



# FPInnovations

Creating forest sector solutions

[www.fpinnovations.ca](http://www.fpinnovations.ca)



## CLT – Structural Design

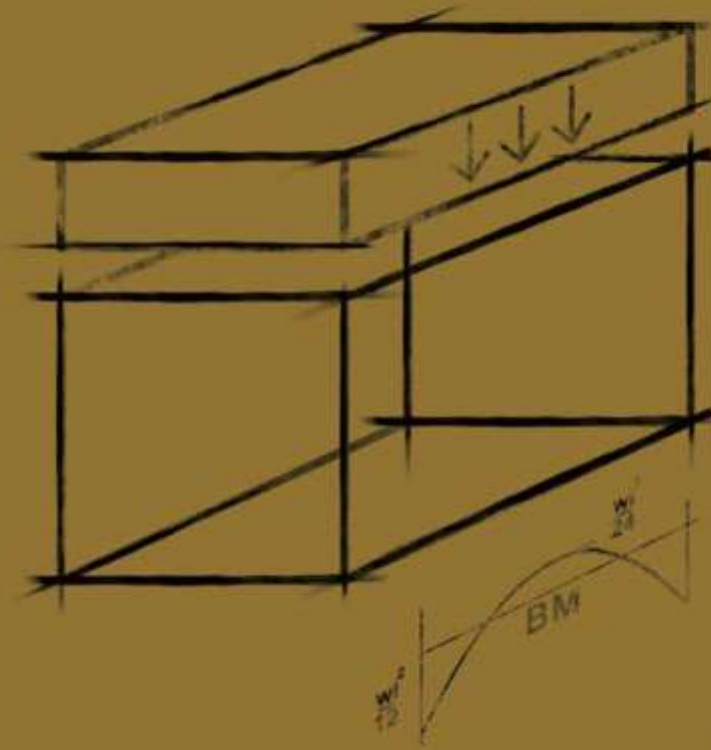
Sylvain Gagnon, Eng.

February 8, 2011  
Vancouver

# Structural Design



## Handbook



# Structural

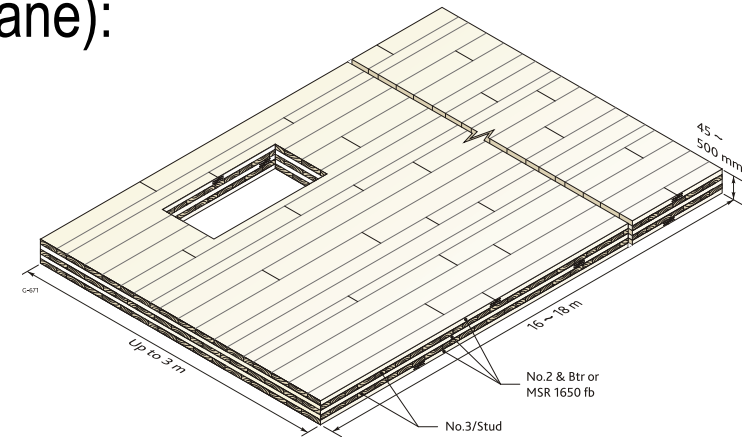
Structural design of  
cross-laminated timber elements

## CHAPTER 3

*Authors*  
Sylvain Gagnon, Eng., FPIinnovations  
Marjan Popovski, Ph.D., P.Eng., FPIinnovations  
*Peer Reviewers*  
Kevin D. Below, Ph.D., Eng., Douglas Consultants Inc.  
Robert Malczyk, M.A.Sc., P.Eng., StructEng, MStructE, MBA, Equilibrium Consulting Inc.  
David Moses, Ph.D., P.Eng., PE, LEED AP, Moses Structural Engineers

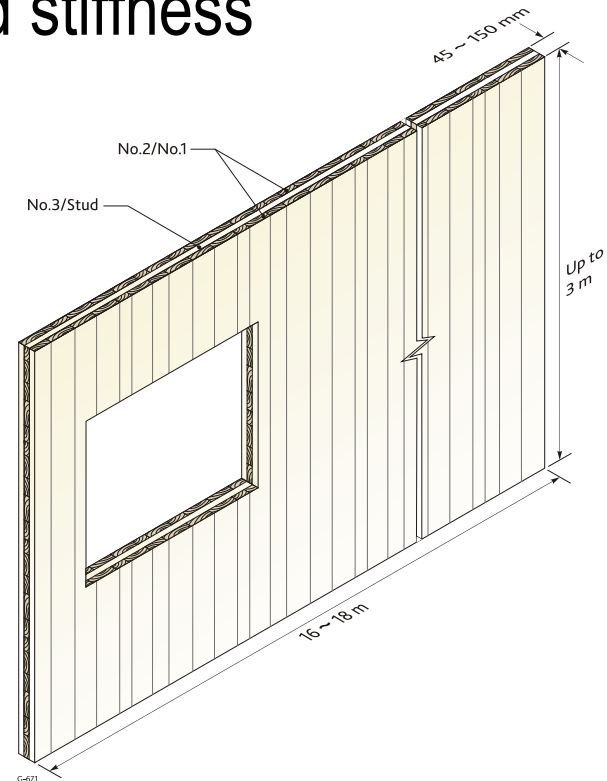
# Critical Characteristics for CLT used as floor/roof

- Short-term and long-term behaviour (out-of-plane):
  - bending and shear strength
  - instantaneous deflection
  - long-term deflection (creep deformation)
  - long-term strength for permanent loading
- Vibration (for floor)
- Compression perpendicular to grain strength (bearing)
- In-plane strength and stiffness (diaphragms)
- Fire performance
- Acoustic performance
- Durability in service



# Critical Characteristics for CLT used as wall

- Load-bearing capacity
- In-plane and out-of-plane strength and stiffness
- Fire performance
- Acoustic performance
- Durability in service

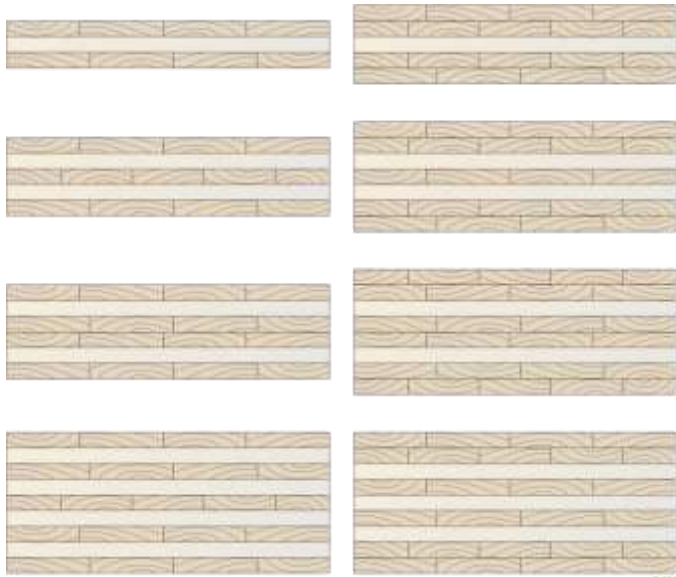


# Outline

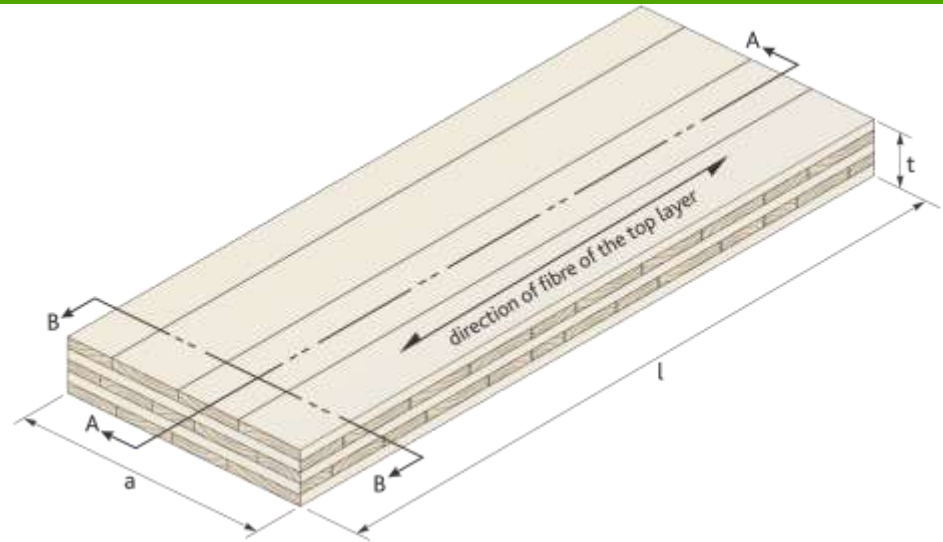
- **Cross-laminated Timber Panels – Introduction**
- Properties
- Proposed Analytical Design Methods for Floor and Roof Systems
- Proposed Analytical Design Methods for Wall Systems
- Proposed Analytical Design Methods for Beams and Lintels
- Modification Factors (CSA O86)

# Configurations

## Some configurations



G-664



Section A – A  
(illustration 5-layered)



