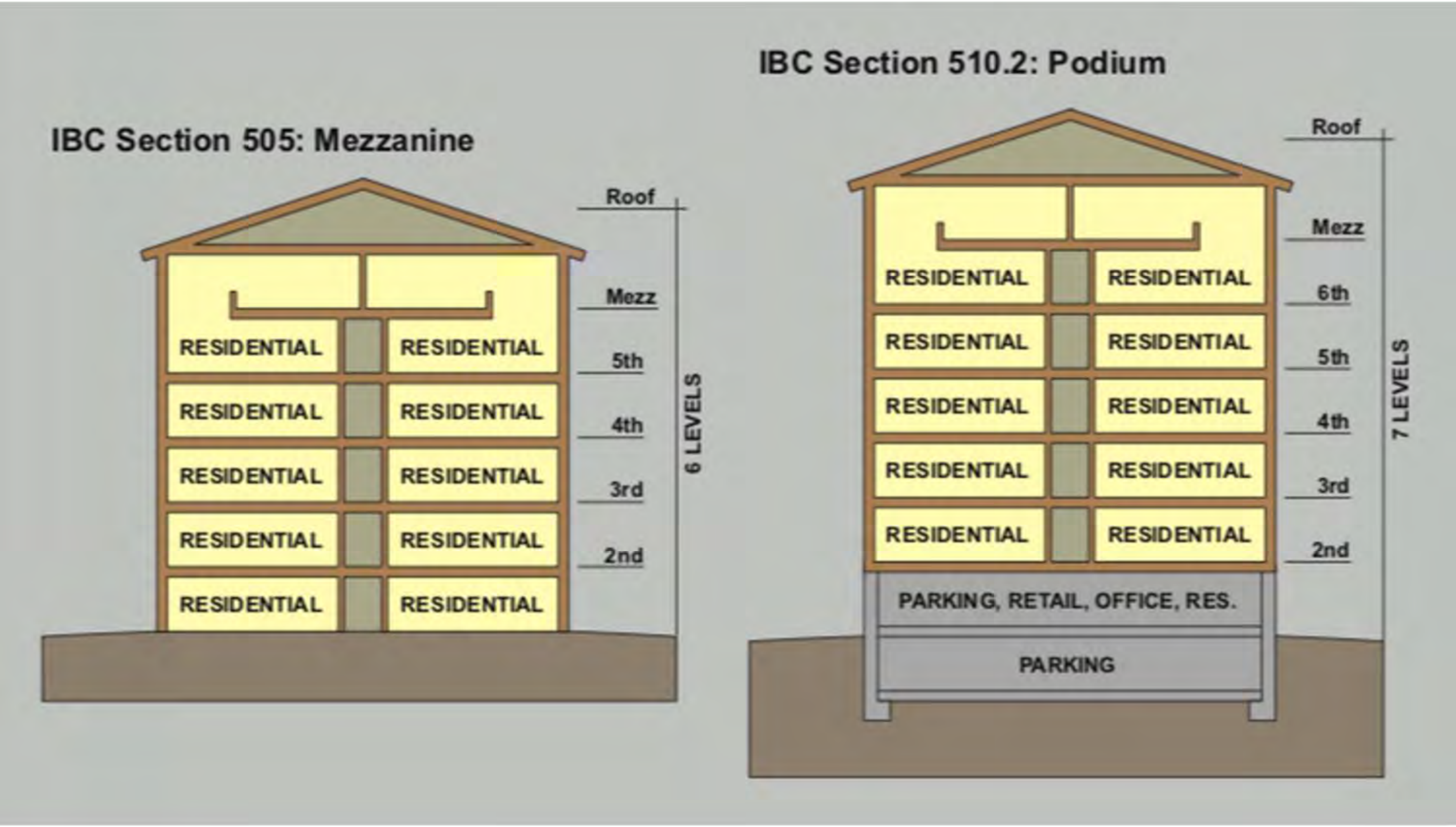
Heights and Areas – IBC 2015

TABLE 506.2[a, b]
ALLOWABLE AREA FACTOR (A_t = NS, S1, S13R, or SM, as applicable) IN SQUARE FEET

OCCUPANCY CLASSIFICATION	SEE FOOTNOTES	TYPE OF CONSTRUCTION								
		TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
		A	B	A	B	A	B	HT	A	B
A-1	NS	UL	UL	15,500	8,500	14,000	8,500	15,000	11,500	5,500
	S1	UL	UL	62,000	34,000	56,000	34,000	60,000	46,000	22,000
	SM	UL	UL	46,500	25,500	42,000	25,500	45,000	34,500	16,500
A-2	NS	UL	UL	15,500	9,500	14,000	9,500	15,000	11,500	6,000
	S1	UL	UL	62,000	38,000	56,000	38,000	60,000	46,000	24,000
	SM	UL	UL	46,500	28,500	42,000	28,500	45,000	34,500	18,000
M	NS	UL	UL	21,500	12,500	18,500	12,500	20,500	14,000	9,000
	S1	UL	UL	86,000	50,000	74,000	50,000	82,000	56,000	36,000
	SM	UL	UL	64,500	37,500	55,500	37,500	61,500	42,000	27,000
R-1	NS[d, h] / S13R	UL	UL	24,000	16,000	24,000	16,000	20,500	12,000	7,000
	S1	UL	UL	96,000	64,000	96,000	64,000	82,000	48,000	28,000
									[illegible]	21,000
R-2									[illegible]	7,000
									[illegible]	28,000
	SM	UL	UL	72,000	48,000	72,000	48,000	61,500	36,000	21,000

Tables include both "base" and increased allowances for use of sprinklers.

Mid-Rise Construction

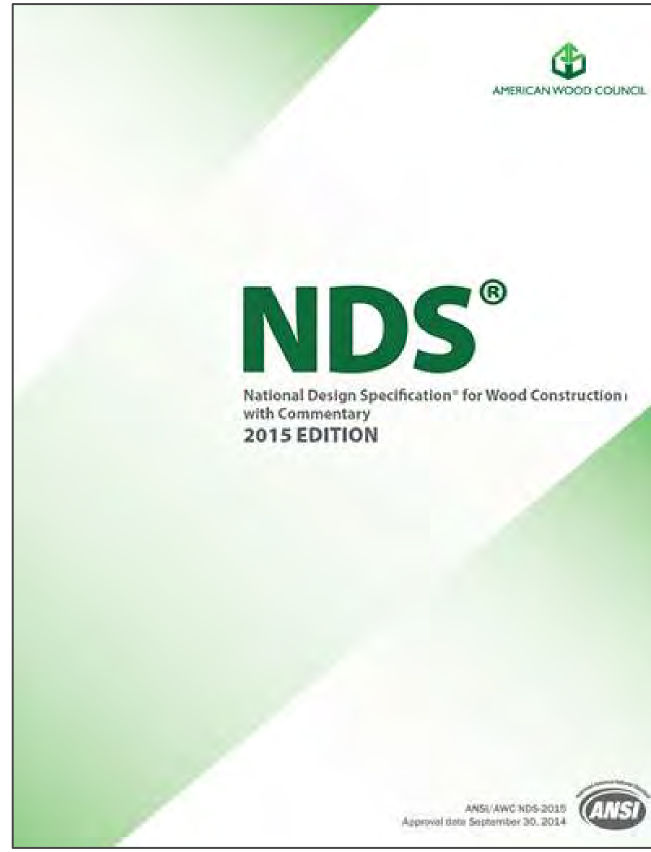


Type III Exterior Walls – FRT

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: 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.



FRT Wood Design Values

FRT manufacturers provide reduction values in literature, ICC ESR's, etc.

Example FRT manufacturer's ESR reduction values:

TABLE 2—DESIGN VALUE ADJUSTMENT FACTORS FOR PYRO-GUARD® TREATED LUMBER

PROPERTY	PYRO-GUARD® WALL/FLOOR SERVICE TEMPERATURE TO 100°F/38°C			PYRO-GUARD® ROOF FRAMING, SERVICE TEMPERATURE TO 150° F/66° C,					
	Douglas fir	Southern pine	Other species	Douglas fir Climate Zone			Southern pine Climate Zone		
				1A	1B	2	1A	1B	2
Extreme fiber stress in bending, F_b	0.97	0.91	0.88	0.90	0.93	0.96	0.80	0.85	0.89
Tension parallel to grain F_t	0.95	0.88	0.83	0.80	0.87	0.93	0.80	0.84	0.88
Compression parallel to grain, F_c	1.00	0.94	0.94	0.94	0.98	1.00	0.94	0.94	0.94
Horizontal shear F_v	0.96	0.95	0.93	0.95	0.95	0.96	0.92	0.93	0.94
Modulus of elasticity, E	0.96	0.95	0.94	0.96	0.96	0.96	0.95	0.95	0.95
Compression perp. to grain F_{cz}	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Fasteners/connectors	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90

FRT Wood Design Values

Shear wall capacity reduction typically handled by increasing sheathing thickness per FRT manufacturer recommendations – or can reduce shearwall capacity by applying connector reduction factors

When fire-retardant-treated plywood is used in a shear wall, the thickness must be one standard size thicker than that determined in the tabulated allowable shear values contained in Section 4.3 of ANSI/AWC Special Design Provisions for Wind and Seismic (SDPWS) or as shown in the tables referenced in Section 2306.3 of the IBC (2306.4 of the 2009 and 2006 IBC). Thickness to be used for FRT plywood compared to untreated plywood shear walls are shown below:

FRT Plywood Thickness (inches)	Untreated Plywood Thickness (inches)
3/8	5/16
7/16	3/8
15/32	7/16
1/2	15/32

Fire Ratings & Assembly Intersections

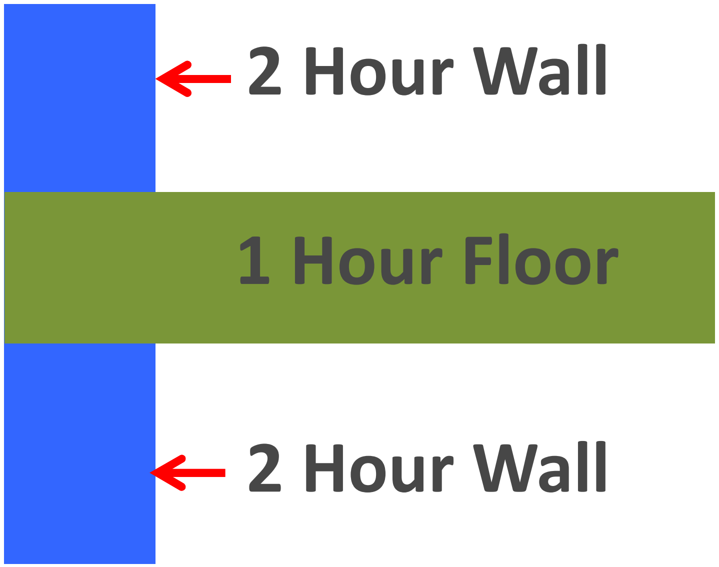
Key Differences in Fire Ratings for Construction Types			
	IIIA	IIIB	VA
Exterior (bearing) wall framing	FRT	FRT	non-FRT
Exterior bearing wall fire rating	2 hr	2 hr	1 hr
Floor assembly fire rating	1 hr	0 hr	1 hr

IBC Tables 601 & 706.4

Note: FRT = Fire Retardant Treated

Intersection of Tested Assemblies

- Many options are available for fire resistance tested floor assemblies and wall assemblies
- Code requirements for intersection details are not clear
- We must understand the <u>intent</u> of the code, provide a rationale that meets the code's intent, and utilize available information and testing results



Exterior Walls – Intersecting Floors

AWC's DCA3 provides floor to wall intersection detailing options

Addresses both continuity provisions and requirements for FRT elements in exterior wall plane

Design for Code Acceptance 3

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 standard fire tests. This document is intended to aid in the design of various wood-frame walls and wood-frame floor/ceiling assemblies, where such assemblies are required by code to be fire-resistance-rated.

Depending on the application, wall assemblies may need to be fire-resistance-rated for exposure from either one side or both sides. Exterior walls are required to be rated for both interior and exterior fire exposure where the wall has a fire separation distance of 10 feet or less. For exterior walls with a fire separation distance of greater than 10 feet, the required fire-resistance-rating applies only to exposure from the interior. The designer should note that some state and local building code amendments may require fire resistance rating for exposure from both sides of exterior walls, regardless of fire separation distance; however,

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) *Fire Resistance Directory*, Intertek Testing Services' *Directory of Listed Products*, and the Gypsum Association's *Fire Resistance Design Manual* (GA 600). The American Wood Council (AWC) and its members have tested a number of wood-frame fire-resistance-rated assemblies (see photos). Descriptions of successfully tested lumber wall assemblies are provided in Table 1 for one-hour fire-resistance-rated wall assemblies and Table 2 for two-hour fire-resistance-rated wall assemblies. Lumber shall be identified by the grade mark of a lumber grading or inspection agency that has been approved by an accreditation body that complies with the *American Softwood Lumber Standard (PS 20)*. The fire-resistance-rated assemblies described in this document, as well as those listed in other sources are not species- or grade-specific unless specifically noted as such.

Exterior Walls – Intersecting Floors

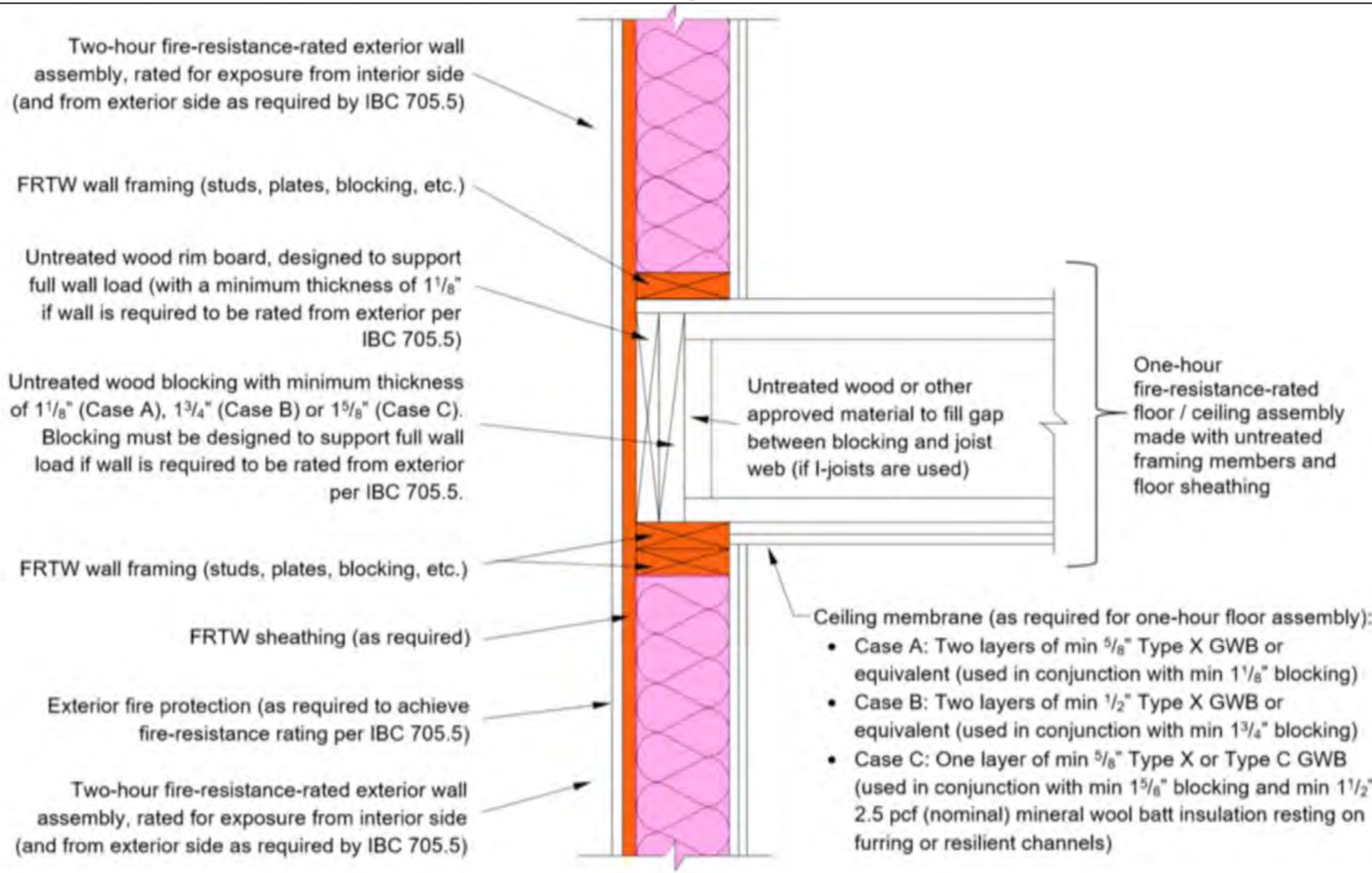
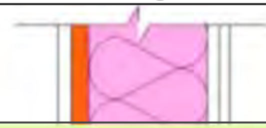


Figure 1A: Example detail for Type III-A exterior wall–floor intersection with rim board and blocking

Exterior Walls – Intersecting Floors



Methodology:

Fire-resistance for exposure from interior side:

- Case A: Minimum $1^{1}/_{8}$-inch-thick inner rim board plus two layers of minimum $^{5}/_{8}$ in. Type X GWB in the ceiling membrane provides 2 hours of protection to the outer rim board, based on the NDS-calculated time for the char depth to reach the inner rim board / outer rim board interface plus 40 minutes for each layer of $^{5}/_{8}$ in. Type X GWB (per IBC Table 722.6.2(1)).
- Case B: Minimum $1^{3}/_{4}$-inch-thick inner rim board plus two layers of minimum $^{1}/_{2}$ in. Type X GWB in the ceiling membrane provides 2 hours of protection to the outer rim board, based on the NDS-calculated time for the char depth to reach the inner rim board / outer rim board interface plus 25 minutes for each layer of $^{1}/_{2}$ in. Type X GWB (per IBC Table 722.6.2(1)).
- Case C: Minimum $1^{5}/_{8}$-inch-thick inner rim board plus one layer of minimum $^{5}/_{8}$ in. Type X GWB in the ceiling membrane plus minimum $1^{1}/_{2}$-inch-thick, 2.5 pcf (nominal) mineral wool batt insulation provides 2 hours of protection to the outer rim board, based on the NDS-calculated time for the char depth to reach the inner rim board / outer rim board interface, plus 40 minutes for the $^{5}/_{8}$ in. Type X GWB (per IBC Table 722.6.2(1)), plus 15 minutes for the mineral wool insulation.

The outer rim board must be designed to support the load from the wall above.

Fire-resistance for exposure from exterior side (where required per IBC Section 705.5): A combination of exterior fire protection, FRTW sheathing, and minimum $1^{1}/_{8}$-inch-thick outer rim board is used to provide two hours of protection to the inner rim board. Layers to the exterior of the outer rim board (e.g., exterior fire protection, FRTW sheathing, etc.) must be sufficient to provide at least 80 minutes of protection to the outer rim board. The inner rim board must be designed to support the load from the wall above.

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


WHY DOES
WOOD SHRINK?

Shrinkage Resource

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

Free resource at woodworks.org

WoodWorks™
WOOD PRODUCTS COUNCIL

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

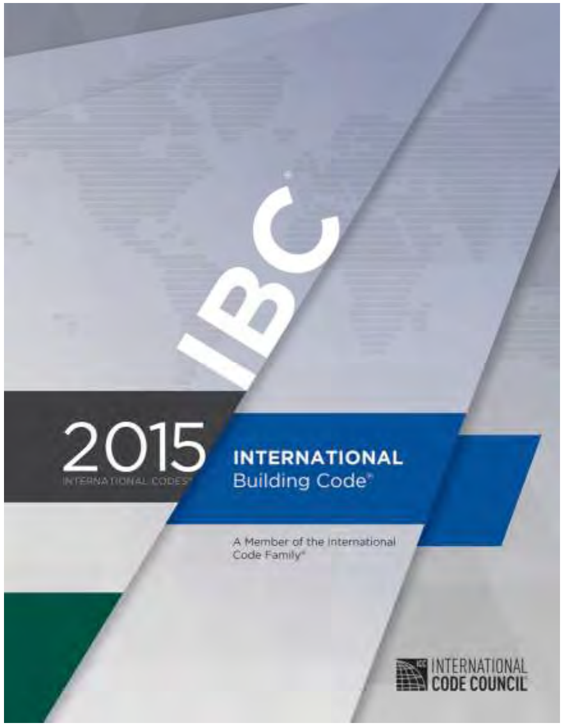
Photo: Pollack Shores, Matrix Residential

Wood Science & Shrinkage

Understanding the cellular structure of wood allows us to understand how moisture and wood interact and identify the paths that moisture typically travels. Within wood, moisture is present in two forms: (1) free water in cell cavities, and (2) bound water in cell walls. Simplistically, wood's cellular structure can be imagined as a bundle of drinking straws held together with a rubber band, with each straw representing 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 point (FSP). Imagine a sponge that has just been taken out of a bucket filled with water. As the sponge is lifted from the bucket, water comes out of the pores. When the sponge is squeezed, more water comes out of the pores. The moment when no water can be squeezed out of the sponge but yet it still feels damp is analogous to the FSP. The moisture retained in the sponge is the bound water and water that has been squeezed out is the free water.

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.



Shrinkage Design Considerations

Image: Schaefer

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.

