CLT Shear Wall and Diaphragm Design

with SDPWS 2021

Presented by:

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Photo credit: KPFF / Reid Zimmerman

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AIA Approved Continuing Education

Course Description

The use of cross-laminated timber (CLT) as structural floor and roof panels has seen incredible growth in the US over the past decade. However, its use as part of a seismic and wind force-resisting system—either as a diaphragm or shear wall—has only recently be codified. This has resulted in designing CLT lateral systems through alternative means. This presentation will introduce new provisions for CLT shear wall and diaphragm design, in the American Wood Council's 2021 Special Design Provisions for Wind and Seismic (SDPWS). The presentation will cover the detailing and design requirements for the newly defined CLT shear walls and diaphragms found in the SPDWS and the range of seismic design parameters (e.g., R values) recognized for CLT shear wall in ASCE 7-22.

Learning Objectives

1. Develop and understanding of design challenges related to using CLT for wind and seismic resistance while meeting the intent if the building code.

2. Discuss the new provisions in the 2021 Edition of Special Design Provisions for Wind and Seismic applicable to all lateral system.

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 floors and roof assemblies as horizontal diaphragms for wind and seismic resistance.

Lateral Systems

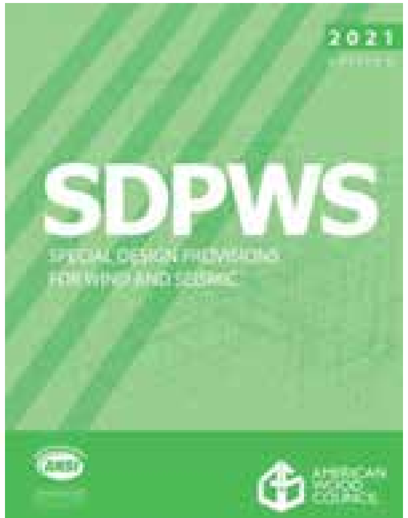

Photo Credit: WoodWorks

Photo Credit: WoodWorks

Photo Credit: Alex Schreyer

Lateral System Choices (Prescriptive)

- ✓ Concrete Shearwalls
- ✓ Steel Braced Frames
- ✓ Steel Moment Frames
- ✓ Light Wood-Frame Shearwalls
- ✓ ***CLT Shearwalls*** **(2021 SDPWS, ASCE 7-22, OR-SAM)**
- ✗ Timber Braced Frames
- ✗ CLT Rocking Walls



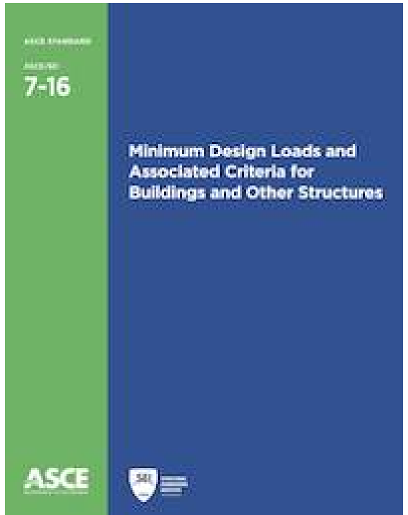
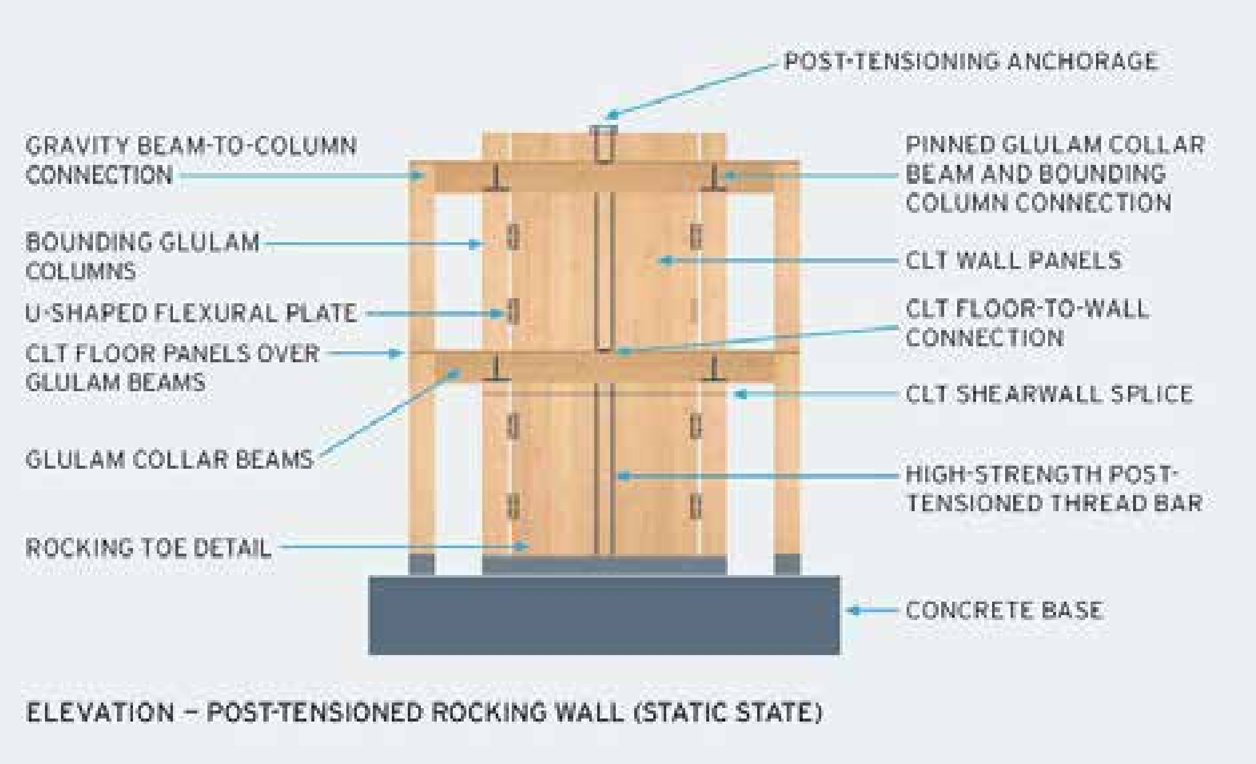


Photo: WoodWorks

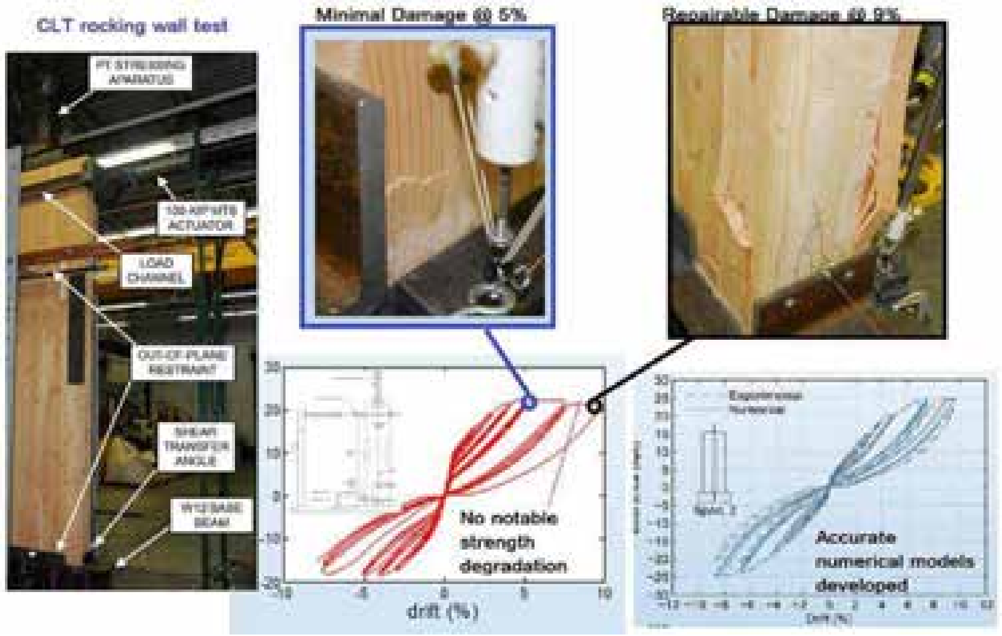

Credit: Alex Schreyer

Photo: WoodWorks   Credit: Hacker Architects

Image: KPFF



Mass Timber Post Tension Rocking Shear Wall Tests



Source: S. PEI et al. http://nheritallwood.mines.edu/

Cross-Laminated Timber (CLT)

Dowel-Laminated Timber (DLT)

Photo: StructureCraft

Nail-Laminated Timber (NLT)

Photo: Think Wood

Glue-Laminated Timber (GLT)

Plank orientation

Photo: StructureCraft

Photo: StructureCraft

Photo: Ema Peter

Photo: Manasc Isaac Architects/Fast + Epp

Cross-Laminated Timber (CLT)

Solid sawn laminations

Cross-Laminated Timber (CLT)

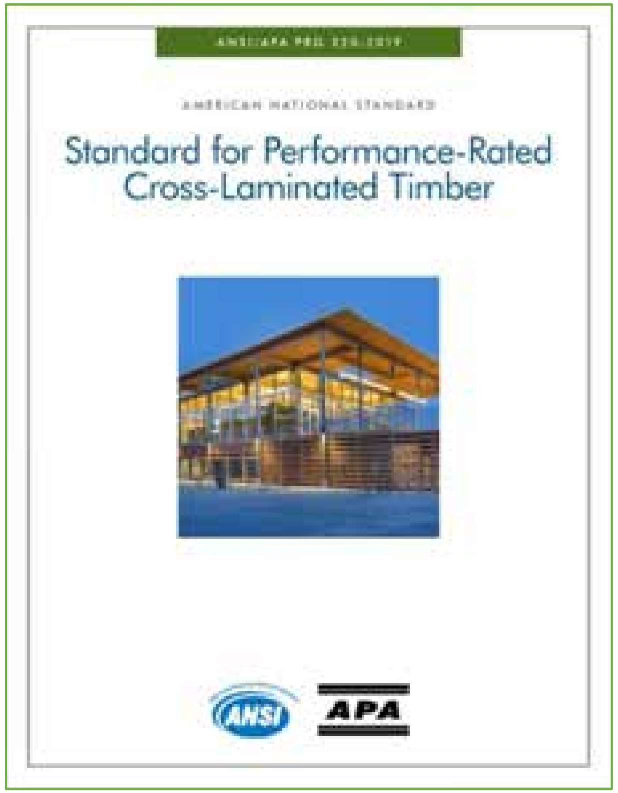
SCL laminations

Photo: Freres Lumber

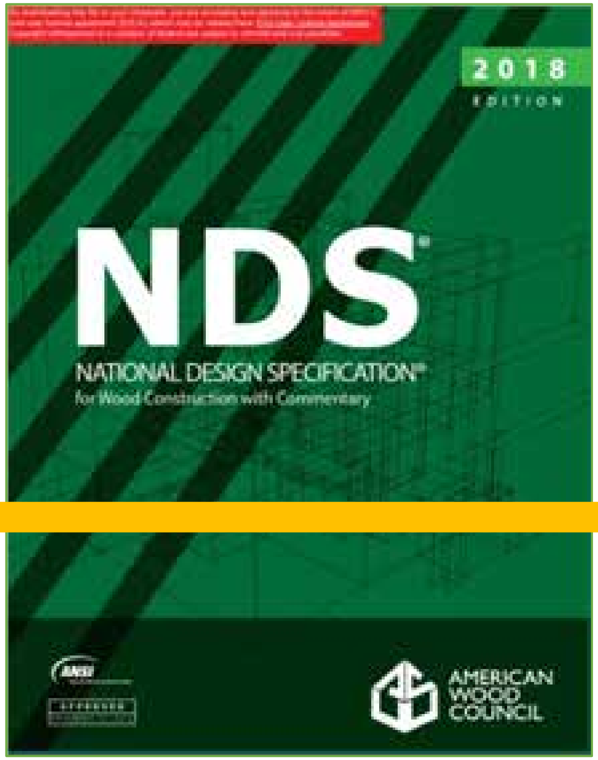
Photo: LendLease

Photo: LEVER Architecture

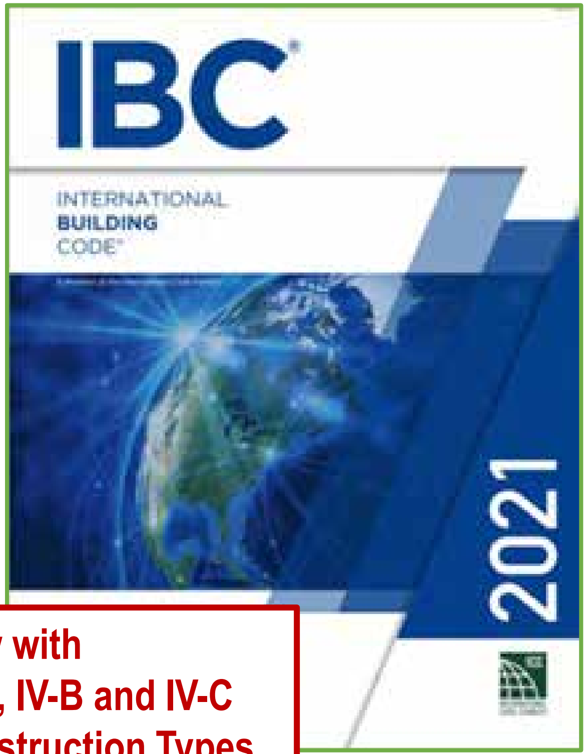
CLT in the U.S. Building Code – IBC 2021



ANSI/APA PRG 320 2019



AWC NDS 2018

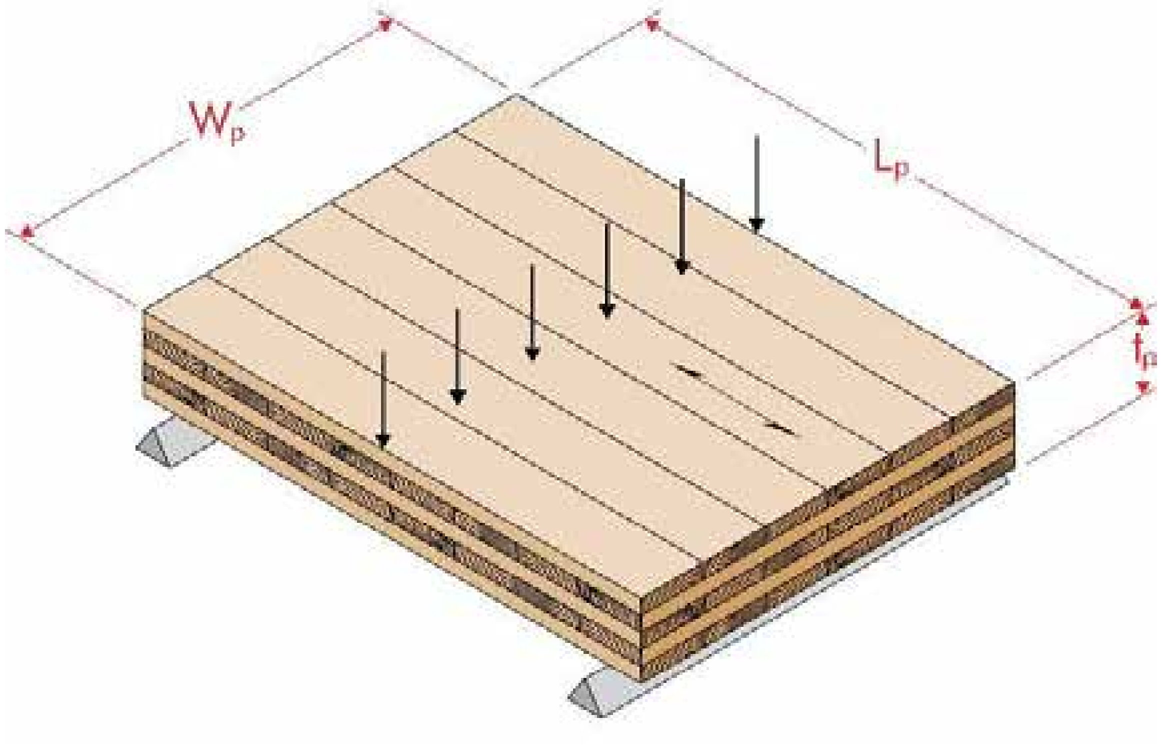


Now with
IV-A, IV-B and IV-C
Construction Types

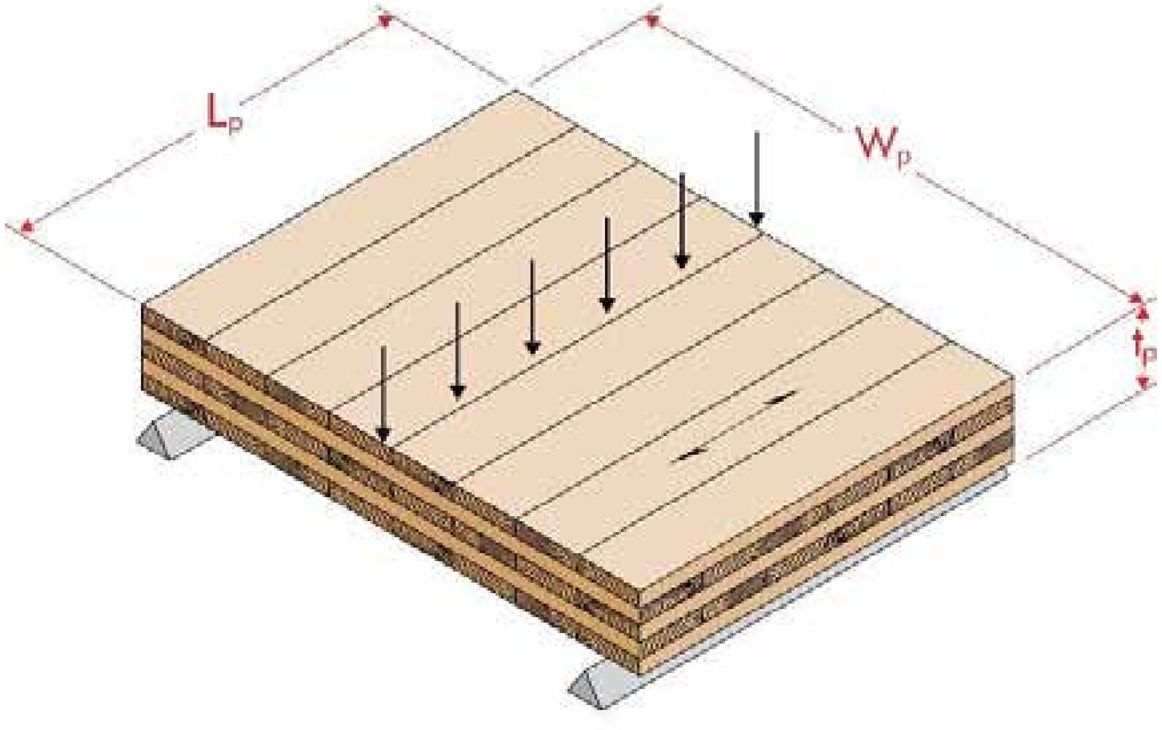
2021 International Building Code

New Type IV Mass Timber Construction up to 18 Stories!

