Structural Design: Member Sizing, Optimized Grids, Connections and Lateral Load Resistance

March 26, 2024

Presented by Anthony Harvey and Kate Carrigg
Early Design Decisions: Priming Mass Timber Projects for Success

Presented by:
Anthony Harvey, PE
Regional Director
OH, IN, KY, MI
Structural Grid
Structural Grid

Grids & Spans

- Consider Efficient Layouts
- Repetition & Scale
- Manufacturer Panel Sizing
- Transportation
Structural Grid

Grids & Spans

- Consider Efficient Layouts
- Repetition & Scale
- Manufacturer Panel Sizing
- Transportation

24’-6” 26’-2” 24’-6” 40’-0”

14’-0”

26’-0”

26’-0”
Structural Grid

Member Sizes
- Impact of FRR on Sizing
- Impact of Sizing on Efficient Spans
- Consider connections – can drive member sizing

0 HR FRR: Consider 3-ply Panel
- Efficient Spans of 10-12 ft
- Grids of 20x20 (1 purlin) to 30x30 (2 purlins) may be efficient

Albina Yard, Portland, OR
20x20 Grid, 1 purlin per bay
3-ply CLT
Image: Lever Architecture
Structural Grid

Member Sizes
- Impact of FRR on Sizing
- Impact of Sizing on Efficient Spans
- Consider connections – can drive member sizing

0 HR FRR: Consider 3-ply Panel
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- Grids of 20x20 (1 purlin) to 30x30 (2 purlins) may be efficient

Platte Fifteen, Denver, CO
30x30 Grid, 2 purlins per bay
3-ply CLT
Image: JC Buck
Structural Grid

Member Sizes
• Impact of FRR on Sizing
• Impact of Sizing on Efficient Spans
• Consider connections – can drive member sizing

1 or 2 HR FRR: Likely 5-ply Panel
• Efficient spans of 14-17 ft
• Grids of 15x30 (no purlins) to 30x30 (1 purlin) may be efficient

First Tech Credit Union, Hillsboro, OR
12x32 Grid, One-Way Beams
5-ply (5.5”) CLT
Image: Swinerton
Structural Grid

Member Sizes
• Impact of FRR on Sizing
• Impact of Sizing on Efficient Spans
• Consider connections – can drive member sizing

1 or 2 HR FRR: Likely 5-ply Panel
• Efficient spans of 14-17 ft
• Grids of 15x30 (no purlins) to 30x30 (1 purlin) may be efficient
Key Early Design Decisions

Construction Type Early Decision Example

7-story building on health campus
• Group B occupancy, NFPA 13 sprinklers throughout
• Floor plate = 22,300 SF
• Total Building Area = 156,100 SF

MT Construction Type Options:
• If Building is < 85 ft
  • 7 stories of IV-C
  • 6 stories of IIIA or IV-HT over 1 story IA podium
• If Building is > 85 ft
  • 7 stories of IV-B
Key Early Design Decisions

Construction Type Early Decision Example

MT Construction Type Options:
• If Building is < 85 ft
  • 7 stories of IV-C
  • 6 stories of IIIA or IV-HT over 1 story IA
• If Building is > 85 ft
  • 7 stories of IV-B

Implications of construction type choice in this example:
• FRR (2 hr vs 1 hr vs min sizes)
• Efficient spans & grid
• Exposed timber limitations
• Concealed spaces
• Cost
• And more…
Key Early Design Decisions

Construction Type Early Decision Example

MT Construction Type Options:
• If Building is < 85 ft
  • **7 stories of IV-C**
  • 6 stories of IIIA or IV-HT over 1 story IA
• If Building is > 85 ft
  • 7 stories of IV-B

Implications of Type IV-C:
• 2 hr FRR, all exposed floor panels, beams, columns
• Likely will need at least 5-ply CLT / 2x6 NLT/DLT
• Efficient spans in the 14-17 ft range
• Efficient grids of that or multiples of that (i.e. 30x25, etc)
• No podium required
Key Early Design Decisions

