Holmes

Application 2021 SDPWS Provisions

Presented by Eric McDonnell
19th May 2023

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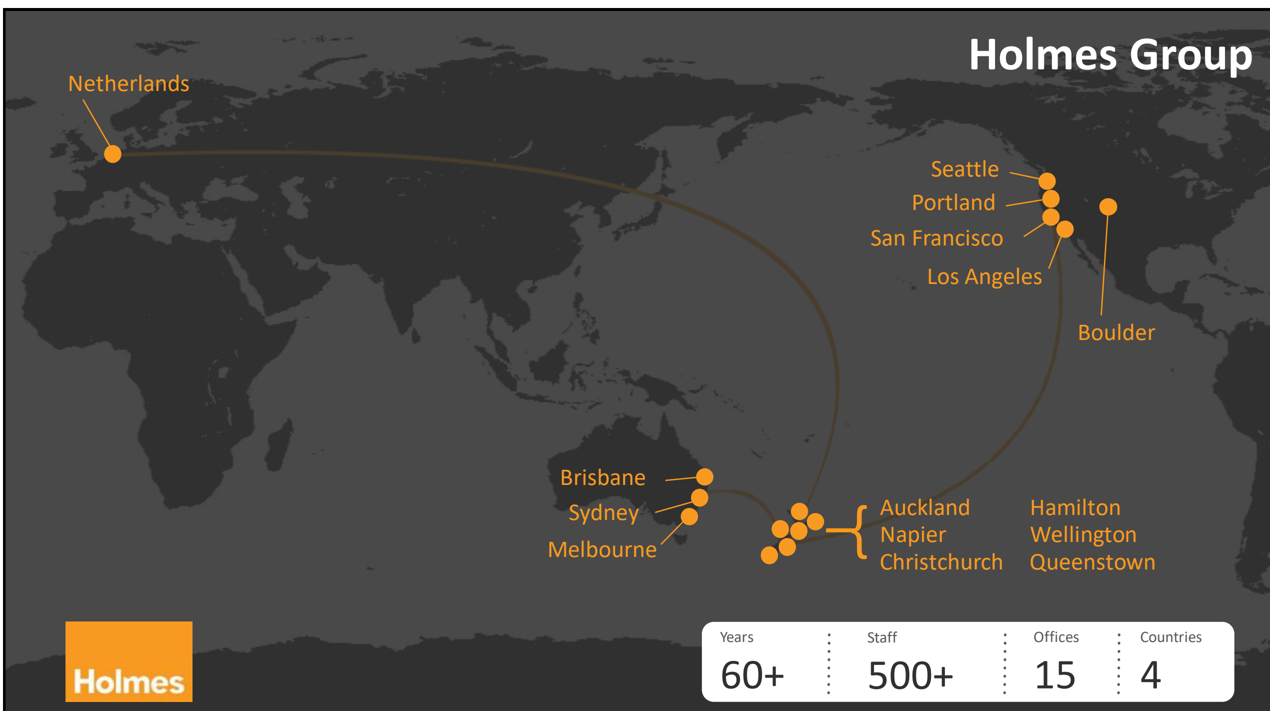

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CLT DIAPHRAGMS

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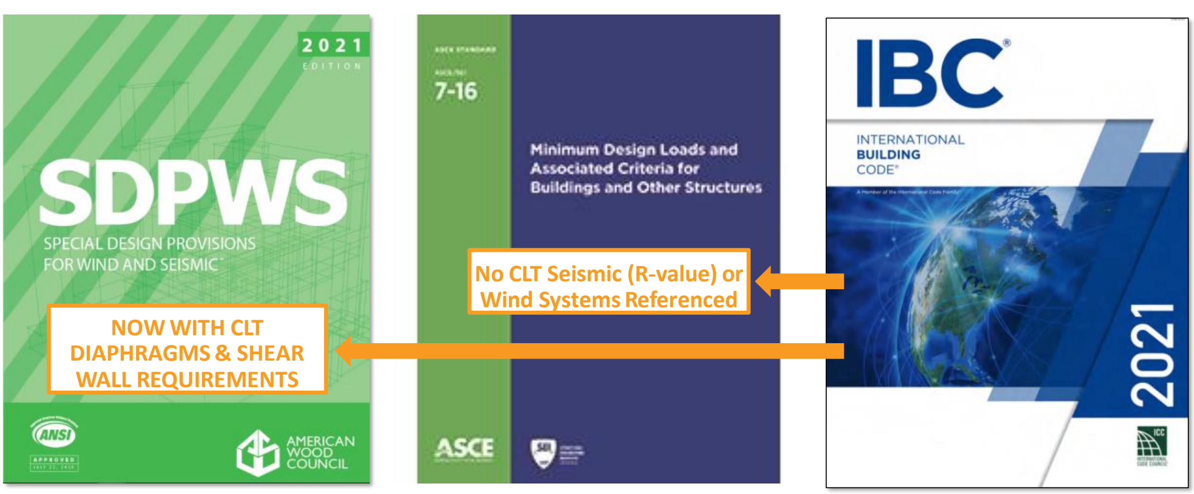
2021
EDITION
SDPWS
SPECIAL DESIGN PROVISIONS FOR WIND AND SEISMIC
NOW WITH CLT DIAPHRAGMS & SHEAR WALL REQUIREMENTS
AMERICAN WOOD COUNCIL
7-16
Minimum Design Loads and Associated Criteria for Buildings and Other Structures
No CLT Seismic (R-value) or Wind Systems Referenced
ASCE
IBC
INTERNATIONAL BUILDING CODE
2021

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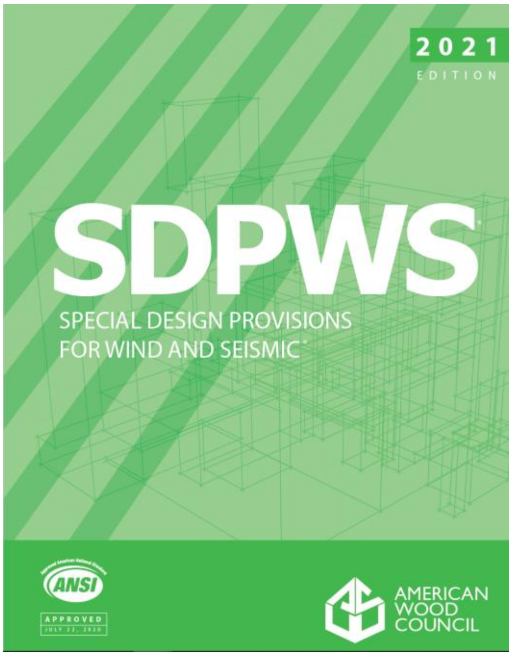

4.5 Cross-Laminated Timber (CLT) Diaphragms

4.5.1 Application Requirements

CLT diaphragms shall be permitted to be used to resist lateral forces provided the 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_n, 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 4.5Z*, where Z* is Z multiplied by all applicable NDS adjustment factors except C_D, K_F, ϕ, and λ; and Z shall be controlled by Mode III$_s$ 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 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$_s$ 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.

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4.5 Cross-Laminated Timber (CLT) Diaphragms

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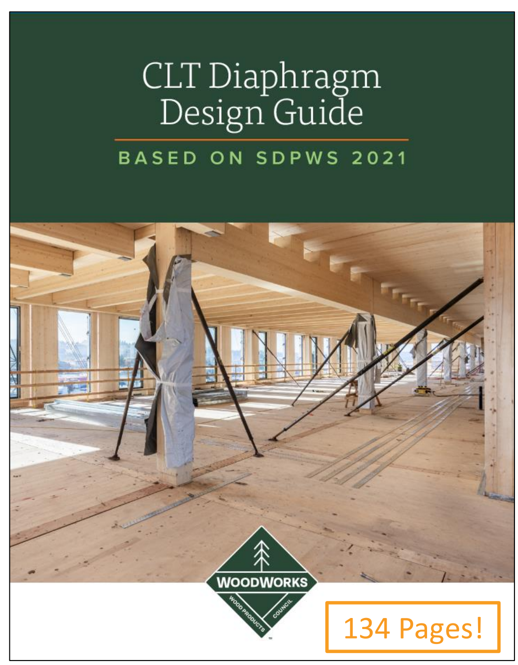

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Organization

- Introduction
- Codes and Standards
- Methodology of CLT Diaphragm Design
- Diaphragm Shear Components
- Diaphragm Boundary Elements
- Diaphragm Deflections & Stiffness
- Special Design Considerations
- Design Examples (3 in total)
- References
- Appendix A – Precalculated Design Capacities
- Appendix B – Literature Review

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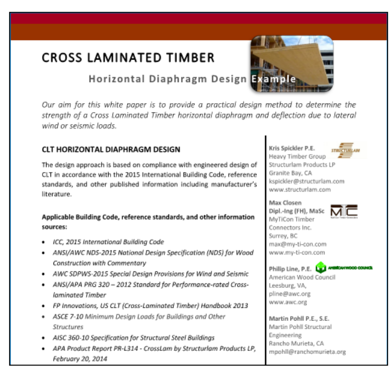
1 Introduction

- Introduction
  - Overview
  - Purpose of the Design Guide
  - State of Practice prior to 2021 SDPWS



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 manufacturer's literature.

