Gravity and Lateral Design of Mass Timber Structures

Presented By:
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September 26, 2023
Mass Timber Structural Design: Engineering Modern Timber Structures
Course Description

This presentation will provide a detailed look at the structural design processes associated with a variety of mass timber (MT) products, including glued-laminated timber (glulam), cross-laminated timber (CLT), and nail-laminated timber (NLT). Applications for the use of these products in gravity force-resisting systems under the 2021 IBC/2022 CBC will be discussed. Other technical topics will include MT floor vibration design and connection details. Also, MT framing components are often left exposed to act as a finish while taking advantage of their aesthetics. As such, they are often required to provide a fire-resistance rating demonstrating their ability to maintain structural integrity in the event of a fire. This presentation will also discuss the structural design of mass timber elements under fire conditions.
Learning Objectives

1. Compare different mass timber framing systems and review their unique design considerations.
2. Highlight common connection details in modern timber structures.
3. Review structural design steps for components in common mass timber framing systems.
4. Demonstrate design steps for calculating fire resistance of exposed timber structural elements.
Mass timber (MT) is a category of framing products often using small wood members formed into large (massive) panelized solid wood elements including CLT, NLT or glulam panels for floor, roof and wall framing.
Mass Timber Products

- Nail-Laminated Timber (NLT)
- Cross-Laminated Timber (CLT)
- Glue-Laminated Timber (GLT)
- Tongue & Groove Decking (T&G)
- Timber/Concrete Composite
- Structural Composite Lumber (SCL)

Image source: StructureCraft
Mass Timber Gravity Framing Systems
Building Code Acceptance of CLT (Gravity)

- Standard for Performance-Rated Cross-Laminated Timber
- National Design Specification (NDS)
- 2022 California Building Code
  - (2021 IBC similar)
Mass Timber Gravity Framing Systems

- Post & Beam
- Mass Timber Walls (Honeycomb)
- Hybrid Light-Frame & Mass Timber
- Two-Way Deck
T3 Minneapolis
Minneapolis, MN

Image Credit: Blaine Brownell
Mass Timber Gravity Framing Systems

- Post & Beam
- Mass Timber Walls (Honeycomb)
- Hybrid Light-Frame & Mass Timber
- Two-Way Deck
Candlewood Suites
Huntsville, AL

Image Credit: Lend Lease
Mass Timber Gravity Framing Systems

- Post & Beam
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Mass Timber Gravity Framing Systems

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- Two-Way Deck
Connection Details
Connection Details

Long self tapping screws used extensively throughout mass timber construction.

Photo Credit: Alex Schreyer
Connection Details – Panel to Panel

**Single Surface Spline**

**Half Lap**

**Butt Joint**

---

1. **Single Surface Spline**
   - 1" Thick Plywood Spline w/ 1/4" x 5/8" Screws @ 8" o.c. Typ.
   - Fire Sealant Where Occurs Ref. Arch.

2. **Half Lap**
   - CL of Spline
   - Fire Sealant Where Occurs Ref. Arch.
   - 1/4" x 5/8" Screws @ 24" o.c.

3. **Butt Joint**
   - CL of Spline
   - Fire Sealant Where Occurs Ref. Arch.
   - 1/4" x 5/8" Screws @ 6" o.c. Typ.
   - (4" o.c. At Lvl 12)
Connection Details – Panel to Beam

- 5/16"Øx12 5/8" ASSY 3.0 SCREWS @ 24" o.c.
- CL OF BEAM
- SIMPSON STRONG-TIE SDWS22800 LOG
- GLULAM BEAM
Simple connections with:

- Metal angles
- Self tapping screws

Source: US CLT Handbook
Component Design (Gravity)
NLT Design Guide includes:

- Architecture
- Fire
- Structure
- Enclosure
- Supply and Fabrication
- Construction and Installation
- Erection engineering

Free download from www.thinkwood.com
CLT Design

The Standard Covers:
- U.S. and Canadian Use
- Panel Dimensions and Tolerances
- Component Requirements
- Structural Performance Requirements
- Panel and Manufacturing Qualification
- Marking (Stamping)
- Quality Assurance
CLT Design – 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.
# CLT Design – PRG 320 Basic Layups

