Mass Timber Structural Design: Engineering Modern Timber Structures

Image: Platte Fifteen / OZ Architecture / KL&A Engineers and Builders / photo JC Buck

December 9, 2025

Presented by

Kate Carrigg, PE

WoodWorks

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

AIA Approved Continuing Education

Course Description

This presentation will provide a detailed look at the structural design processes associated with a variety of mass timber products, including glued-laminated timber (glulam), cross-laminated timber (CLT), and nail-laminated timber (NLT). Applications for the use of these products in gravity force-resisting systems under modern building codes will be discussed. Other technical topics will include mass timber floor panel vibration criteria, connection options and design considerations, and an introduction to lateral systems common in mass timber buildings. Mass timber framing components are often left exposed to act as a finish while taking advantage of their aesthetics. As such, they are often required to provide a fire-resistance rating demonstrating their ability to maintain structural integrity in the event of a fire. This session will also discuss structural design of mass timber elements under fire conditions.

Learning Objectives

1. Compare structural properties and performance characteristics of mass timber products and review their unique design considerations.
2. Review structural design steps for members and connections in common mass timber framing systems.
3. Highlight common connection systems in modern timber structures and resources for associated design values.
4. Demonstrate design steps for calculated fire resistance of exposed structural timber elements.

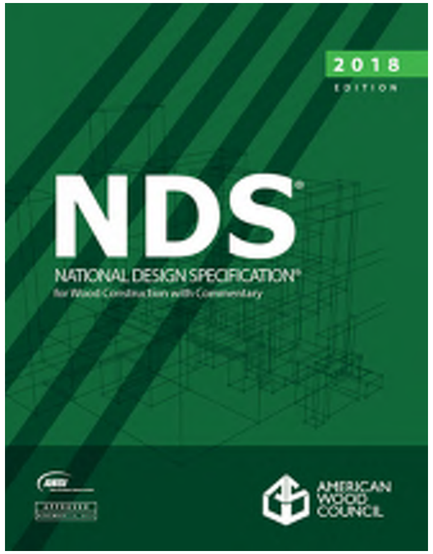
Agenda

- Introduction to Wood
- Mass Timber Products and Systems
- Structural Design – Gravity
- Fire Resistance and Acoustics
- Vibration Design
- Connections
- Structural Design – Lateral

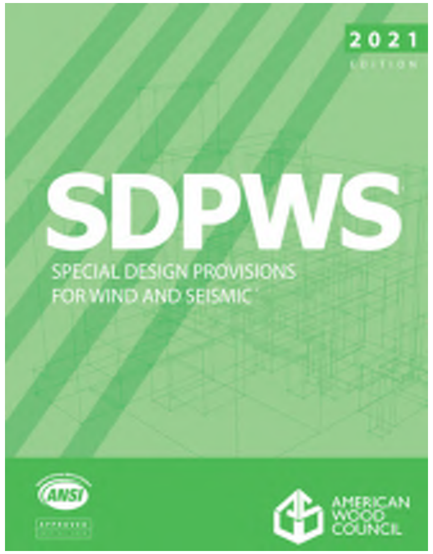
Photo: John Stamets

2021 IBC

2018 NDS



2021 SDPWS



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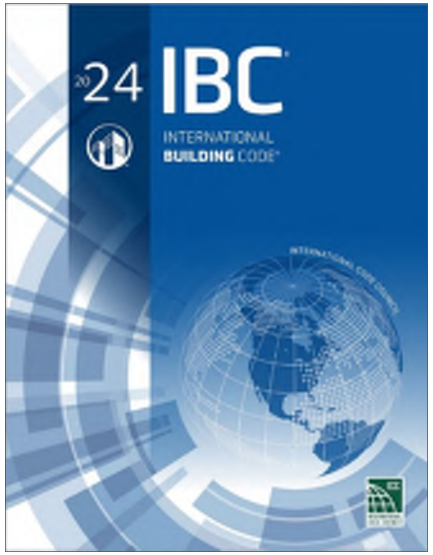
(2016)

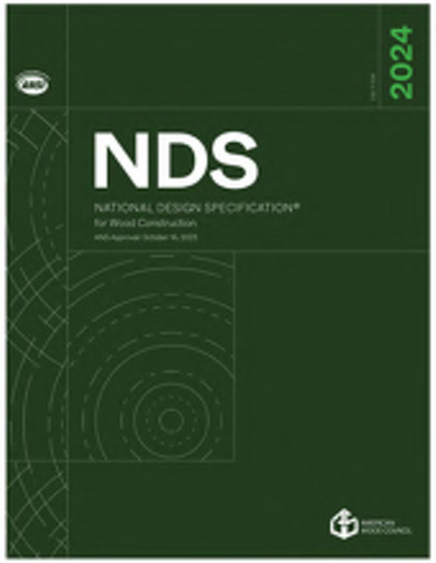
2024 IBC



2024 IBC

INTERNATIONAL BUILDING CODE®

2024 NDS



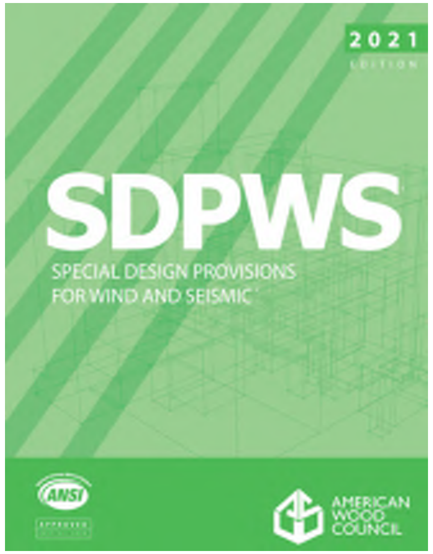
2024

NDS

NATIONAL DESIGN SPECIFICATION®

for Wood Construction

2021 SDPWS



2021 EDITION

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SPECIAL DESIGN PROVISIONS FOR WIND AND SEISMIC

ANSI

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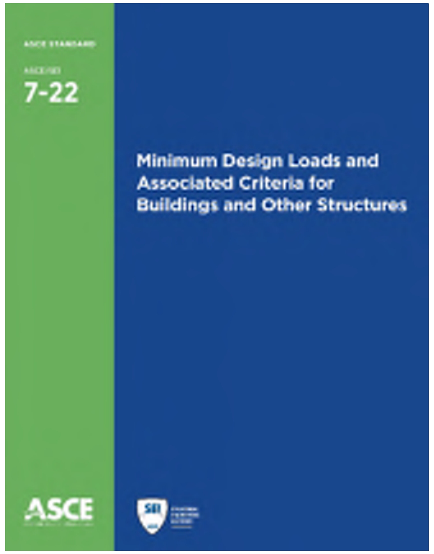


ASCE STANDARD

ASCE/SEI

7-22

Minimum Design Loads and Associated Criteria for Buildings and Other Structures

ASCE

SEI

ASCE 7-22
(2022)

Agenda – Part 1

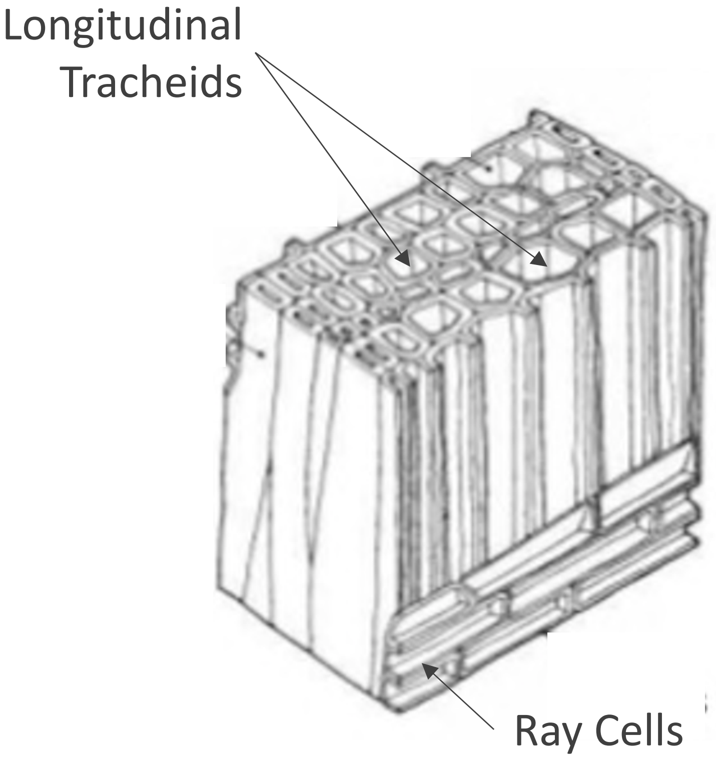
- **Introduction to Wood**
- Mass Timber Products and Systems
- Structural Design – Gravity

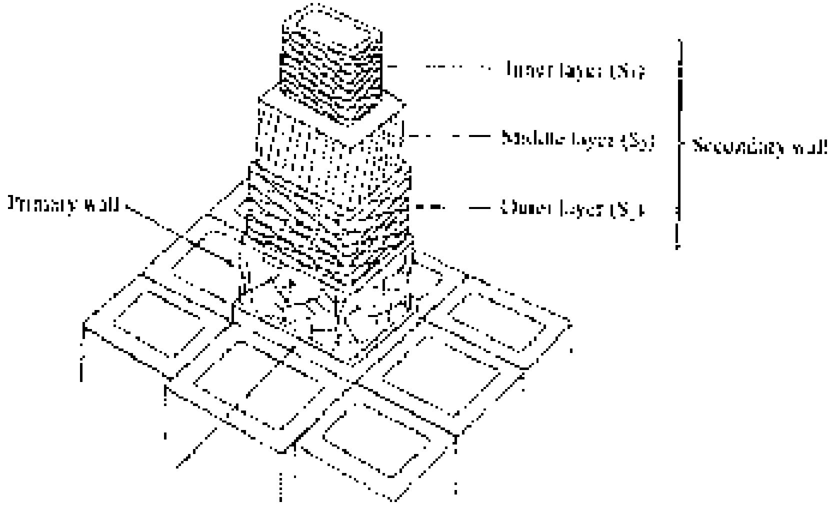
Photo: John Stamets

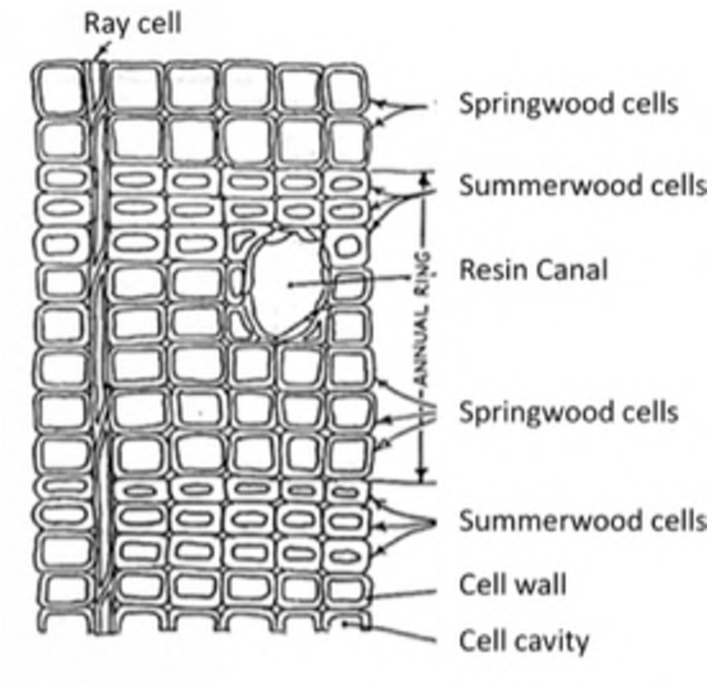
Wood Science

Cell Structure: Anatomy

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

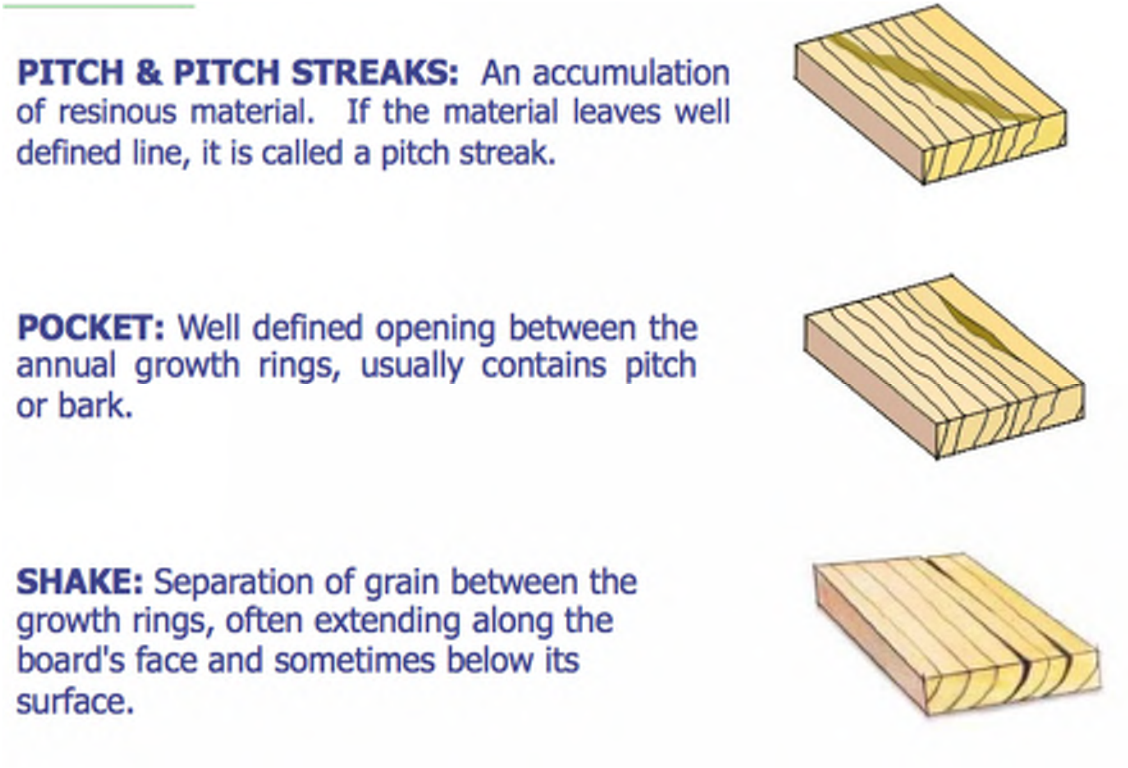






Growth Characteristics

- 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

Understanding species & grading provides the framework for proper design & specification

Geographic Impacts: Growing Regions

Predominant Softwood Species by Region

South:

- Southern Pine

North:

- Mixed pine
- Spruce-fir

Rocky Mountain:

- Juniper
- Fir-spruce-hemlock
- Douglas-fir

Pacific Coast:

- Douglas-fir
- Ponderosa Pine

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

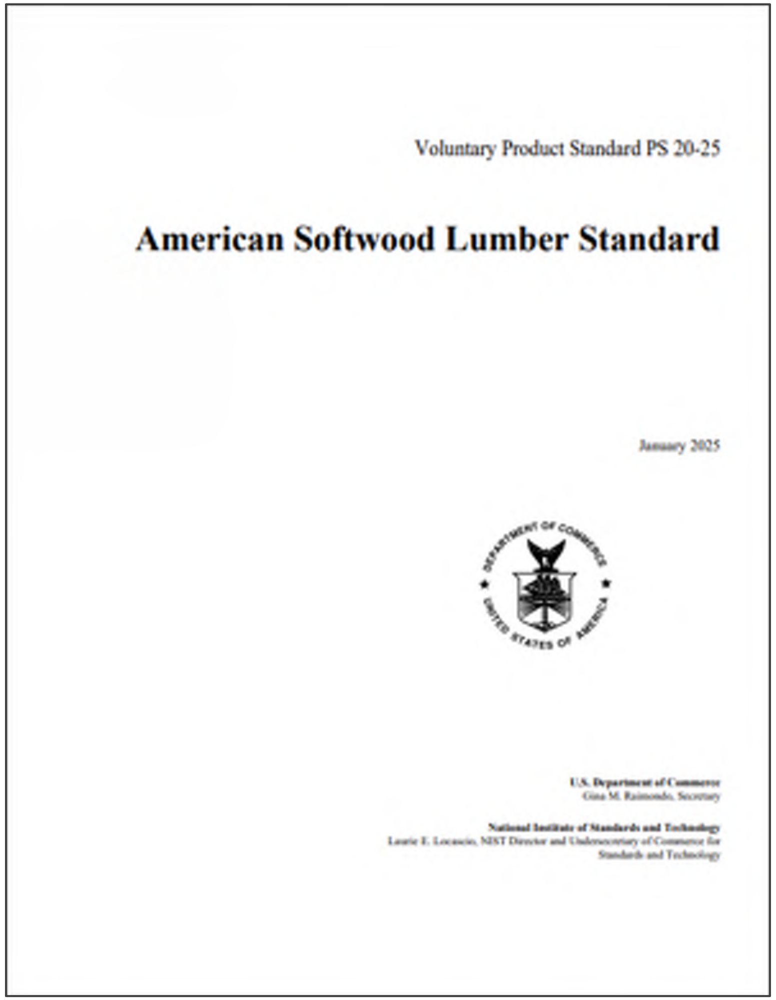
Wood Species & Grading: Building Code

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…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...



Voluntary Product Standard PS 20-25

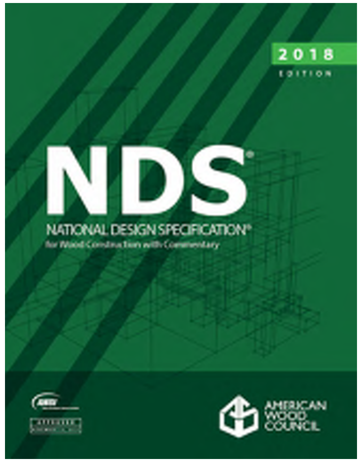
American Softwood Lumber Standard

January 2025

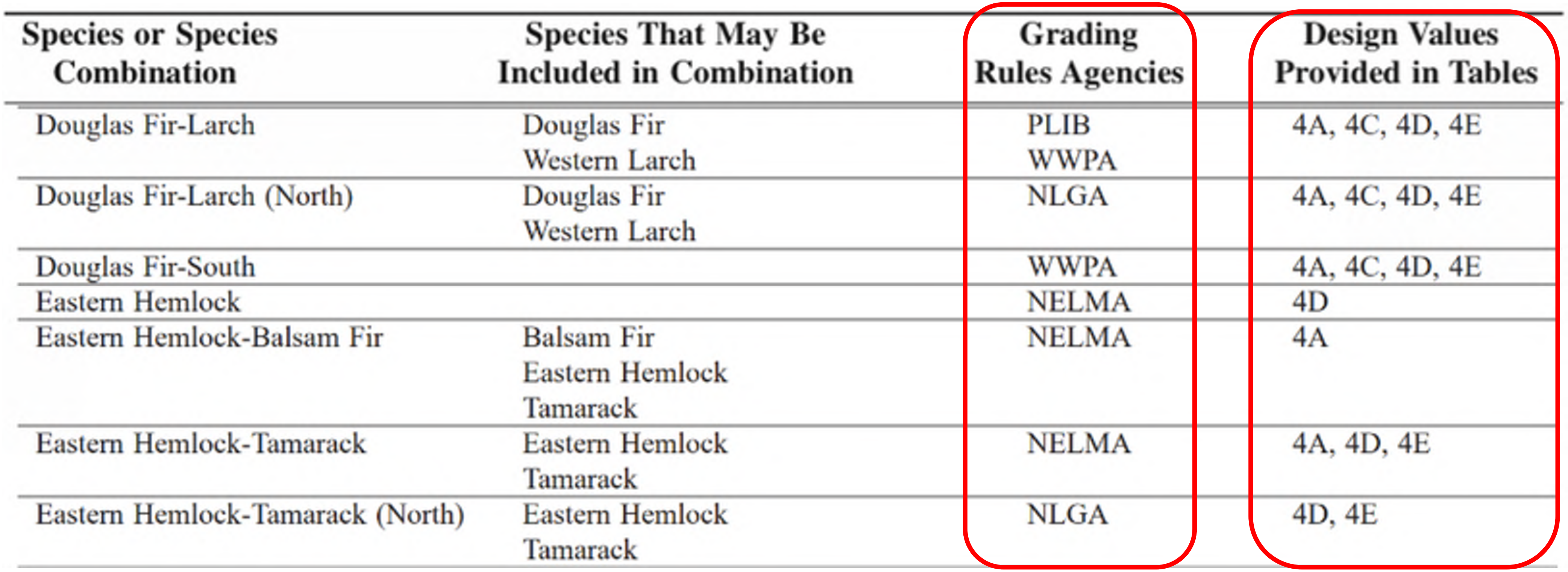
U.S. Department of Commerce
Gina M. Raimondo, Secretary

National Institute of Standards and Technology
Laurie E. Locascio, NIST Director and Undersecretary of Commerce for Standards and Technology

Reference Design Values: Species



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



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	PLIB 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	4D
Eastern Hemlock-Balsam Fir	Balsam Fir Eastern Hemlock Tamarack	NELMA	4A
Eastern Hemlock-Tamarack	Eastern Hemlock Tamarack	NELMA	4A, 4D, 4E
Eastern Hemlock-Tamarack (North)	Eastern Hemlock Tamarack	NLGA	4D, 4E

Reference Design Values: Grading Methods

Grading methods:

- **Visually Graded Lumber (VGL)**
  - Grade is determined by visual inspection
- **Machine Stress Rated (MSR)**
  - Automated, nondestructive method – MOE is determined through an applied bending load
- **Machine Evaluated Lumber (MEL)**
  - Automated, nondestructive method in which MSR lumber undergoes radiographic inspection to measure density
- **NDS groups MSR & MEL into “Mechanically Graded Dimension Lumber”**

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Reference Design Values: Examples

Grading Method

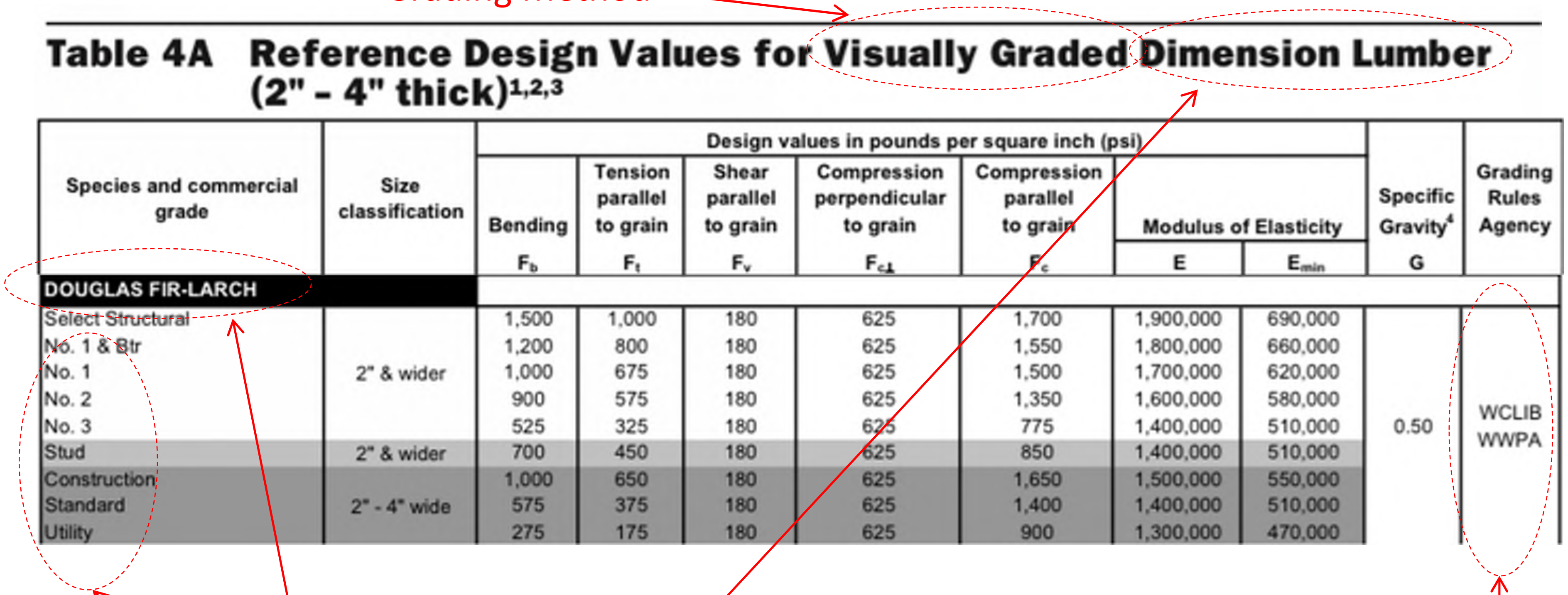


Table 4A Reference Design Values for Visually Graded Dimension Lumber (2" - 4" thick)^{1,2,3}

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

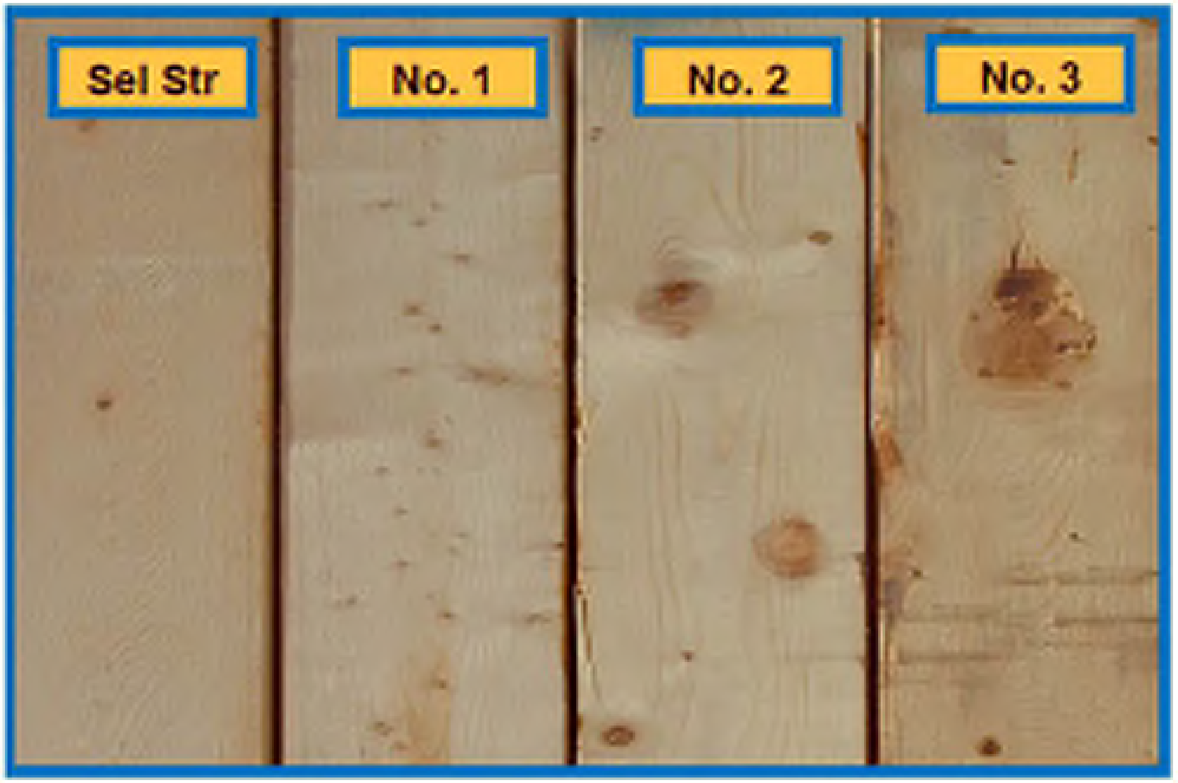
Note: NDS splits Dimension & Timber into separate Reference Design Tables, no structural properties given to Boards

Tables also indicate Grading Rules followed

Reference Design Values: Commercial Grade

Visually Graded Commercial Grades:

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



Reference Design Values: Examples

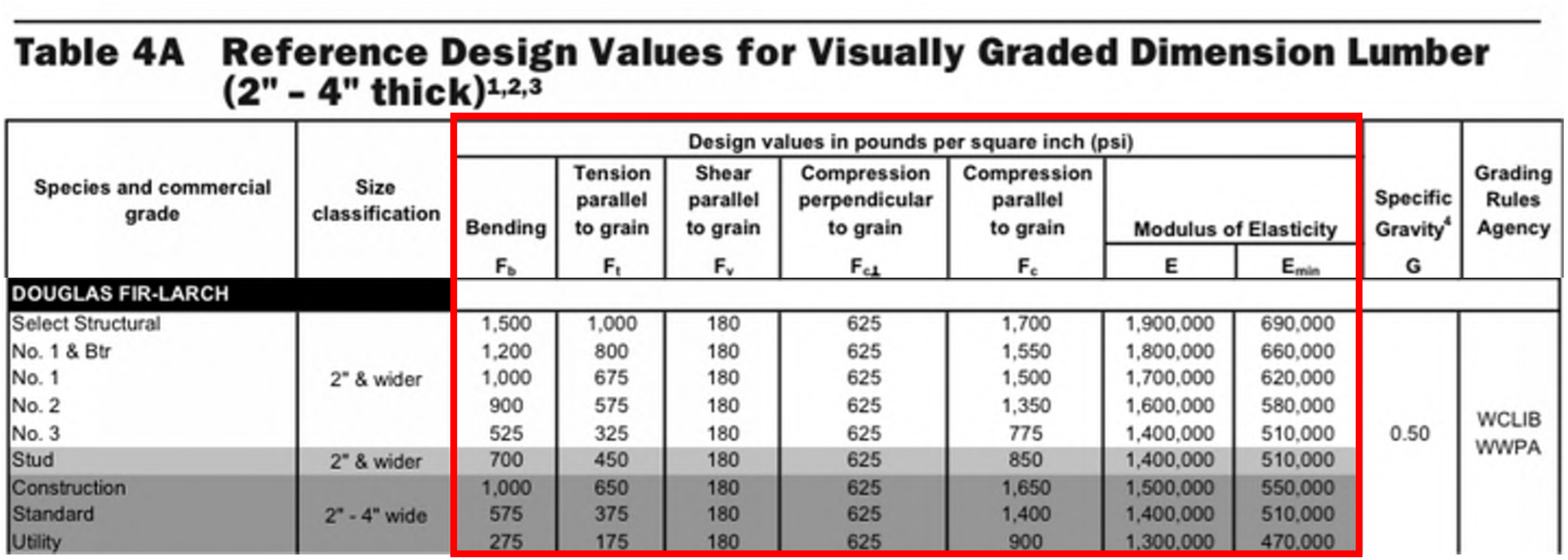


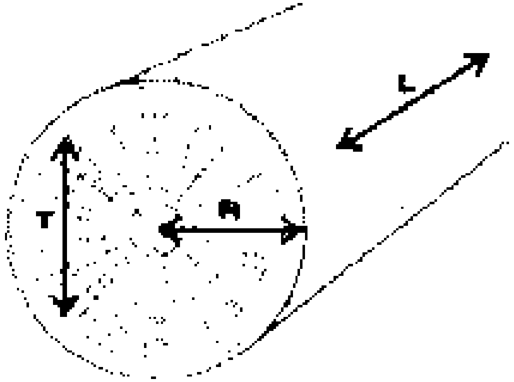
Table 4A Reference Design Values for Visually Graded Dimension Lumber (2" - 4" thick)[1,2,3]

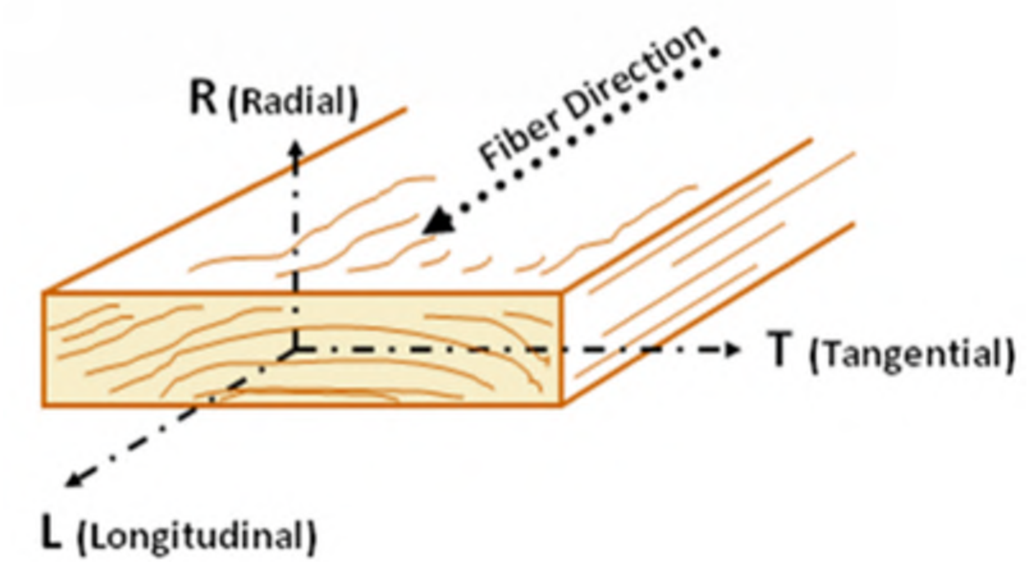
Species and commercial grade	Size classification	Design values in pounds per square inch (psi)							Specific Gravity[4]	Grading Rules Agency
		Bending F_b	Tension parallel to grain F_t	Shear parallel to grain F_v	Compression perpendicular to grain $F_{c\perp}$	Compression parallel to grain F_c	Modulus of Elasticity E	Modulus of Elasticity 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		

Cell Structure: Orthogonal Properties

Wood is orthotropic, 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.





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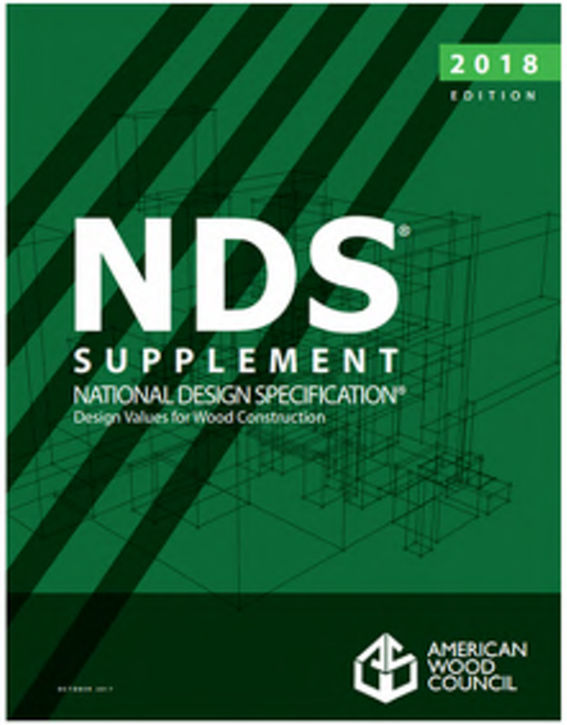
Structural Wood Design: Capacity

Reference Design Values:

- Mechanical properties associated with commercial grades of wood



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Design Values for Wood Construction

AMERICAN
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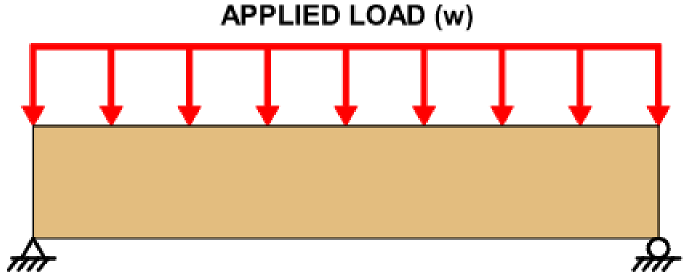
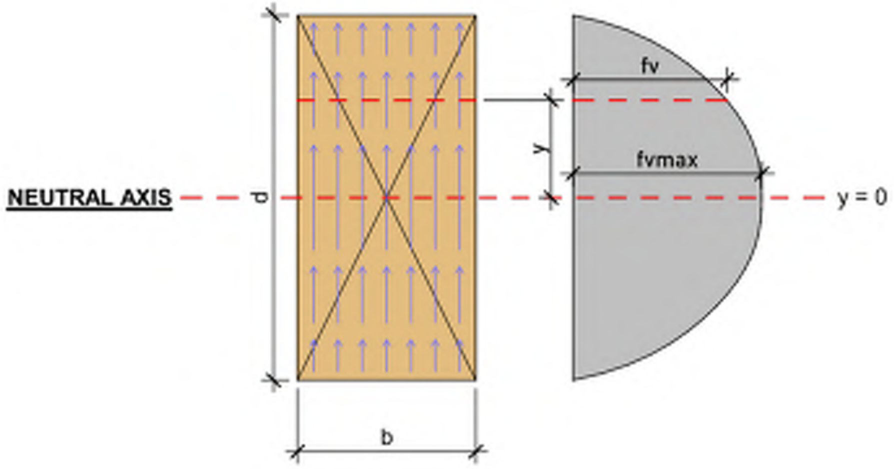
Reference Design Values	
E, E_{min}	Modulus of elasticity
F_c	Compression parallel to grain
$F_{c\perp}$	Compression perpendicular to grain
F_t	Tension parallel to grain
F_b	Bending (parallel to grain)
F_v	Shear parallel to grain

Wood Design: Shear

Shear stress:

- Actual shear stress
  - $f_v = \frac{V * Q}{I * b}$ (NDS Equation 3.4-1)
- For rectangular members
  - $f_v = \frac{3 * V}{2 * b * d}$ (NDS Equation 3.4-2)





Reference Design Values: Examples

Grading Method

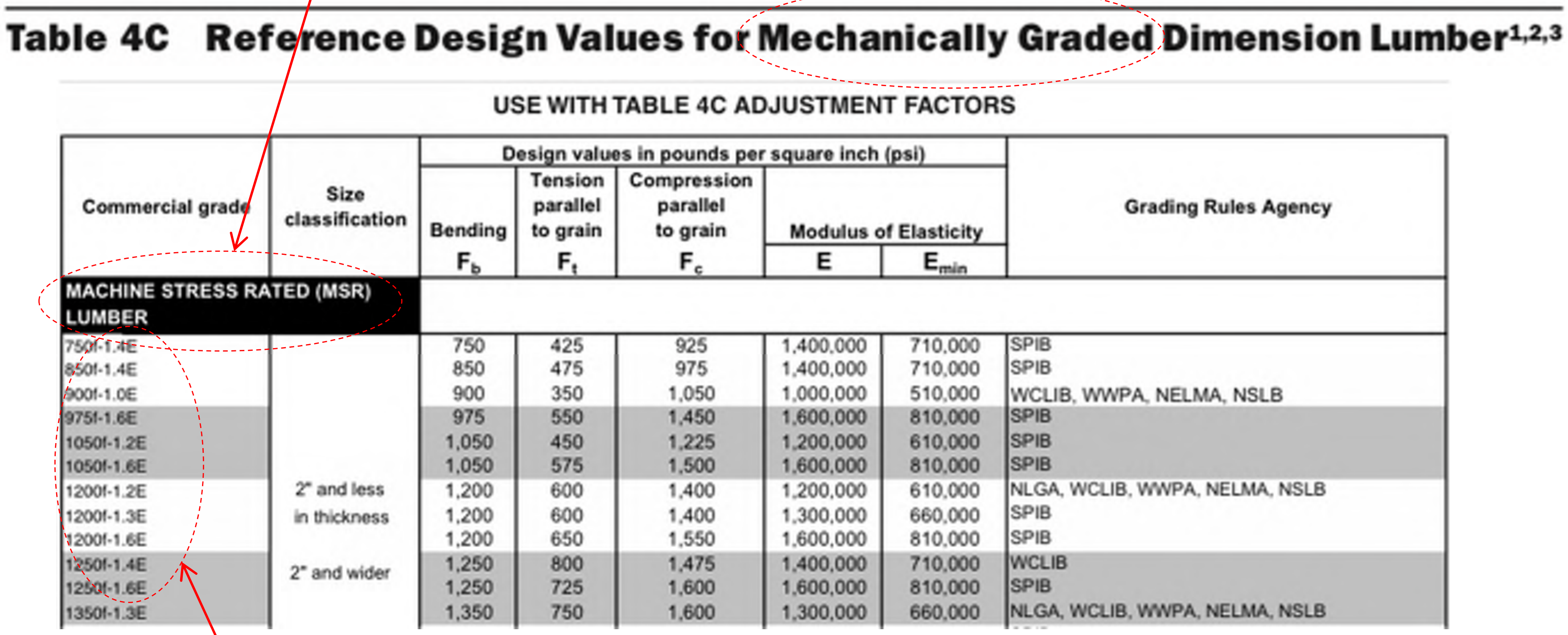


Table 4C Reference Design Values for Mechanically Graded Dimension Lumber[1,2,3]

USE WITH TABLE 4C ADJUSTMENT FACTORS

Commercial grade	Size classification	Design values in pounds per square inch (psi)					Grading Rules Agency
		Bending F_b	Tension parallel to grain F_t	Compression parallel to grain F_c	Modulus of Elasticity 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

Commercial Grade

Structural Wood Design: Capacity

Adjustment Factors:

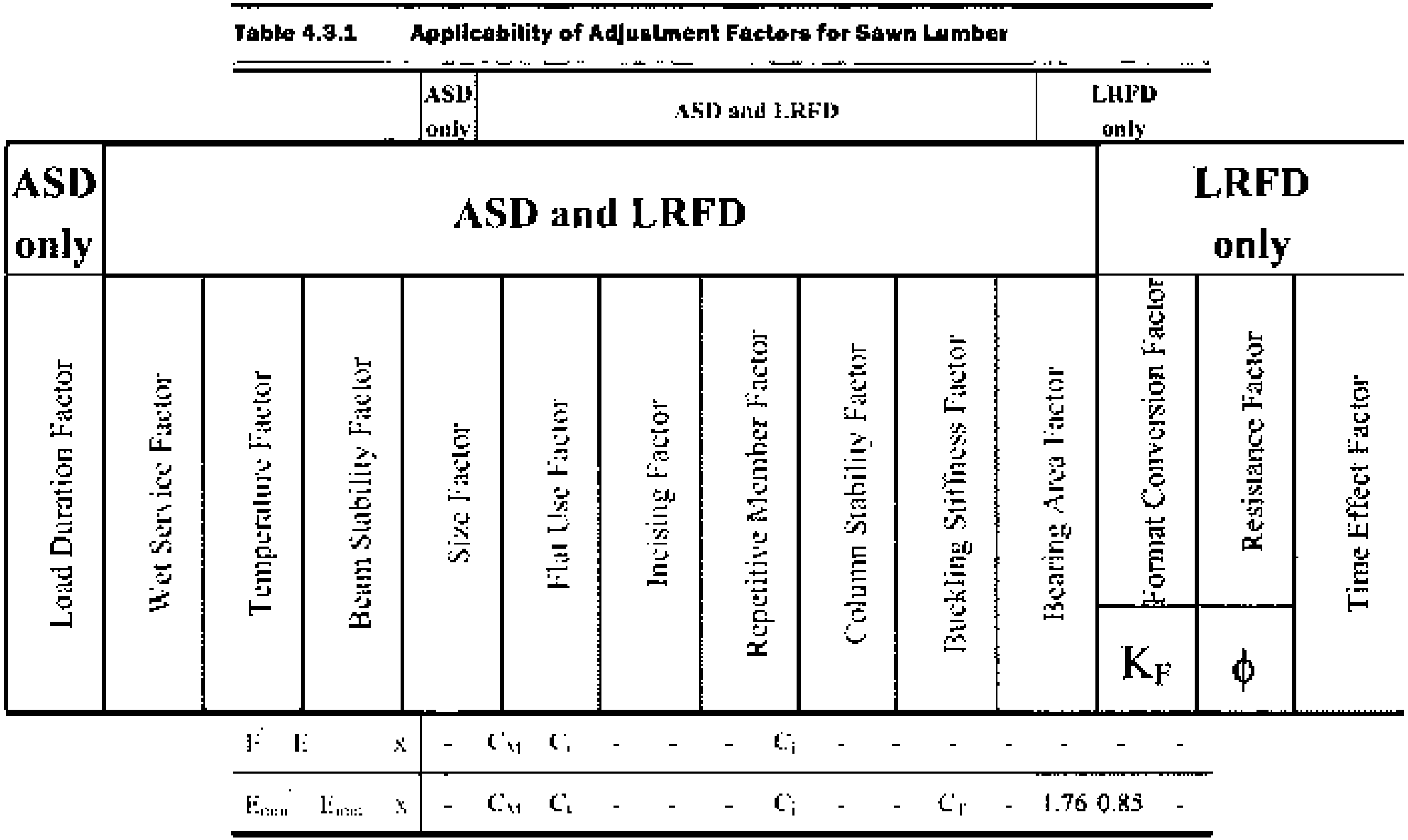


Table 4.3.1 Applicability of Adjustment Factors for Sawn Lumber

		ASD only	ASD and LRFD										LRFD only		
		Load Duration Factor	Wet Service Factor	Temperature Factor	Beam Stability Factor	Size Factor	Flat Use Factor	Incising Factor	Repetitive Member Factor	Column Stability Factor	Buckling Stiffness Factor	Bearing Area Factor	Format Conversion Factor K_F	Resistance Factor ϕ	Time Effect Factor
$F' = E$	x	-	C_M	C_t	-	-	-	C_i	-	-	-	-	-	-	-
$E_{min}' = E_{min}$	x	-	C_M	C_t	-	-	-	C_i	-	-	C_T	-	1.76	0.85	-

AWC NDS, 2018

Introduction to Wood: Structural Gravity Framing Design

Learning Hours: 1

Credits: AIA LU/HSW, ICC CEU

This presentation
is available via:

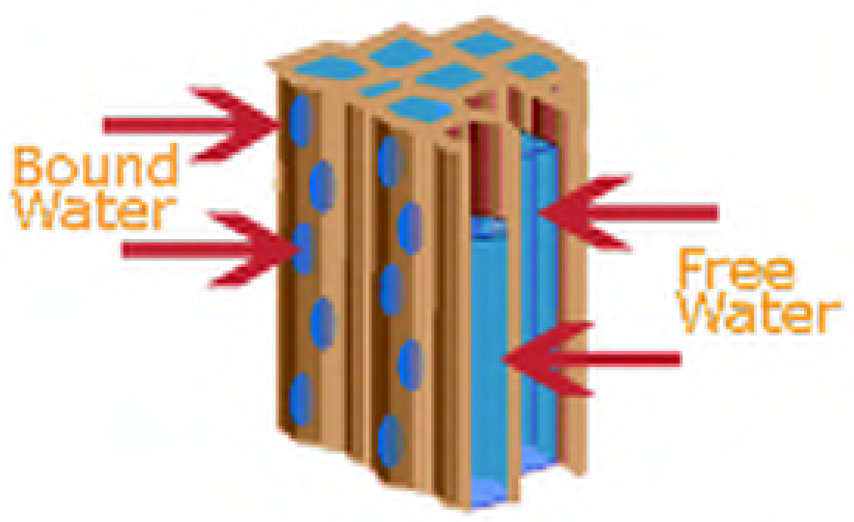
THE WOOD INSTITUTE

www.woodinstitute.org

Ivy Residences at Health Village / Photo Charlan Brock Architects

Cell Structure: Interaction with Water

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.)

