Mass Timber Structural Systems: Implementing Design Through Examples

January 15, 2026

Presented by

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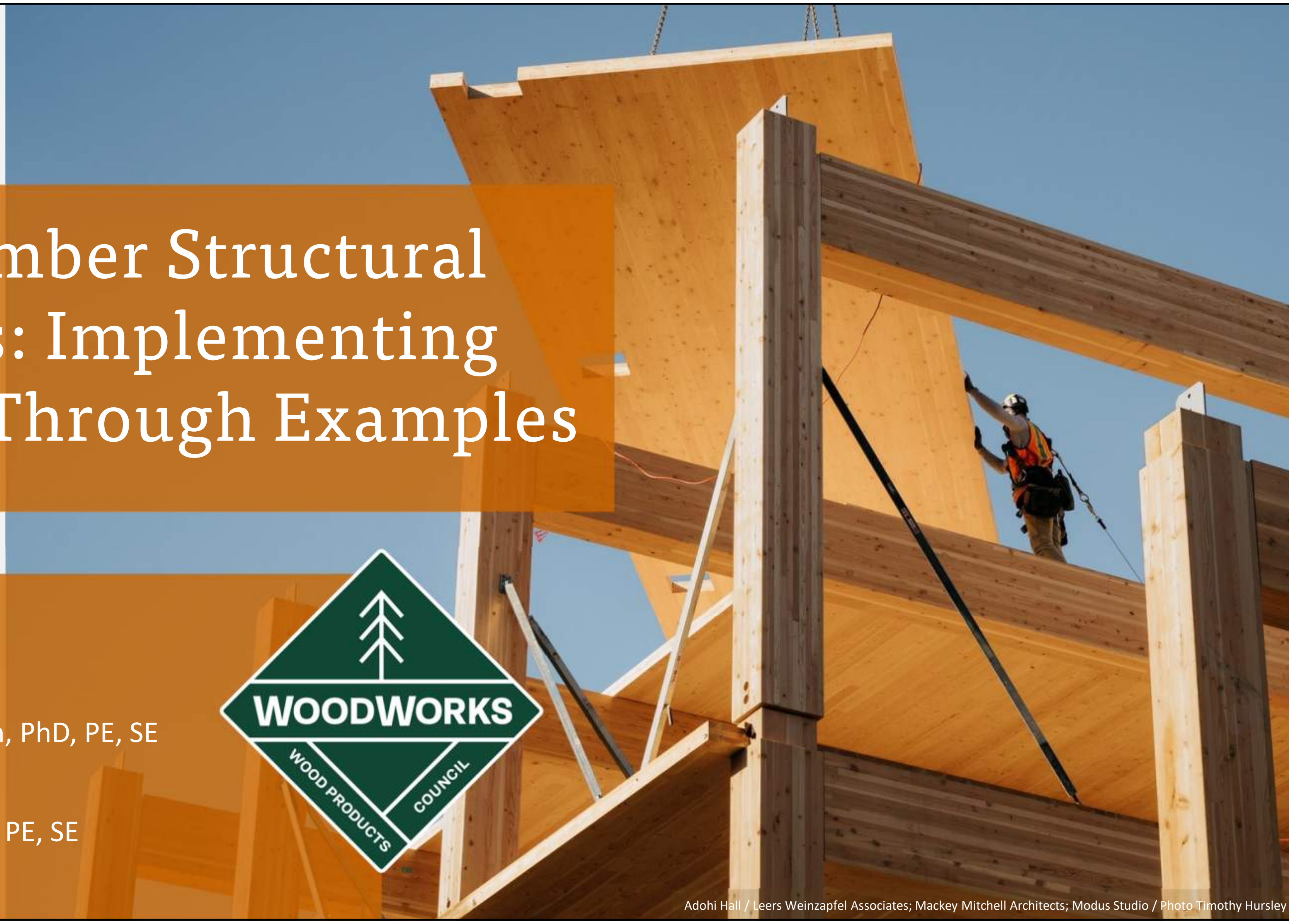
WoodWorks



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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 course navigates the design steps for mass timber elements through the National Design Specification for Wood Construction (NDS) and Fire Design Specification for Wood Construction (FDS). The presentation will outline key design checks for mass timber elements—covering panels, beams, and columns—along with criteria for moment, shear, and deflection. Worked examples accompany this presentation, and a new WoodWorks design guide will be available for download prior to this session. A brief overview of multi-span panel conditions, beam/column connections, and fire design will lay a foundation for a comprehensive design strategy.

Learning Objectives

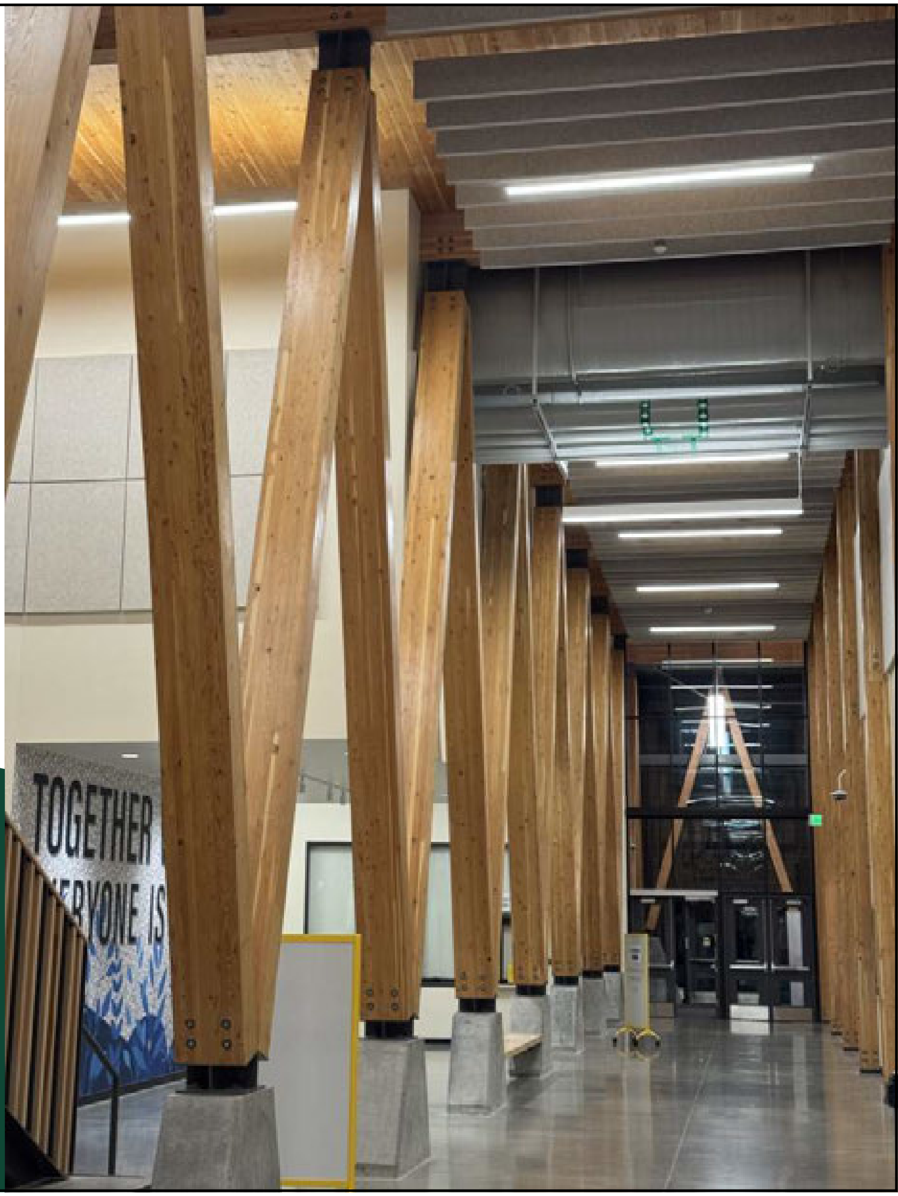
1. Understand the necessary design checks for mass timber elements, including panels, beams, and columns, using the International Building Code (IBC) and its referenced standards, including the National Design Specification (NDS) for Wood Construction and the Fire Design Specification (FDS) for Wood Construction (FDS).
2. Distinguish between various mass timber panel types and their inherent structural and fire protection qualities.
3. Account for multi-span conditions and deflection in mass timber panels to enhance the experience of the building occupant.
4. Become familiar with the building codes, reference standards, and design guides necessary for mass timber floor, wall, beam and column elements.

Introduction

- Structural Design
  - Mass Timber panels: CLT, GLT, DLT, NLT
  - Glulam Beam
  - Glulam Column
- Additional Design Resources for Connections, Fire-Rated and Lateral Elements

Structural Design of Mass Timber Elements: Gravity Design Examples

A new resource with worked examples.



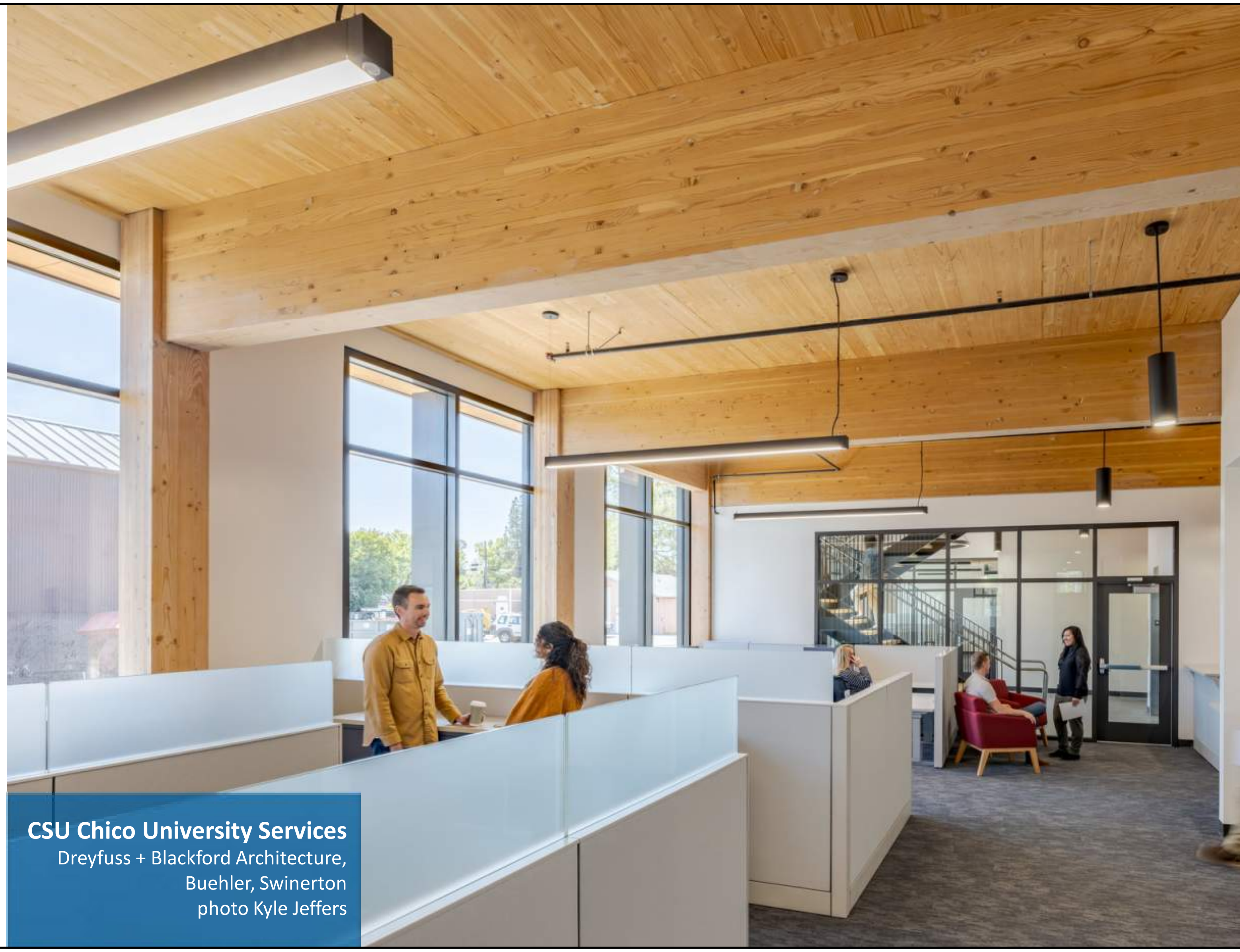

https://www.woodworks.org/resources/structural-design-of-mass-timber-elements-gravity-design-examples/
Structural Design of Mass Timber Elements
Gravity Design Examples
WOODWORKS
WOOD PRODUCTS COUNCIL
Thesis / LEVER Architecture / Holmes / Swinerton
Photo: Lara Swimmer

Table of Contents

Publication reference:

WoodWorks – Wood Products Council. (July 2025). *Structural Design of Mass Timber Elements: Gravity Design Examples.*

CLT



CSU Chico University Services
Dreyfuss + Blackford Architecture,
Buehler, Swinerton
photo Kyle Jeffers

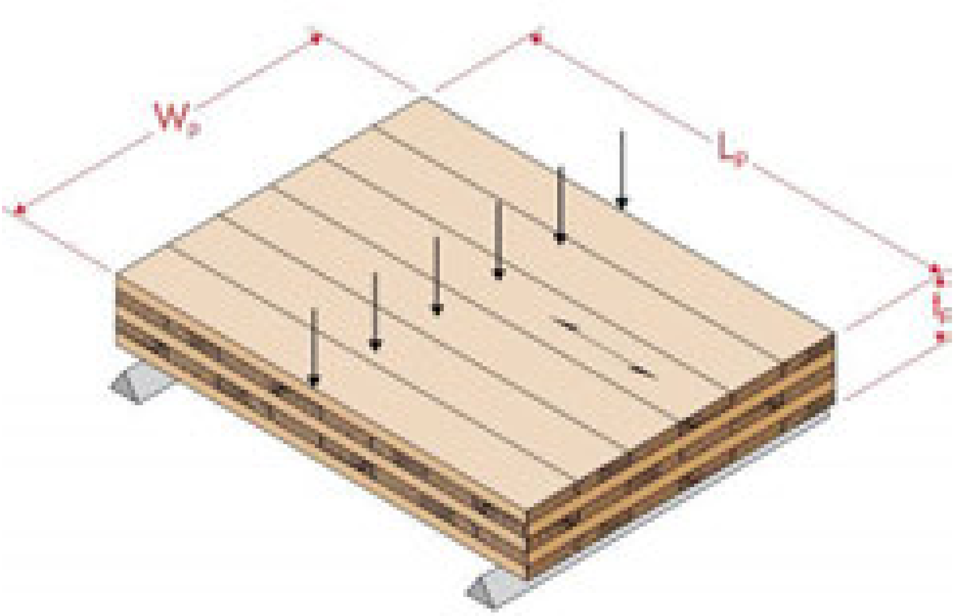
CLT – Cross Laminated Timber panels

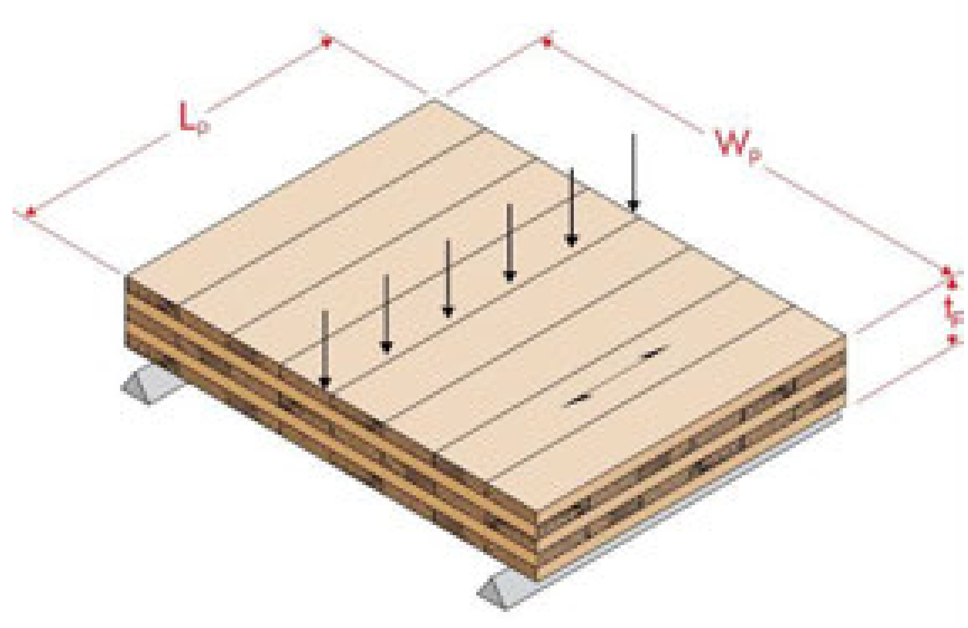
CLT Design includes:

- » Design stresses from PRG-320 or manufacturer's literature
- » Bending: $F_b(S_{eff})$
- » Shear: V, is in pounds per ft of panel width
- » Deflection: EI and GA, flexural and shear stiffnesses

Table of Contents

FLATWISE Panel Loading – “Out of Plane” Behavior



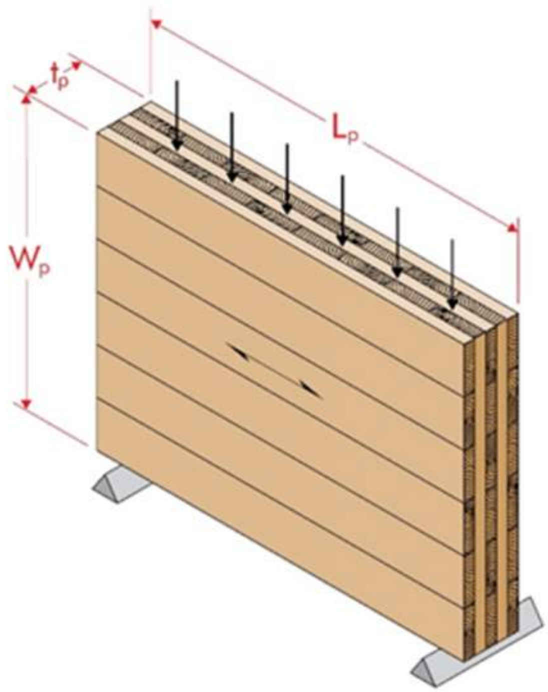


Span in MAJOR Strength Direction
“Parallel” Direction
Use subscript ‘0’ or ‘II” in Notation

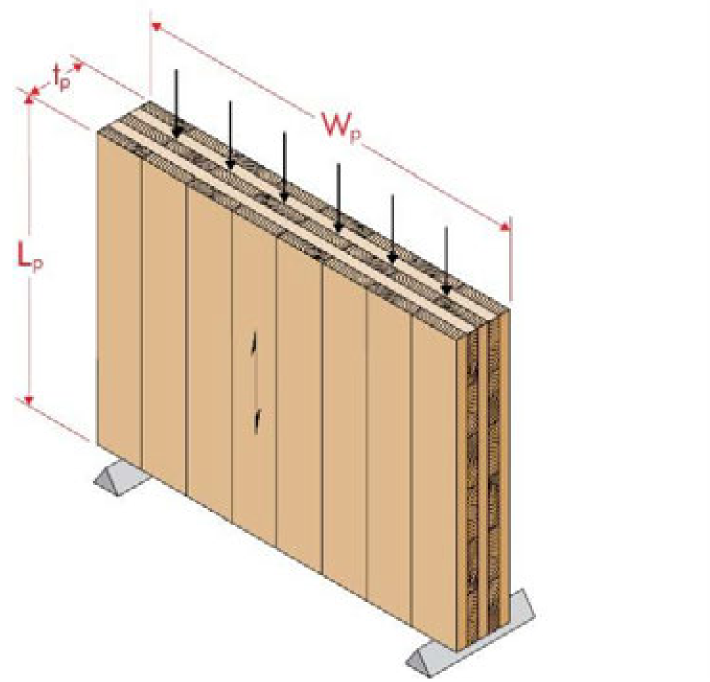
Span in MINOR Strength Direction
“Perpendicular” Direction
Use subscript ‘90’ or “⊥” in Notation