Applicable Building Code, reference standards, and other information 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*
- *ANSI/APA PRG 320 – 2012 Standard for Performance-rated Cross-laminated Timber*
- *FP Innovations, US CLT (Cross-Laminated Timber) Handbook 2013*
- *ASCE 7-10 Minimum Design Loads for Buildings and Other Structures*
- *AISC 360-10 Specification for Structural Steel Buildings*
- *APA Product Report PR-L314 - CrossLam by Structurlam Products LP, February 20, 2014*

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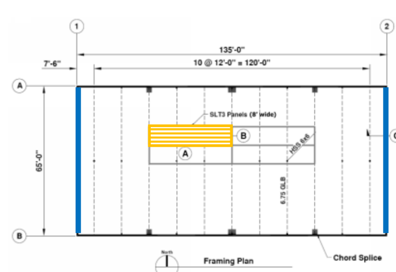

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2 Codes and Standards

- **Basis of Design**
  - 2021 IBC
  - 2019 ANSI/APA PRG 320
  - 2018 NDS
  - 2016 ASCE 7
  - 2021 SWDPWS
    - Nominal Unit Shear Capacity
    - Calculated Method to Justify Rigid Diaphragm Analysis of Cantilevered Diaphragms
    - CLT Diaphragm Provisions

TABLE 2.1: SDPWS 2021 design capacities

Loading	ASD Design Capacity v_n/Ω_D	LRFD Design Capacity $\phi_D v_n$
Seismic	$v_n/2.8$	$0.50\ v_n$
Wind	$v_n/2.0$	$0.80\ v_n$

Where $\emptyset_D$ is the LRFD diaphragm resistant factor

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3 Methodology of CLT Diaphragm Design

- **Components of a CLT Diaphragm**

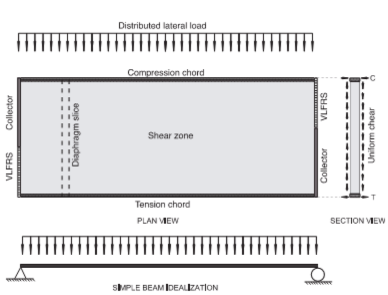

FIGURE 3.1: Diaphragm idealization for design

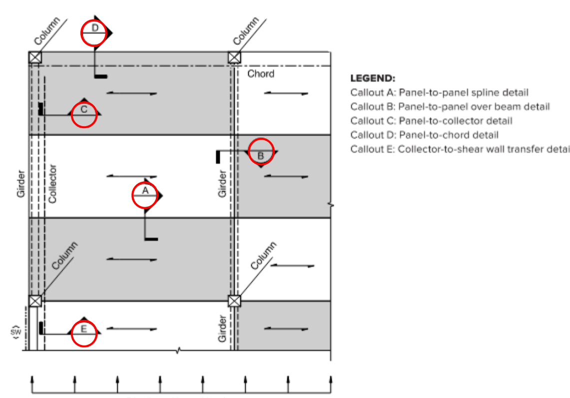

FIGURE 3.2: Example partial plan for CLT diaphragm

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- **Philosophies of CLT Diaphragm Design**
  - Capacity-based design
  - Elastic diaphragm design
  - Force amplification design = 2021 SDPWS CLT Provisions

AWC: 24'x24' CLT Diaphragm Test with Plywood Spline

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- **Diaphragm Design Forces per ASCE 7-16**

$$F_{design} = max\,(F_{px}, F_x) + \Omega_0 * F_{x,transfer}$$

- **CLT Diaphragm Design Provisions per SDPWS**

§4.5.1 – Applicable 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
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- **CLT Diaphragm Design Provisions per SDPWS**
  - Yielding diaphragm components (i.e. shear dowels) are design to the diaphragm design forces **AND** must be controlled by yield modes IIIs or IV.

    $\frac{v_n}{\Omega_D} \geq F_{design,ASD}$ -OR- $\phi_D v_n \geq F_{design,LRFD}$

  - Remaining components are designed to include a force increase factor, γ_D, where R'_{NDS} = adjusted design capacity.

    $R'_{NDS} \geq \gamma_D\ F_{design,ASD}$ -OR- $R'_{NDS} \geq \gamma_D\ F_{design,LRFD}$

    - Combining with ASCE 7-16:

      $\gamma_D\, F_{design} = \gamma_D\, max(F_{px}, F_x) + \gamma_D\ \Omega_0\ F_{x,transfer}$

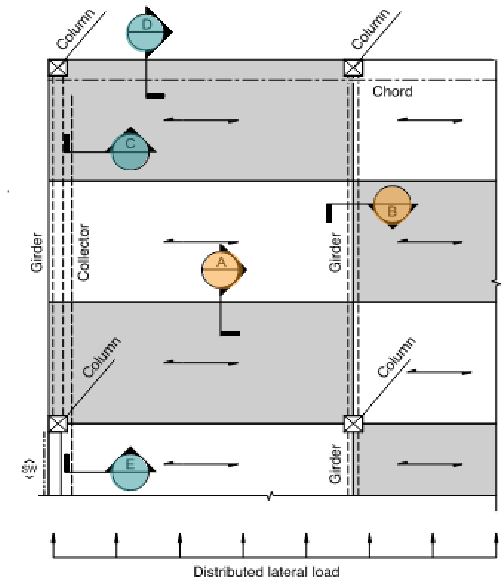

FIGURE 3.2: Example partial plan for CLT diaphragm

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- **CLT Diaphragm Design Provisions per SDPWS (continued)**

§4.5.4 – Additional CLT Diaphragm Design Requirements (Item 1)

CLT diaphragms shall meet the following additional requirements:

§4.5.4, Item 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, ϕ, and λ; and Z shall be controlled by Mode III_s or Mode IV fastener yielding in accordance with NDS §12.3.1 .*

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For Seismic 4.5/2.8 = 1.6!

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- **CLT Diaphragm Design Provisions per SDPWS (continued)**

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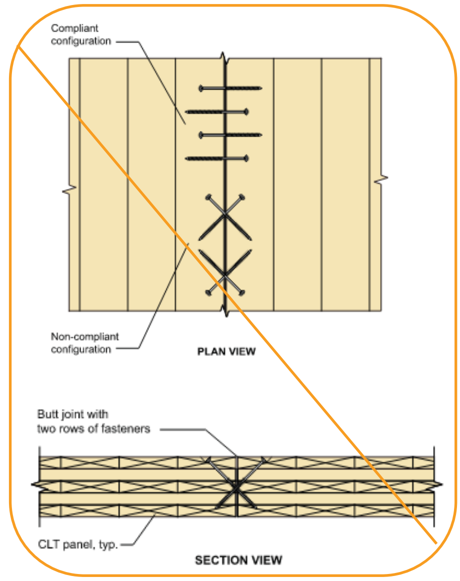
§4.5.4 – Additional CLT Diaphragm Design Requirements (Item 2)
§4.5.4, Item 2. *Connections used to transfer diaphragm shear forces shall not be used to resist diaphragm tension forces.*



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- **CLT Diaphragm Design Provisions per SDPWS (continued)**

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§4.5.4 – Additional CLT Diaphragm Design Requirements (Item 3)
§4.5.4, Item 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_s 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.

