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

March 27, 2023

Presented by Anthony Harvey and Mike Romanowski

Adidas East Village Expansion / LEVER Architecture / photo Jeremy Bittermann

Early Design Decisions: Priming Mass Timber Projects for Success

WOODWORKS
WOOD PRODUCTS COUNCIL

Presented by:
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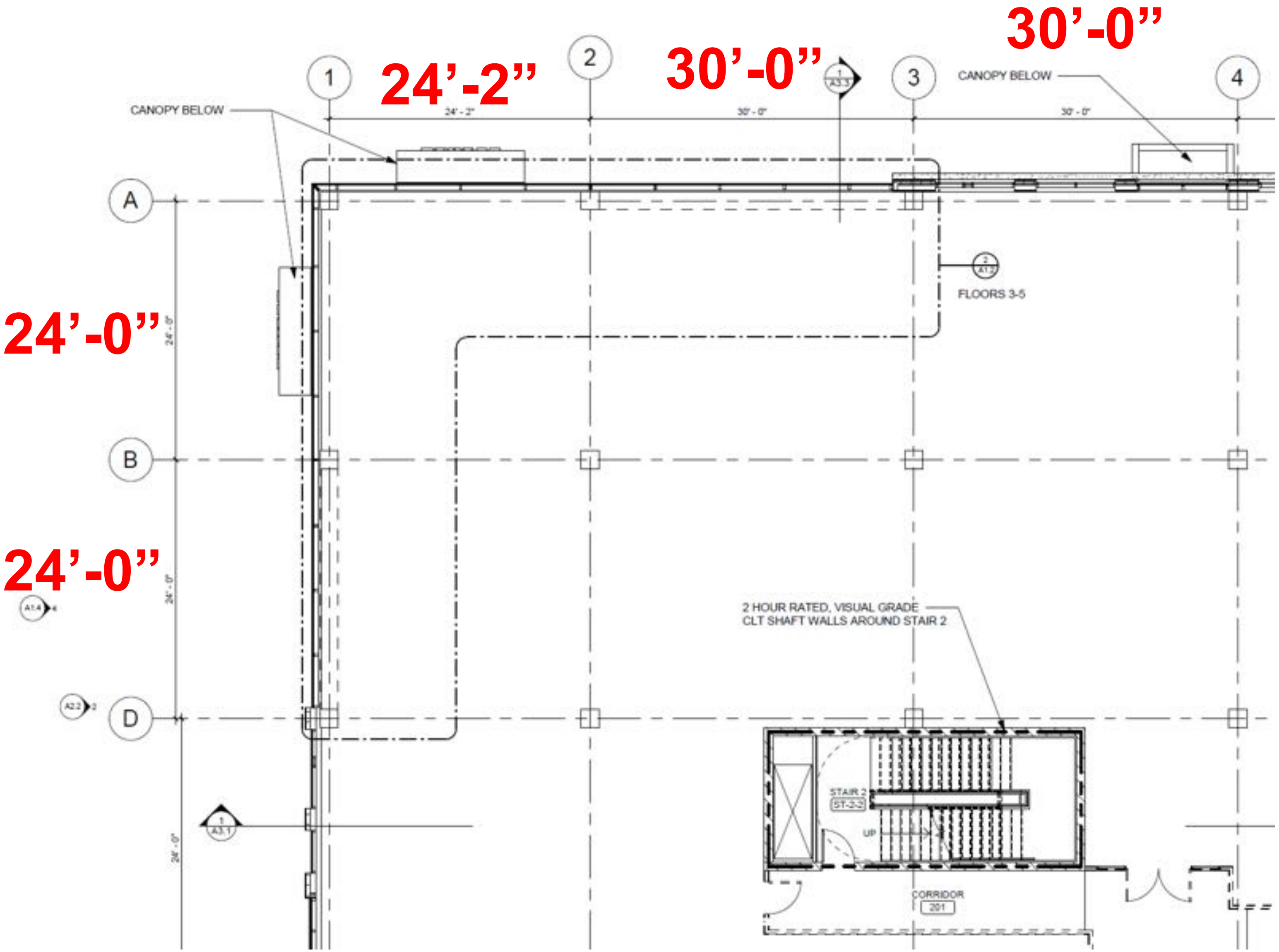
The Canyons, Kaiser+Path, photo Jeremy Bittermann

Structural Grid

Structural Grid

Grids & Spans

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



Structural Grid

Grids & Spans

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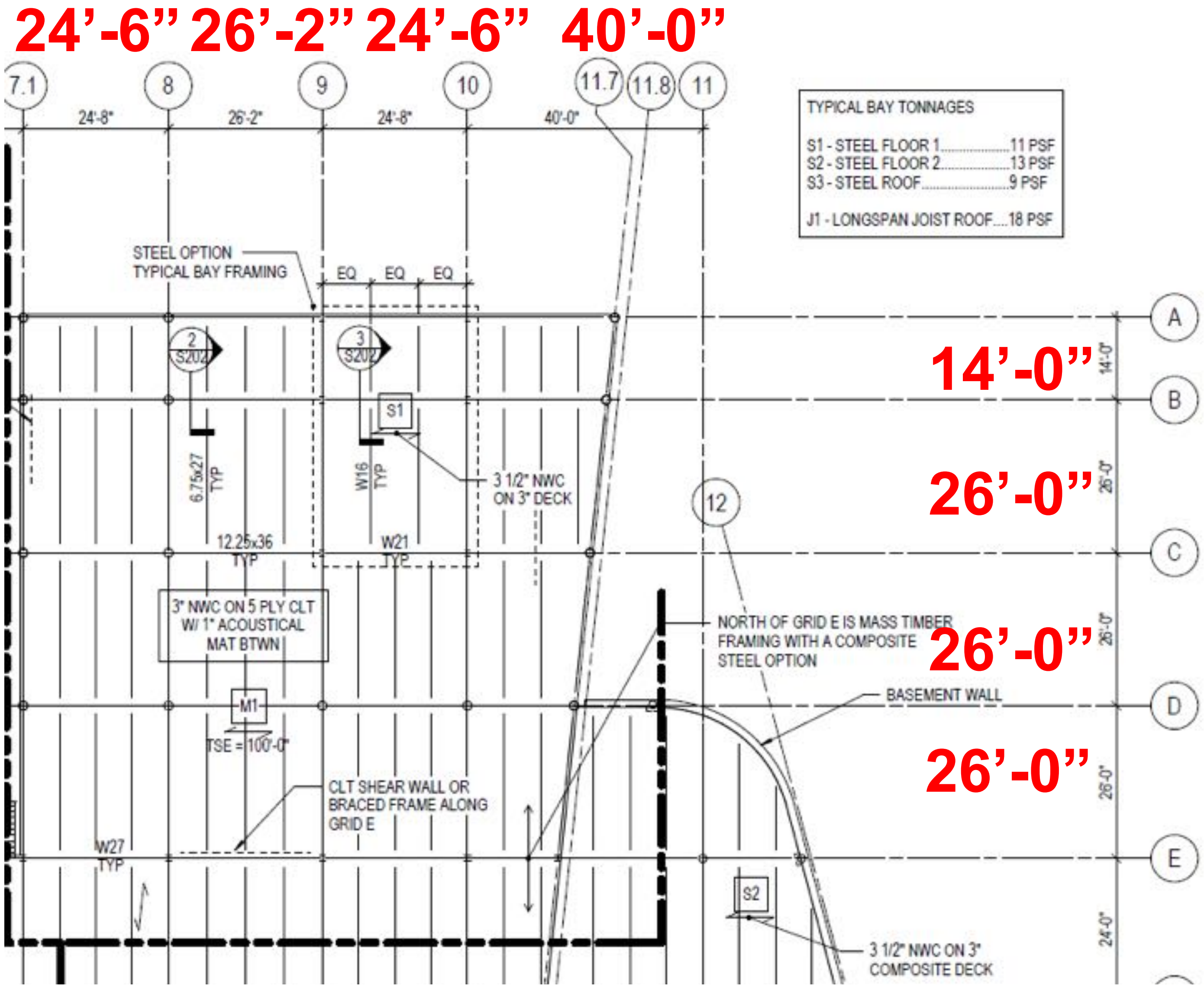

Structural Grid

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

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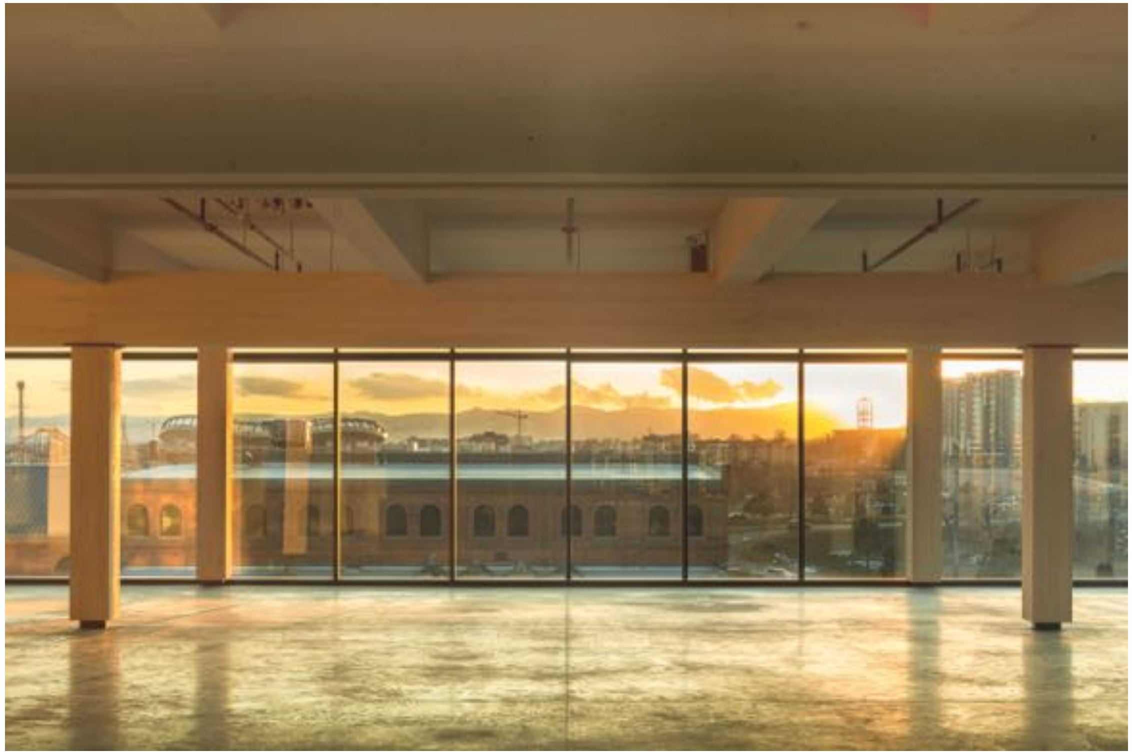


Platte Fifteen, Denver, CO
30x30 Grid, 2 purlins per bay
3-ply CLT
Image: JC Buck

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

Clay Creative, Portland, OR
30x30 Grid, 1 purlin per bay
2x6 NLT
Image: Mackenzie

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**

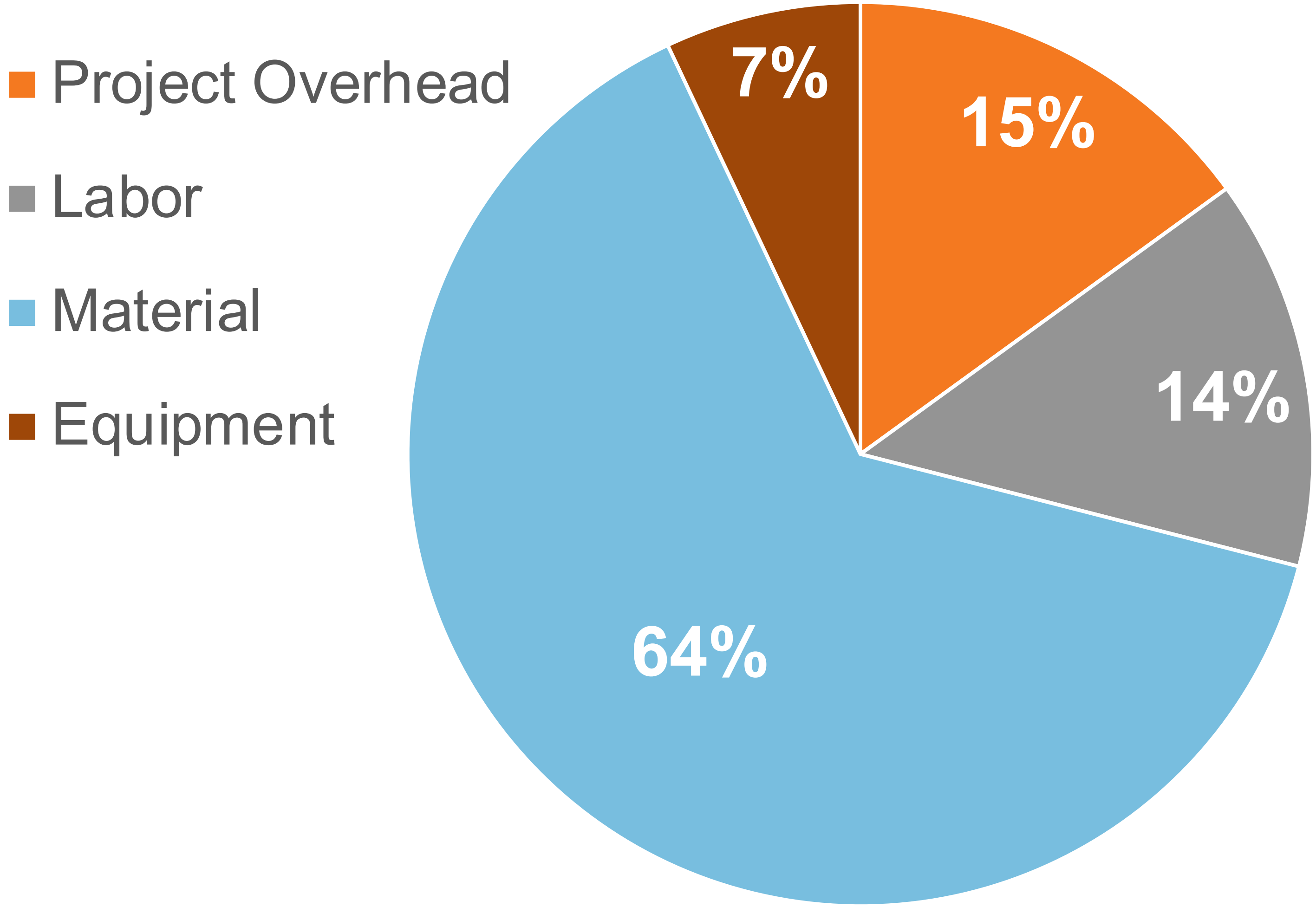
Implications of Type IV-B:
- 2 hr FRR, mostly protected floor panels, beams, columns
- Exposed areas: likely 5-ply / 2x6 NLT/DLT
- Protected areas: potential for thinner panels
- Choose 1 system throughout or multiple systems?
- Does grid vary or consistent throughout?
- No podium required

Key Early Design Decisions

Why so much focus on panel thickness?