Reference & Source: ANSI/APA PRG 320

EDGEWISE Panel Loading – “In-Plane” Behavior



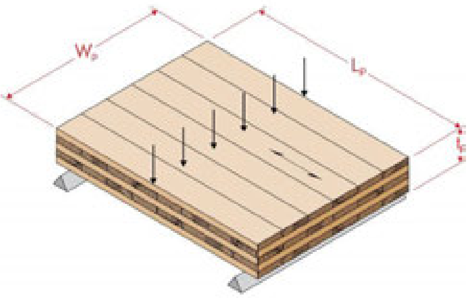
Span in MAJOR Strength Direction

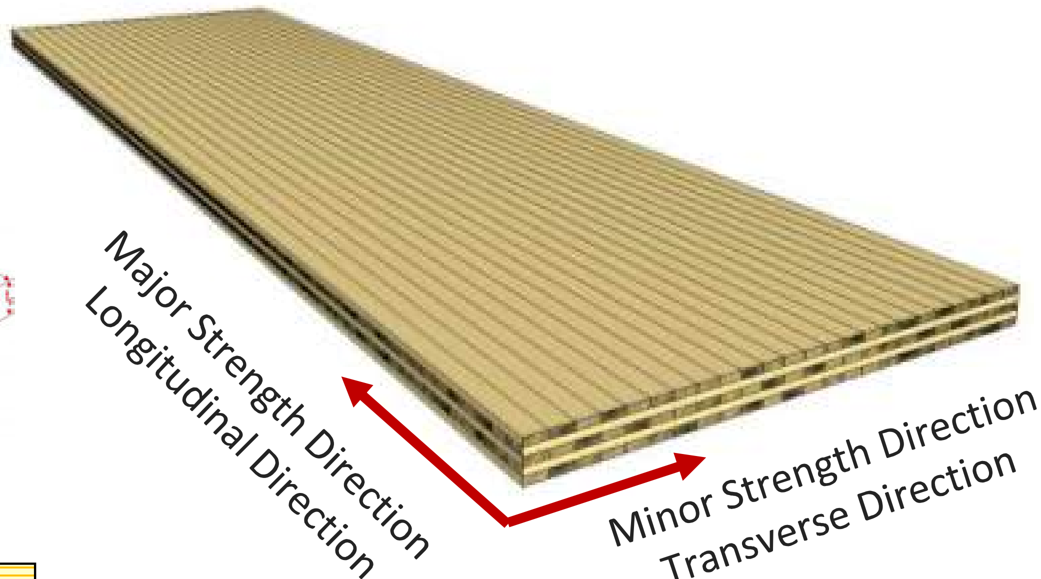


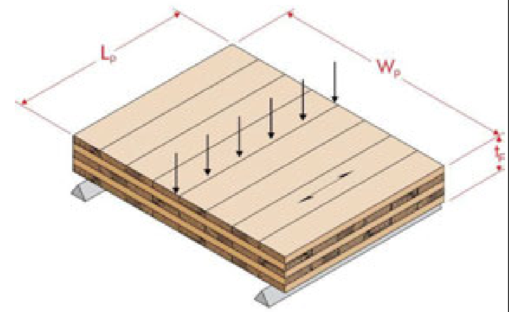
Span in MINOR Strength Direction

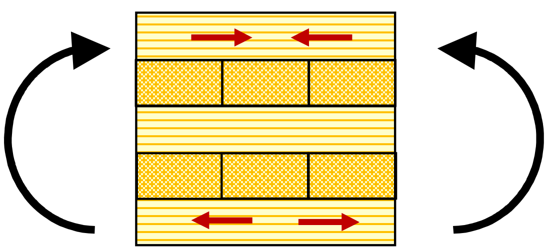
Reference & Source: ANSI/APA PRG 320

Strength Directions of CLT

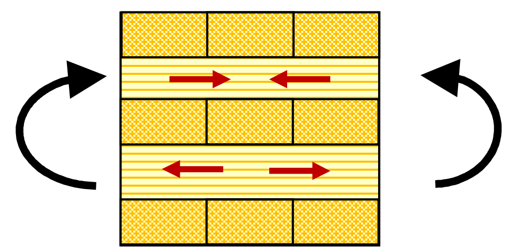








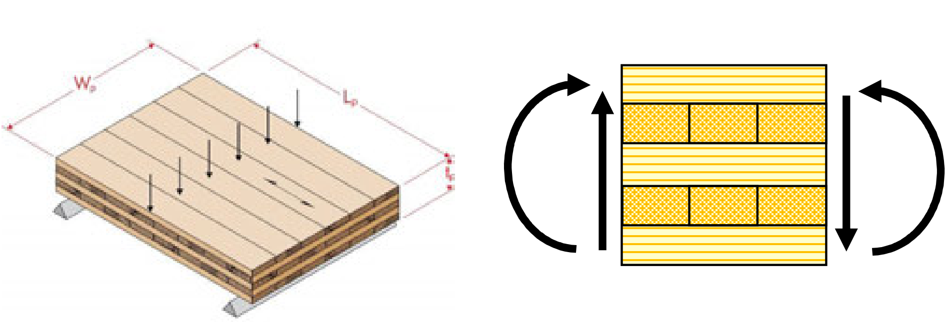
Major Strength Direction Bending



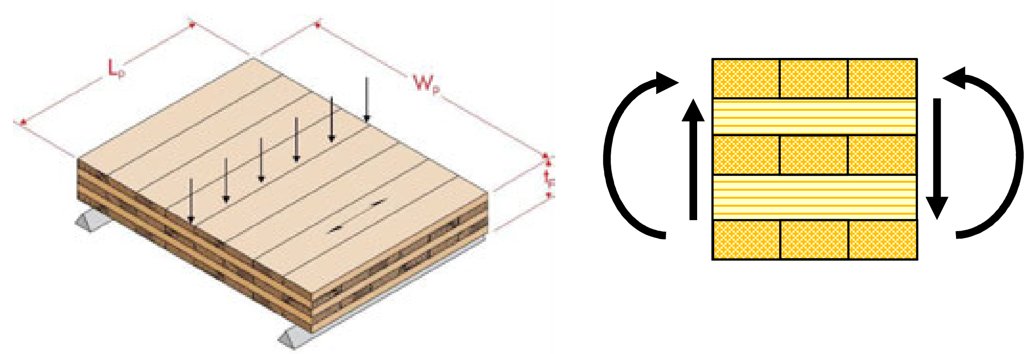
Minor Strength Direction Bending

CLT is an Orthotropic Material

FLATWISE Panel Properties



MAJOR Strength Direction
"Parallel" Direction
Use subscript '0' in Notation



MINOR Strength Direction
"Perpendicular" Direction
Use subscript '90' in Notation

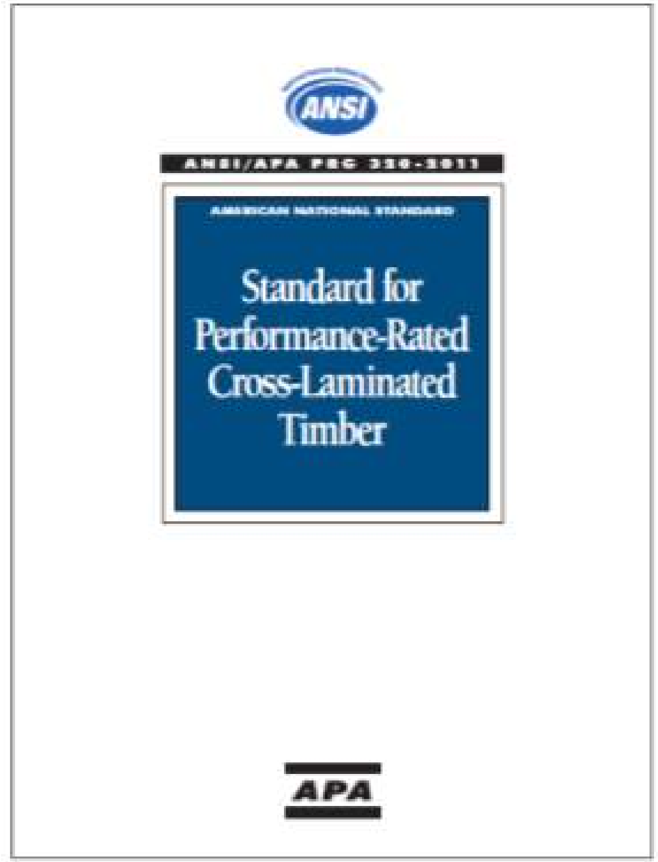
	bending (MAJOR)	shear (MAJOR)	bending (MINOR)	shear (MINOR)
strength	$(F_bS)_{eff,f,0}$	$V_{s,0}$	$(F_bS)_{eff,f,90}$	$V_{s,90}$
stiffness	$(EI)_{eff,f,0}$	$(GA)_{eff,f,0}$	$(EI)_{eff,f,90}$	$(GA)_{eff,f,90}$

Reference: ANSI/APA PRG 320 and Product Reports

North American CLT Product Standard

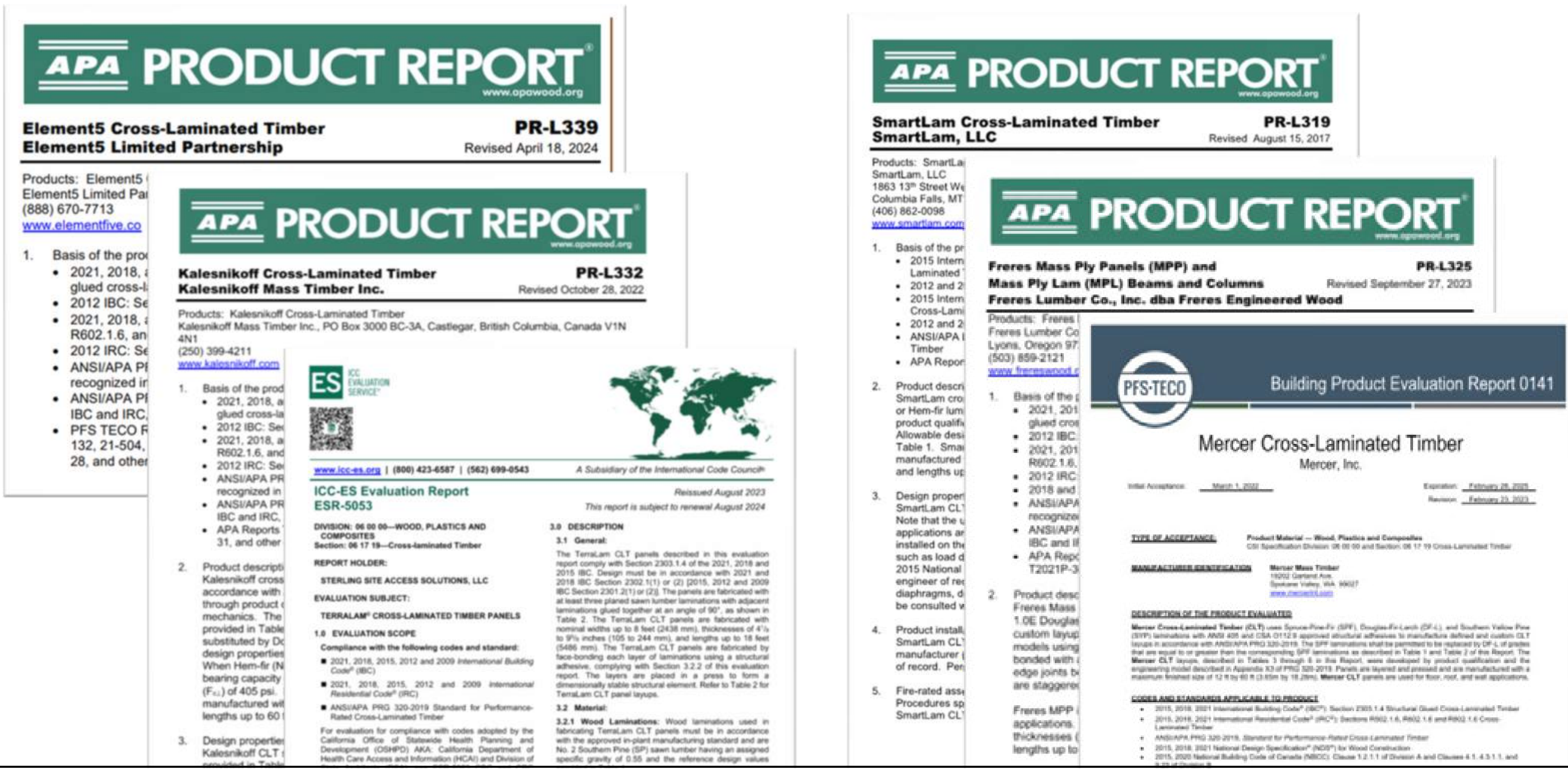
The Standard Covers:

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



ANSI/APA PRG 320 Standard for Performance-Rated Cross-Laminated Timber

3rd Party Product Qualification of CLT



CLT Product Reports

Major Strength Direction Laminations

Minor Strength Direction Laminations

APA Product Report® PR-L347
Issued July 11, 2023

Table 1. ASD Reference Design Values[a] for Lumber Laminations Used in Mercer CrossLam CLT (for Use in the U.S.)

CLT Grade	Laminations Used in Major Strength Direction									Laminations Used in Minor Strength Direction								
	Grade & Species	F_b (psi)	E (10^6 psi)	F_t (psi)	F_c (psi)	F_v (psi)	F_s (psi)	$F_{c\perp}$ (psi)	G	Grade & Species	F_b (psi)	E (10^6 psi)	F_t (psi)	F_c (psi)	F_v (psi)	F_s (psi)	$F_{c\perp}$ (psi)	G
E4M1	2700f-2.2E SP	2,700	2.2	2,150	2,100	190	60	805	0.57	No. 2 SP	750	1.4	450	1,250	175	55	565	0.55
E4M2	2100f-1.8E SP	2,100	1.8	1,575	1,875	175	55	805	0.57	No. 2 SP	750	1.4	450	1,250	175	55	565	0.55
E4M3 & E4M3.1	2100f-1.8E SP	2,100	1.8	1,575	1,875	175	55	805	0.57	No. 3 SP	450	1.3	250	725	175	55	565	0.55
V3 & V3.1	No. 2 SP	750	1.4	450	1,250	175	55	565	0.55	No. 3 SP	450	1.3	250	725	175	55	565	0.55
V3M1	No. 2 SP	750	1.4	450	1,250	175	55	565	0.55	No. 2 SP	750	1.4	450	1,250	175	55	565	0.55

CLT Grade (basic or <u>custom</u>)

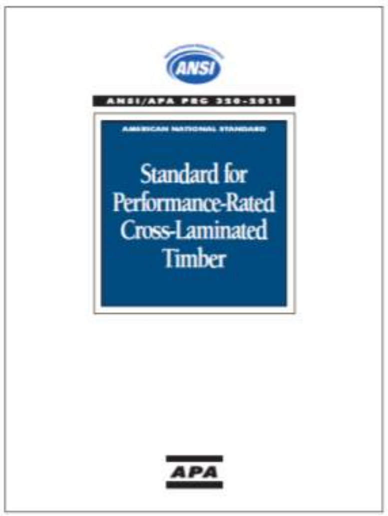
Layup

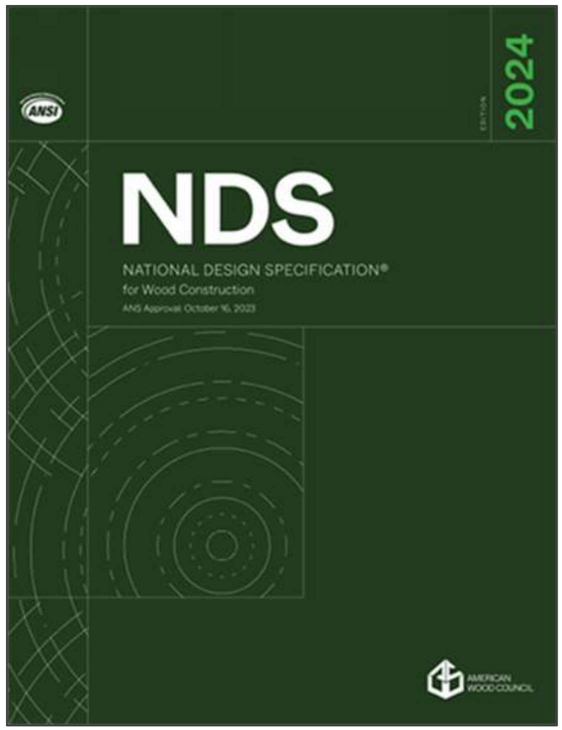
Panel Properties

Table 2. ASD Reference Design Values[a, b] for Mercer CrossLam CLT Listed in Table 1 (for Use in the U.S.) (continued)

CLT Grade[c]	Layup ID[d]	Thick-ness, t_p (in.)	Lamination Thickness (in.) in CLT Layup									Major Strength Direction				Minor Strength Direction			
			=	⊥	=	⊥	=	⊥	=	⊥	=	$(F_bS)_{eff,f,0}$ (lbf-ft/ft)	$(EI)_{eff,f,0}$ (10^6 lbf-in.^{2}/ft)	$(GA)_{eff,f,0}$ (10^6 lbf/ft)	$V_{s,0}$ (lbf/ft)	$(F_bS)_{eff,f,90}$ (lbf-ft/ft)	$(EI)_{eff,f,90}$ (10^6 lbf-in.^{2}/ft)	$(GA)_{eff,f,90}$ (10^6 lbf/ft)	$V_{s,90}$ (lbf/ft)
E4M3.1	87 E	3.43	1.38	0.67	1.38							3,475	72	0.53	1,510	35	0.39	0.38	295
	139 E	5.47	1.38	0.67	1.38	0.67	1.38					7,975	264	1.1	2,410	485	23	0.77	1,200
	191 E	7.52	1.38	0.67	1.38	0.67	1.38	0.67	1.38			14,200	646	1.6	3,300	1,100	91	1.2	2,100
	243 E	9.57	1.38	0.67	1.38	0.67	1.38	0.67	1.38	0.67	1.38	22,075	1,278	2.1	4,200	1,940	229	1.5	3,000

Structural Design Standardization





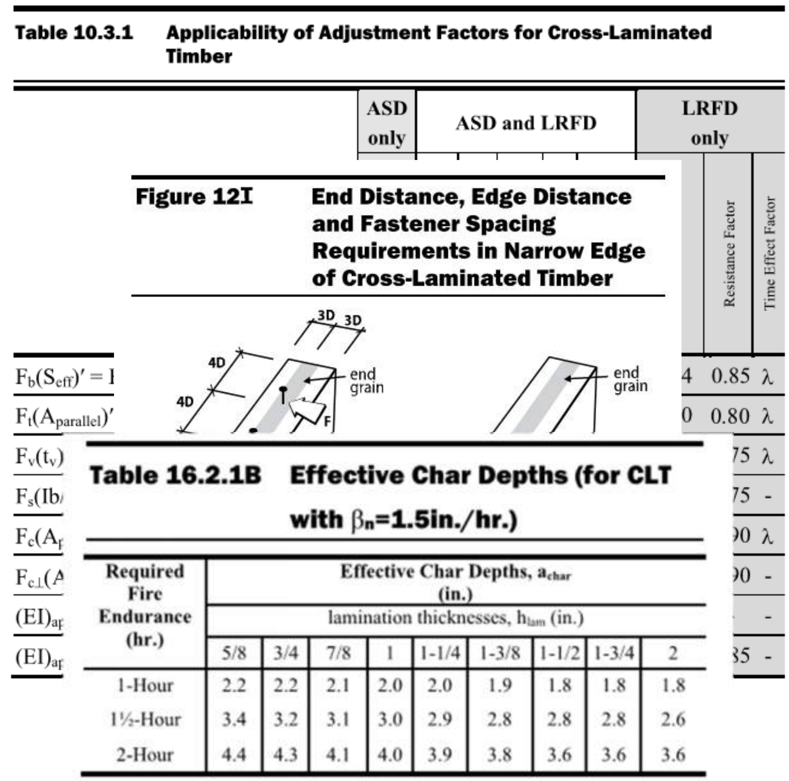
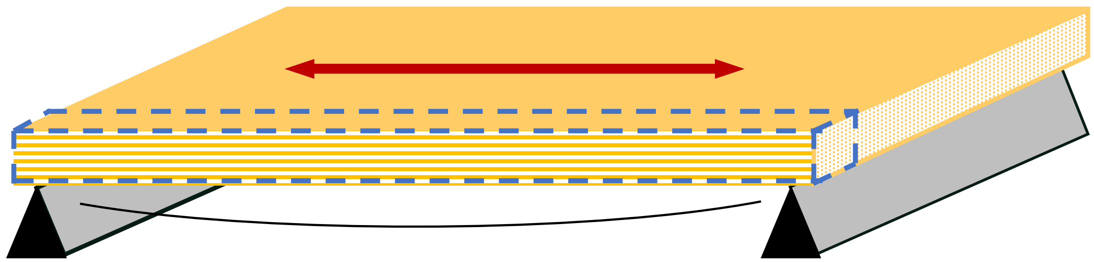


Table 16.2.1B Effective Char Depths (for CLT with β_n=1.5in./hr.)

Required Fire Endurance (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

National Design Specification for Wood Construction

Major Span Direction Analysis

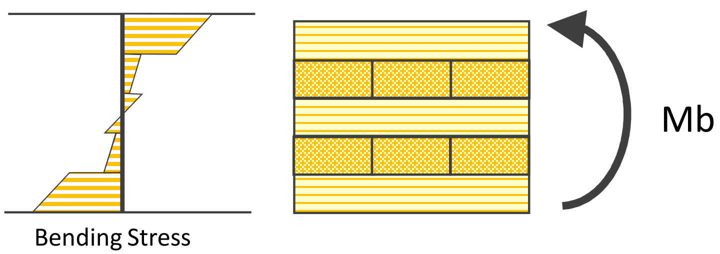


For actions resisted by primarily 1-way spanning behavior, common to analyze as a beam. 1 ft strip a very convenient width.

Can use this approach for multiple spans, cantilevers, etc.