TABLE 3.1: Summary of diaphragm force increase factors per SDPWS §4.5.4 Item 3

Component		γ_D EQ	γ_D Wind	Design Guide Eq. No.
Diaphragm shear connections at CLT panel edges	Dowel-type fasteners in shear in panel-to-panel and panel-to-boundary element diaphragm shear connections	N/A[a]	N/A[a]	3.2 or 3.3
Chord splice connections	Dowel-type fasteners in shear in wood chord splice connections controlled by Mode III_s or Mode IV	1.5[b]	1.5[b]	3.4 or 3.5
	Others	2.0	2.0	
Wood elements and connections to wood not meeting the above	Includes CLT panels, wood sheathing used for splines, wood framing used as chords and collectors	2.0	1.5	
Steel elements and connections between steel elements	Includes steel framing, plates and rods used as chords or collectors and steel splines	2.0	2.0	

[a] Fasteners required to be controlled by Mode III_s or Mode IV per SDPWS §4.5.4 Item 1.
[b] Increase factors for fasteners controlled by Mode III_s or Mode IV per Exception 2 of SDPWS §4.5.4 Item 3.

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- **CLT Diaphragm Design Provisions per SDPWS (continued)**
  - Workflow of CLT Diaphragm Design
  - Amplification of Seismic Design Forces per ASCE 7-16, Chapter 12
    - Increase collector demands by 25% for certain irregularities in Seismic Design Categories D, E & F.
    - Amplify by Ωo, for at discontinuities in vertical lateral system.

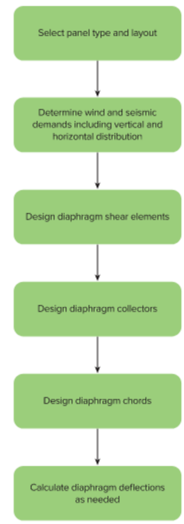

FIGURE 3.5: Generalized workflow for wind and seismic design of CLT diaphragms

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4 Diaphragm Shear Components

- **Analysis and Design for In-plane Actions**

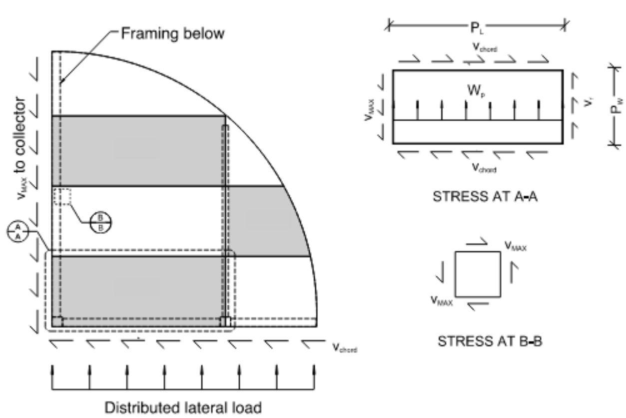

FIGURE 4.1: Free body diagram of corner CLT panel

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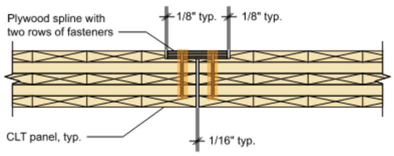
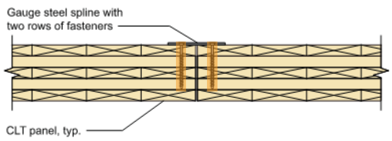
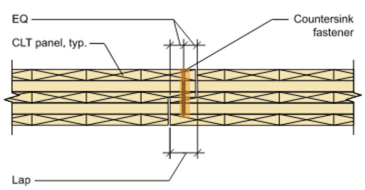
- **Panel-to-Panel Connections**



TYPICAL SPLINE CONNECTION



TYPICAL SURFACE GAUGE STEEL CONNECTION



TYPICAL HALF LAP CONNECTION

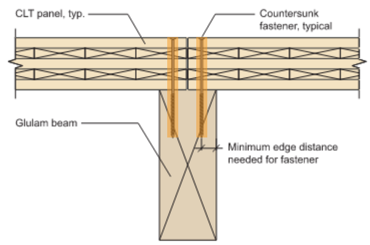


FIGURE 4.6: Example of panel-to-panel over beam connection

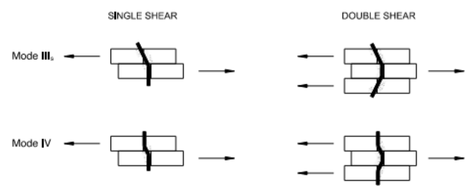


FIGURE 4.2: NDS fastener Modes III$_s$ and IV

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- **CLT Panel Design**

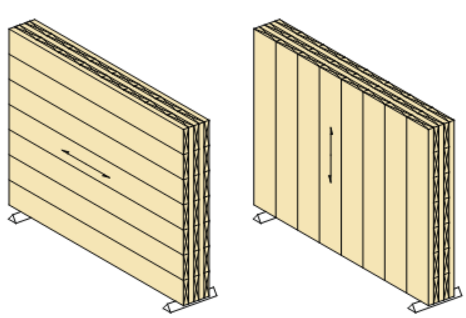

FIGURE 4.3: Edgewise bending in the major (left) and minor (right) CLT strength directions

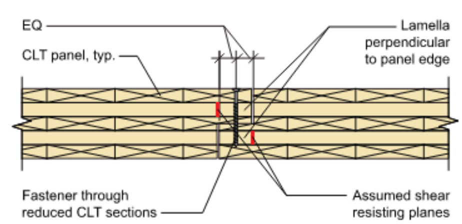

FIGURE 4.4: Typical half-lap connection

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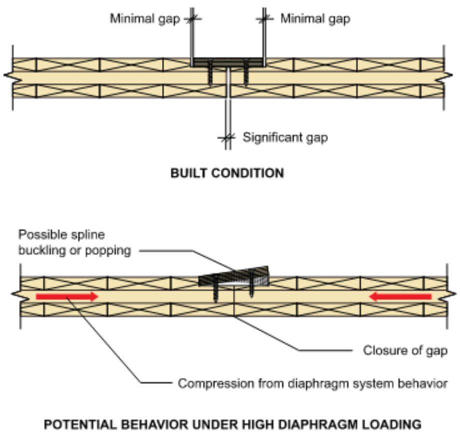
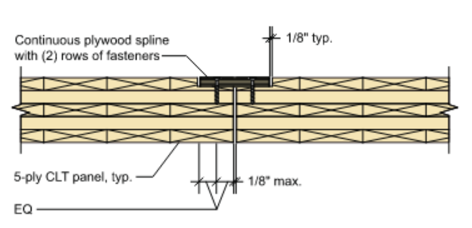
- **Detailing Considerations**





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5 Diaphragm Boundary Elements

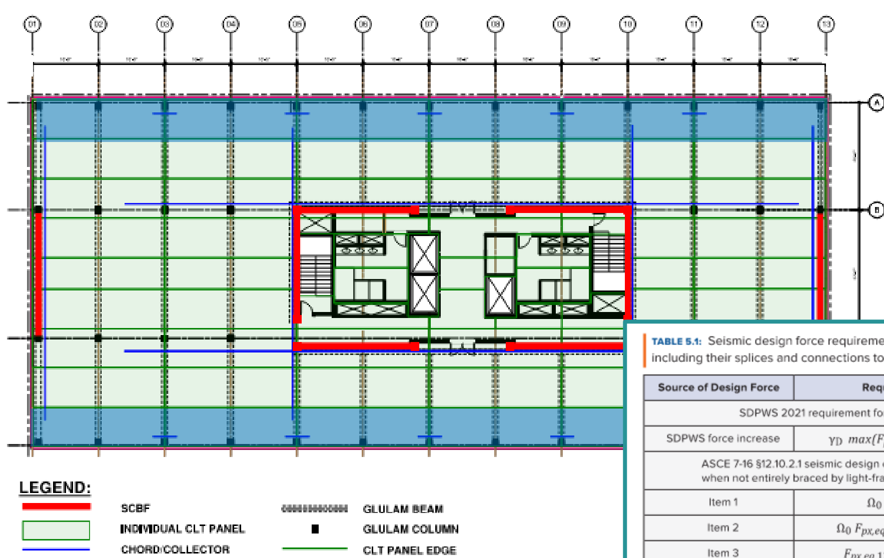

TABLE 5.1: Seismic design force requirements for collectors, including their splices and connections to the VLFRS

Source of Design Force	Required Design Force
SDPWS 2021 requirement for all collectors	
SDPWS force increase	$\gamma_D \ max(F_{px}, F_x) + \gamma_D \ \Omega_0 \ F_{x,transfer}$
ASCE 7-16 §12.10.2.1 seismic design category C through F, when not entirely braced by light-frame wood shear walls	
Item 1	$\Omega_0 \ F_x + \Omega_0 \ F_{x,transfer}$
Item 2	$\Omega_0 \ F_{px,eq\ 12.10-1} + \Omega_0 \ F_{x,transfer}$
Item 3	$F_{px,eq\ 12.10-2} + \Omega_0 \ F_{x,transfer}$

