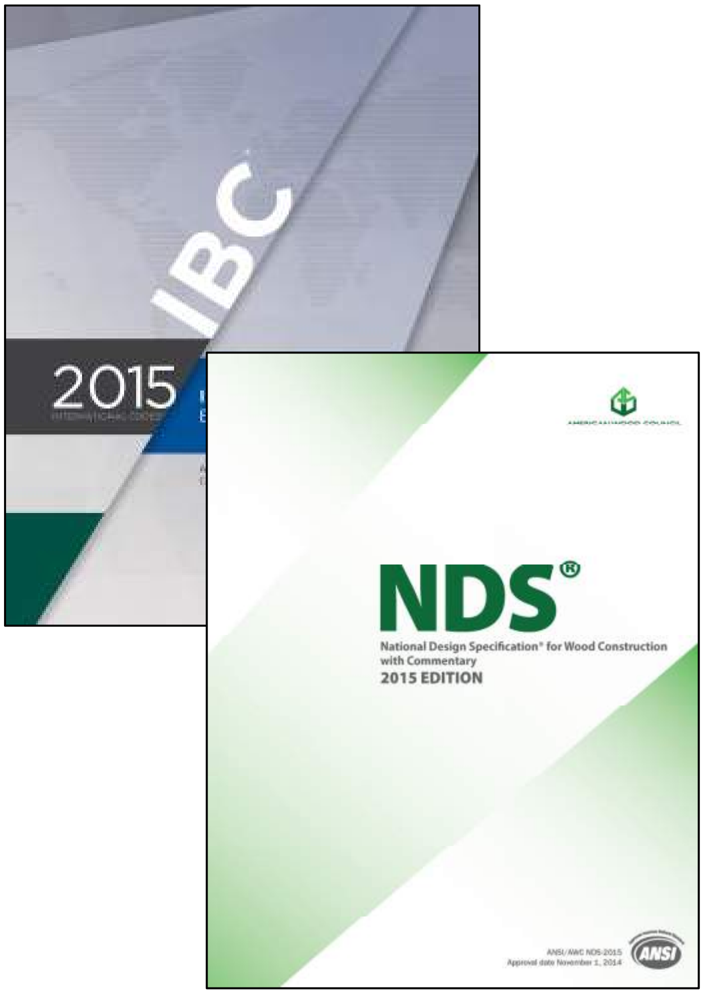
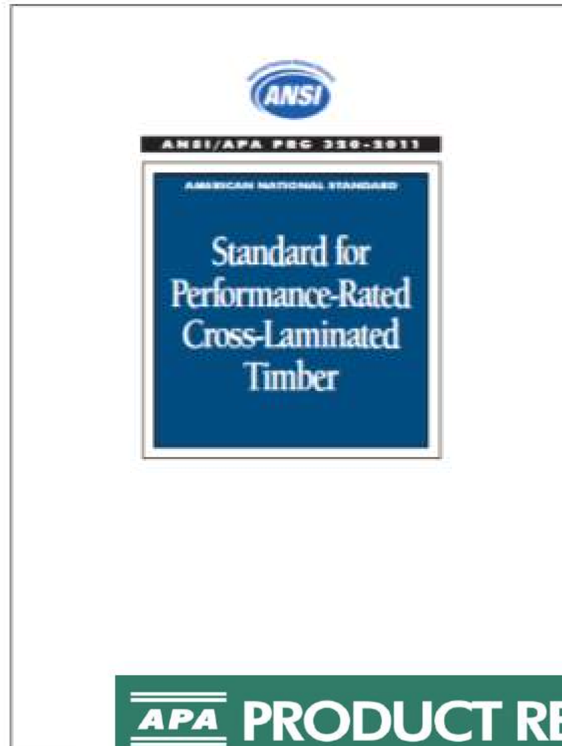
CLT Floor Design: Strength, Deflection and Vibrations

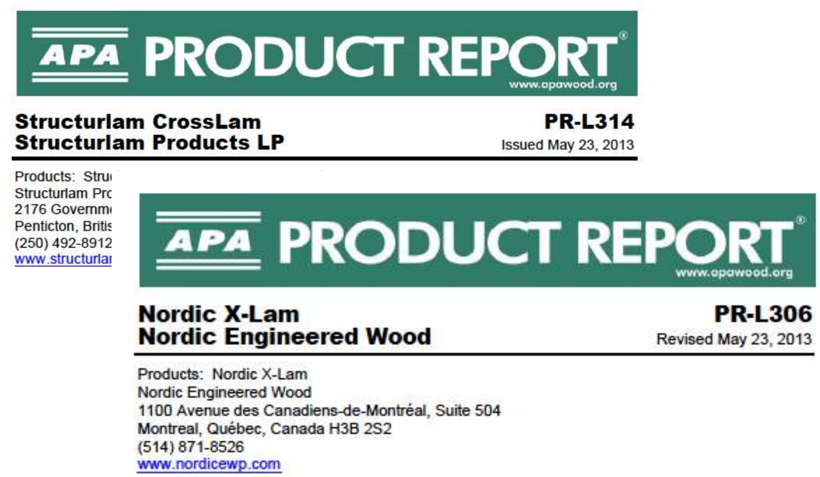
Toward Taller Wood Buildings
November 2014

Scott Breneman, PhD, PE, SE
Senior Technical Director
Architectural and Engineering Solutions
WoodWorks – Wood Products Council

Product Standardization






APA PRODUCT REPORT®
www.apawood.org

Structurlam CrossLam **PR-L314**
Structurlam Products LP Issued May 23, 2013

Products: Stru
Structurlam Pro
2176 Governm
Penticton, Britis
(250) 492-8912
www.structurlar

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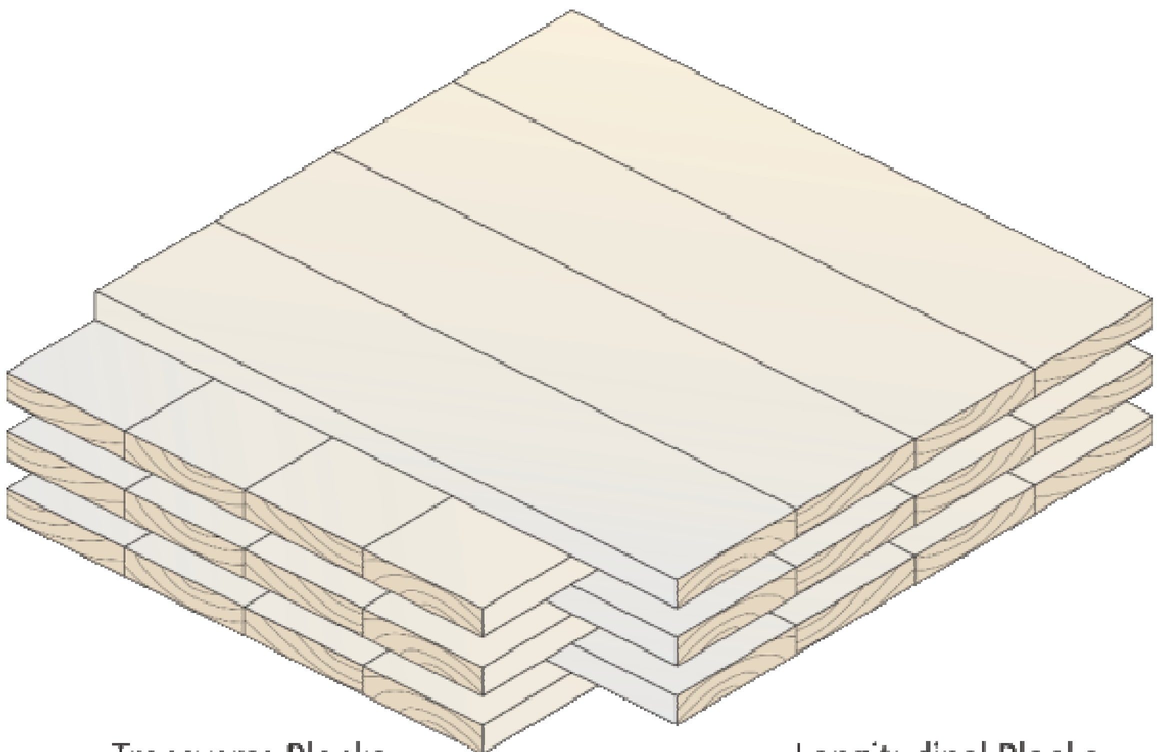
Nordic X-Lam **PR-L306**
Nordic Engineered Wood Revised May 23, 2013

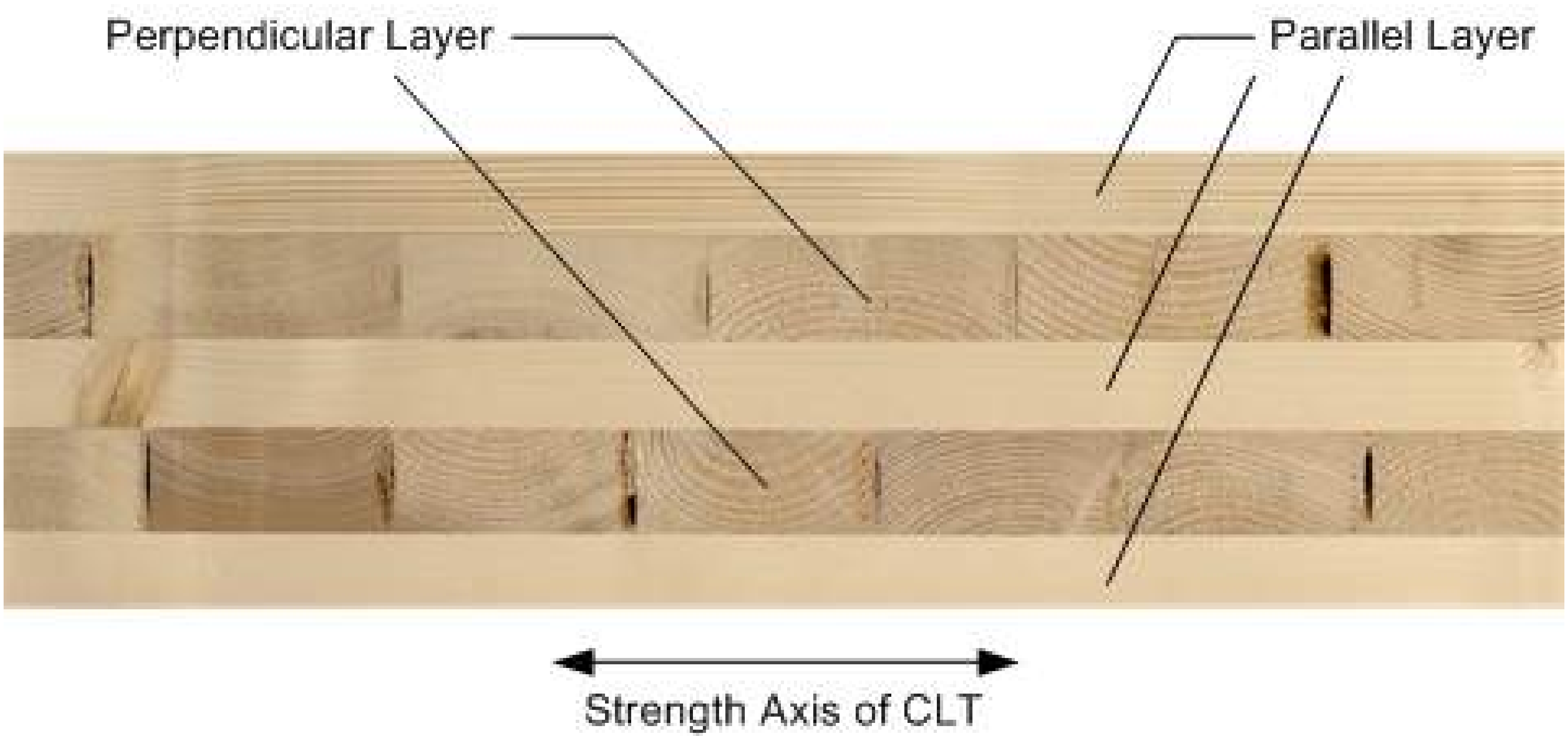
Products: Nordic X-Lam
Nordic Engineered Wood
1100 Avenue des Canadiens-de-Montréal, Suite 504
Montreal, Québec, Canada H3B 2S2
(514) 871-8526
www.nordicewp.com