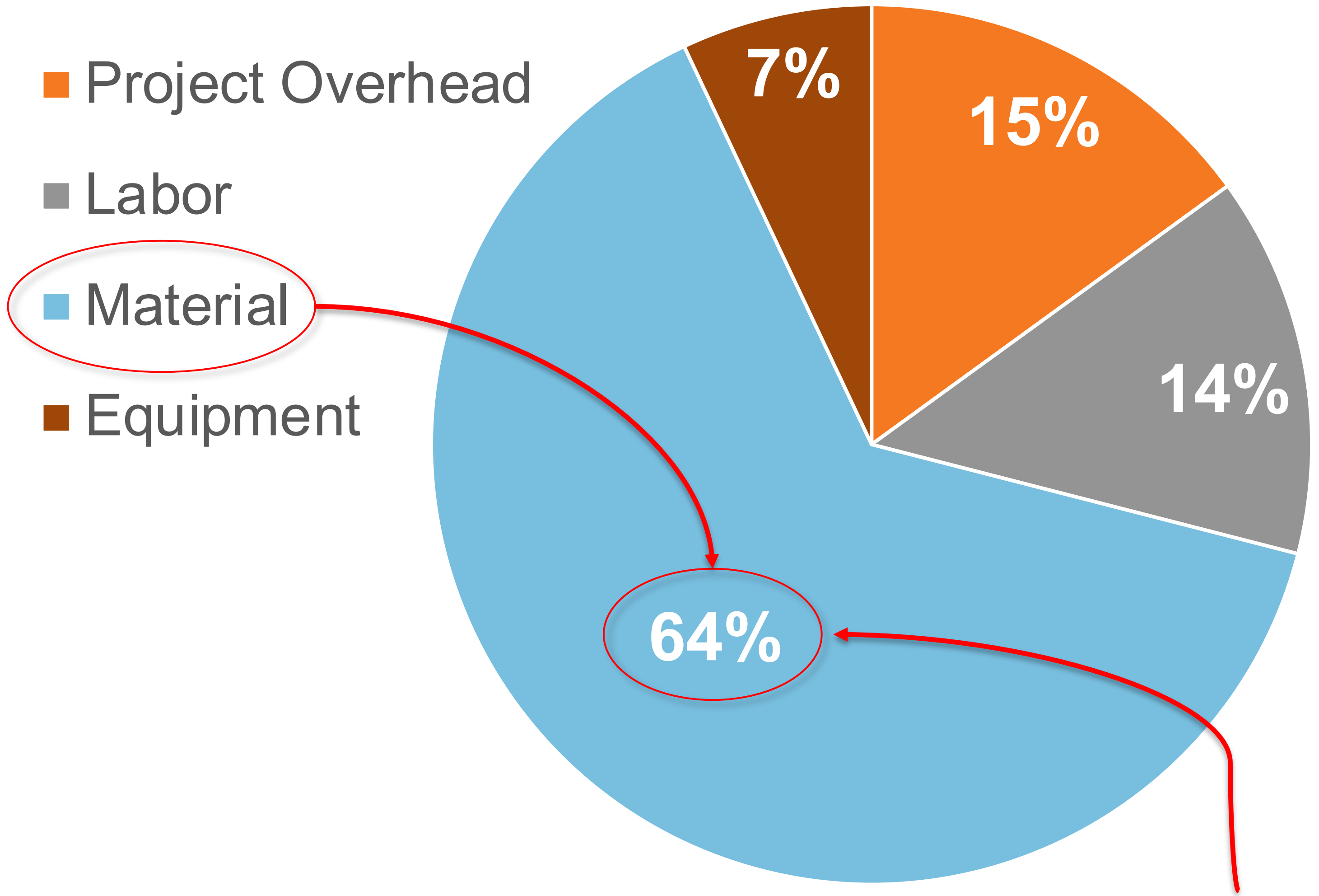
Key Early Design Decisions

Typical MT Package Costs



Source: Swinerton

Key Early Design Decisions

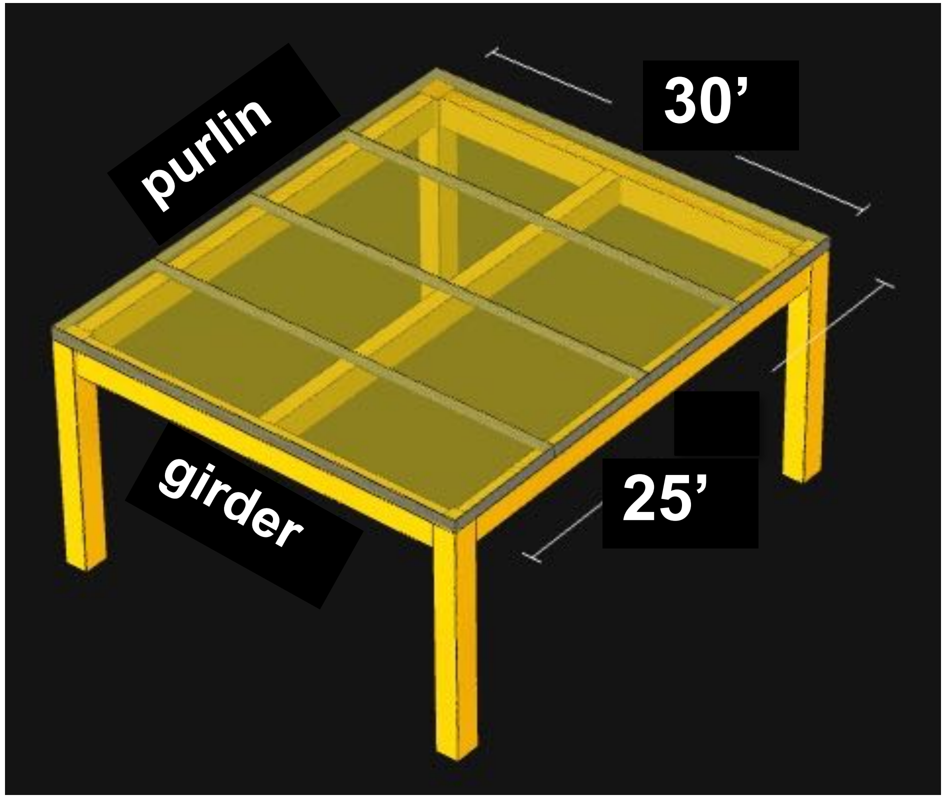


Panels are the biggest part of the biggest piece of the cost pie

Source: Swinerton

Key Early Design Decisions

Panel volume usually 65-80% of MT package volume



Source: Fast + Epp, Timber Bay Design Tool

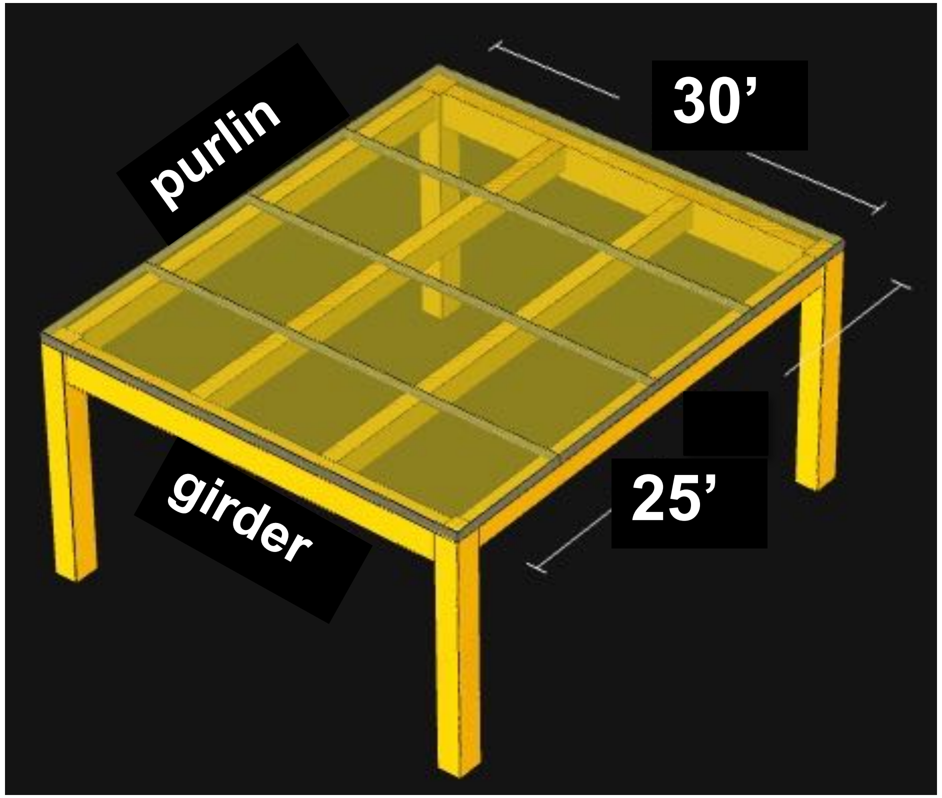
Type IIIA option 1

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

Key Early Design Decisions

Panel volume usually 65-80% of MT package volume



Source: Fast + Epp, Timber Bay Design Tool

Type IIIA option 2

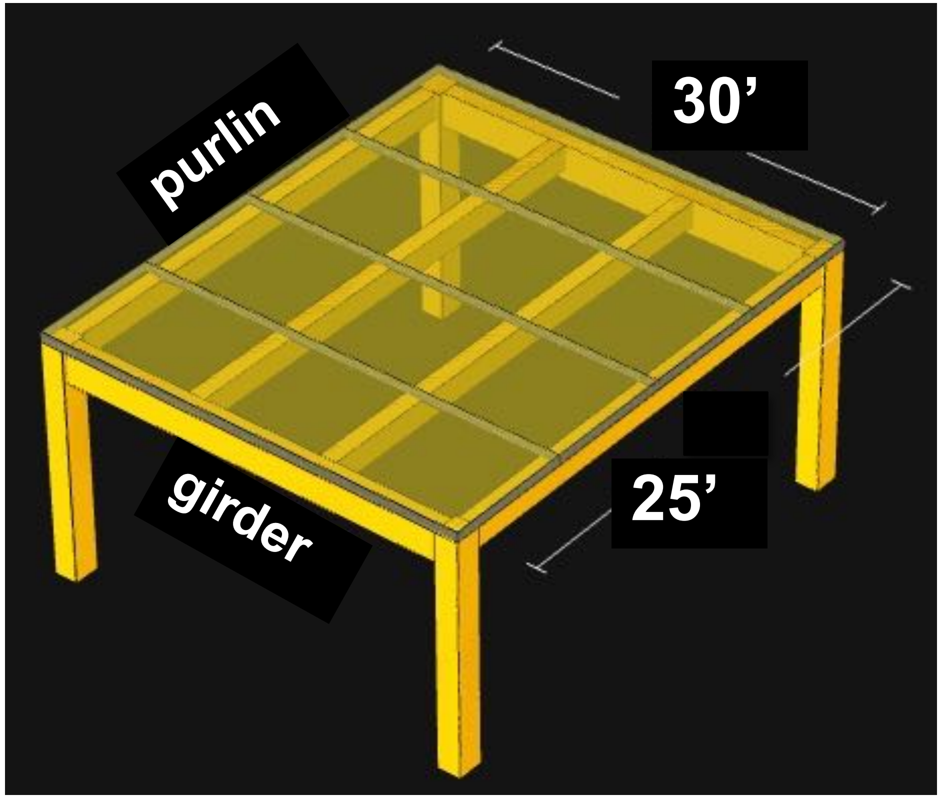
1-hr FRR
Purlin: 5.5”x24”
Girder: 8.75”x33”
Column: 10.5”x10.75”
Floor panel: 5-ply

