CLT Floor and Roof Diaphragms for Seismic and Wind Resistance

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By Scott Breneman, PhD, PE, SE
Scott.Breneman@woodworks.org
Senior Technical Director – Mass Timber
WoodWorks – Wood Products Council
John W. Olver Design Building
At UMass Amherst

Photo Credit: Alex Schreyer
Cheney Park Apartments
CLT floor on Panelized Light Frame Walls
CLT Building Code Acceptance

2015 International Building Code
FLATWISE Panel Loading

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

*Use subscript ‘0’ in Notation*

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

*Use subscript ‘90’ in Notation*

Reference & Source: ANSI/APA PRG 320
EDGEWISE Panel Loading

Span in **MAJOR** Strength Direction

Span in **MINOR** Strength Direction

Reference & Source: ANSI/APA PRG 320
EDGEWISE Panel Loading

Span in **MAJOR** Strength Direction  Span in **MINOR** Strength Direction

*Reference & Source: ANSI/APA PRG 320*
CLT Lateral (Seismic & Wind) Design

CLT Lateral Force Resisting Systems *Not* addressed in

ASCE/SEI 7-10 or 7-16

SDPWS 2015
# CLT in In-Plane (Edgewise) Strength

## Table 3—Reference Design Values for In-Plane Shear of the Structurlam Crosslam® CLT Panels

<table>
<thead>
<tr>
<th>CLT Layup</th>
<th>CLT Panel Thickness Designation</th>
<th>Face Lamination Orientation (psi)</th>
<th>Face Lamination Orientation (lb/ft of width)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n*</td>
<td>1*</td>
<td>n*</td>
</tr>
<tr>
<td>V2M1</td>
<td>99 V</td>
<td>175°</td>
<td>235°</td>
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<tr>
<td></td>
<td>169 V</td>
<td>175°</td>
<td>235°</td>
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<tr>
<td></td>
<td>239 V</td>
<td>175°</td>
<td>235°</td>
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<tr>
<td></td>
<td>309 V</td>
<td>175°</td>
<td>235°</td>
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<tr>
<td></td>
<td>100 V</td>
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<td>290°</td>
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<tr>
<td></td>
<td>175 V</td>
<td>270°</td>
<td>260°</td>
</tr>
<tr>
<td></td>
<td>245 V</td>
<td>270°</td>
<td>290°</td>
</tr>
<tr>
<td></td>
<td>315 V</td>
<td>270°</td>
<td>290°</td>
</tr>
</tbody>
</table>

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

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

Consult with the Manufacturers for Values

Multiply by $Cd = 1.6$ for short term ASD strength

**CLT Panels can have > 9 kips / ft in-plane shear capacity**
2021 Special Design Provisions for Wind and Seismic

• Free view at AWC.org
Unit shear capacity based on dowel-type fastener connections

- Fastener Z value controlled by Mode III\textsubscript{s} or IV per NDS

- Wood elements, steel parts and chord splice connections designed for 2.0 times forces induced from design loads

Exceptions:

1) Wood elements and chord splice connections for wind (1.5 times)

2) Mode III\textsubscript{s} or IV dowels in chord splice connections (1.5 times for seismic, 1.0 times for wind)
Generic Mass Timber Floor System

Typical Panel

Gravity connection not at panel edges

Lateral Load, w
Example CLT Diaphragm Design

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

Diaphragm Shear, v
Collector
Lateral Load
Chord
Example CLT Diaphragm Design

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

Other:
- z – chord and chord splice
- y – collector and collector splice
Panel to Panel Connection Styles

Surface Spline

Half Lap

Butt Joint

Load Sharing… not load bearing
An Efficient Panel to Panel Connection

Self-Tapping Screws as “erection bolts” @ ~ 24” o.c

5 ½” to 6” plywood strip ~ ¾” or 1” Thick

Oversize rabbet cut in CLT (width of groove) 1/8” or more, each side

Nails at spacing required for shear transfer

Graphics: ASPECT Structural Engineers
Example CLT Diaphragm Design

Lateral Load

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 chord
e – shear in panel

Other
z – chord and chord splice
y – collector and collector splice
Panel to Beam Connection Styles

5/16"Øx12 5/8" ASSY 3.0 SCREWS @ 24" o.c.