Construction Type Early Decision Example

MT Construction Type Options:
• If Building is < 85 ft
  • 7 stories of IV-C
  • **6 stories of IIIA or IV-HT over 1 story IA**
• If Building is > 85 ft
  • 7 stories of IV-B

Implications of Type IIIA or IV-HT:
• 1 hr FRR or min. sizes
• Potential to use 3-ply or thin 5-ply CLT
• Efficient spans in the 10-12 ft range
• Efficient grids of that or multiples of that (i.e. 20x25, etc)
• 1 story Type IA podium required
Key Early Design Decisions

Construction Type Early Decision Example

MT Construction Type Options:
• If Building is < 85 ft
  • 7 stories of IV-C
  • 6 stories of IIIA or IV-HT over 1 story IA
• If Building is > 85 ft
  • 7 stories of IV-B

Implications of Type IV-B:
• 2 hr FRR, mostly protected floor panels, beams, columns
• Exposed areas: likely 5-ply / 2x6 NLT/DLT
• Protected areas: potential for thinner panels
• Choose 1 system throughout or multiple systems?
• Does grid vary or consistent throughout?
• No podium required
Key Early Design Decisions

Why so much focus on panel thickness?
Key Early Design Decisions

Typical MT Package Costs

- Project Overhead: 7%
- Labor: 15%
- Material: 64%
- Equipment: 14%

Source: Swinerton
Panels are the biggest part of the biggest piece of the cost pie
Key Early Design Decisions

Panel volume usually 65-80% of MT package volume

Type IIIA option 1
1-hr FRR
Purlin: 5.5”x28.5”
Girder: 8.75”x33”
Column: 10.5”x10.75”
Floor panel: 5-ply

Glulam volume = 118 CF (22% of MT)
CLT volume = 430 CF (78% of MT)
Total volume = 0.73 CF / SF

Source: Fast + Epp, Timber Bay Design Tool
Key Early Design Decisions

Panel volume usually 65-80% of MT package volume

Type IIIA option 2
1-hr FRR
Purlin: 5.5”x24”
Girder: 8.75”x33”
Column: 10.5”x10.75”
Floor panel: 5-ply

Glulam volume = 123 CF (22% of MT)
CLT volume = 430 CF (78% of MT)
Total volume = 0.74 CF / SF

Cost considerations: One additional beam (one additional erection pick), 2 more connections
Key Early Design Decisions

Panel volume usually 65-80% of MT package volume

Type IV-HT
0-hr FRR (min sizes per IBC)
Purlin: 5.5”x24” (IBC min = 5”x10.5”)
Girder: 8.75”x33” (IBC min = 5”x10.5”)
Column: 10.5”x10.75” (IBC min = 6.75”x8.25”)
Floor panel: 3-ply (IBC min = 4” CLT)

Glulam volume = 120 CF (32% of MT)
CLT volume = 258 CF (68% of MT)
Total volume = 0.51 CF / SF

Source: Fast + Epp, Timber Bay Design Tool
Key Early Design Decisions

Panel volume usually 65-80% of MT package volume

Type IV-HT

0-hr FRR (min sizes per IBC)
- Purlin: 5.5”x24” (IBC min = 5”x10.5”)
- Girder: 8.75”x33” (IBC min = 5”x10.5”)
- Column: 10.5”x10.75” (IBC min = 6.75”x8.25”)
- Floor panel: 3-ply (IBC min = 4” CLT)

Glulam volume = 120 CF (32% of MT)
CLT volume = 258 CF (68% of MT)
Total volume = 0.51 CF / SF

Note that if size of building had permitted Type IIIB, member sizing would essentially be the same as IV-HT. But there are other nuances between III and IV, we’ll cover that later…

Source: Fast + Epp, Timber Bay Design Tool
Key Early Design Decisions

Panel volume usually 65-80% of MT package volume

Type IV-C
2-hr FRR
Purlin: 8.75”x28.5”
Girder: 10.75”x33”
Column: 13.5”x21.5”
Floor panel: 5-ply

Glulam volume = 183 CF (30% of MT)
CLT volume = 430 CF (70% of MT)
Total volume = 0.82 CF / SF

Source: Fast + Epp, Timber Bay Design Tool
Key Early Design Decisions

Which is the most efficient option?

