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Mass Timber Structural Design: Engineering Modern Timber Structures

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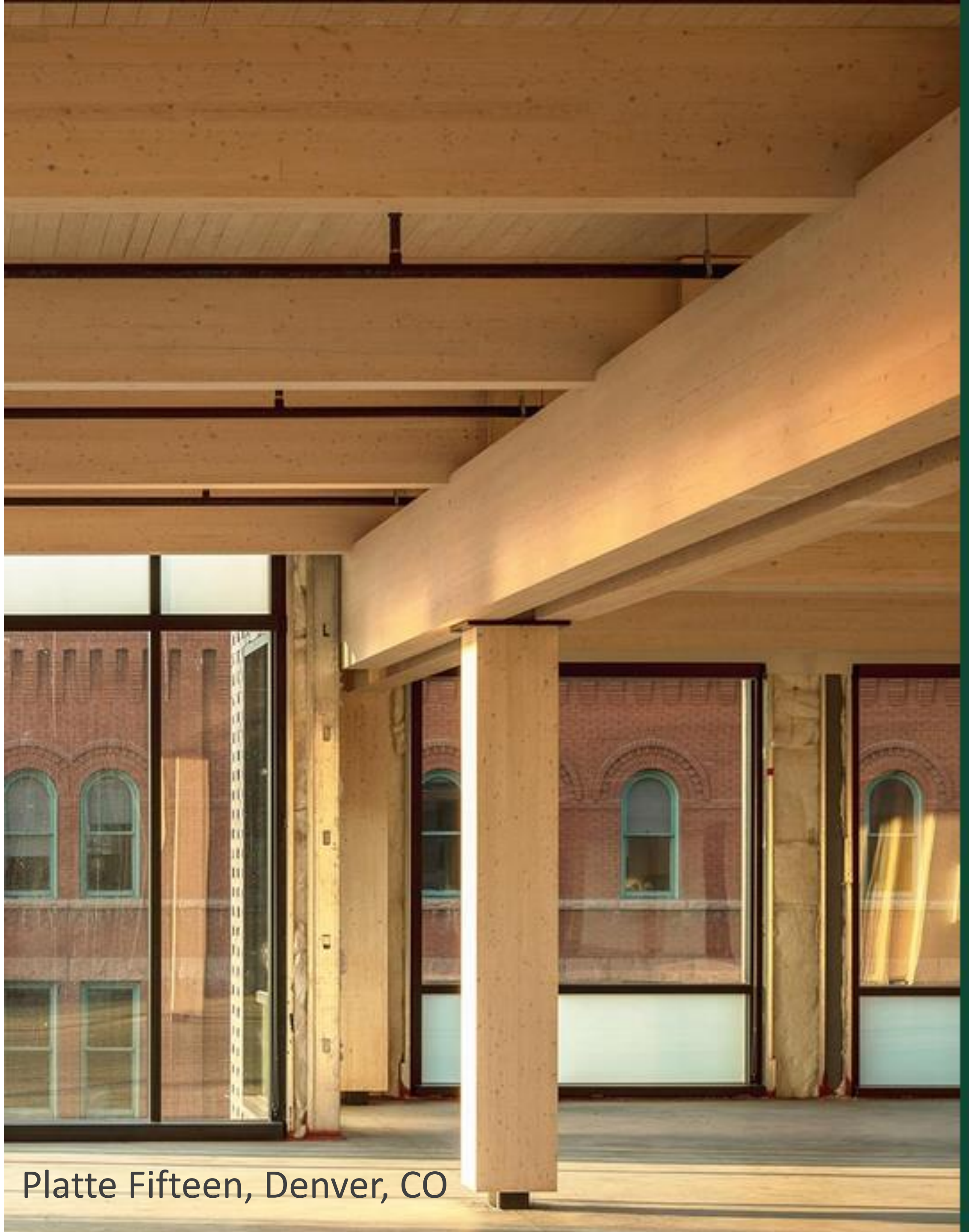
Platte Fifteen, Denver, CO

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

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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

- Mass timber systems and products
- Acoustics
- Structural design - gravity
- Vibration
- Structural design – lateral
- Connections
- Fire

Photo: John Stamets

Agenda

- Mass timber systems and products
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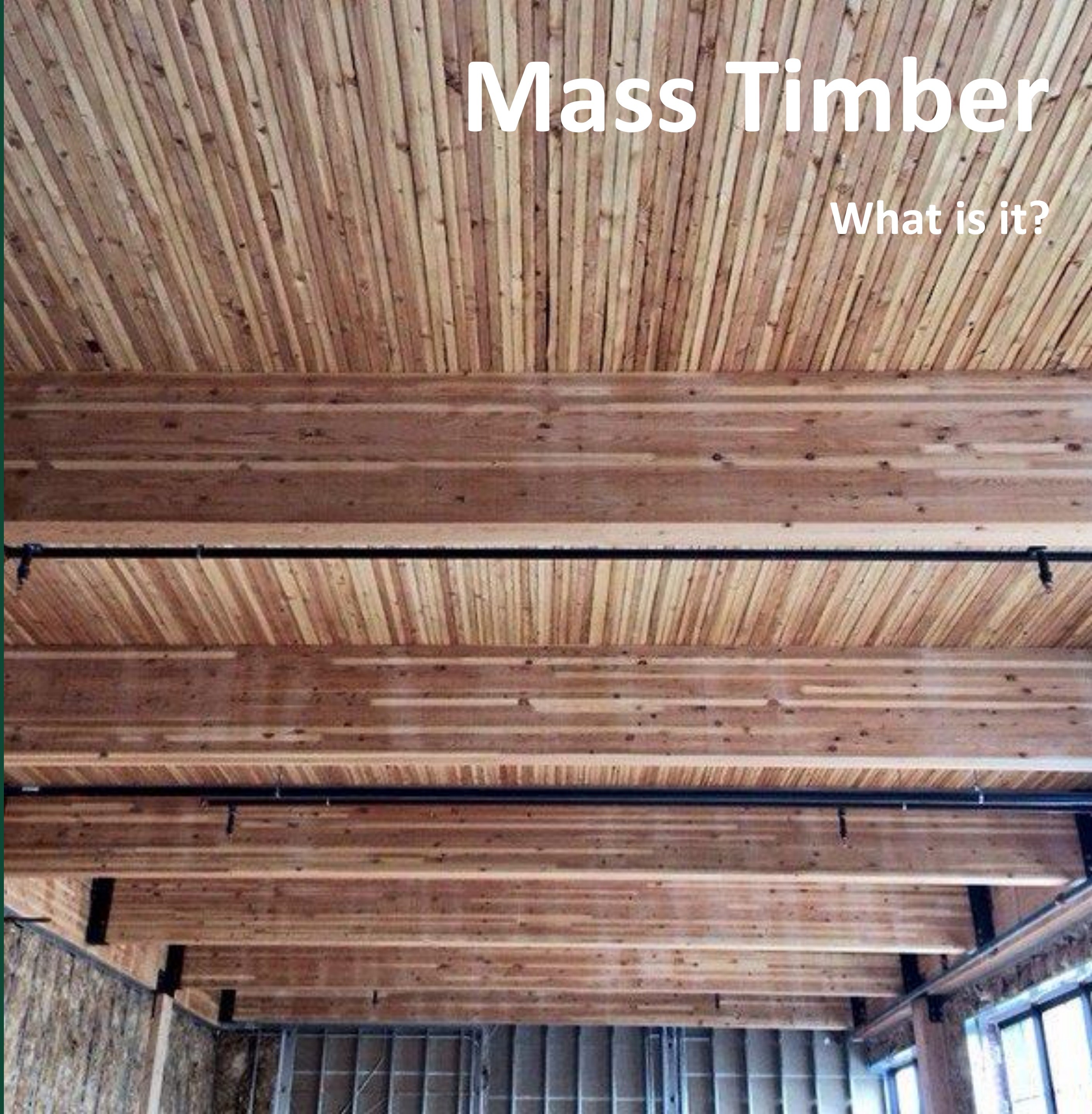
Photo: John Stamets

Mass Timber

What is it?

Mass timber is a category of framing styles often using small wood members formed into large panelized solid wood construction including CLT, NLT or glulam panels for floor, roof and wall framing



Glue Laminated Timber (Glulam)

Beams & columns

Photo: StructureCraft

Cross-Laminated Timber (CLT)

Solid sawn laminations

Photo: LendLease

Cross-Laminated Timber (CLT)

SCL laminations

Photo: Freres Lumber

Photo: LEVER Architecture

Dowel-Laminated Timber (DLT)

Photo: StructureCraft

Photo: StructureCraft

Nail-Laminated Timber (NLT)

Photo: Think Wood

Photo: Ema Peter

Glue-Laminated Timber (GLT)

Plank orientation

Photo: StructureCraft

Photo: Manasc Isaac Architects/Fast + Epp

Glulam Structural Design

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:

Increments per # of lams from 6” to 60”+
Western species lams are typically 1-1/2” thick
Southern pine lams are typically 1-3/8” thick

Typical Species:

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

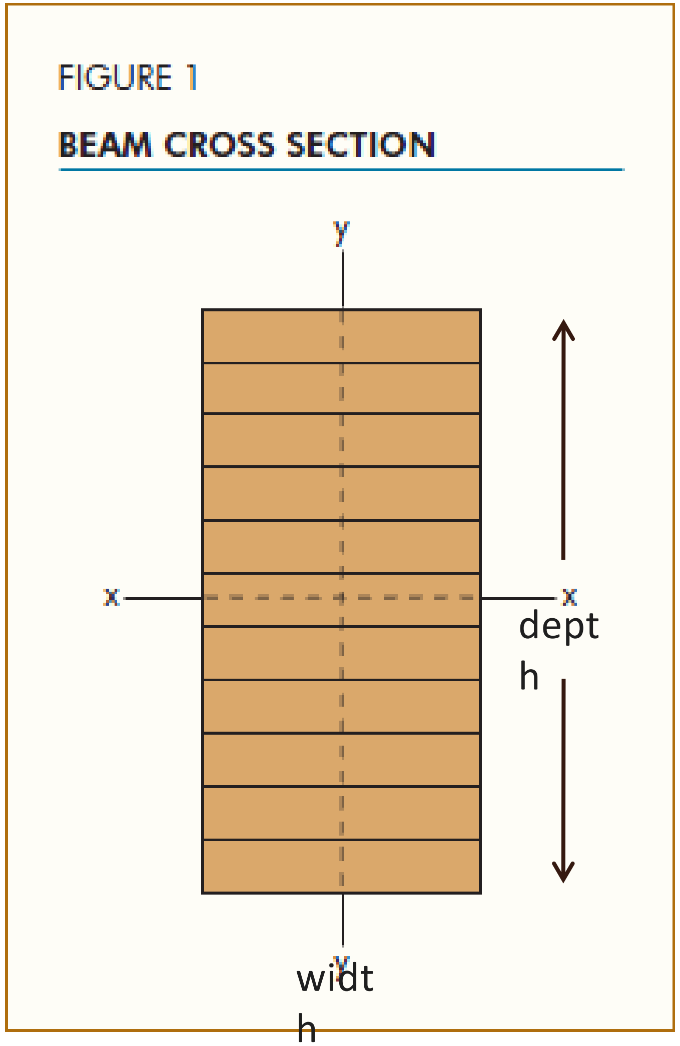
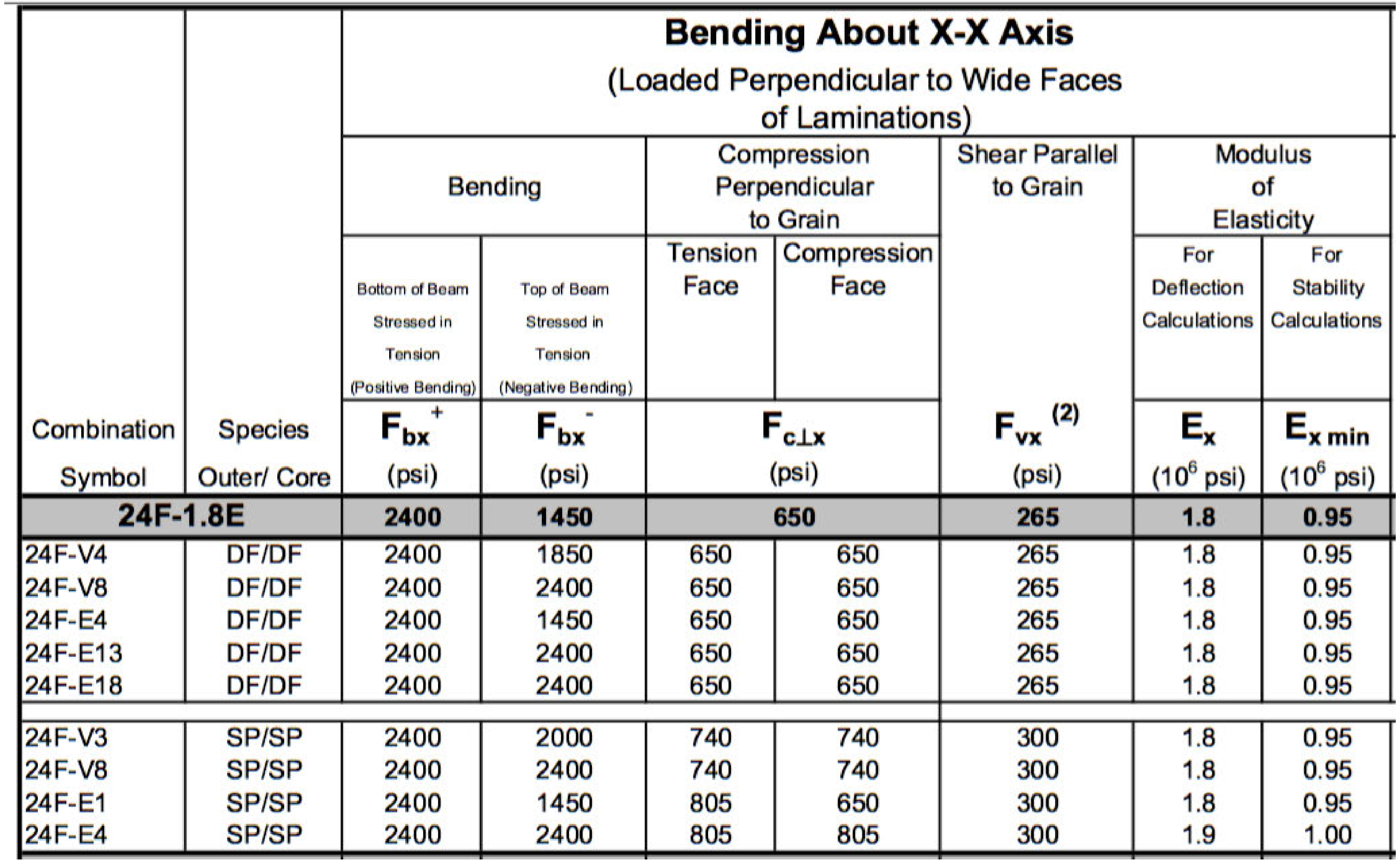
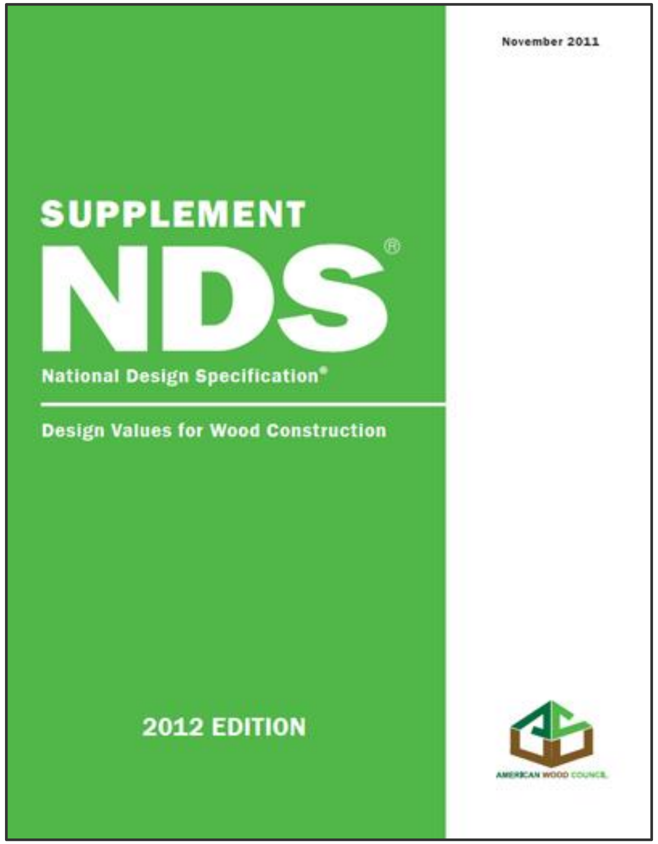


Image: APA Glulam Product Guide

Glulam Design Values



		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



November 2011

SUPPLEMENT

NDS®

National Design Specification®

Design Values for Wood Construction

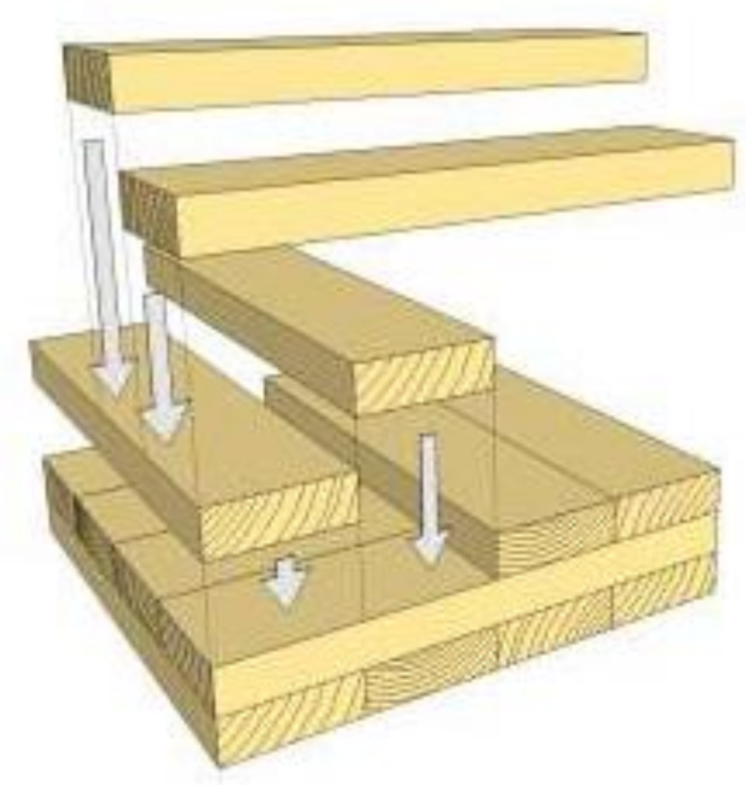
2012 EDITION

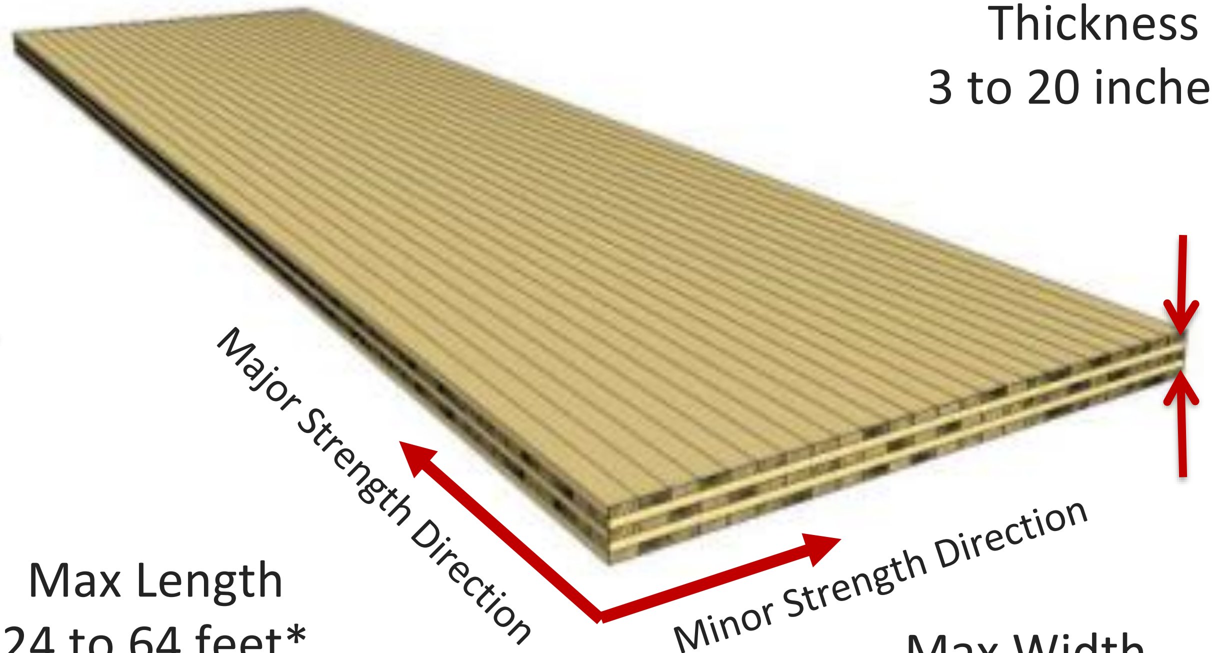
AMERICAN WOOD COUNCIL

Source: NDS supplement Table 5A

What is CLT?

3+ layers of laminations
Typically Solid Sawn Laminations
Cross-Laminated Layup
Glued with Structural Adhesives





Thickness
3 to 20 inches*

Max Length
24 to 64 feet*

Max Width
4 to 12 feet*

*All dimensions are approximate.
Consult with manufacturers

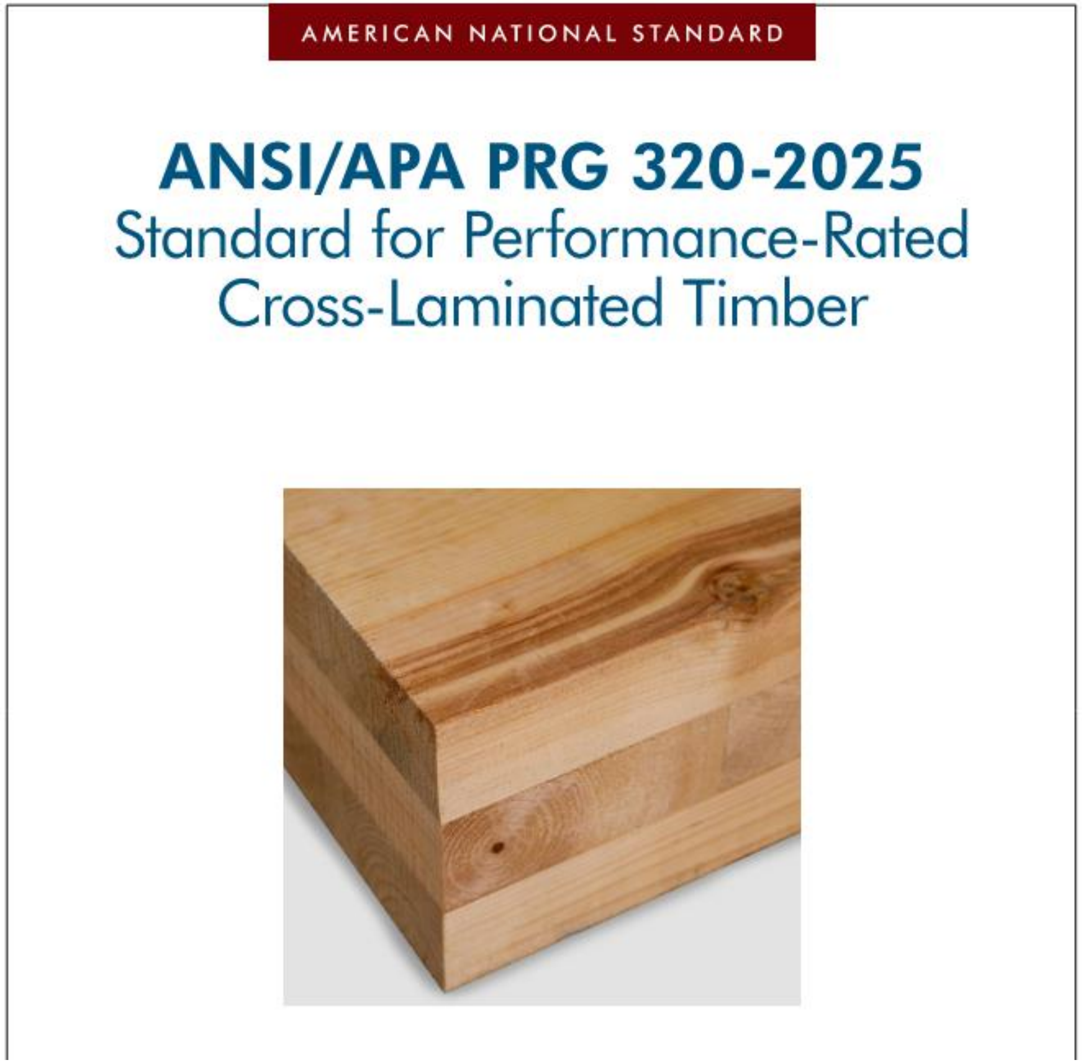
Cross Laminated Timber

Considerations:

- Large light-weight panels
- Dimensionally stable
- Precise CNC machining available
- Recognized by IBC
- Dual Directional span capabilities
- Often architecturally exposed
- Fast on-site construction

Graphic Credit: StructureCraft

North American CLT Product Standard



AMERICAN NATIONAL STANDARD

ANSI/APA PRG 320-2025

Standard for Performance-Rated Cross-Laminated Timber

The Standard Covers:

- U.S. and Canada Use
- Panel Dimensions and Tolerances
- Component Requirements
- Structural Performance Requirements
- Panel and Manufacturing Qualification
- Marking (Stamping)
- Quality Assurance

https://www.apawood.org/ansi-apa-prg-320

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

PRG 320 Defined Layups

CLT Grade (basic)

Layup

Panel Properties

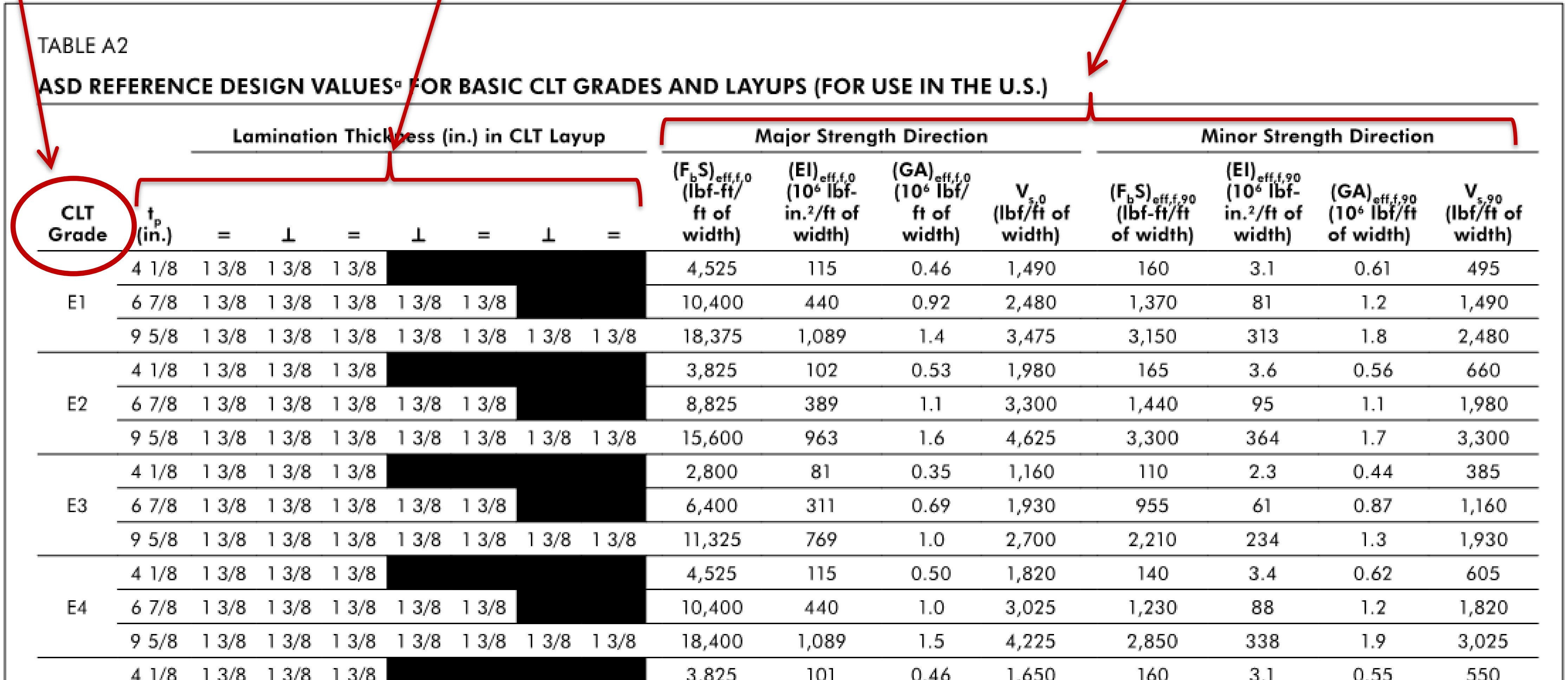


TABLE A2

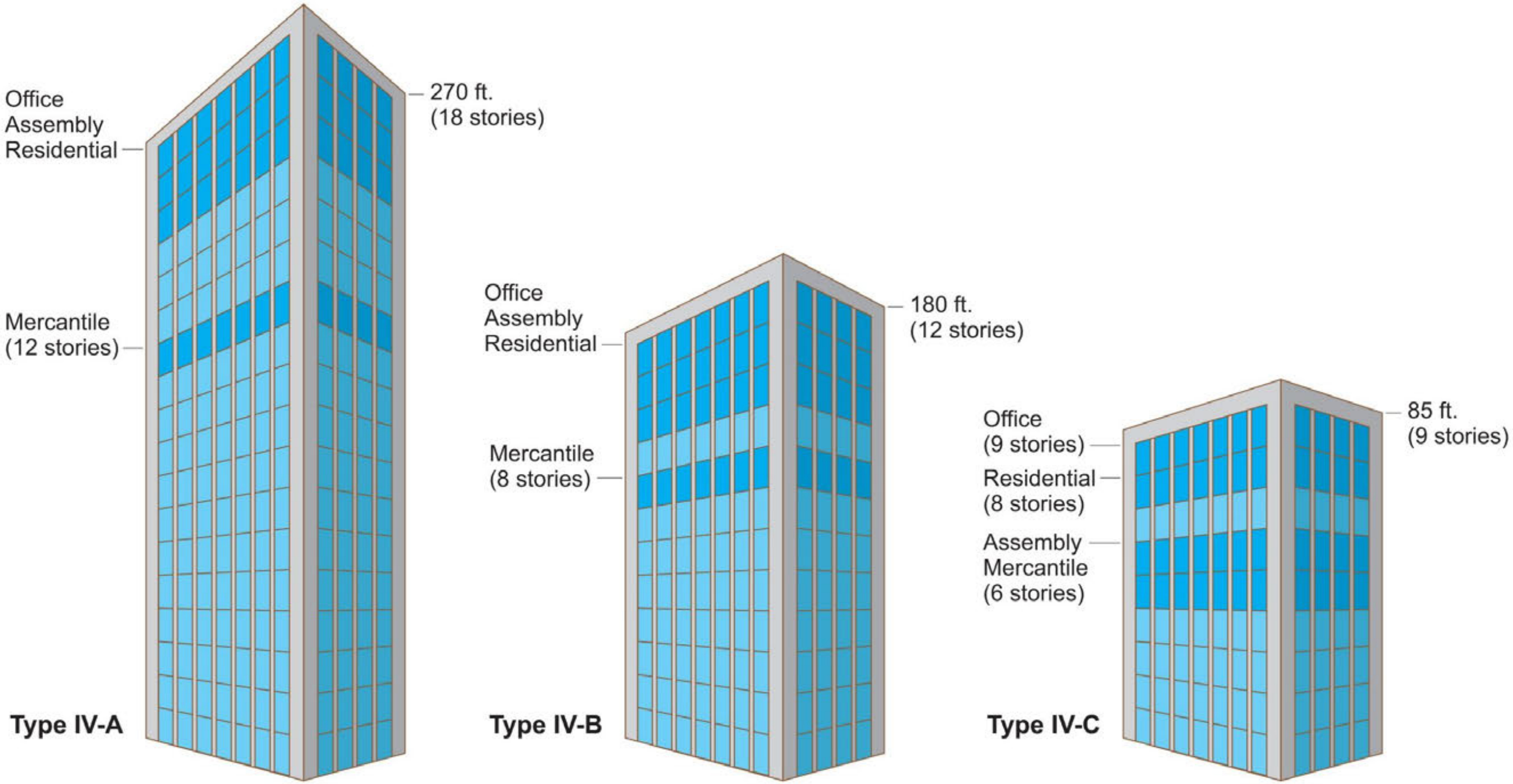
ASD REFERENCE DESIGN VALUES[a] FOR BASIC CLT GRADES AND LAYUPS (FOR USE IN THE U.S.)