CL OF BEAM

SIMPSON STRONG-TIE SDWS22800 LOG

GLULAM BEAM
Diaphragm Shear Transfer Connections

Shear Transfer Details:
- **a** – panel to panel
- **b** – panel to panel over beam
- **c** – panel to wall / collector
- **d** – panel to chord
- **e** – shear in panel
- **z** – chord and chord splice
- **y** – collector and collector splice
Diaphragm shear connections at CLT panel edges:
- Use dowel-type fasteners in shear (nails, screws, bolts)
- Yield Mode III or Mode IV per NDS 12.3.1 controls capacity
Connection Yield Modes Per the NDS

Single Shear Connections

- Mode $I_m$
- Mode $I_s$
- Mode II
- Mode $III_m$
- Mode $III_s$
- Mode IV

Double Shear Connections

CLT Diaphragm Shear Capacity

“m” denotes main member, “s” denotes side member
Nominal capacity of CLT diaphragm shear connection fastener:

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

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

SDPWS 2021 Section 4.5.4(1) and NDS Table 11.3.1
### Table 11.3.1 Applicability of Adjustment Factors for Connections

<table>
<thead>
<tr>
<th></th>
<th>ASD Only</th>
<th>ASD and LRFD</th>
<th>LRFD Only</th>
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<tbody>
<tr>
<td>Load Duration Factor</td>
<td>Wet Service Factor</td>
<td>Temperature Factor</td>
<td>Format Conversion Factor</td>
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<td>Group Action Factor</td>
<td>Geometry Factor ¹</td>
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<td></td>
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<td>Penetration Depth Factor ²</td>
<td>Time Effect Factor</td>
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<td>End Grain Factor ²</td>
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<td>Metal Side Plate Factor ³</td>
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<td>Diaphragm Factor ³</td>
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<td></td>
<td></td>
<td>Toe-Nail Factor ³</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K_f</td>
<td>φ</td>
<td></td>
</tr>
</tbody>
</table>

**Lateral Loads**

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

\[
Z^* = Z \times \begin{bmatrix} 1.0 & 1.0 & 1.0 \end{bmatrix}
\]

\[
C_M \quad C_t \quad 1.0 \quad C_A \quad - \quad C_{cg} \quad - \quad 1.0 \quad C_{tn}
\]

Also 1.0 for CLT Diaphragm Shear Connections

*SDPWS 2021 Section 4.5.4(1) and NDS Table 11.3.1*
Fastener with regular spacing, $S$, nominal unit shear connection capacity is:

$$v_n = \frac{Z_n}{S} = 4.5 \frac{Z^*}{S}$$

Required unit shear strength $\leq$ Design unit shear capacity

**ASD**

$$v = v_{ASD} \leq \frac{v_n}{RF}$$

- $RF$ = 2.8 (seismic)
- $\phi_d = 0.5$ (seismic)

**LRFD**

$$v = v_u \leq \phi_d v_n$$

- $RF$ = 2.0 (wind)
- $\phi_d$ = 0.8 (wind)
Other CLT Diaphragm Components

Diaphragm Shear, $v$

Collector

Lateral Load

Chord

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

Other
- z – chord and chord splice
- y – collector and collector splice
Amplified Diaphragm Design Forces ≤ Design Capacity

\[ \gamma \cdot v \leq v' \]

\( v \) = wind or seismic force demand
\( v' \) = Adjusted capacity calculated per the NDS
\( \gamma \) = 2.0 for wood and steel components, except:
- 1.5 wood members resisting wind loads
- 1.5 chord splice connections controlled by Mode IIIs or IV (seismic)
- 1.0 chord splices connections controlled by Mode IIIs or IV (wind)

