WOODWORKS™
WOOD PRODUCTS COUNCIL

Mass Timber Structural Design: Tips for Practicing Engineers

Scott Breneman, PhD, PE, SE
WoodWorks – Wood Products Council
scott.breneman@woodworks.org

Eloïse Allsop, P.E., CEng, MIStructE, M.Eng.
Fast + Epp
eallsop@fastepp.com

Photo: Manasc Isaac Architects/Fast + Epp

"The Wood Products Council" is a Registered Provider with The American Institute of Architects Continuing Education Systems (AIA/CES), Provider #G516.

Credit(s) earned on completion of this course will be reported to AIA CES for AIA members. Certificates of Completion for both AIA members and non-AIA members are available upon request.

This course is registered with AIA CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product.

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

Course Description

As mass timber's use in commercial and multi-family projects across the US has grown, so too have the depth of questions that often arise when engineering these projects. This presentation will address some of the most common structural design questions related to mass timber buildings, as well as provide tips and resources to aid those working on such projects. Topics will include where to find and how to use the structural properties for mass timber panels; the differences and similarities between basic and custom CLT grades, treatment of holes and notches in CLT, different approaches to achieving fire-resistance ratings and real-world design tips which are not addressed in the design standards.

Learning Objectives

- *Discuss the structural properties and performance characteristics of mass timber products and review their paths to acceptance on building projects.*
- *Review unique design situations for CLT panels and present engineering strategies to address them.*
- *Demonstrate design steps for calculated fire resistance of exposed mass timber panels.*
- *Review lessons learned in the design and construction of buildings using mass timber*

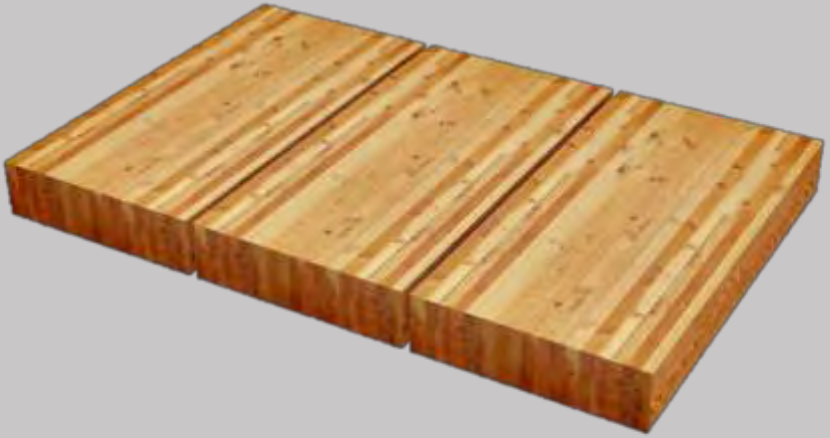
Mass Timber Products

Horizontal Framing

Nail-Laminated Timber (NLT)

Cross-Laminated Timber (CLT)

Glue-Laminated Timber (GLT)



Tongue & groove decking (T&G)

Timber concrete composite

Structural Composite Lumber

Image source: StructureCraft

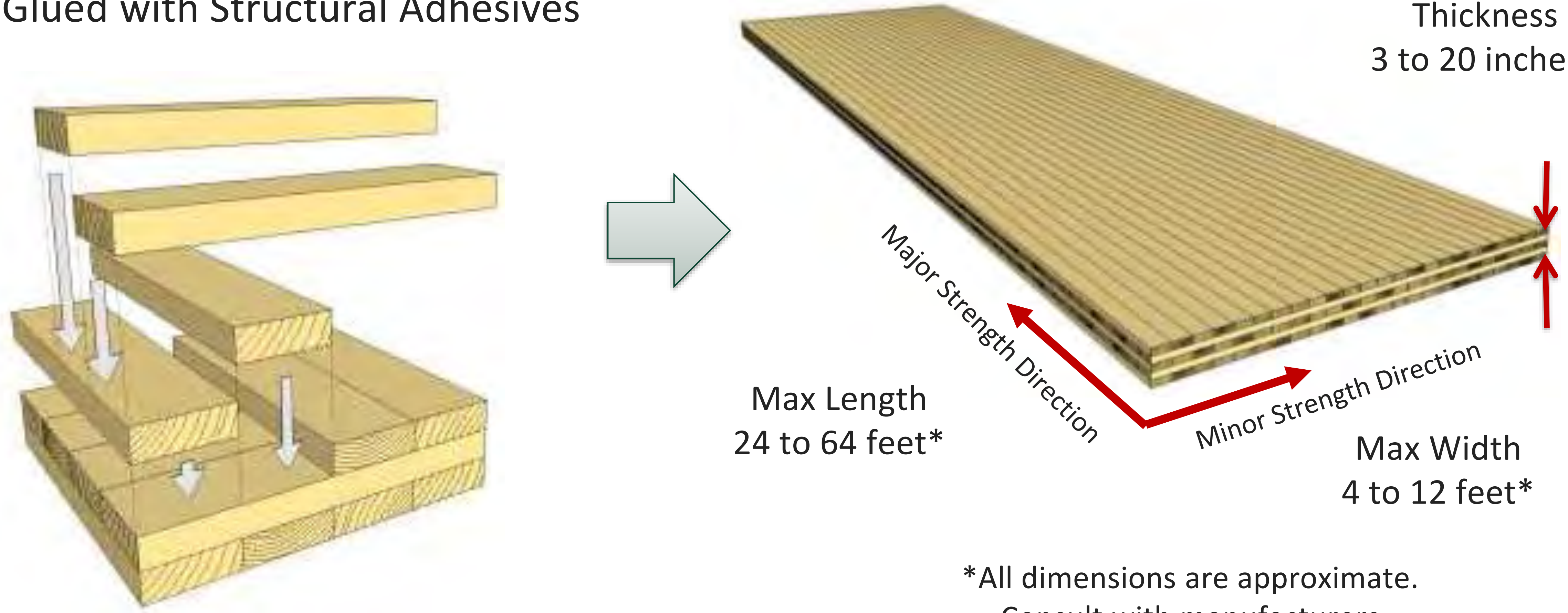
What is CLT?

3+ layers of laminations

Solid Sawn or Structural Composite Lumber 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

Candlewood Suites

Redstone Arsenal, AL

- 62,600 SF, 4 story hotel, 92 private rooms
- CLT utilized for walls, roof panels, and floor panels

Image Credit: Lend Lease

UMass Design Building

Amherst, MA

Photo Credit: Alex Schreyer

Cheney Park Apartments CLT floor on Panelized Light Frame Walls


Photo Credit: WoodWorks


Photo Credit: WoodWorks

CrossFit Center
Spokane, WA

Photo Credit: WoodWorks

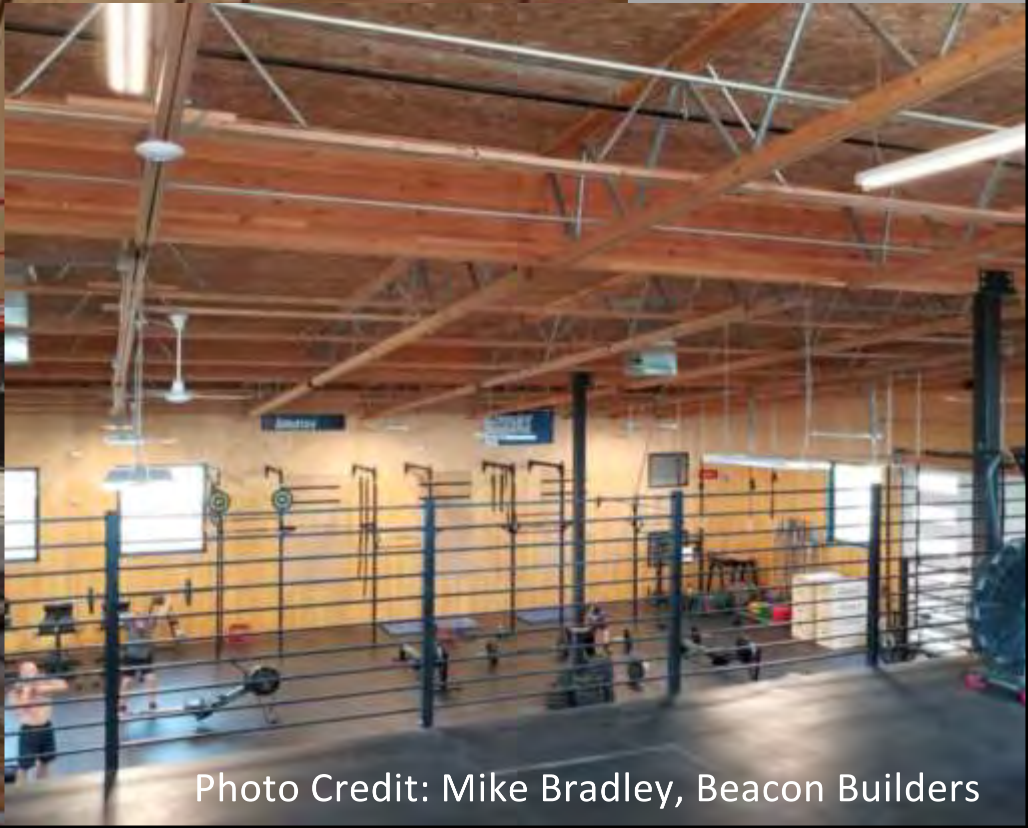


Photo Credit: Mike Bradley, Beacon Builders

BROCK COMMONS

VANCOUVER, BC

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

Images: acton ostry architects

North American CLT Product Standard

Standard for Performance-Rated Cross-Laminated Timber

ANSI/APA PRG 320 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

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

Common CLT Layups

Most Designs
Least $/sf

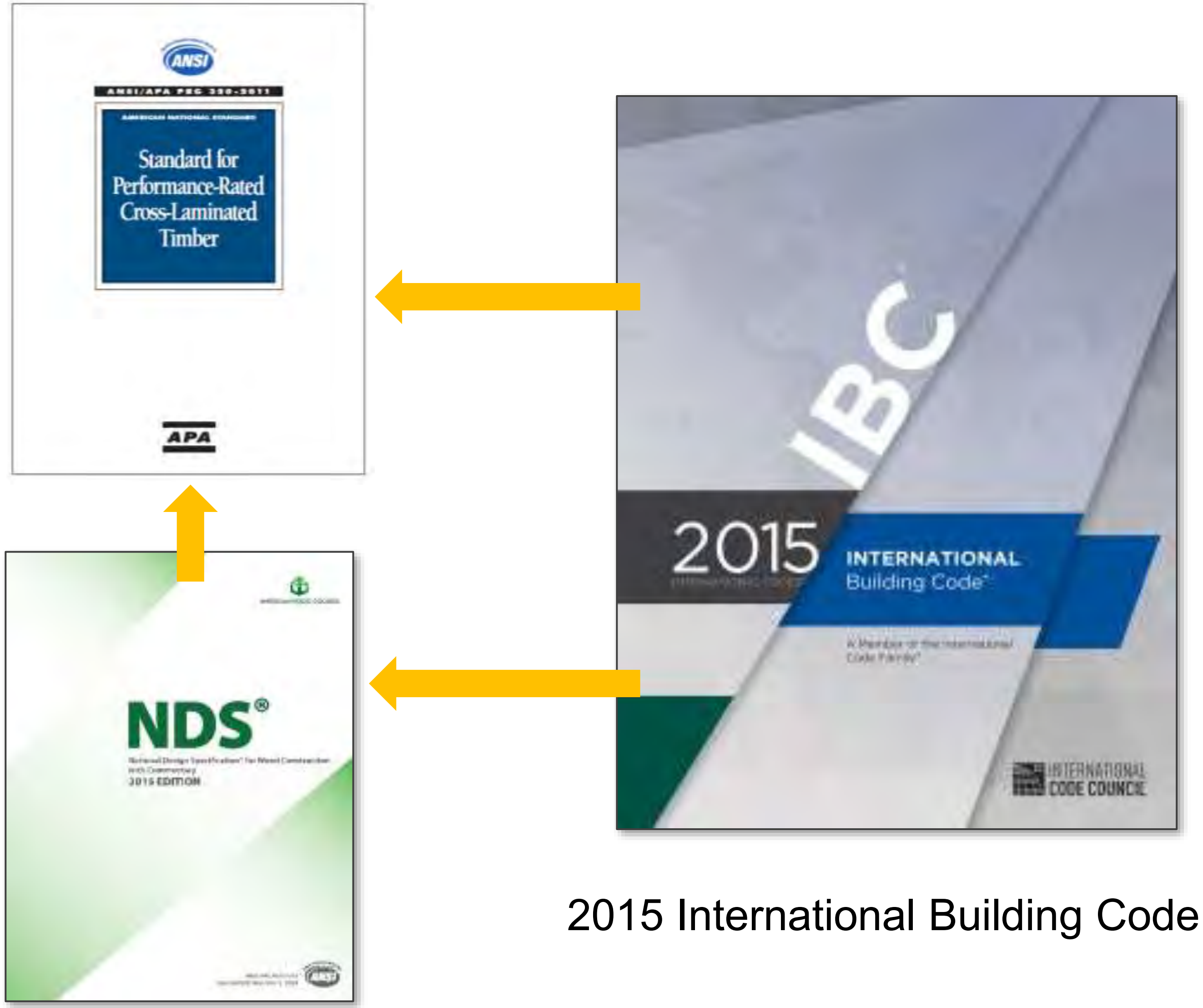
3-ply 3-layer

5-ply 5-layer

7-ply 7-layer

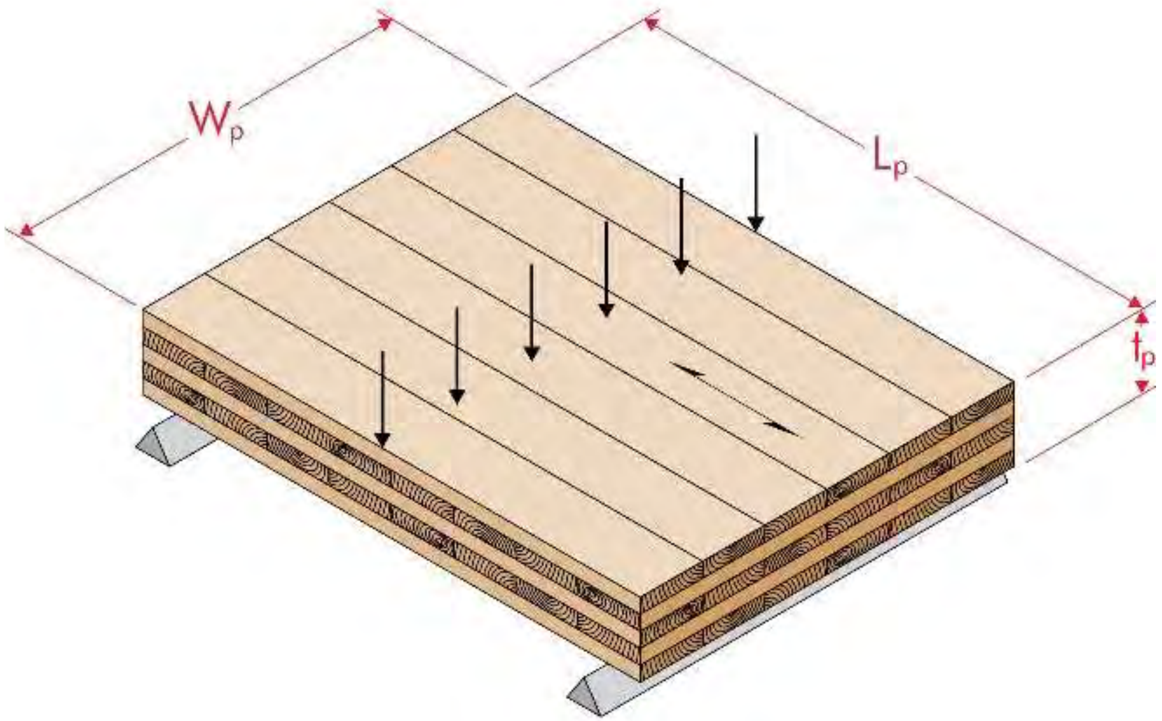
9-ply 9-layer

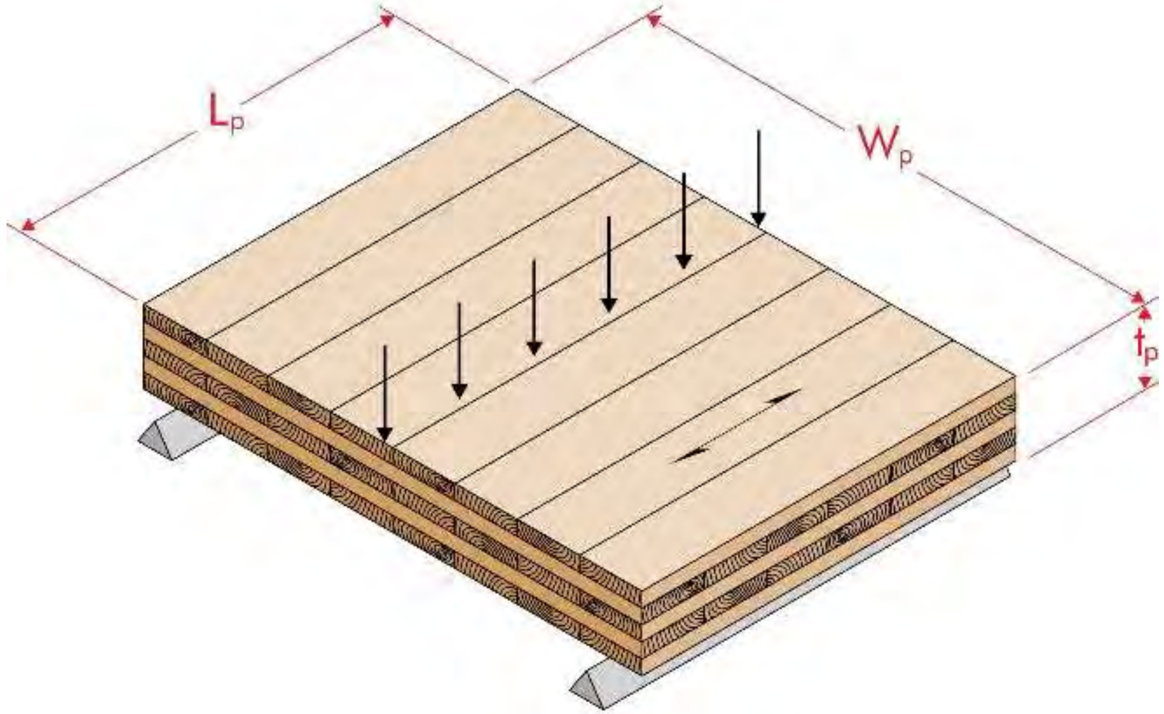
Building Code Acceptance of CLT



2015 International Building Code

FLATWISE Panel Loading





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

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

Reference & Source: ANSI/APA PRG 320

PRG 320 Defined Layups

CLT Grade (basic)

Layup

Panel Properties

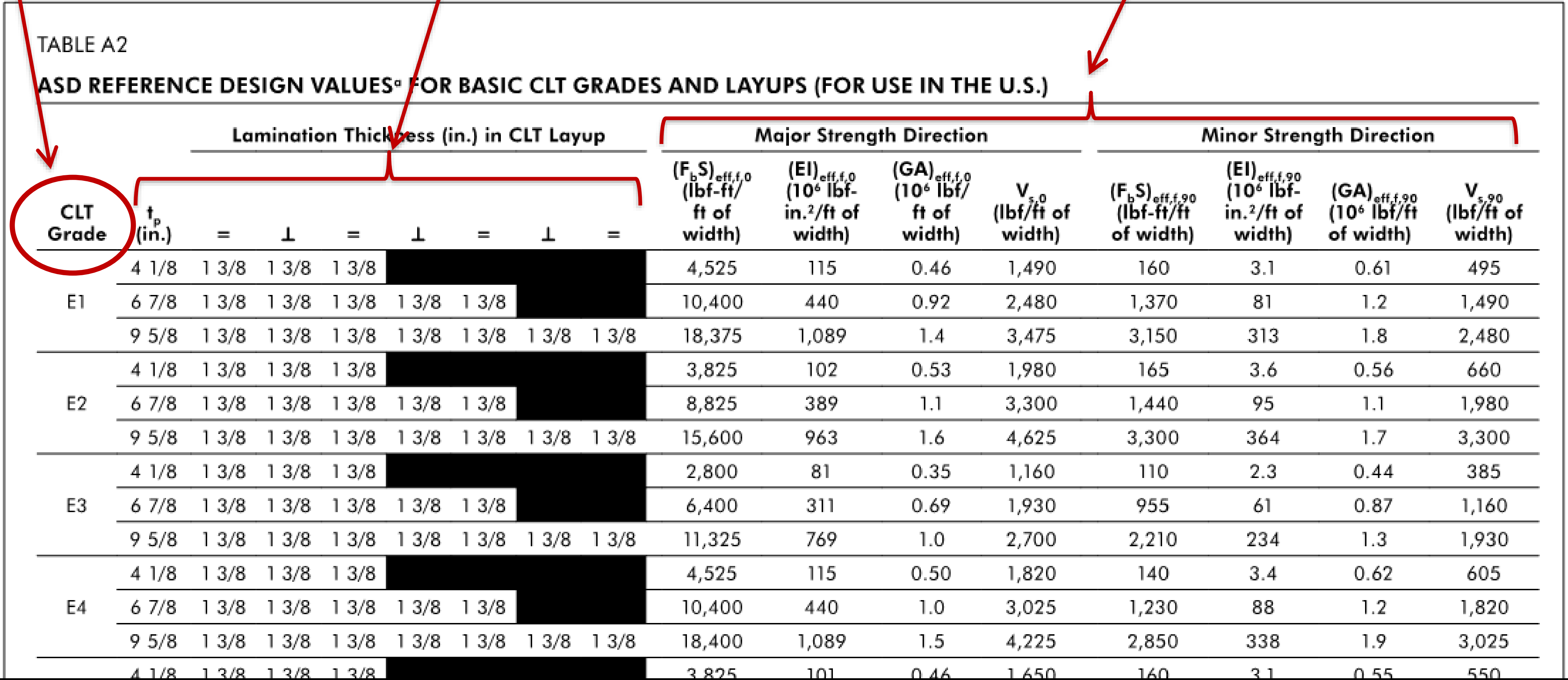
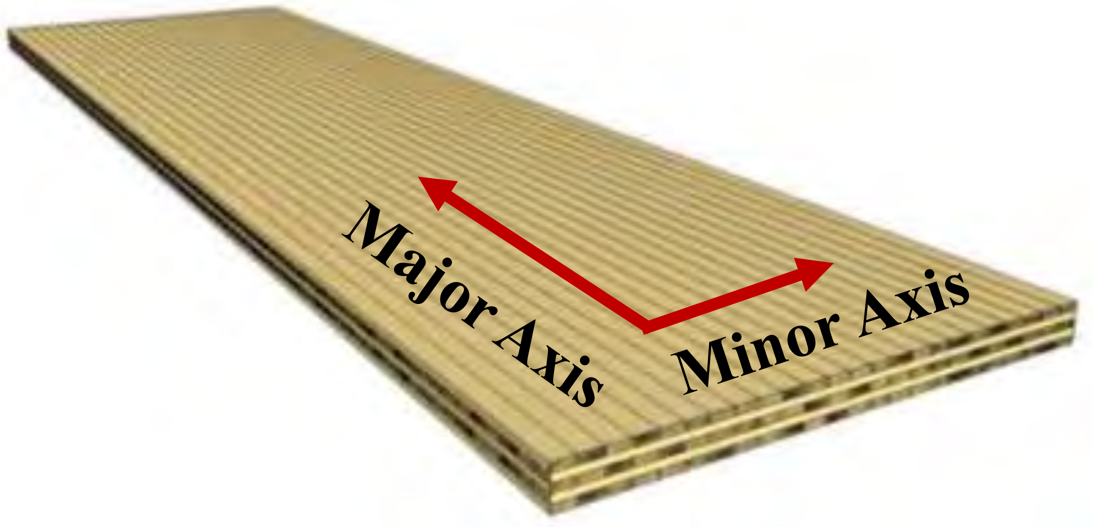