		Lamination Thickness (in.) in CLT Layup							Major Strength Direction				Minor Strength Direction			
CLT Grade	t_p (in.)	=	⊥	=	⊥	=	⊥	=	$(F_bS)_{eff,f,0}$ (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

Model Building Code Acceptance

2015 International Building Code

Tall Mass Timber: Up to 18 Stories in Construction Types IV-A, IV-B or IV-C



Agenda

- Mass timber systems and products
- Acoustics
- Structural design - gravity
- Vibration
- Structural design – lateral
- Connections
- Fire

Photo: John Stamets

Mass timber design

Acoustics – IBC 1207

No acoustical code requirements for many mass timber building types such as offices and assembly. However, many owners require a minimum level of performance

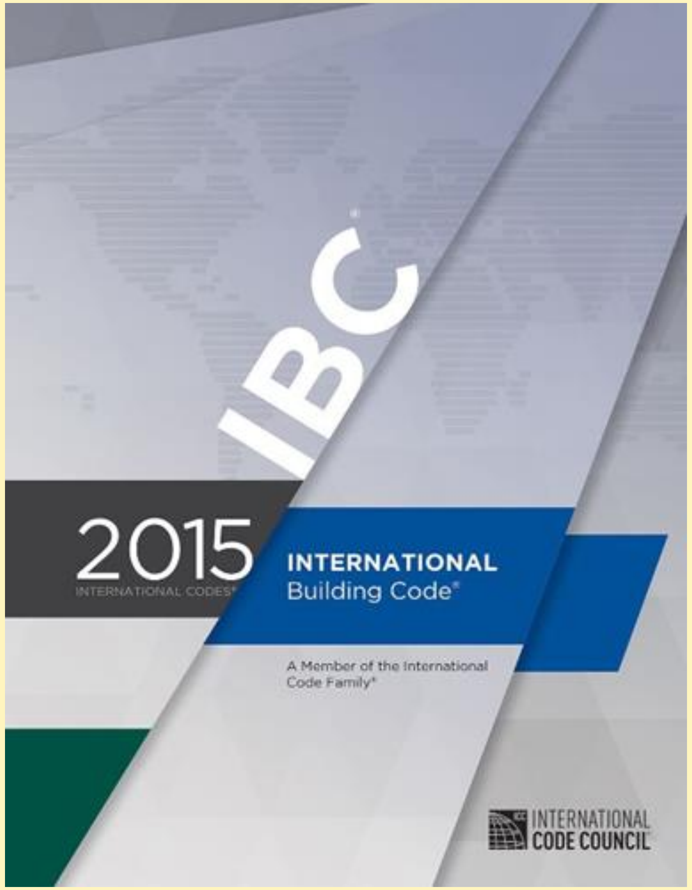
Code requirements for residential occupancies:

Min. STC of 50:

- Walls, Partitions, and Floor/Ceiling Assemblies

Min. IIC of 50 for:

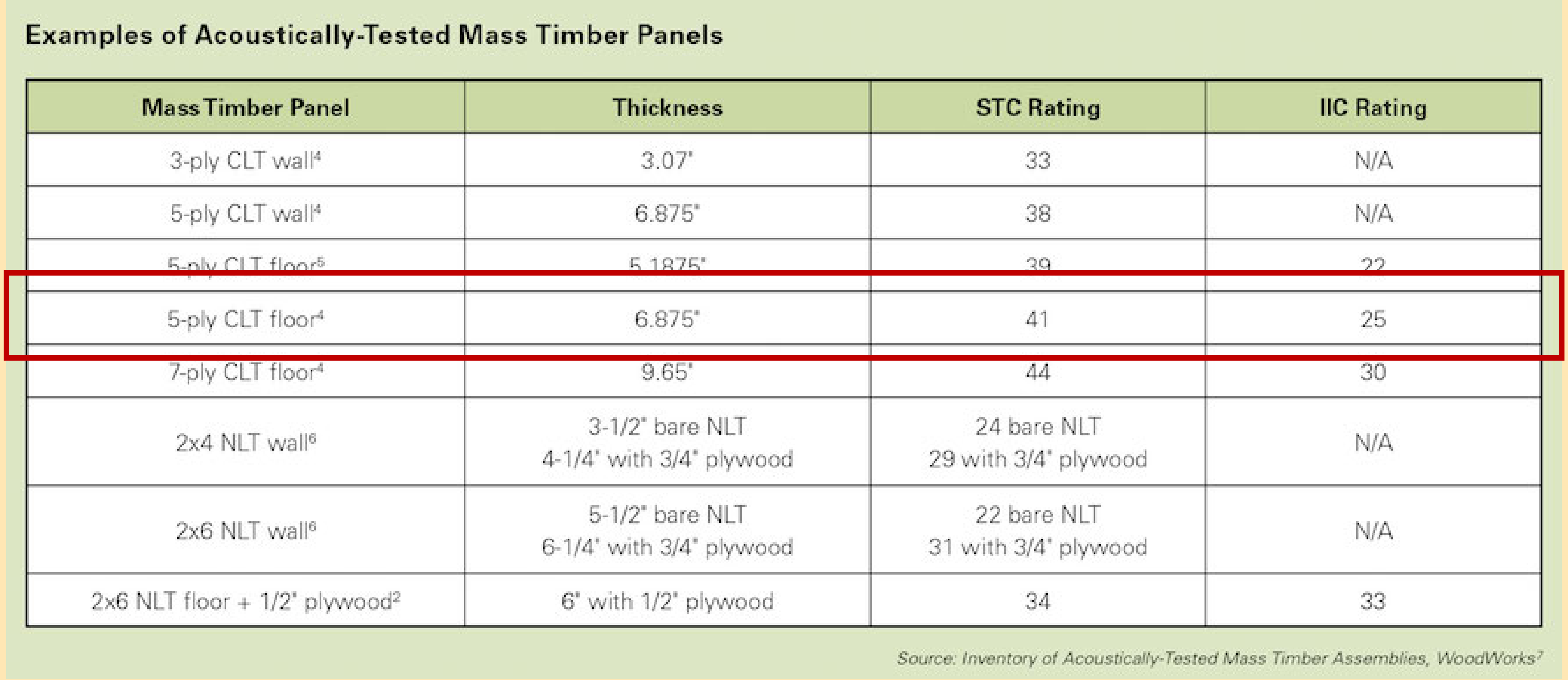
- Floor/Ceiling Assemblies



Mass timber design

Acoustics

Sound Insulation of Bare CLT Floors and Walls



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]

Mass timber design

Acoustics

Common mass timber floor assembly:

- Finish floor (if applicable)
- Underlayment (if finish floor)
- 1.5” to 3” thick concrete/gypcrete topping
- Acoustical mat
- Mass timber floor panels

Image credit: AcoustiTECH

Mass timber design

Acoustics

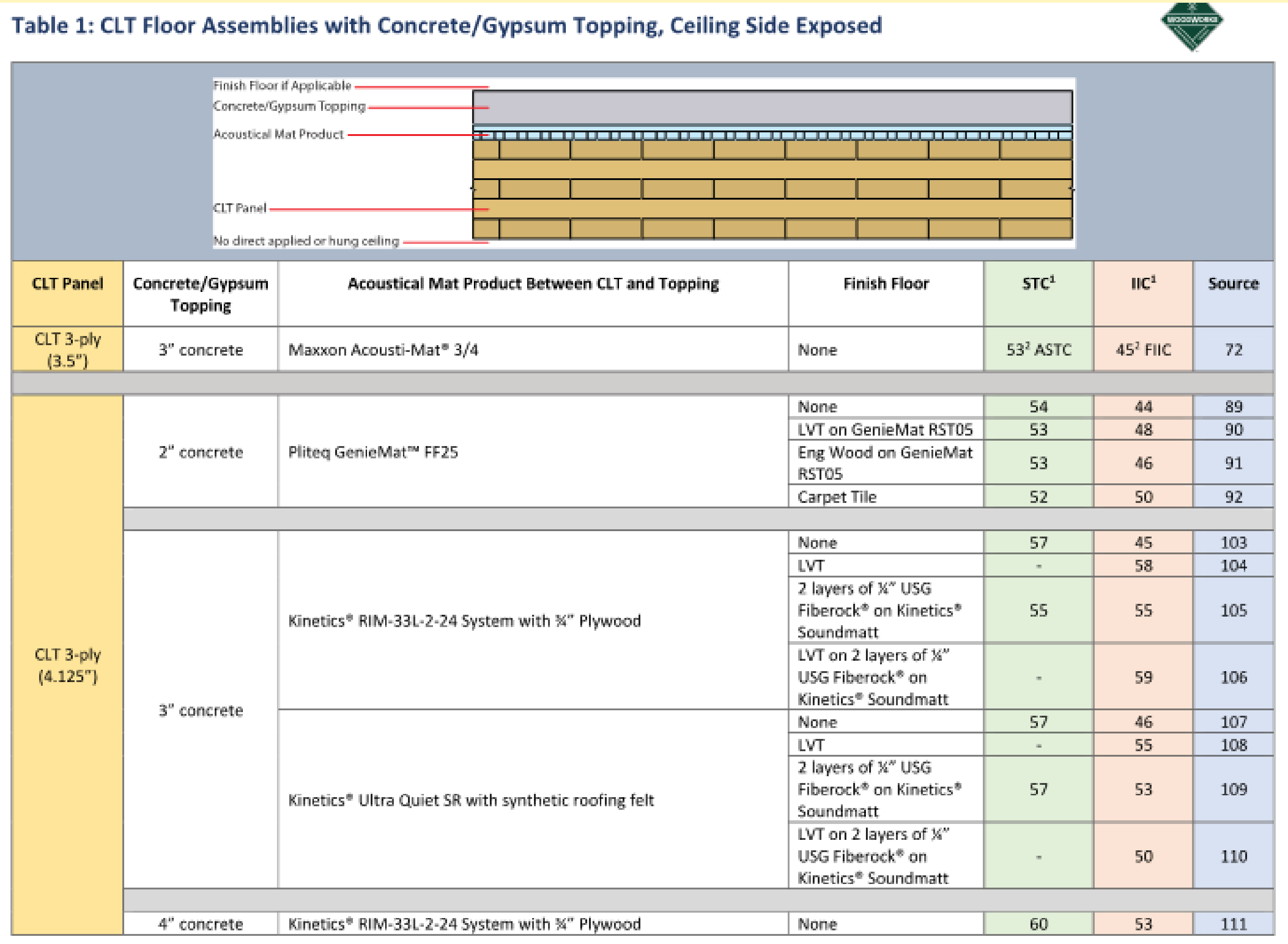


Table 1: CLT Floor Assemblies with Concrete/Gypsum Topping, Ceiling Side Exposed

Finish Floor if Applicable
Concrete/Gypsum Topping
Acoustical Mat Product
CLT Panel
No direct applied or hung ceiling

CLT Panel	Concrete/Gypsum Topping	Acoustical Mat Product Between CLT and Topping	Finish Floor	STC^1	IIC^1	Source
CLT 3-ply (3.5")	3" concrete	Maxxon Acousti-Mat® 3/4	None	53^2 ASTC	45^2 FIIC	72
CLT 3-ply (4.125")	2" concrete	Pliteq GenieMat™ FF25	None	54	44	89
			LVT on GenieMat RST05	53	48	90
			Eng Wood on GenieMat RST05	53	46	91
			Carpet Tile	52	50	92
	3" concrete	Kinetics® RIM-33L-2-24 System with ¾" Plywood	None	57	45	103
			LVT	-	58	104
			2 layers of ¼" USG Fiberock® on Kinetics® Soundmatt	55	55	105
			LVT on 2 layers of ¼" USG Fiberock® on Kinetics® Soundmatt	-	59	106
		Kinetics® Ultra Quiet SR with synthetic roofing felt	None	57	46	107
			LVT	-	55	108
			2 layers of ¼" USG Fiberock® on Kinetics® Soundmatt	57	53	109
			LVT on 2 layers of ¼" USG Fiberock® on Kinetics® Soundmatt	-	50	110
	4" concrete	Kinetics® RIM-33L-2-24 System with ¾" Plywood	None	60	53	111

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Acoustics and Mass Timber:
Room-to-Room Noise Control

Richard McLain, PE, SE • Senior Technical Director • WoodWorks

Photo: Corey Gaffer courtesy Perkins + Will

T3 Minneapolis
Architect: MGA I Michael Green Architecture, DLR Group
Structural Engineer: Magnusson Klemencic Associates
Design Assist + Build: StructureCraft

https://www.woodworks.org/resources/inventory-of-acoustically-tested-mass-timber-assemblies/

Agenda

- Mass timber systems and products
- Acoustics
- Structural design - gravity
- Vibration
- Structural design – lateral
- Connections
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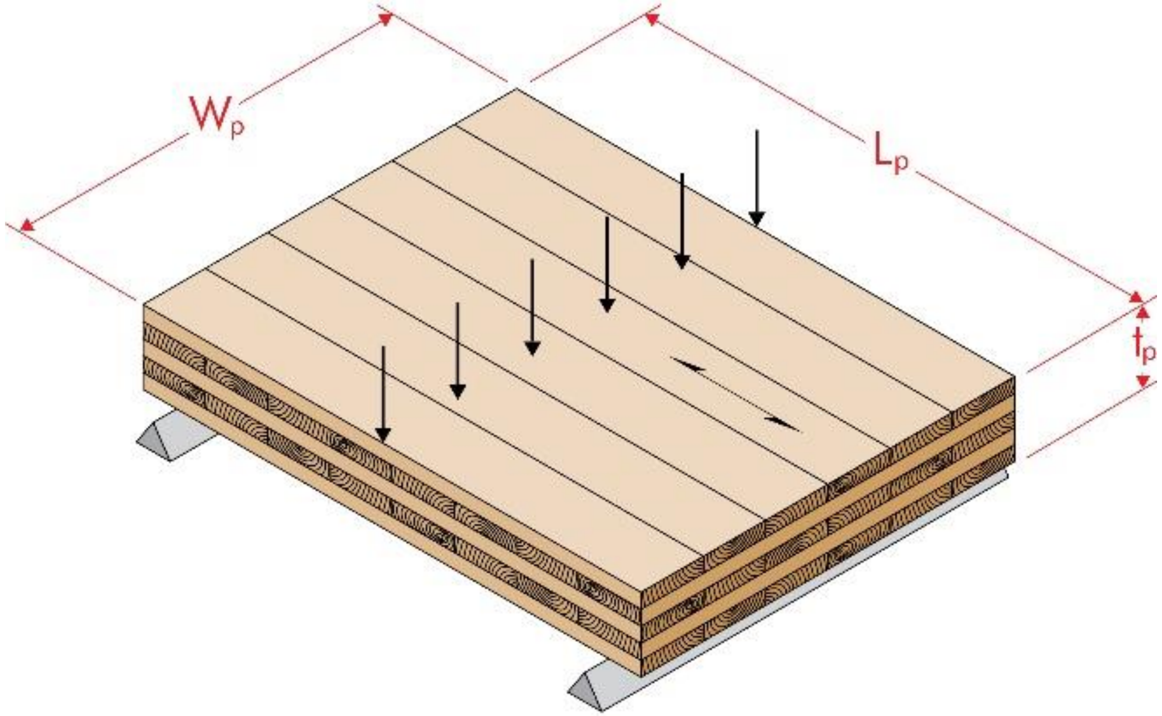
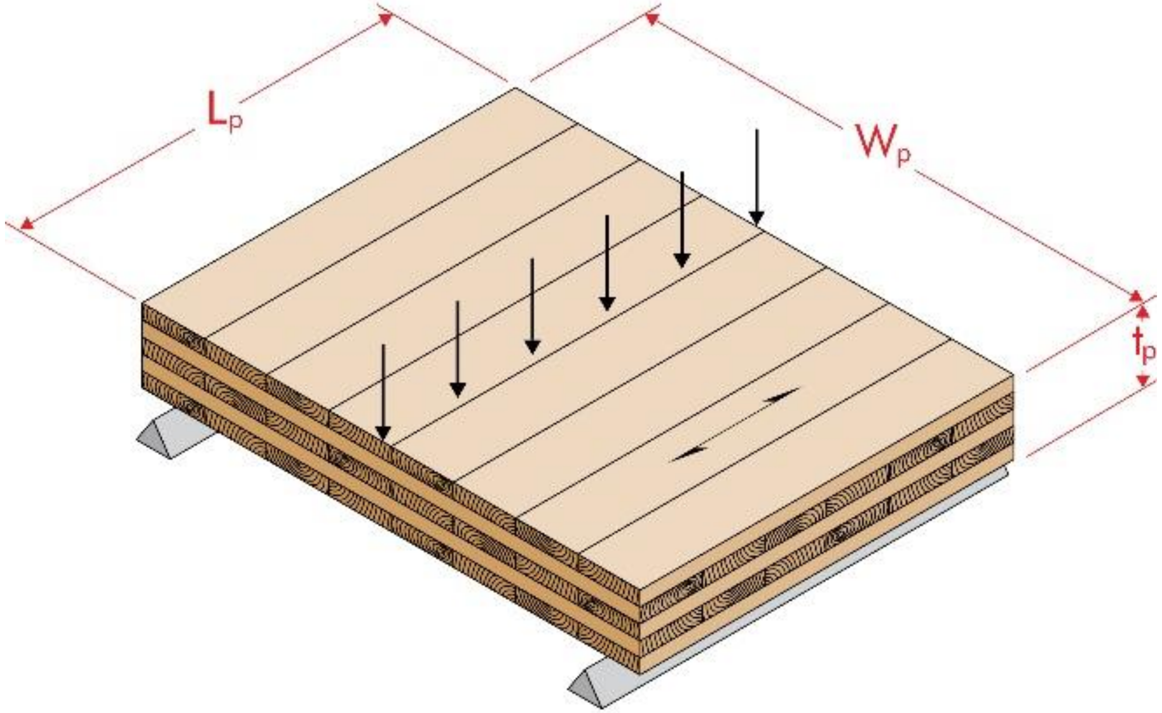
Photo: John Stamets

FLATWISE Panel Loading



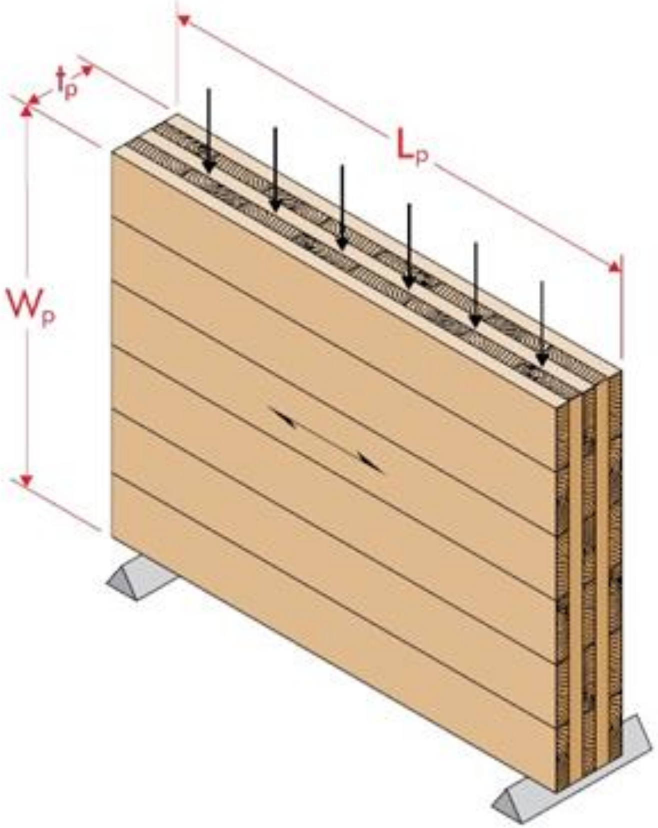
Span in MAJOR Strength Direction
“Parallel” Direction
Use subscript ‘0’ or ‘II” in Notation



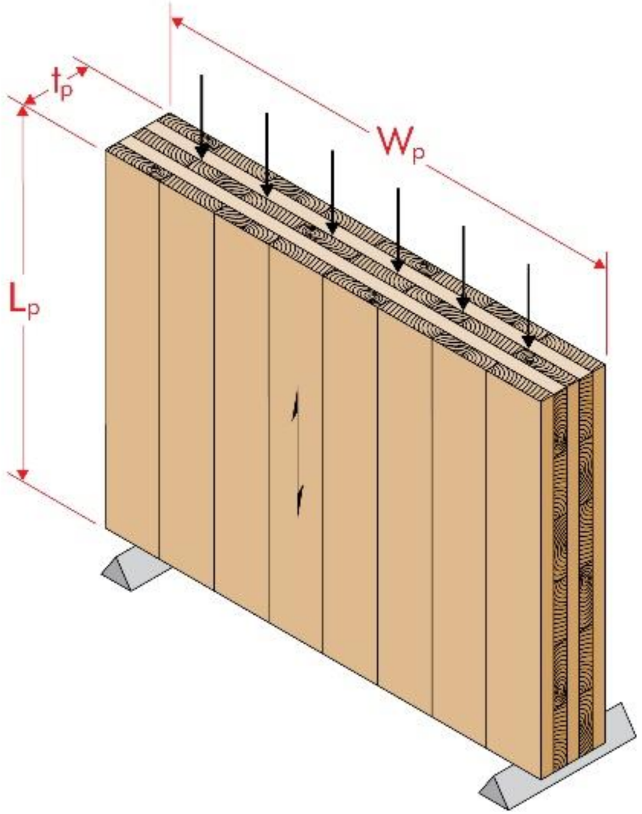
Span in MINOR Strength Direction
“Perpendicular” Direction
Use subscript ‘90’ or “⊥” in Notation

Reference & Source: ANSI/APA PRG 320

EDGEWISE Panel Loading



Span in MAJOR Strength Direction

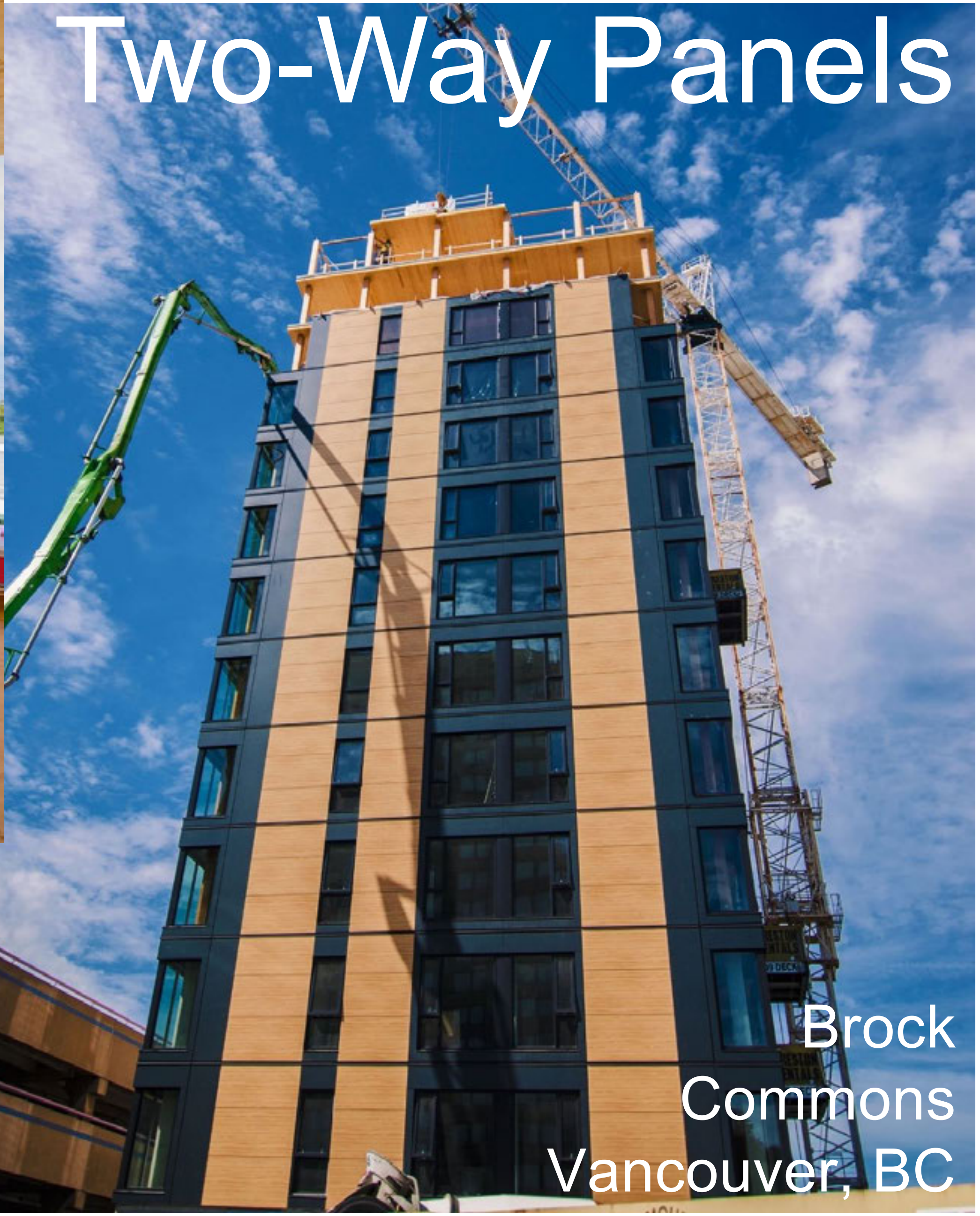


Span in MINOR Strength Direction

Reference & Source: ANSI/APA PRG 320

Two-Way Panels

5 PLY CLT PANELS,
2-WAY SPAN
~9’X13’ GRID OF
COLUMNS

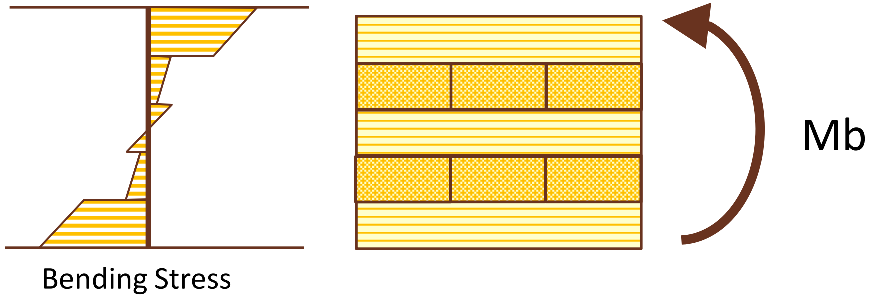


Brock
Commons
Vancouver, BC

Flatwise Flexural Strength

Design properties based on an Extreme Fiber Model:

Flexural Capacity Check:



$$M_b \leq (F_b S_{eff})'$$

M_b = applied bending moment

$(F_b S_{eff})'$ = adjusted bending capacity

S_{eff} = effective section modulus

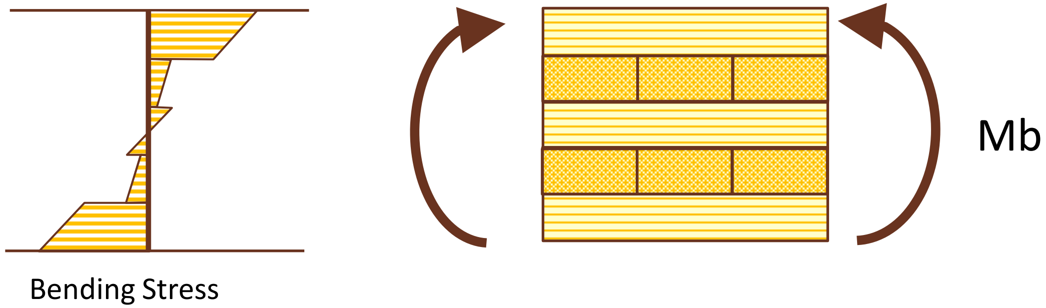
F_b = reference bending design stress of outer lamination

Separate values
for most
components

Reference: NDS

Flatwise Flexural Strength

Flexural Capacity Check (**ASD**)



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

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

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

Reference: NDS

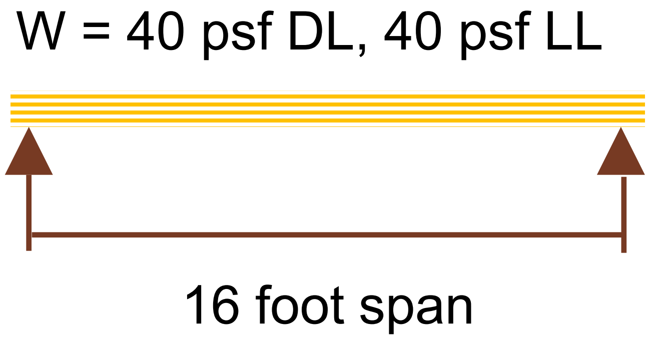
Flatwise Flexural Strength Design Example

Select acceptable CLT section

Given:

16 foot span floor

40 psf live load, 40 psf total dead load



Assume:

one-way spanning action in major strength axis of CLT

Analysis of a 1 ft strip of panel as beam

Calculate ASD Applied Moment using load combo 1.0DL + 1.0LL

$M_b = w\ L^2 / 8 = (40{+}40\text{plf})\ (16\text{ft})^2 / 8 = 2560$ lb-ft/ft

Flatwise Flexural Strength Design Example

Look for Acceptable CLT Grade from PRG 320: $F_bS_{eff,0}$ > 2560 lb-ft/ft

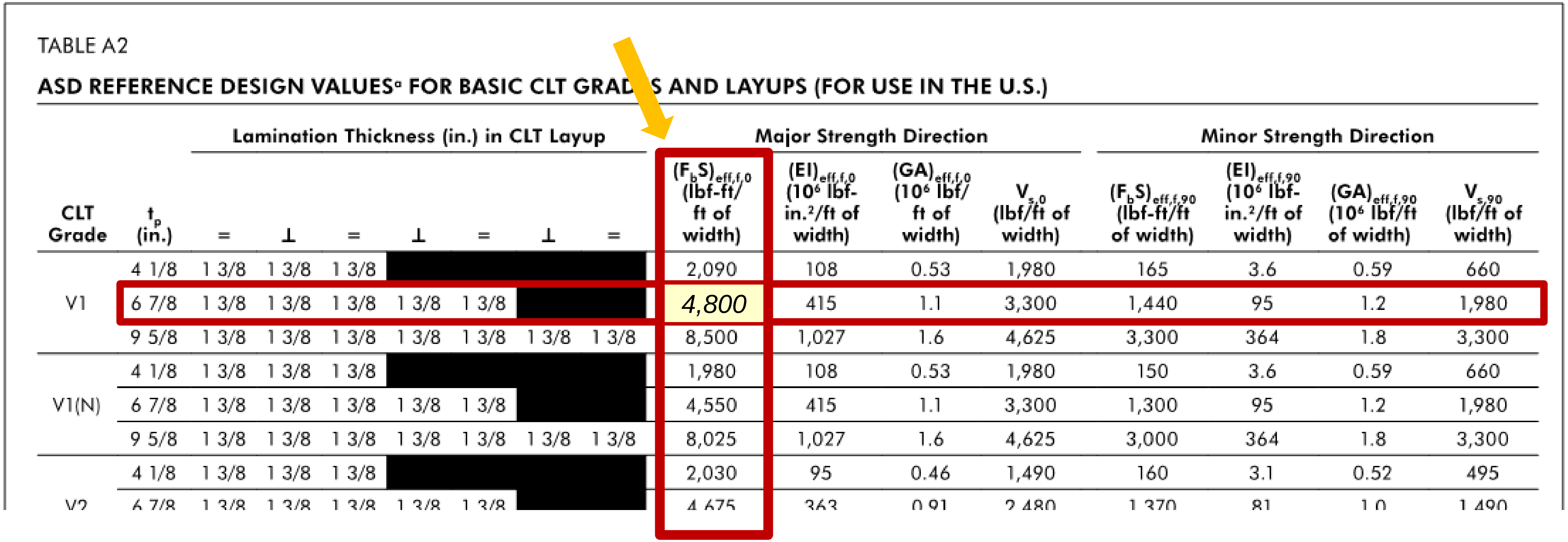


TABLE A2

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

		Lamination Thickness (in.) in CLT Layup							Major Strength Direction				Minor Strength Direction			
CLT Grade	t_p (in.)	=	⊥	=	⊥	=	⊥	=	$(F_bS)_{eff,f,0}$ (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)
V1	4 1/8	1 3/8	1 3/8	1 3/8					2,090	108	0.53	1,980	165	3.6	0.59	660
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			*4,800*	415	1.1	3,300	1,440	95	1.2	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	8,500	1,027	1.6	4,625	3,300	364	1.8	3,300
V1(N)	4 1/8	1 3/8	1 3/8	1 3/8					1,980	108	0.53	1,980	150	3.6	0.59	660
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			4,550	415	1.1	3,300	1,300	95	1.2	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	8,025	1,027	1.6	4,625	3,000	364	1.8	3,300
V2	4 1/8	1 3/8	1 3/8	1 3/8					2,030	95	0.46	1,490	160	3.1	0.52	495
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			4,675	363	0.91	2,480	1,370	81	1.0	1,490

Select 5-Ply 6 7/8" Thick V1 Panel with $F_bS_{eff,0}$ = 4800 lb-ft/ft

Reference: ANSI/APA PRG 320

Flatwise Flexural Strength Design Example

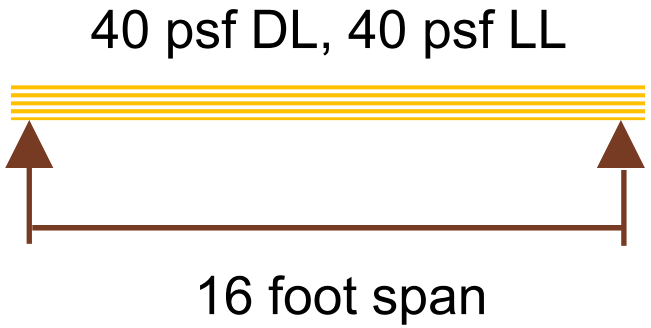
ASD Flexural Capacity:

Dead + Live load, $C_D = 1.0$

$$(F_bS_{eff})' = C_D\ (1.0)\ (F_bS_{eff})$$

$$= 1.0\ (1.0)\ (4800\ \text{lb-ft/ft})$$

$$= 4800\ \text{lb-ft/ft}$$



$$M_b = 2560\ \text{lb-ft/ft} \leq (F_bS_{eff})' = 4800\ \text{lb-ft/ft}$$

Flexural Strength OK

Flatwise Shear Strength

Rolling Shear

Source: CSA O86-14, 2016 Supplement

Flatwise Shear Strength

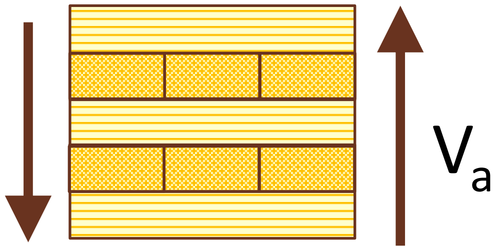
Design Properties based on Extreme Fiber Model:

Shear Capacity Check:

$$V_a \leq \; F_s(Ib/Q)_{eff}'$$

V_a = applied shear

$F_s(IbQ)_{eff}'$ = adjusted shear strength



Jargon Alert! AKA "Planar Shear", "Out-of-Plane Shear", or "Rolling Shear" Strength

Wood Structural Panel Term

Structural Engineering Term

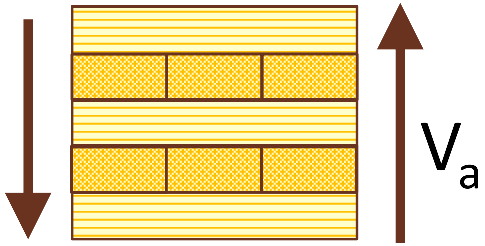
WSP & CLT Term

Reference: NDS 2018

Flatwise Shear Strength

Design Properties based on Extreme Fiber Model:

Shear Capacity Check (ASD):



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

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

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

Reference: NDS & Product Reports

Flatwise Shear Strength

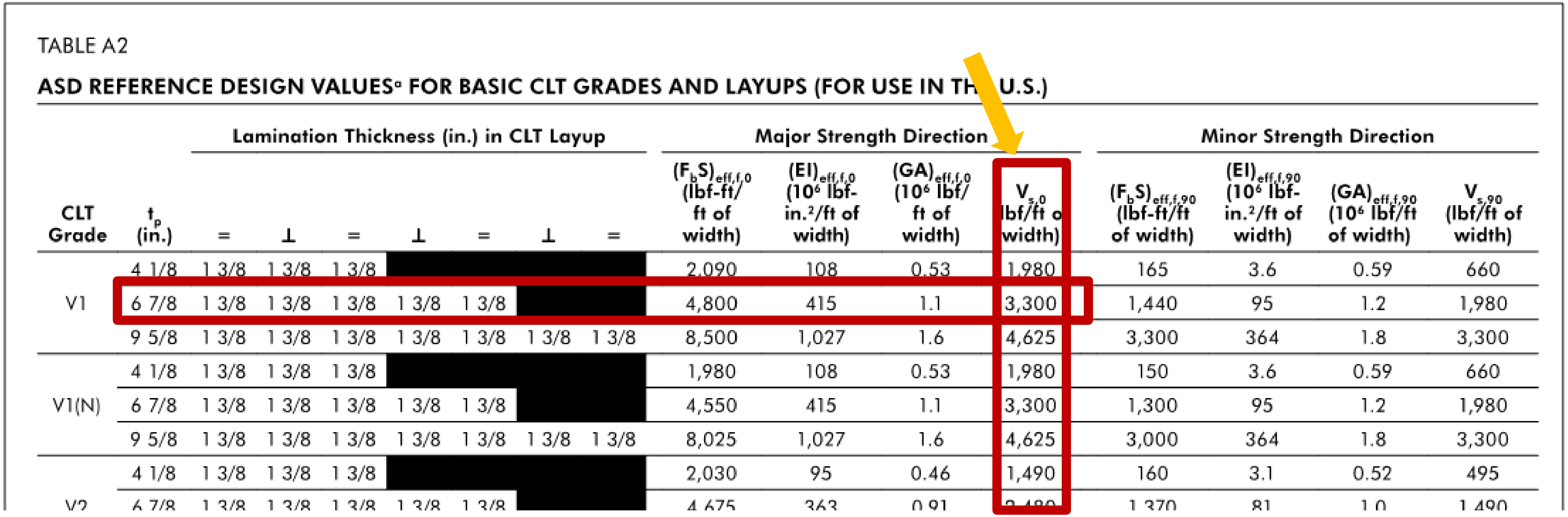


TABLE A2

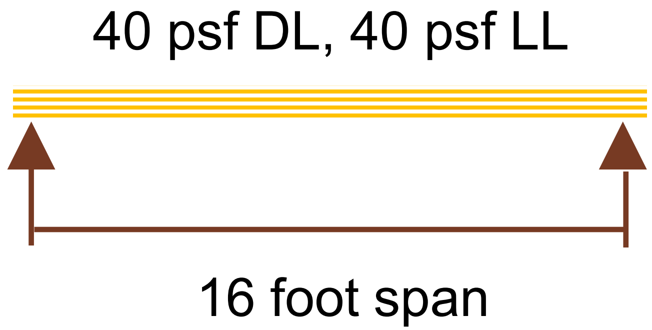
ASD REFERENCE DESIGN VALUES[a] FOR BASIC CLT GRADES AND LAYUPS (FOR USE IN TH U.S.)

		Lamination Thickness (in.) in CLT Layup							Major Strength Direction				Minor Strength Direction			
CLT Grade	t_p (in.)	=	⊥	=	⊥	=	⊥	=	$(F_bS)_{eff,f,0}$ (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 o 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)
V1	4 1/8	1 3/8	1 3/8	1 3/8					2,090	108	0.53	1,980	165	3.6	0.59	660
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			4,800	415	1.1	3,300	1,440	95	1.2	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	8,500	1,027	1.6	4,625	3,300	364	1.8	3,300
V1(N)	4 1/8	1 3/8	1 3/8	1 3/8					1,980	108	0.53	1,980	150	3.6	0.59	660
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			4,550	415	1.1	3,300	1,300	95	1.2	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	8,025	1,027	1.6	4,625	3,000	364	1.8	3,300
V2	4 1/8	1 3/8	1 3/8	1 3/8					2,030	95	0.46	1,490	160	3.1	0.52	495
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			4,675	363	0.91	[illegible]	1,370	81	1.0	1,490

Flatwise Shear Strength

Design Properties based on Extreme Fiber Model:

Shear Capacity Check (ASD):



$$V_a = w\ L\ /\ 2 = (40{+}40\text{psf})\ (16\text{ft})\ /\ 2 = 640\ \text{lb/ft}$$

$$F_s(IbQ)_{eff} = V_s = 3300\ \text{lb/ft}$$

$$F_s(IbQ)_{eff}' = C_M\ C_t\ V_s$$

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

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

Deflection Calculations

General Purpose: 1 Way, Beam Action

Needed Stiffness: $EI_{eff,0}$ $GA_{eff,0}$

Analyze as beam representing a strip (e.g 1. ft) of CLT

Can model multiple spans, cantilevers, etc.

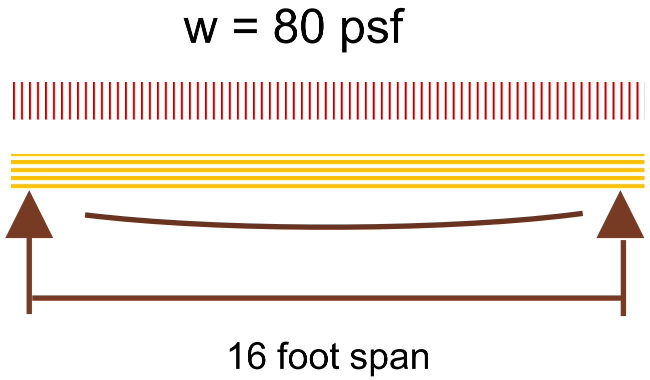
Flatwise Deflection Example

Uniform loading on one way slab:

Beam Analysis using

- Flexural Stiffness: $EI_{eff,0}$
- Shear Stiffness: $GA_{eff,0}$

Maximum Deflection @ Mid-Span

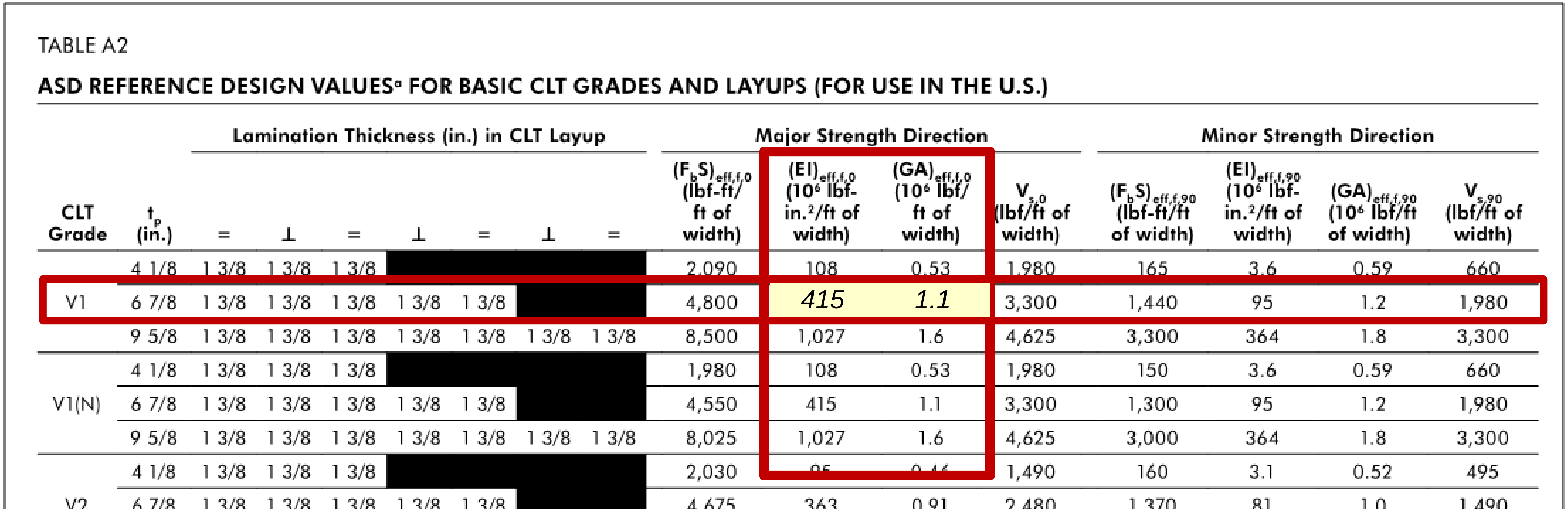


$$\Delta_{max} = \frac{5}{384} * \frac{wL^4}{EI_{eff}} + \frac{1}{8} * \frac{wL^2}{5/6\ GA_{eff}}$$

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 Example

For selected 6 7/8” 5-Ply V1, lookup major strength stiffness values



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	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			4,800	*415*	*1.1*	3,300	1,440	95	1.2	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	8,500	1,027	1.6	4,625	3,300	364	1.8	3,300
V1(N)	4 1/8	1 3/8	1 3/8	1 3/8					1,980	108	0.53	1,980	150	3.6	0.59	660
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			4,550	415	1.1	3,300	1,300	95	1.2	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	8,025	1,027	1.6	4,625	3,000	364	1.8	3,300
V2	4 1/8	1 3/8	1 3/8	1 3/8					2,030	95	0.46	1,490	160	3.1	0.52	495
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			4,675	363	0.91	2,480	1,370	81	1.0	1,490

Reference: ANSI/APA PRG 320

Flatwise Deflection Example

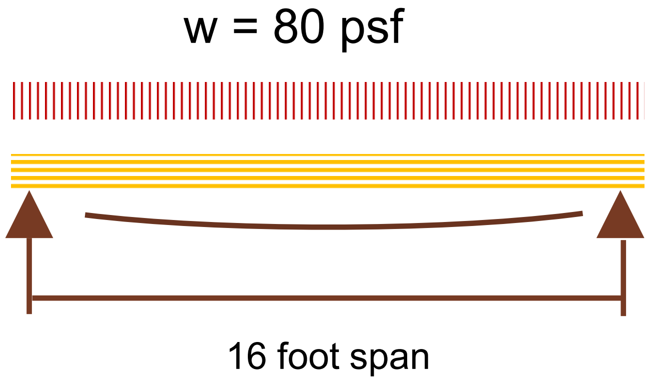
Uniform loading on one way slab:

Beam Analysis using

Flexural Stiffness: $EI_{eff,0}$

Shear Stiffness: $GA_{eff,0}$

Maximum Deflection @ Mid-Span



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

$$= \frac{5}{384} \cdot \frac{80\text{ psf }(16\text{ ft })^4}{415\times 10^6\text{ lbf in}^2/\text{ft}} \cdot (\frac{12\text{ in}}{1\text{ ft}})^3 + \frac{1}{8} \cdot \frac{80\text{ psf }(16\text{ ft })^2}{{}^5/_6\ 1.1\times 10^6\text{ lbf/ft}} \cdot \frac{12\text{ in}}{1\text{ ft}}$$

= 0.284 in + 0.034 in = 0.318 in

= L / 604

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

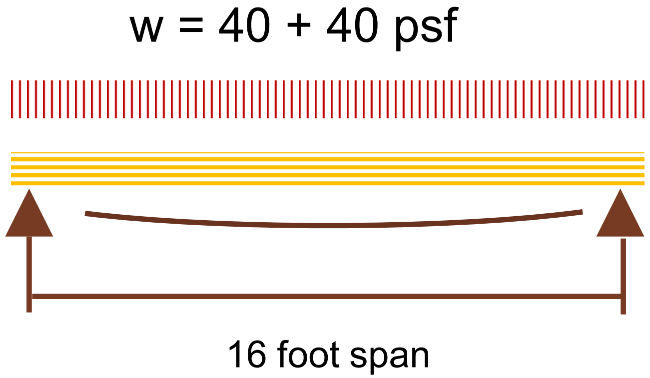
Design Example:

Δ_{ST} from 40psf = 0.159 in (assuming long term = dead)

Δ_{LT} from 40psf = 0.159 in

Δ_T = 2.0 (0.159) + 0.159 = 0.477 in

= L / 403



Reference: NDS 2015

Agenda

- Mass timber systems and products
- Acoustics
- Structural design - gravity
- Vibration
- Structural design – lateral
- Connections
- Fire

Photo: John Stamets

Floor Vibration Design

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

- Hardy Cross

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 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

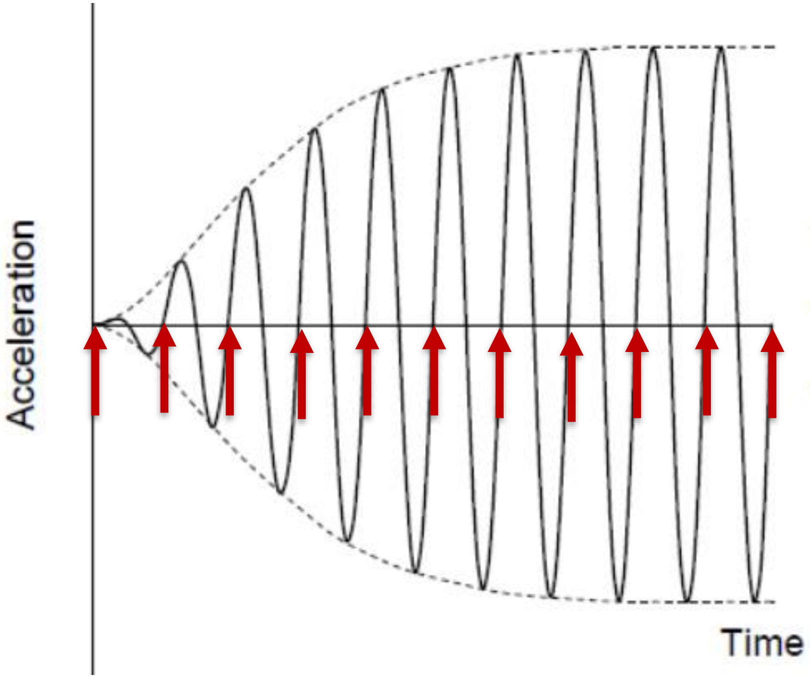
- Generally, the higher the frequency the better the performance

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
<u>Practical Tip</u> - 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

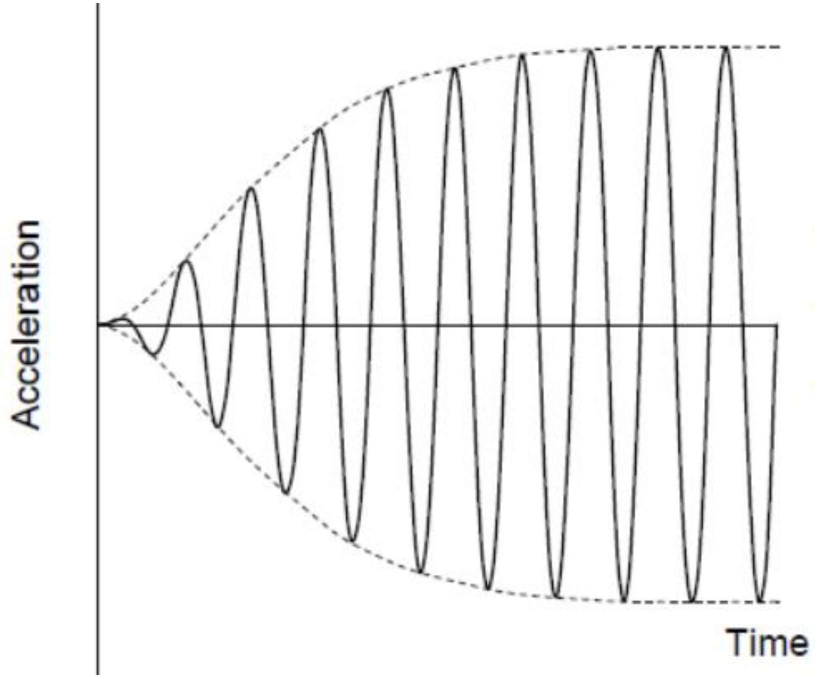
$$n\,f_w = f_n$$

For ‘n’ up to around 4

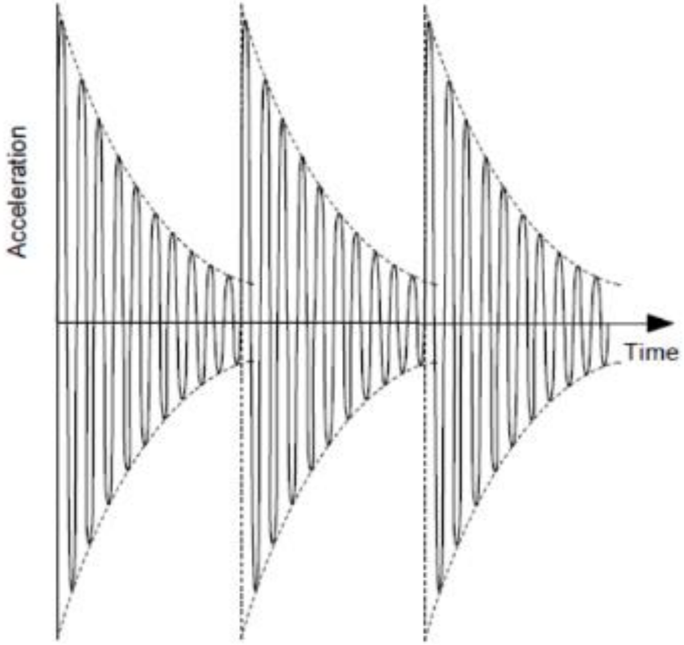
Walking at f_w =2 Hz creates resonance in floor with natural frequency, f_n, at

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

Resonant vs Impulsive Response



Excitation creates <u>Resonant</u> build-up of vibration



Response decays out between load impulses

<u>Resonant Response</u>

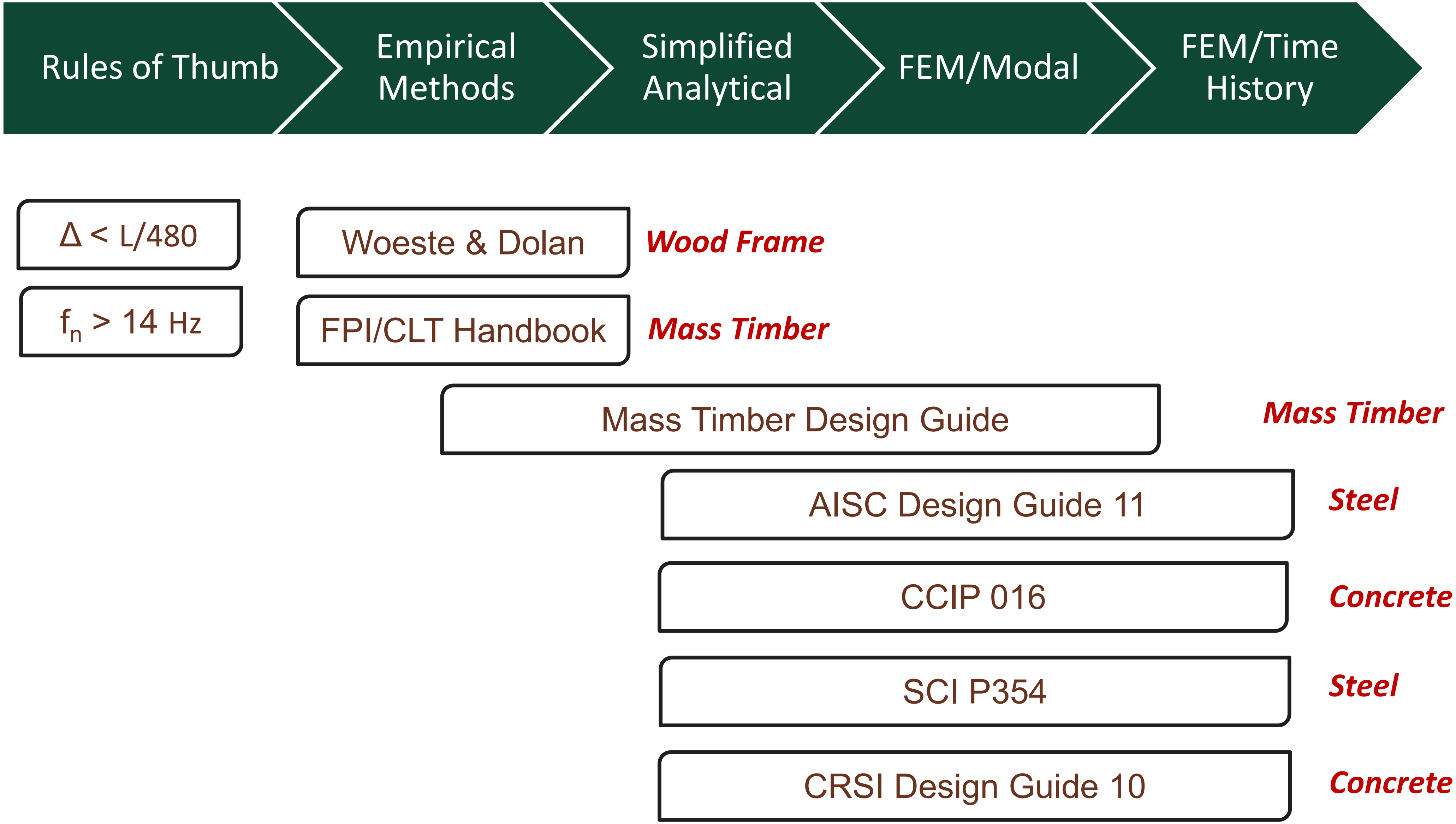
<u>Impulsive/Transient Response</u>

For walking excitations

f_n ~< 8-10 Hz

f_n ~> 8-10 Hz

Vibration Design Methods



Rules of Thumb

Empirical Methods

Simplified Analytical

FEM/Modal

FEM/Time History

$\Delta < L/480$

$f_n > 14$ 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

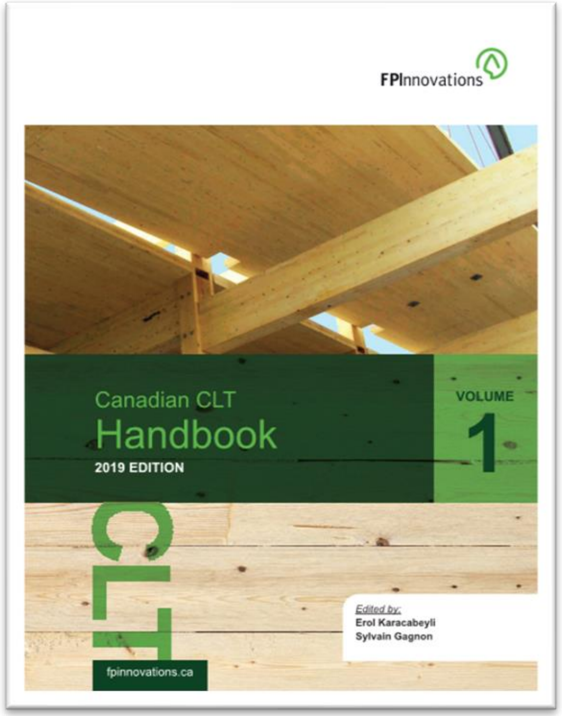
Canadian CLT Handbook 2nd Ed., 2019

FPInnovations

CLT Handbook

CROSS-LAMINATED TIMBER

US EDITION



FPInnovations

Canadian CLT

Handbook

2019 EDITION

VOLUME 1

CLT

Edited by:
Erol Karacabeyli
Sylvain Gagnon

fpinnovations.ca

https://web.fpinnovations.ca/clt/

Floor Vibration

One approach: US CLT Handbook, Chapter 7

Calculated natural frequency of simple span of bare CLT:

$$f = \frac{2.188}{2L^2}\sqrt{\frac{EI_{app}}{\rho A}}$$

Where:

EI_{app} = apparent stiffness for pinned supported, uniformly loaded, simple span (K_s = 11.5) (lb-in^2)

ρ = specific gravity of the CLT

A = the cross section area (thickness x 12 inches) (in^2)

Reference: US CLT Handbook, Chapter 7

CLT Handbook Method

Recommended CLT Floor Span Limit (base value)

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

Based on:

- Un-topped CLT
- Single, Simple span
- Bearing wall supports.