CLT Composition

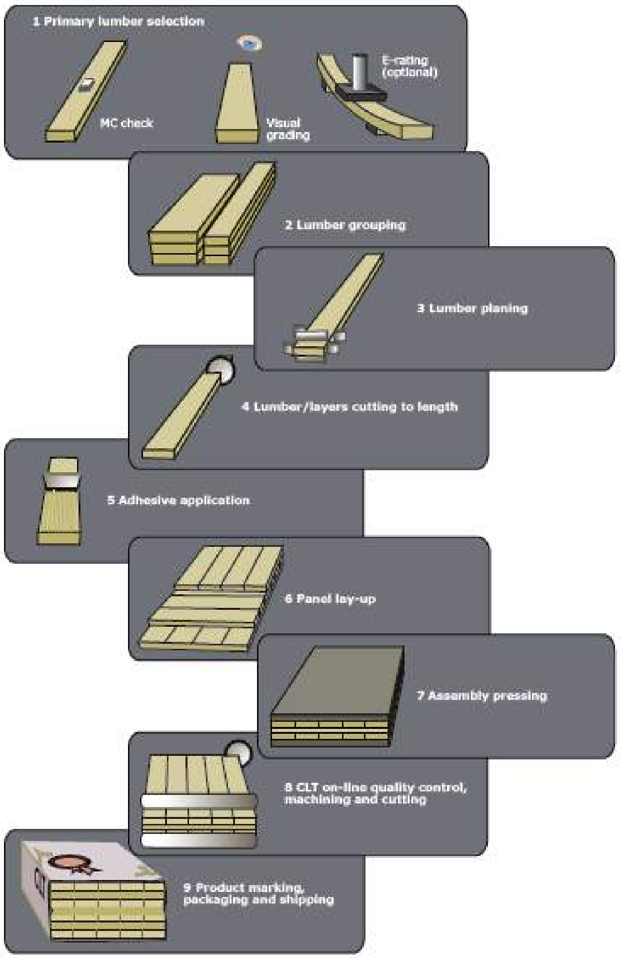
Planks in alternating directions



CLT Composition



CLT Product Standard



ANSI/APA PRG 320

- CLT Stress classes
- Quality Assurance testing
- Identification marking

CLT Grade	CLT Thickness (in.)	Lamination Thickness in CLT Lay-up (in.)							Major Strength Direction			Minor Strength Direction	
		=	⊥	=	⊥	=	⊥	=	$F_bS_{eff,0}$ (lb.-ft./ft.)	$EI_{eff,0}$ (10^6 lb.-in.^{2}/ft.)	$GA_{eff,0}$ (10^6 lb./ft.)	$F_bS_{eff,90}$ (lb.-ft./ft.)	$EI_{eff,90}$ 10^6 lb.-in.^{2}/ft.)
E1	4 1/8	1 3/8	1 3/8	1 3/8					4,525	115	0.46	160	3.1
	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
	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
E2	4 1/8	1 3/8	1 3/8	1 3/8					3,825	102	0.53	165	3.6
	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
	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
E3	4 1/8	1 3/8	1 3/8	1 3/8					2,800	81	0.35	110	2.3
	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

Product Reports

APA PRODUCT REPORT®
www.apawood.org

Structurlam CrossLam
Structurlam Products LP

PR-L314
Issued May 23, 2013

Products: Structurlam CrossLa
Structurlam Products LP
2176 Government Street
Penticton, British Columbia, Ca
(250) 492-8912
www.structurlam.com

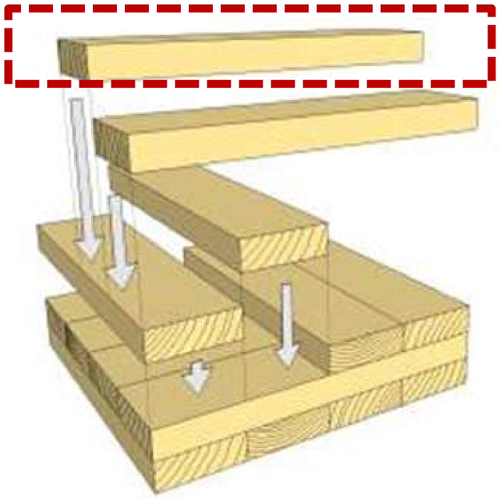
APA PRODUCT REPORT®
www.apawood.org

Nordic X-Lam
Nordic Engineered Wood

PR-L306
Revised May 23, 2013

Products: Nordic X-Lam
Nordic Engineered Wood
1100 Avenue des Canadiens-de-Montréal, Suite 504
Montreal, Québec, Canada H3B 2S2
(514) 871-8526
www.nordicewp.com

Structural Composition of CLT



Laminations: (Per PRG 320-2012)

5/8” to 2” thick.

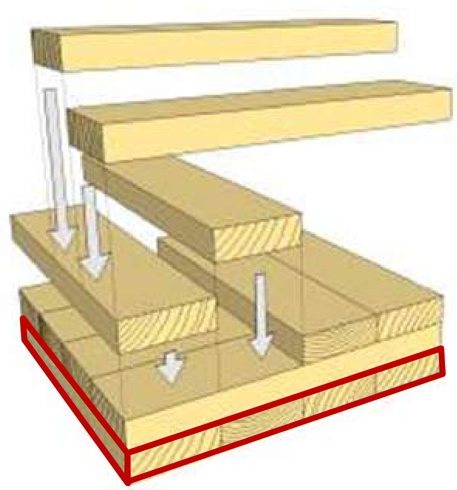
Machine Stress Rated or Visually Graded Dimensional Lumber or SCL

Dried to 12% Moisture Content before layup.

A common NA thickness is 1 3/8” (planed 2x stock)

PRG 320 provides thickness to width requirements of laminations

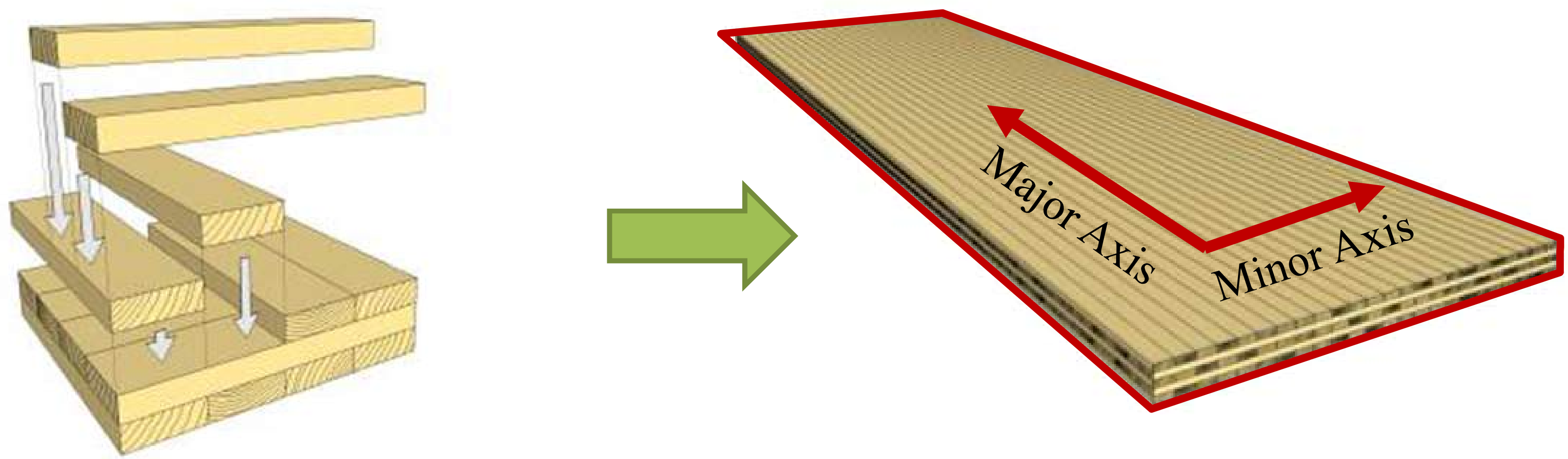
Structural Composition of CLT



Layers: (Per PRG 320-2012)

Oriented in orthogonal arrangement
Odd number of symmetric layers most common
Double parallel exterior layers permitted
Unbalanced layup permitted
Reference glu-lam adhesive standard (AITC 405)

Structural Composition of CLT



Panels, also known as Billets.