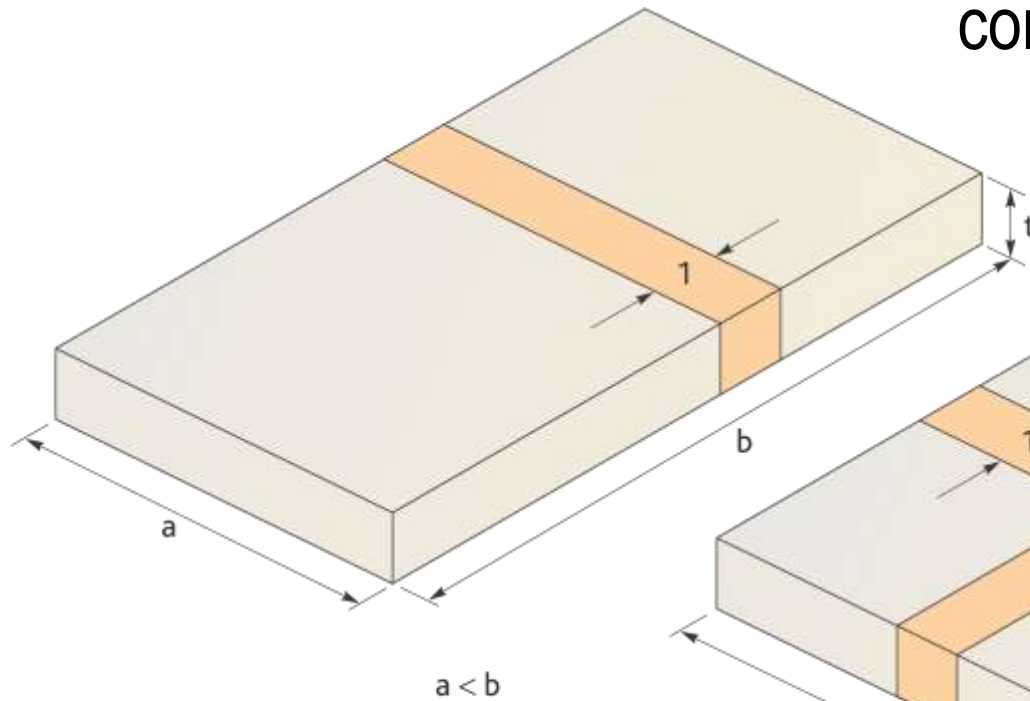
Section B – B  
(illustration 5-layered)



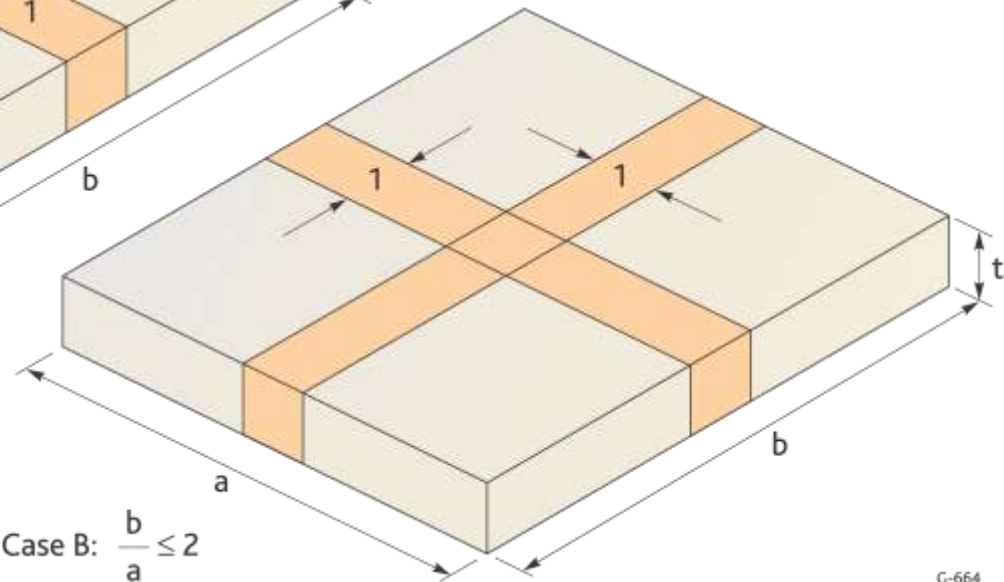
G-664

# One-Way or Two-Way Slab Action

≈ Two way action capability as concrete slab



Case A:  $\frac{b}{a} > 2$

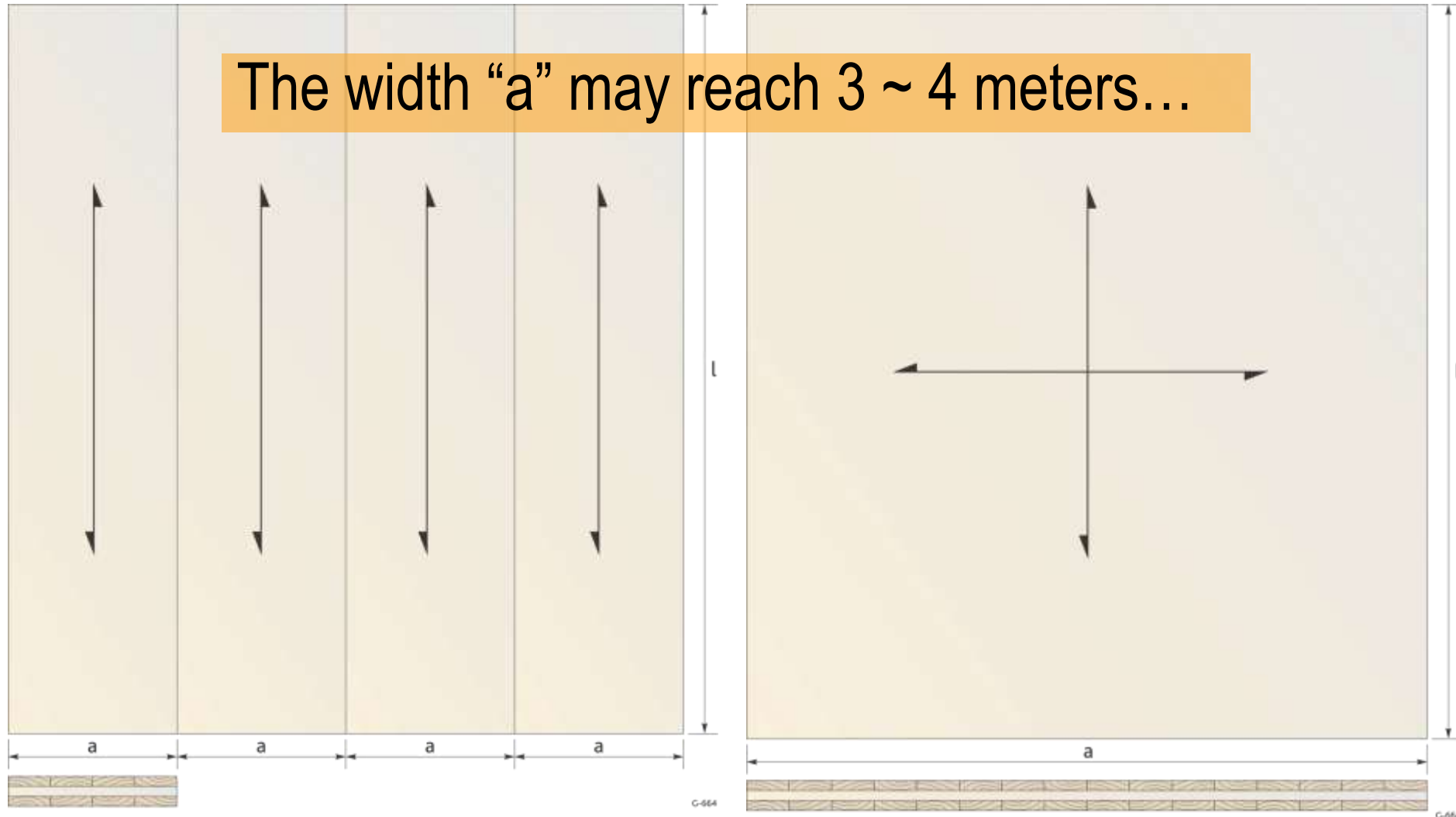


Case B:  $\frac{b}{a} \leq 2$

G-664

# One-Way or Two-Way Slab Action

The width "a" may reach 3 ~ 4 meters...



# Outline

- Cross-laminated Timber Panels – Introduction
- **Properties**
- Proposed Analytical Design Methods for Floor and Roof Systems
- Proposed Analytical Design Methods for Wall Systems
- Proposed Analytical Design Methods for Beams and Lintels
- Modification Factors (CSA O86)

# Board Properties

- Dimensions
  - Thickness of boards varies from ~15 mm to ~50 mm
  - Width of boards may varies considerably (63 ~ 250 mm)
- Moisture Content: 12%  $\pm$  2%