Shrinkage Calculations

Initial or Installed moisture content (MC)

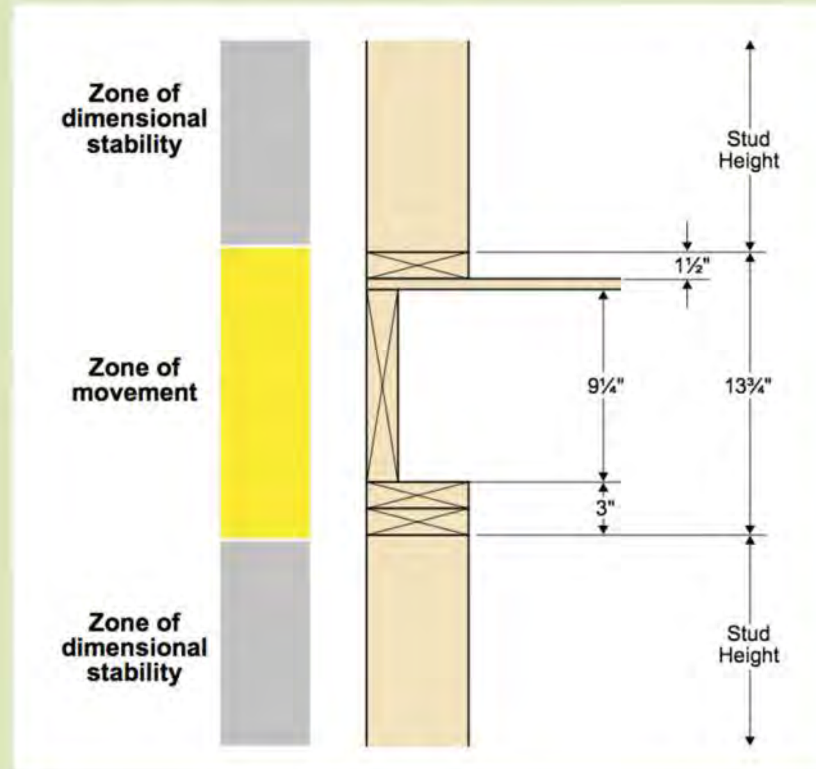
- Typically specified by Structural EoR
- 19% max MC is common – marked as KD, KD19 or MC19
- Green (>19% MC), or 15% max MC also available in select markets
- Important to keep in mind this is the MC when it is manufactured
- MC at time of finish install can be much higher or lower

Shrinkage Calculations – Cross Grain Wood

Shrinkage occurs in cross-grain, but not longitudinal, wood dimensions

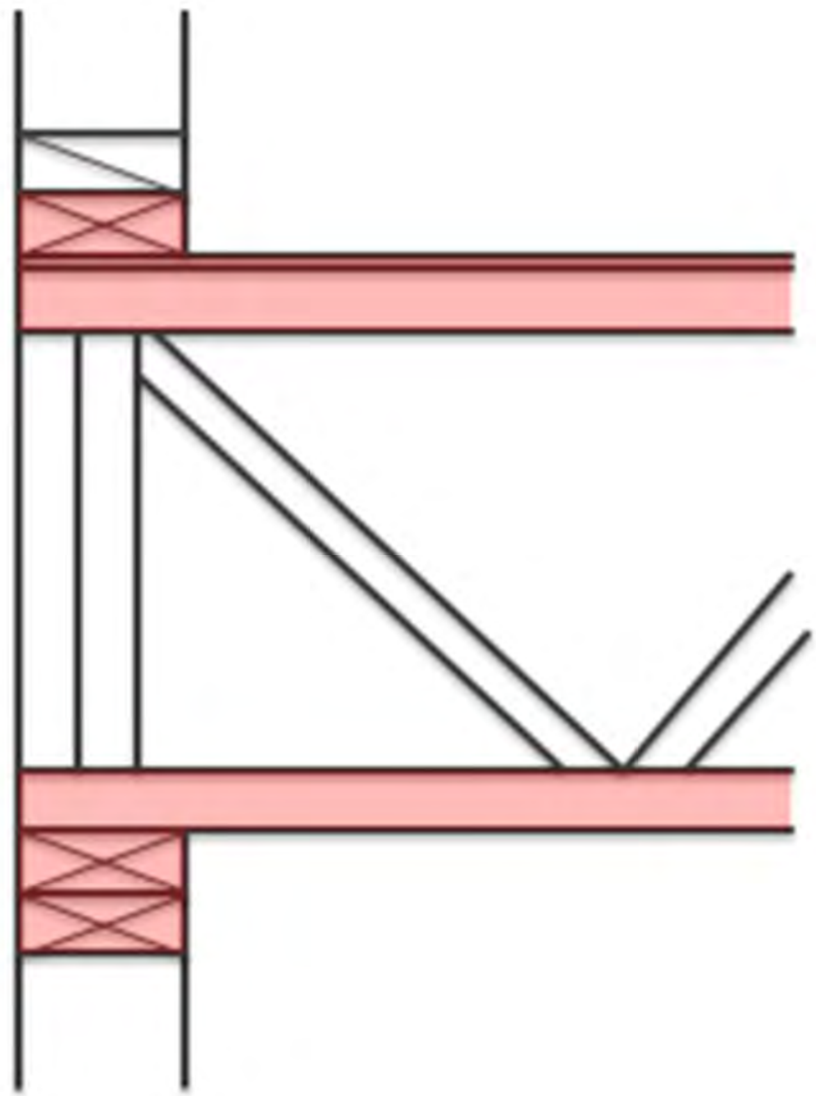
- Primarily in horizontal members
- Wall plates
- Floor/rim joists
- Engineering judgement required when determining what to include in shrinkage zone
- Should Sheathing, I-Joists, Trusses, other products manufactured with low MC be included?

FIGURE 5:
Shrinkage zone in platform-framed detail



Shrinkage Calculations – Cross Grain Wood

In parallel chord trusses, only chords contribute to shrinkage, vertical and diagonal webs don't



Shrinkage Calculations – Running the Numbers

Simplified Method Shrinkage Equation:

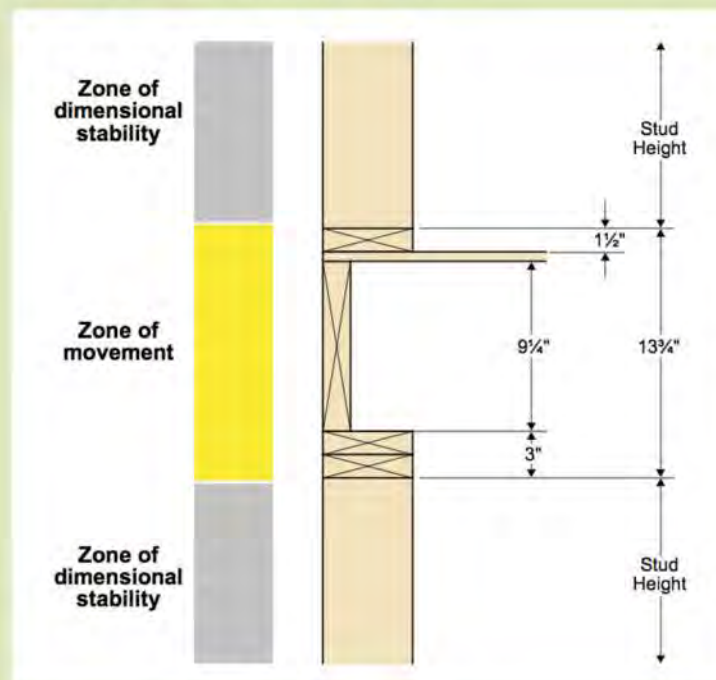
S = 0.0025 in / inch of cross grain wood / % MC change

Let's run Through an Example:
13.75" shrinkage zone
Installed MC = 19%
EMC = 12%

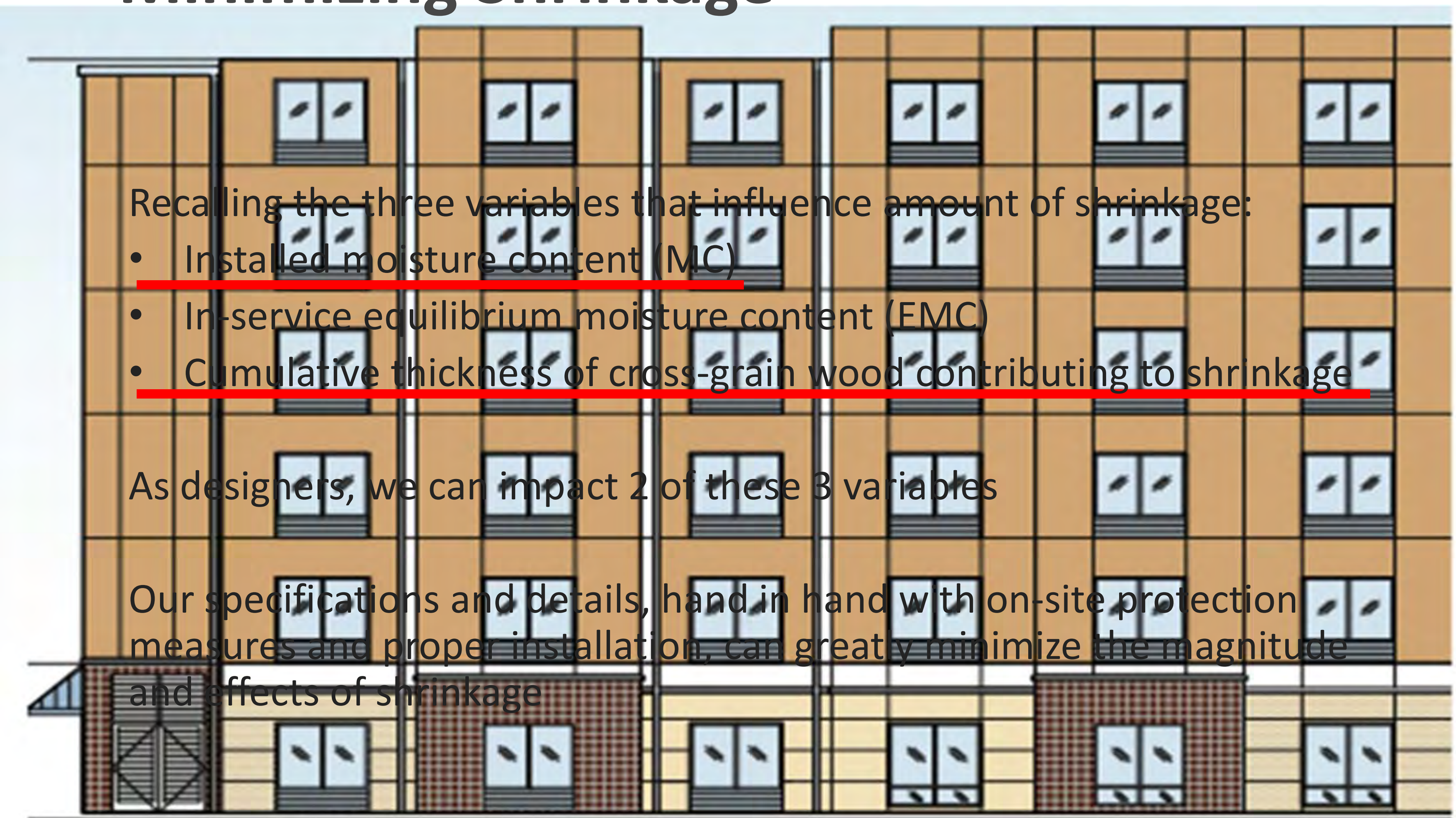
S = (0.0025)(13.75")(12-19) = **-0.24"**

(note: Negative value due to loss in cross section)

FIGURE 5:
Shrinkage zone in platform-framed detail



Minimizing Shrinkage



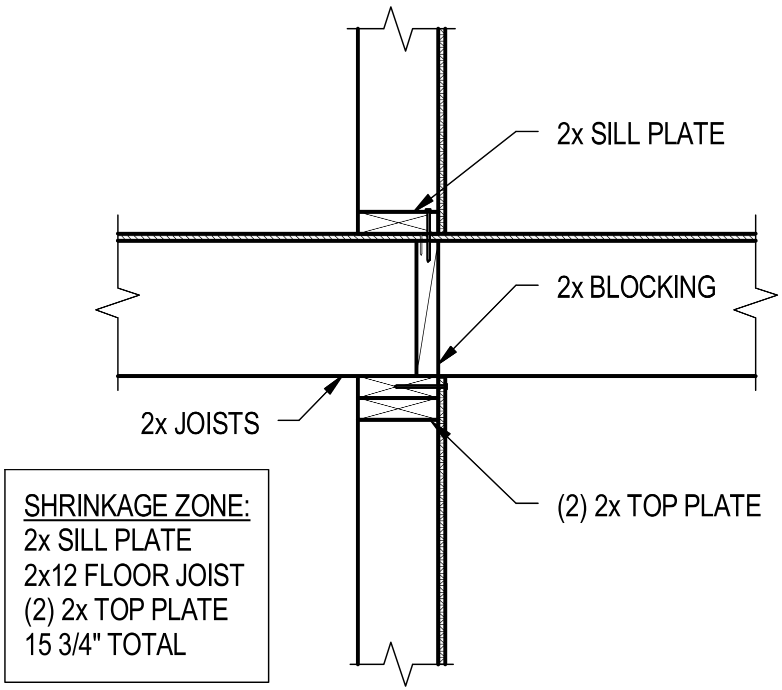
Recalling the three variables that influence amount of shrinkage:

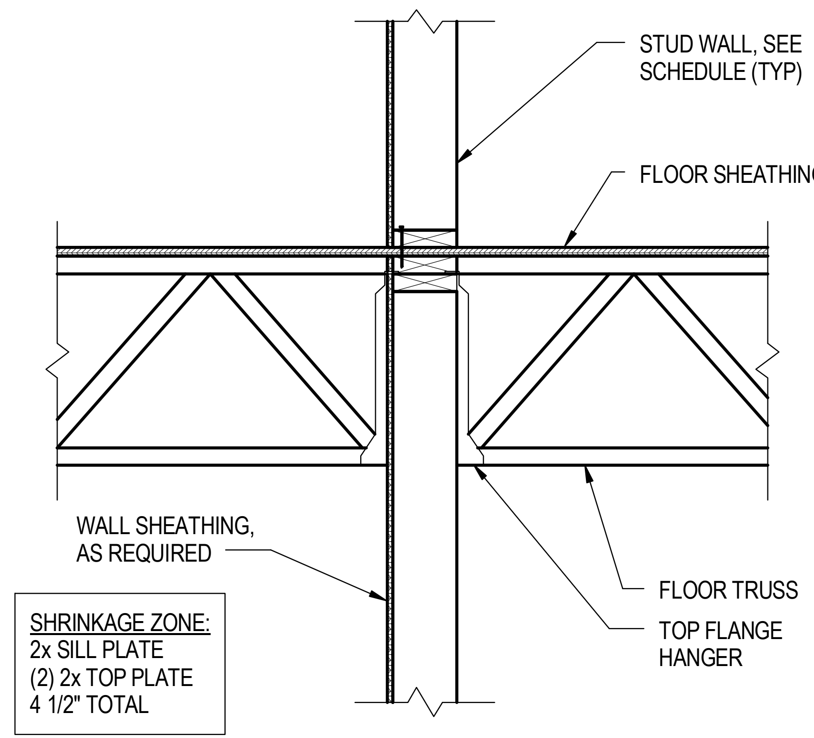
- Installed moisture content (MC)
- In-service equilibrium moisture content (EMC)
- Cumulative thickness of cross-grain wood contributing to shrinkage

As designers, we can impact 2 of these 3 variables

Our specifications and details, hand in hand with on-site protection measures and proper installation, can greatly minimize the magnitude and effects of shrinkage

Minimizing Shrinkage – Detailing





Images: Schaefer

Minimizing Shrinkage – Detailing

Platform Detail:
15.75” Shrinkage Zone
19% MC Initial
12% EMC

S = (0.0025)(15.75”)(12-19) = **0.28”**

5-story building: **1.4” total**

Semi-Balloon Detail:
4.5” Shrinkage Zone
19% MC Initial
12% EMC

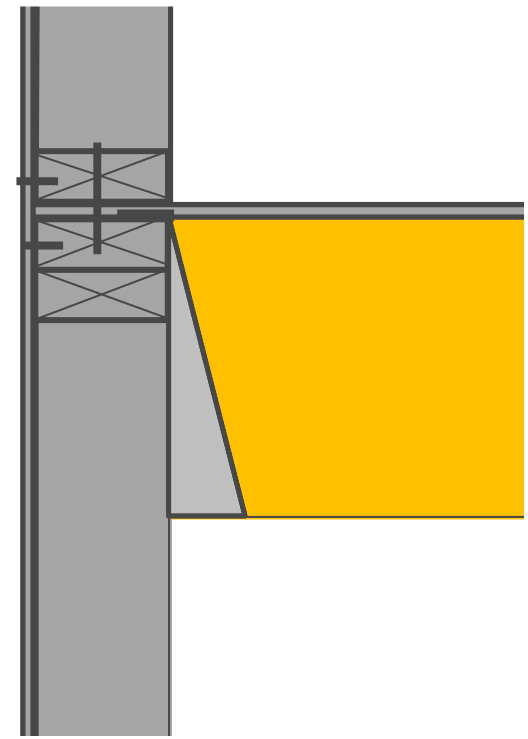
S = (0.0025)(4.5”)(12-19) = **0.08”**

5-story building: **0.4” total**

Minimizing Shrinkage - Detailing

Semi-balloon framing:

- Incorporates floor framing hanging from top plates
- Floor framing/rim joist doesn't contribute to shrinkage



Non-standard stud lengths and increased hardware requirements should be considered

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

Wood Framing & Veneer:

- Veneer Type Transitions
- Openings (Sill, Head, Jambs)

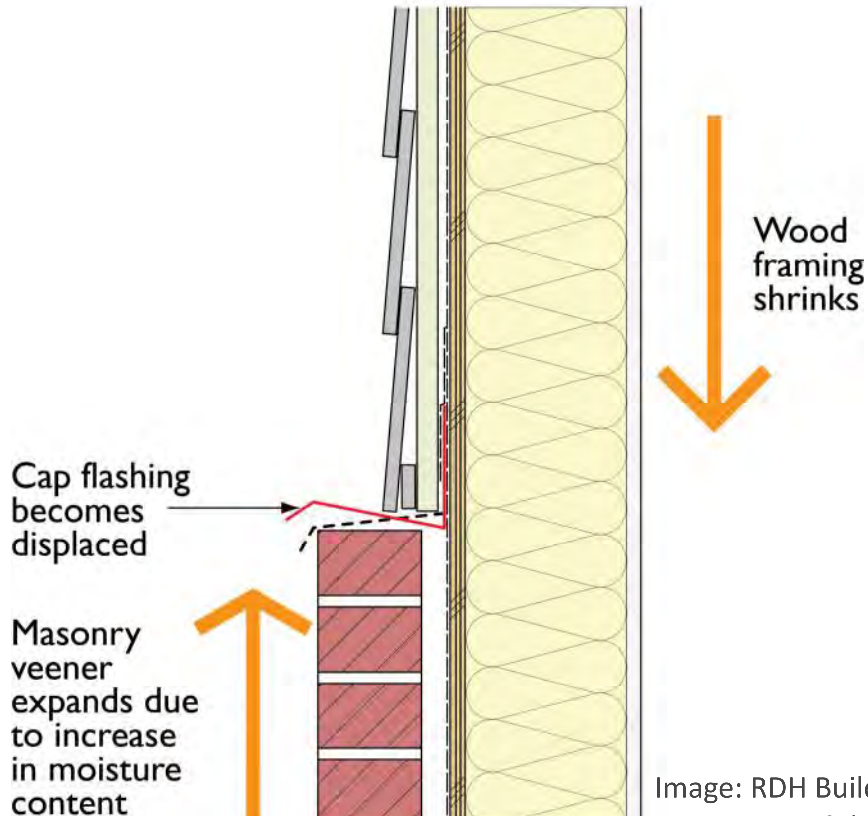


Image: RDH Building Science

Differential Movement – Veneer Transition

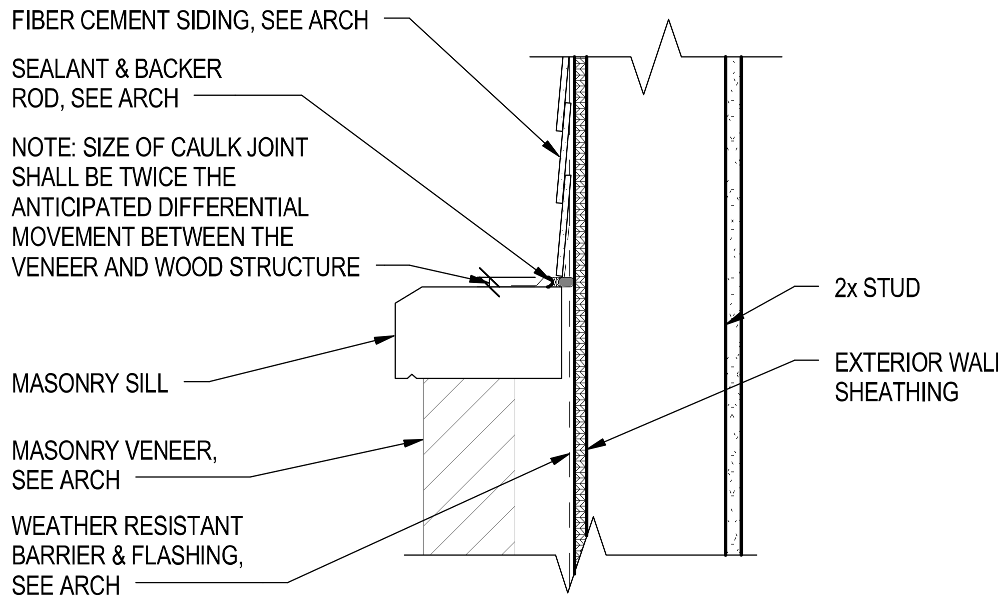
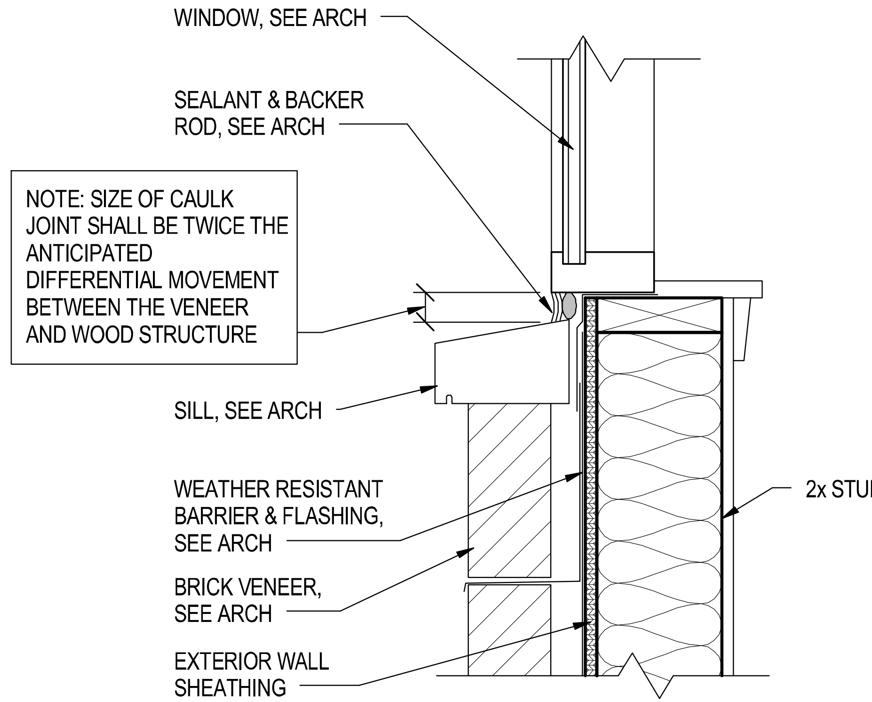


Image: Schaefer

Differential Movement – Veneer Opening



Images: Schaefer

Differential Movement - MEP

MEP main runs often start at base or top of structure, extend throughout height, with horizontal tees at each floor.