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- **Compression Load Path**

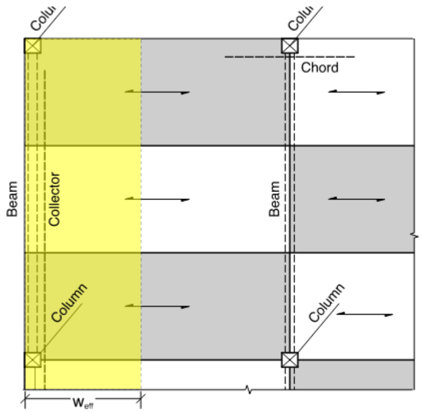

FIGURE 5.5: Effective width in compression – continuous bearing

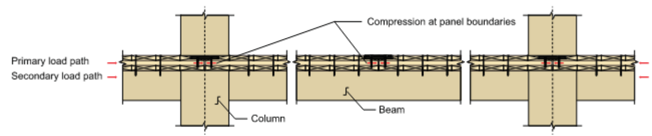

FIGURE 5.4: Compression diagram

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- **Compression Load Path**

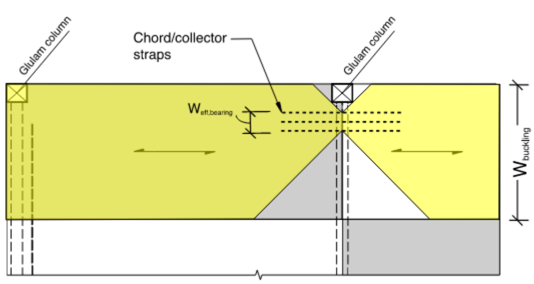

FIGURE 5.6: Effective width in compression – discrete bearing

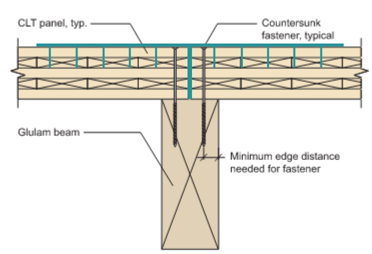

FIGURE 4.6: Example of panel-to-panel over beam connection

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- **Gravity Framing as Lateral Element**
  - If gravity element is intended to serve as lateral element need to check for combined loading
    - Compression buckling of gravity member, in isolation or combination with CLT panel
    - Tension in gravity member, INCLUDING across beam-to-column connection
  - For all timber framed buildings additional checks include:
    - Transfer of diaphragm forces from CLT to supporting gravity element
    - Beam element for tension / compression demand
    - Compression perpendicular to grain at beam-to-column interface
    - Tension load path across beam-to-column joint
      - Maintaining deformation compatibility

For Timber Framed Buildings:
- **Recommend keeping diaphragm forces in the CLT plane**

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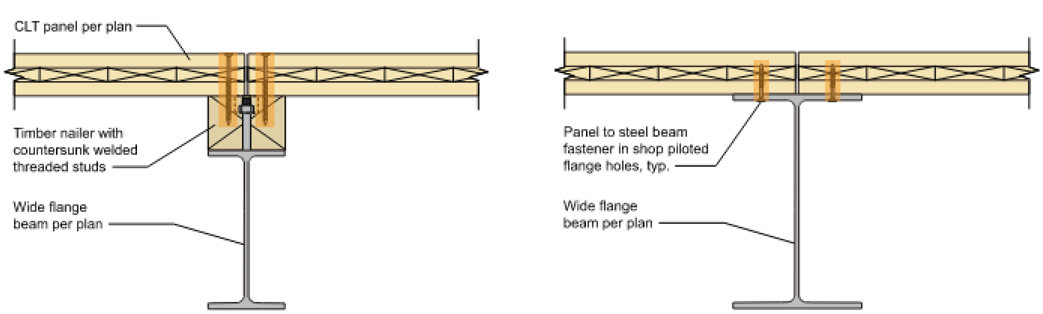
- **Diaphragm & Collector Connections to Steel VLFRS**



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- **Diaphragm & Collector Connections to Concrete Shear Walls**

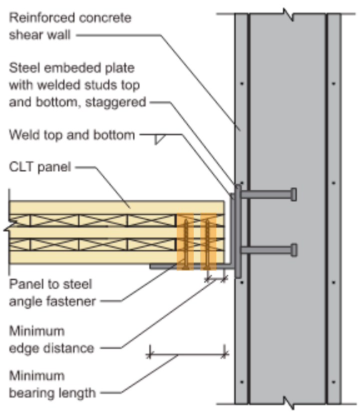

FIGURE 5.9: Diaphragm-to-concrete wall connection

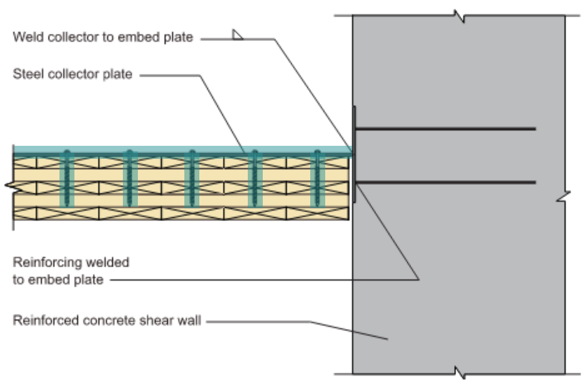

FIGURE 5.10: Collector plate to embed plate in concrete wall connection

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- **Diaphragm & Collector Connections to Concrete Shear Walls (Continued)**

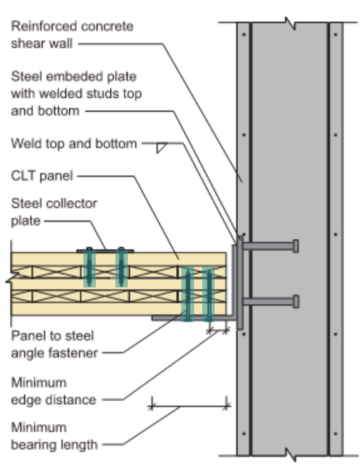

FIGURE 5.11: Collector load path to concrete shear wall through CLT panel

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- **Diaphragm & Collector Connections to Light Framed Shear Walls**

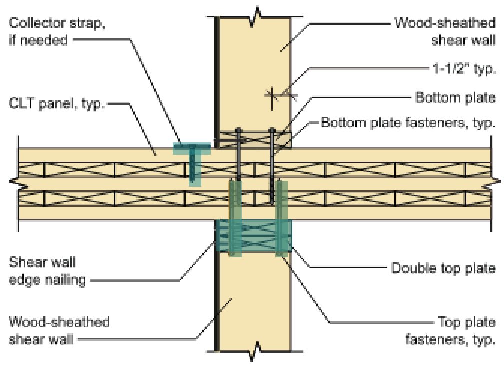

FIGURE 5.15: CLT to wood sheathed shear wall example detail

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6 Diaphragm Deflections & Stiffness

- **Classification of Diaphragm as Flexible or Rigid**

TABLE 6.1: Diaphragm flexibility related to CLT diaphragms

Category	ASCE 7 §12.3.1	IBC §1604.4	SDPWS §4.1.7
Flexible	Permitted when $\frac{\delta_{MDD}}{\Delta_{ADVE}} > 2$	N/A	Per ASCE 7
Rigid	N/A	Permitted when $\frac{\delta_{MDD}}{\Delta_{ADVE}} \leq 2$	
Semi-rigid	When not idealized as flexible or rigid, analysis shall include consideration of diaphragm stiffness	Total lateral force shall be distributed to elements of VLFRS in proportion to their rigidities, considering the rigidity of the diaphragm	Shall consider relative stiffnesses of VLFRS & diaphragms; envelope analysis permitted

δ_{MDD}: Maximum in-plane diaphragm deflection (in.)
Δ_{ADVE}: Average drift of adjoining vertical elements of the VLFRS over the story below the diaphragm under consideration, under tributary lateral load equivalent to that used in the computation of δ_{MDD} (in.)