20 inch max thickness in PRG 320

Up to 8 ft or more wide per manufacturer and shipping

Up to 40 ft or more long per manufacturer and shipping

Major axis: stronger, stiffer, usually long direction

Minor axis: less strong and stiff, usually short direction

CLT Stress Grades

Stress 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
V1	#2 Doug Fir Larch	#3 Doug Fir Larch
V2	#1/#2 Spruce Pine Fir	#3 Spruce Pine Fir
V3	#2 Southern Pine	#3 Southern Pine

Non-mandatory in PRG 320. Other stress grades including SCL permitted

PRG 320 Defined Layups

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

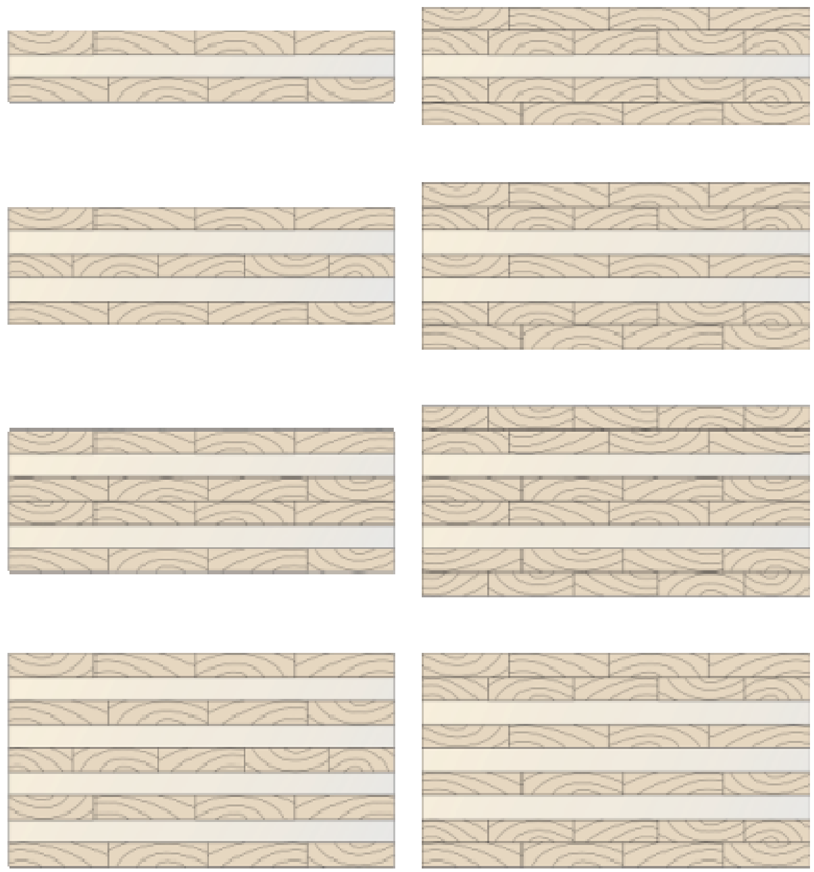
For SI: 1 in. = 25.4 mm; 1 ft = 304.8 mm; 1 lbf = 4.448 N

(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.

Examples of CLT Configurations



3-ply 3-layer

5-ply 3-layer

5-ply 5-layer

7-ply 5-layer

6-ply 5-layer

8-ply 5-layer

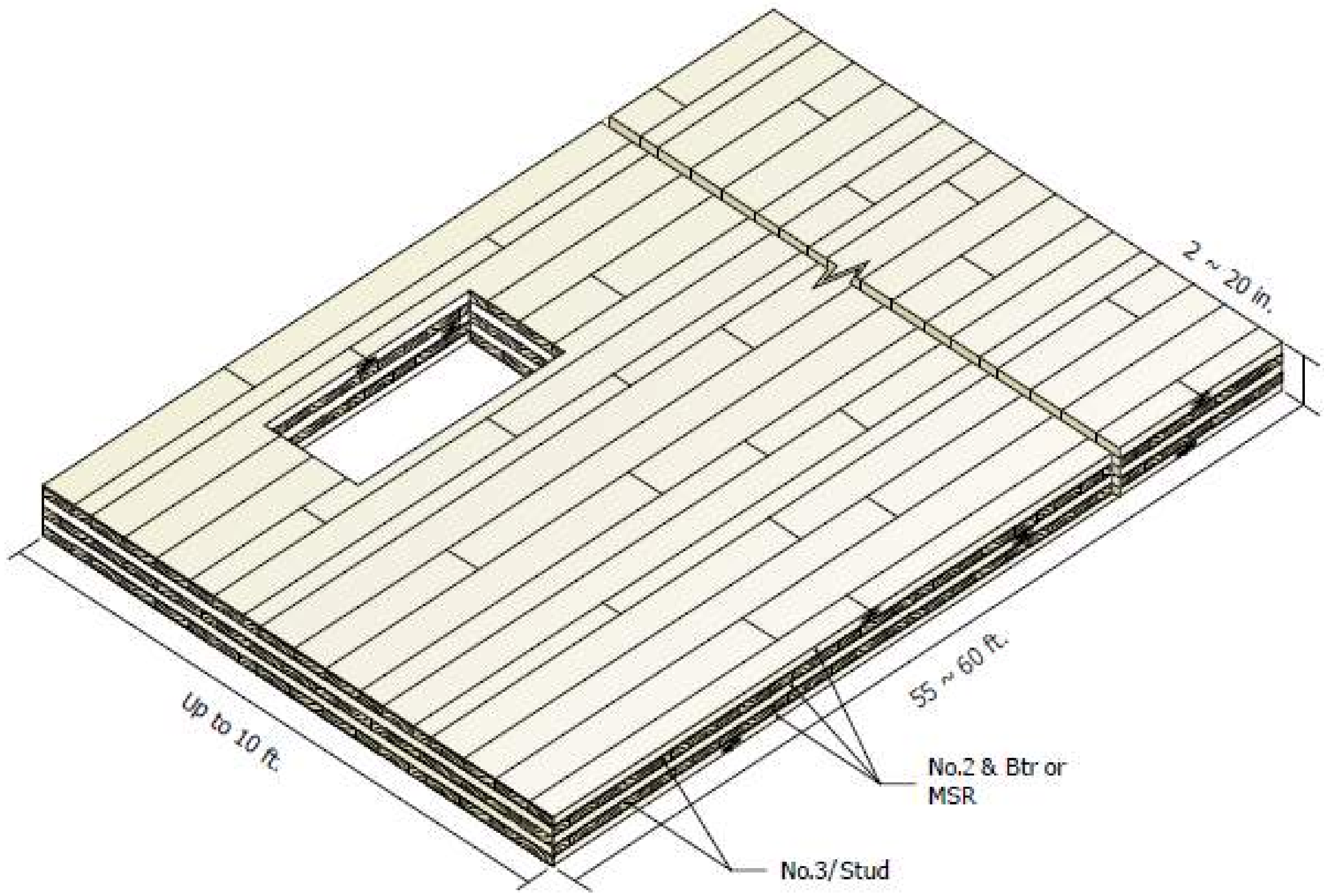
9-ply 9-layer

9-ply 7-layer

Strength

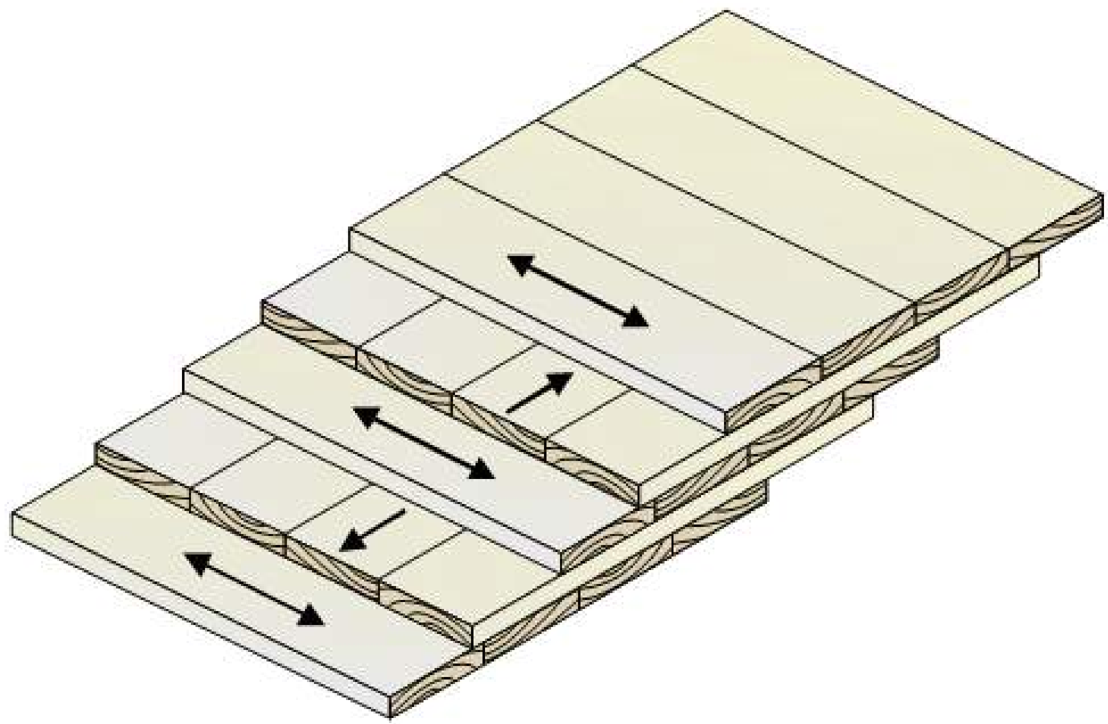
Photos Courtesy Structurlam

Floors



Structural Section Properties

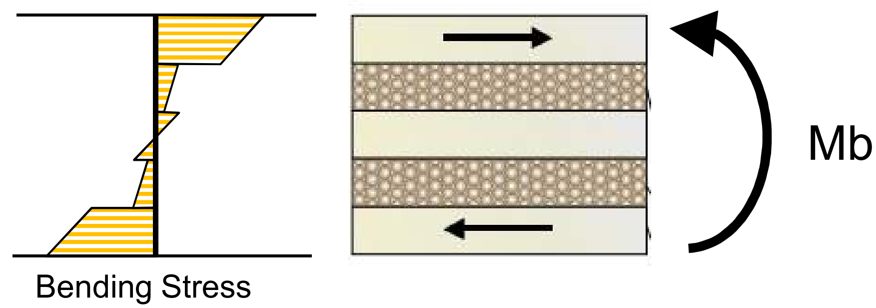
Non-homogenous, anisotropic material



Flexural Strength

Design Properties based on 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

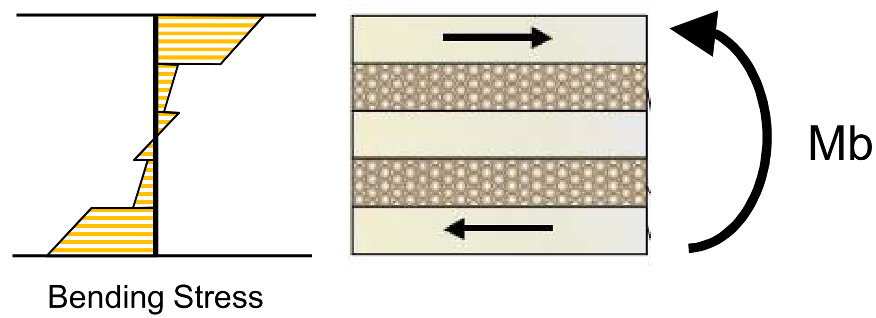
F_b = reference bending design value of outer lamination