# Board Properties for Floor/Roof Panels

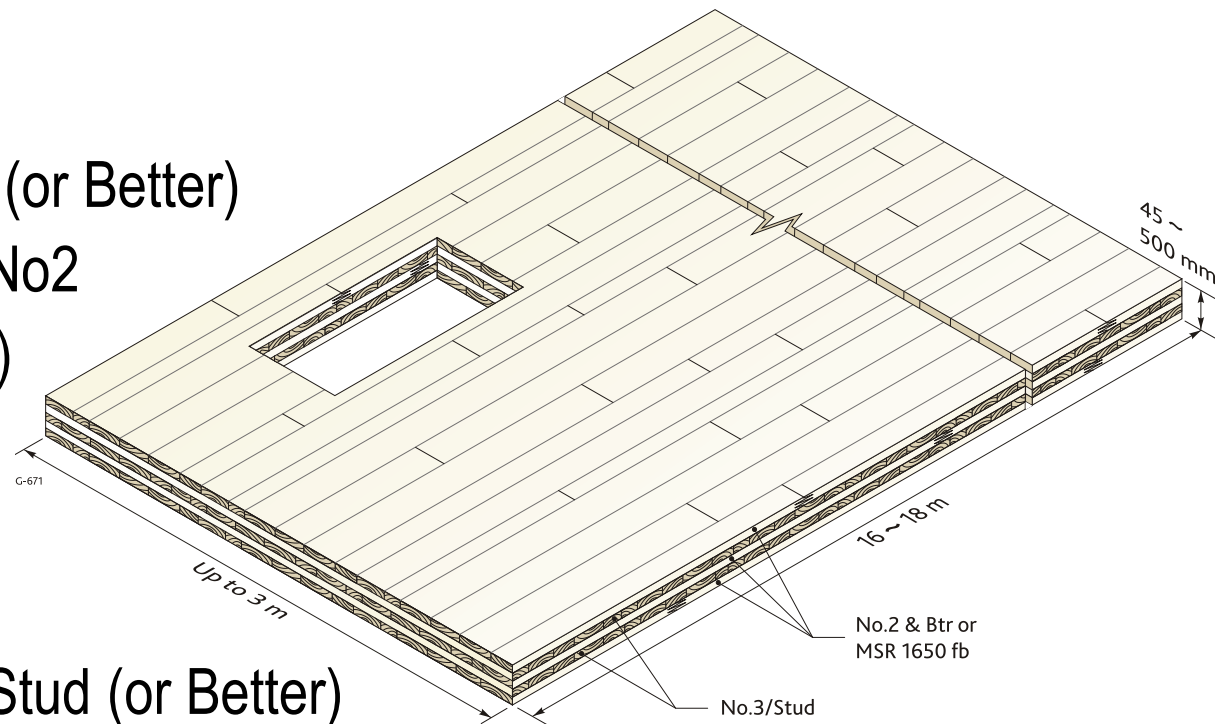
- Lumber grades for floor and roof elements

- Longitudinal Layers

- MSR 1650Fb-1.5E (or Better)
- Visual Grade No1/No2
- Others (proprietary)

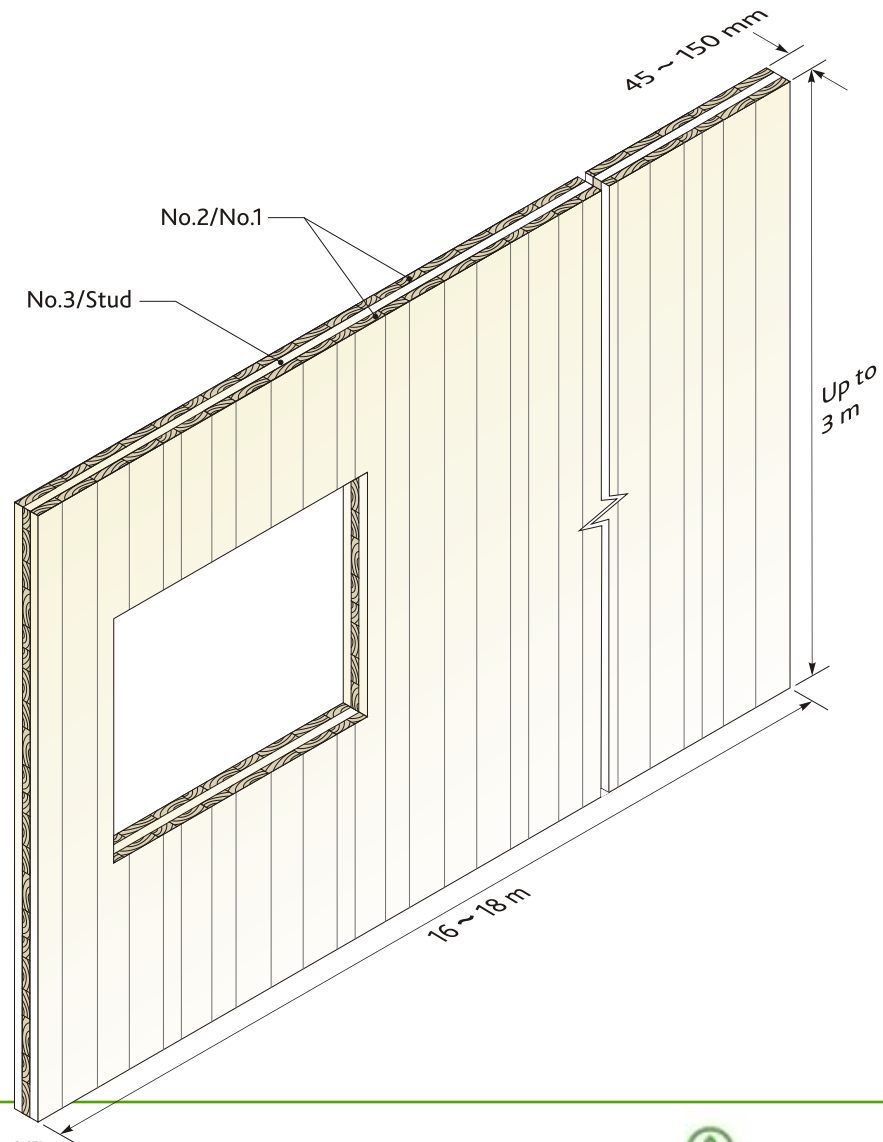
- Transverse Layers

- Visual Grade No3/Stud (or Better)
- Others (proprietary)

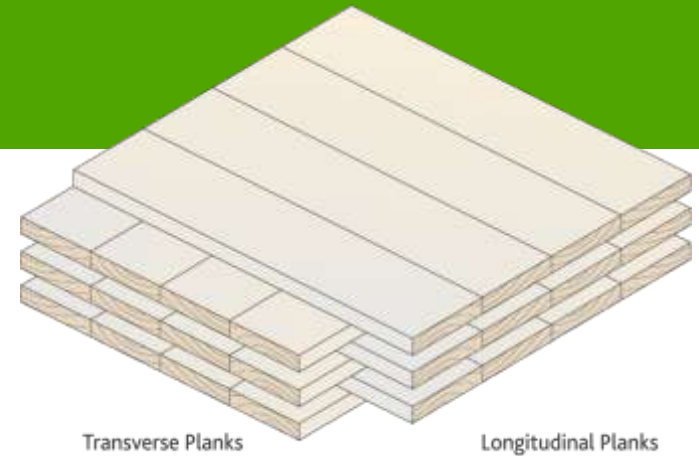


# Board Properties for Wall Panels

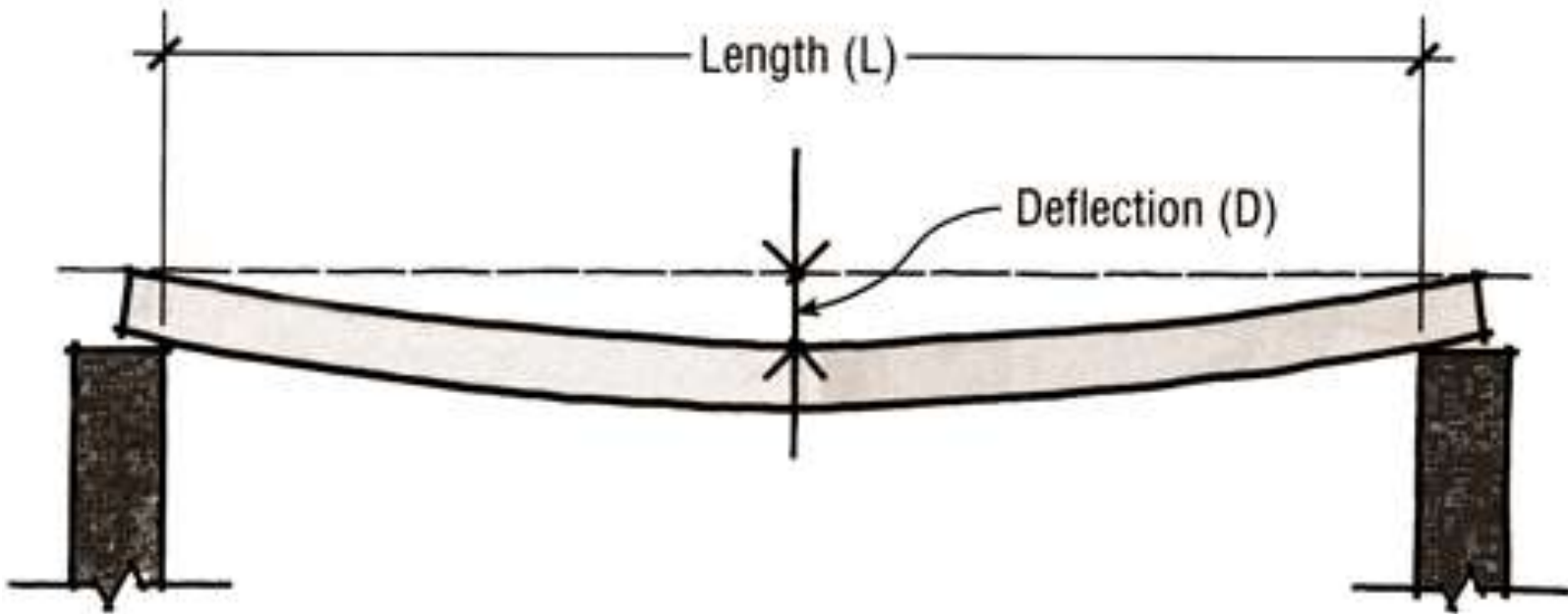
- Lumber grades for walls
  - Vertical Layers
    - Visual Grade No1/No2
    - Others (proprietary)
  - Horizontal Layers
    - Visual Grade No3/Stud
    - Others (proprietary)