Horizontal tees often installed in wood stud partitions

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

Image: Louisiana-Pacific Corporation

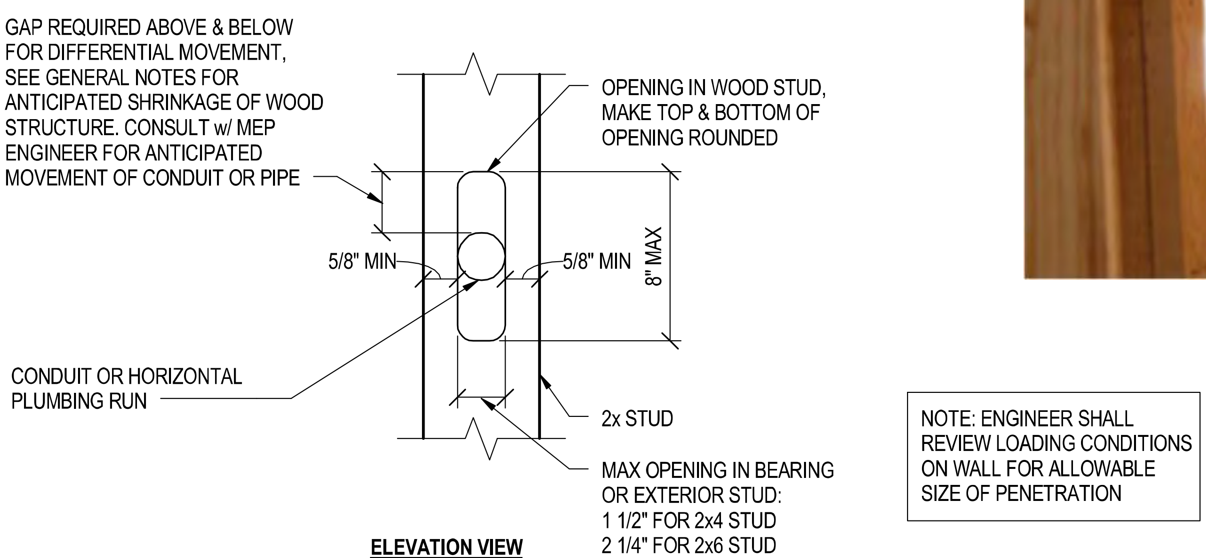


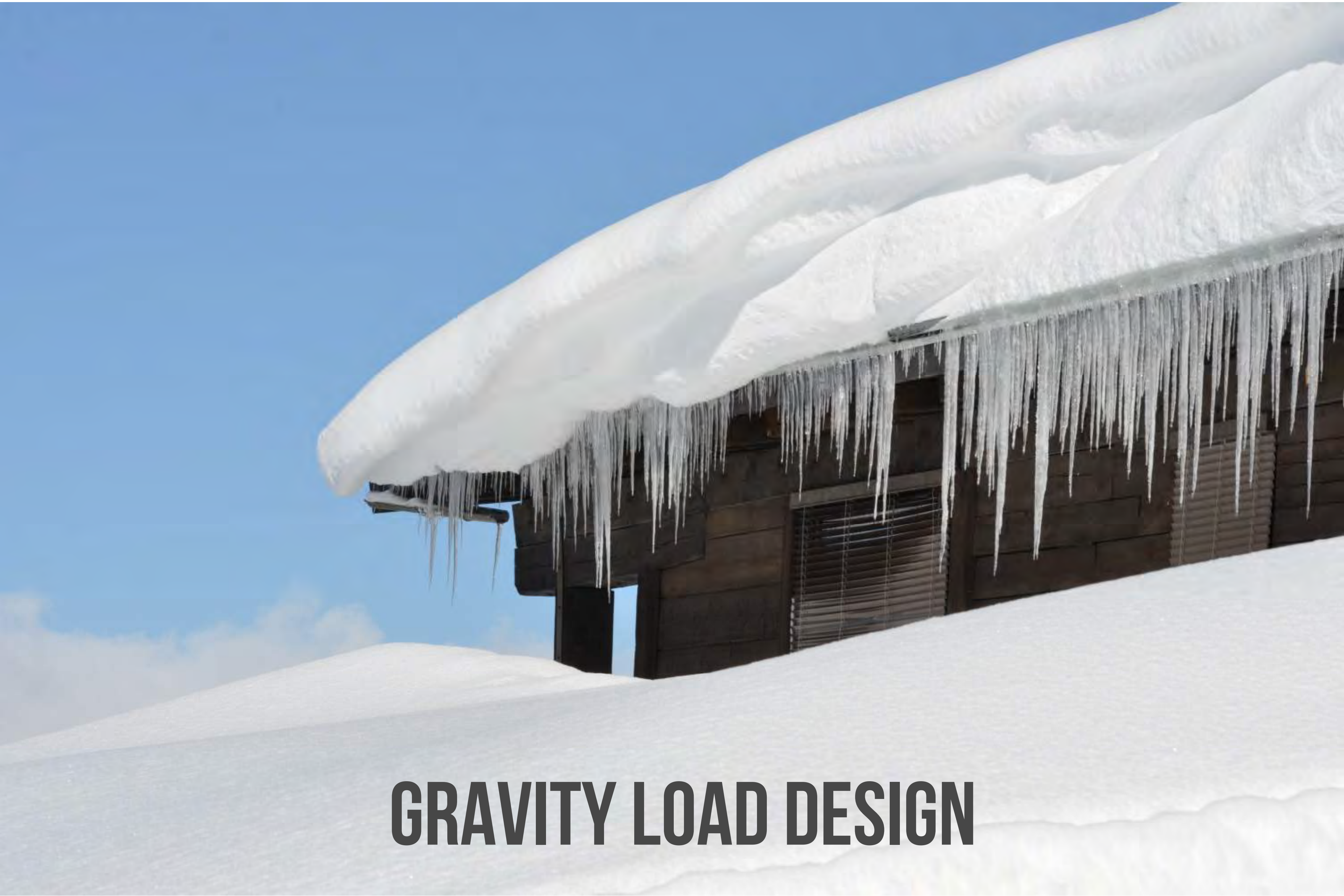
Image: Schaefer

Oval cutout options for Horizontal Pipe

Differential Movement - MEP

A variety of expansion or slip joint connectors are available – allow vertical MEP runs to move with the wood structure

Vertical Stacks – Compensation Devices Installed

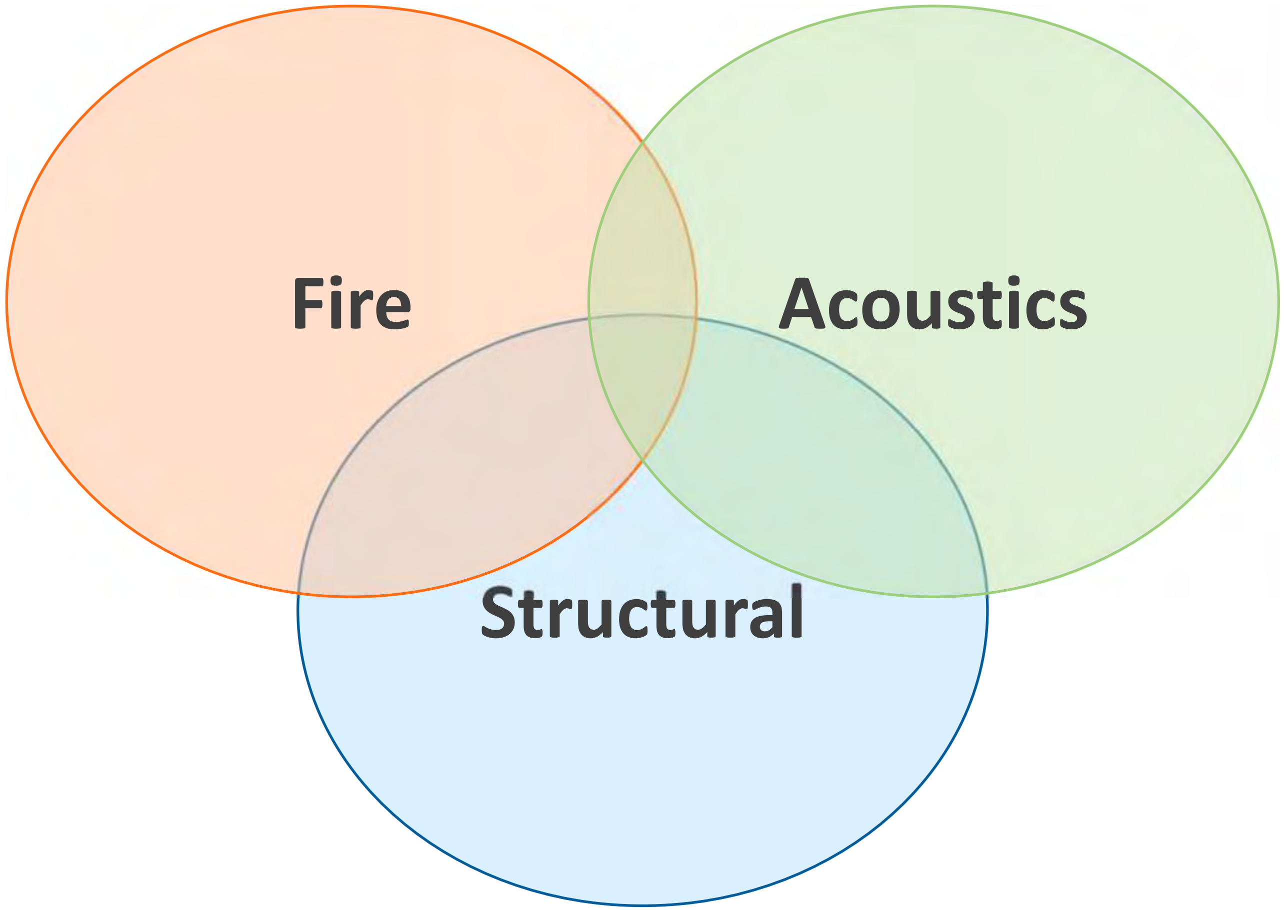


GRAVITY LOAD DESIGN

Multi-Family Gravity Design

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

- **Floor Framing Design**
  - **Vibration & Acoustics**
- **Wall Design**
  - **Bearing versus Non-Bearing**


Fire
Acoustics
Structural

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 & analysis

TABLE 1604.3
DEFLECTION LIMITS[a, b, c, h, i]

CONSTRUCTION	L	S or W^f	$D + L^{d, g}$
Roof members:[e]			
Supporting plaster or stucco ceiling	l/360	l/360	l/240
Supporting nonplaster ceiling	l/240	l/240	l/180
Not supporting ceiling	l/180	l/180	l/120
Floor members	l/360	—	l/240
Exterior walls and interior partitions:			
With plaster or stucco finishes	—	l/360	—
With other brittle finishes	—	l/240	—
With flexible finishes	—	l/120	—
Farm buildings	—	—	l/180
Greenhouses	—	—	l/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). http://www.forestprod.org/buy_publications/wood_design_focus_past_articles.php#volume5

Structural Floor Design - Vibration

IS A "SPRING IN YOUR STEP" CAUSING PROBLEMS?

June 2007 » Feature Article

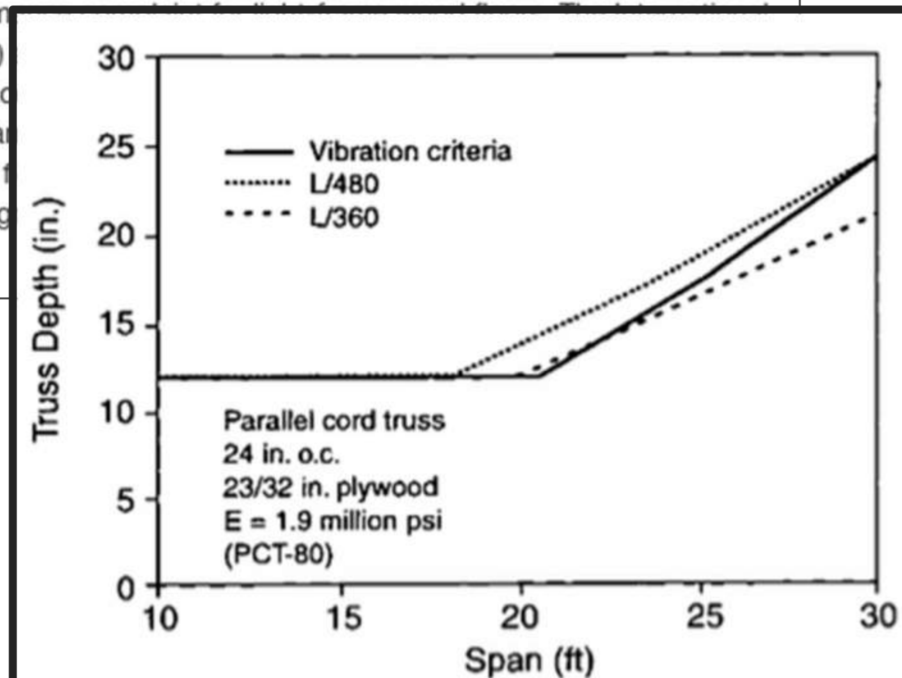
Annoying vibration is probably the most common performance complaint for light-frame wood floors.

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 perform
Code Council's 2006 International Residential Code (IRC)
this issue, yet the engineer-of-record for a project may fac
engineer may be engaged to determine the cause of an a
under the prescriptive provisions of the IRC. While wood f
deserves attention by the design professional at the desig
impossible to fix.

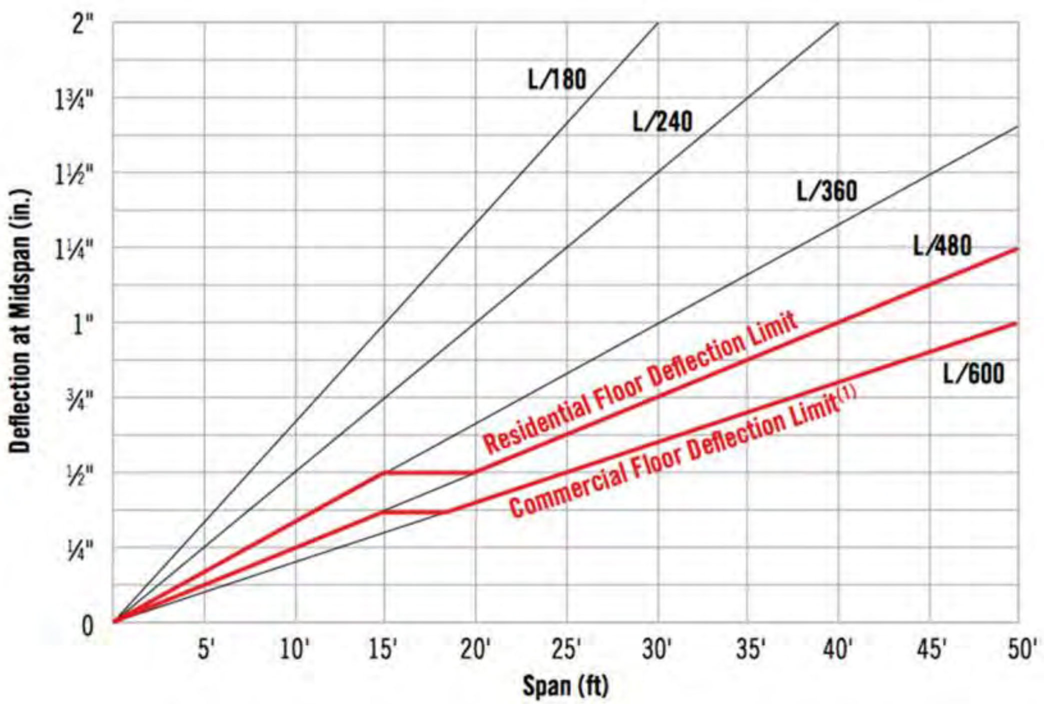
$$f = 1.57\sqrt{\frac{386EI}{WL^3}} \qquad \text{(Equation 1)}$$



Floor Design: Occupant Comfort

Vibration & Deflection Control

Multi-family floor spans in the 24’-30’ range work well from a layout perspective. Floor design of wood members in this span range are often governed by vibration and/or deflection control, not structural capacity.

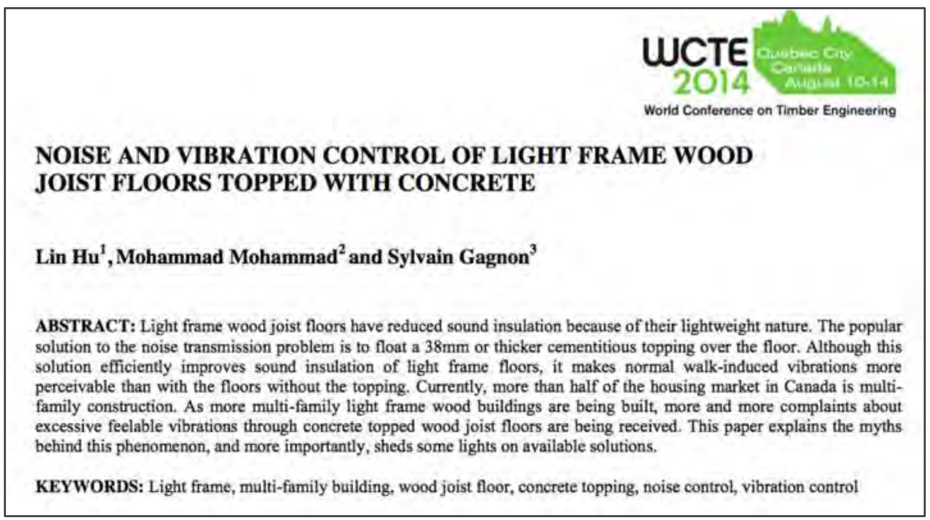


Live Load Deflection Chart, Courtesy: Redbuilt

Floor Design: Occupant Comfort

Tools available to designers

Vibration Analysis: FP Innovations (Spreadsheet available upon request)



WCTE 2014 Quebec City Canada August 10-14

World Conference on Timber Engineering

NOISE AND VIBRATION CONTROL OF LIGHT FRAME WOOD JOIST FLOORS TOPPED WITH CONCRETE

Lin Hu[1], Mohammad Mohammad[2] and Sylvain Gagnon[3]

ABSTRACT: Light frame wood joist floors have reduced sound insulation because of their lightweight nature. The popular solution to the noise transmission problem is to float a 38mm or thicker cementitious topping over the floor. Although this solution efficiently improves sound insulation of light frame floors, it makes normal walk-induced vibrations more perceivable than with the floors without the topping. Currently, more than half of the housing market in Canada is multi-family construction. As more multi-family light frame wood buildings are being built, more and more complaints about excessive feelable vibrations through concrete topped wood joist floors are being received. This paper explains the myths behind this phenomenon, and more importantly, sheds some lights on available solutions.

KEYWORDS: Light frame, multi-family building, wood joist floor, concrete topping, noise control, vibration control

Joist Manufacturer's Rating Systems

What methods exist for checking floor vibration of light-frame wood structures?

http://www.woodworks.org/ask-an-expert/

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.

View All Expert Tips

Project Assistance

Our technical experts offer free projec support from design through construction, on issues ranging from allowable heights and areas to structural design, lateral systems and fire- or acoustical-rated assemblies.

Get Assistance >

Ask an Expert

Q: When is blocking/bracing within wood-frame walls required? What is considered adequate bracing for wooc wall studs in their weak axis?

A: Wood studs used in light-frame wal construction may require horizontally-oriented blocking for a number of reasons—including blocking at shear panel edges, fire blocking, and buckling restraint when subject to axi loads. Structural Blocking Purposes Blocking to Reduce Stud Slenderness Ratio Section 3

- Learn More

Have a question? Email Us >

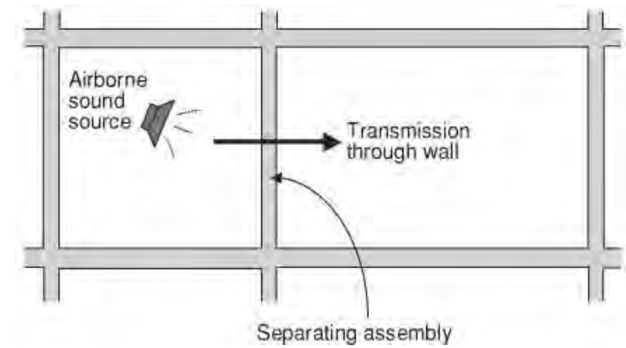
Feature Project

Acoustical Design

<u>Air-Borne Sound</u>: Sound Transmission Class (STC)

Measures how effectively an assembly isolates air-borne sound and reduces the level that passes from one side to the other

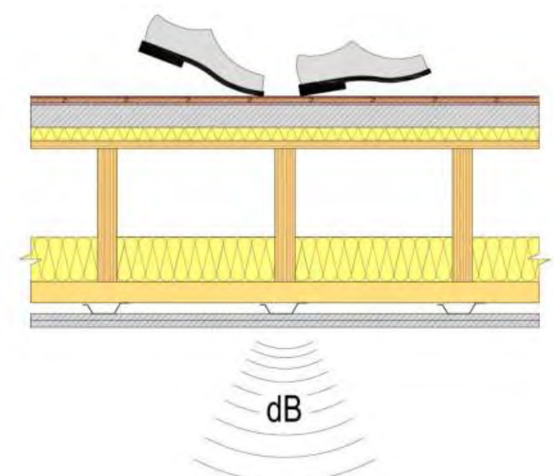
Applies to walls and floor/ceiling assemblies



<u>Structure-borne sound</u>: Impact Insulation Class (IIC)

Evaluates how effectively an assembly blocks impact sound from passing through it

Only applies to floor/ceiling assemblies



Acoustical Criteria – IBC 1206

Code requirements only address residential occupancies:

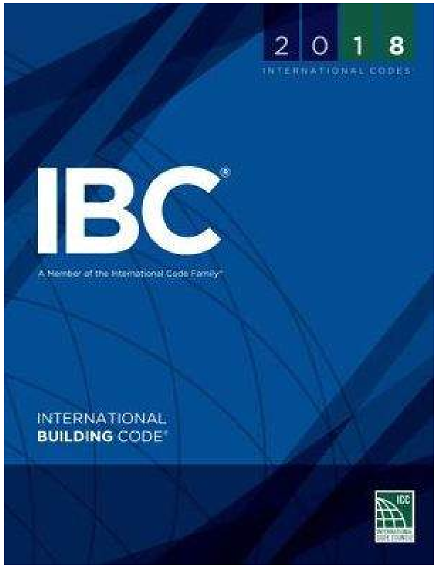
For unit to unit or unit to public or service areas:

Min. STC of 50 (45 if field tested):

- Walls, Partitions, and Floor/Ceiling Assemblies

Min. IIC of 50 (45 if field tested) for:

- Floor/Ceiling Assemblies



Choosing Acoustically Rated Assemblies

Common tested assemblies:

STC: ASTM E90, per IBC 1206.2

IIC: ASTM E492, per IBC 1206.3

- Manufacturers of gypsum, insulation, acoustical products (proprietary tests)
- UL Listings
- Gypsum Catalog
- Industry associations: AWC, APA, others
- Reach out to **WoodWorks**!