Flatwise Flexural Strength

- Design properties based on an Extreme Fiber Model:
- Flexural Capacity Check:

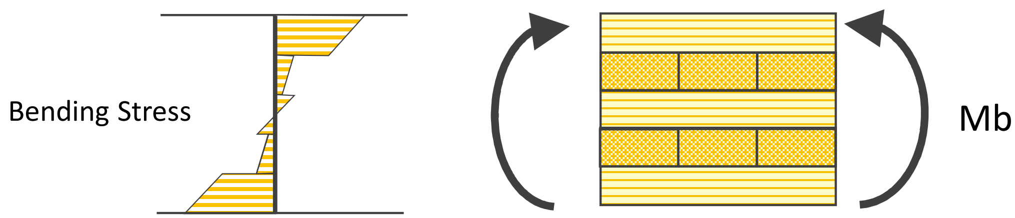


- $M_b \leq (F_b S_{eff})'$
- M_b = applied bending moment
- $(F_b S_{eff})'$ = adjusted bending capacity
- S_{eff} = effective section modulus
- F_b = reference bending design stress of outer lamination

Separate values for most components

Flatwise Flexural Strength

Check applied moment = $M_b \leq (F_b S_{eff})'$ adjusted capacity



Commonly 1.0

For ASD: $(F_b S_{eff})' = C_D\, C_M\, C_t\, C_L\, (F_b S_{eff})$

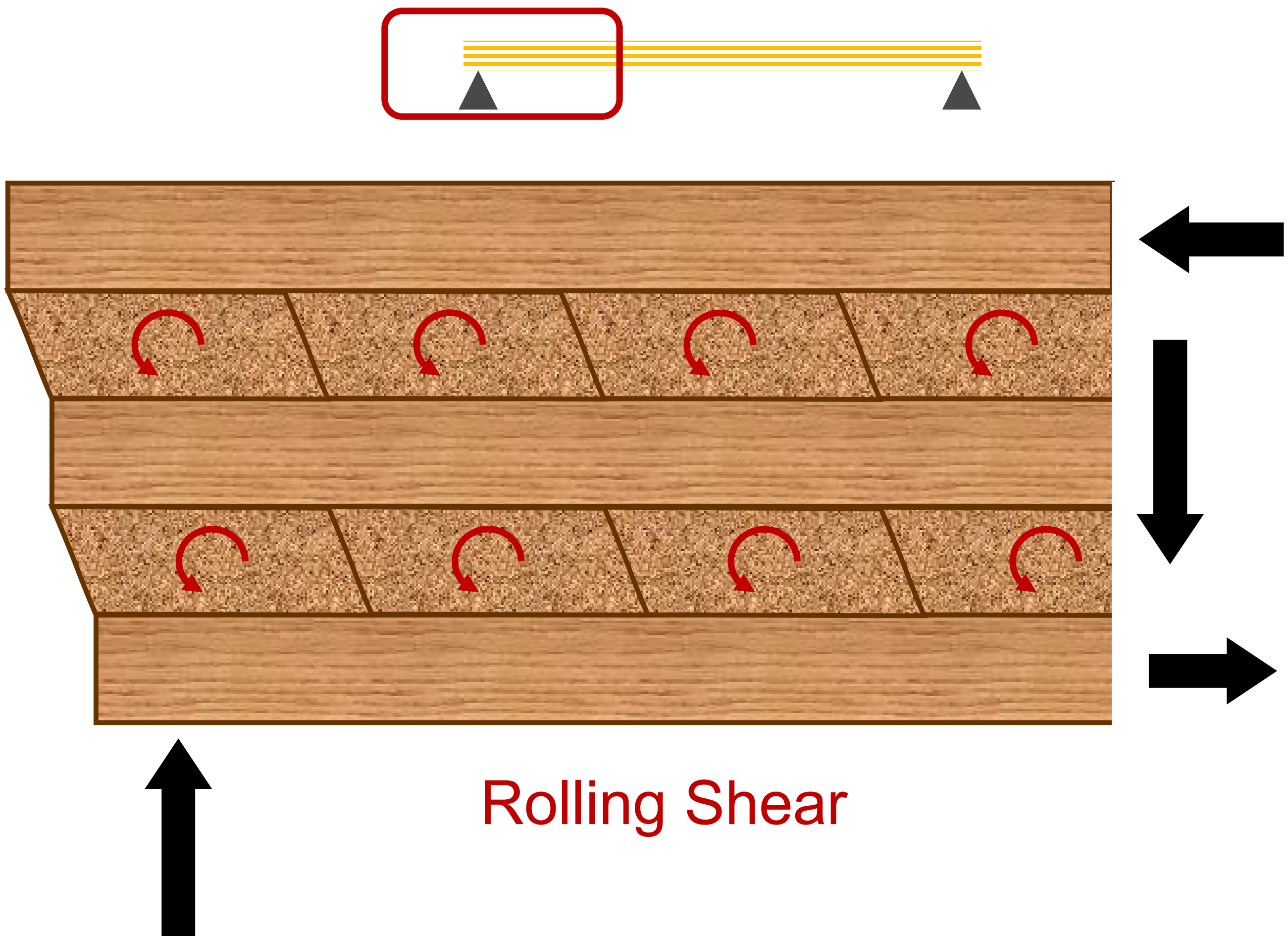
per NDS

Provided

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

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

Flatwise Shear Strength



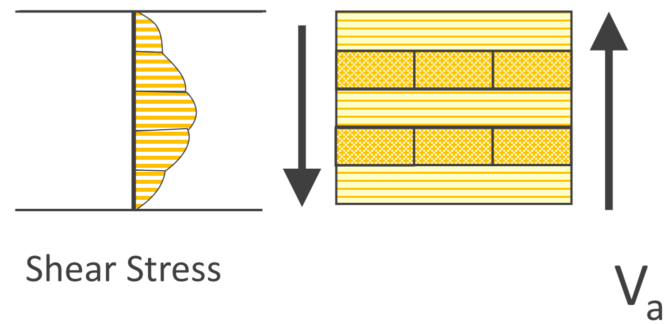
Flatwise Shear Strength

Shear Capacity Check:

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

V_a = applied shear

$F_s(Ib/Q)_{eff}'$ = adjusted shear strength



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

- "Planar Shear": Wood Structural Panel Term
- "Out-of-Plane Shear": Structural Engineering Term
- "Rolling Shear": WSP & CLT Term

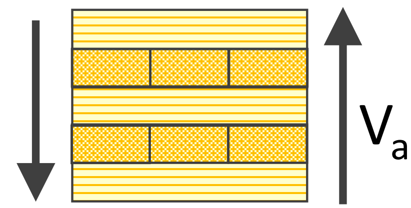
Flatwise Shear Check (ASD)

NDS adjusted shear capacity

NDS reference shear capacity

PRG 320 notation

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



Per NDS.
(Commonly 1.0)

From Manufacturer

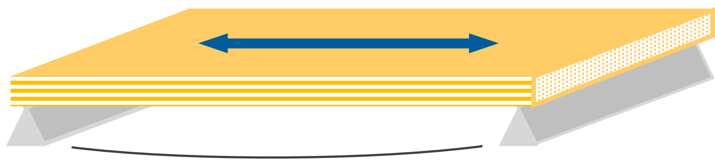
$$V_a \leq (1.0)\, V_s$$

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

Deflection Calculations

» General Purpose: 1 Way, Beam Action

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



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

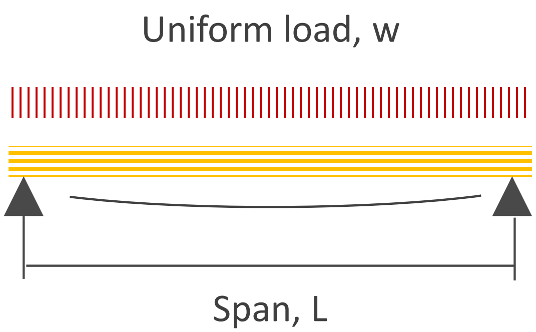
» Can model multiple spans, cantilevers, etc.

Deflection Calculations

Single Span Beam Deflections, *including shear deformations*

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} →

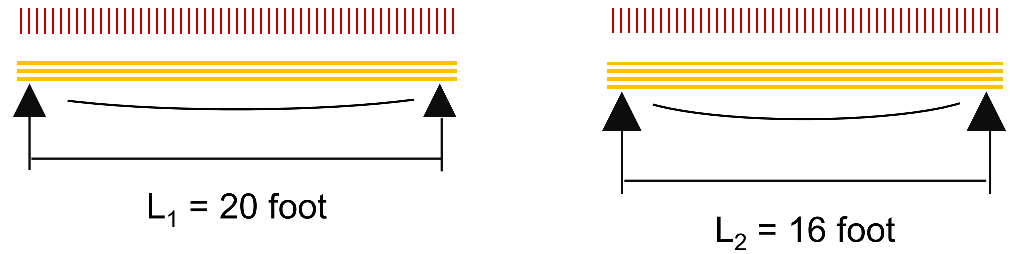
$$EI_{app} = \frac{EI_{eff}}{1 + \frac{11.5EI_{eff}}{GA_{eff}L^2}}$$

Reference: US CLT Handbook & NDS

Deflection Calculations

Apparent Flexural Stiffness depends on Span Length

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



$$EI_{app1} \neq EI_{app2}$$

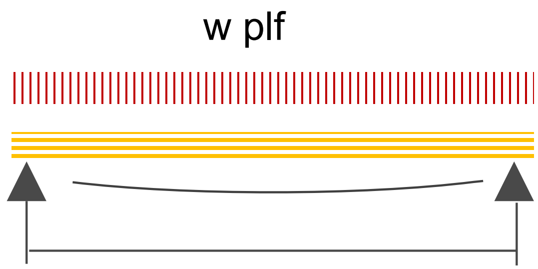
Apparent Flexural Stiffness depends on Load Shape and Support Conditions

NDS Commentary

Table C10.4.1.1 Shear Deformation Adjustment Factors

Loading	End Fixity	k_b	k_s	K_s
Uniformly Distributed	Pinned	5/384	1/8	11.5
	Fixed	1/384	1/8	57.6
Line Load at midspan	Pinned	1/48	1/4	14.4
	Fixed	1/192	1/4	57.6
Line Load at quarter points	Pinned	11/768	1/8	10.5
Constant Moment	-	1/12	0	0
Uniformly Distributed	Cantilevered	1/8	1/2	4.8
Line Load at free-end	Cantilevered	1/3	1	3.6
Column Buckling	Pinned	A	$A\pi^2$	11.8
	Fixed	B	$4B\pi^2$	47.4

Deflection Calculations



Long Term Deformation to Loads:

$$\Delta_T = K_{cr}\,\Delta_{LT} + \Delta_{ST}$$ NDS Eq 3.5-1

Δ_{ST} Deflection due to short-term loading (e.g. live load)

Δ_{LT} Immediate deflection due to long-term loading (e.g. dead load)

K_{cr} 2.0 for CLT in dry service conditions

In addition to code (IBC) required deflection limits, also check total deformations, including creep.

Particularly in exposed long-span roof panels, where only meeting code minimums may lead to undesirable visible panel deflections.

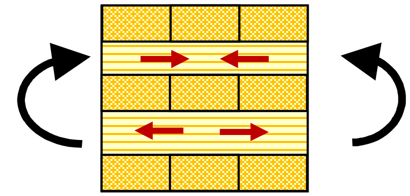
Two-way CLT design


Cooley Landing Project in East Palo Alto. Photo: WoodWorks

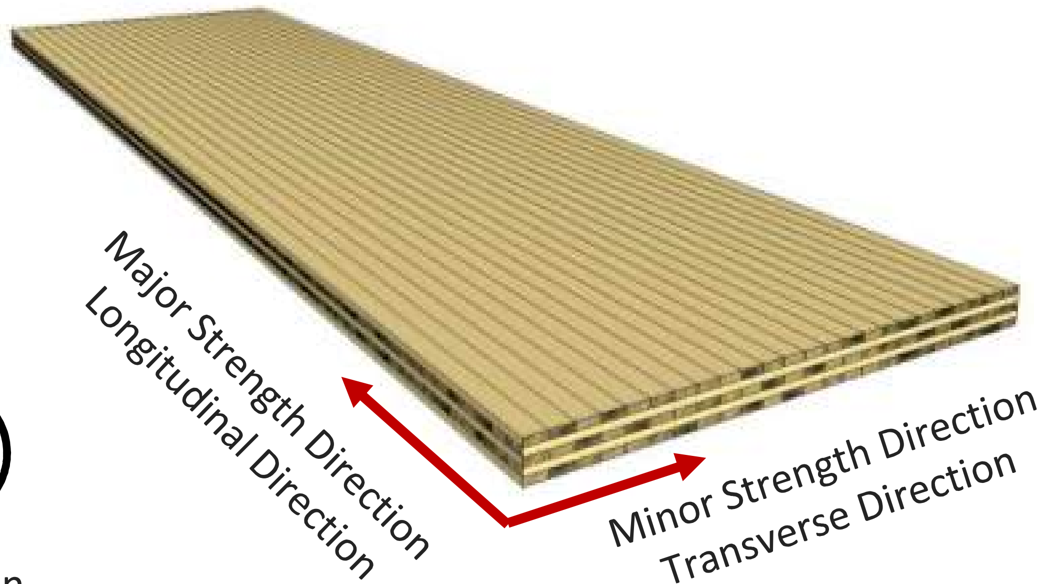

Brock Commons in Vancouver, BC.
Photo: Acton Ostry Architects

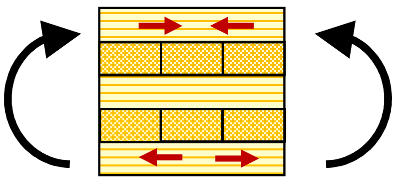

Photo: Swinterton

CLT is an Orthotropic Material



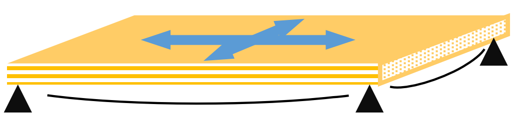
Minor Strength Direction
Stiffness





Major Strength Direction
Stiffness

$(EI)_{eff,f,0}$ 3 to 30+ times $(EI)_{eff,f,90}$



Equal property plate analysis not accurate

Flatwise Two-Way CLT Analysis

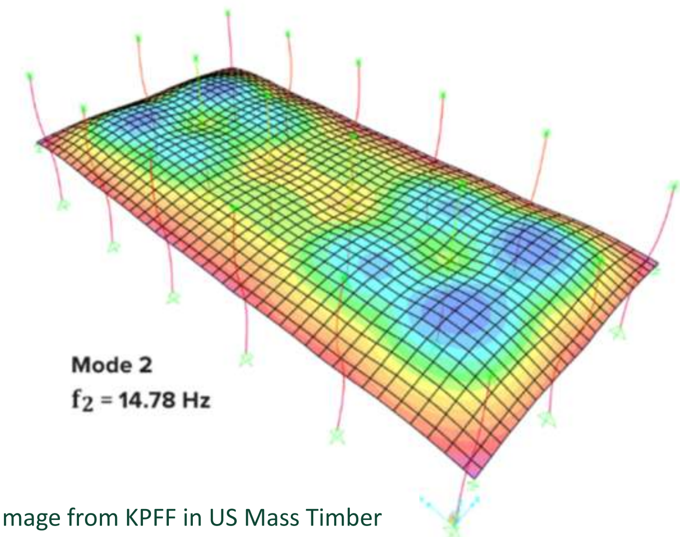


Image from KPFF in US Mass Timber Floor Vibration Design Guide

Finite Element Model

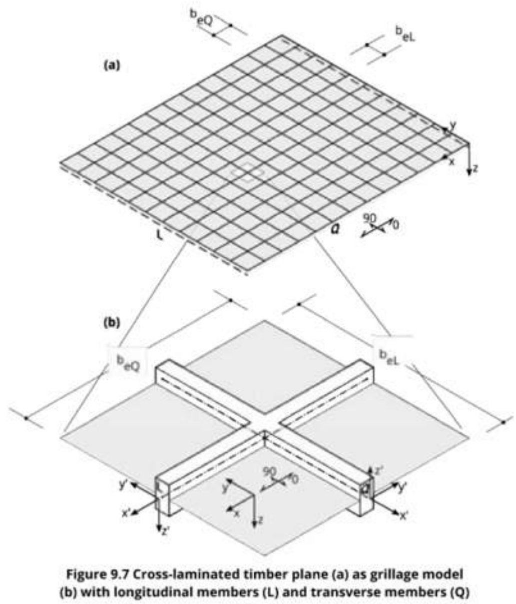


Image from proHolz Cross-Laminated Timber Structural Design, Vol 2

Grillage Model

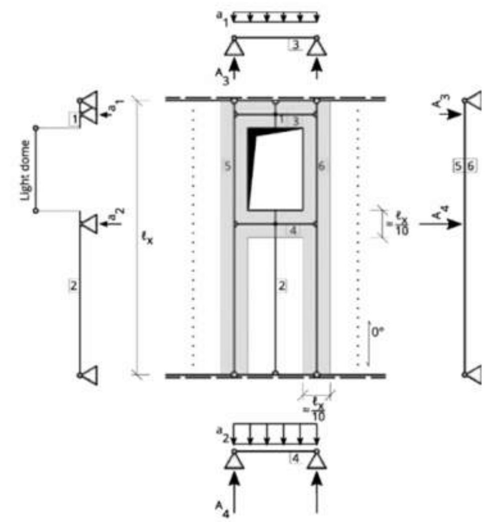
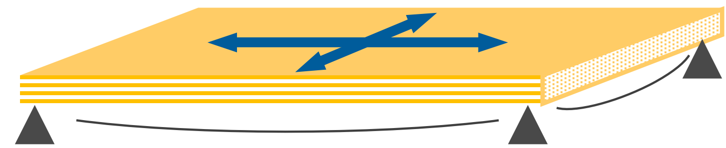


Image from proHolz Cross-Laminated Timber Structural Design, Vol 2

Approximate Strip Analysis

Point Supported Plates



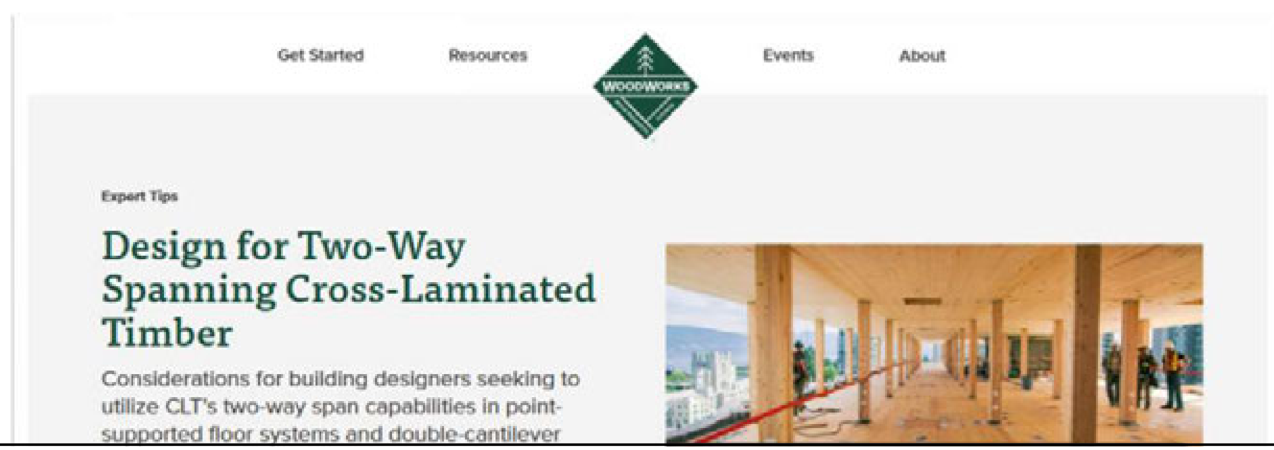
Possible, however not common.

Structural design issues include:

» Compression perp to grain at support points
» Bi-directional bending stress interactions
» Punching shear

Not covered in NDS

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

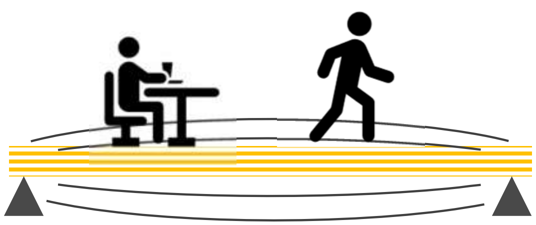


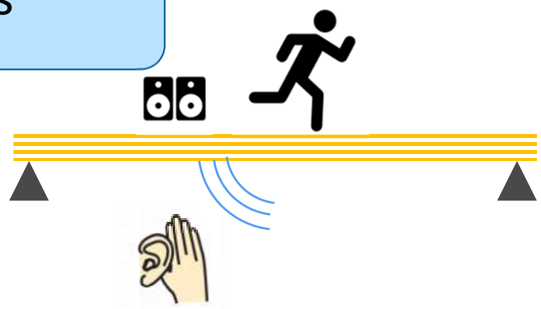
Acoustics and Vibration in Mass Timber Panels

Image: AcoustiTECH

Vibrations vs Acoustics

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





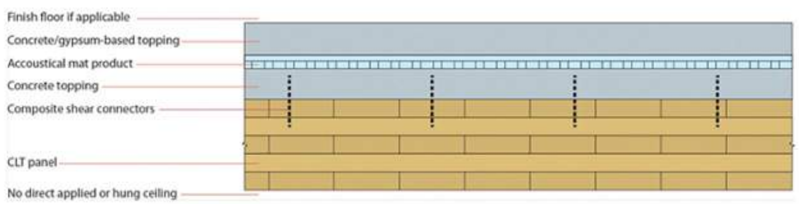
NEW ONLINE TOOL

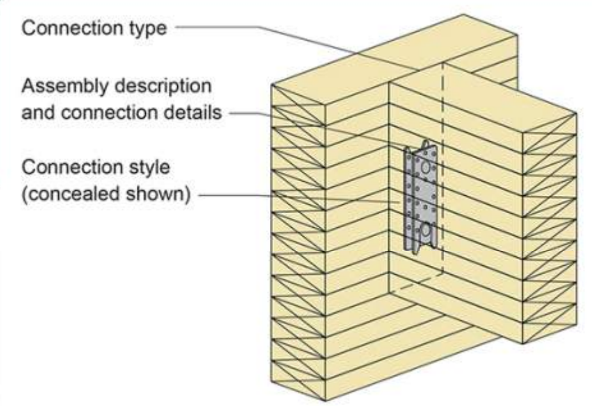
Mass Timber Fire & Acoustic Database

Search tested and approved assemblies

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

CLT-Concrete Composite Floor Assemblies, Ceiling Side Exposed





< 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

This illustration s... for specific const...