FLATWISE Panel Loading



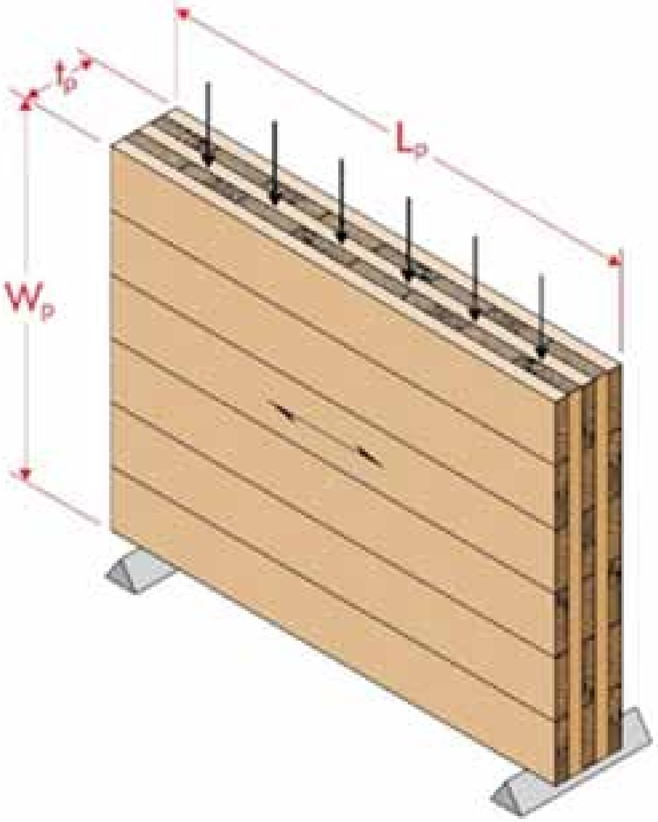
Span in MAJOR Strength Direction
"Parallel" Direction
Use subscript '0' in Notation



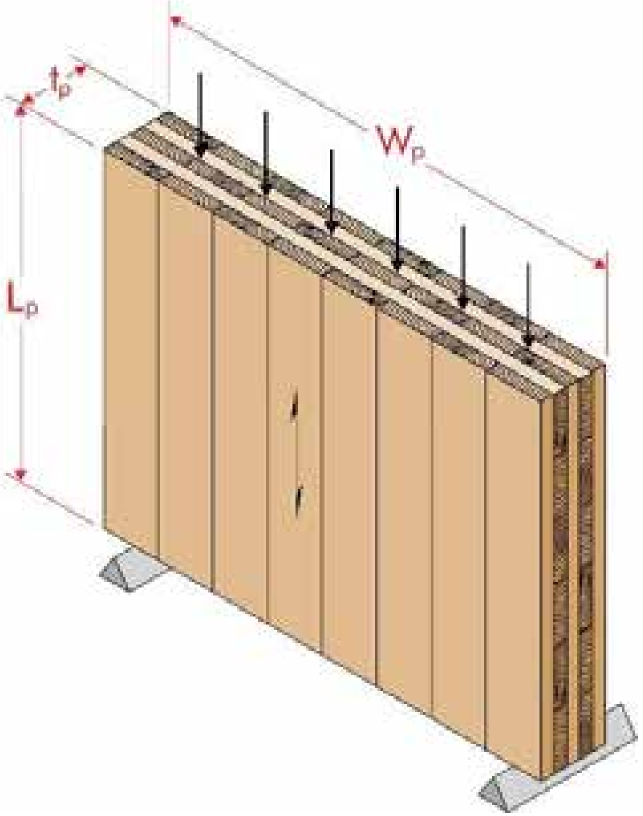
Span in MINOR Strength Direction
"Perpendicular" Direction
Use subscript '90' in Notation

Reference & Source: ANSI/APA PRG 320

EDGEWISE Panel Loading



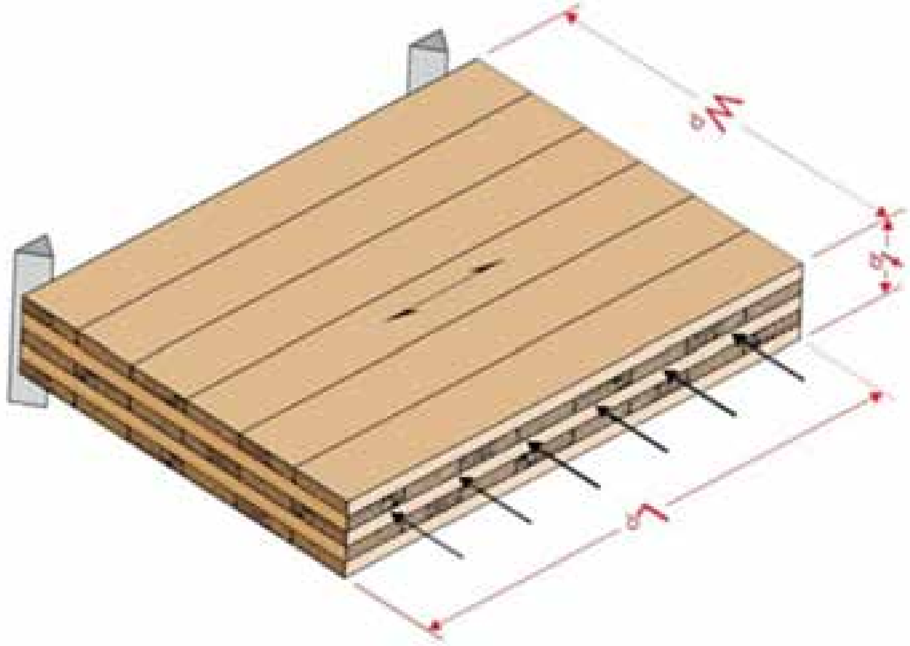
Span in MAJOR Strength Direction



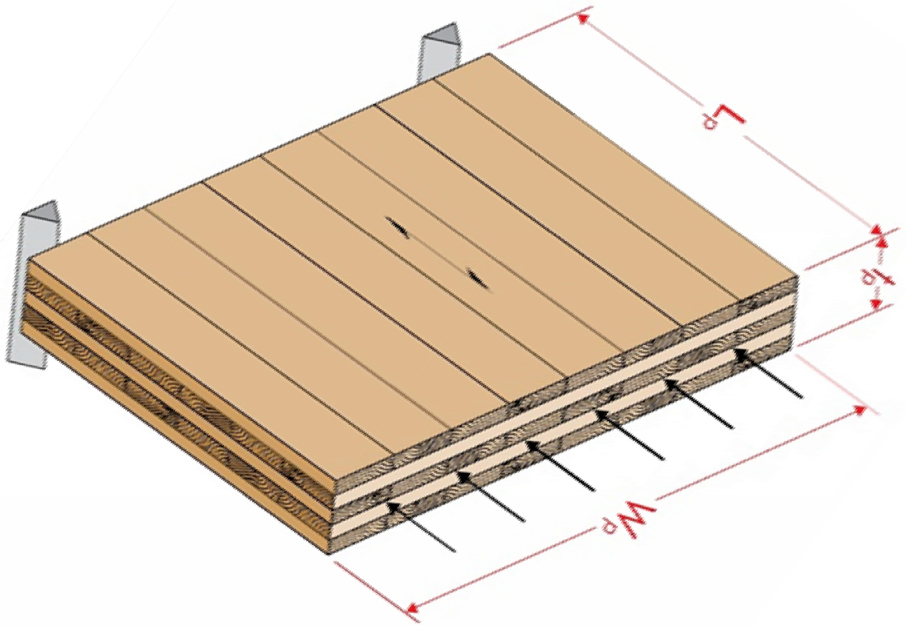
Span in MINOR Strength Direction

Reference & Source: ANSI/APA PRG 320-2017

EDGEWISE Panel Loading



Span in MAJOR Strength Direction



Span in MINOR Strength Direction

Reference & Source: ANSI/APA PRG 320-2017

PRG 320 Defined Layups

CLT Grade (basic)

Layup

Panel Properties

TABLE A2

ASD REFERENCE DESIGN VALUES[a] FOR BASIC CLT GRADES AND LAYUPS (FOR USE IN THE U.S.)

	Lamination Thickness (in.) in CLT Layup								Major Strength Direction				Minor Strength Direction			
CLT Grade	t_p (in.)	=	⊥	=	⊥	=	⊥	=	$(F_bS)_{eff,f,0}$ (lbf-ft/ft of width)	$(EI)_{eff,f,0}$ (10^6 lbf-in.^{2}/ft of width)	$(GA)_{eff,f,0}$ (10^6 lbf/ft of width)	$V_{s,0}$ (lbf/ft of width)	$(F_bS)_{eff,f,90}$ (lbf-ft/ft of width)	$(EI)_{eff,f,90}$ (10^6 lbf-in.^{2}/ft of width)	$(GA)_{eff,f,90}$ (10^6 lbf/ft of width)	$V_{s,90}$ (lbf/ft of width)
E1	4 1/8	1 3/8	1 3/8	1 3/8					4,525	115	0.46	1,490	160	3.1	0.61	495
E1	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			10,400	440	0.92	2,480	1,370	81	1.2	1,490
E1	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	18,375	1,089	1.4	3,475	3,150	313	1.8	2,480
E2	4 1/8	1 3/8	1 3/8	1 3/8					3,825	102	0.53	1,980	165	3.6	0.56	660
E2	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			8,825	389	1.1	3,300	1,440	95	1.1	1,980
E2	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	15,600	963	1.6	4,625	3,300	364	1.7	3,300
E3	4 1/8	1 3/8	1 3/8	1 3/8					2,800	81	0.35	1,160	110	2.3	0.44	385
E3	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			6,400	311	0.69	1,930	955	61	0.87	1,160
E3	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	11,325	769	1.0	2,700	2,210	234	1.3	1,930
E4	4 1/8	1 3/8	1 3/8	1 3/8					4,525	115	0.50	1,820	140	3.4	0.62	605
E4	6 7/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8			10,400	440	1.0	3,025	1,230	88	1.2	1,820
E4	9 5/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	1 3/8	18,400	1,089	1.5	4,225	2,850	338	1.9	3,025
	4 1/8	1 3/8	1 3/8	1 3/8					3,825	101	0.46	1,650	160	3.1	0.55	550

3rd Party Product Qualification of CLT

CLT in In-Plane (Edgewise) Strength

TABLE 3—REFERENCE DESIGN VALUES FOR IN-PLANE SHEAR OF THE STRUCTURLAM CROSSLAM® CLT PANELS[1]

CLT LAYUP[2]	CLT PANEL THICKNESS DESIGNATION	FACE LAMINATION ORIENTATION[3] (psi)		FACE LAMINATION ORIENTATION[3] (lbf/ft of width)	
		∥[4]	⊥[4]	∥[4]	⊥[4]
V2M1	99 V	175	235	8,200	11,000
	169 V	175	235	14,000	18,800
	239 V	175	235	19,800	26,600
	309 V	175	235	25,600	34,300
V2M1.1	105V	195	290	9,700	14,400
	175V	270	290	22,400	24,000
	245V	270	290	31,300	33,600
	315V	270	290	40,200	43,200

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

Reference Design Values for Nordic X-Lam Listed in Table 1 (For Use in

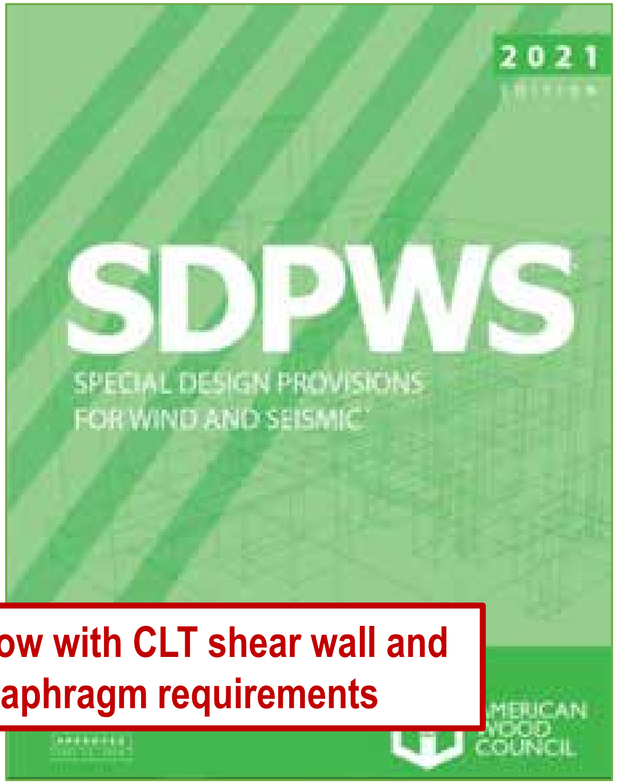
			Major Strength Direction		Minor Strength Direction	
			$F_{v,e,0}$[(a)] (psi)	$G_{e,0}\,t_p$[(d)] (10^6 lbf/ft)	$F_{v,e,90}$[(a)] (psi)	$G_{e,90}\,t_p$[(d)] (10^6 lbf/ft)
			155[(b)]	1.36	190[(b)]	1.36
			155	1.52	190[(b)]	1.52
			155	1.79	190	1.79
			185[(c)]	2.23	215[(c)]	2.23
E1	140-4s	5 1/2	145	2.39	190[(b)]	2.39
	143-5s	5 5/8	185[(c)]	2.44	215[(c)]	2.44
	175-5s	6 7/8	185	2.99	215	2.99
	197-7s	7 3/4	155[(b)]	3.37	215[(c)]	3.37
	213-7l	8 3/8	185[(c)]	3.64	215[(c)]	3.64
	220-7s	8 5/8	185[(c)]	3.75	215[(c)]	3.75
	244-7s	9 5/8	185[(c)]	4.18	215[(c)]	4.18
	244-7l	9 5/8	185[(c)]	4.18	215[(c)]	4.18
	267-9l	10 1/2	155[(b)]	4.56	215[(c)]	4.56
	314-9l	12 3/8	185[(c)]	5.38	215[(c)]	5.38

Source: *APA Product Report PR-L306*

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

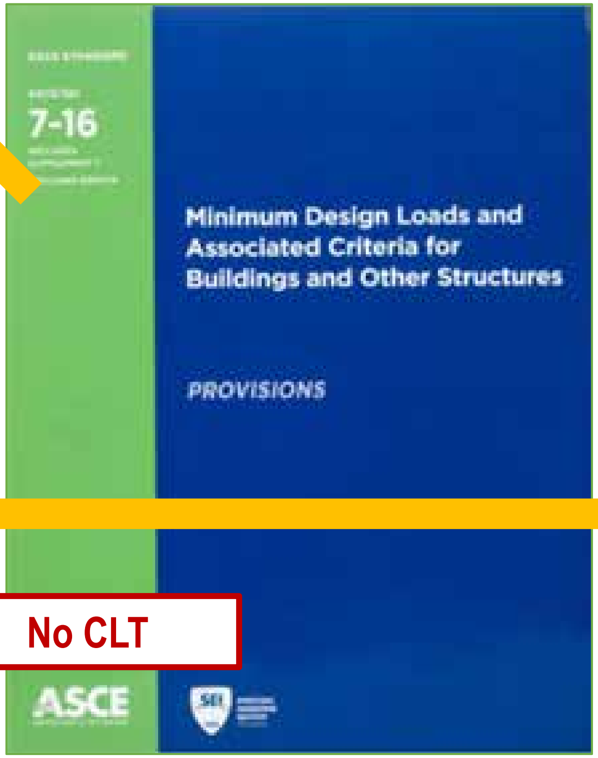
CLT in the U.S. Building Code – Lateral in IBC 2021

SDPWS 2015



Now with CLT shear wall and diaphragm requirements

AWC SDPWS 2021



No CLT

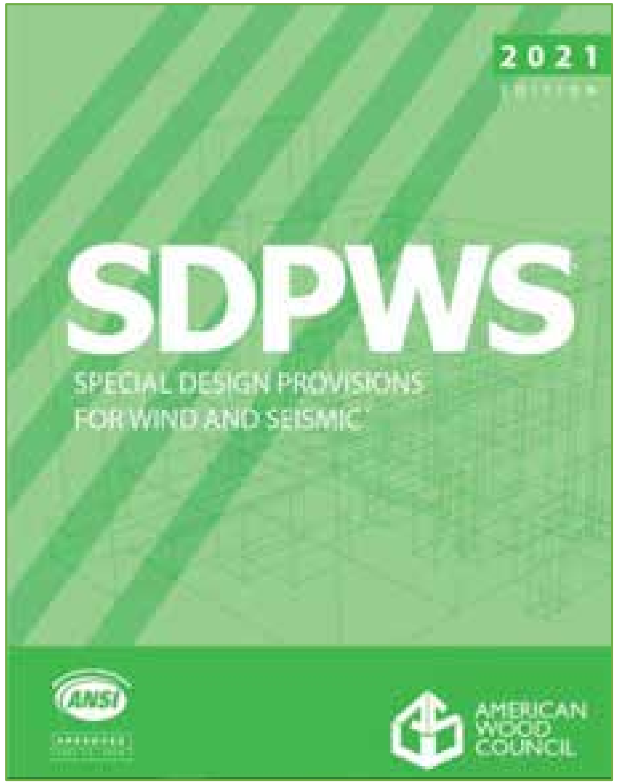
ASCE/SEI 7-16

2021 International Building Code

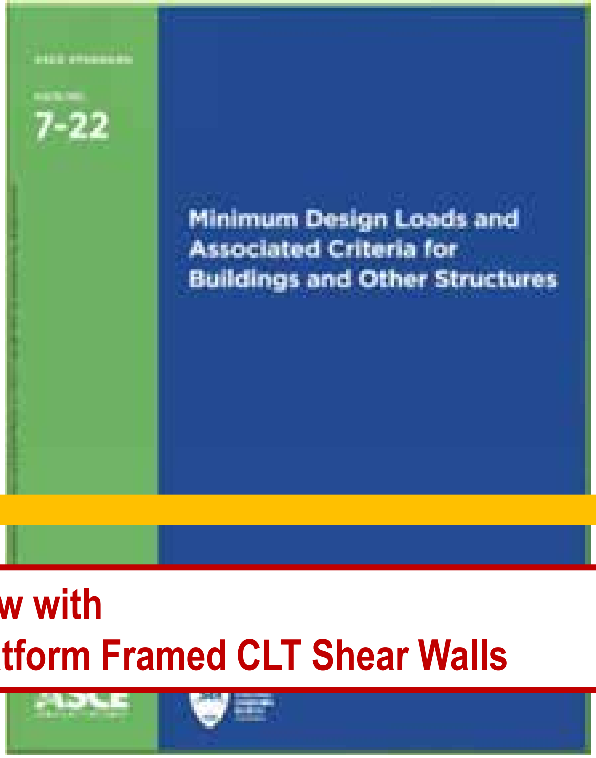
New Requirements for CLT Lateral Systems!