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



Source: Fast + Epp, Timber Bay Design Tool

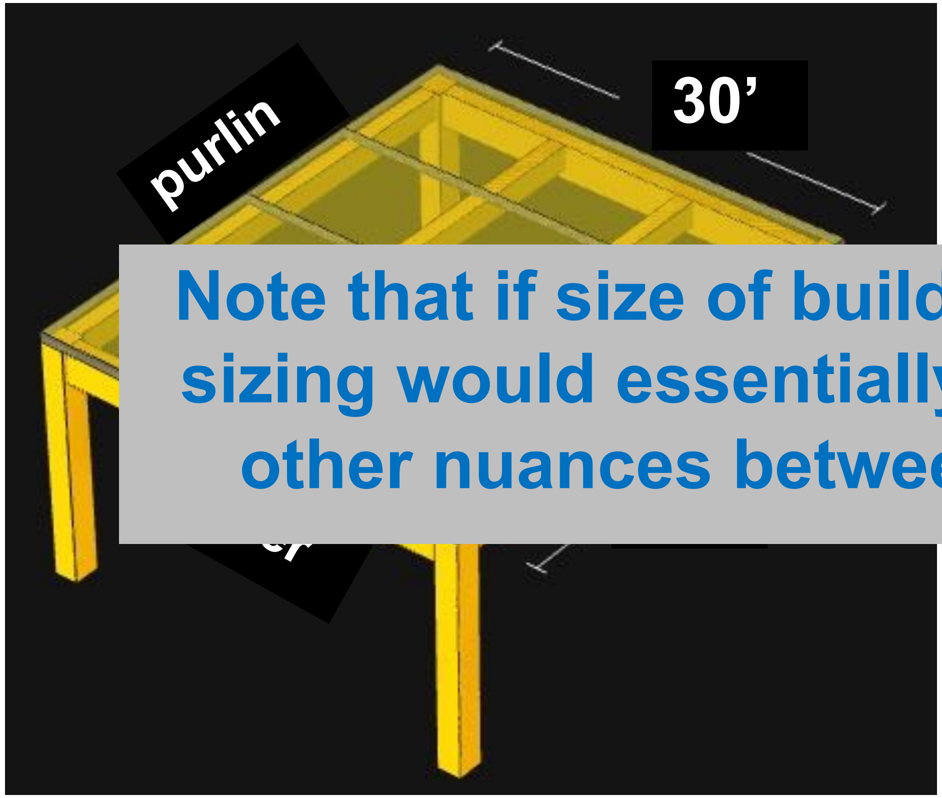
Type IV-HT

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

Key Early Design Decisions

Panel volume usually 65-80% of MT package volume



Source: Fast + Epp, Timber Bay Design Tool

Type IV-HT

0-hr FRR (min sizes per IBC)

Purlin: 5.5”x24” (IBC min = 5”x10.5”)

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…

25”)

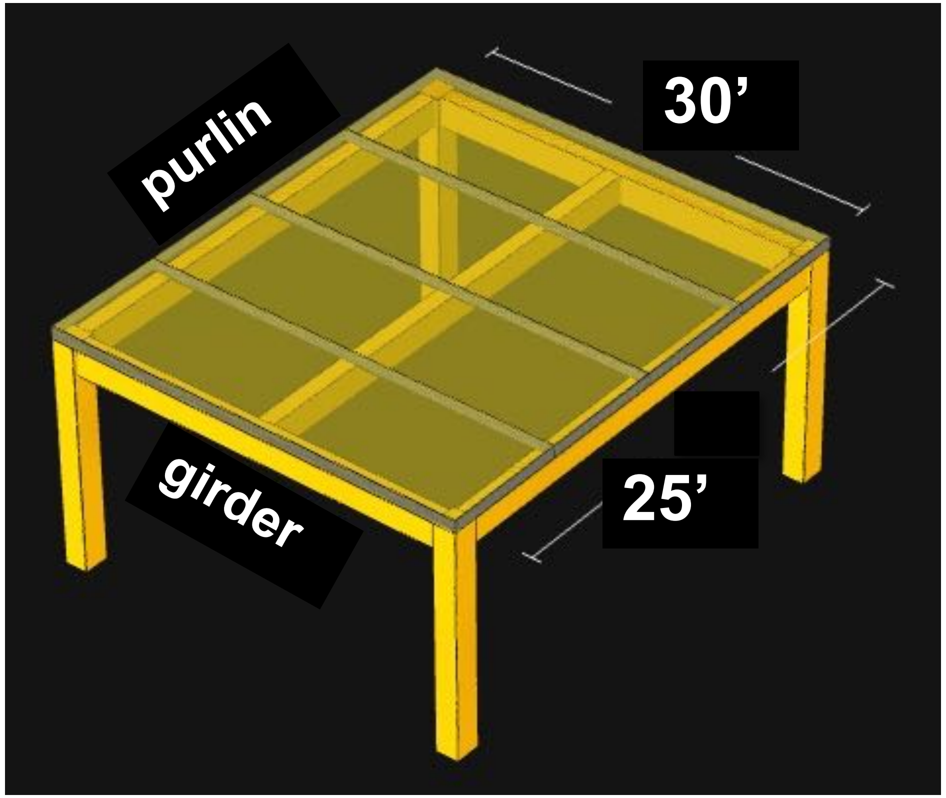
Glulam volume = 120 CF (32% of MT)

CLT volume = 258 CF (68% of MT)

Total volume = 0.51 CF / SF

Key Early Design Decisions

Panel volume usually 65-80% of MT package volume



Source: Fast + Epp, Timber Bay Design Tool

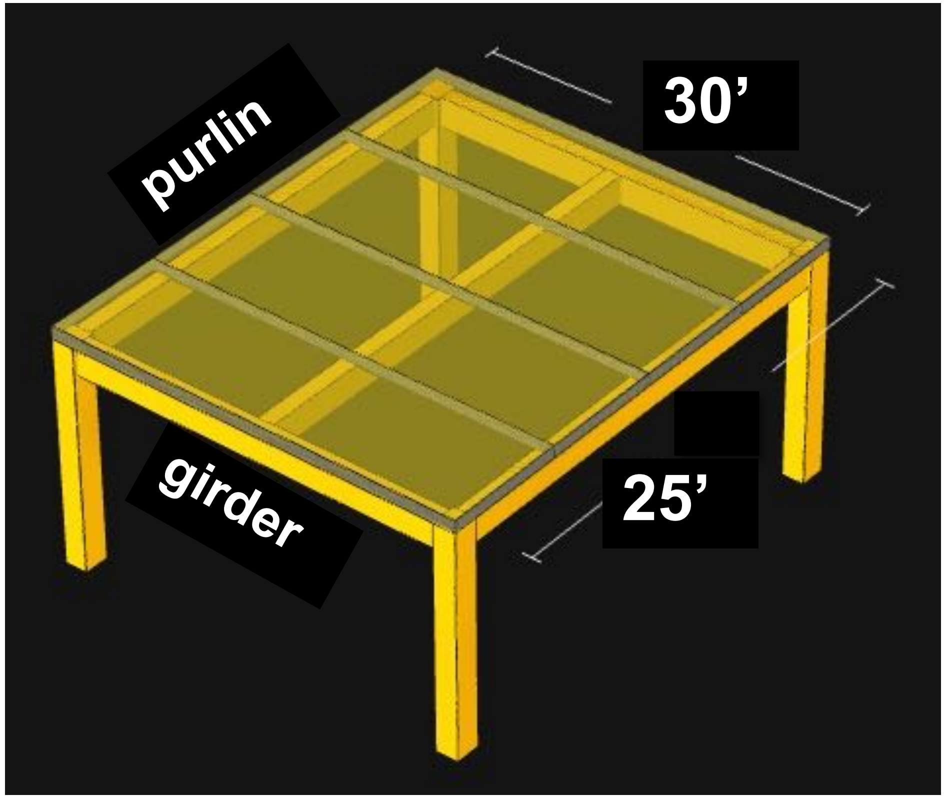
Type IV-C

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

Key Early Design Decisions

Which is the most efficient option?



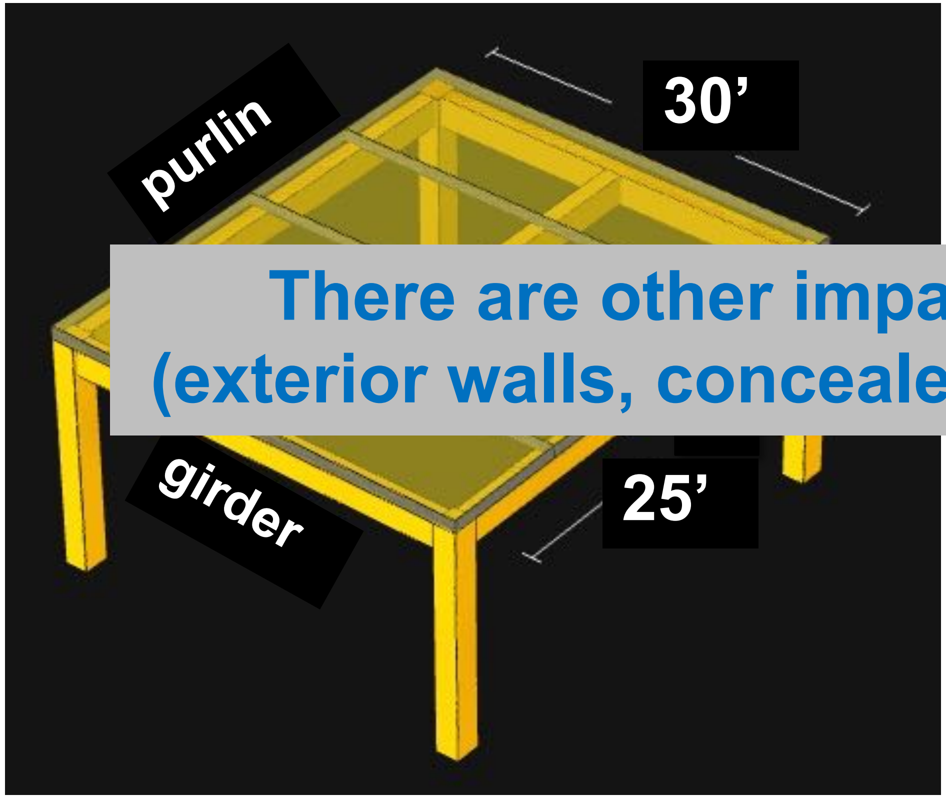
Source: Fast + Epp, Timber Bay Design Tool

	Timber Volume Ratio	Podium on 1st Floor?
IIIA – Option 1	0.73 CF / SF	Yes
IIIA – Option 2	0.74 CF / SF	Yes
IV-HT	0.51 CF / SF	Yes
IV-C	0.82 CF / SF	No

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?



Source: Fast + Epp, Timber Bay Design Tool

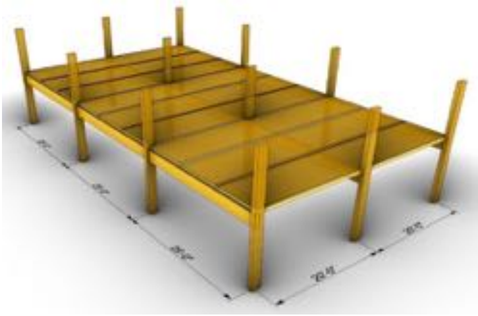
	Timber Volume Ratio	Podium on 1st Floor?
IIIA – Option 1	0.73 CF / SF	Yes
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
IV-C	0.82 CF / SF	No

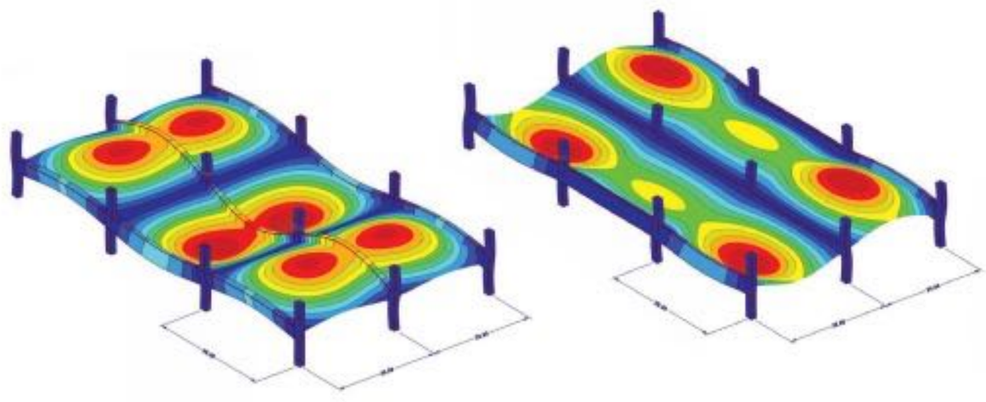
There are other impacts of constriction type selection (exterior walls, concealed spaces) that should be considered

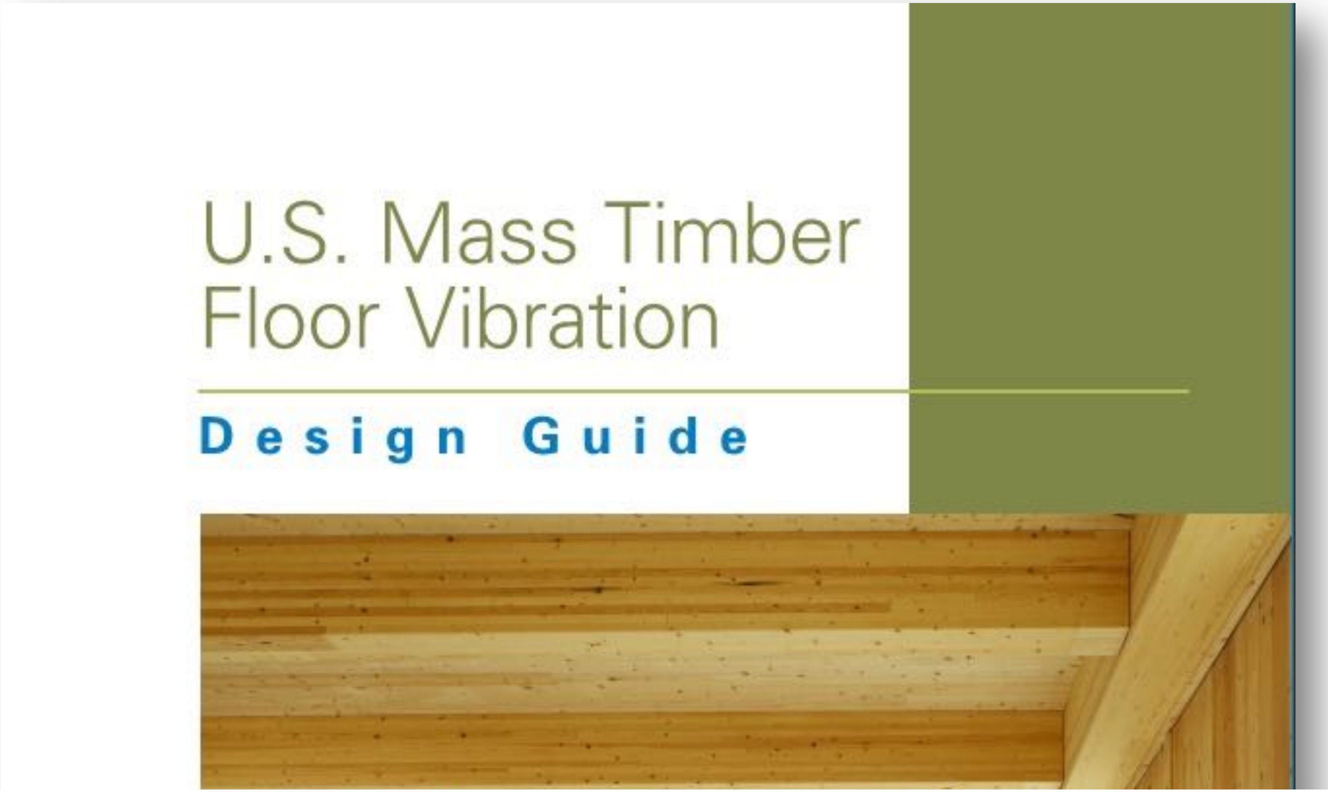
A general rule of thumb for efficient mass timber fiber volume is no higher than 0.75 CF per SF. Ratios in the 0.85 to 1.0 CF / SF range tend to become cost prohibitive