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

Vibration Criteria for CLT Floor Span

CLT Floor Span Limit (base value) from FPInnovations method

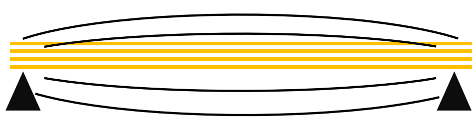
$$L_{lim} \leq \frac{1}{12.05} \frac{\left(EI_{eff}\right)^{0.293}}{(\overline{\rho}A)^{0.122}} \text{ [ft]}$$

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

$$L_{lim} \leq \frac{1}{13.34} \frac{\left(EI_{eff}\right)^{0.293}}{(w)^{0.122}} \text{ [ft]}$$

Where, for 12 in wide strip:
EI_{eff} = effective flexural stiffness (lbf-in^2)
w = CLT weight per area (lbf/ft^2)

Reference "US Mass Timber Floor Vibration Design Guide" Chapter 4



Vibration Criteria: Floor Topping Impacts

Recommended CLT Floor Span Limit (adjusted for floor topping):

Decrease span by 10% when topping is greater than 2 x panel self weight

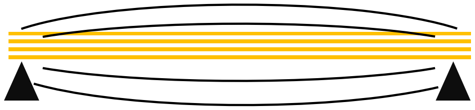
CLT self weight = 16.1 psf

2 x self weight = 32.2 psf

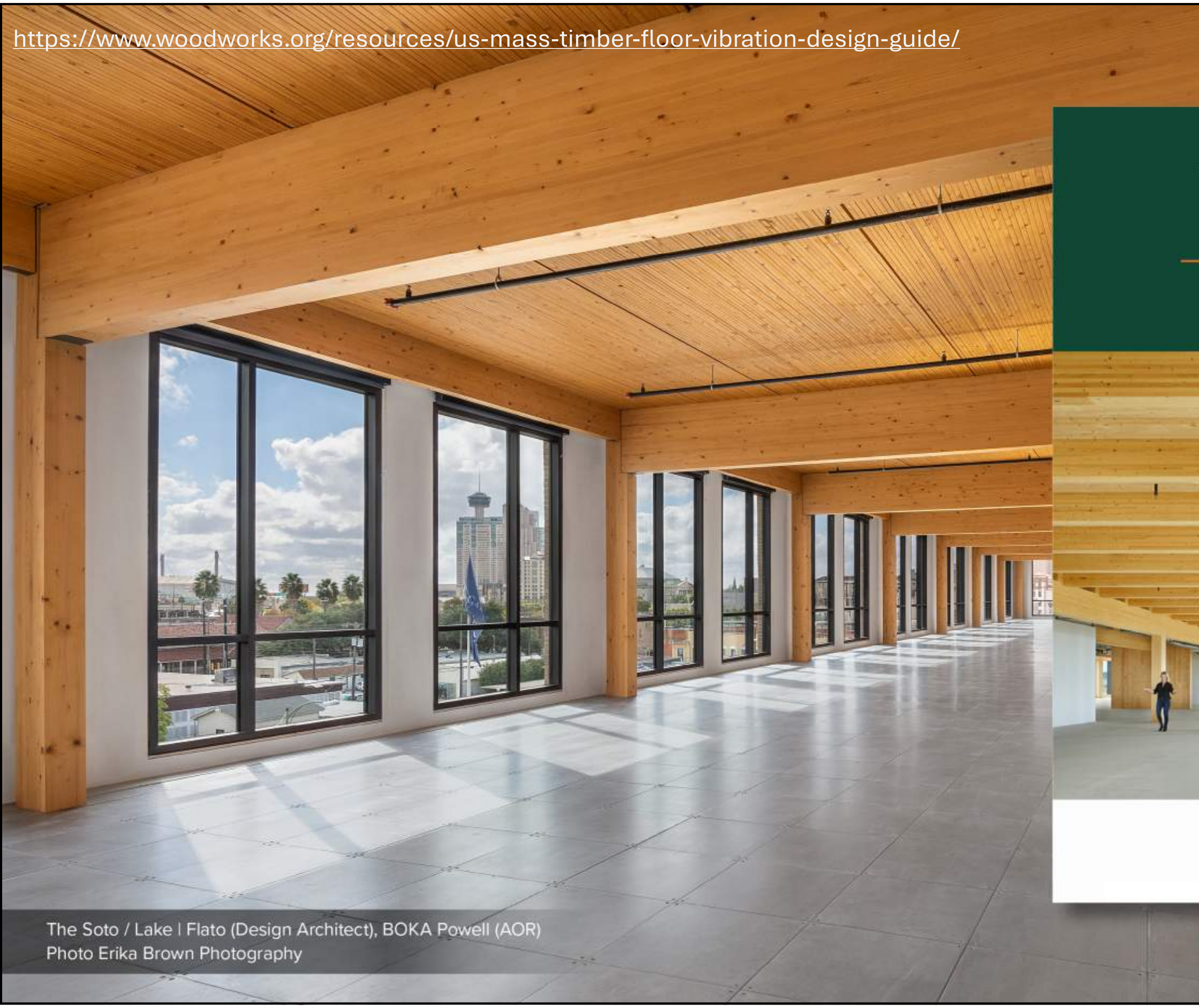
Concrete topping weight = (2 in/12 in)(150 pcf) = 25 psf

Topping is not greater than 2 x self weight, therefore no adjustment.
Otherwise, decrease span by 10%.

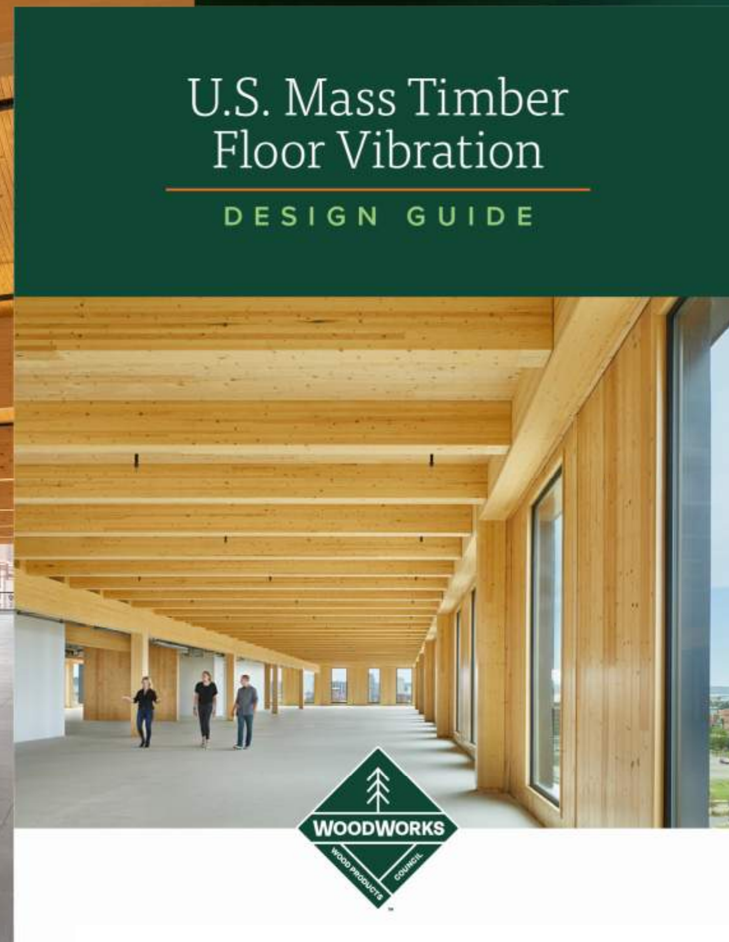
Reference "US Mass Timber Floor Vibration Design Guide" Chapter 4.2



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

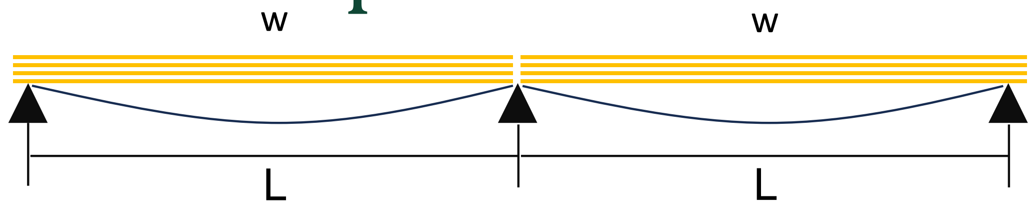


The Soto / Lake | Flato (Design Architect), BOKA Powell (AOR)
Photo Erika Brown Photography



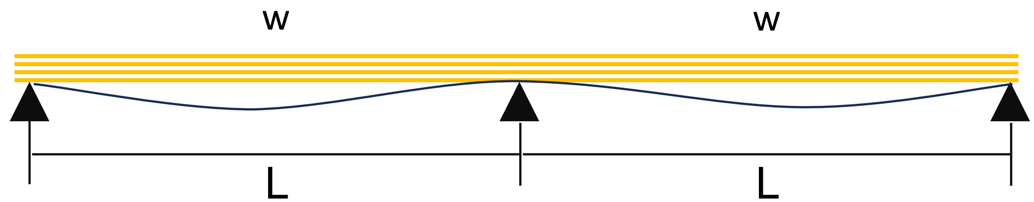
Multi-span CLT Panels as Simple Beams

Single span



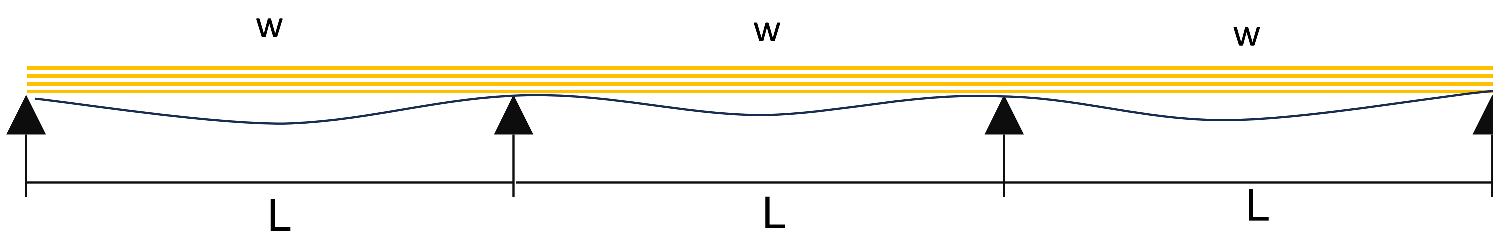
$M_{max} = \frac{1}{8} wL^2$ $V_{max} = \frac{1}{2} wL$ $R_{max} = wL$ $\delta_{max} = \frac{5wL^4}{385\ EI}$

Double span



$M_{max} = \frac{1}{8} wL^2$ $V_{max} = \frac{5}{8} wL$ $R_{max} = \frac{5}{4} wL$ $\delta_{max} = \frac{wL^4}{185\ EI}$

Triple span



* Skip loading can be higher

$M_{max} = \frac{1}{10} wL^2$ * $V_{max} = \frac{6}{10} wL$ * $R_{max} = \frac{11}{10} wL$* $\delta_{max} = 0.0069 \frac{wL^4}{EI}$ *

Uniform Load, Equal Spans, Comparison of Critical Design Values

	Moment M_{max}	*Shear* V_{max}	*Deflection* δ_{max}	*Reaction* R_{max}
Single span	$.125\ wL^2$	$.500\ wL$	$.0130\ \frac{wL^4}{EI}$	$1.00\ wL$
Double span	$.125\ wL^2$	$.625\ wL$	$.0054\ \frac{wL^4}{EI}$	$1.25\ wL$
Triple span	$.100\ wL^2$	$.600\ wL$	$.0069\ \frac{wL^4}{EI}$	$1.10\ wL$
Triple span Skip load (2 of 3)	$.117\ wL^2$	$.617\ wL$	$.0099\ \frac{wL^4}{EI}$	$1.20\ wL$

Sources of span tables:

- AWC Design Aid No. 6 - Beam Design Formulas with Shear and Moment Diagrams
- AISC Manual of Steel Construction

Uniform Load, Equal Spans, Comparison of Critical Design Values

	Moment M_{max}	*Shear* V_{max}	*Deflection* δ_{max}	*Reaction* R_{max}
Single span	$\mathbf{.125\, wL^2}$	$.500\, wL$	$\mathbf{.0130\, \frac{wL^4}{EI}}$	$1.00\, wL$
Double span	$\mathbf{.125\, wL^2}$	$\mathbf{.625\, wL}$	$.0054\, \frac{wL^4}{EI}$	$\mathbf{1.25\, wL}$
Triple span	$.100\, wL^2$	$.600\, wL$	$.0069\, \frac{wL^4}{EI}$	$1.10\, wL$
Triple span Skip load (2 of 3)	$.117\, wL^2$	$.617\, wL$	$.0099\, \frac{wL^4}{EI}$	$1.20\, wL$

What if the number of spans per panel is unknown?

Often the case in design before a manufacturer is selected.

Uniform Load, Equal Spans, Comparison of Critical Design Values

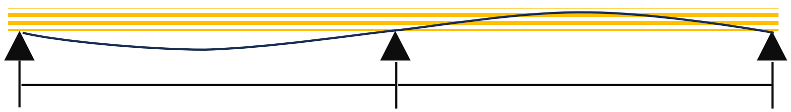
	Moment M_{max}	*Shear* V_{max}	*Deflection* δ_{max}	*Reaction* R_{max}
Single span	$\mathbf{.125\ wL^2}$	$.500\ wL$	$\mathbf{.0130\ \frac{wL^4}{EI}}$	$1.00\ wL$
Double span	$\mathbf{.125\ wL^2}$	$\mathbf{.625\ wL}$	$.0054\ \frac{wL^4}{EI}$	$\mathbf{1.25\ wL}$
Triple span	$.100\ wL^2$	$.600\ wL$	$.0069\ \frac{wL^4}{EI}$	$1.10\ wL$
Triple span Skip load (2 of 3)	$.117\ wL^2$	$.617\ wL$	$.0099\ \frac{wL^4}{EI}$	$1.20\ wL$

A panel design strategy for unknown panel layout of regular 1-way span lengths:

- Design CLT panels as single span
- Design interior support points for potential 25% increase in reaction

Vibration Criteria for CLT Floor Span

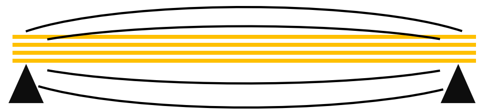
What’s the impact of multi-span panels on floor vibrations?



- Check the longest span, if unequal

- Recommend a 20% increase in the Base Span Limit when non-structural elements are present which provide enhanced stiffening effect*

  *Partition walls, finishes, ceilings



Reference “US Mass Timber Floor Vibration Design Guide” Chapter 4

GLT – Glue-Laminated Timber panels

GLT Design includes:

- » GLT panels are glulam sections laid on their side (plank orientation)
- » Sections are 12 to 48 inches wide (in plank).
- » Glulam beams (and sometimes columns have laminations with varying structural properties
- » GLT panels often use “column” sections with uniform structural properties
- » NDS Supplement Table 5B (Members stressed primarily in axial tension or compression)

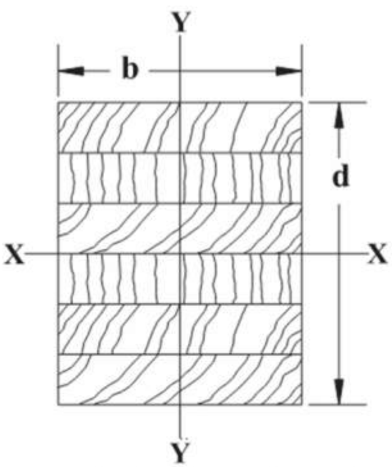
Table of Contents

Photo credit: Unalam

GLT – Glue-Laminated Timber panels

Layup:

- » Table 5B & adjustment factors
- » C_V = 1.0 as plank loaded
- » Flat Use factor, C_{fu}
  - Use Table or Calc per NDS 5.3.7



Structural Glued Laminated Timber

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

(Members stressed primarily in axial tension or compression) (Tabulated design values are for normal load duration and dry service conditions. See NDS 5.3 for a comprehensive description of design value adjustment factors.)

Use with Table 5B Adjustment Factors

Combination Symbol	Species	Grade	All Loading: Modulus of Elasticity, For Shear-Free Deflection Calculations E_{true}[6] (10^6 psi)	All Loading: Modulus of Elasticity, For Beam Deflection Calculations E[7] (10^6 psi)	All Loading: Modulus of Elasticity, For Stability Calculations E_{min}[8] (10^6 psi)	All Loading: Compression Perpendicular to Grain $F_{c\perp}$ (psi)	Axially Loaded: Tension Parallel to Grain, 2 or More Laminations F_t (psi)	Axially Loaded: Compression Parallel to Grain, 4 or More Laminations F_c (psi)	Axially Loaded: Compression Parallel to Grain, 2 or 3 Laminations F_c (psi)	Bending about Y-Y Axis (Loaded Parallel to Wide Faces of Laminations): Bending, 4 or More Laminations F_{byy} (psi)	Bending about Y-Y Axis: Bending, 3 Laminations F_{byy} (psi)	Bending about Y-Y Axis: Bending, 2 Laminations F_{byy} (psi)	Bending about Y-Y Axis: Shear Parallel to Grain[1][2][3] F_{vy} (psi)	Bending About X-X Axis (Loaded Perpendicular to Wide Faces of Laminations): Bending, 2 Laminations to 15 in. Deep[4] F_{bxx} (psi)	Bending About X-X Axis: Shear Parallel to Grain[3] F_{vx} (psi)	Fasteners: 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
22[5]	SW	L3	1.1	1.0	0.53	315	525	850	725	800	700	575	170	725	195	0.35
69	AC	L3	1.3	1.2	0.63	470	725	1150	1100	1100	975	775	230	1000	265	0.46
70	AC	L2	1.4	1.3	0.69	470	975	1450	1450	1400	1250	1000	230	1350	265	0.46
71	AC	L1D	1.7	1.6	0.85	560	1250	1900	1900	1850	1650	1400	230	1750	265	0.46
72	AC	L1S	1.7	1.6	0.85	560	1250	1900	1900	1850	1650	1400	230	1900	265	0.46
73	POC	L3	1.4	1.3	0.69	470	775	1500	1200	1200	1050	825	230	1050	265	0.46
74	POC	L2	1.5	1.4	0.74	470	1050	1900	1550	1450	1300	1100	230	1400	265	0.46
75	POC	L1D	1.8	1.7	0.90	560	1350	2300	2050	1950	1750	1500	230	1850	265	0.46
Visually Graded Southern Pine																
47	SP	N2M12	1.5	1.4	0.74	650	1200	1900	1150	1750	1550	1300	260	1400	300	0.55
47 1:10	SP	N2M10	1.5	1.4	0.74	650	1150	1700	1150	1750	1550	1300	260	1400	300	0.55
47 1:8	SP	N2M	1.5	1.4	0.74	650	1000	1500	1150	1600	1550	1300	260	1400	300	0.55
48	SP	N2D12	1.8	1.7	0.90	740	1400	2200	1350	2000	1800	1500	260	1600	300	0.55
48 1:10	SP	N2D10	1.8	1.7	0.90	740	1350	2000	1350	2000	1800	1500	260	1600	300	0.55
48 1:8	SP	N2D	1.8	1.7	0.90	740	1150	1750	1350	1850	1800	1500	260	1600	300	0.55
49	SP	N1M16	1.8	1.7	0.90	650	1350	2100	1450	1950	1750	1500	260	1800	300	0.55
49 1:14	SP	N1M14	1.8	1.7	0.90	650	1350	2000	1450	1950	1750	1500	260	1800	300	0.55
49 1:12	SP	N1M12	1.8	1.7	0.90	650	1300	1900	1450	1950	1750	1500	260	1800	300	0.55
49 1:10	SP	N1M	1.8	1.7	0.90	650	1150	1700	1450	1850	1750	1500	260	1800	300	0.55
50	SP	N1D14	2.0	1.9	1.00	740	1550	2300	1700	2300	2100	1750	260	2100	300	0.55
50 1:12	SP	N1D12	2.0	1.9	1.00	740	1500	2200	1700	2300	2100	1750	260	2100	300	0.55
50 1:10	SP	N1D	2.0	1.9	1.00	740	1350	2000	1700	2100	2100	1750	260	2100	300	0.55

1. For members with 2 or 3 laminations, the reference shear design value for transverse loads parallel to the wide faces of the laminations, F_{vy}, shall be reduced by multiplying by a factor of 0.84 or 0.95, respectively.
2. The reference shear design value for transverse loads applied parallel to the wide faces of the laminations, F_{vy}, shall be multiplied by 0.4 for members with 5, 7, or 9 laminations manufactured from multiple piece laminations (across width) that are not edge bonded. The reference shear design value, F_{vy}, shall be multiplied by 0.5 for all other members manufactured from multiple piece laminations with unbonded edge joints. This reduction shall be cumulative with the adjustments in footnotes 1 and 3.
3. The reference design values for shear, F_{vx} and F_{vy}, shall be multiplied by the shear reduction factor, C_{vr}, for the conditions defined in NDS 5.3.10.
4. For members greater than 15 in. deep, the reference bending design value, F_{bxx}, shall be reduced by multiplying by a factor of 0.88.
5. When Western Cedars, Western Cedars (North), Western Woods, and Redwood (open grain) are used in combinations for Softwood Species (SW), the reference design value for modulus of elasticity, E, shall be reduced by 100,000 psi and E_{min} shall be reduced by 52,800 psi. When Coast Sitka Spruce, Coast Species, Western White Pine, and Eastern White Pine are used in combinations for Softwood Species (SW) reference design values for shear parallel to grain, F_{vx} and F_{vy}, shall be reduced by 10 psi, before applying any other adjustments.
6. E_{true} = Shear-free modulus of elasticity for use in beam deflection calculations when shear deflection is required to be considered separately from bending deflection, such as when the span-to-depth ratio of the beam is small (see ANSI 117, *Standard Specification for Structural Glued Laminated Timber of Softwood Species*, for more information).
7. E = Reference modulus of elasticity in either the X-X or Y-Y direction for use in beam deflection calculations when layups are used as beams. The term is referred to as the apparent modulus of elasticity, E_{app}, in ANSI 117.
8. E_{min} = Minimum modulus of elasticity for use in beam stability and column stability calculations.