# Deformation (Deflection)



G-064

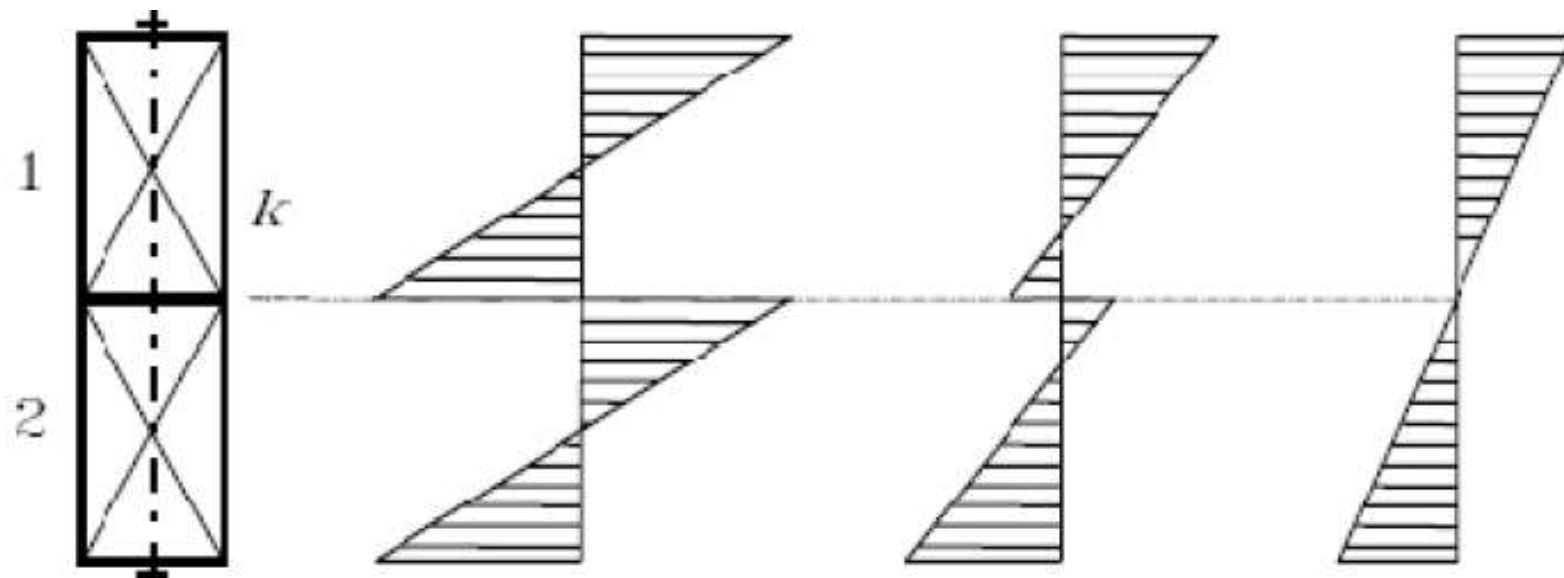


# Degree of interaction (rigidity) between layers

No interaction  
between members

Some  
interaction

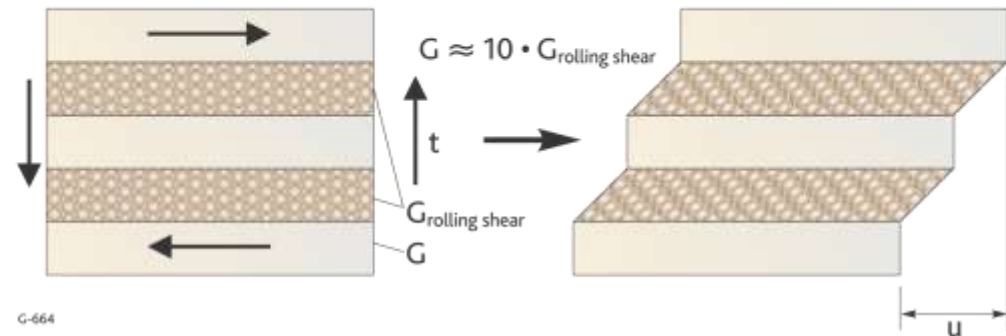
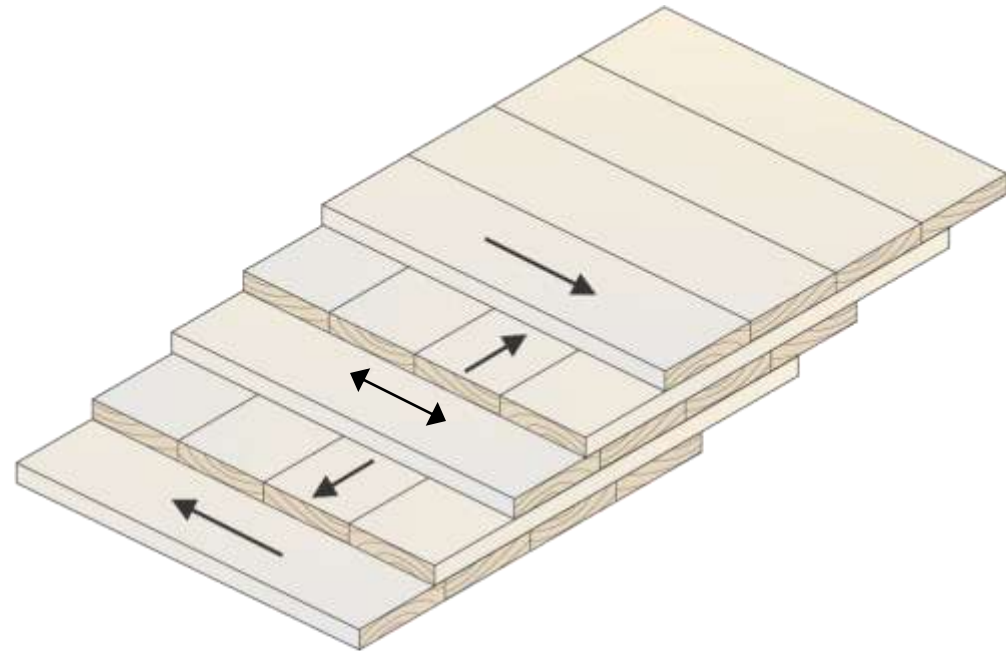
Complete  
interaction



Courtesy of Norsk Treteknisk Institutt

# Rolling Shear Modulus and Strength

- Shear Modulus  
Perpendicular to Grain
  - **Rolling Shear Modulus  $G_R$**
- Shear Strength  
Perpendicular to Grain
  - **Rolling Shear Strength  $F_{V,R}$**



# Rolling Shear Modulus, $G_R$

- Rolling Shear Modulus ( $G_R$ )
  - Generally assumed to be 10% of the shear modulus parallel to the grain of the boards ( $G$ )
  - $G \approx E/16$  for softwood species
  - For example: SPF Lumber No2/No1
    - Modulus of Elasticity ( $E$ ): 9500 MPa
    - $G \approx 9500/16 = 595$  MPa
    - $G_R \approx 595/10 = 59.5$  MPa
  - Assuming  $G_R = 50$  MPa is conservative

# Rolling Shear Strength, $F_{v,R}$

- Rolling Shear Strength ( $F_{v,R}$ )
    - Rolling shear strength varies between 18% to 28% of parallel-to-grain shear values ( $\approx 0.3$  to  $0.6$  MPa)  
(As published in the Wood Handbook)
- $\approx$  *Tension Perpendicular to Grain Strength*

# Shear Deformation of Panels in Bending

## In summary:

- Deformation due to Rolling shear may be significant
- In addition to the rolling shear deformation, there is a shear deformation of the longitudinal boards
  - Shear modulus parallel to the grain of the boards,  $G$  ( $\approx E/16$ )
- In general, the shear deformation of CLT panels may be neglected for floor elements having a span-to-depth ratio of about 30

# Outline

- Cross-laminated Timber Panels – Introduction
- Properties
- **Proposed Analytical Design Methods for Floor and Roof Systems**
- Proposed Analytical Design Methods for Wall Systems
- Proposed Analytical Design Methods for Beams and Lintels
- Modification Factors (CSA O86)

# Proposed Analytical Design Methods for CLT Elements used in Floor and Roof Systems

- Proposed design methods:

- 1) Mechanically Jointed Beams Theory (Gamma Method)

- Bending Stiffness
- Bending Strength
- Shear Strength

- 2) Composite Theory (k Method)

- Bending Stiffness
- Bending Strength

- 3) Shear Analogy (Kreuzinger)