Alternate Method: IBC 1206.2 & 1206.3

- Both STC and IIC may be "established by engineering analysis based on a comparison of floor-ceiling assemblies having [STC/IIC] ratings as determined by the test procedures."

Acoustical Detailing

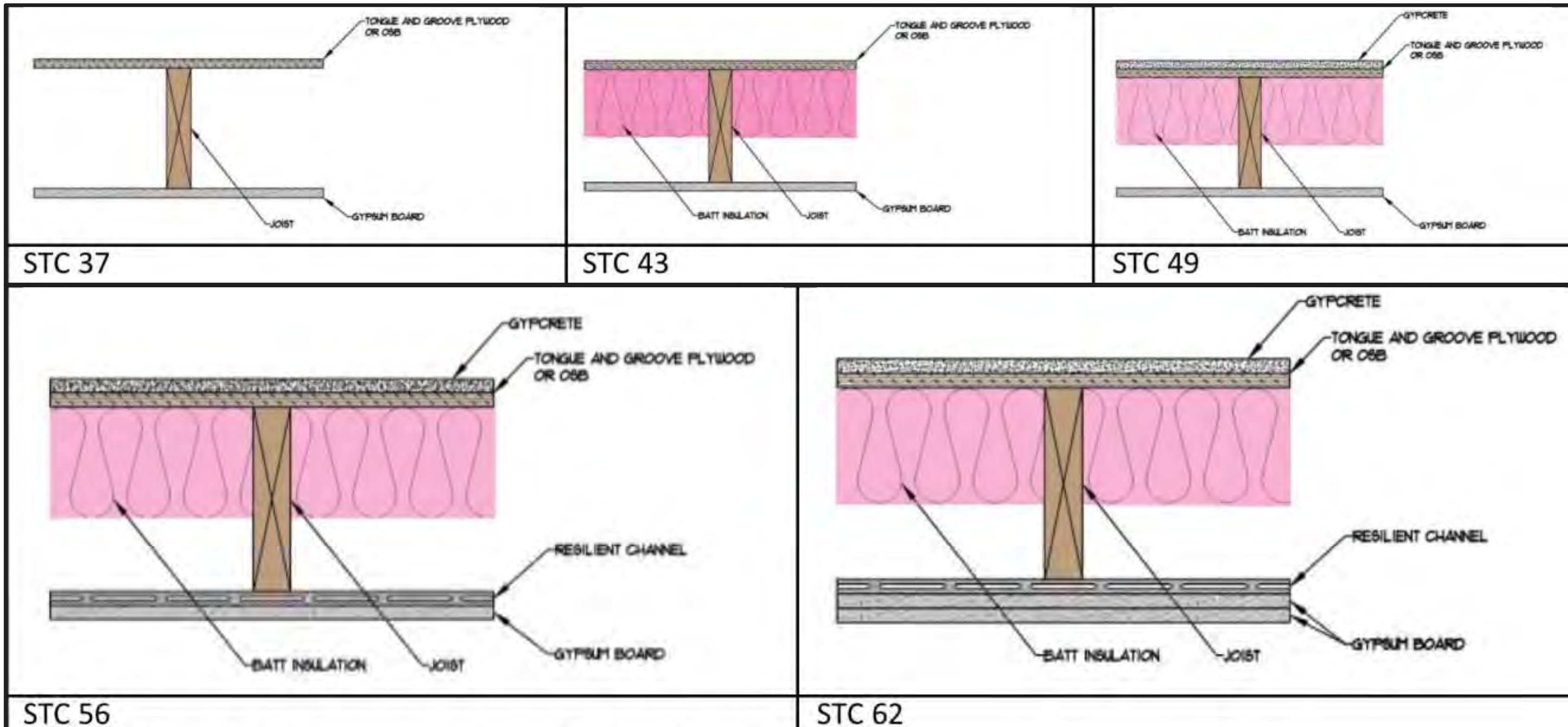


Figure 1 - Acoustical Progression in Wood Framed Floor / Ceilings


WALL DESIGN

Exterior Wall – Bearing vs. Non Bearing

Non loading-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:

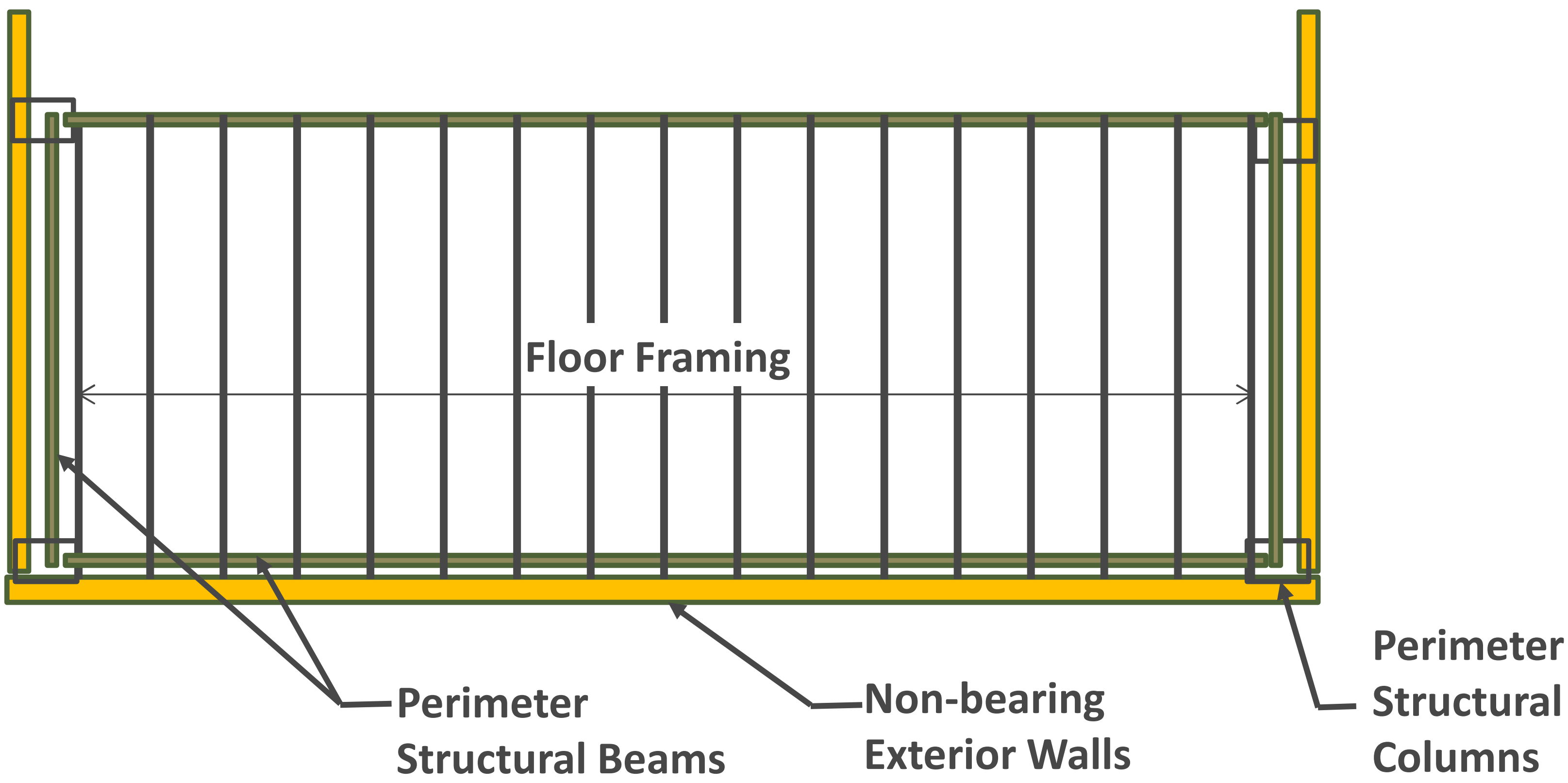
1. Any metal or wood stud wall that supports more than 100 pounds per linear foot (1459 N/m) of vertical load in addition to its own weight.

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

Exterior Walls – Bearing vs. Non-Bearing

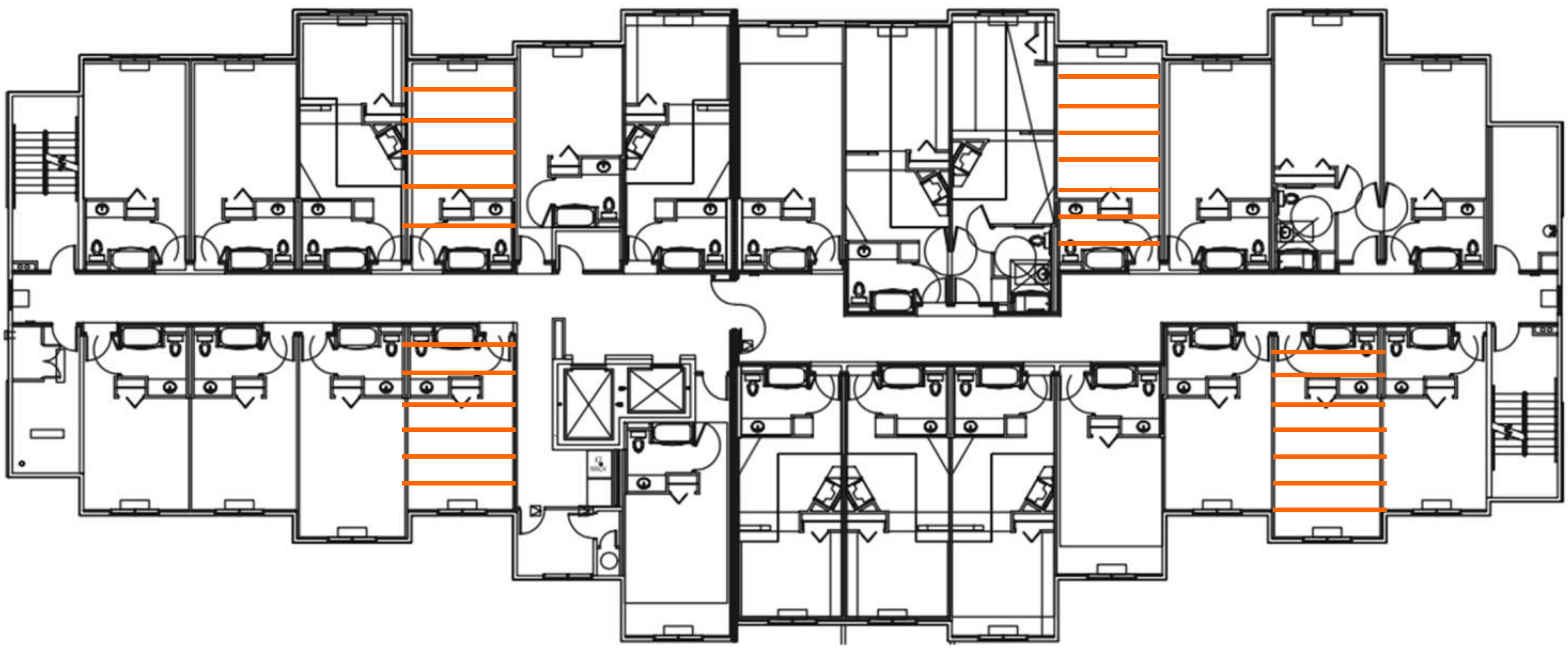
Utilization of structural beams in-board or directly over exterior walls can make walls non-bearing and reduce required fire resistance rating to 1 HR or 0 HR (IBC Table 602)

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



Exterior Walls – Bearing vs. Non-Bearing

- If framing parallel to long exterior walls is possible, minimizes area of load bearing <u>exterior</u> walls
- Alternatively, framing from corridor to exterior wall may reduce length of load bearing walls & associated fire resistance ratings



Bearing Wall Studs: Stacking Loads

In mid-rise structures, bearing wall loads accumulate – may result in increased stud requirements at lower levels

Example: 5 Story Building, Exterior Bearing Wall Supports 28' Span Trusses

Roof: DL = 20 psf, SL = 40 psf
Floor: DL = 30 psf, LL = 40 psf
Wall: DL = 10 psf

Total Bearing Wall Load at Lowest Level = 4650 plf or 6200 lbs per stud @ 16" o.c.

May need 2-2x6 studs @ 16" o.c.

Bearing Wall Studs: Stacking Loads

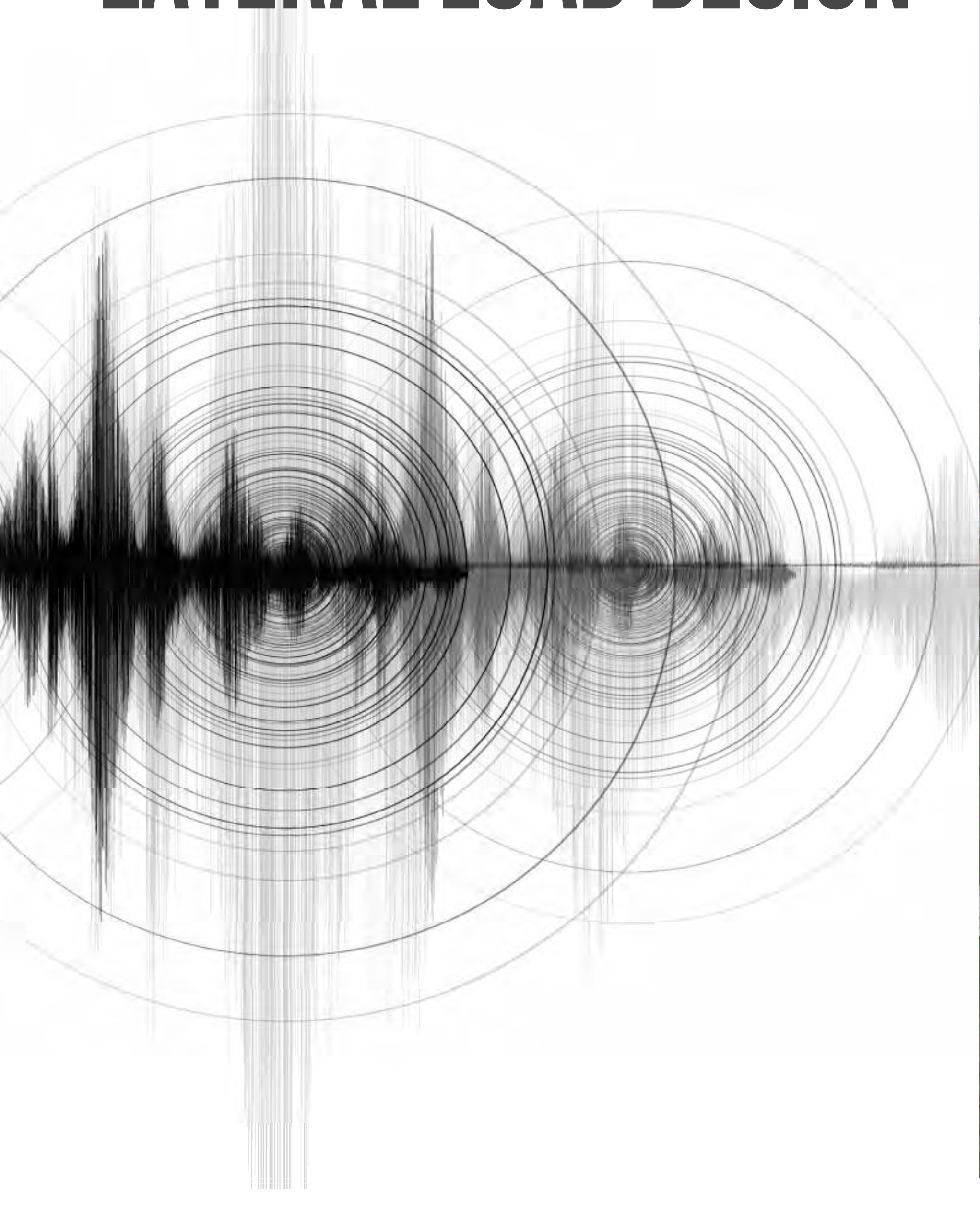
Options for lower level, stacked bearing wall studs:

- Specify SP or DF plates – up to 40% increase in allowable loads
  - Fc perp= 565 psi to 625psi
- 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

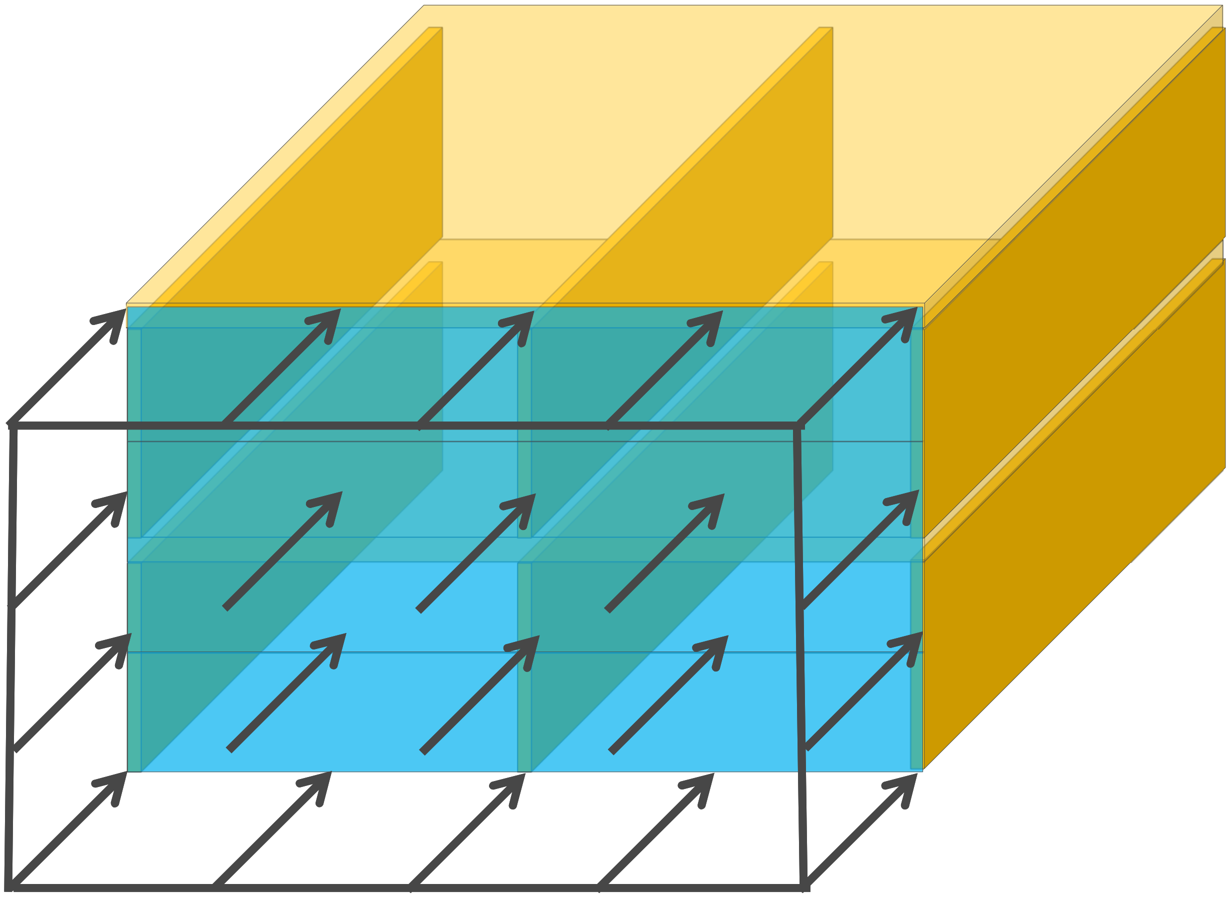
Bearing Wall Studs: Stacking Loads

If Type III Exterior Walls:
Include FRT capacity reduction for Fc perp on wall plates
Manufacturers reduction values can vary between 5% and 13%