GLT – Glue-Laminated Timber panels

E_{app}

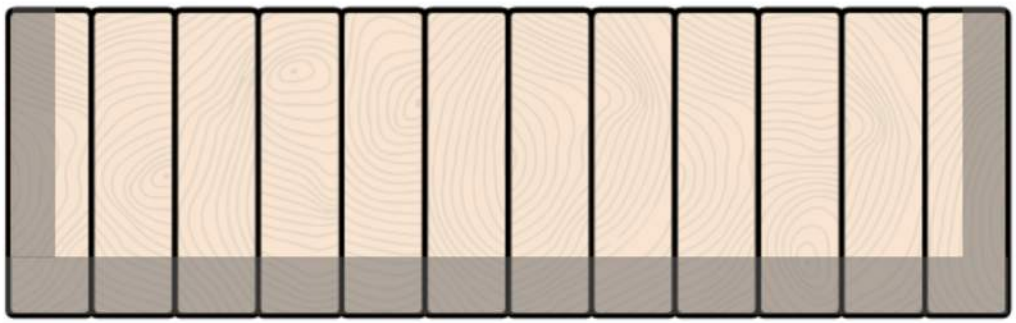
5B Adjustment Factors

Combination Symbol	Species	Grade	All Loading – Modulus of Elasticity – For Shear-Free Deflection Calculations E_{true} (10^6 psi)	All Loading – Modulus of Elasticity – For Beam Deflection Calculations $E^{(7)}$ (10^6 psi)	All Loading – Modulus of Elasticity – For Stability Calculations $E_{min}^{(8)}$ (10^6 psi)	[Compr]ession [Par]allel [to G]rain – 2 or 3 Laminations F_c (psi)	Bending about Y-Y Axis, Loaded Parallel to Wide Faces of Laminations – Bending – 4 or More Laminations F_{by} (psi)	Bending about Y-Y Axis – Bending – 3 Laminations F_{by} (psi)	Bending about Y-Y Axis – Bending – 2 Laminations F_{by} (psi)	Bending about Y-Y Axis – Shear Parallel to Grain(1)(2)(3) F_{vy} (psi)	Bending About X-X Axis, Loaded Perpendicular to Wide Faces of Laminations – Bending – 2 Laminations to 15 in. Deep(4) F_{bx} (psi)	Bending About X-X Axis – Shear Parallel to Grain(3) F_{vx} (psi)	Fasteners – Specific Gravity for Fastener Design G
Visually Graded Western Species													
1	DF	L3	1.6	1.5	0.79	1250	1450	1250	1000	230	1250	265	0.50
2	DF	L2	1.7	1.6	0.85	1600	1800	1600	1300	230	1700	265	0.50
3	DF	L2D	2.0	1.9	1.00	1900	2100	1850	1550	230	2000	265	0.50
4	DF	L1CL	2.0	1.9	1.00	1950	2200	2000	1650	230	2100	265	0.50
5	DF	L1	2.1	2.0	1.06	2100	2400	2100	1800	230	2200	265	0.50
14	HF	L3	1.4	1.3	0.69	1050	1200	1050	850	190	1100	215	0.43
15	HF	L2	1.5	1.4	0.74	1350	1500	1350	1100	190	1450	215	0.43
16	HF	L1	1.7	1.6	0.85	1500	1750	1550	1300	190	1600	215	0.43
17	HF	L1D	1.8	1.7	0.90	1750	2000	1850	1550	190	1900	215	0.43
22(5)	SW	L3	1.1	1.0	0.53	725	800	700	575	170	725	195	0.35
69	AC	L3	1.3	1.2	0.63	1100	1100	975	775	230	1000	265	0.46
70	AC	L2	1.4	1.3	0.69	1450	1400	1250	1000	230	1350	265	0.46
71	AC	L1D	1.7	1.6	0.85	1900	1850	1650	1400	230	1750	265	0.46
72	AC	L1S	1.7	1.6	0.85	1900	1850	1650	1400	230	1900	265	0.46
73	POC	L3	1.4	1.3	0.69	1200	1200	1050	825	230	1050	265	0.46

GLT – Glue-Laminated Timber panels

GLT Design includes:

» Fire Design per NDS Chapter 16 for beams exposed on three sides.



Char on 3 exposed sides, typically

DLT – Dowel Laminated Timber panels

DLT Design includes:

- » Proprietary testing by the DLT manufacturer produces stress values
- » Design values found in catalog or ICC report
- » Bending: $F_b(S_{eff})$ similar to CLT design
- » Shear: V, is in pounds per ft of panel width
- » Deflection: EI, combined for species and grade
- » Very few manufacturer’s at this time

DLT – Dowel Laminated Timber panels

ICC EVALUATION SERVICE®

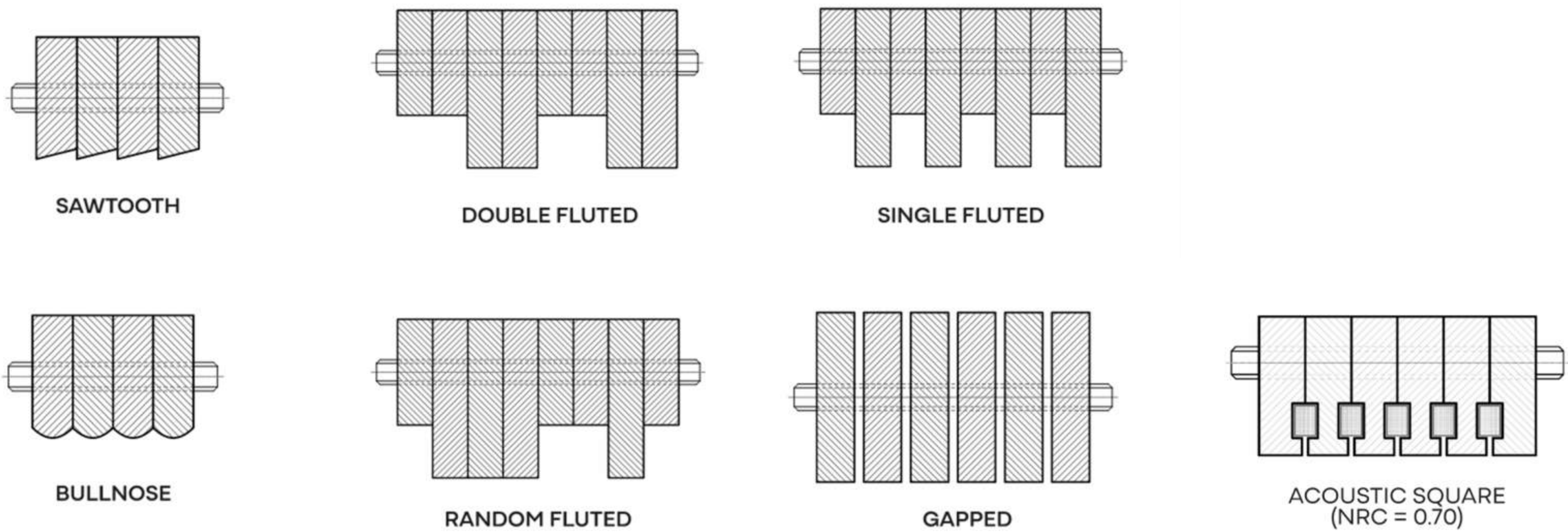
TABLE 1—REFERENCE DESIGN VALUES (ASD) FOR STRUCURECRAFT DOWEL-LAMINATED TIMBER DECKING [4,5,6]

SPRUCE-PINE-FIR DLT					
Grade	Nominal Size [1] (Panel Thickness) (in.)	$F_b(S_{eff})C_r$ or $F_b(S_{eff})C_FC_r$ [2,7] (lbf-ft/ft)	EI ($x10^6$ lbf-in.^{2}/ft)	V [3] (lbf/ft)	R [8] (lbf/ft-in.)
2100f-1.8E	2x4 (3.5)	4,880	77	2,970	5,100
	2x6 (5.5)	12,145	299	5,130	5,100
1950f-1.7E	2x8 (7.25)	18,315	648	7,020	5,100
Select Structural	2x4 (3.5)	4,360	64	2,970	5,100
	2x6 (5.5)	9,400	250	5,130	5,100
	2x8 (7.25)	14,085	572	7,020	5,100
	2x10 (9.25)	20,450	1,187	9,180	5,100
	2x12 (11.25)	27,965	2,136	11,340	5,100
No.1/No.2	2x4 (3.5)	3,050	60	2,970	5,100
	2x6 (5.5)	6,580	233	5,130	5,100
	2x8 (7.25)	9,860	534	7,020	5,100
	2x10 (9.25)	14,315	1,108	9,180	5,100
	2x12 (11.25)	19,575	1,993	11,340	5,100
No.3	2x4 (3.5)	1,745	51	2,970	5,100
	2x6 (5.5)	3,760	200	5,130	5,100
	2x8 (7.25)	5,635	457	7,020	5,100
	2x10 (9.25)	8,180	950	9,180	5,100
	2x12 (11.25)	11,185	1,709	11,340	5,100

DLT – Dowel Laminated Timber panels

DLT Design includes:

- Non-standard and Acoustical profiles can be tricky.
- Contact the manufacturer for design values for these profiles.

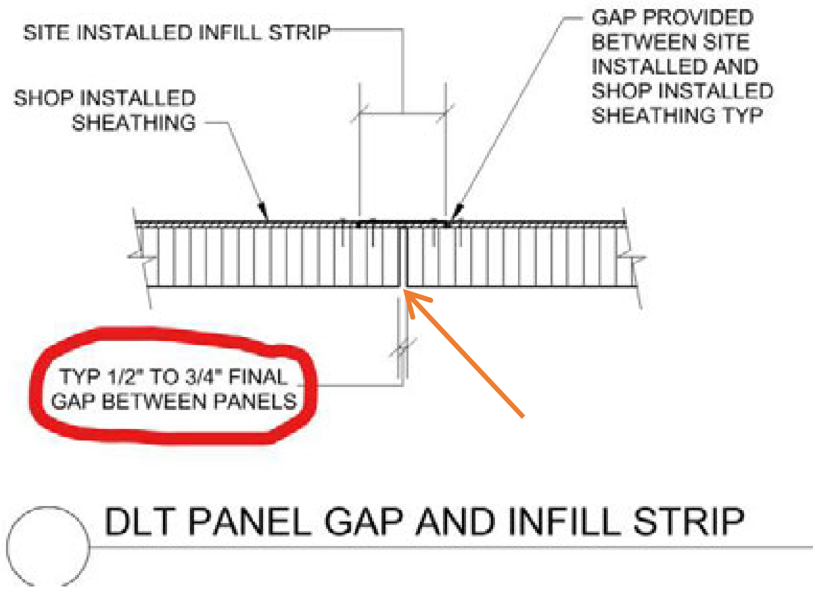


Credit: DowelLam

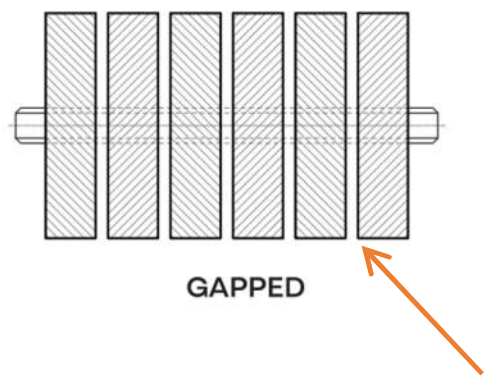
DLT – Dowel Laminated Timber panels

DLT Design includes:

- » Fire design: be mindful of gaps between panels (FDS 3.2.3)
- » Char depth, per FDS, shares NLT approach
- » Affected by panel profile as well



Credit: DowelLam



Credit: DowelLam

NLT – Nail Laminated Timber panels

NLT Design includes:

- Determine if finger-jointed or not, simple-span or random
- Design values found in the NDS Supplement Tables 4A thru 4C – Sawn Lumber
- F_b, F_v, E, similar to beam design
- Applicable adjustment factors from
  NDS Chapter 4
- Repetitive Member Factor, C_r often 1.15
  (NDS 4.5.9)
- Size Factor, C_F often greater than 1.0
  (NDS Supplement)

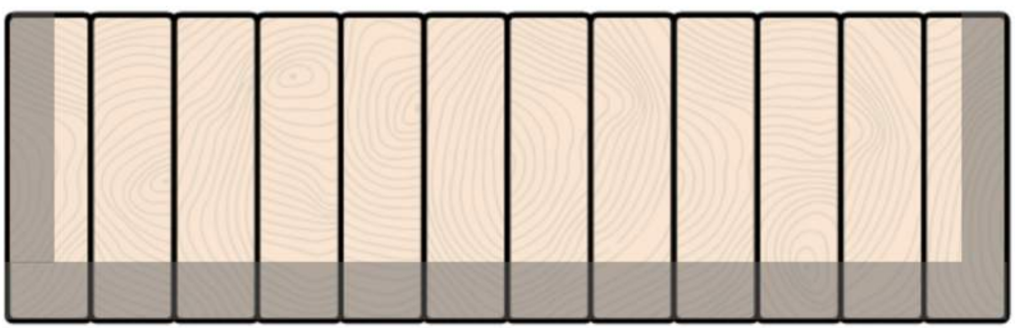
Table of Contents

Photo: Think Wood

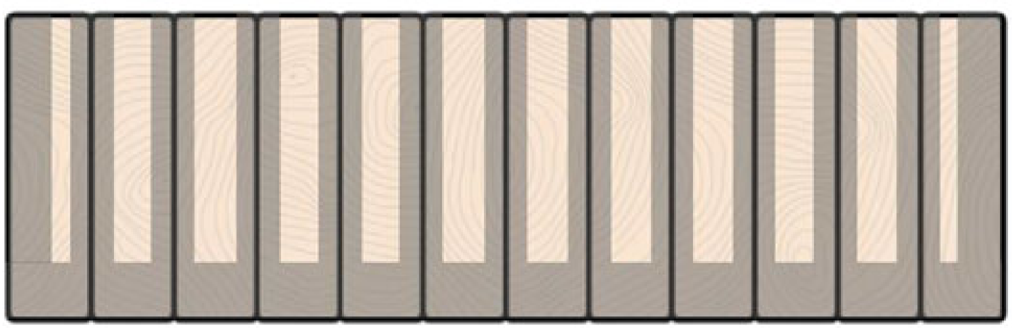
NLT – Nail Laminated Timber panels

NLT Design includes:

- Fire Design: uni-directional or bi-directional char
- NLT Guide talks more on this as well as our new paper “Fire Design of Mass Timber Structural Members: Demonstrating Fire Resistance Rating of Mass Timber Products”
- Design Example assumes uni-directional (NDS 16.3.1) similar to a beam



Uni-directional char
(bottom surface only)

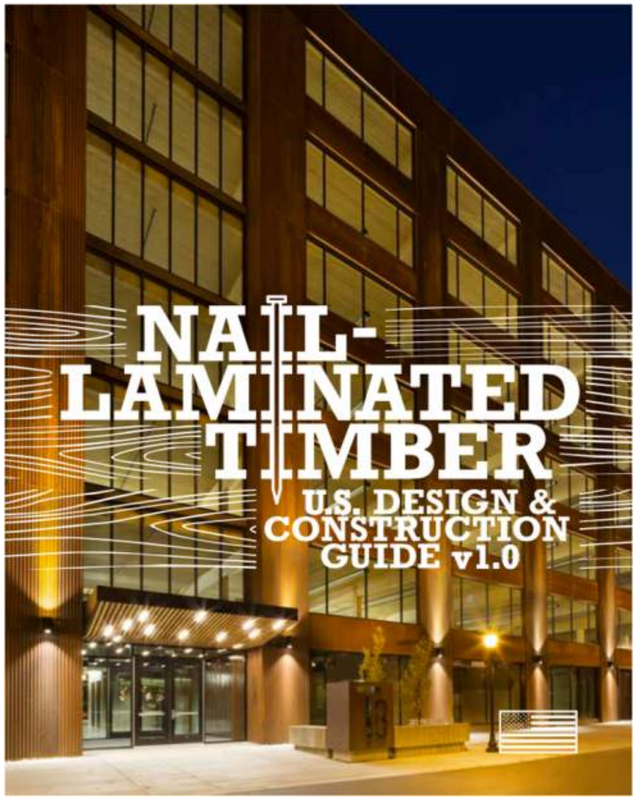


Bi-directional char
(bottom surface and between laminations)

NLT Structural Design

NLT Design Guide includes:

- » Architecture
- » Fire
- » Structure
- » Fluted Sections
- » Enclosure
- » Supply and Fabrication
- » Construction and Installation
- » Erection engineering
- » Free download from www.thinkwood.com



https://info.thinkwood.com/download/nlt-design-and-construction-guide-usa

Glulam Beam & Column Design

- Allowable building material in IBC Section 2303.1.3 when manufactured in accordance with ANSI/APA A190.1
- NDS Chapter 5 – Structural Glue Laminated Timber
- NDS Supplement – Tables 5A thru 5D design values
- Covered in many excellent sources:

  Timber Construction Manual (AITC),

  Design of Wood Structures (Breyer)

- American Institute of Timber Construction ->
  Pacific Lumber Inspection Bureau (PLIB.org)

Table of Contents

Glulam Beam Design

» Reduction for Notches, NDS Section 5.3.10

The applicable adjustment factors for shear in NDS Table 5.3.1 are:

- load duration, C_D
- wet service factor, C_M
- temperature factor, C_t and
- ***shear reduction factor, C_{vr}.***

5.3.10 Shear Reduction Factor, C_{vr}

The reference shear design values, F_{vx} and F_{vy}, shall be multiplied by the shear reduction factor, $C_{vr} = 0.72$ where any of the following conditions apply:

1. Design of non-prismatic members.
2. Design of members subject to impact or repetitive cyclic loading.
3. Design of members at notches (3.4.3.2).
4. Design of members at connections (3.4.3.3, 11.1.2, 11.2.2).