- Bending Stiffness and Shear Stiffness

- 4) Simplified Design Methods

- Bending Strength
- Shear Strength



# Proposed Analytical Design Methods for CLT Elements used in Floor and Roof Systems

## 1) Mechanically Jointed Beams Theory (Gamma Method)

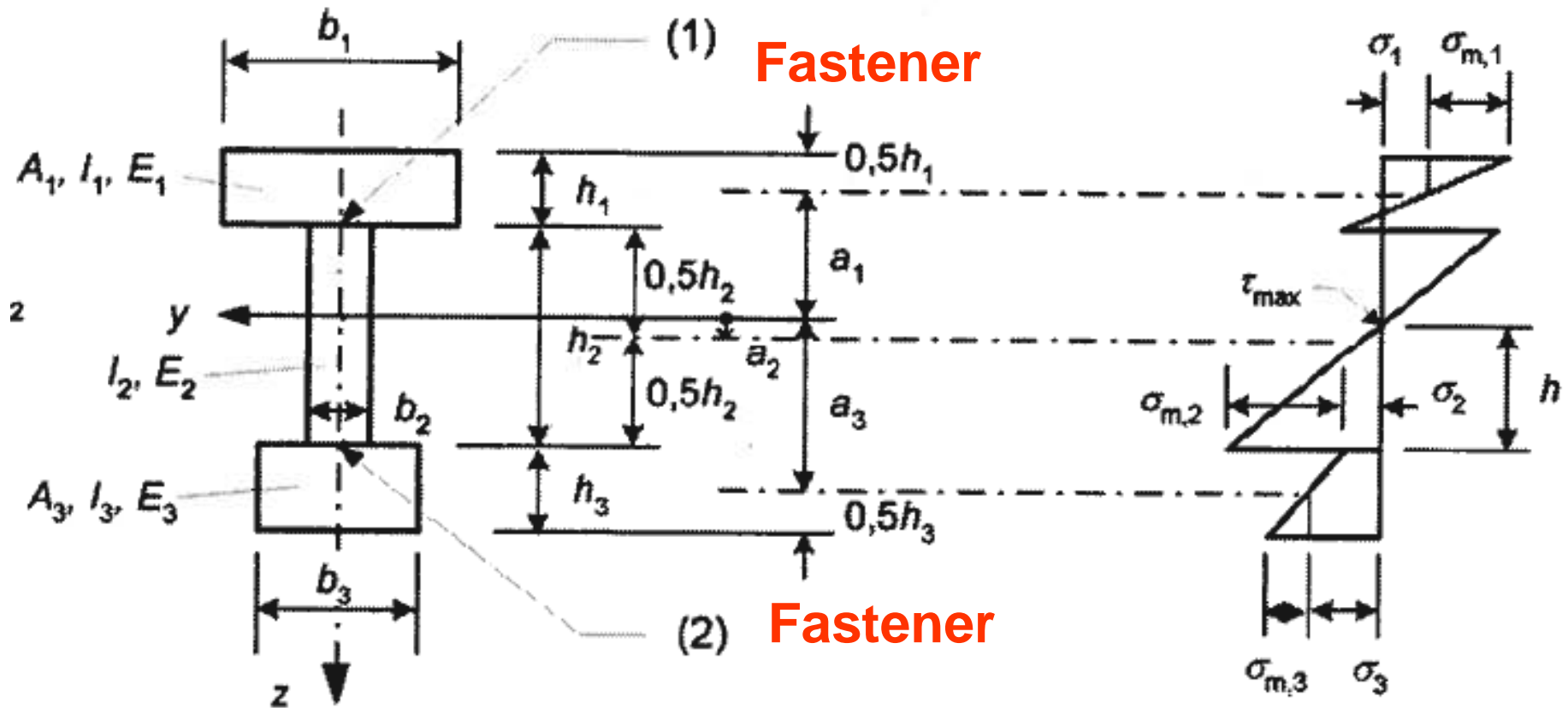
- Based on Annex B of Eurocode 5 (EN 1995:2004)
- Developed for beams connected together with mechanical fasteners with stiffness  $k$  uniformly spaced at distance  $s$
- Only layers acting in the direction of loading are used
- Shear deformation of longitudinal layers is neglected
  - For span-to-depth ratio  $\geq 30$

# Proposed Analytical Design Methods for CLT Elements used in Floor and Roof Systems

## 1) Mechanically Jointed Beams Theory (Gamma Method)

- This method takes into account the rolling shear stiffness ( $G_R$ ) of the cross layers using “imaginary fasteners”
- Longitudinal layers are taken as beam elements connected with “imaginary” fasteners that have stiffness equal to that of rolling shear deformation of cross layers
- Recommended for 3 and 5 layers CLT panels

# Proposed Analytical Design Methods for CLT Elements used in Floor and Roof Systems



***Equivalent to a 5-layer CLT panel***

Source: Eurocode 5

# Proposed Analytical Design Methods for CLT Elements used in Floor and Roof Systems

## 1) Mechanically Jointed Beams Theory (Gamma Method)

**Bending Stiffness:**

$$(EI)_{eff} = \sum_{i=1}^n (E_i I_i + \gamma_i E_i A_i a_i^2)$$

Where  $0 < \gamma \leq 1$

$\gamma = 1$  for **rigid connection** and  $\gamma = 0$  for **no connection**

*But typically  $\gamma$  varies from 0.85 to 0.99*

# Proposed Analytical Design Methods for CLT Elements used in Floor and Roof Systems

- Proposed design methods:

- 1) Mechanically Jointed Beams Theory (Gamma Method)

- Bending Stiffness
- Bending Strength
- Shear Strength

- 2) Composite Theory (k Method)

- Bending Stiffness
- Bending Strength

- 3) Shear Analogy (Kreuzinger)

- Bending Stiffness and Shear Stiffness

- 4) Simplified Design Methods

- Bending Strength
- Shear Strength



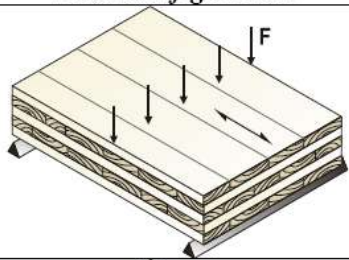
# Proposed Analytical Design Methods for CLT Elements used in Floor and Roof Systems

## 2) Composite Theory (k method)

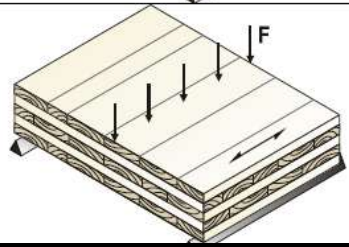
- Based on a theory used for plywood
- Stiffness of all layers is used
  - Stiffness of cross layers is taken as  $E_{90} = E_0 / 30$
- Compositions factors ( $k_i$ ) are determined for certain loading configurations
- Effective values of strength and stiffness are calculated using a composition factor  $k_i$
- Shear deformation is neglected
  - For span-to-depth ratio  $\geq 30$

*Load configuration*

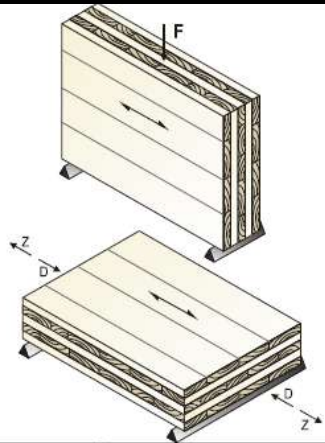
*k<sub>i</sub>*



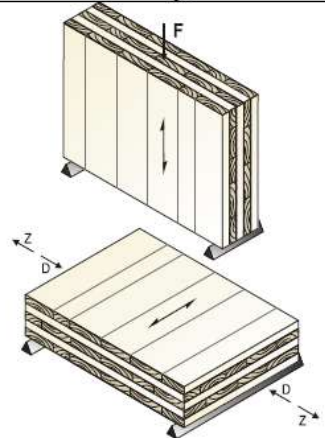
$$k_1 = 1 - \left(1 - \frac{E_{90}}{E_0}\right) \cdot \frac{a_{m-2}^3 - a_{m-4}^3 + \dots \pm a_1^3}{a_m^3}$$



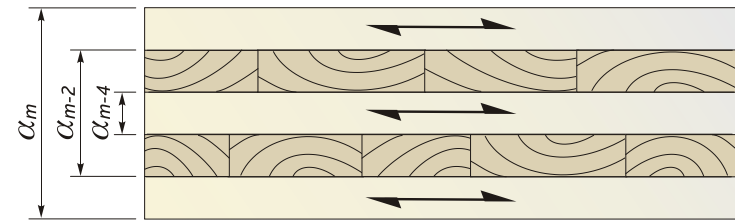
$$k_2 = \frac{E_{90}}{E_0} + \left(1 - \frac{E_{90}}{E_0}\right) \cdot \frac{a_{m-2}^3 - a_{m-4}^3 + \dots \pm a_1^3}{a_m^3}$$



$$k_3 = 1 - \left(1 - \frac{E_{90}}{E_0}\right) \cdot \frac{a_{m-2} - a_{m-4} + \dots \pm a_1}{a_m}$$



$$k_4 = \frac{E_{90}}{E_0} + \left(1 - \frac{E_{90}}{E_0}\right) \cdot \frac{a_{m-2} - a_{m-4} + \dots \pm a_1}{a_m}$$



G-670

# Proposed Analytical Design Methods for CLT Elements used in Floor and Roof Systems

## 2) Composite Theory (k method)

Loading	To the grain of outer skins	Effective strength value	Effective stiffness value
<b>Perpendicular to the plane loading</b>			
<b>Bending</b>	Parallel	$f_{b,0,eff} = f_{b,0} \cdot k_1$	$E_{b,0,eff} = E_0 \cdot k_1$
	Perpendicular	$f_{b,90,eff} = f_{b,0} \cdot k_2 \cdot a_m/a_{m-2}$	$E_{b,90,eff} = E_0 \cdot k_2$
<b>In-plane loading</b>			
<b>Bending</b>	Parallel	$f_{b,0,eff} = f_{b,0} \cdot k_3$	$E_{b,0,eff} = E_0 \cdot k_3$
	Perpendicular	$f_{b,90,eff} = f_{b,0} \cdot k_4$	$E_{b,90,eff} = E_0 \cdot k_4$
<b>Tension</b>	Parallel	$f_{t,0,eff} = f_{t,0} \cdot k_3$	$E_{t,0,eff} = E_0 \cdot k_3$
	Perpendicular	$f_{t,90,eff} = f_{t,0} \cdot k_4$	$E_{t,90,eff} = E_0 \cdot k_4$
<b>Compression</b>	Parallel	$f_{c,0,eff} = f_{c,0} \cdot k_3$	$E_{c,0,eff} = E_0 \cdot k_3$
	Perpendicular	$f_{c,90,eff} = f_{c,0} \cdot k_4$	$E_{c,90,eff} = E_0 \cdot k_4$