(but R values for CLT Shear Walls not in ASCE 7-16)

CLT in the U.S. Building Code – Lateral in the IBC 2024?



AWC SDPWS 2021



Now with
Platform Framed CLT Shear Walls

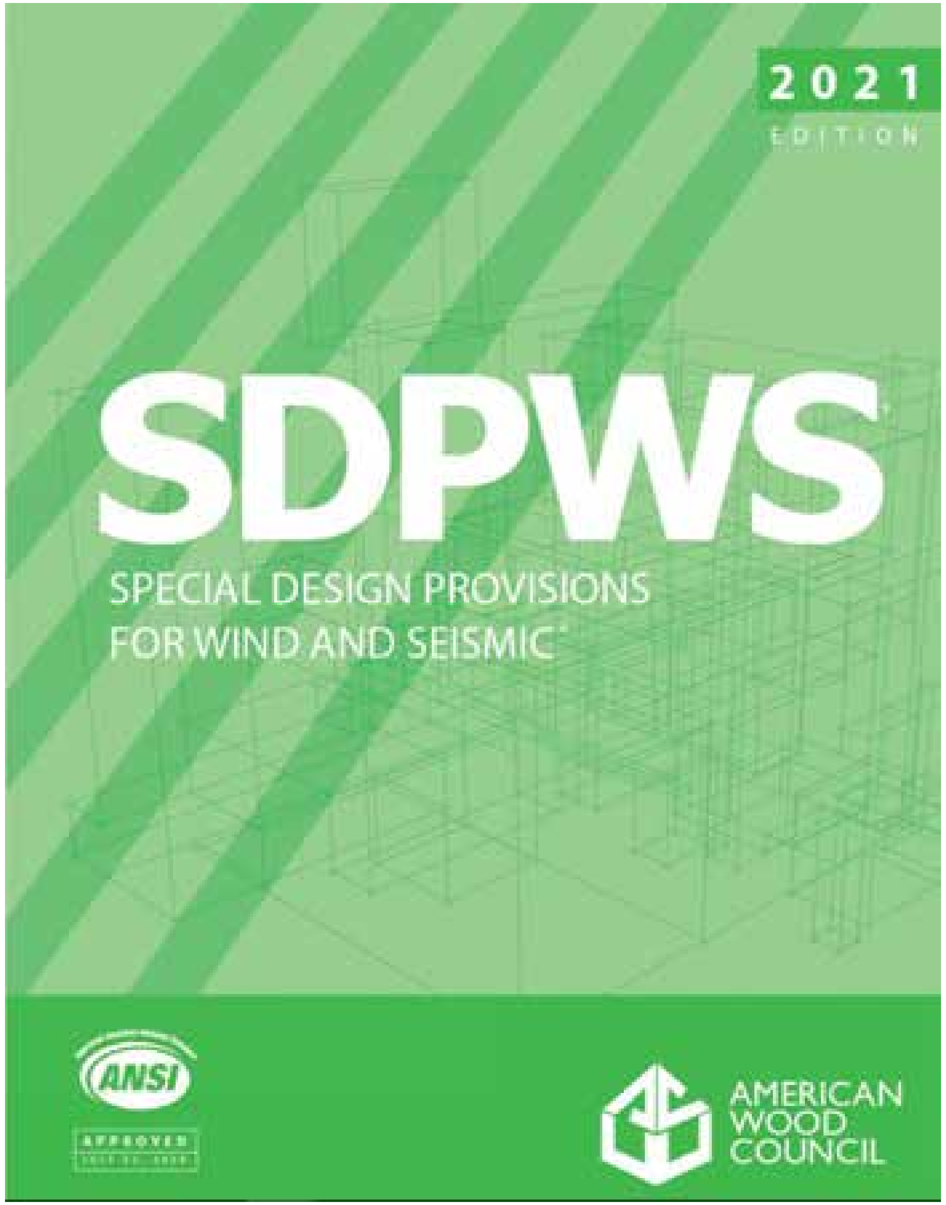
ASCE/SEI 7-22

2024 International Building Code
(In Process)

Future Full Recognition of CLT Lateral Systems

2021 SPDWS

2021 Special Design Provisions for Wind and Seismic



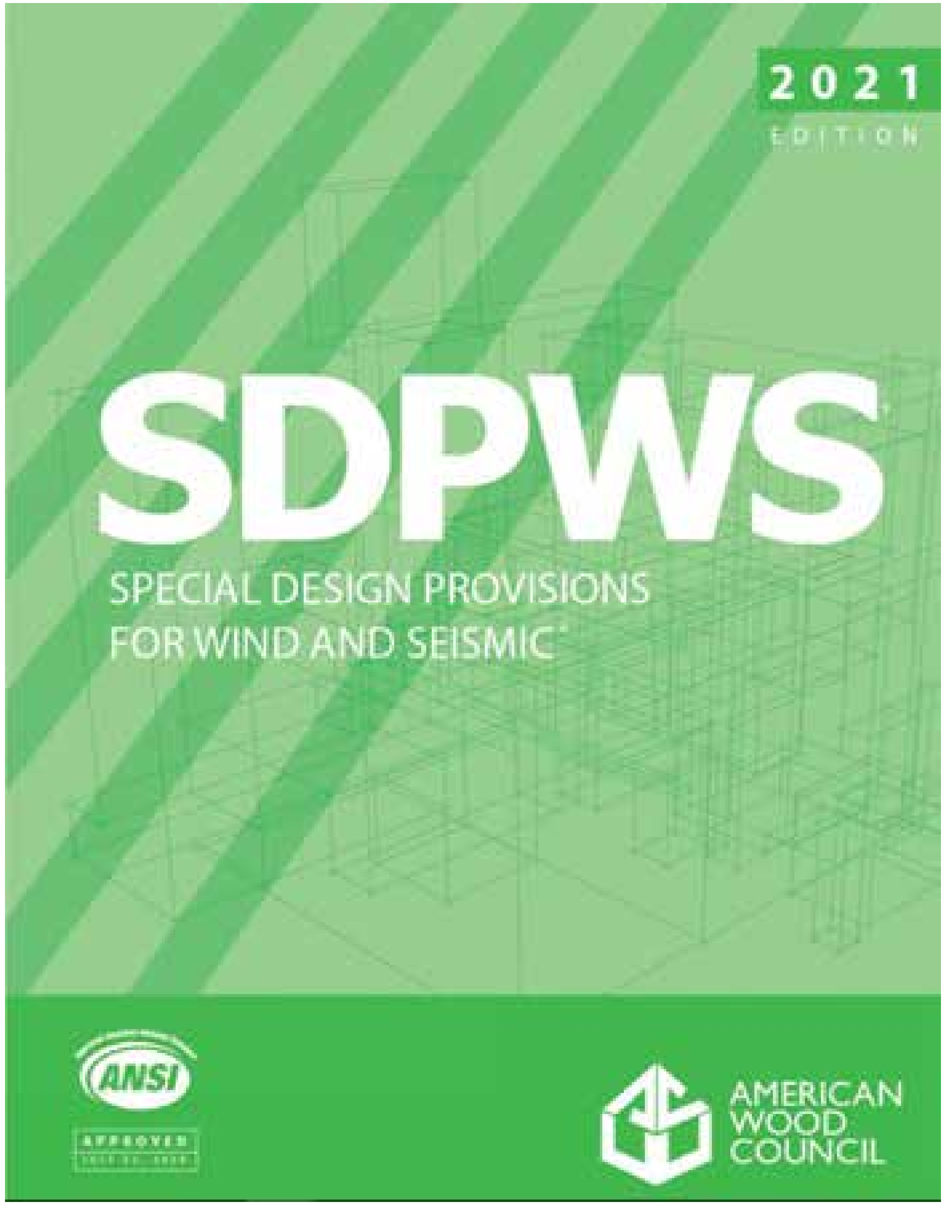
Top Changes Relevant to CLT Lateral Systems:

- **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!

2021 SDPWS – Unified Nominal Shear Capacity



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

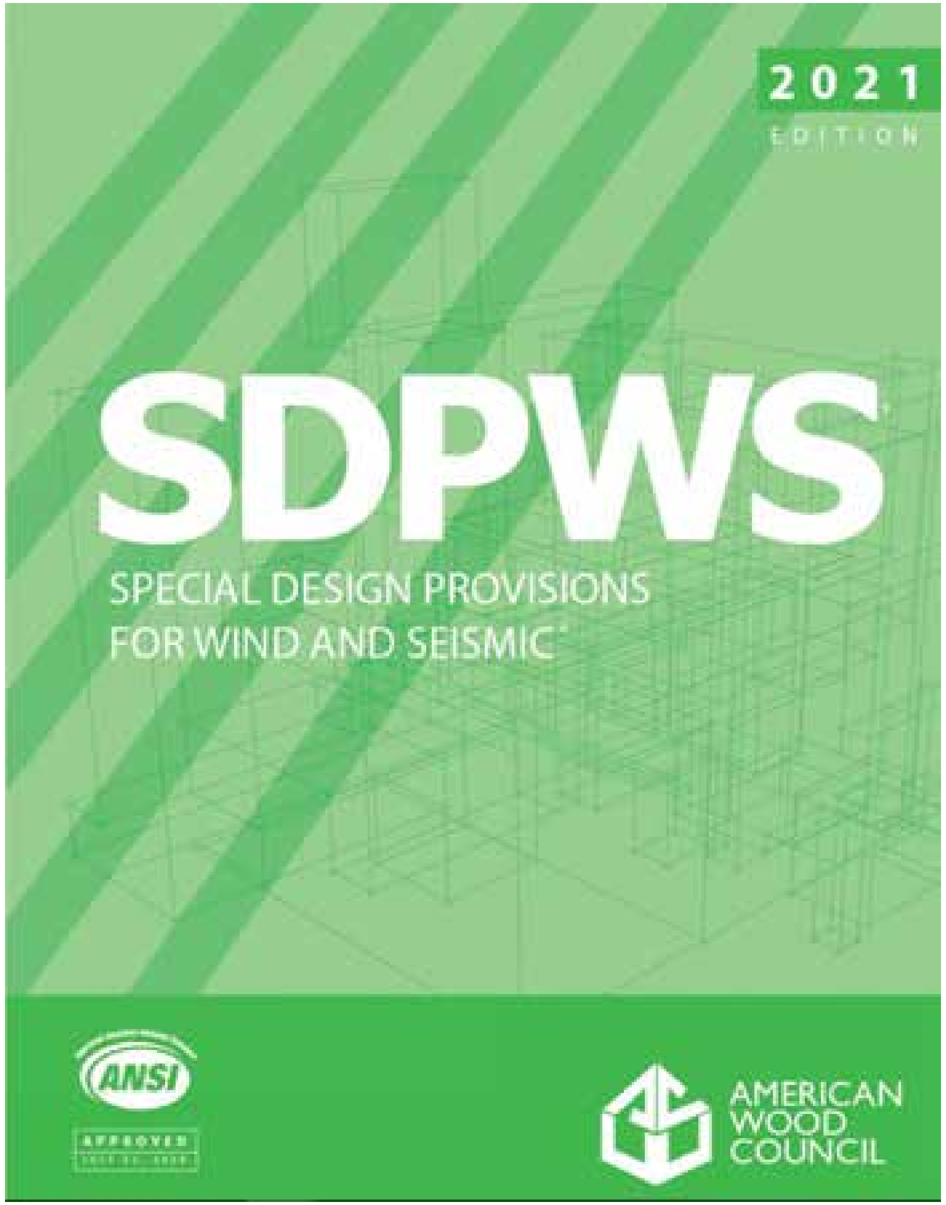
v_s Nominal shear capacity for seismic loads

v_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)

v_n Nominal shear capacity

2021 SDPWS – Unified Nominal Shear Capacity

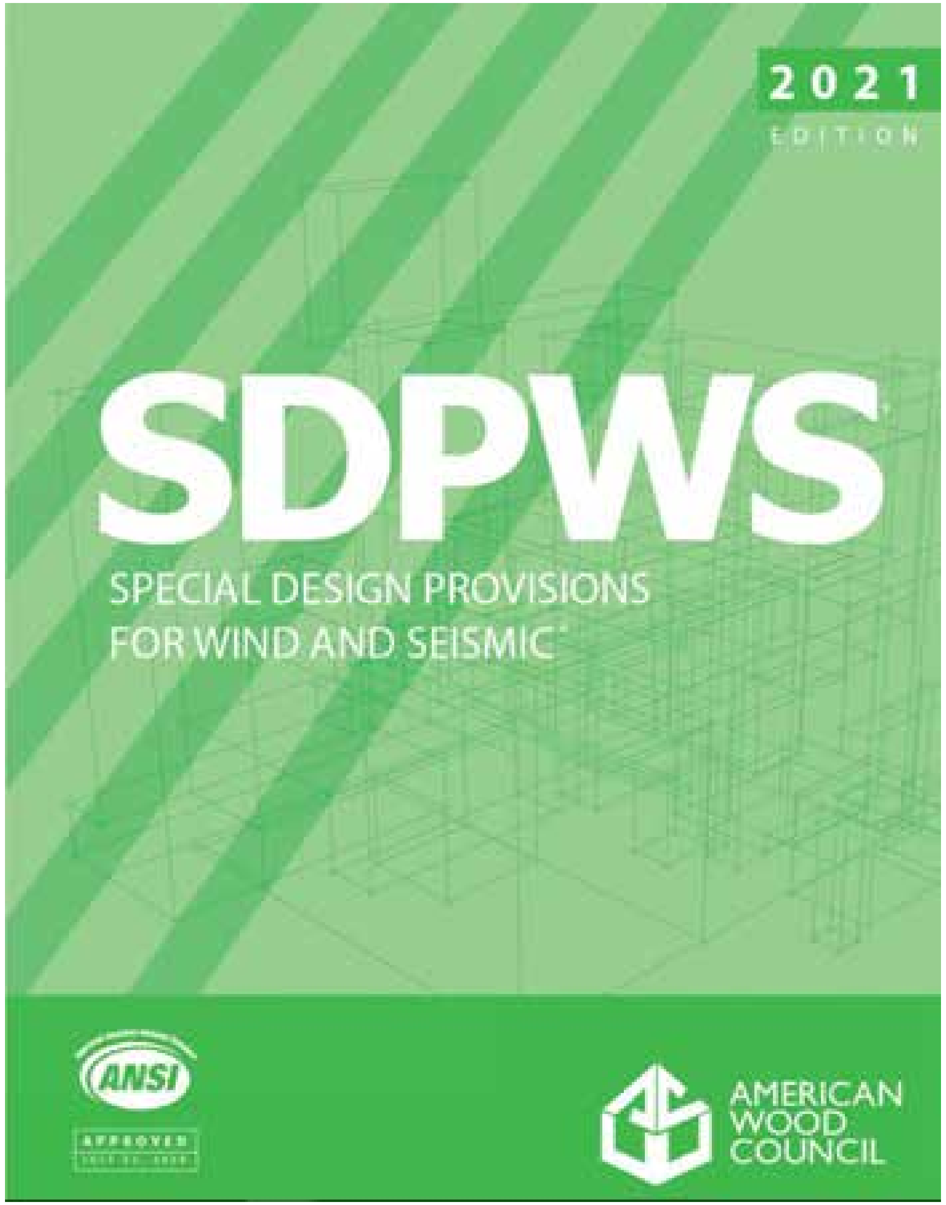


To calculate the ASD or LRFD shear capacity, SDPWS 2021 has <u>different reduction</u> factors for wind and seismic

	Design shear capacity	
	ASD	LRFD
Wind	$v_n/2.0$	$0.8\ v_n$
Seismic	$v_n/2.8$	$0.5\ v_n$

SDPWS 2021 Section 4.1.4

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

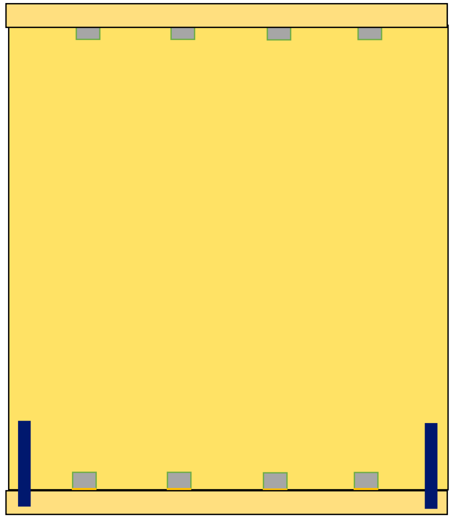
View for free at awc.org

PowerPoint IS NOT the CODE!

What R-Values can I use?