Wood Science: Moisture Content

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

Where:

MC = Moisture Content

W_{wet} = current weight of wood

W_{dry} = oven dry weight of wood

Fiber Saturation Point is generally around MC 30%

Wood Science: Shrinkage

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

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

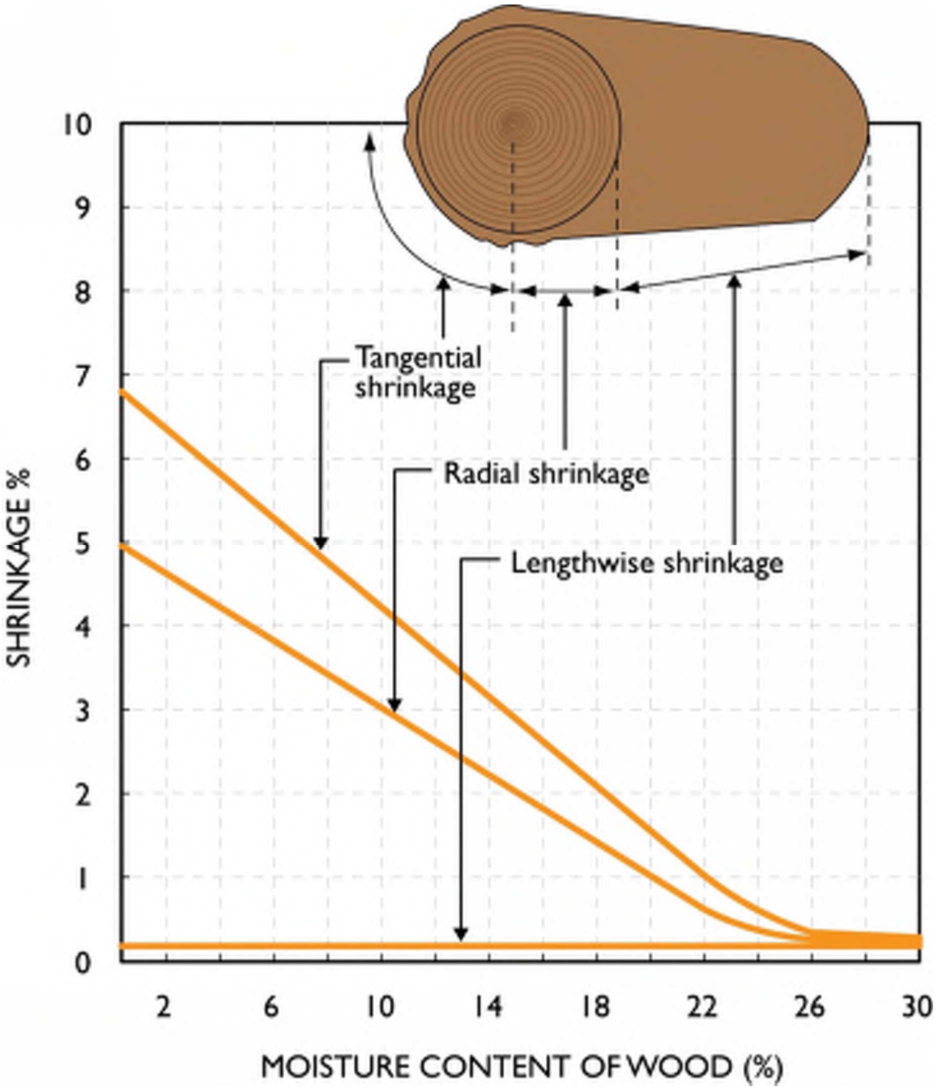


Image: RDH Building Science, Inc.

https://www.woodworks.org/resources/differential-material-movement-in-tall-mass-timber-structures/

https://www.woodworks.org/resources/accommodating-shrinkage-in-multi-story-wood-frame-structures/

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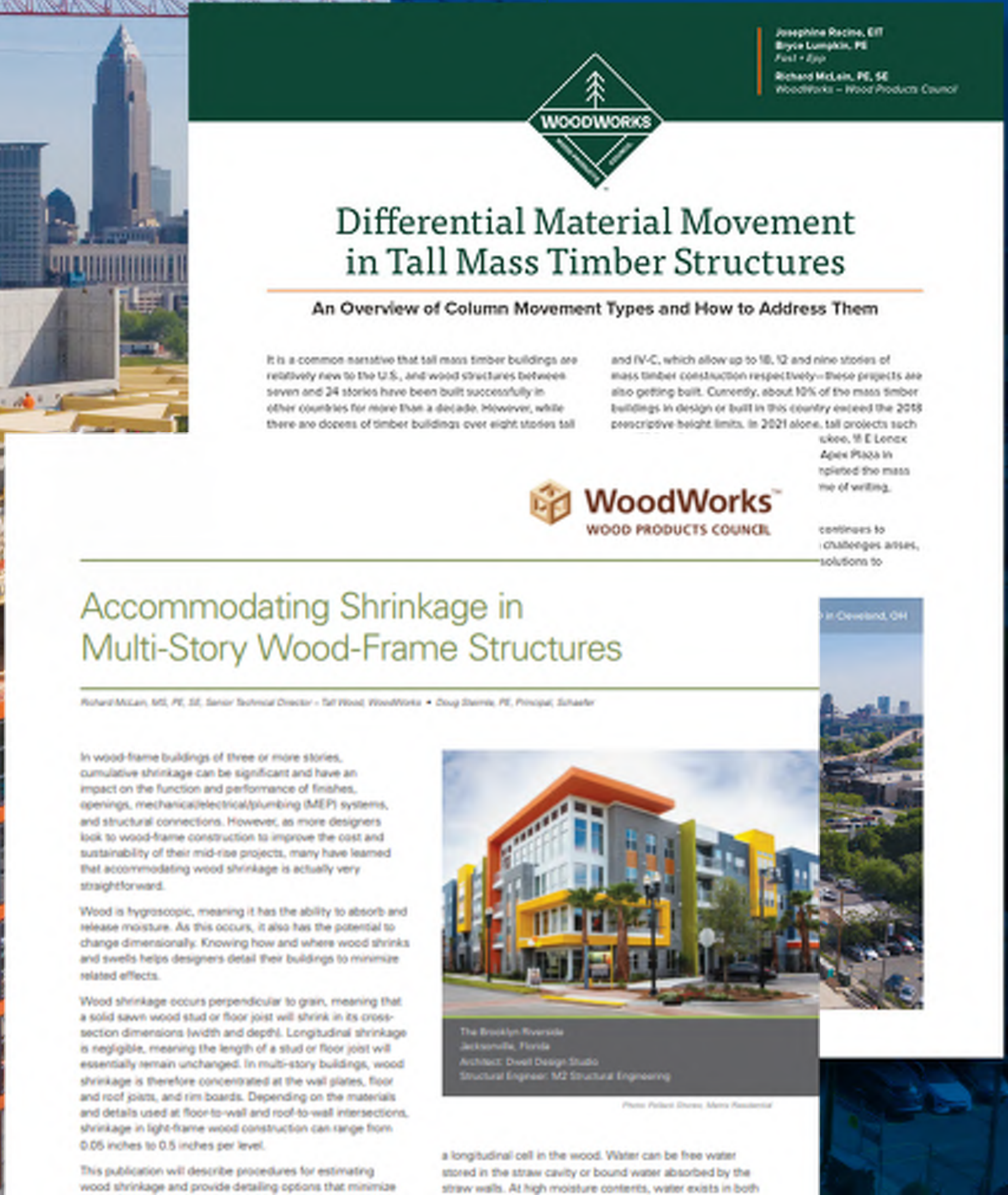

Josephine Racine, EIT
Bryce Lumpkin, PE
Fast + Epp
Richard McLain, PE, SE
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WOODWORKS

Differential Material Movement in Tall Mass Timber Structures

An Overview of Column Movement Types and How to Address Them

It is a common narrative that tall mass timber buildings are relatively new to the U.S., and wood structures between seven and 24 stories have been built successfully in other countries for more than a decade. However, while there are dozens of timber buildings over eight stories tall

and IV-C, which allow up to 18, 12 and nine stories of mass timber construction respectively—these projects are also getting built. Currently, about 10% of the mass timber buildings in design or built in this country exceed the 2018 prescriptive height limits. In 2021 alone, tall projects such

ukee, 11 E Lenox
Apex Plaza in
npleted the mass
me of writing.

continues to
challenges arises,
solutions to

in Cleveland, OH

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WOOD PRODUCTS COUNCIL

Accommodating Shrinkage in Multi-Story Wood-Frame Structures

Richard McLain, MS, PE, SE, Senior Technical Director – Tall Wood, WoodWorks • Doug Sterrie, 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

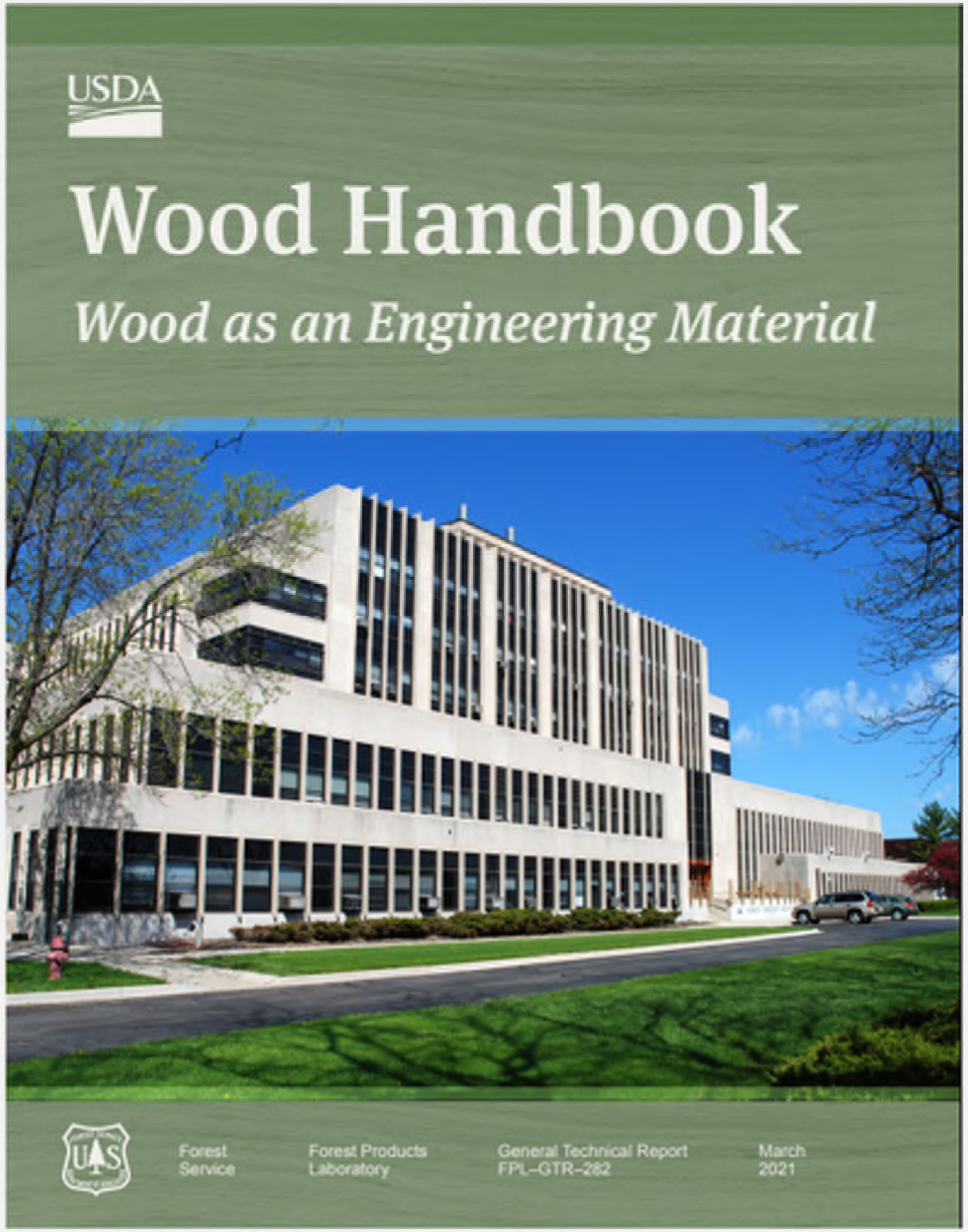
The Brooklyn Riverside
Jacksonville, Florida
Architect: Dwell Design Studio
Structural Engineer: M2 Structural Engineering

Photo: Pollack Shores, Metro Residential

a longitudinal cell in the wood. Water can be free water stored in the straw cavity or bound water absorbed by the straw walls. At high moisture contents, water exists in both

Wood Handbook

Free to Download:
https://research.fs.usda.gov/treesearch/62200



Agenda – Part 1

- Introduction to Wood
- **Mass Timber Products and Systems**
- Structural Design – Gravity

Photo: John Stamets

Mass Timber Products

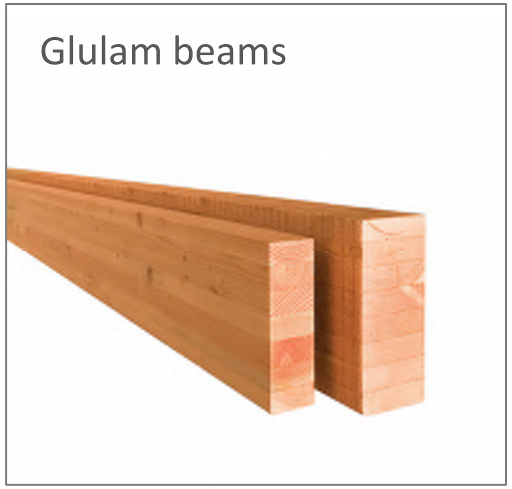
Panels

- Cross-Laminated Timber / CLT
- Glue-Laminated Timber / GLT
- Dowel-Laminated Timber / DLT
- Nail-Laminated Timber / NLT

Columns and Beams

- Glue-Laminated Timber / Glulam
- Structural Composite Lumber / SCL

The Canyons
Kaiser+Path / catena consulting engineers / R&H Construction
Photo Marcus Kauffman



Glulam beams

Boise Cascade

SCL columns

Weyerhaeuser

Prefabricated and Precise

- Tight fabrication tolerances
- Computer Numerically Controlled (CNC)

Photo credit: naturally:wood

Photo: Structurlam

Panelized Construction

Glue-Laminated Timber (GLT)

Plank orientation

Photo: StructureCraft

Photo: Manasc Isaac Architects/Fast + Epp

Nail-Laminated Timber (NLT)

Photo: Think Wood

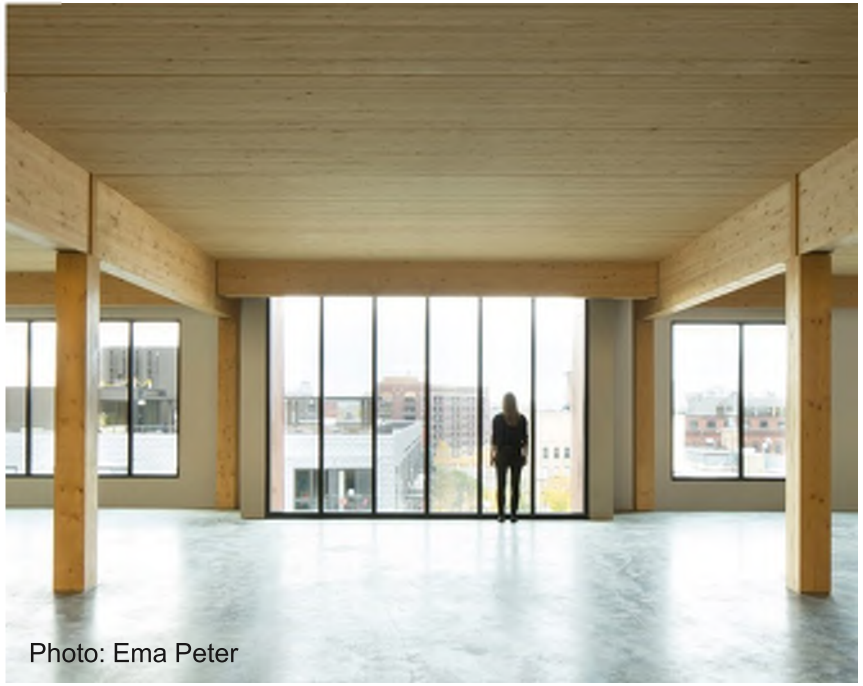


Photo: Ema Peter

Dowel-Laminated Timber (DLT)

Photo: StructureCraft

Photo: StructureCraft

Cross-Laminated Timber (CLT)

Solid sawn laminations

Photo: LendLease

Cross-Laminated Timber (CLT)

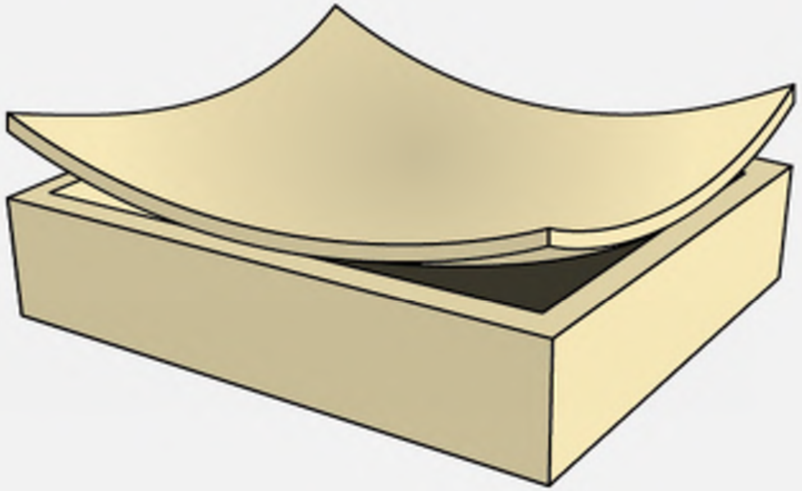
SCL laminations

Photo:
Freres Lumber

Photo: LEVER Architecture

CLT

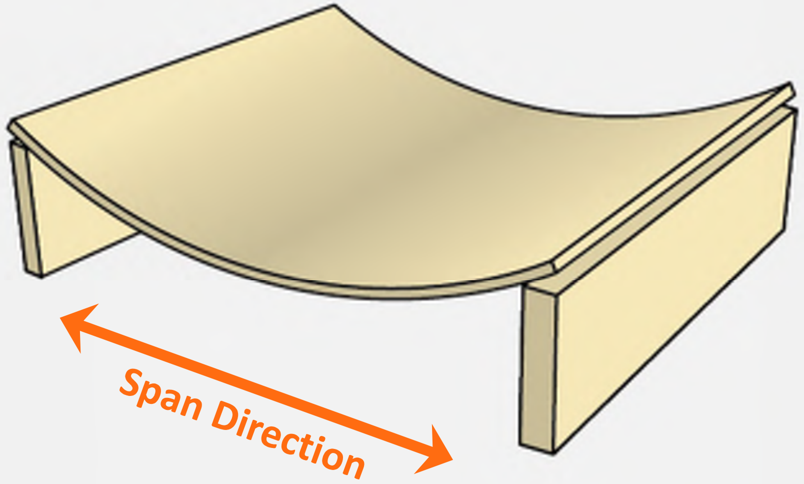
bends in two directions



Deformation of two-way slab

GLT, DLT and NLT

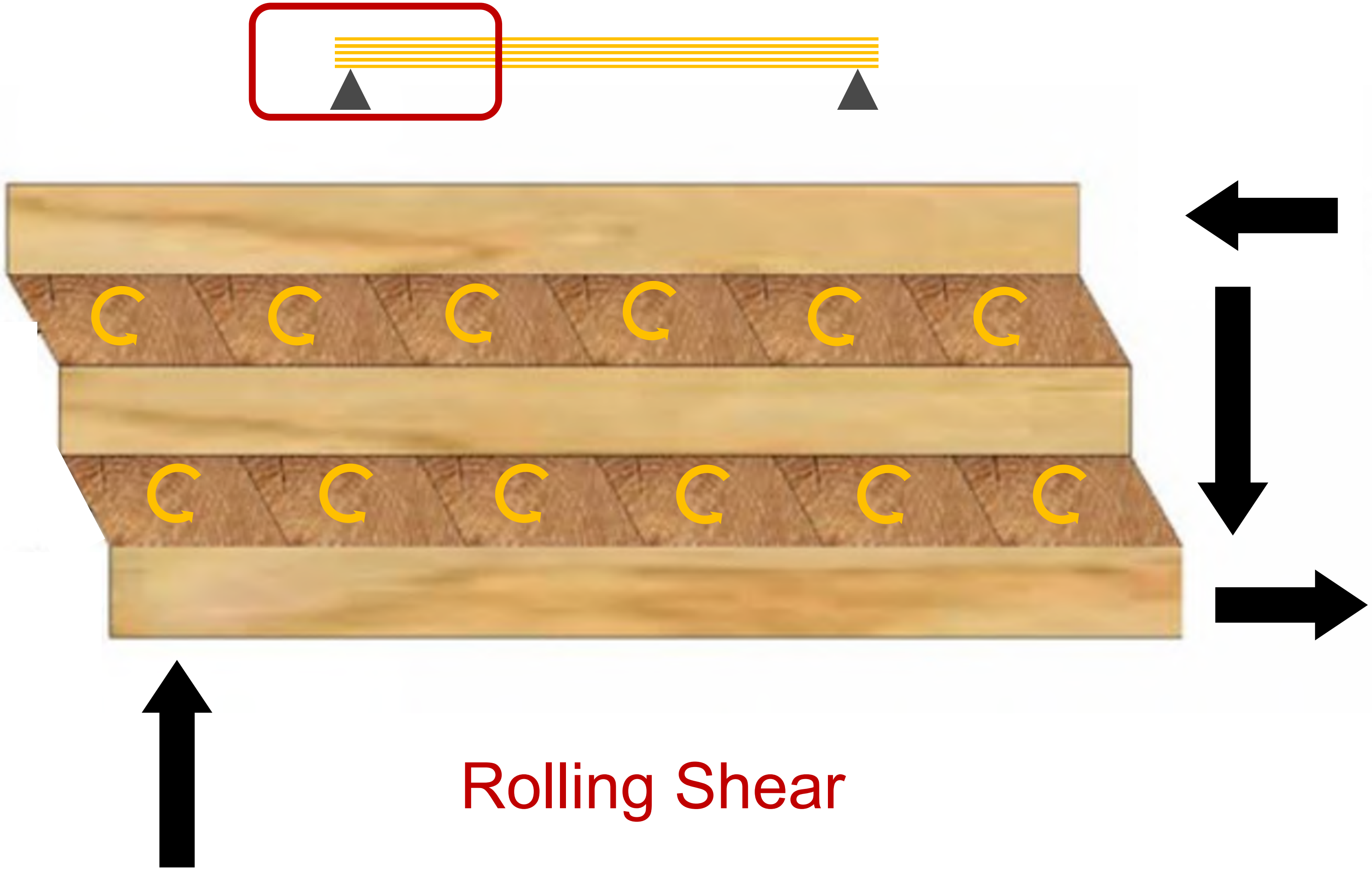
bend in one direction only



Deformation of one-way slab

Images WoodWorks

CLT Shear Deformation



Rolling Shear

Source: CSA O86-14, 2016 Supplement

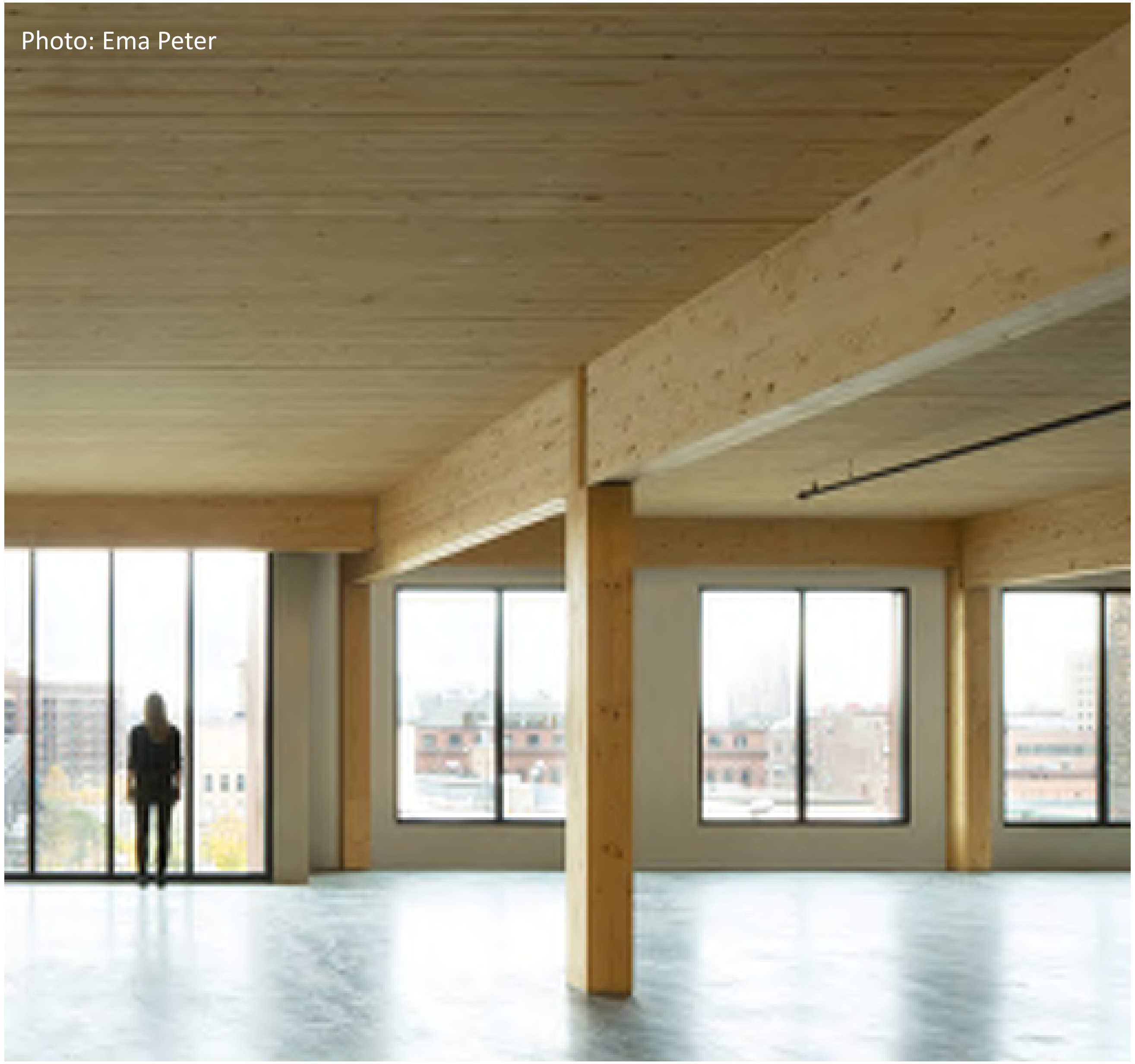


Photo: Ema Peter

POST, BEAM + PLATE


Photo: Seagate Structures

POST + PLATE

Photo: Lendlease

Photo: John Klein

HONEYCOMB

HYBRID LIGHT-FRAME + MASS TIMBER

EXPERT TIP

Hybrid Design: Mass Timber Floor and Roof Panels Over Light-Frame Wood Walls

https://www.woodworks.org/resources/hybrid-design-mass-timber-floor-and-roof-panels-over-light-frame-wood-walls/

Explores construction type and fire-resistance ratings, lateral system options, and acoustic performance

EXPERT TIP

CLT on Cold-Formed Steel Stud Bearing Walls: Engineering Tips for Hybrid Construction

Bunker Hill Housing Redevelopment – Stellata, Stantec, McNamara / Salvia, Leggat McCall Properties
Photo Bryan Maltais
https://www.woodworks.org/resources/clt-on-cold-formed-steel-stud-bearing-walls/

Considerations for mass timber floor and roof panels on cold-formed steel (CFS) stud bearing walls

LEVER Architecture, photo Jeremy Bittermann

HYBRID CONCRETE + MASS TIMBER

HYBRID CONCRETE + STEEL

Lateral Systems

Prescriptive Code Compliance:

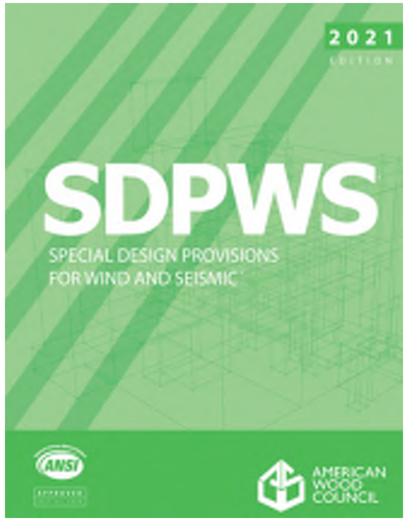
☑ Concrete Shear Walls

☑ Steel Braced Frames

☑ Light Frame Wood Shear Walls (65 ft max)

☑ CLT Shear Walls (65 ft max) –

Per 2021 SDPWS/ASCE 7-22

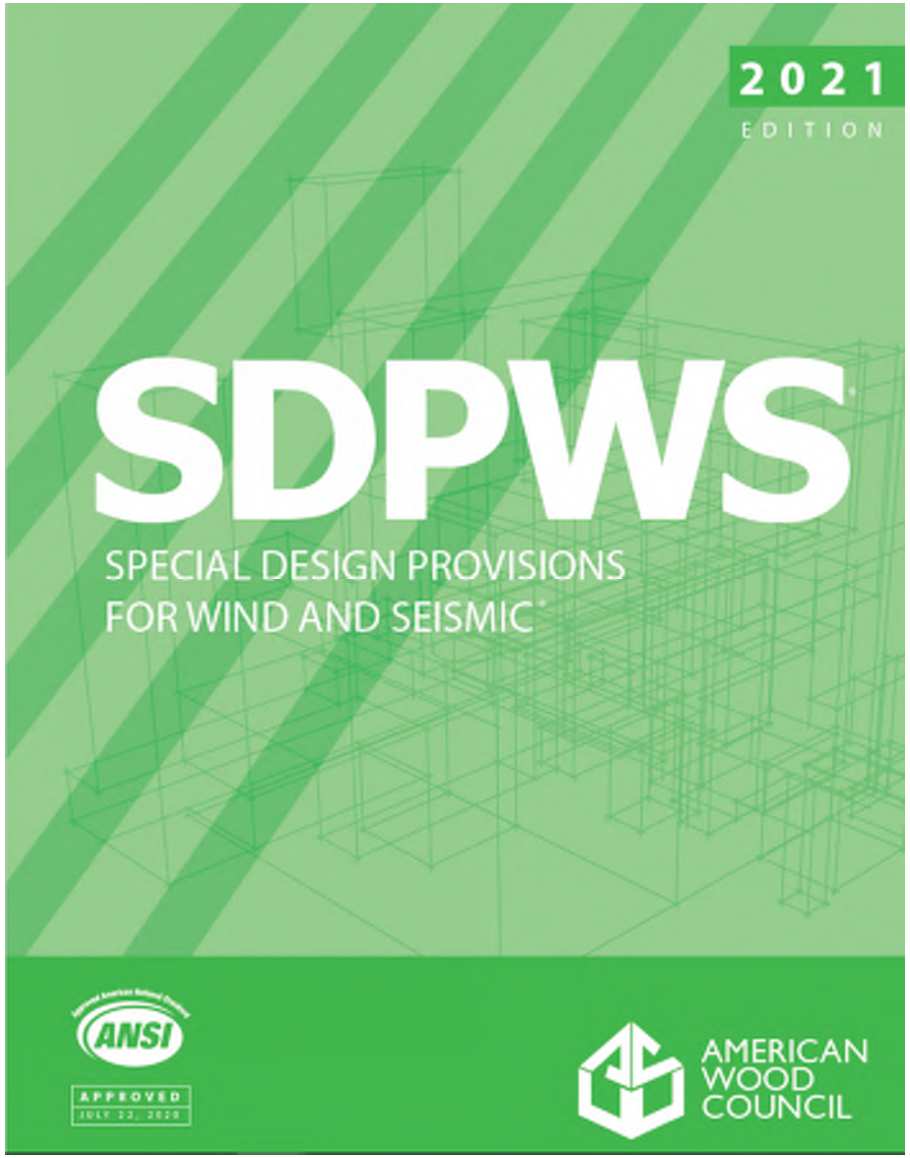


2021 Special Design Provisions for Wind and Seismic

Top Changes Relevant to CLT Lateral Systems:

- New unified nominal shear capacity
- New CLT Shear Wall requirements
- New CLT Diaphragm requirements

View for free at awc.org

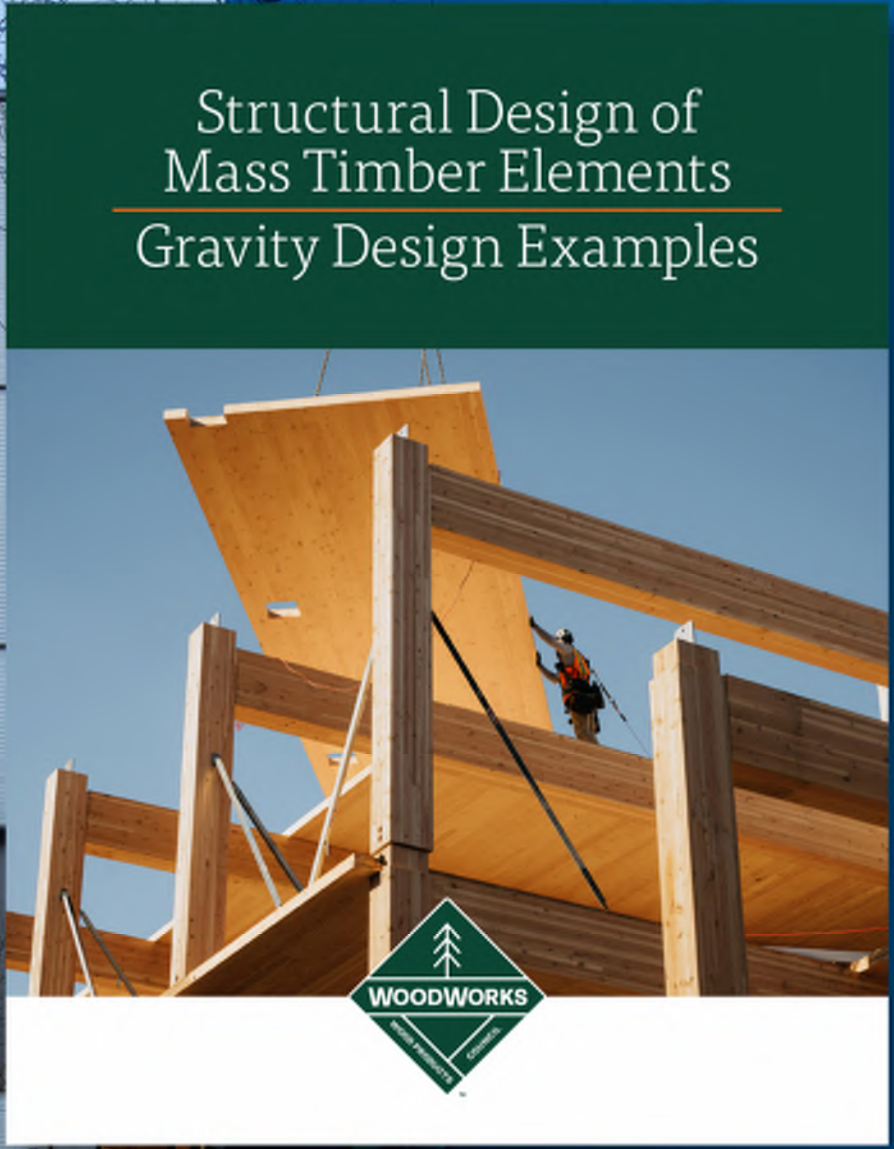


Agenda – Part 1

- Introduction to Wood
- Mass Timber Products and Systems
- **Structural Design – Gravity**

Photo: John Stamets

Thesis / LEVER Architecture / Holmes / Swinerton
Photo: Lara Swimmer



Structural Design of Mass Timber Elements

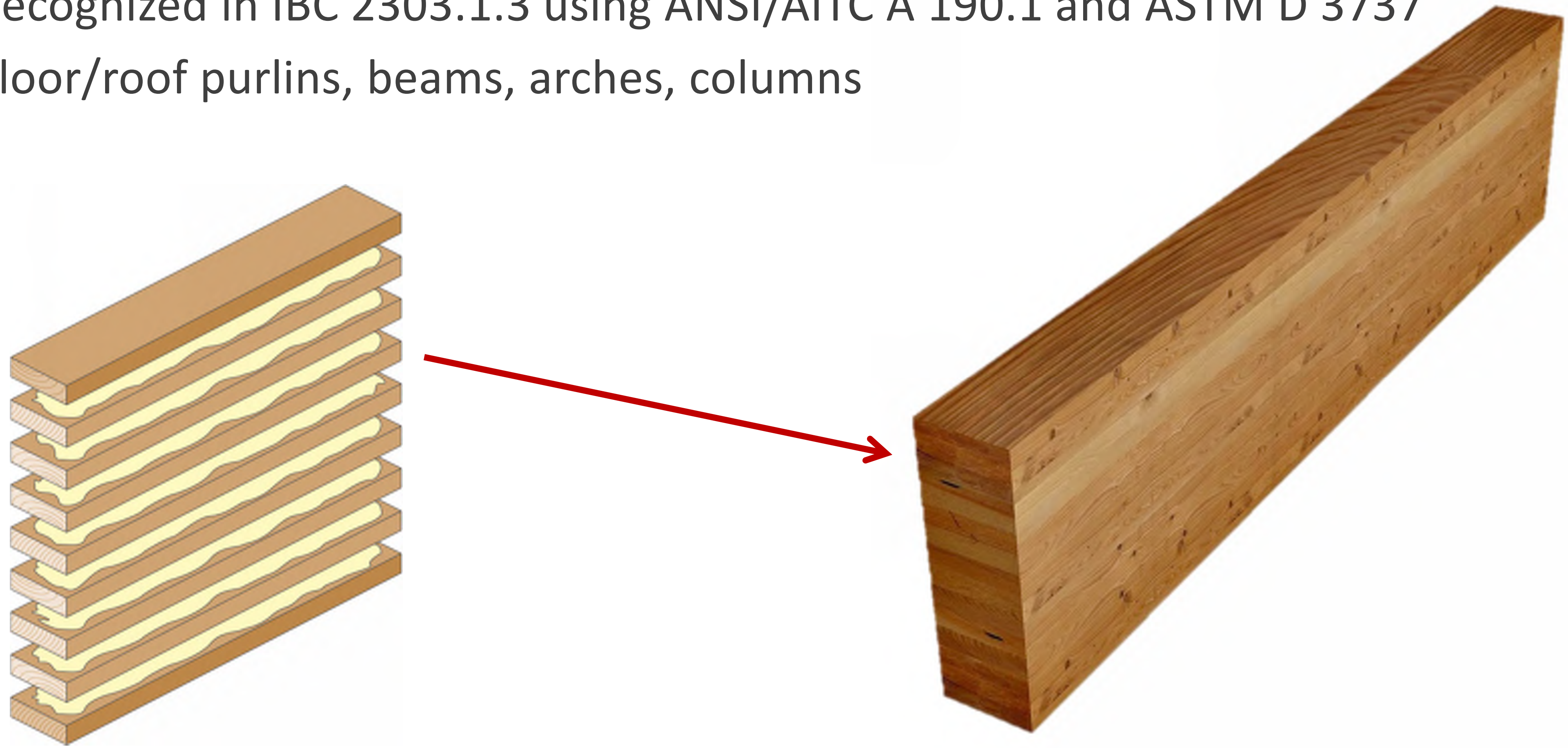
Gravity Design Examples

https://www.woodworks.org/resources/structural-design-of-mass-timber-elements-gravity-design-examples/

Glulam

Glulam = structural composite of lumber and adhesives

- Recognized in IBC 2303.1.3 using ANSI/AITC A 190.1 and ASTM D 3737
- Floor/roof purlins, beams, arches, columns



Glulam Specs

Typical Widths

- 3-1/8”, 3-1/2”, 5-1/8”, 5-1/2”, 6-3/4”, 8-3/4”, 10-3/4”, 12-1/4”

Typical Depths

- Based on number of lams: 6” to 60”+
- Western species lams: Typically 1-1/2” thick
- Southern pine lams: Typically 1-3/8” thick

Typical Species

- Douglas-Fir, Southern Pine, Spruce
- Also available in Cedar & others

FIGURE 1

BEAM CROSS SECTION

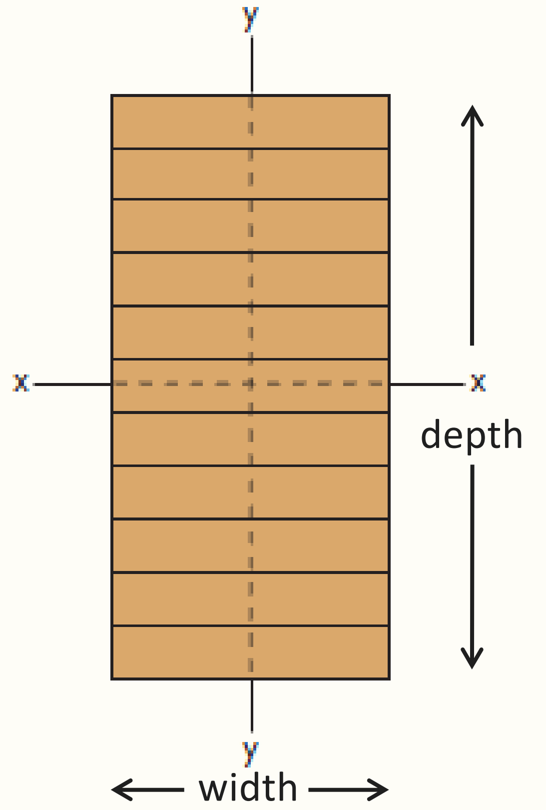


Image: APA Glulam Product Guide

Glulam Built-Up Sections

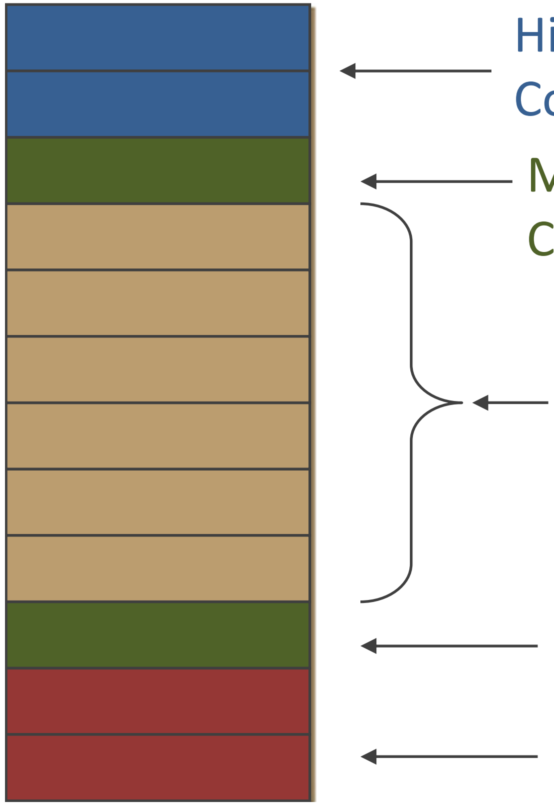
Built-Up Sections:

- Available from some manufacturers
- Widths of 24”+ available

Photo: Unalam

Glulam Layup – Balanced & Unbalanced

Image: APA



High Strength Outer Compression Lams

Medium Grade Inner Compression Lam

Lower Grade Inner Lams

Medium Grade Inner Compression Lam

High Strength Outer Tension Lams

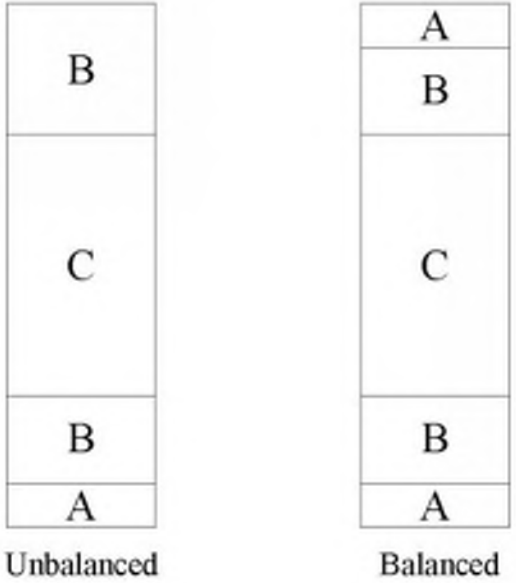
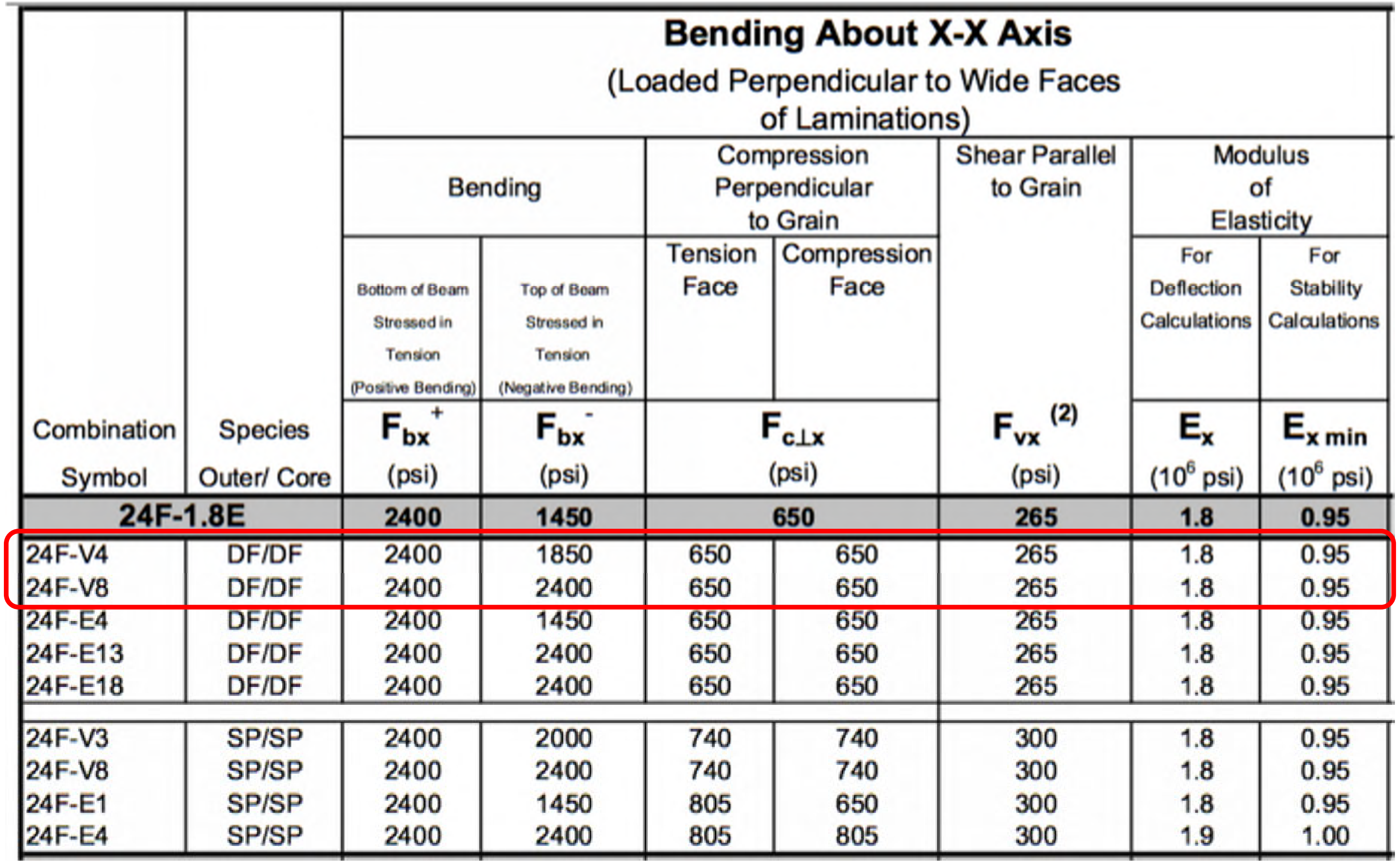
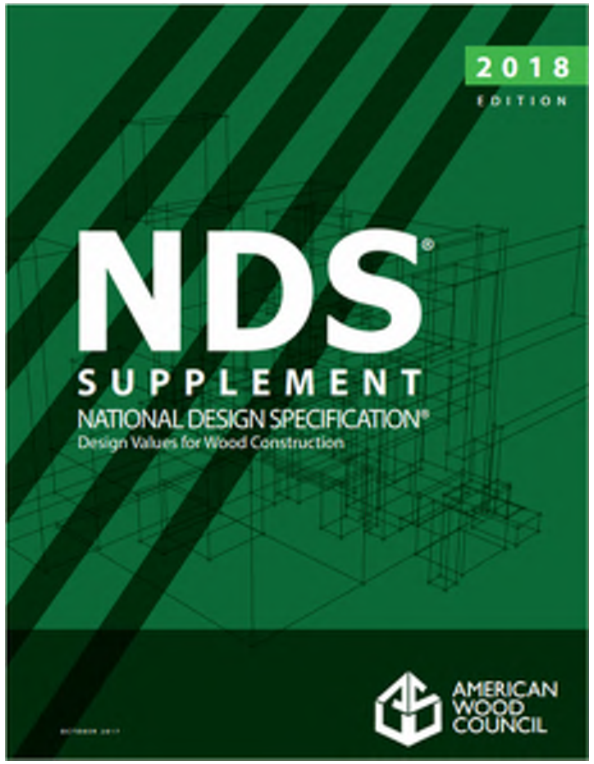


Image: AITC

Glulam Design Values: Table 5A



		Bending About X-X Axis (Loaded Perpendicular to Wide Faces of Laminations)						
		Bending		Compression Perpendicular to Grain		Shear Parallel to Grain	Modulus of Elasticity	
		Bottom of Beam Stressed in Tension (Positive Bending)	Top of Beam Stressed in Tension (Negative Bending)	Tension Face	Compression Face		For Deflection Calculations	For Stability Calculations
Combination Symbol	Species Outer/ Core	F_{bx}^{+} (psi)	F_{bx}^{-} (psi)	$F_{c\perp x}$ (psi)		F_{vx} (2) (psi)	E_x (10^6 psi)	$E_{x\,min}$ (10^6 psi)
24F-1.8E		**2400**	**1450**	**650**		**265**	**1.8**	**0.95**
24F-V4	DF/DF	2400	1850	650	650	265	1.8	0.95
24F-V8	DF/DF	2400	2400	650	650	265	1.8	0.95
24F-E4	DF/DF	2400	1450	650	650	265	1.8	0.95
24F-E13	DF/DF	2400	2400	650	650	265	1.8	0.95
24F-E18	DF/DF	2400	2400	650	650	265	1.8	0.95
24F-V3	SP/SP	2400	2000	740	740	300	1.8	0.95
24F-V8	SP/SP	2400	2400	740	740	300	1.8	0.95
24F-E1	SP/SP	2400	1450	805	650	300	1.8	0.95
24F-E4	SP/SP	2400	2400	805	805	300	1.9	1.00



Source: NDS Supplement Table 5A

Structural Wood Design: Capacity

Adjustment Factors:

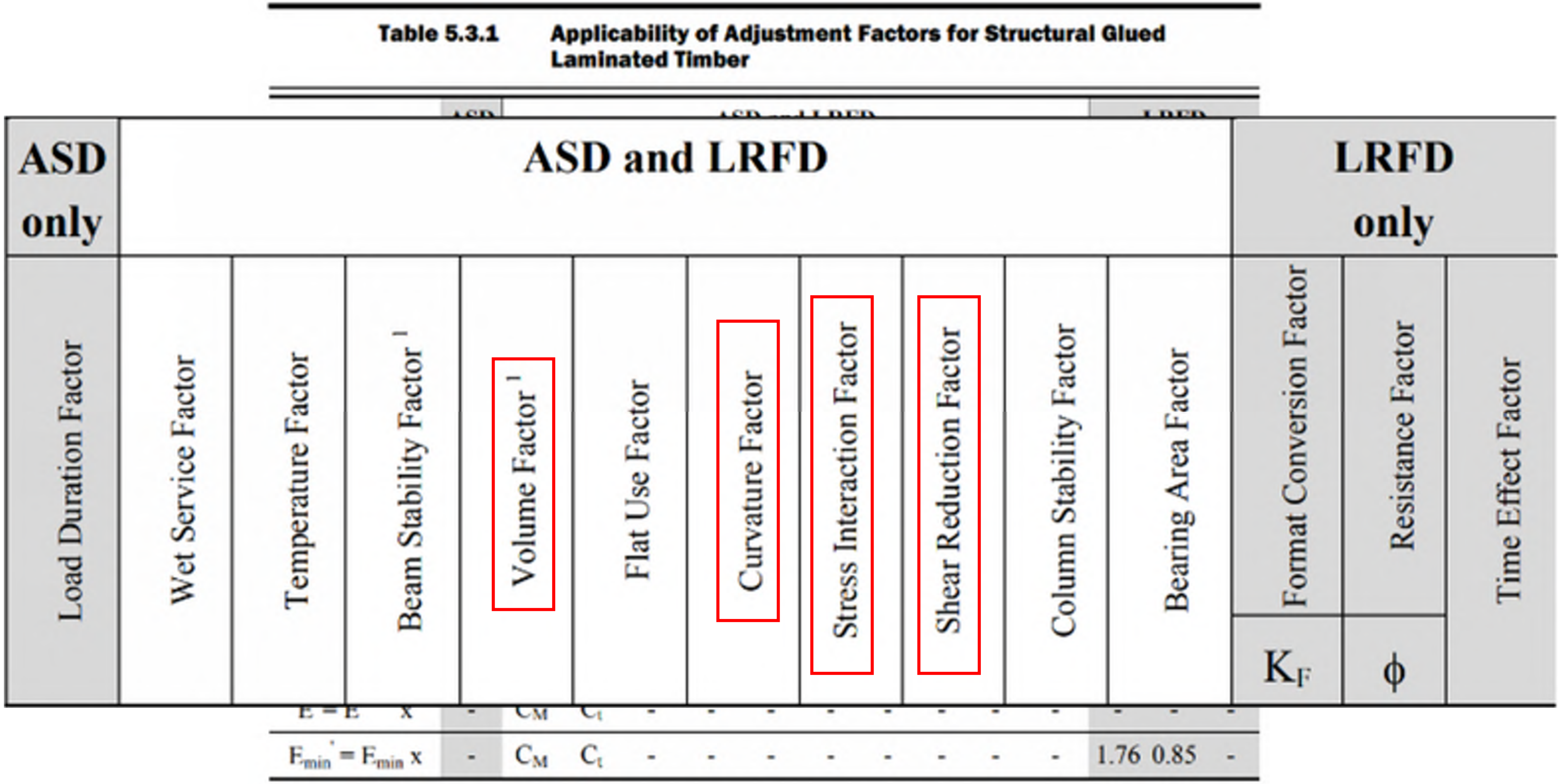


Table 5.3.1 Applicability of Adjustment Factors for Structural Glued Laminated Timber

	ASD only	ASD and LRFD										LRFD only		
	Load Duration Factor	Wet Service Factor	Temperature Factor	Beam Stability Factor[1]	Volume Factor[1]	Flat Use Factor	Curvature Factor	Stress Interaction Factor	Shear Reduction Factor	Column Stability Factor	Bearing Area Factor	Format Conversion Factor K_F	Resistance Factor ϕ	Time Effect Factor
$E = E$ x	-	C_M	C_t	-	-	-	-	-	-	-	-	-	-	-
$E_{min}' = E_{min}$ x	-	C_M	C_t	-	-	-	-	-	-	-	-	1.76	0.85	-

AWC NDS, 2018

Glulam Camber

- Can be manufactured with camber
- Recommended camber:
  - 1.0 to 1.5 x calculated Dead Load deflection

FIGURE 2

BEAM CAMBER PARAMETERS

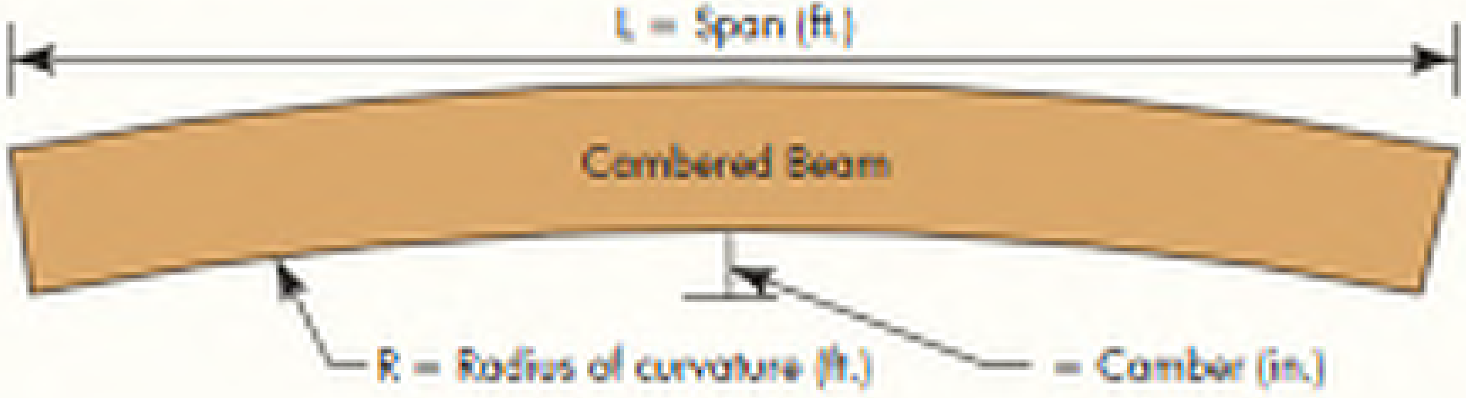
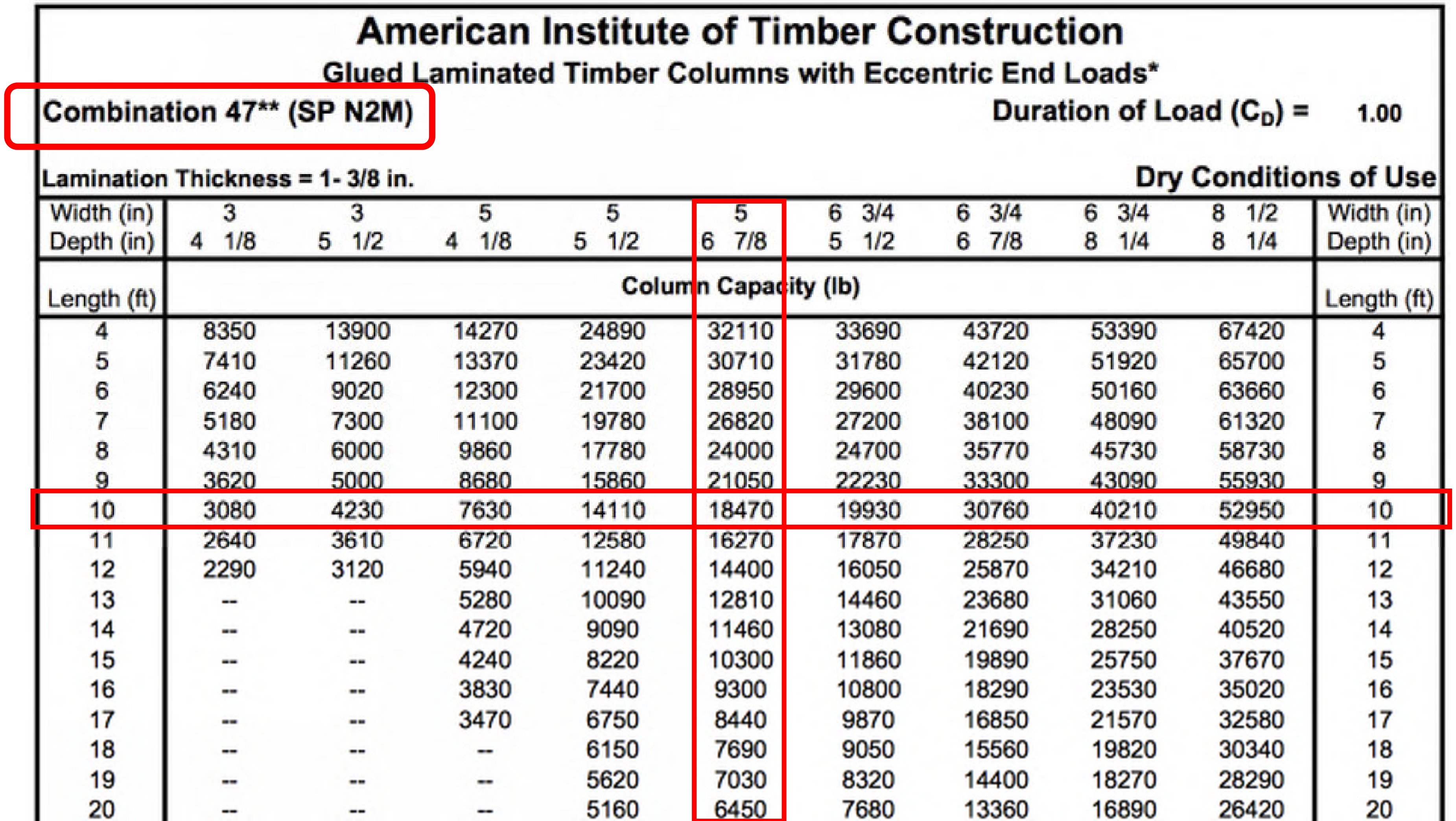


Image: APA Glulam Product Guide

Glulam Column Capacities

AMERICAN INSTITUTE OF TIMBER CONSTRUCTION

AITC Column Capacity Tables
http://www.aitc-glulam.org/column.asp



American Institute of Timber Construction

Glued Laminated Timber Columns with Eccentric End Loads*

Combination 47 (SP N2M)** Duration of Load (C_D) = 1.00

Lamination Thickness = 1- 3/8 in. **Dry Conditions of Use**

Width (in)	3	3	5	5	5	6 3/4	6 3/4	6 3/4	8 1/2	Width (in)
Depth (in)	4 1/8	5 1/2	4 1/8	5 1/2	6 7/8	5 1/2	6 7/8	8 1/4	8 1/4	Depth (in)
Length (ft)	Column Capacity (lb)									Length (ft)
4	8350	13900	14270	24890	32110	33690	43720	53390	67420	4
5	7410	11260	13370	23420	30710	31780	42120	51920	65700	5
6	6240	9020	12300	21700	28950	29600	40230	50160	63660	6
7	5180	7300	11100	19780	26820	27200	38100	48090	61320	7
8	4310	6000	9860	17780	24000	24700	35770	45730	58730	8
9	3620	5000	8680	15860	21050	22230	33300	43090	55930	9
10	3080	4230	7630	14110	18470	19930	30760	40210	52950	10
11	2640	3610	6720	12580	16270	17870	28250	37230	49840	11
12	2290	3120	5940	11240	14400	16050	25870	34210	46680	12
13	--	--	5280	10090	12810	14460	23680	31060	43550	13
14	--	--	4720	9090	11460	13080	21690	28250	40520	14
15	--	--	4240	8220	10300	11860	19890	25750	37670	15
16	--	--	3830	7440	9300	10800	18290	23530	35020	16
17	--	--	3470	6750	8440	9870	16850	21570	32580	17
18	--	--	--	6150	7690	9050	15560	19820	30340	18
19	--	--	--	5620	7030	8320	14400	18270	28290	19
20	--	--	--	5160	6450	7680	13360	16890	26420	20

Glue Laminated Timber (GLT) Panels

Photo credit: Structure Fusion

Photo credit: Unalam

Glue Laminated Timber (GLT) Panels

- Design values for bending in NDS Supplement
- Beam Layup combinations optimized for beams, not GLT deckings

Image source: StructureCraft

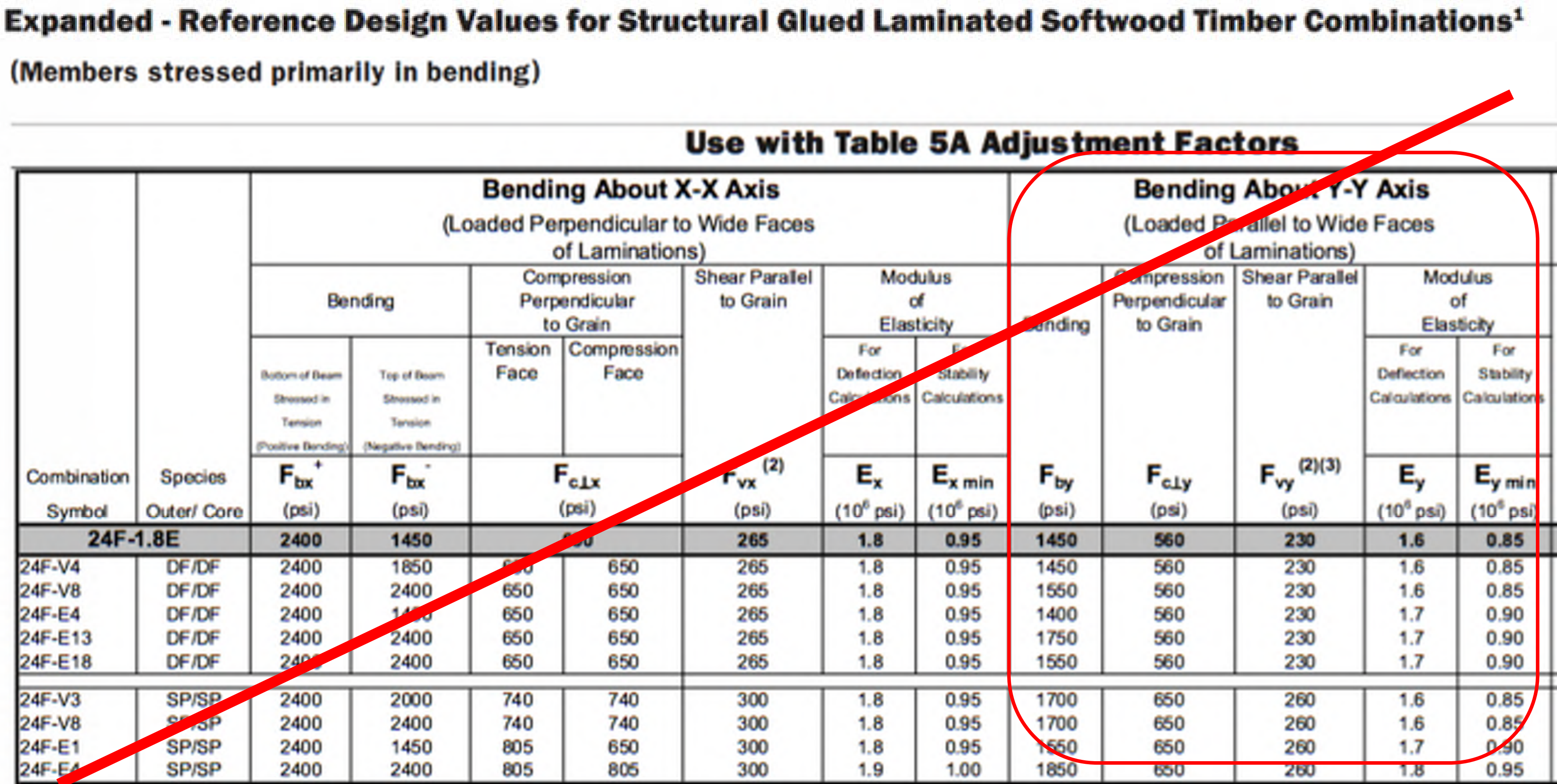


Table 5A Expanded - Reference Design Values for Structural Glued Laminated Softwood Timber Combinations[1]

(Members stressed primarily in bending)

Use with Table 5A Adjustment Factors

		Bending About X-X Axis (Loaded Perpendicular to Wide Faces of Laminations)							Bending About Y-Y Axis (Loaded Parallel to Wide Faces of Laminations)				
		Bending		Compression Perpendicular to Grain		Shear Parallel to Grain	Modulus of Elasticity		Bending	Compression Perpendicular to Grain	Shear Parallel to Grain	Modulus of Elasticity	
		Bottom of Beam Stressed in Tension (Positive Bending)	Top of Beam Stressed in Tension (Negative Bending)	Tension Face	Compression Face		For Deflection Calculations	For Stability Calculations				For Deflection Calculations	For Stability Calculations
Combination Symbol	Species Outer/ Core	F_{bx}^{+} (psi)	F_{bx}^{-} (psi)	$F_{c\perp x}$ (psi)		F_{vx} (2) (psi)	E_x (10^6 psi)	$E_{x\,min}$ (10^6 psi)	F_{by} (psi)	$F_{c\perp y}$ (psi)	F_{vy} (2)(3) (psi)	E_y (10^6 psi)	$E_{y\,min}$ (10^6 psi)
24F-1.8E		**2400**	**1450**	**650**		**265**	**1.8**	**0.95**	**1450**	**560**	**230**	**1.6**	**0.85**
24F-V4	DF/DF	2400	1850	650	650	265	1.8	0.95	1450	560	230	1.6	0.85
24F-V8	DF/DF	2400	2400	650	650	265	1.8	0.95	1550	560	230	1.6	0.85
24F-E4	DF/DF	2400	1450	650	650	265	1.8	0.95	1400	560	230	1.7	0.90
24F-E13	DF/DF	2400	2400	650	650	265	1.8	0.95	1750	560	230	1.7	0.90
24F-E18	DF/DF	2400	2400	650	650	265	1.8	0.95	1550	560	230	1.7	0.90
24F-V3	SP/SP	2400	2000	740	740	300	1.8	0.95	1700	650	260	1.6	0.85
24F-V8	SP/SP	2400	2400	740	740	300	1.8	0.95	1700	650	260	1.6	0.85
24F-E1	SP/SP	2400	1450	805	650	300	1.8	0.95	1550	650	260	1.7	0.90
24F-E4	SP/SP	2400	2400	805	805	300	1.9	1.00	1850	650	260	1.8	0.95

Glue Laminated Timber (GLT) Panels

- Design values for bending in NDS Supplement
- Beam Layup combinations optimized for beams, not GLT deckings

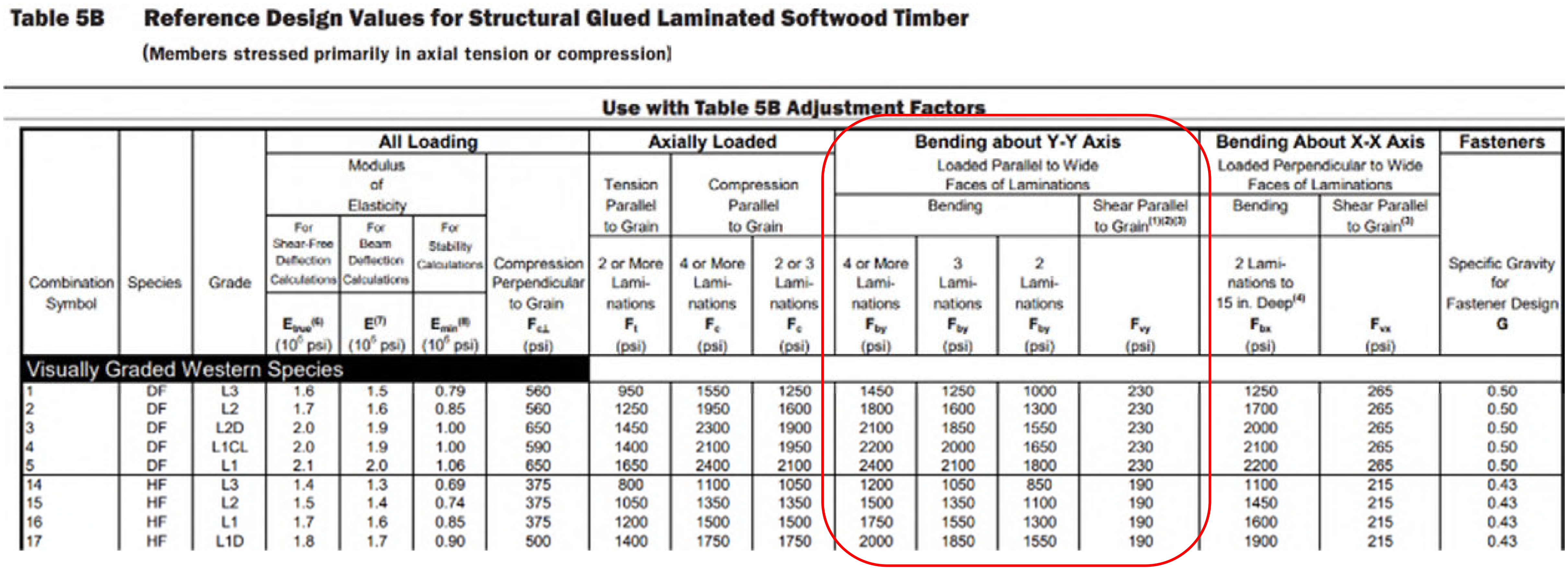


Table 5B **Reference Design Values for Structural Glued Laminated Softwood Timber**

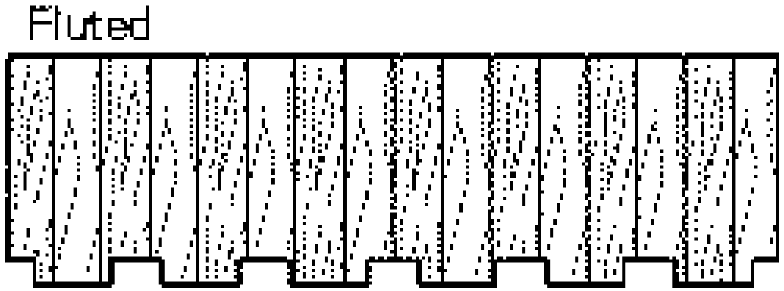
(Members stressed primarily in axial tension or compression)

Use with Table 5B Adjustment Factors

			All Loading				Axially Loaded			Bending about Y-Y Axis				Bending About X-X Axis		Fasteners
			Modulus of Elasticity				Tension Parallel to Grain	Compression Parallel to Grain		Loaded Parallel to Wide Faces of Laminations				Loaded Perpendicular to Wide Faces of Laminations		
			For Shear-Free Deflection Calculations	For Beam Deflection Calculations	For Stability Calculations					Bending			Shear Parallel to Grain$^{(1)(2)(3)}$	Bending	Shear Parallel to Grain$^{(3)}$	
Combination Symbol	Species	Grade	$E_{true}^{(6)}$ (10^6 psi)	$E^{(7)}$ (10^6 psi)	$E_{min}^{(8)}$ (10^6 psi)	Compression Perpendicular to Grain $F_{c\perp}$ (psi)	2 or More Laminations F_t (psi)	4 or More Laminations F_c (psi)	2 or 3 Laminations F_c (psi)	4 or More Laminations F_{by} (psi)	3 Laminations F_{by} (psi)	2 Laminations F_{by} (psi)	F_{vy} (psi)	2 Laminations to 15 in. Deep$^{(4)}$ F_{bx} (psi)	F_{vx} (psi)	Specific Gravity for Fastener Design G
Visually Graded Western Species																
1	DF	L3	1.6	1.5	0.79	560	950	1550	1250	1450	1250	1000	230	1250	265	0.50
2	DF	L2	1.7	1.6	0.85	560	1250	1950	1600	1800	1600	1300	230	1700	265	0.50
3	DF	L2D	2.0	1.9	1.00	650	1450	2300	1900	2100	1850	1550	230	2000	265	0.50
4	DF	L1CL	2.0	1.9	1.00	590	1400	2100	1950	2200	2000	1650	230	2100	265	0.50
5	DF	L1	2.1	2.0	1.06	650	1650	2400	2100	2400	2100	1800	230	2200	265	0.50
14	HF	L3	1.4	1.3	0.69	375	800	1100	1050	1200	1050	850	190	1100	215	0.43
15	HF	L2	1.5	1.4	0.74	375	1050	1350	1350	1500	1350	1100	190	1450	215	0.43
16	HF	L1	1.7	1.6	0.85	375	1200	1500	1500	1750	1550	1300	190	1600	215	0.43
17	HF	L1D	1.8	1.7	0.90	500	1400	1750	1750	2000	1850	1550	190	1900	215	0.43

Glue Laminated Timber (GLT) Panels

- Gap panels to allow movement
- Cover with wood structural panel for blocked, sheathed diaphragm
- Available in variety of lamination options



Nail Laminated Timber (NLT) Panels

Photo: Think Wood

Construction options:

- On-site/ in-place

Photo Credit:
John Stamets

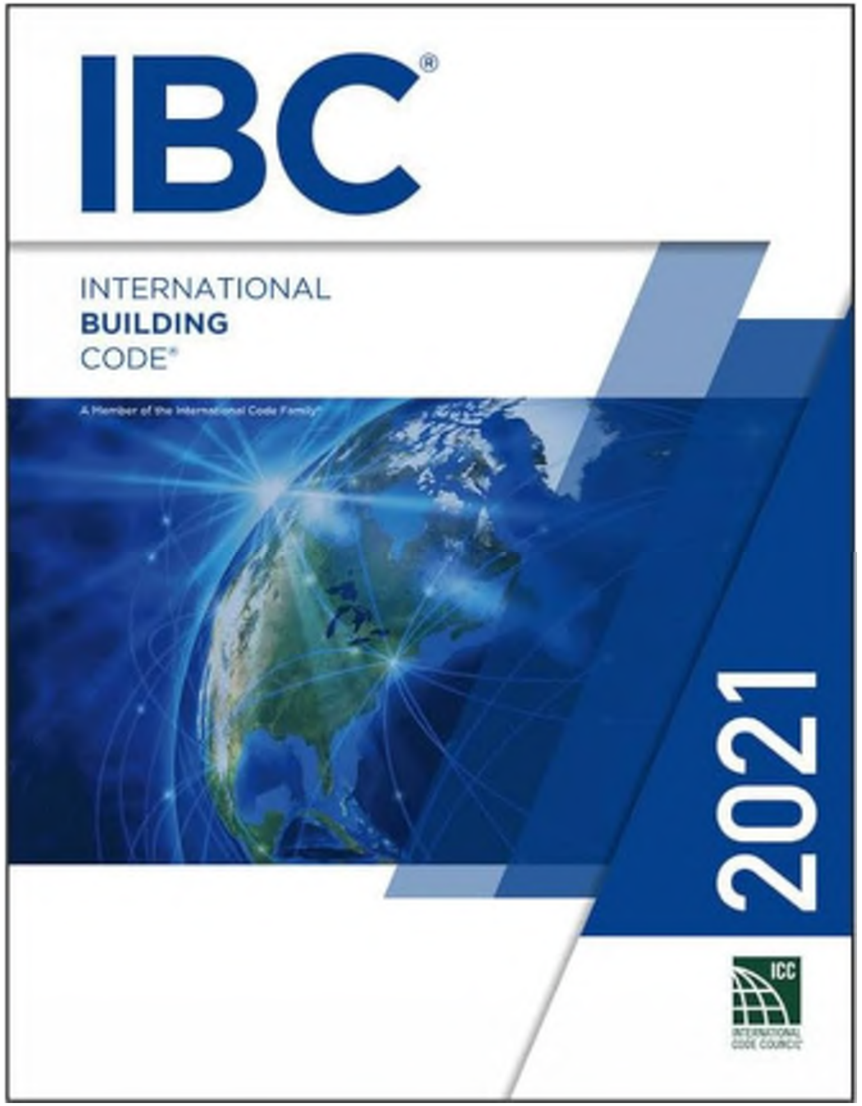
- Prefabricated offsite

Photo Credit:
StructureCraft

Nail Laminated Timber (NLT) Panels

When does the code allow it to be used?

- IBC defines NLT as mechanically laminated decking per IBC 2304.9.3
- Permitted anywhere that combustible materials and heavy timber are allowed, plus more



Nail Laminated Timber (NLT) Panels

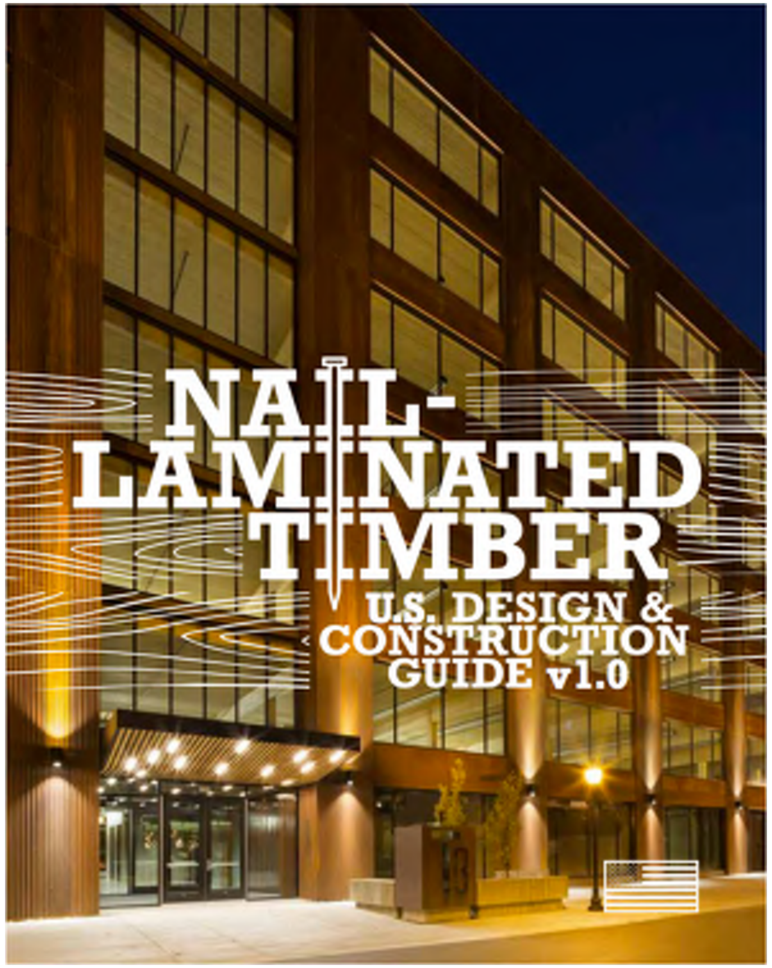
- Cover with wood structural panel for blocked, sheathed diaphragm
- Leave one ply out per 8’-10’ wide panel
- Can vary lamination depths for fluted panels

Photo credit: StructureCraft Builders

Nail Laminated Timber (NLT) Panels

Content includes:

- Architecture
- Fire
- Structure
- Enclosure
- Supply and Fabrication
- Construction and Installation
- Erection engineering
- Free download at www.thinkwood.com/nltguide



Dowel Laminated Timber (DLT)

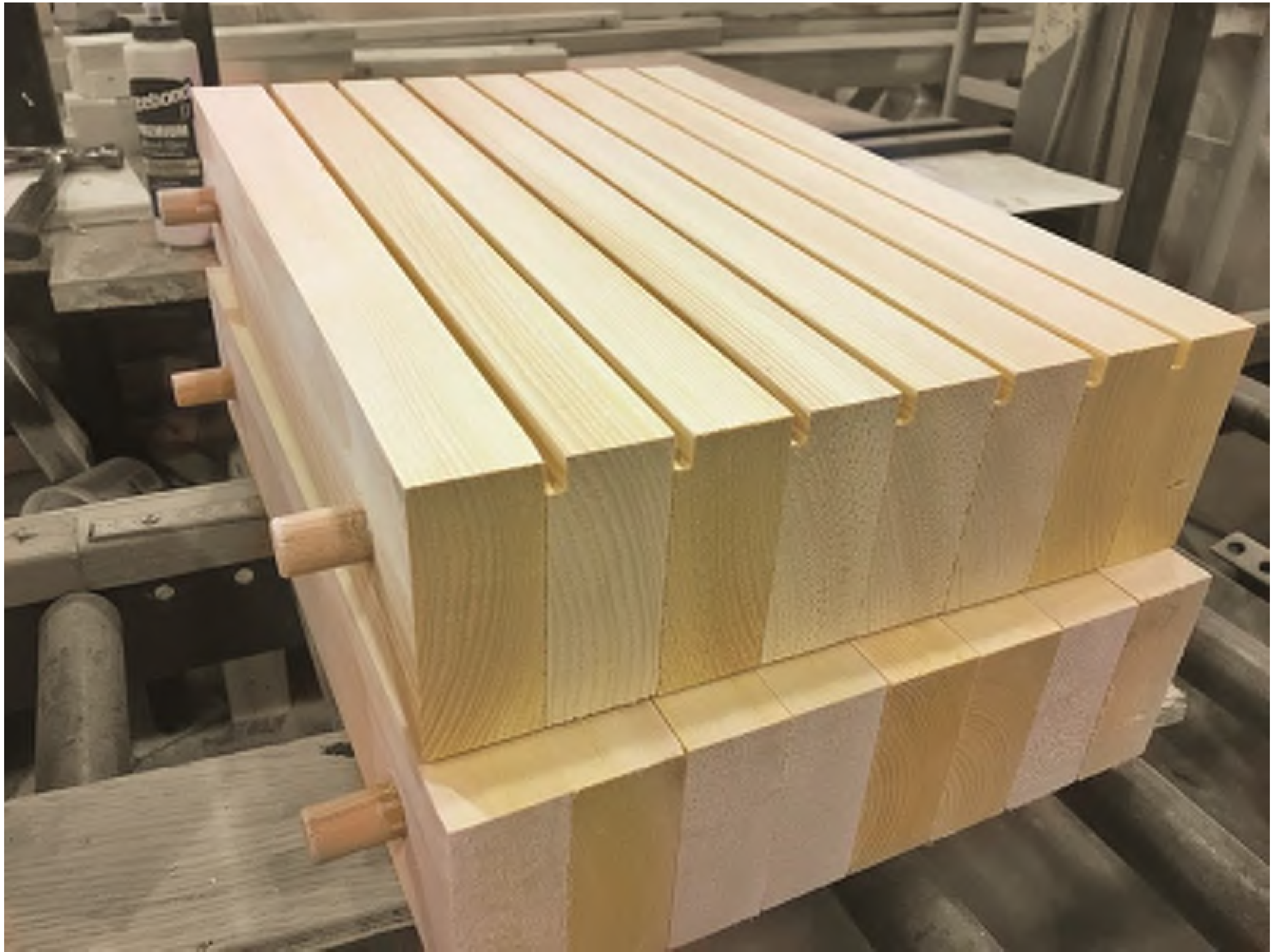


Photo credit: StructureCraft Builders

Dowel Laminated Timber (DLT) Panels

What is it?

- Similar to NLT
  - Dowels instead of Nails connecting lams
- Not recognized in IBC
- Sheath with wood structural panel

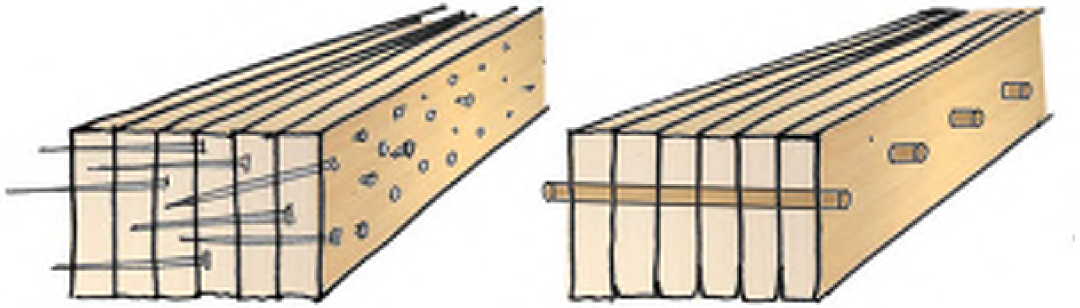


Photo credit: StructureCraft

Dowel Laminated Timber (DLT) Panels

- Resources:
  - DLT Design Guides from Manufacturers
  - Timber Framers Guild (for dowel design)

DESIGN AND PROFILE GUIDE

Dowel Laminated Timber

THE ALL WOOD MASS TIMBER PANEL

Credit: StructureCraft

Cross Laminated Timber (CLT)

Cross Laminated Timber (CLT) Resources

CLT Handbook

CROSS-LAMINATED TIMBER

US EDITION

FPInnovations

Canadian CLT Handbook

2019 EDITION

VOLUME 1

CLT

Edited by:
Erol Karacabeyli
Sylvain Gagnon

fpinnovations.ca

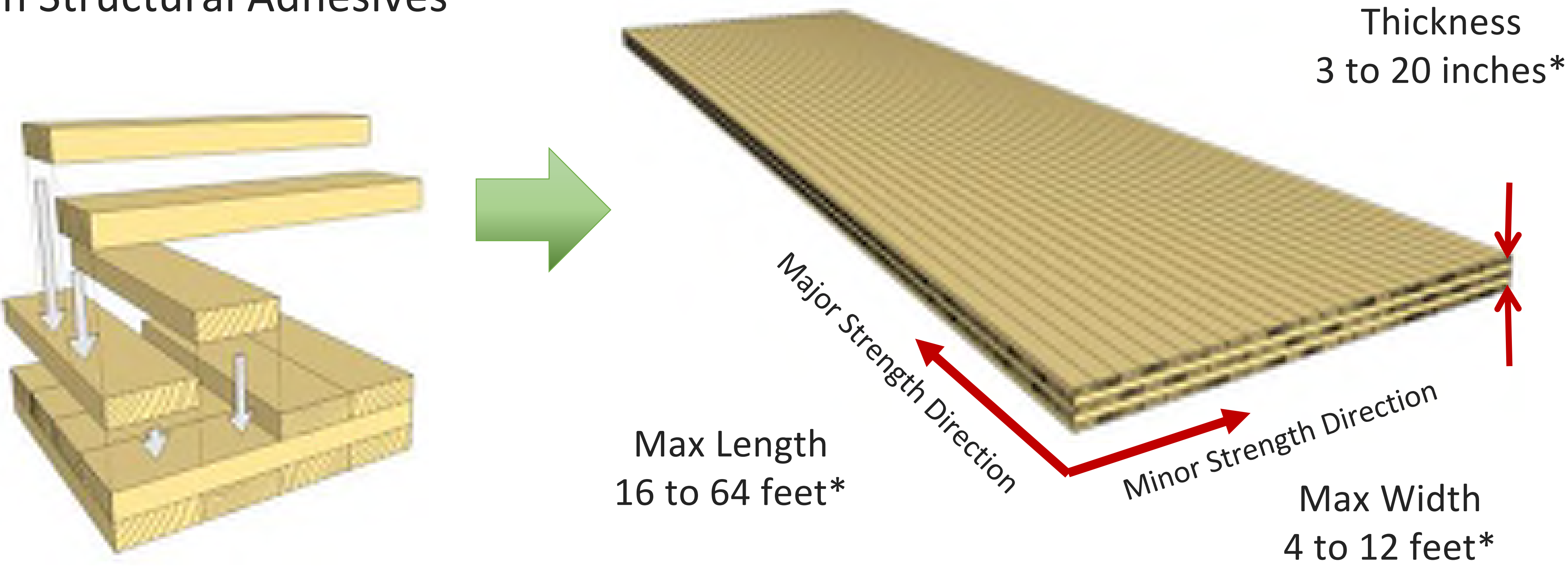
What is CLT?

3+ layers of laminations

Solid Sawn or **Structural Composite Lumber (SCL) Laminations**

Cross-Laminated Layup

Glued with Structural Adhesives



Thickness
3 to 20 inches*

Major Strength Direction

Minor Strength Direction

Max Length
16 to 64 feet*

Max Width
4 to 12 feet*

*All dimensions are approximate. Consult with manufacturers

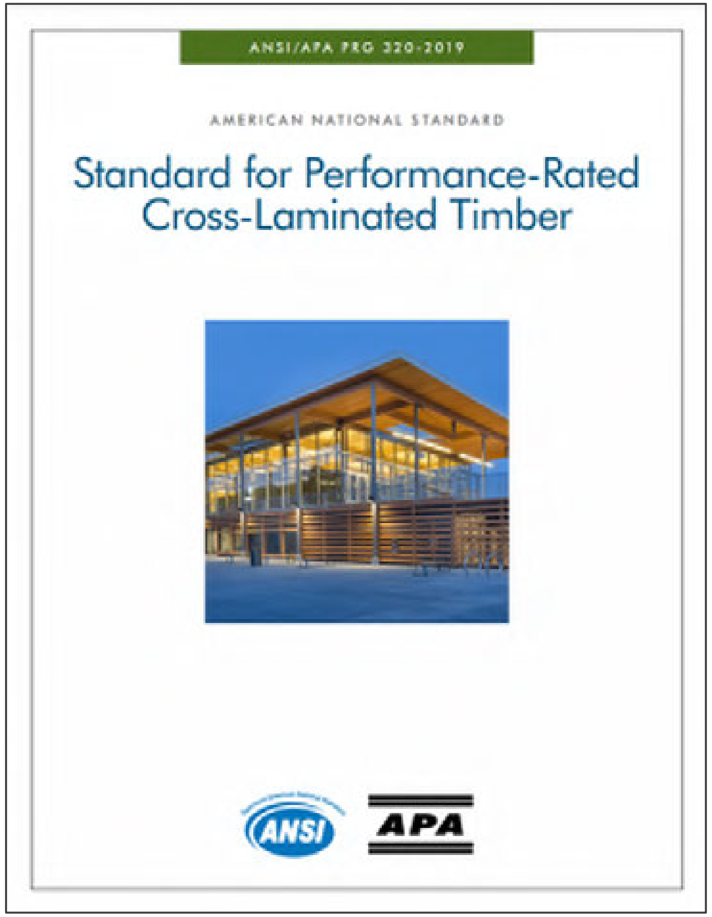
SCL Cross-Laminated Timber


Photo: LEVER Architecture


Photo: Freres Lumber

Cross Laminated Timber (CLT) Standards

- ANSI / APA PRG 320 Standard

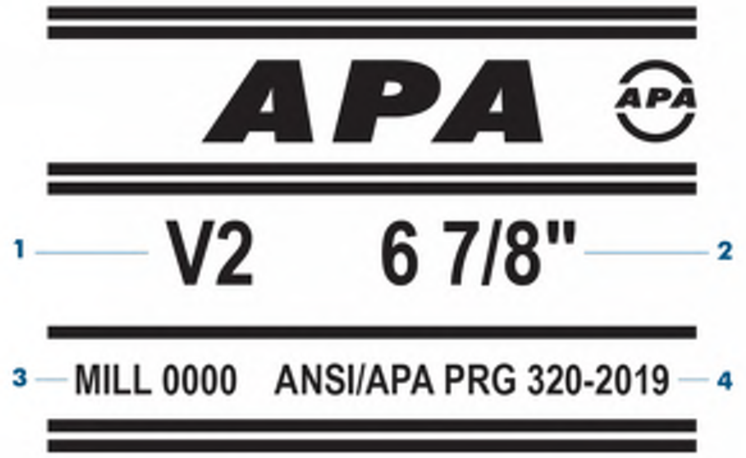


ANSI/APA PRG 320-2019

AMERICAN NATIONAL STANDARD

Standard for Performance-Rated Cross-Laminated Timber

CLT Trademark Example:



1. Grade qualified in accordance with ANSI/APA PRG 320.
2. Product thickness.
3. APA mill number.
4. Referenced product standard.

Source: Structure Magazine, April 2022

CLT Basic Stress Grades

CLT Grade	Major Strength Direction	Minor Strength Direction
E1	1950f-1.7E MSR SPF	#3 Spruce Pine Fir
E2	1650f-1.5E MSR DFL	#3 Doug Fir Larch
E3	1200f-1.2E MSR Misc	#3 Misc
E4	1950f-1.7E MSR SP	#3 Southern Pine
E5	1650f-1.5E MSR Hem-Fir	#3 Hem-Fir
V1	#2 Doug Fir Larch	#3 Doug Fir Larch
V1(N)	#2 Doug-Fir Larch (North)	#3 Doug-Fir Larch (North)
V2	#1/#2 Spruce Pine Fir	#3 Spruce Pine Fir
V3	#2 Southern Pine	#3 Southern Pine
V4	#2 Spruce Pine Fir (South)	#3 Spruce Pine Fir (South)
V5	#2 Hem-Fir	#3 Hem-Fir

Basic solid sawn CLT stress grade in PRG 320-2019.