## CLT Grade (basic)

## Layup

## Panel Properties

### Table A2.

<table>
<thead>
<tr>
<th>CLT Grade</th>
<th>CLT t (in.)</th>
<th>Major Strength Direction</th>
<th>Minor Strength Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$F_{S,\text{eff,0}}$ (lbf/ft)</td>
<td>$E_{I,\text{eff,0}}$ (lbf-in.$^2$/ft$^2$)</td>
</tr>
<tr>
<td>E1</td>
<td>4 1/8</td>
<td>13/8</td>
<td>13/8</td>
</tr>
<tr>
<td></td>
<td>5 7/8</td>
<td>13/8</td>
<td>13/8</td>
</tr>
<tr>
<td></td>
<td>9 5/8</td>
<td>13/8</td>
<td>13/8</td>
</tr>
<tr>
<td>E2</td>
<td>4 1/8</td>
<td>13/8</td>
<td>13/8</td>
</tr>
<tr>
<td></td>
<td>6 7/8</td>
<td>13/8</td>
<td>13/8</td>
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<tr>
<td></td>
<td>9 5/8</td>
<td>13/8</td>
<td>13/8</td>
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<tr>
<td>E3</td>
<td>4 1/8</td>
<td>13/8</td>
<td>13/8</td>
</tr>
<tr>
<td></td>
<td>6 7/8</td>
<td>13/8</td>
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<tr>
<td></td>
<td>9 5/8</td>
<td>13/8</td>
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<td>E4</td>
<td>4 1/8</td>
<td>13/8</td>
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<tr>
<td></td>
<td>9 5/8</td>
<td>13/8</td>
<td>13/8</td>
</tr>
<tr>
<td>E5</td>
<td>4 1/8</td>
<td>13/8</td>
<td>13/8</td>
</tr>
<tr>
<td>V1</td>
<td>6 7/8</td>
<td>13/8</td>
<td>13/8</td>
</tr>
</tbody>
</table>
### CLT Grade (basic or custom)

<table>
<thead>
<tr>
<th>CLT Grade</th>
<th>Panel Properties</th>
<th>Layup</th>
</tr>
</thead>
<tbody>
<tr>
<td>SL-V4</td>
<td>775</td>
<td>1.1</td>
</tr>
</tbody>
</table>

### Layup

### Panel Properties

#### Table 1. Allowable Design Properties

<table>
<thead>
<tr>
<th>CLT Grade</th>
<th>$F_{b,0}$ (psi)</th>
<th>$E_0$ (10^6 psi)</th>
<th>$F_{l,0}$ (psi)</th>
<th>$F_{l,0}$ (psi)</th>
<th>$F_{v,0}$ (psi)</th>
<th>$F_{v,0}$ (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SL-V4</td>
<td>775</td>
<td>1.1</td>
<td>350</td>
<td>1,000</td>
<td>135</td>
<td>45</td>
</tr>
</tbody>
</table>

For SL 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

<table>
<thead>
<tr>
<th>CLT Grade</th>
<th>Layup #</th>
<th>Thickness (in.)</th>
<th>Lamination Thickness (in.) in CLT Layup</th>
<th>Major Strength Direction</th>
<th>Minor Strength Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>SL-V4(b)</td>
<td>7-alt</td>
<td>13/8</td>
<td>13/8</td>
<td>13/8</td>
<td>13/8</td>
</tr>
<tr>
<td></td>
<td>5-mxxx</td>
<td>13/8</td>
<td>13/8</td>
<td>13/8</td>
<td>13/8</td>
</tr>
<tr>
<td></td>
<td>5-alt</td>
<td>13/8</td>
<td>13/8</td>
<td>13/8</td>
<td>13/8</td>
</tr>
<tr>
<td></td>
<td>4-maxx</td>
<td>13/8</td>
<td>13/8</td>
<td>13/8</td>
<td>13/8</td>
</tr>
<tr>
<td></td>
<td>3-alt</td>
<td>13/8</td>
<td>13/8</td>
<td>13/8</td>
<td>13/8</td>
</tr>
</tbody>
</table>

# CLT Design – Product Report Custom Layups
CLT Design – **FLATWISE** Panel Loading

Span in **MAJOR** Strength Direction
“Parallel” Direction

Span in **MINOR** Strength Direction
“Perpendicular” Direction

*Reference: ANSI/APA PRG 320*
CLT Design – Flatwise Flexural Strength

Design properties based on an Extreme Fiber Stress Model:

Flexural Capacity Check:

\[ M_b \leq \left( F_b S_{\text{eff}} \right)' \]

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

Reference: NDS
CLT Design – Flatwise Flexural Strength

Flexural Capacity Check (ASD):

\[
(F_b S_{\text{eff}})’ = C_D \ C_M \ C_t \ C_L \ (F_b S_{\text{eff}})
\]

per NDS

Commonly 1.0

Provided as combined value by manufacturer

\[
M_b \leq C_D \ (1.0) \ (F_b S_{\text{eff}})
\]

Reference: NDS
Design properties based on Extreme Fiber Stress Model:

Shear Capacity Check:

\[ V_a \leq F_s \left( \frac{\text{lb}}{Q} \right)_{\text{eff}}' \]

\( V_a \) = applied shear

\( F_s \left( \frac{\text{lb}}{Q} \right)_{\text{eff}}' \) = adjusted shear strength