Reference: NDS 2015 & US CLT Handbook

Flexural Strength

Design Properties based on Extreme Fiber Model:

Flexural Capacity Check (**ASD**)



$$(F_bS_{eff})' = C_D\ \underbrace{C_M\ C_t\ C_L}_{\text{Commonly 1.0}}\ \underbrace{(F_bS_{eff})}_{\text{From Manufacturer*}}$$

per NDS

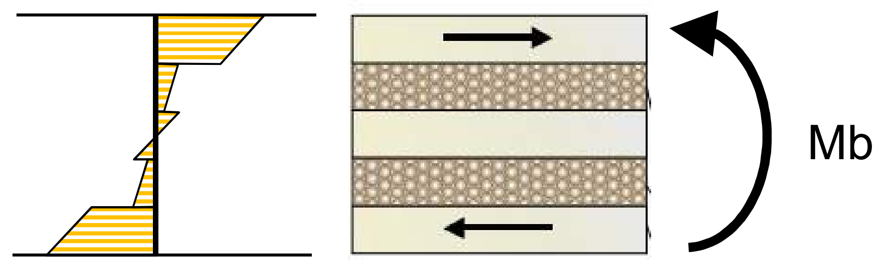
$$M_b \leq C_D\ (1.0)\ (F_bS_{eff})$$

Reference: NDS 2015 & US CLT Handbook

Flexural Strength

Design Properties based on Extreme Fiber Model:

Flexural Capacity Check (**LRFD**)



Bending Stress

$$(F_bS_{eff})' = \underbrace{C_M\ C_t\ C_L}_{\text{Commonly } 1.0}\ \underbrace{(F_bS_{eff})}_{\text{From Manufacturer}}\ \underbrace{K_f\ \phi\ \lambda}_{\text{per NDS 2015 \& CLT Handbook}}$$

$$M_b \leq (1.0)\,(F_bS_{eff})\,(2.54)(0.85)\,\lambda$$

Reference: NDS 2015 & US CLT Handbook

Design Example: Flexure

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 axis of CLT

ASD Dead + Live Flexural Demands:

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

Design Example: Flexure

Try 5 ply, (6 7/8 in thick) CLT Grade V2 Section

TABLE A2.
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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

Reference: ANSI/APA PRG 320-2012

Design Example: Flexure

ASD Flexural Capacity:

Dead + Live load, $C_D = 1.0$

$(F_b S_{eff})' = C_D\,(1.0)\,(F_b\ S_{eff})$

$= 1.0\,(1.0)\,(4675\ \text{lb-ft/ft})$

$= 4675\ \text{lb-ft/ft}$

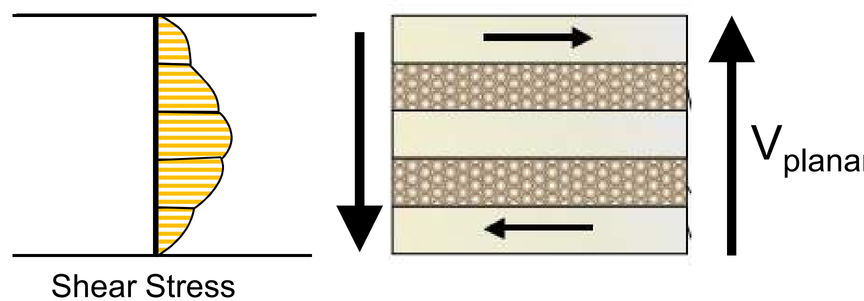
$M_b = 2560\ \text{lb-ft/ft} \leq F'_b\ S_{eff} = 4675\ \text{lb-ft/ft}$

Flexural Strength OK

Shear Strength

Design Properties based on Extreme Fiber Model:

Shear Capacity Check:



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

V_{planar} = applied shear

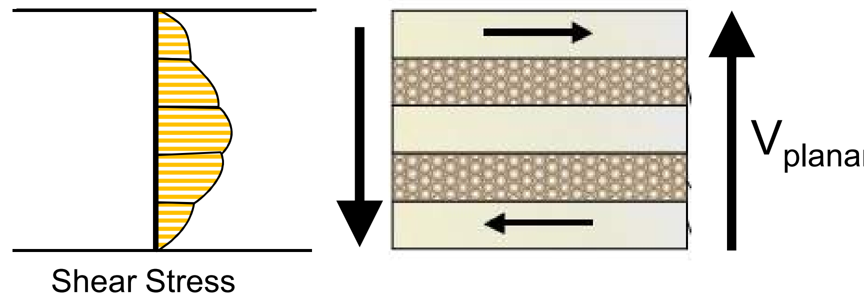
$F_s\ (IbQ_{eff})'$ = adjusted shear strength

Reference: NDS 2015 & US CLT Handbook

Shear Strength

Design Properties based on Extreme Fiber Model:

Shear Capacity Check (ASD):



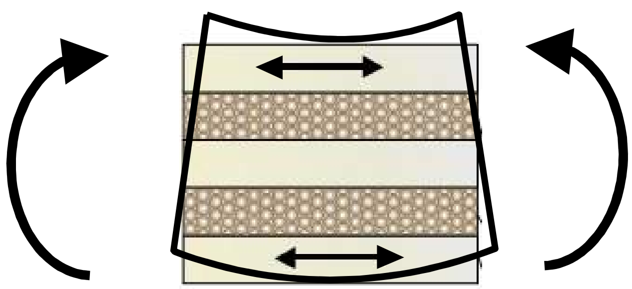
$$F_s(IbQ)_{eff}' = \underbrace{C_M\, C_t}_{\text{Commonly 1.0}}\ \underbrace{(F_s(IbQ)_{eff})}_{\text{From Manufacturer for Standard Sections}} = C_M\, C_t\, \underbrace{V_s}$$

$$V_{planar} \le (1.0)\, V_s$$

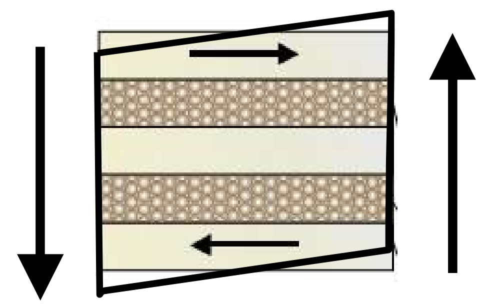
Reference: NDS 2015 & US CLT Handbook

Stiffness & Deflection

Major Axis Stiffness

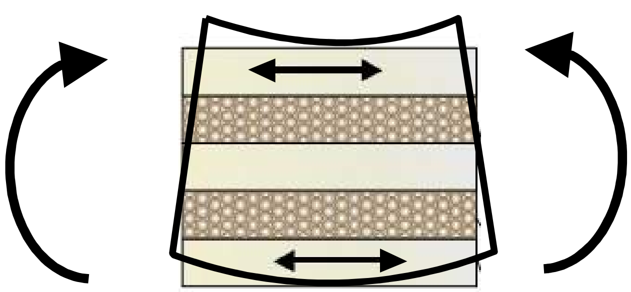


$EI_{eff,0}$

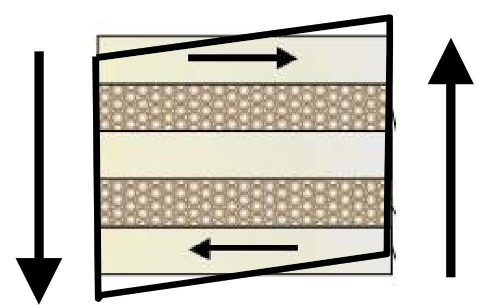


$GA_{eff,0}$

Minor Axis Stiffness



$EI_{eff,90}$



$GA_{eff,90}$

Structural Material Assumptions

Assumptions Used in CLT Handbook and ANSI/APA PRG 320-2012 to develop section properties.

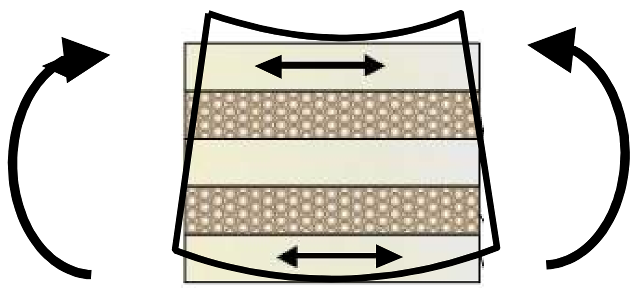
Given lumber for a lamination with modulus of elasticity for bending in major strength direction, E_0, assume:

- $E_{90} = E_0 / 30$
- $G_0 = E_0 /16$
- $G_{90} = G_0 / 10 = E_0 / 160$

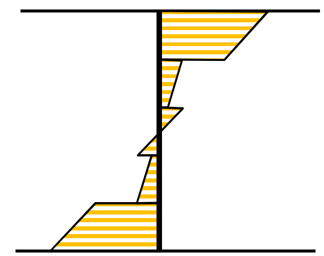
Reference: US CLT Handbook & PRG 320

Flexural Stiffness

Shear Analogy Method



$\mathrm{EI}_{\mathrm{eff}}$



Bending Stress

$$S_{eff} = \frac{2EI_{eff}}{E_1 h}$$

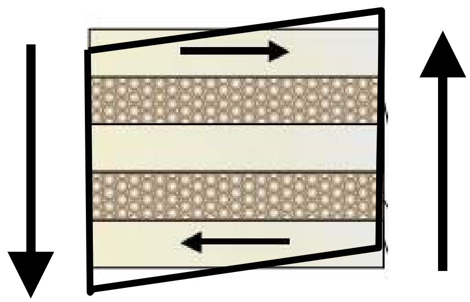
$$EI_{eff} = \sum_{i=1}^{n} E_i \cdot b_i \cdot \frac{h_i^3}{12} + \sum_{i=1}^{n} E_i \cdot A_i \cdot z_i^2$$

$$(Ib/Q)_{eff} = \frac{EI_{eff}}{\sum_{i=1}^{n/2} E_i h_i z_i}$$

Reference: US CLT Handbook Chapter 3

Shear Stiffness

Shear Analogy Method

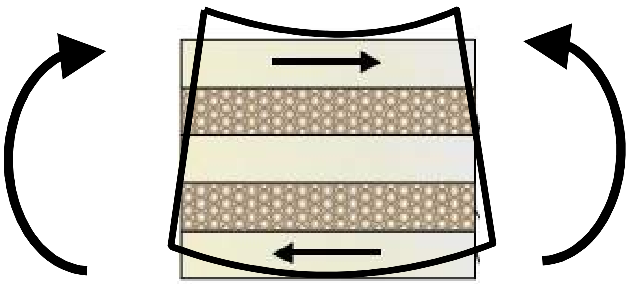


GA$_{eff}$

$$GA_{eff} = \frac{a^2}{\left[\left(\frac{h_1}{2 \cdot G_1 \cdot b}\right) + \left(\sum_{i=2}^{n-1} \frac{h_i}{G_i \cdot b_i}\right) + \left(\frac{h_n}{2 \cdot G_n \cdot b}\right)\right]}$$