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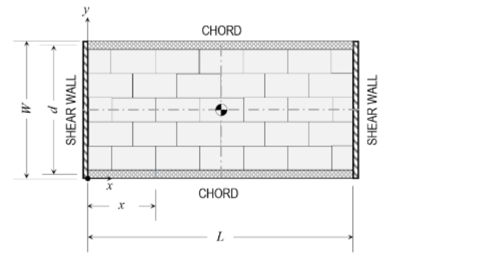
- **Semi-Rigid Diaphragm Analysis**

TABLE 6.2: Diaphragm bounding analysis possibilities

Bounding Analysis	Stiff Case	Flexible Case
Envelope procedure	Rigid diaphragm idealization	Flexible diaphragm idealization
Semi-rigid bounding	"Stiff" semi-rigid analysis	"Flexible" semi-rigid analysis
Rigid and semi-rigid bounding	Rigid diaphragm idealization	"Flexible" semi-rigid analysis
Semi-rigid and flexible bounding	"Stiff" semi-rigid analysis	Flexible diaphragm idealization



- **Diaphragm Deflection Equations**
  - Previously referenced equations

$$\delta_{\text{dia}} = \frac{5vL^3}{8EAW} + \frac{vL}{4G_v t_v} + CLe_n + \frac{\Sigma(x\Delta_c)}{2W}$$

  - Proposed CLT specific equation by Lawson, et al

$$\delta_{\text{dia}} = \boxed{\left(\frac{12\text{ in}}{1\text{ ft}}\right)\frac{5vWL^3}{96EAd^2}} + \boxed{\frac{vL}{4G_v t_v}} + \boxed{\frac{L}{4}\left(\frac{n_{\parallel}e_{f\parallel}}{P_{\perp}} + \frac{n_{\perp}e_{f\perp}}{P_{\parallel}}\right)} + \boxed{\frac{\Sigma(x\Delta_c)}{2d}}$$

$$\delta_{\text{cant,u}} = \left(\frac{12\text{ in}}{1\text{ ft}}\right)\frac{vW'L'^3}{4EAd^2} + \frac{vL'}{2G_v t_v} + \frac{L'}{2}\left(\frac{n_{\parallel}e_{f\parallel}}{P_{\perp}} + \frac{n_{\perp}e_{f\perp}}{P_{\parallel}}\right) + \frac{\Sigma(x'\Delta_c)}{d}$$

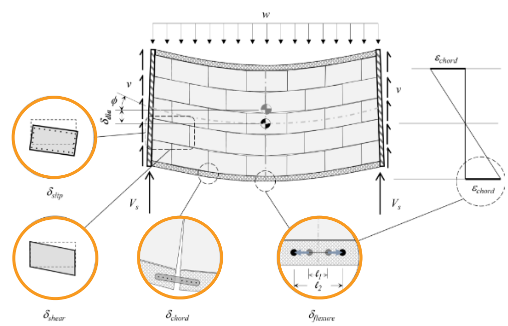


Fig. 1. Deflection parameters of a simple span diaphragm.

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- **Fastener Slip Relationships**
  - Limited in the NDS
  - Manufacture Specific Data
  - European Guidance
- **Analytical Modeling of CLT Behavior**
  - Homogenous Model
  - Discrete Models
  - Component Models
- **Estimating Inelastic Seismic Deflections**

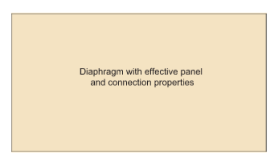

FIGURE 6.1: Homogenous modeling of diaphragm

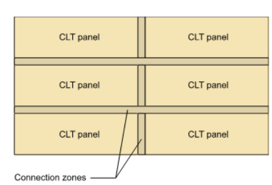

FIGURE 6.2: Discrete panels with effective connection modeling of diaphragm

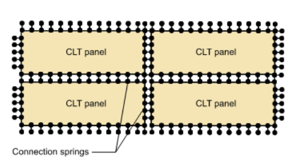

FIGURE 6.3: Component approach

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7 Special Design Considerations

- Sub-diaphragms
- Staggered CLT Panel Layouts
- Alternate Diaphragm Procedures
- Durability

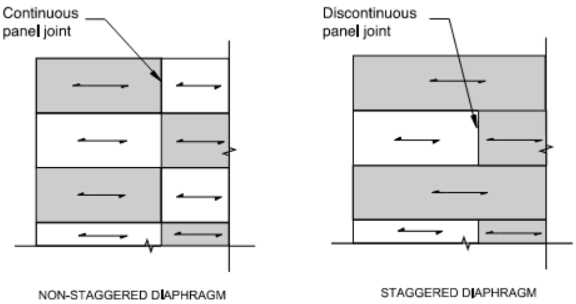

FIGURE 7.1: Non-staggered and staggered diaphragm conditions

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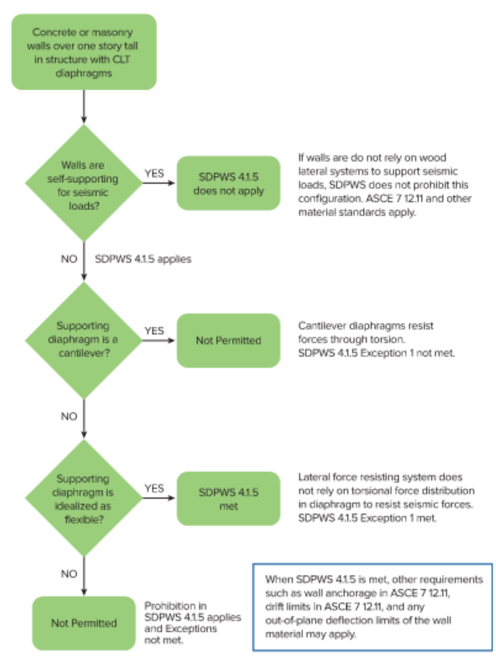
- **Bracing of CMU / Concrete Walls w/ CLT Diaphragms**
  - Acceptable provided walls are self-supporting

4.1.5 Wood Members and Systems Resisting Seismic Forces Contributed by Concrete and Masonry Wa[redacted]s

Wood-frame shear walls, wood-frame diaphragms, trusses, and other wood members and systems shall not be used to resist seismic forces contributed by concrete or masonry walls in structures over one story in height.

Exceptions:

1. Wood floor and roof members shall be permitted to be used in diaphragms and horizontal trusses to resist horizontal seismic forces contributed by masonry or concrete walls provided such forces do not result in torsional force distribution through the diaphragm or truss.



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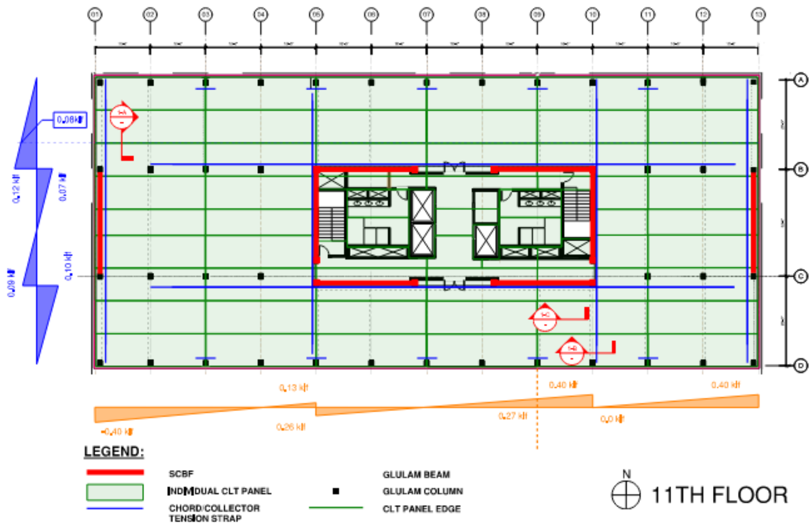
8 Example 1: 12-Story Office w/ Distributed Frames

- **Savannah, Georgia: Wind vs Seismic Checks**



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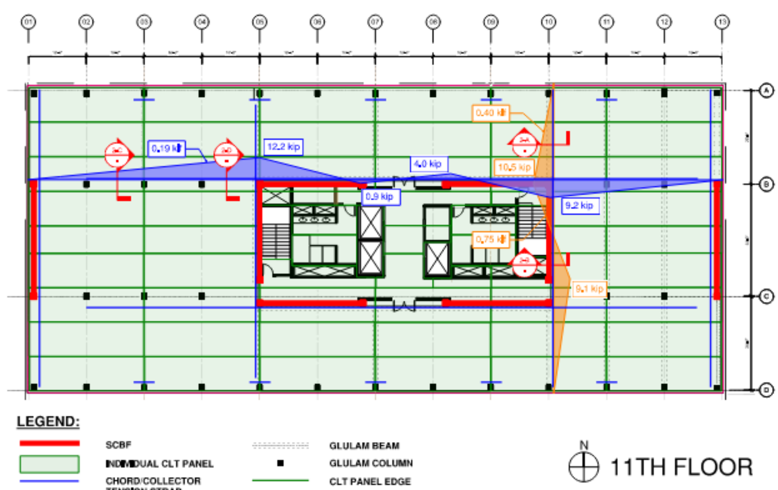
- **Collector Design Checks**