Reference: NDS
**CLT Design – Flatwise Shear Strength**

Design properties based on Extreme Fiber Stress Model:

Shear Capacity Check (ASD):

\[
F_s (\text{lb/Q})_{\text{eff}}' = C_M C_t (F_s (\text{lb/Q})_{\text{eff}}) = C_M C_t V_s
\]

Commonly

1.0

Provided as combined value by manufacturer

\[
V_{\text{planar}} \leq (1.0) V_s
\]

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

*Reference: NDS & CLT Product Reports*
CLT Design – Flatwise Deflection Calculations

General Purpose: One-Way, Beam Action
Needed Stiffness: $EI_{\text{eff}}$, $GA_{\text{eff}}$

Analyze as beam representing a 1 ft wide strip of CLT
Can model multiple spans, cantilevers, etc.
CLT Design – Flatwise Flexural and Shear Stiffness

\[
(EL)_{eff,0} = \sum_{i=1}^{n} E_i b_0 \frac{t_i^3}{12} + \sum_{i=1}^{n} E_i b_0 t_i z_i^2
\]

\[
(GA)_{eff,0} = \frac{(t_1 - \frac{t_1}{2} - \frac{t_n}{2})^2}{\left(\frac{t_1}{2G_1b_0}\right) + \left(\sum_{i=2}^{n-1} \frac{t_i}{G_ib_0}\right) + \left(\frac{t_n}{2G_nb_0}\right)}
\]

Reference: ANSI/APA PRG 320 Appendix X3
CLT Design – Flatwise Deflection Calculations

Simplified Beam Deflections:
For single span, simply supported uniform load

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

What is **Apparent** Flexural Stiffness, \(EI_{\text{app}}\), such that

\[
\Delta_{\text{max}} = \frac{5}{384} \cdot \frac{wL^4}{EI_{\text{app}}}
\]

Set equal to each other and solve for \(EI_{\text{app}}\)

\[
EI_{\text{app}} = \frac{EI_{\text{eff}}}{1 + \frac{11.5 \cdot EI_{\text{eff}}}{GA_{\text{eff}} L^2}}
\]

Reference: US CLT Handbook & NDS
The natural frequency of a floor, and harmonics of the fundamental frequency, are the most important parameters in vibration design and evaluation.

Most practical floors have fundamental frequencies in the range of 5 to 15 Hz, although values outside this range are possible.

Generally, the higher the frequency the better.
Vibration sources are complex:
• Footfall, running, aerobics, etc.
• Machinery and equipment
• Vehicular traffic, rail traffic, forklifts
• Ground-borne, structure-borne, air-borne
• Steady-state, episodic, periodic
• Harmonic, pulse, random
• Moving, stationary
One approach: US CLT Handbook, Chapter 7 (FPI Method)

Limit CLT floor span such that:

\[ L \leq \frac{1}{12.05} \left( \frac{EI_{app}}{\rho A} \right)^{0.293} \]

Where:

- \( L \) = floor span (ft)
- \( EI_{app} \) = apparent stiffness for pinned supported, uniformly loaded, simple span beam, 1 ft wide (lb-in²)
- \( \rho \) = specific gravity of the CLT
- \( A \) = the cross-sectional area (thickness × 12) (in²)

Reference: US CLT Handbook, Chapter 7
CLT Design – Floor Vibration

FPI Method recommends limiting CLT Floor Span such that:

\[ L \leq \frac{1}{12.05} \left( \frac{EI_{app}}{(\rho A)^{0.122}} \right)^{0.293} \]

Recall: \( EI_{app} = \frac{EI_{eff}}{1 + \frac{11.5 \cdot EI_{eff}}{GA_{eff} L^2}} \)

Using iterative approach:

1) Estimate \( L \)
2) Calculate \( EI_{app} \)
3) Calculate \( L \)
4) Repeat until \( L \) converges

OR use values provided by manufacturer

Reference: US CLT Handbook, Chapter 7
Experience has shown that the FPI Method consistently produces well performing floors

Does not consider

- Multi-span panels (improves performance)
- Flexibility of supports, e.g. beams (lowers performance)
- Impact of topping slabs (may improve or lower performance)

Recommend 20% increase in acceptable span length for multi-span panels with non-structural elements that are considered to provide an enhanced stiffening effect, including partition walls, finishes and ceilings, etc.
NEW MASS TIMBER FLOOR VIBRATION DESIGN GUIDE

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

Worked office, lab and residential examples
Fire Resistance
Fire Resistance – Charring

For exposed wood members, CBC Section 722.1 references AWC’s NDS Chapter 16 (AWC’s TR 10 is a design aid to NDS Chapter 16)
Fire Resistance – Charring

Similar to heavy timber, mass timber products have inherent fire resistance properties

Source: AWC’s TR 10
Fire Resistance - Glulams

Glulam beam fire design:
- Add 1 additional outer tension lam at bottom for each hour of resistance required
- Widen as required
Fire Resistance – CLT

CLT fire design:
- Neutral axis shifts as charring occurs at exposed layers
Fire Resistance – CLT

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

See WoodWorks for Inventory of Tested Assemblies.
Additional Resources
NEW MASS TIMBER DESIGN MANUAL

110+ pages of mass timber technical resources, case studies and more. Links directly to many additional resources.