Reference: US CLT Handbook Chapter 3

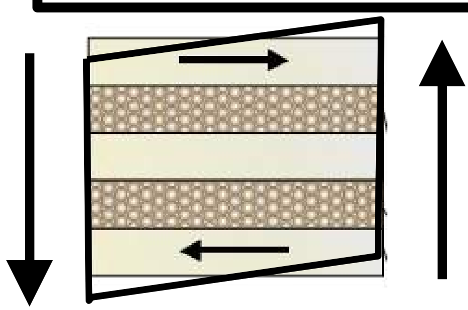
Flexural Stiffness



$$EI_{eff} = \sum_{i=1}^{n} E_i \cdot b_i \cdot \frac{h_i^3}{12} + \sum_{i=1}^{n} E_i \cdot A_i \cdot z_i^2$$

Important to develop properties of new CLT Sections.

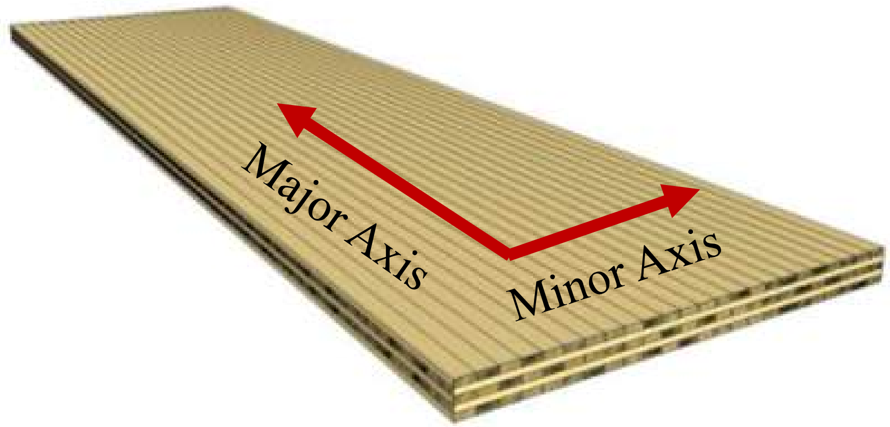
Not to use standard CLT Sections



$$GA_{eff} = \frac{a^2}{\left[\left(\frac{h_1}{2 \cdot G_1 \cdot b} \right) + \left(\sum_{i=2}^{n-1} \frac{h_i}{G_i \cdot b_i} \right) + \left(\frac{h_n}{2 \cdot G_n \cdot b} \right) \right]}$$

GA_{eff}

Structural Section Properties

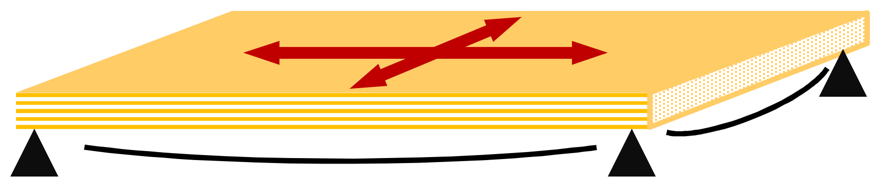


Flexural Strength:	$F_bS_{eff,0}$	$F_bS_{eff,90}$
Flexural Stiffness:	$EI_{eff,0}$	$EI_{eff,90}$
Shear Strength:	$V_{s,0}$	$V_{s,90}$
Shear Stiffness:	$GA_{eff,0}$	$GA_{eff,90}$

Values in RED provided by CLT manufacturer

Reference: PRG 320 and CLT Product Reports

Deflection Calculations



General Purpose, 2 Way, Plate Action

Flexural Stiffness

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

Shear Stiffness:

$5/6\ GA_{eff,0}$ $5/6\ GA_{eff,90}$

5/6 from $A' = 5/6\ A$ for rectangular sections

Deflection Calculations

General Purpose: 1 Way, Beam Action

Stiffness: $EI_{eff,0}$ $5/6\ GA_{eff,0}$

Can model multiple spans, cantilevers, etc.

Example Deflection Calculations

Example Calculation:

Uniform loading on one way slab:

Beam Analysis using

Flexural Stiffness: $EI_{eff,0}$

Shear Stiffness: $5/6\ GA_{eff,0}$

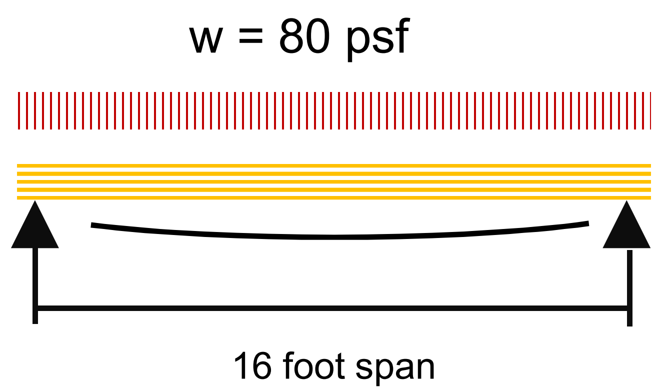
Maximum Deflection @ Mid-Span

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

Design Example:

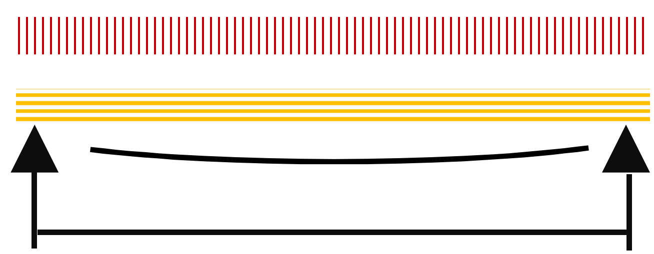
= 0.161 in + 0.02 in = 0.183 in

= L / 1050



Deflection Calculations

Simplified Beam Deflections:



Given load pattern and support conditions:

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

Find ***Apparent*** Flexural Stiffness, EI_{app}, such that

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

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

Reference: US CLT Handbook

Deflection Calculations

Simplified Beam Deflections

For single span, simple loading patterns, Apparent Flexural Stiffness, EI_{app}, to determine maximum (mid-span) deflection:

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

US CLT Handbook

$$EI_{app} = \frac{EI_{eff}}{1 + \frac{16 K_s I_{eff}}{A_{eff} L^2}}$$

NDS 2015

For Major Axis Spans:

$$I_{eff} = {EI_{eff}}/{E_o}$$

$$A_{eff} = GA_{eff}/G_o$$

$$G_o = E_o/16$$

Reference: US CLT Handbook & NDS 2015

Deflection Calculations

Simplified Beam Deflections

For single span, simple loading patterns, Apparent Flexural Stiffness, EI_{app}, to determine maximum (mid-span) deflection:

$$EI_{app} = \frac{EI_{eff}}{1 + \frac{K_s EI_{eff}}{GA_{eff}L^2}} \qquad EI_{app} = \frac{EI_{eff}}{1 + \frac{16K_s I_{eff}}{A_{eff}L^2}}$$

Apparent Flexural Stiffness depends on Load Pattern and Support Conditions

Loading	End Supports	Ks
Uniform	Pinned	11.5
	Fixed	57.6
Midspan Line	Pinned	14.4
	Fixed	57.6

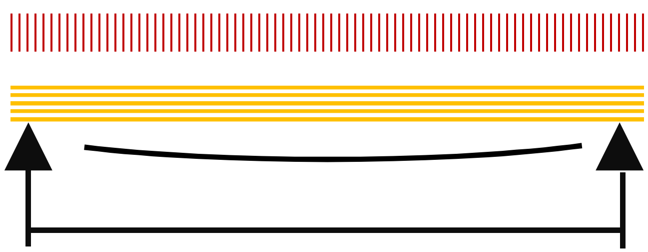
Deflection Calculations

Simplified Beam Deflections

For single span, simple loading patterns, Apparent Flexural Stiffness, EI_{app}, to determine maximum (mid-span) deflection:

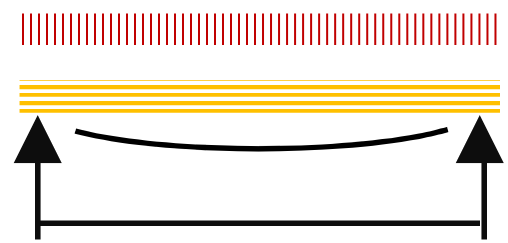
$$EI_{app} = \frac{EI_{eff}}{1 + \frac{K_s EI_{eff}}{GA_{eff} L^2}} \qquad EI_{app} = \frac{EI_{eff}}{1 + \frac{16 K_s I_{eff}}{A_{eff} L^2}}$$

Apparent Flexural Stiffness depends on Span Length



L_1 = 20 foot

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



L_2 = 16 foot

Creep Factor

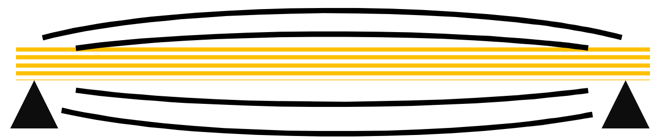
Deformation to Long Term Loads

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

Reference: US CLT Handbook & NDS 2015

Floor Vibration



Occupant perception of vibration is a highly recommended design consideration.