TABLE A2

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

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

Flatwise CLT Panel Section Properties



Flexural Strength:	$F_bS_{eff,0}$	$F_bS_{eff,90}$
Flexural Stiffness:	$EI_{eff,0}$	$EI_{eff,90}$
Shear Strength:	$V_{s,0}$	$V_{s,90}$
Shear Stiffness:	$GA_{eff,0}$	$GA_{eff,90}$

Values in RED provided by CLT manufacturer

Reference: PRG 320 and CLT Product Reports

Structural Design Standardization


ANSI

ANSI/APA PRG 320-2011

AMERICAN NATIONAL STANDARD

Standard for Performance-Rated Cross-Laminated Timber

APA


AMERICAN WOOD COUNCIL

NDS®

National Design Specification® for Wood Construction with Commentary

2015 EDITION

ANSI/AWC NDS-2015
Approval date November 1, 2014

ANSI

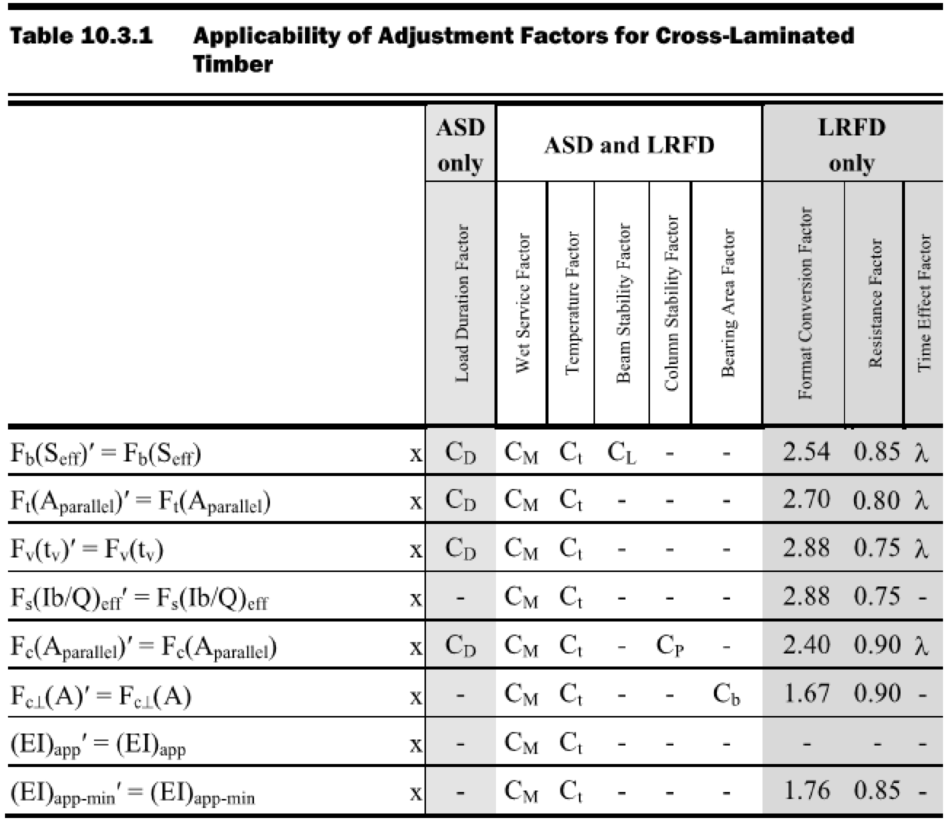


Table 10.3.1 Applicability of Adjustment Factors for Cross-Laminated Timber

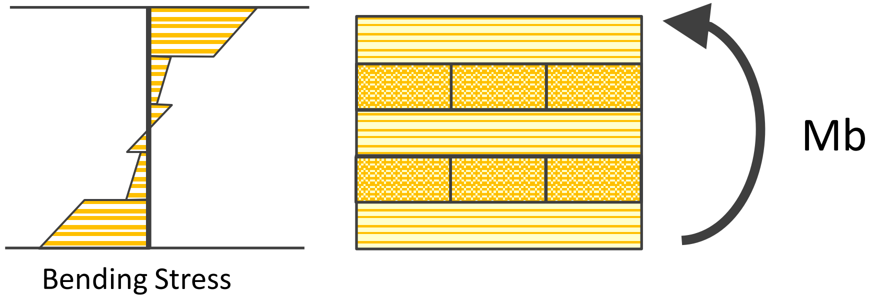
		ASD only	ASD and LRFD					LRFD only		
		Load Duration Factor	Wet Service Factor	Temperature Factor	Beam Stability Factor	Column Stability Factor	Bearing Area Factor	Format Conversion Factor	Resistance Factor	Time Effect Factor
$F_b(S_{eff})' = F_b(S_{eff})$	x	C_D	C_M	C_t	C_L	-	-	2.54	0.85	λ
$F_t(A_{parallel})'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

National Design Specification for Wood Construction
2015 & 2018 Edition

Flatwise Flexural Strength

Design properties look like 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

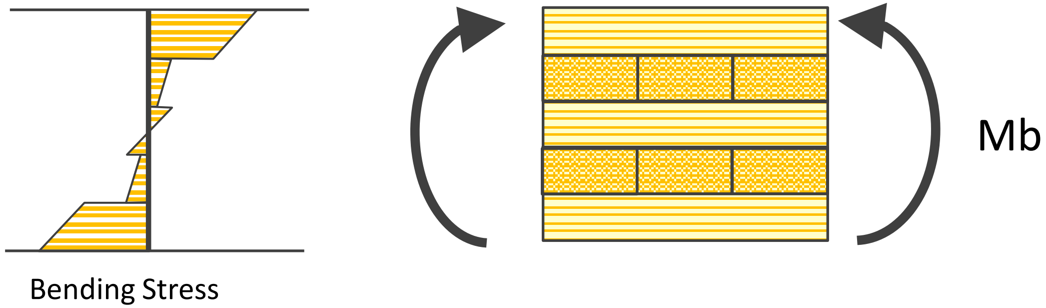
F_b = reference bending design stress of outer lamination

Separate values for most components

Reference: NDS

Flatwise Flexural Strength

Flexural Capacity Check (**ASD**)



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

$$M_b \le C_D\,(1.0)\,({\color{red}F_bS_{eff}})$$

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

Reference: NDS

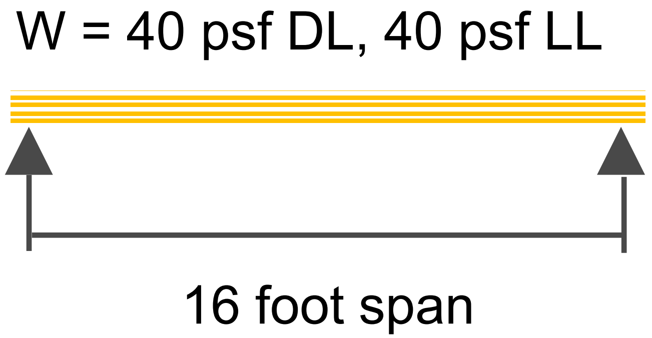
Flatwise Flexural Strength Design Example

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

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

Flatwise Flexural Strength Design Example

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

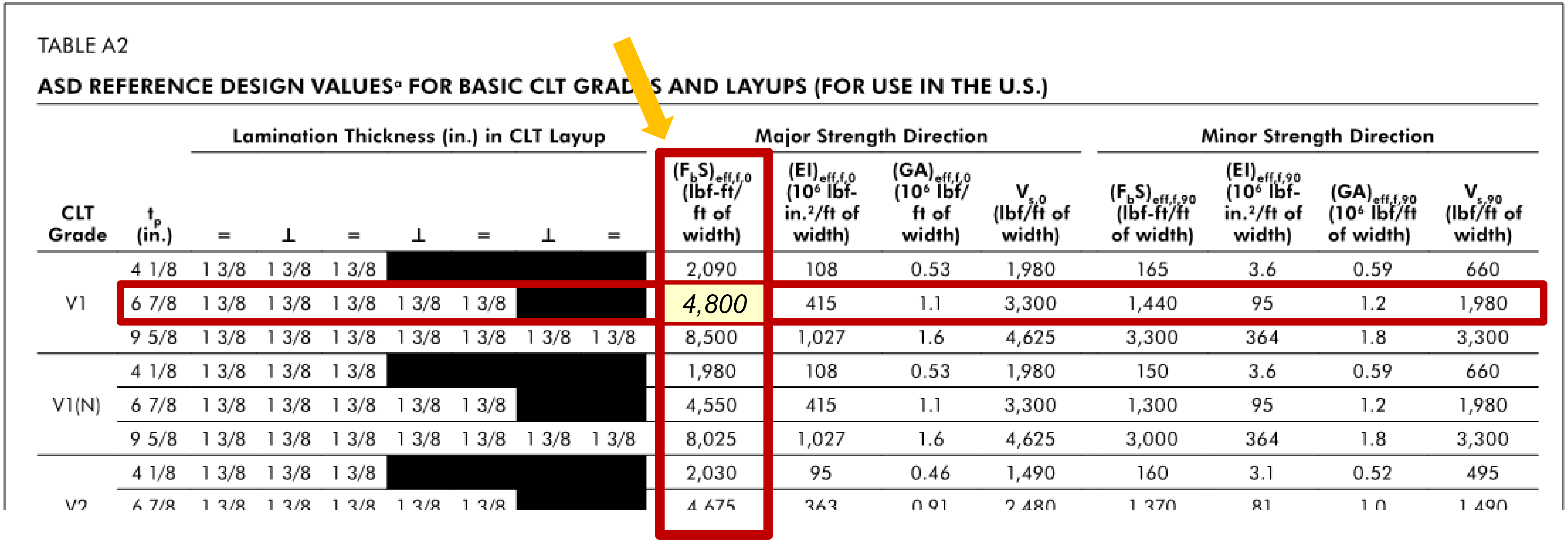


TABLE A2

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

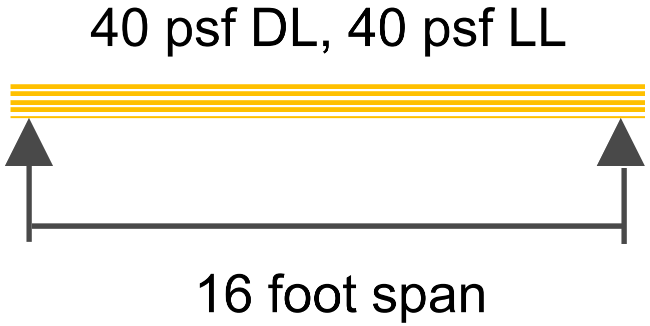
ASD Flexural Capacity:

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

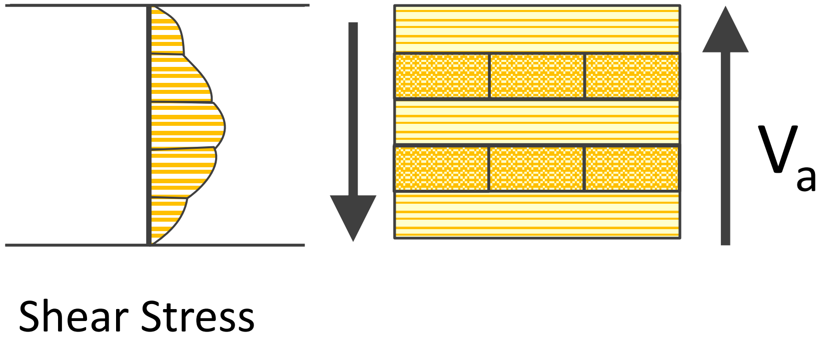
Flatwise Shear Strength

Shear Capacity Check:

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

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

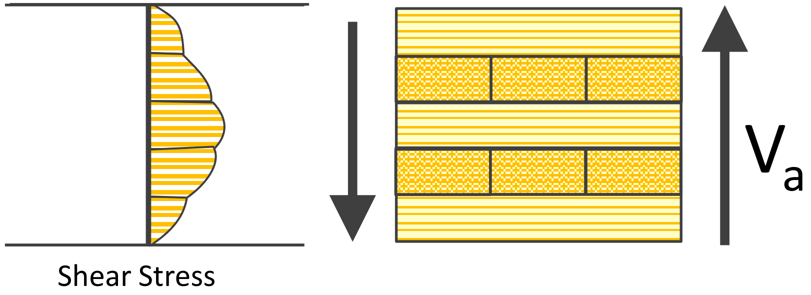
Structural Engineering Term

WSP & CLT Term

Reference: NDS 2018

Flatwise Shear Strength

Shear Capacity Check (ASD):



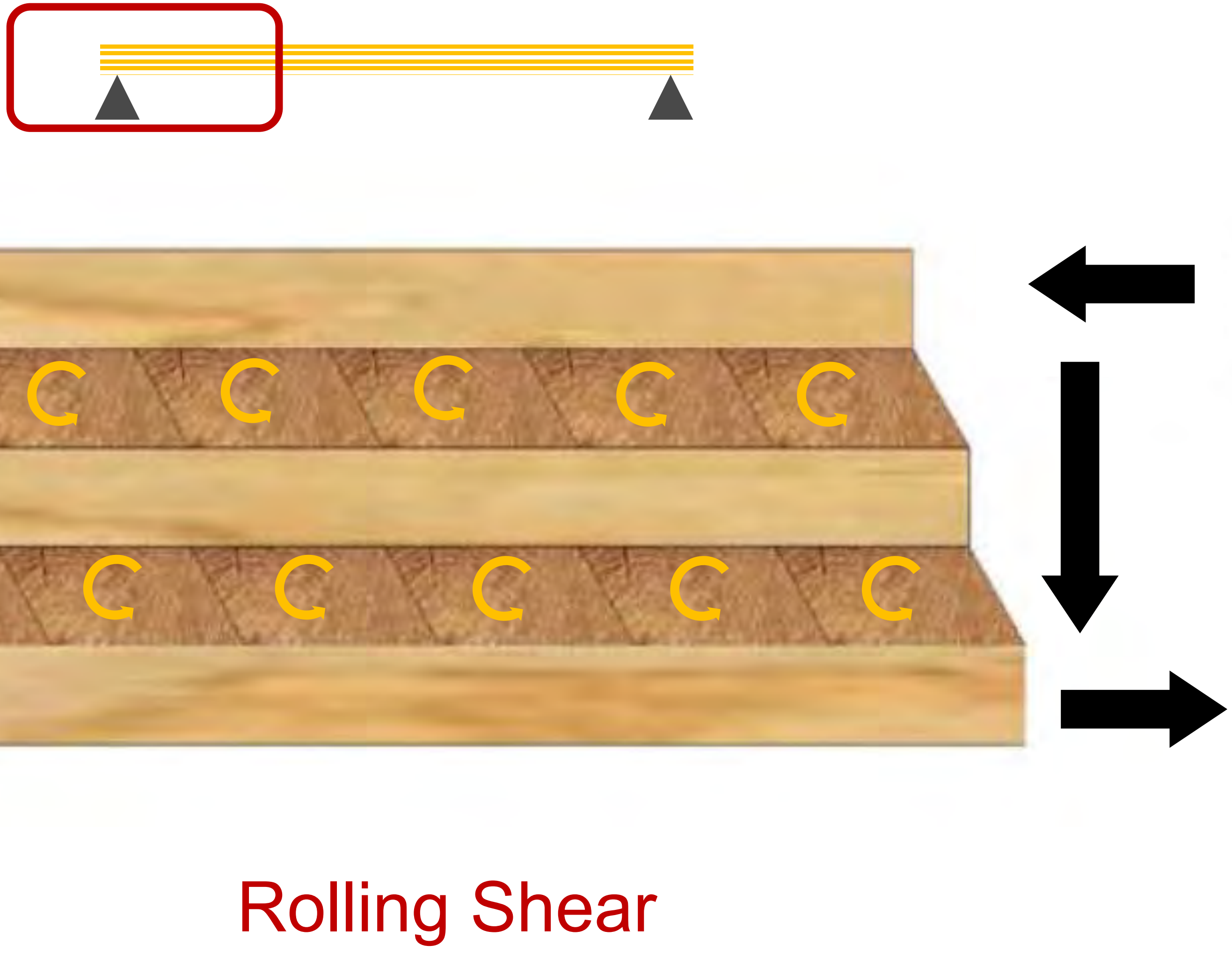
$$F_s(IbQ)_{eff}' = \underbrace{C_M\,C_t}_{\text{Commonly 1.0}}\ \underbrace{(F_s(IbQ)_{eff})}_{\text{From Manufacturer}} = C_M\,C_t\,\underbrace{V_s}$$

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

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

Reference: NDS & Product Reports

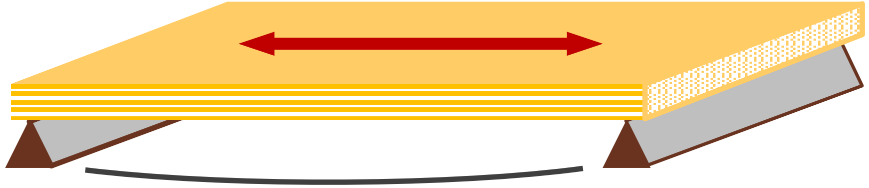
Flatwise Shear Strength



Rolling Shear

Source: CSA O86-14, 2016 Supplement

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

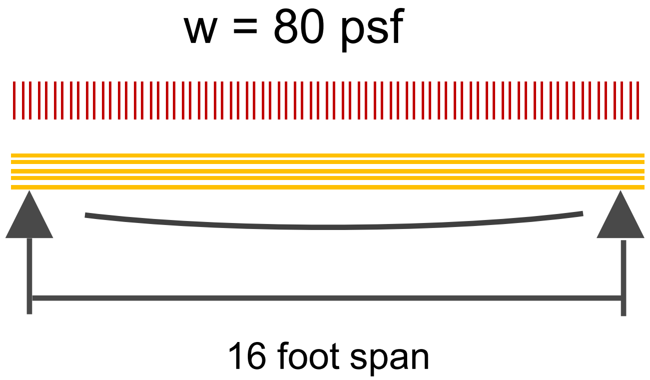
Uniform loading on one way slab:

Beam Analysis using

Flexural Stiffness: $EI_{eff,0}$

Shear Stiffness: $GA_{eff,0}$

Maximum Deflection @ Mid-Span



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

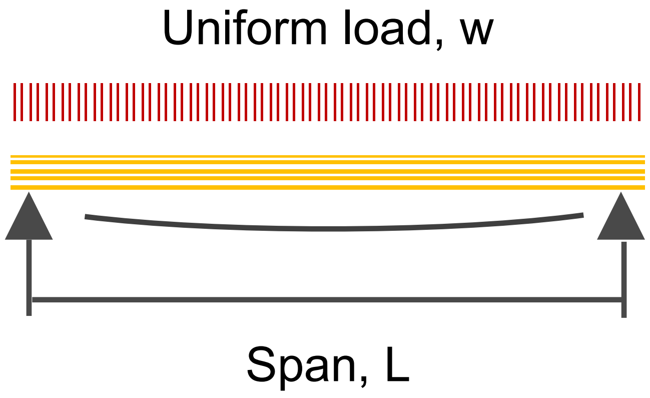
Note: 5/6 is shear deformation form factor for rectangular section from mechanics of materials. See NDS C10.4.1, FPL “Wood Handbook”, etc.