Jointly Produced By:

WoodWorks™
WOOD PRODUCTS COUNCIL

THINK WOOD

https://info.thinkwood.com/masstimberdesignmanual
For many years, exposed heavy timber framing elements have been permitted in U.S. buildings due to their inherent fire-resistance properties. The predictability of wood's behavior has been well-established for decades and has long been recognized in building codes and standards.

Today, one of the exciting trends in building design is the growing use of mass timber—i.e., large solid wood panel products such as cross-laminated timber (CLT) and nail-laminated timber (NLT)—for floor, wall and roof construction. Like heavy timber, mass timber products have inherent fire resistance that allows them to be left exposed and still achieve a fire-resistance rating. Because of their stronger dimensional stability, these products also offer an alternative to steel, concrete, and masonry for many applications, and much lighter carbon footprint. It is this combination of endurance and strength that developers and designers acclimated to wood are finding appealing.

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

<table>
<thead>
<tr>
<th>CLT Panel</th>
<th>Manufacturer</th>
<th>CLT Grade or Major's Minor Grade</th>
<th>Ceiling Protection</th>
<th>Panel Connection</th>
<th>Floor Topping</th>
<th>Load Rating</th>
<th>Fire Resistance Achieved (Hours)</th>
<th>Source</th>
<th>Testing Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-ply CLT</td>
<td>Nordic</td>
<td>SPF 16/81/0.5 EFR MSR x SPF 60</td>
<td>None</td>
<td>Topspile</td>
<td>None</td>
<td>Redwood</td>
<td>1.0 in proprietary gypsum over Massiv material</td>
<td>NRC Fire Laboratory</td>
<td>NRC Fire Laboratory</td>
</tr>
<tr>
<td>(67mm x 6.409)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50% Moment Capacity</td>
<td>30 (Test 1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-ply CLT</td>
<td>Structurlam</td>
<td>SPF 0.122 x SPF 0.122</td>
<td>2 layers 5/8&quot; Type X gypsum</td>
<td>Half-Lap</td>
<td>None</td>
<td>Redwood</td>
<td>1.0 in prop. gypsum over Massiv material</td>
<td>NRC Fire Laboratory</td>
<td>NRC Fire Laboratory</td>
</tr>
<tr>
<td>(67mm x 6.409)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>35% Moment Capacity</td>
<td>30 (Test 5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-ply CLT</td>
<td>Nordic</td>
<td>SPF 0.122 x SPF 0.122</td>
<td>None</td>
<td>Topspile</td>
<td>2 layers 5/8&quot; cement board</td>
<td>Loadbearing</td>
<td>2.0 in prop. gypsum over Massiv material</td>
<td>NRC Fire Laboratory</td>
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</tr>
<tr>
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</tr>
<tr>
<td>5-ply CLT</td>
<td>Nordic</td>
<td>SPF 0.122 x SPF 0.122</td>
<td>3 layers 5/8&quot; Type X gypsum</td>
<td>Topspile</td>
<td>3/4 in prop. gypsum over Massiv material</td>
<td>Loadbearing</td>
<td>3.0 in prop. gypsum over Massiv material</td>
<td>NRC Fire Laboratory</td>
<td>NRC Fire Laboratory</td>
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<tr>
<td>(67mm x 6.409)</td>
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</tr>
</tbody>
</table>

### Additional Resources – woodworks.org

WoodWorks is a council of the American Forest & Paper Association, bringing together more than 100 companies representing the entire forest and forest product industry. WoodWorks’ primary focus is driving innovation in wood materials and solutions in the building marketplace, and supporting the advancement of wood in new applications, industries, and regions. For more information, visit woodworks.org.
CLT Shear Wall and Diaphragm Design Under the 2021 SDPWS
The use of cross-laminated timber (CLT) panels for structural floor and roof assemblies has seen incredible growth in the U.S. over the past decade. However, CLT’s use as part of a seismic or wind force-resisting system—either as a shear wall or a diaphragm—has only recently been codified. Up until now, this has required the use of the Alternate Materials and Methods Request (AMMR) process for CLT lateral force-resisting system design. This presentation will introduce the new provisions for CLT shear wall and diaphragm design contained in the American Wood Council’s 2021 Special Design Provisions for Wind and Seismic (SDPWS), including detailing and design requirements, and the range of seismic response modification coefficients (e.g., “R” values) recognized for CLT shear wall design in ASCE 7-22.
Learning Objectives

1. Develop an understanding of the design challenges related to using CLT for wind and seismic resistance while meeting the intent of the 2021 IBC/2022 CBC.