Does not account for:

- Supporting beam flexibility
- Multi-span conditions
- Additional floor mass (topping slab, etc)

Reference: US & Canadian CLT Handbooks, Chapter 7

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 In Practice

- Experience shown it consistently produces well performing floors

- Does not consider
    - Multi-span panels
    - Flexibility of supports, e.g. beams
    - Impact of topping slabs
      (more mass, but lower frequency)

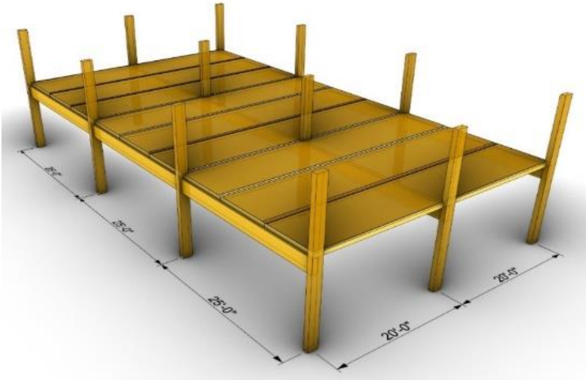
Improves Performance

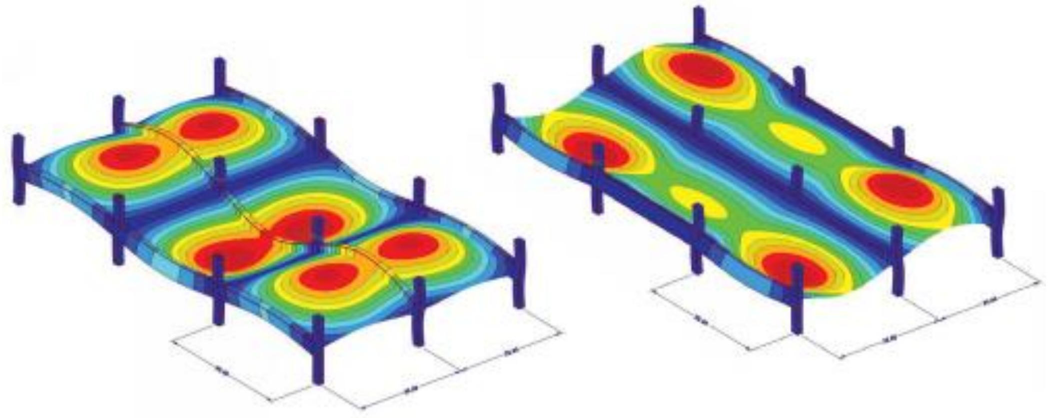
Lowers Performance

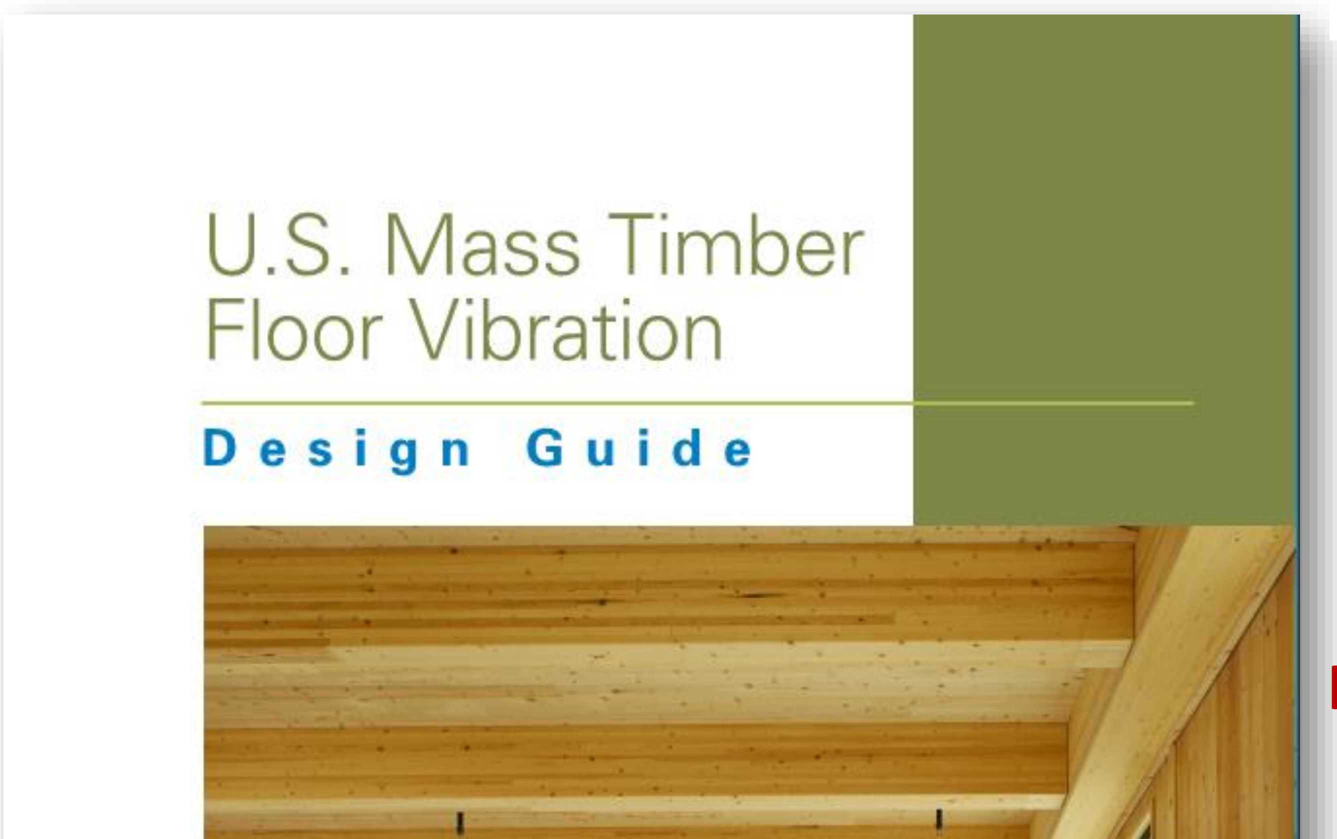
Performance??

- 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.

NEW MASS TIMBER FLOOR VIBRATION DESIGN GUIDE







U.S. Mass Timber
Floor Vibration

Design Guide

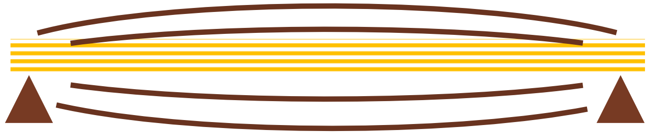
Worked office, lab and residential Examples

Covers simple and complex methods for bearing wall and frame supported floor systems

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

Parameters of Modal Superposition Methods

Excitation Force(s) → Structure → Vibration Response

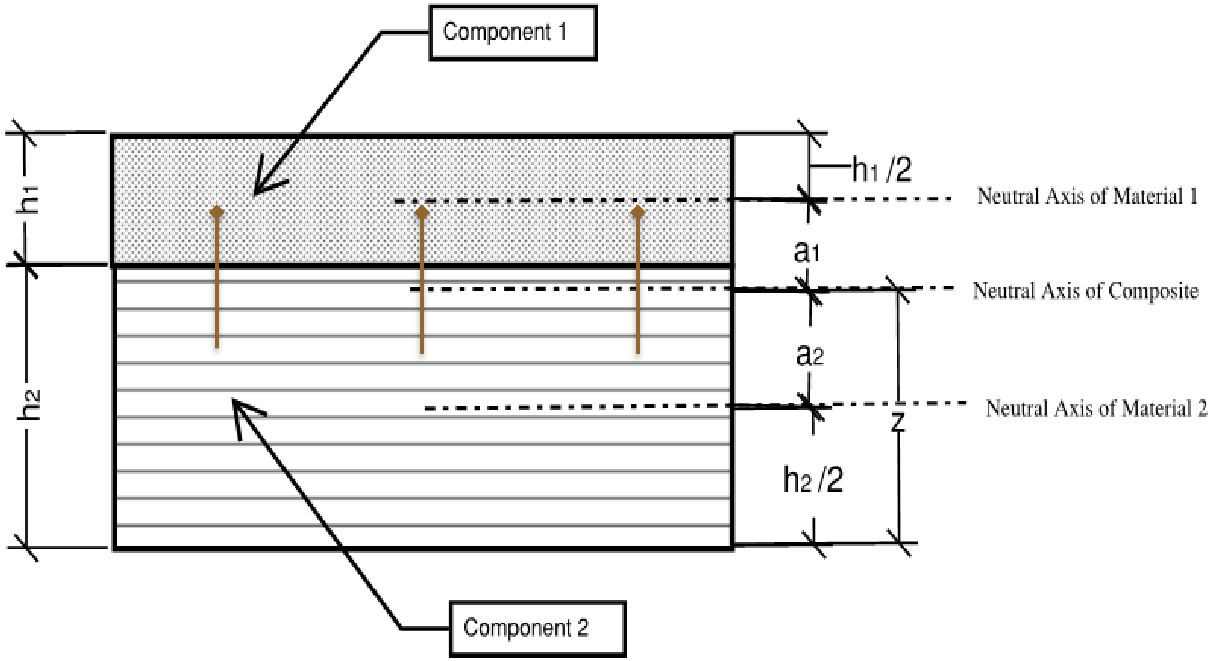


Walking Frequency, f_w
…
Walking Location
Walking Path

Stiffness
Mass/Weight
Damping
Boundary Conditions

Performance Targets

Composite Behavior



$$EI_{eff} > EI_1 + EI_2$$

$$GA_{eff} > GA_1 + GA_2$$

Even if NOT designed as a composite for code required strength and stiffness, real systems can show *partial composite action* for vibrations

Incidental Composite Behavior

	Consider Composite for:		
Composite Behavior	Strength	Deflection	Vibration
Explicit	Yes	Yes	Yes
Incidental	No	No	Yes

Reference: US Mass Timber Floor Vibration Design Guide

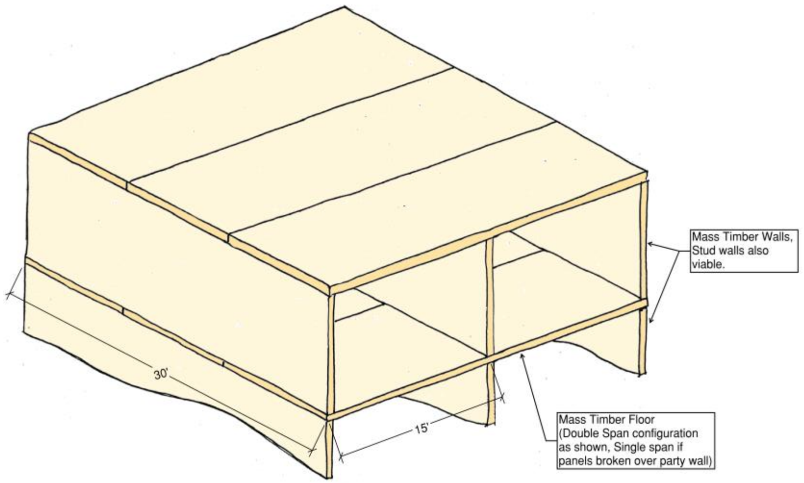
Damping Values

Selection Based on Judgement and Experience

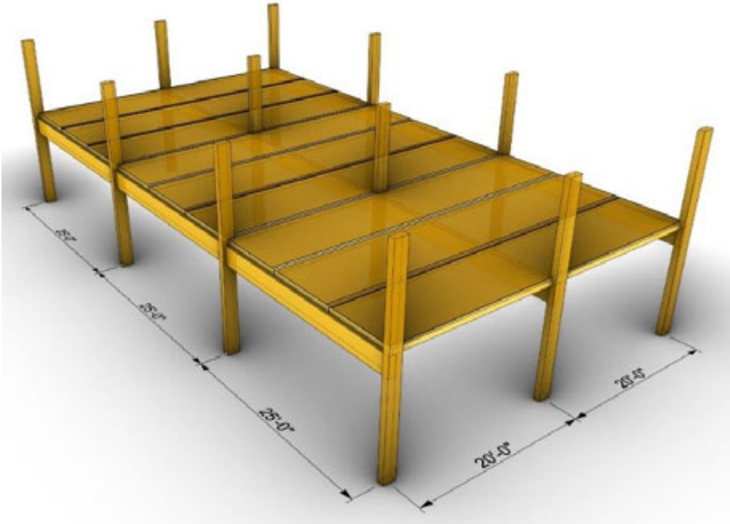
Category	Range of Damping ζ (% critical)	Discussion
Lightly damped	1-2%	The lower end includes bare floors without topping and with minimal furnishing. The higher end includes floors with concrete topping and furnishings.
Moderately damped	2-4%	Lower values include bare timber-concrete composite floors, or timber floors with a floating concrete layer and full furnishings. The higher values include floors with floating floor layers, raised floors, full furnishings, and mechanical systems. Floors with both furnishings and permanent partitions, not otherwise accounted for, could also be represented on the higher end of this damping range.
Heavily damped	4-5%	Floors in this range represent the upper limit of inherent damping. These floors likely include floating toppings, raised floors, suspended ceilings, furnishings, fixtures, and/or permanent partitions not otherwise accounted for.

Details of U.S. Mass Timber Floor Vibration Design Guide

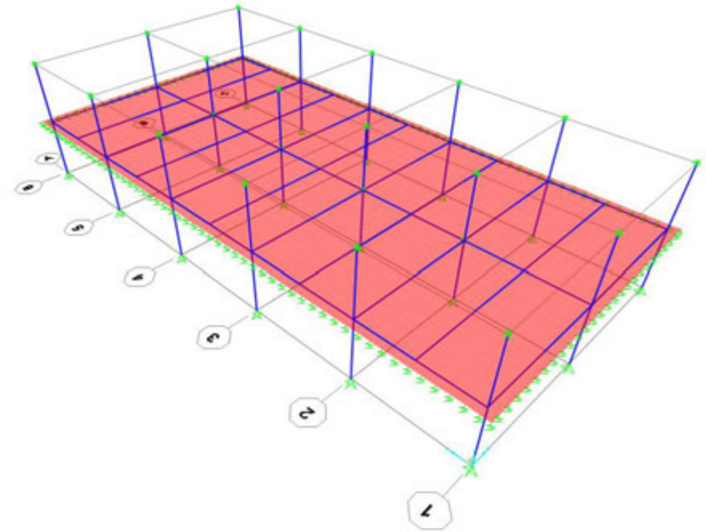
Vibration Design Examples



Residential Bearing Wall Building with CLT



Open Office with NLT on Glulam Frame



High Performance Lab Space with CLT on Glulam Frame

Available for free from www.woodworks.org/publications-media/solution-papers/

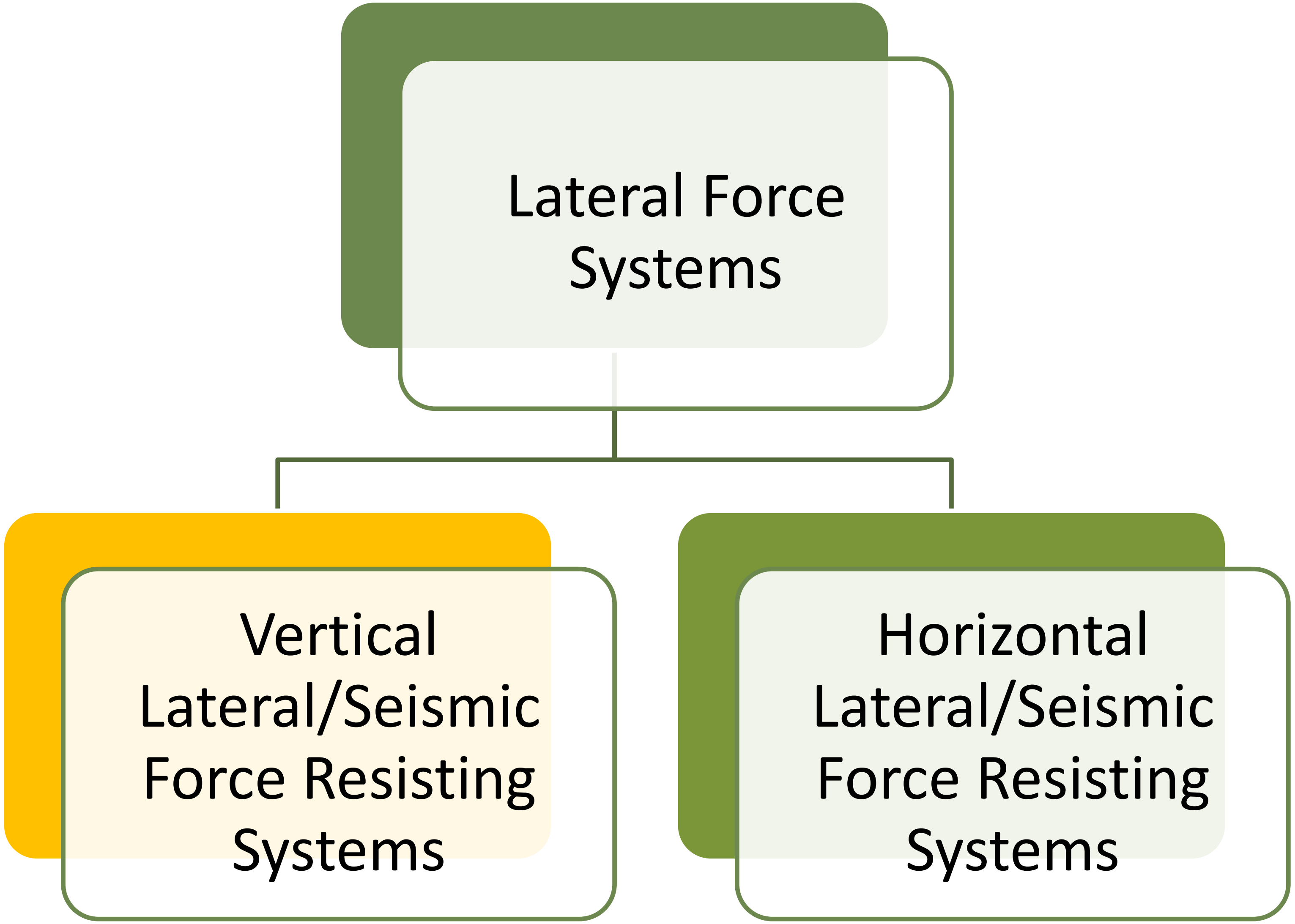
SB

Agenda

- » Mass timber systems and products
- » Acoustics
- » Structural design - gravity
- » Vibration
- » Structural design – lateral
- » Connections
- » Fire

Photo: John Stamets

Mass Timber Lateral Systems



Lateral Force Systems

Vertical Lateral/Seismic Force Resisting Systems

Horizontal Lateral/Seismic Force Resisting Systems

Shear Walls
Moment Frames
Etc.

Floor and Roof Diaphragms

Code Recognized Vertical Seismic System

Photos: WoodWorks

Mass Timber Design

Lateral framing systems

Central Core – concrete shearwalls

Photo Credit: structurecraft

Mass Timber Design

Lateral framing systems

Steel Braced Frame

Photo Credit: john stamets

Mass Timber Design

Lateral framing systems

Mass Timber Shearwalls

Photo Credit: alex schreyer

CLT in In-Plane (Edgewise) Strength

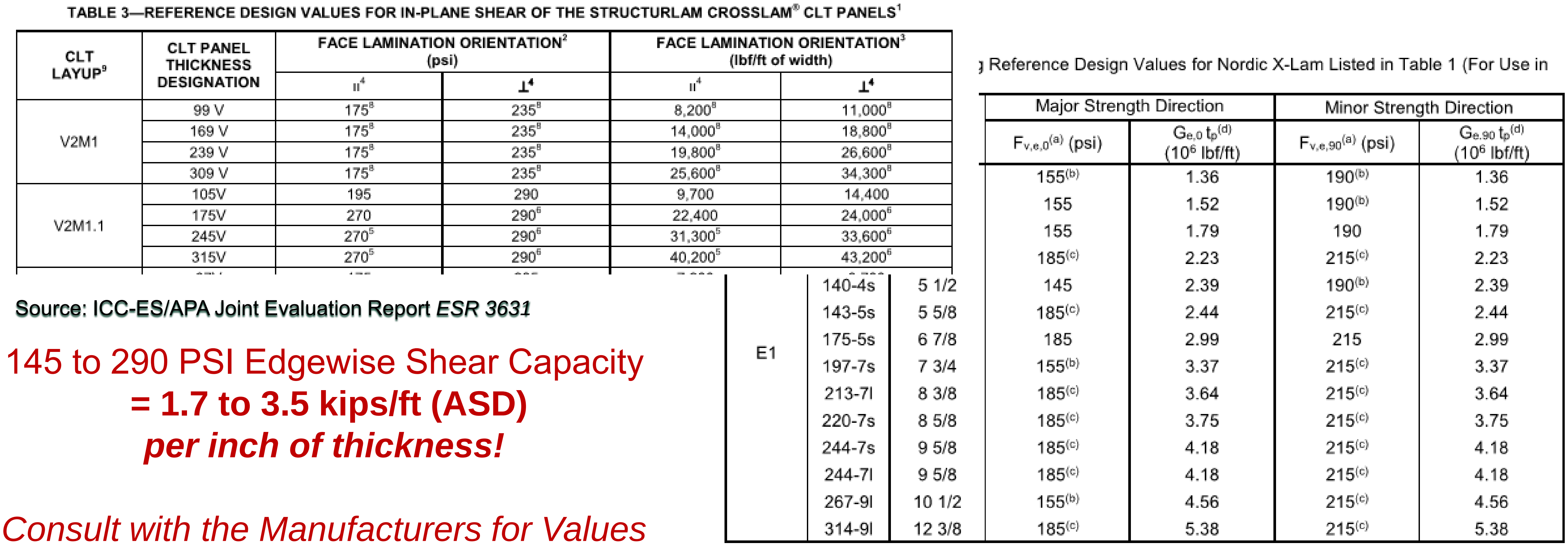


TABLE 3—REFERENCE DESIGN VALUES FOR IN-PLANE SHEAR OF THE STRUCTURLAM CROSSLAM® CLT PANELS[1]

CLT LAYUP[9]	CLT PANEL THICKNESS DESIGNATION	FACE LAMINATION ORIENTATION[2] (psi)		FACE LAMINATION ORIENTATION[3] (lbf/ft of width)	
		∥[4]	⊥[4]	∥[4]	⊥[4]
V2M1	99 V	175[8]	235[8]	8,200[8]	11,000[8]
	169 V	175[8]	235[8]	14,000[8]	18,800[8]
	239 V	175[8]	235[8]	19,800[8]	26,600[8]
	309 V	175[8]	235[8]	25,600[8]	34,300[8]
V2M1.1	105V	195	290	9,700	14,400
	175V	270	290[6]	22,400	24,000[6]
	245V	270[5]	290[6]	31,300[5]	33,600[6]
	315V	270[5]	290[6]	40,200[5]	43,200[6]

Source: ICC-ES/APA Joint Evaluation Report *ESR 3631*

Reference Design Values for Nordic X-Lam Listed in Table 1 (For Use in

			Major Strength Direction		Minor Strength Direction	
			$F_{v,e,0}$(a) (psi)	$G_{e,0}\,t_p$(d) (10^6 lbf/ft)	$F_{v,e,90}$(a) (psi)	$G_{e,90}\,t_p$(d) (10^6 lbf/ft)
			155(b)	1.36	190(b)	1.36
			155	1.52	190(b)	1.52
			155	1.79	190	1.79
			185(c)	2.23	215(c)	2.23
E1	140-4s	5 1/2	145	2.39	190(b)	2.39
	143-5s	5 5/8	185(c)	2.44	215(c)	2.44
	175-5s	6 7/8	185	2.99	215	2.99
	197-7s	7 3/4	155(b)	3.37	215(c)	3.37
	213-7l	8 3/8	185(c)	3.64	215(c)	3.64
	220-7s	8 5/8	185(c)	3.75	215(c)	3.75
	244-7s	9 5/8	185(c)	4.18	215(c)	4.18
	244-7l	9 5/8	185(c)	4.18	215(c)	4.18
	267-9l	10 1/2	155(b)	4.56	215(c)	4.56
	314-9l	12 3/8	185(c)	5.38	215(c)	5.38

Source: *APA Product Report PR-L306*

145 to 290 PSI Edgewise Shear Capacity

= 1.7 to 3.5 kips/ft (ASD)

per inch of thickness!

Consult with the Manufacturers for Values

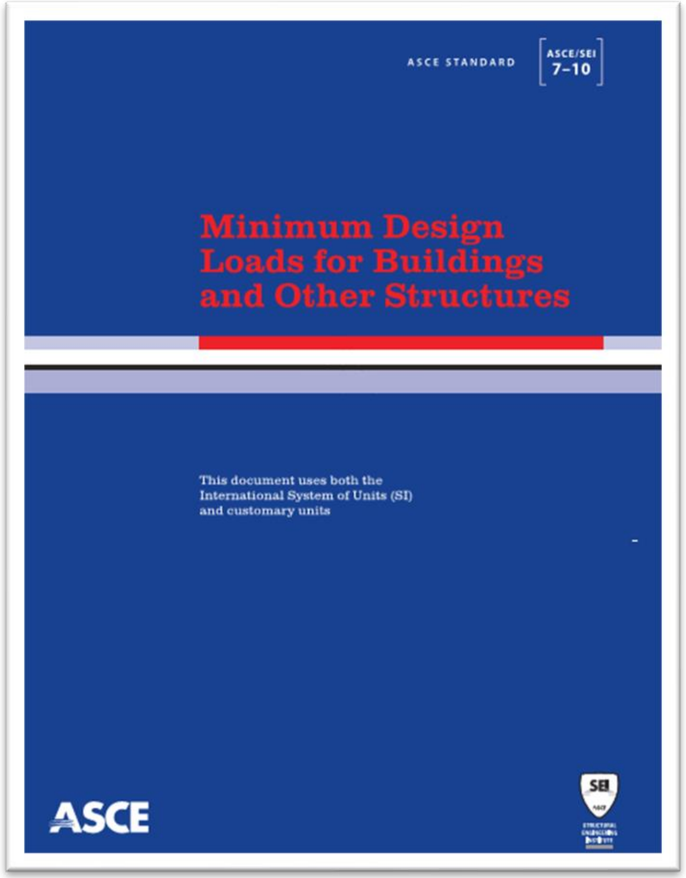
Multiply by ***Cd = 1.6***

for short term ASD strength

CLT Panels can have > 9 kips / ft in-plane shear capacity

CLT Seismic Design

CLT Seismic Force Resisting Systems **Not** addressed In



ASCE STANDARD

ASCE/SEI 7–10

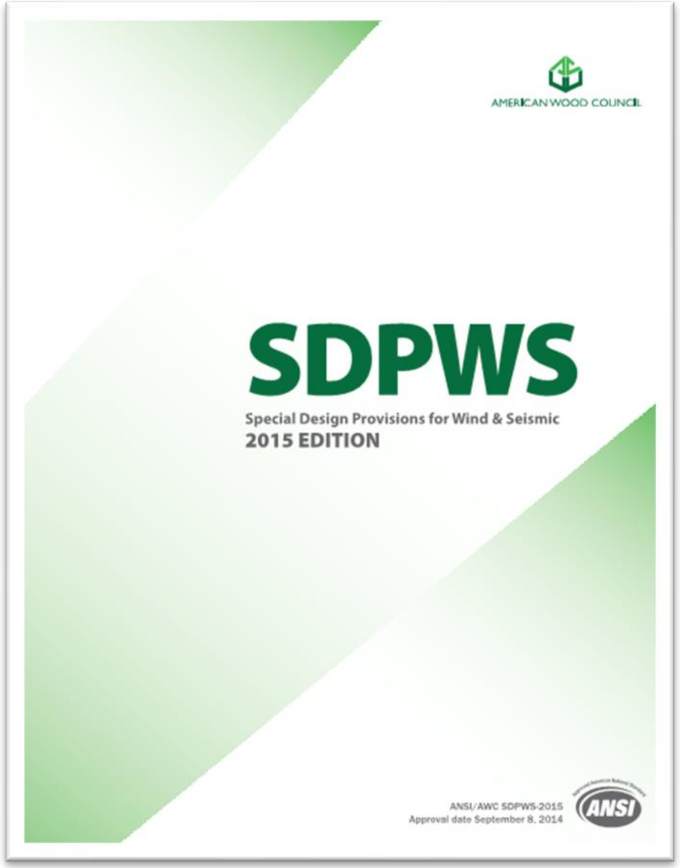
Minimum Design Loads for Buildings and Other Structures

This document uses both the International System of Units (SI) and customary units

ASCE

SEI

ASCE/SEI 7-10 or 7-16



AMERICAN WOOD COUNCIL

SDPWS

Special Design Provisions for Wind & Seismic

2015 EDITION

ANSI/AWC SDPWS-2015

Approval date September 8, 2014

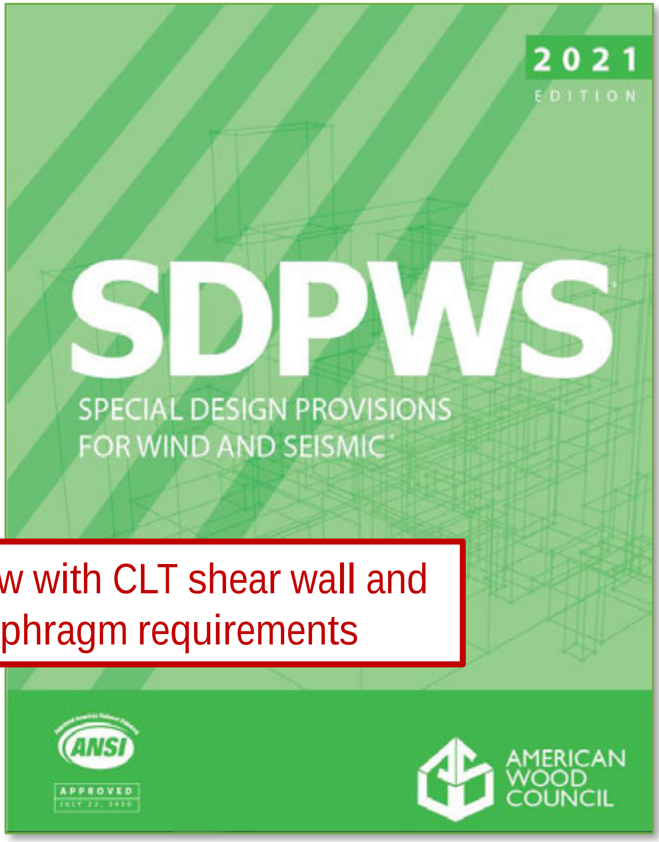
ANSI

SDPWS 2015

ASCE/SEI 7-10 12.2.1:

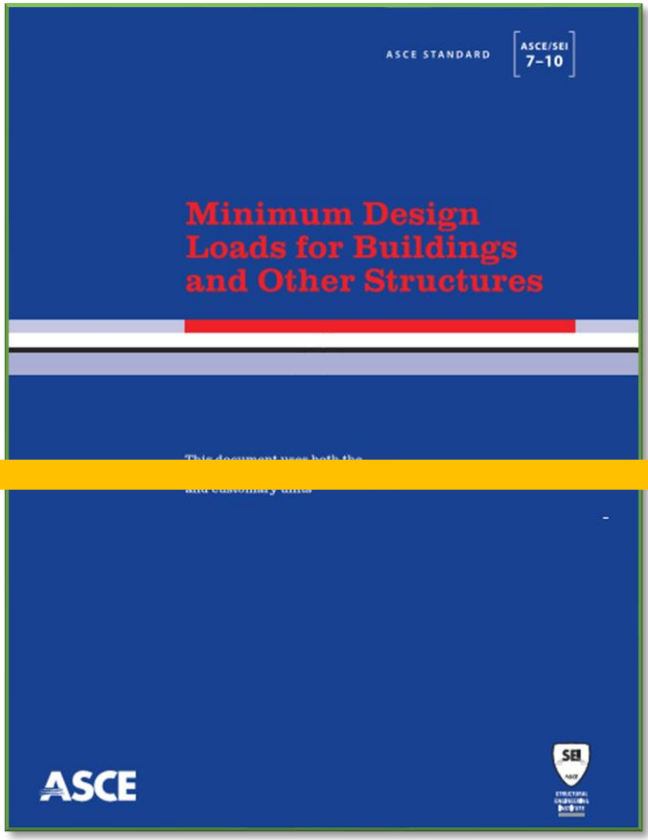
Seismic force-resisting systems not contained in Table 12.2-1 are permitted provided analytical and test data are submitted to the authority having jurisdiction for approval that establish ……

CLT in the U.S. Building Code – IBC 2021 (Lateral)

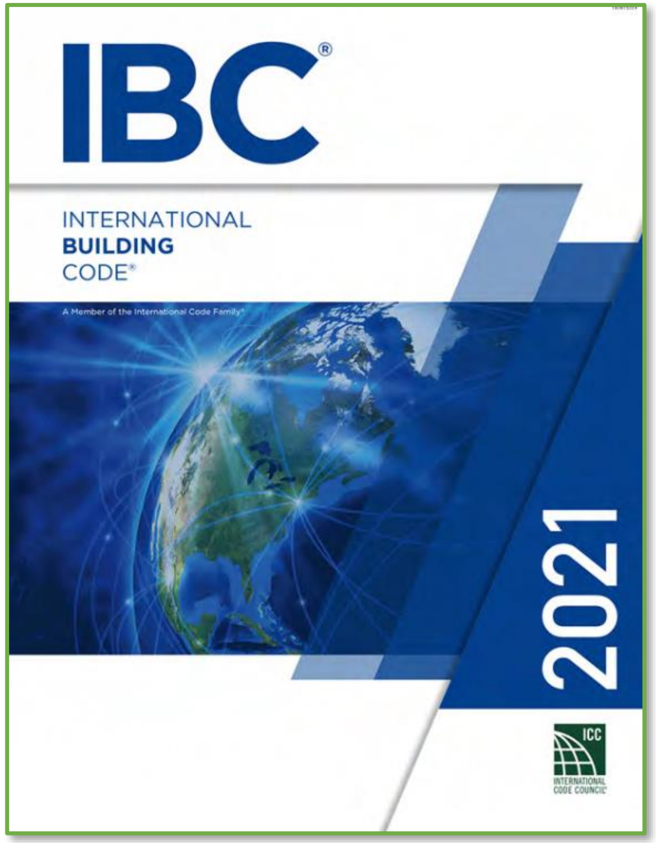


Now with CLT shear wall and diaphragm requirements

AWC SDPWS 2021



ASCE/SEI 7-16

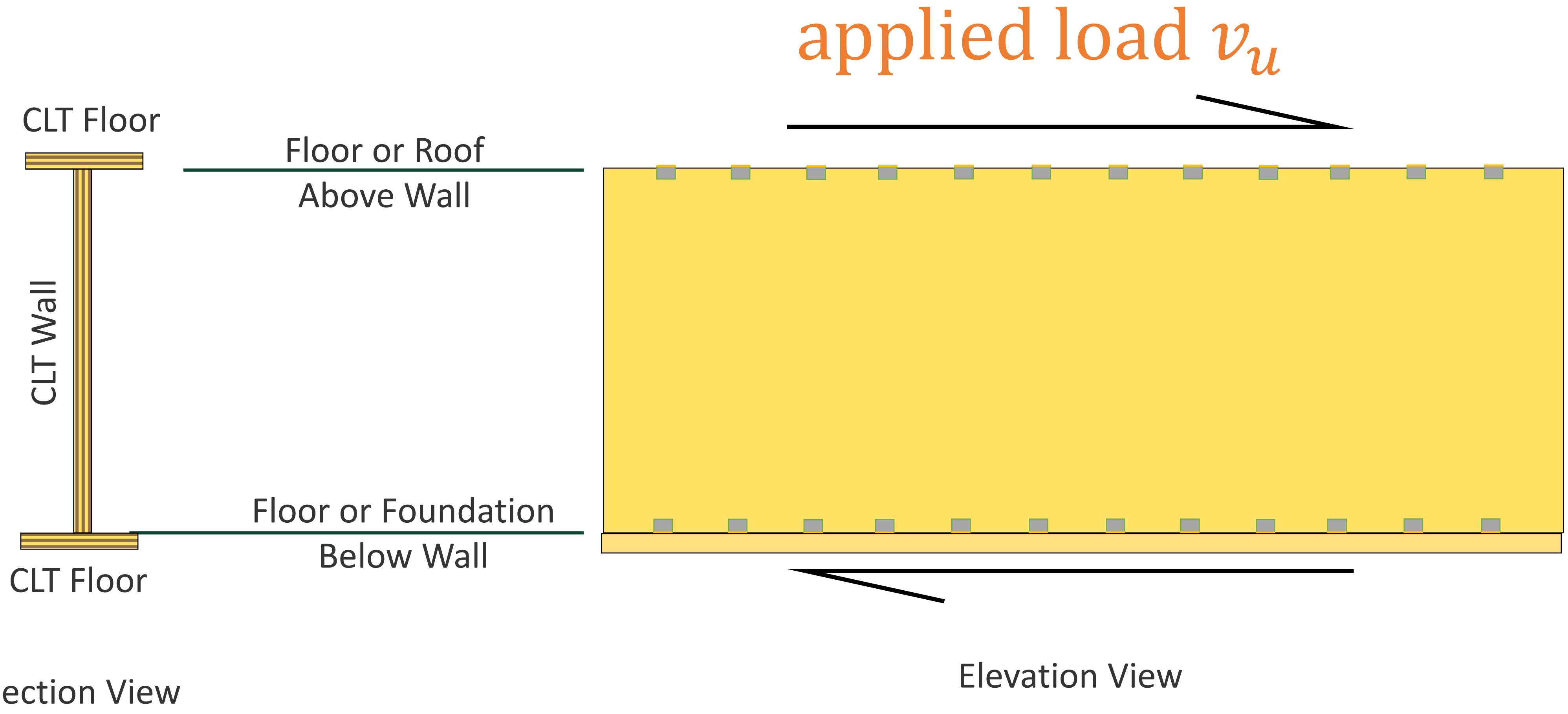


2021 International Building Code

New Requirements for CLT Lateral Systems in SDPWS 2021!
Referenced from IBC 2021

CLT Shear Walls in SDPWS 2021

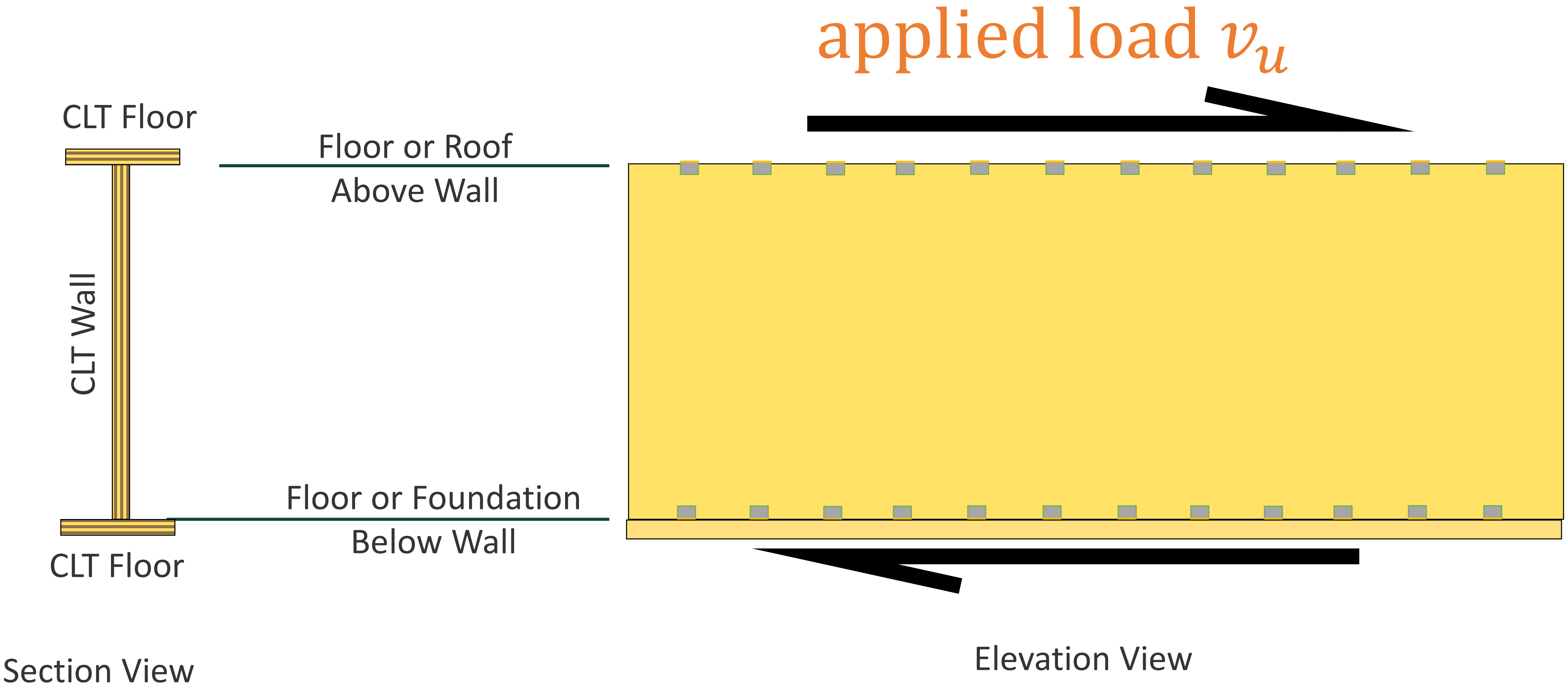
Platform Framed CLT Construction



SDPWS 2021 Section 4.1.4

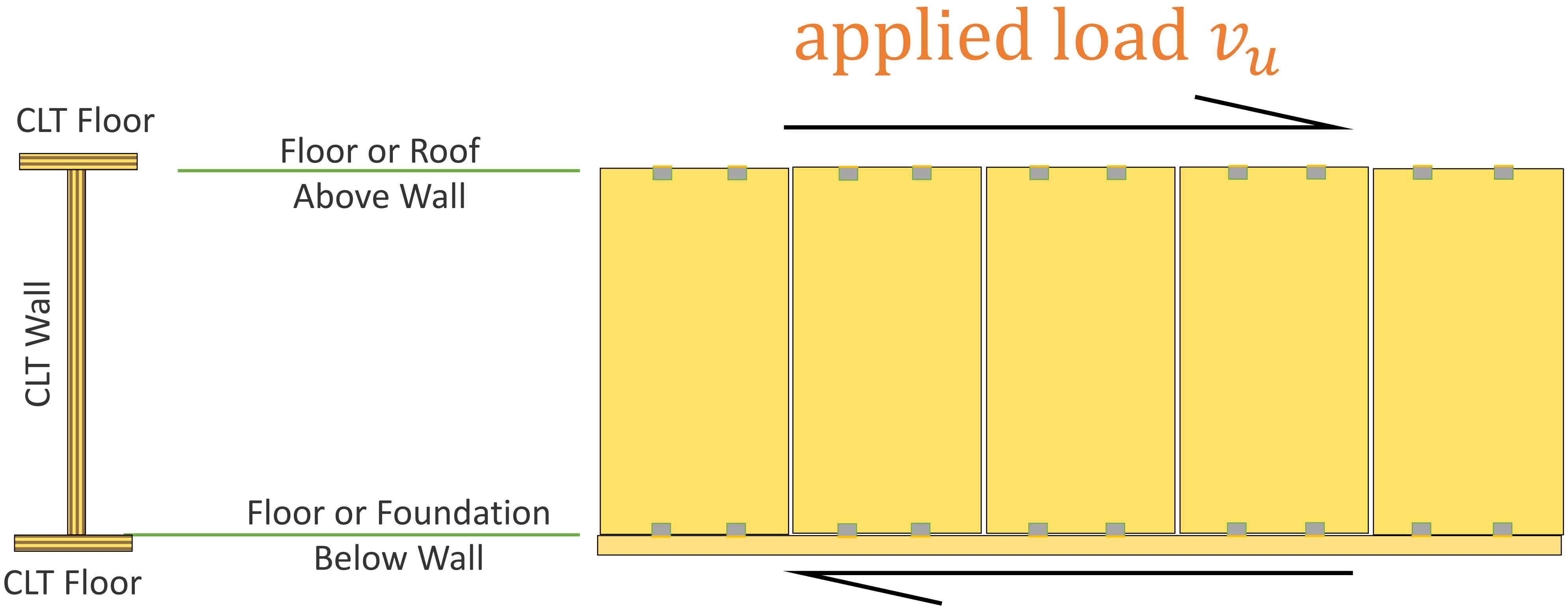
CLT Shear Walls in SDPWS 2021

Platform Framed CLT Construction



CLT Shear Walls in SDPWS 2021

Platform Framed CLT Construction

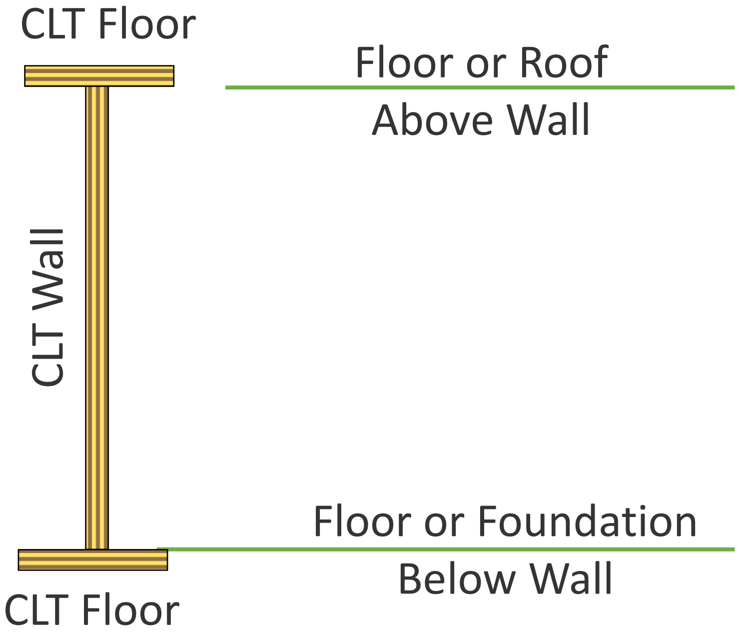


Section View

Elevation View

CLT Shear Walls in SDPWS 2021

Platform Framed CLT Construction



CLT Floor

Floor or Roof

Above Wall

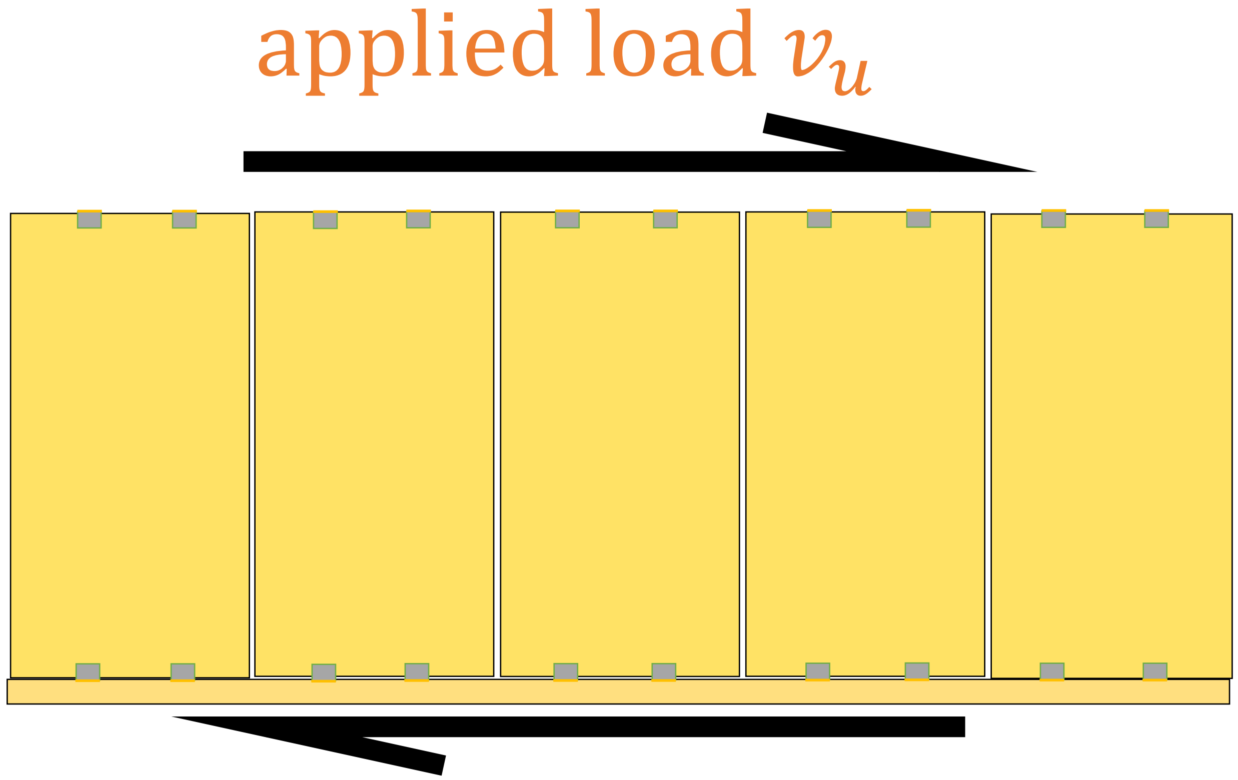
CLT Wall

Floor or Foundation

Below Wall

CLT Floor

Section View

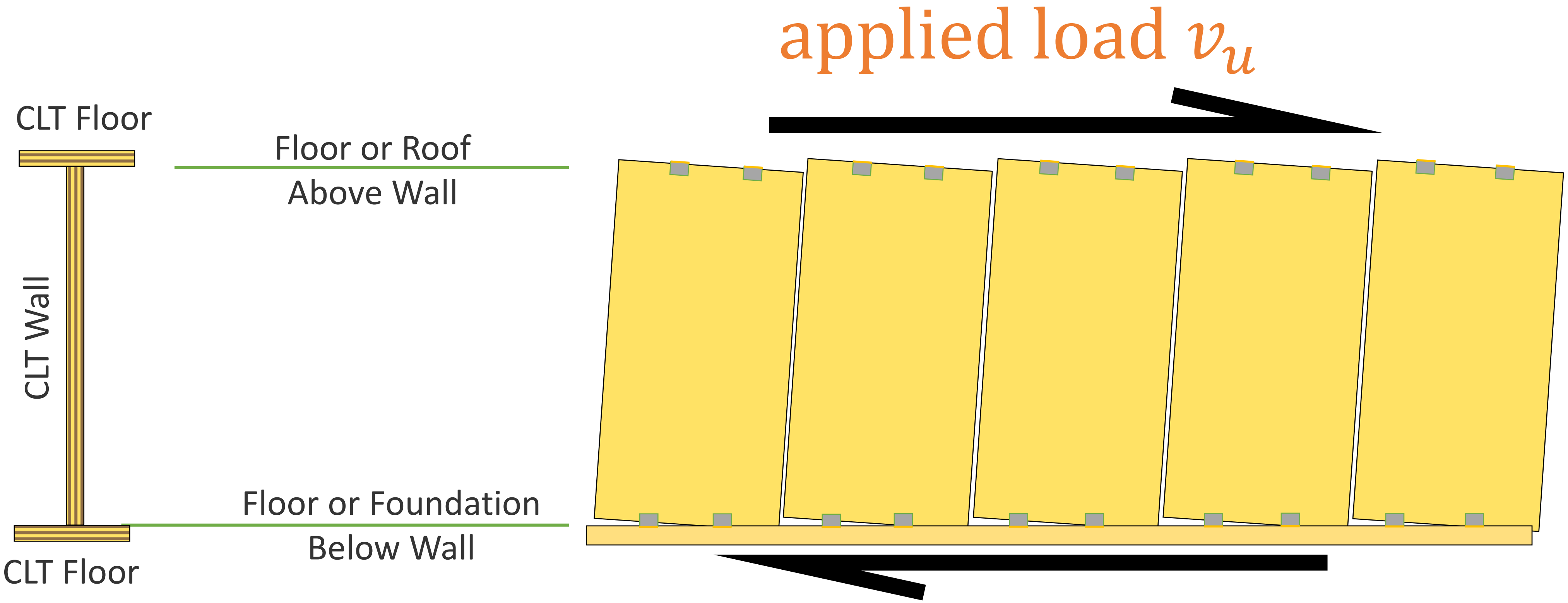


applied load v_u

Elevation View

CLT Shear Walls in SDPWS 2021

Platform Framed CLT Construction



applied load v_u

CLT Floor

Floor or Roof

Above Wall

CLT Wall

Floor or Foundation

Below Wall

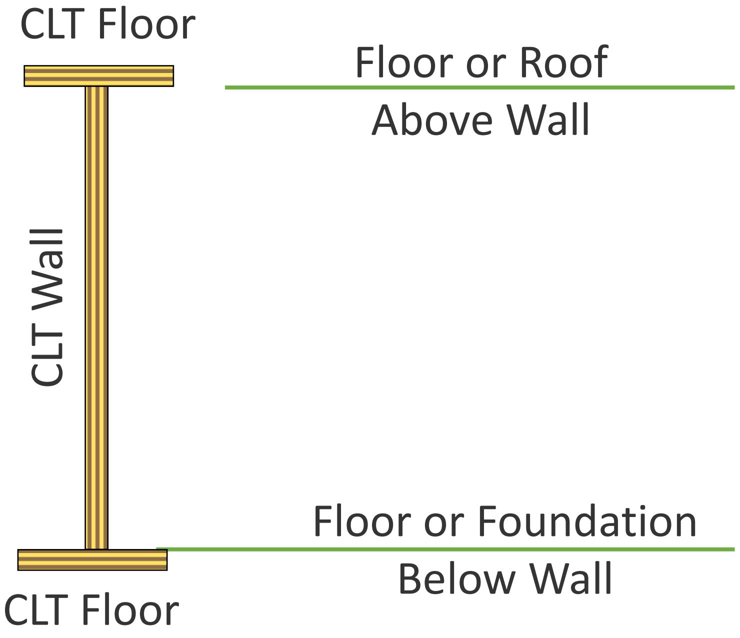
CLT Floor

Section View

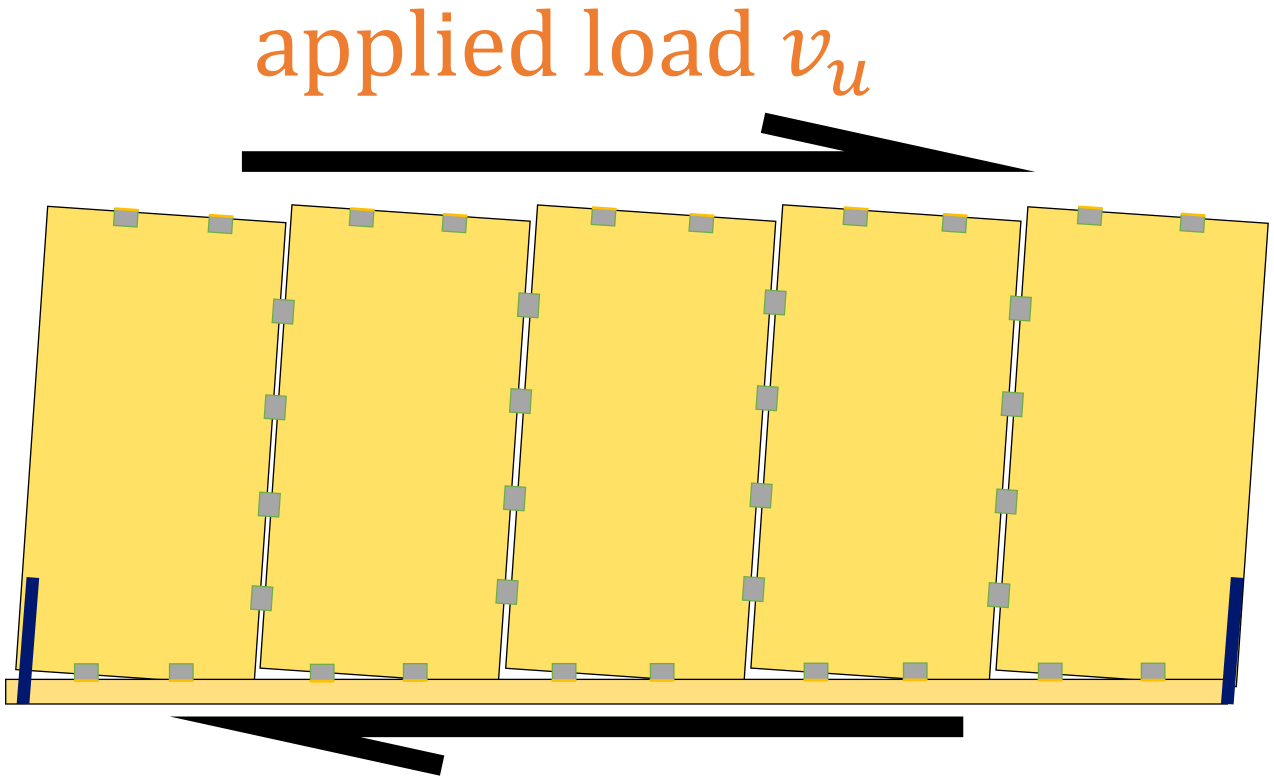
Elevation View

CLT Shear Walls in SDPWS 2021

Platform Framed CLT Construction



Section View

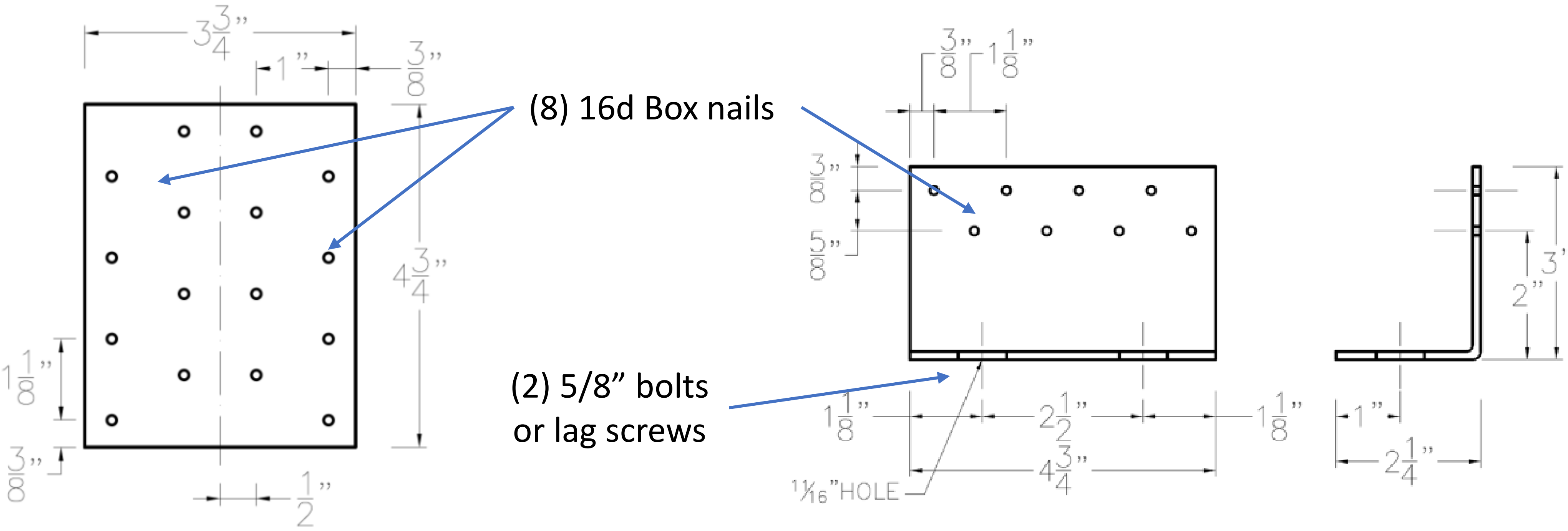


Elevation View

CLT Shear Walls in SDPWS 2021

Panel to Panel Connections

Panel to Platform Connection



(8) 16d Box nails

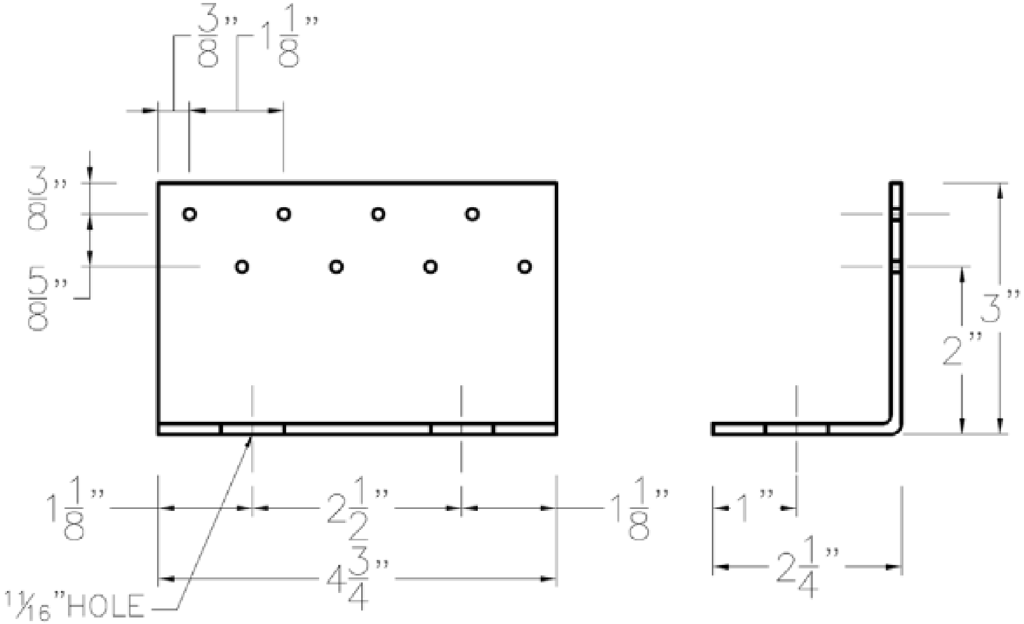
(2) 5/8" bolts
or lag screws

0.105" ASTM A653 Grade 33 Steel
(8) 16d box nails to each wall panel
3.5" long x 0.135"Ø shank with 0.344" Ø head