Deflection Calculations

Simplified Beam Deflections:

For single span, simply supported uniform load

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



What is ***Apparent*** Flexural Stiffness, EI$_{app}$, such that

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

Set equal to each other and solve for EI$_{app}$ →

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

Reference: US CLT Handbook & NDS

Deflection Creep Factor

Deformation 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:

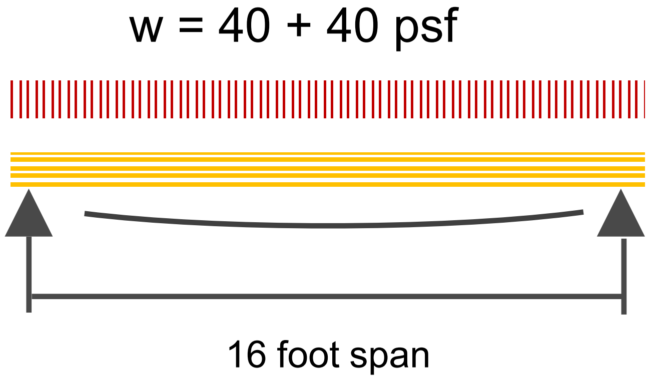
Δ_{ST} from 40psf = 0.159 in (assuming long term = dead)

Δ_{LT} from 40psf = 0.159 in

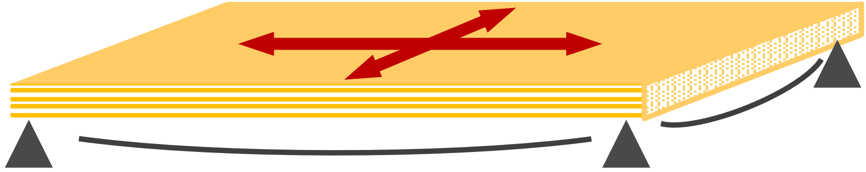
Δ_T = 2.0 (0.159) + 0.159 = 0.477 in

= L / 403

Reference: NDS 2015



Deflection Calculations



General Purpose, 2 Way, Plate Action

Flexural Stiffness

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

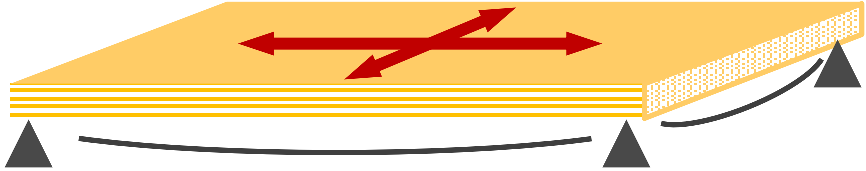
Shear Stiffness:

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

Analyze as plate in bending using FEM analysis software

Note, CLT is not a symmetric isotropic plate

Point Supported Plates



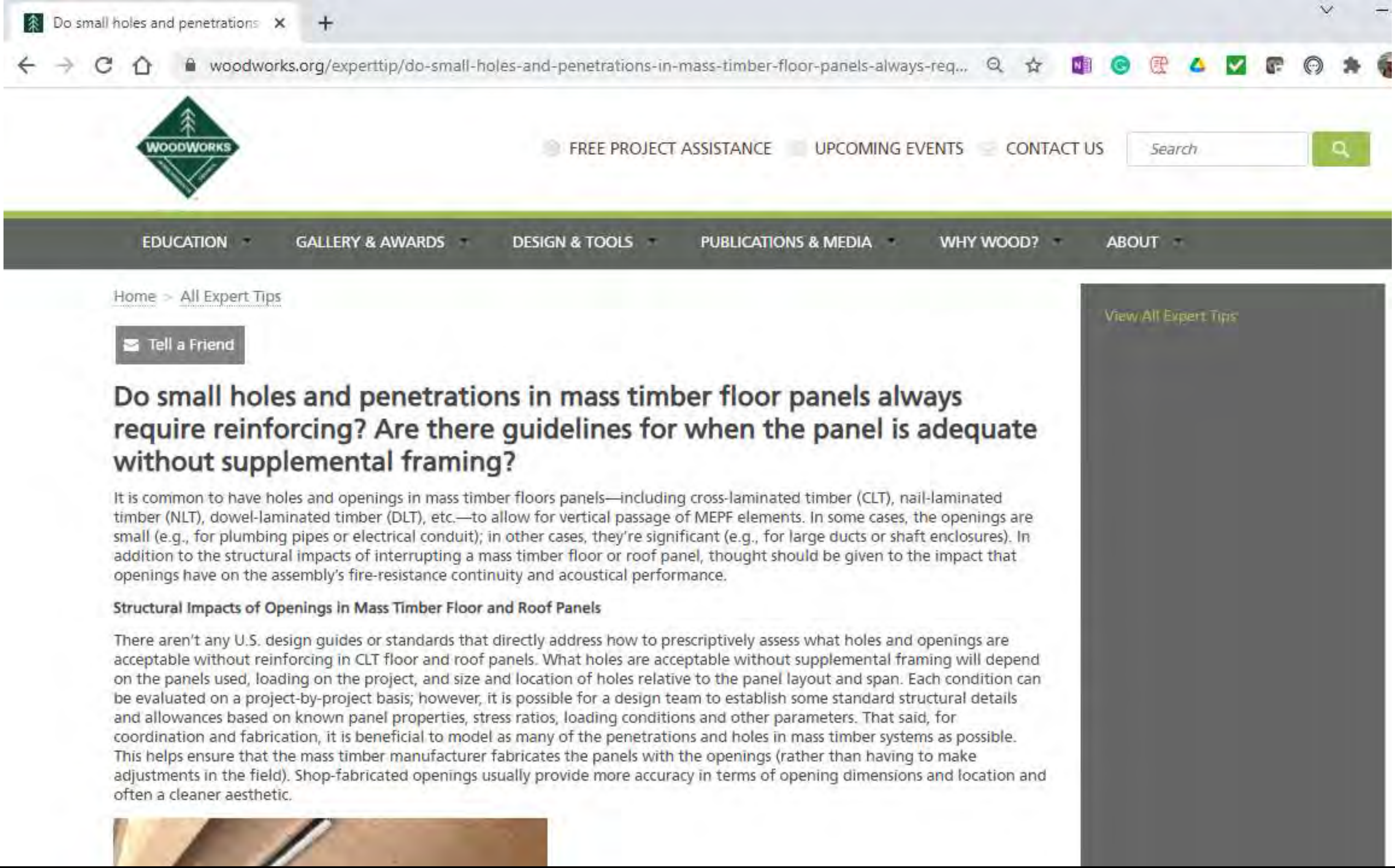
Possible, however not common.

Structural design issues include:

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

} Not covered in NDS

Holes in Mass Timber Panels



Do small holes and penetrations in mass timber floor panels always require reinforcing? Are there guidelines for when the panel is adequate without supplemental framing?

It is common to have holes and openings in mass timber floors panels—including cross-laminated timber (CLT), nail-laminated timber (NLT), dowel-laminated timber (DLT), etc.—to allow for vertical passage of MEPF elements. In some cases, the openings are small (e.g., for plumbing pipes or electrical conduit); in other cases, they're significant (e.g., for large ducts or shaft enclosures). In addition to the structural impacts of interrupting a mass timber floor or roof panel, thought should be given to the impact that openings have on the assembly's fire-resistance continuity and acoustical performance.

Structural Impacts of Openings in Mass Timber Floor and Roof Panels

There aren't any U.S. design guides or standards that directly address how to prescriptively assess what holes and openings are acceptable without reinforcing in CLT floor and roof panels. What holes are acceptable without supplemental framing will depend on the panels used, loading on the project, and size and location of holes relative to the panel layout and span. Each condition can be evaluated on a project-by-project basis; however, it is possible for a design team to establish some standard structural details and allowances based on known panel properties, stress ratios, loading conditions and other parameters. That said, for coordination and fabrication, it is beneficial to model as many of the penetrations and holes in mass timber systems as possible. This helps ensure that the mass timber manufacturer fabricates the panels with the openings (rather than having to make adjustments in the field). Shop-fabricated openings usually provide more accuracy in terms of opening dimensions and location and often a cleaner aesthetic.

Using PRG 320 Basic Grades for Design?

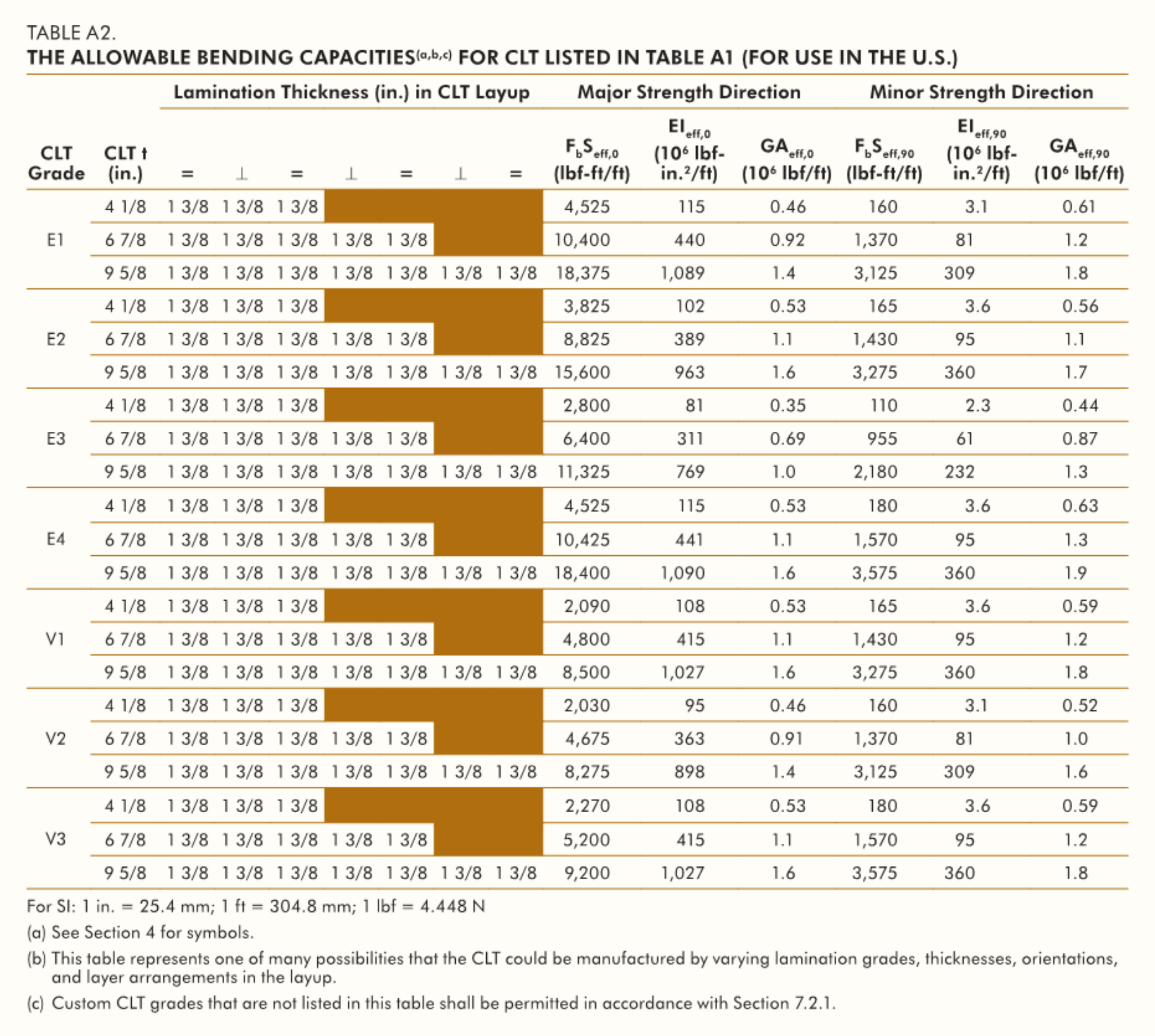


TABLE A2.

THE ALLOWABLE BENDING CAPACITIES[a,b,c] FOR CLT LISTED IN TABLE A1 (FOR USE IN THE U.S.)

		Lamination Thickness (in.) in CLT Layup							Major Strength Direction			Minor Strength Direction		
CLT Grade	CLT t (in.)	=	⊥	=	⊥	=	⊥	=	$F_bS_{eff,0}$ (lbf-ft/ft)	$EI_{eff,0}$ (10^6 lbf-in.²/ft)	$GA_{eff,0}$ (10^6 lbf/ft)	$F_bS_{eff,90}$ (lbf-ft/ft)	$EI_{eff,90}$ (10^6 lbf-in.²/ft)	$GA_{eff,90}$ (10^6 lbf/ft)
E1	4 1/8	1 3/8	1 3/8	1 3/8					4,525	115	0.46	160	3.1	0.61
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			10,400	440	0.92	1,370	81	1.2
	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	3,125	309	1.8
E2	4 1/8	1 3/8	1 3/8	1 3/8					3,825	102	0.53	165	3.6	0.56
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			8,825	389	1.1	1,430	95	1.1
	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	3,275	360	1.7
E3	4 1/8	1 3/8	1 3/8	1 3/8					2,800	81	0.35	110	2.3	0.44
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			6,400	311	0.69	955	61	0.87
	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	2,180	232	1.3
E4	4 1/8	1 3/8	1 3/8	1 3/8					4,525	115	0.53	180	3.6	0.63
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			10,425	441	1.1	1,570	95	1.3
	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	1,090	1.6	3,575	360	1.9
V1	4 1/8	1 3/8	1 3/8	1 3/8					2,090	108	0.53	165	3.6	0.59
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			4,800	415	1.1	1,430	95	1.2
	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	3,275	360	1.8
V2	4 1/8	1 3/8	1 3/8	1 3/8					2,030	95	0.46	160	3.1	0.52
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			4,675	363	0.91	1,370	81	1.0
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	8,275	898	1.4	3,125	309	1.6
V3	4 1/8	1 3/8	1 3/8	1 3/8					2,270	108	0.53	180	3.6	0.59
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			5,200	415	1.1	1,570	95	1.2
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	9,200	1,027	1.6	3,575	360	1.8

For SI: 1 in. = 25.4 mm; 1 ft = 304.8 mm; 1 lbf = 4.448 N

(a) See Section 4 for symbols.

(b) This table represents one of many possibilities that the CLT could be manufactured by varying lamination grades, thicknesses, orientations, and layer arrangements in the layup.

(c) Custom CLT grades that are not listed in this table shall be permitted in accordance with Section 7.2.1.

PRG 320 includes pre-defined Stress Grades, Layups and related Design Properties

Is doesn't tell you what CLT grades and layups are available.

Coordinate with manufacturers availability and information

3rd Party Product Qualification of CLT

APA PRODUCT REPORT

DRJ Cross-Laminated Timber
Riddle Laminators, Inc.

PR-L320
Issued January 25, 2017

APA PRODUCT REPORT

Structurlam CrossLam
Structurlam Products LP

PR-L314
Revised May 9, 2016

Products: Structurlam CrossLam Cross-Laminated Timber
Structurlam Products LP
2176 Government Street

ICC EVALUATION SERVICE

Most Widely Accepted and Trusted

ICC-ES Report

ESR-3631

DIVISION: 06 00 00—WOOD, PLASTICS AND COMPOSITES
SECTION: 06 17 19—CROSS-LAMINATED TIMBER

REPORT HOLDER:

STRUCTURLAM PRODUCTS LP

2176 GOVERNMENT STREET
PENTICTON, BRITISH COLUMBIA V2A 8B5
CANADA

EVALUATION SUBJECT:

STRUCTURLAM CROSSLAM® CLT

APA PRODUCT REPORT

SmartLam Cross-Laminated Timber
SmartLam, LLC

PR-L319
Revised August 15, 2017

Products: SmartLam Cross-Laminated Timber

APA PRODUCT REPORT

Nordic X-Lam
Nordic Structures

PR-L306
Revised March 26, 2016

Products: Nordic X-Lam
Nordic Structures

Intertek

LISTING INFORMATION OF KLH Massivholz GmbH – Massivholzplatten (solid wood slabs) CLT

SPEC ID: 36204

KLH Massivholz GmbH
Katsch an der Mur 202

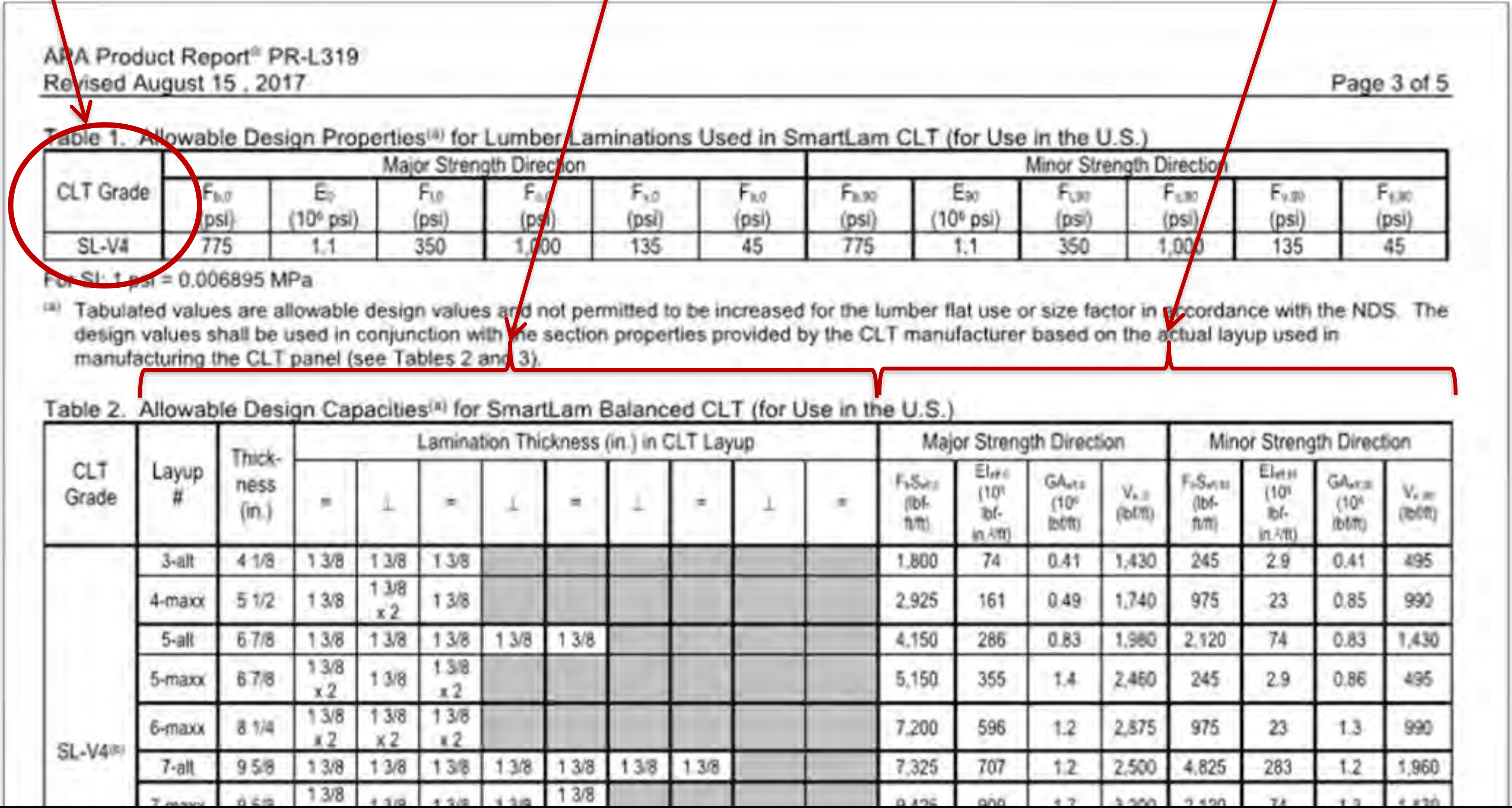
Teufenbach-Katsch, A-8842
Austria

CLT Product Reports

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

Layup

Panel Properties



APA Product Report® PR-L319
Revised August 15 , 2017 Page 3 of 5

Table 1. Allowable Design Properties[a] for Lumber Laminations Used in SmartLam CLT (for Use in the U.S.)

CLT Grade	Major Strength Direction						Minor Strength Direction					
	$F_{b,0}$ (psi)	E_0 (10^6 psi)	$F_{t,0}$ (psi)	$F_{c,0}$ (psi)	$F_{v,0}$ (psi)	$F_{s,0}$ (psi)	$F_{b,90}$ (psi)	E_{90} (10^6 psi)	$F_{t,90}$ (psi)	$F_{c,90}$ (psi)	$F_{v,90}$ (psi)	$F_{s,90}$ (psi)
SL-V4	775	1.1	350	1,000	135	45	775	1.1	350	1,000	135	45

For SI: 1 psi = 0.006895 MPa

[a] Tabulated values are allowable design values and not permitted to be increased for the lumber flat use or size factor in accordance with the NDS. The design values shall be used in conjunction with the section properties provided by the CLT manufacturer based on the actual layup used in manufacturing the CLT panel (see Tables 2 and 3).

Table 2. Allowable Design Capacities[a] for SmartLam Balanced CLT (for Use in the U.S.)

CLT Grade	Layup #	Thickness (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)
SL-V4[b]	3-alt	4 1/8	1 3/8	1 3/8	1 3/8							1,800	74	0.41	1,430	245	2.9	0.41	495
	4-maxx	5 1/2	1 3/8	1 3/8 x 2	1 3/8							2,925	161	0.49	1,740	975	23	0.85	990
	5-alt	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8					4,150	286	0.83	1,980	2,120	74	0.83	1,430
	5-maxx	6 7/8	1 3/8 x 2	1 3/8	1 3/8 x 2							5,150	355	1.4	2,460	245	2.9	0.86	495
	6-maxx	8 1/4	1 3/8 x 2	1 3/8 x 2	1 3/8 x 2							7,200	596	1.2	2,875	975	23	1.3	990
	7-alt	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			7,325	707	1.2	2,500	4,825	283	1.2	1,960
	[illegible]	[illegible]	1 3/8	[illegible]	[illegible]	[illegible]	1 3/8					[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Working with CLT: Know Your Supply Chain

- CLT Manufactures different CLT grades and maximum panel sizes
- CLT Manufacturers have specific CNC capabilities
- 3rd Party Fabricators can have additional CNC capabilities

Photo: DR Johnson

Photo: Sauter Timber

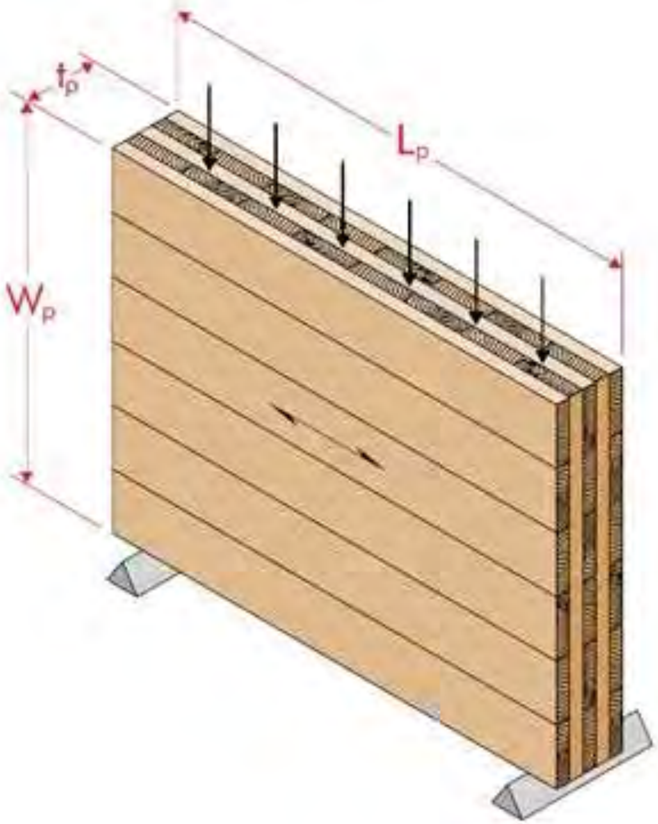
Scope of PRG 320

CLT Panels shall be used in dry service conditions, such as in most covered structures, where the average equilibrium content of solid wood is less than 16 percent… CLT panels qualified in accordance with the provisions of this standard are intended to resist the effects of moisture on structural performance as may occur due to construction delays or other conditions of similar severity.