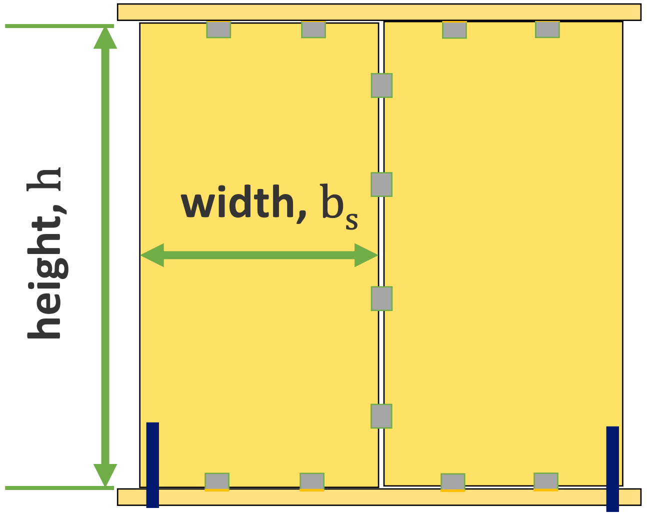
CLT Shear Walls in SDPWS 2021

(other)
CLT Shear Walls
not meeting Appendix B

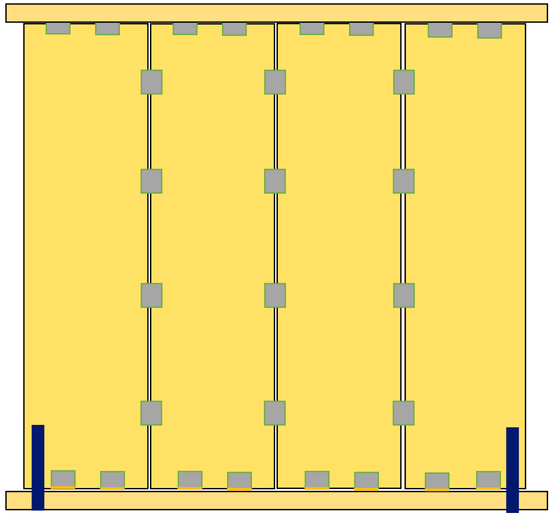


SDC A or SDC B
and ≤ 65’ tall
in SDPWS 4.6.3 Exception

CLT Shear Walls
meeting SDPWS 2021 Appendix B



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



(SDPWS B.3.7)