Other custom stress grades including structural composite lumber (SCL) permitted

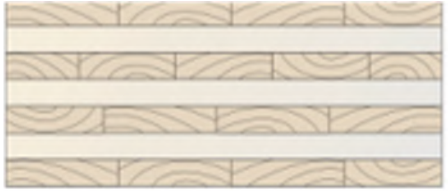
Cross Laminated Timber (CLT) Common Layups

Most Designs
Least $/sf

3-ply 3-layer

5-ply 5-layer

7-ply 7-layer

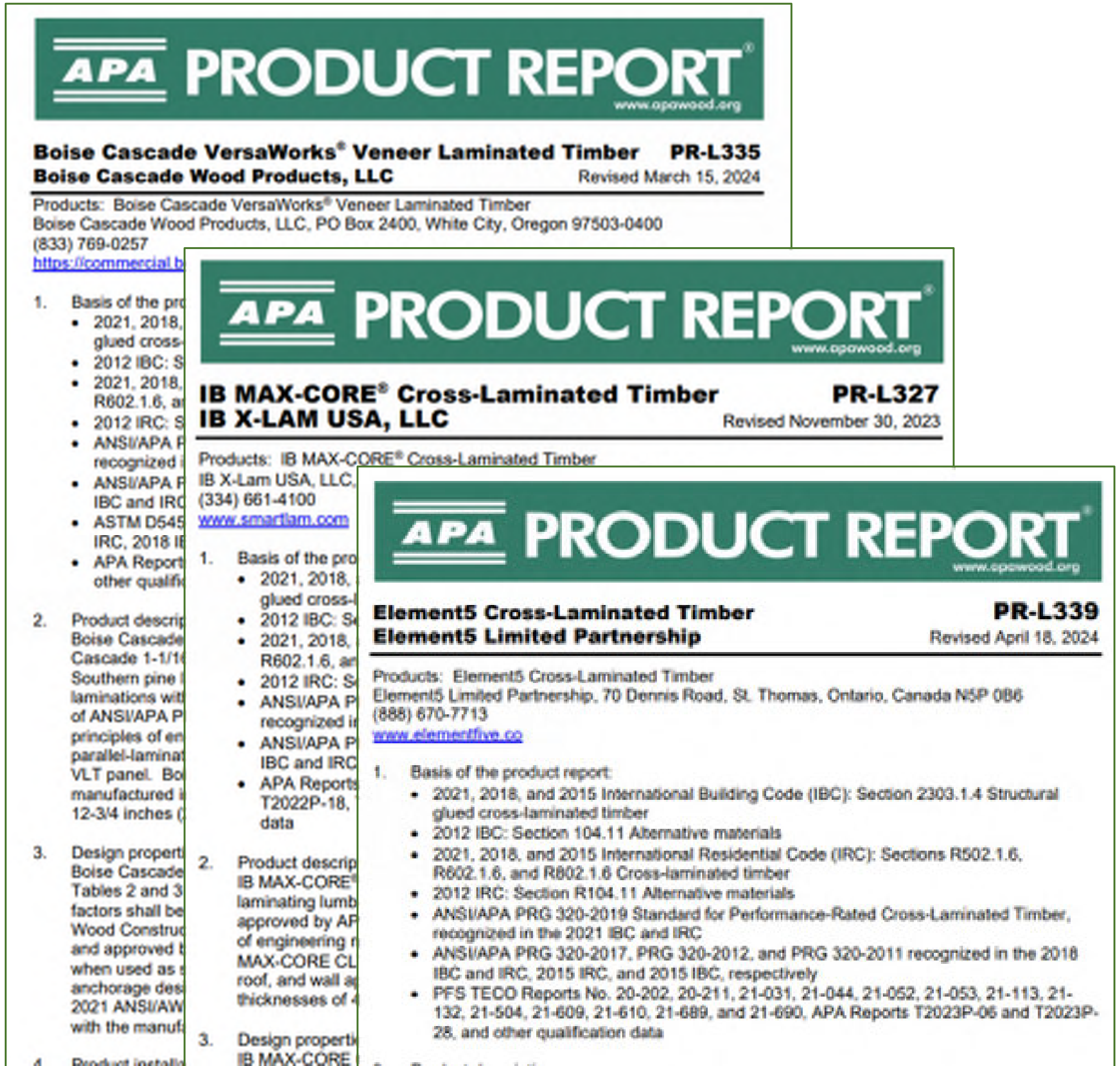


9-ply 9-layer

7-ply 5-layer

9-ply 7-layer

Cross Laminated Timber (CLT) Product Reports



APA PRODUCT REPORT®
www.apawood.org

Boise Cascade VersaWorks® Veneer Laminated Timber **PR-L335**
Boise Cascade Wood Products, LLC Revised March 15, 2024

Products: Boise Cascade VersaWorks® Veneer Laminated Timber
Boise Cascade Wood Products, LLC, PO Box 2400, White City, Oregon 97503-0400
(833) 769-0257
https://commercial.b

1. Basis of the pr
   - 2021, 2018,
     glued cross-
   - 2012 IBC: S
   - 2021, 2018,
     R602.1.6, a
   - 2012 IRC: S
   - ANSI/APA P
     recognized i
   - ANSI/APA P
     IBC and IRC
   - ASTM D545
     IRC, 2018 I
   - APA Report
     other qualifi
2. Product descri
   Boise Cascade
   Cascade 1-1/1
   Southern pine
   laminations wit
   of ANSI/APA P
   principles of en
   parallel-laminat
   VLT panel. Bo
   manufactured i
   12-3/4 inches (
3. Design propert
   Boise Cascade
   Tables 2 and 3
   factors shall be
   Wood Construc
   and approved b
   when used as
   anchorage des
   2021 ANSI/AW
   with the manuf
4. Product installa

APA PRODUCT REPORT®
www.apawood.org

IB MAX-CORE® Cross-Laminated Timber **PR-L327**
IB X-LAM USA, LLC Revised November 30, 2023

Products: IB MAX-CORE® Cross-Laminated Timber
IB X-Lam USA, LLC,
(334) 661-4100
www.smartlam.com

1. Basis of the pro
   - 2021, 2018,
     glued cross-
   - 2012 IBC: S
   - 2021, 2018,
     R602.1.6, ar
   - 2012 IRC: S
   - ANSI/APA P
     recognized i
   - ANSI/APA P
     IBC and IRC
   - APA Reports
     T2022P-18,
     data
2. Product descrip
   IB MAX-CORE
   laminating lumb
   approved by AP
   of engineering
   MAX-CORE CL
   roof, and wall a
   thicknesses of
3. Design properti
   IB MAX-CORE

APA PRODUCT REPORT®
www.apawood.org

Element5 Cross-Laminated Timber **PR-L339**
Element5 Limited Partnership Revised April 18, 2024

Products: Element5 Cross-Laminated Timber
Element5 Limited Partnership, 70 Dennis Road, St. Thomas, Ontario, Canada N5P 0B6
(888) 670-7713
www.elementfive.co

1. Basis of the product report:
   - 2021, 2018, and 2015 International Building Code (IBC): Section 2303.1.4 Structural glued cross-laminated timber
   - 2012 IBC: Section 104.11 Alternative materials
   - 2021, 2018, and 2015 International Residential Code (IRC): Sections R502.1.6, R602.1.6, and R802.1.6 Cross-laminated timber
   - 2012 IRC: Section R104.11 Alternative materials
   - ANSI/APA PRG 320-2019 Standard for Performance-Rated Cross-Laminated Timber, recognized in the 2021 IBC and IRC
   - ANSI/APA PRG 320-2017, PRG 320-2012, and PRG 320-2011 recognized in the 2018 IBC and IRC, 2015 IRC, and 2015 IBC, respectively
   - PFS TECO Reports No. 20-202, 20-211, 21-031, 21-044, 21-052, 21-053, 21-113, 21-132, 21-504, 21-609, 21-610, 21-689, and 21-690, APA Reports T2023P-06 and T2023P-28, and other qualification data

---

APA PRODUCT REPORT®
www.apawood.org

Freres Mass Ply Panels (MPP) and **PR-L325**
Mass Ply Lam (MPL) Beams and Columns Revised May 2, 2024
Freres Lumber Co., Inc. dba Freres Engineered Wood

Products: Freres Mass Ply Panels (MPP) and Mass Ply Lam (MPL) Beams and Columns
Freres Lumber Co., Inc. d
Lyons, Oregon 97358
(503) 859-2121
www.frereswood.com

1. Basis of the product
   - 2021, 2018, and 2
     glued cross-lamin
   - 2012 IBC: Section
   - 2021, 2018, and 2
     R602.1.6, and R8
   - 2012 IRC: Section
   - 2018 and 2015 AN
   - ANSI/APA PRG 3
     recognized in the
   - ANSI/APA PRG 3
     IBC and IRC, 201
   - APA Reports T20
     T2021P-38, and
2. Product description:
   Freres Mass Ply Pan
   1.0E Douglas-fir LVL
   custom layups of AN
   models using princip
   bonded with approve
   edge joints between
   are staggered betwe

   Freres MPP is availa
   applications. Freres
   thicknesses (t) of 2-1
   lengths up to 48 feet

   Freres Mass Ply Lam
   as beams in the joist
   permitted to be rip-c
   F16, F16A, or F10.
   of 2-1/16 to 24-1/2 in
   Freres F21, F19, and
   between any 1-inch

APA PRODUCT REPORT®
www.apawood.org

Kalesnikoff Cross-Laminated Timber **PR-L332**
Kalesnikoff Mass Timber Inc. Revised October 28, 2023

Products: Kalesnikoff Cross-Laminated Timber
Kalesnikoff Mass Timb
4N1
(250) 399-4211
www.kalesnikoff.com

1. Basis of the prod
   - 2021, 2018, a
     glued cross-la
   - 2012 IBC: Sec
   - 2021, 2018, a
     R602.1.6, and
   - 2012 IRC: Sec
   - ANSI/APA PR
     recognized in
   - ANSI/APA PR
     IBC and IRC,
   - APA Reports T
     31, and other
2. Product descripti
   Kalesnikoff cross
   accordance with
   through product
   mechanics. The
   provided in Table
   substituted by Do
   design properties
   When Hem-fir (N
   bearing capacity

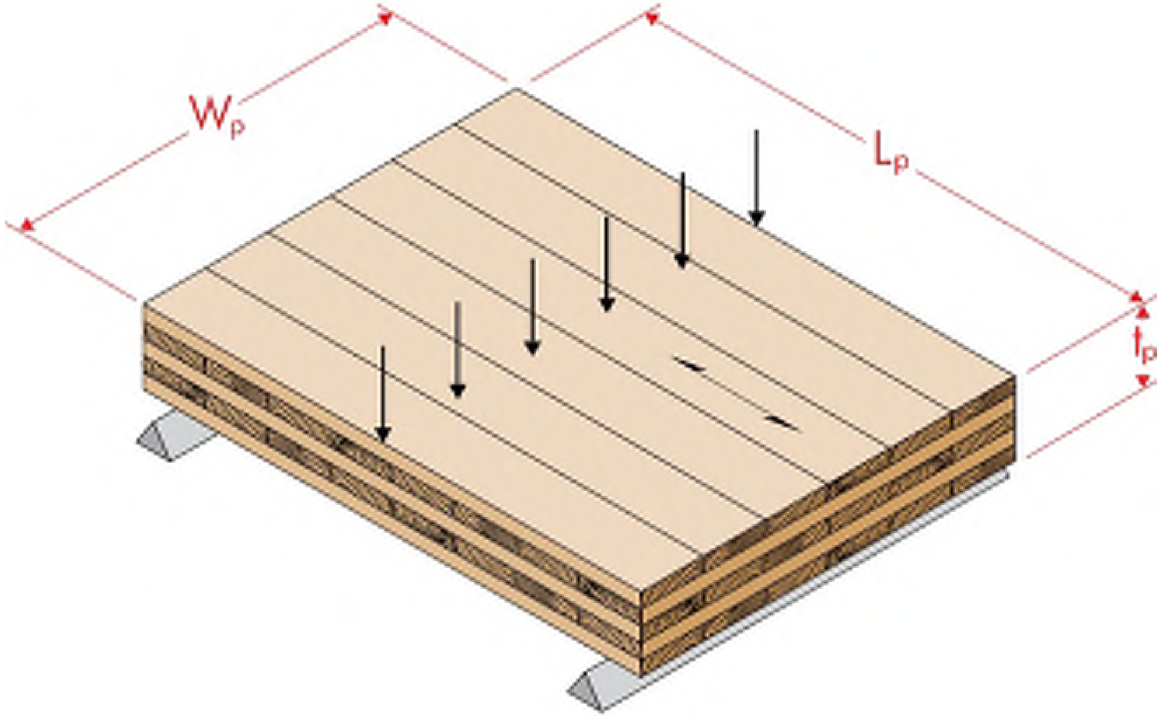
APA PRODUCT REPORT®
www.apawood.org

Vaagen Cross-Laminated Timber **PR-L328**
Vaagen Timbers, LLC Revised January 9, 2024

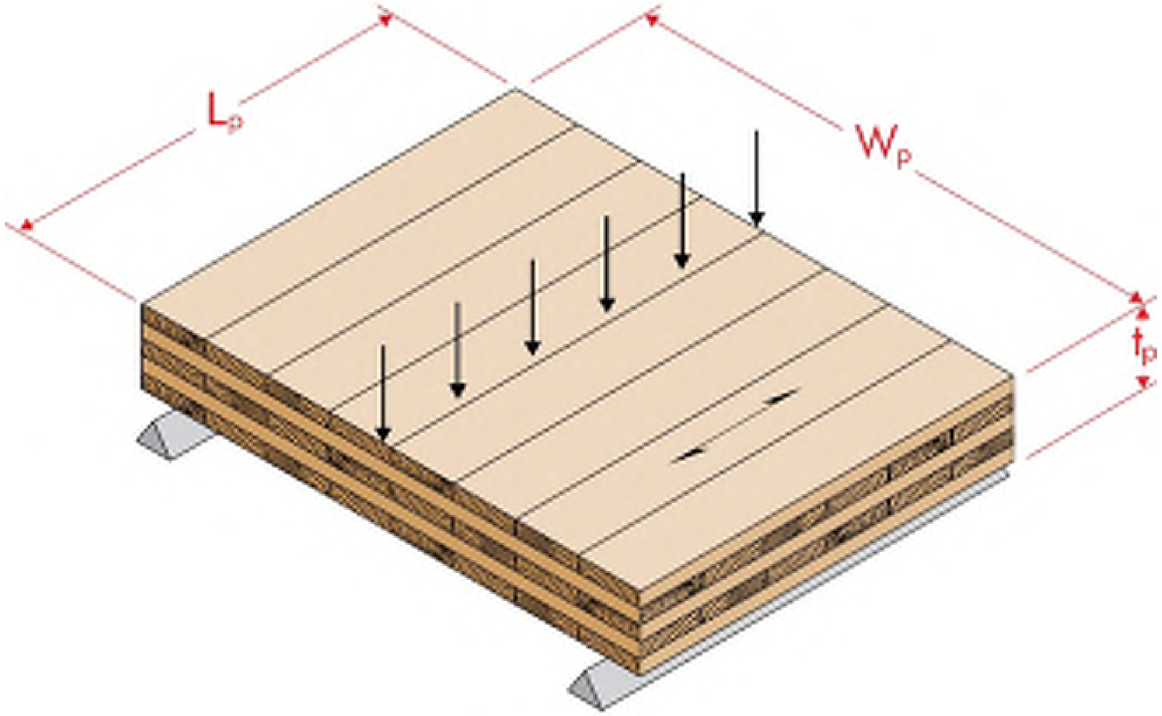
Products: Vaagen Cross-Laminated Timber
Vaagen Timbers, LLC, 1245 N Highway, Colville, WA 99114
(509) 684-3678
www.vaagentimbers.com

1. Basis of the product report:
   - 2021, 2018, and 2015 International Building Code (IBC): Section 2303.1.4 Structural glued cross-laminated timber
   - 2012 IBC: Section 104.11 Alternative materials
   - 2021, 2018, and 2015 International Residential Code (IRC): Sections R502.1.6, R602.1.6, and R802.1.6 Cross-laminated timber
   - 2012 IRC: Section R104.11 Alternative materials
   - ANSI/APA PRG 320-2019 Standard for Performance-Rated Cross-Laminated Timber recognized in the 2021 IBC and IRC
   - ANSI/APA PRG 320-2017, PRG 320-2012, and PRG 320-2011 recognized in the 2018 IBC and IRC, 2015 IRC, and 2015 IBC, respectively
   - APA Reports T2019P-38, T2021P-41, T2022P-05, T2023P-05, T2023P-14, and T2023P-50, PFS TECO Reports No. 20-016 (Rev. 21-08-17), No. 20-089, No. 20-090, No. 20-522, No. 21-068, No. 21-187, and No. 21-583, and other qualification data

FLATWISE Panel Loading



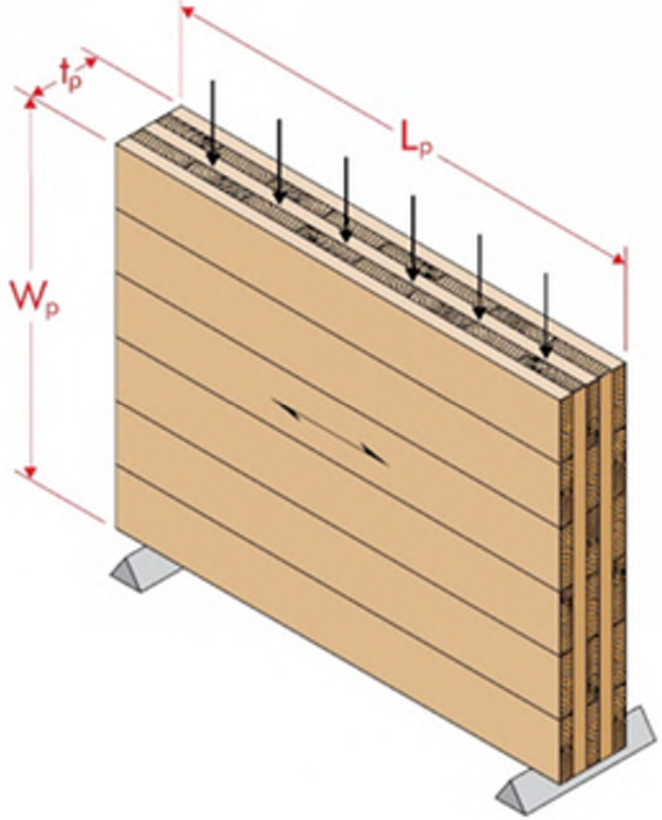
Span in MAJOR Strength Direction
“Parallel” Direction
Use subscript ‘0’ or ‘II” in Notation



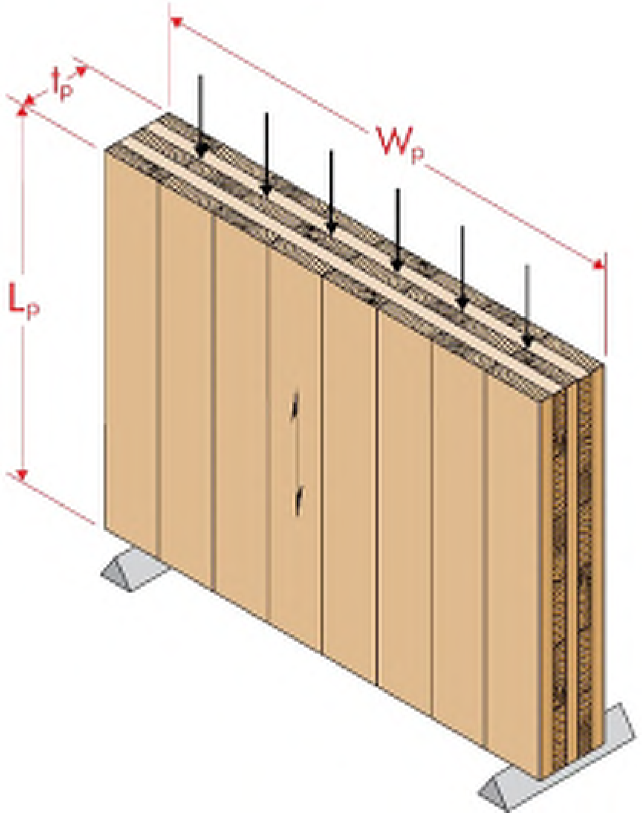
Span in MINOR Strength Direction
“Perpendicular” Direction
Use subscript ‘90’ or “⊥” in Notation

Reference & Source: ANSI/APA PRG 320

EDGEWISE Panel Loading



Span in MAJOR Strength Direction



Span in MINOR Strength Direction

Reference & Source: ANSI/APA PRG 320

PRG320 Defined Layups

CLT Grade (basic)

Layup

Panel Properties (flatwise bending)

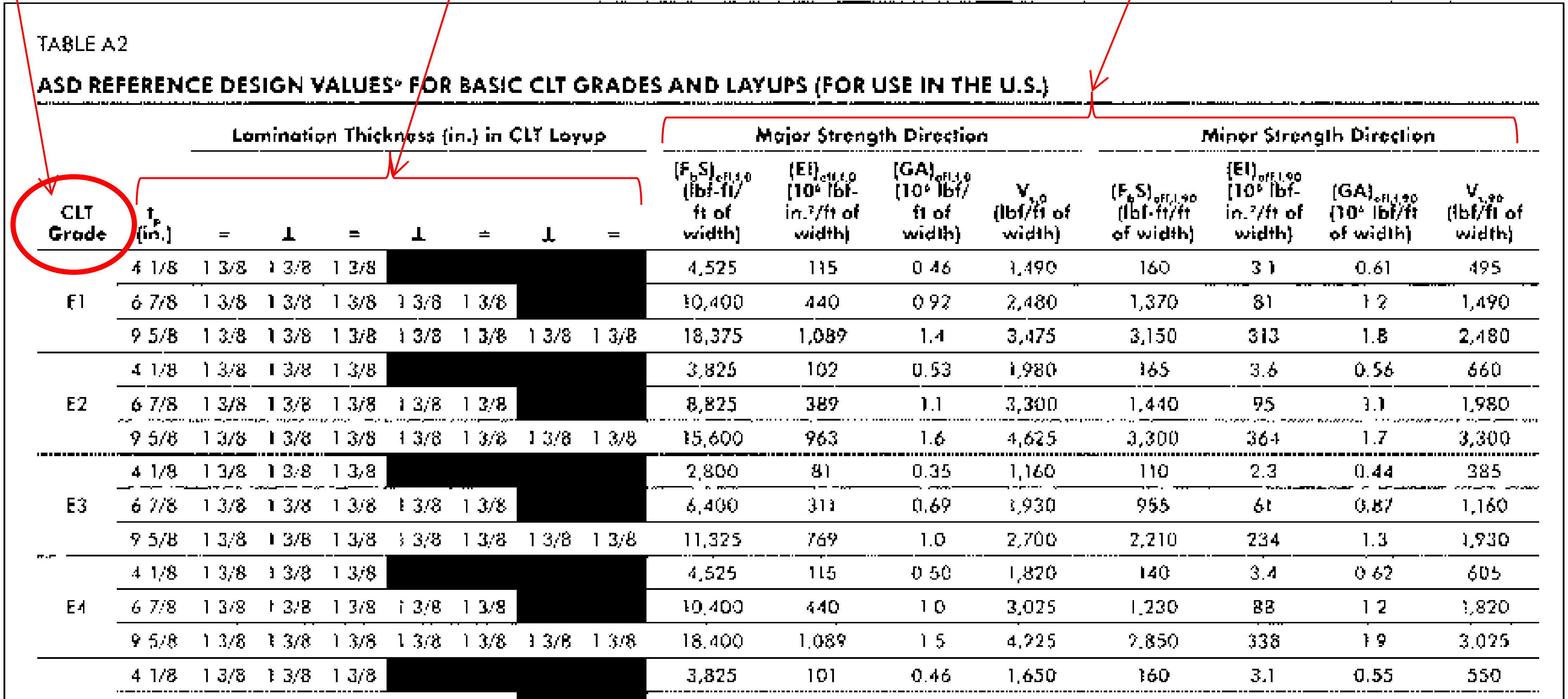
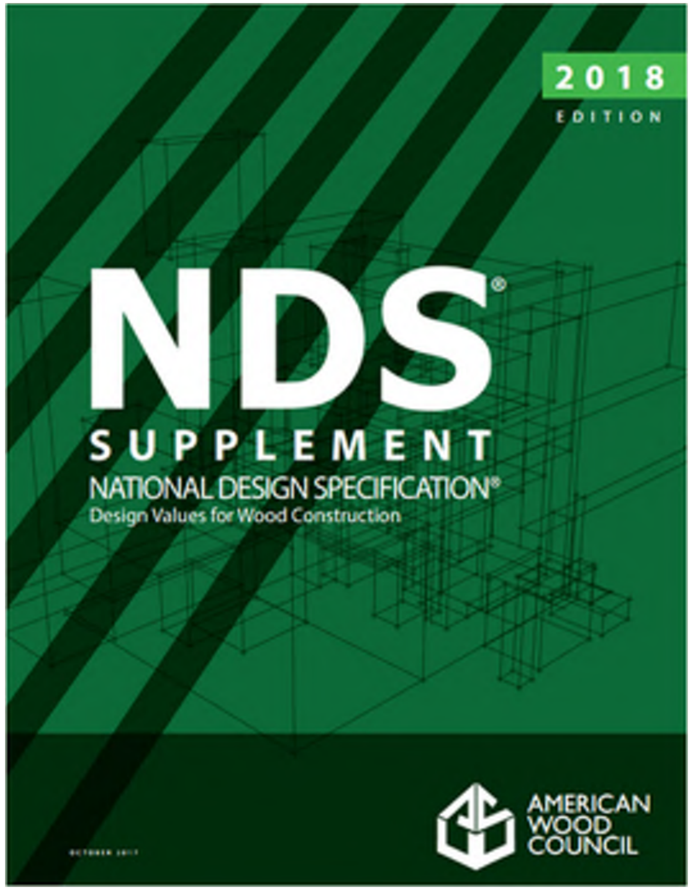


TABLE A2

ASD REFERENCE DESIGN VALUES[a] FOR BASIC CLT GRADES AND LAYUPS (FOR USE IN THE U.S.)

CLT Grade	t_p (in.)	Lamination Thickness (in.) in CLT Layup							Major Strength Direction				Minor Strength Direction			
		=	⊥	=	⊥	=	⊥	=	$(F_bS)_{eff,f,0}$ (lbf-ft/ft of width)	$(EI)_{eff,f,0}$ [10^6 lbf-in.^{2}/ft of width]	$(GA)_{eff,f,0}$ [10^6 lbf/ft of width]	$V_{s,0}$ (lbf/ft of width)	$(F_bS)_{eff,f,90}$ (lbf-ft/ft of width)	$(EI)_{eff,f,90}$ [10^6 lbf-in.^{2}/ft of width]	$(GA)_{eff,f,90}$ (10^6 lbf/ft of width)	$V_{s,90}$ (lbf/ft of width)
E1	4 1/8	1 3/8	1 3/8	1 3/8					4,525	115	0.46	1,490	160	3.1	0.61	495
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			10,400	440	0.92	2,480	1,370	81	1.2	1,490
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	18,375	1,089	1.4	3,475	3,150	313	1.8	2,480
E2	4 1/8	1 3/8	1 3/8	1 3/8					3,825	102	0.53	1,980	165	3.6	0.56	660
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			8,825	389	1.1	3,300	1,440	95	1.1	1,980
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	15,600	963	1.6	4,625	3,300	364	1.7	3,300
E3	4 1/8	1 3/8	1 3/8	1 3/8					2,800	81	0.35	1,160	110	2.3	0.44	385
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			6,400	311	0.69	1,930	955	61	0.87	1,160
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	11,325	769	1.0	2,700	2,210	234	1.3	1,930
E4	4 1/8	1 3/8	1 3/8	1 3/8					4,525	115	0.50	1,820	140	3.4	0.62	605
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			10,400	440	1.0	3,025	1,230	88	1.2	1,820
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	18,400	1,089	1.5	4,225	2,850	338	1.9	3,025
	4 1/8	1 3/8	1 3/8	1 3/8					3,825	101	0.46	1,650	160	3.1	0.55	550

Adjustment Factors



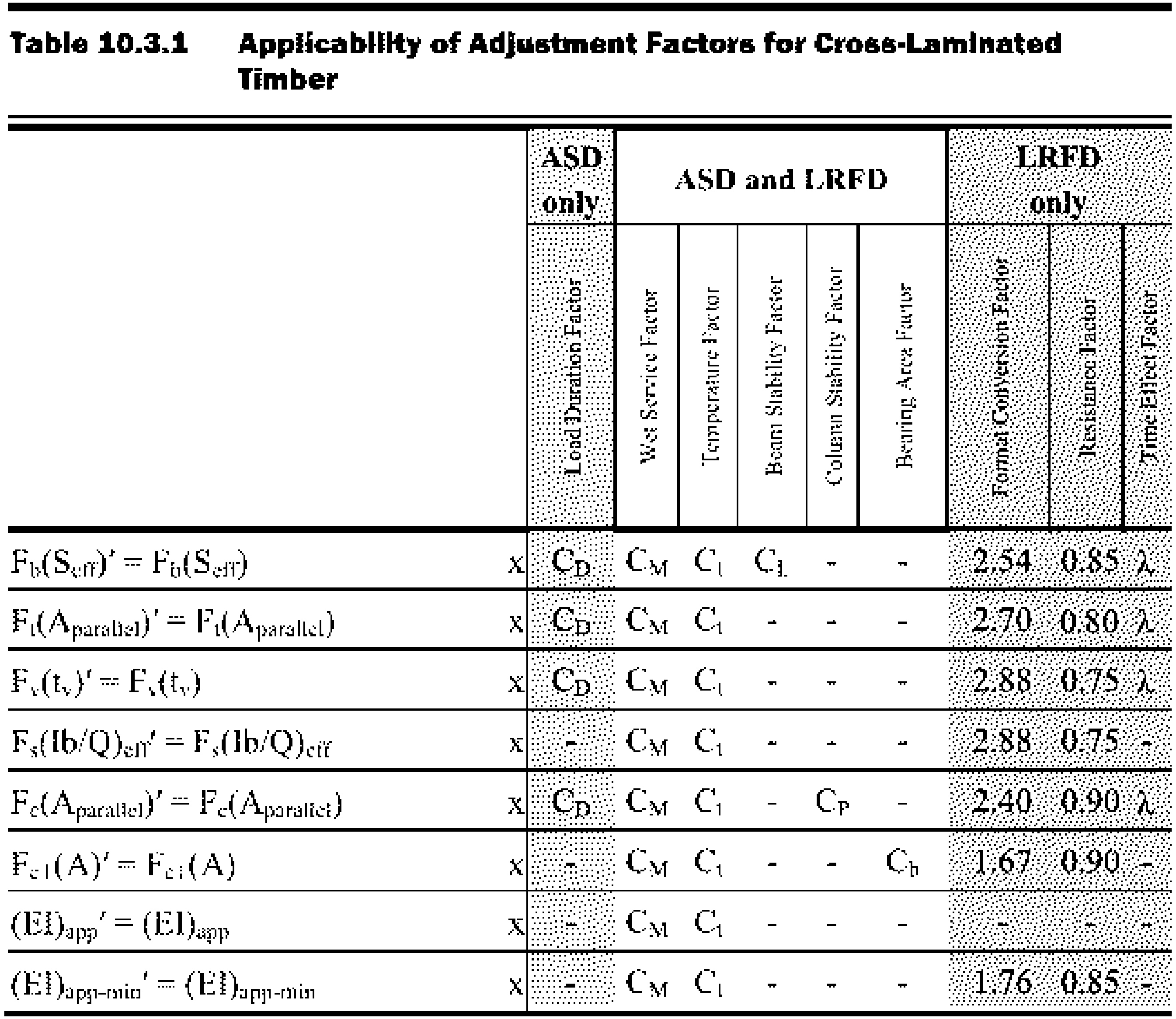


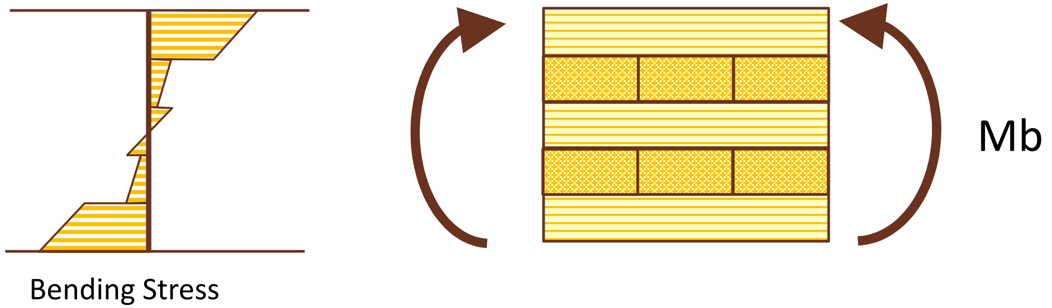
Table 10.3.1 Applicability of Adjustment Factors for Cross-Laminated Timber

		ASD only	ASD and LRFD					LRFD only		
		Load Duration Factor	Wet Service Factor	Temperature Factor	Beam Stability Factor	Column Stability Factor	Bearing Area Factor	Format Conversion Factor	Resistance Factor	Time Effect Factor
$F_b(S_{eff})' = F_b(S_{eff})$	x	C_D	C_M	C_t	C_L	-	-	2.54	0.85	λ
$F_t(A_{parallel})' = F_t(A_{parallel})$	x	C_D	C_M	C_t	-	-	-	2.70	0.80	λ
$F_v(t_v)' = F_v(t_v)$	x	C_D	C_M	C_t	-	-	-	2.88	0.75	λ
$F_s(Ib/Q)_{eff}' = F_s(Ib/Q)_{eff}$	x	-	C_M	C_t	-	-	-	2.88	0.75	-
$F_c(A_{parallel})' = F_c(A_{parallel})$	x	C_D	C_M	C_t	-	C_P	-	2.40	0.90	λ
$F_{c\perp}(A)' = F_{c\perp}(A)$	x	-	C_M	C_t	-	-	C_b	1.67	0.90	-
$(EI)_{app}' = (EI)_{app}$	x	-	C_M	C_t	-	-	-	-	-	-
$(EI)_{app\text{-}min}' = (EI)_{app\text{-}min}$	x	-	C_M	C_t	-	-	-	1.76	0.85	-

Reference: NDS

Flatwise Flexural Strength

Flexural Capacity Check (**ASD**): $M_b \leq (F_bS_{eff})'$



$$(F_bS_{eff})' = \underset{\text{per NDS}}{C_D}\ \underbrace{C_M\ C_t\ C_L}_{\text{Commonly 1.0}}\ \underbrace{(F_bS_{eff})}_{\text{Provided as combined value}}$$

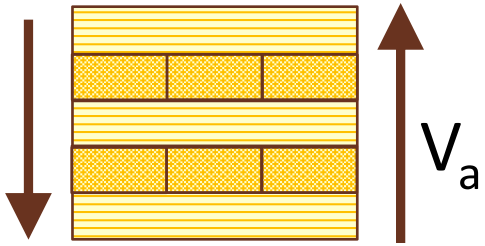
$$M_b \leq C_D\,(1.0)\,(F_bS_{eff})$$

Here and in the following, items in RED are provided CLT properties

Reference: NDS

Flatwise Shear Strength

Shear Capacity Check (**ASD**): $V_a \leq F_s(lb/Q)_{eff}'$



$$F_s(lb/Q)_{eff}' = \underbrace{C_M \, C_t}_{\text{Commonly } 1.0} \, \underbrace{(F_s(lb/Q)_{eff})} = C_M \, C_t \, \underbrace{V_s}_{\text{From Manufacturer}}$$

$$V_a \leq (1.0) \, V_s$$

Reference: NDS & Product Reports

Note: Duration of Load Effects (Cd and λ) NOT applicable to Flatwise Shear Strength in the NDS

Flatwise Deflection

Uniform loading on one way slab:

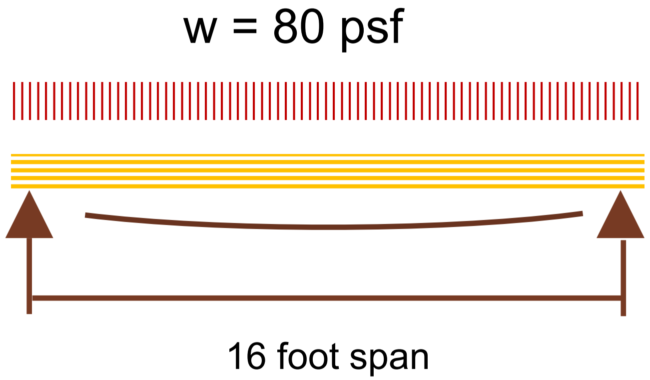
Beam Analysis using

Flexural Stiffness: $EI_{eff,0}$

Shear Stiffness: $GA_{eff,0}$

Maximum Deflection @ Mid-Span

$$\Delta_{max} = \frac{5}{384} * \frac{wL^4}{EI_{eff}} + \frac{1}{8} * \frac{wL^2}{5/6\ GA_{eff}}$$



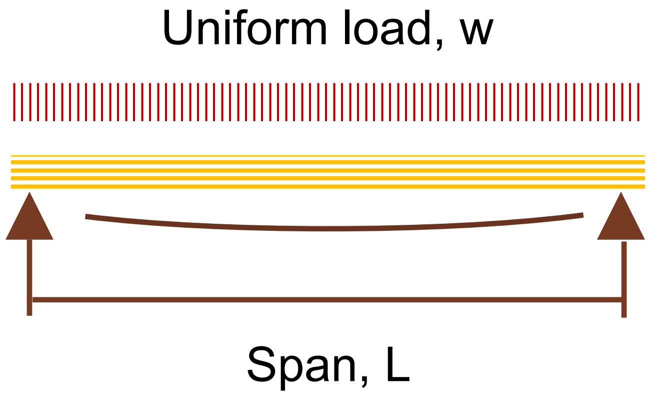
Note: 5/6 is shear deformation form factor for rectangular section from mechanics of materials. See NDS C10.4.1, FPL “Wood Handbook”, etc.

Flatwise Deflection

Simplified Beam Deflections:

For single span, simply supported uniform load

$$\Delta_{max} = \frac{5}{384} * \frac{wL^4}{EI_{eff}} + \frac{1}{8} * \frac{wL^2}{5/6\ GA_{eff}}$$



What is ***Apparent*** Flexural Stiffness, EI_{app}, such that

$$\Delta_{max} = \frac{5}{384} \cdot \frac{wL^4}{EI_{app}}$$

Set equal to each other and solve for EI_{app}

$$EI_{app} = \frac{EI_{eff}}{1 + \frac{11.5 EI_{eff}}{GA_{eff} L^2}}$$

K_s per NDS Table 10.4.1.1

Reference: US CLT Handbook & NDS

Deflection Creep Factor

Deformation due to Long Term Loads

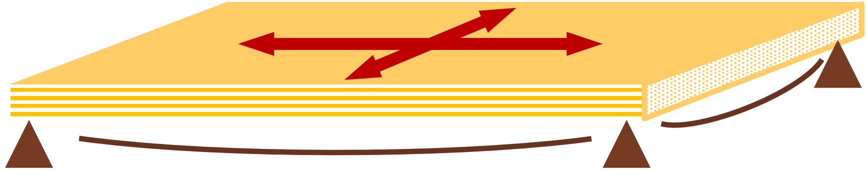
$$\Delta_T = K_{cr}\,\Delta_{LT} + \Delta_{ST}$$

NDS Eq 3.5-1

Δ_{ST}	Deflection due to short-term loading
Δ_{LT}	Immediate deflection due to long term loading
K_{cr}	2.0 for CLT in dry service conditions

Reference: NDS 2015

Deflection Calculations



General Purpose, 2 Way, Plate Action

Flexural Stiffness

$EI_{eff,0}$ $EI_{eff,90}$

Shear Stiffness:

$GA_{eff,0}$ $GA_{eff,90}$

Not supported in current codes, requires testing

Note, CLT is not a symmetric isotropic plate

Keep in mind compression perpendicular to grain may control at bearing

EXPERT TIP

Design for Two-Way Spanning Cross-Laminated Timber

Considerations for building designers seeking to utilize CLT's two-way span capabilities

Brock Commons Tallwood House in Vancouver, BC / Photo Acton Ostry Architects

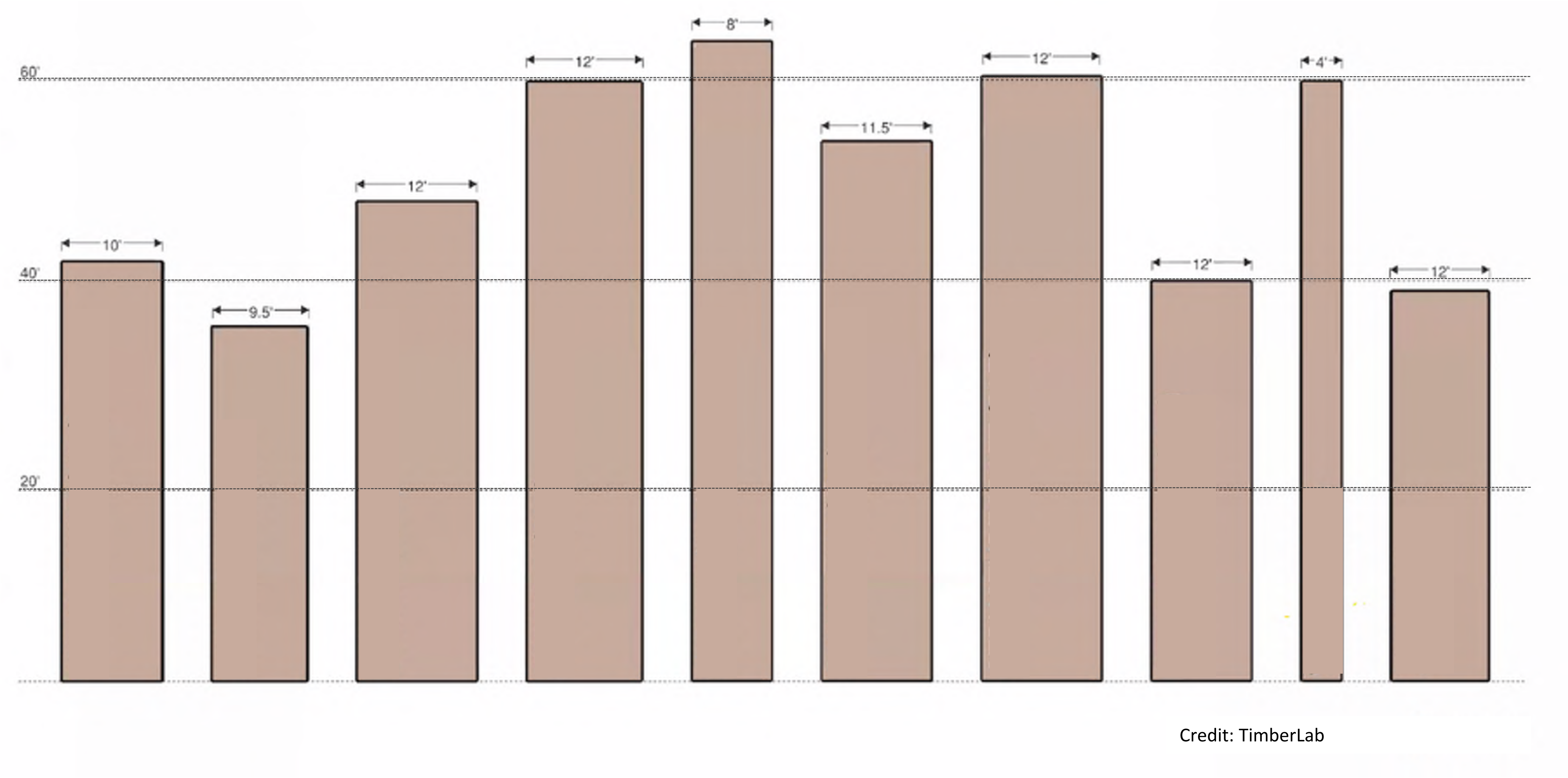
https://www.woodworks.org/resources/design-strategies-for-two-way-spanning-cross-laminated-timber/

Understand Manufacturer's Capabilities

Photo: DR Johnson

- Manufacturers offer different species, grades, and maximum panel/beam sizes
- Manufacturers have specific CNC capabilities
- 3rd Party Fabricators can have additional CNC capabilities
- Trucking/Shipping Logistics and Cost

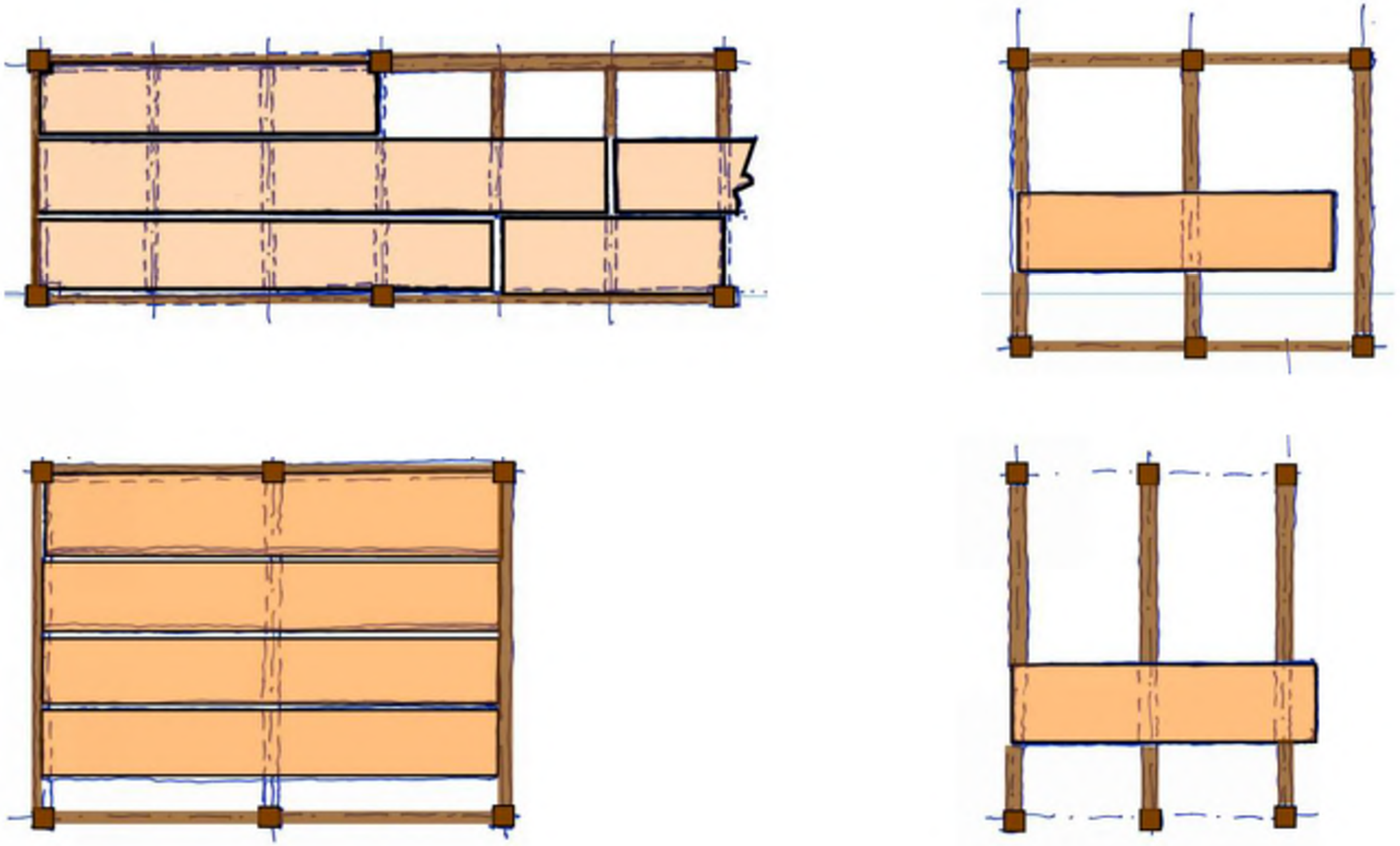
Understand Manufacturer’s Capabilities



Credit: TimberLab

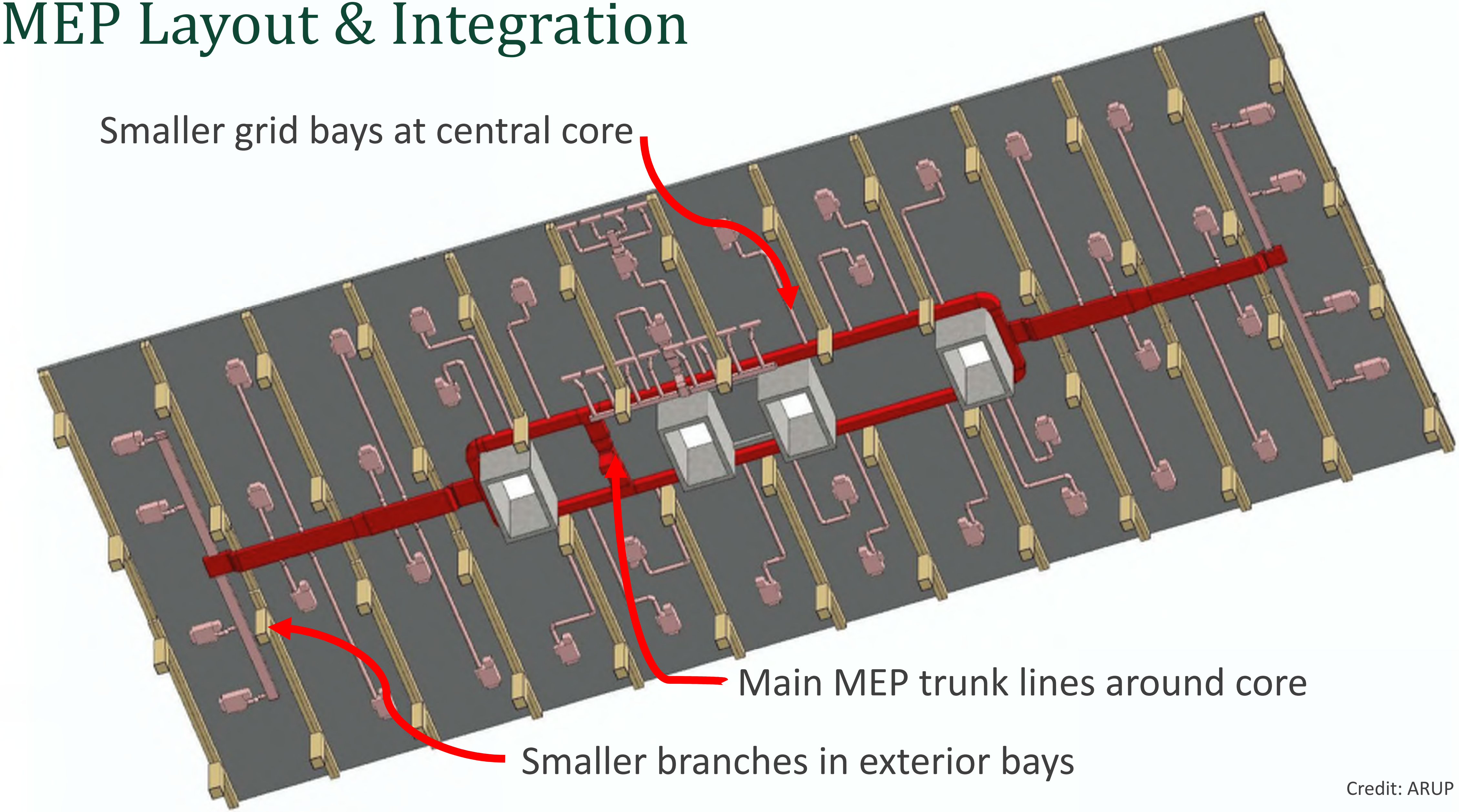
Structural Grid

- Consider Efficient Layouts
- Manufacturer Panel Sizing
- Transportation
- Repetition & Scale



Credit: Tanya Luthi, Entuitive

MEP Layout & Integration



Smaller grid bays at central core

Main MEP trunk lines around core

Smaller branches in exterior bays

Credit: ARUP

Practical Lessons for Structural Analysis and Design of Cross-Laminated Timber

Learning Hours: 1.5

Credits: AIA LU/HSW, ICC CEU, PHD

This presentation
is available via:

THE WOOD INSTITUTE

www.woodinstitute.org

WOODWORKS
WOOD PRODUCTS COUNCIL

Catalyst / MGA | Michael Green Architecture / KPFF Consulting Engineers / Photo Katerra

Agenda – Part 2

- Fire Resistance and Acoustics
- Vibration Design
- Connections
- Structural Design – Lateral

Photo: John Stamets

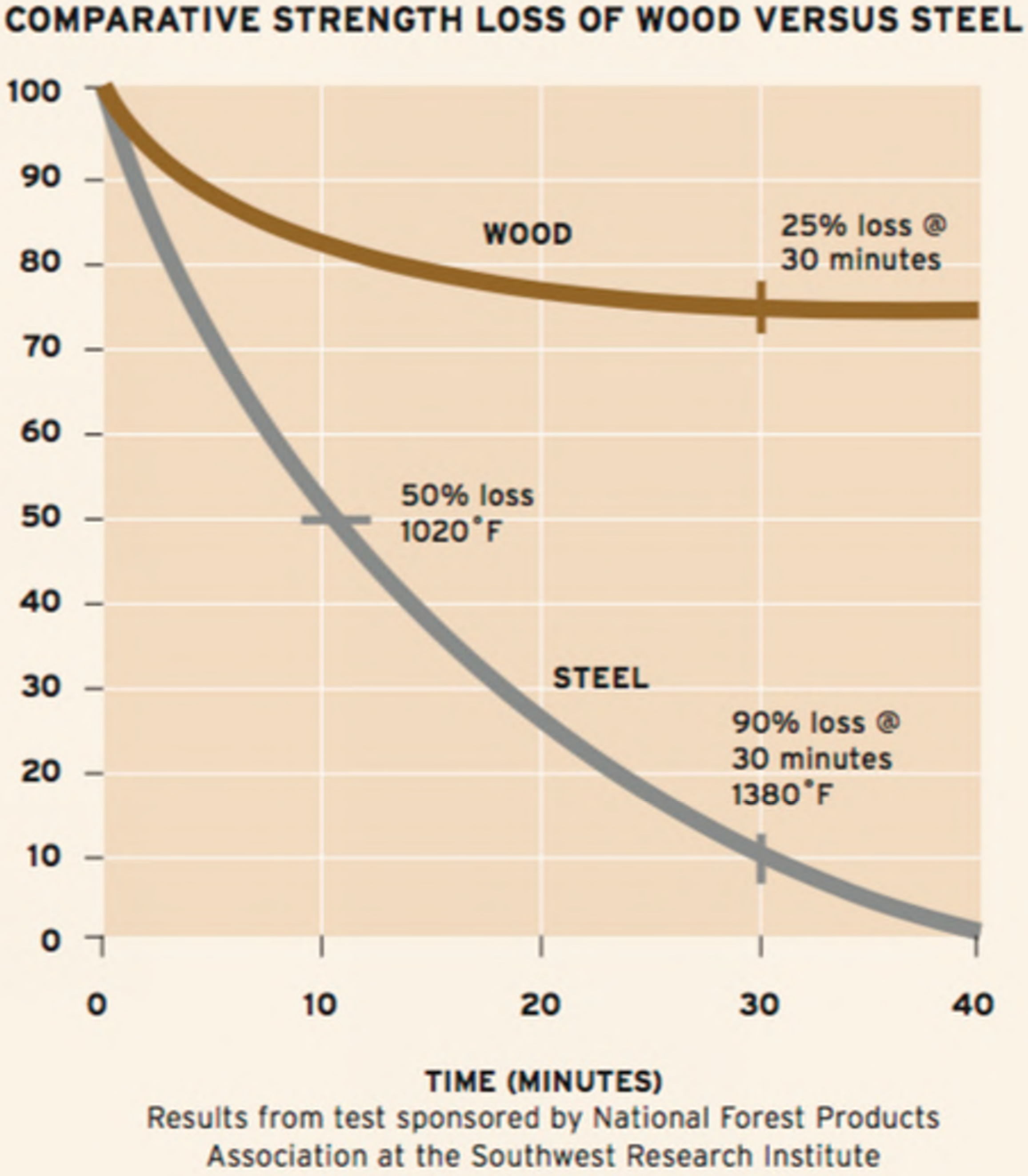
Agenda – Part 2

- » **Fire Resistance and Acoustics**
- » Vibration Design
- » Connections
- » Structural Design – Lateral

Photo: John Stamets

Fire Resistance

Source: AITC



Results from test sponsored by National Forest Products Association at the Southwest Research Institute https://www.woodworks.org/resources/fire-design-of-mass-timber-members-code-applications-construction-types-and-fire-ratings/

Richard McLain, PE, SE
Senior Technical Director
Scott Breneman, PhD, PE, SE
Senior Technical Director
WoodWorks – Wood Products Council

Fire Design of Mass Timber Members

Code Applications, Construction Types and Fire Ratings

For many years, exposed heavy timber framing elements have been permitted in U.S. buildings due to their inherent fire-resistance properties. The predictability of wood's char rate has been well-established for decades and has long been recognized in building codes and standards.