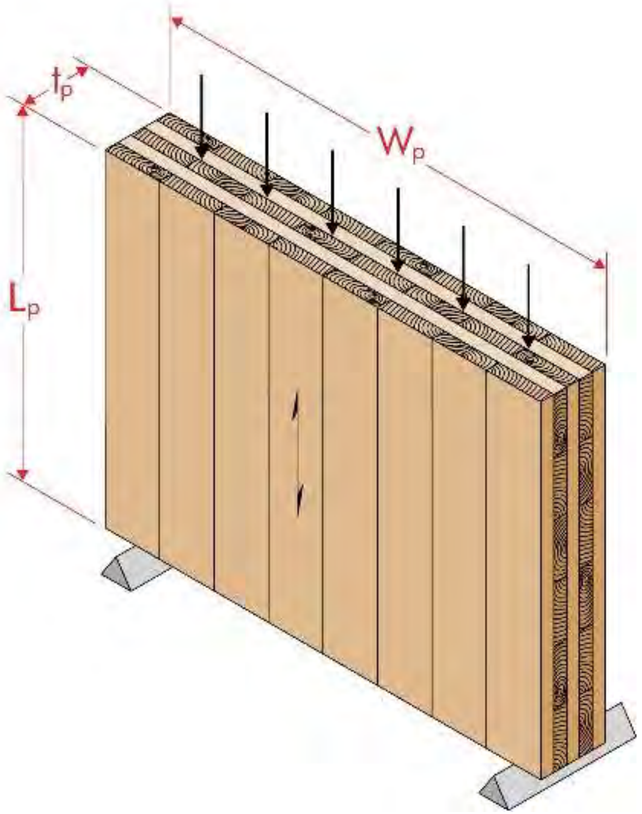
International Community Health Services Shoreline, WA

Photo Credit: Andrew Pogue Photography

EDGEWISE Panel Loading



Span in MAJOR Strength Direction



Span in MINOR Strength Direction

Reference & Source: ANSI/APA PRG 320

In-Plane (Edgewise) Shear Testing per PRG 320

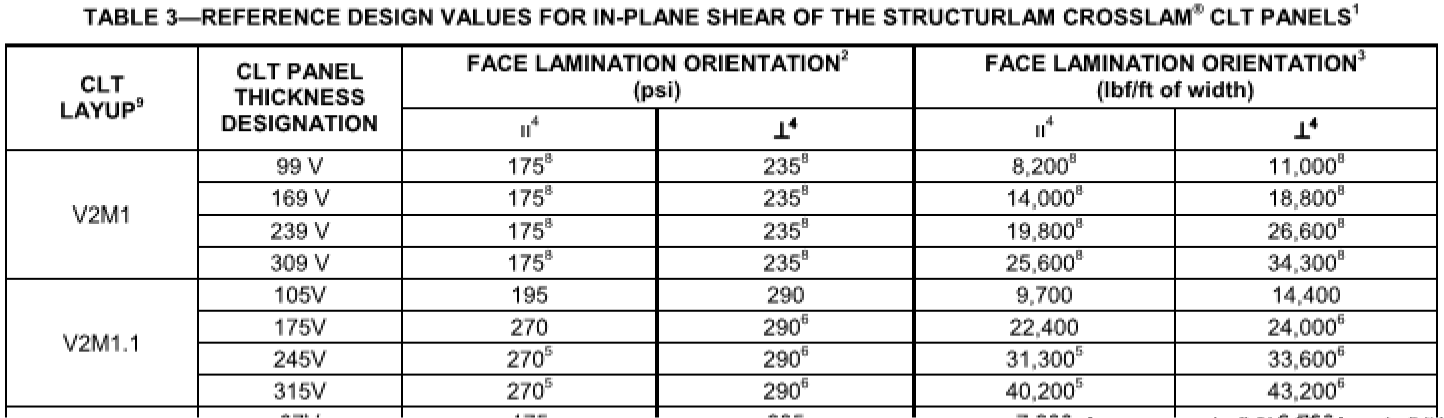


TABLE 3—REFERENCE DESIGN VALUES FOR IN-PLANE SHEAR OF THE STRUCTURLAM CROSSLAM® CLT PANELS[1]

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*

145 to 290 PSI Reference Shear Capacity

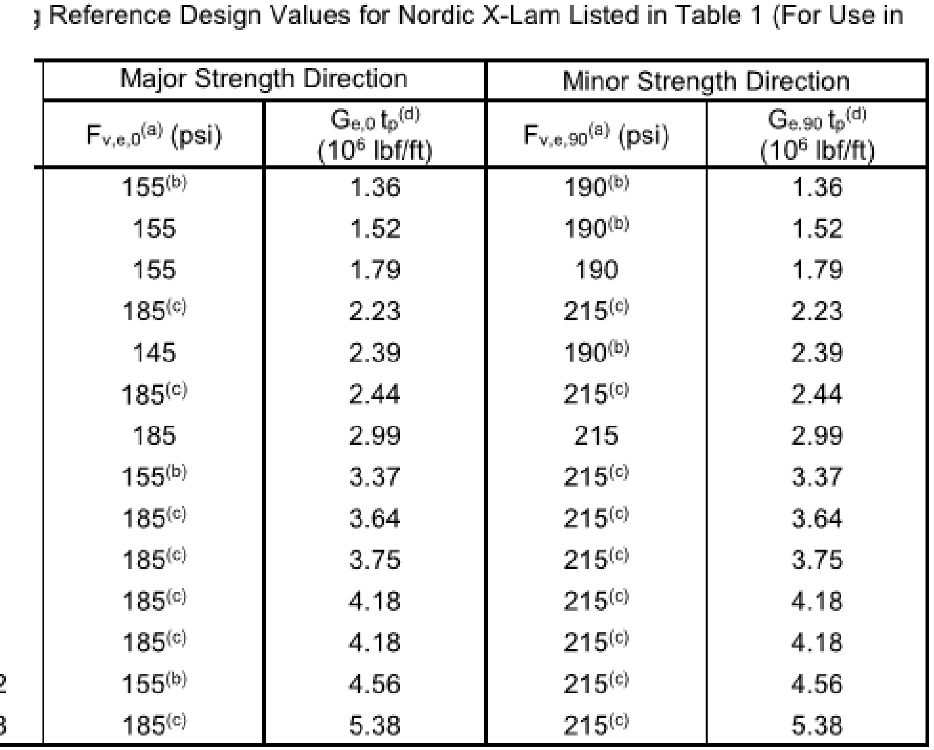
= 1.7 to 3.5 kips/ft

per inch of thickness!

See Manufacturers and Evaluation Reports for Values

Multiply by ***Cd = 1.6***

for short term ASD strength



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*

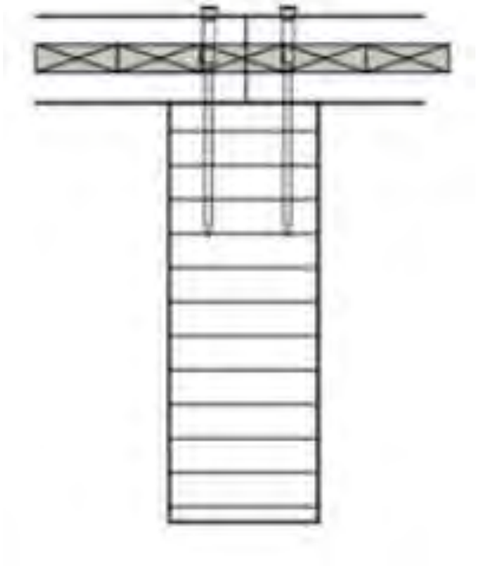
Mass Timber Design

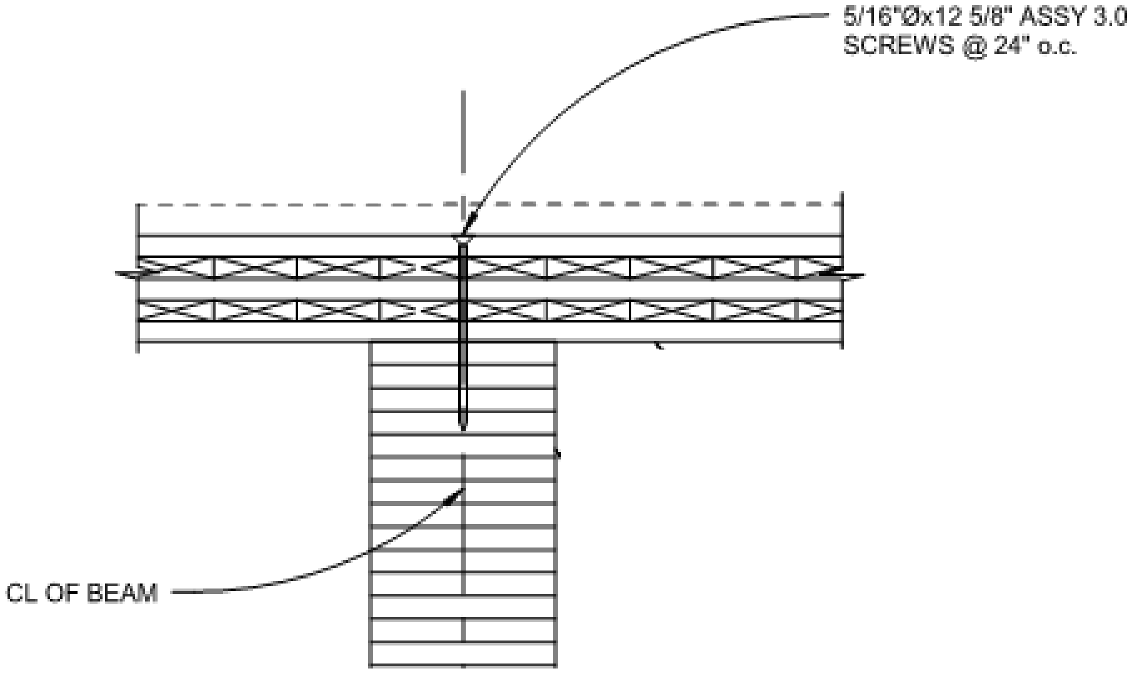
Connections

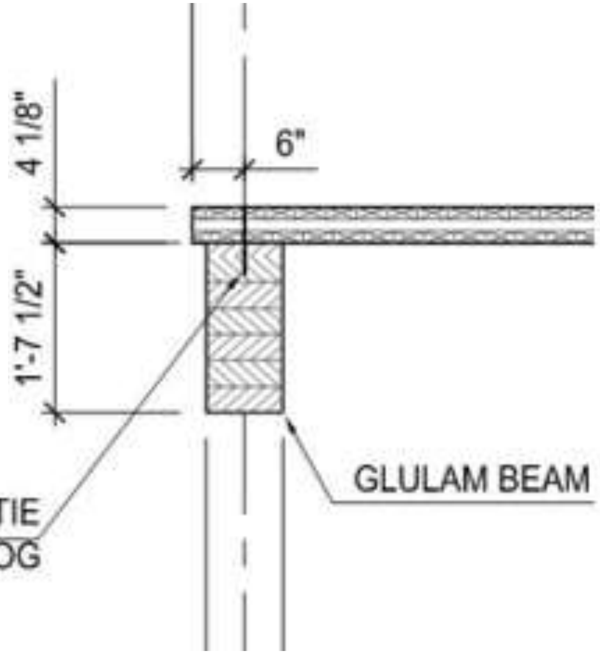
Photo Credit: Alex Schreyer

Long self tapping screws used extensively throughout mass timber construction

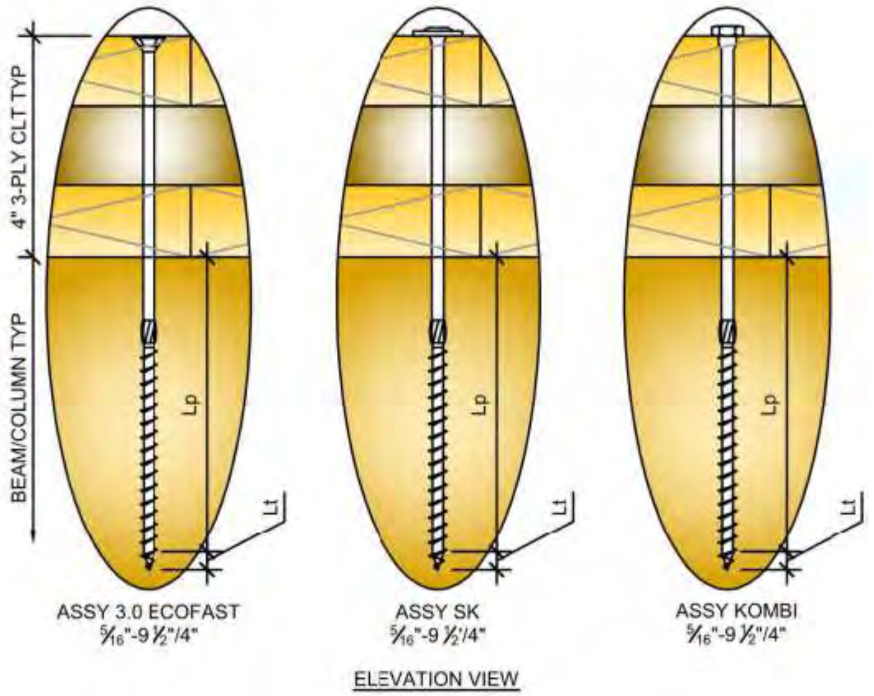
Panel to Beam Connection Styles



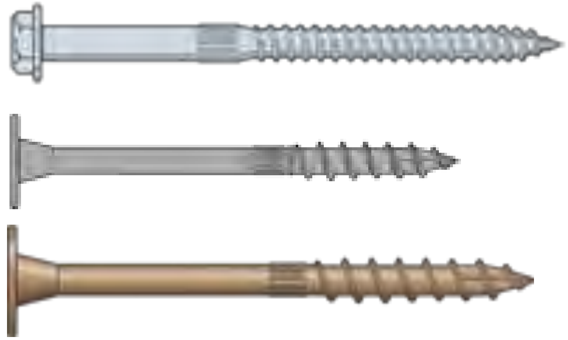




Proprietary Products



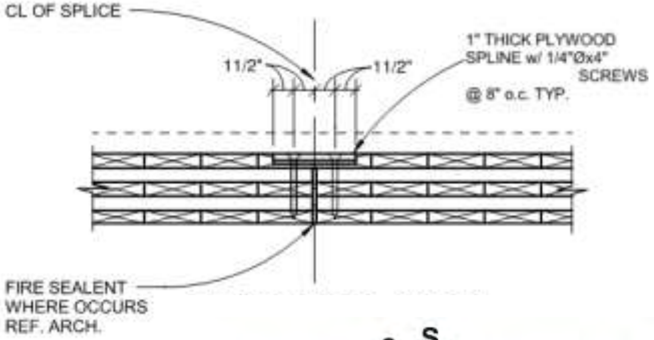
Source: MTC Solutions

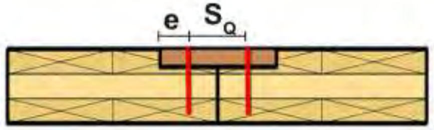


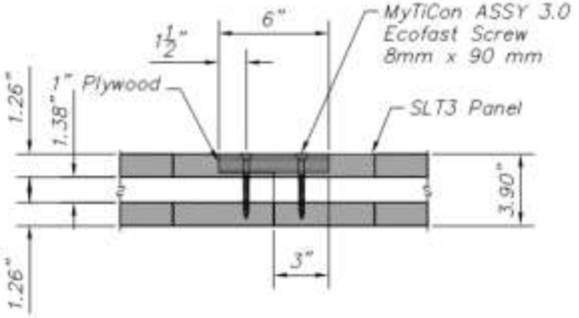
Variety of Self Tapping Screws

Panel to Panel Connection Styles

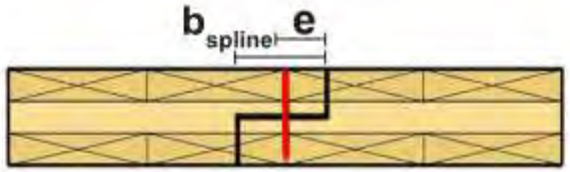
Surface Spline

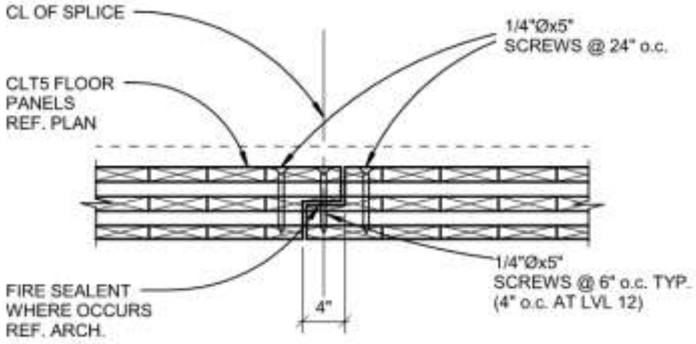






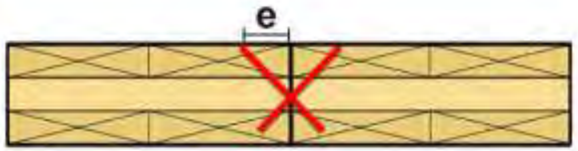
Half Lap



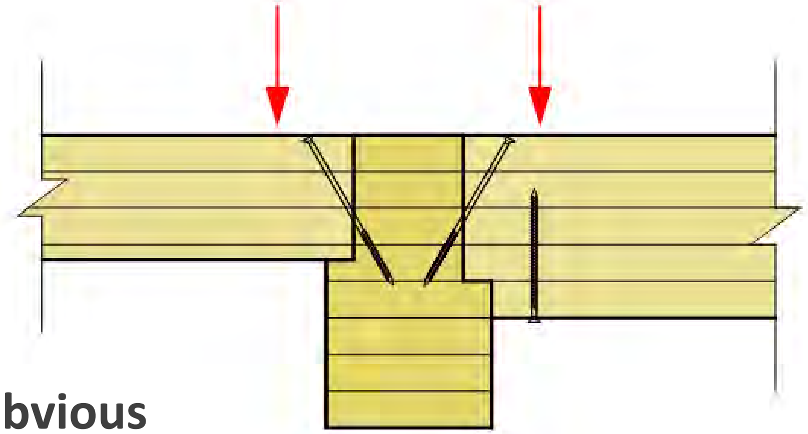


Load Sharing…
not load bearing

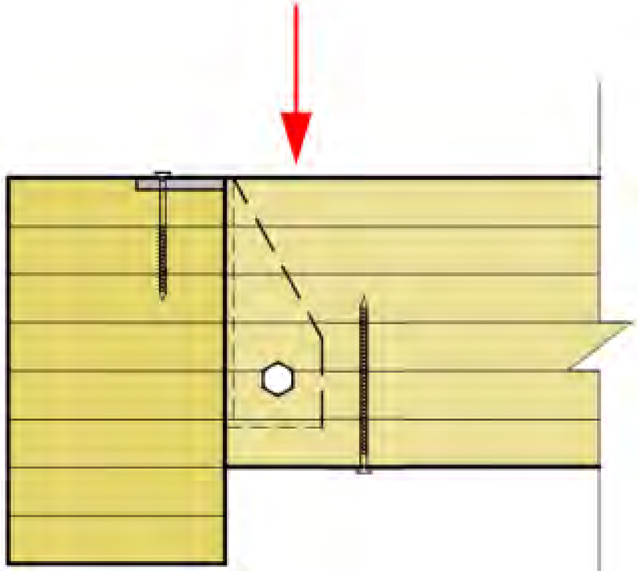
Butt Joint



Notched Beams



Obvious



Subtle

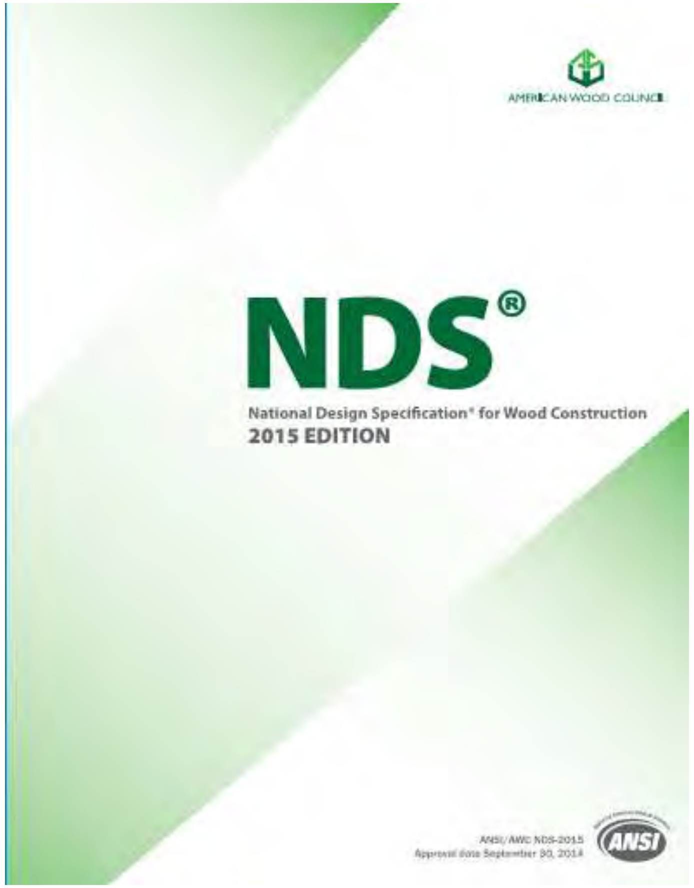
NDS covers notches on tenson side of beams at support up to:

- 1/4th depth for solid sawn
- 1/10th dept for SCL
- 1/10th depth for Glulam beams

Reinforcement methods, outside the NDS, possible for notches beyond this.