One approach: CLT Handbook, Chapter 7

Calculated natural frequency of simple span:

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

Where:

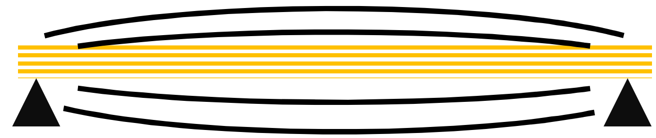
EI_{app} = apparent stiffness for 1 foot strip, pinned supported, uniformly loaded, simple span (K_s = 11.5) (lb-in^2)

ρ = specific gravity of the CLT

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

Reference: US CLT Handbook, Chapter 7

Floor Vibration



CLT Handbook, Chapter 7 recommends,

$$f = \frac{2.188}{2L^2}\sqrt{\frac{EI_{app}}{\rho A}} \geq 9.0\ Hz$$

and

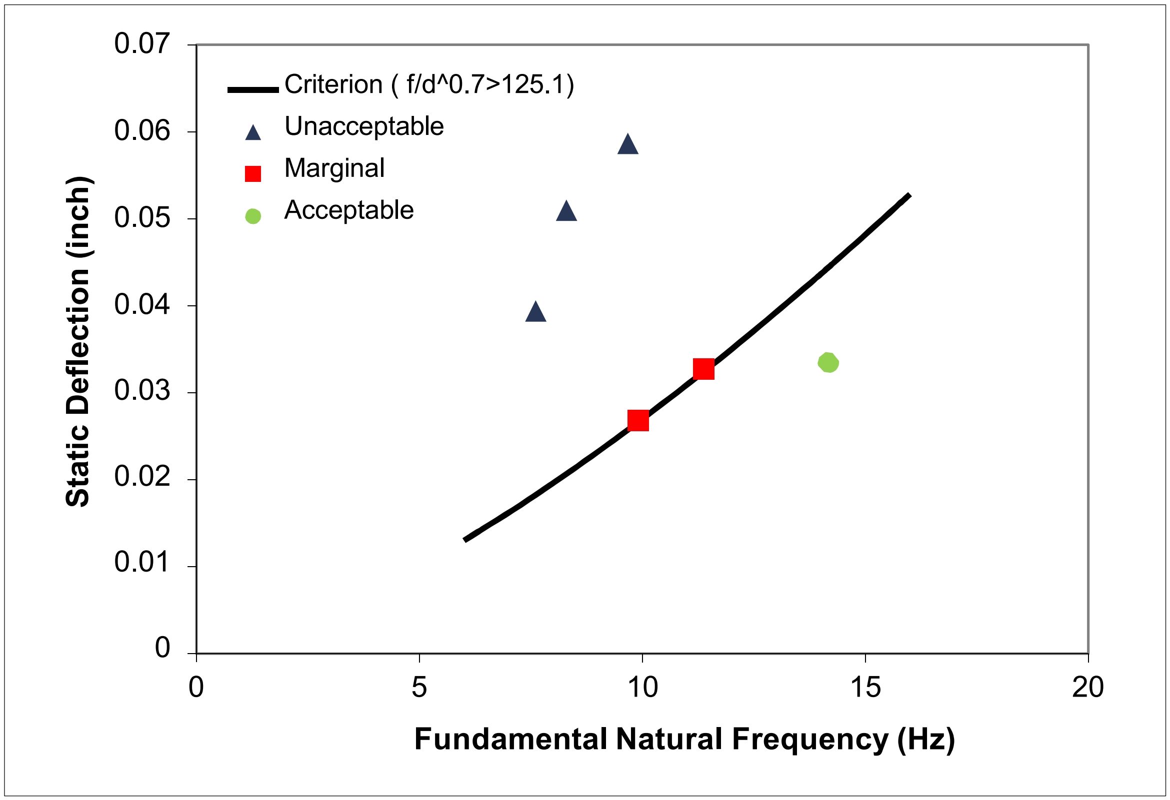
Max span $$L \leq \frac{1}{12.05}\frac{(EI_{app})^{0.293}}{(\rho A)^{0.122}}$$

Reference: US CLT Handbook, Chapter 7

Floor Vibration

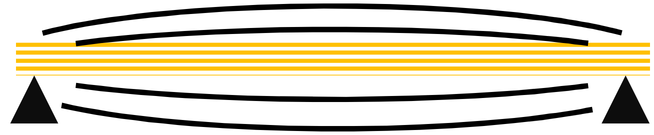
CLT Handbook, Chapter 7 Recommendations

Experimental Verification – Results



Research by Lin Hu, et al. at FPInnovations

Floor Vibration



CLT Handbook, Chapter 7 method:

Natural frequencies above 9 Hz and:

$$\text{Max span} \quad L \leq \frac{1}{12.05} \frac{(EI_{app})^{0.293}}{(\rho A)^{0.122}}$$

EI_{app} depends on L, so an iterative calculation required.

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

Only depends on CLT section properties, so…

Values calculated and provided by CLT Manufactures

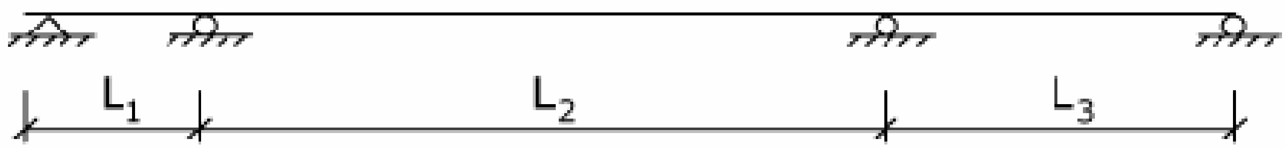
16ft span example: V2 Grade 5 ply (6 7/8 in) L max = 16.7 feet.

Reference: US CLT Handbook, Chapter 7

Floor Vibration

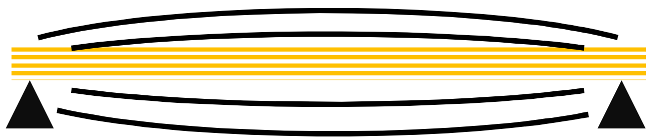
CLT Handbook, Chapter 7 Recommendations

Continuous multi-span floor



- L_2 is the longest span
- Use the design method to determine L_2 assuming it is a single span floor

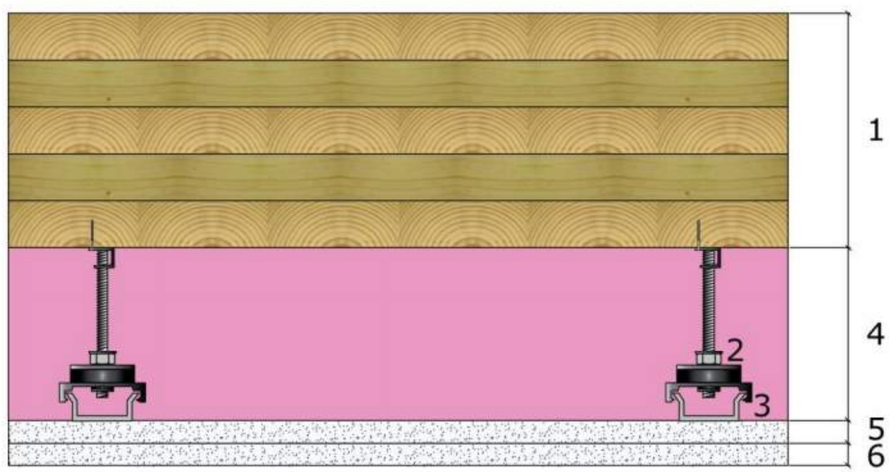
Floor Vibration



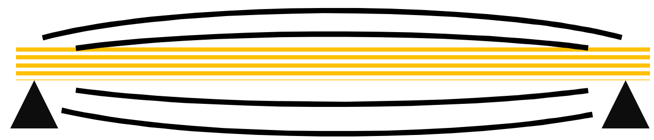
CLT Handbook, Chapter 7 Recommendations

With Suspended Ceiling

Use the design method ***without*** including the mass and stiffness of the drywall



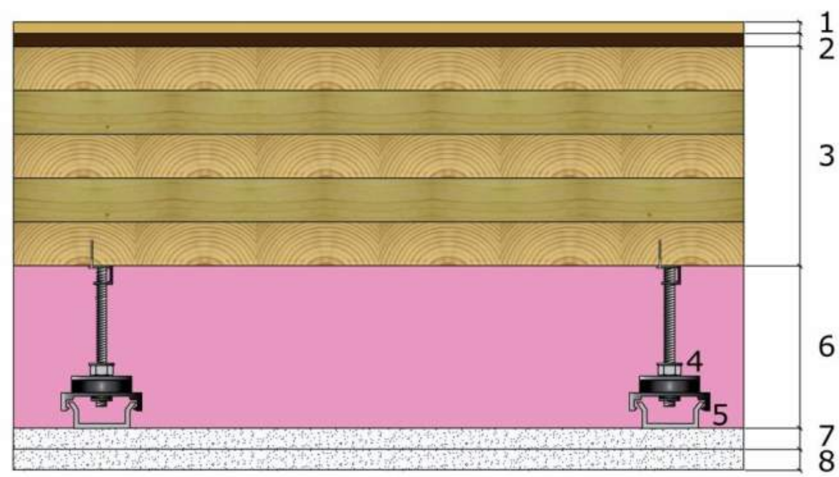
Floor Vibration



CLT Handbook, Chapter 7 Recommendations

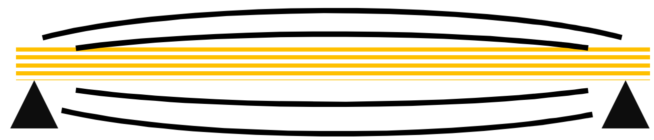
With lightweight topping (<20 lb./ft.2) and drywall

- Lightweight topping examples:
  - Wood panel
  - Gypsum board
  - Cement fibreboard



- Use proposed design method without including the mass and stiffness of the drywall and the topping

Floor Vibration



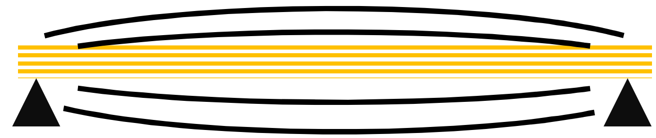
CLT Handbook, Chapter 7 Recommendations

With heavy topping (>20 lb./ft.2)

Preliminary Recommendations

- Use the design method without including the mass and stiffness of the heavy topping to determine the span
- Reduce the bare floor stiffness and mass by 10%