Today, one of the exciting trends in building design is the growing use of mass timber—i.e., large solid wood panel products such as cross-laminated timber (CLT) and nail-laminated timber (NLT)—for floor, wall and roof construction. Like heavy timber, mass timber products have inherent fire resistance that allows them to be left exposed and still achieve a fire-resistance rating (FRR). Because of their strength and dimensional stability, these products also offer an alternative to steel, concrete, and masonry for many applications, but have a much lighter carbon footprint. It is this combination of exposed structure and strength that developers and designers across the country are leveraging to create innovative designs with a warm yet modern aesthetic, often for projects that go beyond traditional norms.

This paper has been written to support architects and engineers exploring the use of mass timber for commercial and multi-family construction. It focuses on how to meet fire-resistance requirements in the International Building Code (IBC), including calculation and testing-based methods. Unless otherwise noted, references refer to the 2021 IBC.

Mass Timber & Construction Type

Before demonstrating FRRs of exposed mass timber elements, it's important to understand under what circumstances the code currently allows the use of mass timber in commercial and multi-family construction.

A building's assigned construction type is the main indicator of where and when all wood systems can be used. IBC Section 602 defines five main options (Type I through V); Types I, II, III and V have subcategories A and B, while Type IV has subcategories IV-HT, IV-A, IV-B, and IV-C. Types III, IV and V permit the use of wood framing throughout much of the structure and are used extensively for modern mass timber buildings.

Type III (IBC 602.3) – Timber elements can be used in floors, roofs and interior walls. Fire-retardant-treated wood (FRTW) framing is permitted in exterior walls required to have an FRR of 2 hours or less.

Type V (IBC 602.5) – Timber elements can be used throughout the structure, including floors, roofs and both interior and exterior walls.

University of Washington Founders Hall
LMN Architects / Magnusson Klemencic Associates

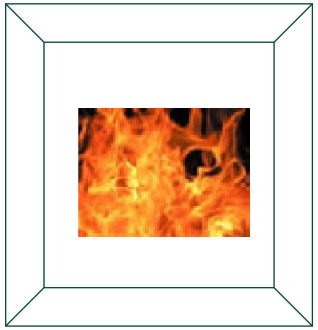
1 De Haro / SKS Partners / Perkins&Will / DCI Engineers

Fire Resistance

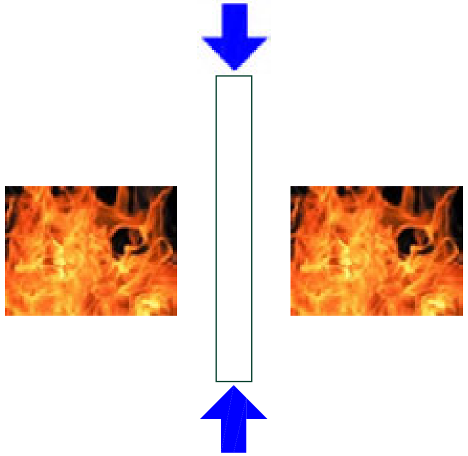
Fire-Resistance Rating: The period of time a building element, component or assembly maintains the ability to confine a fire, continues to perform a given structural function, or both, as determined by the tests, or the methods based on tests, prescribed in Section 703.

Tested under a standardized test fire exposure for a given duration to:

1. Prevent the passage of flame and temperature rise from one side to the other
2. Continue to provide vertical structural support when exposed to fire and elevated temperatures



Fire Confinement



Structural Performance

Fire Resistance

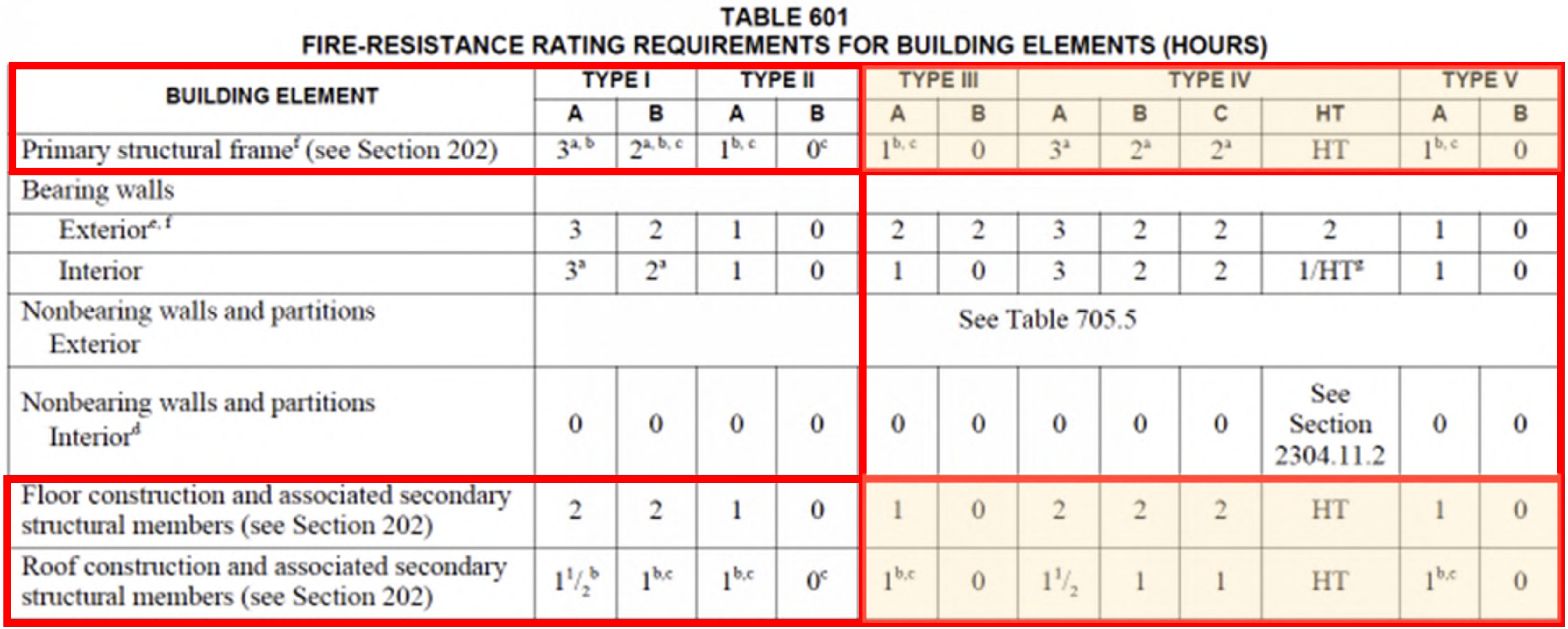


TABLE 601
FIRE-RESISTANCE RATING REQUIREMENTS FOR BUILDING ELEMENTS (HOURS)

BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV				TYPE V	
	A	B	A	B	A	B	A	B	C	HT	A	B
Primary structural frame[f] (see Section 202)	3[a, b]	2[a, b, c]	1[b, c]	0[c]	1[b, c]	0	3[a]	2[a]	2[a]	HT	1[b, c]	0
Bearing walls												
Exterior[e, f]	3	2	1	0	2	2	3	2	2	2	1	0
Interior	3[a]	2[a]	1	0	1	0	3	2	2	1/HT[g]	1	0
Nonbearing walls and partitions Exterior	See Table 705.5											
Nonbearing walls and partitions Interior[d]	0	0	0	0	0	0	0	0	0	See Section 2304.11.2	0	0
Floor construction and associated secondary structural members (see Section 202)	2	2	1	0	1	0	2	2	2	HT	1	0
Roof construction and associated secondary structural members (see Section 202)	$1^1/_2$[b]	1[b,c]	1[b,c]	0[c]	1[b,c]	0	$1^1/_2$	1	1	HT	1[b,c]	0

Source: 2021 IBC

Fire Resistance in the IBC

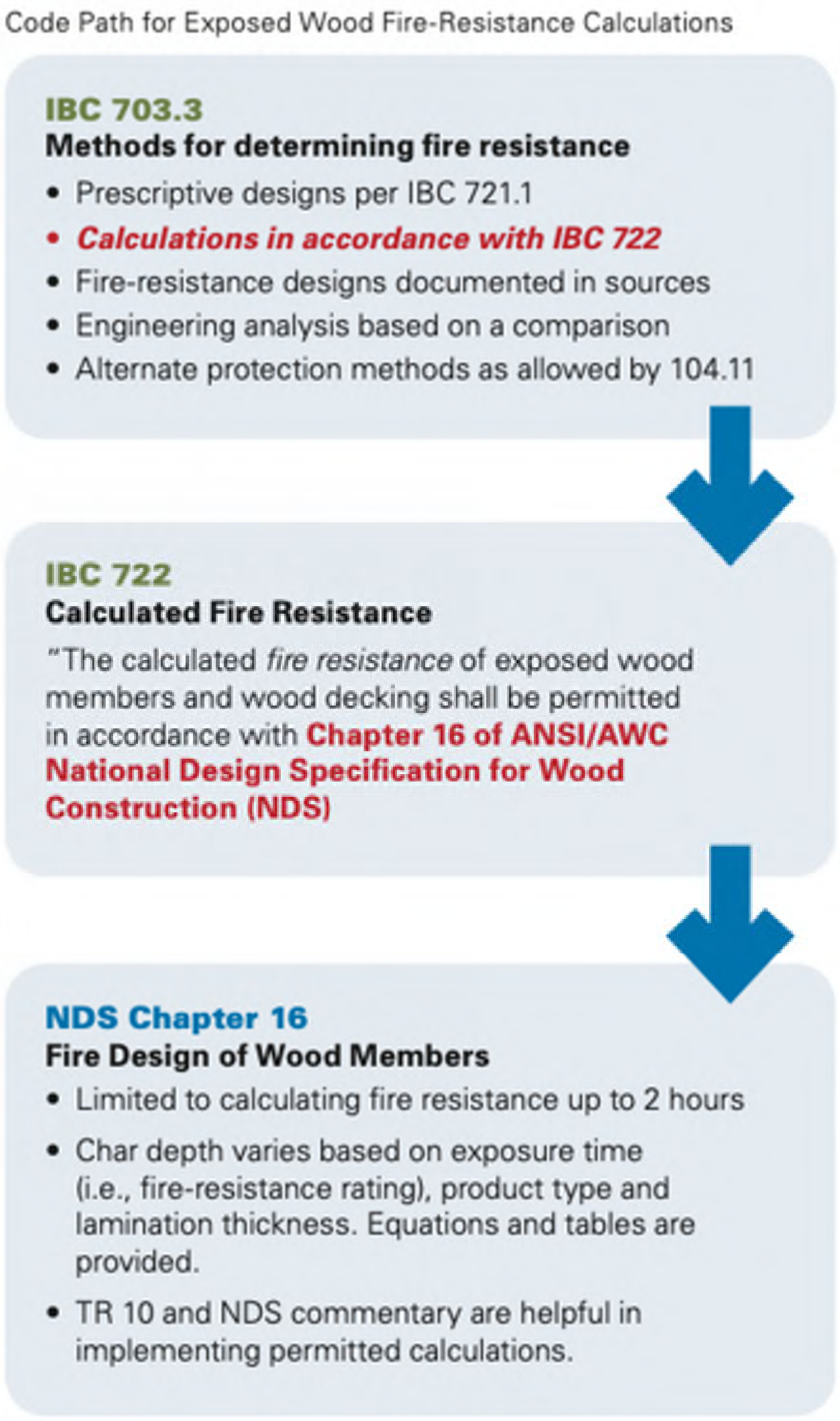
Prescriptive fire resistance requirements:

- » Type IV-HT: minimum timber* sizes per IBC 2304.11

- » <u>Other than Type IV</u>: Demonstrated fire resistance:
  - » IBC 703.2 allows several options, including:
    - » ASTM E119 tested assembly
    - » Prescriptive FRR per IBC 721
    - » Calculations per IBC 722
      - » NDS Chapter 16

- » Type IV-A, B, and C: minimum sizes AND demonstrated fire resistance

FIRE DESIGN OF WOOD MEMBERS



Code Path for Exposed Wood Fire-Resistance Calculations

IBC 703.3
Methods for determining fire resistance

- Prescriptive designs per IBC 721.1
- ***Calculations in accordance with IBC 722***
- Fire-resistance designs documented in sources
- Engineering analysis based on a comparison
- Alternate protection methods as allowed by 104.11

IBC 722
Calculated Fire Resistance

"The calculated *fire resistance* of exposed wood members and wood decking shall be permitted in accordance with **Chapter 16 of ANSI/AWC National Design Specification for Wood Construction (NDS)**

NDS Chapter 16
Fire Design of Wood Members

- Limited to calculating fire resistance up to 2 hours
- Char depth varies based on exposure time (i.e., fire-resistance rating), product type and lamination thickness. Equations and tables are provided.
- TR 10 and NDS commentary are helpful in implementing permitted calculations.

Fire Design of Mass Timber

Method of demonstrating FRR (calculations or testing) can impact member sizing

Each has unique benefits:

Testing:

- Can result in higher FRR for some assemblies when compared to calculations (i.e. 2-hr FRR with 5-ply CLT panel).
- Seen as more acceptable by some building officials

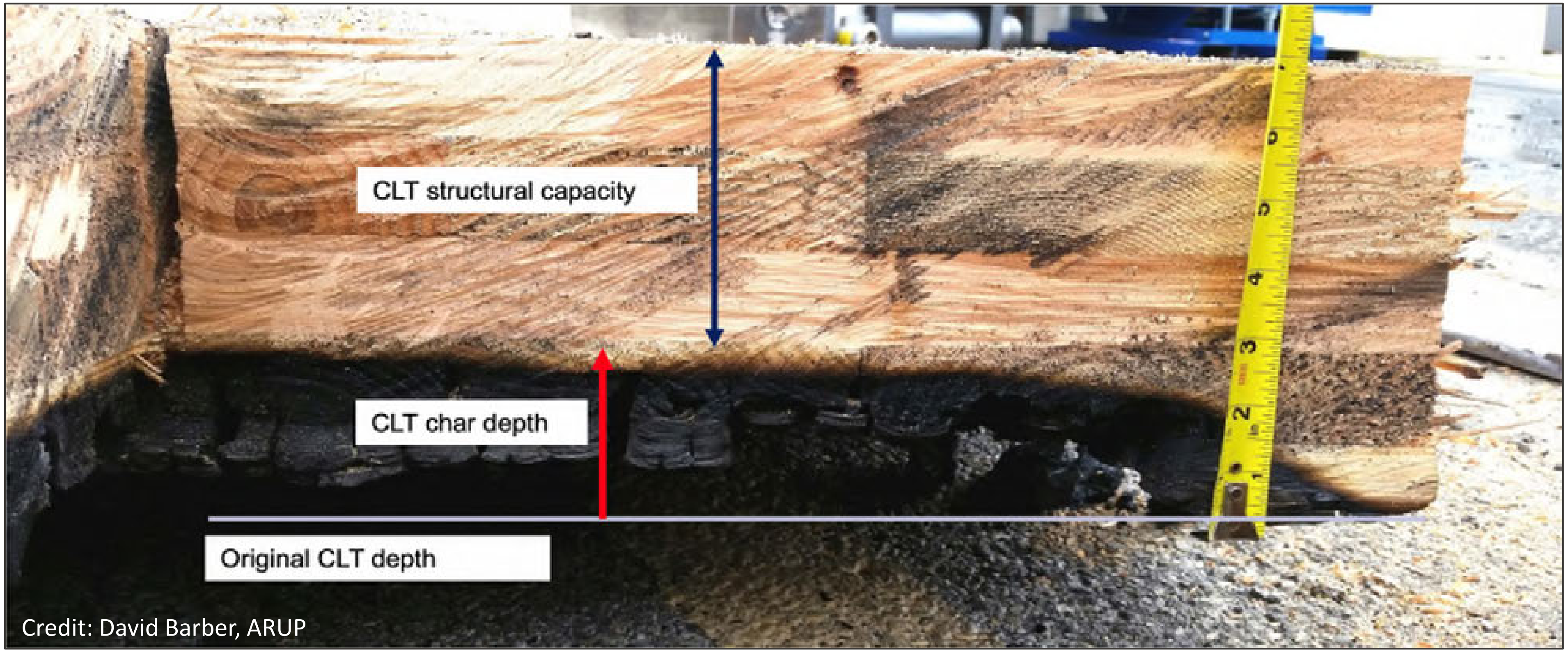
Calculations:

- Can provide more design flexibility
- Allows for project span and loading specific analysis

Fire Design of Mass Timber

Two structural capacity checks performed:

1. On entire cross section neglecting fire effects
2. On post-fire remaining section, with stress increases



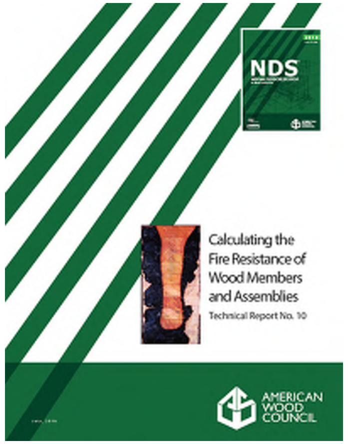
Credit: David Barber, ARUP

Fire Design of Mass Timber

Fire design conditions adjustment factors:

» NDS Table 16.2.2

Adjustment factors for Shear Strength are included in AWC's TR-10



NDS

Calculating the Fire Resistance of Wood Members and Assemblies

Technical Report No. 10

AMERICAN WOOD COUNCIL

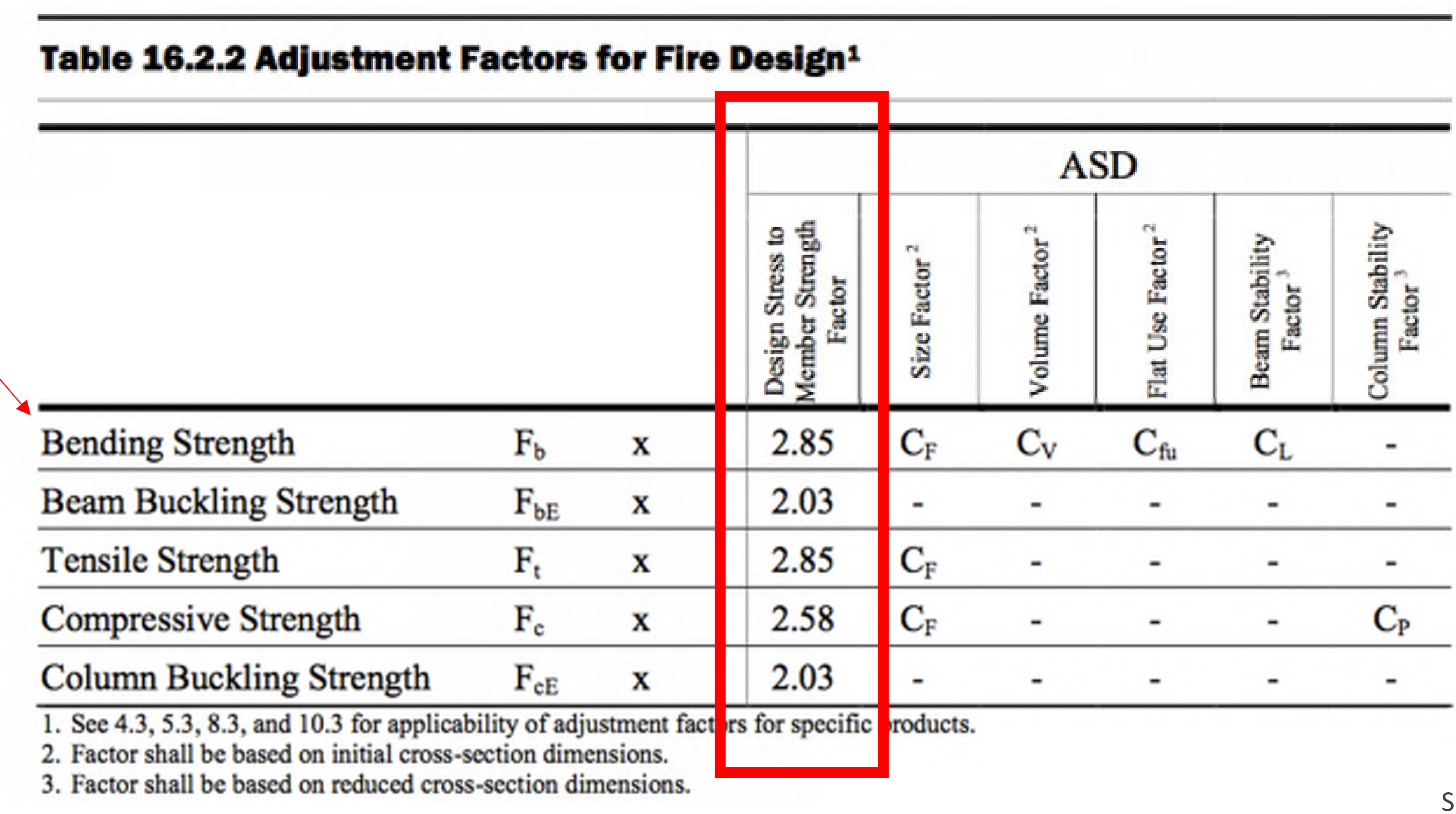


Table 16.2.2 Adjustment Factors for Fire Design[1]

			ASD					
			Design Stress to Member Strength Factor	Size Factor [2]	Volume Factor [2]	Flat Use Factor [2]	Beam Stability Factor [3]	Column Stability Factor [3]
Bending Strength	F_b	x	2.85	C_F	C_V	C_{fu}	C_L	-
Beam Buckling Strength	F_{bE}	x	2.03	-	-	-	-	-
Tensile Strength	F_t	x	2.85	C_F	-	-	-	-
Compressive Strength	F_c	x	2.58	C_F	-	-	-	C_P
Column Buckling Strength	F_{cE}	x	2.03	-	-	-	-	-

1. See 4.3, 5.3, 8.3, and 10.3 for applicability of adjustment fact rs for specific roducts.
2. Factor shall be based on initial cross-section dimensions.
3. Factor shall be based on reduced cross-section dimensions.

Source: 2018 AWC NDS

Fire Design of Mass Timber: Glulam

- Nominal char rate of 1.5”/HR is recognized in NDS.
- Effective char depth calculated to account for duration, structural reduction in heat-affected zone

Solid Sawn, Glulam, SCL

$$a_{char} = \beta_t t^{0.813}$$

Effective Char Depth

$$a_{eff} = 1.2a_{char}$$

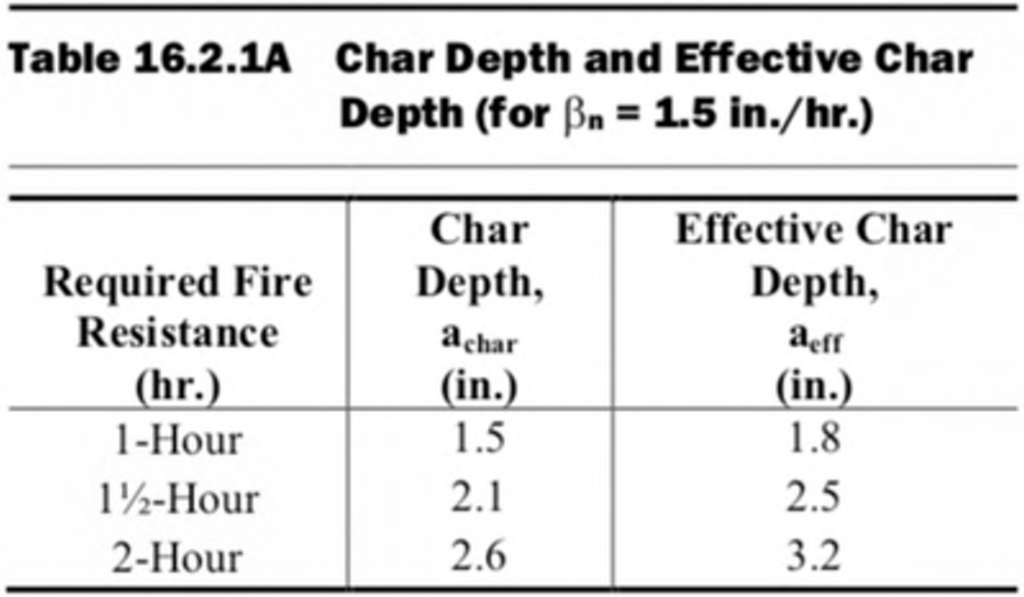


Table 16.2.1A Char Depth and Effective Char Depth (for β_n = 1.5 in./hr.)

Required Fire Resistance (hr.)	Char Depth, a_{char} (in.)	Effective Char Depth, a_{eff} (in.)
1-Hour	1.5	1.8
1½-Hour	2.1	2.5
2-Hour	2.6	3.2

Source: 2018 AWC NDS

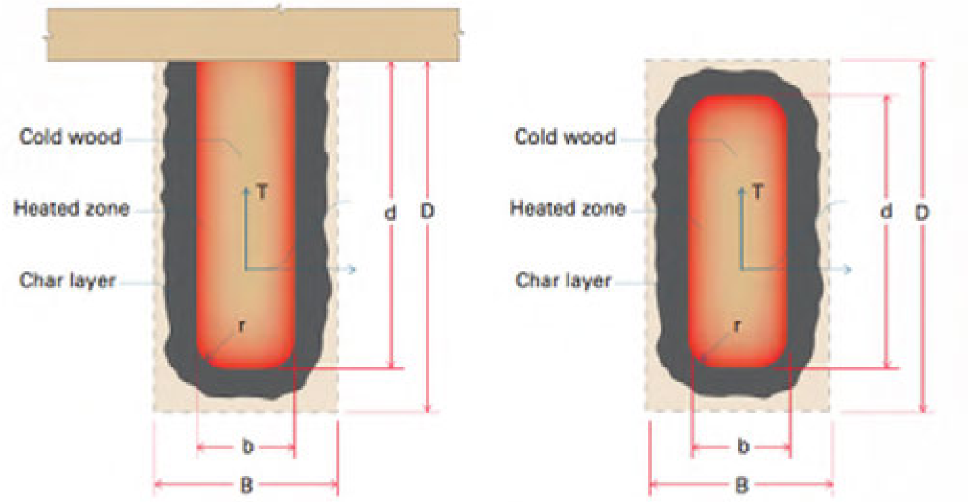


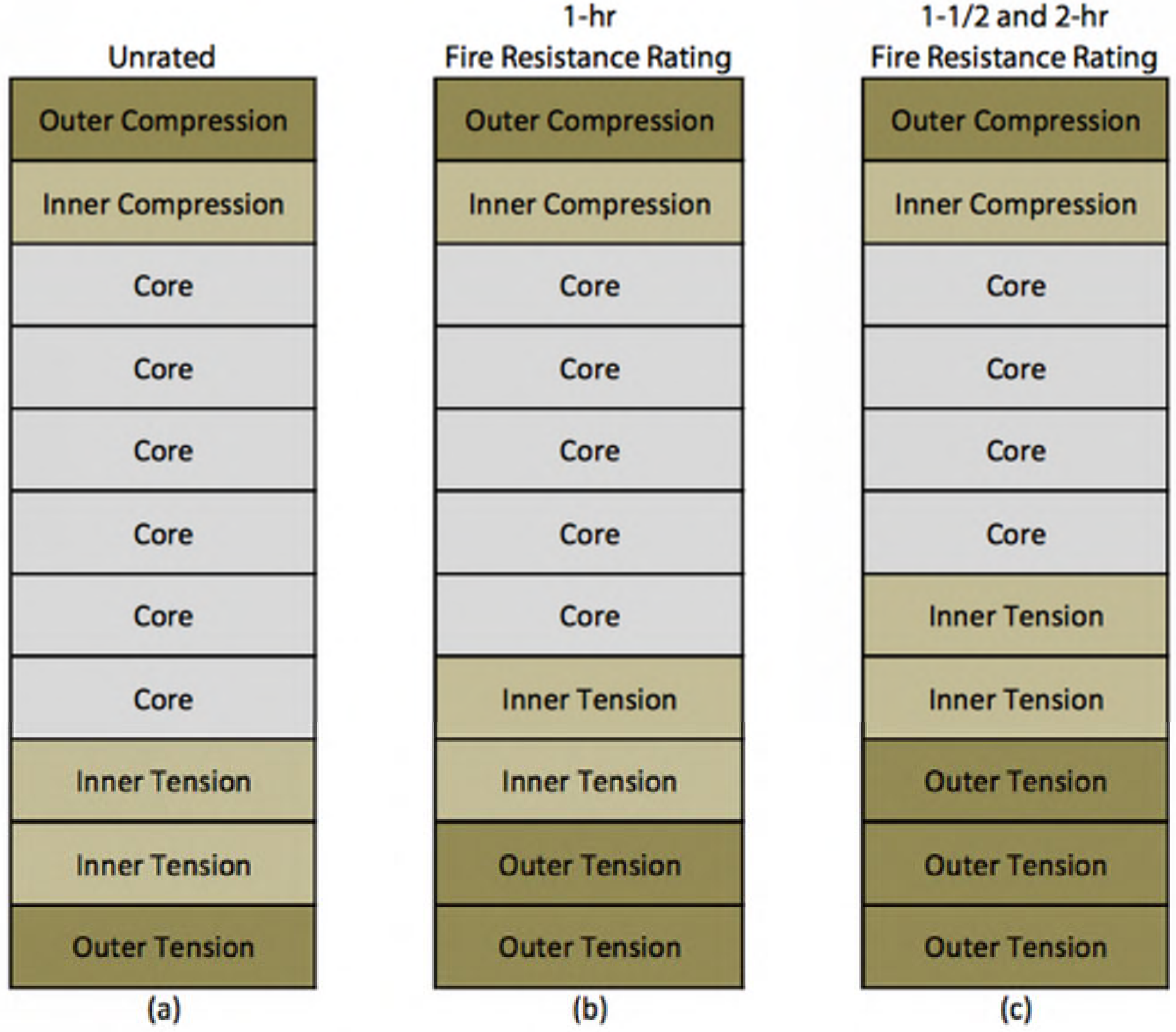
Figure 1-1 Reduction in member breadth and depth over time, t

Source: AWC’s TR 10

Fire Design of Mass Timber: Glulam

<u>Glulam beam fire design</u>:

- Unbalanced beams:
  - 1-hour: Substitute 1 core lam for 1 tension lam
  - 2-hour: Substitute 2 core lams for 2 tension lams
- For balanced beams, match on compression side



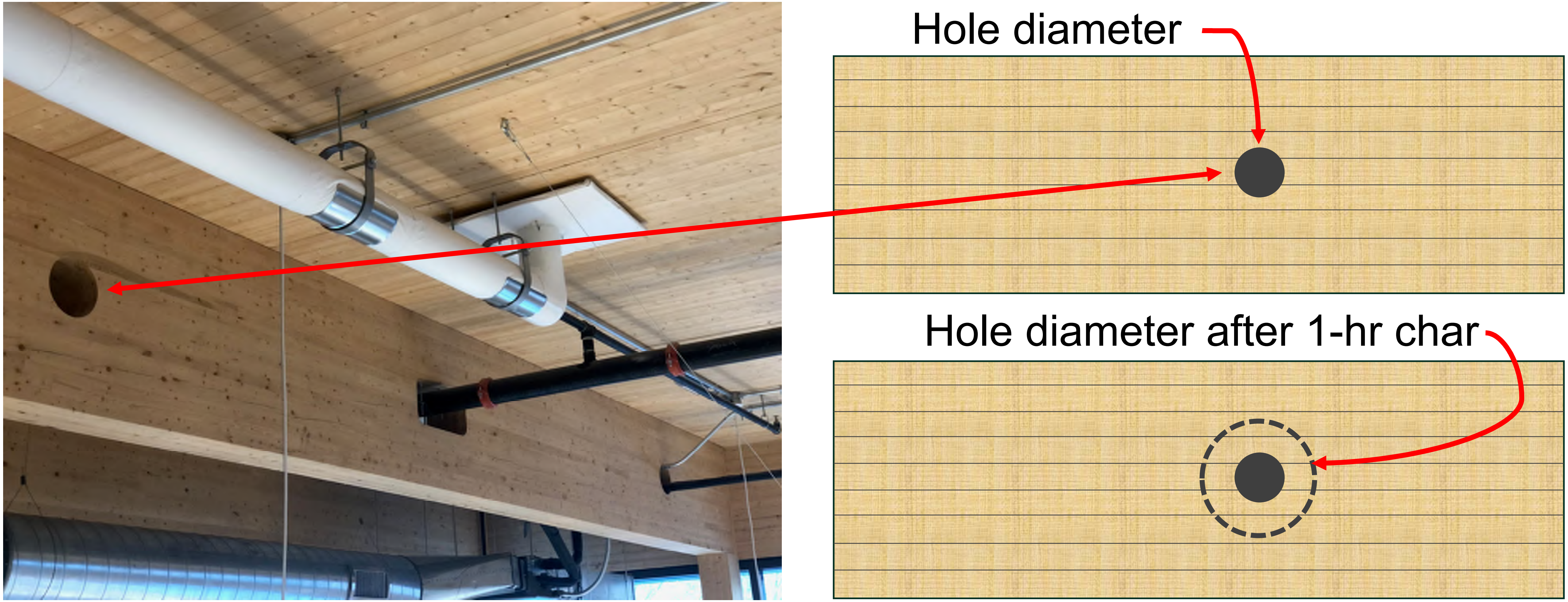
Unrated	1-hr Fire Resistance Rating	1-1/2 and 2-hr Fire Resistance Rating
Outer Compression	Outer Compression	Outer Compression
Inner Compression	Inner Compression	Inner Compression
Core	Core	Core
Core	Core	Core
Core	Core	Core
Core	Core	Core
Core	Core	Inner Tension
Core	Inner Tension	Inner Tension
Inner Tension	Inner Tension	Outer Tension
Inner Tension	Outer Tension	Outer Tension
Outer Tension	Outer Tension	Outer Tension
(a)	(b)	(c)

Figure 3-1 Typical glulam unbalanced beam layups

Source: AWC's TR 10

MEP Layout Integration

Fire resistance rated beam penetrations



Fire Design of Mass Timber: CLT

- Nominal char rate of 1.5”/HR is recognized in NDS.
- Lam thickness affects char depth

CLT (w/ lams of equal thickness)

$$a_{char} = n_{lam}\, h_{lam} + \beta_t \left(t - \left(n_{lam}\, t_{gi} \right) \right)^{0.813}$$

Effective Char Depth

$$a_{eff} = 1.2a_{char}$$

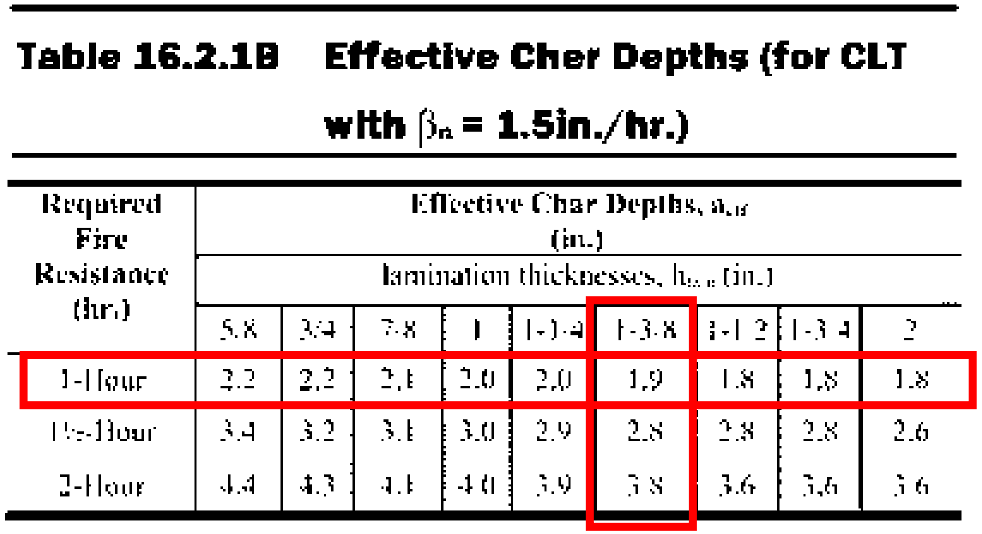
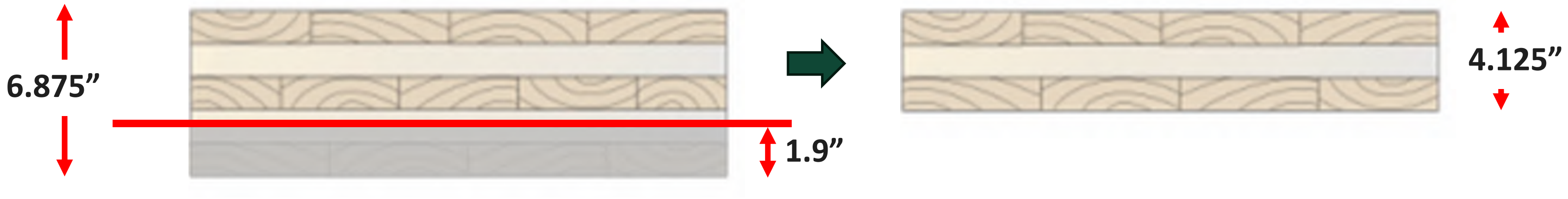


Table 16.2.1B Effective Char Depths (for CLT with β_n = 1.5in./hr.)

Required Fire Resistance (hr.)	Effective Char Depths, a_{char} (in.)								
	lamination thicknesses, h_{lam} (in.)								
	5/8	3/4	7/8	1	1-1/4	1-3/8	1-1/2	1-3/4	2
1-Hour	2.2	2.2	2.1	2.0	2.0	1.9	1.8	1.8	1.8
1½-Hour	3.4	3.2	3.1	3.0	2.9	2.8	2.8	2.8	2.6
2-Hour	4.4	4.3	4.1	4.0	3.9	3.8	3.6	3.6	3.6

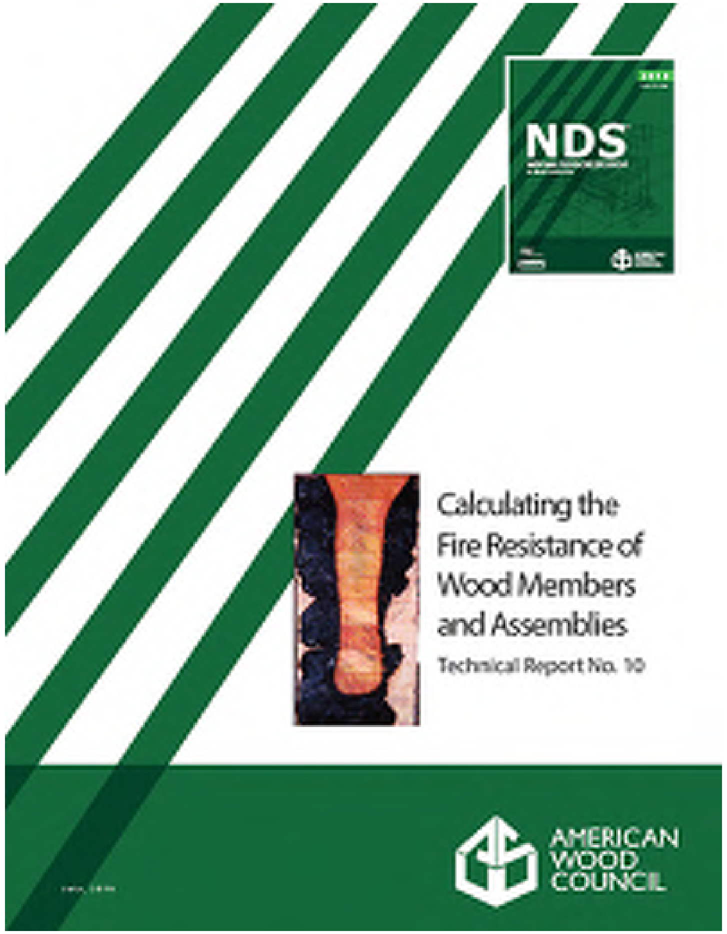
Source: 2018 AWC NDS

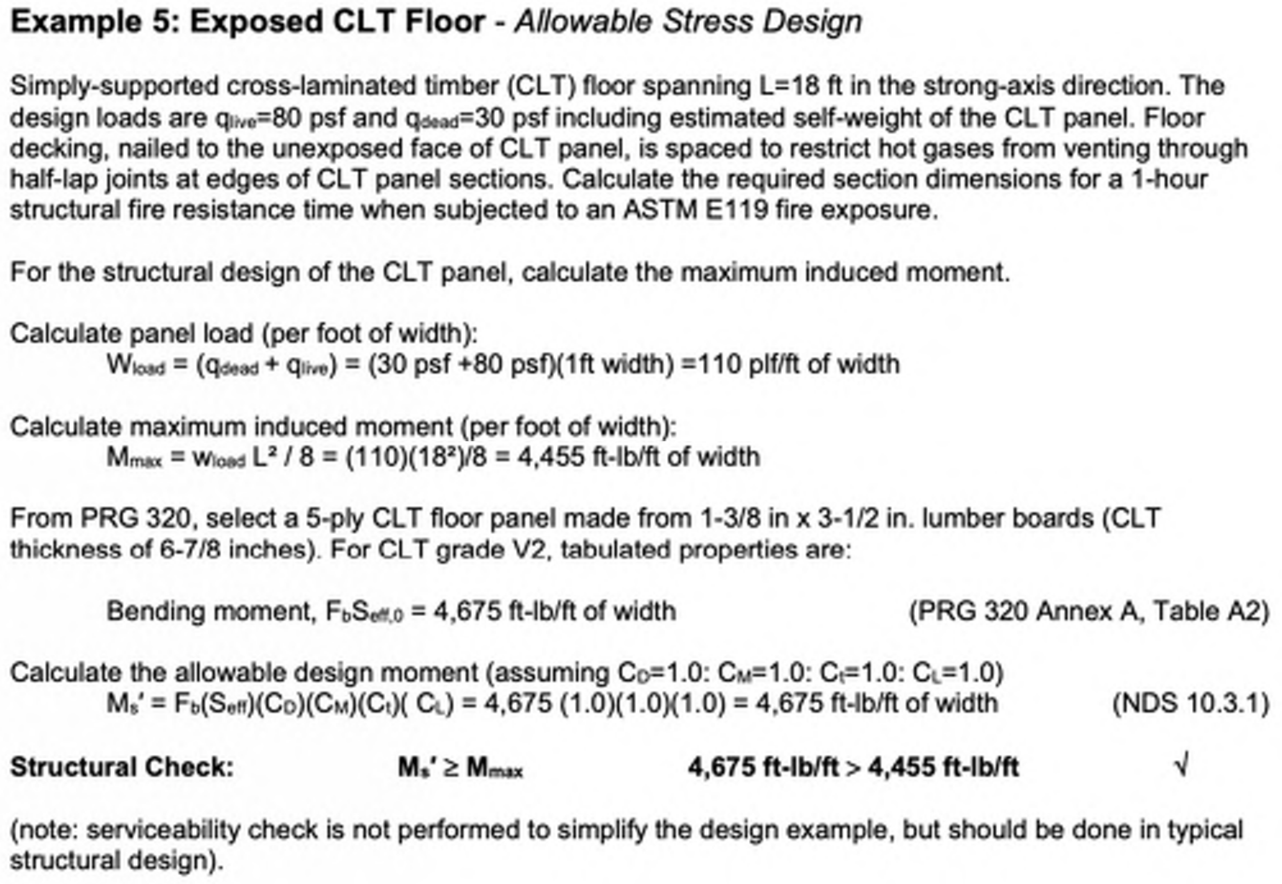
- Partially charred cross layers neglected for structural checks



Fire Design of Mass Timber

AWC's TR10 is a technical design guide, aids in the use of NDS Chapter 16 calculations





Example 5: Exposed CLT Floor - *Allowable Stress Design*

Simply-supported cross-laminated timber (CLT) floor spanning L=18 ft in the strong-axis direction. The design loads are q_{live}=80 psf and q_{dead}=30 psf including estimated self-weight of the CLT panel. Floor decking, nailed to the unexposed face of CLT panel, is spaced to restrict hot gases from venting through half-lap joints at edges of CLT panel sections. Calculate the required section dimensions for a 1-hour structural fire resistance time when subjected to an ASTM E119 fire exposure.

For the structural design of the CLT panel, calculate the maximum induced moment.

Calculate panel load (per foot of width):

$W_{load} = (q_{dead} + q_{live}) = (30 \text{ psf} + 80 \text{ psf})(1\text{ft width}) = 110$ plf/ft of width

Calculate maximum induced moment (per foot of width):

$M_{max} = w_{load} L^2 / 8 = (110)(18^2)/8 = 4{,}455$ ft-lb/ft of width

From PRG 320, select a 5-ply CLT floor panel made from 1-3/8 in x 3-1/2 in. lumber boards (CLT thickness of 6-7/8 inches). For CLT grade V2, tabulated properties are:

Bending moment, $F_bS_{eff,0}$ = 4,675 ft-lb/ft of width (PRG 320 Annex A, Table A2)

Calculate the allowable design moment (assuming C_D=1.0: C_M=1.0: C_t=1.0: C_L=1.0)

$M_s' = F_b(S_{eff})(C_D)(C_M)(C_t)(C_L) = 4{,}675\ (1.0)(1.0)(1.0) = 4{,}675$ ft-lb/ft of width (NDS 10.3.1)

Structural Check: $M_s' \geq M_{max}$ **4,675 ft-lb/ft > 4,455 ft-lb/ft** √

(note: serviceability check is not performed to simplify the design example, but should be done in typical structural design).