Mass Timber 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

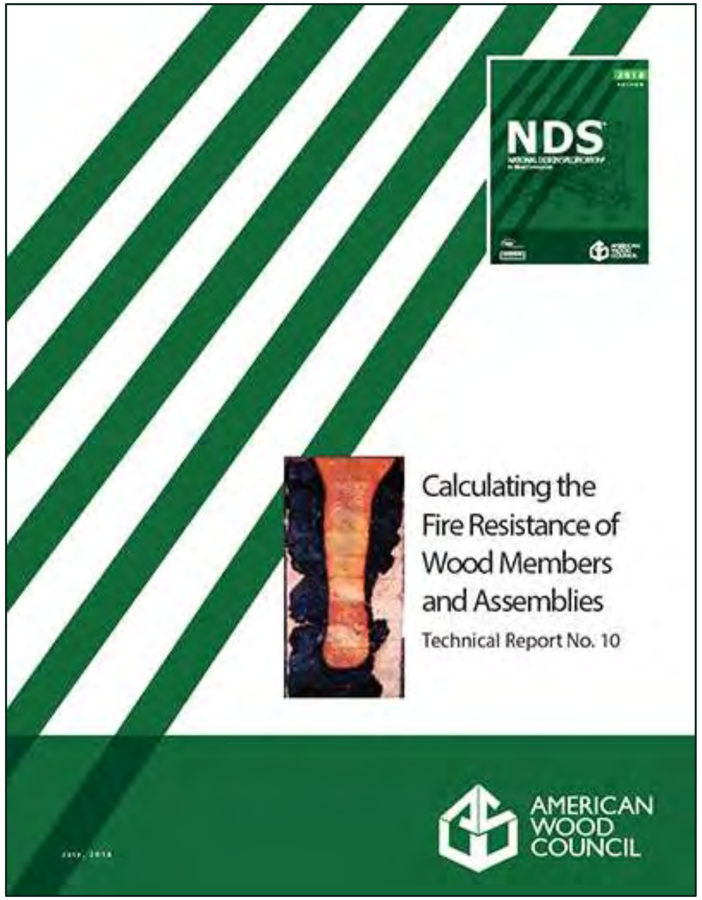
ANSI/AWC NDS-2015
Approval date September 30, 2014

NATIONAL DESIGN SPECIFICATION FOR WOOD CONSTRUCTION

FIRE DESIGN OF WOOD MEMBERS

16.1 General 150
16.2 Design Procedures for Exposed Wood Members 150
16.3 Wood Connections 151
Table 16.2.1 Effective Char Rates and Char Layer Thicknesses (for β_n = 1.5 in./hr.) 150
Table 16.2.2 Adjustment Factors for Fire Design 151

16



NDS

Calculating the Fire Resistance of Wood Members and Assemblies
Technical Report No. 10

AMERICAN WOOD COUNCIL

Mass Timber Fire Resistance

NDS Chapter 16 includes calculation of fire resistance of NLT, CLT, Glulam, Solid Sawn and SCL wood products

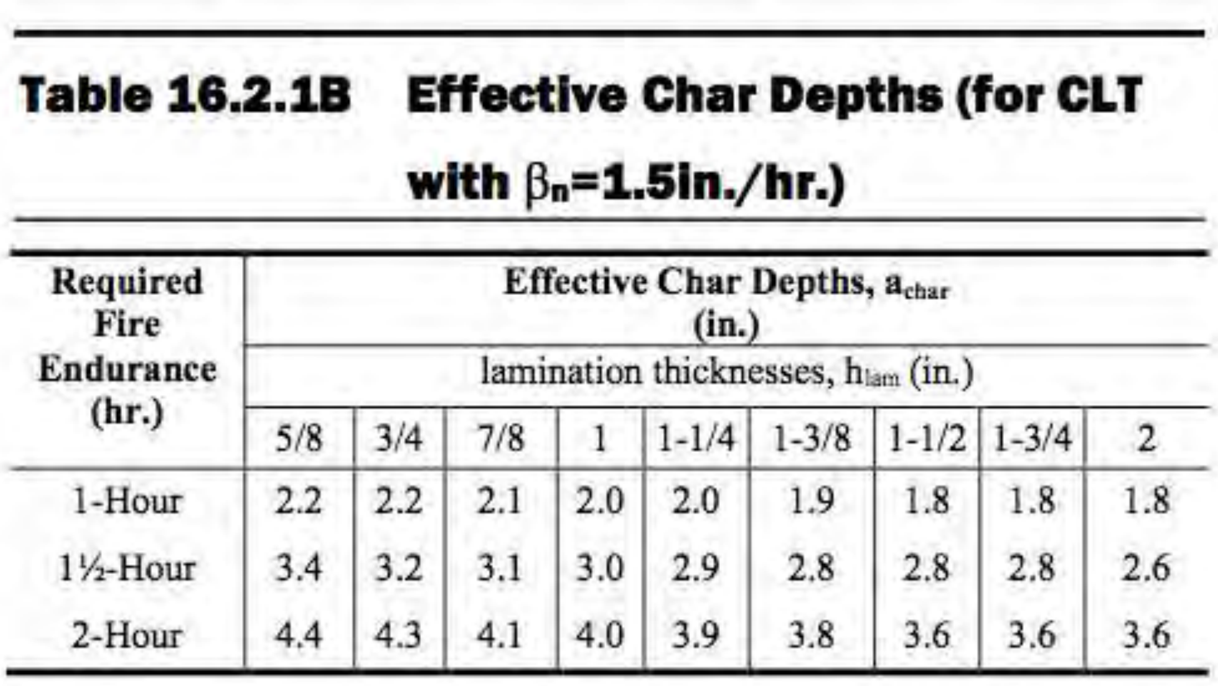
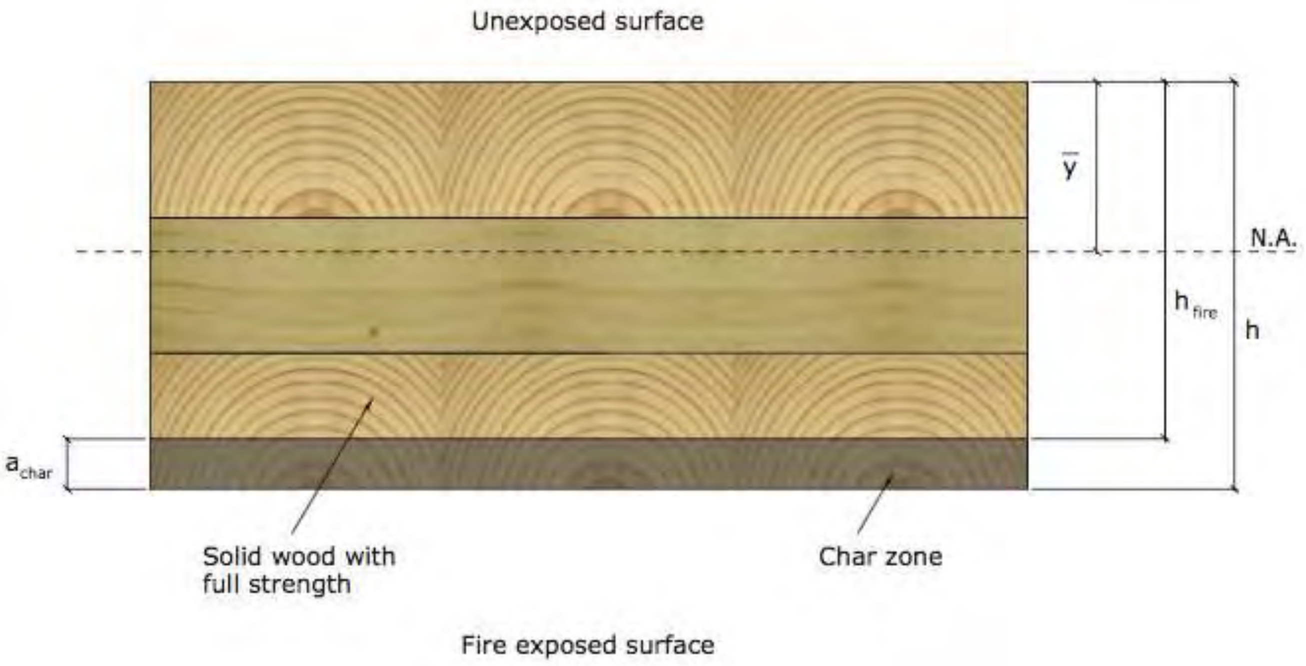


Table 16.2.1B Effective Char Depths (for CLT with β_n=1.5in./hr.)

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

Source: AWC’s NDS

Mass Timber Fire Resistance



Source: US CLT Handbook

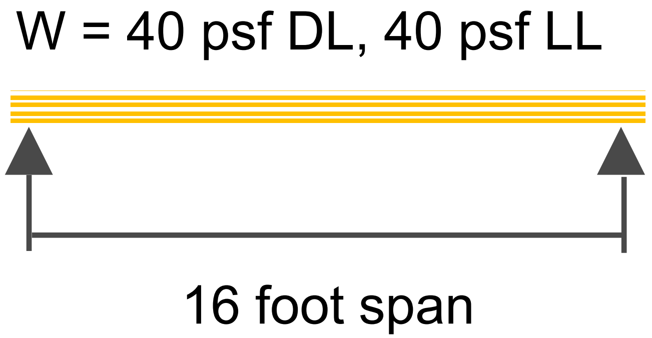
CLT fire design:

- Lam thickness affects char depth
- For simplicity, partially charred cross layers are often neglected for structural checks

CLT Fire Design Example

Given:

16 foot span floor
40 psf live load, 40 psf total dead load
Selected 5ply 6 7/8” V1 Panel



Check 1 hour fire resistance rating required

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

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

CLT Fire Design Example

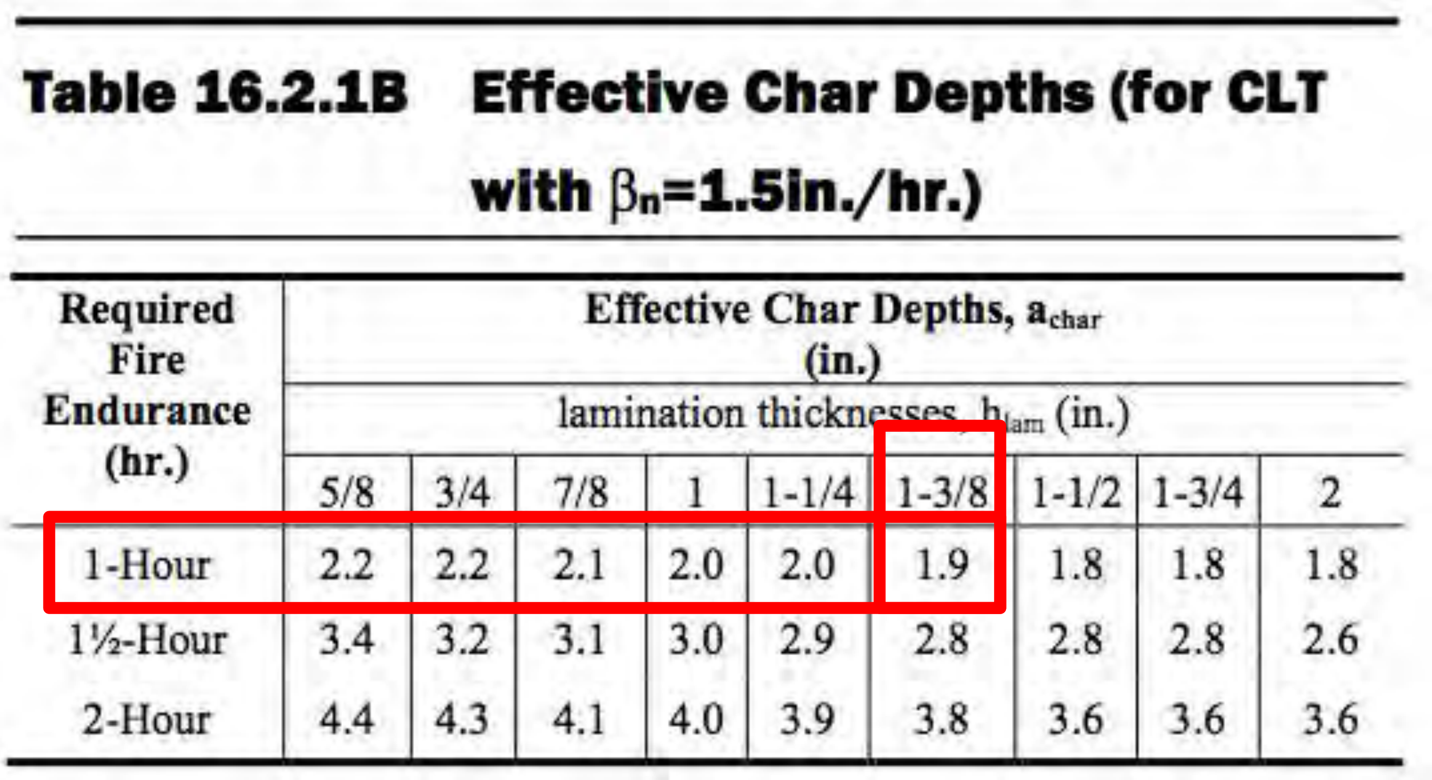
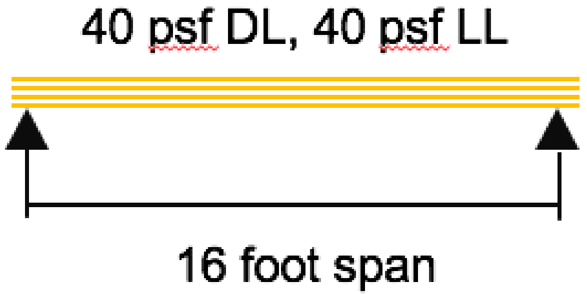
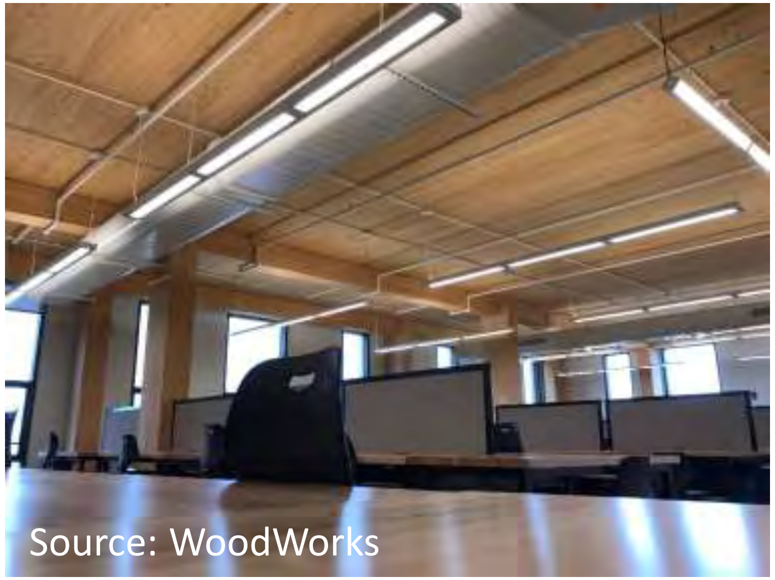


Table 16.2.1B Effective Char Depths (for CLT with β_n=1.5in./hr.)

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

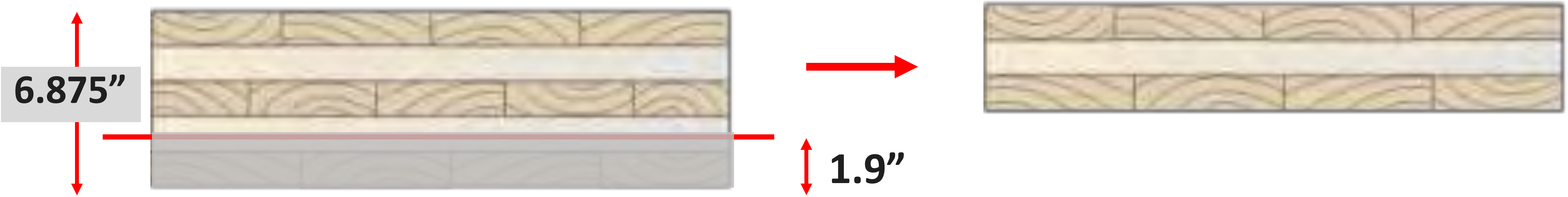
Source: AWC’s NDS





Source: WoodWorks

CLT Fire Design Example



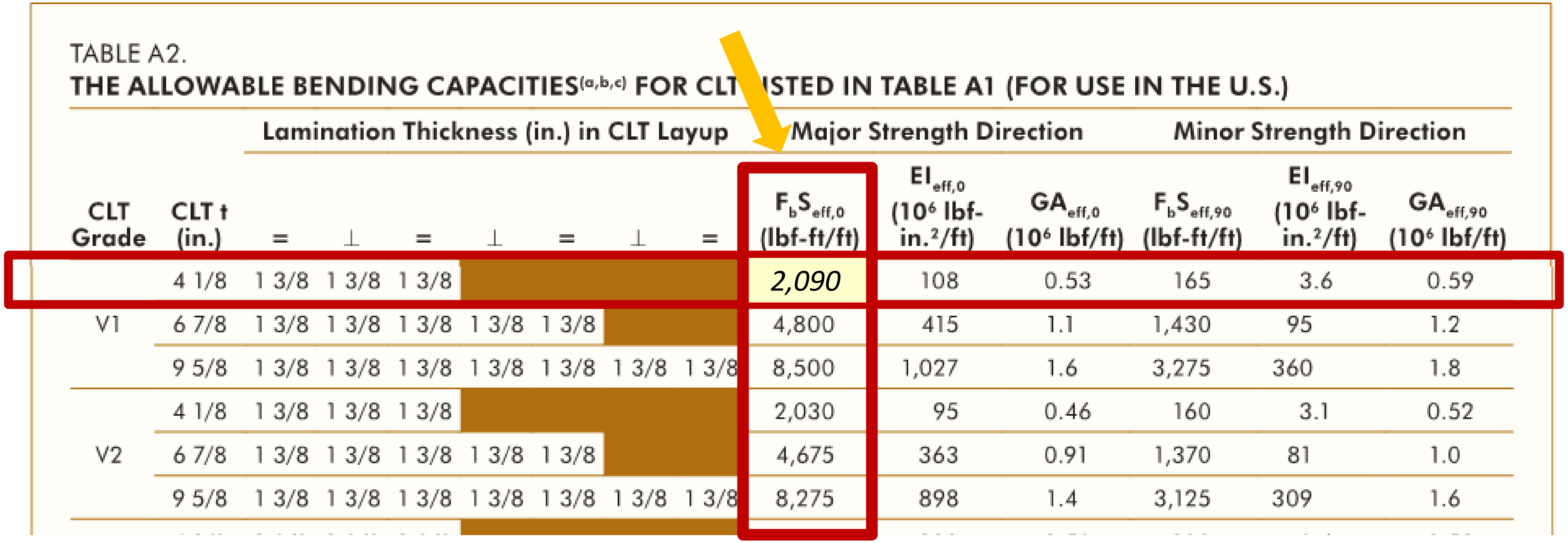


TABLE A2.

THE ALLOWABLE BENDING CAPACITIES[a,b,c] FOR CLT LISTED IN TABLE A1 (FOR USE IN THE U.S.)