Floor Vibration



Occupant perception of vibration a recommended design consideration

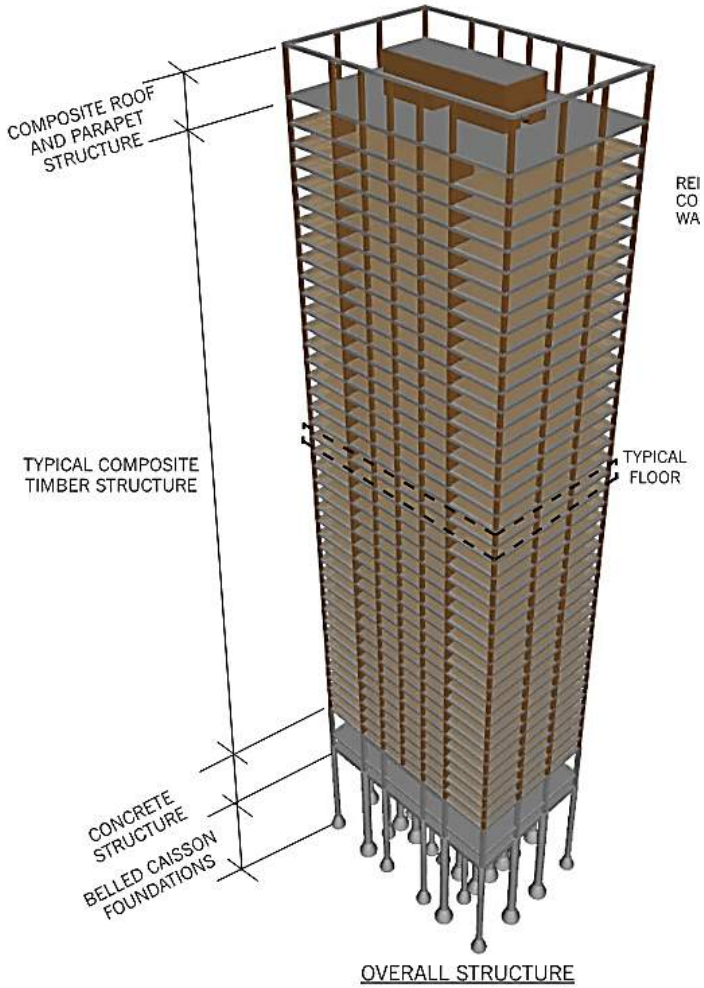
CLT Handbook, Chapter 7 recommends natural frequencies above 9 Hz and:

$$\text{Max span} \quad L \leq \frac{1}{12.05}\frac{(EI_{app})^{0.293}}{(\rho A)^{0.122}}$$

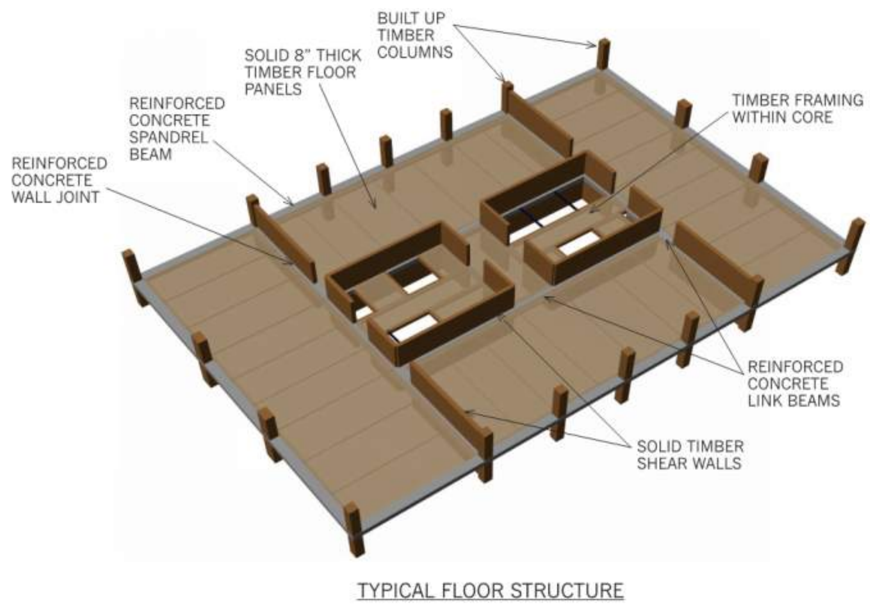
Limitations:

- Potential advantages of topping slab stiffness not taken into account
- Potential advantages of multiple spans or other restraining details
- Long spans can be uneconomical to keep natural frequency above 9 Hz.

SOM Timber Tower

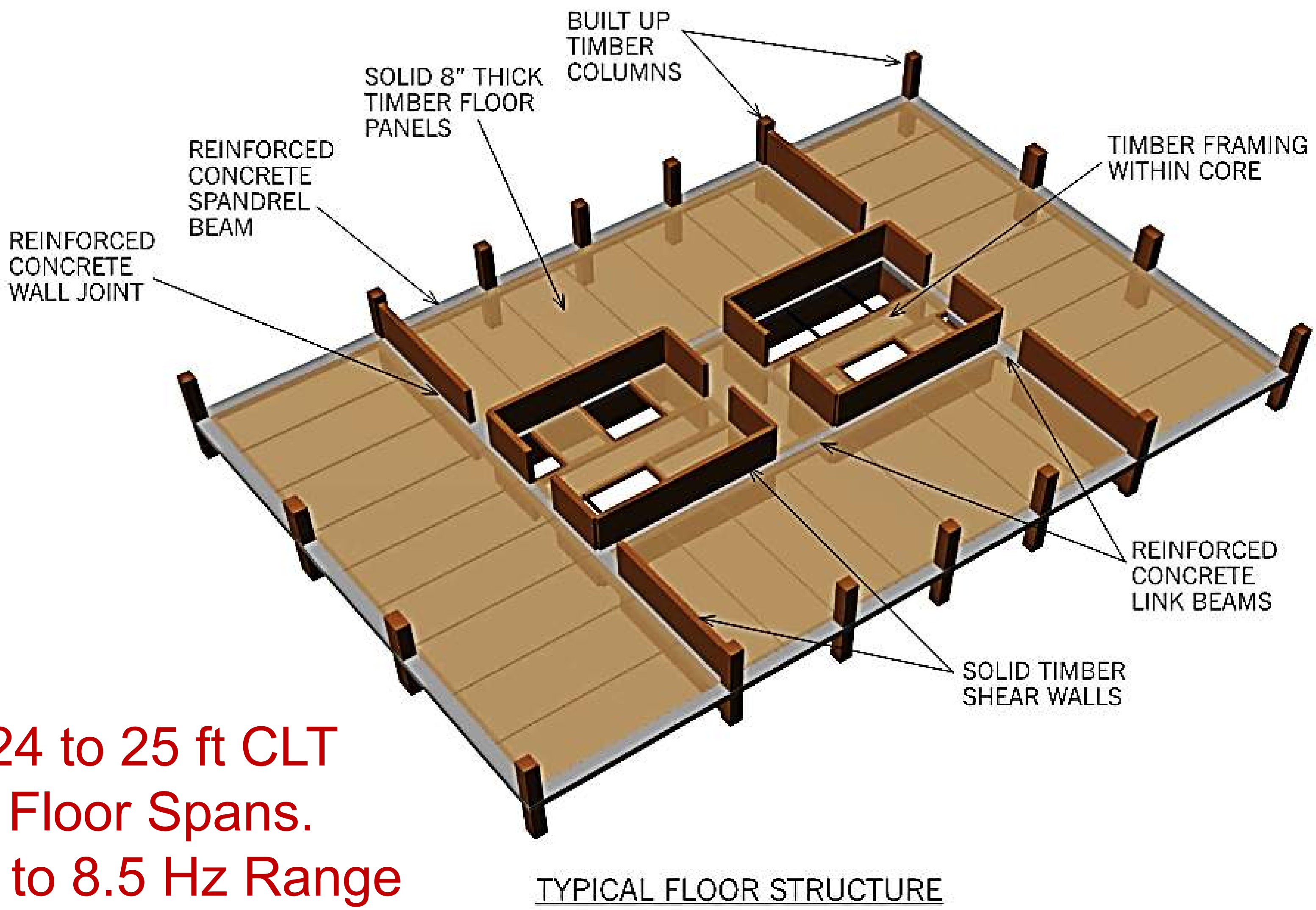


Prototype Building



Source: *SOM Timber Tower Research Project,* May 2013

SOM Timber Tower



24 to 25 ft CLT
Floor Spans.
6.5 to 8.5 Hz Range

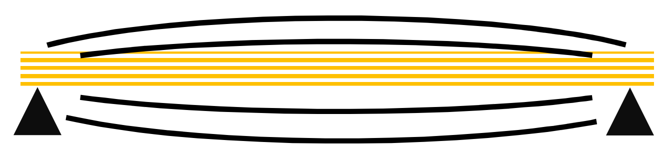
Alternative Vibration Criteria

Long spans can be designed using **CLT Handbook Criteria**:

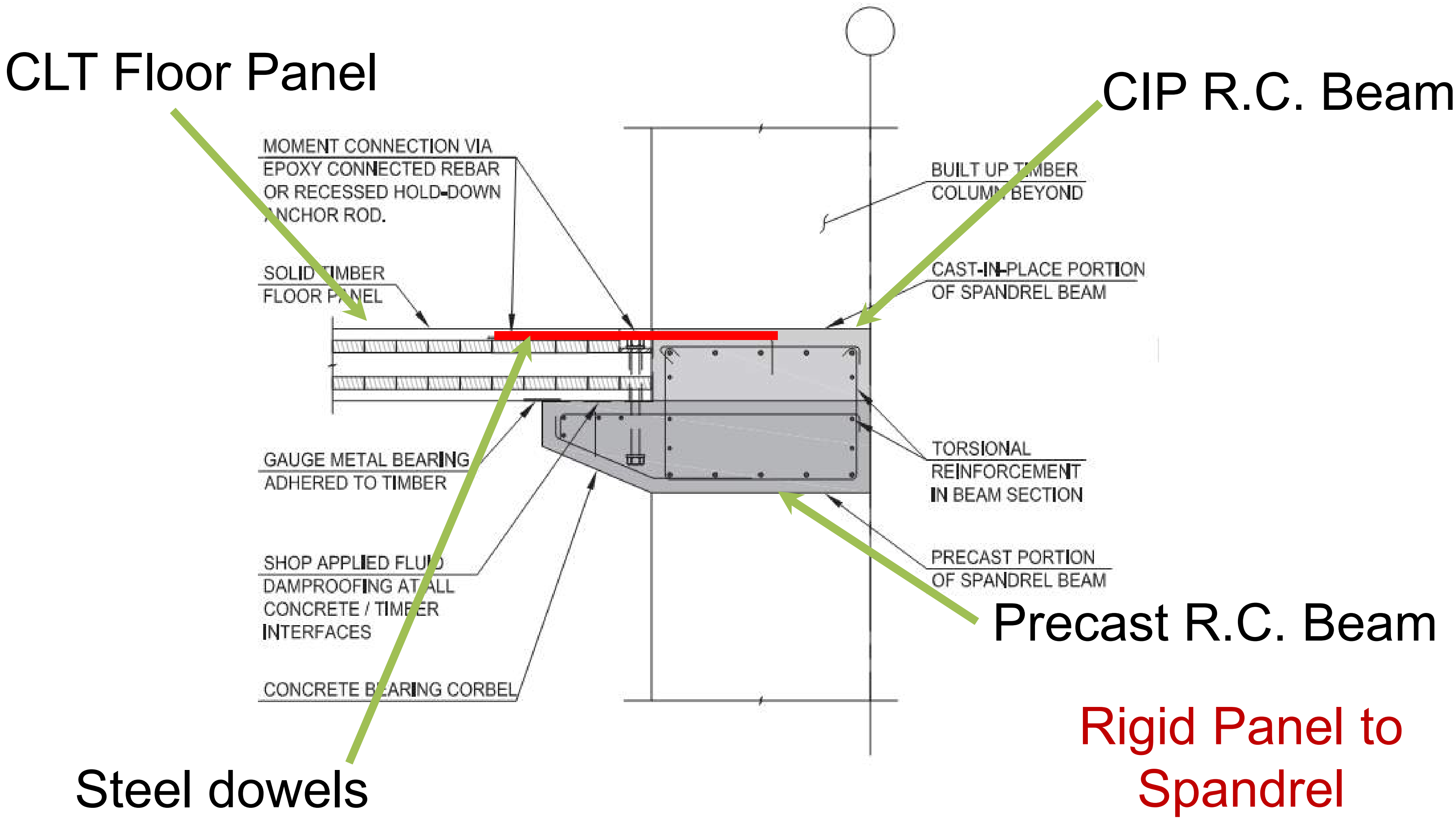
Keep Fundamental Frequency > 9 hz

Idealized as Single Span, Simply Supported Panels

24 foot spans result in ~12 inch thick or greater CLT floors.



SOM Timber Tower



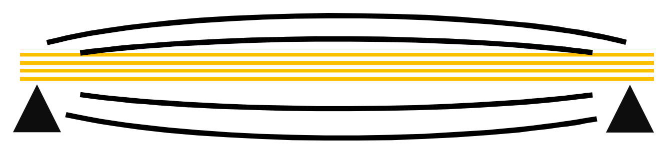
Exterior Spandrel Beam

Rigid Panel to Spandrel Connection

Alternative Vibration Criteria

Alternative: Use acceptance criteria which address low frequency floors and alternative support configurations.

Calibration of dynamic modeling with physical testing valuable



Alternative Vibration Criteria

SOM Timber Tower used:

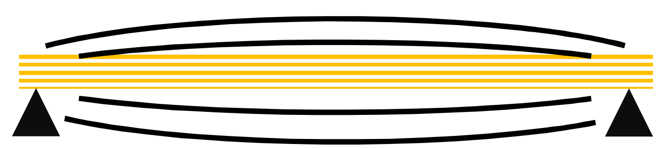
- AISC Design Guide 11, Velocity Criteria (Chapter 6)
- Acceptance Criteria selected:
  - ≤ 16,000 μ-in/sec w/ moderate walking in living areas
  - ≤ 8,000 μ-in/sec w/ slow walking pace in sleeping areas.

AISC DG 11 suggests approximate velocity limit of human perception

- 8,000 μ-in/sec at 8 Hz and above.

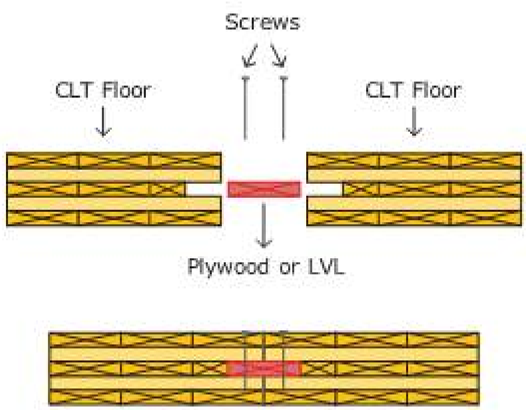
AISC Design Guide 11 not for dynamic modeling of CLT floors

SOM Timber Tower Resulted in 8" Thick Floor

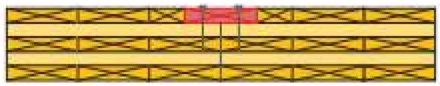


Connection Styles

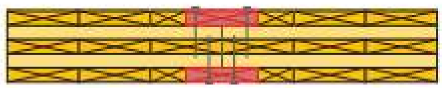
Floor Panel to Floor Panel



Interior Spline



Single Surface Spline

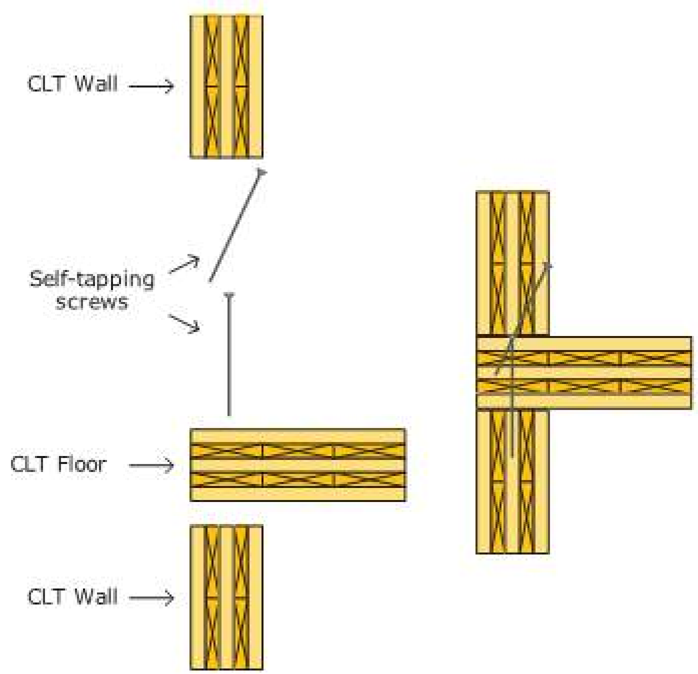


Double Surface Spline

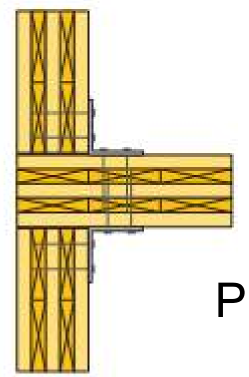
Half Lap

Connection Styles

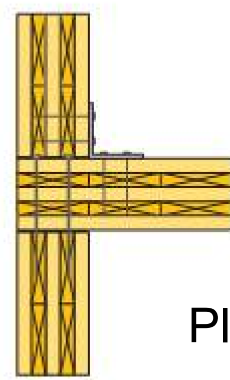
Floor Panel to Wall



Platform Frame
With Only Screws



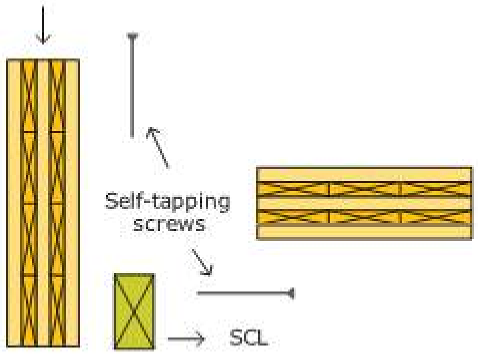
Platform Frame with
Double Brackets

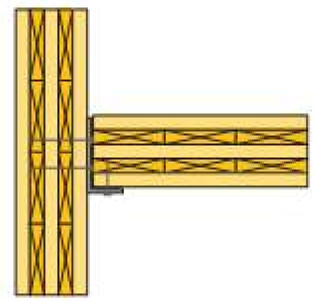


Platform Frame with
Single Brackets

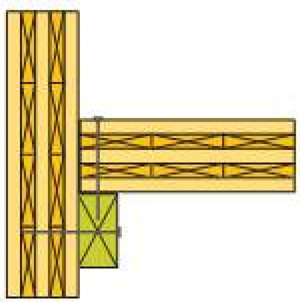
Connection Styles

Floor Panel to Wall

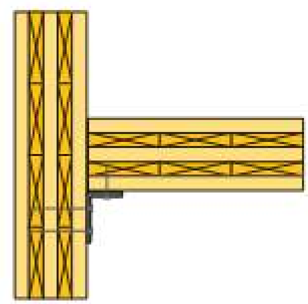




Platform Frame with
Hidden Bracket



Balloon Frame
With Supporting
Ledger



Platform Frame with
Bracket

US CLT Handbook

1. Introduction
2. Manufacturing
3. Structural
4. Lateral
5. Connections
6. DOL and Creep
7. Vibration
8. Fire
9. Sound
10. Enclosure
11. Environmental
12. Lifting

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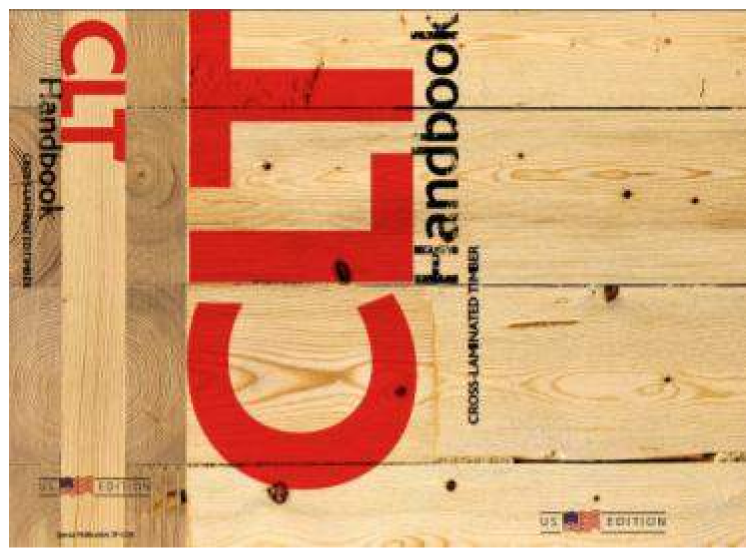

WoodWorks

CLT Floor Design: Strength, Deflection and Vibrations

Scott Breneman, PhD, PE, SE

Scott.Breneman@WoodWorks.org

Questions?

Scott Breneman, PhD, PE, SE

Scott.Breneman@woodworks.org

Project Assistance also available at help@woodworks.org