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

Connections

Credit: Structurlam

Key Early Design Decisions

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


Photo: John Stamets


Photo: Josh Partee


Photo: Christian Columbres

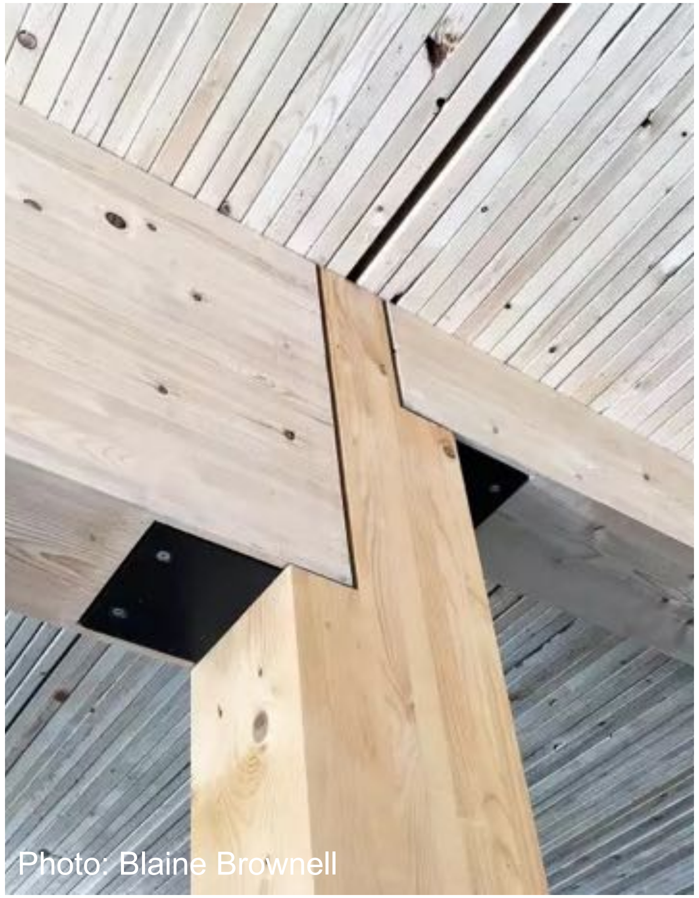
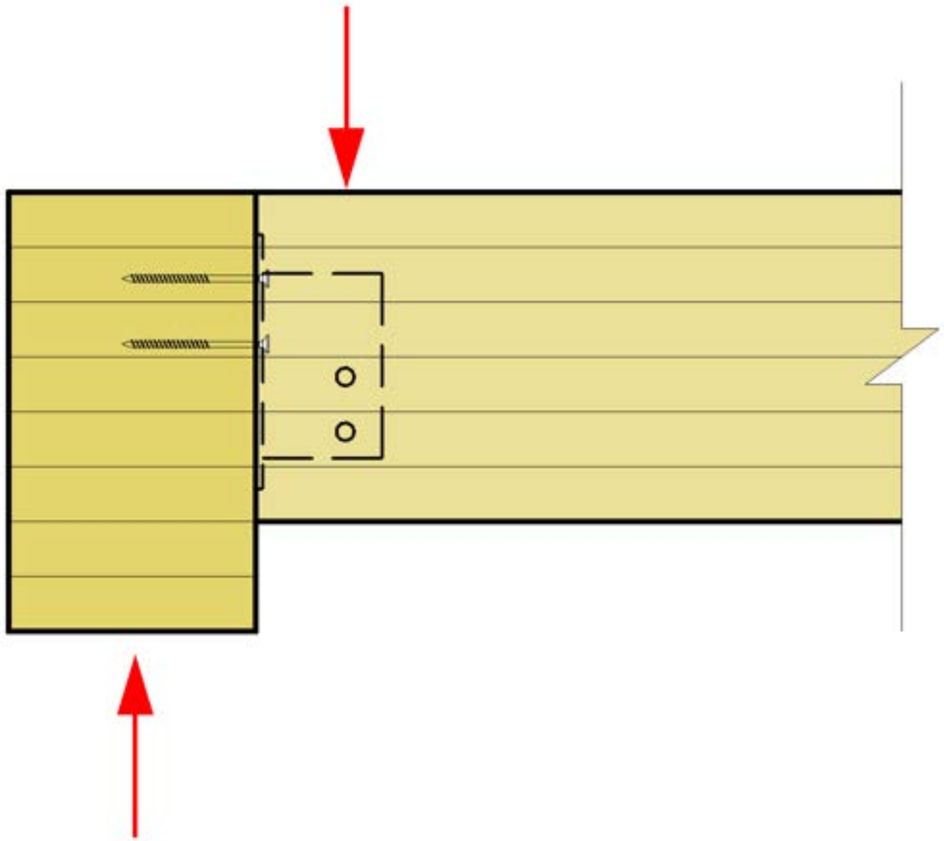


Photo: Blaine Brownell

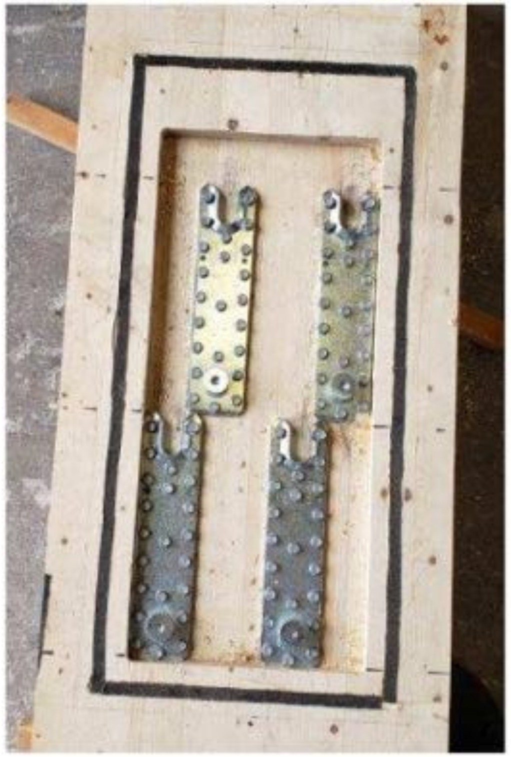
Key Early Design Decisions

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

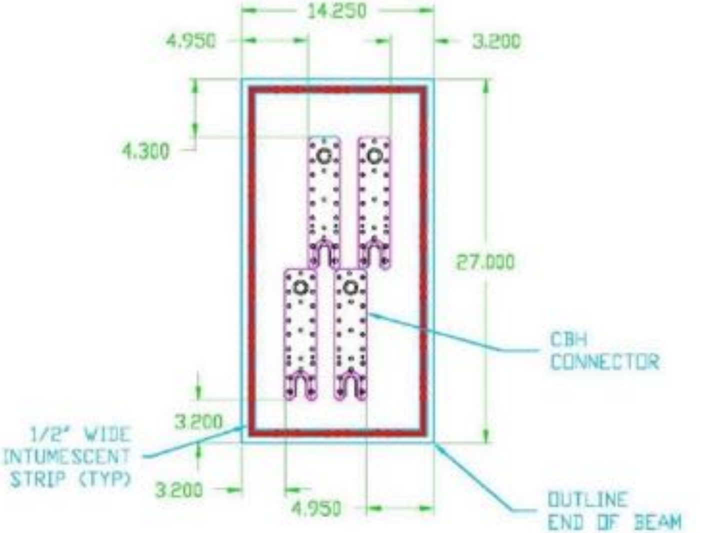


Photo: LEVER Architecture

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

Test	Beam	Connector	Applied Load	FRR
1	8.75” x 18” (222mm x 457mm)	1 x Ricon S VS 290x80	3,905lbs (17.4kN)	1hr
2	10.75” x 24” (273mm x 610mm)	Staggered double Ricon S VS 200x80	16,620lbs (73.9kN)	1.5hrs
3	10.75” x 24” (273mm x 610mm)	1 x Megant 430	16,620lbs (73.9kN)	1.5hrs

Key Early Design Decisions

Softwood Lumber Board

Glulam Connection Fire Test

Summary Report

Issue | June 5, 2017

SOUTHWEST RESEARCH INSTITUTE

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CHEMISTRY AND CHEMICAL ENGINEERING DIVISION

FIRE TECHNOLOGY DEPARTMENT
WWW.FIRE.SWRI.ORG
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FIRE PERFORMANCE EVALUATION OF A LOAD BEARING GLULAM BEAM TO COLUMN CONNECTION, INCLUDING A CLT PANEL, TESTED IN GENERAL ACCORDANCE WITH ASTM E119-16a, *STANDARD TEST METHODS FOR FIRE TESTS OF BUILDING CONSTRUCTION AND MATERIALS*

FINAL REPORT
Consisting of 32 Pages

Full Report Available at:

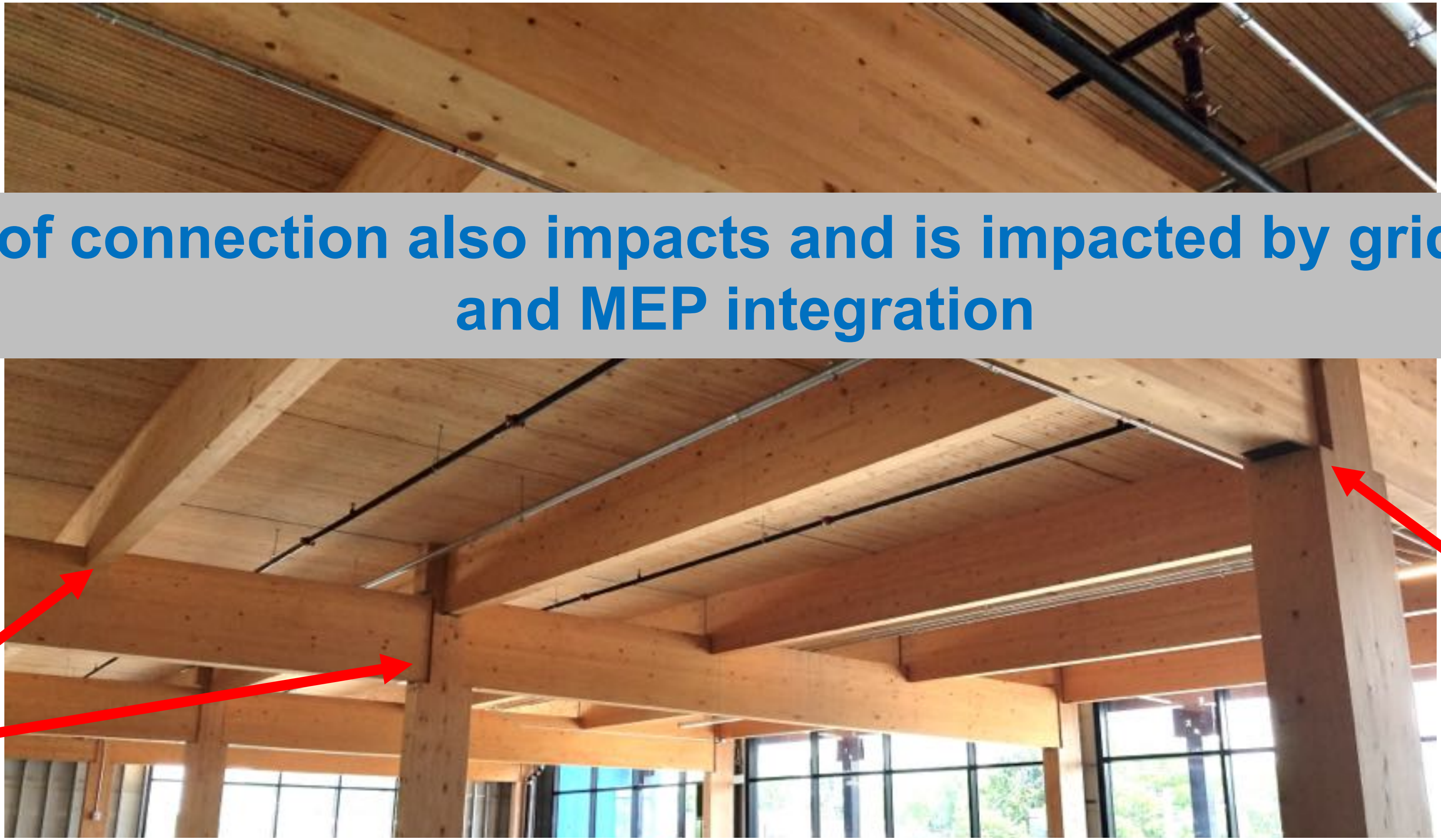
https://www.thinkwood.com/wp-content/uploads/2018/01/reThink-Wood-Arup-SLB-Connection-Fire-Testing-Summary-web.pdf