# Proposed Analytical Design Methods for CLT Elements used in Floor and Roof Systems

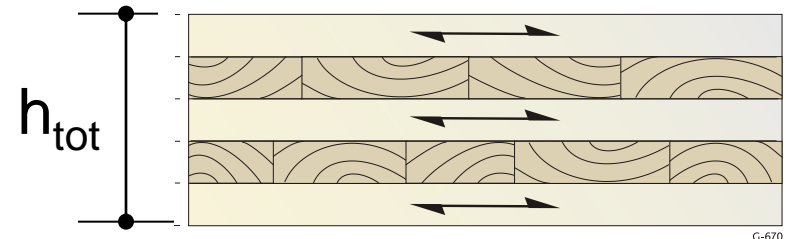
## 2) Composite Theory (k method)

### Bending Stiffness

$$E_{b,0,eff} = E_0 \cdot k_1 = E_{eff}$$

for width =  $b$  and thickness =  $h_{tot}$

$$(EI)_{eff} = E_{eff} \cdot \frac{b \cdot h_{tot}^3}{12}$$



# Proposed Analytical Design Methods for CLT Elements used in Floor and Roof Systems

- Proposed design methods:

- 1) Mechanically Jointed Beams Theory (Gamma Method)

- Bending Stiffness
- Bending Strength
- Shear Strength

- 2) Composite Theory (k Method)

- Bending Stiffness
- Bending Strength

- 3) Shear Analogy (Kreuzinger)

- Bending Stiffness and Shear Stiffness

- 4) Simplified Design Methods

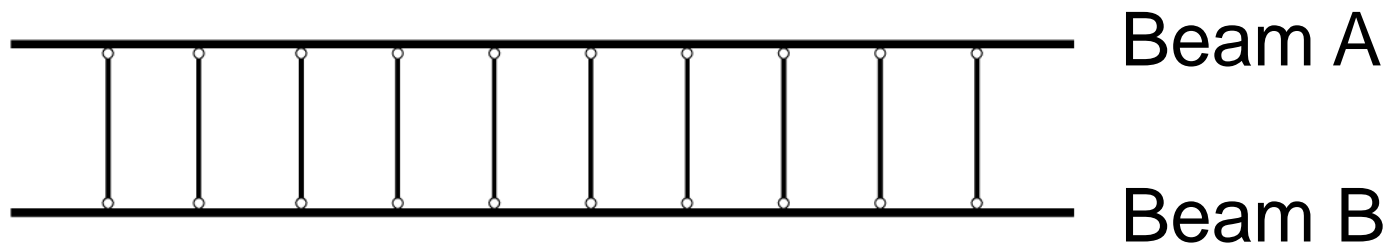
- Bending Strength
- Shear Strength



# Proposed Analytical Design Methods for CLT Elements used in Floor and Roof Systems

## 3) Shear Analogy (Kreuzinger)

- Consider the different modulus of elasticity and shear modulus of single layers (both directions)
- The effect of shear deformations is **not** neglected
- Stiffness of cross layers is taken as  $E_{90} = E_0 / 30$
- Multi-layer CLT panels are separated into two virtual beams A and B



# Proposed Analytical Design Methods for CLT Elements used in Floor and Roof Systems

## 3) Shear Analogy (Kreuzinger)

$$(EI)_{eff} = (EI)_A + (EI)_B = \sum_{i=1}^n E_i \cdot b_i \cdot \frac{h_i^3}{12} + \sum_{i=1}^n E_i \cdot A_i \cdot z_i^2$$

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

# Proposed Analytical Design Methods for CLT Elements used in Floor and Roof Systems

## 3) Shear Analogy (Kreuzinger)

The maximum deflection  $\Delta_{max}$  in the middle of the CLT slab under a uniformly distributed load ( $w$ ) can be calculated as a sum of the contribution due to bending and to shear:

$$\Delta_{max} = \frac{5}{384} \cdot \frac{wL^4}{(EI)_{eff}} + \frac{1}{8} \cdot \frac{wL^2 k}{(GA)_{eff}}$$

where  $k$  is the shear coefficient form factor = 1.2 (Timoshenko)

# Proposed Analytical Design Methods for CLT Elements used in Floor and Roof Systems

- Proposed design methods:

- 1) Mechanically Jointed Beams Theory (Gamma Method)

- Bending Stiffness
- Bending Strength
- Shear Strength

- 2) Composite Theory (k Method)

- Bending Stiffness
- Bending Strength

- 3) Shear Analogy (Kreuzinger)

- Bending Stiffness and Shear Stiffness

- 4) Simplified Design Methods

- Bending Strength
- Shear Strength



# Proposed Analytical Design Methods for CLT Elements used in Floor and Roof Systems

## 4) Simplified Design Methods

Bending Strength:

$$M_r = \phi \cdot F_b \cdot \frac{(EI)_{eff}}{E_1} \cdot \frac{1}{0.5h_{tot}}$$

$$M_r = \phi \cdot F_b \cdot \frac{I_{eff}}{0.5h_{tot}}$$

when  $E_1=E_2=E_3\dots$

# Proposed Analytical Design Methods for CLT Elements used in Floor and Roof Systems

## 4) Simplified Design Methods

**Shear Strength:**

$$\tau_v = \frac{1.5 \times V}{c \cdot A_{gross}}$$

where

$$c = \frac{I_{eff}}{I_{gross}}$$

when  $E1=E2=E3...$

# Outline

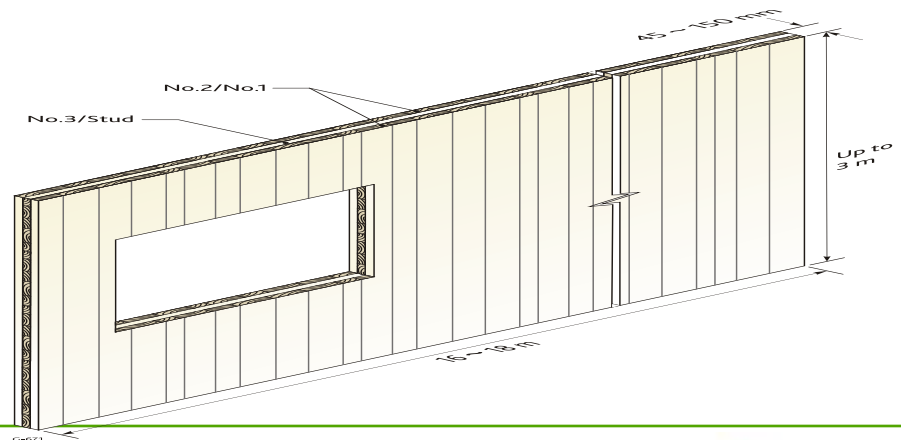
- Cross-laminated Timber Panels – Introduction
- Properties
- Proposed Analytical Design Methods for Floor and Roof Systems
- **Proposed Analytical Design Methods for Wall Systems**
- Proposed Analytical Design Methods for Beams and Lintels
- Modification Factors (CSA O86)

# Proposed Analytical Design Methods for CLT Elements used in Wall Systems

- Proposed design methods for CLT wall panels under axial in-plane and out-of-plane loads

1) Theory of Mechanically Jointed Columns (Eurocode 5)

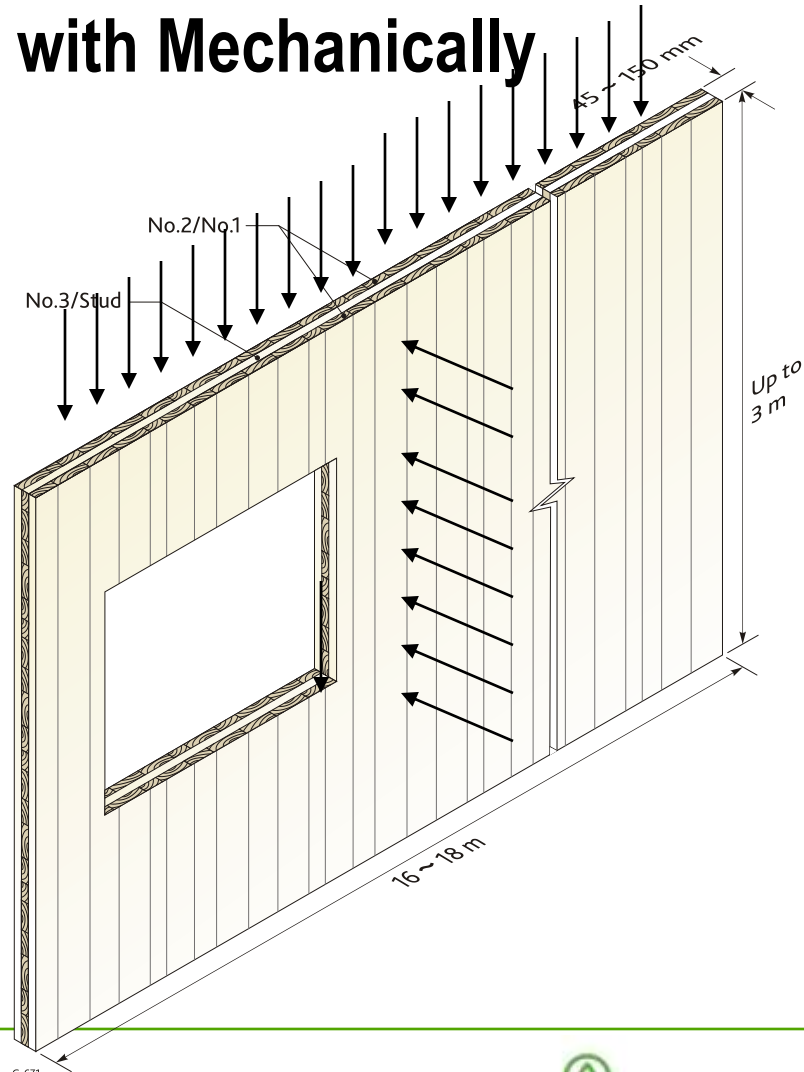
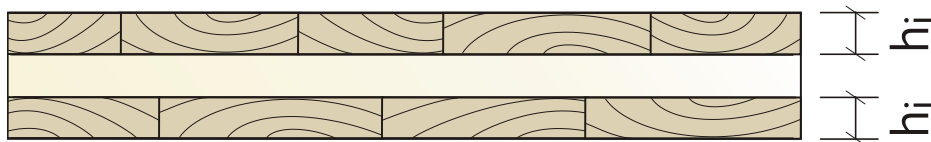
2) CSA O86-09 Approach Combined with Mechanically Connected Beams Theory