Photo: Adam Hunter

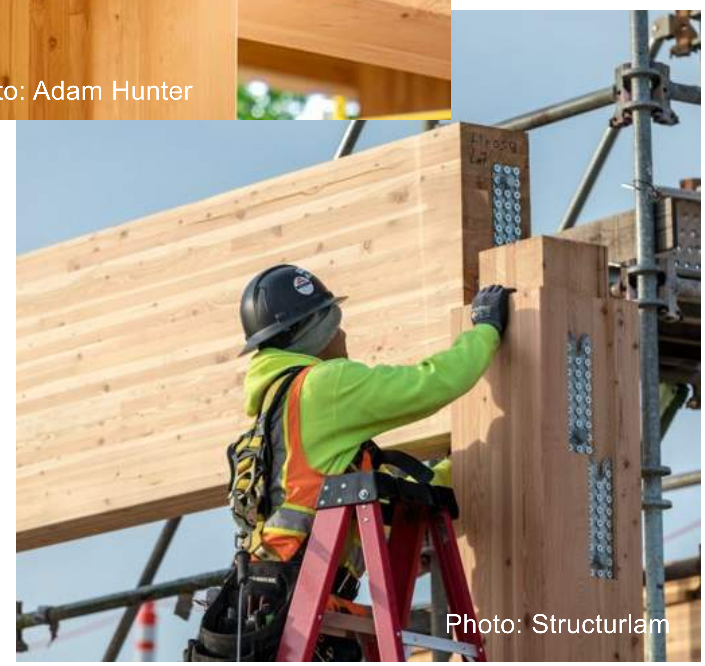


Photo: Structurlam

Glulam Column Design

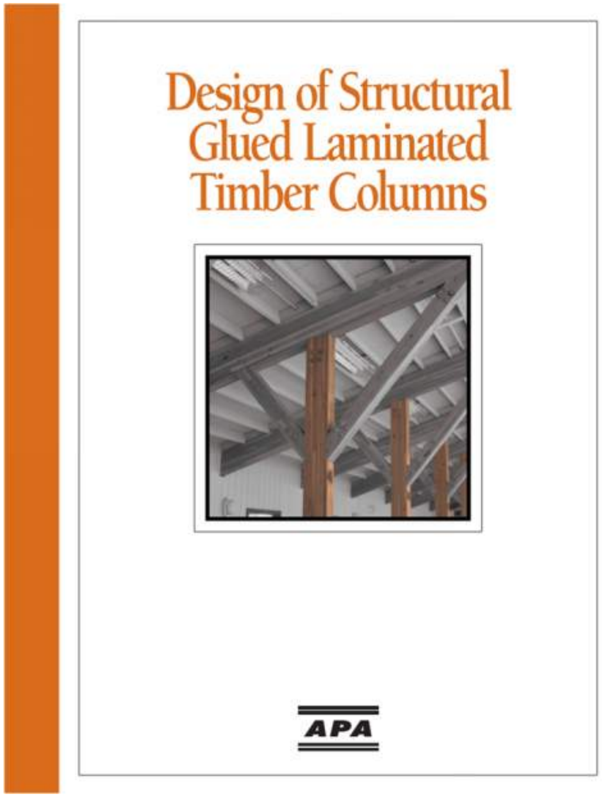
Start with a basis of design column size and then check actual loading conditions to assess adequacy, assuming a load duration of 1.0 and a maximum eccentricity of d/6.

Design steps include:

- Preliminary Glulam column size- Table 9 of APA's Y240 – Design of Structural Glued Laminated Timber Columns
- Glulam column slenderness ratio
- Glulam column axial and buckling
- Glulam column axial and buckling – structural fire resistance.

Table G1 in NDS Appendix G provides effective length factors for different column end support conditions.

Per NDS Section 3.7.1.4, the slenderness ratio (Le/d) should not exceed 50.



https://www.apawood.org/publication-search?q=Y240&tid=1

Glulam Beam & Column Design

» Fire Design per NDS Chapter 16 included

Main differences from a non-fire check:
• Uses reduced beam cross-sectional dimensions.
• Adjustment Factors for Fire Design per NDS Table 16.3.3

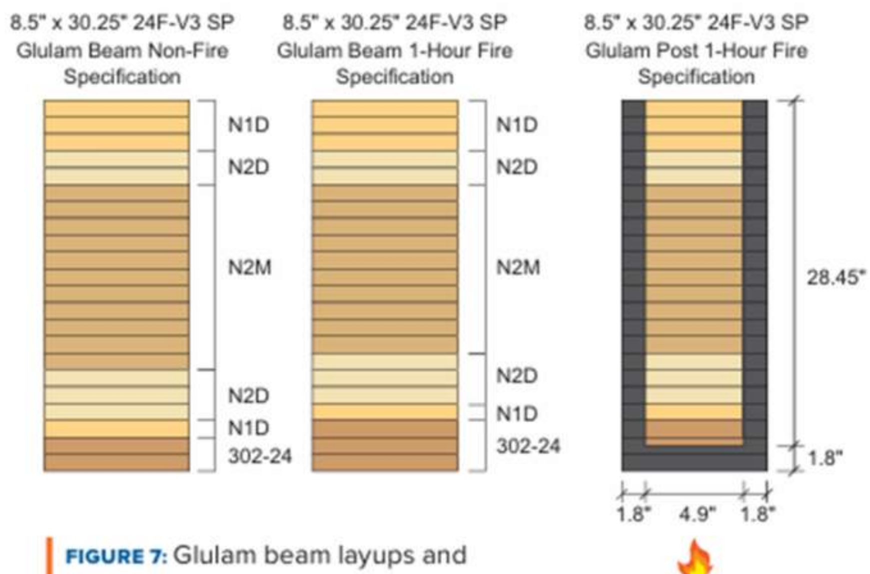


FIGURE 7: Glulam beam layups and calculated post-fire dimensions

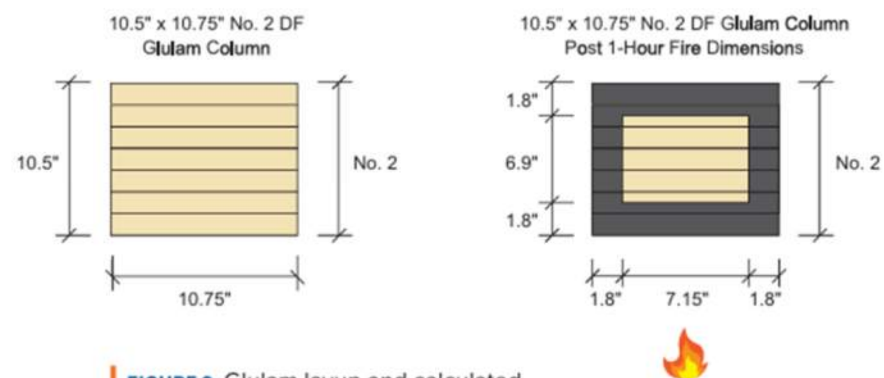


FIGURE 9: Glulam layup and calculated post-fire dimensions

Connections

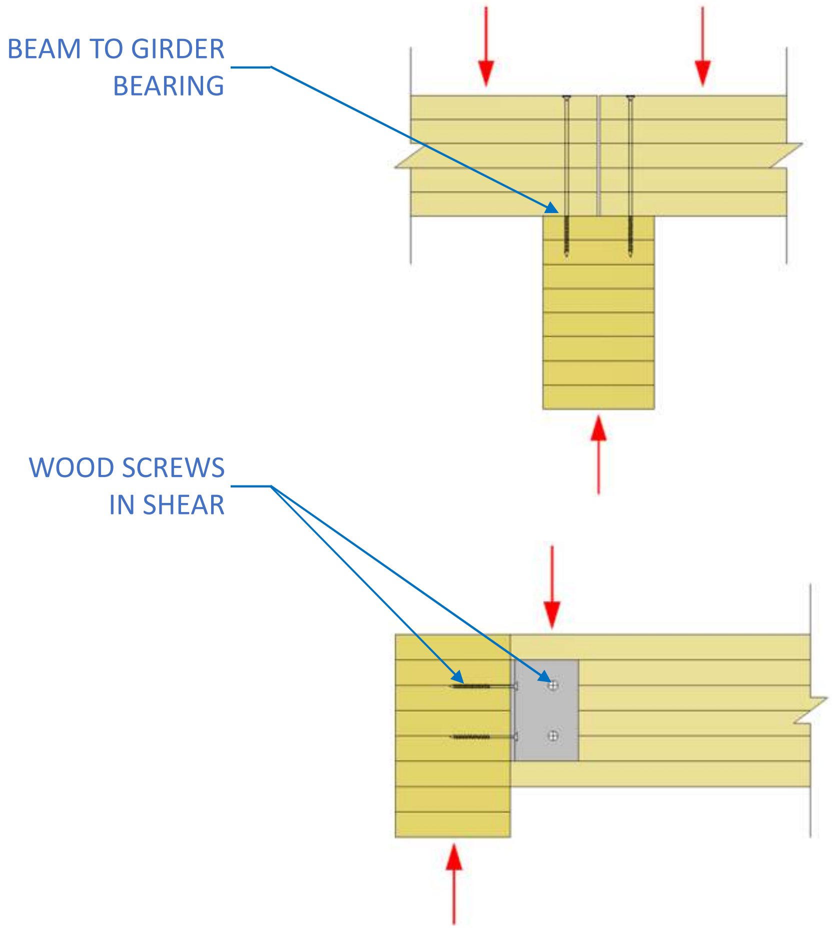
Photo: Adam Hunter

Photo: Structurlam

Connections

Wood 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



Connections

Wood Design Reminders

- Bearing is Better than Dowel-Type Fasteners
- Parallel is Better than Perpendicular to Grain
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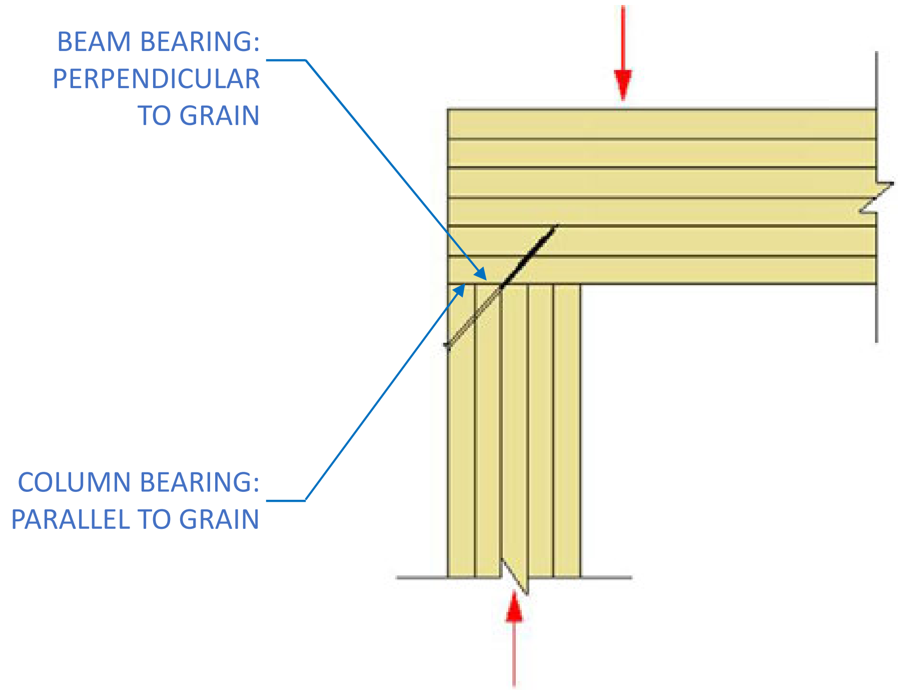
- Notch with Care

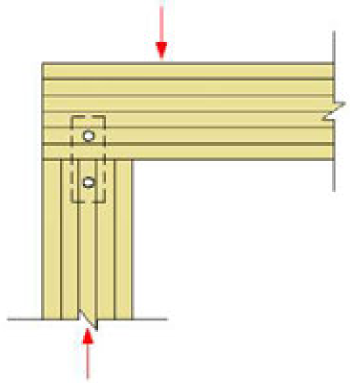


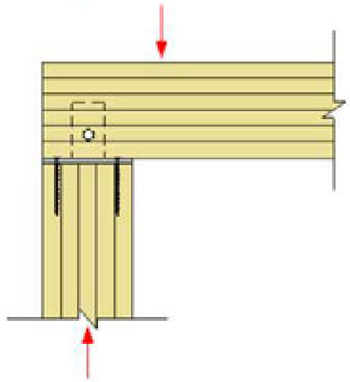
Connections

Wood Design Reminders

2018 AWC NDS, Section 12.2.2.3

- 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



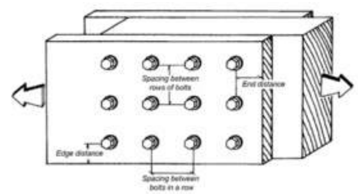


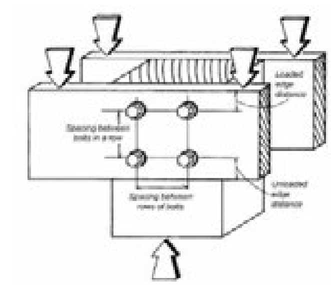
Connections

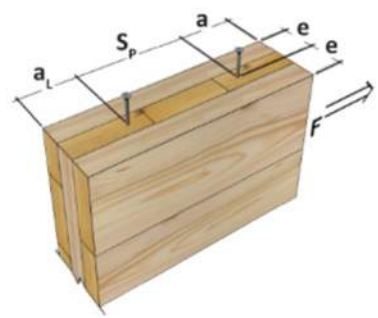
Wood Design Reminders

- 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 12.5
- Manufacturer's Literature





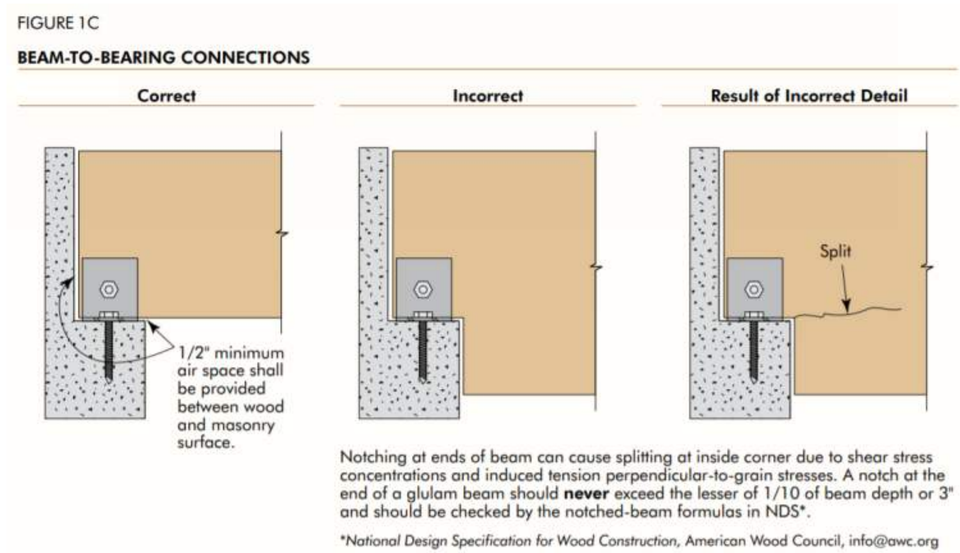


Connections

Wood 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*
- MTC Solutions *ASSY Screws as Tensile Reinforcement in Notched Beams*

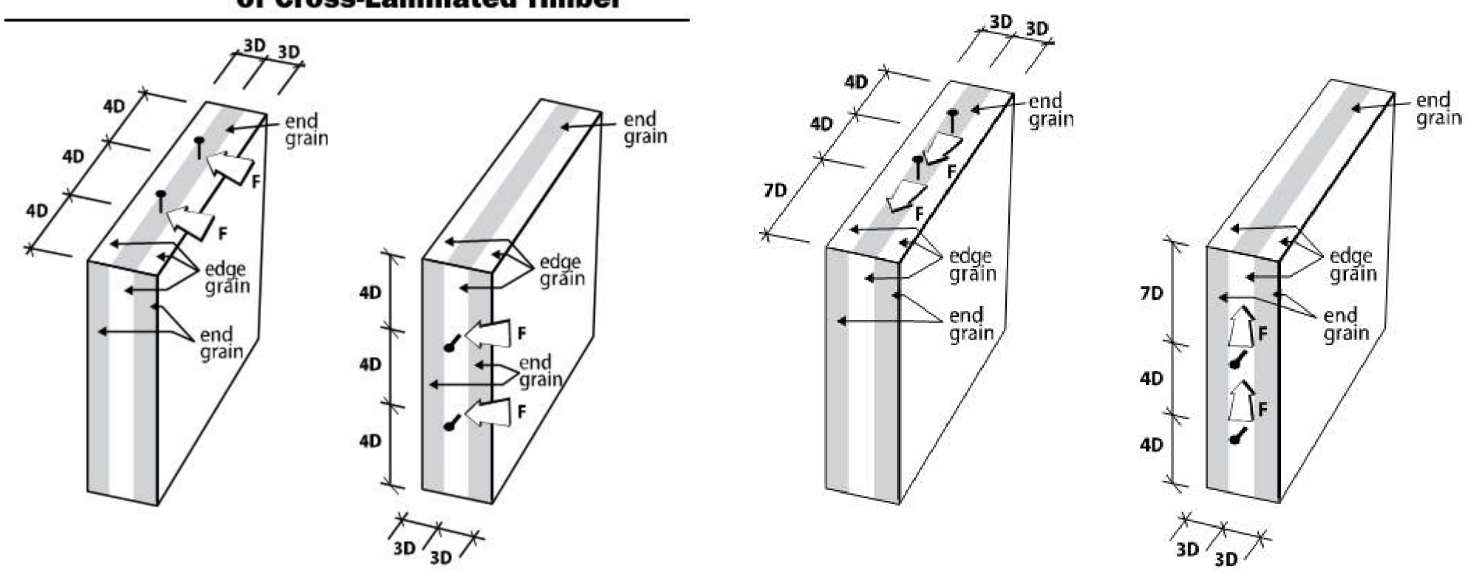


(APA T300)

Connections

- » Connectors for CLT in the NDS – Chapter 12
- » Dowel type fasteners: lag screws, nails, bolts
- » Reductions for end distance, edge distance and fastener spacing

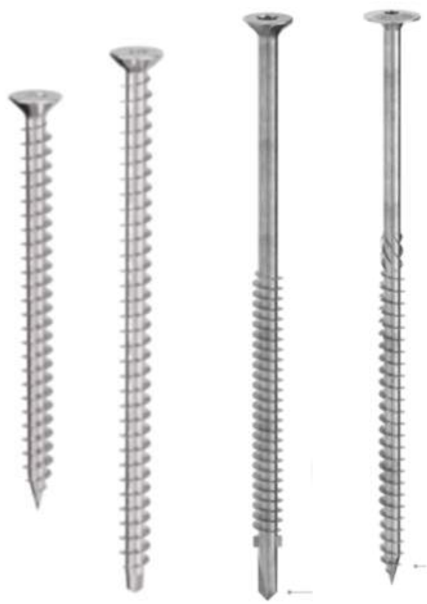
Figure 12I **End Distance, Edge Distance and Fastener Spacing Requirements in Narrow Edge of Cross-Laminated Timber**



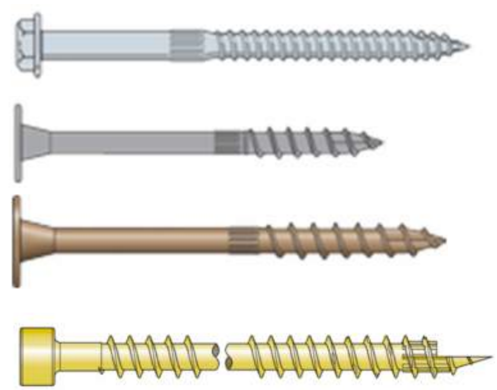
Direction of loading perpendicular to the plane of CLT

Direction of loading parallel to the plane of CLT

Proprietary Products



Source: rothoblaas



Source: Simpson Strong-Tie

Variety of Self Tapping Screws

MASS TIMBER CONNECTIONS INDEX

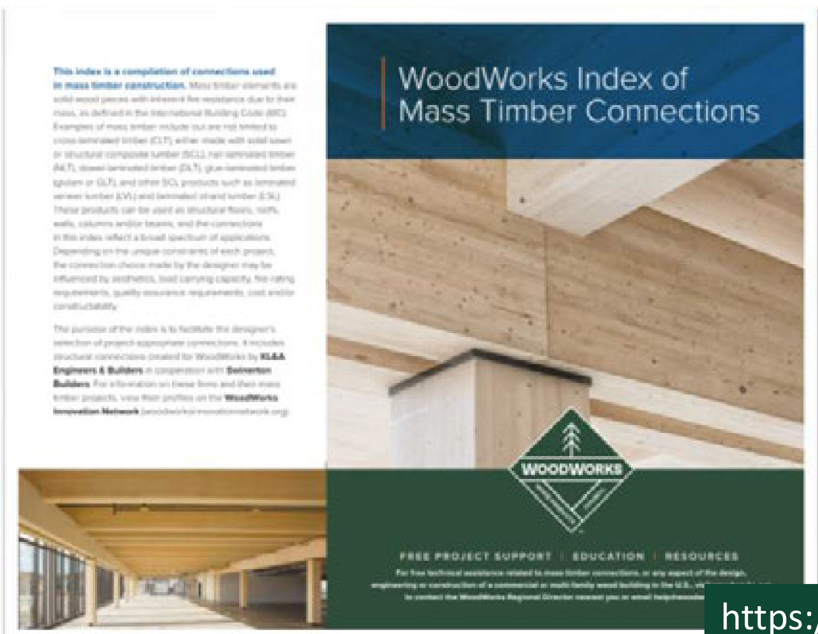
WOODWORKS
WOOD PRODUCTS COUNCIL

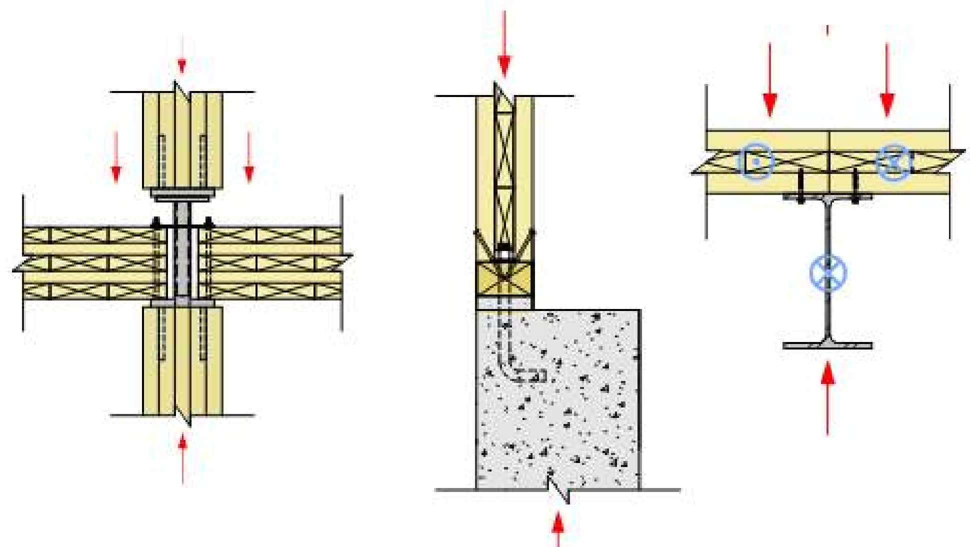
KL&A
Engineers & Builders

OZ
ARCHITECTURE
URBAN DESIGN
INTERIOR DESIGN

SWINERTON
MASS TIMBER

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/

Fire Design of Mass Timber

- Fire Resistance Requirements for Mass Timber Members
- Found in Table 601 IBC – vary by building type and structural usage
- Fire Resistance Ratings can be determined through:
- Testing –