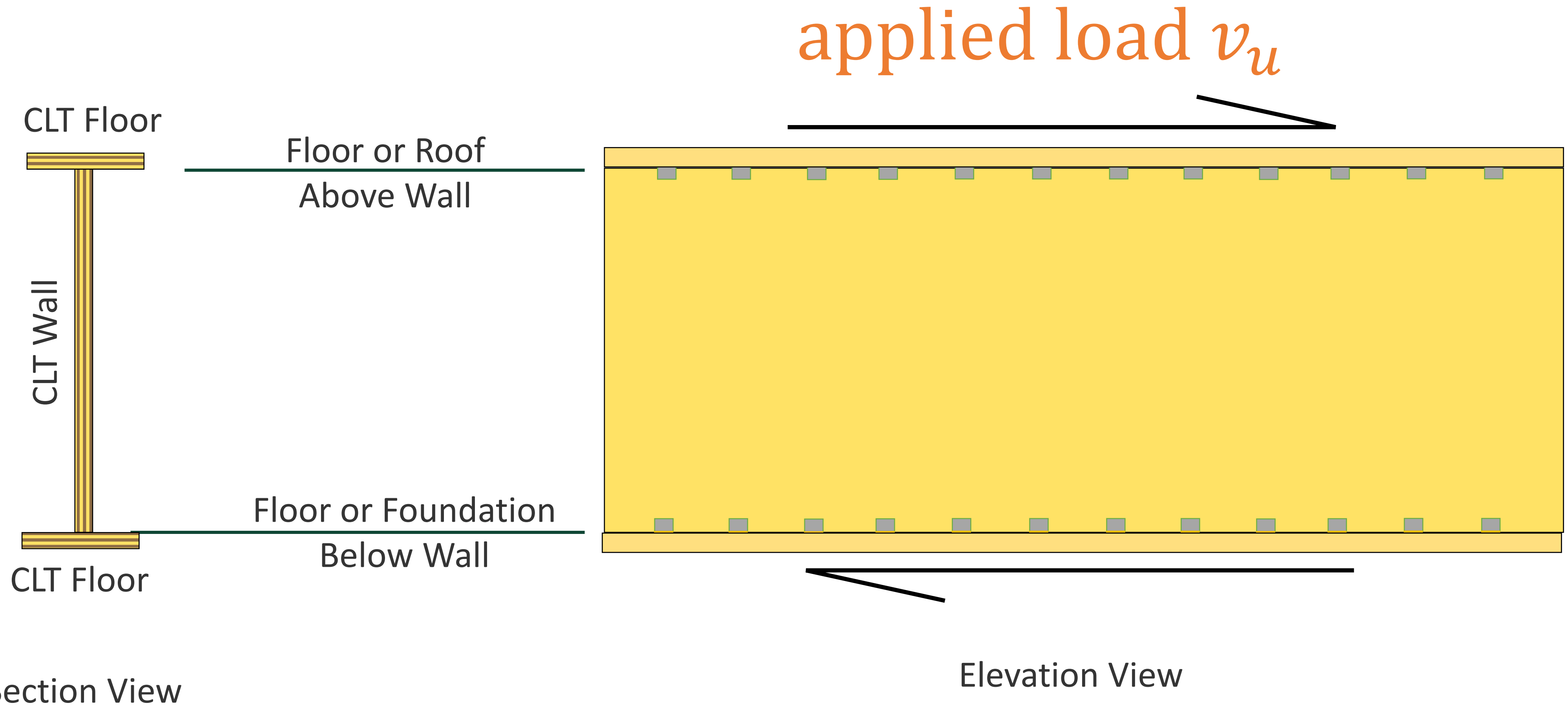
Panel aspect ratios
$h/b_s = 4$

$R = 3!$

or $4!$ or $1.5?$

CLT Shear Walls in SDPWS 2021

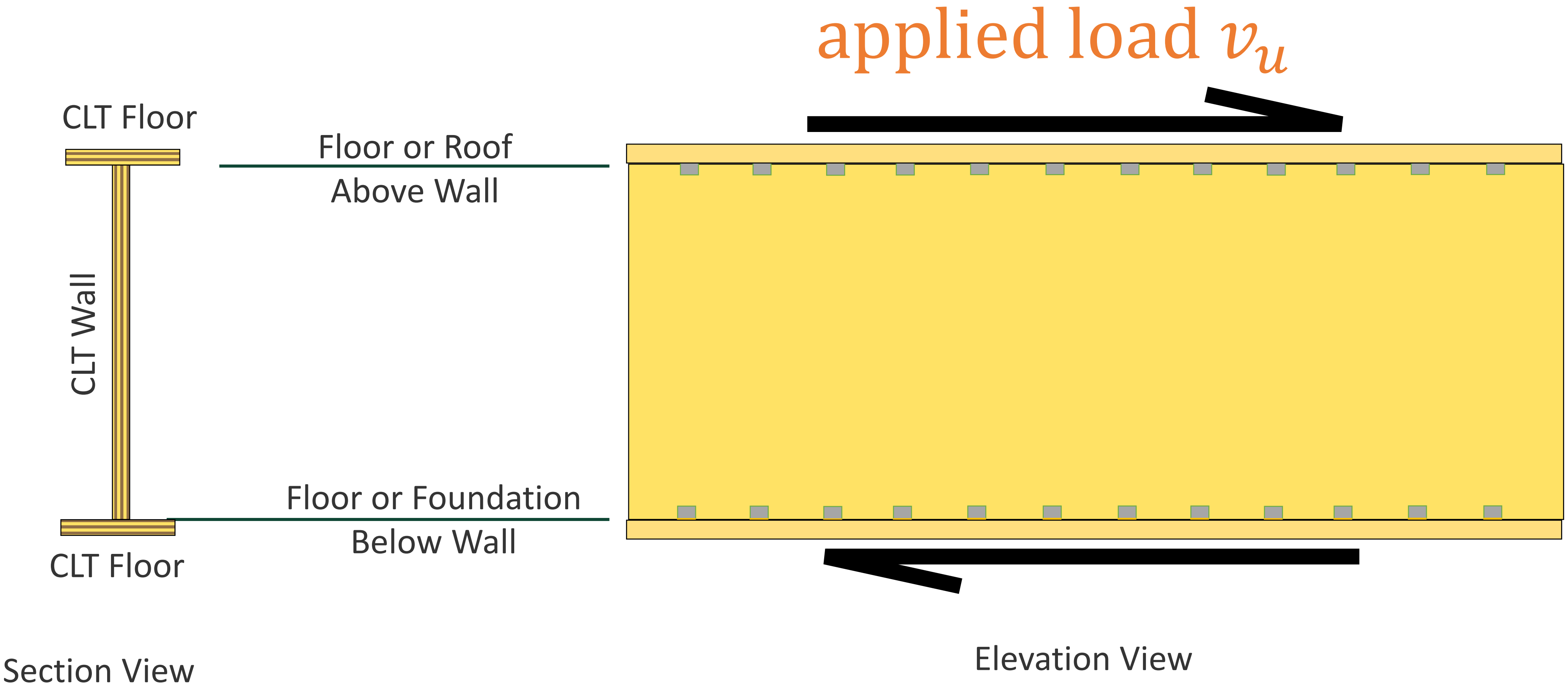
Platform Framed CLT Construction



SDPWS 2021 Section 4.1.4

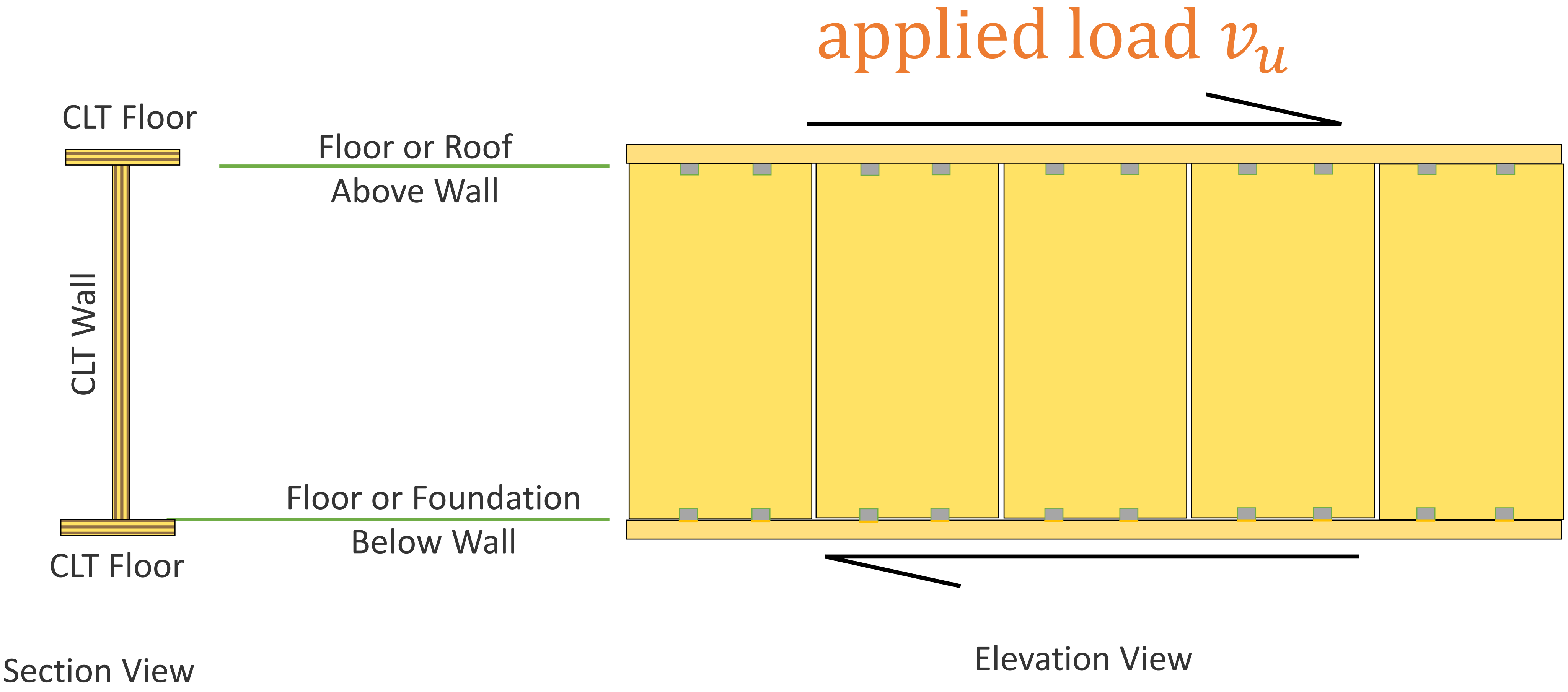
CLT Shear Walls in SDPWS 2021

Platform Framed CLT Construction



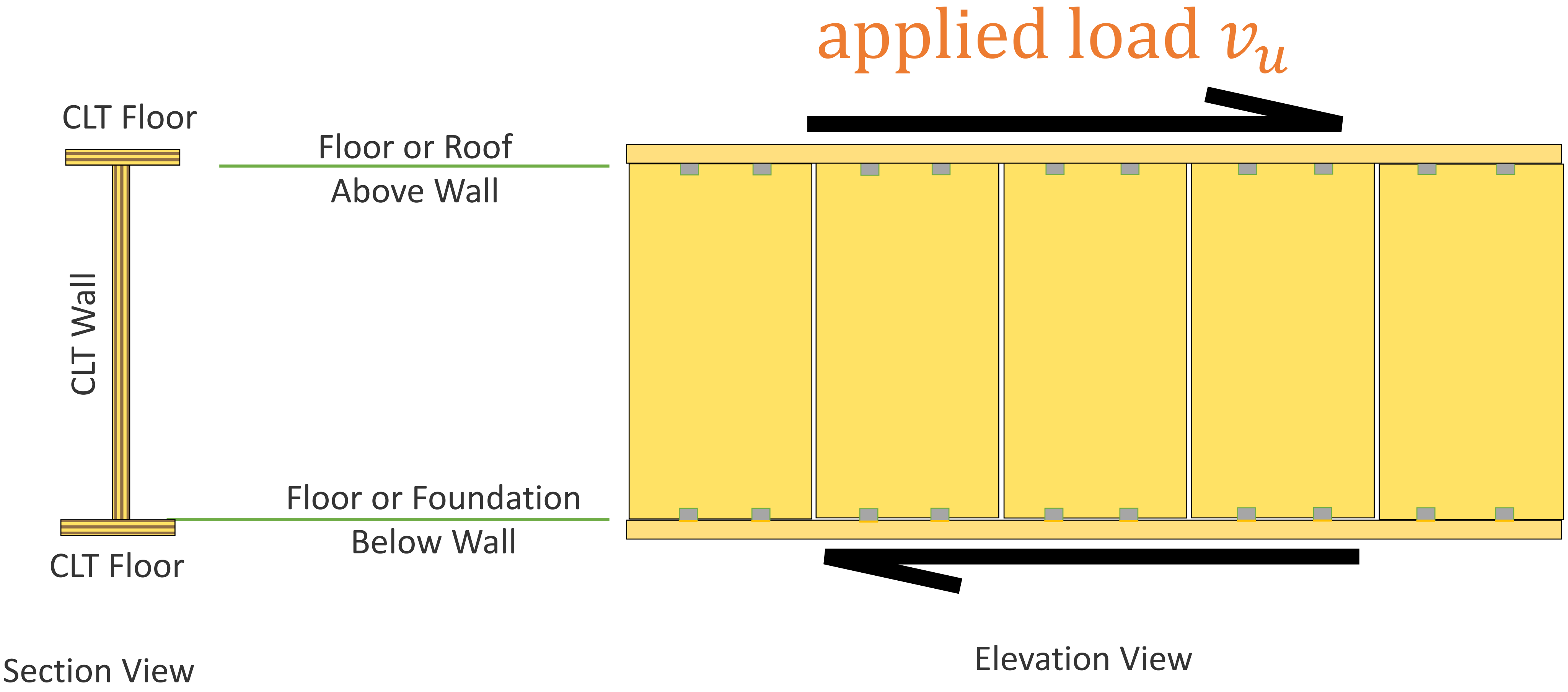
CLT Shear Walls in SDPWS 2021

Platform Framed CLT Construction



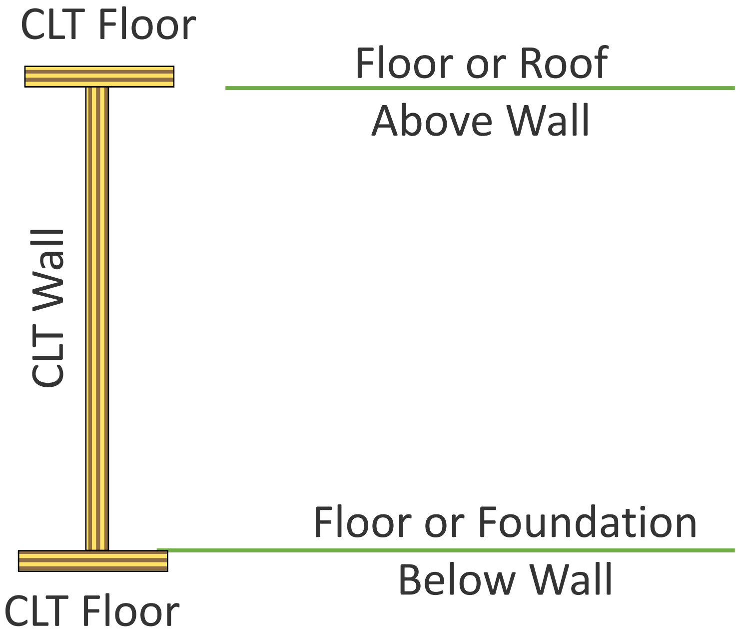
CLT Shear Walls in SDPWS 2021

Platform Framed CLT Construction

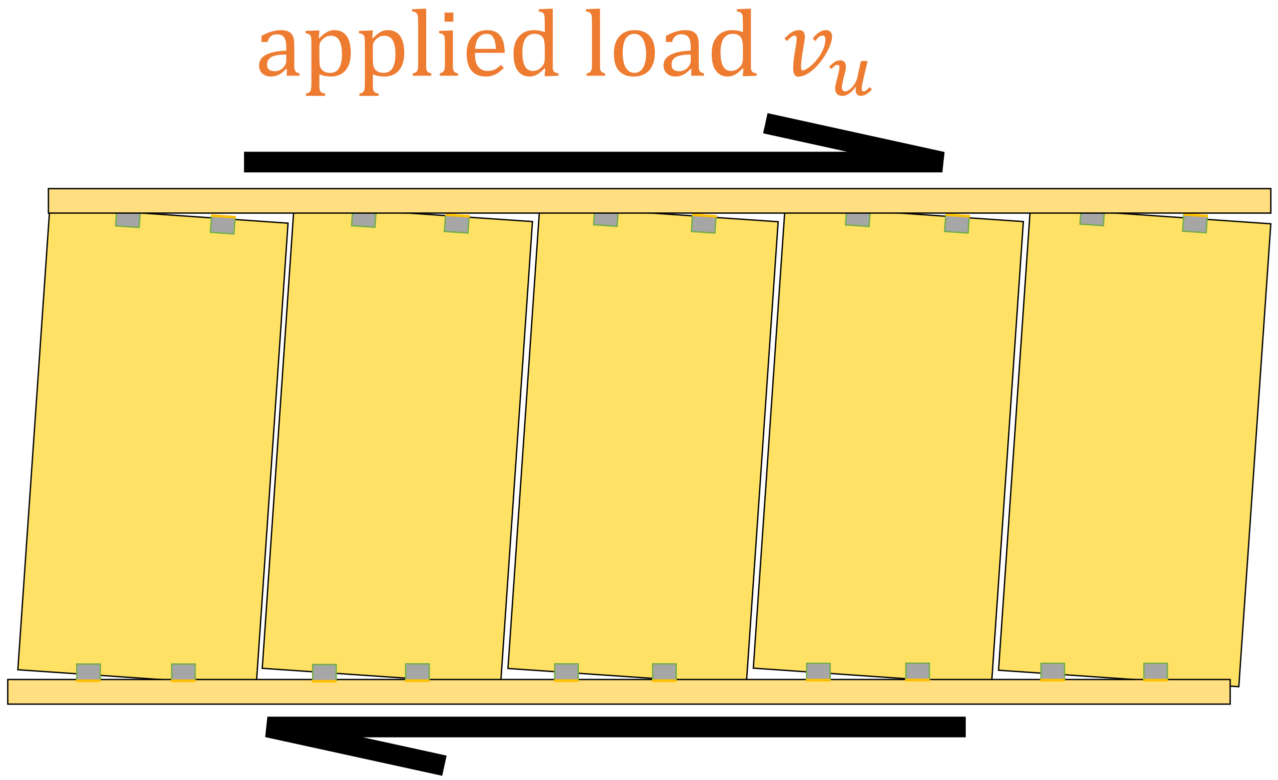


CLT Shear Walls in SDPWS 2021

Platform Framed CLT Construction



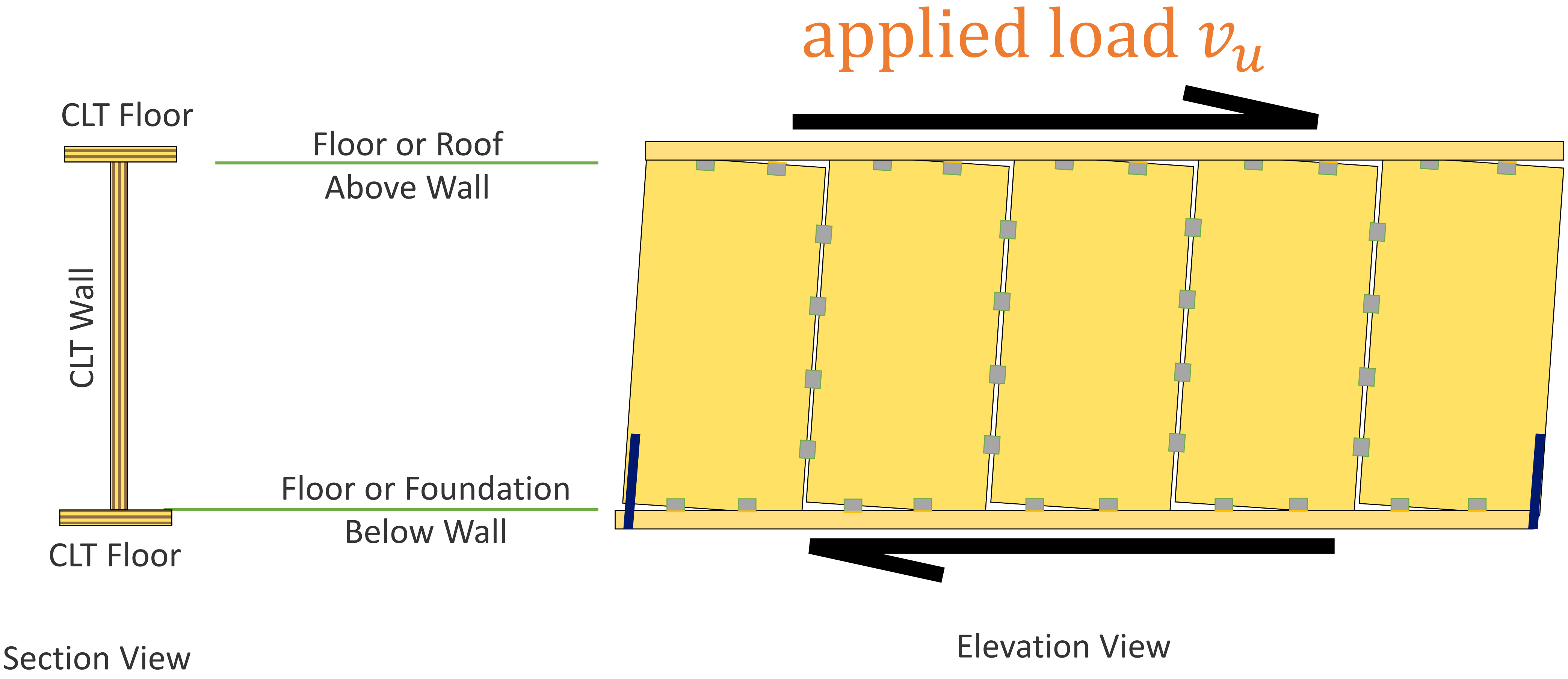
Section View



Elevation View

CLT Shear Walls in SDPWS 2021

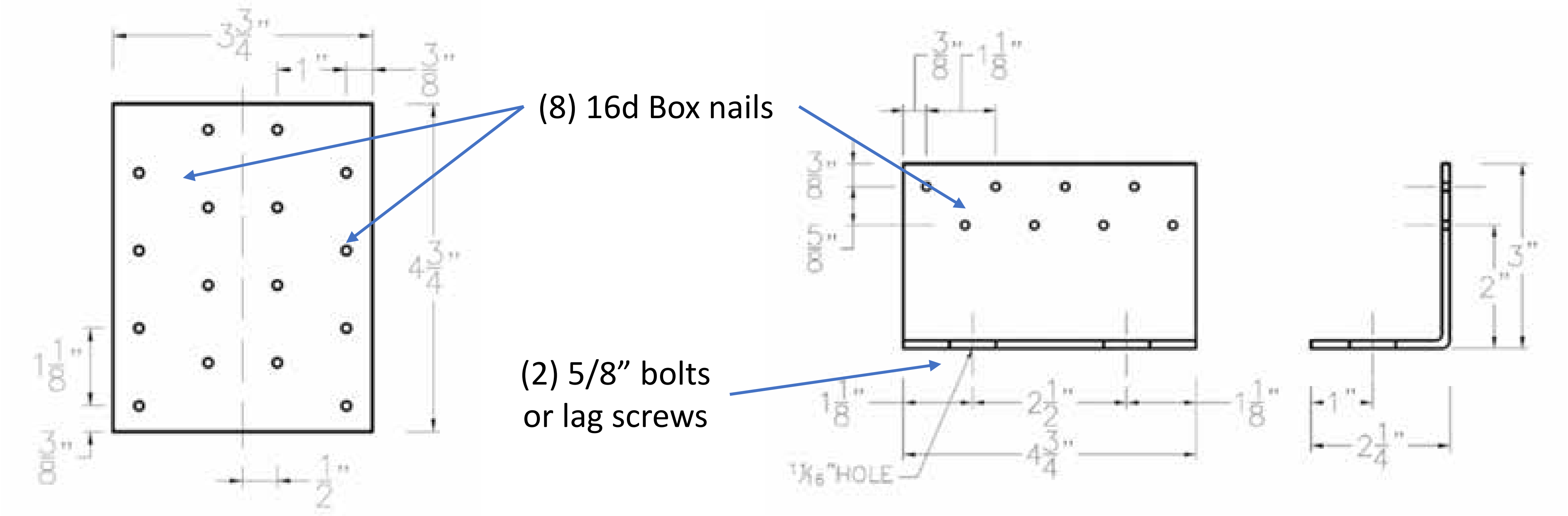
Platform Framed CLT Construction



CLT Shear Walls in SDPWS 2021

Panel to Panel Connections

Panel to Platform Connection

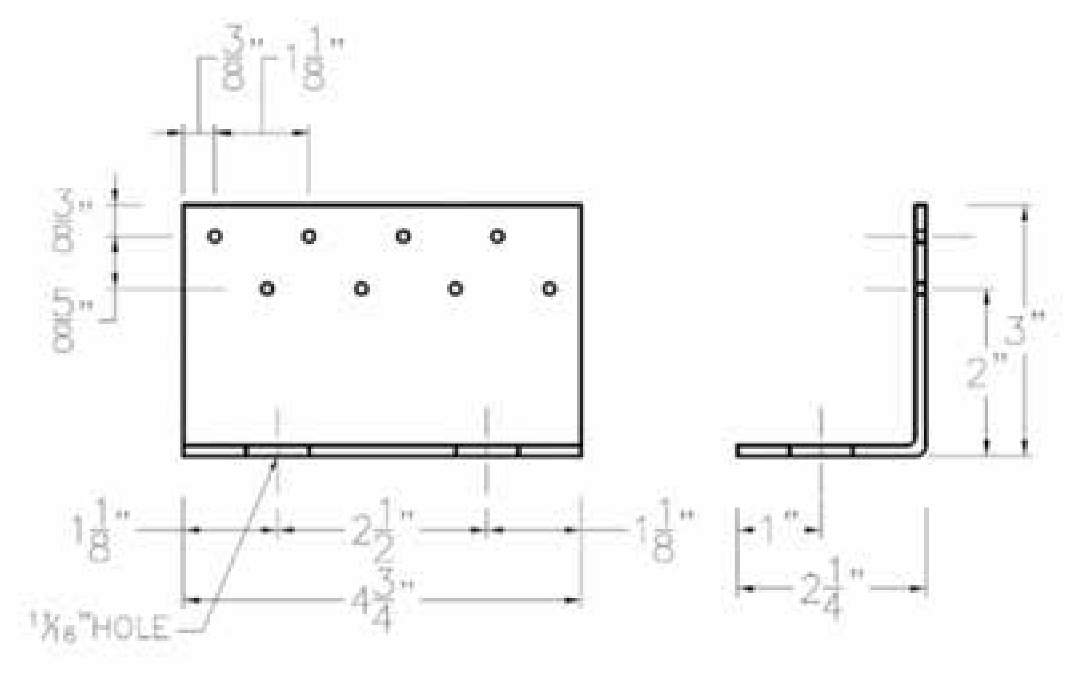


0.105” ASTM A653 Grade 33 Steel
(8) 16d box nails to each wall panel
3.5” long x 0.135”Ø shank with 0.344” Ø head

Same steel plate and nails plus
5/8” Ø bolts or lag screws to roof, floor or foundation

CLT Shear Walls in SDPWS 2021

Panel to Platform Connection



Nominal shear capacity of connector:

v_n = 2605 C_G [lbs] per angle connector

C_G adjusts for specific gravity, G of CLT

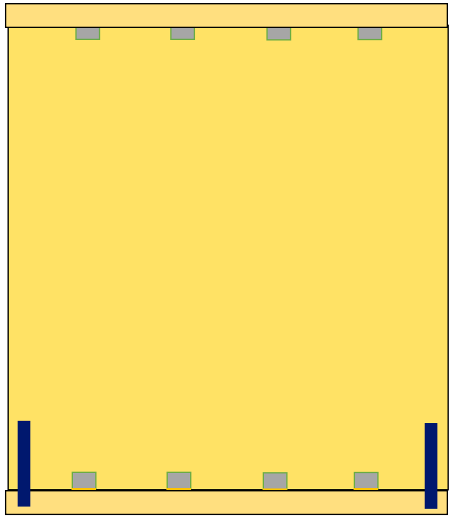
C_G = 1.0 for $G \geq 0.42$
= 0.86 for $G = 0.35$
= 1.0 – 2 (0.42-G) for $0.42 > G > 0.35$

Nominal unit shear capacity:

v_n = n (2605 / b_s) C_G [lbs/ft]

R Values for CLT Shear Walls in SDPWS 2021

(other)
CLT Shear Walls
not meeting Appendix B

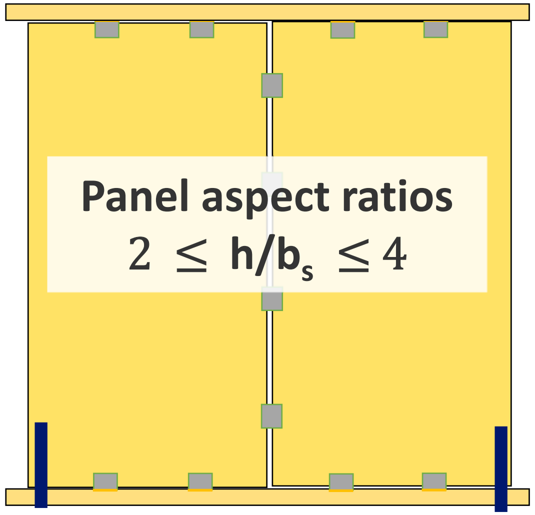


R = 1.5

C_d = 1.5 Ω_o = 2.5

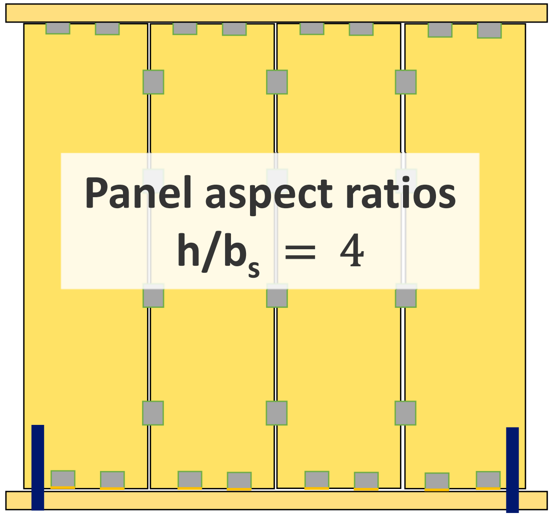
In SDPWS 2021 4.6.3

CLT Shear Walls
meeting SDPWS 2021 Appendix B



R = 3.0*

C_d = 3.0 Ω_o = 3.0



R = 4.0*

C_d = 4.0 Ω_o = 3.0

* ASCE 7-22

CrossFit Center

Spokane, WA

Photo Credit: WoodWorks

Photo Credit: Mike Bradley, Beacon Builders

Photo Credit:
WoodWorks

State of Oregon Statewide Alternative

Statewide Alternate Method
January 2015

State of Oregon
Building Codes Division
Better Buildings for Oregon

No. 15-01
Cross-Laminated Timber Provisions
(Ref.: ORS 455.060)

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 designer; 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: 2014 Oregon Structural Specialty Code (OSSC)

Code Section: OSSC Section 602.4 Type IV, Heavy Timber

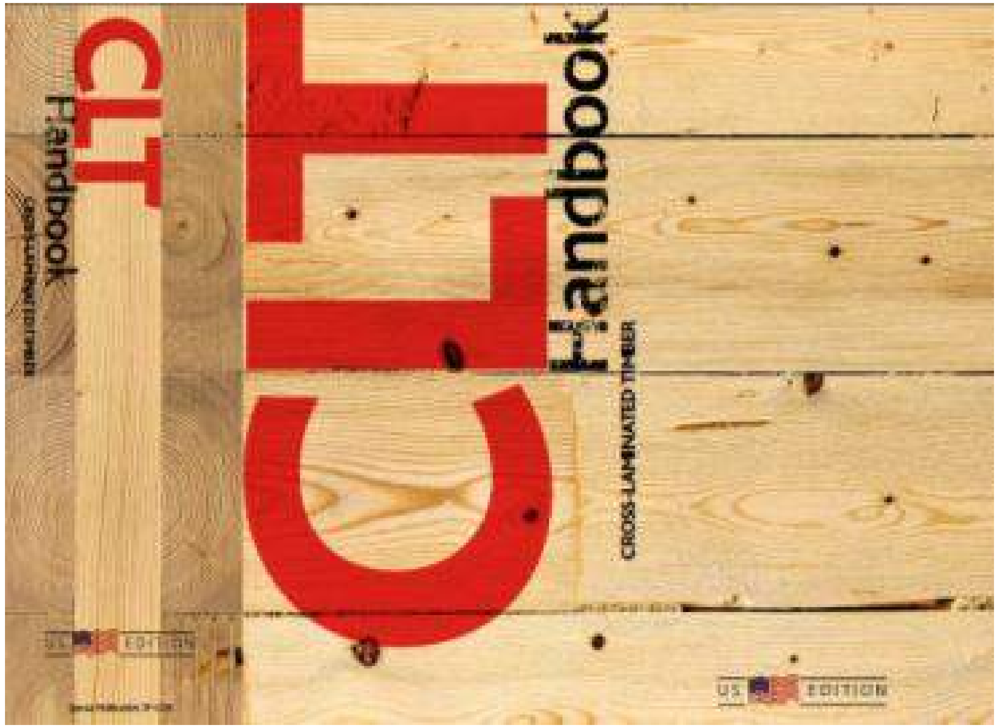
Date: January 15, 2015

Initiated by: Building Codes Division

Subject: Cross-Laminated Timber

Background:

Cross-laminated timber (CLT) is an emerging wood product with applications in both residential and non-residential buildings. Oregon BCD has prepared this alternate method which recognizes nationally adopted acceptance of CLT in Type IV Construction through the International Codes Council process. This classification will allow roughly 50 percent taller and larger buildings than



State of Oregon Statewide Alternative Method

www.oregon.gov/bcd/codes-stand/Documents/sam-15-01-crosslaminatedtimber.pdf
Or search for “Oregon CLT SAM 15-01”

Statewide Alternate Method No. 15-01

BCD | Building Codes Division
Department of Consumer and Business Services

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

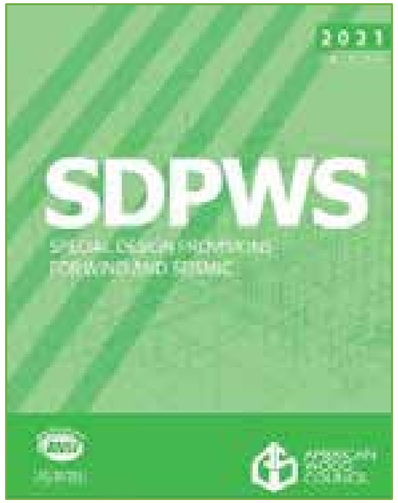
Background:

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.