# Proposed Analytical Design Methods for CLT Elements used in Wall Systems

## 2) CSA O86-09 Approach Combined with Mechanically Connected Beams Theory

Only the layers oriented parallel to the axial force carry the load

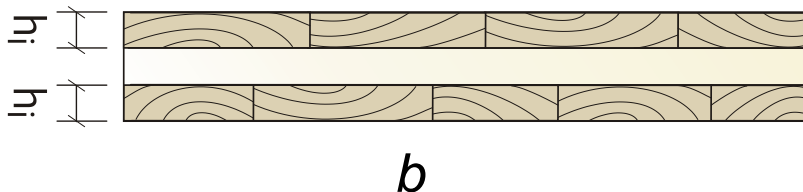


# Proposed Analytical Design Methods for CLT Elements used in Wall Systems

## 2) CSA O86-09 Approach Combined with Mechanically Connected Beams Theory

Using CSA O86-09 Clause 5.5.6.2.2, the slenderness ratio  $C_c$  for rectangular CLT walls can be calculated as:

$$C_c = \frac{H}{d} = \frac{H}{2\sqrt{3} \cdot r_{eff}} \quad \text{where} \quad r_{eff} = \sqrt{\frac{I_{eff}}{A_{eff}}}$$



$$A_{eff} = b \cdot h_{eff} = b \cdot \sum_i h_i$$

# Proposed Analytical Design Methods for CLT Elements used in Wall Systems

## 2) CSA O86-09 Approach Combined with Mechanically Connected Beams Theory

$$r_{eff} = \sqrt{\frac{I_{eff}}{A_{eff}}}$$

Many producers in Europe limit the panel slenderness ratio  $H/r_{eff}$  to 150

# Proposed Analytical Design Methods for CLT Elements used in Wall Systems

## 2) CSA O86-09 Approach Combined with Mechanically Connected Beams Theory

The design procedure for determining the buckling strength can continue as specified in Clause 5.5.6 of CSA O86-09, substituting the cross section area  $A$  with  $A_{eff}$ , and the total thickness  $d$  with the effective thickness  $h_{eff}$ :

$$P_r = \phi \cdot F_C \cdot A_{eff} \cdot K_{ZC} \cdot K_C$$

# Proposed Analytical Design Methods for CLT Elements used in Wall Systems

## 2) CSA O86-09 Approach Combined with Mechanically Connected Beams Theory

The compressive resistance of CLT walls with combined axial and out-of-plane (bending) loading should be calculated using Section 5.5.10 of CSA O86-09:

$$\left( \frac{P_f}{P_r} \right)^2 + \frac{M_{f,P-\Delta}}{M_r} \leq 1$$

# Proposed Analytical Design Methods for CLT Elements used in Wall Systems

## 2) CSA O86-09 Approach Combined with Mechanically Connected Beams Theory

where  $P_f$  is the factored compressive axial load,  $M_r$  is the factored bending moment resistance and  $M_{f, P-\Delta}$  is the factored bending moment that includes  $P-\Delta$  effects calculated as:

$$M_{f, P-\Delta} = M_f + \frac{P_f \cdot (\Delta_f + e_0 + \Delta_0)}{1 - \frac{P_f}{P_e}}$$

# Proposed Analytical Design Methods for CLT Elements used in Wall Systems

## 2) CSA O86-09 Approach Combined with Mechanically Connected Beams Theory

$$M_{f,P-\Delta} = M_f + \frac{P_f \cdot (\Delta_f + e_0 + \Delta_0)}{1 - \frac{P_f}{P_e}}$$

$\Delta_f$  = deflection due to out of plane loading (bending);

$e_0$  = panel deflection due to axial load eccentricity. Eccentricity should be taken as  $d/6$ , where  $d$  is the panel thickness;

$\Delta_0$  = initial wall imperfections in the mid of the panel usually taken as  $H/500$ , where  $H$  is the wall height;

$P_e$  = Euler buckling load in the plane of the bending moment using  $I_{eff}$  and  $E_{05}$  of boards parallel to the axial load.

# Proposed Analytical Design Methods for CLT Elements used in Wall Systems

## 2) CSA O86-09 Approach Combined with Mechanically Connected Beams Theory

Since shear deformations play a significant role in determining the properties of CLT panels, it is important to include them in the calculation of the axial load capacity of the walls.

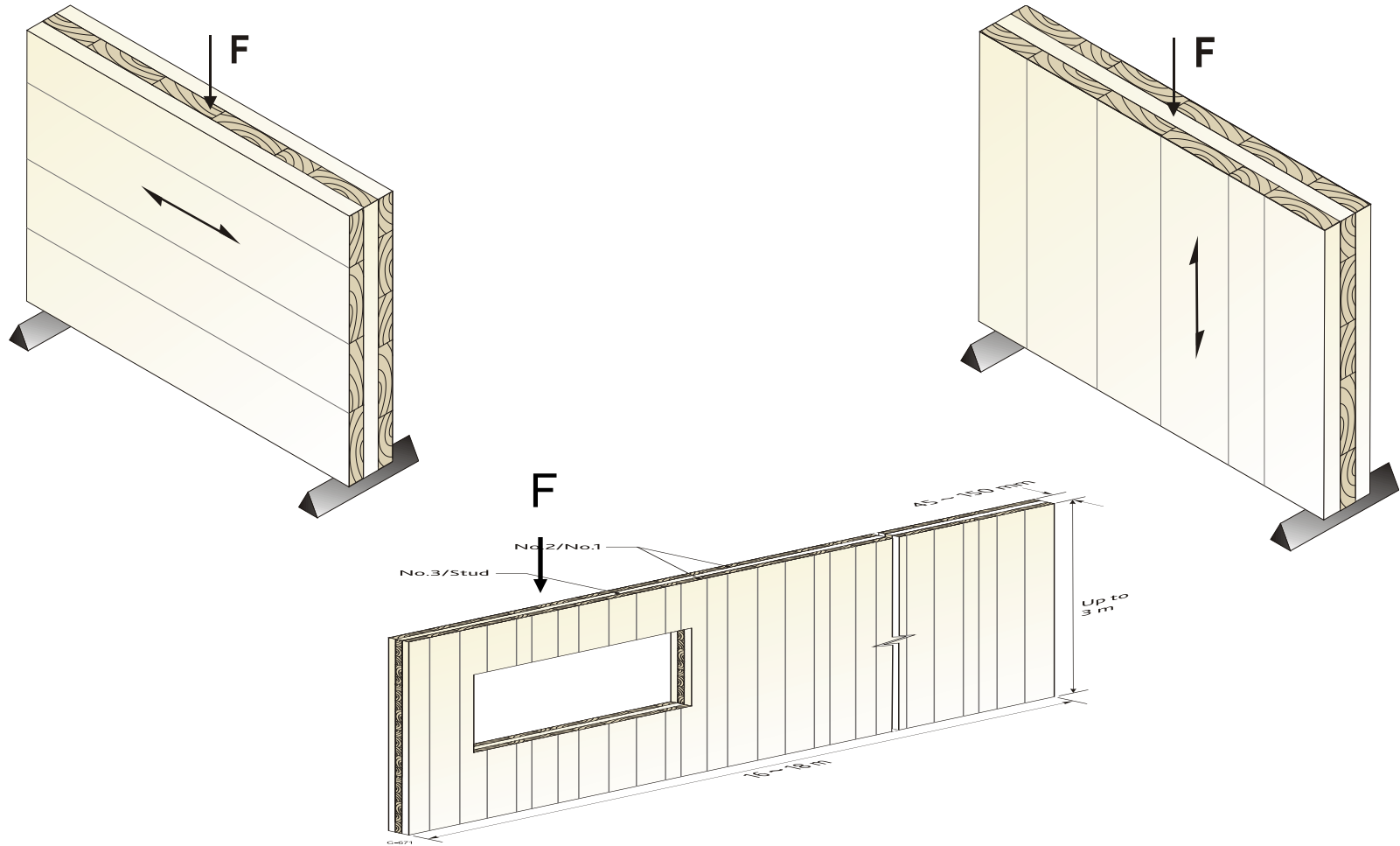
Using basic buckling formula that accounts for shear deformations and substituting  $(GA)_{eff}$  for  $GA$ , the axial load capacity is given as:

$$P_{e,v} = \frac{P_e}{1 + \frac{\kappa \cdot P_e}{(GA)_{eff}}}$$

# Outline

- Cross-laminated Timber Panels – Introduction
- Properties
- Proposed Analytical Design Methods for Floor and Roof Systems
- Proposed Analytical Design Methods for Wall Systems
- **Proposed Analytical Design Methods for Beams and Lintels**
- Modification Factors (CSA O86)

# Proposed Analytical Design Methods for CLT Elements used as Beams and Lintels



CLT beams/lintels under axial in-plane loads

# Proposed Analytical Design Methods for CLT Elements used as Beams and Lintels

- Proposed design methods for CLT Elements used as Beams and Lintels
  - 1) Simplified Design Methods for Calculating Bending Strength
  - 2) Composite Theory – k Method