2. Discuss the new provisions in the 2021 Special Design Provisions for Wind and Seismic (SDPWS) applicable to all lateral systems.

3. Understand the new detailing options and path to code acceptance of several CLT shear wall systems.

4. Review the engineering design requirements for using CLT floor and roof assemblies as horizontal diaphragms for wind and seismic resistance.
What is CLT?

**Solid-sawn or Structural Composite Lumber (SCL) laminations**
- 3 layers minimum
- Each layer rotated 90° (sim. to plywood sheathing)
- Glued with structural adhesives

*All dimensions are approximate. Check with specific manufacturers*
CLT Lateral Systems
EDGEWISE Panel Loading

Span in MAJOR Strength Direction

Span in MINOR Strength Direction

Source: PRG 320
Shear Force Terminology

Through-the-Thickness Shear

In-plane Shear Forces

EDGEWISE Shear in PRG 320-2018

Source: PRG 320

Source: 2018 NDS Commentary

2018 NDS: $F_v(t_v)$
PRG 320: $F_{v,e,0} t_p$ & $F_{v,e,90} t_p$
CLT In-Plane (Edgewise) Strength

145 to 290 PSI Edgewise Shear Capacity = 1.7 to 3.5 kips/ft (ASD) per inch of thickness!

Consult with manufacturers for values

Multiply by \(Cd = 1.6\) for short term ASD strength

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

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

Source: APA Product Report PR-L306
CLT in the 2021 IBC/2022 CBC (Lateral)

Where seismic ("R" values) and wind systems are referenced – No CLT

Now with CLT shear wall and diaphragm requirements

CLT lateral systems from the 2021 SDPWS (not "R" values for shear wall design) are referenced in the 2021 IBC/2022 CBC
Top Changes Relevant to CLT Lateral Systems:
- New unified nominal shear capacity
- New CLT Shear Wall requirements
- New CLT Diaphragm requirements

Free (view only) version at awc.org
2021 Special Design Provisions for Wind and Seismic

Top Changes Relevant to CLT Lateral Systems:
- **New unified nominal shear capacity**
- New CLT Shear Wall requirements
- New CLT Diaphragm requirements
For Wood Structural Panel (WSP) shear walls and diaphragms, the 2015 SDPWS has two nominal shear capacities:

- $\nu_S$ Nominal shear capacity for seismic loads
- $\nu_W$ Nominal shear capacity for wind loads

The 2021 SDPWS has one nominal shear capacity for both wind and seismic loads (for all systems such as WSP and CLT):

- $\nu_n$ Nominal shear capacity
To calculate the ASD or LRFD shear capacity, the 2021 SDPWS has different reduction factors for wind and seismic loading.

<table>
<thead>
<tr>
<th>Loading</th>
<th>ASD Design Capacity $v_n / \Omega_D$</th>
<th>LRFD Design Capacity $\phi_D v_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seismic</td>
<td>$v_n / 2.8$</td>
<td>0.50 $v_n$</td>
</tr>
<tr>
<td>Wind</td>
<td>$v_n / 2.0$</td>
<td>0.80 $v_n$</td>
</tr>
</tbody>
</table>

Source: 2021 SDPWS Section 4.1.4
CLT Shear Wall Design
CLT Shear Wall Design

Denver University Burwell Center for Career Achievement Photo Credit: WoodWorks
2021 Special Design Provisions for Wind and Seismic

Top Changes Relevant to CLT Lateral Systems:

- New unified nominal shear capacity
- **New CLT Shear Wall requirements**
- New CLT Diaphragm requirements
2021 SDPWS – CLT Shear Wall requirements

Section View

Elevation View

applied load $\nu_u$
2021 SDPWS – CLT Shear Wall requirements

Section View

Elevation View

applied load $\nu_u$
2021 SDPWS – CLT Shear Wall requirements

Section View

Elevation View

applied load $v_u$
Panel to Panel Connection

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

Panel to Platform Connection

- Same steel plate material and nails plus
  (2) 5/8” Ø bolts or lag screws to roof, floor or foundation
2021 SDPWS – CLT Shear Wall requirements

Panel to Platform Connection

Nominal shear capacity of connector

\[ \mathcal{V}_n = 2605 \ C_G \ [\text{lbs}] \text{ per angle connector} \]

\( C_G \) adjusts for specific gravity, \( G \) of CLT

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

Nominal unit shear capacity:

\[ \mathcal{V}_n = n \left( \frac{2605}{b_s} \right) C_G \ [\text{lbs/ft}] \]
2021 SDPWS – CLT Shear Wall requirements

(Platform or balloon-framed)