		Lamination Thickness (in.) in CLT Layup							Major Strength Direction			Minor Strength Direction		
CLT Grade	CLT t (in.)	=	⊥	=	⊥	=	⊥	=	$F_bS_{eff,0}$ (lbf-ft/ft)	$EI_{eff,0}$ (10^6 lbf-in.^{2}/ft)	$GA_{eff,0}$ (10^6 lbf/ft)	$F_bS_{eff,90}$ (lbf-ft/ft)	$EI_{eff,90}$ (10^6 lbf-in.^{2}/ft)	$GA_{eff,90}$ (10^6 lbf/ft)
V1	4 1/8	1 3/8	1 3/8	1 3/8					*2,090*	108	0.53	165	3.6	0.59
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			4,800	415	1.1	1,430	95	1.2
	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	3,275	360	1.8
V2	4 1/8	1 3/8	1 3/8	1 3/8					2,030	95	0.46	160	3.1	0.52
	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			4,675	363	0.91	1,370	81	1.0
	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	8,275	898	1.4	3,125	309	1.6

SOURCE: ANSI/APA PRG 320

CLT Fire Design Example

NDS Table 16.2.2 stress adjustment factors applied to adjust to average ultimate strength under fire design conditions

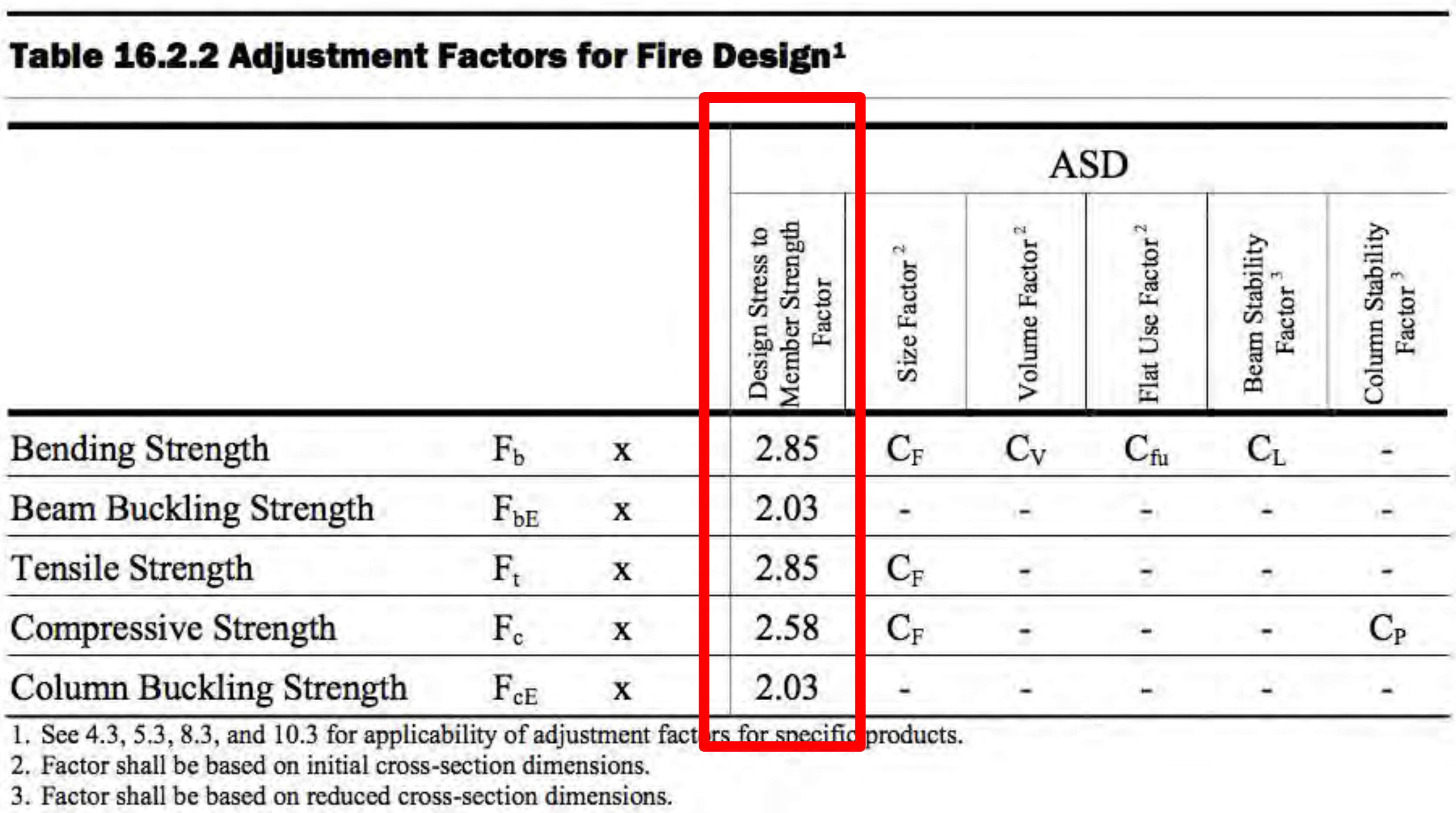


Table 16.2.2 Adjustment Factors for Fire Design[1]

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

SOURCE: AWC'S NDS

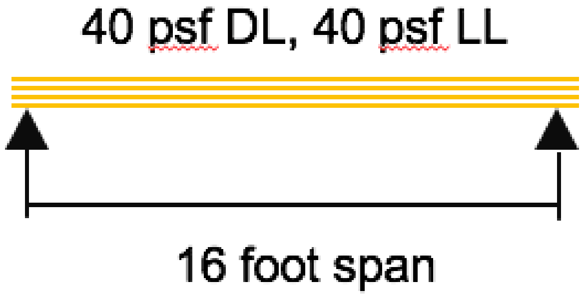
CLT Fire Design Example

$M_f' = (2.85)(F_b S_{eff})(C_L) = (2.85)(2090)(1.0) = 5957$ lb-ft/ft

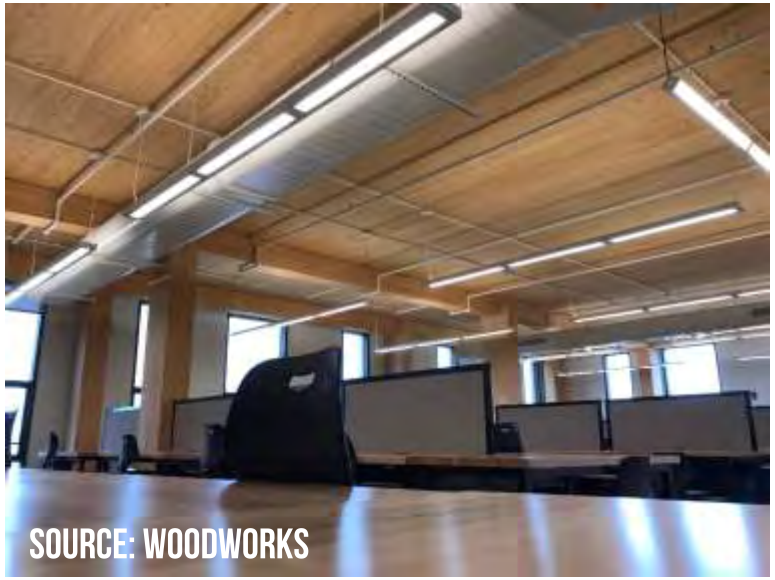
Fire Check: $M_f' > M_b$

$M_f' = 5957$ lb-ft/ft $> M_b = 2560$ lb-ft/ft

5-PLY V1 CLT adequate for 1 Hour Fire Exposure



SOURCE: WOODWORKS



SOURCE: WOODWORKS

CLT Fire Design Example

Many successful CLT fire tests have been conducted, both with and without gypsum board protection

NGC "Testing Services"

Fire Testing Laboratory

IAS ACCREDITED Testing Laboratory TL-218

TEST REPORT

Page 1 of 53

for

American Wood Council

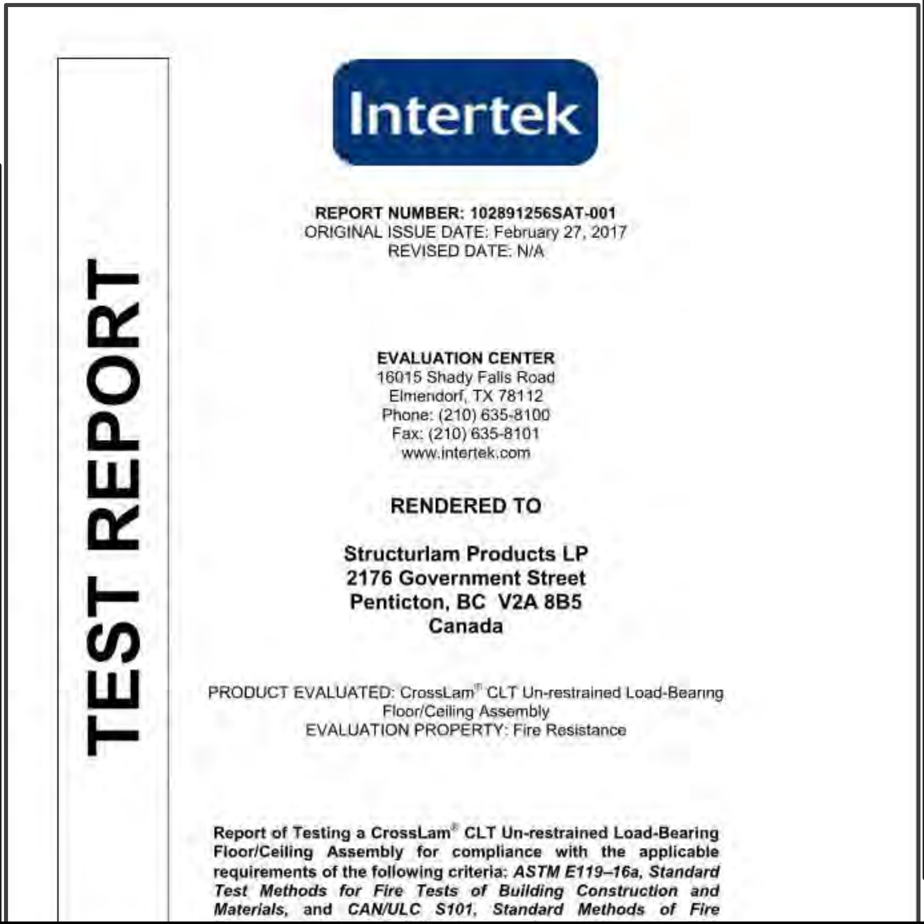
222 Catoctin Circle SE, Suite 201
Leesburg, VA 20175

Standard Methods of
Fire Tests of Building Construction and Materials
ASTM E 119 – 11a

Test Report No: WP-1950
Assignment No: K-1088
Subject Material: Cross-Laminated Timber and Gypsum Board Wall Assembly (Load-Bearing)
Test Date: October 4, 2012
Report Date: October 15, 2012

Prepared by:
Michael J. Rizzo
Test Engineer

Reviewed by:
Robert J. Menchetti



TEST REPORT

Intertek

REPORT NUMBER: 102891256SAT-001
ORIGINAL ISSUE DATE: February 27, 2017
REVISED DATE: N/A

EVALUATION CENTER
16015 Shady Falls Road
Elmendorf, TX 78112
Phone: (210) 635-8100
Fax: (210) 635-8101
www.intertek.com

RENDERED TO

Structurlam Products LP
2176 Government Street
Penticton, BC V2A 8B5
Canada

PRODUCT EVALUATED: CrossLam® CLT Un-restrained Load-Bearing Floor/Ceiling Assembly
EVALUATION PROPERTY: Fire Resistance

Report of Testing a CrossLam® CLT Un-restrained Load-Bearing Floor/Ceiling Assembly for compliance with the applicable requirements of the following criteria: *ASTM E119–16a, Standard Test Methods for Fire Tests of Building Construction and Materials,* and *CAN/ULC S101, Standard Methods of Fire*

FPInnovations
NRC·CNRC

Project No. 301006155
Final Report 2012/13

Preliminary CLT Fire Resistance Testing Report

by

Lindsay Osborne, M.A.Sc.
Christian Dagenais, Eng., M.Sc.
Scientists
Advanced Building Systems – Serviceability and Fire Group

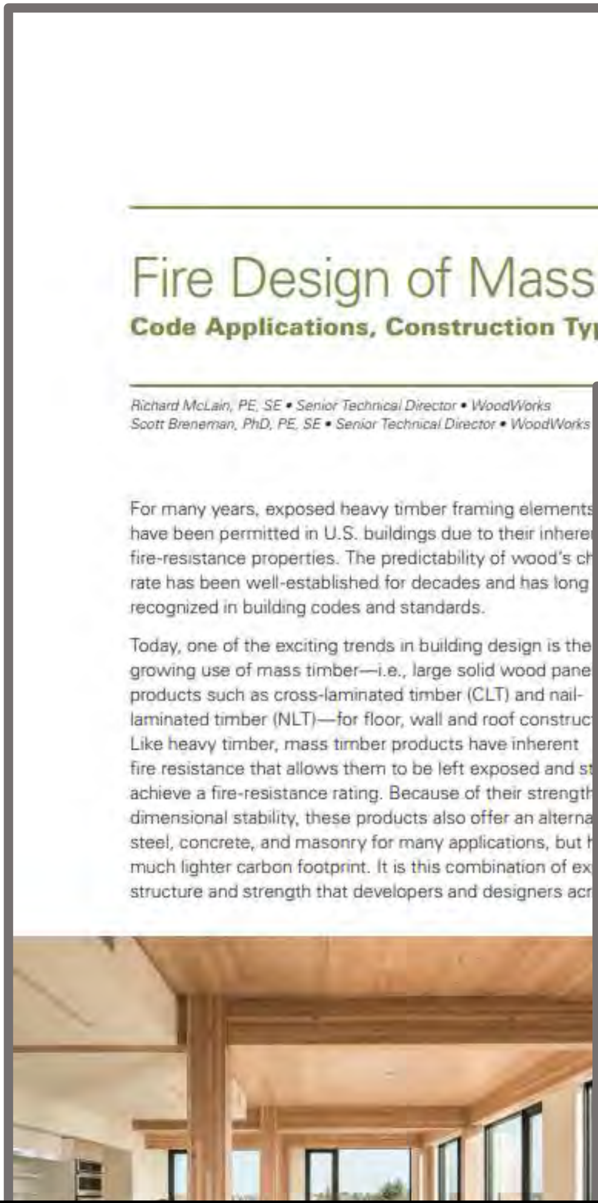
and

Noureddine Bénichou, Ph.D.
Senior Research Officer
National Research Council of Canada – Fire Research Resource Centre

July 2012

Lindsay Osborne Project Leader	Noureddine Bénichou Reviewer	Conroy Lum Research Leader

Additional Resources – WoodWorks.org



WoodWorks™
WOOD PRODUCTS COUNCIL

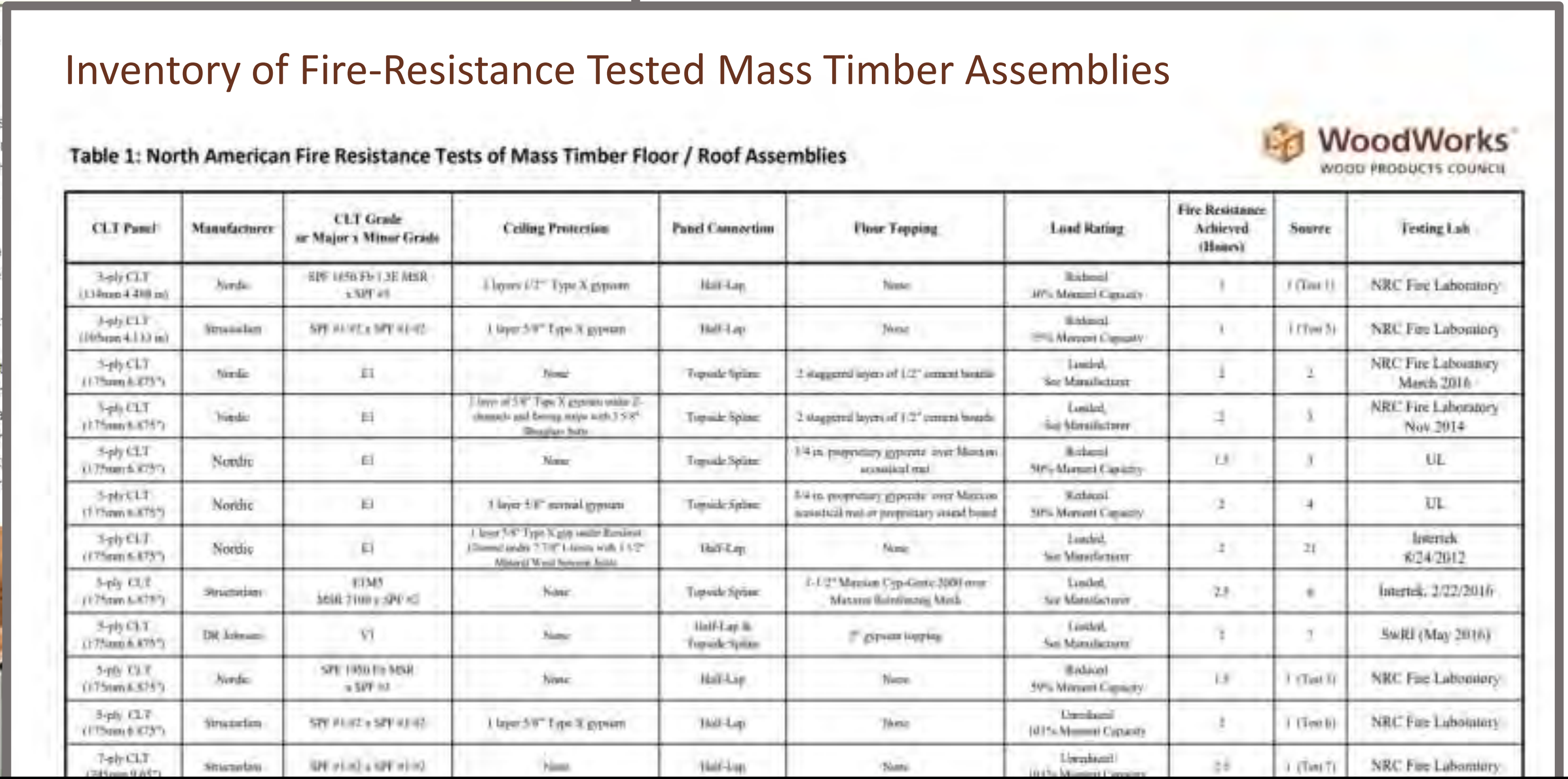
Fire Design of Mass Timber Members

Code Applications, Construction Types and Fire Ratings

Richard McLain, PE, SE • Senior Technical Director • WoodWorks
Scott Breneman, PhD, PE, SE • Senior Technical Director • WoodWorks

For many years, exposed heavy timber framing elements
have been permitted in U.S. buildings due to their inhere
fire-resistance properties. The predictability of wood's ch
rate has been well-established for decades and has long
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 pane
products such as cross-laminated timber (CLT) and nail-
laminated timber (NLT)—for floor, wall and roof construc
Like heavy timber, mass timber products have inherent
fire resistance that allows them to be left exposed and st
achieve a fire-resistance rating. Because of their strength
dimensional stability, these products also offer an alterna
steel, concrete, and masonry for many applications, but h
much lighter carbon footprint. It is this combination of ex
structure and strength that developers and designers acr



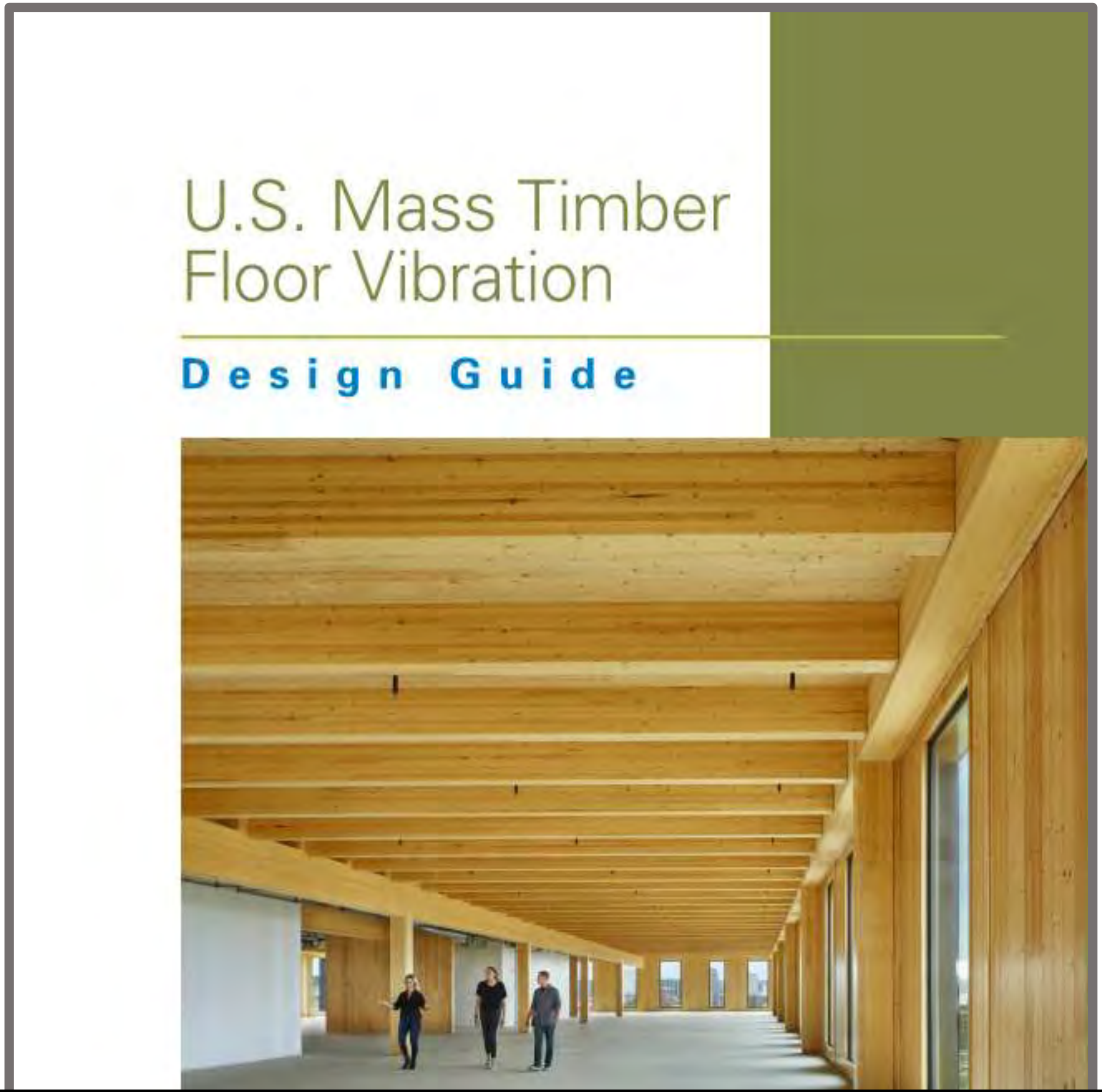
Inventory of Fire-Resistance Tested Mass Timber Assemblies