Source: AWC's TR10

Calculating FRR of Floor Elements

Chapter 16 of the **2024 NDS** references the Fire Design Specification for Wood Construction

NATIONAL DESIGN SPECIFICATION FOR WOOD CONSTRUCTION 149

FIRE DESIGN OF WOOD MEMBERS

16

2024 NDS - 16.1 General

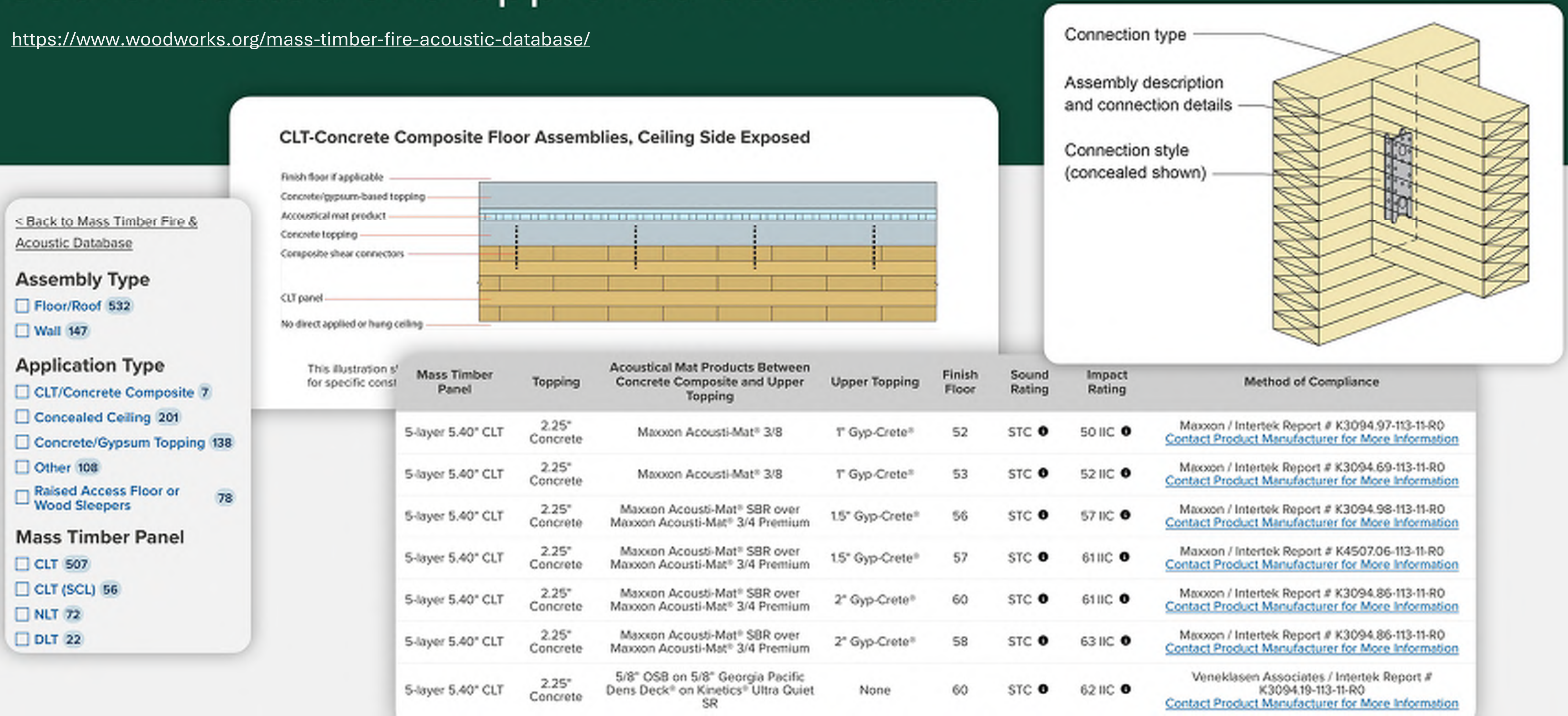
Where determinations of thermal separation and burn-through resistance are required, calculations shall be in accordance with the *Fire Design Specification for Wood Construction*

NEW ONLINE TOOL

Mass Timber Fire & Acoustic Database

Search tested and approved assemblies

https://www.woodworks.org/mass-timber-fire-acoustic-database/



< Back to Mass Timber Fire & Acoustic Database

Assembly Type

☐ Floor/Roof 532
☐ Wall 147

Application Type

☐ CLT/Concrete Composite 7
☐ Concealed Ceiling 201
☐ Concrete/Gypsum Topping 138
☐ Other 108
☐ Raised Access Floor or Wood Sleepers 78

Mass Timber Panel

☐ CLT 507
☐ CLT (SCL) 56
☐ NLT 72
☐ DLT 22

CLT-Concrete Composite Floor Assemblies, Ceiling Side Exposed

Mass Timber Panel	Topping	Acoustical Mat Products Between Concrete Composite and Upper Topping	Upper Topping	Finish Floor	Sound Rating	Impact Rating	Method of Compliance
5-layer 5.40" CLT	2.25" Concrete	Maxxon Acousti-Mat® 3/8	1" Gyp-Crete®	52	STC ⓘ	50 IIC ⓘ	Maxxon / Intertek Report # K3094.97-113-11-R0 Contact Product Manufacturer for More Information
5-layer 5.40" CLT	2.25" Concrete	Maxxon Acousti-Mat® 3/8	1" Gyp-Crete®	53	STC ⓘ	52 IIC ⓘ	Maxxon / Intertek Report # K3094.69-113-11-R0 Contact Product Manufacturer for More Information
5-layer 5.40" CLT	2.25" Concrete	Maxxon Acousti-Mat® SBR over Maxxon Acousti-Mat® 3/4 Premium	1.5" Gyp-Crete®	56	STC ⓘ	57 IIC ⓘ	Maxxon / Intertek Report # K3094.98-113-11-R0 Contact Product Manufacturer for More Information
5-layer 5.40" CLT	2.25" Concrete	Maxxon Acousti-Mat® SBR over Maxxon Acousti-Mat® 3/4 Premium	1.5" Gyp-Crete®	57	STC ⓘ	61 IIC ⓘ	Maxxon / Intertek Report # K4507.06-113-11-R0 Contact Product Manufacturer for More Information
5-layer 5.40" CLT	2.25" Concrete	Maxxon Acousti-Mat® SBR over Maxxon Acousti-Mat® 3/4 Premium	2" Gyp-Crete®	60	STC ⓘ	61 IIC ⓘ	Maxxon / Intertek Report # K3094.86-113-11-R0 Contact Product Manufacturer for More Information
5-layer 5.40" CLT	2.25" Concrete	Maxxon Acousti-Mat® SBR over Maxxon Acousti-Mat® 3/4 Premium	2" Gyp-Crete®	58	STC ⓘ	63 IIC ⓘ	Maxxon / Intertek Report # K3094.86-113-11-R0 Contact Product Manufacturer for More Information
5-layer 5.40" CLT	2.25" Concrete	5/8" OSB on 5/8" Georgia Pacific Dens Deck® on Kinetics® Ultra Quiet SR	None	60	STC ⓘ	62 IIC ⓘ	Veneklasen Associates / Intertek Report # K3094.19-113-11-R0 Contact Product Manufacturer for More Information

Acoustical Design

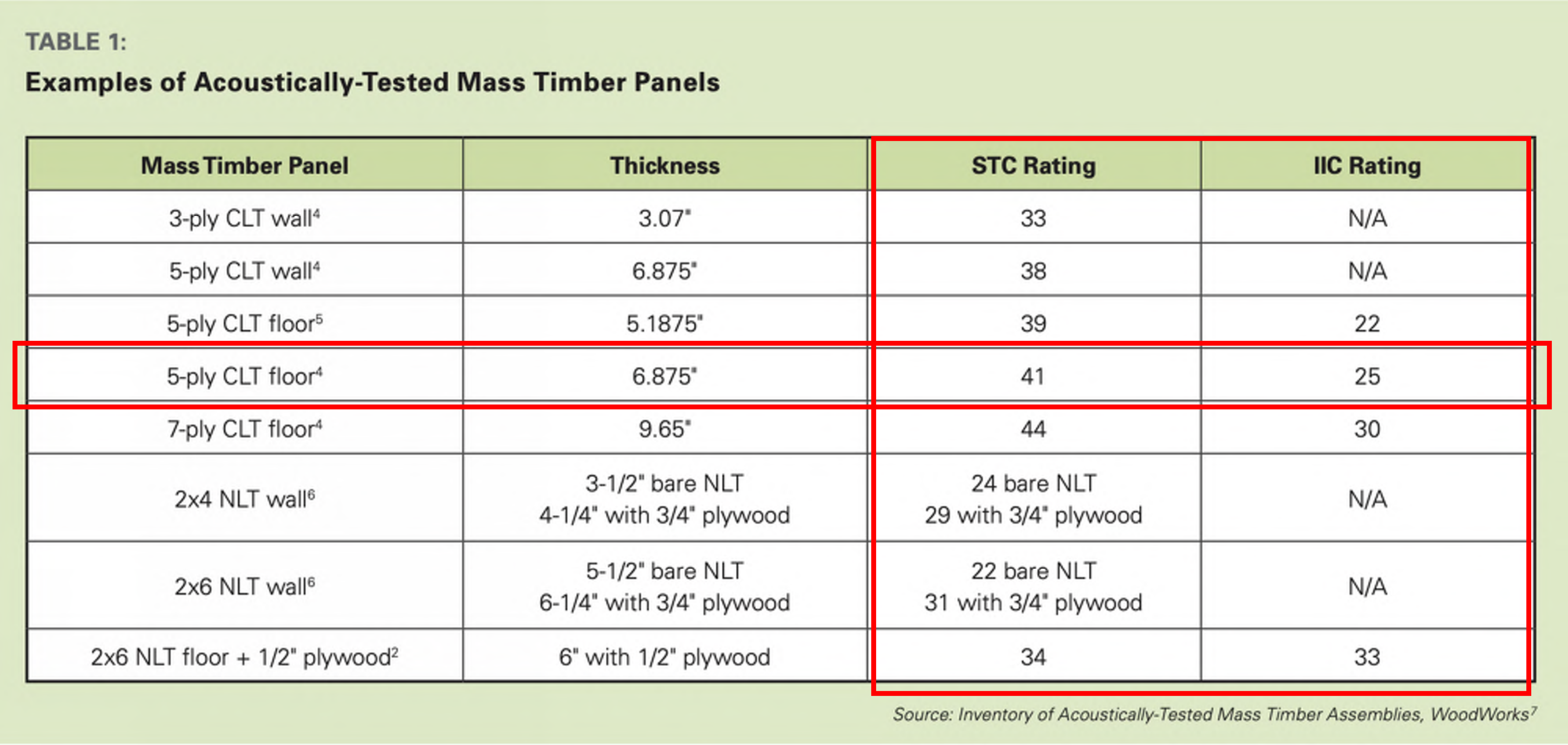


TABLE 1:

Examples of Acoustically-Tested Mass Timber Panels

Mass Timber Panel	Thickness	STC Rating	IIC Rating
3-ply CLT wall[4]	3.07"	33	N/A
5-ply CLT wall[4]	6.875"	38	N/A
5-ply CLT floor[5]	5.1875"	39	22
5-ply CLT floor[4]	6.875"	41	25
7-ply CLT floor[4]	9.65"	44	30
2x4 NLT wall[6]	3-1/2" bare NLT 4-1/4" with 3/4" plywood	24 bare NLT 29 with 3/4" plywood	N/A
2x6 NLT wall[6]	5-1/2" bare NLT 6-1/4" with 3/4" plywood	22 bare NLT 31 with 3/4" plywood	N/A
2x6 NLT floor + 1/2" plywood[2]	6" with 1/2" plywood	34	33

Source: Inventory of Acoustically-Tested Mass Timber Assemblies, WoodWorks[7]

Acoustical Design

Regardless of the structural materials used in a wall or floor ceiling assembly, there are 3 effective methods of improving acoustical performance:

1. Add mass
2. Add noise absorbers
3. Decouple (add air space or disconnect structure/finish from carrying all the way through the assembly)

Image: AcoustiTECH

“One might almost say that **strength is essential** and **otherwise unimportant**”

- Hardy Cross

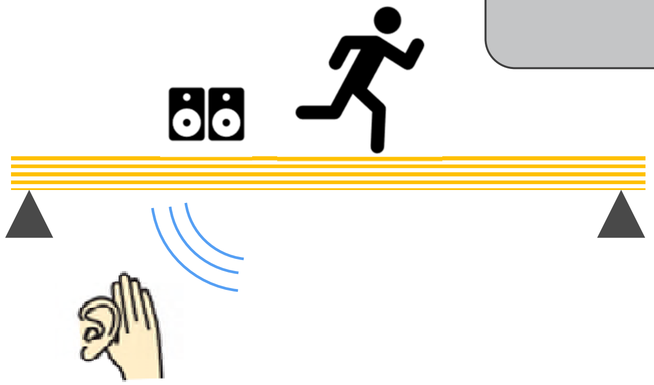
Agenda

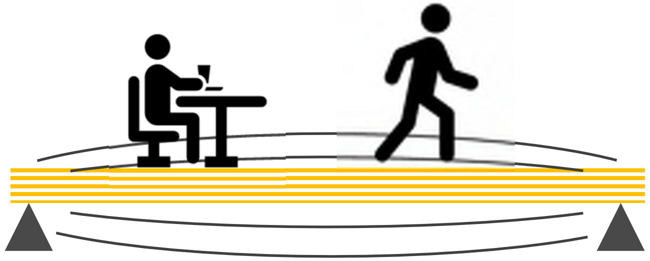
- Fire Resistance and Acoustics
- **Vibration Design**
- Connections
- Structural Design – Lateral

Photo: John Stamets

Vibrations vs. Acoustics

Acoustic Vibrations	Structural Vibrations
20 Hz – 15,000 Hz	1 Hz – 100 Hz
Transmitted through air, walls, floors, windows	Transmitted through structure or through ground
Audible effects	Physical effects





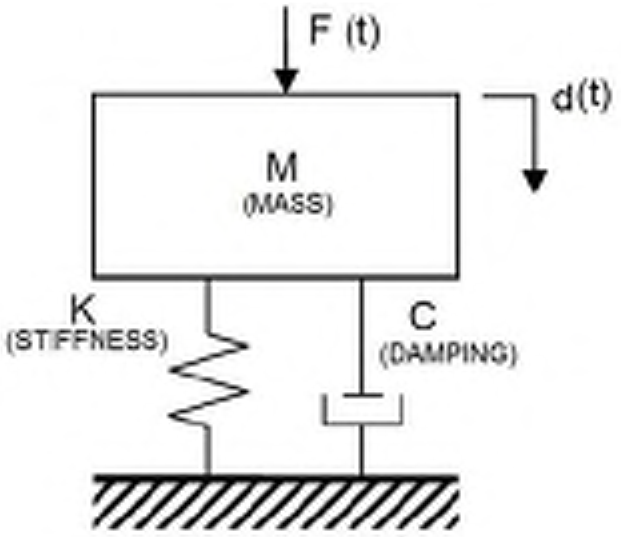
US Building Code Requirements for Vibration

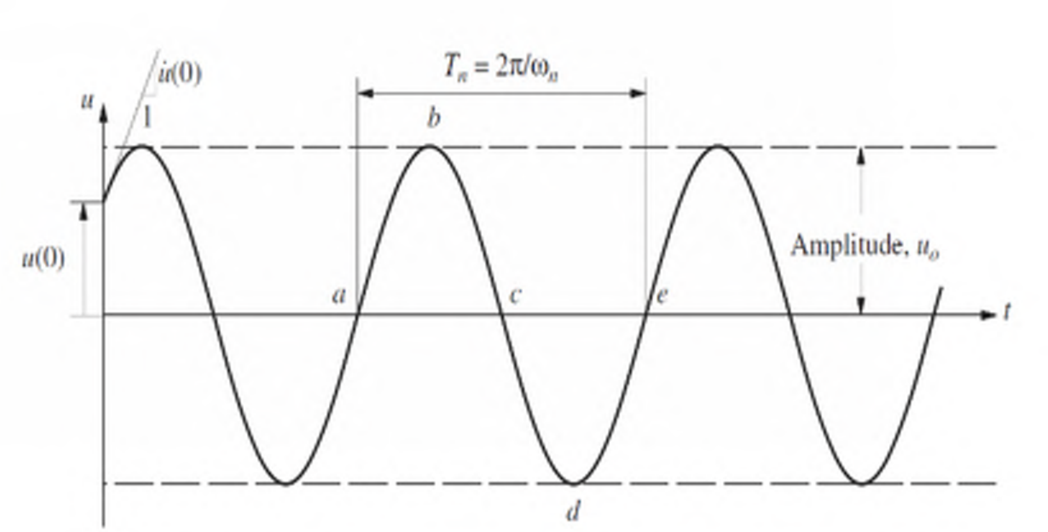
None

Barely discussed in IBC, NDS, etc.

ASCE 7 Commentary Appendix C has some discussion, no requirements

Floor Vibration Dynamics





Undamped Free Response

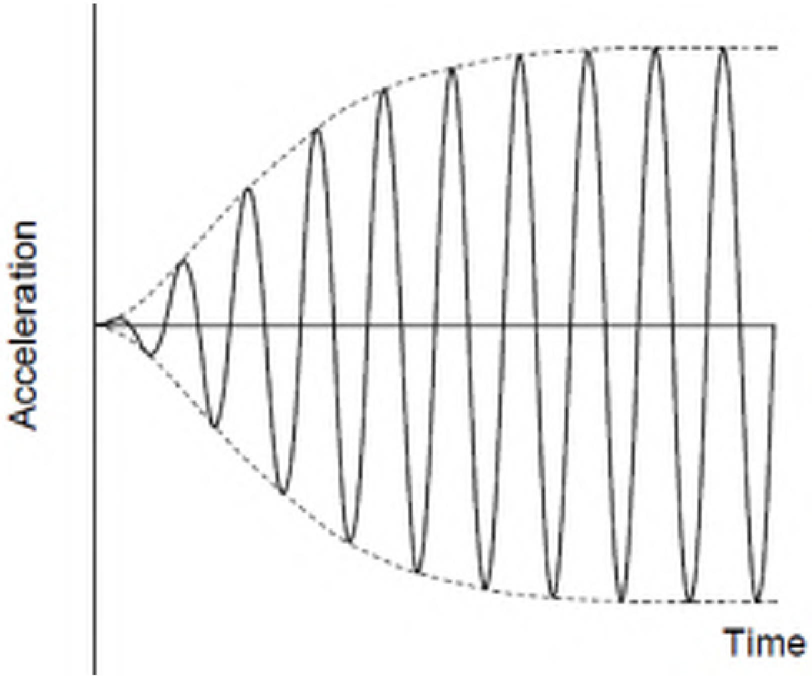
- Natural Frequency

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

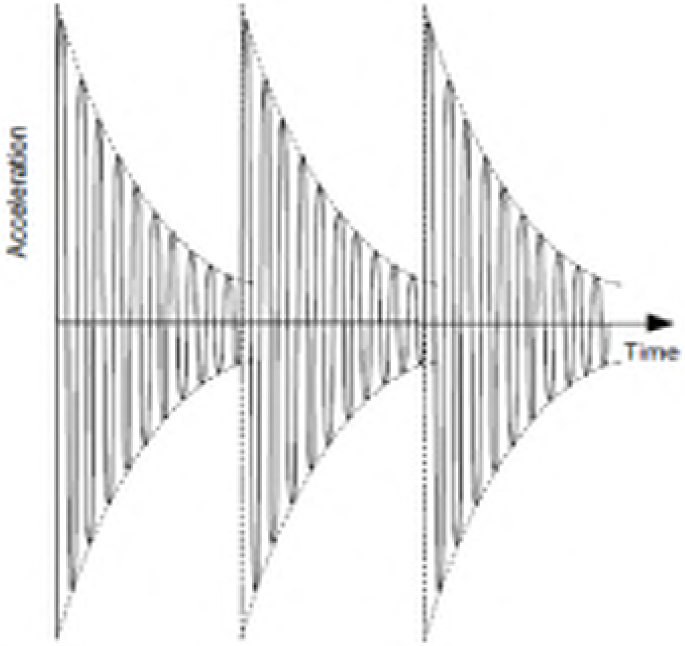
- Period

$$T = 1 / f_n$$

Resonant vs Impulsive Response



Excitation creates Resonant build-up of vibration



Response decays out between load impulses

Resonant Response

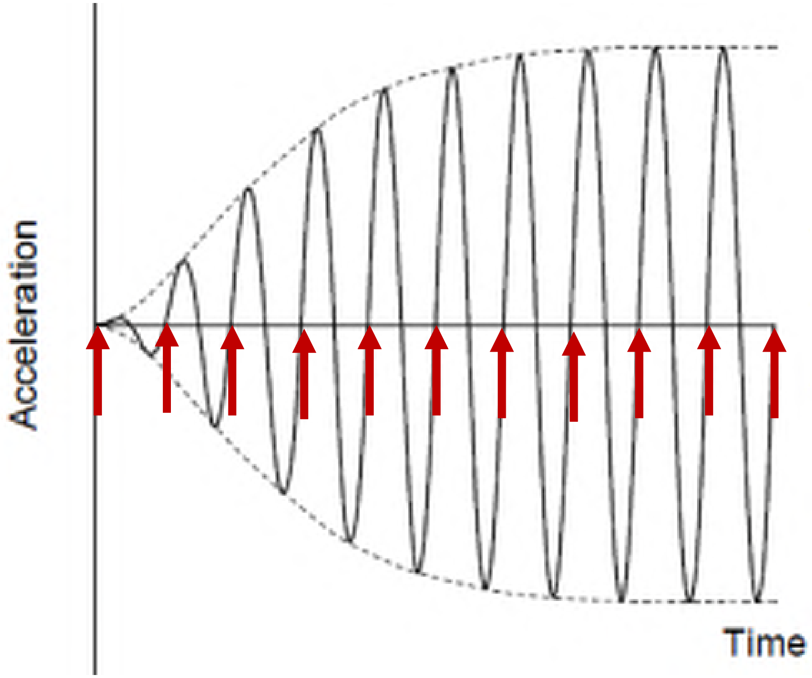
Impulsive/Transient Response

Walking Frequency f_w

Walking Speed	Walking Frequency	Steps Per Minute
Very Slow	1.25 Hz	75 SPM
Slow	1.6 Hz	95 SPM
Moderate	1.85 Hz	110 SPM
Fast	2.1 Hz	126 SPM
Running	Up to 4.0 Hz	240 SPM
Practical Tip - walk to a metronome too understand the range		

The range of walking frequencies considered is an important consideration of vibration analysis

Resonant vs Impulsive Response



Excitation Frequency not >> Natural Frequency
Excitation Creates Resonant Build-up of Vibration

Resonant Response

Resonance occurs when
walking frequency = natural frequency

$$f_w = f_n$$

Also occurs when a harmonic of the walking frequency ~= natural frequency

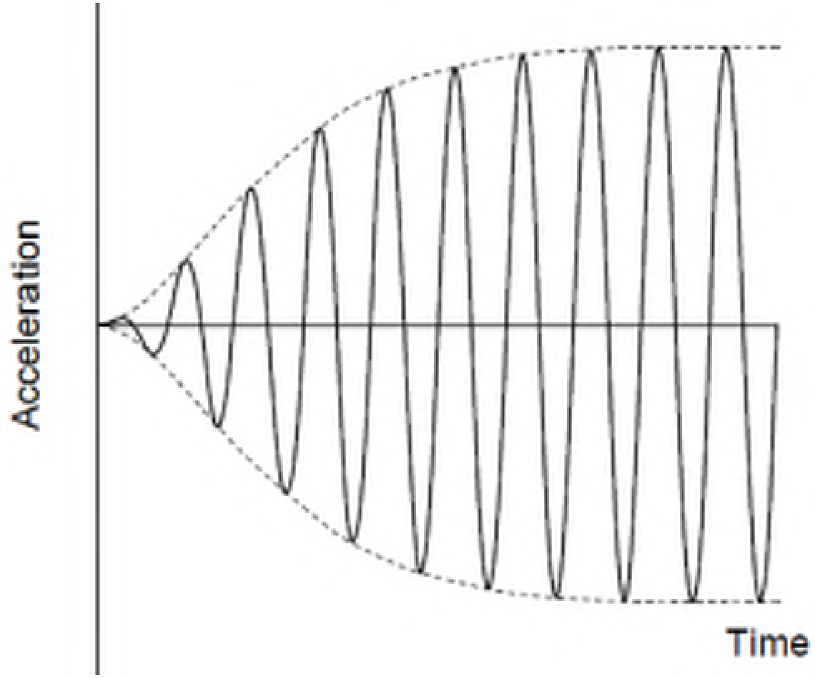
$$n\, f_w = f_n$$

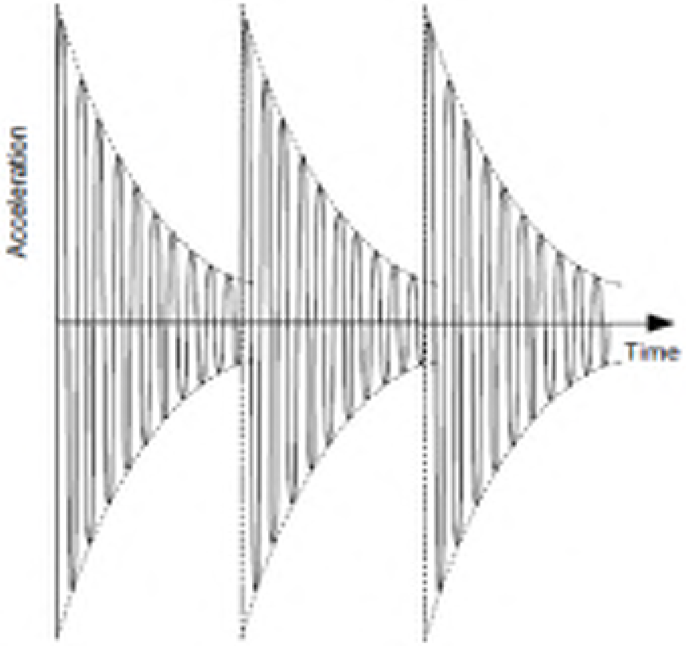
For ‘n’ up to around 4

Walking at f_w =2 Hz creates resonance in floor with natural frequency, f_n, at

2Hz, 4 Hz, 6 Hz, and 8Hz

Resonant vs Impulsive Response





Excitation creates Resonant build-up of vibration

Response decays out between load impulses

Resonant Response

Impulsive/Transient Response

For walking excitations

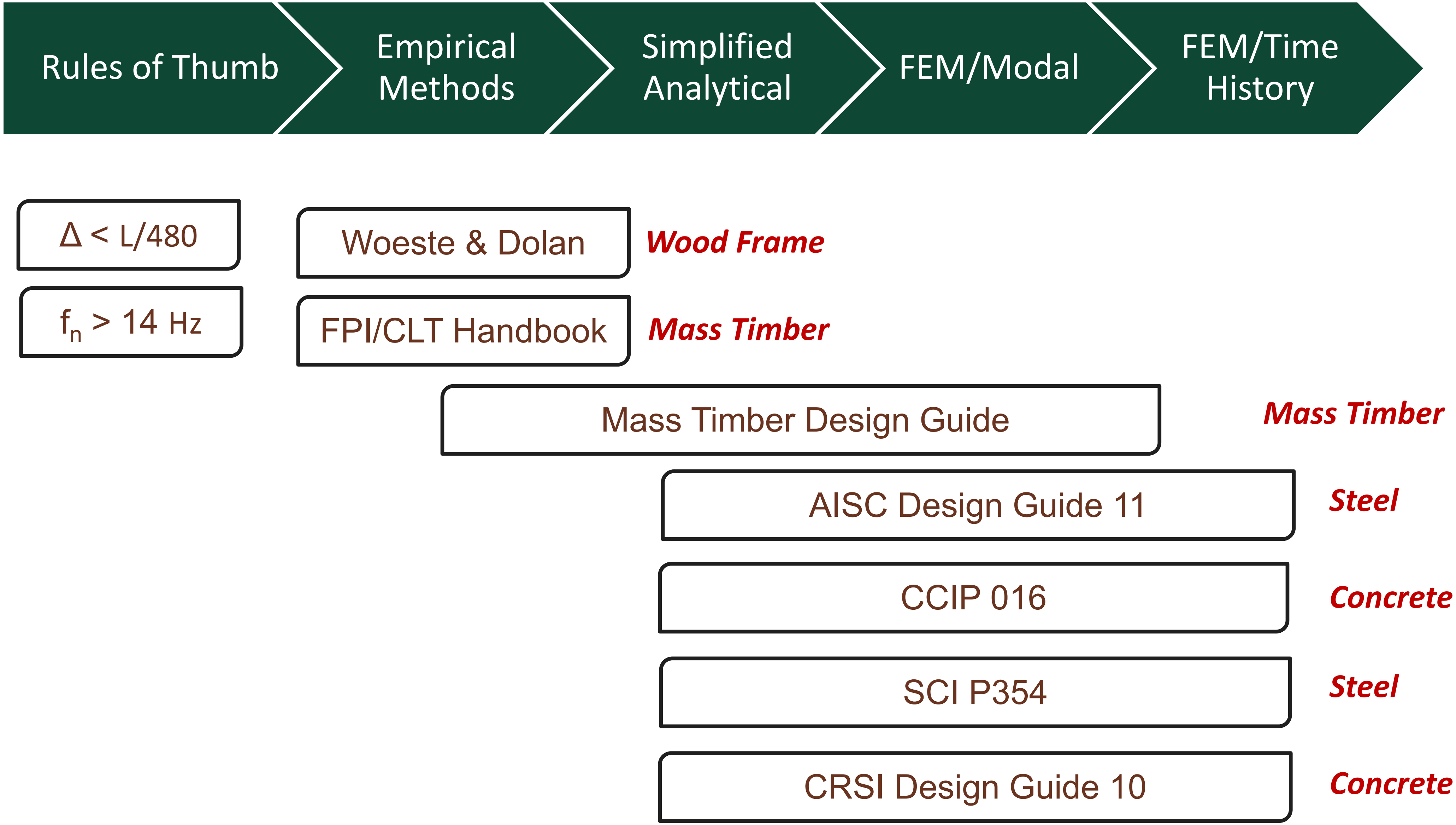
f_n ~< 8-10 Hz

f_n ~> 8-10 Hz

Floor Vibration Concepts

- The natural frequency of a floor, and harmonics of the fundamental frequency, are the most important parameters in vibration design and evaluation
- Most practical floors have fundamental frequencies in the range of 5 to 15 Hz, although values outside this range are possible
- Generally, the higher the frequency the better the performance

Vibration Design Methods



Rules of Thumb

Empirical Methods

Simplified Analytical

FEM/Modal

FEM/Time History

Δ < L/480

$f_n > 14$ Hz

Woeste & Dolan — ***Wood Frame***

FPI/CLT Handbook — ***Mass Timber***

Mass Timber Design Guide — ***Mass Timber***

AISC Design Guide 11 — ***Steel***

CCIP 016 — ***Concrete***

SCI P354 — ***Steel***

CRSI Design Guide 10 — ***Concrete***

Vibration Design Methods

Rules of Thumb → Empirical Methods → Simplified Analytical → FEM/Modal Superposition → FEM/Time History

Mass Timber

CLT Handbook Method

U.S. CLT Handbook, 2013
Canadian CLT Handbook 2nd Ed., 2019
FPInnovations

CLT Handbook Method

Recommended CLT Floor Span Limit (base value)

$$L_{lim} \leq \frac{1}{12.05} \frac{\left(EI_{eff}\right)^{0.293}}{(\overline{\rho}A)^{0.122}} \text{ [ft]}$$

Where, for 12 in wide strip:

EI_{eff} = effective flexural stiffness (lbf-in^2)

$\overline{\rho}$ = in-service specific gravity of the CLT, unitless
e.g. weight normalized by weight of water

A = the cross-section area (in^2) = thickness * 12 in

Reference: US & Canadian CLT Handbooks, Chapter 7

CLT Handbook In Practice

- Experience shown it consistently produces well performing floors

- Does not consider

Multi-span panels	**Improves Performance**
Flexibility of supports, e.g. beams	**Lowers Performance**
Impact of topping slabs (more mass, but lower frequency)	**Performance??**

- Recommend 20% increase in acceptable span length OK for multi-span panels with non-structural elements that are considered to provide an enhanced stiffening effect, including partition walls, finishes and ceilings, etc.

CLT Handbook Base Span Limit

For PRG 320-2019 Basic CLT Grades and Layups from Solid Sawn Lumber

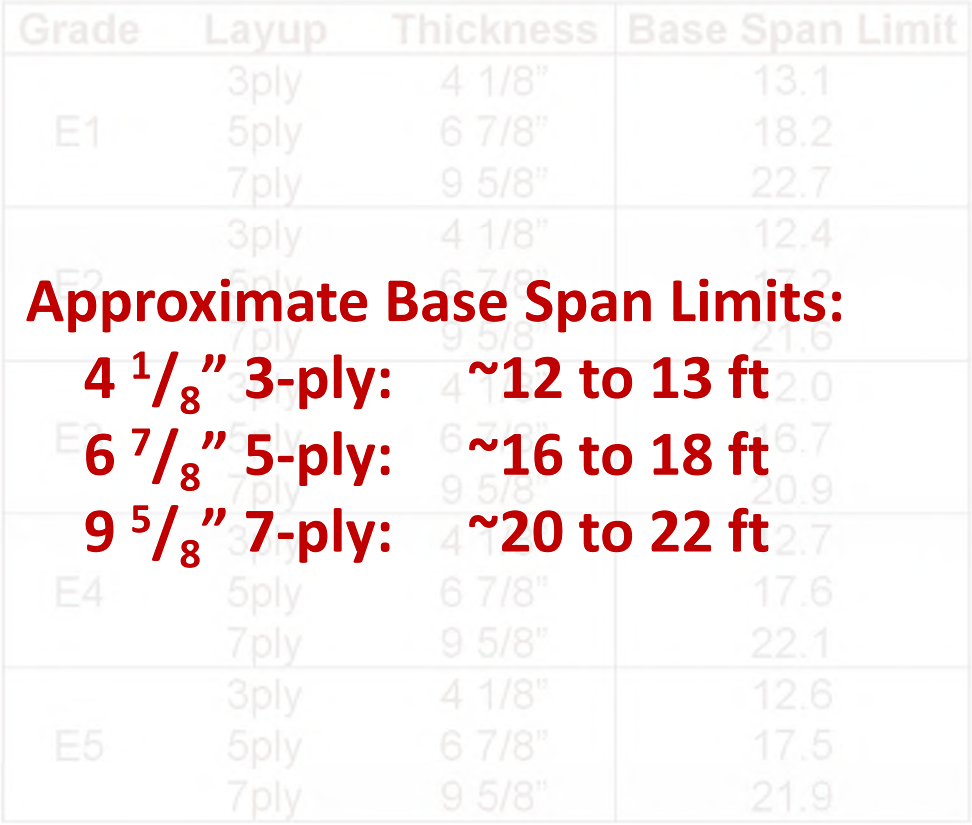
Grade	Layup	Thickness	Base Span Limit
E1	3ply	4 1/8”	13.1
	5ply	6 7/8”	18.2
	7ply	9 5/8”	22.7
E2	3ply	4 1/8”	12.4
	5ply	6 7/8”	17.2
	7ply	9 5/8”	21.6
E3	3ply	4 1/8”	12.0
	5ply	6 7/8”	16.7
	7ply	9 5/8”	20.9
E4	3ply	4 1/8”	12.7
	5ply	6 7/8”	17.6
	7ply	9 5/8”	22.1
E5	3ply	4 1/8”	12.6
	5ply	6 7/8”	17.5
	7ply	9 5/8”	21.9

Grade	Layup	Thickness	FPI Span Limit
V1	3ply	4 1/8”	12.6
	5ply	6 7/8”	17.6
	7ply	9 5/8”	22.0
V1(N)	3ply	4 1/8”	12.6
	5ply	6 7/8”	17.6
	7ply	9 5/8”	22.0
V2	3ply	4 1/8”	12.4
	5ply	6 7/8”	17.2
	7ply	9 5/8”	21.5
V3	3ply	4 1/8”	12.0
	5ply	6 7/8”	16.7
	7ply	9 5/8”	20.9
V4	3ply	4 1/8”	11.7
	5ply	6 7/8”	16.3
	7ply	9 5/8”	20.4
V5	3ply	4 1/8”	12.1
	5ply	6 7/8”	16.8
	7ply	9 5/8”	21.0

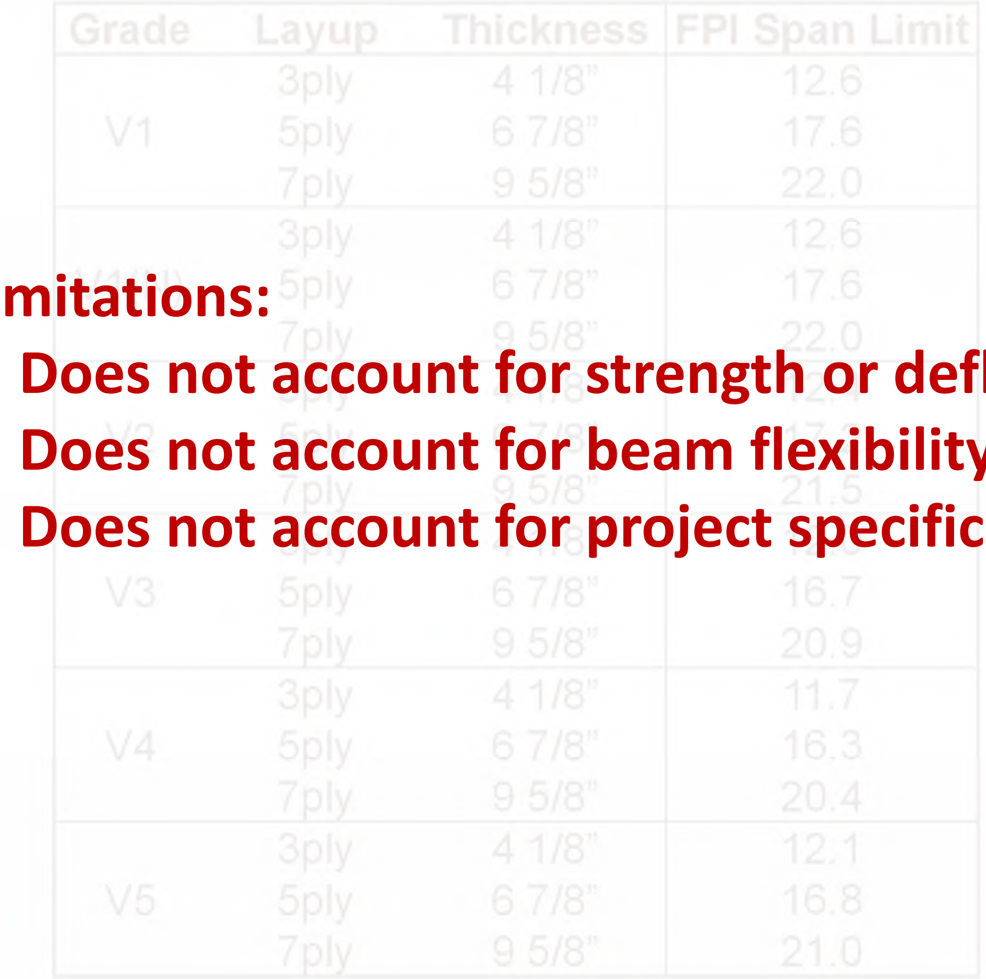
Reference: US Mass Timber Floor Vibration Design Guide, assuming 12% M.C.

CLT Handbook Base Span Limit

For PRG 320-2019 Basic CLT Grades and Layups from Solid Sawn Lumber



Grade	Layup	Thickness	Base Span Limit
E1	3ply	4 1/8"	13.1
	5ply	6 7/8"	18.2
	7ply	9 5/8"	22.7
E2	3ply	4 1/8"	12.4
	5ply	6 7/8"	17.2
	7ply	9 5/8"	21.6
E3	3ply	4 1/8"	[illegible]
	5ply	6 7/8"	16.7
	7ply	9 5/8"	20.9
E4	3ply	4 1/8"	[illegible]
	5ply	6 7/8"	17.6
	7ply	9 5/8"	22.1
E5	3ply	4 1/8"	12.6
	5ply	6 7/8"	17.5
	7ply	9 5/8"	21.9



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	7ply	9 5/8"	21.5
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	7ply	9 5/8"	20.4
V5	3ply	4 1/8"	12.1
	5ply	6 7/8"	16.8
	7ply	9 5/8"	21.0

Approximate Base Span Limits:

4 $^{1}/_{8}$" 3-ply:	**~12 to 13 ft**
6 $^{7}/_{8}$" 5-ply:	**~16 to 18 ft**
9 $^{5}/_{8}$" 7-ply:	**~20 to 22 ft**

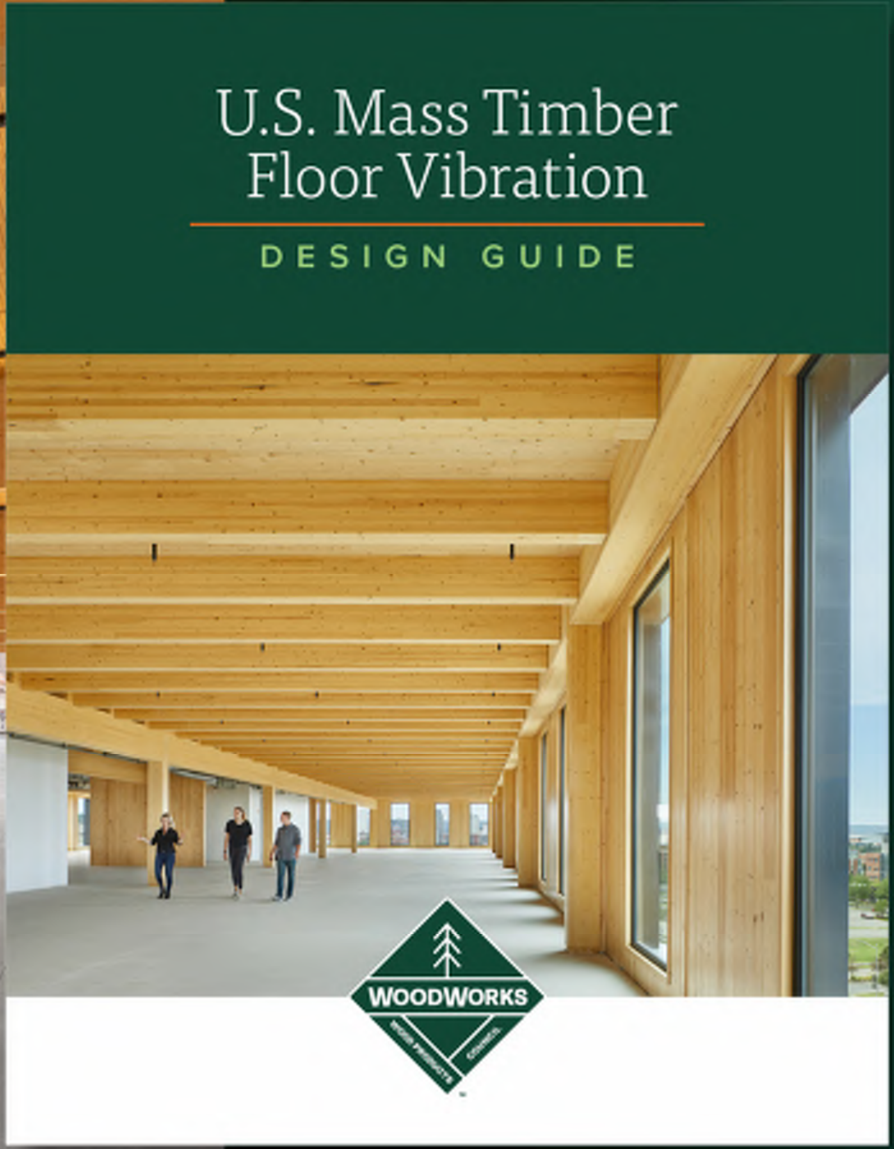
Limitations:

- **Does not account for strength or deflections**
- **Does not account for beam flexibility**
- **Does not account for project specifics**

Reference: US Mass Timber Floor Vibration Design Guide, assuming 12% M.C.

https://www.woodworks.org/resources/us-mass-timber-floor-vibration-design-guide/

The Soto / Lake | Flato (Design Architect), BOKA Powell (AOR)
Photo Erika Brown Photography



U.S. Mass Timber
Floor Vibration

DESIGN GUIDE

WOODWORKS
WOOD PRODUCTS COUNCIL

Agenda

- Fire Resistance and Acoustics
- Vibration Design
- **Connections**
- Structural Design – Lateral

Photo: John Stamets

Connection Design

- Structural capacity
- Shrinkage
- Aesthetics
- Constructability
- Cost
- Fire Resistance

John W. Olver Design
Building at UMass Amherst
Leers Weinzapfel Associates / Equilibrium Consulting / Simpson Gumpertz & Heger (EOR) / Suffolk Construction
Photo Alex Schreyer

GUIDES, MANUALS & INVENTORIES

WoodWorks Index of Mass Timber Connections

A compilation of connections used in mass timber construction

Platte Fifteen / OZ Architecture / KL&A Engineers & Builders
Photo Alan Ferrin
https://www.woodworks.org/resources/index-of-mass-timber-connections/

Index of Mass Timber Connections

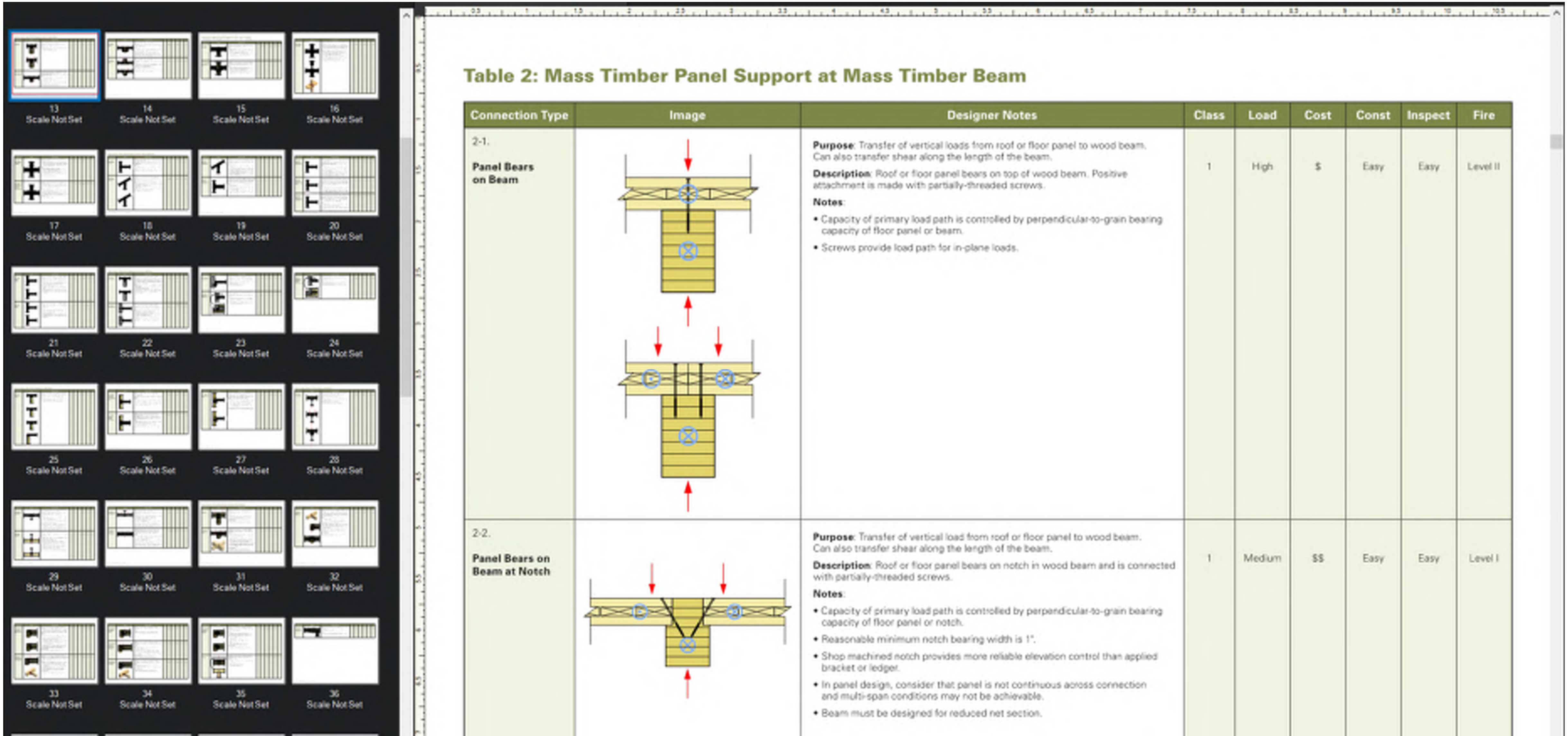
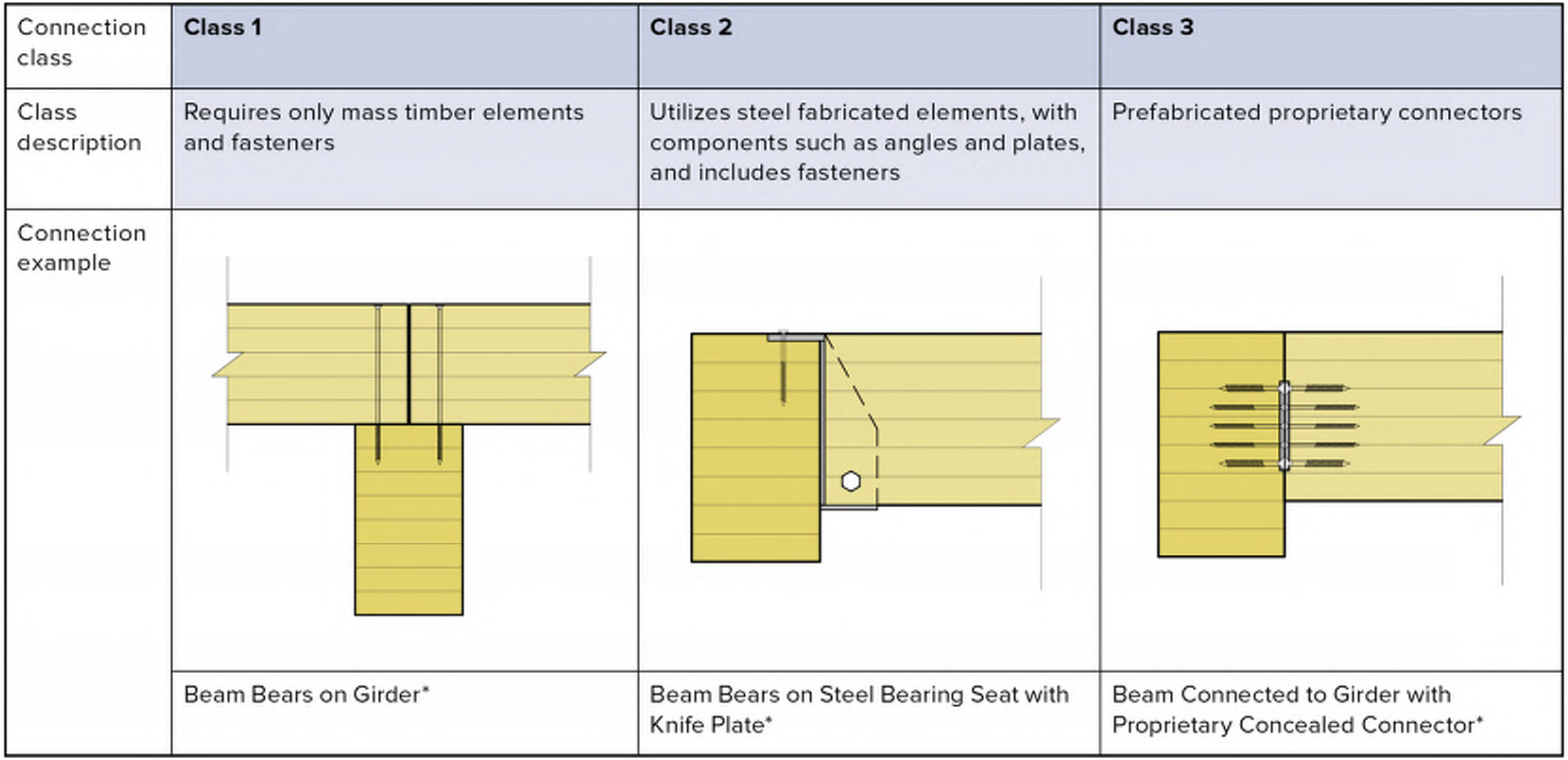