CLT Shear Walls
not meeting 2021 SDPWS Appendix B

- Seismic Design Category A or B only
  (2021 SDPWS 4.6.3)

(Platform-framed only)

CLT Shear Walls
meeting 2021 SDPWS Appendix B

- Panel aspect ratios
  \[2 \leq \frac{h}{b_s} \leq 4\]

- Shear resistance provided by high aspect ratio panels only
  (2021 SDPWS B.3.7)

- Panel aspect ratios
  \[\frac{h}{b_s} = 4\]
What “R” value can I use?
2021 SDPWS – “R” Values for CLT Shear Walls
(platform or balloon framed)

CLT Shear Walls
not meeting 2021 SDPWS Appendix B

“R” = 1.5
$C_d = 1.5$, $\Omega_o = 2.5$, max. ht. = 65’
(2021 SDPWS 4.6.3)

CLT Shear Walls
meeting 2021 SDPWS Appendix B

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

“R” = 3.0
$C_d = 3.0$, $\Omega_o = 3.0$, max. ht. = 65’
(ASCE 7-22)

Panel aspect ratios
$h/b_s = 4$

“R” = 4.0
$C_d = 4.0$, $\Omega_o = 3.0$, max. ht. = 65’
(ASCE 7-22)

(CL)T Shear Walls
(platform-framed only)
CLT in the 2024 IBC/2025 CBC (Lateral)

CLT lateral systems will be fully recognized in the 2024 IBC/2025 CBC

Now with CLT shear wall and diaphragm requirements

Will have “R” values for CLT shear walls
CLT Post-Tensioned Rocking Shear Wall System Tests

Source: S. PEI et al. [http://nheritallwood.mines.edu/](http://nheritallwood.mines.edu/)
CLT Diaphragm Design
Top Changes Relevant to CLT Lateral Systems:
- New unified nominal shear capacity
- New CLT Shear Wall requirements
- New CLT Diaphragm requirements
CLT Diaphragms

Strength of connections (covered by NDS and proprietary fastener Evaluation Reports) governs design. Strength of CLT should never govern.
4.5 Cross-Laminated Timber (CLT) Diaphragms

4.5.1 Application Requirements

CLT diaphragms shall be permitted to be used to resist lateral forces provided the deflection in the plane of the diaphragm, as determined by calculations, tests, or analogies drawn therefrom, does not exceed the maximum permissible deflection limit of attached load distributing or resisting elements. Permissible deflection shall be that deflection that will permit the diaphragm and any attached elements to maintain their structural integrity and continue to support their prescribed loads as determined by the applicable building code or standard.

4.5.2 Deflection

CLT diaphragm deflection shall be determined using principles of engineering mechanics.

4.5.3 Unit Shear Capacity

CLT diaphragms shall be designed in accordance with principles of engineering mechanics using design values for wood members and connections in accordance with NDS provisions.

The nominal unit shear capacity, \( V_u \), of CLT diaphragms shall be based on the nominal shear capacity for dowel-type fastener connections used to transfer diaphragm shear forces, as calculated per 4.5.4.1. ASD allowable shear capacity or LRFD factored shear resistance for the CLT diaphragm and diaphragm shear connections shall be determined in accordance with 4.1.1.

4.5.4 Additional CLT Diaphragm Design Requirements

CLT diaphragms shall meet the following additional requirements:

1. The nominal shear capacity for dowel-type fastener connections used to transfer diaphragm shear forces between CLT panels and between CLT panels and diaphragm boundary elements (chords and collectors) shall be taken as 4.5\( V^* \), where \( V^* = Z \times \text{yielding} \times (K_m \times K_e \times K_i \times K_d) \times (K_n \times K_s \times K_l) \), and \( Z \) shall be controlled by Mode III or Mode IV fastener yielding in accordance with NDS 12.3.1.

2. Connections used to transfer diaphragm shear forces shall not be used to resist diaphragm tension forces.

3. Wood elements, steel parts, and wood or steel chord splice connections shall be designed for 1.5 times the diaphragm forces associated with the shear forces induced by the design loads.

Exceptions:

1. Wood elements and wood splice connections shall be permitted to be designed for 1.5 times the diaphragm forces associated with the shear forces induced by the wind design loads.

2. Where dowel-type fasteners are used in chord splice connections and the connection is controlled by Mode III, or Mode IV fastener yielding in accordance with NDS 12.3.1, fasteners in the connection shall be permitted to be designed for 1.3 and 1.4 times the diaphragm forces associated with the shear forces induced by the prescribed seismic and wind design loads, respectively.