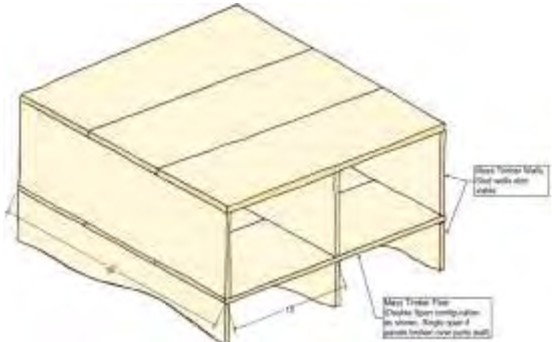
WoodWorks
WOOD PRODUCTS COUNCIL

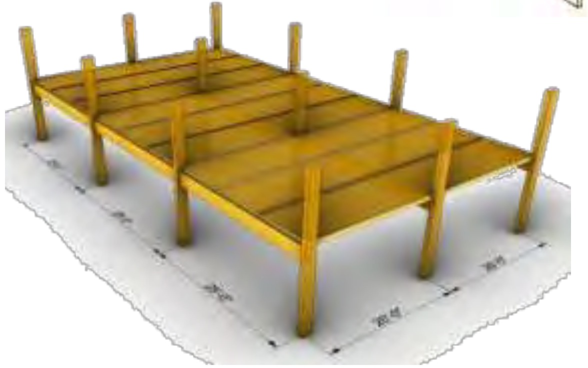
Table 1: North American Fire Resistance Tests of Mass Timber Floor / Roof Assemblies

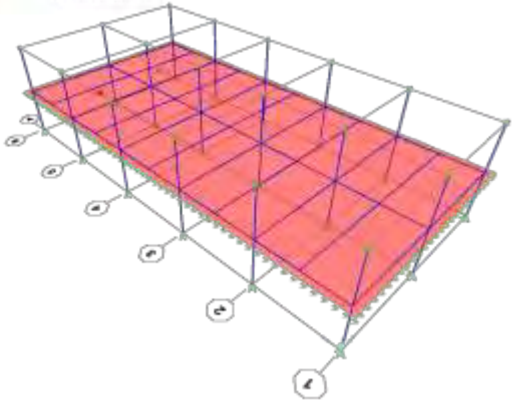
CLT Panel	Manufacturer	CLT Grade or Major x Minor Grade	Ceiling Protection	Panel Connection	Floor Topping	Load Rating	Fire Resistance Achieved (Hours)	Source	Testing Lab

Additional Resources – WoodWorks.org









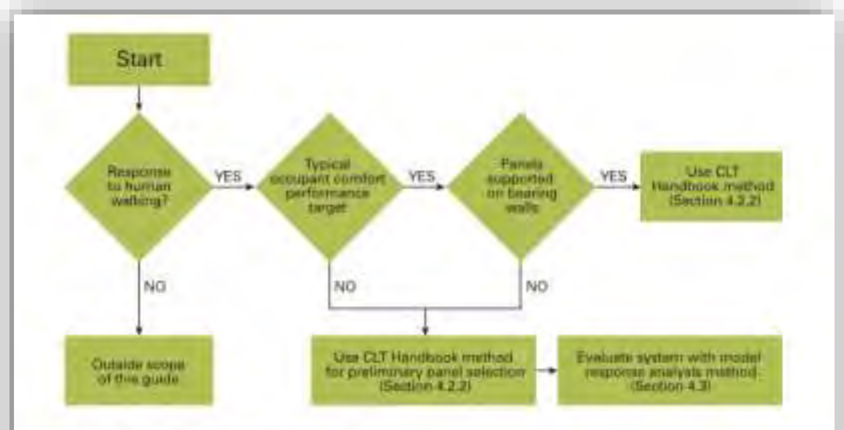
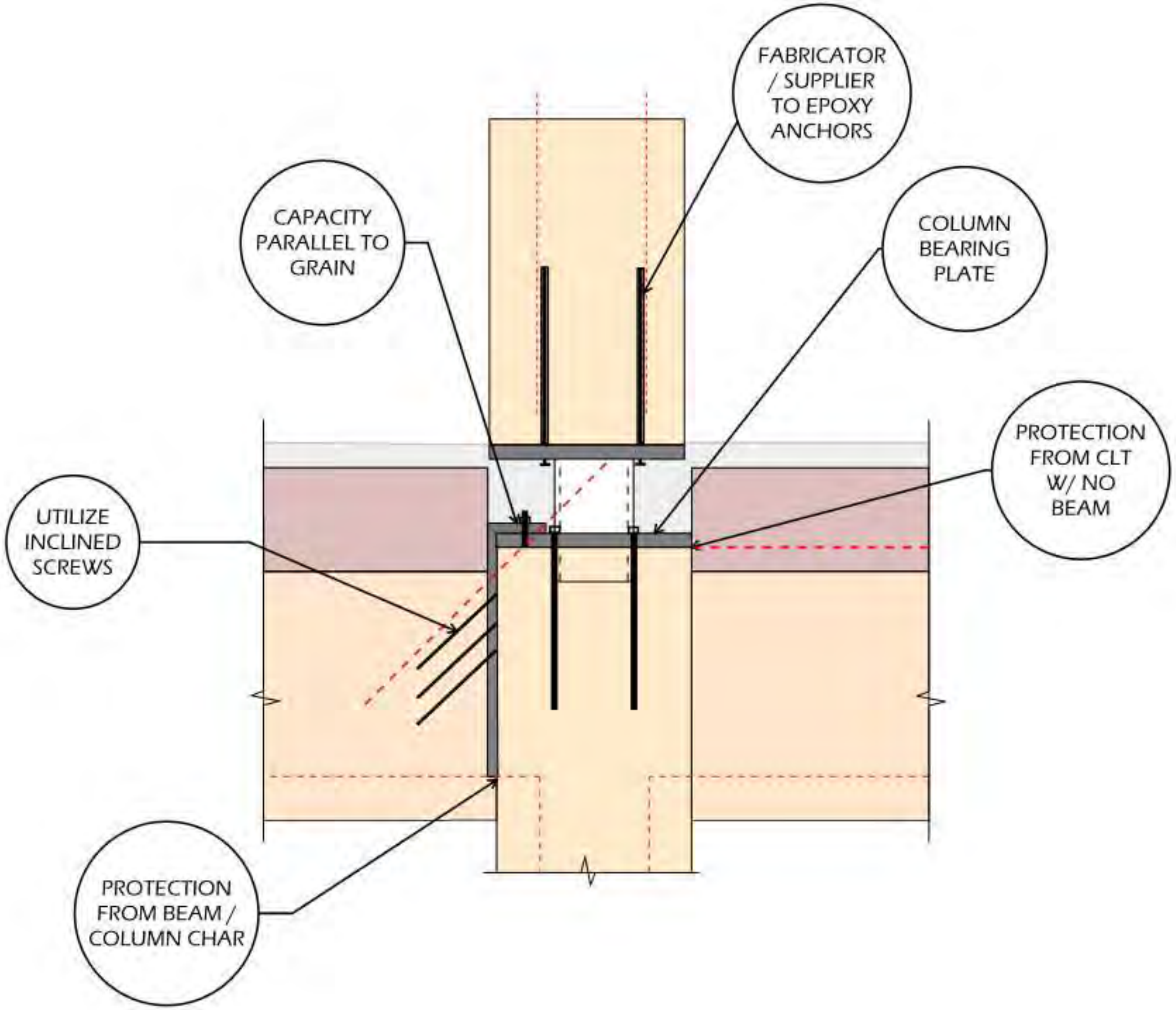


FIGURE 4-1: Vibration design flow chart

CONNECTIONS

RENDERING: Hartshorne Plunkard Architecture

Disclaimer: This presentation was developed by a third party and is not funded by WoodWorks or the Softwood Lumber Board



CAPACITY PARALLEL TO GRAIN

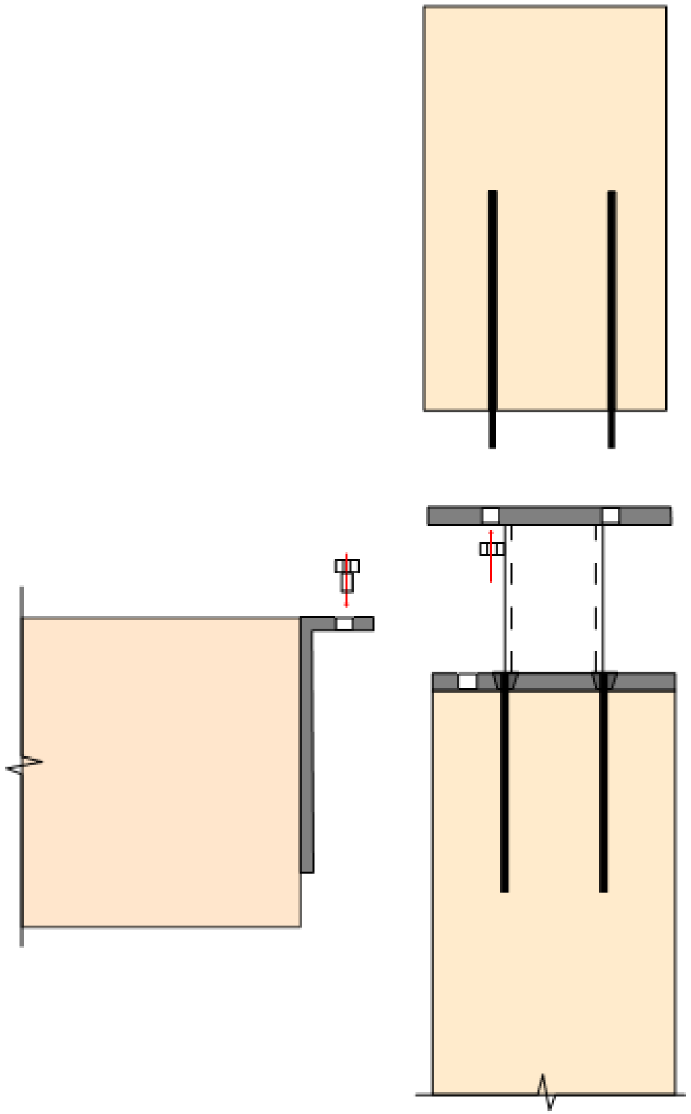
FABRICATOR / SUPPLIER TO EPOXY ANCHORS

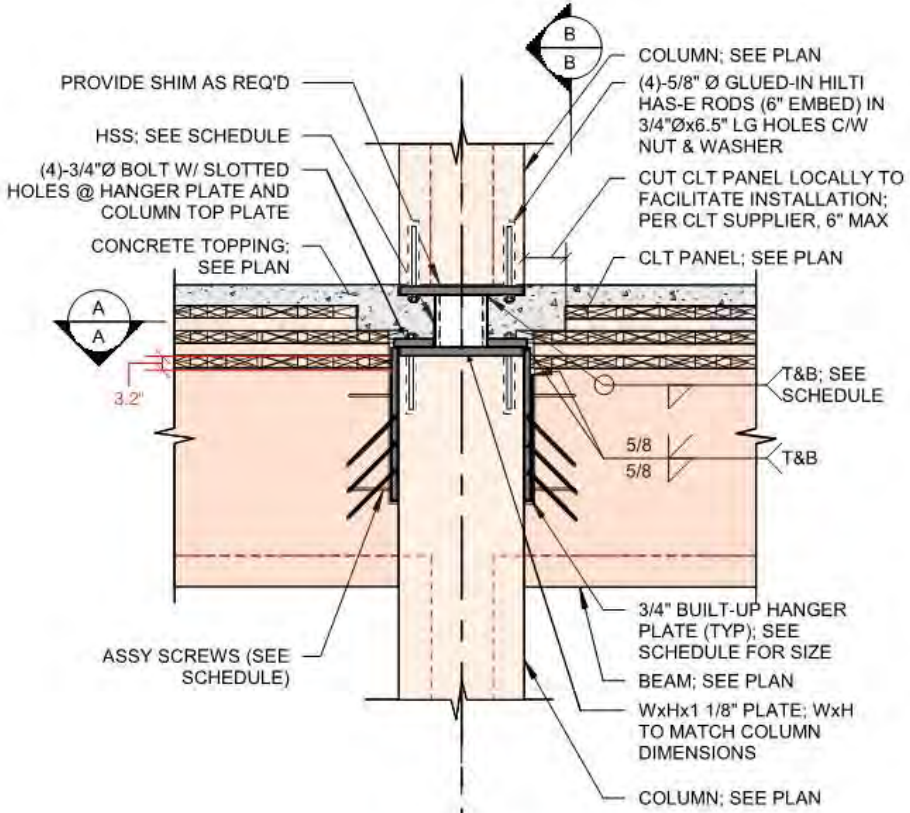
COLUMN BEARING PLATE

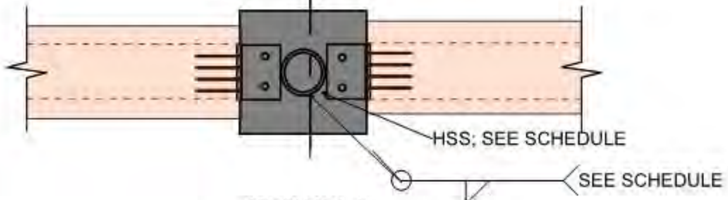
UTILIZE INCLINED SCREWS

PROTECTION FROM CLT W/ NO BEAM

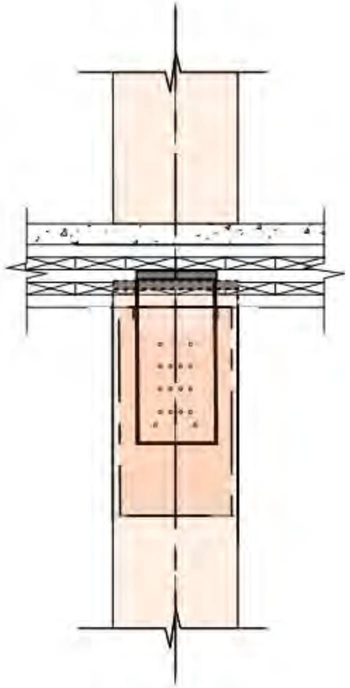
PROTECTION FROM BEAM / COLUMN CHAR



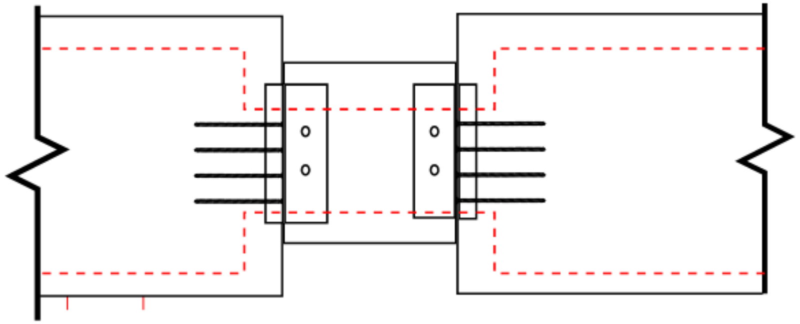


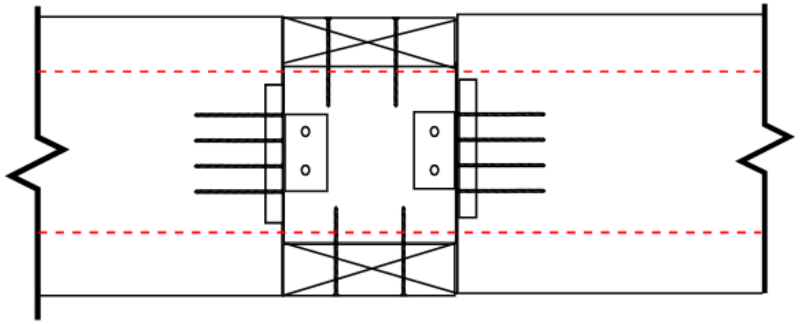


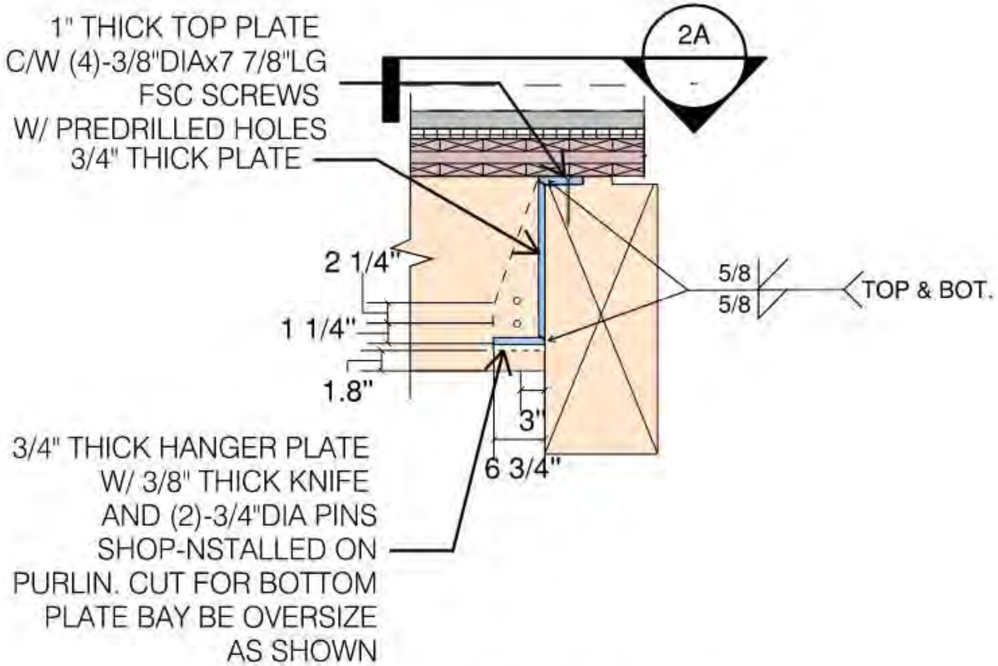
SECTION A-A



SECTION B-B



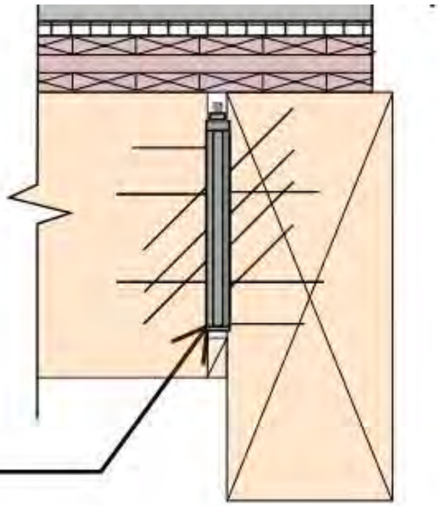




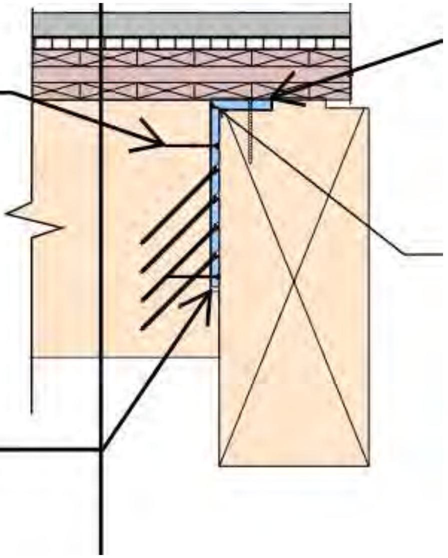
1
-

FLUSH PURLIN - OPT 1

SECTION



PRE-ENGINEERED
PROPRIETARY BEAM HANGER
SEE SCHEDULE

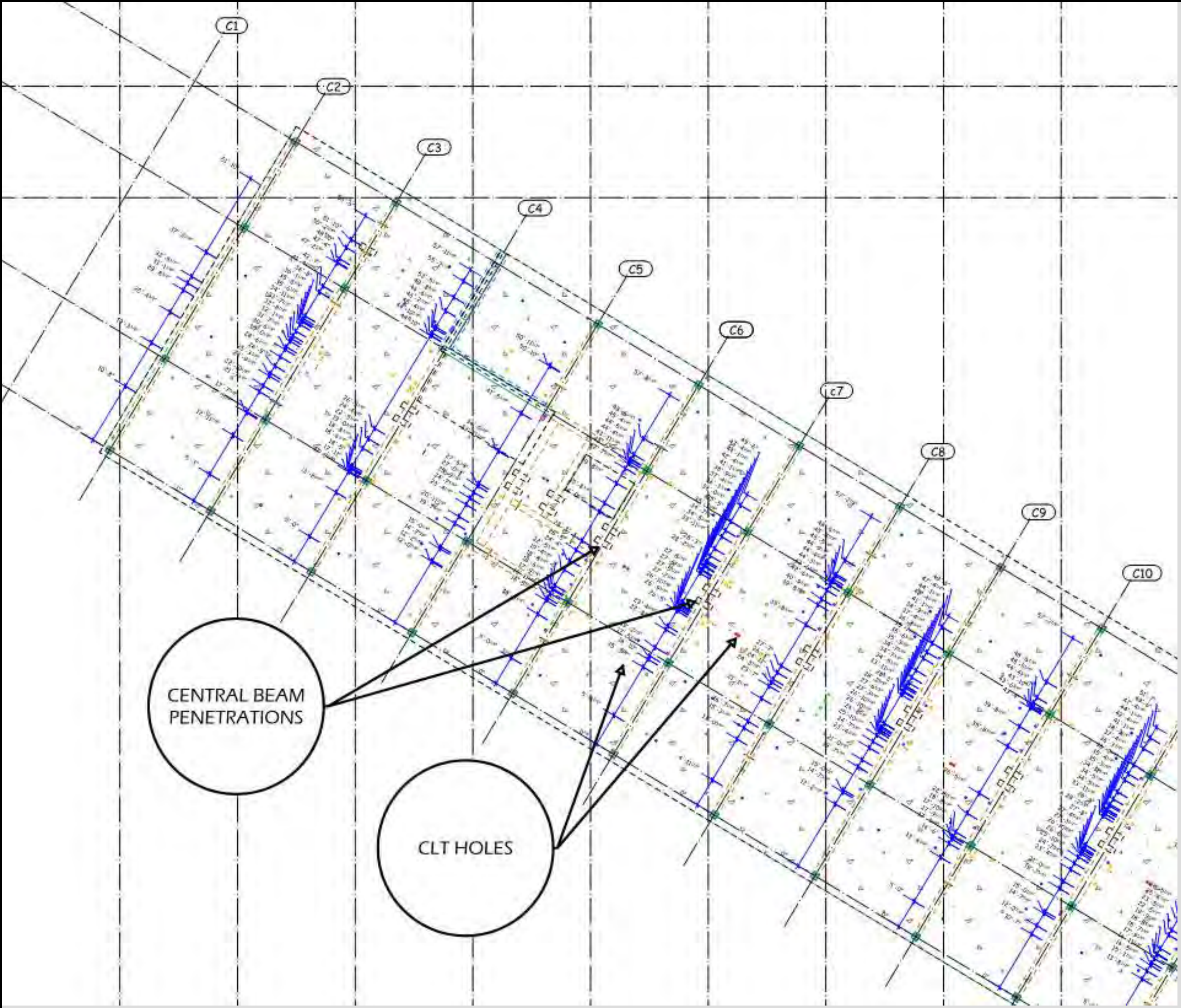


(4)-5/16"Øx3 1/8"LG PSC
SCREWS FOR INSTALLATION
(2 TOP AND BOTTOM)