Same steel plate and nails plus
5/8" Ø bolts or lag screws to roof, floor or foundation

CLT Shear Walls in SDPWS 2021

Panel to Platform Connection



Nominal shear capacity of connector:

v_n = 2605 C_G [lbs] per angle connector

C_G adjusts for specific gravity, G of CLT

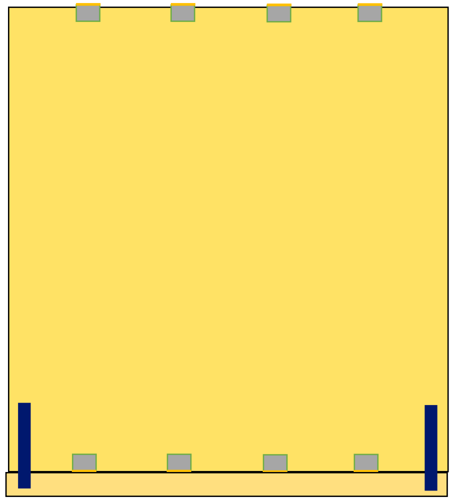
C_G = 1.0 for $G \geq 0.42$
= 0.86 for G = 0.35
= 1.0 – 2 (0.42-G) for $0.42 > G > 0.35$

Nominal unit shear capacity:

v_n = n (2605 / b_s) C_G [lbs/ft]

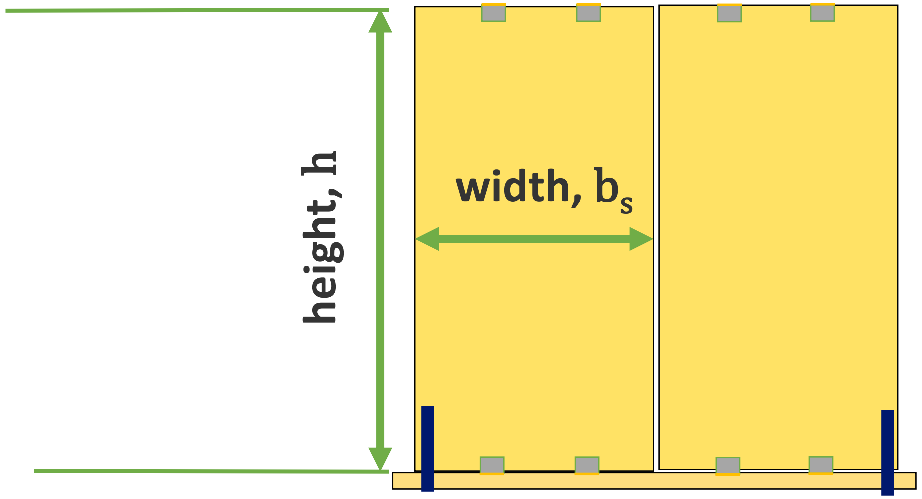
CLT Shear Walls in SDPWS 2021

(other)
CLT Shear Walls
not meeting Appendix B

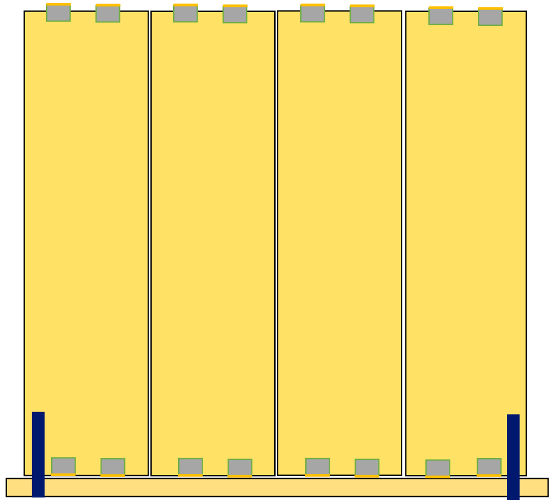


Seismic Design Category A
or SDC B and ≤ 65’ tall
in SDPWS 4.6.3 Exception

CLT Shear Walls
meeting SDPWS 2021 Appendix B



Panel aspect ratios
$2 \leq h/b_s \leq 4$



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

Panel aspect ratios
$h/b_s = 4$

So what’s the R-value?

R = 3!

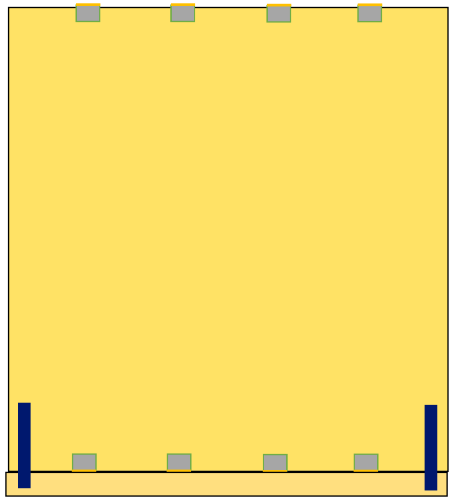
or 4 or 1.5?

R Values for CLT Shear Walls in SDPWS 2021

(other)

CLT Shear Walls

not meeting Appendix B



R = 1.5

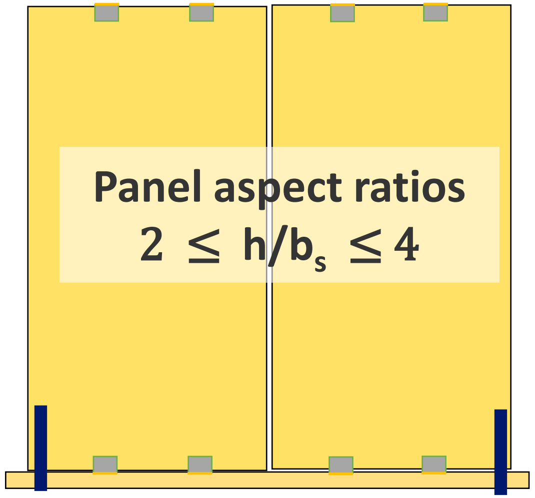
$C_d = 1.5$ $\Omega_o = 2.5$

In SDPWS 2021 4.6.3

Platform Framed

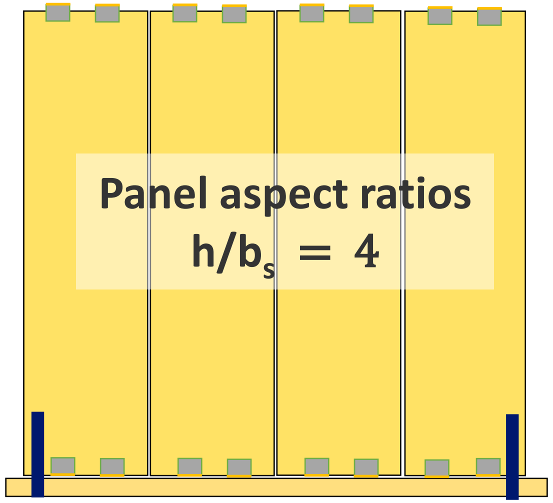
CLT Shear Walls

meeting SDPWS 2021 Appendix B



R = 3.0*

$C_d = 3.0$ $\Omega_o = 3.0$



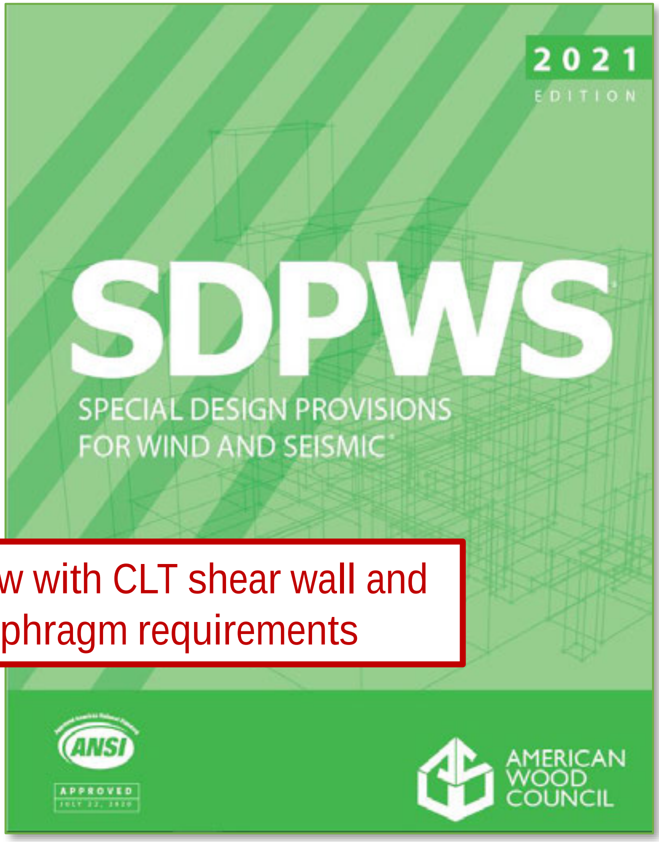
R = 4.0*

$C_d = 4.0$ $\Omega_o = 3.0$

* ASCE 7-22

CLT in the U.S. Building Code – Lateral in IBC 2021

SDPWS 2015

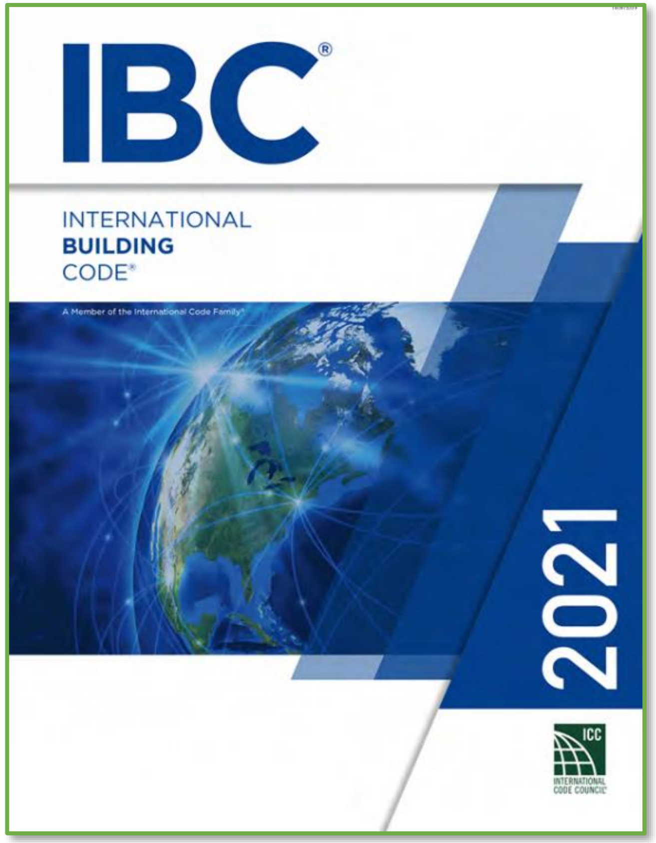


Now with CLT shear wall and diagrammm requirements

AWC SDPWS 2021

Where Seismic (R values) and Wind Systems are Referenced. No CLT

ASCE/SEI 7-16

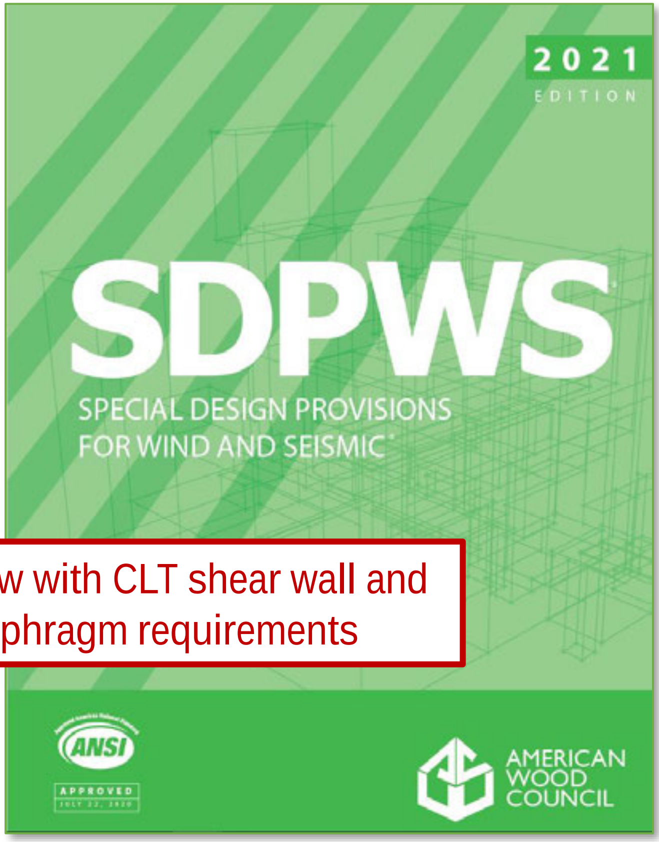


2021 International Building Code

New Requirements for CLT Lateral Systems!

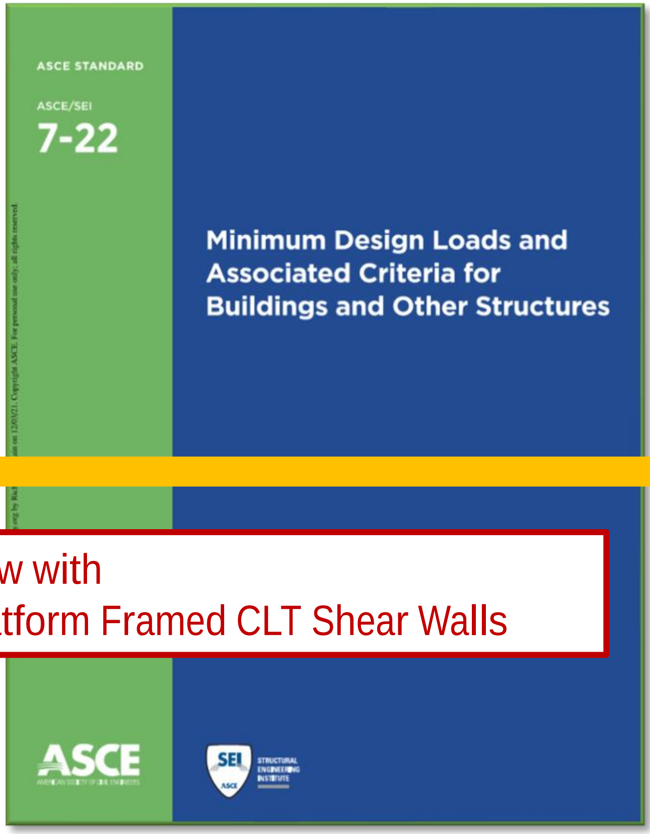
(but R values for CLT Shear Walls not in ASCE 7-16)

CLT in the U.S. Building Code – Lateral in the IBC 2024?



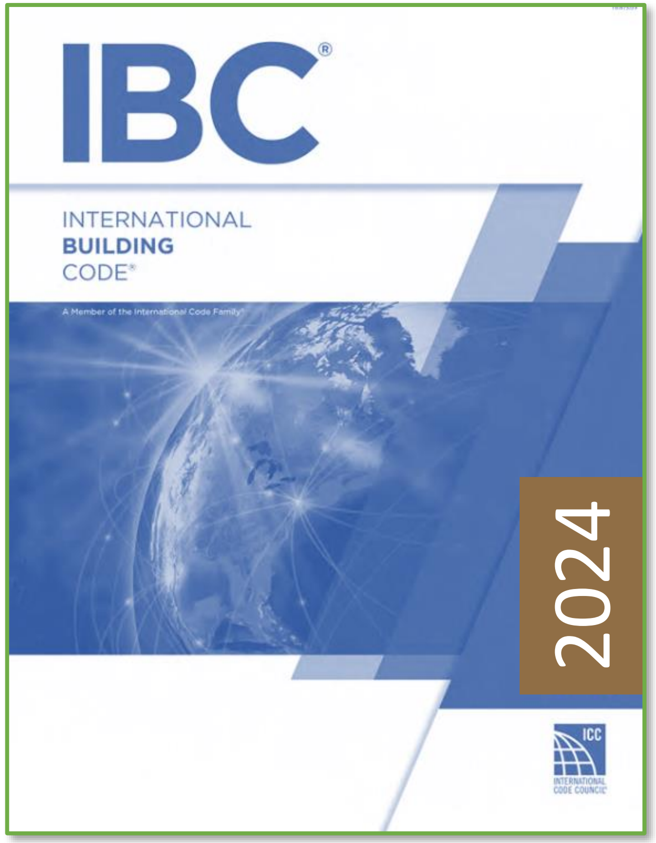
Now with CLT shear wall and diaphragm requirements

AWC SDPWS 2021



Now with
Platform Framed CLT Shear Walls

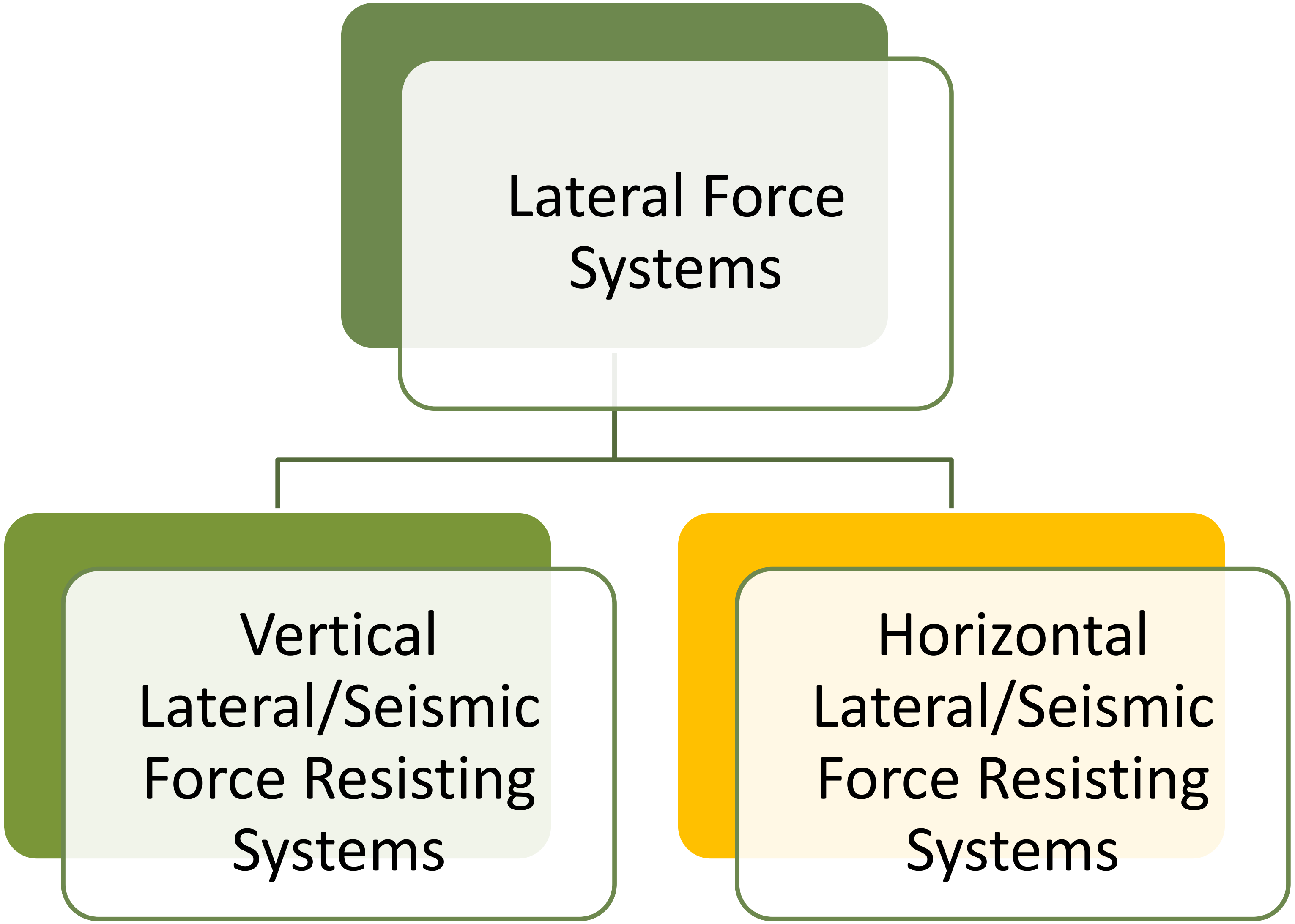
ASCE/SEI 7-22



2024 IBC

Future Full Recognition of CLT Lateral Systems

Mass Timber Lateral Systems



Lateral Force Systems

Vertical Lateral/Seismic Force Resisting Systems

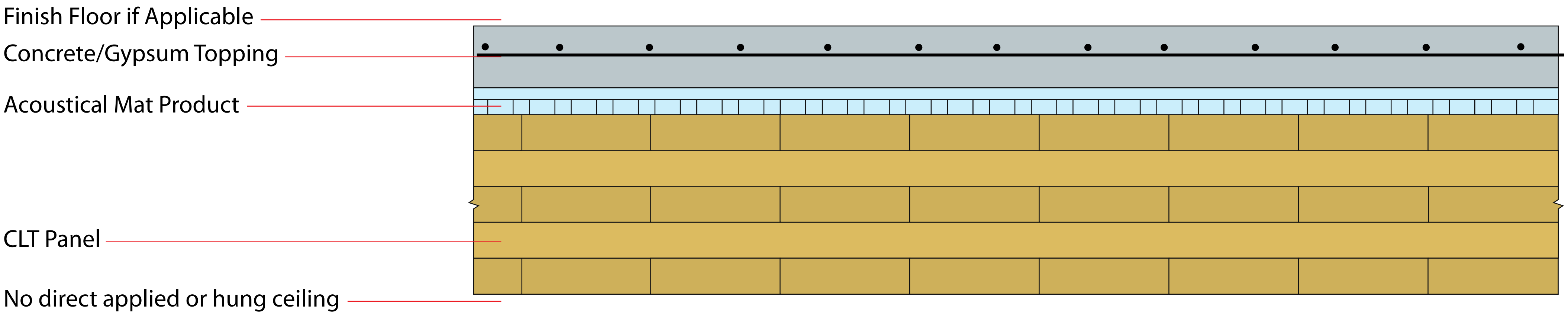
Horizontal Lateral/Seismic Force Resisting Systems

Shear Walls
Moment Frames
Etc.

Floor and Roof
Diaphragms

Diaphragm Strategies with Horizontal CLT

- Option 1: Structural Topping as Horizontal Diaphragm
- (1A) Structural Concrete Topping



Finish Floor if Applicable

Concrete/Gypsum Topping

Acoustical Mat Product

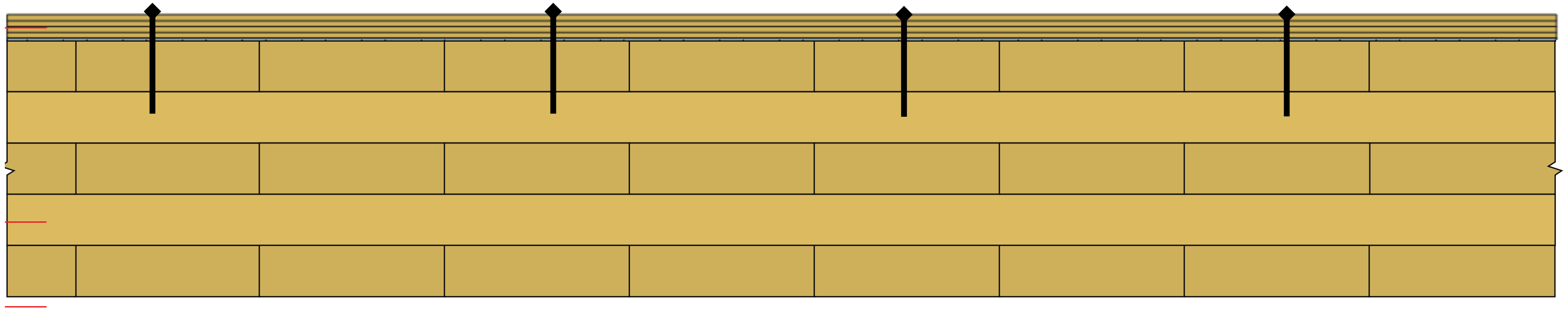
CLT Panel

No direct applied or hung ceiling

Careful detailing to provide adequate load path, minimum rebar cover, etc.

Diaphragm Strategies with Horizontal CLT

- Option 1: Structural Topping as Horizontal Diaphragm
- (1B) Wood Structural Panel Topping



WSP as diaphragm

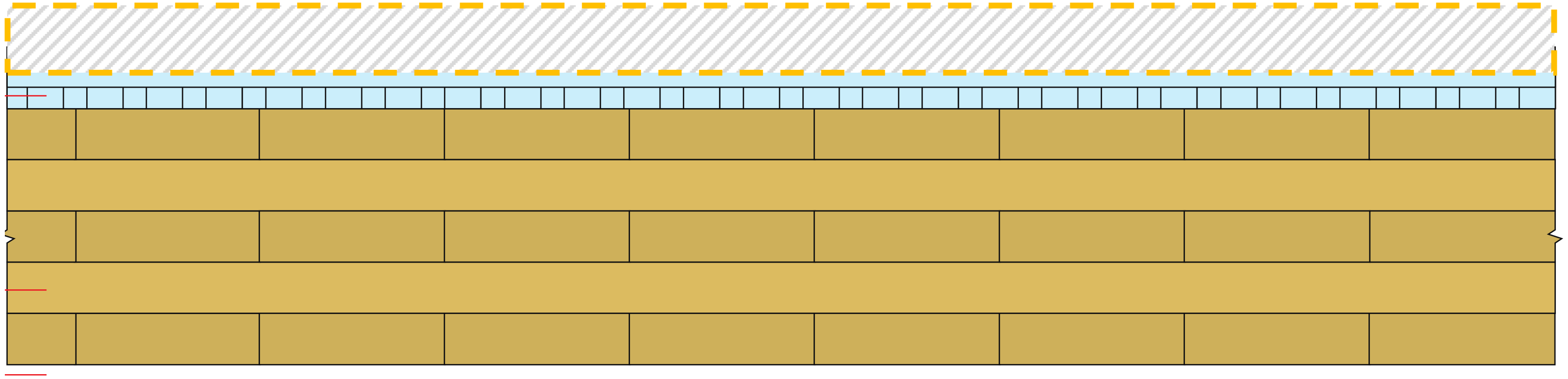
CLT Panel as laminated decking

Classify as blocked WSP diaphragm per SDPWS 2015 4.2.7.1?

19/32” thick 4ft by 8ft panel vs 4 1/8” thick 8ft by 24 ft panel?

Diaphragm Strategies with Horizontal CLT

- Option 2: CLT as a Diaphragm via Engineering Principles

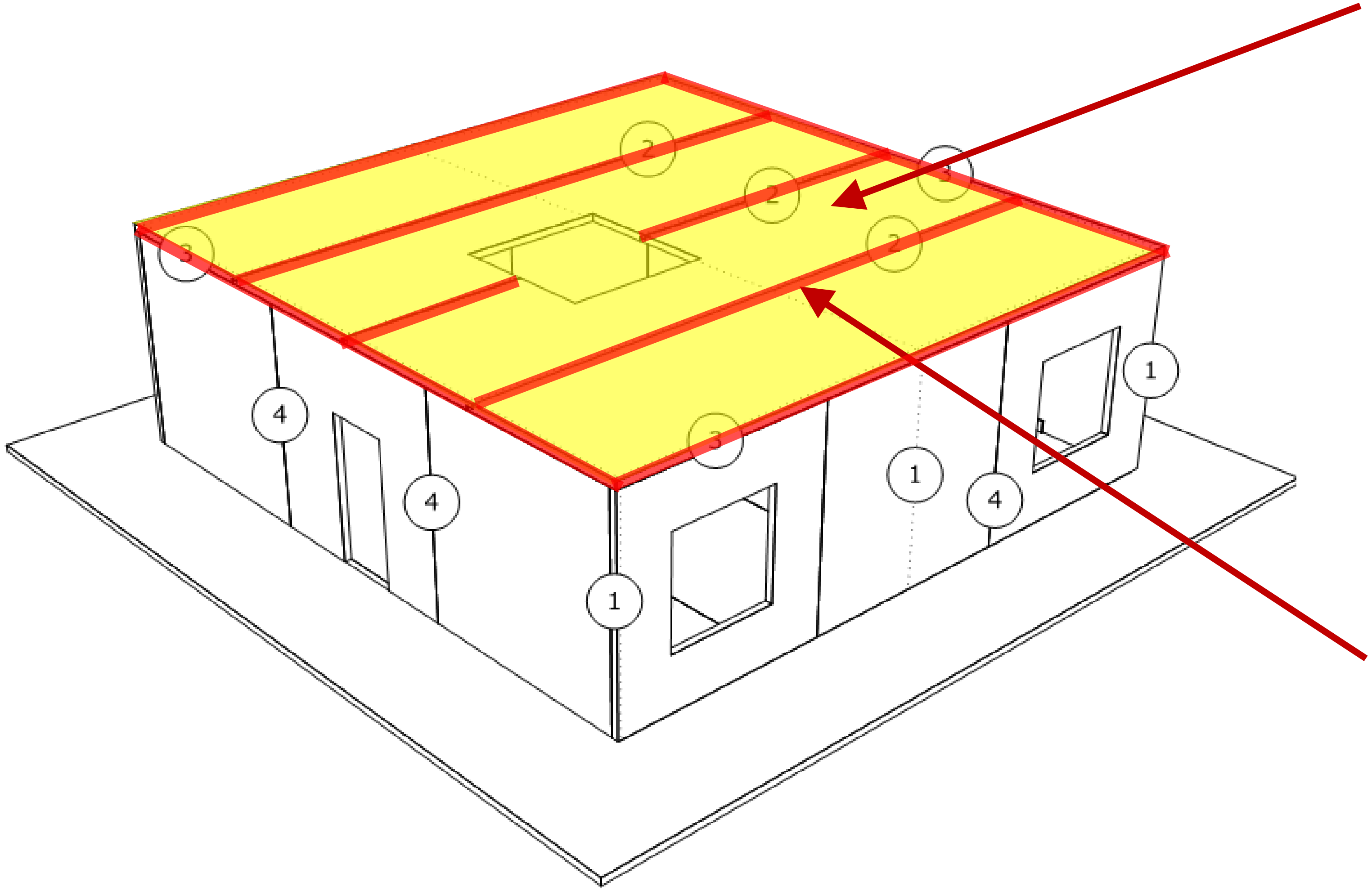


Topping and Flooring as needed

CLT Panel as Diaphragm

CLT Diaphragms not Recognized in IBC 2018 and Reference Standards.