Diaphragm chord elements and chord splice connections using materials other than wood or steel shall be designed using provisions in NDS 1.4.
24’ x 24’ CLT Diaphragm Test with Plywood Spline Joints by AWC

Strong and Stiff Panels

Diaphragm behavior controlled by connections
4.5 Cross-Laminated Timber (CLT) Diaphragms

4.5.1 Application Requirements

CLT diaphragms shall be permitted to be used to resist lateral forces provided the deflection in the plane of the diaphragm, as determined by calculations, tests, or analogies, does not exceed the maximum permissible deflection limit of attached load distributing or resisting elements. Permissible deflection shall be that deflection that will permit the diaphragm and any attached elements to maintain their structural integrity and continue to support their prescribed loads as determined by the applicable building code or standard.

4.5.2 Deflection

CLT diaphragm deflection shall be determined using principles of engineering mechanics.

4.5.3 Unit Shear Capacity

CLT diaphragms shall be designed in accordance with principles of engineering mechanics using design values for wind moments and connections in accordance with NDS provisions.

The nominal unit shear capacity, vs., of CLT diaphragms shall be based on the nominal shear capacity for dowel-type fastener connections used to transfer diaphragm shear forces, as calculated per 4.5.4, Item 1. ASD allowable shear capacity or LRFD factored shear resistance for the CLT diaphragms and diaphragm shear connections shall be determined in accordance with 4.1.1.

4.5.4 Additional CLT Diaphragm Design Requirements

CLT diaphragms shall meet the following additional requirements:

1. The nominal shear capacity for dowel-type fastener connections used to transfer diaphragm shear forces between CLT panels and between CLT panels and diaphragm boundary elements (chords and collectors) shall be taken as 4.5Z*, where Z* is Z multiplied by all applicable NDS adjustment factors except C_D, K_F, C_L, and Z shall be controlled by Mode III or Mode IV fastener yielding in accordance with NDS 12.3.1.

2. Connections used to transfer diaphragm shear forces shall not be used to resist diaphragm tension forces.

3. Wood elements, steel parts, and wood or steel chord splice connections shall be designed for 2.9 times the diaphragm forces associated with the shear forces induced by the wind design loads.

Exceptions:

1. Wood elements and wood splice connections shall be permitted to be designed for 1.5 times the diaphragm forces associated with the shear forces induced by the wind design loads.

2. Where dowel-type fasteners are used in chord splice connections and the connection is controlled by Mode III or Mode IV fastener yielding in accordance with NDS 12.3.1, fasteners in the connection shall be permitted to be designed for 1.5 and 1.0 times the diaphragm forces associated with the shear forces induced by the prescribed seismic and wind design loads, respectively.

Diaphragm chord elements and chord splice connections using materials other than wood or steel shall be designed using provisions in NDS 1.4.

4.5.4 Additional CLT Diaphragm Design Requirements

CLT diaphragms shall meet the following additional requirements:

1. The nominal shear capacity for dowel-type fastener connections used to transfer diaphragm shear forces between CLT panels and between CLT panels and diaphragm boundary elements (chords and collectors) shall be taken as 4.5Z*, where Z* is Z multiplied by all applicable NDS adjustment factors except C_D, K_F, C_L, and Z shall be controlled by Mode III or Mode IV fastener yielding in accordance with NDS 12.3.1.
Generic CLT Floor/Roof Diaphragm

- Typical CLT Panel
- Joists not at panel edges

Legend:
- Columns
- Girders
- Joists
- CLT Panels
- Shear Walls

Lateral Load
Generic CLT Floor/Roof Diaphragm

Collector

Chord

Shear Zone

Collector

Chord

Lateral Load
Generic CLT Floor/Roof Diaphragm

**Shear Transfer Details:**
- a – panel to panel
- b – panel to panel over beam
- c – panel to wall/collector
- d – panel to wall/chord
- e – shear in panel

**Other:**
- z – chord (and splice)
- y – collector (and splice)
CLT Diaphragm Shear Transfer Connections

Lateral Load

Chord

Diaphragm Shear, v

Collector

Shear Transfer Details:
a – panel to panel
b – panel to panel over beam
c – panel to wall/collector
d – panel to wall/chord
e – shear in panel

Other:
z – chord (and splice)
y – collector (and splice)
Diaphragm shear transfer connections at CLT panel edges:
- Use dowel-type fasteners in shear (nails, screws, bolts)
- Yield Mode III or IV per NDS 12.3.1 must control capacity
Connection Yield Modes Per the NDS

- Single Shear Connections
  - Mode I_m
  - Mode I_s
  - Mode II
  - Mode III_m

- Double Shear Connections
  - Mode III_s
  - Mode IV

“m” denotes main member, “s” denotes side member
Panel to Panel Connection Styles

Top Surface Spline

Source: Simpson Strong-Tie
<table>
<thead>
<tr>
<th>SB1</th>
<th>New version of slide</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scott Breneman, 3/7/2017</td>
</tr>
</tbody>
</table>
Panel to Panel Connection Styles