2 Alternatives:

#1: CLT Shear walls per
ASCE 7-22 and SDPWS 2021



State of Oregon Statewide Alternative Method

#2: ASCE 7-16 Table 12.2-1 modified by Oregon Buildings Code Division

Alternate method path 2: When this alternate method path is selected, moderate ductility CLT shear walls shall be used as a SFRS subject to all of the following requirements.

I. Seismic design factors

Moderate ductility CLT shear walls shall be considered a bearing wall SFRS per ASCE 7-16 Section 12.2.1.

ASCE 7-16, Table 12.2-1, *Design Coefficients and Factors for Seismic Force-Resisting Systems*, shall be modified to include the following item no. 19 under *Bearing Wall Systems*:

Table 12.2-1 Design Coefficients and Factors for Seismic Force-Resisting Systems

Seismic Force-Resisting System	ASCE 7 Section Where Detailing Requirements Are Specified	Response Modification Coefficient, R^a	Overstrength Factor, Ω_0^b	Deflection Amplification Factor, C_d^c	Structural System Limitations Including Structural Height, h_n (ft) Limits[d]				
					Seismic Design Category				
					B	C	D[e]	E[e]	F[f]
A. BEARING WALL SYSTEMS									
19. Moderate ductility cross-laminated timber shear walls	14.5	2	2½	2	65	65	65	65	65

www.oregon.gov/bcd/codes-stand/Documents/sam-15-01-crosslaminatedtimber.pdf

State of Oregon Statewide Alternative Method

Alternate Path 2: Special Design and Detailing Requirements

II. **Designated moderately ductile global mode.** Moderate ductility cross-laminated shear walls designed in accordance with this statewide alternate method shall be designed and detailed to achieve ductility through any of the following global yield modes:

A. Yielding of the hold-downs/straps at the base of balloon-framed moderate ductility CLT shear walls

B. Yielding of the shear connectors at the base of balloon-framed moderate ductility CLT shear walls

C. Yielding of the hold-downs/straps at the base in combination with yielding of the shear connectors at wall panel vertical joints for balloon-framed moderate ductility CLT shear walls

D. Yielding of the hold-downs/straps at horizontal panel joints of platform-framed moderate ductility CLT shear walls

E. Yielding of the shear connectors at horizontal panel joints of platform-framed moderate ductility CLT shear walls

F. Yielding of the hold-downs/straps at horizontal panel joints in combination with yielding of the shear connectors at wall panel vertical joints for platform-framed moderate ductility CLT shear walls

Moderate ductility CLT shear walls with designated global yield mode

Design other components of shear wall system using overstrength loads

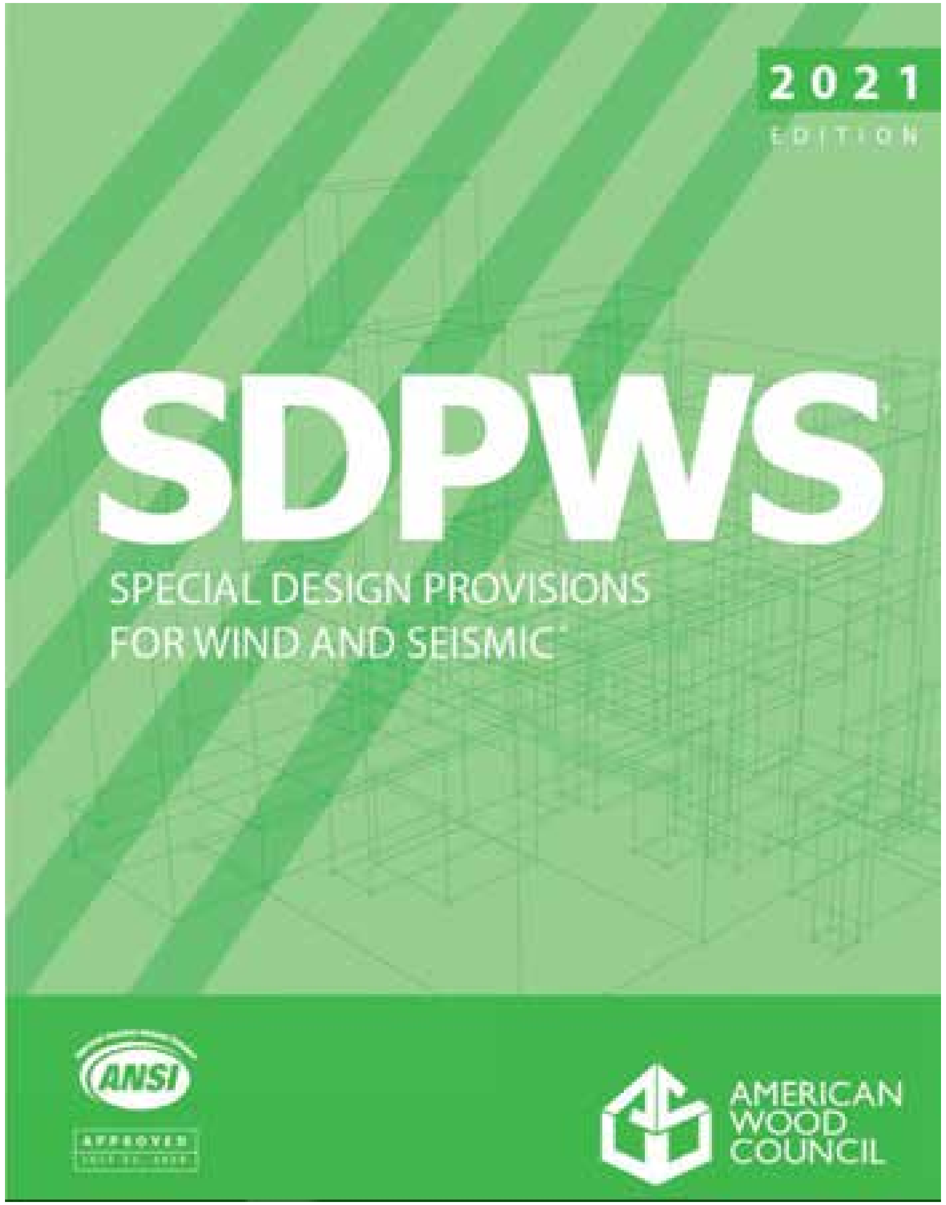
III. **Overstrength load combinations in Seismic Design Categories D through F.** For structures assigned to Seismic Design Category D, E or F, all components and elements of the SFRS except those actions which contribute to the ductile mode shall be designed for the overstrength loads of ASCE 7-16 Section 12.4.3 using the lesser of the Overstrength Factor, Ω_o, and the capacity-limited load effect in ASCE 7-16 Section 12.4.3.2. The capacity-limited load effect shall be calculated for the ductile global mode using resistance factors of unity and expected material properties for the actions contributing to the ductile global mode. Expected material properties shall be calculated in accordance with ASCE 41-17 or material standards referenced in the OSSC. The capacity-limited load effect shall not be permitted to be taken less than the demands from the seismic load combinations of OSSC Section 1605.

EXCEPTIONS:

1. Foundation and soil actions need not be designed for the overstrength loads unless required elsewhere in the OSSC or ASCE 7-16.
2. Diaphragms and diaphragm chords need not be designed for the overstrength loads unless required elsewhere in the OSSC or ASCE 7-16.

www.oregon.gov/bcd/codes-stand/Documents/sam-15-01-crosslaminatedtimber.pdf

2021 Special Design Provisions for Wind and Seismic



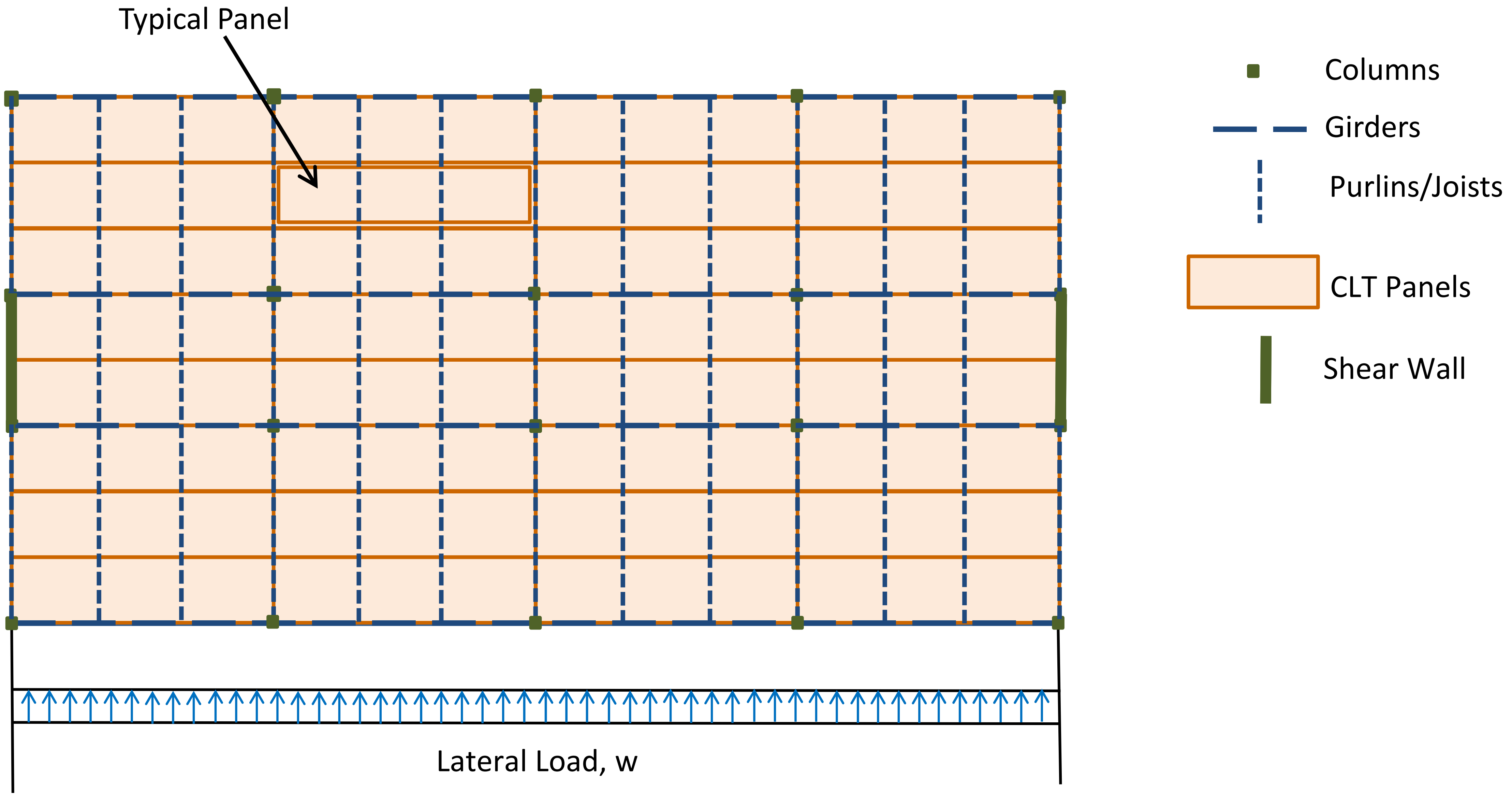
Top Changes Relevant to CLT Lateral Systems:

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

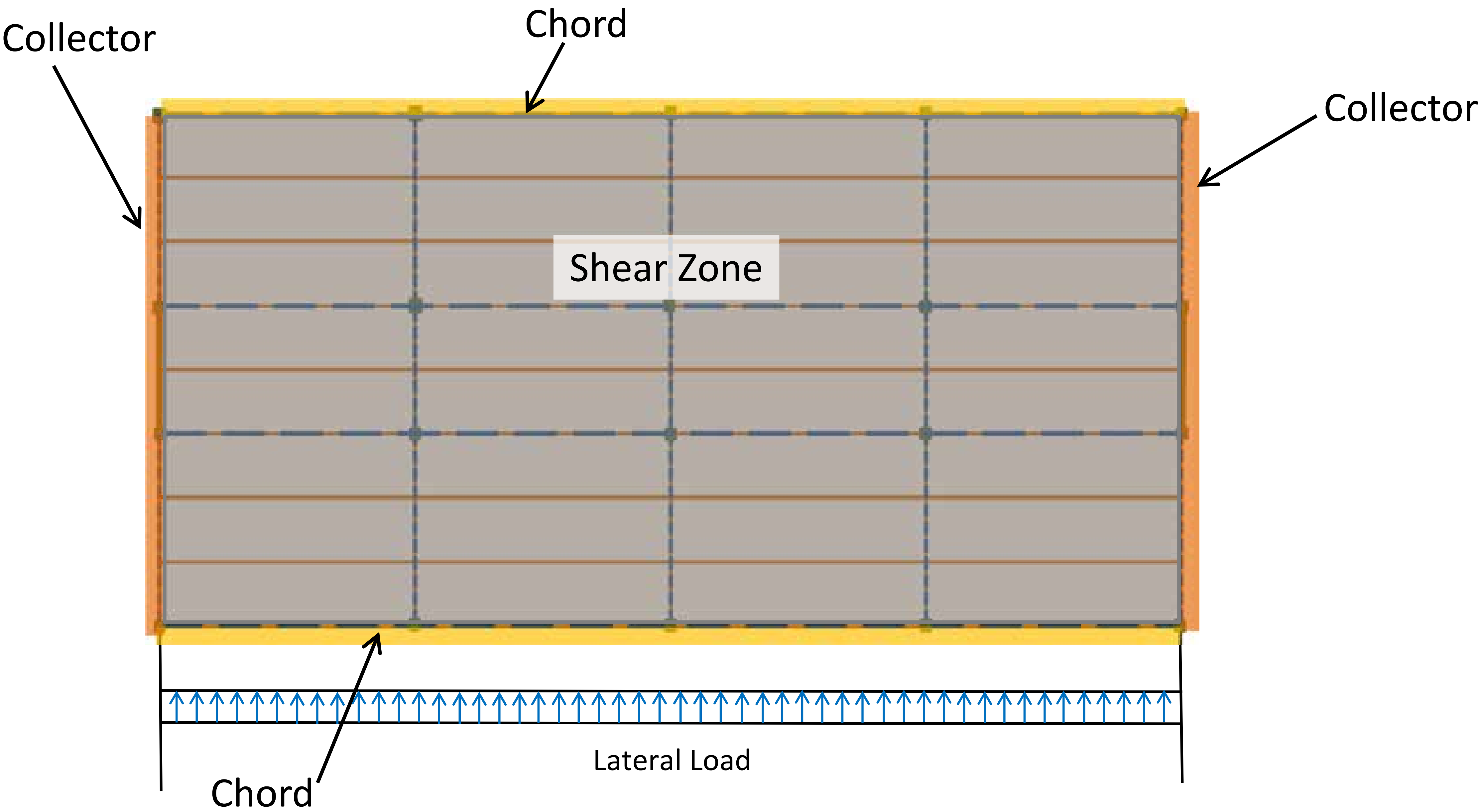
View for free at awc.org

PowerPoint IS NOT the CODE!