A general rule of thumb for efficient mass timber fiber volume is no higher than 0.75 CF per SF. Ratios in the 0.85 to 1.0 CF / SF range tend to become cost prohibitive.
Key Early Design Decisions

Which is the most efficient option?

<table>
<thead>
<tr>
<th></th>
<th>Timber Volume Ratio</th>
<th>Podium on 1st Floor?</th>
</tr>
</thead>
<tbody>
<tr>
<td>IIIA – Option 1</td>
<td>0.73 CF / SF</td>
<td>Yes</td>
</tr>
<tr>
<td>IV-CH</td>
<td>0.82 CF / SF</td>
<td>No</td>
</tr>
</tbody>
</table>

There are other impacts of constriction type selection (exterior walls, concealed spaces) that should be considered.

A general rule of thumb for efficient mass timber fiber volume is no higher than 0.75 CF per SF. Ratios in the 0.85 to 1.0 CF / SF range tend to become cost prohibitive.
Key Early Design Decisions

NEW MASS TIMBER FLOOR VIBRATION DESIGN GUIDE

worked office, lab and residential Examples

Covers simple and complex methods for bearing wall and frame supported floor systems
Key Early Design Decisions

Many ways to demonstrate connection fire protection: calculations, prescriptive NC, test results, others as approved by AHJ
Key Early Design Decisions

Steel hangers/hardware fully concealed within a timber-to-timber connection is a common method of fire protection
Key Early Design Decisions

Connection FRR and beam reactions could impact required beam/column sizes

Photos: Simpson Strong-Tie

Photo: LEVER Architecture
Key Early Design Decisions

2017 Glulam Beam to Column Connection Fire Tests under standard ASTM E119 time-temperature exposure
# Key Early Design Decisions

## Fire Test Results

<table>
<thead>
<tr>
<th>Test</th>
<th>Beam</th>
<th>Connector</th>
<th>Applied Load</th>
<th>FRR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.75” x 18”</td>
<td>1 x Ricon S VS 290x80</td>
<td>3,905lbs (17.4kN)</td>
<td>1hr</td>
</tr>
<tr>
<td></td>
<td>(222mm x 457mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>10.75” x 24”</td>
<td>Staggered double Ricon S VS 200x80</td>
<td>16,620lbs (73.9kN)</td>
<td>1.5hrs</td>
</tr>
<tr>
<td></td>
<td>(273mm x 610mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>10.75” x 24”</td>
<td>1 x Megant 430</td>
<td>16,620lbs (73.9kN)</td>
<td>1.5hrs</td>
</tr>
<tr>
<td></td>
<td>(273mm x 610mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Key Early Design Decisions

Softwood Lumber Board
Glulam Connection Fire Test
Summary Report

Issue | June 5, 2017

Full Report Available at:
Key Early Design Decisions

Member to member bearing also commonly used, can avoid some/all steel hardware at connection
Key Early Design Decisions

Member to member bearing also commonly used, can avoid some/all steel hardware at connection

Style of connection also impacts and is impacted by grid layout and MEP integration
Key Early Design Decisions

MASS TIMBER CONNECTIONS INDEX

A library of commonly used mass timber connections with designer notes and information on fire resistance, relative cost and load-carrying capacity.
Connections

Other connection design considerations:
• Structural capacity
• Shrinkage
• Constructability
• Aesthetics
• Cost
Lateral Systems
Lateral Systems

Prescriptive Code Compliance:

- Light Frame Wood Shear Walls (65 ft max)
- Concrete Shear Walls
- Steel Braced Frames
- CLT Shear Walls (65 ft max) – Per 2021 SDPWS/ASCE 7-22
- **CLT Rocking Walls**