Half-Lap

Source: Simpson Strong-Tie
Nominal capacity of CLT diaphragm shear transfer connection fastener:

\[ Z_n = 4.5 \, Z^* \]

Where \( Z^* \) is reference lateral capacity \( Z \) from NDS multiplied by all applicable factors except \( C_D, K_p, \phi, \lambda = 1.0 \)

Source: 2021 SDPWS 4.5.4(1) and 2018 NDS Table 11.3.1
Table 11.3.1  Applicability of Adjustment Factors for Connections

| Source 2021 SDPWS 4.5.4(1) and 2018 NDS Table 11.3.1 |

Dowel-type Fasteners (e.g. bolts, lag screws, wood screws, nails, spikes, drift bolts, & drift pins)

\[ Z^* = Z \times 1.0 \]

<table>
<thead>
<tr>
<th>1.0</th>
<th>( C_M )</th>
<th>( C_t )</th>
<th>( C_g )</th>
<th>( C_\Delta )</th>
<th>-</th>
<th>( C_{eg} )</th>
<th>-</th>
<th>1.0</th>
<th>( C_{tn} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K_F )</td>
<td>( \phi )</td>
<td>( 1.0 )</td>
<td>( 1.0 )</td>
<td>( 1.0 )</td>
<td>( 1.0 )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Also 1.0 for CLT Diaphragm Shear Transfer Connections
Other CLT Diaphragm Components

Shear Transfer Details:
- a – panel to panel
- b – panel to panel over beam
- c – panel to wall/collector
- d – panel to wall/chord
- e – shear in panel

Other:
- z – chord (and splice)
- y – collector (and splice)
4.5 Cross-Laminated Timber (CLT) Diaphragms

4.5.1 Application Requirements

CLT diaphragms shall be permitted to be used to resist lateral forces provided the deflection in the plane of the diaphragm, as determined by calculations, tests, or analogues drawn therefrom, does not exceed the maximum permissible deflection limit of attached load distributing or resisting elements. Permissible deflection shall be that deflection that will permit the diaphragm and any attached elements to maintain their structural integrity and continue to support their prescribed loads as determined by the applicable building code or standard.

4.5.2 Deflection

CLT diaphragm deflection shall be determined using principles of engineering mechanics.

4.5.3 Unit Shear Capacity

CLT diaphragms shall be designed in accordance with principles of engineering mechanics using design values for wood members and connections in accordance with NDS provisions.

The nominal unit shear capacity, \( v_u \), of CLT diaphragms shall be based on the nominal shear capacity for dowel-type fastener connections used to transfer diaphragm shear forces, as calculated per 4.5.4, Item 1, ASD allowable shear capacity or LRFD factored shear resistance for the CLT diaphragm and diaphragm shear connections shall be determined in accordance with 4.1.1.

4.5.4 Additional CLT Diaphragm Design Requirements

CLT diaphragms shall meet the following additional requirements:

1. The nominal shear capacity for dowel-type fastener connections used to transfer diaphragm shear forces between CLT panels and between CLT panels and diaphragm boundary elements (chords and collectors) shall be taken as 4.50", where \( Z' \) is \( Z \) multiplied by all applicable NDS adjustment factors except \( C_0 \), \( K_0 \), \( \phi \), and \( j \), and \( Z \) shall be controlled by Mode III or Mode IV fastener yielding in accordance with NDS 12.3.1.
2. Connections used to transfer diaphragm shear forces shall be used to resist diaphragm tensile or tensile yields.
3. Wood elements, steel parts, and wood or steel chord splice connections shall be designed for 2.0 times the diaphragm forces associated with the shear forces induced from the design loads.

Exceptions:

1. Wood elements and wood splice connections shall be permitted to be designed for 1.5 times the diaphragm forces associated with the shear forces induced by the wind design loads.
2. Where dowel-type fasteners are used in chord splice connections and the connection is controlled by Mode III or Mode IV fastener yielding in accordance with NDS 12.3.1, fasteners in the connection shall be permitted to be designed for 1.5 and 1.0 times the diaphragm forces associated with the shear forces induced by the prescribed seismic and wind design loads, respectively.
Other CLT Diaphragm Components

Amplified Diaphragm Design Forces ≤ Design Capacity

\[ \gamma \cdot \nu \leq \nu' \]

\(\nu\) = wind or seismic force demand

\(\nu'\) = Adjusted capacity calculated per the NDS

\(*See 2021 SPDWS 4.5.4 for the full information* 

\(\gamma = \)

- 2.0 for wood and steel components, except:
- 1.5 for wood members resisting wind loads
- 1.5 for chord splice connections controlled by Mode III or IV (seismic)
- 1.0 for chord splice connections controlled by Mode III or IV (wind)
Additional Resources

Available from woodworks.org

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

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

Funded By:
Questions? Ask me anything.

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Please take our survey!