Generic Mass Timber Floor System

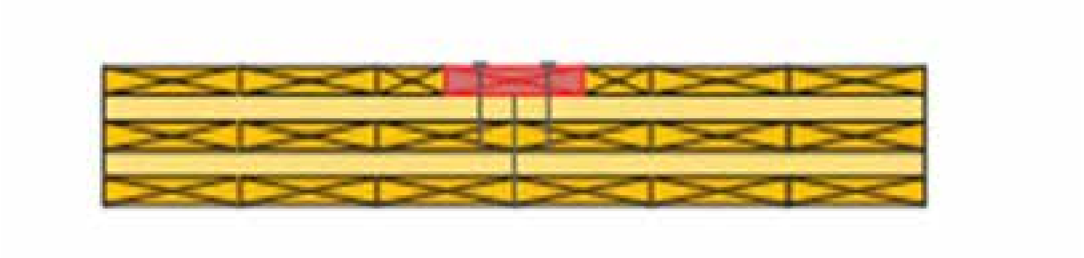


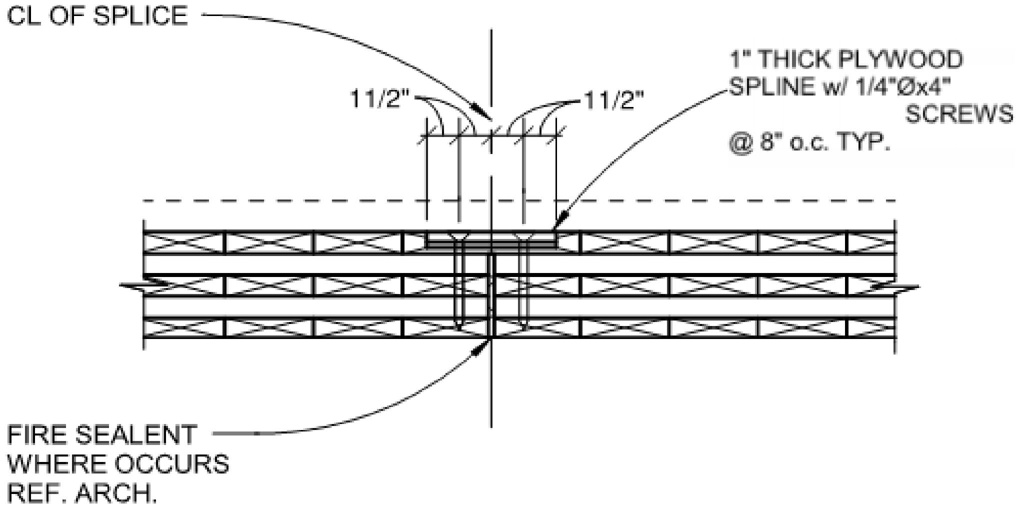
Example CLT Diaphragm Design

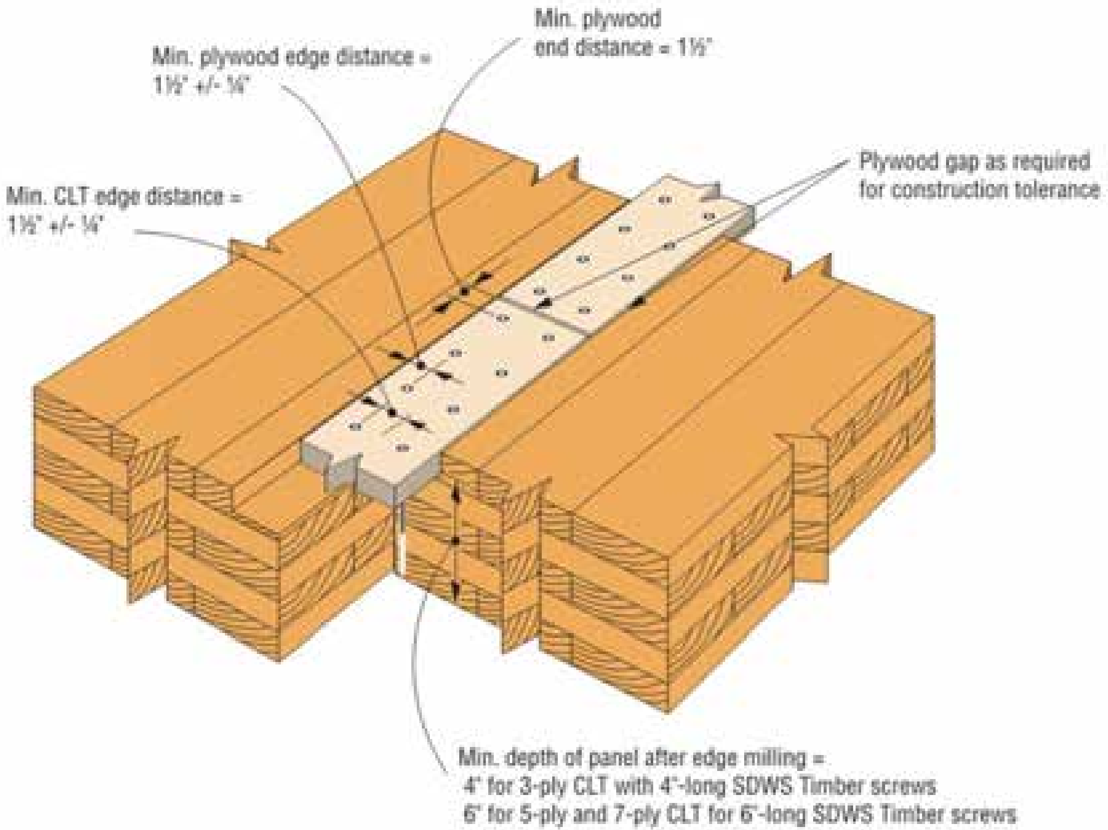


Panel to Panel Connection Styles

Single Surface Spline



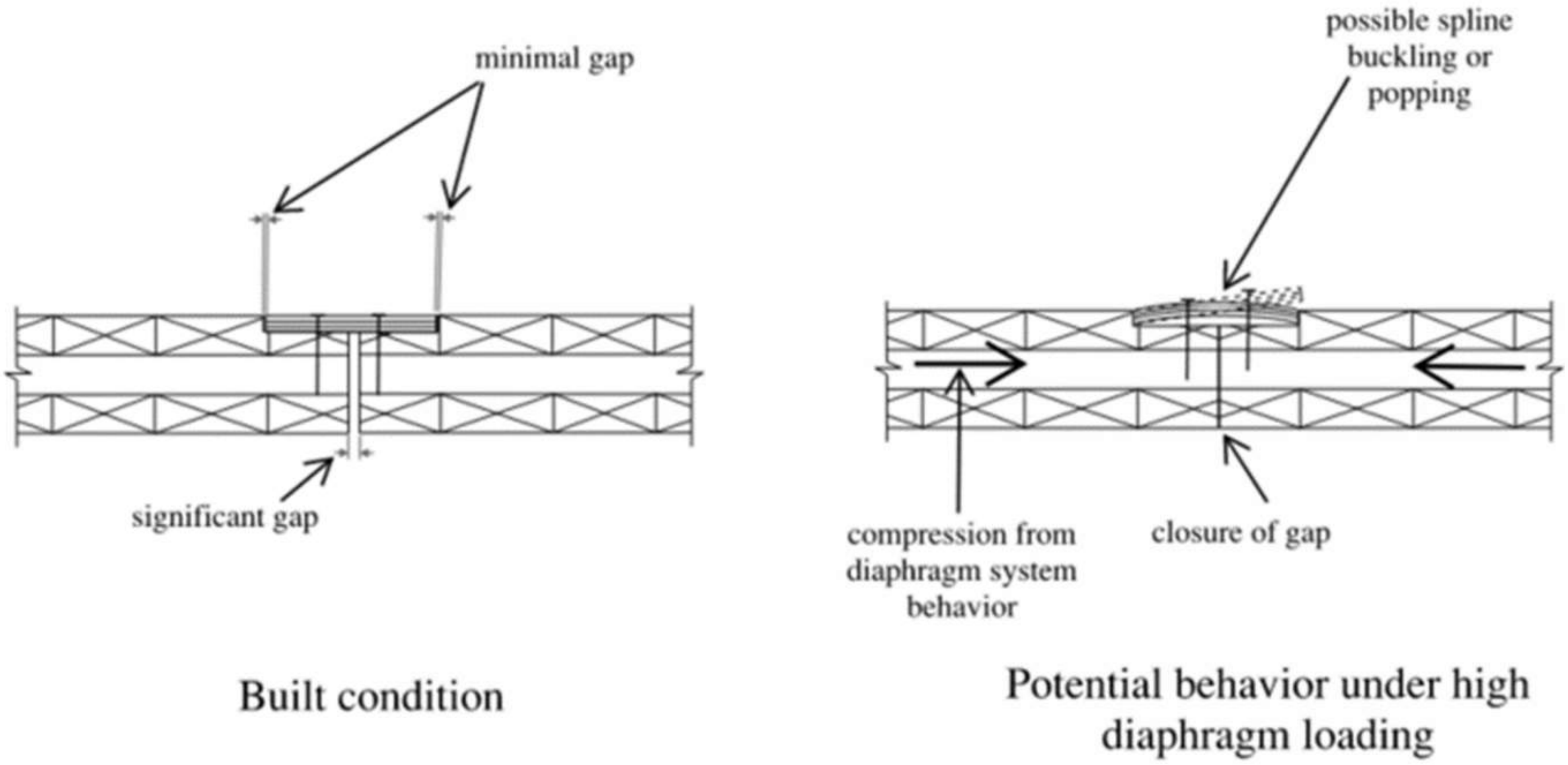




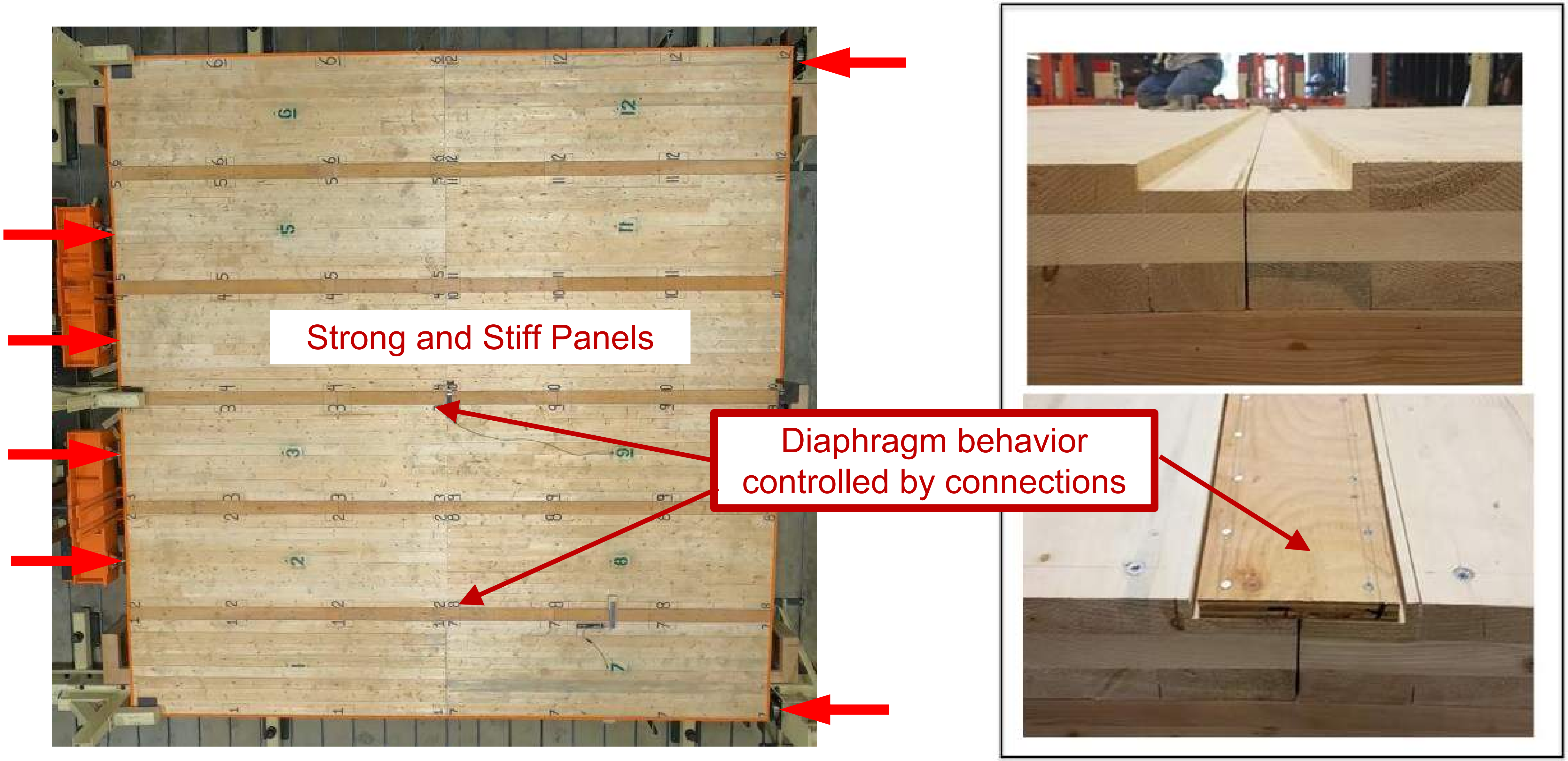
Source: Simpson Strong-Tie


Photo credit: KPFF / Reid Zimmerman

Panel to Panel Connection Tolerances



24' x 24' CLT Diaphragm Test with Plywood Spline by AWC



2021 Special Design Provisions for Wind and Seismic

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 IIIs 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, 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.

Only 1 page of requirements for CLT Diaphragms

2021 Special Design Provisions for Wind and Seismic

4.5 Cross-Laminated Timber (CLT) Diaphragms

4.5.1 Application Requirements

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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.

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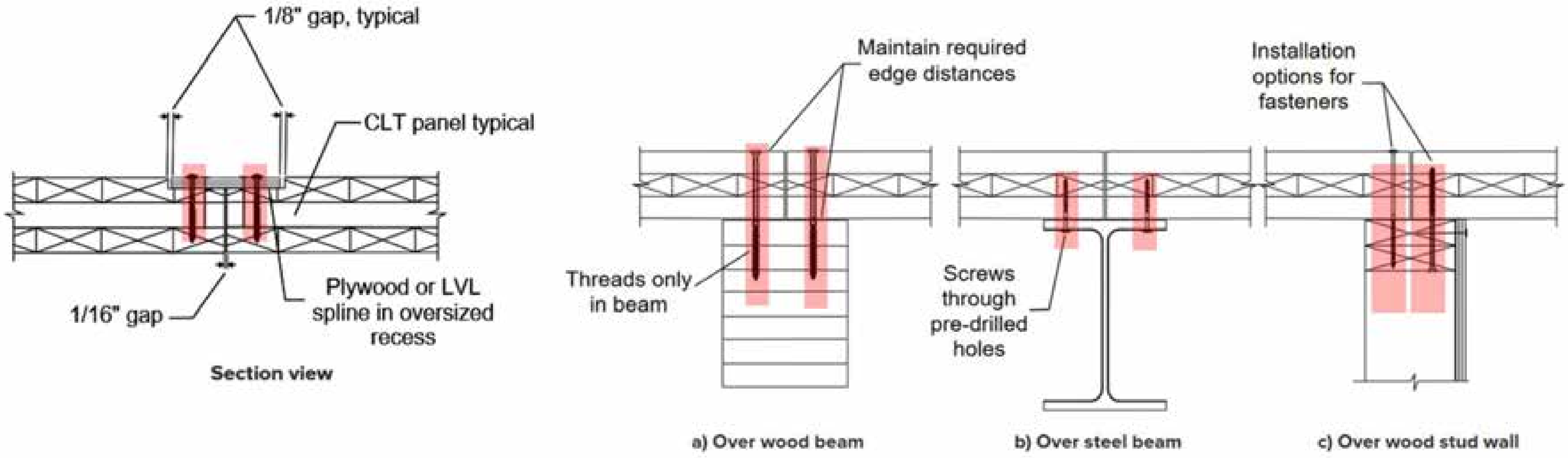
Diaphragm chord elements and chord splice connections using materials other than wood or steel shall be designed using provisions in NDS 1.4.

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, ϕ, and λ; and Z shall be controlled by Mode IIIs 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 IIIs or Mode IV** per NDS 12.3.1 controls capacity

Connection Yield Modes Per the NDS

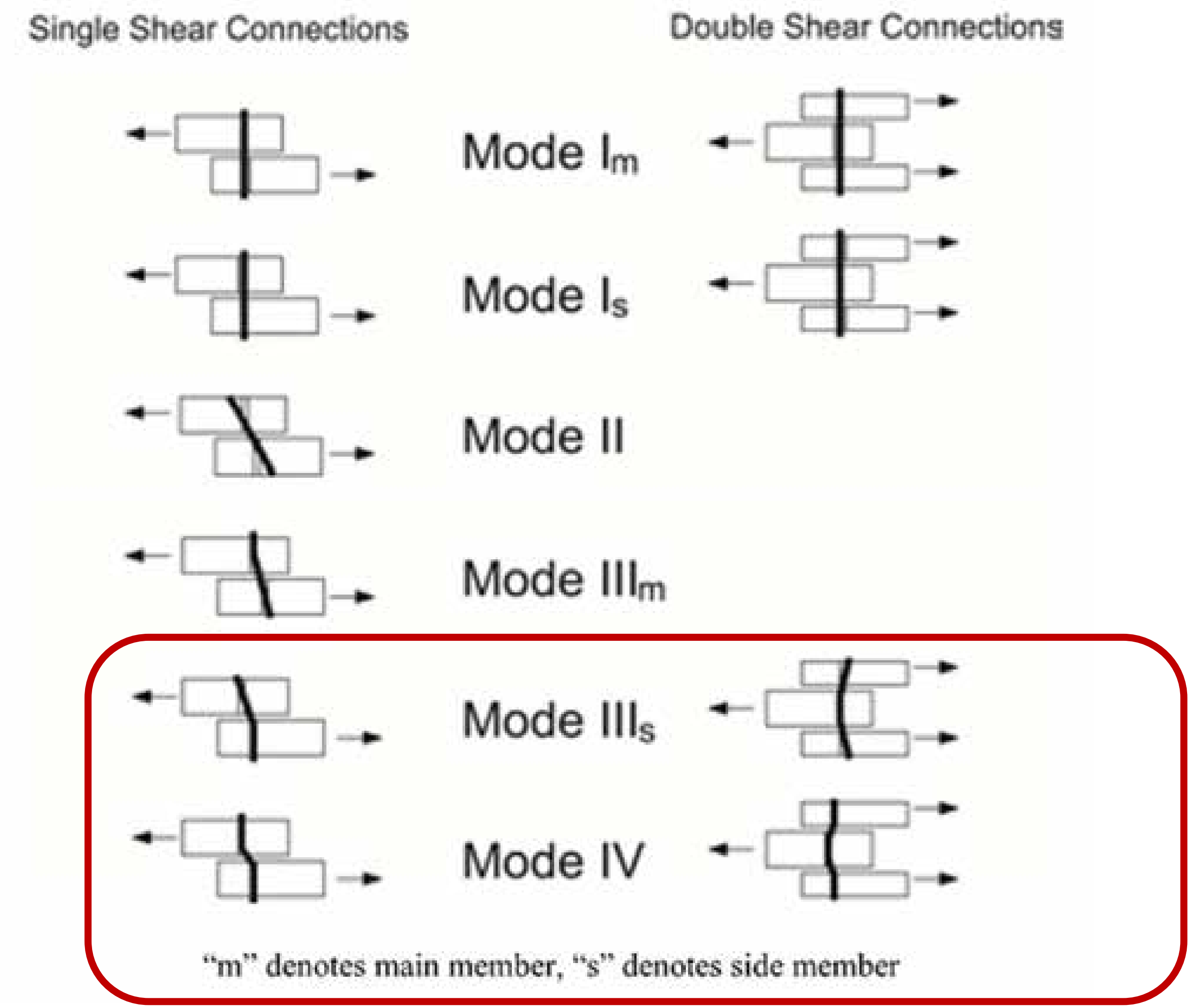


Table 11.3.1 Applicability of Adjustment Factors for Connections

		ASD Only	ASD and LRFD										LRFD Only		
		Load Duration Factor[1]	Wet Service Factor	Temperature Factor	Group Action Factor	Geometry Factor[3]	Penetration Depth Factor[3]	End Grain Factor[3]	Metal Side Plate Factor[3]	Diaphragm Factor[3]	Toe-Nail Factor[3]	Format Conversion Factor	Resistance Factor	Time Effect Factor
												K_F	ϕ	
Lateral Loads														
Dowel-type Fasteners (e.g. bolts, lag screws, wood screws, nails, spikes, drift bolts, & drift pins)	$Z^* = \boxed{Z \times}$	1.0	C_M	C_t	C_g	C_Δ	-	C_{eg}	-	1.0	C_{tn}	1.0	1.0	1.0