See SDPWS 2021 Section 4.5.4 for the full information
CLT Diaphragms

Is the Diaphragm Rigid or Flexible?
12.3.1.3 Calculated Flexible Diaphragm Condition. Diaphragms not satisfying the conditions of Sections 12.3.1.1 or 12.3.1.2 are permitted to be idealized as flexible provided:

\[
\frac{\delta_{\text{MDD}}}{\Delta_{\text{ADVE}}} > 2
\]  

(12.3-1)

where \(\delta_{\text{MDD}}\) and \(\Delta_{\text{ADVE}}\) are as shown in Fig. 12.3-1. The loading used in this calculation shall be that prescribed in Section 12.8.
IBC 1604.4: A diaphragm is rigid for the purpose of distribution of story shear and torsional moment when the lateral deformation of the diaphragm is less than or equal to two times the average story drift.
CLT Diaphragm Deflection Requirements

SDPWS 2021 Section 4.5.2 Requirement:

*CLT diaphragm deflection shall be determined using principles of engineering mechanics.*
2015 White Paper on CLT Diaphragms

CROSS LAMINATED TIMBER

Horizontal Diaphragm Design Example

Our aim for this white paper is to provide a practical design method to determine the strength of a Cross Laminated Timber horizontal diaphragm and deflection due to lateral wind or seismic loads.

CLT HORIZONTAL DIAPHRAGM DESIGN

The design approach is based on compliance with engineered design of CLT in accordance with the 2015 International Building Code, reference standards, and other published information including literature.

Applicable Building Code, reference standards, and sources:

- ICC, 2015 International Building Code
- ANSI/AWC NDS-2015 National Design Specification (NDS) for Wood Construction with Commentary
- AWC SDPWS-2015 Special Design Provisions for Wind and Seismic
- ASCE 7-10 Minimum Design Loads for Buildings and Other Structures
- AISC 360-10 Specification for Structural Steel Buildings
- ICC CE Evaluation Report 55B 3110, ICC Council on Metal-Covered CLT

Kris Speichler P.E.
Heavy timber group
Structurlam Products LP
Orinda, CA
www.structurlam.com

Philip Liao, P.E.
American Wood Council
Lexington, VA
phil@awc.org
www.awc.org

Martin Polhill P.E., S.E.
Martin Polhill Structural Engineering
San Mateo, CA
mpmshill@quantummins.org

Disclaimer - This white paper

Developed in 2015, predates SDPWS 2021 design requirements

Available from structurlam.com
2015 White Paper on CLT Diaphragms

- Design example following SDPWS 2015, US CLT Handbook
- Includes Modified 4-term wood panel sheathed diaphragm equation in SDPWS 2015

\[
\delta_{dia} = \frac{5vL^3}{8EAW} + \frac{vL}{4G_v t_v} + C L e_n + \frac{\sum(x\Delta_c)}{2W}
\]

- **Chord Flexure**
- **Panel Shear**
- **Connector Slip**
- **Chord Slip**

\[
C = \frac{1}{2} \left( \frac{1}{P_L} + \frac{1}{P_W} \right)
\]

- \( P_L \) is panel length
- \( P_W \) is panel width
- \( e_n \) is connector slip at diaphragm edge
An Approach to CLT Diaphragm Modeling for Seismic Design with Application to a U.S. High-Rise Project

ABSTRACT:
A candidate cross-laminated timber (CLT) diaphragm analysis model approach is presented and evaluated as an engineering design tool motivated by the needs of seismic design in the United States. The modeling approach consists of explicitly modeling CLT panels as discrete orthotropic shell elements with connections between panels and connections from panels to structural framing modeled as two-point springs. The modeling approach has been compared to a developed CLT diaphragm design example based on U.S. standards showing the ability to obtain matching deflection results. The sensitivity of the deflection calculations to considering CLT panel-to-panel connection gap closure is investigated using a simple diaphragm example. The proposed modeling approach...
WoodWorks CLT Diaphragm Guideline with Examples

3 Examples
High and Low Seismic & Wind

Example from Holmes Structures
Thank You! Questions?

Scott Breneman
Senior Technical Director
Scott.Breneman@woodworks.org
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