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

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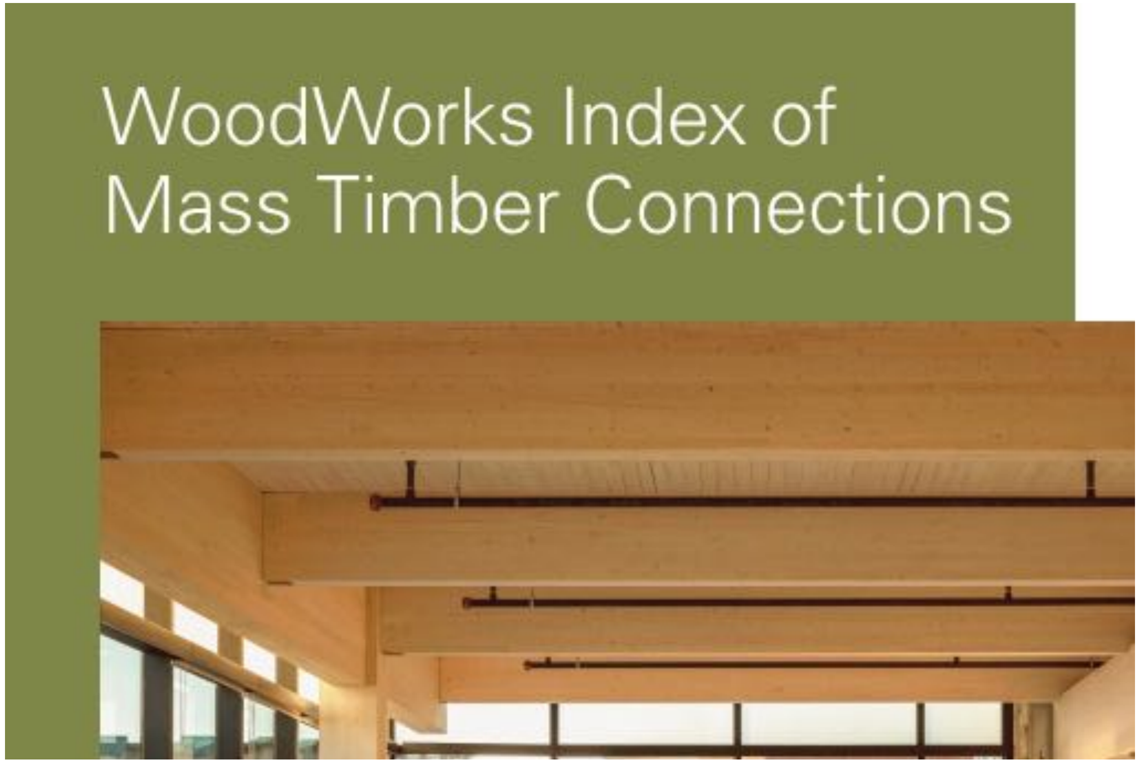
KL&A Engineers & Builders

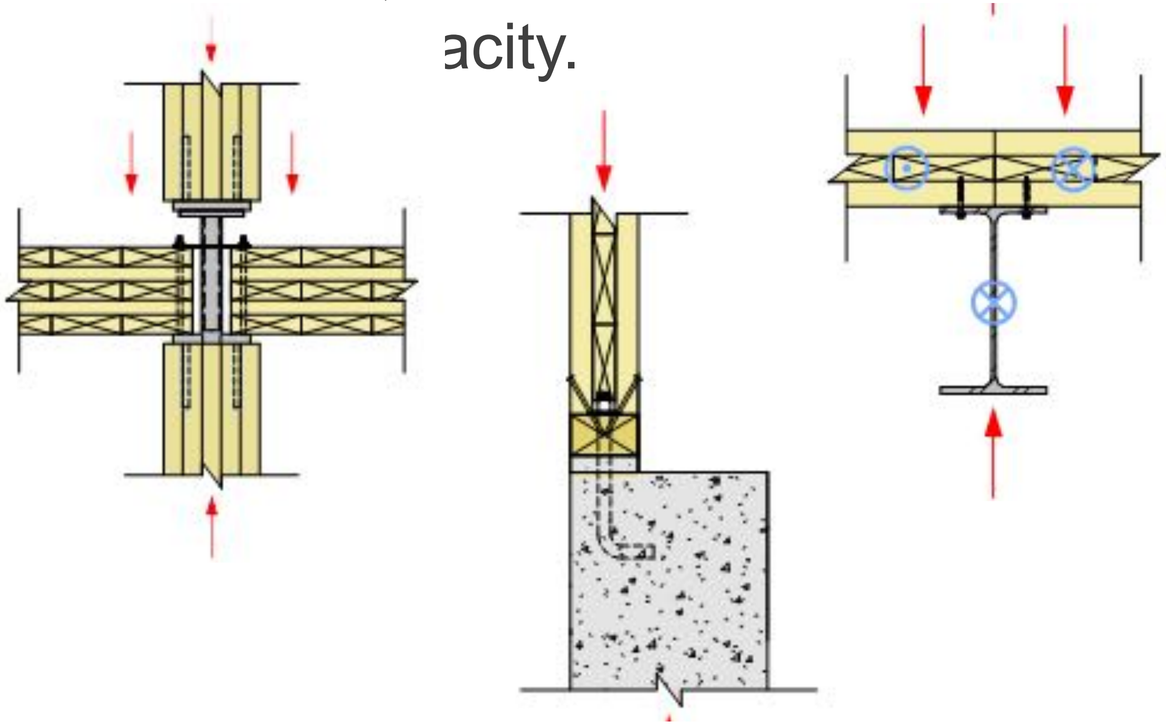
OZ ARCHITECTURE URBAN DESIGN INTERIOR DESIGN

SWINERTON MASS TIMBER



MASS TIMBER CONNECTIONS INDEX

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



Connections

Other connection design considerations:

- Structural capacity
- Shrinkage
- Constructability
- Aesthetics
- Cost

Credit: Alex Schreyer

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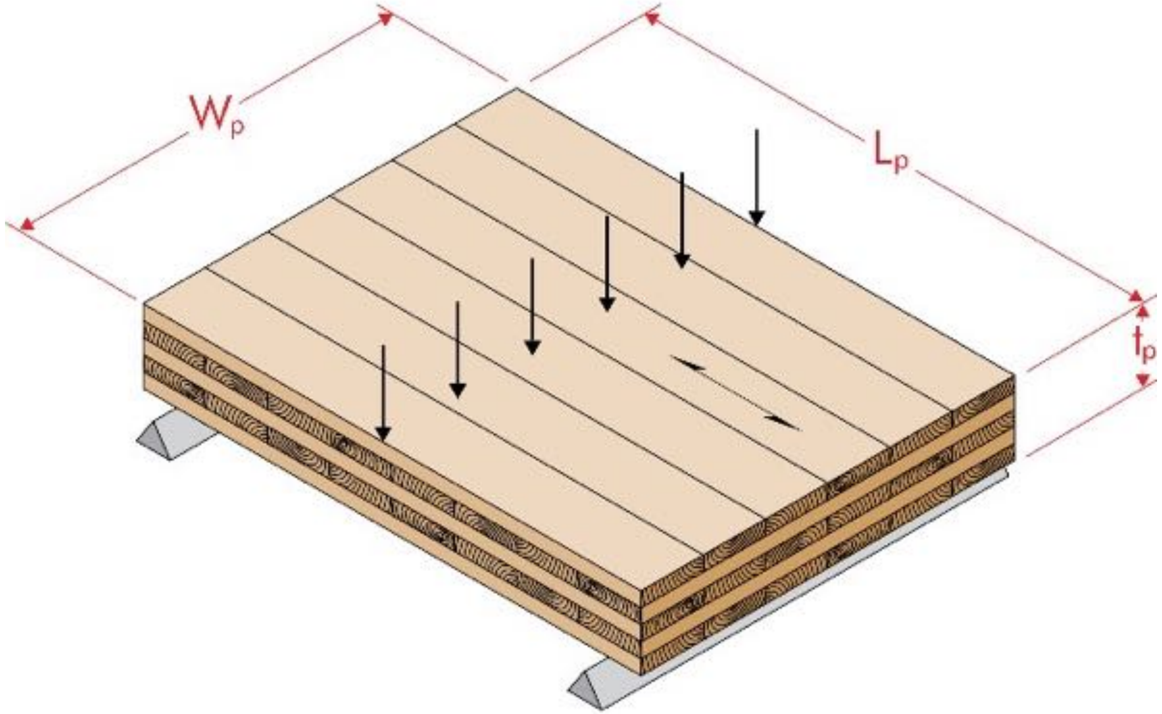
CLT Shear Wall and Diaphragm Design Under the 2021 SDPWS

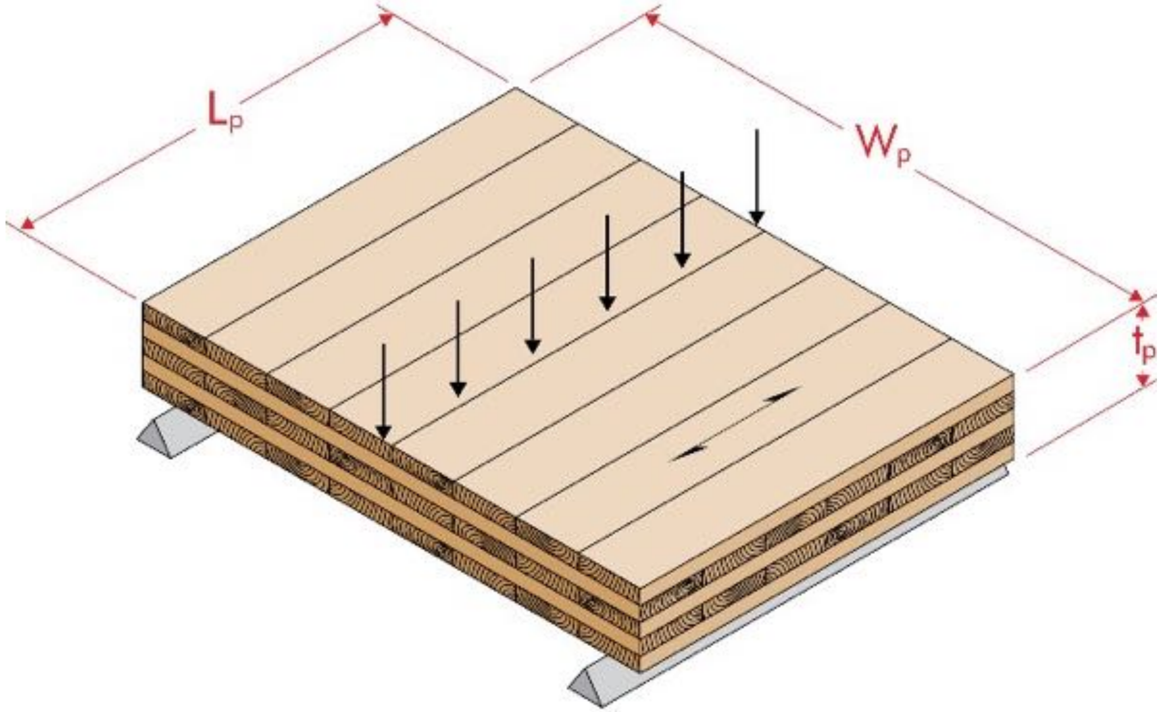
Photo credit: KPFF / Reid Zimmerman

CLT Gravity Systems

FLATWISE Panel Loading



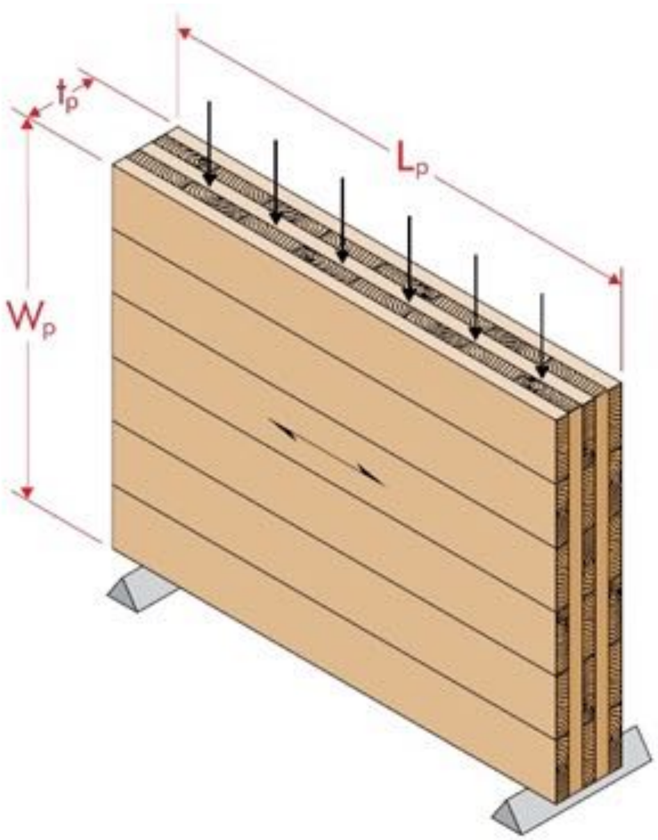
Span in MAJOR Strength Direction
"Parallel" Direction
Use subscript '0' in Notation