  -IBC 703.2.1 Tested Assemblies. (ASTM E119 or UL263)
- Calculations –

  -IBC Section 722 – Calculated Fire Resistance

  -Chapter 16 of the NDS Char calculations along with AWC's Fire Design Spec (FDS)
- Examples are provided within the new Woodworks publication:

  -*Structural Design of Mass Timber Elements: Gravity Design Examples*

  -Fire design checks for mass timber panels, beam, column included

Fire Resistance Requirements in the IBC

» 2024 IBC Table 601 (Same as 2021 IBC)

SECTION 601—GENERAL

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

For SI: 1 foot = 304.8 mm.

a. Roof supports: Fire-resistance ratings of primary structural frame and bearing walls are permitted to be reduced by 1 hour where supporting a roof only.

b. Except in Group F-1, H, M and S-1 occupancies, fire protection of structural members in roof construction shall not be required, including protection of primary structural frame members, roof framing and decking where every part of the roof construction is 20 feet or more above any floor or mezzanine immediately below. Fire-retardant-treated wood members shall be allowed to be used for such unprotected members.

c. In all occupancies, heavy timber complying with Section 2304.11 shall be allowed for roof construction, including primary structural frame members, where a 1-hour or less fire-resistance rating is required.

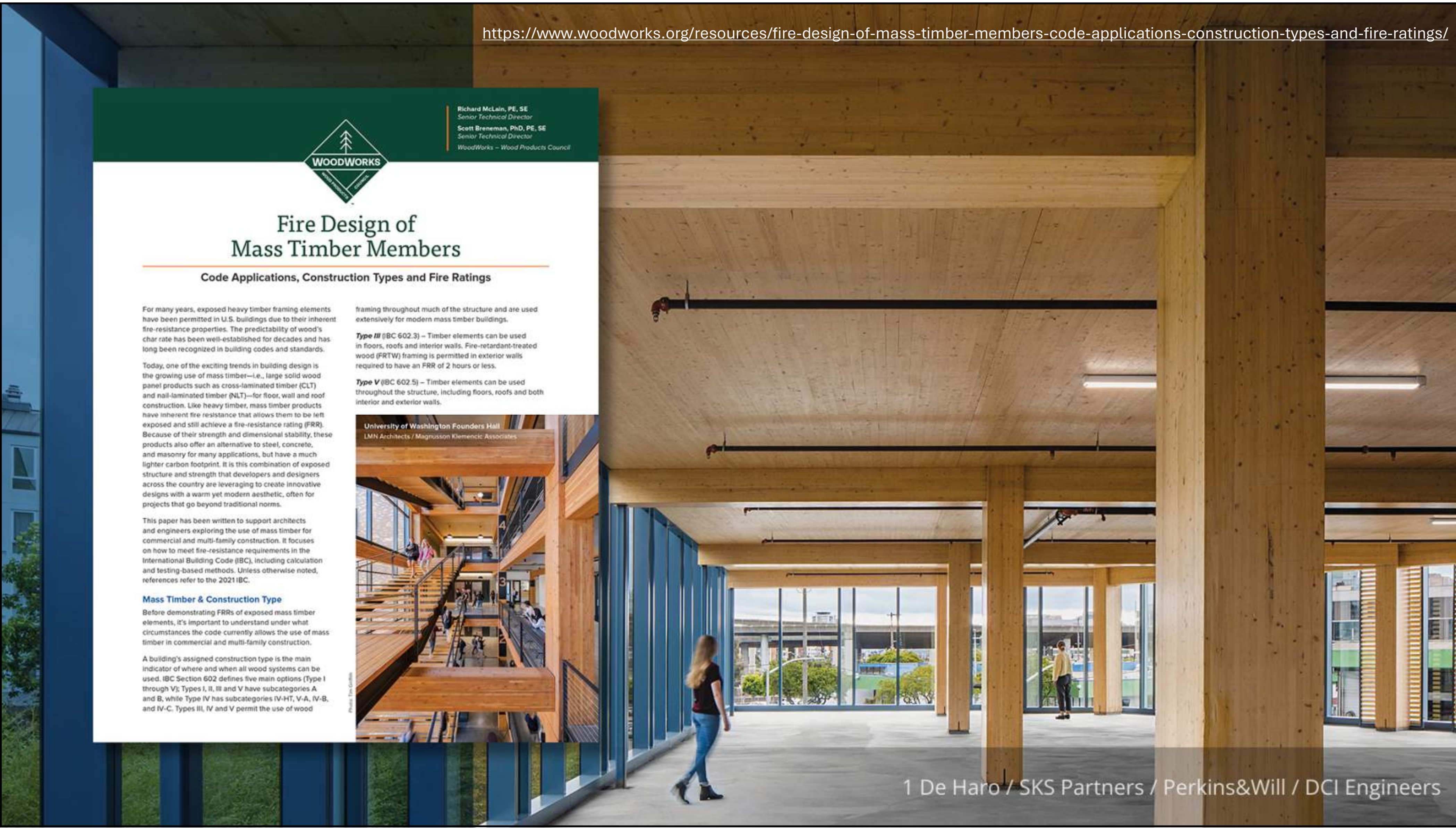
d. Not less than the fire-resistance rating required by other sections of this code.

e. Not less than the fire-resistance rating based on fire separation distance (see Table 705.5).

f. Not less than the fire-resistance rating as referenced in Section 704.9.

g. Heavy timber bearing walls supporting more than two floors or more than a floor and a roof shall have a fire-resistance rating of not less than 1 hour.

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, V-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

Scott Breneman, PhD, PE, SE
WoodWorks – Wood Products Council

WOODWORKS

Fire Design of Mass Timber Structural Members

Demonstrating Fire-Resistance Ratings of Mass Timber Products

Traditionally, the role of the structural engineer on building projects has focused on structure-related tasks—member sizing, connection detailing, general notes, and specifications for structural components. Design criteria such as fire-resistance ratings (FRRs), acoustics, and aesthetics have primarily been the architect's domain. However, when it comes to mass timber, the structure often contributes to the building's passive fire resistance. This can happen when the structure is functioning as an exposed finish or when partial fire resistance is provided by a covering over the timber and the rest is provided by the timber itself. This combination of structure, finish, and fire resistance makes the mass timber design process a necessarily collaborative effort between architect and engineer.

This paper presents several methods for demonstrating the FRR of a mass timber element, particularly when the mass timber structural members are required to be fire-resistance-rated. These elements include horizontal assemblies (floors, roofs) and walls, which serve both structural and fire containment purposes, and structural members such as beams and columns where the purpose is mainly structural. While much of the information is introductory, it covers how to evaluate the suitability of tested horizontal cross-laminated timber (CLT) assemblies with reduced load ratings for different spans and loading conditions and the different models for calculating structural FRRs of nail-laminated timber (NLT).

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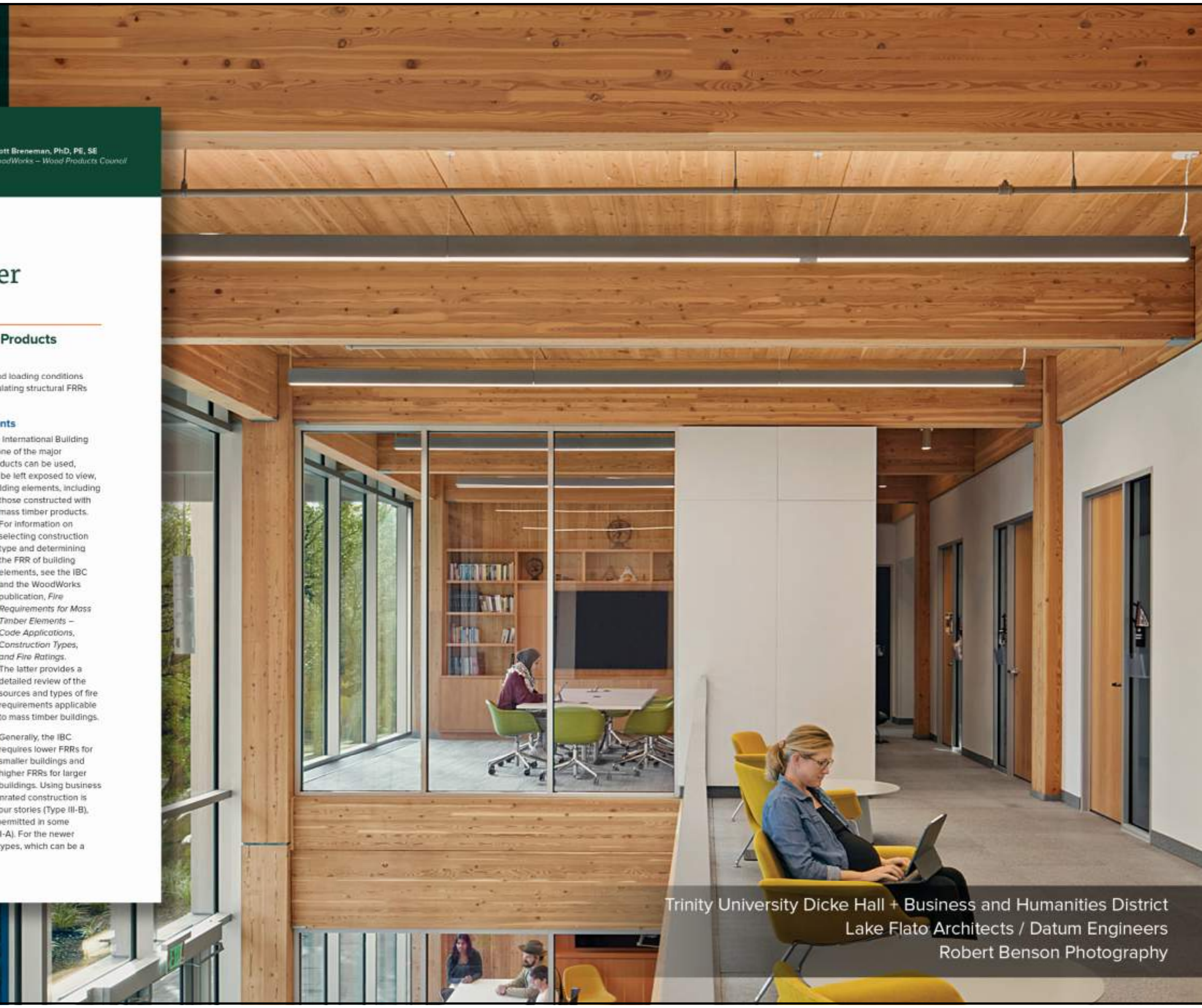
Lake Flato Architects / Datum Engineers

Robert Benson Photography

Sources of FRR Requirements

For buildings designed under the International Building Code (IBC), construction type is one of the major determinants of which timber products can be used, whether the timber products can be left exposed to view, and the FRR requirements for building elements, including those constructed with mass timber products. For information on selecting construction type and determining the FRR of building elements, see the IBC and the WoodWorks publication, *Fire Requirements for Mass Timber Elements – Code Applications, Construction Types, and Fire Ratings*. The latter provides a detailed review of the sources and types of fire requirements applicable to mass timber buildings.

Generally, the IBC requires lower FRRs for smaller buildings and higher FRRs for larger buildings. Using business occupancies (B) as an example, unrated construction is allowed in some buildings up to four stories (Type III-B), and 1-hour-rated construction is permitted in some buildings up to six stories (Type III-A). For the newer Type IV-C and IV-B construction types, which can be a



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Lake Flato Architects / Datum Engineers
Robert Benson Photography

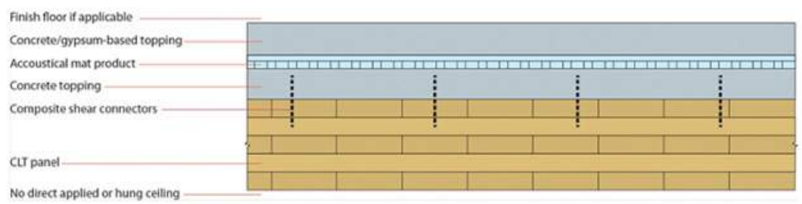
NEW ONLINE TOOL

Mass Timber Fire & Acoustic Database

Search tested and approved assemblies

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

CLT-Concrete Composite Floor Assemblies, Ceiling Side Exposed



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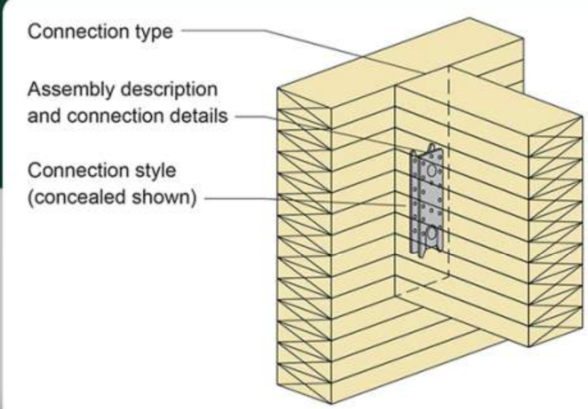

< Back to Mass Timber Fire & Acoustic Database

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

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

Lateral Systems

- Concrete shear wall or frame systems
- Steel braced frames
- CLT Shear walls
- Wood Light-Frame shear walls & Cold-Formed Steel
- CLT Rocking Walls and Timber Braced Frames

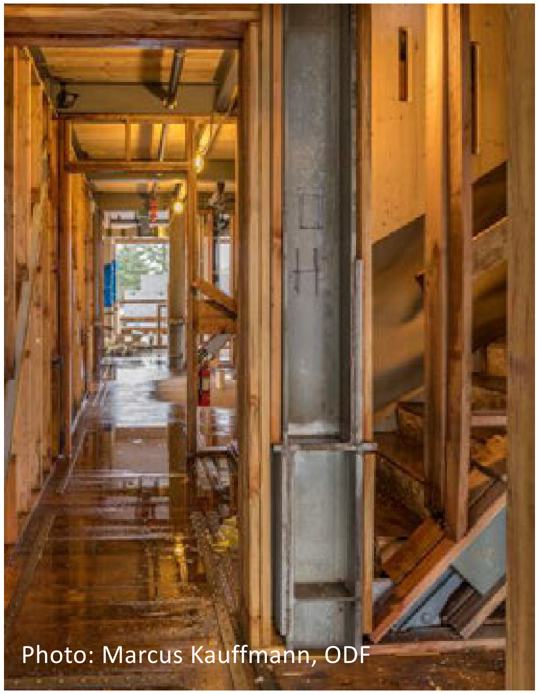

Photo: Marcus Kauffmann, ODF

Photo: Alex Schreyer

Credit: KL&A Engineers & Builders

CLT Shear Walls Options in the U.S.

See the WoodWorks Expert Tip

CLT Shear Wall Options in the U.S.

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

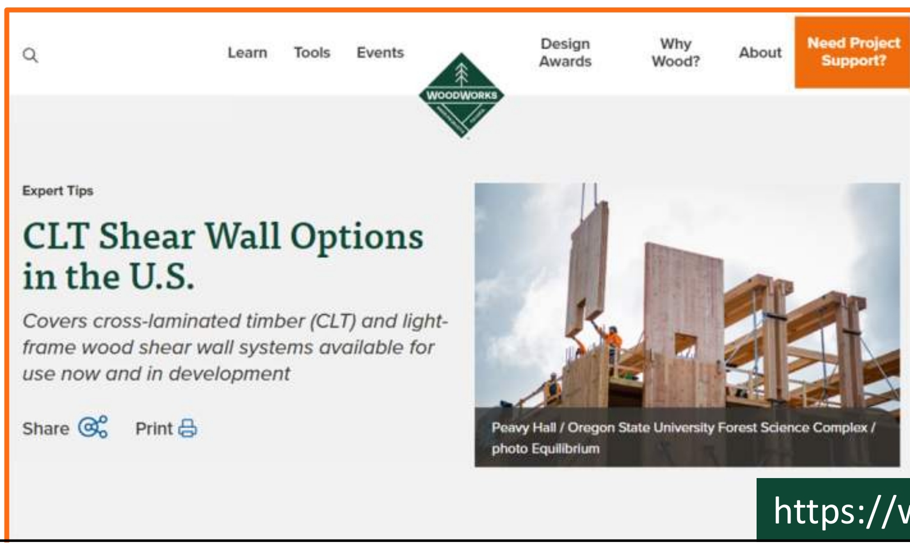

TABLE 1 – Timber shear wall structural parameters

System	Standards	Seismic Design Coefficients			Structural Height Limit per Seismic Design Category (ft)			
		R	Ω_0	C_d	A	B	C	D
SDPWS Appendix B CLT shear walls	SDPWS 2021 ASCE 7-22	3	3	3	NL	65	65	65
(with shear resistance provided by high-aspect-ratio panels only)		4	3	4	NL	65	65	65
SDPWS Section 4.6.3 Exception CLT shear walls	SDPWS 2021	1.5	2.5	1.5	NL	65	NP	NP
Mass timber rocking shear walls	Targeting SDPWS 2027 and ASCE 7-28	TBD (> 5)	TBD	TBD	NL	TBD (> 100 ft)		
Oregon SAM CLT path 2 shear walls	Oregon SAM 15-01	2	2.5	2	NL	65	65	65
Light-frame wood walls sheathed with WSPs	SDPWS ASCE 7	6.5	3	4	NL	NL	NL	65

NL = No Limit
NP = Not permitted

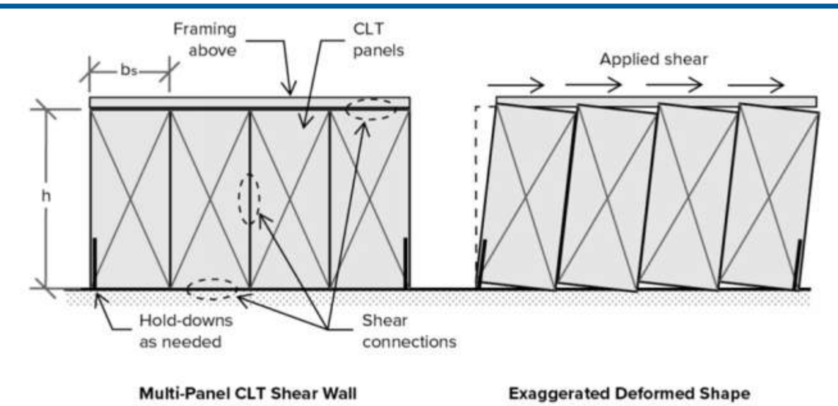

FIGURE 1: Multi-panel CLT shear wall construction*

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


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

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Course Name: lateral system
Learning Hours:
Provider: WoodWorks
Credits:

Keyword Tags: No selection
Enter tags...

Search
Clear

SORT BY NAME | DATE

Offset Diaphragms and Shear Walls

Lateral force resisting systems in in today's structures are much more complex than they were several decades ago, incorporating multiple horizontal and vertical offsets in the diaphragms, multiple irregularities, and fewer lateral resisting elements. This

Learning Hours: 1
Provider: WoodWorks
Credits: AIA LU/HSW, ICC CEU

UMass Design Building: A Firsthand Account from Design through Owner Occupancy

Completed in early 2017, the Design Building at the University of Massachusetts Amherst is the first of its kind in the US. At four stories and 87,000 sf, this mass timber project features a glued-laminated (glulam) timber column-and-beam frame, mass timber

Learning Hours: 1
Provider: WoodWorks
Credits: AIA LU/HSW, ICC CEU

Designing Light-Frame Wood Structures Over Podiums: Wind Considerations

This course highlights wind design considerations for mid-rise light-frame wood buildings over concrete podiums, a common structural configuration in urban residential development. Through an abbreviated design example, participants will explore

Learning Hours: 1
Provider: WoodWorks
Credits: AIA LU/HSW, ICC CEU

https://www.woodinstitute.org

QUESTIONS?