LATERAL LOAD DESIGN

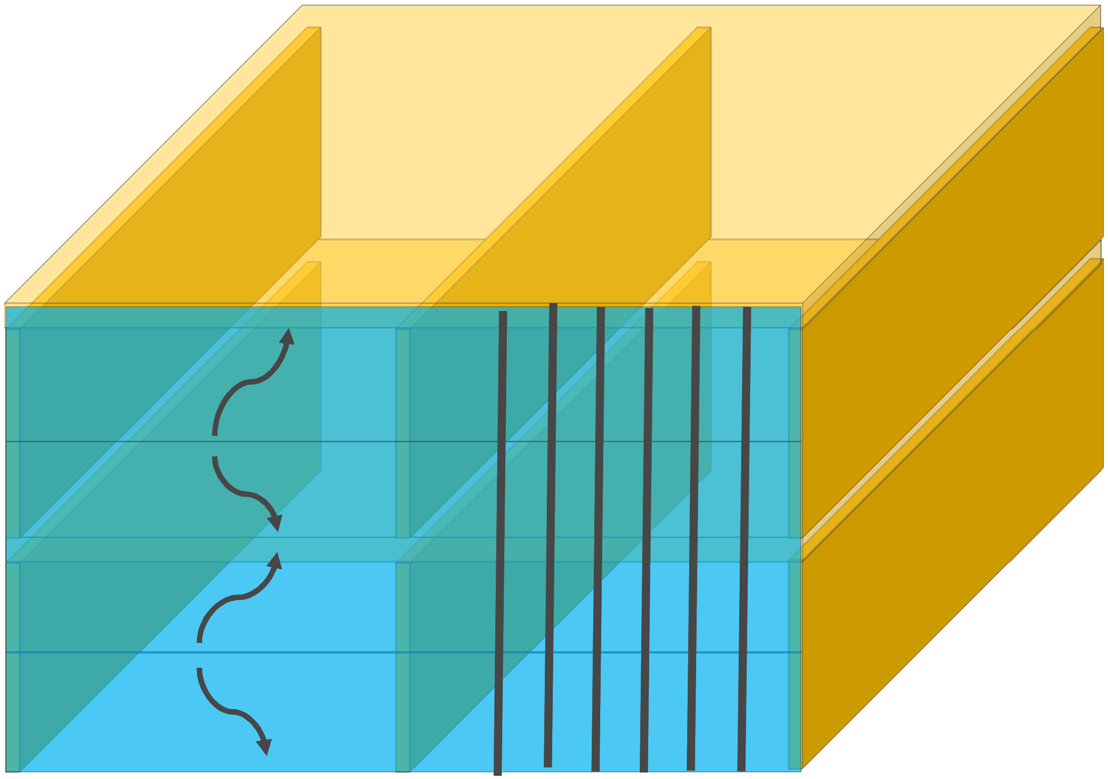


Multi-Story Wind Load Design



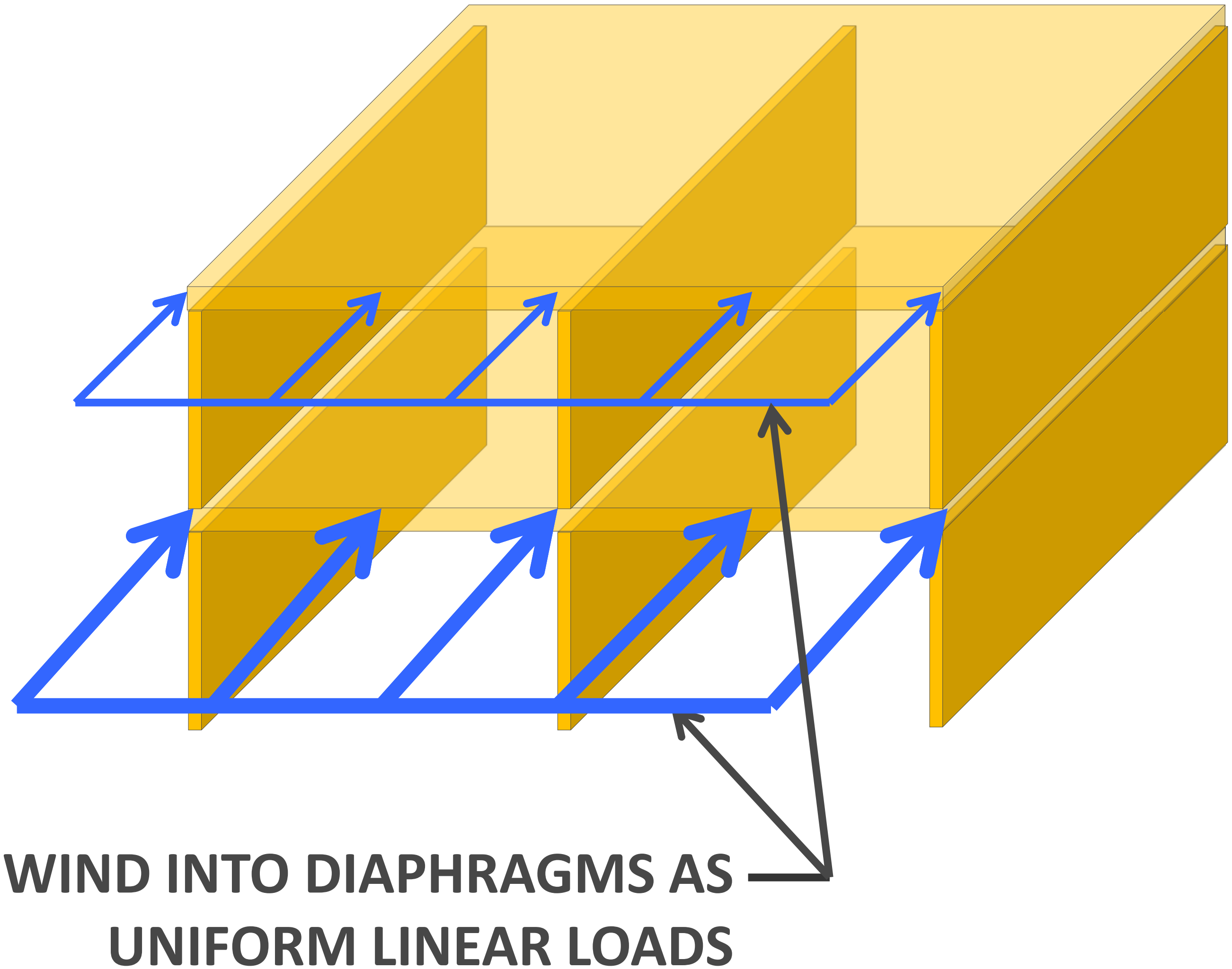
**WIND SURFACE
LOADS ON WALLS**

Multi-Story Wind Load Design

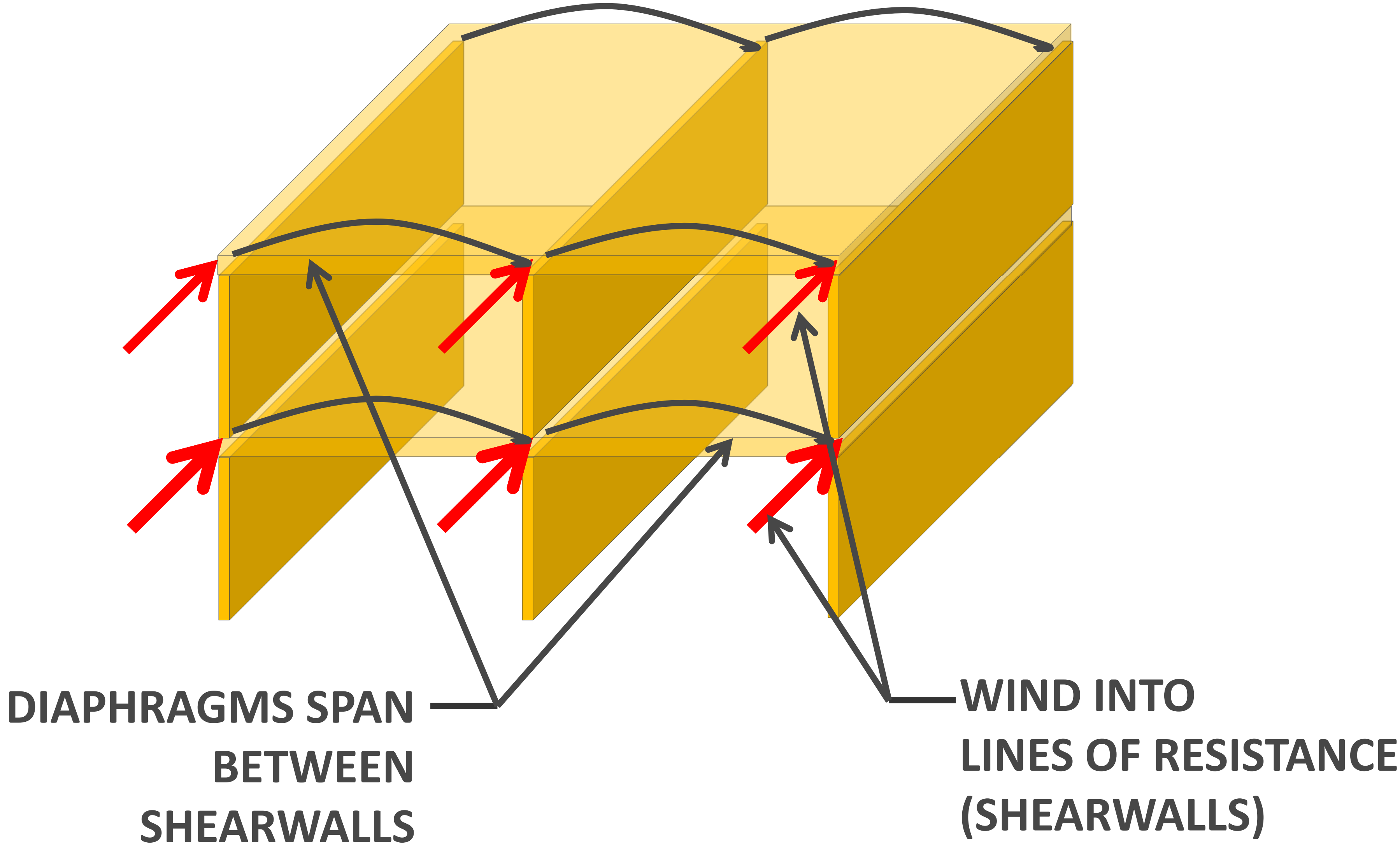


STUDS RESIST SURFACE LOADS IN BENDING, STUD REACTIONS DISTRIBUTE SURFACE LOADS TO DIAPHRAGMS

Multi-Story Wind Load Design

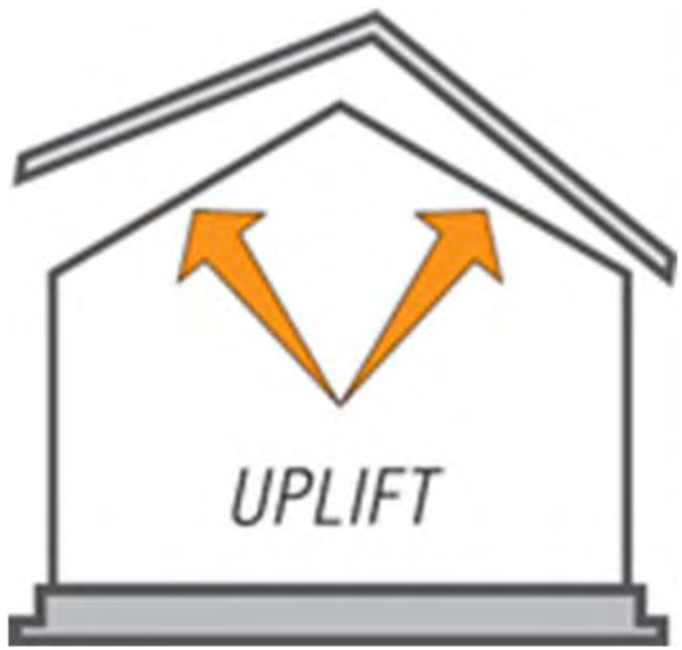


Multi-Story Wind Load Design



Uplift Wind Loads

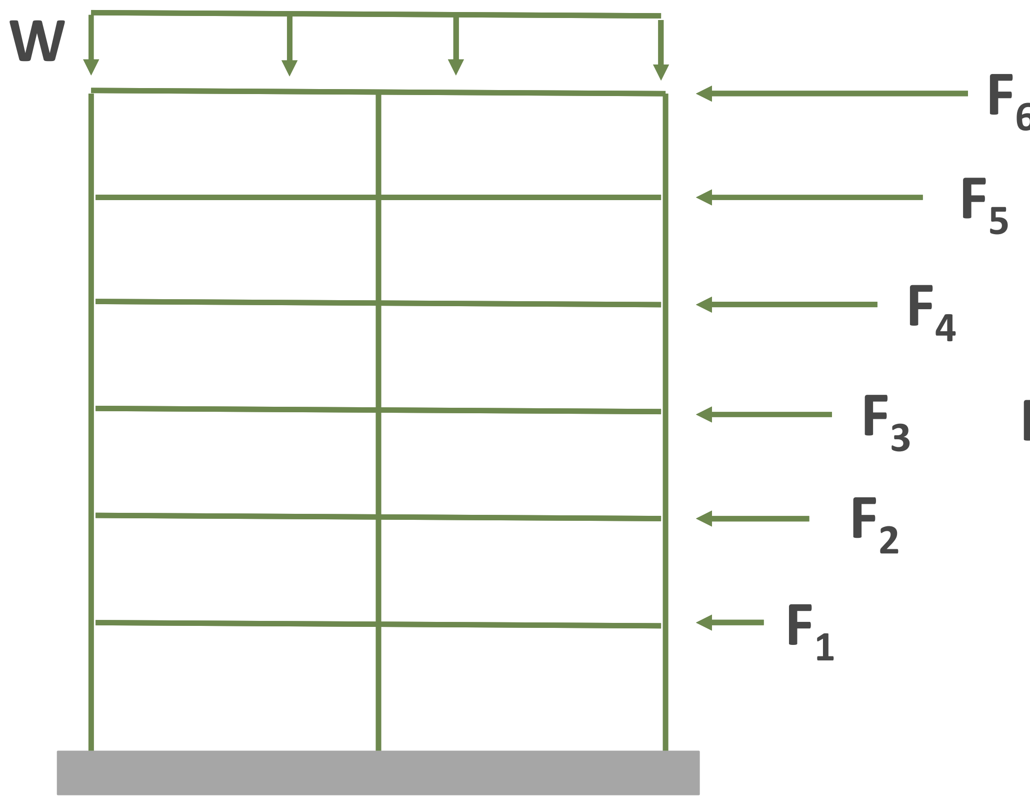
Uplift – Outward (suction) force acting on roof



Load path - roof to foundation required unless dead load is greater than uplift

Multi-Story Seismic Load Design

SEISMIC FORCES A FUNCTION OF STRUCTURE MASS, SITE SPECIFIC COEFFICIENTS (BASED ON SOIL PROPERTIES), IMPORTANCE FACTOR

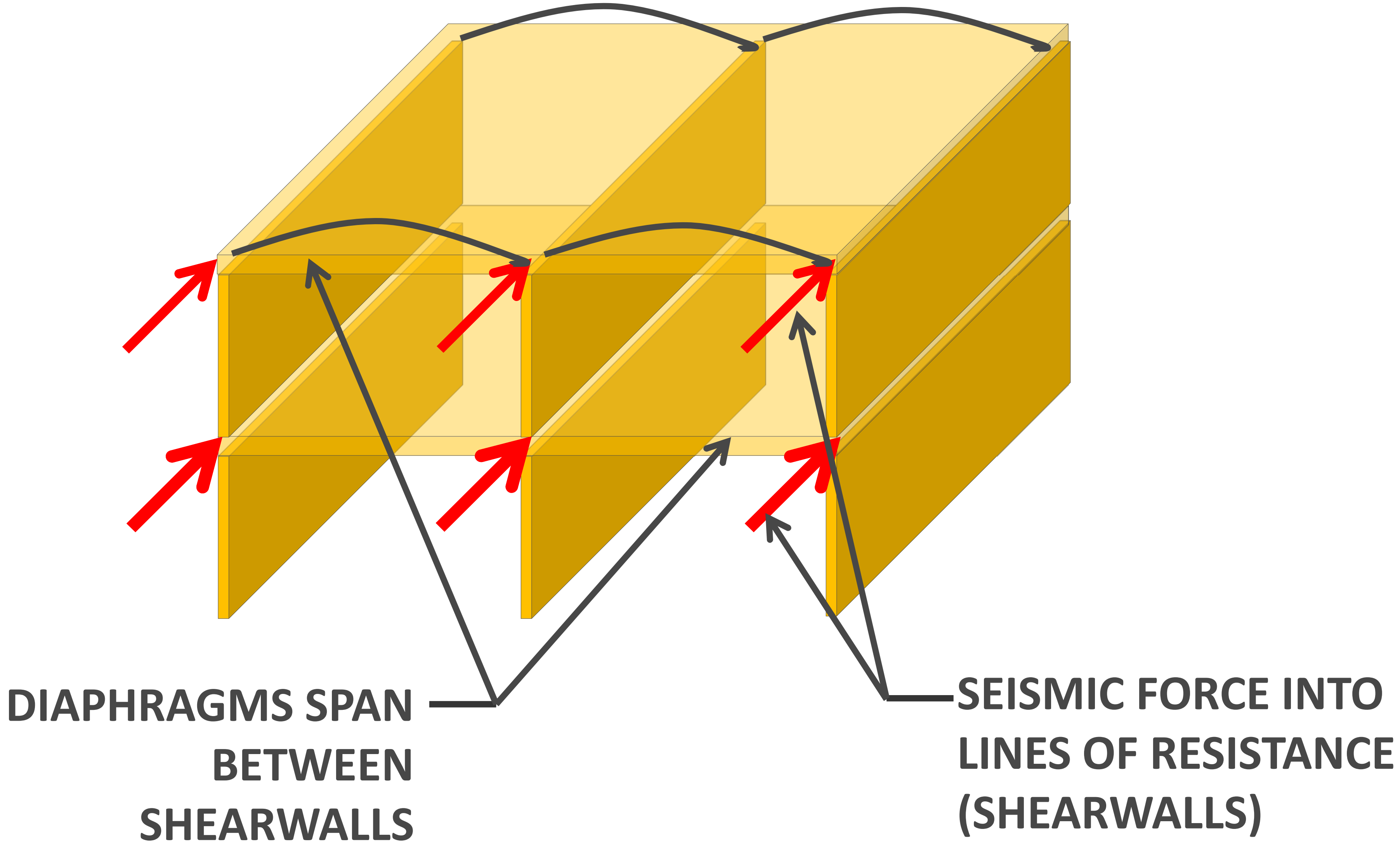


$F_x = C_{vx} * V$

ASCE 7-16 Eq. 12.8-1
& Eq. 12.8-11

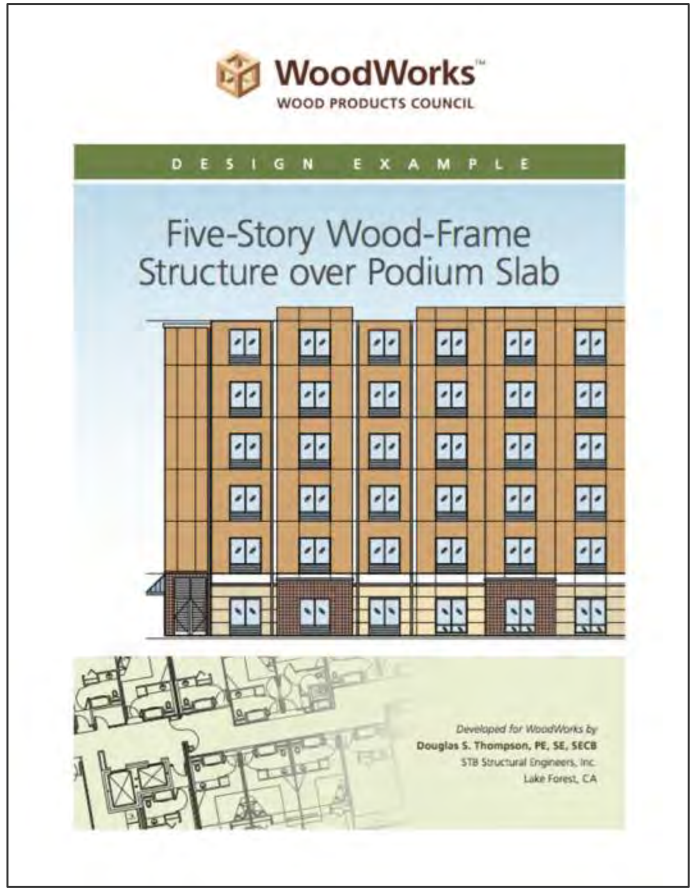
SEISMIC BASE SHEAR → $V = C_S * W = \Sigma F$

Multi-Story Seismic Load Design



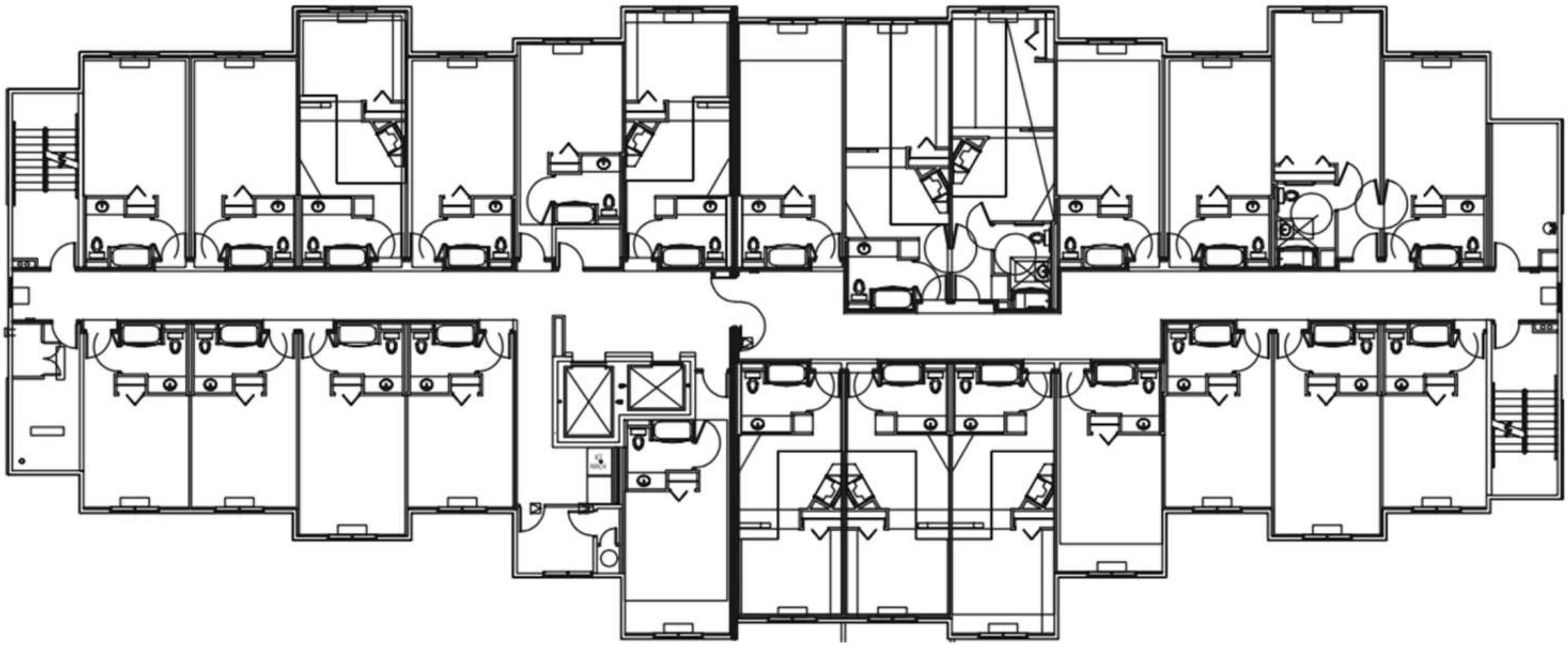
Design Example: Five Over One Wood Frame