Currently in development!
Mass Timber Post Tension Rocking Shear Wall Tests

Source: S. PEI et al. http://nheritallwood.mines.edu/
CLT Shear Wall and Diaphragm Design with SDPWS 2021

Presented by:
Kate Carrigg, PE
Regional Director (OR, ID-So, HI)

Photo credit: KPFF / Reid Zimmerman
Cross-Laminated Timber (CLT)
Solid sawn laminations

Cross-Laminated Timber (CLT)
SCL laminations

Photo: LendLease

Photo: Freres Lumber

Photo: LendLease

Photo: LEVER Architecture
CLT in the U.S. Building Code – IBC 2018

Now with test methods for in-plane shear capacities!

ANSI/APA PRG 320 2017

AWC NDS 2018

2018 International Building Code

General improvements
### TABLE A2

**ASD Reference Design Values** for Basic CLT Grades and Layups (for use in the U.S.)

<table>
<thead>
<tr>
<th>CLT Grade</th>
<th>Lamination Thickness (in.) in CLT Layup</th>
<th>Major Strength Direction</th>
<th>Minor Strength Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>4 1/8 1 3/8 1 3/8 1 3/8</td>
<td>[F_s]_{major} (lbft/ft of width)</td>
<td>[E_l]_{major} (10^3 lb/in.²/ft of width)</td>
</tr>
<tr>
<td>E2</td>
<td>6 7/8 1 3/8 1 3/8 1 3/8</td>
<td>10,400</td>
<td>440</td>
</tr>
<tr>
<td>E3</td>
<td>9 5/8 1 3/8 1 3/8 1 3/8</td>
<td>18,870</td>
<td>1,089</td>
</tr>
<tr>
<td>E4</td>
<td>6 7/8 1 3/8 1 3/8 1 3/8</td>
<td>8,820</td>
<td>389</td>
</tr>
<tr>
<td>E5</td>
<td>9 5/8 1 3/8 1 3/8 1 3/8</td>
<td>15,600</td>
<td>963</td>
</tr>
</tbody>
</table>

Notes:
- CLT Grade (basic)
- Layup
- Panel Properties

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PRG 320 Defined Layups

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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*
3rd Party Product Qualification of CLT
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
CLT in the U.S. Building Code – Lateral in IBC 2021

New Requirements for CLT Lateral Systems!
(but R values for CLT Shear Walls are not in ASCE 7-16)
CLT in the U.S. Building Code – Lateral in the IBC 2024?

Future Full Recognition of CLT Lateral Systems

AWC SDPWS 2021 → ASCE/SEI 7-22 → Future Code

Now with Platform Framed CLT Shear Walls

2024 International Building Code (In Process)
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

View for free at awc.org

PowerPoint IS NOT the CODE!
Top Changes Relevant to CLT Lateral Systems:

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

View for free at awc.org

PowerPoint IS NOT the CODE!
2021 SDPWS – Unified Nominal Shear Capacity

For sheathed wood frame shear walls and diaphragms, SDPWS 2015 has two nominal shear capacities

\[ \nu_s \] Nominal shear capacity for seismic loads

\[ \nu_w \] Nominal shear capacity for wind loads

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

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

<table>
<thead>
<tr>
<th>Design shear capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ASD</strong></td>
</tr>
<tr>
<td>Wind</td>
</tr>
<tr>
<td>Seismic</td>
</tr>
</tbody>
</table>

SDPWS 2021 Section 4.1.4
Top Changes Relevant to CLT Lateral Systems:

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

View for free at awc.org

**PowerPoint IS NOT the CODE!**
CLT Shear Walls in SDPWS 2021

CLT Shear Walls not meeting Appendix B
- SDC A or SDC B
- and ≤ 65’ tall
- in SDPWS 4.6.3 Exception

CLT Shear Walls meeting SDPWS 2021 Appendix B
- Panel aspect ratios
  - $2 \leq h/b_s \leq 4$
- Panel aspect ratios
  - $h/b_s = 4$