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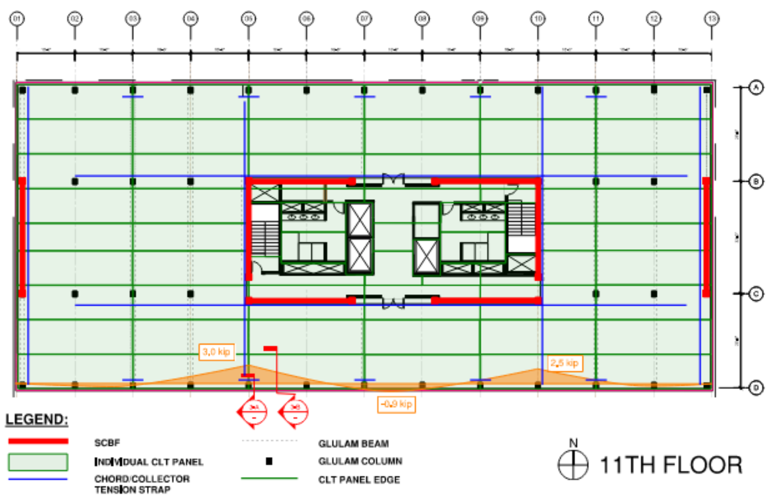
- **Chord Design Checks**



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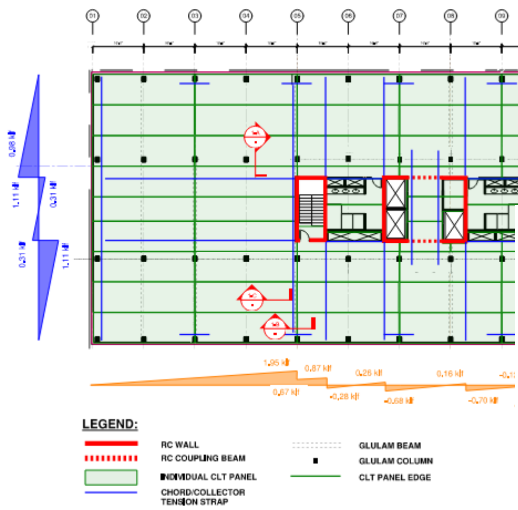
9 Example 2: 12-Story Office w/ Concrete Cores

- San Francisco, California



4.2 Sheathed Wood-Frame Diaphragms

4.2.1 Application Requirements

Sheathed wood-frame 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. Framing members, blocking, and connections shall extend into the diaphragm a sufficient distance to develop the force transferred into the diaphragm.

4.2.2 Diaphragm Aspect Ratios

Size and shape of diaphragms shall be limited to the aspect ratios in Table 4.2.2.

Table 4.2.2 Maximum Diaphragm Aspect Ratios
(Flat or Sloped Diaphragms)

Sheathed Wood-Frame Diaphragm Assemblies	Maximum L/W Ratio
Wood structural panel, unblocked	3:1
Wood structural panel, blocked	4:1
Single-layer horizontally-sheathed lumber	2:1
Single-layer diagonally-sheathed lumber	3:1
Double-layer diagonally-sheathed lumber	4:1

4.2.3 Deflection

Calculations of diaphragm deflection shall account for bending and shear deflections, fastener deformation, chord splice slip, and other contributing sources of deflection.

The diaphragm deflection, δ_{dia}, shall be permitted to be calculated by use of the equations in Table 4.2.3.

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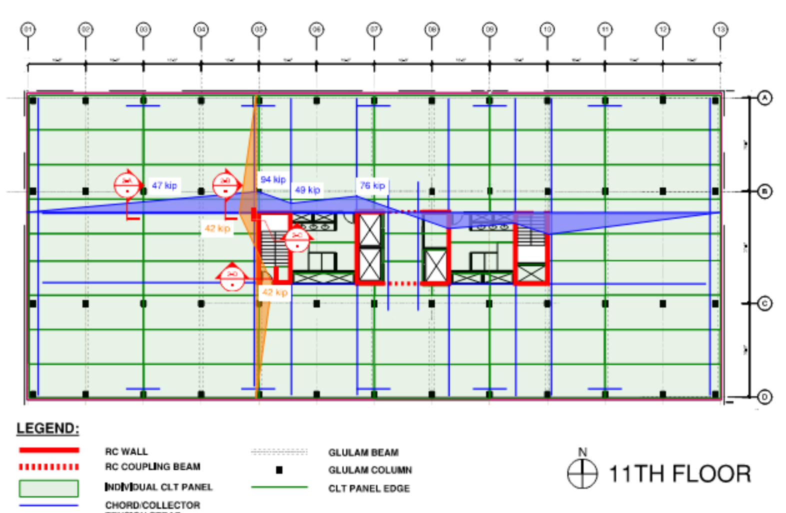
- Collector Design Checks



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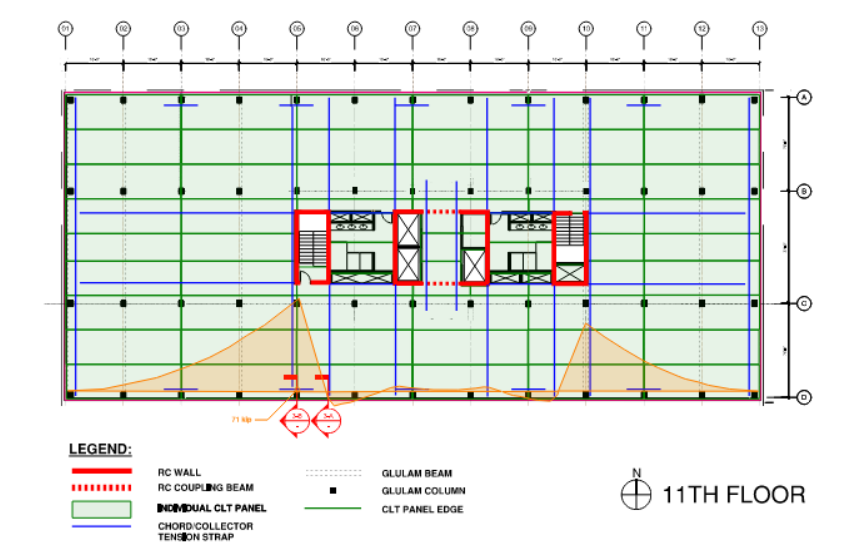
- **Chord Design Checks**



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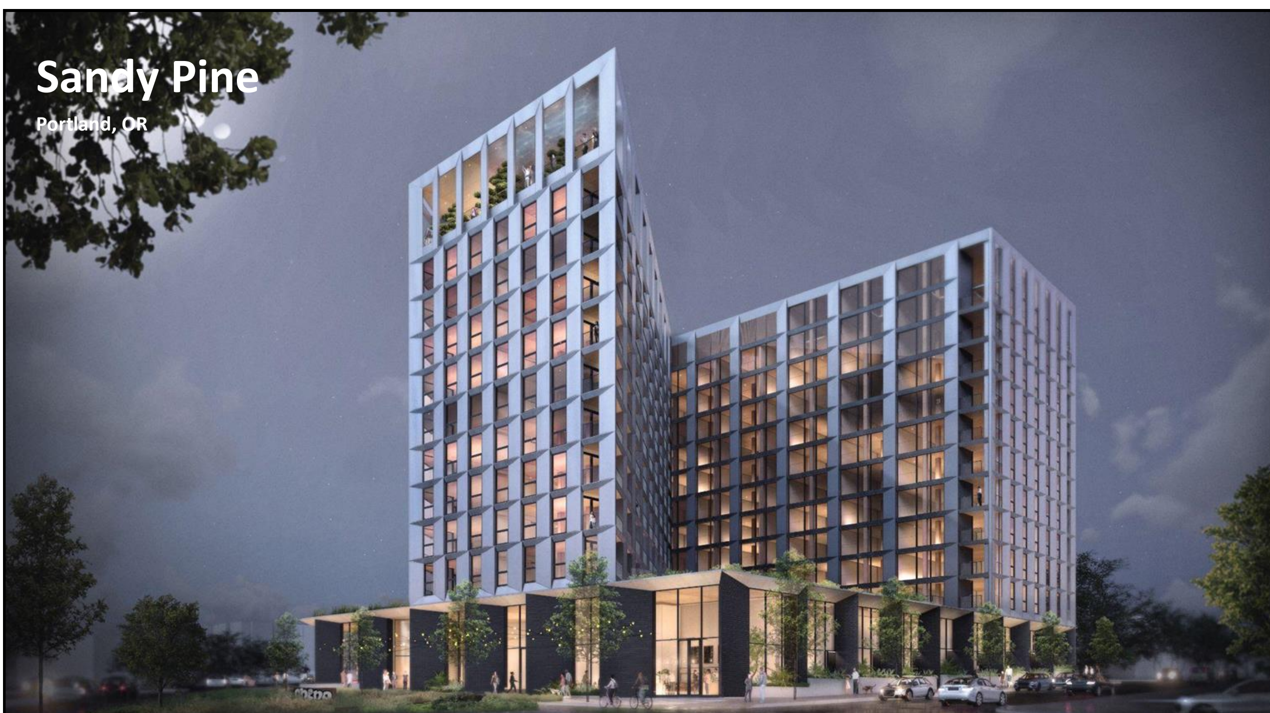