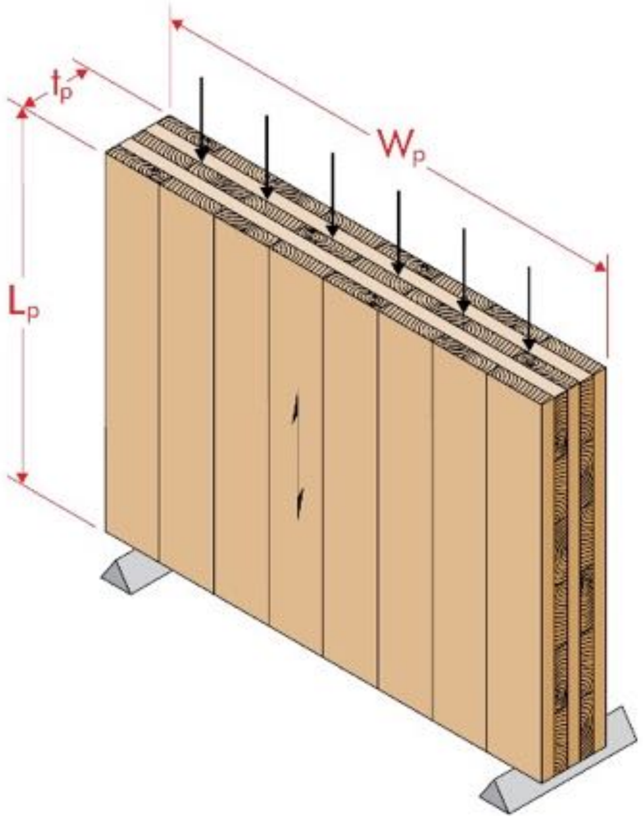
Span in MINOR Strength Direction
"Perpendicular" Direction
Use subscript '90' in Notation

Source: PRG 320-2018

EDGEWISE Panel Loading



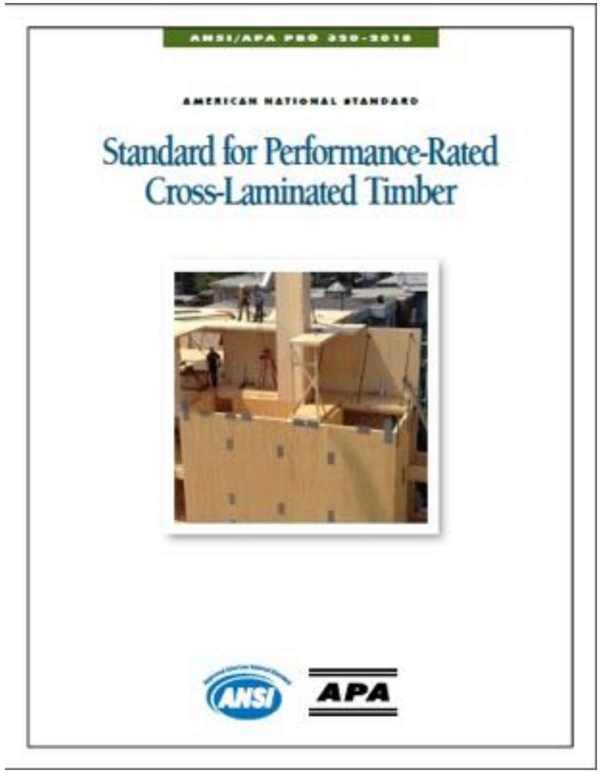
Span in MAJOR Strength Direction



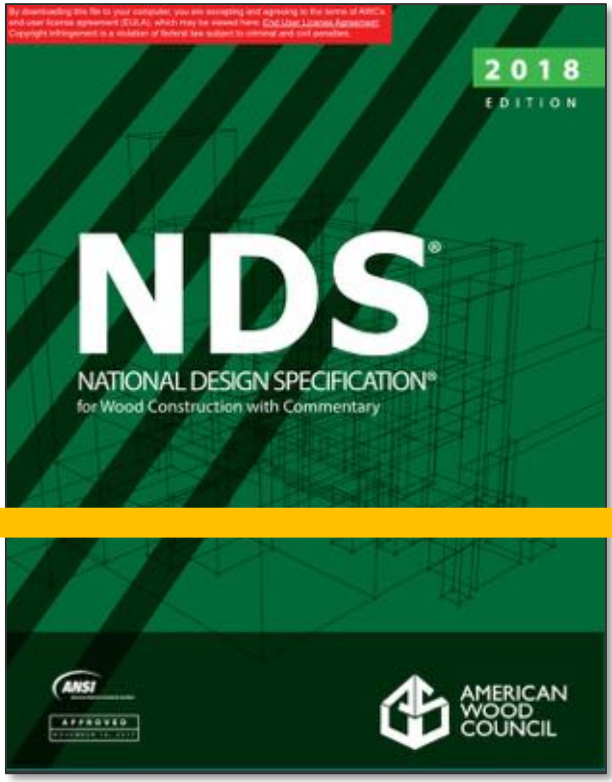
Span in MINOR Strength Direction

Source: PRG 320-2018

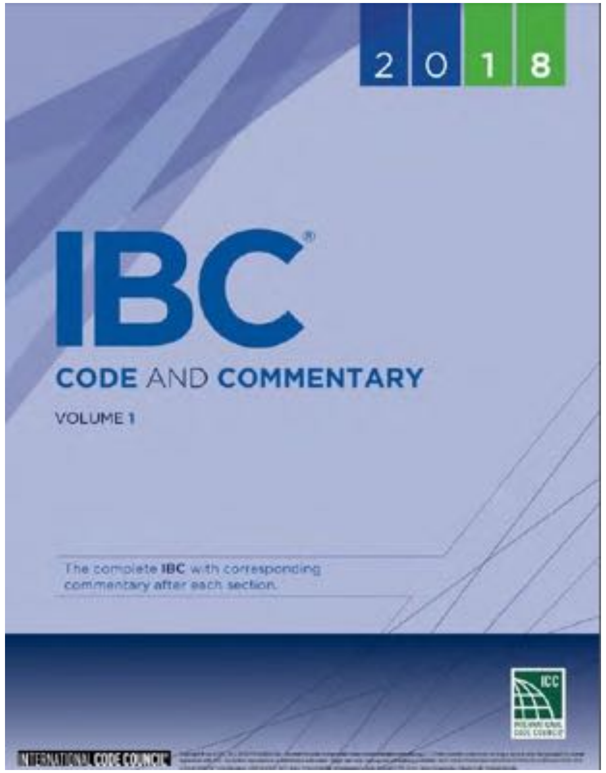
CLT in the 2015 & 2018 IBC (Gravity)



PRG 320-2018
(PRG 320-2011 sim.)



2018 NDS
(2015 NDS sim.)

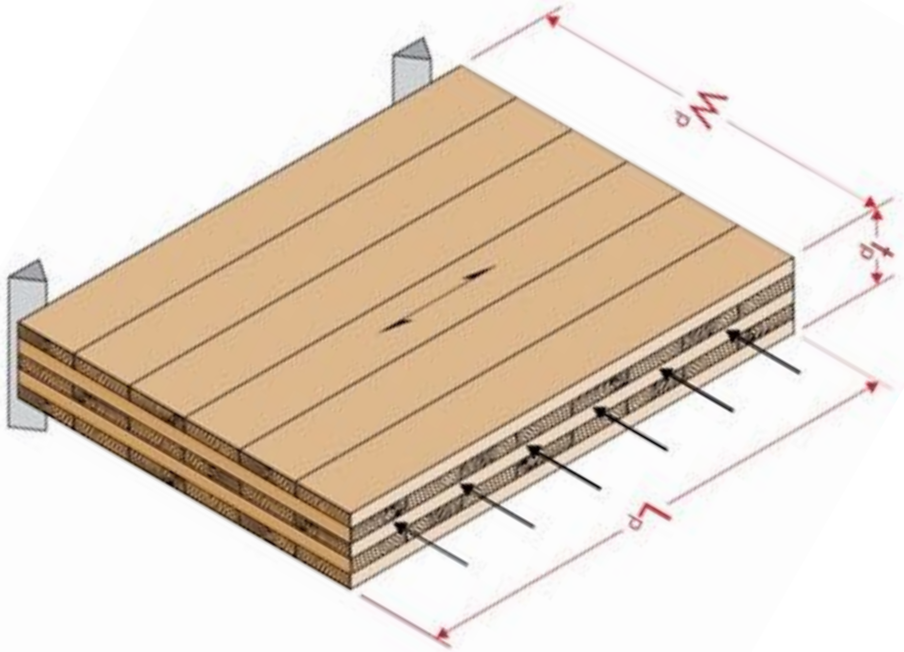


2018 IBC
(2015 IBC sim.)

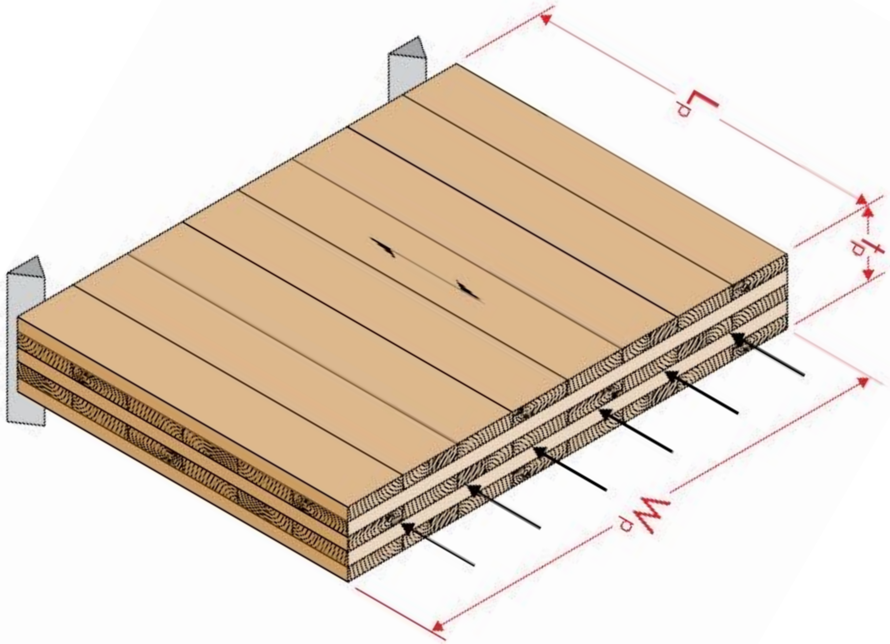
CLT is recognized in the 2015 & 2018 International Building Code for gravity systems only

CLT Lateral Systems

EDGEWISE Panel Loading



Span in MAJOR Strength Direction



Span in MINOR Strength Direction

Source: PRG 320-2018

CLT in In-Plane (Edgewise) Strength

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

CLT LAYUP[9]	CLT PANEL THICKNESS DESIGNATION	FACE LAMINATION ORIENTATION[2] (psi)		FACE LAMINATION ORIENTATION[3] (lbf/ft of width)	
		॥[4]	⊥[4]	॥[4]	⊥[4]
V2M1	99 V	175[8]	235[8]	8,200[8]	11,000[8]
	169 V	175[8]	235[8]	14,000[8]	18,800[8]
	239 V	175[8]	235[8]	19,800[8]	26,600[8]
	309 V	175[8]	235[8]	25,600[8]	34,300[8]
V2M1.1	105V	195	290	9,700	14,400
	175V	270	290[6]	22,400	24,000[6]
	245V	270[5]	290[6]	31,300[5]	33,600[6]
	315V	270[5]	290[6]	40,200[5]	43,200[6]

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
	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
E1	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*

145 to 290 PSI Edgewise Shear Capacity

= 1.7 to 3.5 kips/ft (ASD)

per inch of thickness!

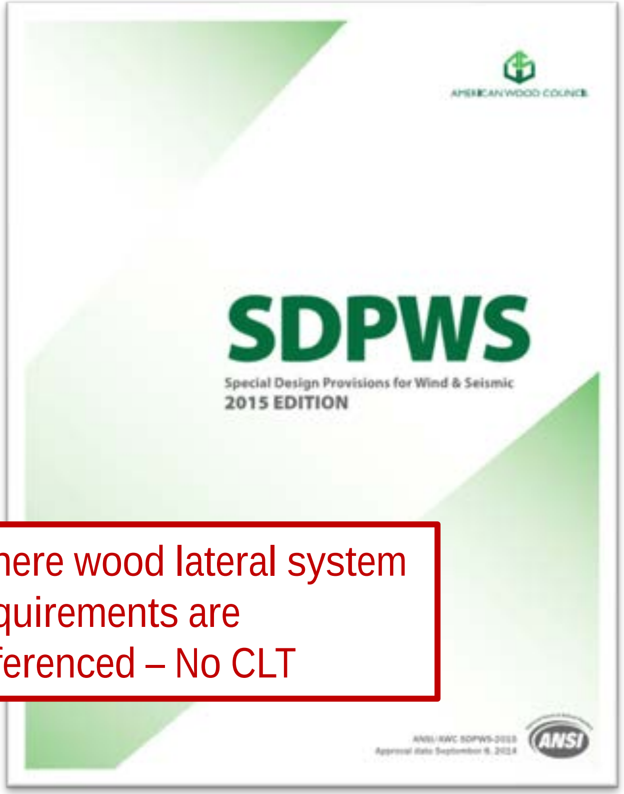
Consult with manufacturers for values

Multiply by ***Cd = 1.6***

for short term ASD strength

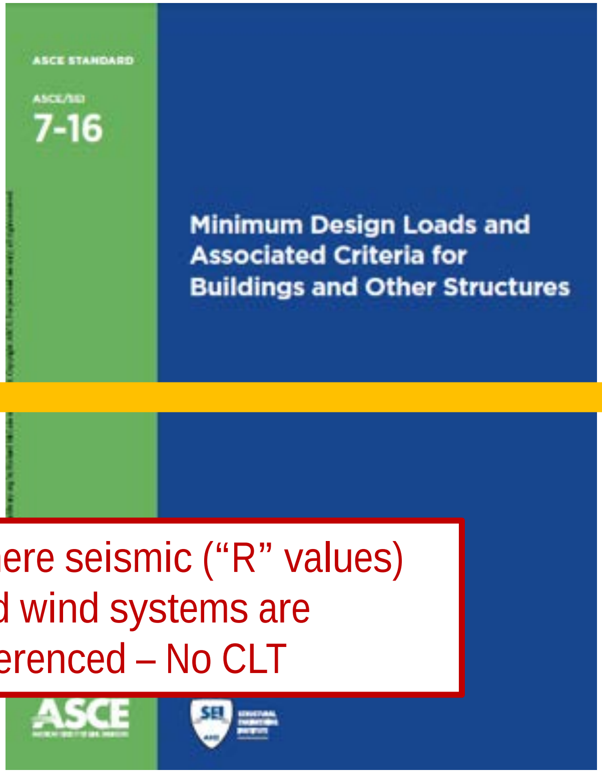
CLT Panels can have > 9 kips / ft in-plane shear capacity