3/4" THICK HANGER PLATE
C/W (16)-5/16"Øx9 1/2"LG
FSC ASSY SCREW
45°-INCLINED IN 4 ROWS SHOP
INSTALLED ON PURLIN

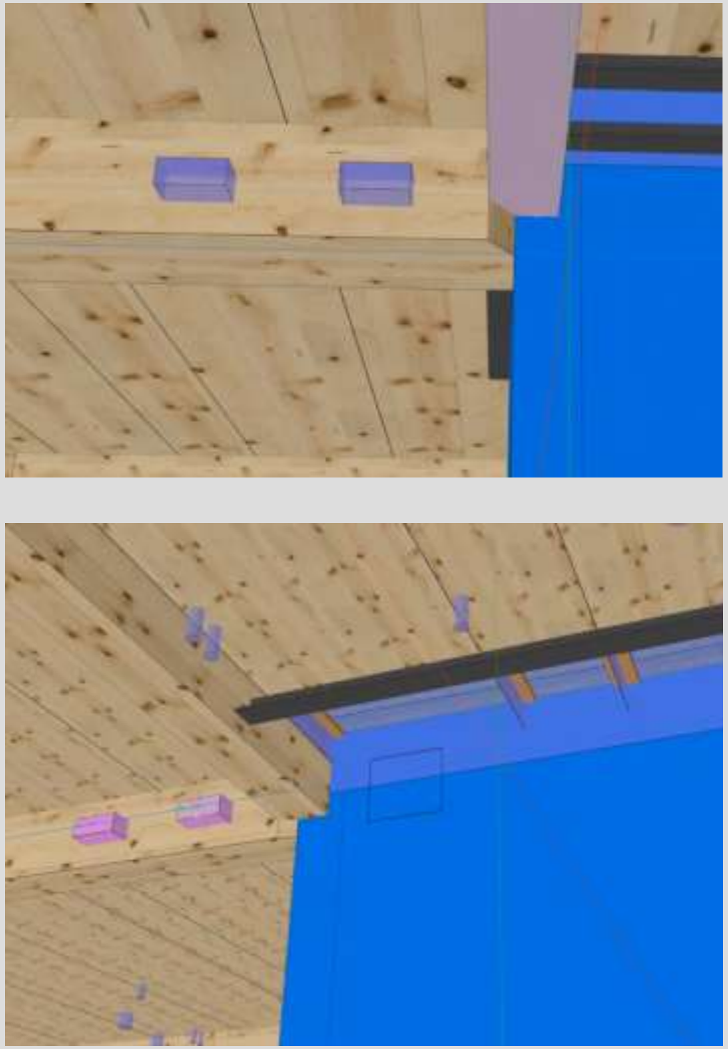
PENETRATIONS

RENDERING: Hartshorne Plunkard Architecture



CENTRAL BEAM PENETRATIONS

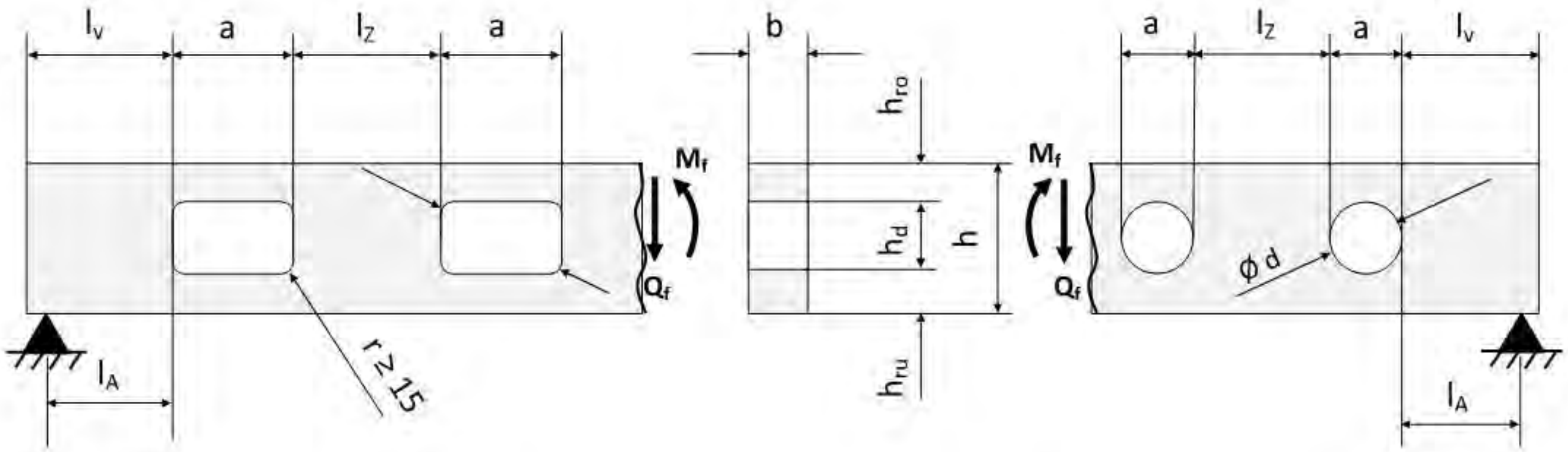
CLT HOLES

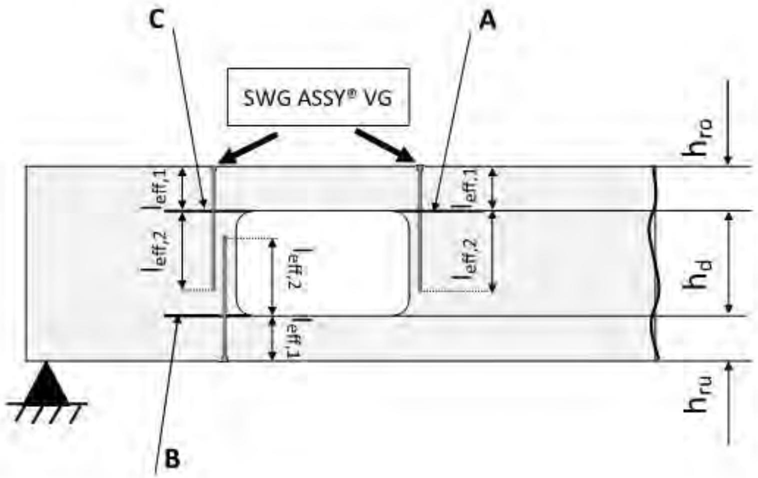


MODEL: Lignum Design

MyTiCon Timber Connectors White Paper

Full thread SWG ASSY® Screws as Reinforcement



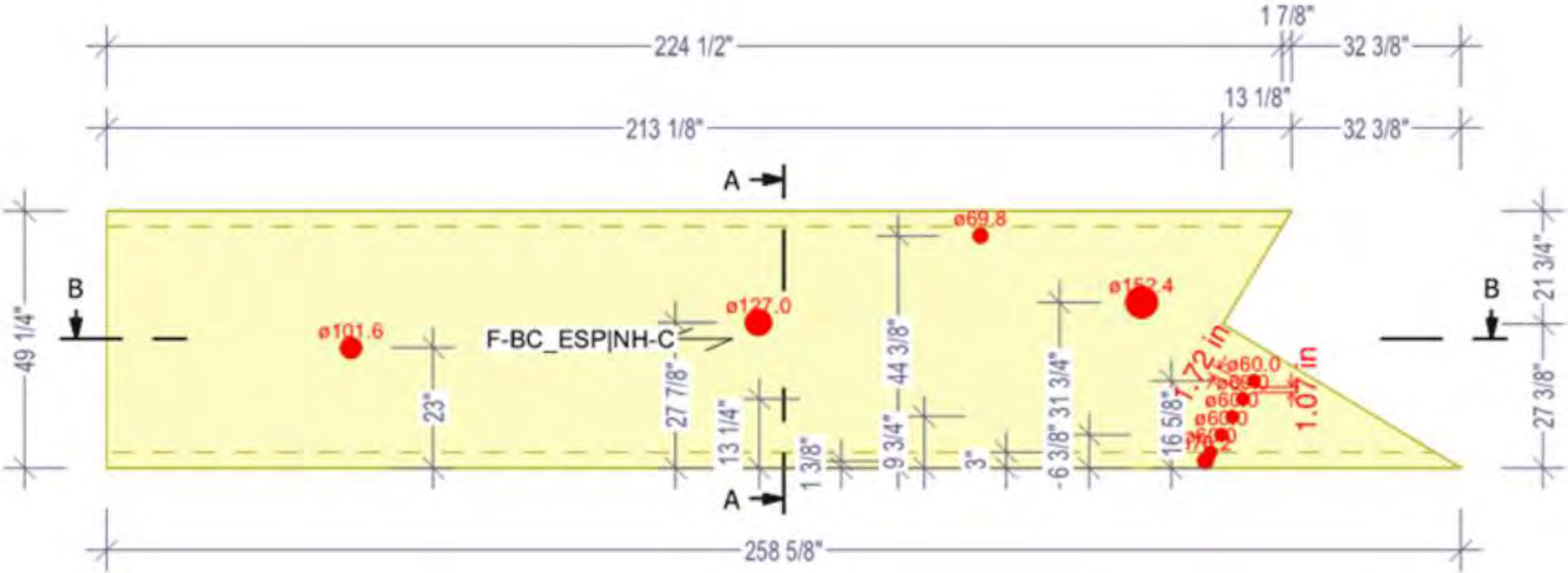


APA

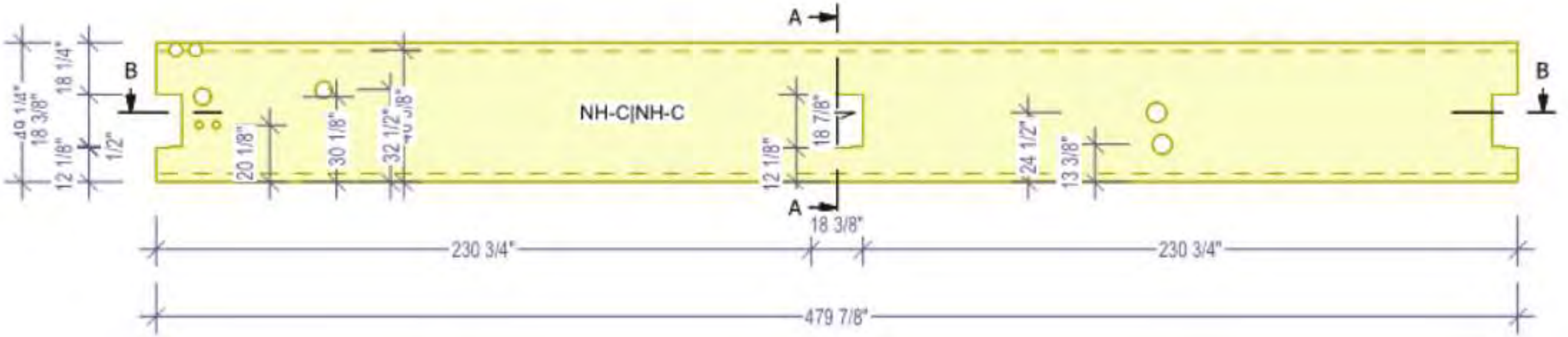
www.apawood.org

TECHNICAL NOTE

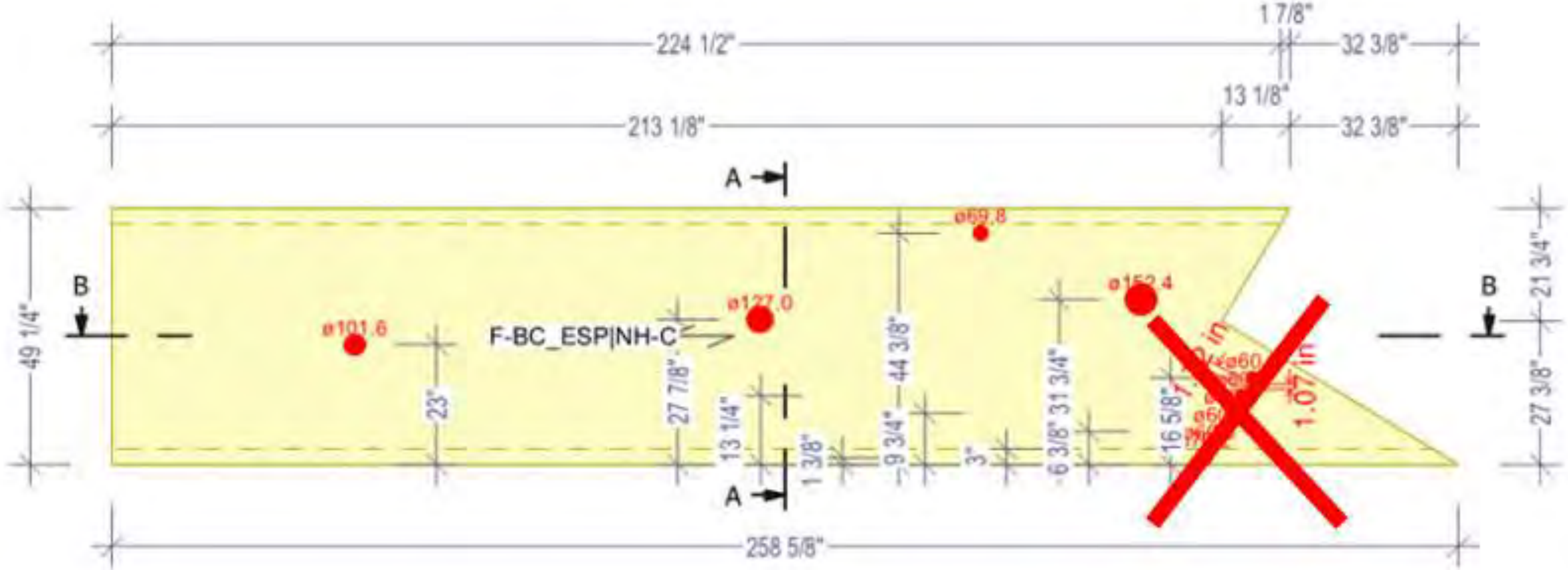
Effect of Large Diameter Horizontal Holes on the Bending and Shear Properties of Structural Glued Laminated Timber

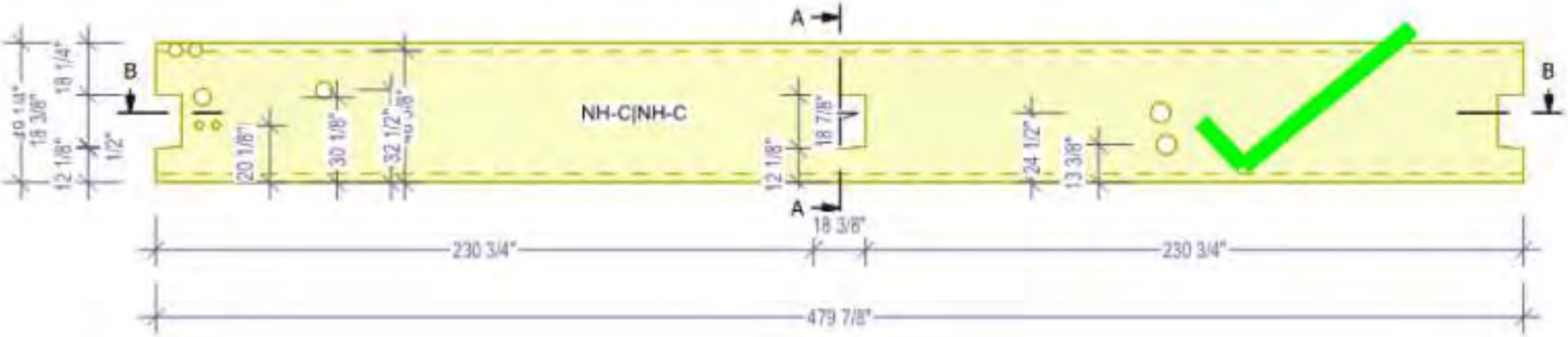


224 1/2"
1 7/8"
32 3/8"
213 1/8"
13 1/8"
32 3/8"
A
A
B
B
ø69.8
ø152.4
ø127.0
ø101.6
F-BC_ESP|NH-C
49 1/4"
23"
27 7/8"
13 1/4"
1 3/8"
44 3/8"
9 3/4"
3"
31 3/4"
6 3/8"
16 5/8"
1.72 in
1.07 in
ø60.0
ø60.0
ø60.0
ø60.0
ø60.0
ø70.2
21 3/4"
27 3/8"
258 5/8"



A
A
B
B
49 1/4"
18 3/8"
12 1/8"
18 1/4"
1/2"
20 1/8"
30 1/8"
32 1/2"
40 3/8"
NH-C|NH-C
18 7/8"
12 1/8"
24 1/2"
13 3/8"
18 3/8"
230 3/4"
230 3/4"
479 7/8"

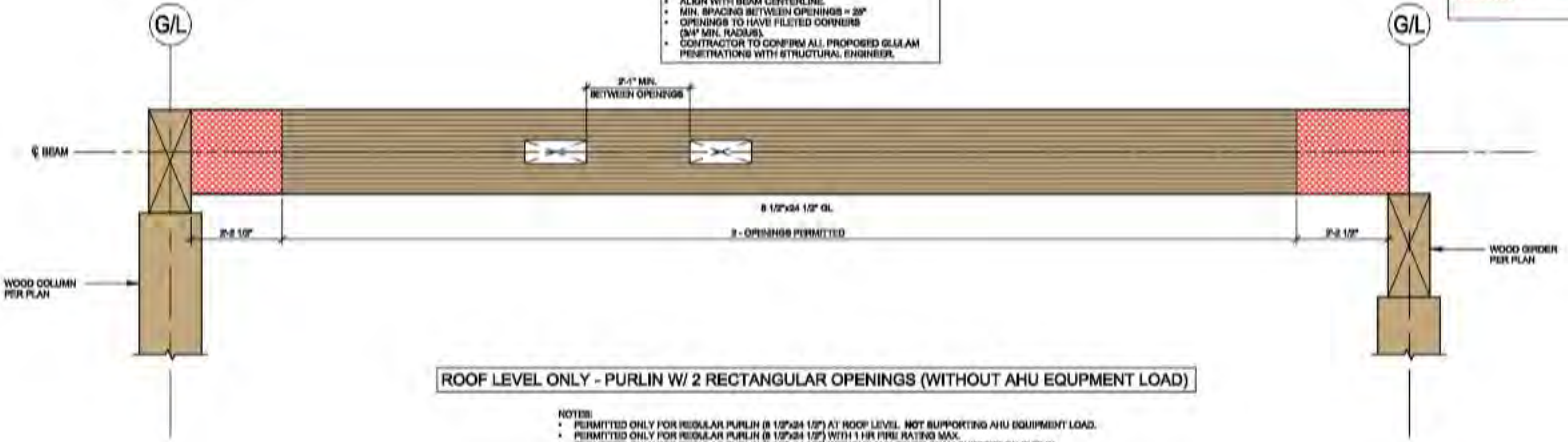

224 1/2"
1 7/8"
32 3/8"
13 1/8"
213 1/8"
32 3/8"
A
ø69.8
ø152.4
ø127.0
ø101.6
B
B
F-BC_ESP|NH-C
49 1/4"
23"
27 7/8"
13 1/4"
1 3/8"
9 3/4"
44 3/8"
3"
6 3/8"
31 3/4"
16 5/8"
ø60
1.07 in
21 3/4"
27 3/8"
A
258 5/8"


A
B
B
18 1/4"
18 3/8"
12 1/8"
1/2"
20 1/8"
30 1/8"
32 1/2"
NH-C|NH-C
18 7/8"
12 1/8"
24 1/2"
13 3/8"
A
18 3/8"
230 3/4"
230 3/4"
479 7/8"

LEGEND

🟥 NO PENETRATION ZONE

OPENING LIMITATIONS:
- 2 - RECTANGULAR OPENINGS MAX.
- OPENING SIZE MAX.: 17 1/2"WD. x7"HIGH
- ALIGN WITH BEAM CENTERLINE.
- MIN. SPACING BETWEEN OPENINGS = 25"
- OPENINGS TO HAVE FILETED CORNERS (3/4" MIN. RADIUS).
- CONTRACTOR TO CONFIRM ALL PROPOSED GLULAM PENETRATIONS WITH STRUCTURAL ENGINEER.



ROOF LEVEL ONLY - PURLIN W/ 2 RECTANGULAR OPENINGS (WITHOUT AHU EQUPMENT LOAD)

NOTES:
- PERMITTED ONLY FOR REGULAR PURLIN (8 1/2"x24 1/2") AT ROOF LEVEL. **NOT** SUPPORTING AHU EQUIPMENT LOAD.
- PERMITTED ONLY FOR REGULAR PURLIN (8 1/2"x24 1/2") WITH 1 HR FIRE RATING MAX.
- PERMITTED ONLY FOR REGULAR PURLIN (8 1/2"x24 1/2") WITHOUT ANY OTHER BEAM SUPPORT ON PURLIN.

MOISTURE

RENDERING: Hartshorne Plunkard Architecture

Questions?

This concludes The American Institute of Architects Continuing Education Systems Course

Scott Breneman, PhD, PE, SE
WoodWorks – Wood Products Council
scott.breneman@woodworks.org

Eloïse Allsop, P.E., CEng, MIStructE, M.Eng.
Fast + Epp
eallsop@fastepp.com

Copyrighted Materials

This presentation is protected by US and International Copyright laws. Reproduction, distribution, display and use of the presentation without written permission of the speaker is prohibited.

© The Wood Products Council 2021

and

© Fast + Epp 2021