Also 1.0 for CLT Diaphragm Shear Connections

SDPWS 2021 Section 4.5.4(1) and NDS Table 11.3.1

CLT Diaphragm Shear Connection Design

Nominal capacity of CLT diaphragm shear connection fastener:

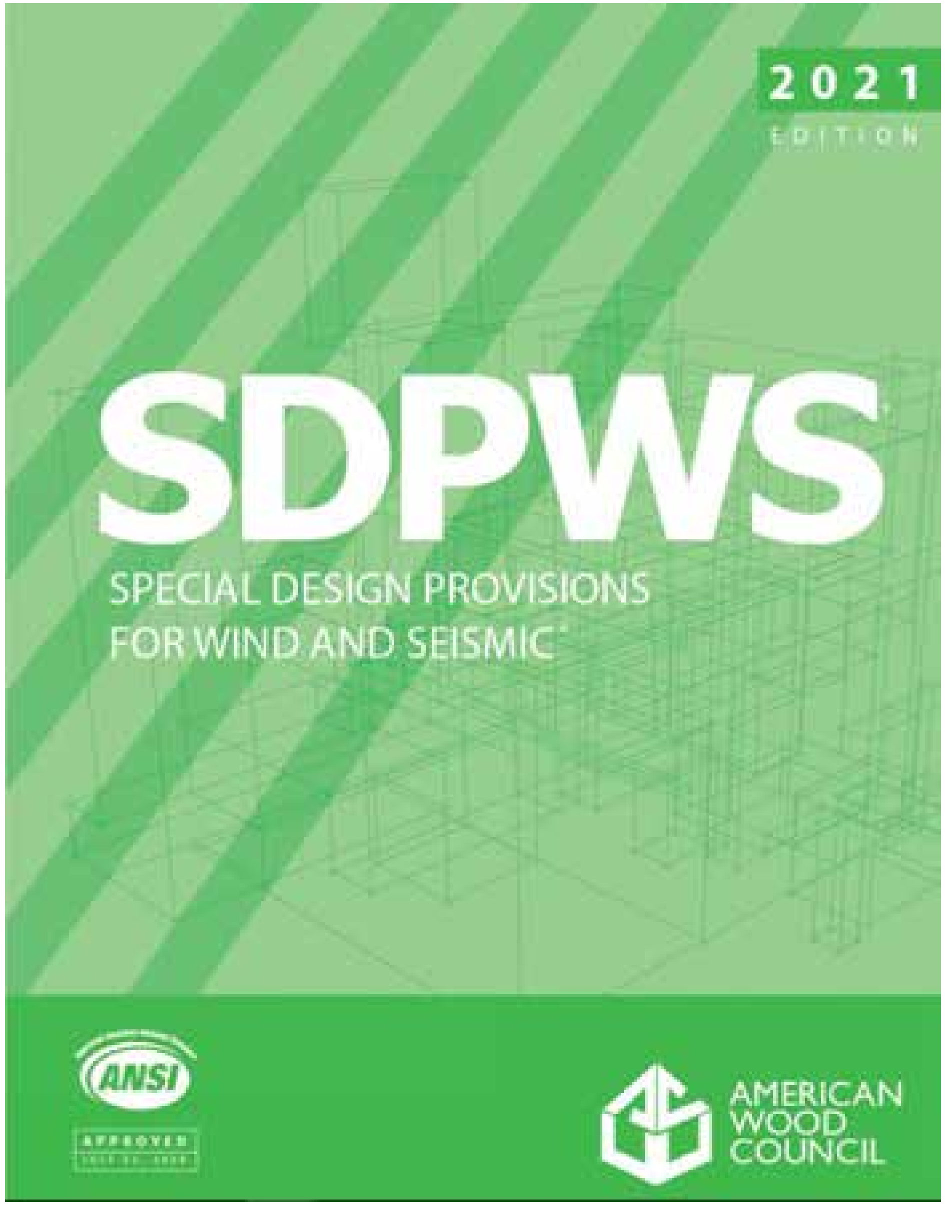
$$Z_n = 4.5\,Z^*$$

Where Z^* is reference lateral capacity Z of NDS

multiplied by all applicable factors *except* C_D, K_F, ϕ, λ = 1.0

SDPWS 2021 Section 4.5.4(1) and NDS Table 11.3.1

2021 SDPWS – Unified Nominal Shear Capacity



To calculate the ASD or LRFD shear capacity, SDPWS 2021 has different reduction factors for wind and seismic

	Design shear capacity	
	ASD	LRFD
Wind	$v_n/2.0$	$0.8\ v_n$
Seismic	$v_n/2.8$	$0.5\ v_n$

ASD seismic design capacity:

$4.5\ Z^* / 2.8 = 1.61\ Z^* \approx C_D\ Z = 1.6\ Z$

2021 Special Design Provisions for Wind and Seismic

4.5 Cross-Laminated Timber (CLT) Diaphragms

4.5.1 Application Requirements

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4.5.2 Deflection

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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, ϕ, and λ; and Z shall be controlled by Mode IIIs 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, 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.

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.
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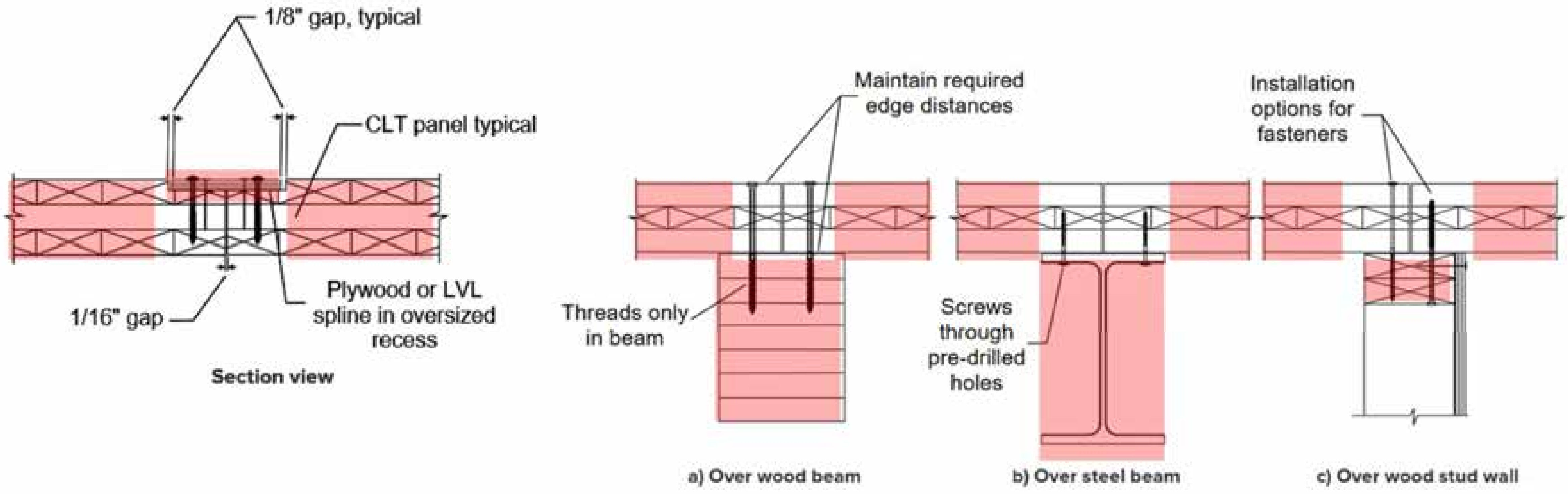
Other CLT Diaphragm Components



Other CLT Diaphragm Components

Increased Diaphragm Design Forces ≤ Design Capacity

$$\gamma_D \cdot v \leq v'$$

v = wind or seismic force demand

v' = Adjusted capacity calculated per the NDS

$\gamma_D =$

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 splice connections controlled by Mode IIIs or IV (wind)

*See **SDPWS 2021 Section 4.5.4** for the full information*

CLT Diaphragm Design Resource

WOODWORKS

CLT Diaphragm Design for Wind and Seismic Resistance

Using SDPWS 2021 and ASCE 7-22

Cross-laminated timber (CLT) has become increasingly prominent in building construction and can be seen in buildings throughout the world. Specifically, the use of CLT floor and roof panels as a primary gravity force-resisting component has become relatively commonplace. Now, with availability of the 2021 *Special Design Provisions for Wind and Seismic* (SDPWS 2021) from the American Wood Council (AWC), U.S. designers have a standardized path to utilize CLT floor and roof panels as a structural diaphragm. Prior to publication of this document, projects typically had to receive approval to use CLT as a structural diaphragm on a case-by-case basis from the local Authority Having Jurisdiction (AHJ).

This paper highlights important provisions of SDPWS 2021 for CLT diaphragm design and recommendations developed by the authors in the more extensive *CLT Diaphragm Design Guide*, based on SDPWS 2021, published by WoodWorks – Wood Products Council.

AWC SDPWS 2021

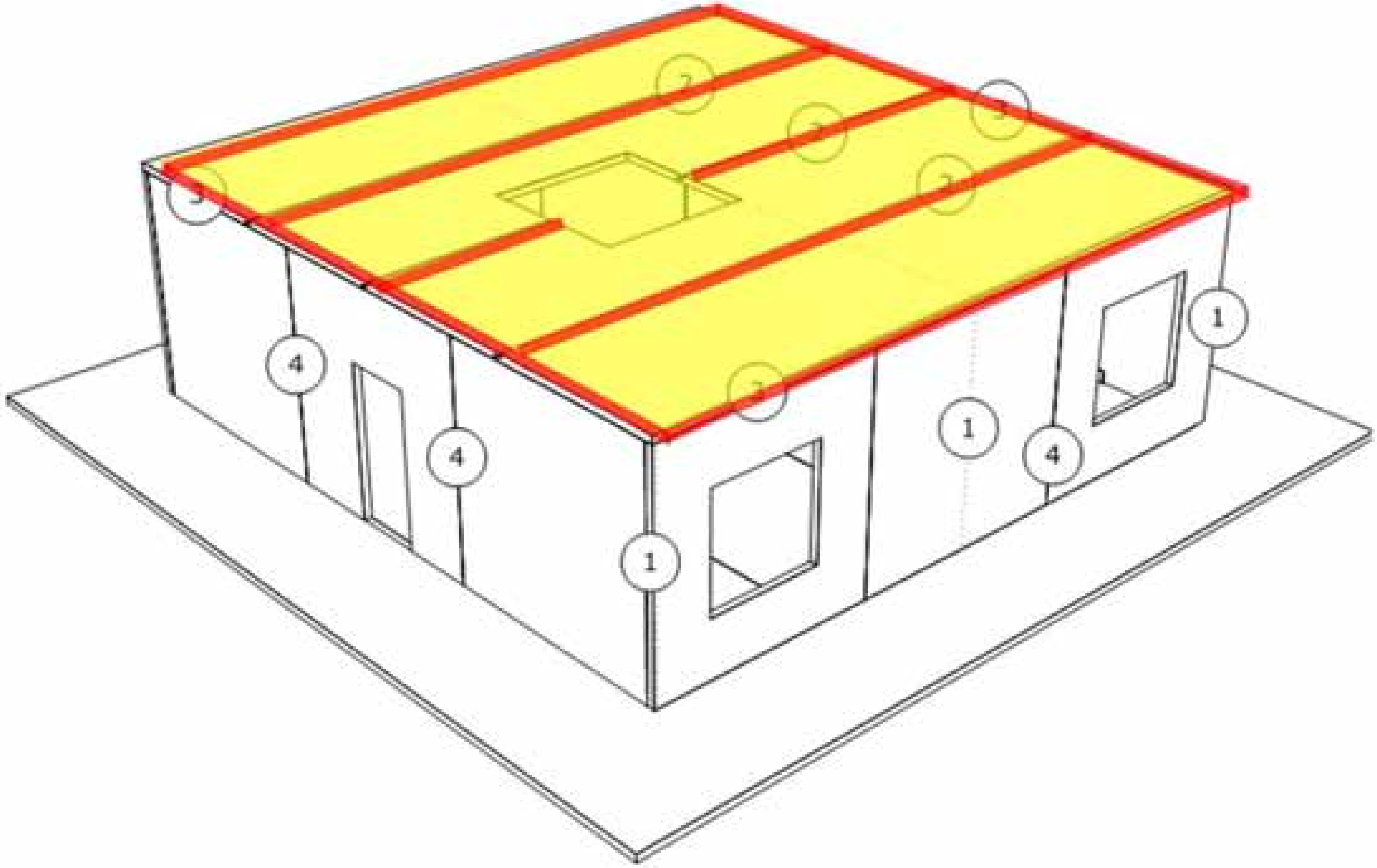
SDPWS 2021 is the first edition to provide direct provisions for CLT to be used as an element in a diaphragm or shear wall. To differentiate between CLT and light-frame lateral force-resisting systems, it adopts the terminology *sheathed wood-frame* for light-frame diaphragms (SDPWS §4.2) and shear walls (SDPWS §4.3), and includes new sections for CLT diaphragms (SDPWS §4.5) and shear walls (SDPWS §4.6). SDPWS 2021 is referenced in the 2021 International Building Code (IBC).

Shear Capacity

SDPWS 2021 has a single nominal shear capacity for each set of construction details, v_n, defined in §4.1.4 for use with both wind and seismic design. From this nominal shear capacity, the Allowable Stress Design (ASD) and Load and Resistance Factor Design (LRFD) wind and seismic design capacities are determined by dividing by the ASD reduction

Free at **woodworks.org**

CLT Diaphragms

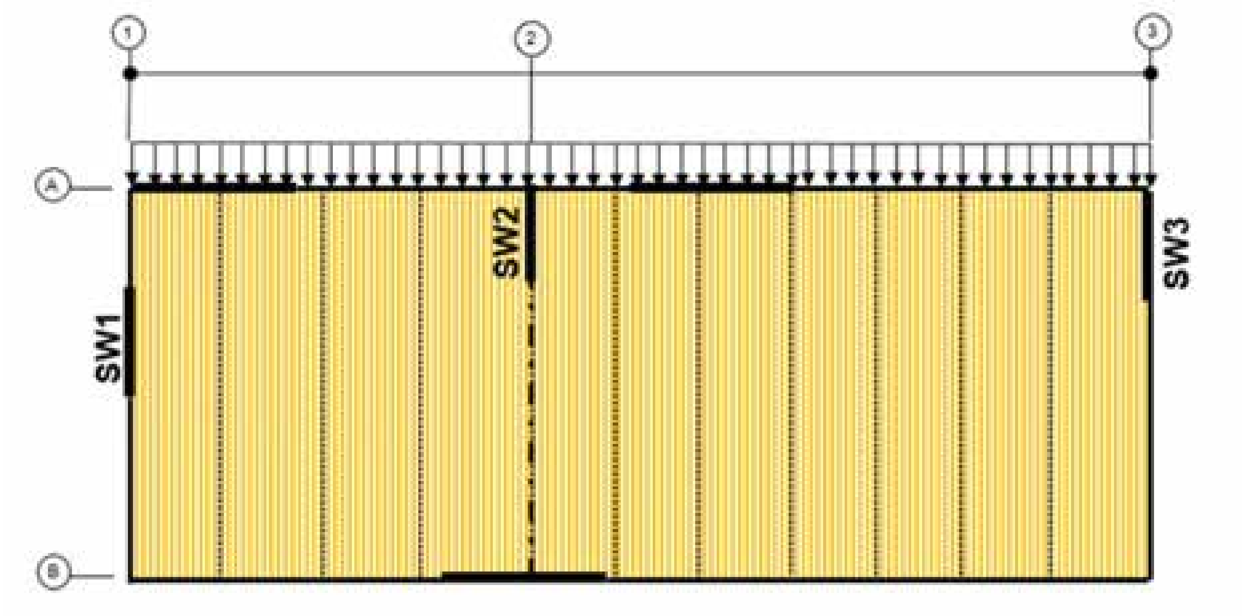


Is the Diaphragm
Rigid or Flexible?

CLT Diaphragm Deflection Requirements

SDPWS 2021 Section 4.5.2 Requirement:

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



CLT Diaphragm Design Guide

WOODWORKS
WOOD PRODUCTS COUNCIL

CLT DIAPHRAGM DESIGN GUIDE

BASED ON THE 2021 SDPWS

» Under Development By:

WOODWORKS
WOOD PRODUCTS COUNCIL

Holmes Structures

kpff

SWINERTON
MASS TIMBER

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USDA

Solutions Paper on CLT Modeling

WoodWorks™
WOOD PRODUCTS COUNCIL

An Approach to CLT Diaphragm Modeling for Seismic Design with Application to a U.S. High-Rise Project

Adapted from a paper by Scott Breneman, Eric McDonnell* and Reid B. Zimmerman,* presented at the 2018 World Conference on Timber Engineering*

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 is also applied to the candidate floor diaphragm design for the Framework project, a winner of the U.S. Tall Wood Building Prize Competition, currently under design. Observations from this effort are that the proposed method, while a more refined model than typically used during building design, shows promise to meet the needs of innovative CLT seismic designs where appropriate simpler diaphragm models are not available.

(Not per SPDWS 2021)

Free at **woodworks.org**

Questions? Ask us anything.

WOODWORKS
WOOD PRODUCTS COUNCIL

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Regional Director | OR, ID-South, HI
(303) 902-3151

kate.carrigg@woodworks.org

901 East Sixth, Thoughtbarn-Delineate Studio, Leap!Structures, photo Casey Dunn

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Funding provided in part by the Softwood Lumber Board