Table 2: Mass Timber Panel Support at Mass Timber Beam

Connection Type	Image	Designer Notes	Class	Load	Cost	Const	Inspect	Fire
2-1. **Panel Bears on Beam**		**Purpose**: Transfer of vertical loads from roof or floor panel to wood beam. Can also transfer shear along the length of the beam. **Description**: Roof or floor panel bears on top of wood beam. Positive attachment is made with partially-threaded screws. **Notes**: • Capacity of primary load path is controlled by perpendicular-to-grain bearing capacity of floor panel or beam. • Screws provide load path for in-plane loads.	1	High	$	Easy	Easy	Level II
2-2. **Panel Bears on Beam at Notch**		**Purpose**: Transfer of vertical load from roof or floor panel to wood beam. Can also transfer shear along the length of the beam. **Description**: Roof or floor panel bears on notch in wood beam and is connected with partially-threaded screws. **Notes**: • Capacity of primary load path is controlled by perpendicular-to-grain bearing capacity of floor panel or notch. • Reasonable minimum notch bearing width is 1". • Shop machined notch provides more reliable elevation control than applied bracket or ledger. • In panel design, consider that panel is not continuous across connection and multi-span conditions may not be achievable. • Beam must be designed for reduced net section.	1	Medium	$$	Easy	Easy	Level I

Connection Class



Connection class	**Class 1**	**Class 2**	**Class 3**
Class description	Requires only mass timber elements and fasteners	Utilizes steel fabricated elements, with components such as angles and plates, and includes fasteners	Prefabricated proprietary connectors
Connection example	Beam Bears on Girder*	Beam Bears on Steel Bearing Seat with Knife Plate*	Beam Connected to Girder with Proprietary Concealed Connector*

*Table 8 in the **Index of Mass Timber Connections***

Hardware

Wide range of:

- plates
- hangers
- straps
- angle brackets
- tie-rod systems
- concealed connectors
- lifting hardware
- and more

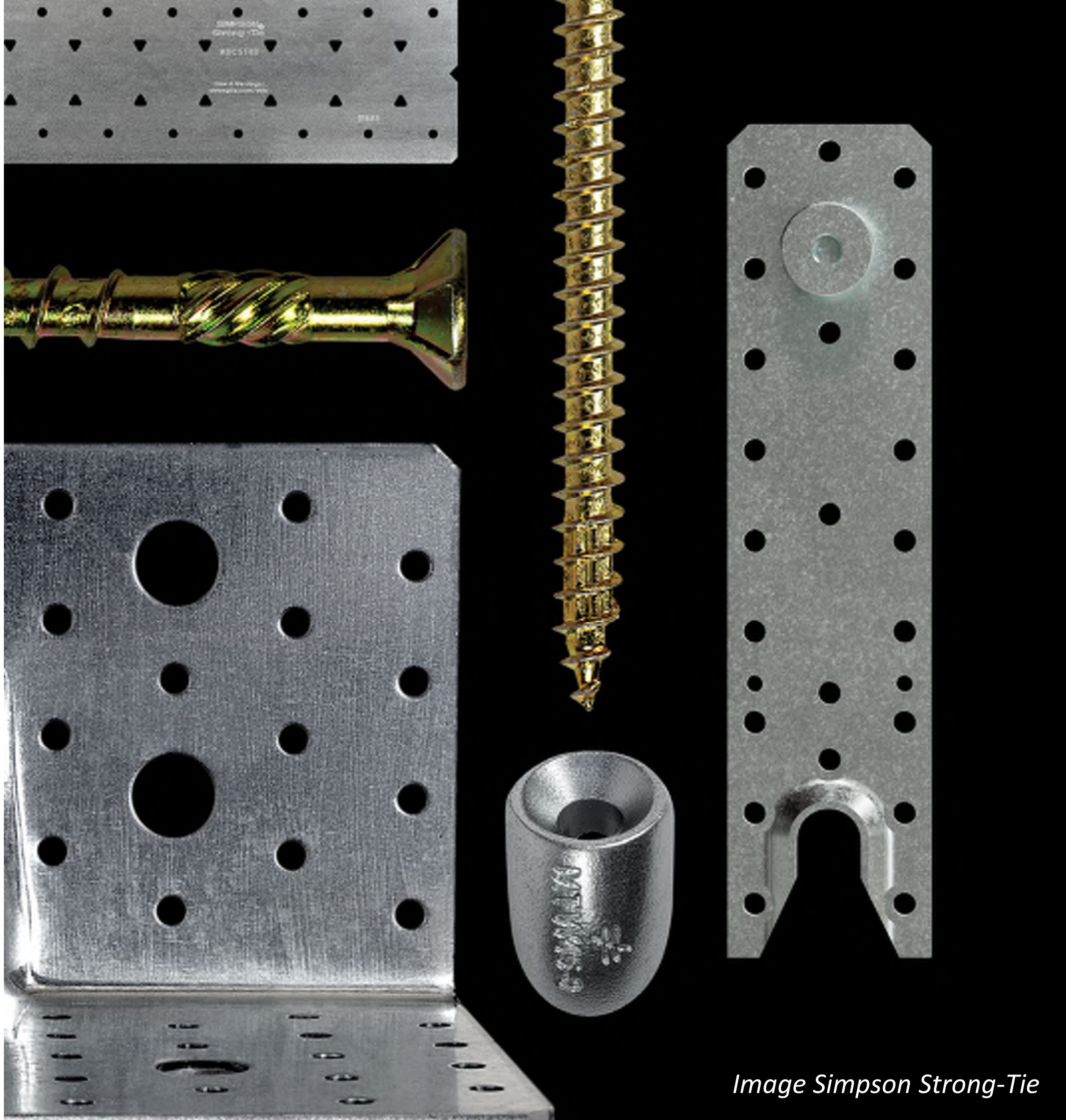
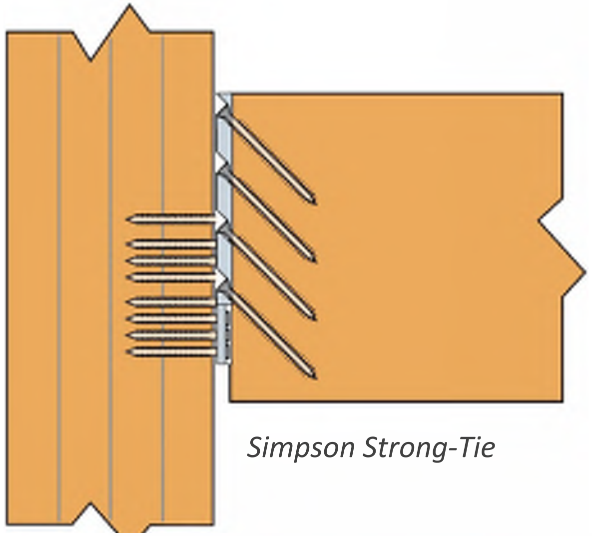
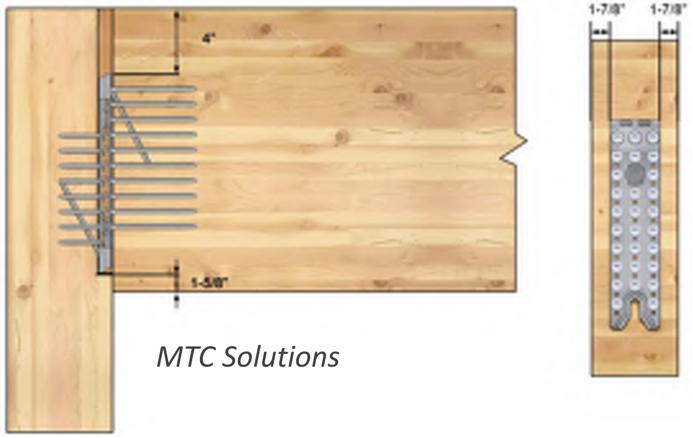


Image Simpson Strong-Tie

Concealed Hanger Connectors



Simpson Strong-Tie

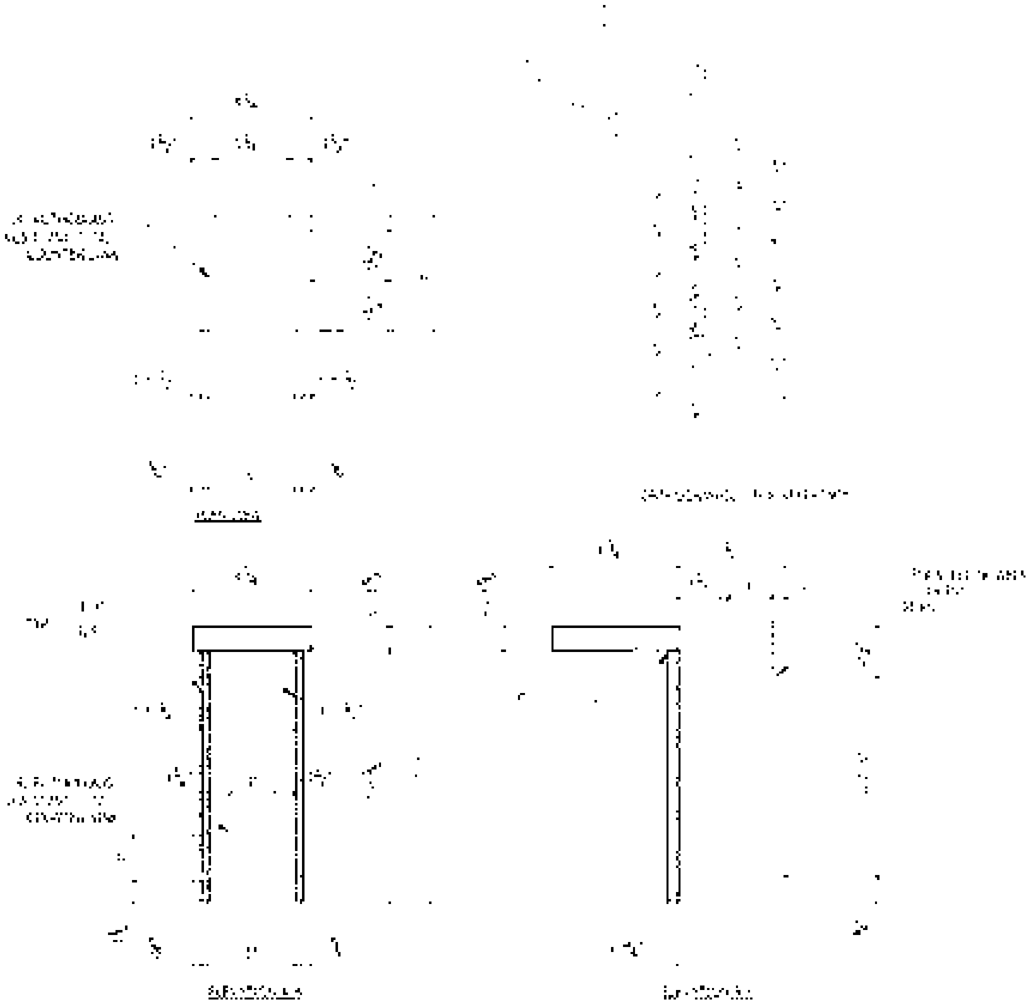


MTC Solutions

MTC Solutions

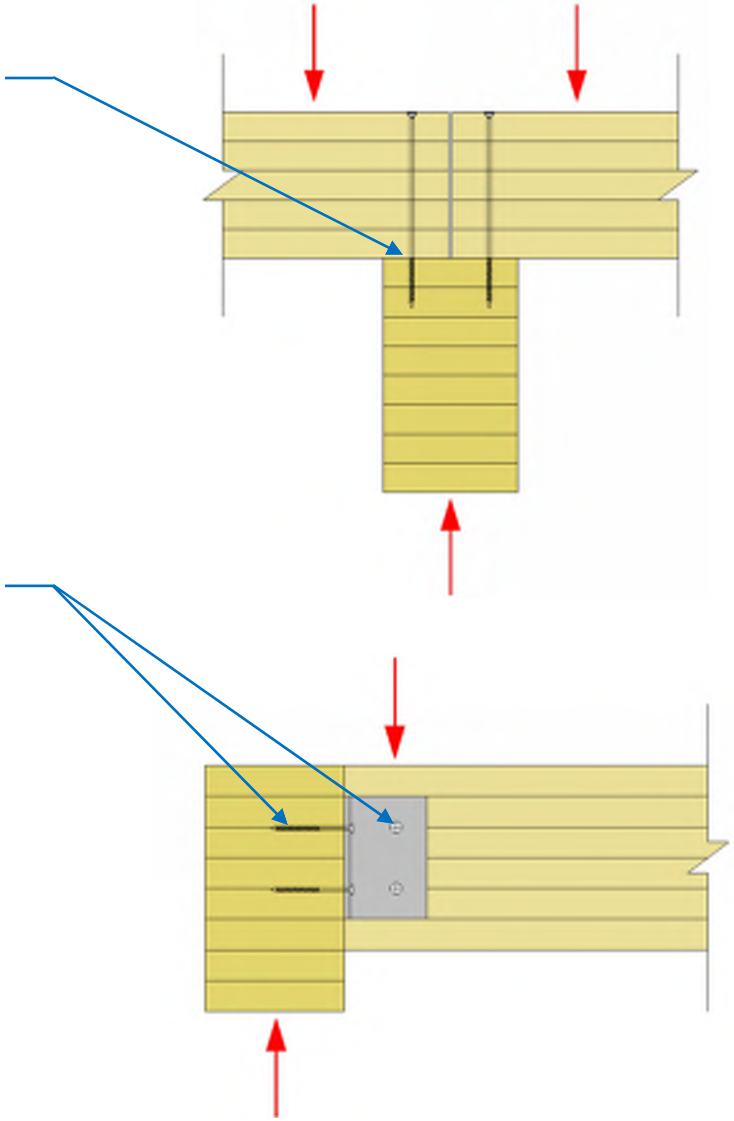
Example: Concealed Knife Plate with Holes

Image Foust Fabrication, T3 Timbers



Wood Connection Design Reminders

- **Bearing is Better than Dowel-Type Fasteners**

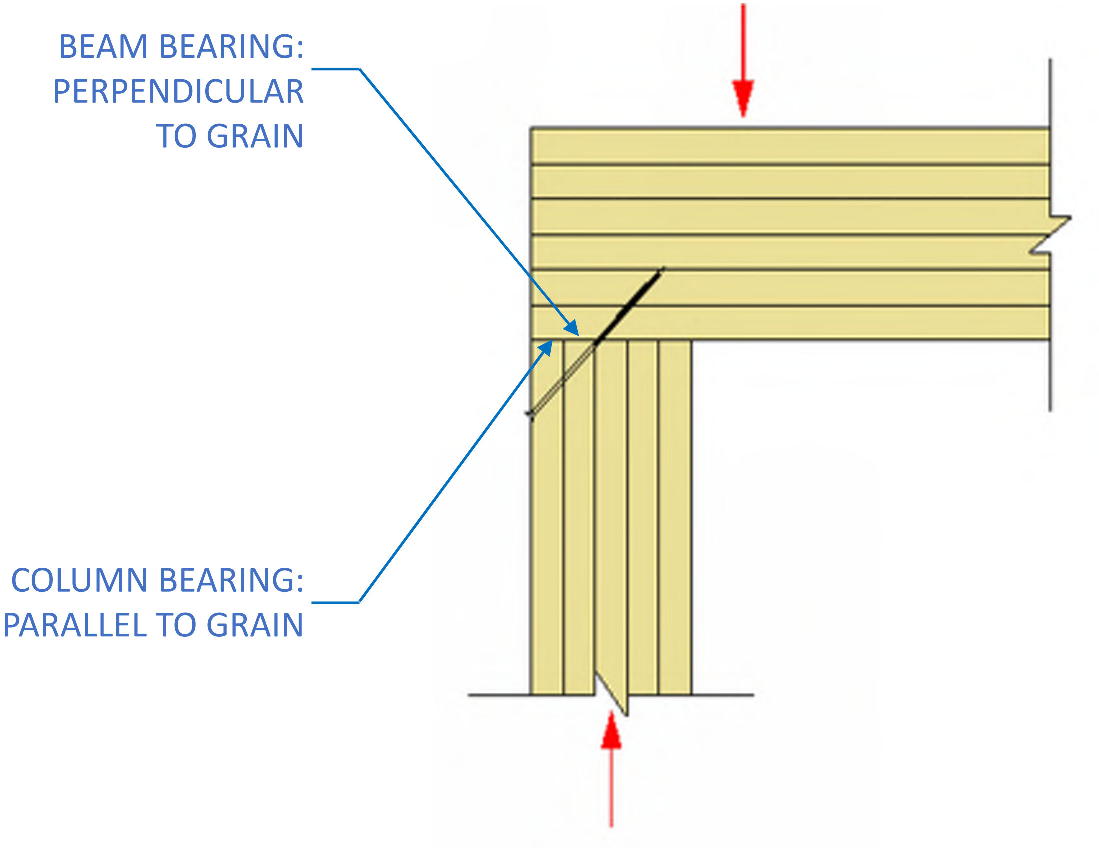


BEAM TO GIRDER BEARING

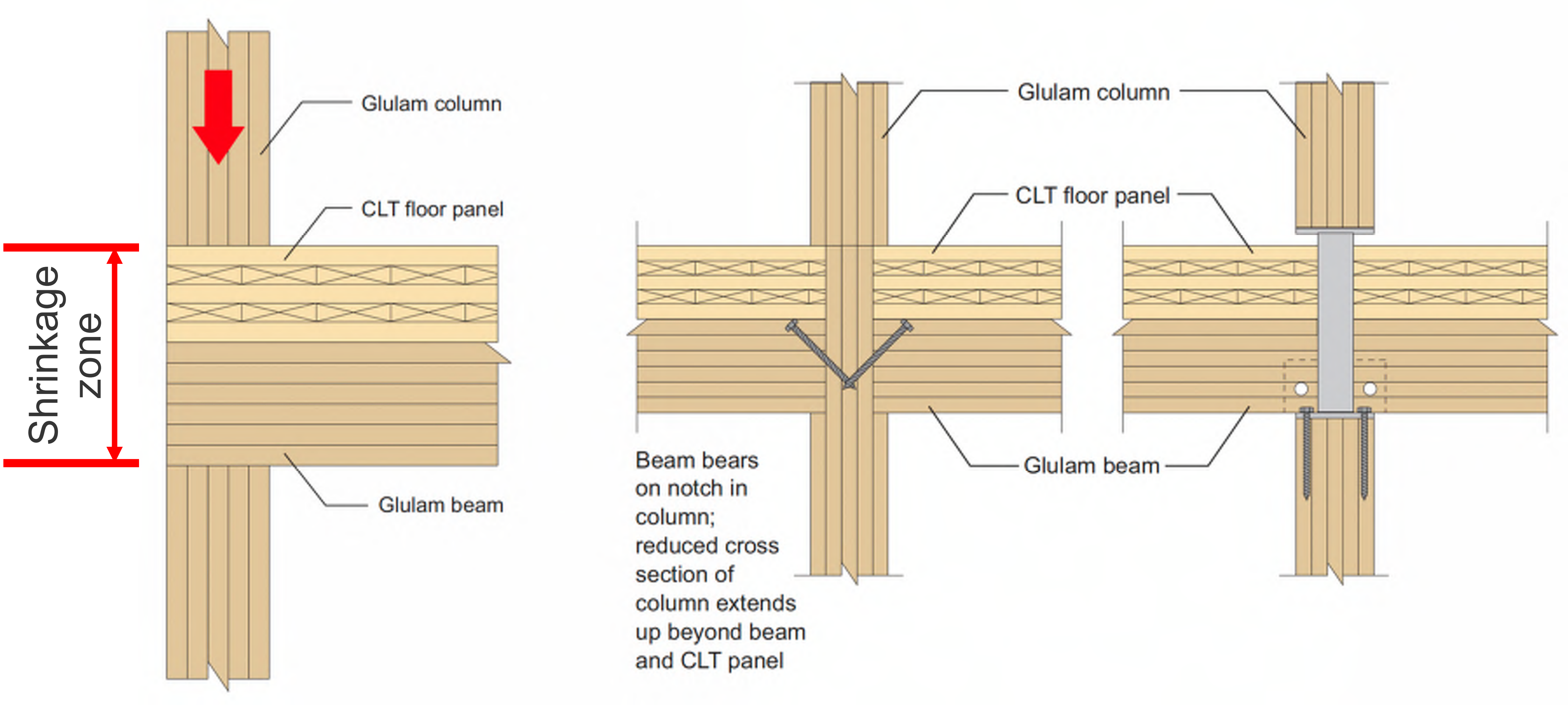
WOOD SCREWS IN SHEAR

Wood Connection Design Reminders

- Bearing is Better than Dowel-Type Fasteners
- **Parallel is Better than Perpendicular to Grain**



Beam & Panel Shrinkage

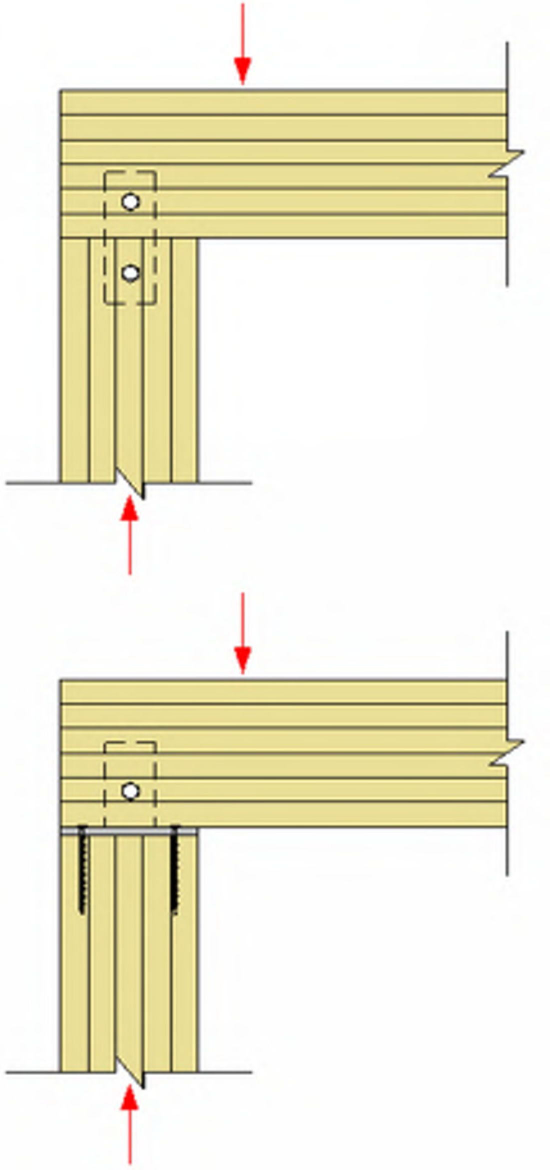


Beam bears on notch in column; reduced cross section of column extends up beyond beam and CLT panel

Wood Connection Design Reminders

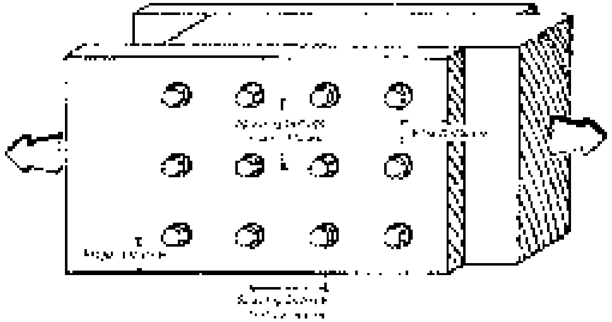
- Bearing is Better than Dowel-Type Fasteners
- Parallel is Better than Perpendicular to Grain
- **No Screw Withdrawal from End Grain**

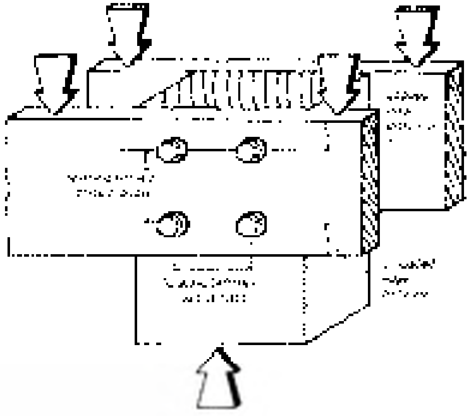
2018 AWC NDS, Section 12.2.2.3

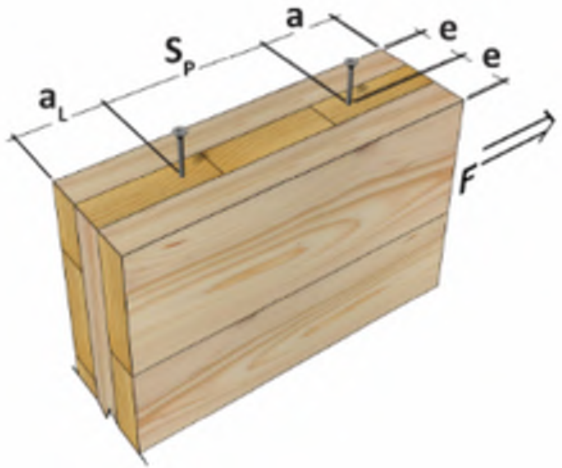


Wood Connection Design Reminders

- Bearing is Better than Dowel-Type Fasteners
- Parallel is Better than Perpendicular to Grain
- No Screw Withdrawal from End Grain
- **Edge Distances and Spacing are Important**
  - 2018 AWC NDS, Section 12.5
  - Manufacturer's Literature

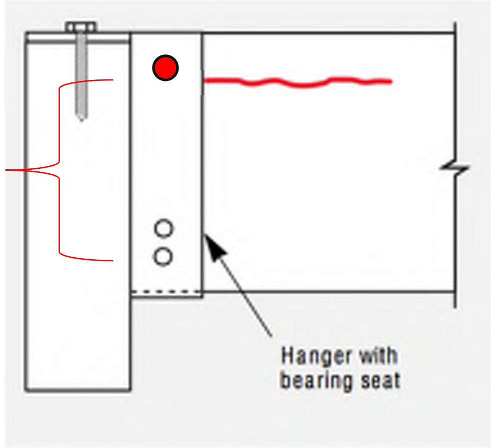




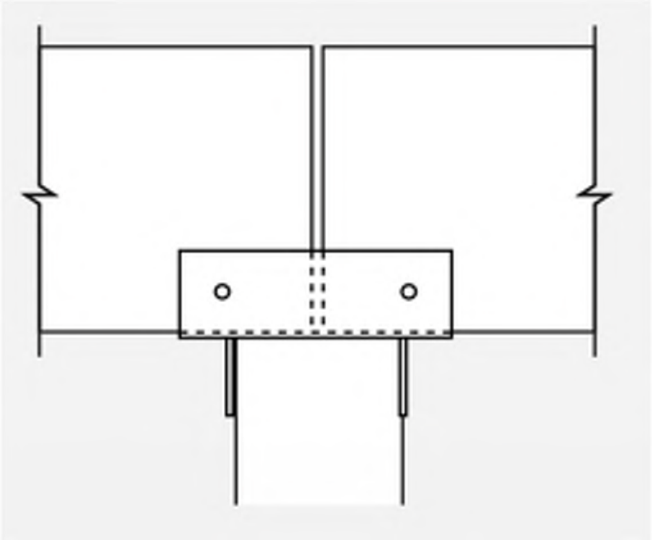


Bolted Connections: Shrinkage

- Consider shrinkage in connected members
- Avoid restraining shrinkage in connection – place connections on one edge of member rather than on both edges
- Best practice is to connect to lower half of beams, use of slotted holes aids in avoiding shrinkage cracks



Source: APA



Source: APA

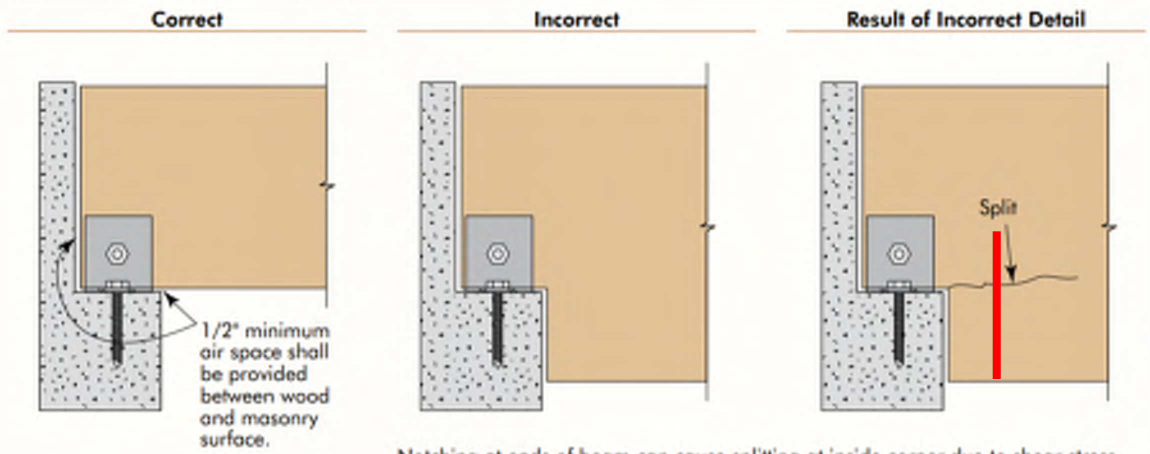
Wood Connection Design Reminders

- Bearing is Better than Dowel-Type Fasteners
- Parallel is Better than Perpendicular to Grain
- No Screw Withdrawal from End Grain
- Edge Distances and Spacing are Important
- **Notch with Care**

- 2018 AWC NDS, Section 5.4.5
- APA – The Engineered Wood Association (EWS) T300 *Glulam Connection Details Construction Guide*
- *Proprietary Screws as Tensile Reinforcement in Notched Beams*

FIGURE 1C

BEAM-TO-BEARING CONNECTIONS



Notching at ends of beam can cause splitting at inside corner due to shear stress concentrations and induced tension perpendicular-to-grain stresses. A notch at the end of a glulam beam should **never** exceed the lesser of 1/10 of beam depth or 3" and should be checked by the notched-beam formulas in NDS*.

**National Design Specification for Wood Construction, American Wood Council, info@awc.org*

(APA T300)

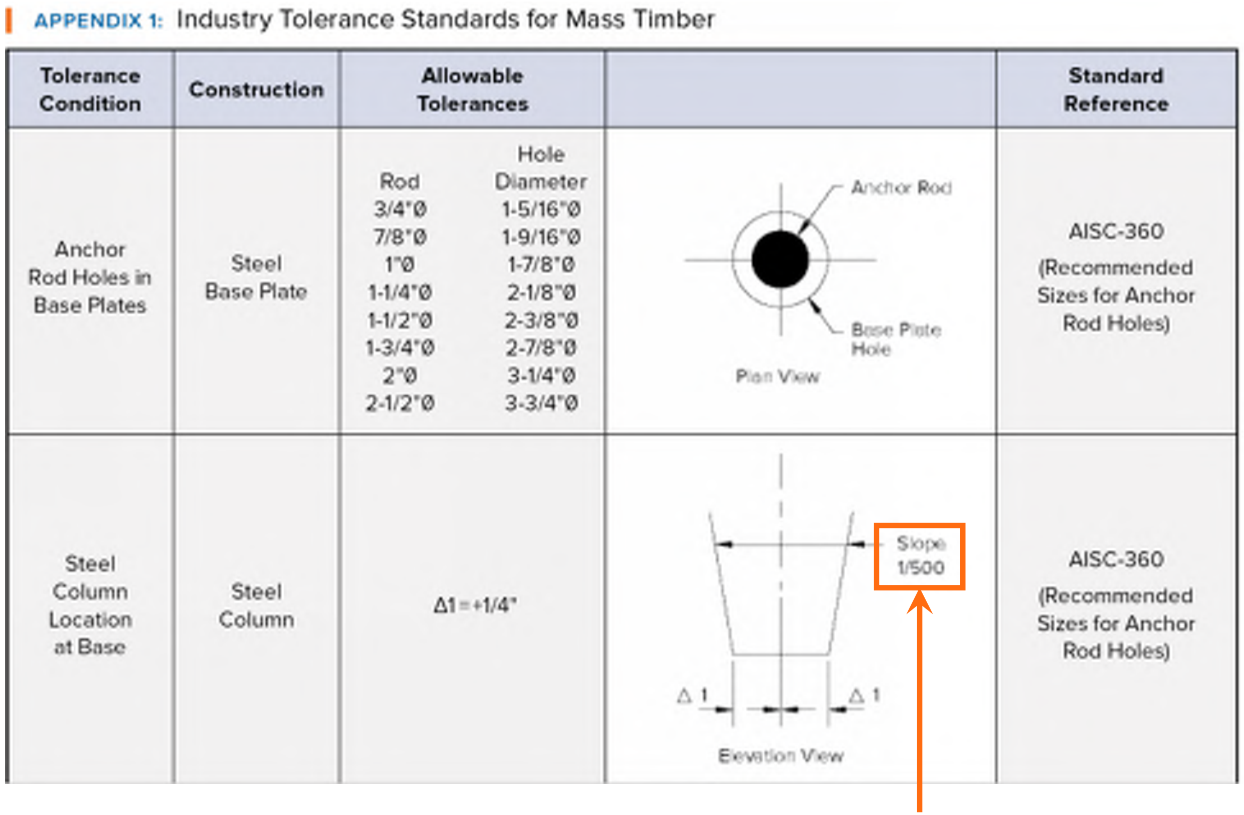
Burwell Center for Career Achievement

Lake|Flato Architects / Shears Adkins Rockmore Architects / KL&A Engineers & Builders / PCL Construction Services

Photos WoodWorks (L); KL&A

Tolerances Between Materials

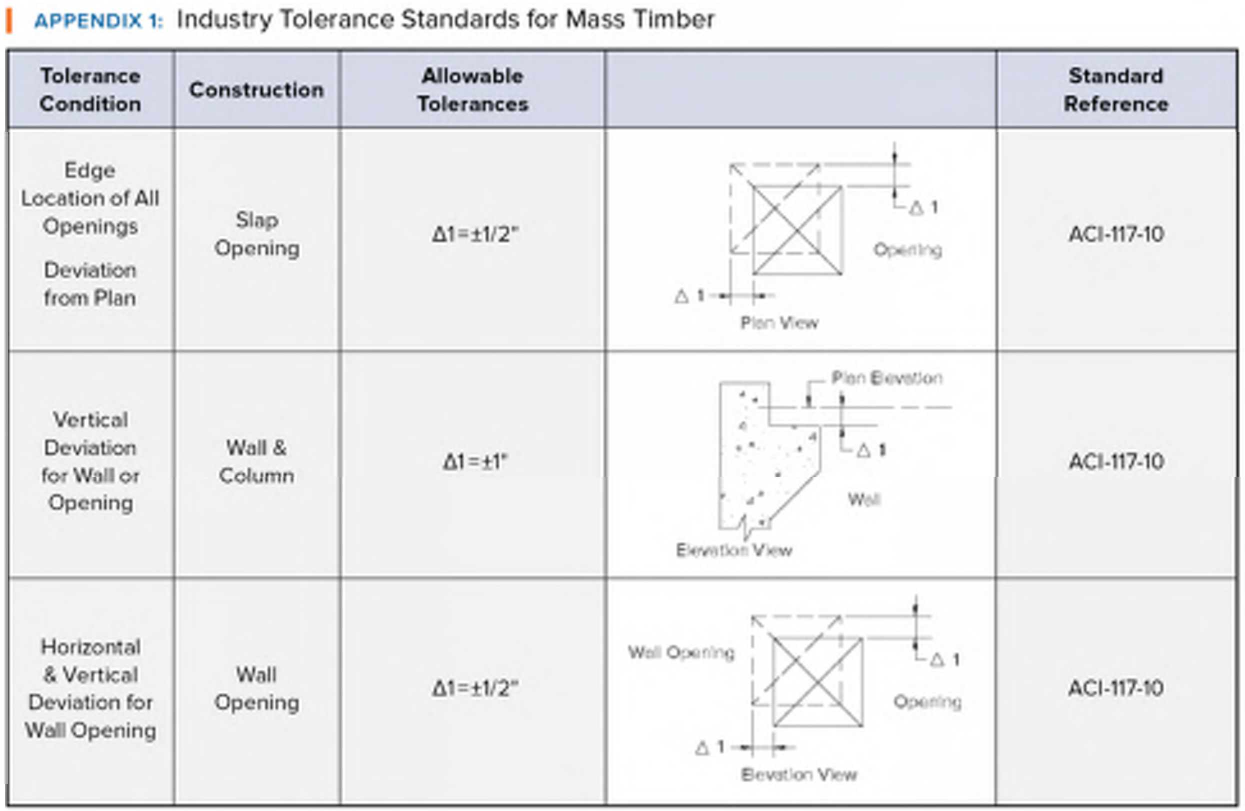
- Examples of tolerances for steel and concrete.



APPENDIX 1: Industry Tolerance Standards for Mass Timber

Tolerance Condition	Construction	Allowable Tolerances		Standard Reference
Anchor Rod Holes in Base Plates	Steel Base Plate	Rod | Hole Diameter 3/4"Ø | 1-5/16"Ø 7/8"Ø | 1-9/16"Ø 1"Ø | 1-7/8"Ø 1-1/4"Ø | 2-1/8"Ø 1-1/2"Ø | 2-3/8"Ø 1-3/4"Ø | 2-7/8"Ø 2"Ø | 3-1/4"Ø 2-1/2"Ø | 3-3/4"Ø	Plan View	AISC-360 (Recommended Sizes for Anchor Rod Holes)
Steel Column Location at Base	Steel Column	Δ1=+1/4"	Elevation View	AISC-360 (Recommended Sizes for Anchor Rod Holes)

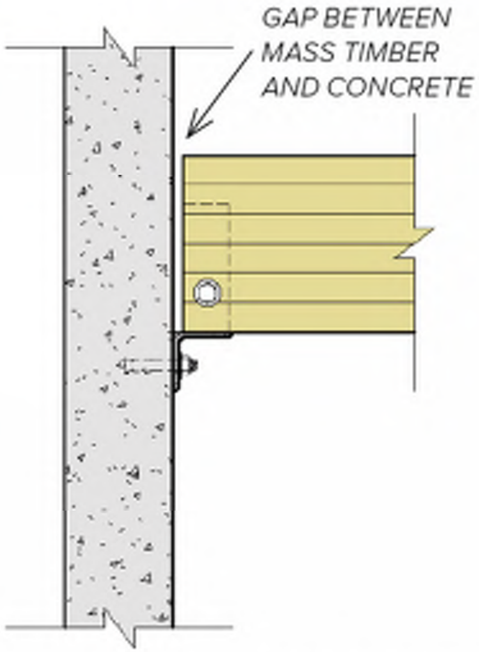
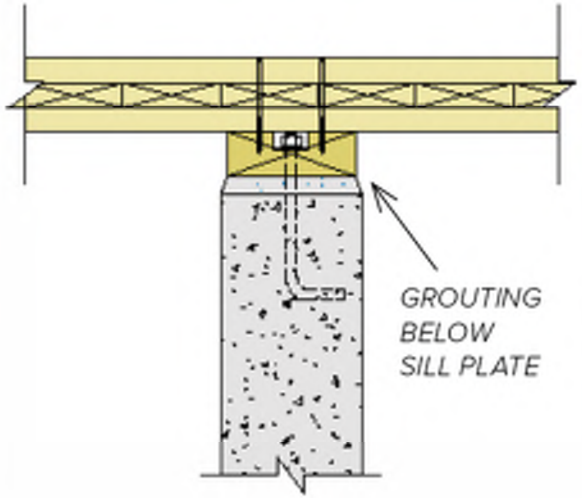
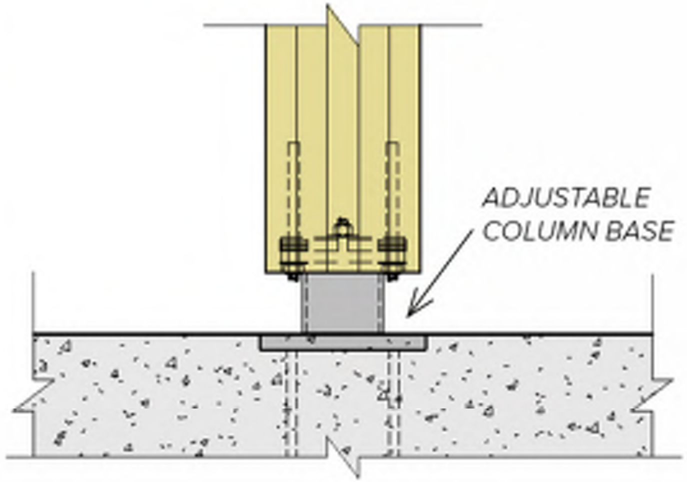
Maximum “out of plumbness” of the column, per AISC 360 Section C2



APPENDIX 1: Industry Tolerance Standards for Mass Timber

Tolerance Condition	Construction	Allowable Tolerances		Standard Reference
Edge Location of All Openings Deviation from Plan	Slap Opening	Δ1=±1/2"	Plan View	ACI-117-10
Vertical Deviation for Wall or Opening	Wall & Column	Δ1=±1"	Elevation View	ACI-117-10
Horizontal & Vertical Deviation for Wall Opening	Wall Opening	Δ1=±1/2"	Elevation View	ACI-117-10

Tolerance Solutions

Solution	**Gap Between Mass Timber Beam and Concrete Wall**	**Grouting Below Sill Plate at Mass Timber Panel to Concrete Wall**	**Adjustable Column Base at Mass Timber Column to Concrete**
Connection example			
	Beam Perpendicular to Wall Connected to Face of Wall	Panel Bears at Top of Wall	Column Bears on Concrete with Adjustable Standoff Base

Mass Timber Gravity Connection Design and Detailing

Learning Hours: 1

Credits: AIA LU/HSW, ICC CEU

This presentation
is available via:

www.woodinstitute.org

The High Line – Moynihan Connector / Skidmore, Owings & Merrill /
Photo Lorenzo Sanjuan, Thornton Tomasetti

Fire Design of Mass Timber Connections: Detailing Strategies and Compliance Paths

Learning Hours: 1

Credits: AIA LU/HSW, ICC CEU

This presentation is available via:

www.woodinstitute.org

University of Washington Founders Hall, LMN Architects, photo Tim Griffith

Agenda

- Fire Resistance and Acoustics
- Vibration Design
- Connections
- **Structural Design – Lateral**

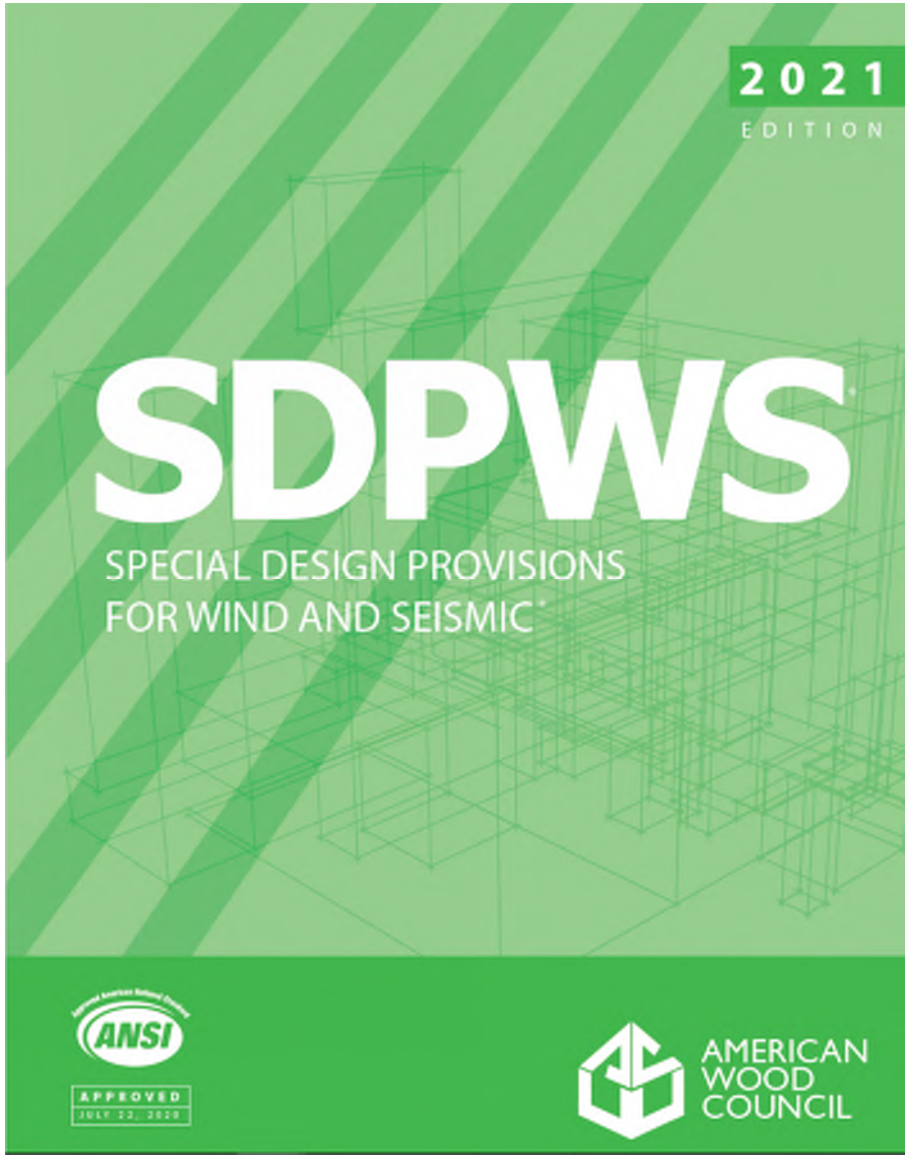
Photo: John Stamets

2021 Special Design Provisions for Wind and Seismic

Top Changes Relevant to CLT Lateral Systems:

- New unified nominal shear capacity
- New CLT Shear Wall requirements
- New CLT Diaphragm requirements