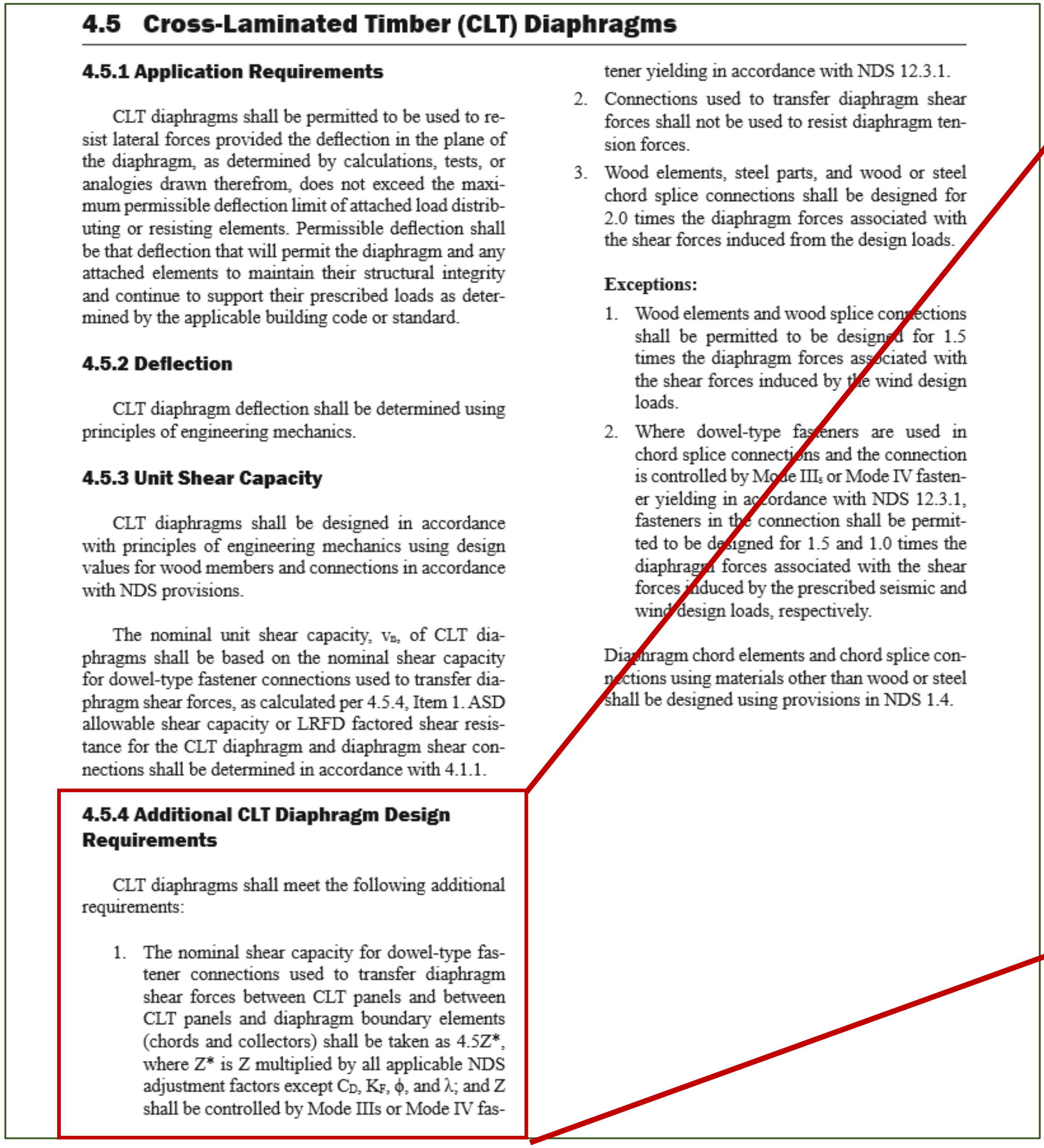
CLT Diaphragms



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

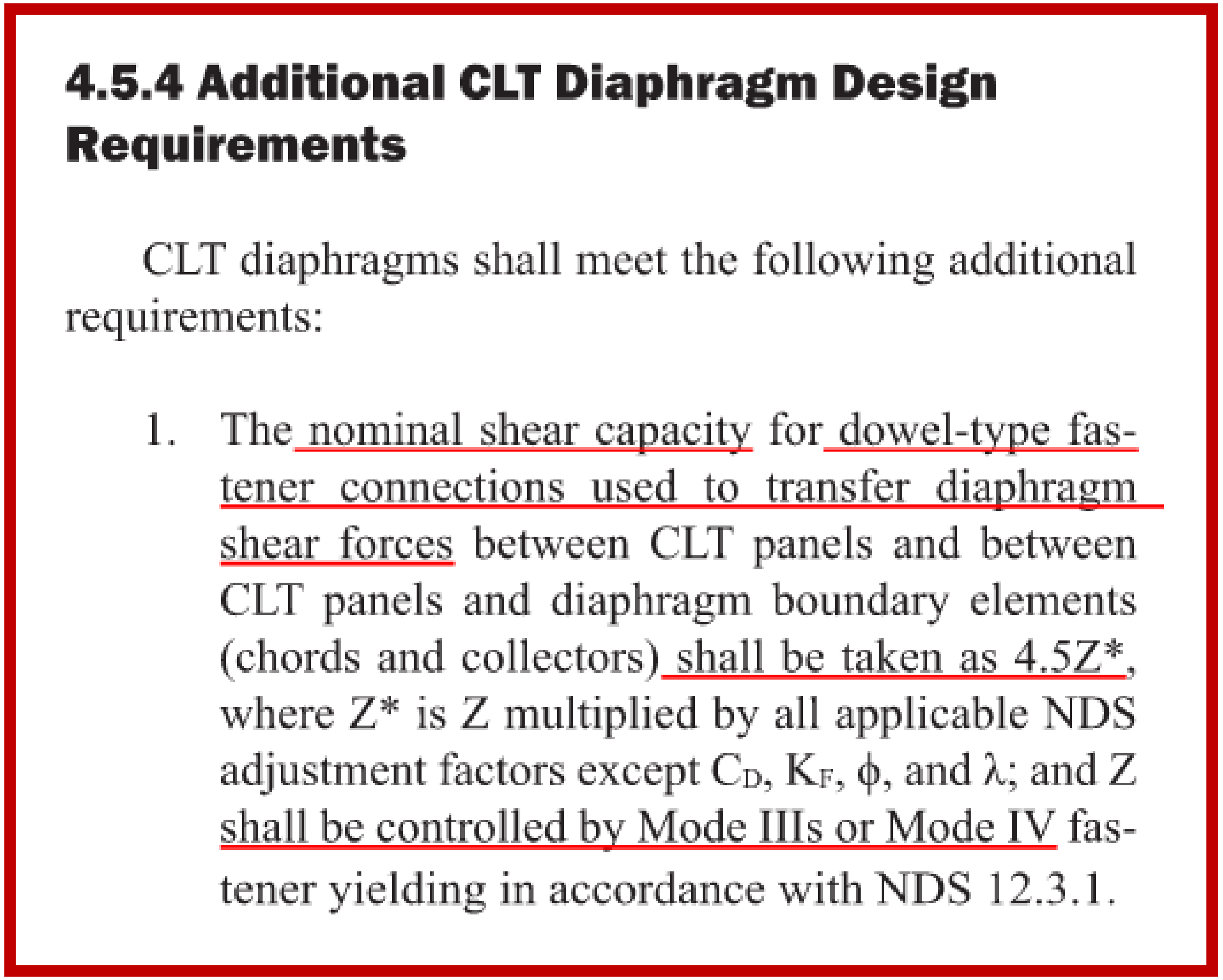
CLT diaphragms shall meet the following additional requirements:

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 III_s 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.



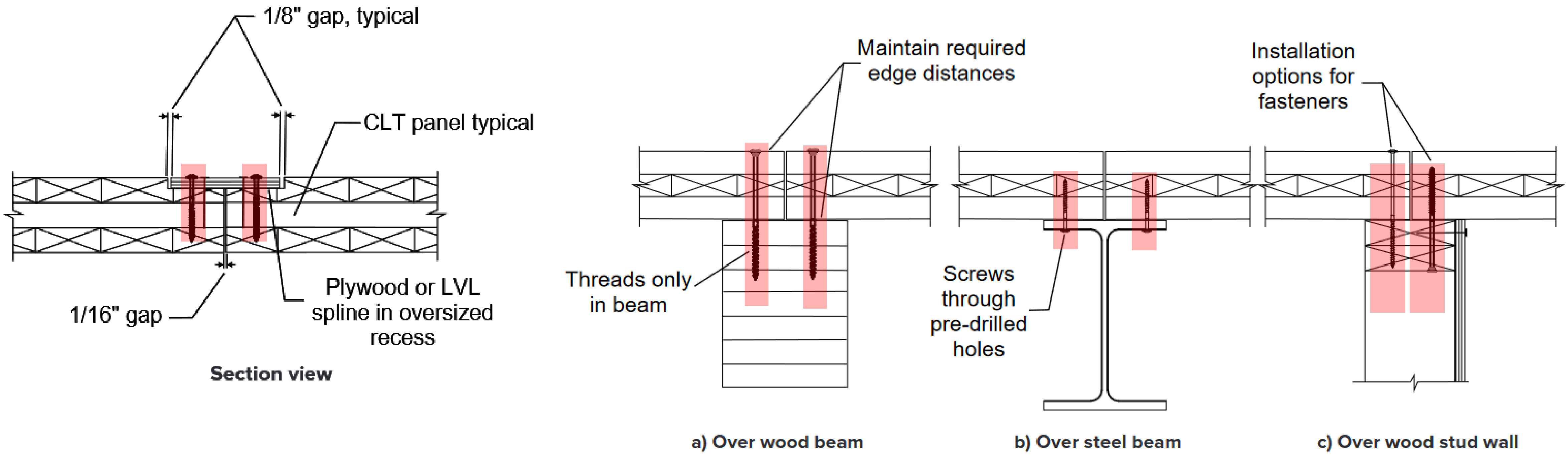
4.5.4 Additional CLT Diaphragm Design Requirements

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.

Requirements for the shear connections

CLT Diaphragm Shear Connections

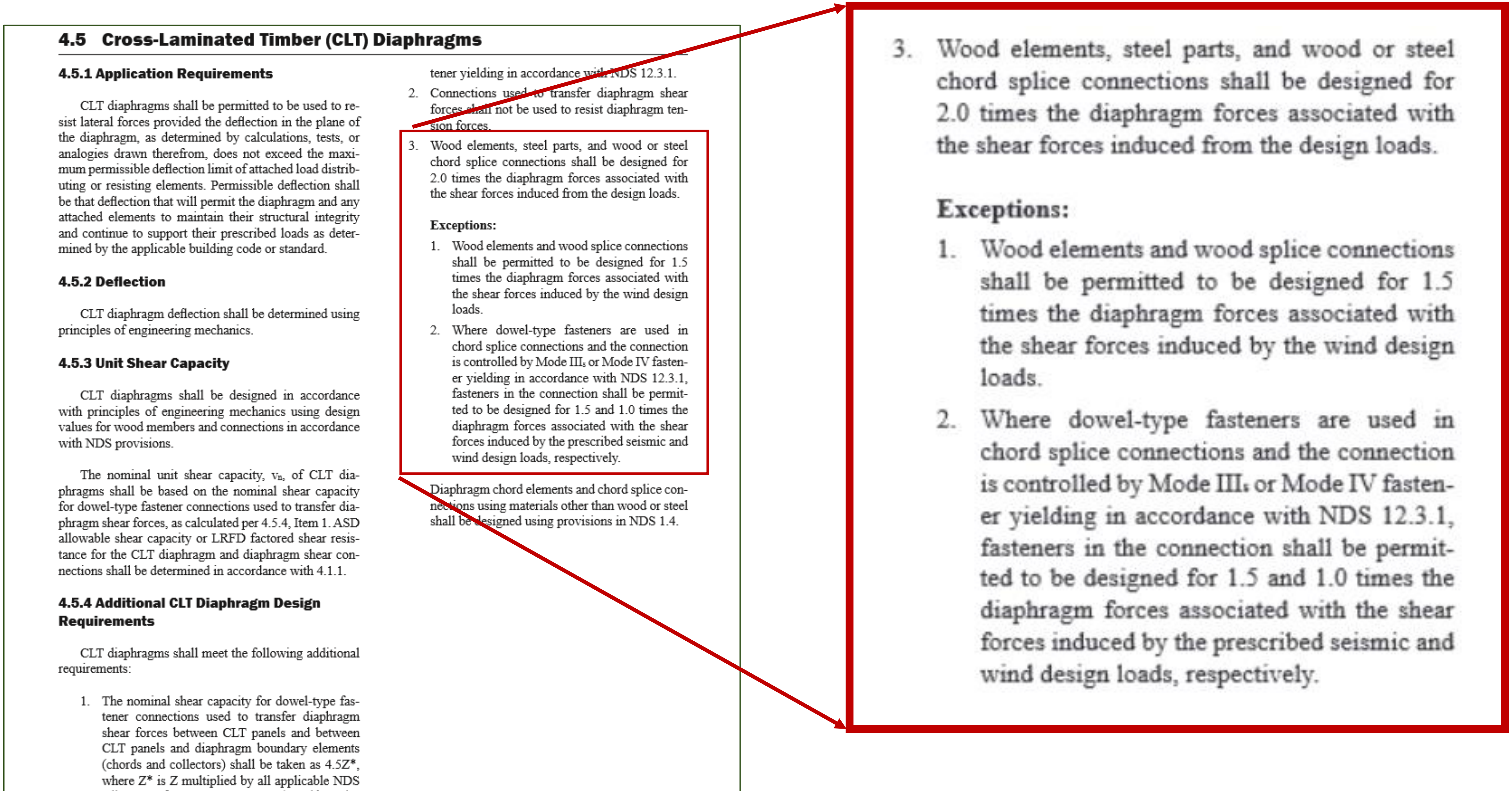


- Diaphragm **shear connections** at CLT panel edges:

\- Use dowel-type fasteners in shear (nails, screws, bolts)

\- Yield **Mode IIIs or Mode IV** per NDS 12.3.1 controls capacity

Other Diaphragm Components



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

tener 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.

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.

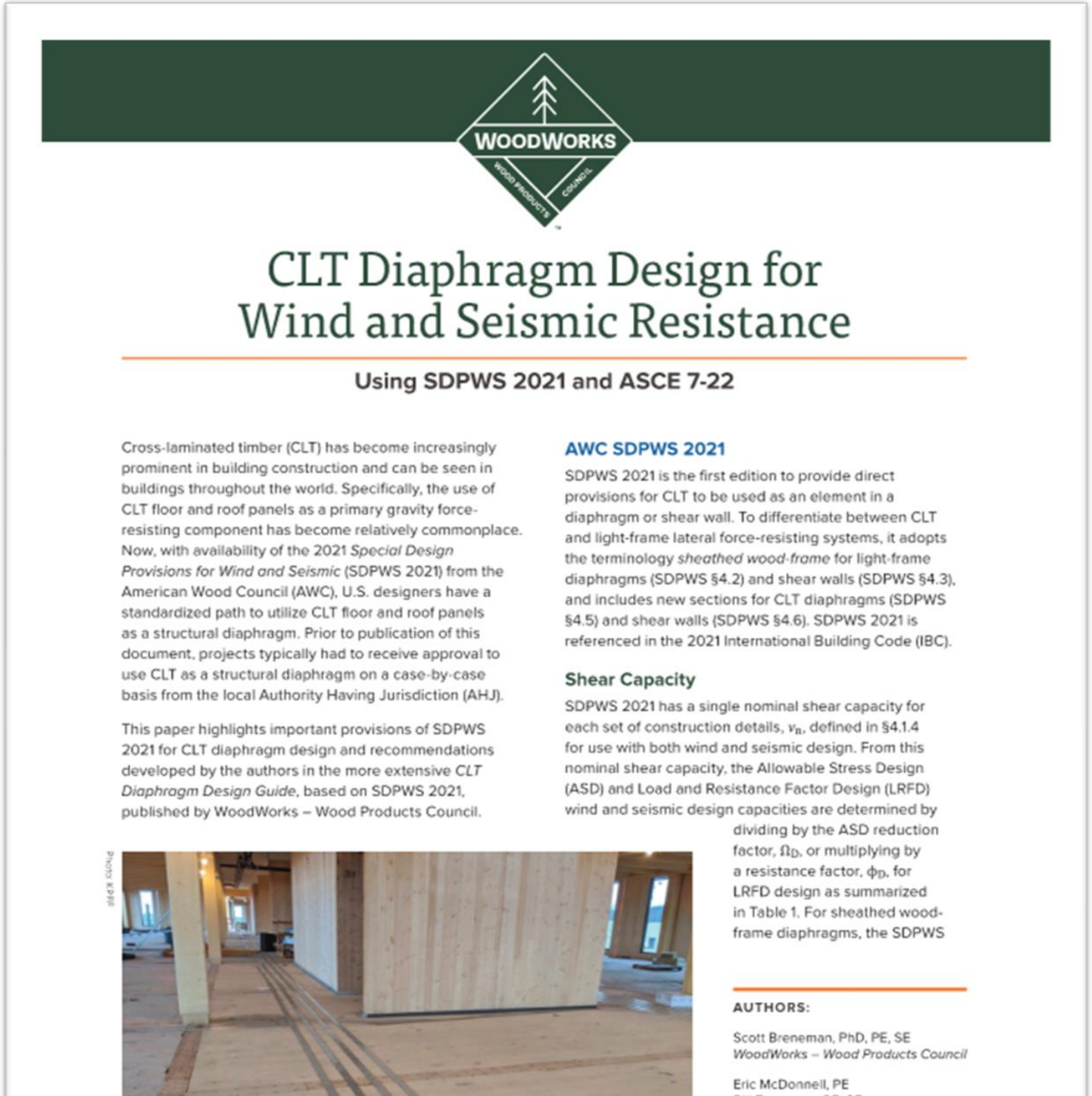
Exceptions:

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.

Additional Information

Short Paper Available from woodworks.org

https://www.woodworks.org/resources/clt-diaphragm-design-for-wind-and-seismic-resistance/



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CLT Diaphragm Design for Wind and Seismic Resistance

Using SDPWS 2021 and ASCE 7-22

Cross-laminated timber (CLT) has become increasingly prominent in building construction and can be seen in buildings throughout the world. Specifically, the use of CLT floor and roof panels as a primary gravity force-resisting component has become relatively commonplace. Now, with availability of the 2021 *Special Design Provisions for Wind and Seismic* (SDPWS 2021) from the American Wood Council (AWC), U.S. designers have a standardized path to utilize CLT floor and roof panels as a structural diaphragm. Prior to publication of this document, projects typically had to receive approval to use CLT as a structural diaphragm on a case-by-case basis from the local Authority Having Jurisdiction (AHJ).

This paper highlights important provisions of SDPWS 2021 for CLT diaphragm design and recommendations developed by the authors in the more extensive *CLT Diaphragm Design Guide*, based on SDPWS 2021, published by WoodWorks – Wood Products Council.

Photo: KPFF

AWC SDPWS 2021

SDPWS 2021 is the first edition to provide direct provisions for CLT to be used as an element in a diaphragm or shear wall. To differentiate between CLT and light-frame lateral force-resisting systems, it adopts the terminology *sheathed wood-frame* for light-frame diaphragms (SDPWS §4.2) and shear walls (SDPWS §4.3), and includes new sections for CLT diaphragms (SDPWS §4.5) and shear walls (SDPWS §4.6). SDPWS 2021 is referenced in the 2021 International Building Code (IBC).

Shear Capacity

SDPWS 2021 has a single nominal shear capacity for each set of construction details, v_n, defined in §4.1.4 for use with both wind and seismic design. From this nominal shear capacity, the Allowable Stress Design (ASD) and Load and Resistance Factor Design (LRFD) wind and seismic design capacities are determined by dividing by the ASD reduction factor, Ω_D, or multiplying by a resistance factor, ϕ_D, for LRFD design as summarized in Table 1. For sheathed wood-frame diaphragms, the SDPWS

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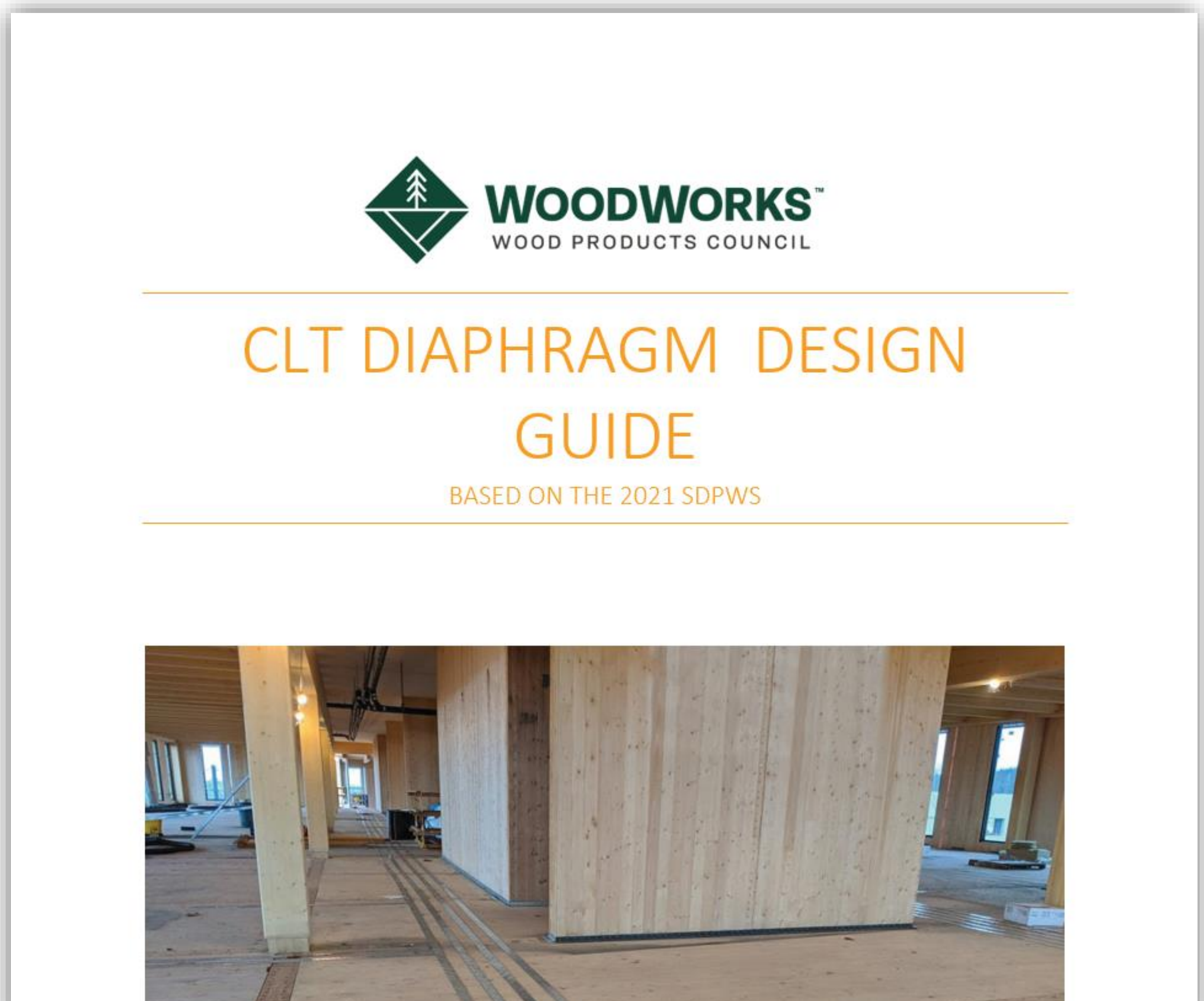
WoodWorks – Wood Products Council

Eric McDonnell, PE

WoodWorks CLT Diaphragm Design Guide

https://www.woodworks.org/resources/clt-diaphragm-design-guide/



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CLT DIAPHRAGM DESIGN GUIDE

BASED ON THE 2021 SDPWS

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Holmes Structures

kpff

SWINERTON
MASS TIMBER

Funded By:

U.S. Endowment
for Forestry and Communities

USDA

Agenda

- Mass timber systems and products
- Acoustics
- Structural design - gravity
- Vibration
- Structural design – lateral
- Connections
- Fire

Photo: John Stamets

NEW MASS TIMBER CONNECTIONS INDEX

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KL&A
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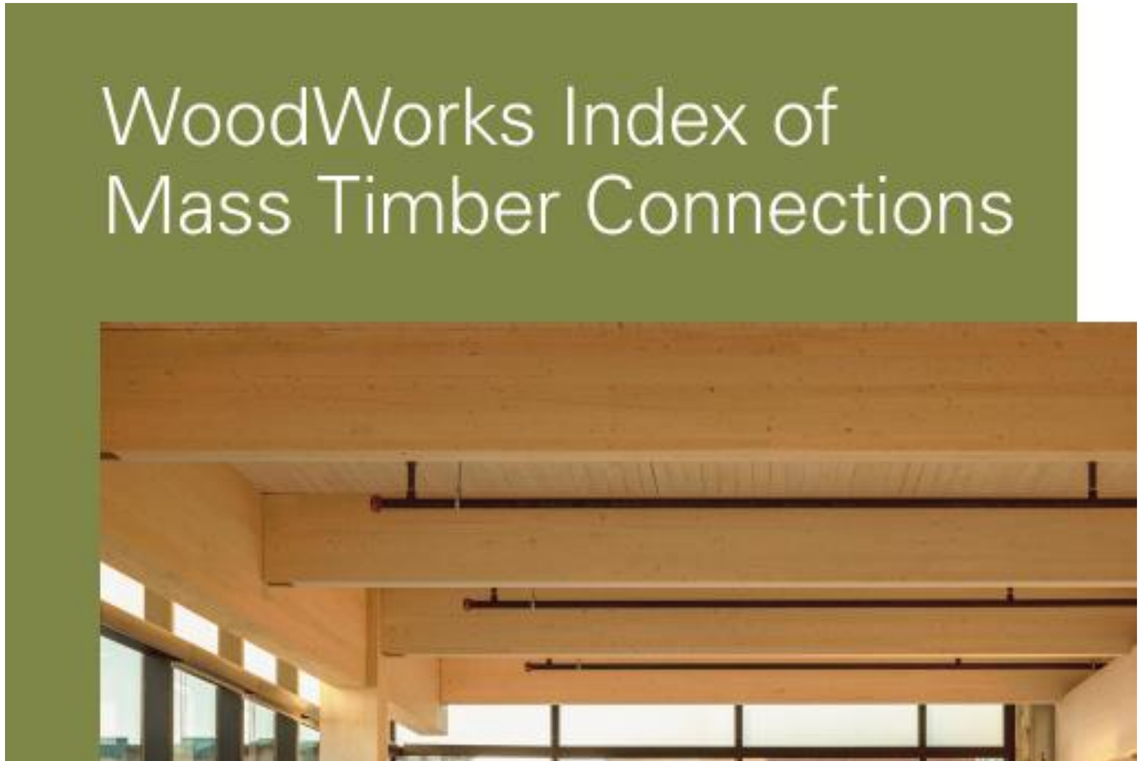
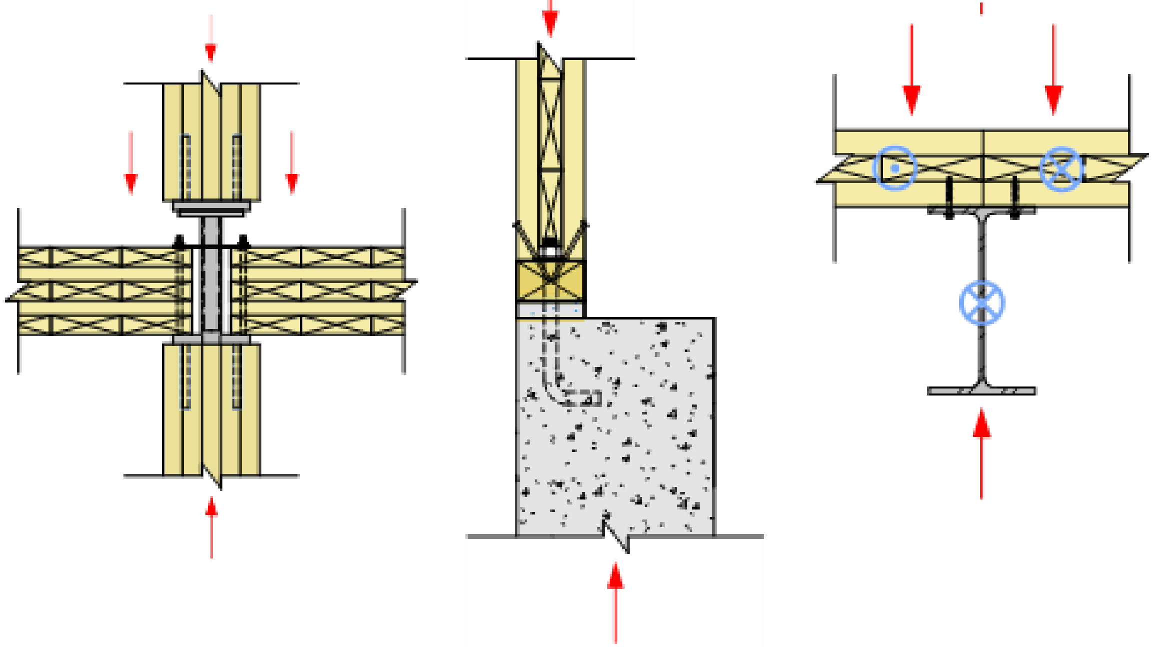
OZ
ARCHITECTURE
URBAN DESIGN
INTERIOR DESIGN

SWINERTON
MASS TIMBER



WoodWorks Index of Mass Timber Connections

A library of commonly used mass timber connections with designer notes and information on fire resistance, relative cost and load-carrying capacity.