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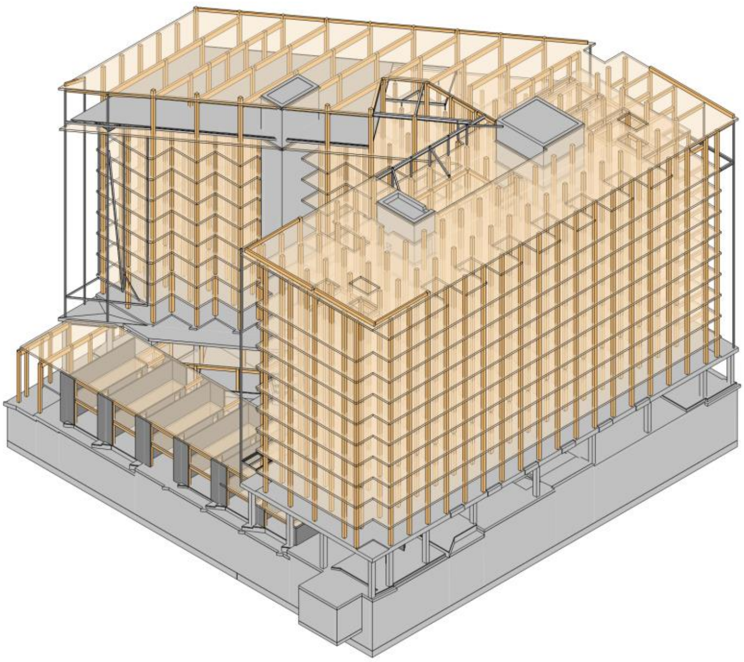

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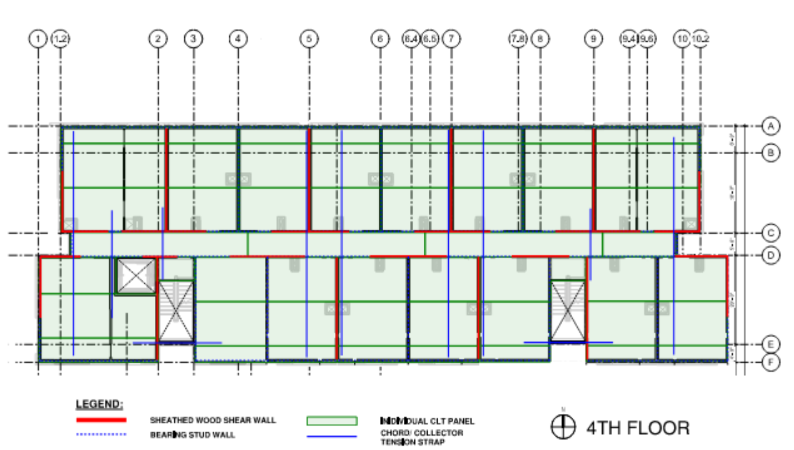
10 Example 3: 5-Story Residential w/ Sheathed SW's

- **Portland, OR**



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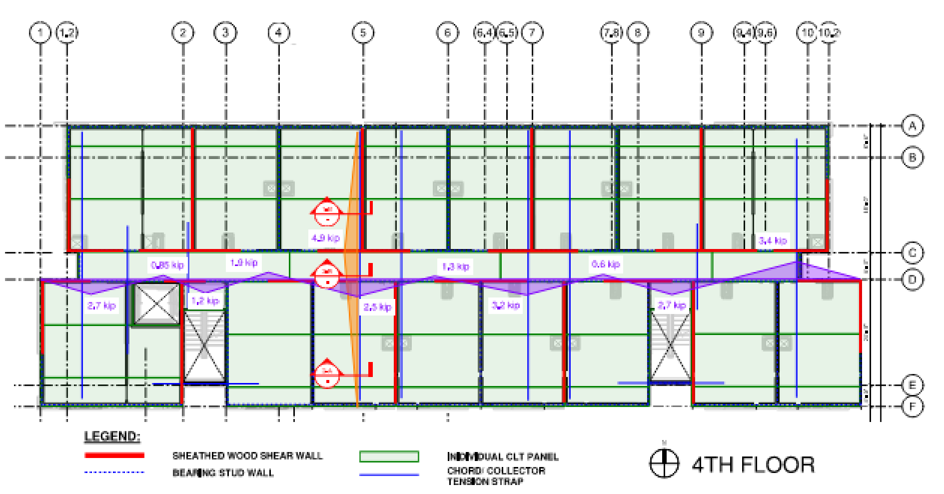
- **Collector Design Checks**



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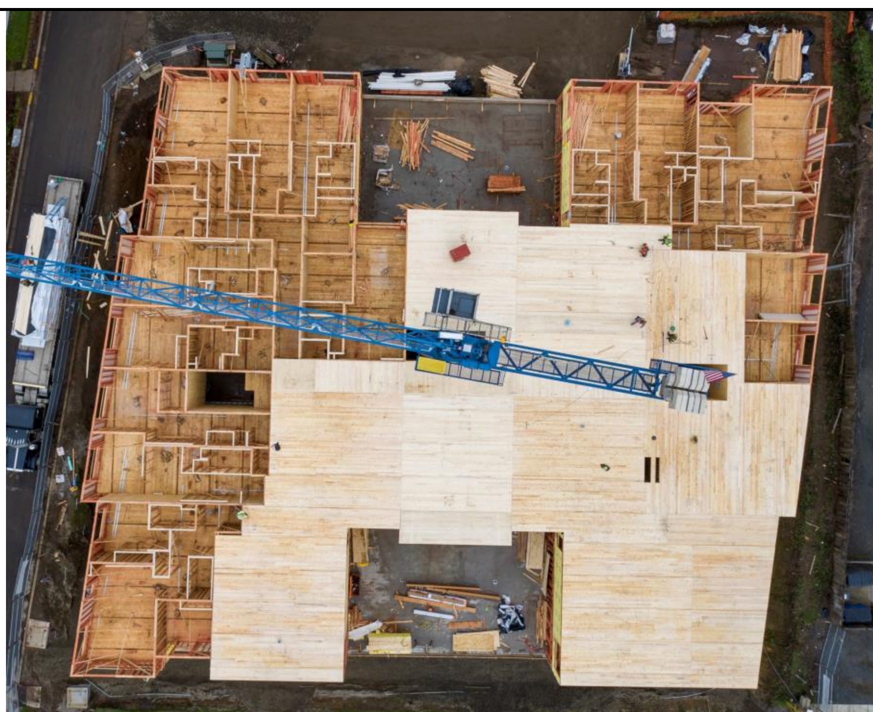