This concludes The American Institute of Architects Continuing Education Systems Course

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CLT Shear Wall Options in the U.S.


Expert Tips

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

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

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

Structural Design of Mass Timber Elements: Gravity Design Examples

2.4.6 CLT Deflection Check – Total Load

For total load deflection, use the same approach as the live load deflection check. First check the panel for total loads with the deflection equations above, and then perform a long-term (creep) deflection check.

To account for the long-term effects of creep in a CLT floor/roof panel, apply a creep factor, K_{cr}, to the deflection associated with the long-term loads (dead loads). Add the result to the short-term load deflection (live loads) to arrive at a final total. Reference APA's Technical Topic 123 (TT-123) for additional commentary, as well as AWC's FAQ page on long-term deflection.[1]
The equation is:

$$\Delta_T = K_{cr}\Delta_{LT} + \Delta_{ST} \qquad \textit{NDS Equation 3.5-1}$$

Where:

- Δ_T = Total load deflection
- Δ_{ST} = Deflection due to short-term loading (live loads)
- Δ_{LT} = Immediate deflection due to long-term loading (dead load)
- K_{cr} = 2.0 for CLT in dry service conditions per NDS Section 3.5

The total dead load on the panels includes the superimposed dead load, partition load, and panel self-weight = 30 + 15 + 18 = 63 psf.

Estimate of total deflection including creep:

$$\Delta = (2)\left[0.013\left(\frac{\left(\frac{63}{12}\right)((16.5)(12))^4}{440\text{x}10^6}\right) + 0.15\left(\frac{\left(\frac{63}{12}\right)((16.5)(12))^2}{0.92\text{x}10^6}\right)\right]$$
$$+\left[0.013\left(\frac{\left(\frac{40}{12}\right)((16.5)(12))^4}{440\text{x}10^6}\right) + 0.15\left(\frac{\left(\frac{40}{12}\right)((16.5)(12))^2}{0.92\text{x}10^6}\right)\right] = 0.47 + 0.06 + 0.15 + 0.02 = 0.7 \text{ in.}$$

Alternatively, we can use the EI_{app} calculated above to get the same result:

$$\Delta_T = (2)\left[0.013\left(\frac{\left(\frac{63}{12}\right)((16.5)(12))^4}{386\text{x}10^6}\right)\right] + \left[0.013\left(\frac{\left(\frac{40}{12}\right)((16.5)(12))^4}{386\text{x}10^6}\right)\right] = 0.54 + 0.17 = 0.71 \text{ in.}$$

Table of Contents

Structural Design of Mass Timber Elements: Gravity Design Examples

2.4.7 CLT Vibration Check

While there are several methods for checking CLT floor vibration, the following approach, developed by researchers at FPInnovations and included in the WoodWorks publication, *U.S. Mass Timber Floor Vibration Design Guide*, is a simple way to design CLT floors for occupant comfort related to walking excitation. In this method, a recommended span limit for a CLT panel is calculated based on key variables, using the following equation:

Simplifying the first term, the equation is:

$$L_{lim} \leq \frac{1}{13.34}\left(\frac{(EI_{eff})^{0.293}}{w^{0.122}}\right) \qquad L_{lim} \leq 0.075\left(\frac{(EI_{eff})^{0.293}}{w^{0.122}}\right)$$

Where:

- L_{lim} = Panel span limit (ft)
- w = CLT self-weight (psf)
- EI_{eff} = CLT stiffness (EI_{eff} = 440 x 10^6 lb-in.^{2}/ft for this example as previously noted)

If not provided by the CLT manufacturer, panel self-weight can be calculated using the following equations. First, the moisture-adjusted specific gravity of the panel is:

$$\bar{\rho} = \left(\frac{G}{1+G(0.009)MC}\right)\left(1+\frac{MC}{100}\right) \qquad \text{NDS Supplement Equation 3.1.3}$$

Where:

- $\bar{\rho}$ = Reference-specific gravity of wood species in the panel, per NDS Supplement
- MC = In-service moisture content of CLT

MC is commonly assumed to be 12% for two reasons:

- PRG 320 requires that CLT be manufactured with input lumber having an MC of 12% +/- 3%.
- An in-service equilibrium MC of 10-12% is common for interior, conditioned spaces.

For more information on the moisture content of wood as a function of temperature and relative humidity, see Table 4-2 of the U.S. Forest Service *Wood Handbook* (USDA, 2021).

Table of Contents

CLT Diaphragm Design for Wind and Seismic Resistance

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.

Catalyst in Spokane Washington

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_s, 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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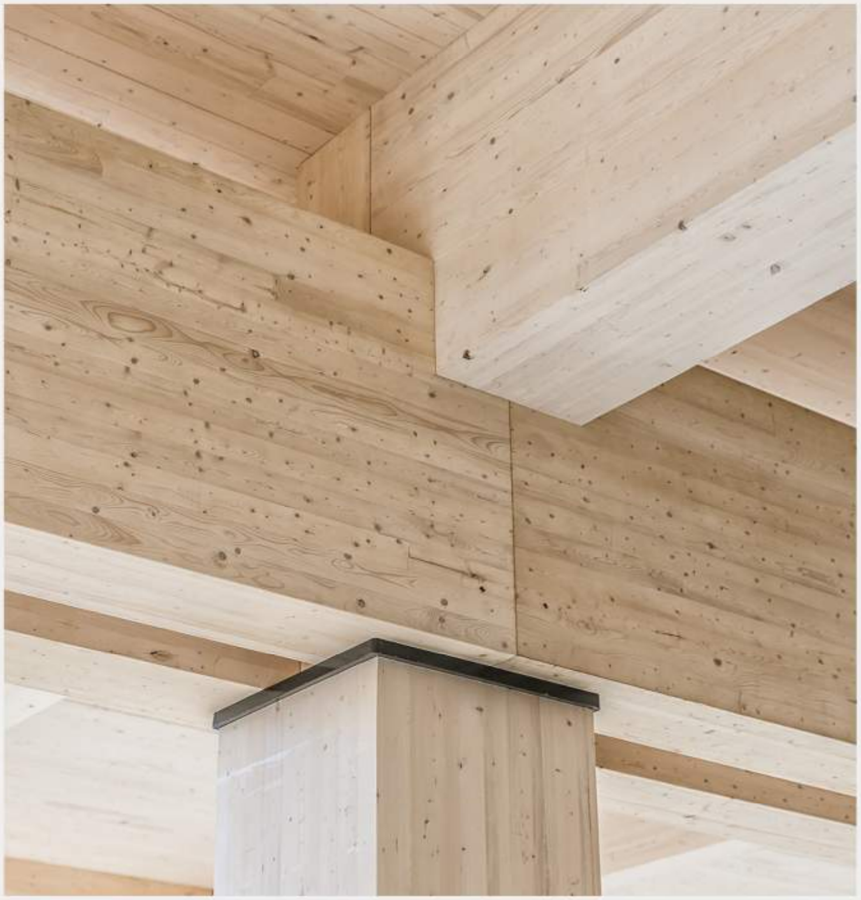
Timberlab

Highlights important provisions for SDPWS 2021 for CLT diaphragm design

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

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/

Fire Resistance Requirements in the IBC


Fire Design of Mass Timber Members

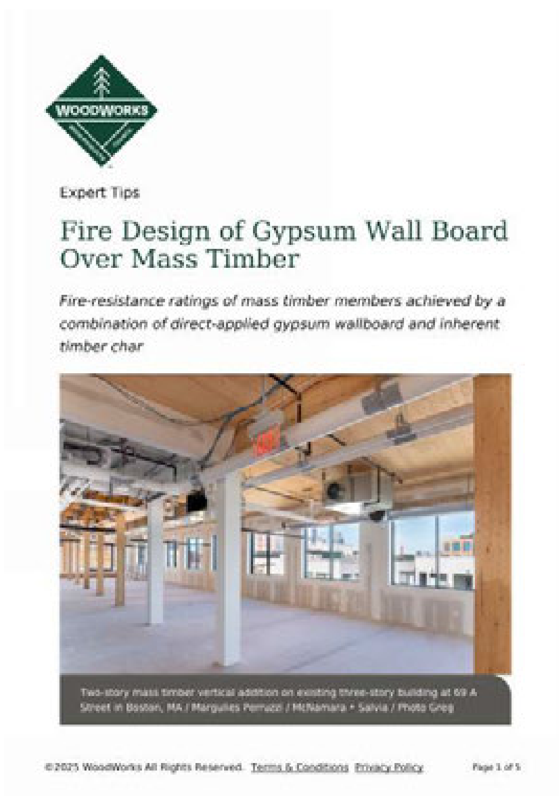
Code Applications, Construction Types and Fire Ratings

Mass Timber & Construction Type

Focuses on how to meet fire resistance requirements in the IBC through tested and calculated methods.

https://www.woodworks.org/resources/fire-design-of-mass-timber-members-code-applications-construction-types-and-fire-ratings/

Fire Resistance Ratings – Calculated Assemblies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Expert Tips

Fire Design of Gypsum Wall Board Over Mass Timber

Fire-resistance ratings of mass timber members achieved by a combination of direct-applied gypsum wallboard and inherent timber char

Two-story mass timber vertical addition on existing three-story building at 69 A Street in Boston, MA / Margulies Perruzzi / McNamara • Salvia / Photo Greg

Fire resistance ratings of mass timber members achieved by a combination of direct-applied gypsum wallboard and inherent char

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

Connections

Wood 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

Fluted NLT Design

$K_{section}$ is always <1 and applied assuming full panel depth of x_1

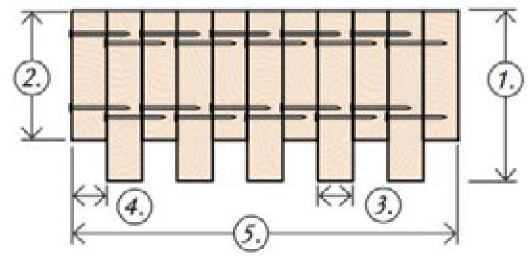
STIFFNESS ($K_{section.E}$)	BENDING ($K_{section.b}$)	SHEAR ($K_{section.v}$)
$K_{section.E} = X_1 + X_2 \left[\frac{d_2}{d_1}\right]^3$	$K_{section.b} = X_1 + X_2 \left[\frac{d_2}{d_1}\right]^3$	$K_{section.v} = X_1$

Example: 2x4 and 2x6 alternating lams

$$x_1 = x_2 = 0.5$$

$$K_{section,b} = 0.5 + 0.5\left[\frac{3.5}{5.5}\right]^3 = 0.63$$

See NLT Design & Construction Guide for Details



⑥ $x_i = \frac{n_i b_{lam\ i}}{b_{panel}}$

Figure 4.3: *Staggered NLT Cross Section*

Key

1. *NLT deep lamination depth (d_1)*
2. *NLT shallow lamination depth (d_2)*
3. *NLT deep lamination thickness (b_{lam1})*
4. *NLT shallow lamination thickness (b_{lam2})*
5. *NLT panel width (b)*
6. *Ratio of lamination depths (x_i), where n_i = the number of laminations of depth d_i*

Fire Resistance Ratings – Tested Assemblies

» Mass Timber Fire & Acoustic Database: Fire Resistance

< Back to Mass Timber Fire & Acoustic Database

Application Type

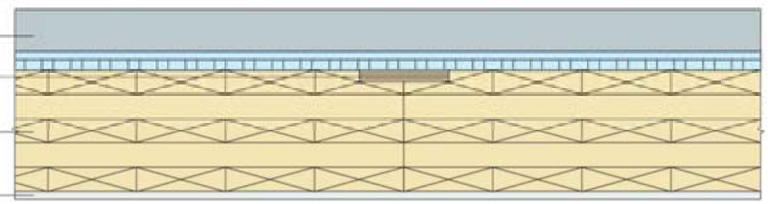
- ☐ Fire-Resistance Rated Mass Timber Floor/Roof Assemblies 30
- ☐ Fire-Resistance Rated Mass Timber Wall Assemblies 26
- ☐ Firestop Systems For Penetrations in Mass Timber Assemblies 57
- ☐ Fire-Resistance Rated Mass Timber Connections 21
- ☐ Perimeter Fire Containment Systems in Mass Timber Structures 5
- ☐ Noncombustible Protection of Mass Timber Building Elements 4

Mass Timber Panel

- ☐ CLT 108
- ☐ CLT (SCL) 1
- ☐ NLT 3
- ☐ DLT 3
- ☐ GLT 2
- ☐ SCL 1
- ☐ T&G

Number of Layers

Fire-Resistance Rated Mass Timber Floor/Roof Assemblies



Fire-resistance ratings of assemblies are demonstrated through fire-resistance tests, recognized calculations, or approved alternatives. The IBC recognizes US testing standards ASTM E119 and UL 236 while the Canadian standard ULC S101 has the same fire exposure and performance criteria. Fire-resistance ratings developed using these standards may be acceptable to building officials in either country.

Mass Timber Panel	Structural Grade	Exposed Side Protection	Unexposed Side Protection	Panel Connection	Load Rating	Fire-Resistance Rating (Hours)	Test Protocol	Method of Compliance
3-layer 4.13" (105mm) CLT	ANY	None	None	TBD	Varies, Determined by Calculation	1	ASTM E119	Calculated Fire-Resistance Rating by NDS Chapter 16 WoodWorks Paper Fire Design of Mass Timber Members
5-layer 6.88" (175mm) CLT	ANY	None	None	TBD	Varies, Determined by Calculation	1	ASTM E119	Calculated Fire-Resista[nce Rating by] NDS Chapte[r 16] WoodWorks Paper Fi[re Design of] Mass Timber M[embers]
5-layer 6.88" (175mm) CLT	ANY	None	None	TBD	Varies, Determined by [illegible]	2	ASTM E119	Calculated Fire-Resista[nce Rating by] NDS Chapter 16 WoodWorks Paper Fire Design of [illegible]

Print Results

Need Project Support?

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

Nail-Laminated Timber (NLT)

Photo: StructureCraft

Photo: Think Wood

Nail-Laminated Timber (NLT)

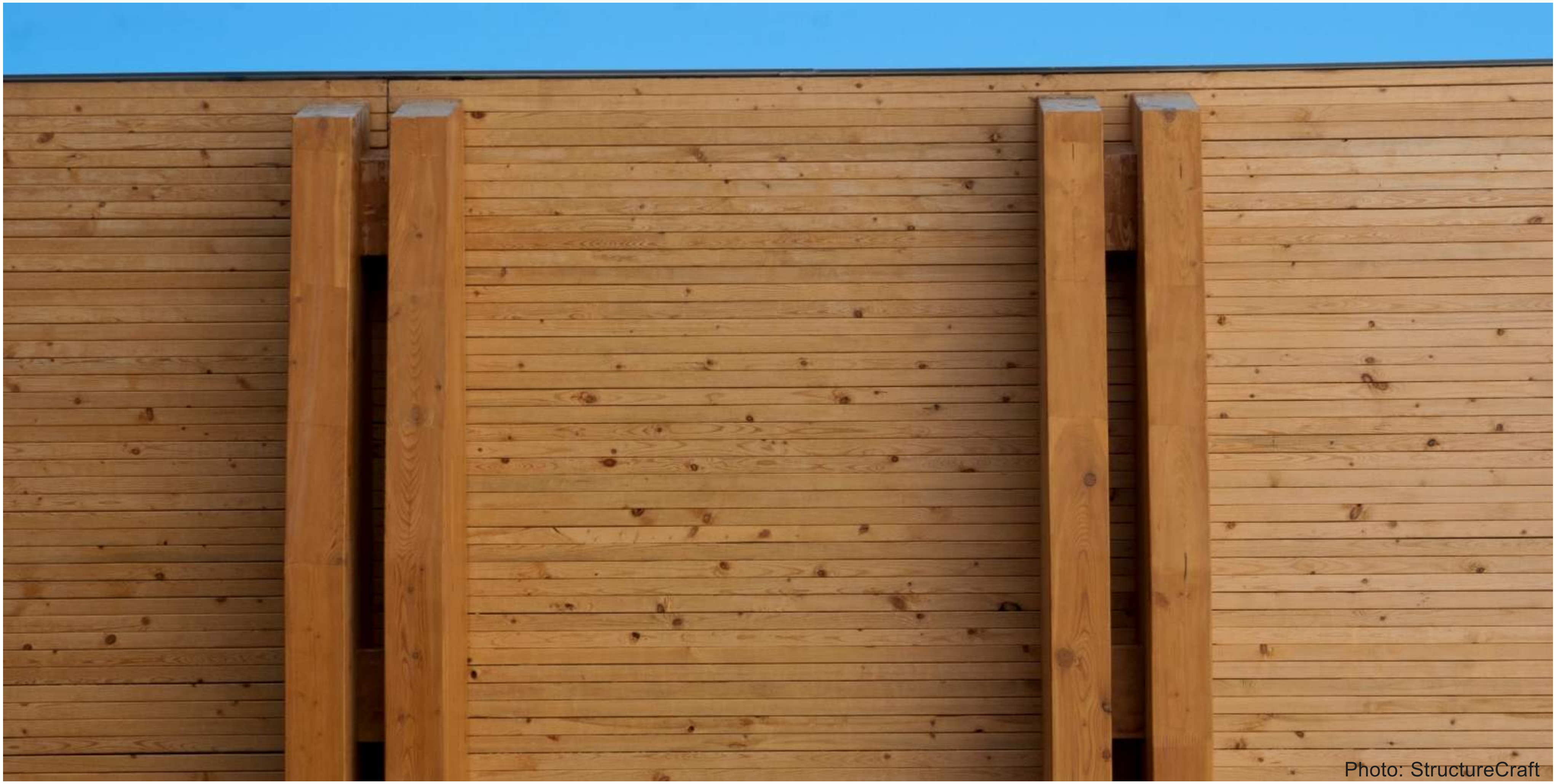


Photo: StructureCraft

5.1.4 Glulam Beam Shear Check – Structural Fire Resistance

The shear check for the routed-in hidden connector for structural fire resistance follows a similar design approach as the initial check.

Main differences this check:

- Uses reduced beam cross-sectional dimensions.
- Increases the allowable shear stress by the 2.75 factor from NDS Table 16.3.3

5.1.6 Glulam Beam Deflection Check – Total Load

Long-term deflection in glulam beams is much closer to NLT/DLT panel design than CLT panel design. This is because the creep effect factor is 1.5 per NDS Section 3.5.2.

5.1.7 Glulam Beam Vibration Check

Common floor panel vibration analysis methods assume fully rigid supports (i.e., bearing walls).

- Many mass timber projects are supported on beams.
- The overall floor assembly as a system will dictate vibration performance, not just the panels:
  - It might be appropriate to design the MT floor panel/GLB connection with a level of assumed composite action,
  - or, composite action can be neglected.
  - or, some engineers even adapt the design principles of AISC Design Guide 11 to that of a mass timber system, including beams.

The engineer should assess the required level of vibration performance, determine whether panel-to-beam connections can provide some composite action, and analyze the beams for vibration accordingly.

5.2 Column Design

Start with a basis of design column size and then check actual loading conditions to assess adequacy, assuming a load duration of 1.0 and a maximum eccentricity of d/6.

Design steps include:

- Preliminary Glulam column size- Table 9 of APA – The Engineered Wood Association's Design of Structural Glued Laminated Timber Columns (APA, 2009)
- Glulam column slenderness ratio
- Glulam column axial and buckling
- Glulam column axial and buckling – structural fire resistance.

Table G1 in NDS Appendix G provides effective length factors for different column end support conditions.

Per NDS Section 3.7.1.4, the slenderness ratio (Le/d) should not exceed 50.

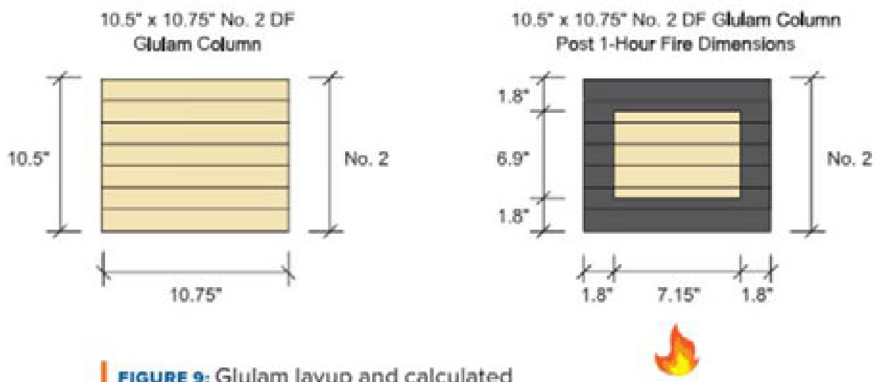


FIGURE 9: Glulam layup and calculated post-fire dimensions

Structural Fire Resistance Check