(SDPWS B.3.7)
CLT Shear Walls in SDPWS 2021

Platform Framed CLT Construction

SDPWS 2021 Section 4.1.4
CLT Shear Walls in SDPWS 2021

Platform Framed CLT Construction

Section View

Elevation View
CLT Shear Walls in SDPWS 2021

Platform Framed CLT Construction

Section View

Elevation View

CLT Floor

CLT Wall

Floor or Roof Above Wall

Floor or Foundation Below Wall

applied load $\nu_\ell$
CLT Shear Walls in SDPWS 2021

Platform Framed CLT Construction

applied load $\nu_u$
Panel to Panel Connections

(8) 16d Box nails

Panel to Platform Connection

(2) 5/8” bolts or lag screws

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

Same steel plate and nails plus
5/8” Ø bolts or lag screws to roof, floor or foundation
Nominal shear capacity of connector:

\[ \nu_n = 2605 \ C_G \ [\text{lbs}] \text{ per angle connector} \]

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

\( C_G = 1.0 \) \quad \text{for } G \geq 0.42

\( = 0.86 \) \quad \text{for } G = 0.35

\( = 1.0 - 2(0.42-G) \) \quad \text{for } 0.42 > G > 0.35

Nominal unit shear capacity:

\[ \nu_n = n \left( 2605 / b_s \right) C_G \ [\text{lbs/ft}] \]
What R-Values can I use?
R Values for CLT Shear Walls in SDPWS 2021

(other)

CLT Shear Walls not meeting Appendix B

CLT Shear Walls meeting SDPWS 2021 Appendix B

Panel aspect ratios

\[ 2 \leq \frac{h}{b_s} \leq 4 \]

\[ \frac{h}{b_s} = 4 \]

\( R = 3.0^* \)

\( C_d = 3.0 \quad \Omega_o = 3.0 \)

\( R = 4.0^* \)

\( C_d = 4.0 \quad \Omega_o = 3.0 \)

* ASCE 7-22
State of Oregon Statewide Alternative

Cross-laminated timber
Seismic force-resisting systems

Statewide Alternate Methods are approved by the division administrator in consultation with the appropriate advisory board. The advisory board’s review includes technical and scientific facts of the proposed alternate method. In addition:

- Building officials shall approve the use of any material, design or method of construction addressed in a statewide alternate method;
- The decision to use a statewide alternate method is at the discretion of the applicant; and
- Statewide alternate methods do not limit the authority of the building official to consider other proposed alternate methods encompassing the same subject matter.

Code/edition/section: 2022 Oregon Structural Specialty Code (OSSC) — Section 1613
American Society of Civil Engineers (ASCE) 7-2016 or ASCE 7-2022

Date:
Issued—Jan. 15, 2015
Updated—Feb. 2, 2023

Subject: Cross-laminated timber (CLT)—Seismic force-resisting system

Background:

Cross-laminated timber (CLT) is a wood product with both residential and nonresidential applications. CLT is defined and recognized as a viable construction material subject to specific construction requirements within Chapters 2, 5, 6, 7, 17 and 23 of the 2022 OSSC. Building Codes Division has prepared this statewide alternate method to recognize CLT shear walls as a seismic force-resisting system (SFRS) for the application of ASCE 7-16 or ASCE 7-22, Minimum Design Loads and Associated Criteria for Buildings and Other Structures, Section 12.2, utilizing prescriptive design procedures.

Structures exceeding the prescriptive design procedures contained in this statewide alternate method will need to follow the performance-based procedures as outlined in OSSC Section 104.10 and ASCE 7-16 Section 1.3.1.3.

Discussion:

ASCE 7-16 is the standard referenced in OSSC Section 1613 for the development of seismic design loads and associated criteria for structures. ASCE 7-16 Chapter 12 establishes seismic design coefficients and factors for design of CLT shear walls.
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

View for free at awc.org

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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 deflections in the plane of the diaphragm, as determined by calculations, tests, or analogies drawn therefrom, do 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 the 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, $v$, 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 columns) shall be taken as $4.5Z^*$, where $Z^*$ is $Z$ multiplied by all applicable NDS adjustment factors except $C_b$, $K_0$, $q$, and $l$ and $Z$ shall be controlled by Mode IIF 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 2.0 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 1.5 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.
CLT Diaphragm Design Resource

CLT Diaphragm Design Guide

Based on SDPWS 2021

Free at woodworks.org
24’ x 24’ CLT Diaphragm Test with Plywood Spline 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 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.