# Proposed Analytical Design Methods for CLT Elements used as Beams and Lintels

## 1) Simplified Design Methods

If we use the CSA O86-09 design analogy, we can let:

$$\sigma_{\max} \leq \phi \cdot F_b$$

$$M_r = \phi \cdot F_b \cdot \frac{(EI)_{\text{eff}}}{E_{\text{mean}}} \cdot \frac{1}{0.5H}$$

where  $E_{\text{mean}}$  is the mean modulus of elasticity of the longitudinal layer in tension and  $(EI)_{\text{eff}}$  is determined using the net cross-section

# Proposed Analytical Design Methods for CLT Elements used as Beams and Lintels

## 1) Simplified Design Methods

When the modulus of elasticity of all longitudinal layers are equal:

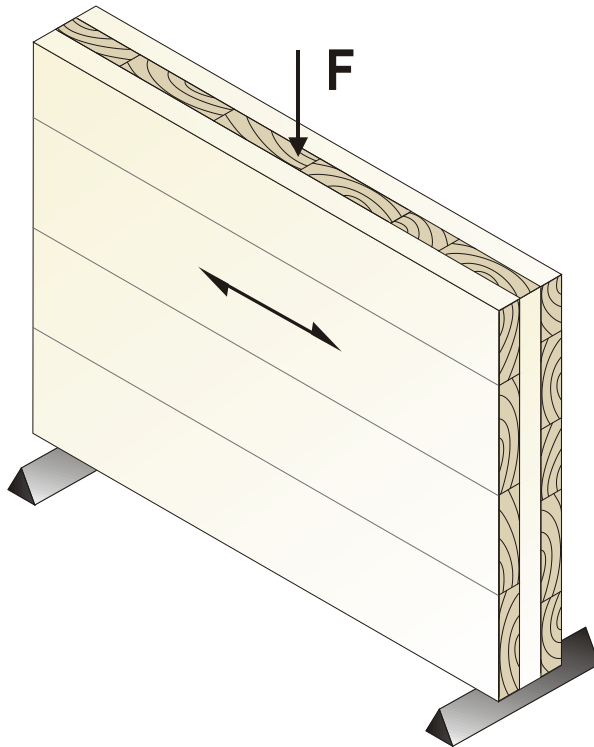
$$M_r = \phi \cdot F_b \cdot \frac{I_{eff}}{0.5H}$$

Where

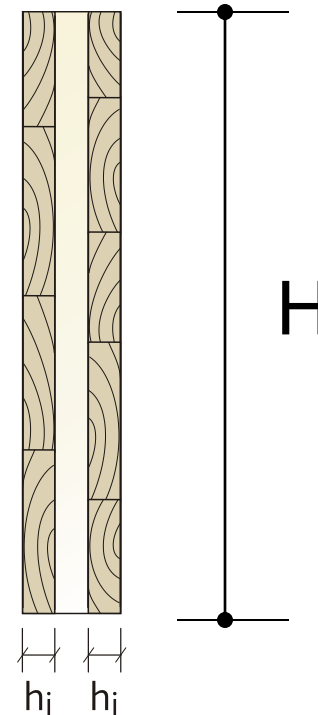
$$I_{eff} = \frac{h_{eff} \cdot H^3}{12} = \frac{H^3}{12} \cdot \sum_i h_i$$

# Proposed Analytical Design Methods for CLT Elements used as Beams and Lintels

## 1) Simplified Design Methods



$$I_{eff} = \frac{h_{eff} \cdot H^3}{12} = \frac{H^3}{12} \cdot \sum_i h_i$$



# Outline

- Cross-laminated Timber Panels – Introduction
- Properties
- Proposed Analytical Design Methods for Floor and Roof Systems
- Proposed Analytical Design Methods for Wall Systems
- Proposed Analytical Design Methods for Beams and Lintels
- **Modification Factors (CSA O86)**

# Modification Factors (CSA O86)

- Load Duration Factor  $K_D$
- Service Condition Factor  $K_S$
- System Factor  $K_H$
- Treatment Factor  $K_T$
- Lateral Stability Factor  $K_L$  (beams and lintels)
- Size Factor for Bending  $K_{Zb}$

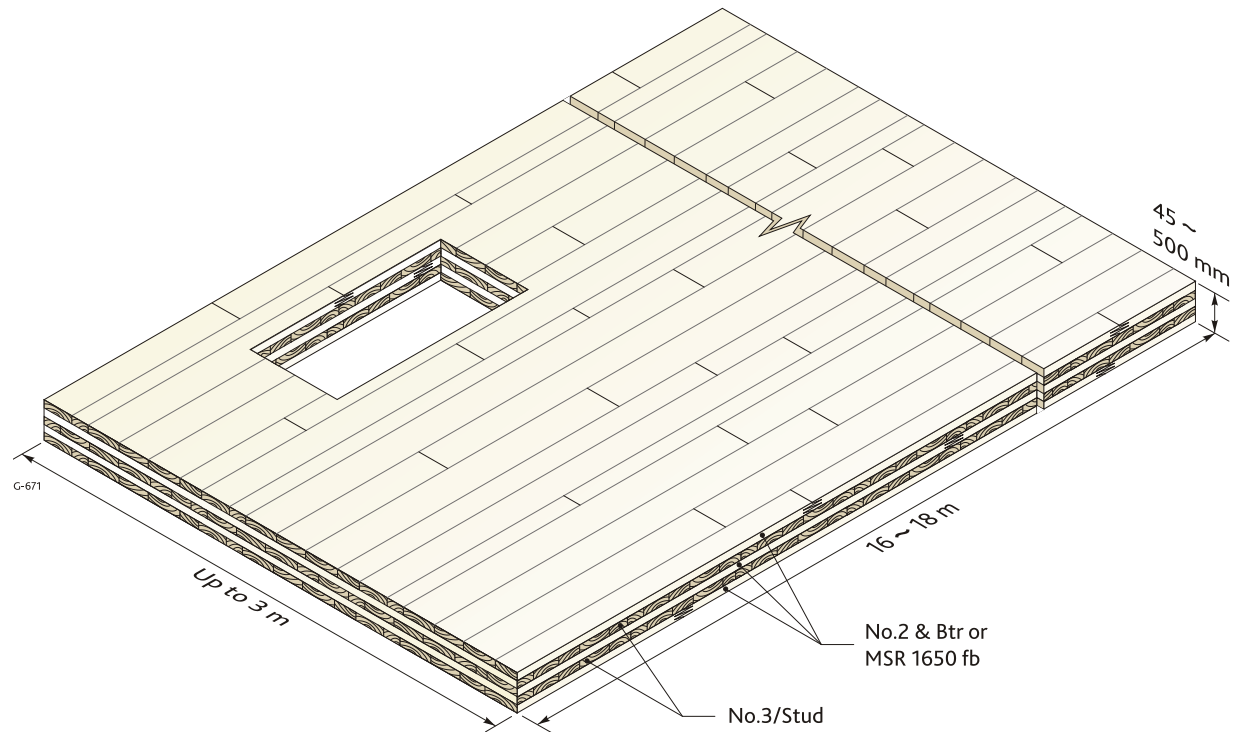
# What is the Maximum Span for this Floor?

- 5-ply CLT panels : 34-19-34-19-34 = **140 mm thick (h)**
- Longitudinal Layers: No.2 S-P-F (MOE = 9500 MPa)
- Transverse Layers: No.3 S-P-F (MOE = 9000 MPa)
- Dead Load: 2.5 kPa
- Live Load: 2.4 kPa (offices)



# What is the Maximum Span for this Floor?

1. Deflection under Live Load:  $L/360$
2. Deflection under Total Load:  $L/240$
3. Bending Moment ( $M_r < M_f$ )
4. Shear ( $V_r < V_f$ )
5. Vibration
6. Creep



# What is the Maximum Span for this Floor?

Good approximation: minimum thickness  $\approx \frac{\textit{Span}}{28}$  to  $\frac{\textit{Span}}{32}$

Then:

$$140 \text{ mm} \times (28 \text{ to } 32) = 3920 \text{ mm to } 4480 \text{ mm}$$

# What is the Maximum Span for this Floor?

Using Shear Analogy:

$$(EI)_{\text{eff}} = 1.916 \times 10^{12} \text{ N-mm}^2$$

$$(GA)_{\text{eff}} = 1.417 \times 10^7 \text{ N}$$



$$\Delta = \frac{5wl^4}{384 \cdot (EI)_{\text{eff}}} + \frac{1}{8} \cdot \frac{wl^2k}{(GA)_{\text{eff}}}$$

Where:

$l$  = simple span in mm

$w$  = uniform load in N/mm for 1 m wide strip

$k = 1.2$  (shear coefficient form factor)

# What is the Maximum Span for this Floor?

## Deflection:

Maximum span for Live Load: 5445 mm (for  $\Delta \leq L/360$ )

Maximum span for Total Load: 4895 mm (for  $\Delta \leq L/240$ )

## Vibration:

Maximum span for vibration: 4440 mm ( $\approx h \times 32$ )

# Concrete Slab?

## CSA A23.3 (Design of Concrete Structures)

- Minimum thickness for a two-way concrete slab without drop panels:

$$h_s \geq \frac{l_n (0.6 + f_y / 1000)}{30} = \frac{l_n}{30} \quad \text{when } f_y = 400 \text{ MPa}$$

- ✓ Then, similar thickness for regular two-way concrete slab using steel bar of  $f_y = 400 \text{ MPa}$  (without considering the vibration of floor)



# FPInnovations

Creating forest sector solutions

[www.fpinnovations.ca](http://www.fpinnovations.ca)



## CLT – Structural Design

Sylvain Gagnon, Eng.

February 8, 2011

Vancouver