Covers lateral design approaches, seismic emphasis



Free download at woodworks.org

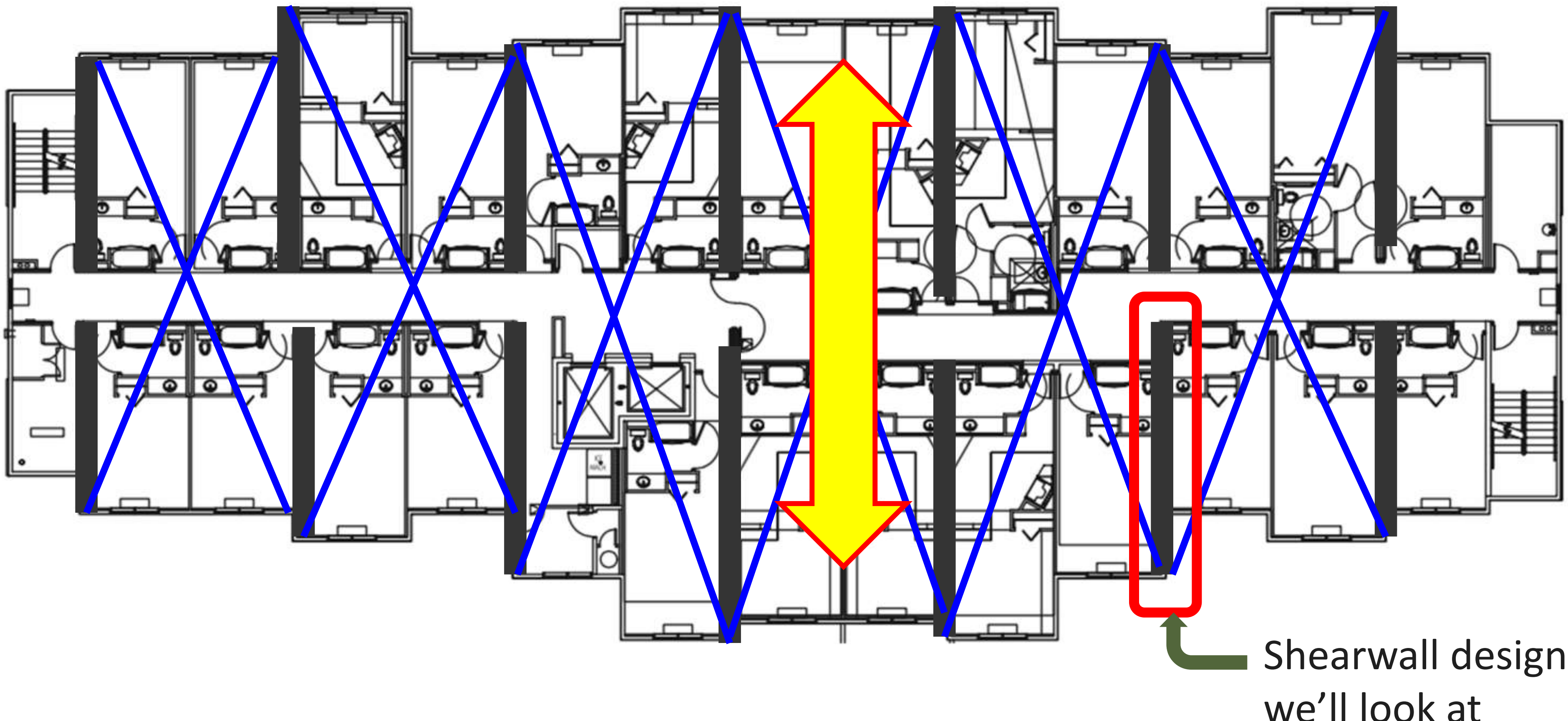
Multi-Story Lateral Design



Floor Plan

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example

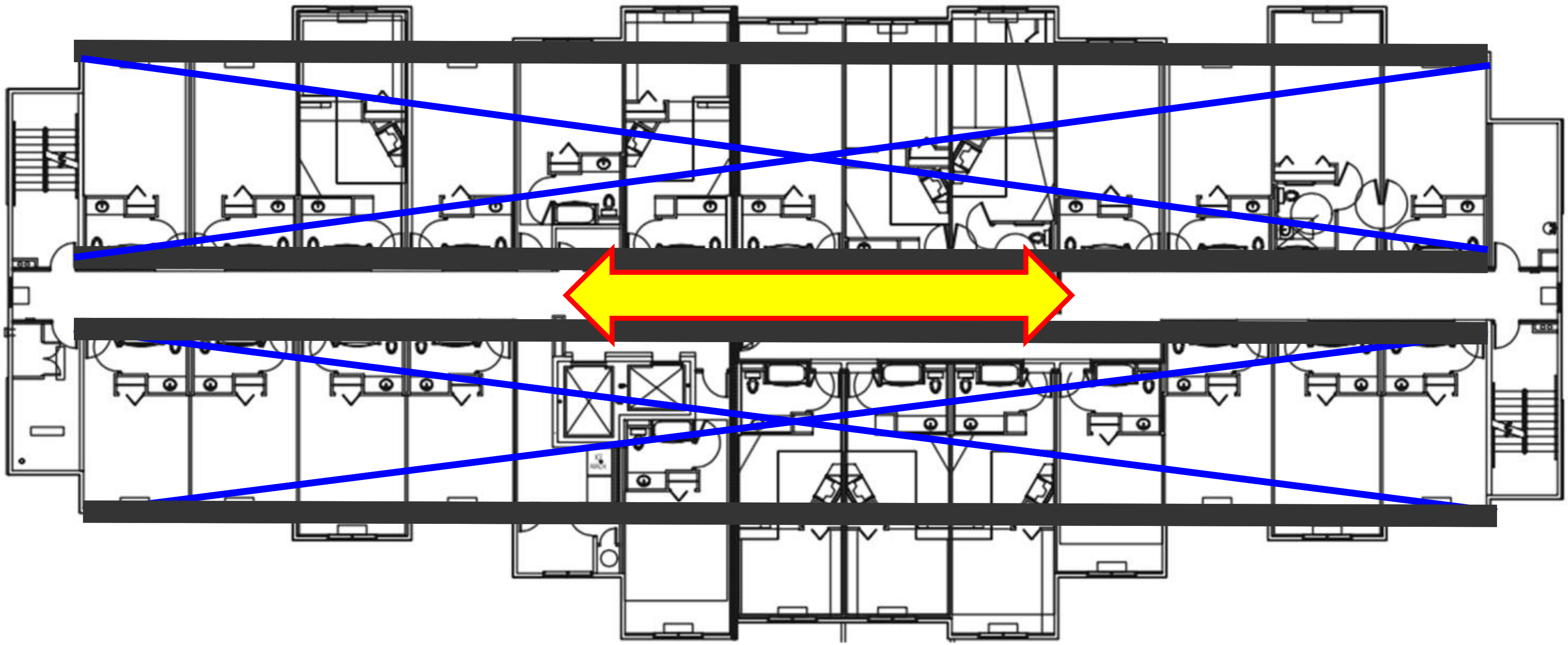
Multi-Story Lateral Design



Shearwall Layout

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example

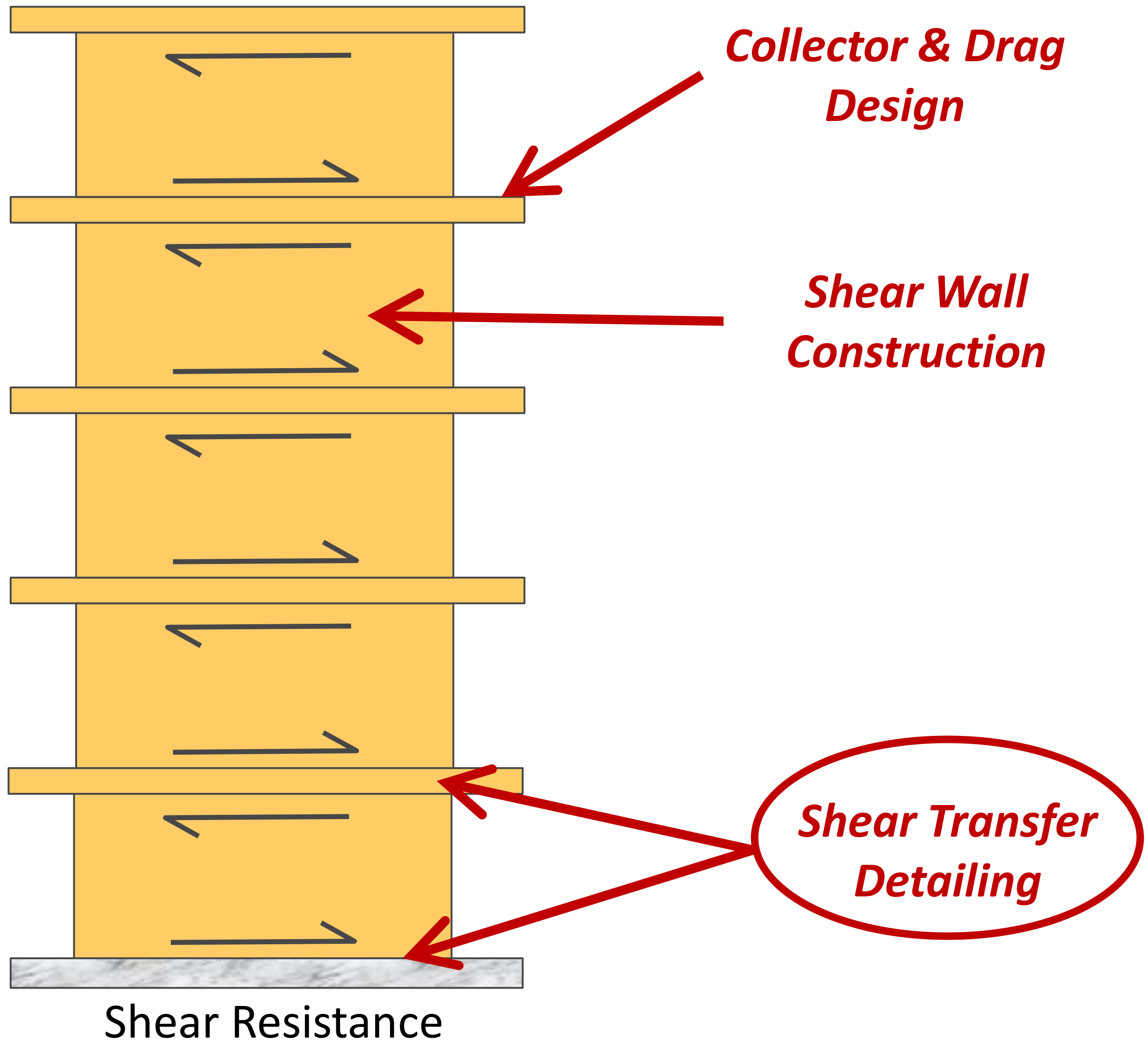
Multi-Story Lateral Design



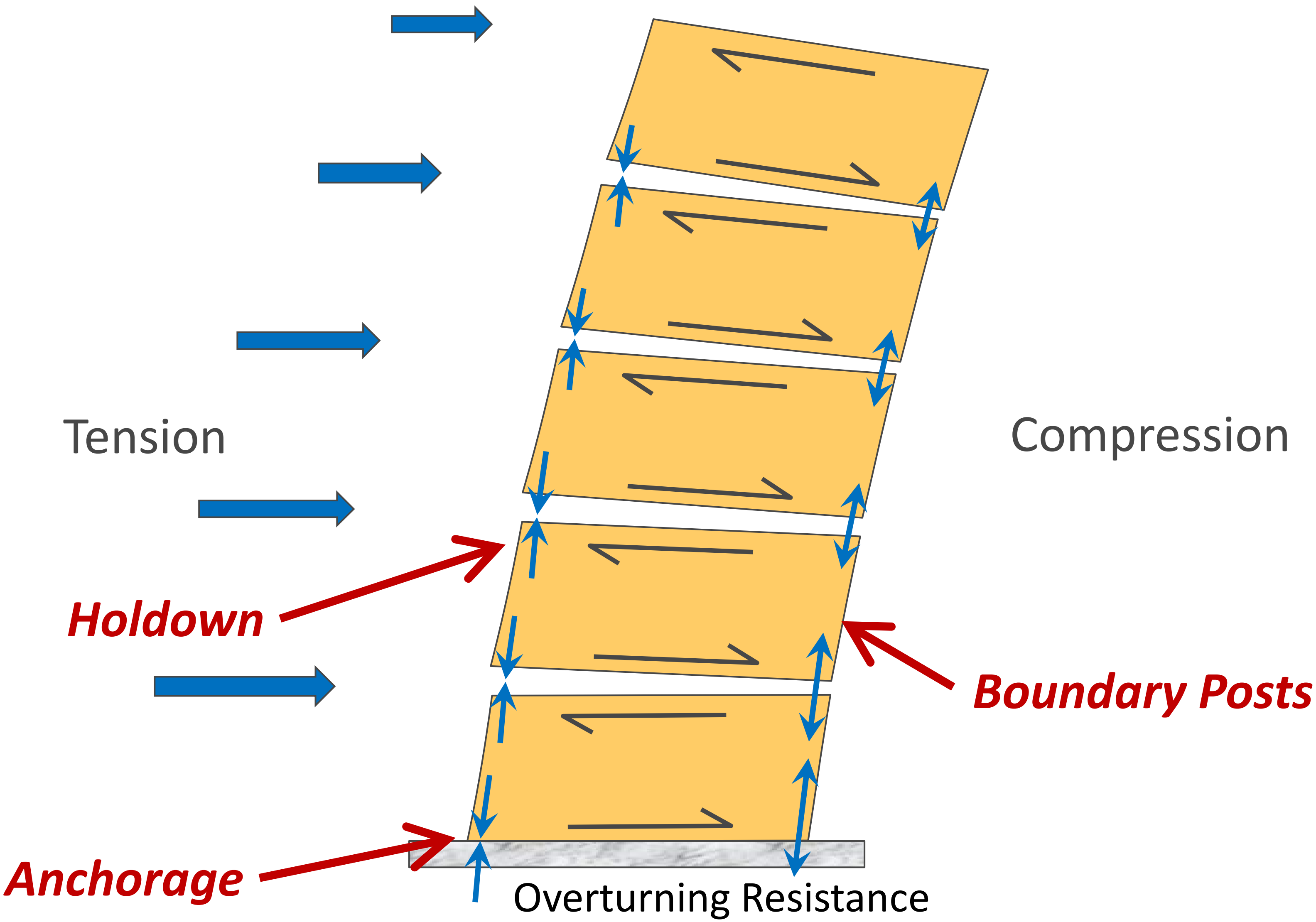
<u>Shearwall Layout</u>

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example

Components of Shear Wall Design

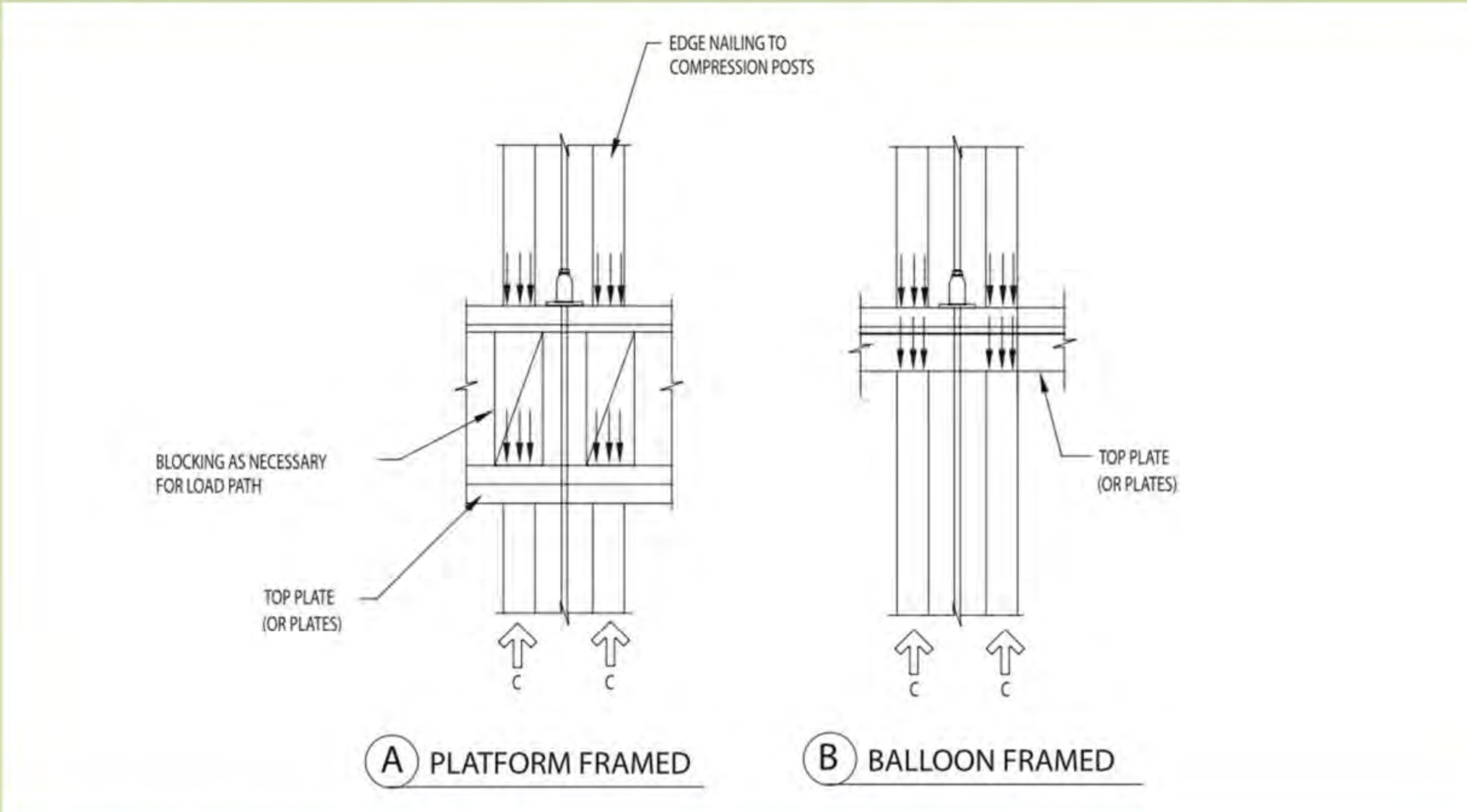


Components of Shear Wall Design



Story to Story Compression Force Transfer

Figure 13. *Load Transfer from Compression Posts to Compression Posts*

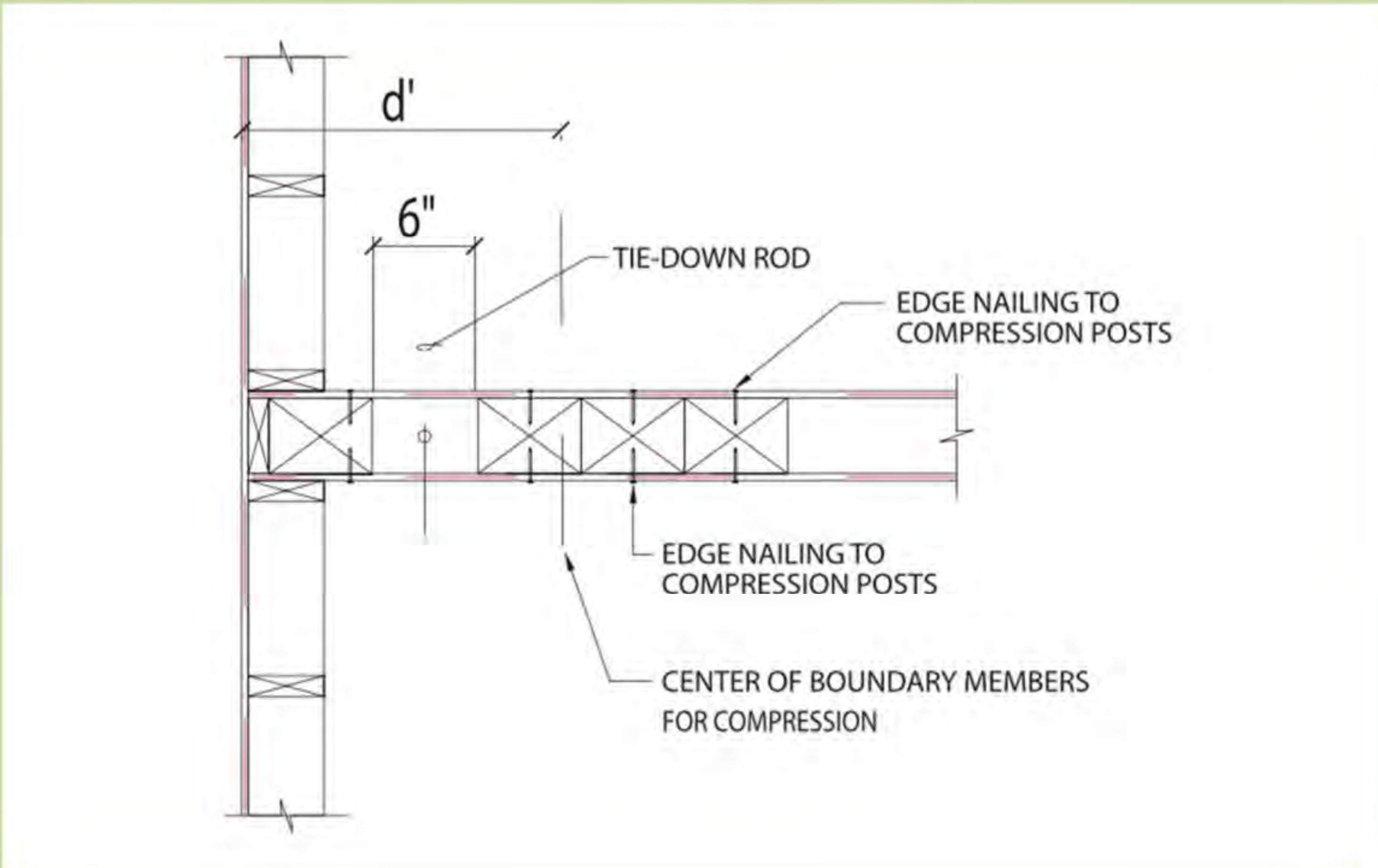


Notes for Figure 13:
Detail A (at platform framed) may have a single block with a drilled hole for the tie-down rod (see Figure 15).

Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example

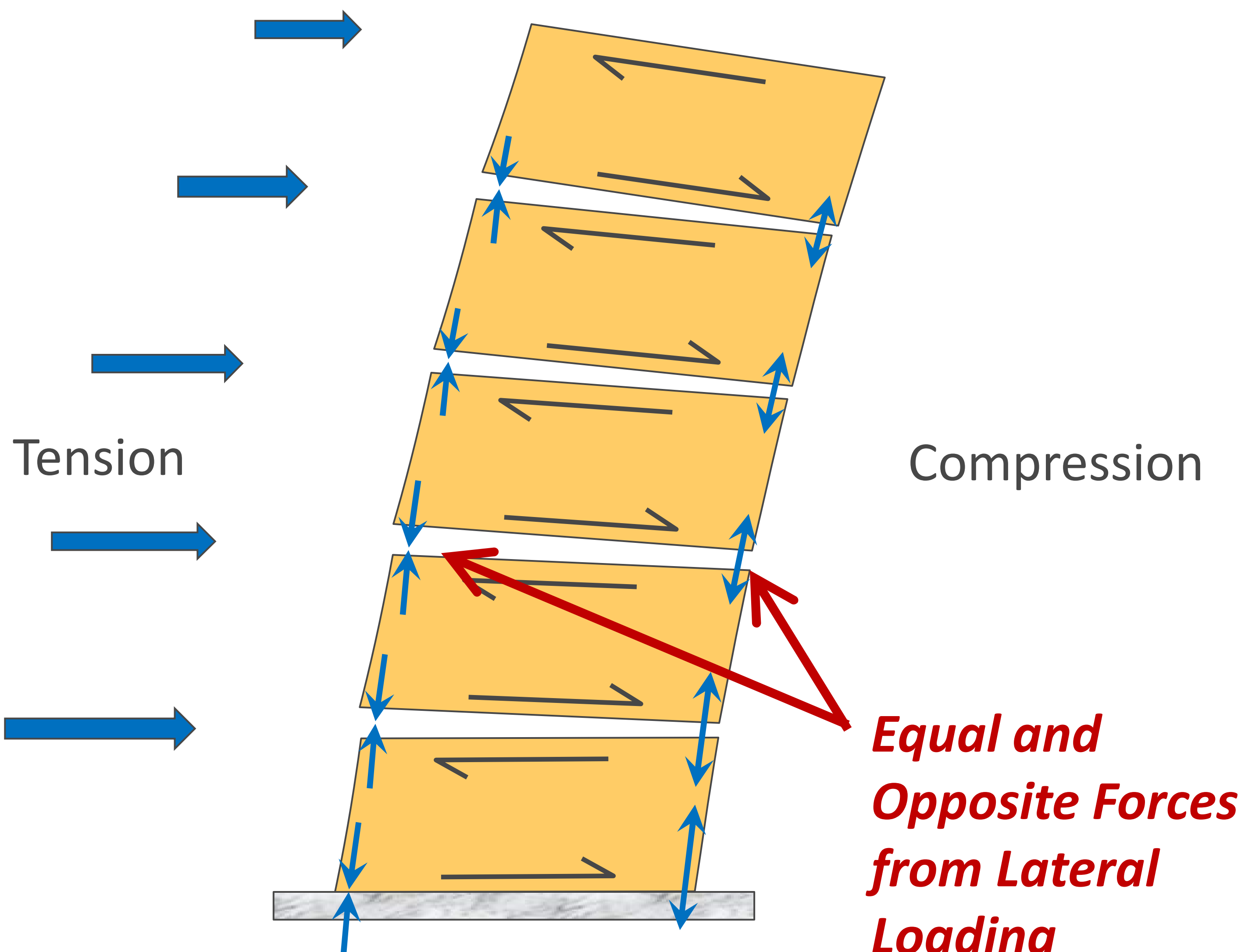
Increasing Compression Post Size

Figure 10. *Example Plan Section at Boundary Members*



Source: WoodWorks Five-Story Wood-Frame Structure over Podium Slab Design Example

Overturning Tension

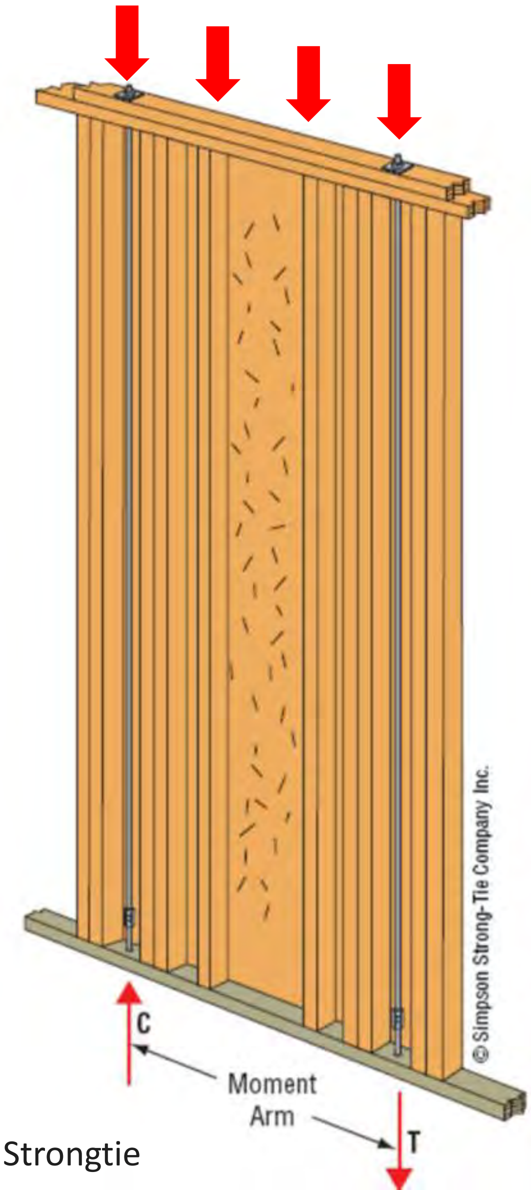


Using Dead Load to Resist Overturning

ASD Load Combinations of ASCE 7-16:

<u>0.6D</u> + 0.6W

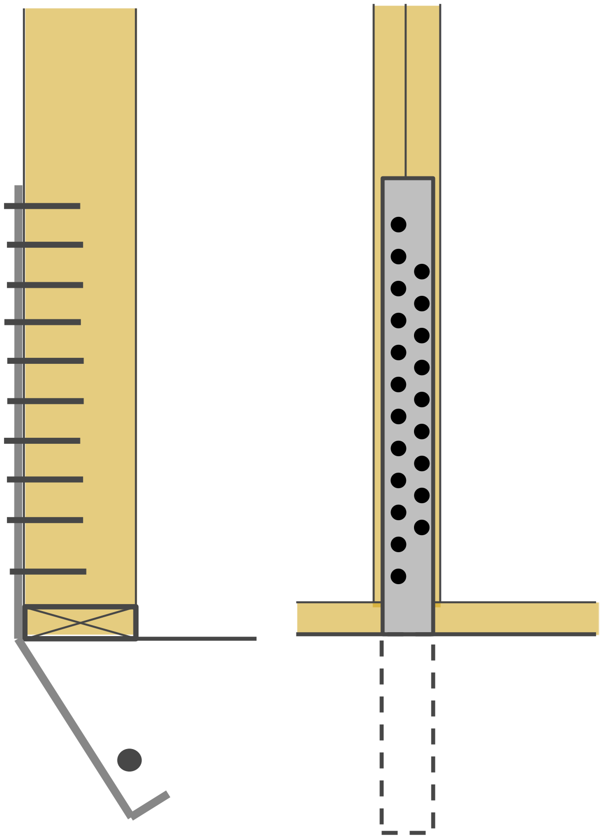
<u>0.6D</u> + 0.7E



Source: Strongtie

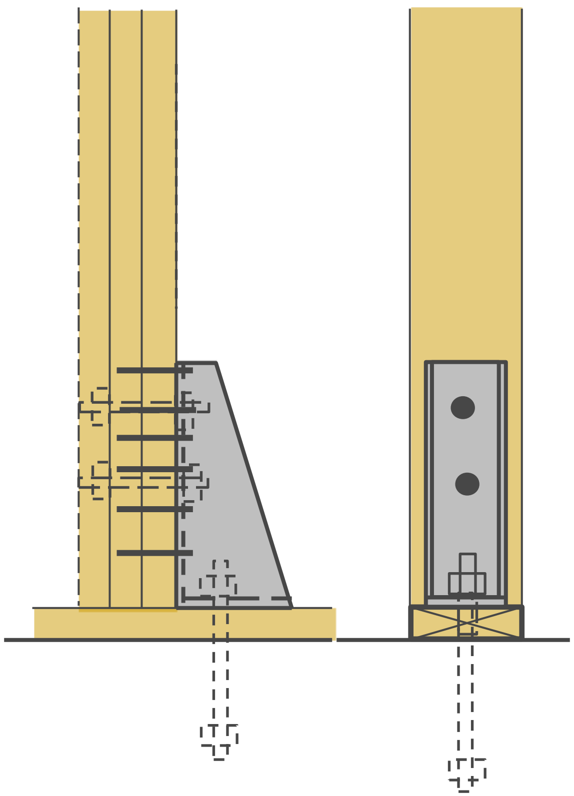
Dead load from above (Wall, Floor, Roof) can be used to resist some or all overturning forces, depending on magnitude

Shear Wall Holdown Options



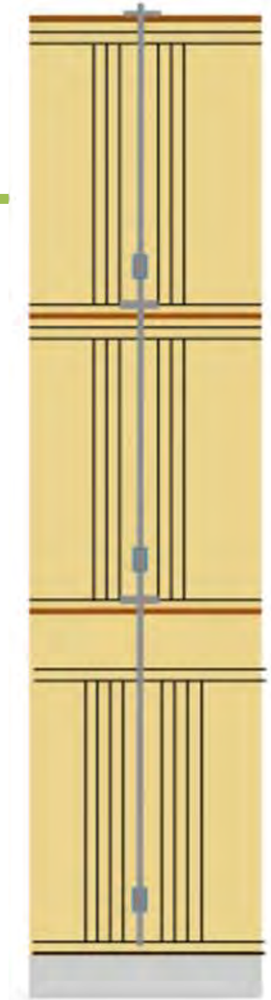
Strap Holdown

6+ kip story to story capacities



Bucket-Style Holdown

13+ kip capacities



Continuous Rod Tiedown Systems

100+ kip capacities
20+ kips/level

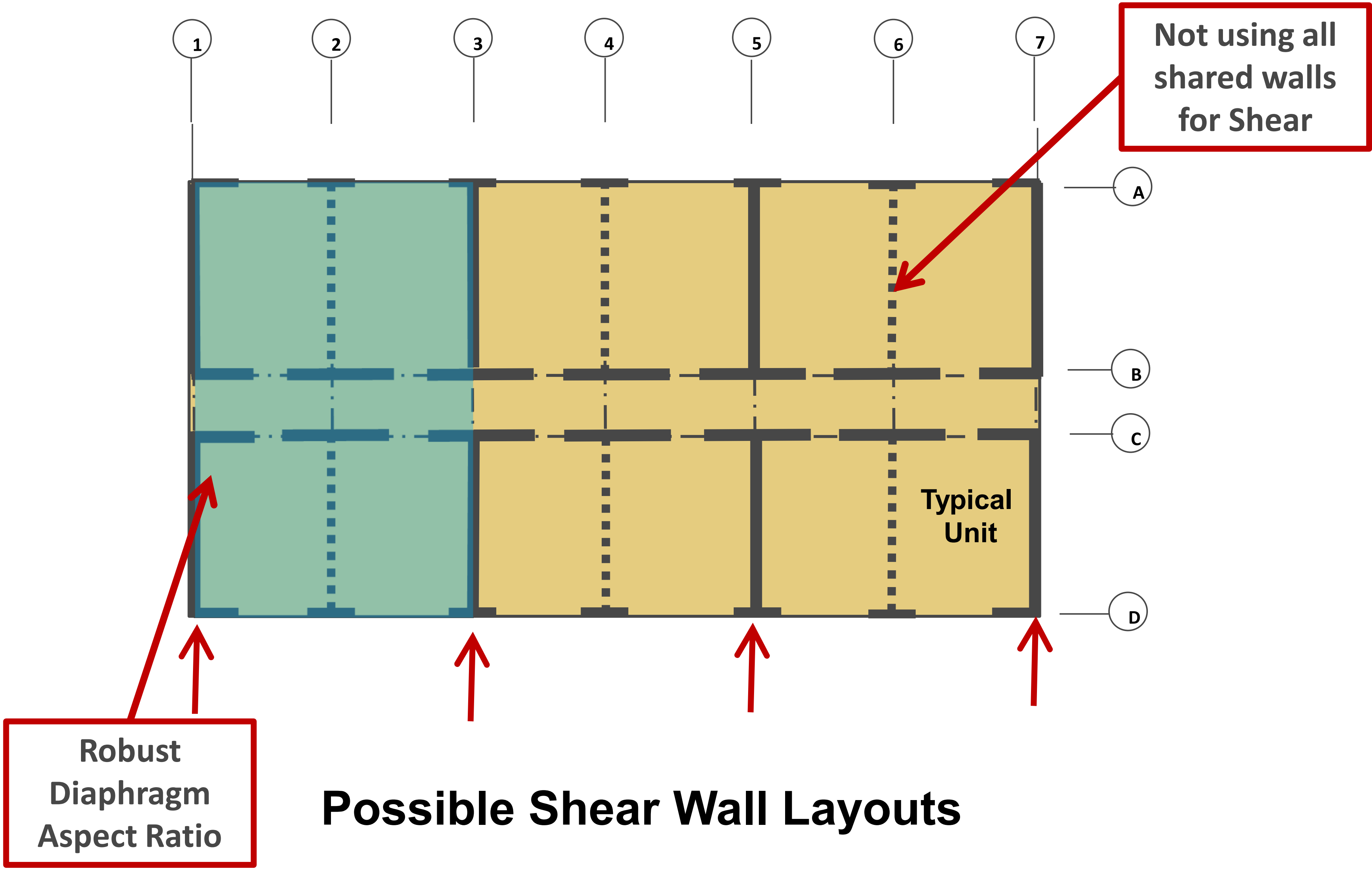
Threaded Rod Tie Down w/Take Up Device

Source: Strongtie

Source: hardyframe.com

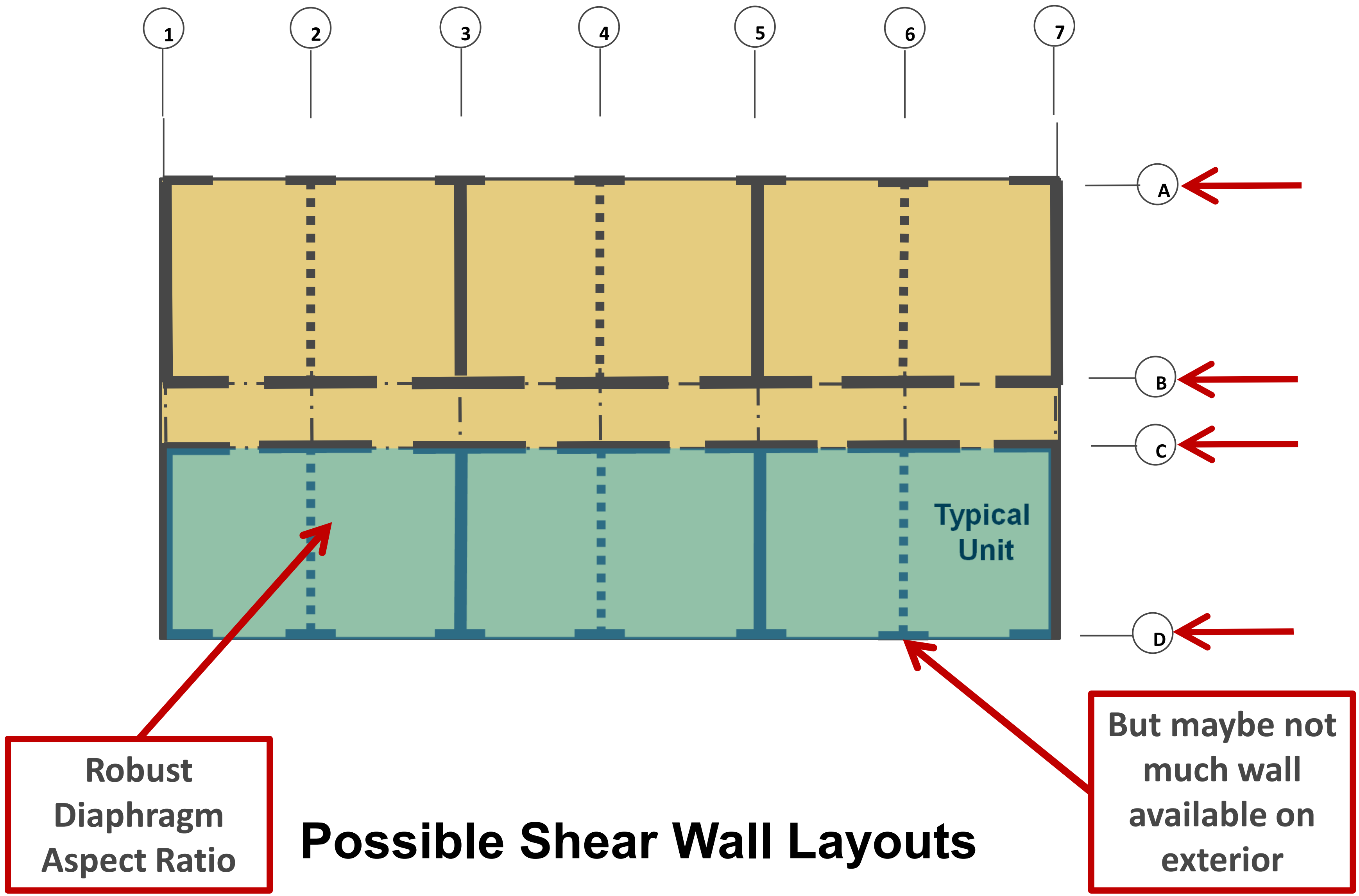
Threaded Rod Tie Down w/o Take Up Device

Diaphragm Modeling Methods



Possible Shear Wall Layouts

Diaphragm Modeling Methods



Possible Shear Wall Layouts

Rigid or Flexible Diaphragm?

Light Frame Wood Diaphragms often default to Flexible Diaphragms

Code Basis: ASCE 7-10 26.2 Definitions (Wind)

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

Code Basis: ASCE 7-10 12.3.1.1 (Seismic)

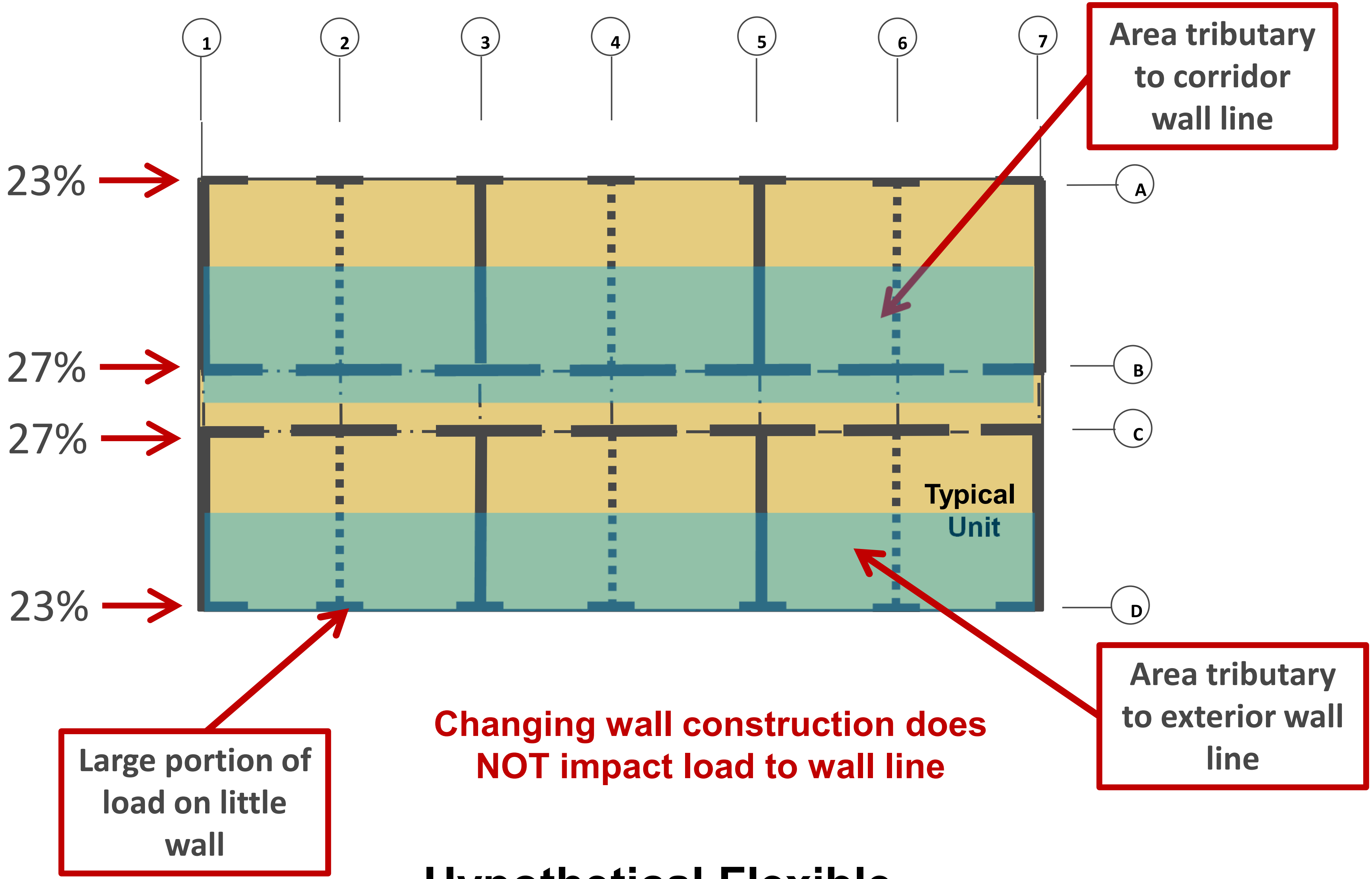
Diaphragms constructed of untopped steel decking or wood structural panels are permitted to be idealized as flexible if any of the following conditions exist:

[…]

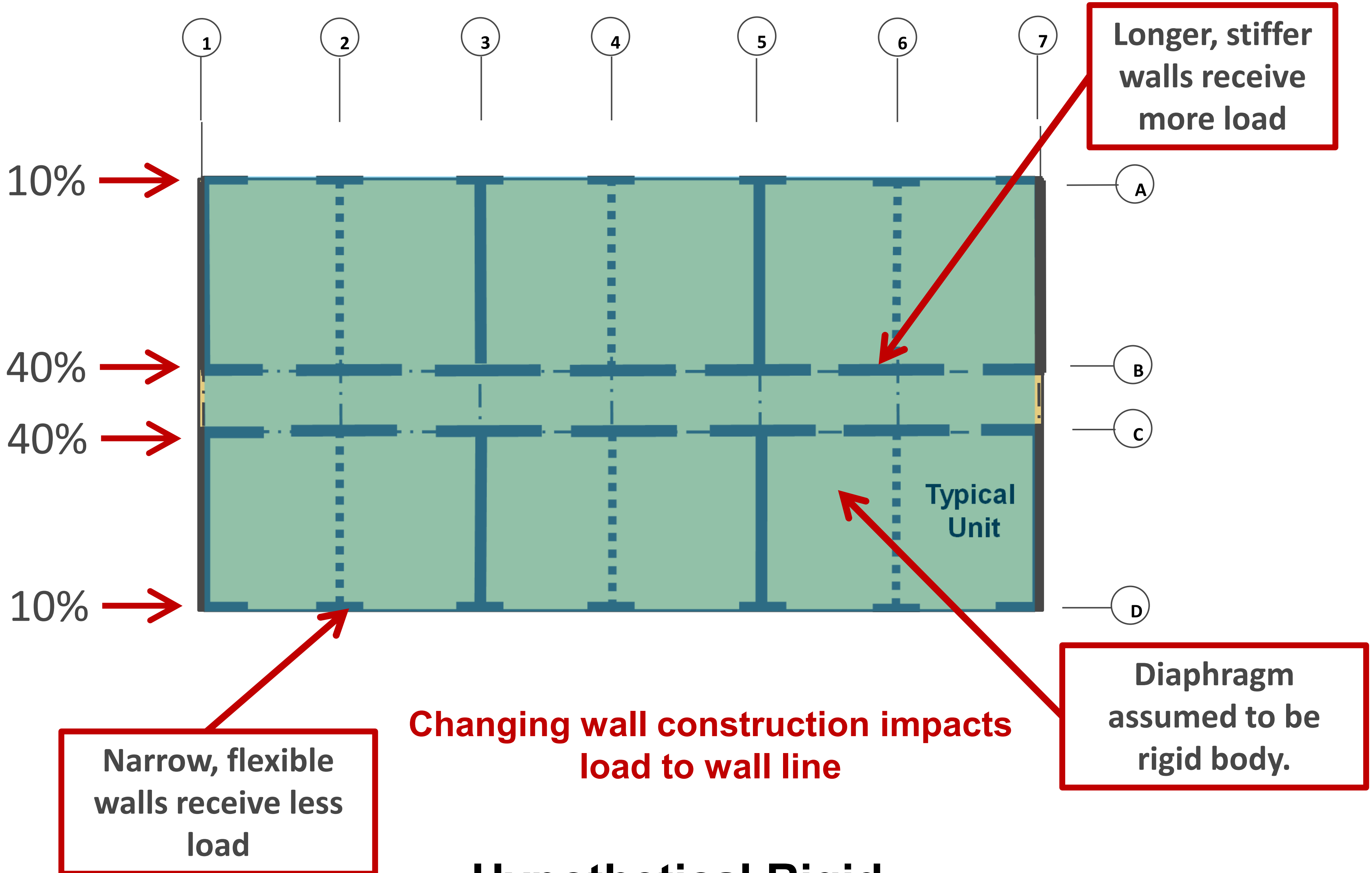
c. In structures of light-frame construction where all of the following conditions are met:

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



Changing wall construction impacts load to wall line

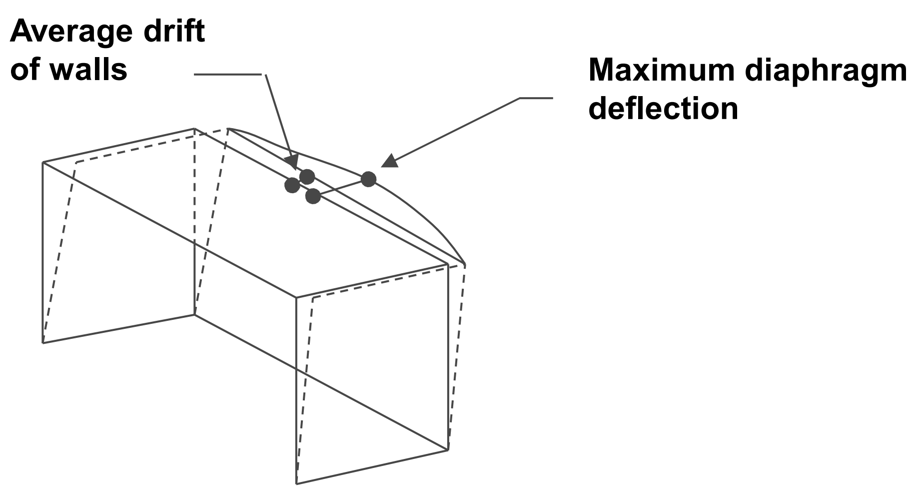
Hypothetical Rigid Diaphragm Distribution

Can a Rigid Diaphragm be Justified?