View for free at awc.org



2021 EDITION

SDPWS

SPECIAL DESIGN PROVISIONS FOR WIND AND SEISMIC

ANSI

APPROVED

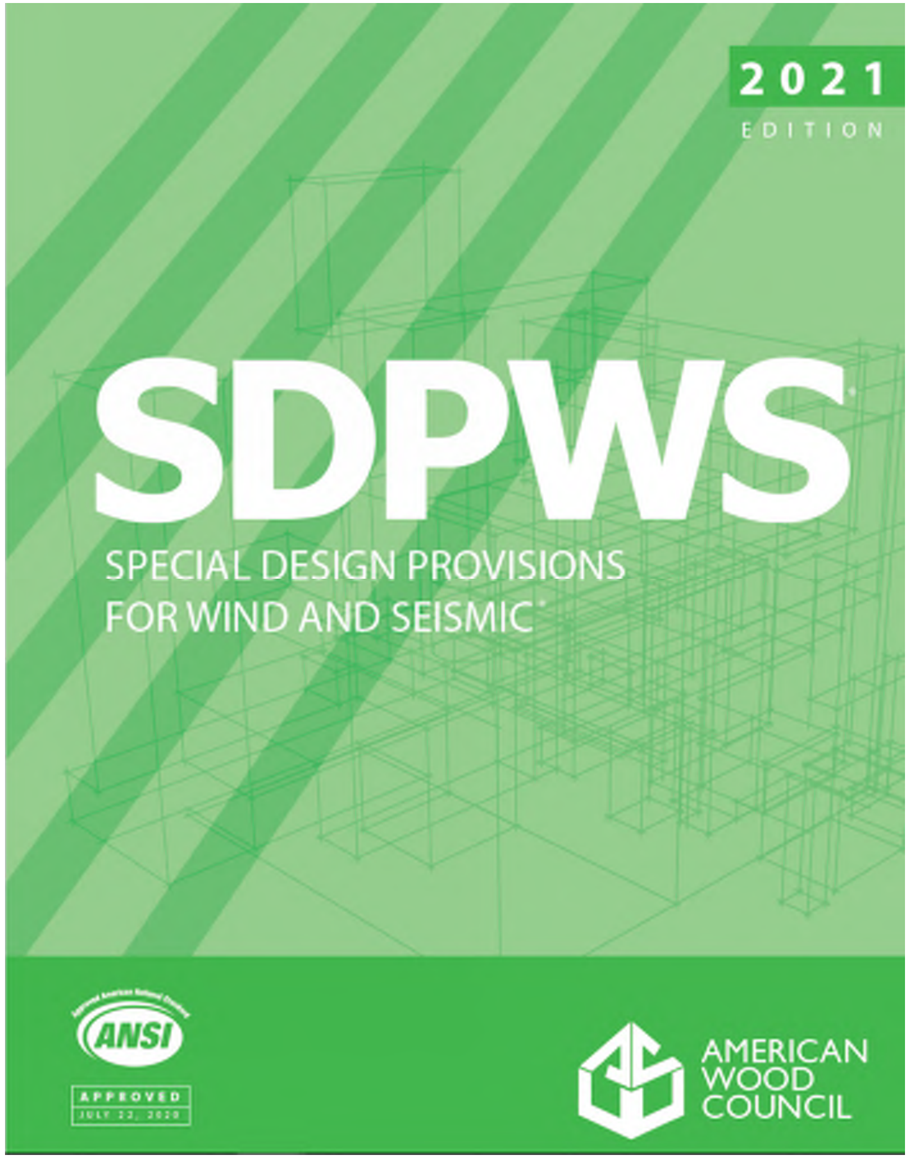
AMERICAN WOOD COUNCIL

2021 SDPWS – Unified Nominal Shear Capacity

To calculate the ASD or LRFD shear capacity, SDPWS 2021 has different reduction factors for wind and seismic

	Design shear capacity	
	ASD	LRFD
Wind	$v_n/2.0$	$0.8\ v_n$
Seismic	$v_n/2.8$	$0.5\ v_n$

SDPWS 2021 Section 4.1.4



2021
EDITION

SDPWS

SPECIAL DESIGN PROVISIONS
FOR WIND AND SEISMIC

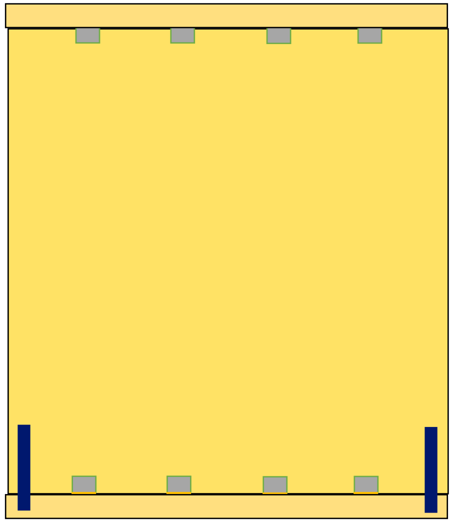
ANSI
APPROVED

AMERICAN
WOOD
COUNCIL

CLT Shear Walls in SDPWS 2021

CLT Shear Walls

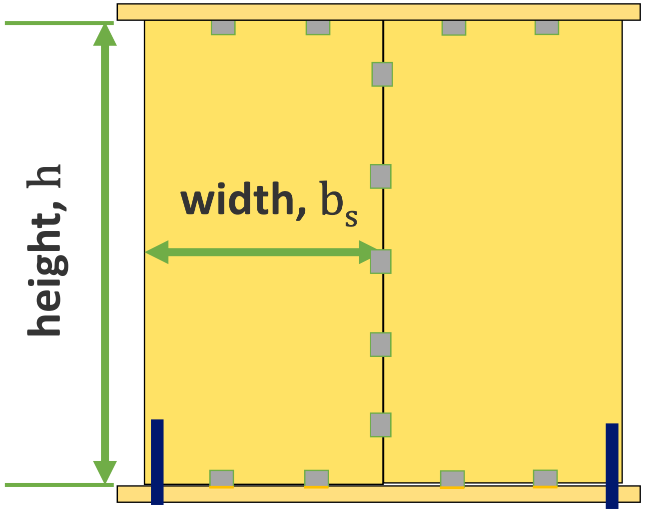
not meeting Appendix B



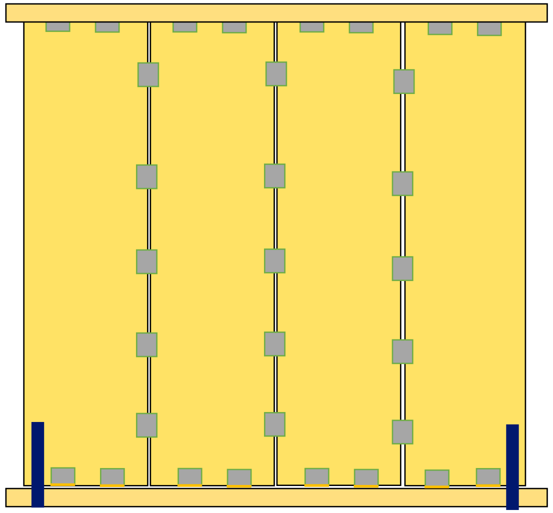
Seismic Design Category A
or SDC B and ≤ 65’ tall
in SDPWS 4.6.3 Exception

CLT Shear Walls

meeting SDPWS 2021 Appendix B



Panel aspect ratios
$2 \leq \mathbf{h/b_s} \leq 4$



with shear resistance provided by high aspect ratio panels only (SDPWS B.3.7)

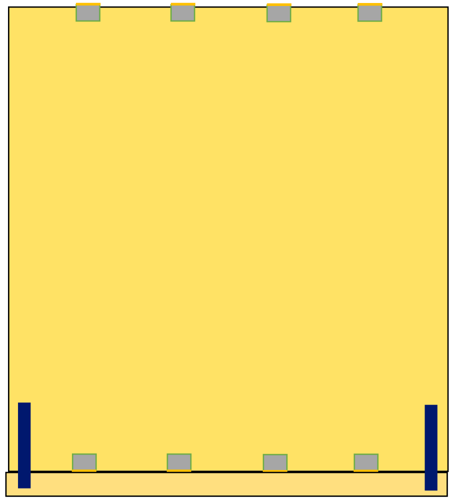
Panel aspect ratios
$\mathbf{h/b_s} = 4$

R Values for CLT Shear Walls in SDPWS 2021

(other)

CLT Shear Walls

not meeting Appendix B



R = 1.5

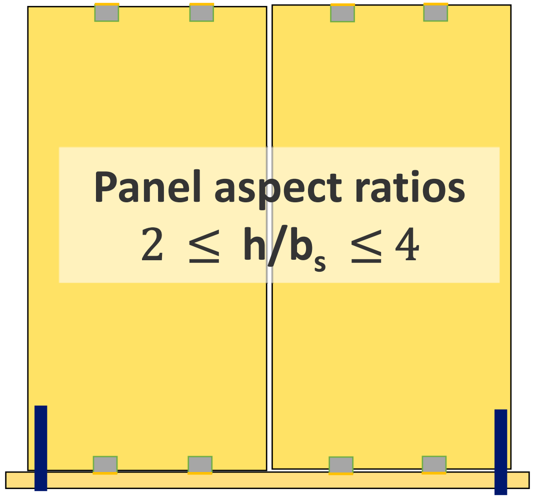
$C_d = 1.5$ $\Omega_o = 2.5$

In SDPWS 2021 4.6.3

Platform Framed

CLT Shear Walls

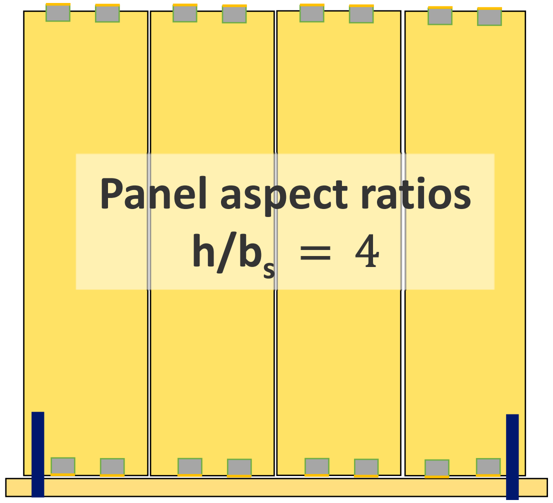
meeting SDPWS 2021 Appendix B



Panel aspect ratios
$2 \leq \mathbf{h/b_s} \leq 4$

R = 3.0*

$C_d = 3.0$ $\Omega_o = 3.0$



Panel aspect ratios
$\mathbf{h/b_s} = 4$

R = 4.0*

$C_d = 4.0$ $\Omega_o = 3.0$

* ASCE 7-22

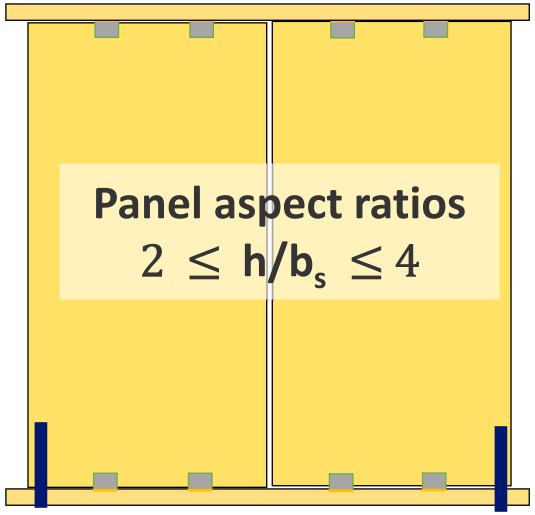
CLT Shear Walls in SDPWS 2021

Additional important requirements

- Platform framed
- Only specific connectors recognized
- Hold-downs designed to 2.0 times the design shear capacity
- Only gravity loads on panel directly attached to hold-down can be used to resist overturning moment
- CLT walls which are not designated shear walls need to meet same panel aspect ratio limits and connection detailing requirements

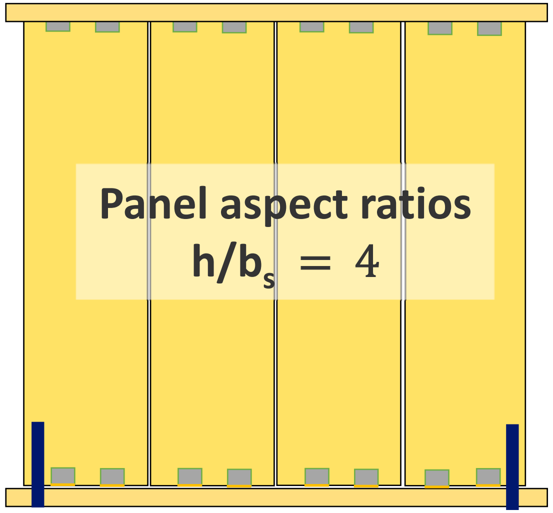
PowerPoint IS NOT the CODE!

Platform Framed
CLT Shear Walls
meeting SDPWS 2021 Appendix B



Panel aspect ratios

$2 \leq \mathbf{h/b_s} \leq 4$



Panel aspect ratios

$\mathbf{h/b_s} = 4$

R = 3.0*

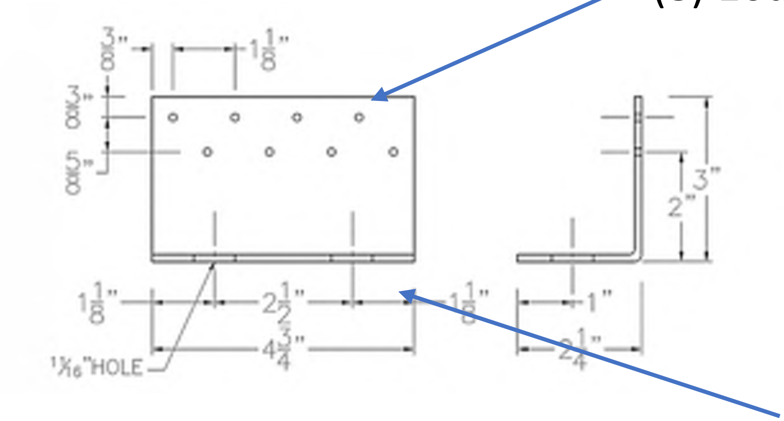
$C_d = 3.0$ $\Omega_o = 3.0$

R = 4.0*

$C_d = 4.0$ $\Omega_o = 3.0$

* ASCE 7-22

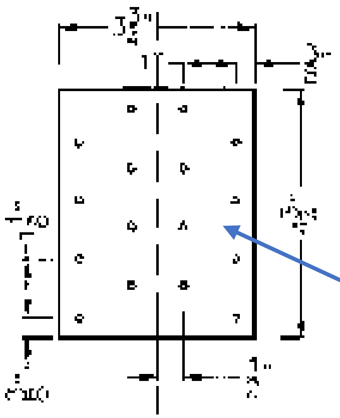
Platform Framed CLT Shear Walls



(8) 16d Box nails

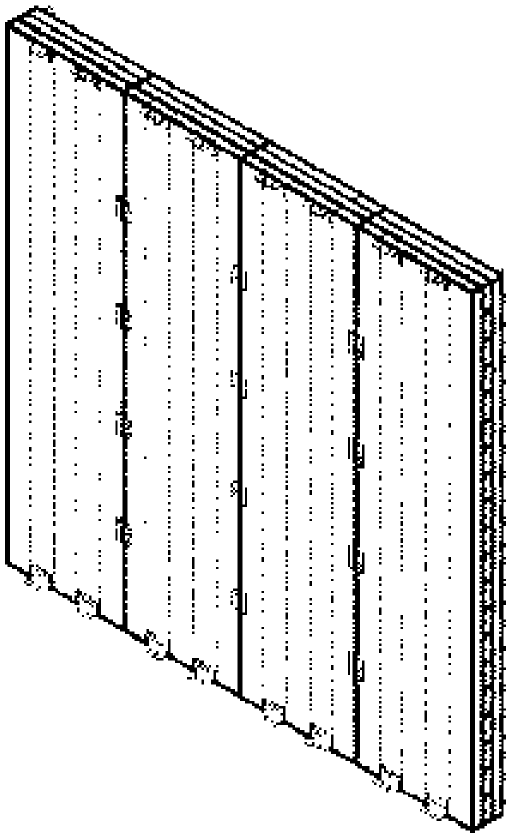
(2) 5/8” bolts
or lag screws

Top and Bottom of Wall Connector
.105” A653 Grade 33 Steel



(8) 16d Box nails
each side

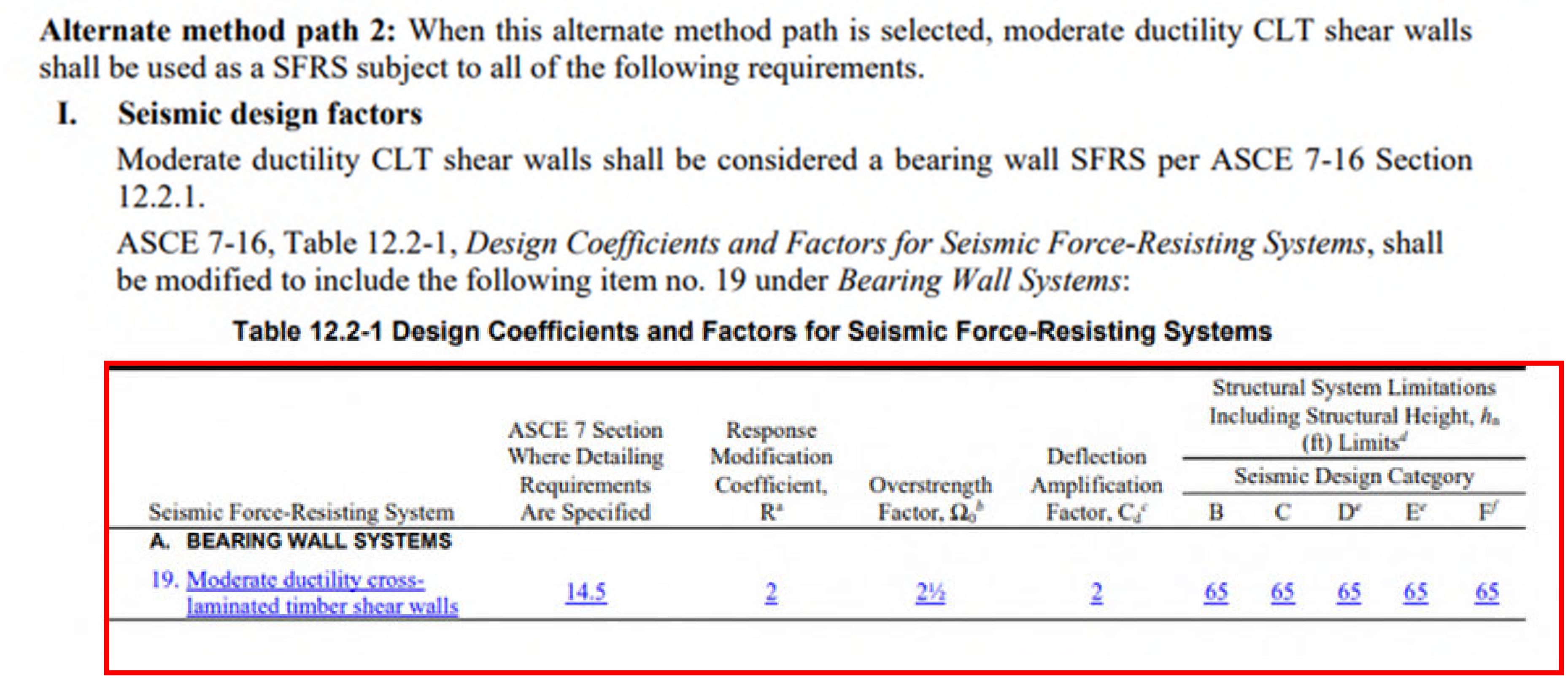
Panel to Panel Connector
.105” A653 Grade 33 Steel



Shear Wall System

State of Oregon Statewide Alternative Method

#2: ASCE 7-16 Table 12.2-1 modified by Oregon Buildings Code Division



Alternate method path 2: When this alternate method path is selected, moderate ductility CLT shear walls shall be used as a SFRS subject to all of the following requirements.

I. Seismic design factors

Moderate ductility CLT shear walls shall be considered a bearing wall SFRS per ASCE 7-16 Section 12.2.1.

ASCE 7-16, Table 12.2-1, *Design Coefficients and Factors for Seismic Force-Resisting Systems*, shall be modified to include the following item no. 19 under *Bearing Wall Systems*:

Table 12.2-1 Design Coefficients and Factors for Seismic Force-Resisting Systems

Seismic Force-Resisting System	ASCE 7 Section Where Detailing Requirements Are Specified	Response Modification Coefficient, R^a	Overstrength Factor, Ω_0^b	Deflection Amplification Factor, C_d^c	Structural System Limitations Including Structural Height, h_n (ft) Limits^d				
					Seismic Design Category				
					B	C	D^e	E^e	F^f
A. BEARING WALL SYSTEMS									
19. Moderate ductility cross-laminated timber shear walls	14.5	2	2½	2	65	65	65	65	65

www.oregon.gov/bcd/codes-stand/Documents/sam-15-01-crosslaminatedtimber.pdf

EXPERT TIP

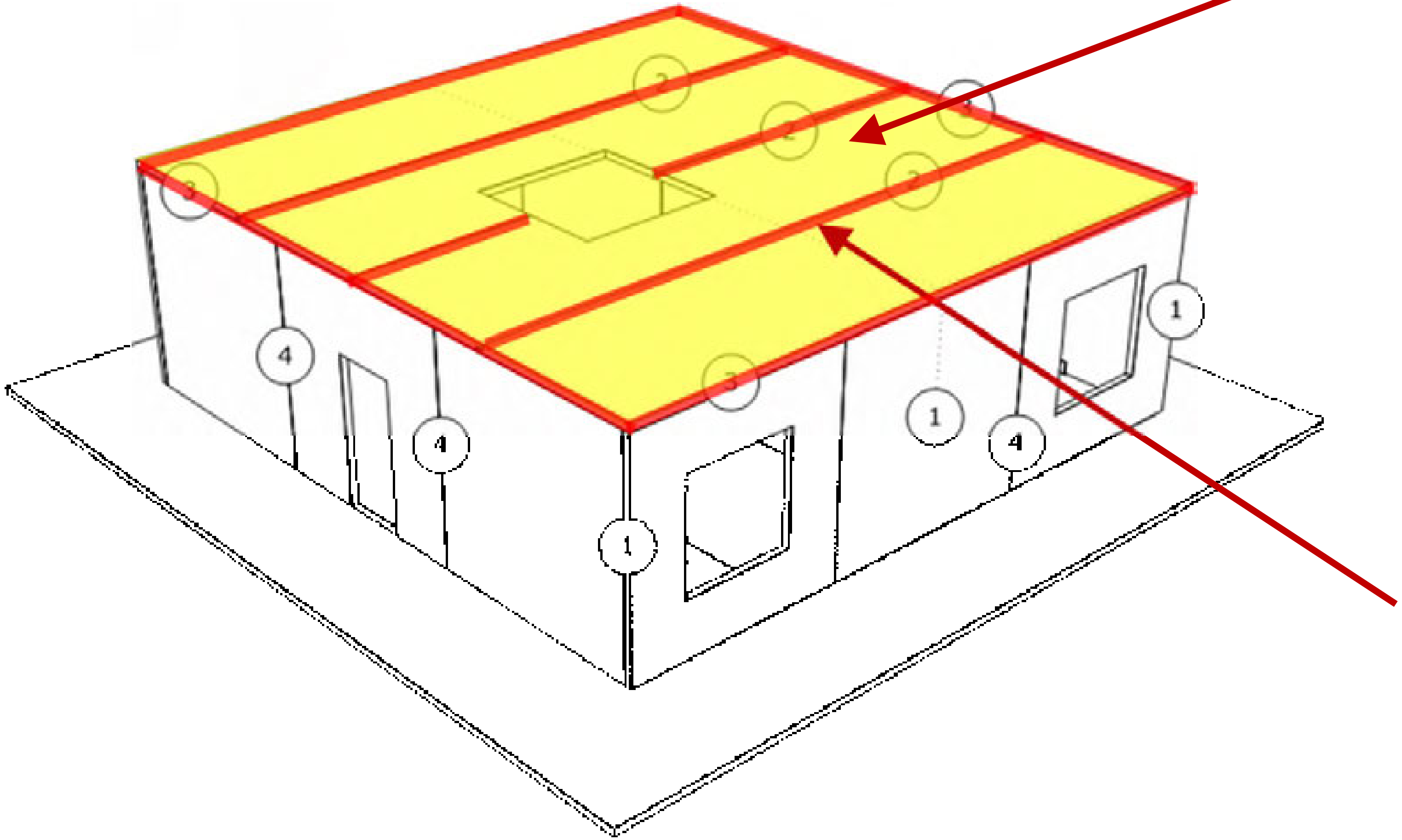
CLT Shear Wall Options in the U.S.

https://www.woodworks.org/resources/clt-shear-wall-options-in-the-u-s/

Covers cross-laminated timber (CLT) and light-frame wood shear wall systems available for use now and in development

Peavy Hall / Oregon State University Forest Science Complex
Photo Equilibrium

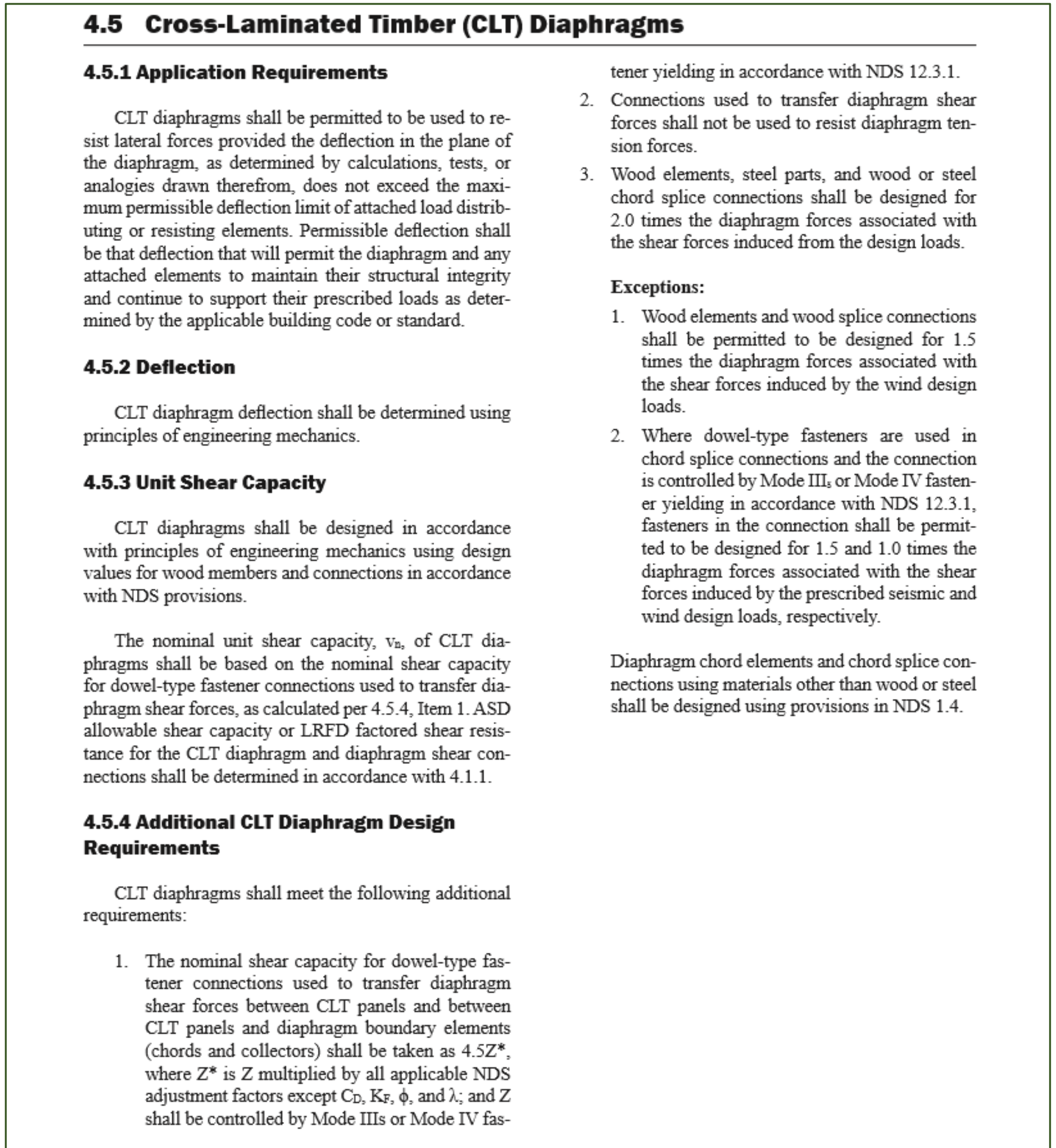
CLT Diaphragms



Strength of CLT rarely governs.

Strength of Connections covered by NDS and Proprietary Fastener Evaluation Reports

2021 Special Design Provisions for Wind and Seismic



4.5 Cross-Laminated Timber (CLT) Diaphragms

4.5.1 Application Requirements

CLT diaphragms shall be permitted to be used to resist lateral forces provided the deflection in the plane of the diaphragm, as determined by calculations, tests, or analogies drawn therefrom, does not exceed the maximum permissible deflection limit of attached load distributing or resisting elements. Permissible deflection shall be that deflection that will permit the diaphragm and any attached elements to maintain their structural integrity and continue to support their prescribed loads as determined by the applicable building code or standard.

4.5.2 Deflection

CLT diaphragm deflection shall be determined using principles of engineering mechanics.

4.5.3 Unit Shear Capacity

CLT diaphragms shall be designed in accordance with principles of engineering mechanics using design values for wood members and connections in accordance with NDS provisions.

The nominal unit shear capacity, v_n, of CLT diaphragms shall be based on the nominal shear capacity for dowel-type fastener connections used to transfer diaphragm shear forces, as calculated per 4.5.4, Item 1. ASD allowable shear capacity or LRFD factored shear resistance for the CLT diaphragm and diaphragm shear connections shall be determined in accordance with 4.1.1.

4.5.4 Additional CLT Diaphragm Design Requirements

CLT diaphragms shall meet the following additional requirements:

1. The nominal shear capacity for dowel-type fastener connections used to transfer diaphragm shear forces between CLT panels and between CLT panels and diaphragm boundary elements (chords and collectors) shall be taken as 4.5Z*, where Z* is Z multiplied by all applicable NDS adjustment factors except C_D, K_F, ϕ, and λ; and Z shall be controlled by Mode IIIs or Mode IV fastener yielding in accordance with NDS 12.3.1.
2. Connections used to transfer diaphragm shear forces shall not be used to resist diaphragm tension forces.
3. Wood elements, steel parts, and wood or steel chord splice connections shall be designed for 2.0 times the diaphragm forces associated with the shear forces induced from the design loads.

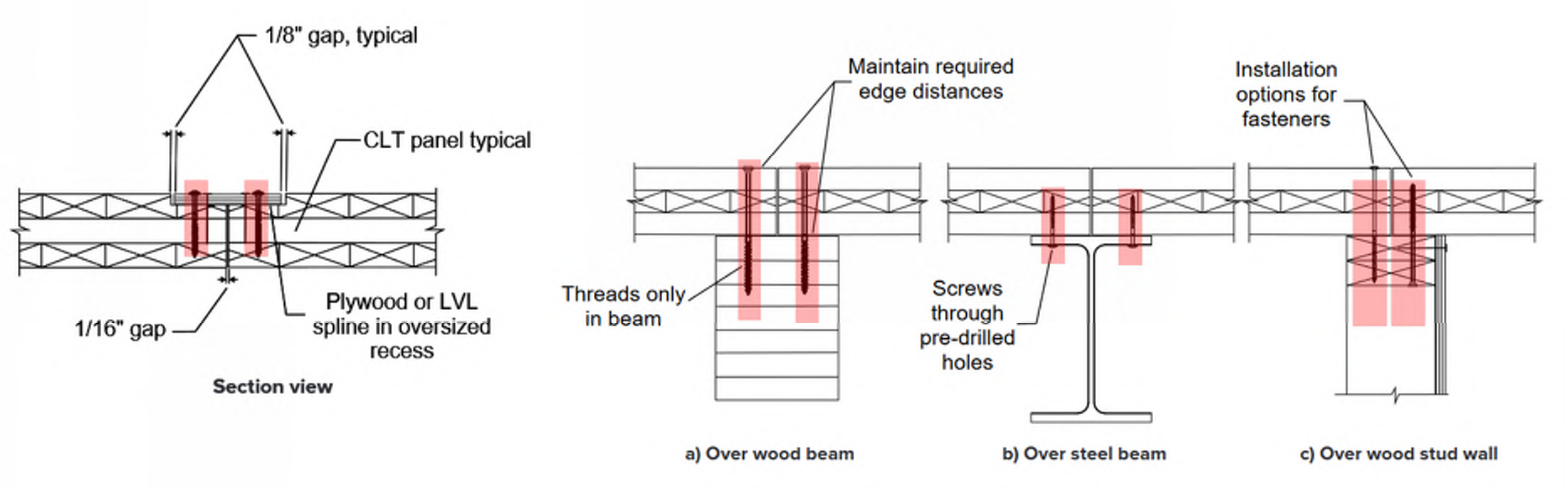
Exceptions:

1. Wood elements and wood splice connections shall be permitted to be designed for 1.5 times the diaphragm forces associated with the shear forces induced by the wind design loads.
2. Where dowel-type fasteners are used in chord splice connections and the connection is controlled by Mode III_s or Mode IV fastener yielding in accordance with NDS 12.3.1, fasteners in the connection shall be permitted to be designed for 1.5 and 1.0 times the diaphragm forces associated with the shear forces induced by the prescribed seismic and wind design loads, respectively.

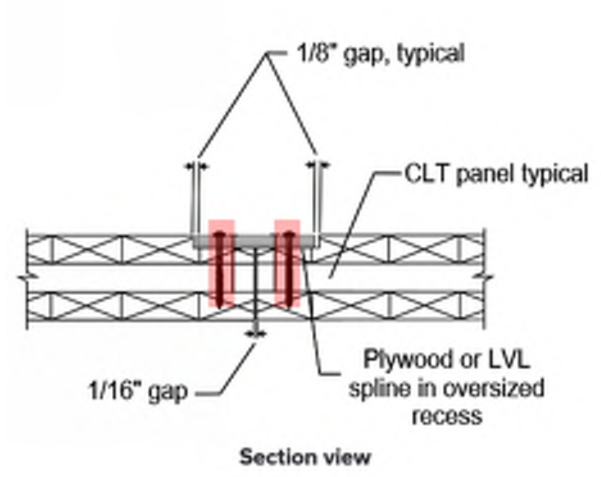
Diaphragm chord elements and chord splice connections using materials other than wood or steel shall be designed using provisions in NDS 1.4.

Only 1 page of requirements for CLT Diaphragms

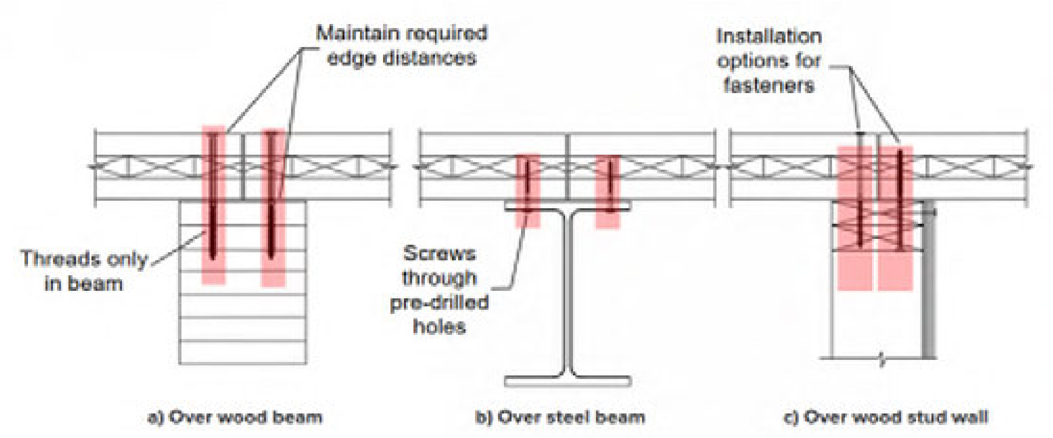
CLT Diaphragm Shear Connections



CLT Diaphragm Shear Connections



1) Diaphragm shear connections between adjacent CLT panels and between CLT and diaphragm boundary elements (chords and collectors) shall use dowel-type fasteners in shear to transfer diaphragm shear forces.



a) Over wood beam

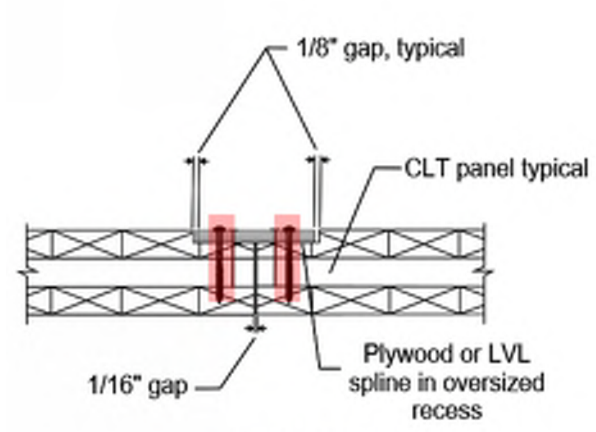
b) Over steel beam

c) Over wood stud wall

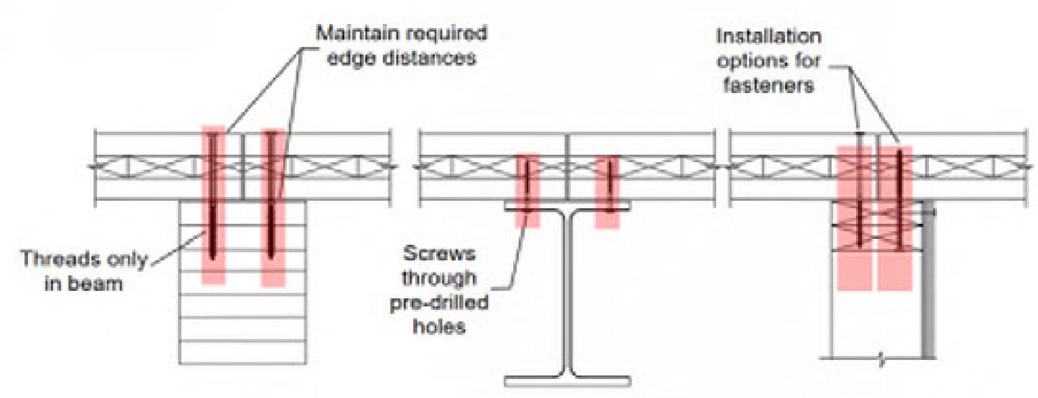
Nails or screws installed perpendicular to the face of the CLT are dowel-type fasteners in shear.

SDPWS 2021 Section 4.5.3

CLT Diaphragm Shear Connections



Section view

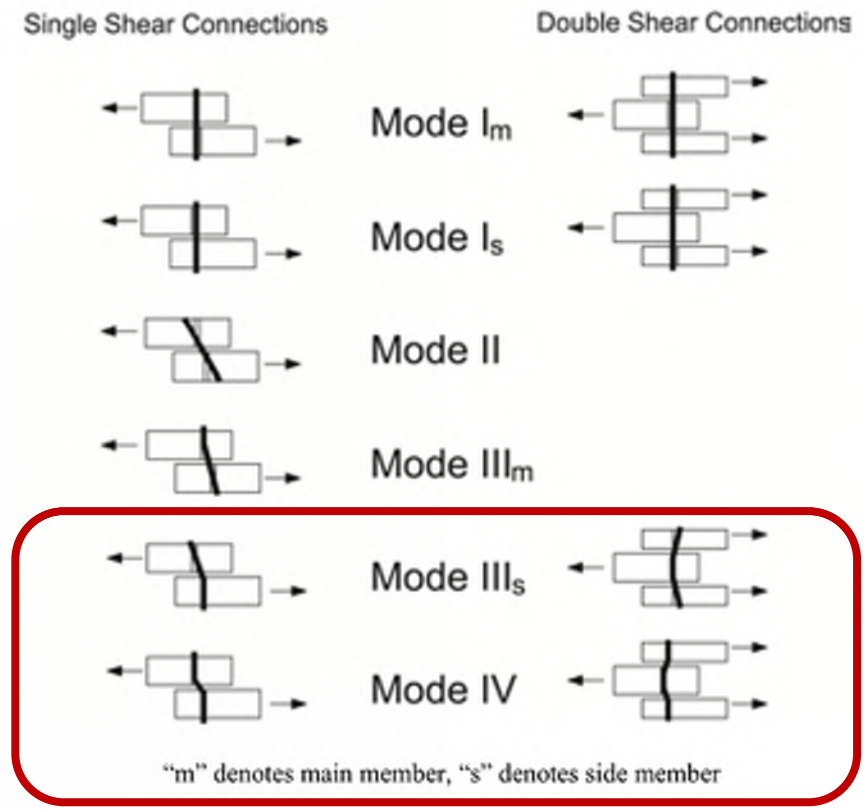


a) Over wood beam

b) Over steel beam

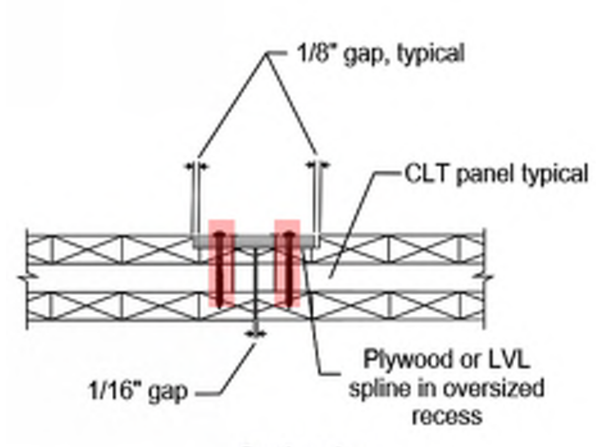
c) Over wood stud wall

2) The reference design value of the fastener connection, Z, shall be calculated per NDS 12.3.1 and only connections controlled by fastener yield Mode IIIs or Mode IV are permitted.

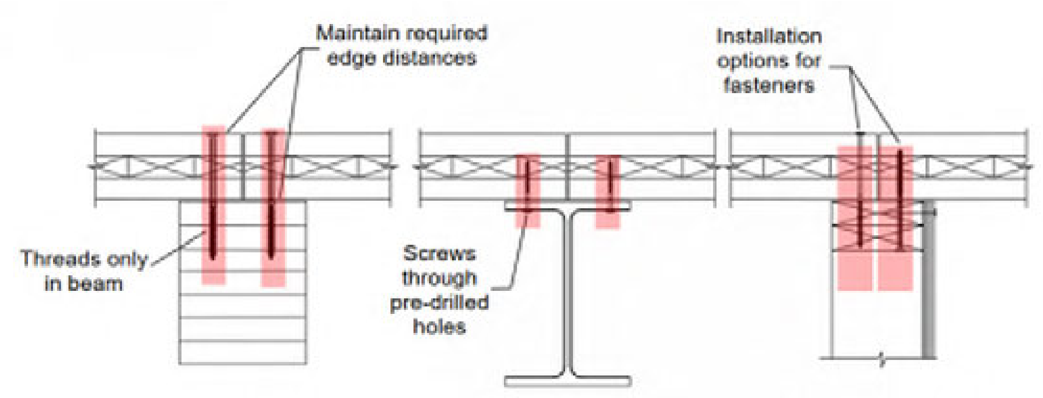


Skinny fasteners usually controlled by these modes

CLT Diaphragm Shear Connections



Section view



a) Over wood beam b) Over steel beam c) Over wood stud wall

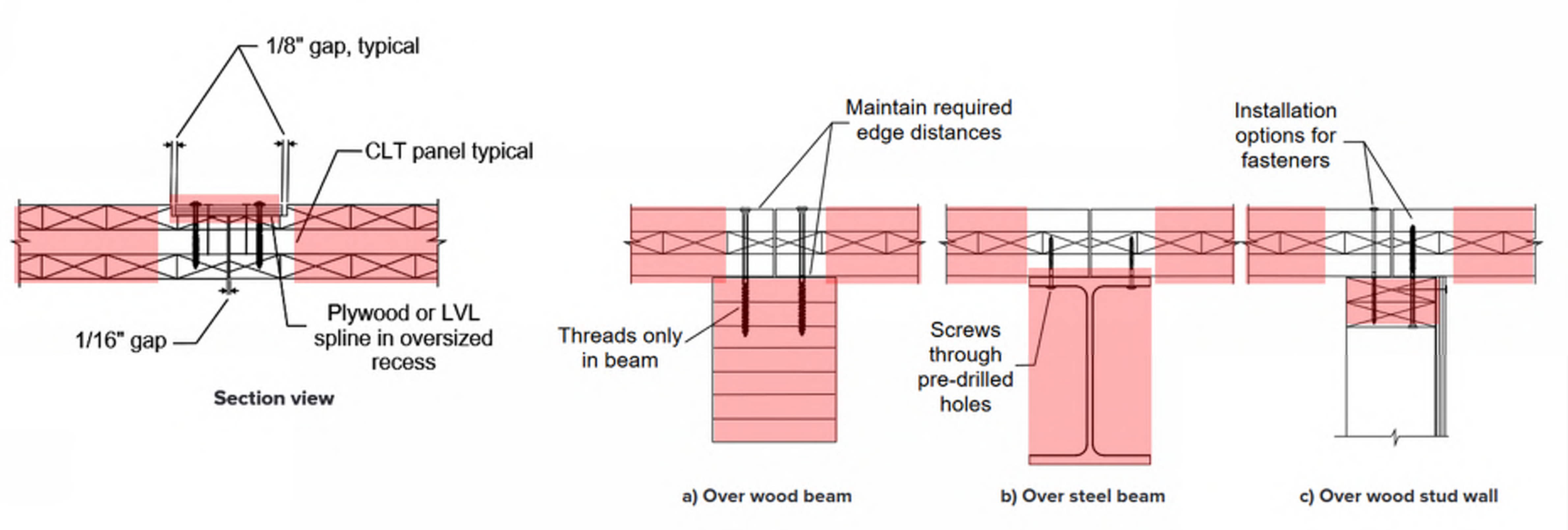
3) The nominal shear capacity for the dowel-type fastener connection shall be taken as 4.5 Z*

$$V_n = 4.5\ \mathrm{Z}^*$$

where Z^* is reference lateral capacity Z multiplied by all applicable factors *except* C_D, K_F, ϕ, $\lambda = 1.0$

SDPWS 2021 Section 4.5.4(1)

Other CLT Diaphragm Components



Designed for **amplified** diaphragm design forces

Other CLT Diaphragm Components

Component Design Capacity ≥ Increased Diaphragm Design Forces

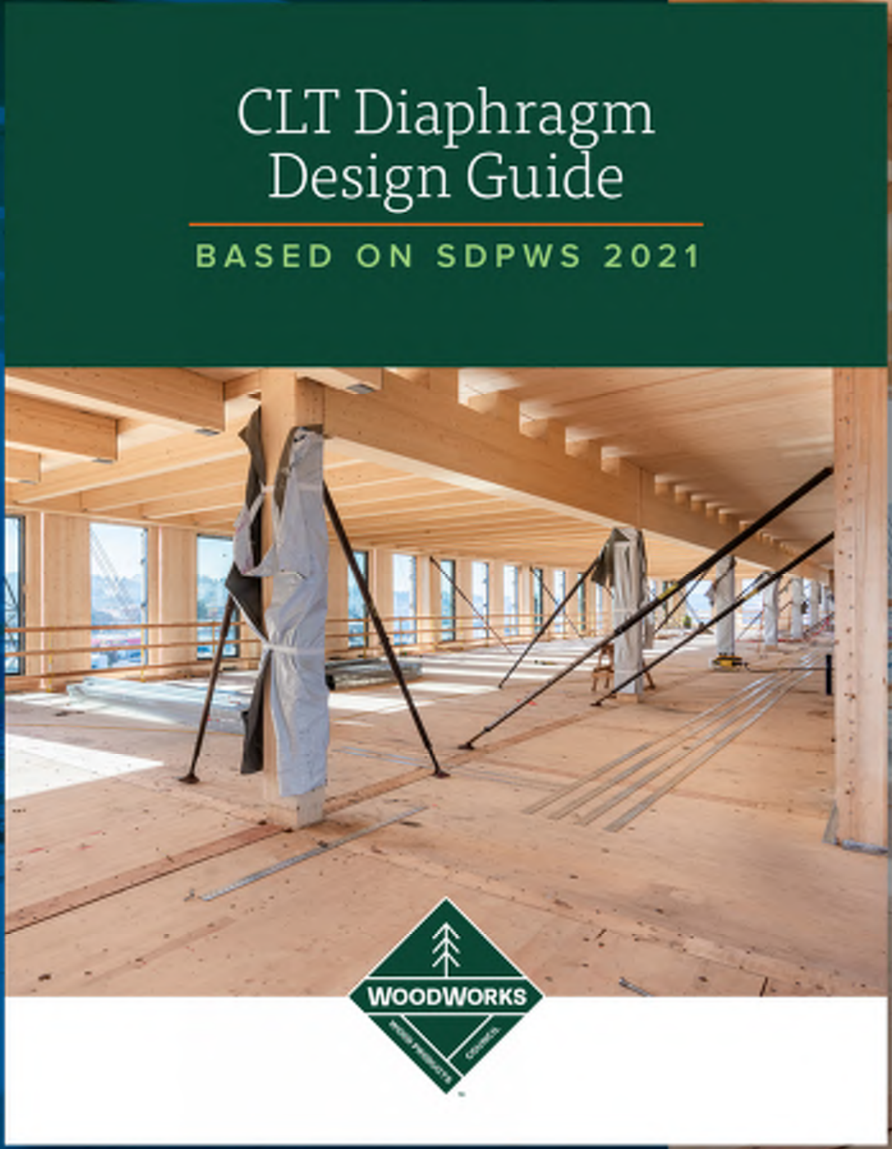
$$v' \geq \gamma_D \, v$$

v' = Adjusted capacity calculated per the NDS
*not 4.5 Z**

v = wind or seismic diaphragm design force

γ_D = 2.0 for wood and steel components, except:
1.5 wood members resisting wind loads
1.5 chord splice connections controlled by Mode IIIs or IV (seismic)
1.0 chord splice connections controlled by Mode IIIs or IV (wind)

*See **SDPWS 2021 Section 4.5.4** for the full information* https://www.woodworks.org/resources/clt-diaphragm-design-guide/



CLT Diaphragm Design Guide

BASED ON SDPWS 2021

WOODWORKS

Catalyst / MGA | Michael Green Architecture
Photo KPFF

Behavior and Modelling of Mass Timber CLT Diaphragms

Learning Hours: 1

Credits: AIA LU/HSW, ICC CEU

This presentation is available via:

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Funding provided in part by the Softwood Lumber Board

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