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

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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.

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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 \( C_D \), \( K_F \), \( \phi \), and \( \lambda \); and Z shall be controlled by Mode III or Mode IV fastener yielding in accordance with NDS 12.3.1.
CLT Diaphragm Shear Connections

- 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

“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 \( C_D, K_F, \varphi, \lambda = 1.0 \)

*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>Loading Factor</th>
<th>ASD Only</th>
<th>ASD and LRFD</th>
<th>LRFD Only</th>
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<tbody>
<tr>
<td>Load Duration Factor 1</td>
<td></td>
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<td></td>
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<tr>
<td>Wet Service Factor</td>
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<td></td>
<td></td>
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<tr>
<td>Temperature Factor</td>
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<tr>
<td>Group Action Factor</td>
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<td></td>
<td></td>
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<tr>
<td>Geometry Factor</td>
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<td>Prefabrication Factor</td>
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<td>End Grain Factor</td>
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<td>Metal Side Plate Factor</td>
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<td>Diaphragm Factor</td>
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<td>Toe-Nail Factor</td>
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</table>
| Dowel-type Fasteners (e.g. bolts, lag screws, nails, spikes, drift bolts, & drift pins) | \[Z^* = Z \times 1.0\] | \[\begin{array}{cccccc}
C_M & C_t & C_g & C_{\Delta} & - & C_{eg} \\
\end{array}\] | 1.0 |

Also 1.0 for CLT Diaphragm Shear Connections

*SDPWS 2021 Section 4.5.4(1) and NDS Table 11.3.1*
To calculate the ASD or LRFD shear capacity, SDPWS 2021 has different reduction factors for wind and seismic events.

<table>
<thead>
<tr>
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<th>Design shear capacity</th>
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<tbody>
<tr>
<td>ASD</td>
<td>LRFD</td>
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<tr>
<td>Wind</td>
<td>$v_n/2.0$</td>
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<tr>
<td>Seismic</td>
<td>$v_n/2.8$</td>
</tr>
</tbody>
</table>

ASD seismic design capacity:

$$4.5 \, Z^* \div 2.8 = 1.61 \, Z^* \approx C_D \, Z = 1.6 \, Z$$
Other Diaphragm Components

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. The 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 $4.5Z_{a}$, where $Z_{a}$ is $Z$ multiplied by all applicable NDS factors.

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, the fastener 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

1/8" gap, typical

CLT panel typical

Plywood or LVL spline in oversized recess

1/16" gap

Section view

Maintain required edge distances

Installation options for fasteners

Threads only in beam

Screws through pre-drilled holes

a) Over wood beam

b) Over steel beam

c) Over wood stud wall
Other CLT Diaphragm Components

Increased Diaphragm Design Forces ≤ Design Capacity

\[ \gamma_D \cdot \nu \leq \nu' \]

\( \nu = \text{wind or seismic force demand} \)

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

\( \gamma_D = \text{2.0 for wood and steel components, except:} \)

1.5 wood members resisting wind loads
1.5 chord splice connections controlled by Mode III or IV (seismic)
1.0 chord splice connections controlled by Mode III or IV (wind)

See SDPWS 2021 Section 4.5.4 for the full information
CLT Diaphragm Design Resource

CLT Diaphragm Design Guide

Based on SDPWS 2021

- Detailing for performance and constructability
- Combination SDPWS $\gamma_D$ and ACSE 7 $\Omega_o$ and $\rho$
- Precalculated connection capacities
- Determination of diaphragm flexibility
- Calculation of diaphragm deflections

Free at woodworks.org
CLT Diaphragms

Is the Diaphragm Rigid or Flexible?
Questions? Ask us anything.

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