ASCE 7-16 does not provide a method to idealize a diaphragm as rigid via calculation.

IBC 2018 1604.4 Analysis (See also SDPWS 4.2.2 & 4.3.2)

*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.***



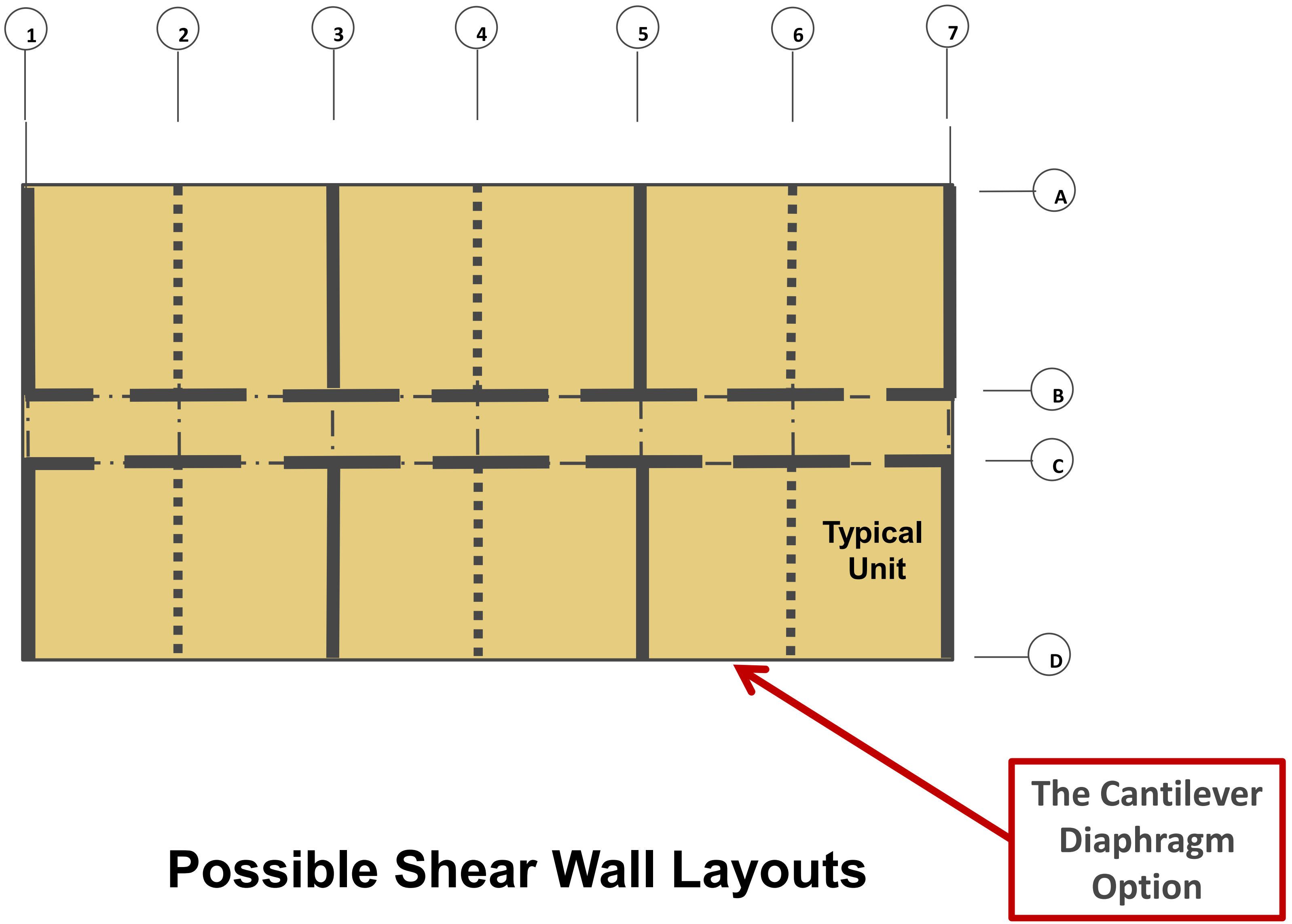
Rigid Diaphragm Analysis

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

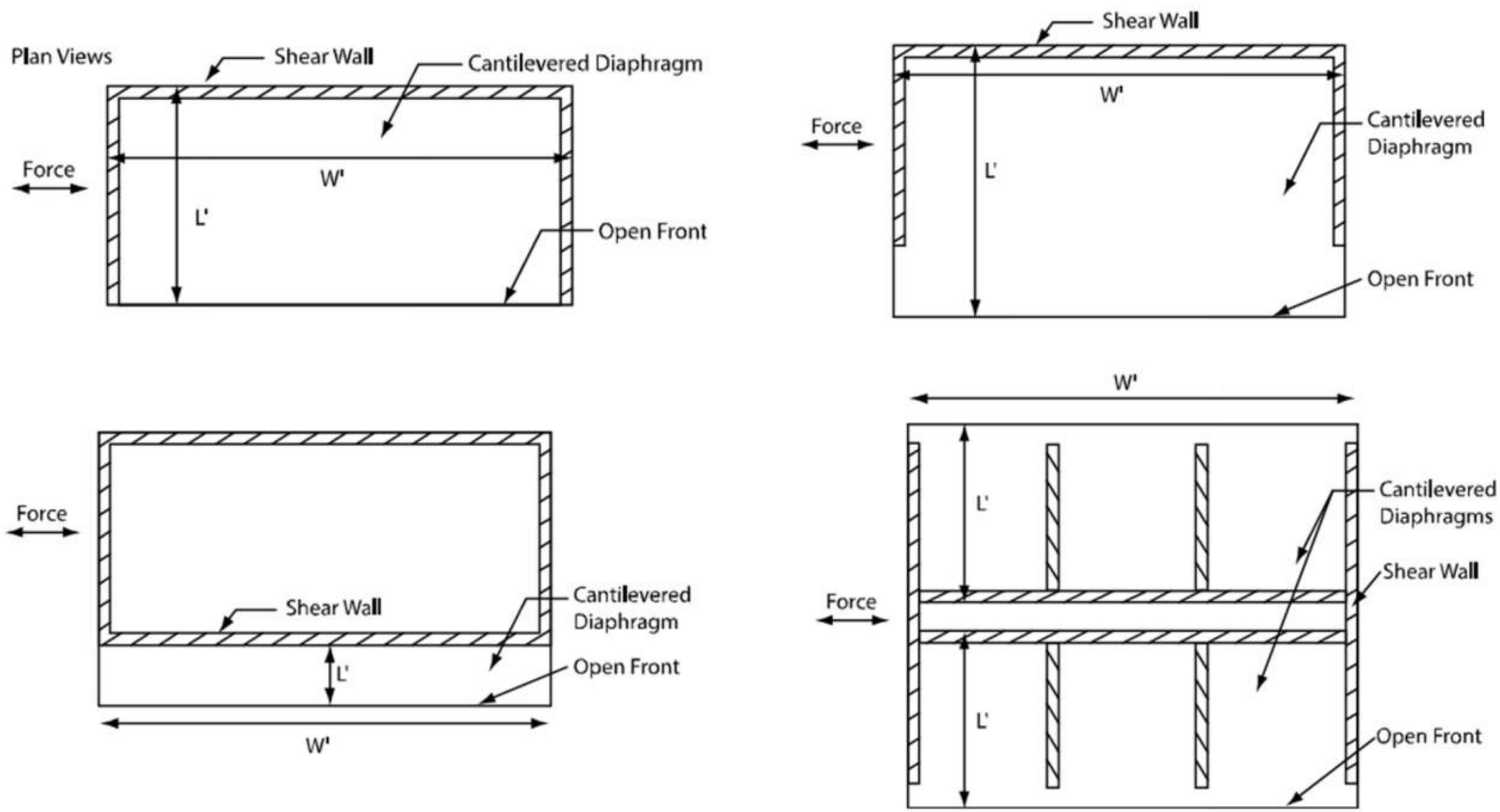
- Considerations of torsional loading necessary
- More complicated calculations to distribute load to shear walls
- May underestimate “Real” loads to narrow exterior walls
- Justification of rigid assumption



Possible Shear Wall Layouts

Cantilevered Diaphragms in SDPWS 2015

Open Front Structure with a Cantilevered Diaphragm



AWC SDPWS 2015 Figure 4A

Seismic Design – Podium Projects

ASCE 7-16 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.

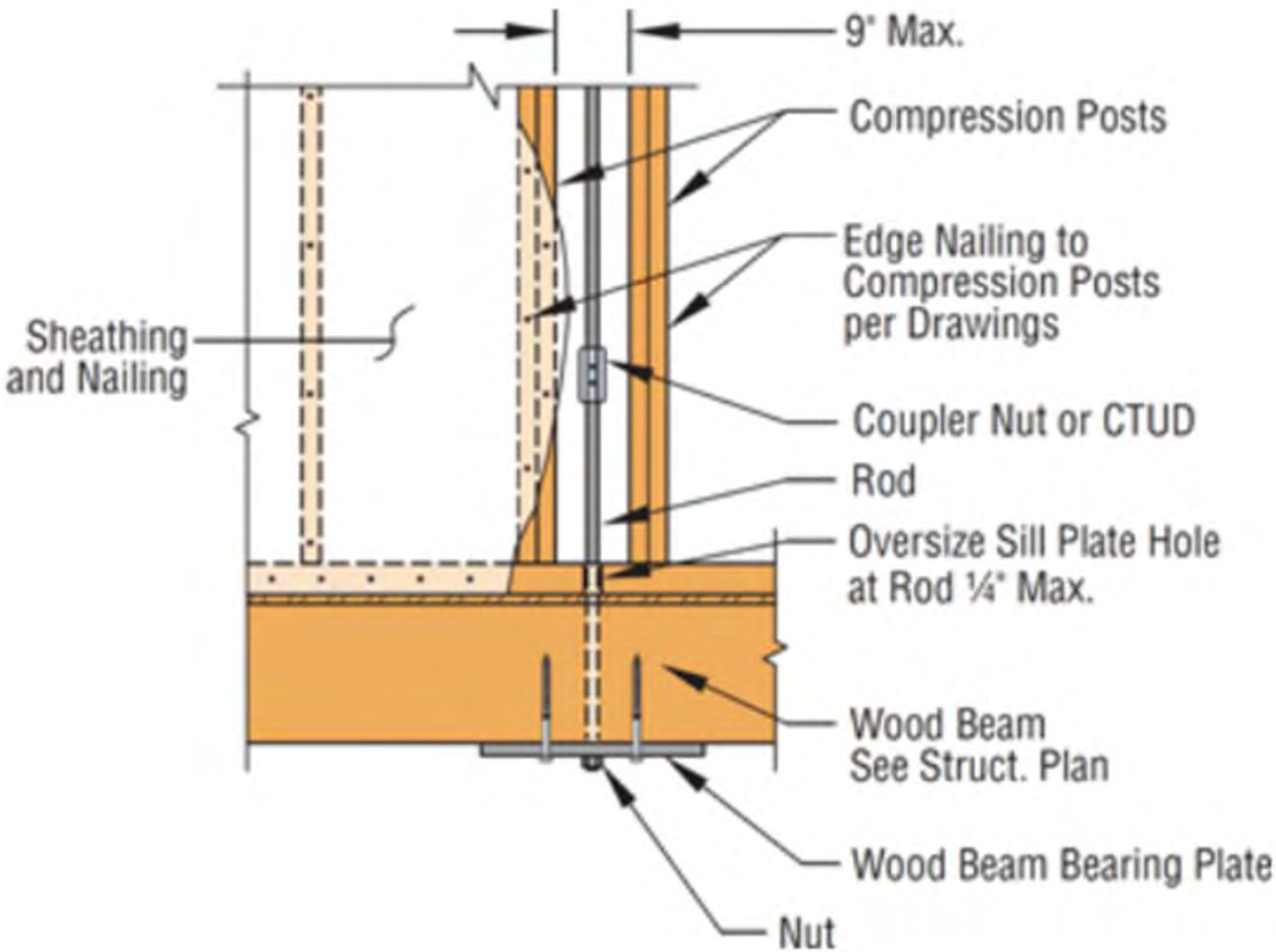
Source: ASCE 7-16

Discontinuous Shear Walls

Karuna I
Holst Architecture

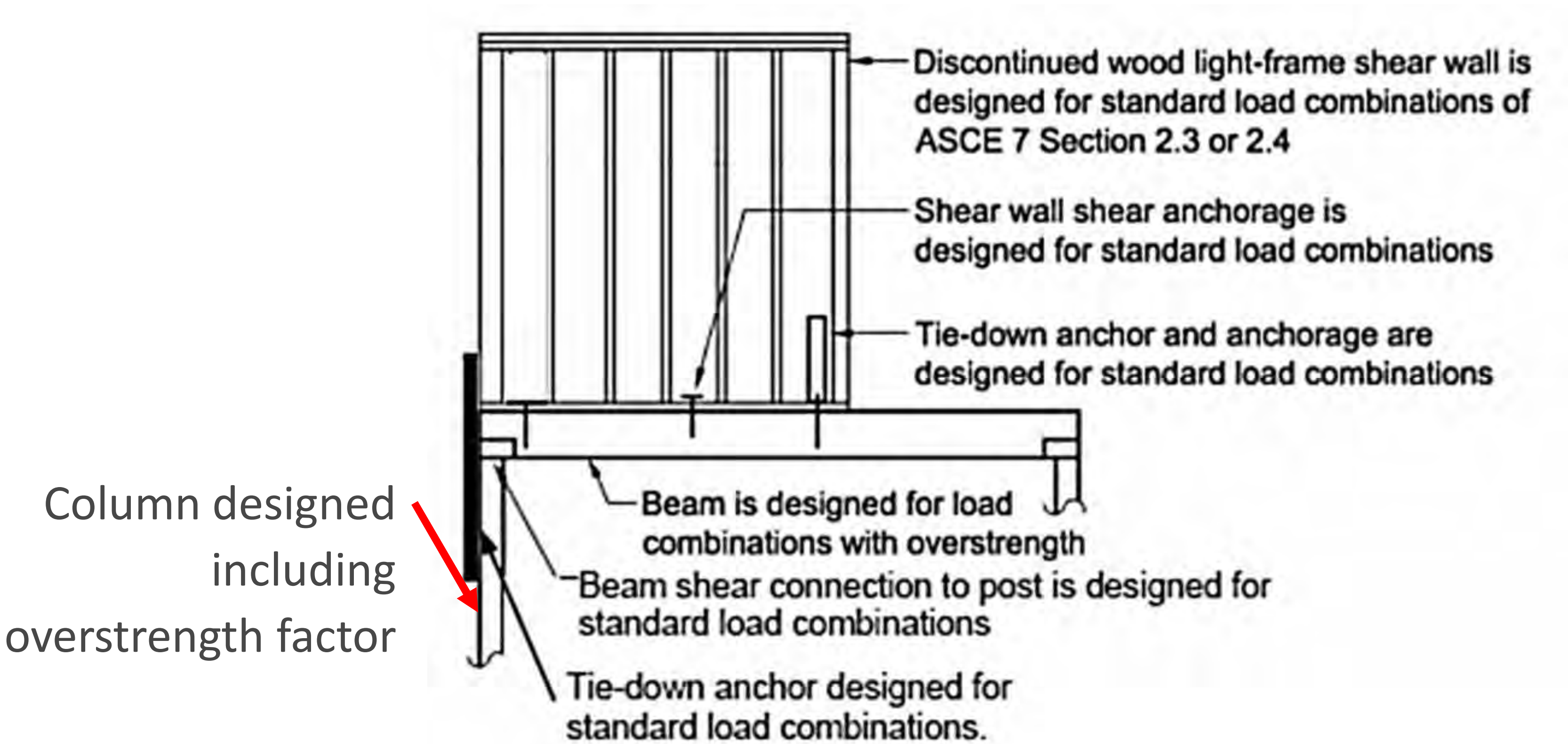
Photo: Terry Malone

Offset Shear Wall Overturning Resistance

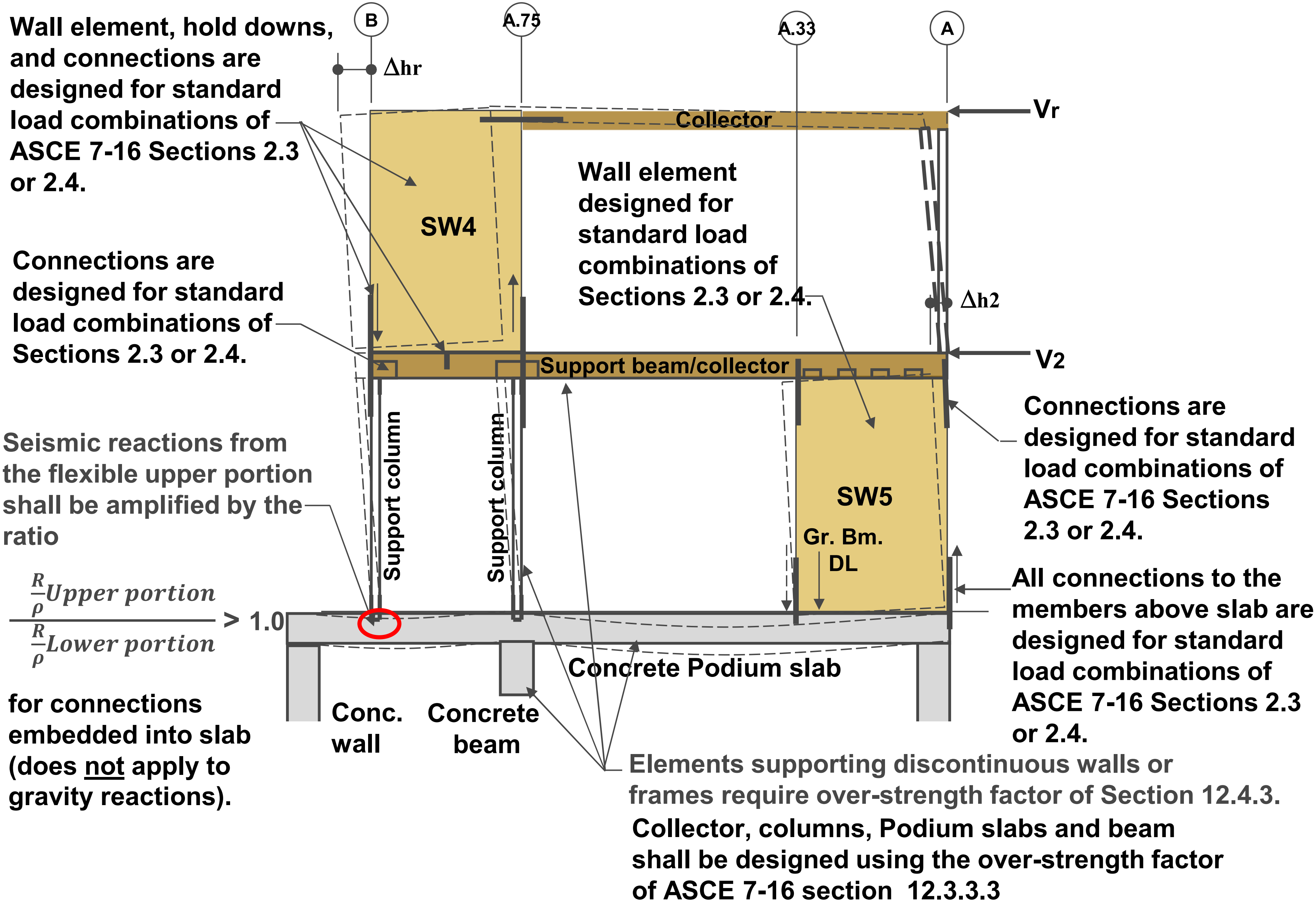


Source: Strongtie

Shear Wall to Podium Slab Interface



ASCE 7-16 Section 12.3.3.3 and Commentary C12.3.3.3 provides guidance on seismic load requirements for various elements supporting discontinuous shear walls



Discontinuous Shear wall system at Podium Slab

Thank You

UW MercerCourt, credit WG Clark Construction
and Ankrom Moisan Architects

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