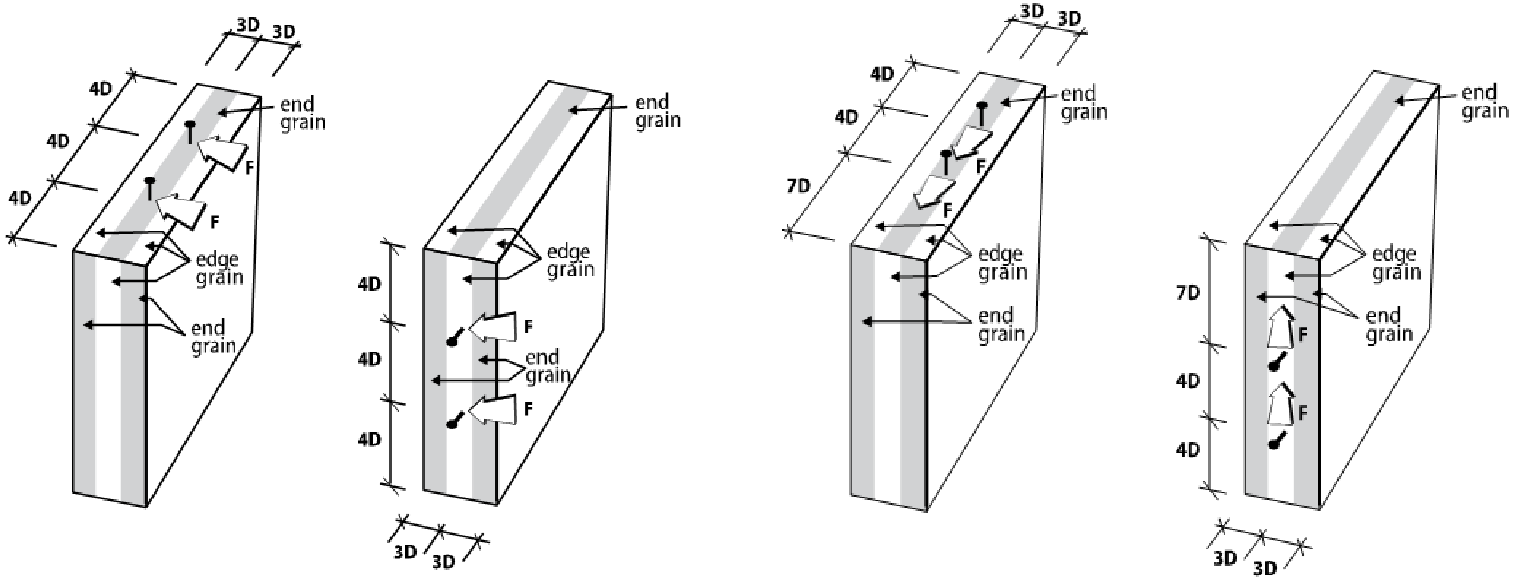
https://www.woodworks.org/resources/index-of-mass-timber-connections/

CLT in NDS 2015 - Connectors

Connectors for CLT in NDS 2015:

Dowel Type Fasteners, e.g. Lag Screws, Bolts and Nails

Figure 12I **End Distance, Edge Distance and Fastener Spacing Requirements in Narrow Edge of Cross-Laminated Timber**



Direction of loading perpendicular to the plane of CLT

Direction of loading parallel to the plane of CLT

Agenda

- Mass timber systems and products
- Acoustics
- Structural design - gravity
- Vibration
- Structural design – lateral
- Connections
- Fire

Photo: John Stamets

Mass Timber's Fire-Resistive Performance is Well-Tested, Documented and Recognized via Code Acceptance

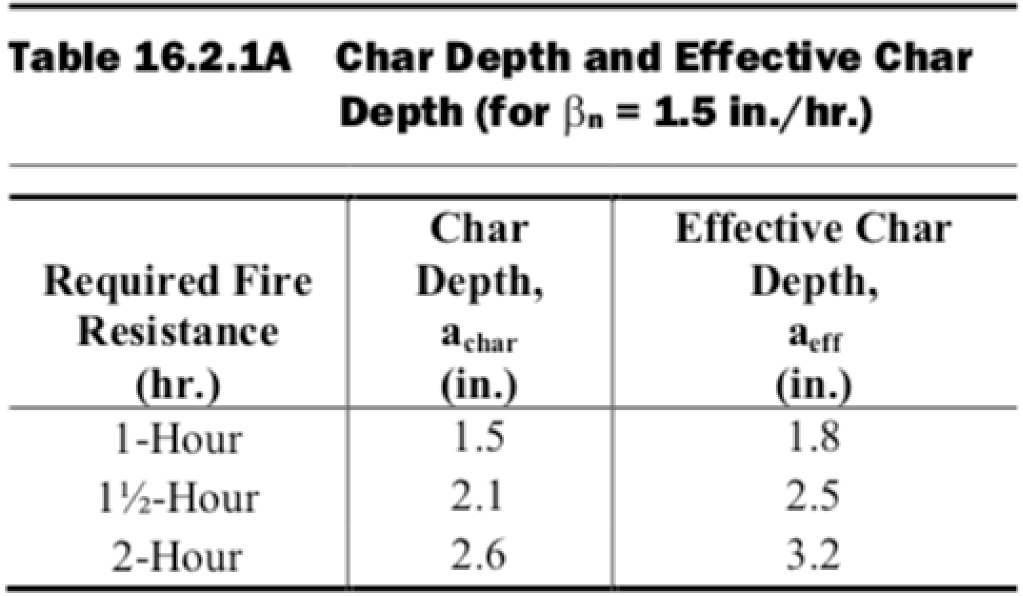
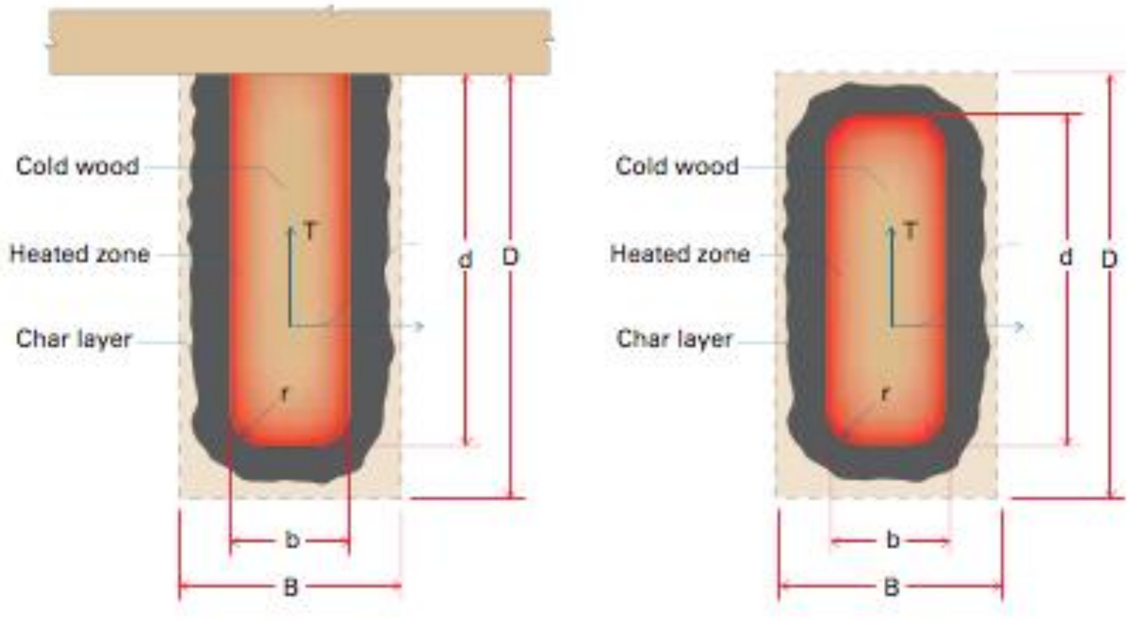


Table 16.2.1A Char Depth and Effective Char Depth (for β_n = 1.5 in./hr.)

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: AWC's NDS



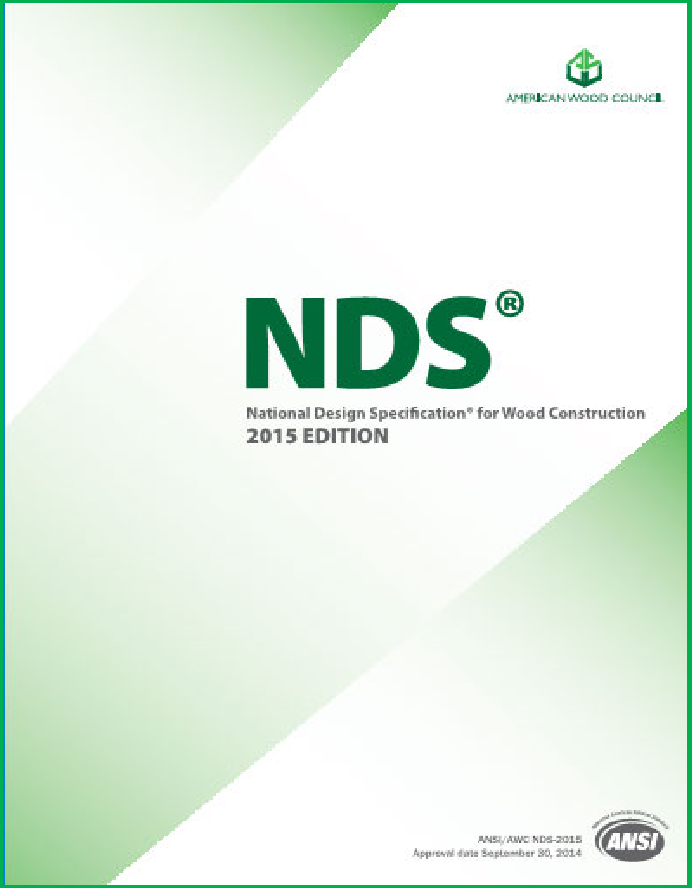
Source: AWC's TR 10

Credit: David Barber; ARUP

Mass timber design

Fire resistance

For Exposed Wood Members: IBC 722.1 References AWC’s NDS Chapter 16 (AWC’s TR 10 is a design aid to NDS Chapter 16)



AMERICAN WOOD COUNCIL

NDS®

National Design Specification® for Wood Construction
2015 EDITION

ANSI/AWC NDS-2015
Approval date September 30, 2014

ANSI

NATIONAL DESIGN SPECIFICATION FOR WOOD CONSTRUCTION 149

FIRE DESIGN
OF WOOD
MEMBERS

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16.2 Design Procedures for Exposed Wood Members 150
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16

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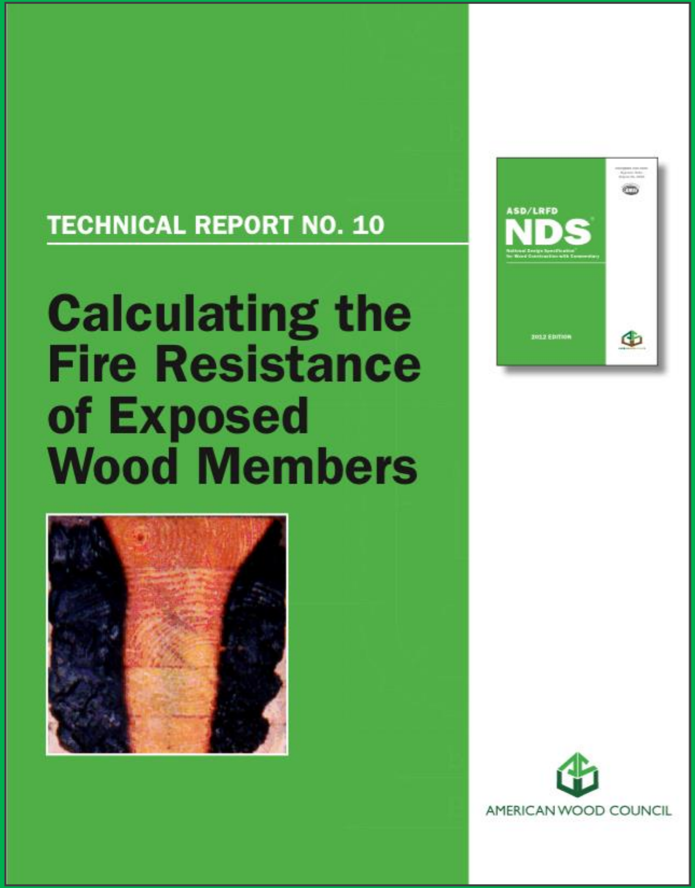


TECHNICAL REPORT NO. 10

Calculating the Fire Resistance of Exposed Wood Members

ASD/LRFD
NDS®

AMERICAN WOOD COUNCIL

Mass timber design

Fire resistance

NDS Table 16.2.2 Design stress adjustment factors applied to adjust to average ultimate strength

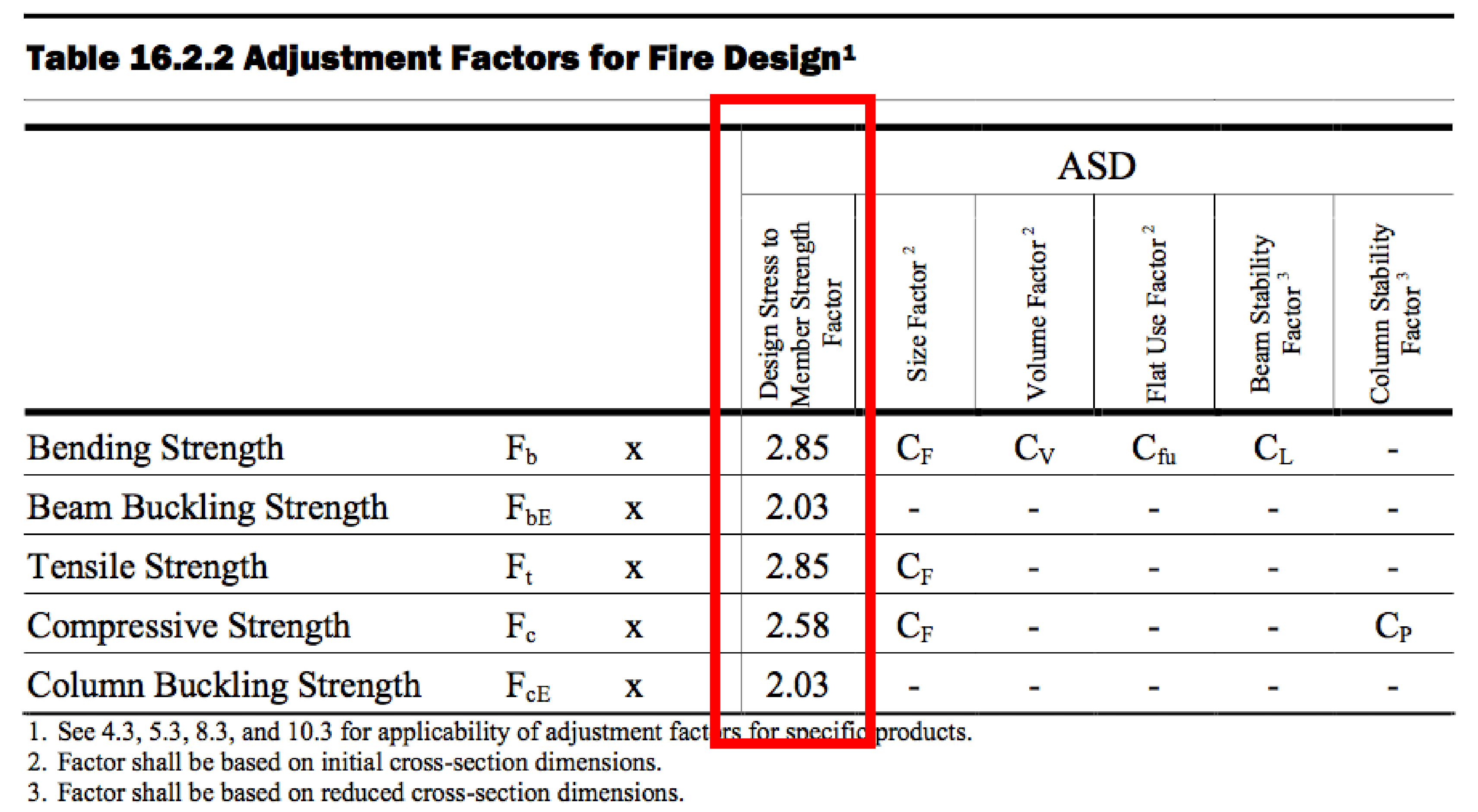


Table 16.2.2 Adjustment Factors for Fire Design[1]

				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 products.
2. Factor shall be based on initial cross-section dimensions.
3. Factor shall be based on reduced cross-section dimensions.

KEY EARLY DESIGN DECISIONS

Inventory of Fire Tested MT Assemblies

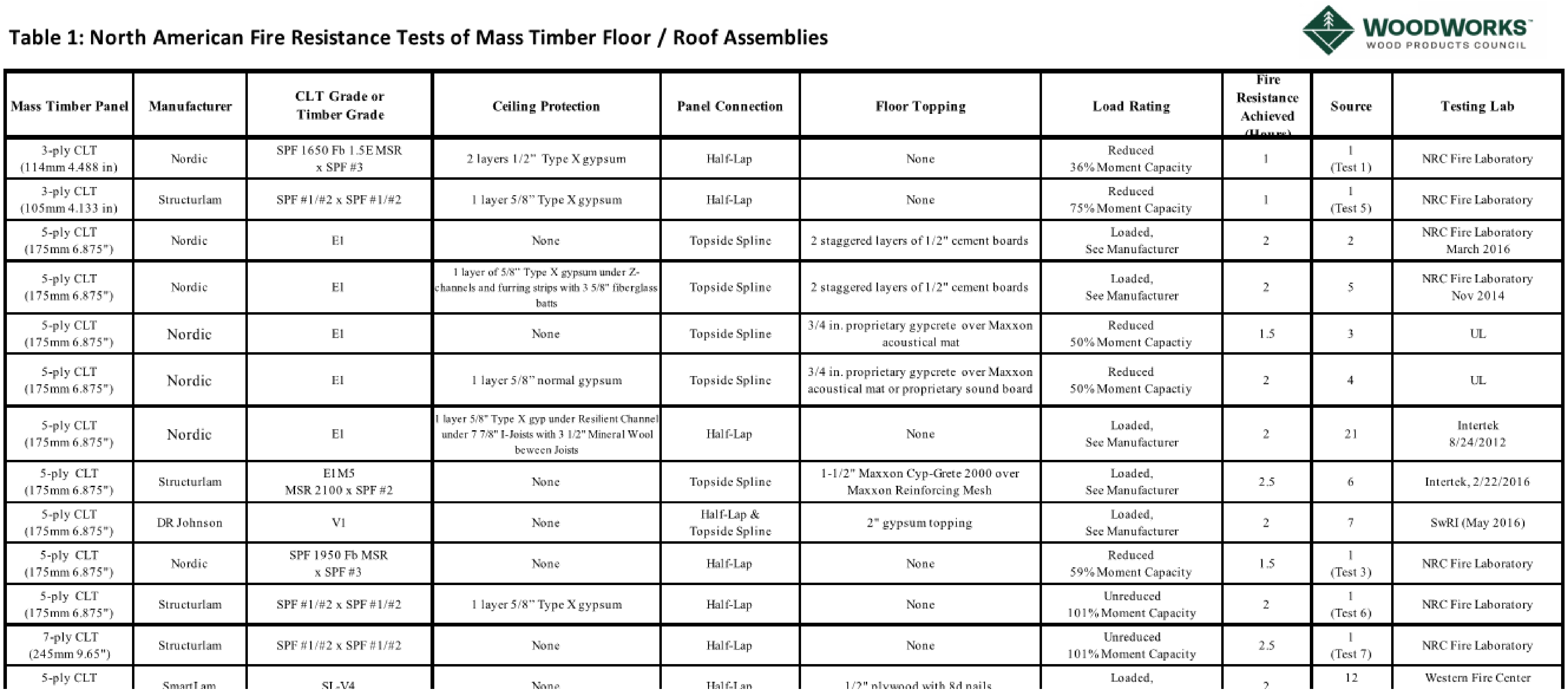


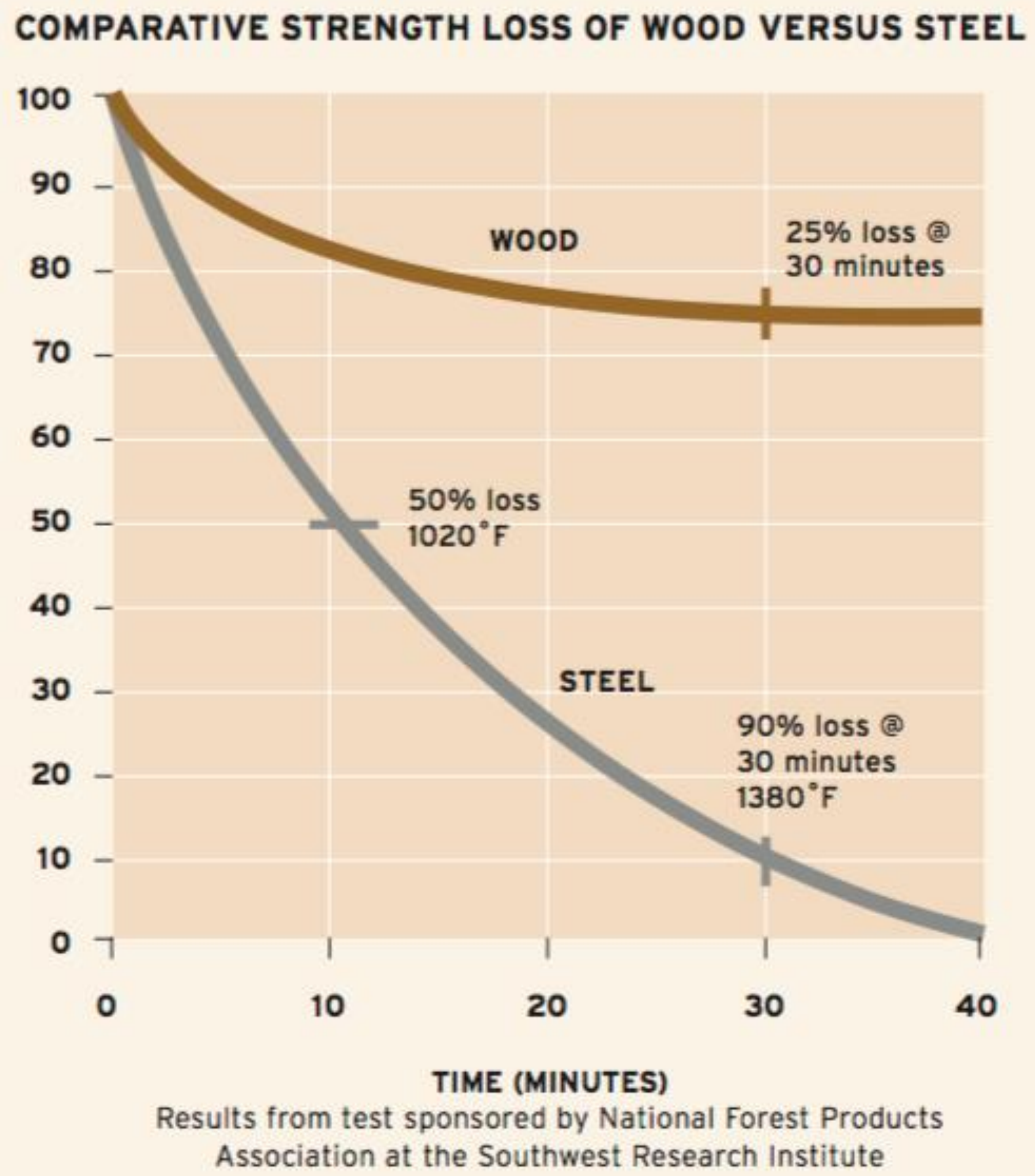
Table 1: North American Fire Resistance Tests of Mass Timber Floor / Roof Assemblies

Mass Timber Panel	Manufacturer	CLT Grade or Timber Grade	Ceiling Protection	Panel Connection	Floor Topping	Load Rating	Fire Resistance Achieved (Hours)	Source	Testing Lab
3-ply CLT (114mm 4.488 in)	Nordic	SPF 1650 Fb 1.5E MSR x SPF #3	2 layers 1/2" Type X gypsum	Half-Lap	None	Reduced 36% Moment Capacity	1	1 (Test 1)	NRC Fire Laboratory
3-ply CLT (105mm 4.133 in)	Structurlam	SPF #1/#2 x SPF #1/#2	1 layer 5/8" Type X gypsum	Half-Lap	None	Reduced 75% Moment Capacity	1	1 (Test 5)	NRC Fire Laboratory
5-ply CLT (175mm 6.875")	Nordic	E1	None	Topside Spline	2 staggered layers of 1/2" cement boards	Loaded, See Manufacturer	2	2	NRC Fire Laboratory March 2016
5-ply CLT (175mm 6.875")	Nordic	E1	1 layer of 5/8" Type X gypsum under Z-channels and furring strips with 3 5/8" fiberglass batts	Topside Spline	2 staggered layers of 1/2" cement boards	Loaded, See Manufacturer	2	5	NRC Fire Laboratory Nov 2014
5-ply CLT (175mm 6.875")	Nordic	E1	None	Topside Spline	3/4 in. proprietary gypcrete over Maxxon acoustical mat	Reduced 50% Moment Capactiy	1.5	3	UL
5-ply CLT (175mm 6.875")	Nordic	E1	1 layer 5/8" normal gypsum	Topside Spline	3/4 in. proprietary gypcrete over Maxxon acoustical mat or proprietary sound board	Reduced 50% Moment Capactiy	2	4	UL
5-ply CLT (175mm 6.875")	Nordic	E1	1 layer 5/8" Type X gyp under Resilient Channel under 7 7/8" I-Joists with 3 1/2" Mineral Wool beween Joists	Half-Lap	None	Loaded, See Manufacturer	2	21	Intertek 8/24/2012
5-ply CLT (175mm 6.875")	Structurlam	E1 M5 MSR 2100 x SPF #2	None	Topside Spline	1-1/2" Maxxon Cyp-Crete 2000 over Maxxon Reinforcing Mesh	Loaded, See Manufacturer	2.5	6	Intertek, 2/22/2016
5-ply CLT (175mm 6.875")	DR Johnson	V1	None	Half-Lap & Topside Spline	2" gypsum topping	Loaded, See Manufacturer	2	7	SwRI (May 2016)
5-ply CLT (175mm 6.875")	Nordic	SPF 1950 Fb MSR x SPF #3	None	Half-Lap	None	Reduced 59% Moment Capacity	1.5	1 (Test 3)	NRC Fire Laboratory
5-ply CLT (175mm 6.875")	Structurlam	SPF #1/#2 x SPF #1/#2	1 layer 5/8" Type X gypsum	Half-Lap	None	Unreduced 101% Moment Capacity	2	1 (Test 6)	NRC Fire Laboratory
7-ply CLT (245mm 9.65")	Structurlam	SPF #1/#2 x SPF #1/#2	None	Half-Lap	None	Unreduced 101% Moment Capacity	2.5	1 (Test 7)	NRC Fire Laboratory
5-ply CLT	SmartLam	SL-V4	None	Half-Lap	1/2" plywood with 8d nails	Loaded,	2	12	Western Fire Center

https://www.woodworks.org/resources/inventory-of-fire-resistance-tested-mass-timber-assemblies-penetrations/

MASS TIMBER DESIGN

FIRE RESISTANCE

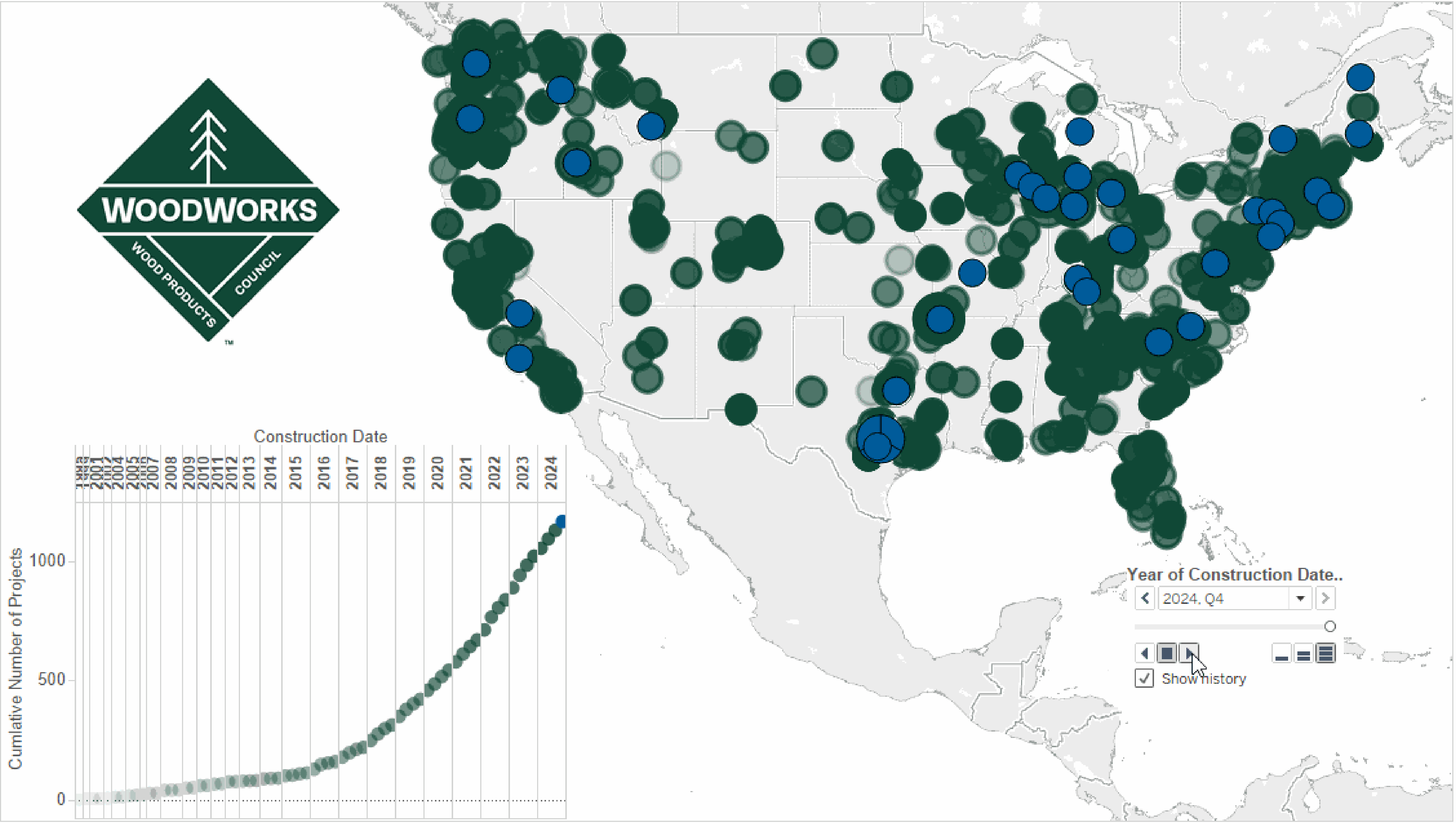


Results from test sponsored by National Forest Products Association at the Southwest Research Institute

SOURCE: AITC

Current State of Mass Timber Projects Over Time

US Market Year-End 2024



Year of Construction Date..
2024, Q4

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❯ QUESTIONS?

This concludes The American Institute of Architects Continuing Education Systems Course

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