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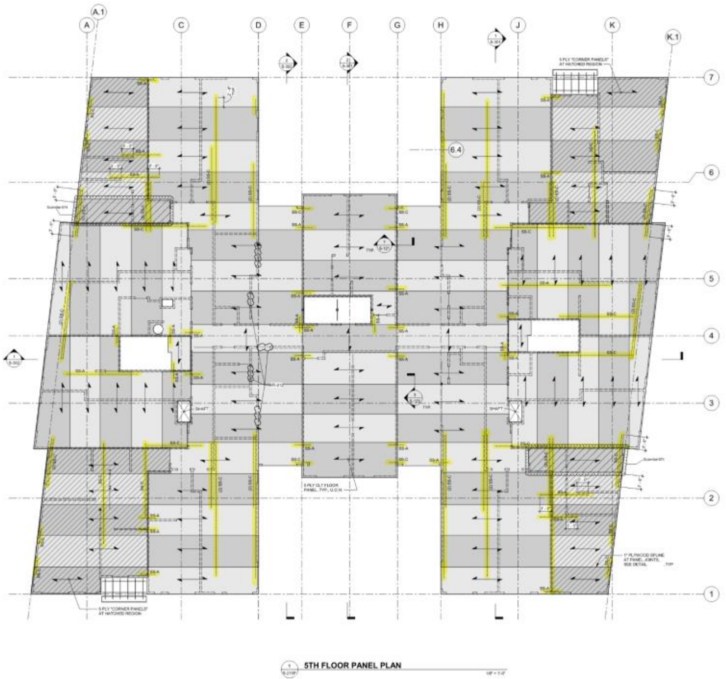

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A Precalculated Design Capacities

- Individual Fasteners
- Spline Capacities
- Fasteners / Spline Capacities
- Steel Strap Capacities

TABLE A.1.4: Nominal diaphragm shear capacity for spaced fastener in spline *continued*

Spline Material	Fastener	Nominal Diaphragm Shear Capacity of Fasteners, $v_n = 4.5Z^*/S$, @ Spacing, $S^{a,c}$ (plf)					Reference Spline Shear Capacity, $F_v t_v{}^b$ (plf)
		12-in. o.c.	6-in. o.c.	4-in. o.c.	3-in. o.c.	2-in. o.c.	
CLT SG = 0.50							
General sheathing (23/32)	8d common nail	330	659	989	1,318	1,977	1,176
General sheathing (23/32)	10d common nail	388	776	1,164	1,552	2,328	1,176
General sheathing (23/32)	Example screw 1	363	726	1,089	1,452	2,178	1,176
General sheathing (23/32)	Example screw 2	428	857	1,285	1,714	2,571	1,176
Structural 1 sheathing (23/32)	8d common nail	397	793	1,190	1,586	2,379	1,512
Structural 1 sheathing (23/32)	10d common nail	463	926	1,390	1,853	2,779	1,512
Structural 1 sheathing (23/32)	Example screw 1	423	847	1,270	1,693	2,540	1,512
Structural 1 sheathing (23/32)	Example screw 2	506	1,012	1,518	2,024	3,036	1,512
General sheathing (7/8)	10d common nail	423	847	1,270	1,694	2,540	1,440
General sheathing (7/8)	16d common nail	486	972	1,458	1,943	2,915	1,440
General sheathing (7/8)	Example screw 1	386	773	1,159	1,546	2,319	1,440
General sheathing (7/8)	Example screw 2	462	925	1,387	1,849	2,774	1,440
Structural 1 sheathing (7/8)	10d common nail	517	1,033	1,550	2,067	3,100	1,584
Structural 1 sheathing (7/8)	16d common nail	587	1,174	1,761	2,349	3,523	1,584
Structural 1 sheathing (7/8)	Example screw 1	461	923	1,384	1,845	2,768	1,584
Structural 1 sheathing (7/8)	Example screw 2	559	1,117	1,676	2,234	3,351	1,584
General sheathing (1-1/8)	10d common nail	484	968	1,452	1,936	2,904	1,920
General sheathing (1-1/8)	16d common nail	555	1,109	1,664	2,218	3,327	1,920
General sheathing (1-1/8)	Example screw 1	434	868	1,302	1,735	2,603	1,920
General sheathing (1-1/8)	Example screw 2	528	1,055	1,583	2,110	3,165	1,920
Structural 1 sheathing (1-1/8)	10d common nail	529	1,058	1,586	2,115	3,173	2,112
Structural 1 sheathing (1-1/8)	16d common nail	634	1,267	1,901	2,534	3,801	2,112
Structural 1 sheathing (1-1/8)	Example screw 1	527	1,054	1,581	2,108	3,161	2,112
Structural 1 sheathing (1-1/8)	Example screw 2	603	1,206	1,810	2,413	3,619	2,112

a. Tabulated values based on all adjustment factors applicable to Z^* in NDS Table 11.3.1 equal to 1.0. ($Z^* = Z$). Designer to verify applicability. All fastener capacity values provided are controlled by Mode III_s or IV fastener yielding.

b. Adjusted design spline capacity to be calculated from reference spine capacity using NDS Table 9.3.1.

c. Before using highlighted fastener capacity values, verify the adjusted design spline capacity is greater than the amplified demands per SDPWS §4.5.4:

Verify adjusted spline capacity is greater than SDPWS §4.5.4.3 Exception 1 for wind design.

Verify adjusted spline capacity is greater than SDPWS §4.5.4.3 for seismic design and SDPWS 4.5.4.3 Exception 1 for wind design.

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B Literature Review

- Component Level Testing
- Full Scale Diaphragm Testing
- Diaphragm Design Literature
- Other References

B.5 Summary of Significant Tests and Related References

TABLE B.1: Literature on small-scale CLT panel-panel connection tests

Article Title	Connection Type	Fastener & Loading	Type of Loading	Loading Direction	Reported Results	Additional Notes	Reported Fastener Slip Modulus
[Sandhaas et al., 2009] Analysis of X-Lam Panel-to-Panel Connections Under Monotonic and Cyclic Loading	LVL surface spline	8x80mm and 8x100mm STS; fasteners loaded in shear	Monotonic and cyclic	Parallel to shear plane	Load displacement at monotonic and cyclic loadings; peak load; damping; fastener initial and plastic stiffness	Test results compared with EC5 strength and stiffness prediction equations;	K_{ser} (0.4Fmax) and K_2 (post yielding stiffness)
[Follesa et al., 2010] Mechanical In-Plane Joints Between Cross Laminated Timber Panels	Internal spline, half-lap and surface spline	6mm and 8mm STS with and without washer; 3.1mm smooth nail and 3.1/3.4 threaded shank nails	Monotonic	Parallel to shear plane	Load-carrying capacity; stiffness	Authors observed significant difference between tested stiffness and EN1995 method;	K_{ser} and K_u (ultimate limit state stiffness)
[Joyce et al., 2011] Mechanical Behaviour of In-Plane Shear Connections Between CLT Wall Panels	Double spline and butt joints	8x100mm and 10x100mm for double spline; 8x160 partially-threaded (PT) and fully-threaded (FT) for butt joint	Monotonic and cyclic	Parallel to shear plane	Monotonic and cyclic loadings; peak load; allowable load; ductility and elastic fastener slip modulus	Fully-threaded angled screw option provides a significantly higher stiffness	$K_{elastic}$
[Ashtari, 2012] In-Plane Stiffness of Cross-Laminated Timber Floors	Butt joint	8mmx180-250mm ASSY VG in shear and withdrawal combination	Monotonic	Parallel to shear plane	Peak and ultimate forces; fastener stiffness	Author calibrated the connection model in ANSYS and modeled a 5mx10.8m CLT diaphragm	K_S (0.4 to 0.7F_{max})
[Gavric et al., 2012] Strength and Deformation Characteristics of Typical X-Lam Connections	Lap and spline joints	Wall-to-wall (parallel): 8x80mm; wall-to-wall (perpendicular): 10x180mm; floor-to-floor: 10x140mm; wall-to-floor: 10x260mm	Monotonic and cyclic	Parallel and perpendicular to shear planes	12 tested configurations; 15 reported tested statistics for each configuration	Each configuration includes 1 monotonic and 6 cyclic tests; perpendicular to shear plane test results also available	K_{ser} and K_2
[Bratulic et al., 2014] Monotonic and Cyclic Behavior of Joints with Self-Tapping Screws in CLT Structures	Surface spline	Fastener type not reported; loaded in shear	Monotonic and cyclic	Parallel to shear plane	For floor-wall connection: load-displacement at monotonic and cyclic loadings; peak load; initial stiffness; yield displacement; ductility	Load-carrying capacity calculated per Johansen's yield theory	K_{ser}

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CLT Diaphragm Design Guide

BASED ON SDPWS 2021

FIRST EDITION, APRIL, 2023

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Thank you

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