CLT in the 2015 & 2018 IBC (Lateral)



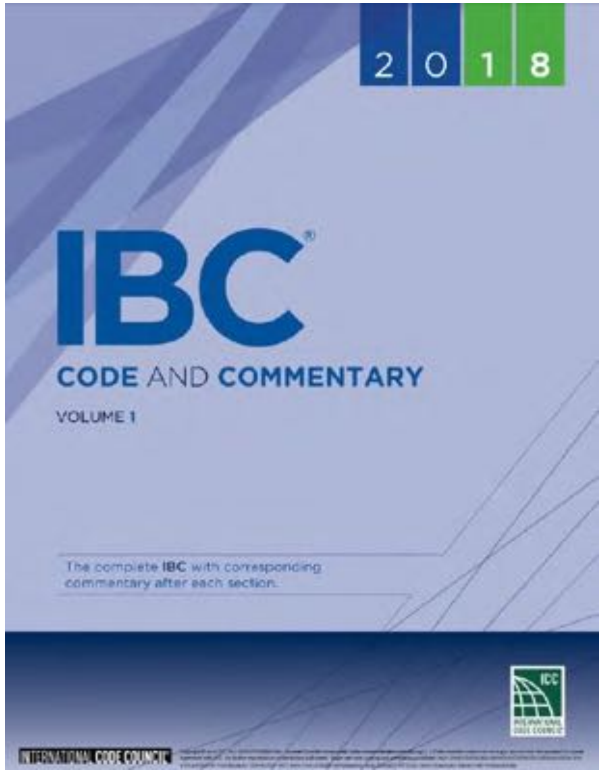
Where wood lateral system requirements are referenced – No CLT

2015 SDPWS



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

ASCE/SEI 7-16
(ASCE 7-10 sim.)



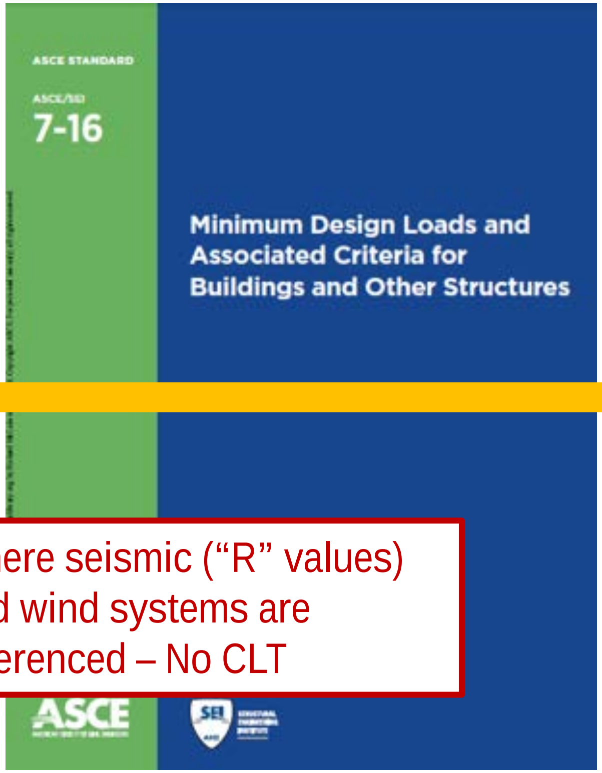
2018 IBC
(2015 IBC sim.)

CLT lateral systems (including "R" values for shear wall design) are <u>not</u> recognized in the 2015 & 2018 International Building Code

CLT in the 2021 IBC (Lateral)

Now with CLT shear wall and diaphragm requirements

2021 SDPWS



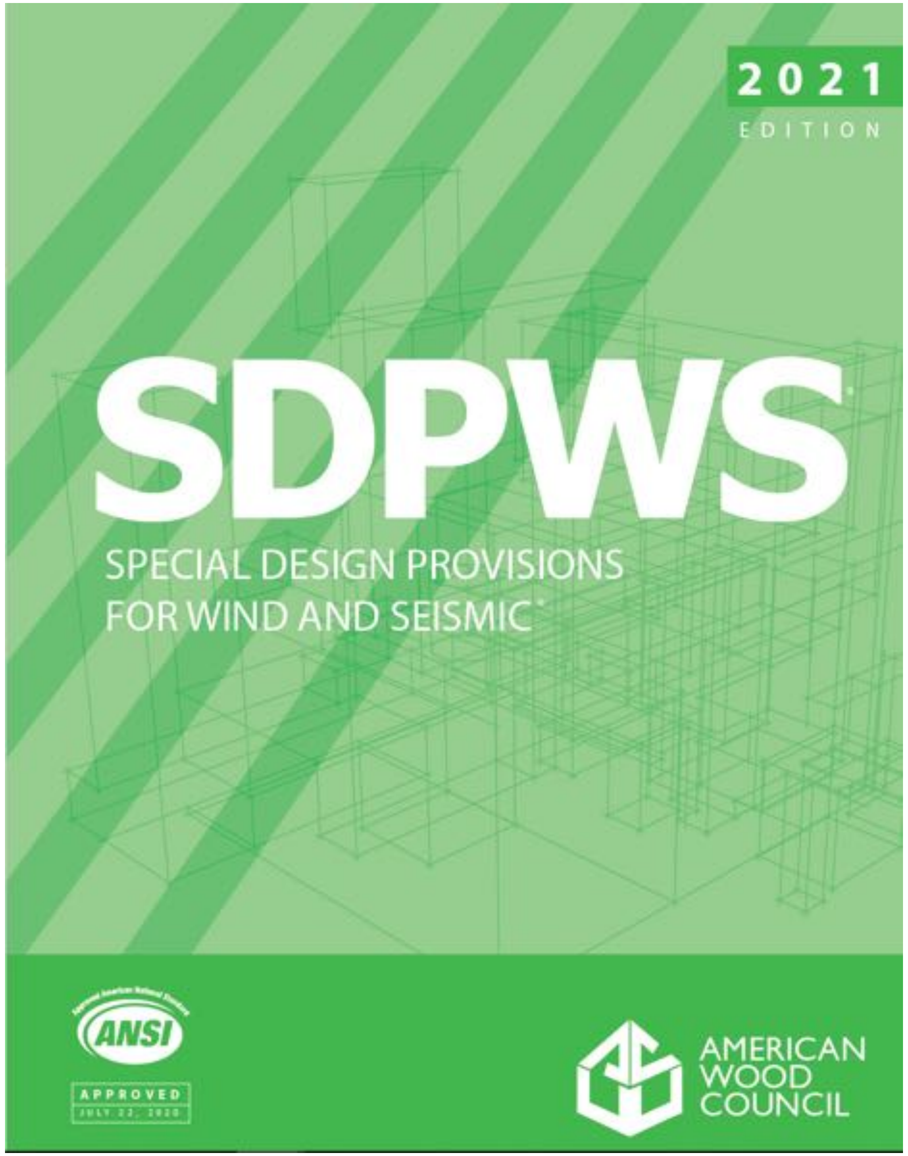
Where seismic ("R" values) and wind systems are referenced – No CLT

ASCE/SEI 7-16

2021 IBC

CLT lateral systems from the 2021 SDPWS (not "R" values for shear wall design) are referenced in the 2021 International Building Code

2021 Special Design Provisions for Wind and Seismic

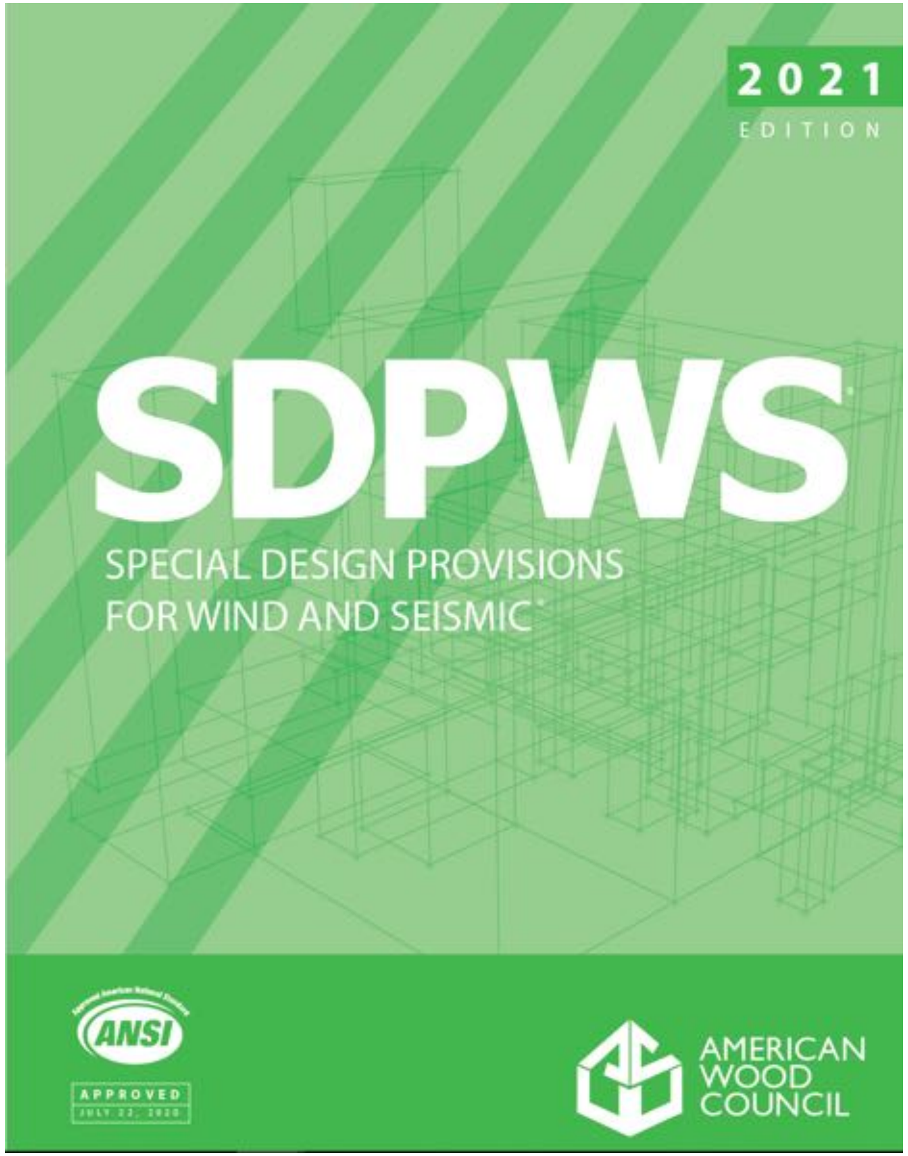


Top Changes Relevant to CLT Lateral Systems:

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

View for free at awc.org

2021 Special Design Provisions for Wind and Seismic

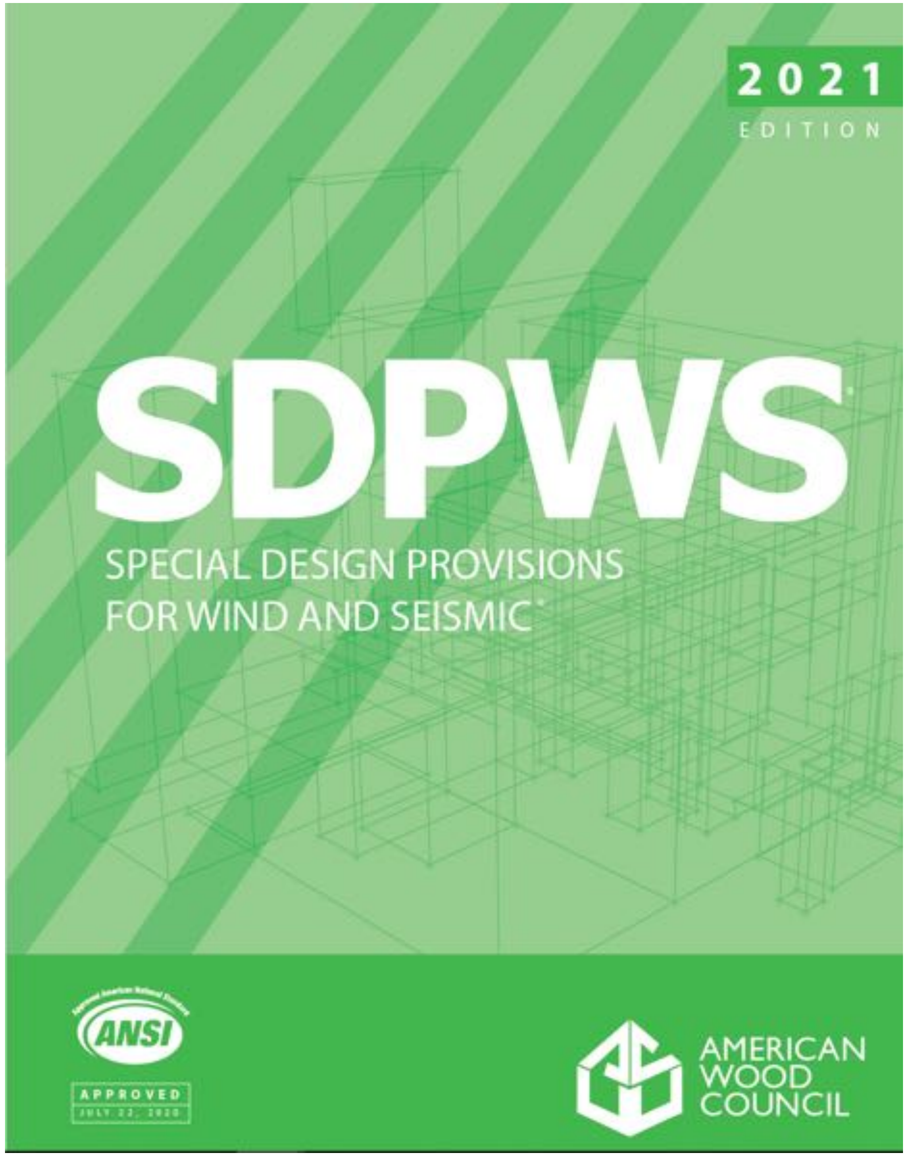


Top Changes Relevant to CLT Lateral Systems:

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

View for free at awc.org

2021 SDPWS – Unified Nominal Shear Capacity



For Wood Structural Panel (WSP) shear walls and diaphragms, the 2015 SDPWS has two nominal shear capacities:

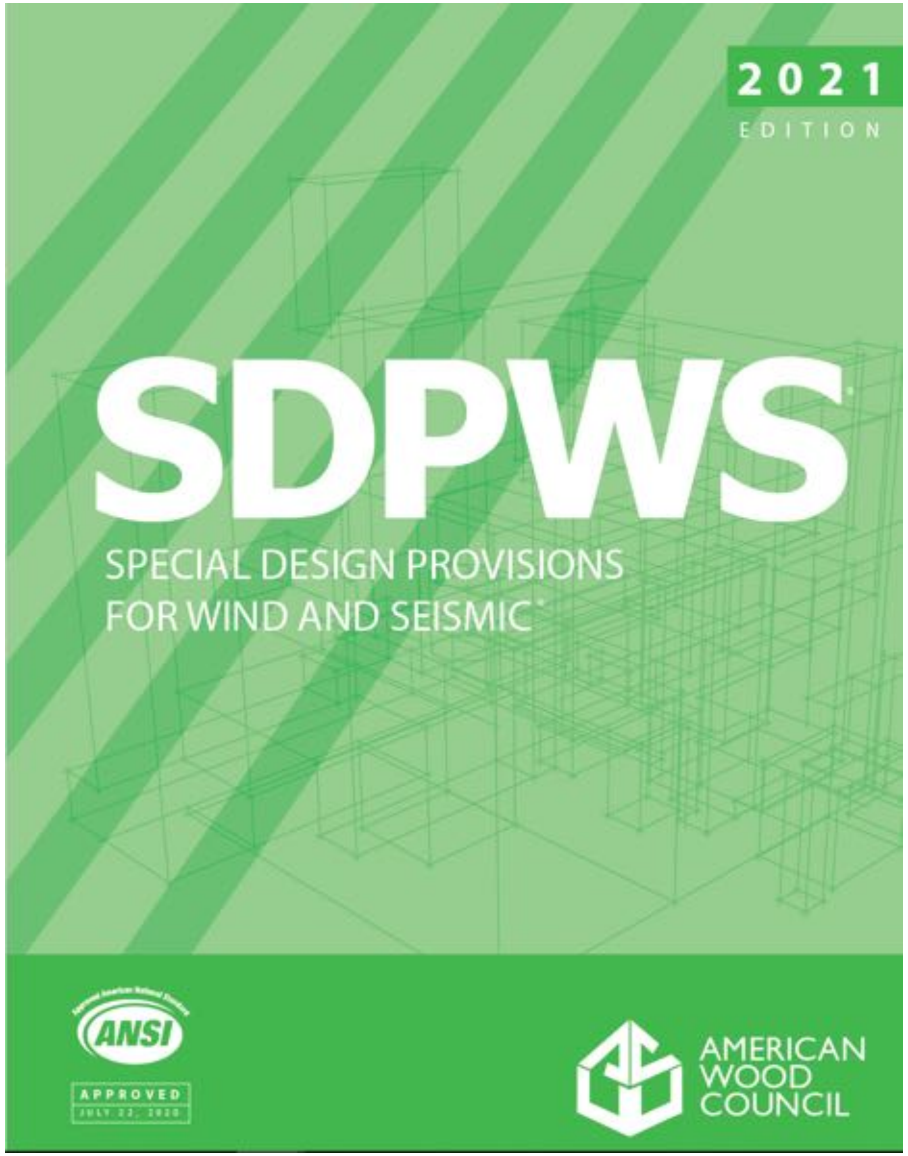
v_s Nominal shear capacity for <u>seismic</u> loads

v_w Nominal shear capacity for <u>wind</u> loads

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

v_n Nominal shear capacity

2021 SDPWS – Unified Nominal Shear Capacity



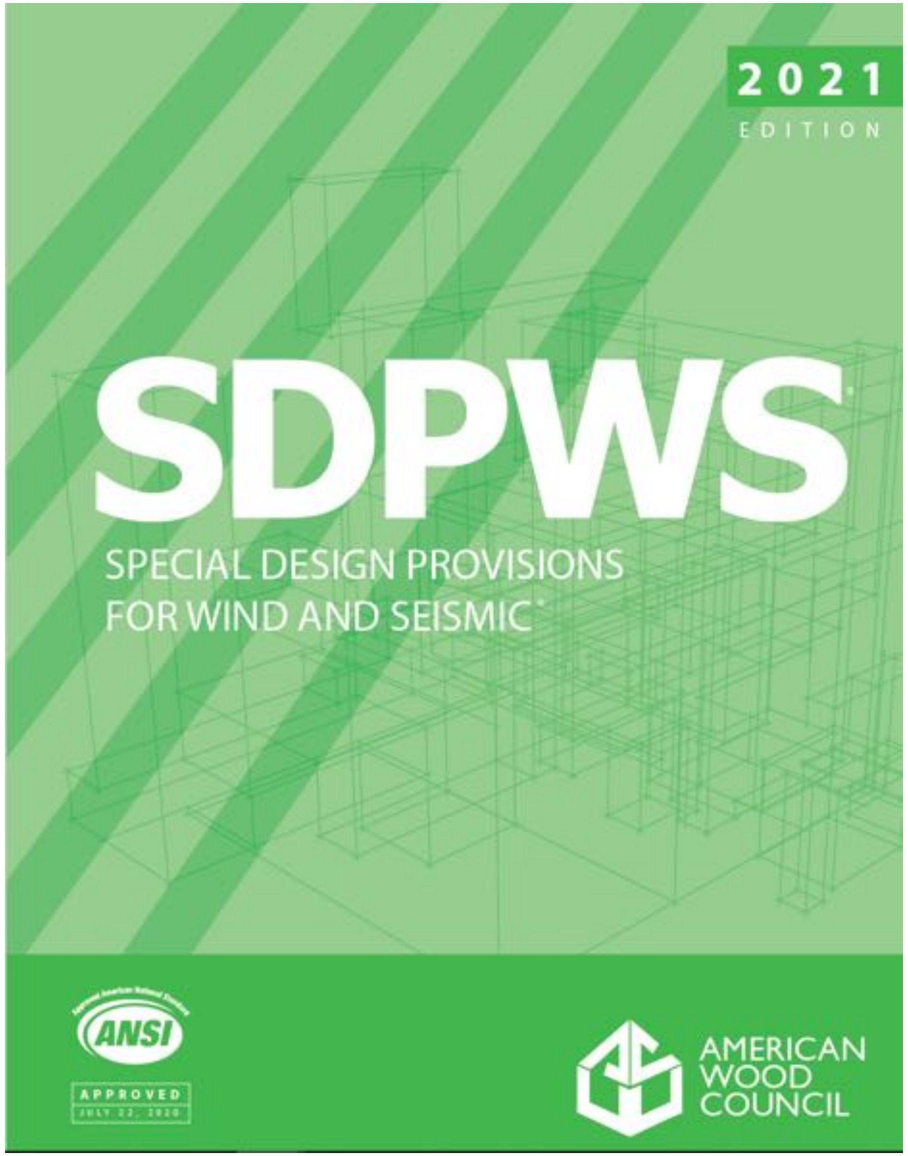
To calculate the ASD or LRFD shear capacity, the 2021 SDPWS has different reduction factors for wind and seismic

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	$v_n/2.0$	$0.80\ v_n$

Source: 2021 SDPWS Section 4.1.4

CLT Shear Wall Design

2021 Special Design Provisions for Wind and Seismic

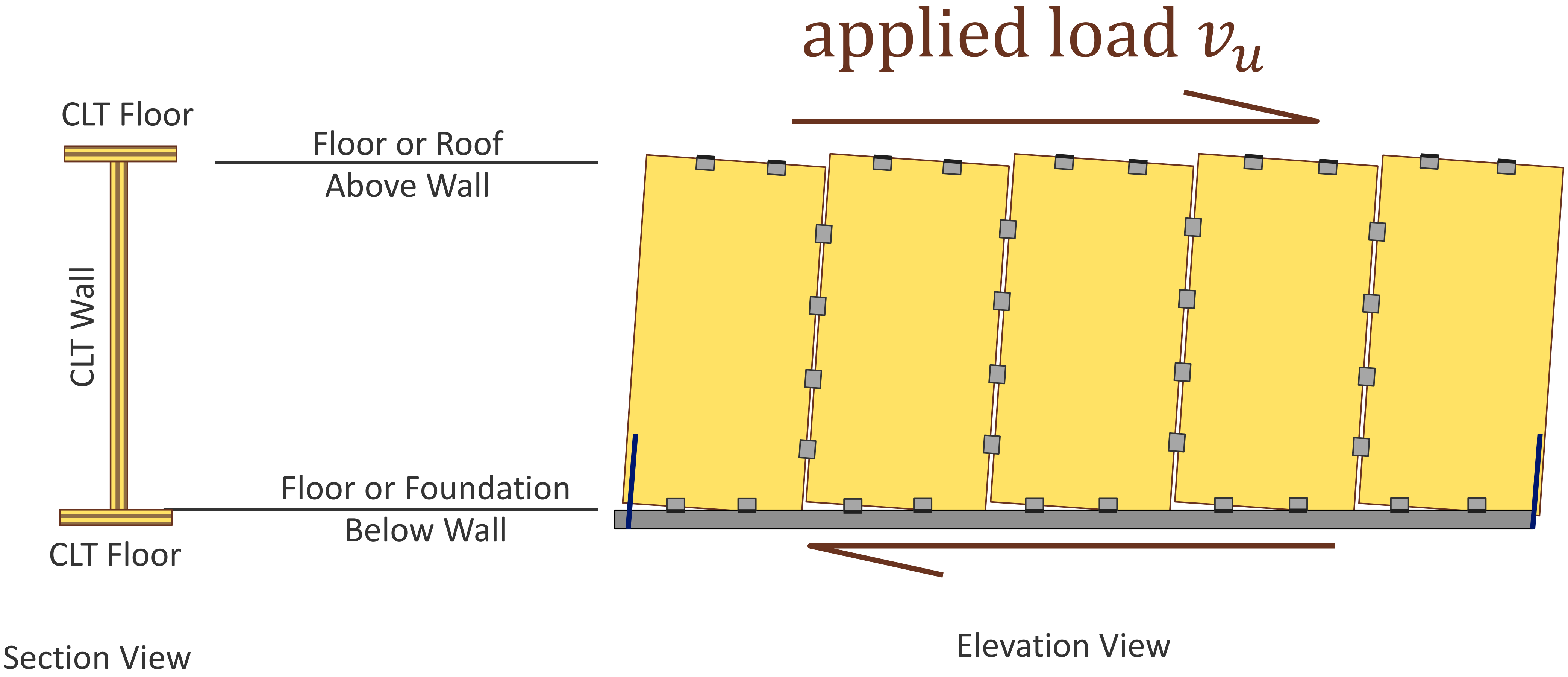


Top Changes Relevant to CLT Lateral Systems:

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

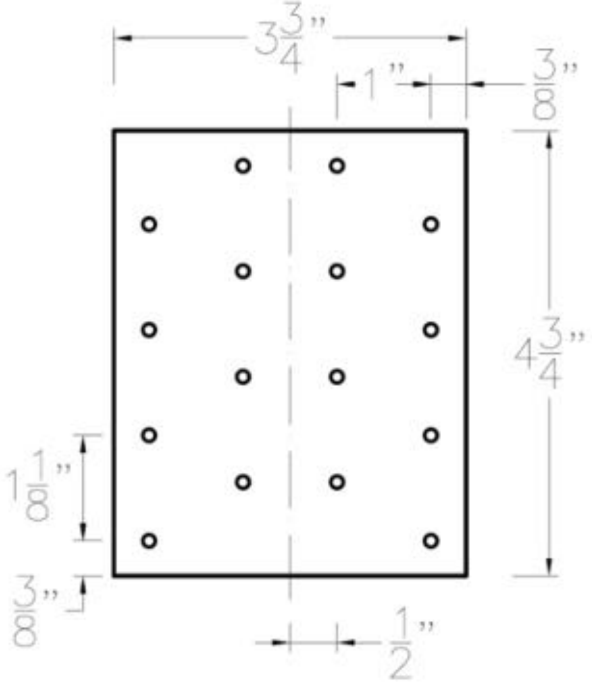
View for free at awc.org

2021 SDPWS – CLT Shear Wall requirements



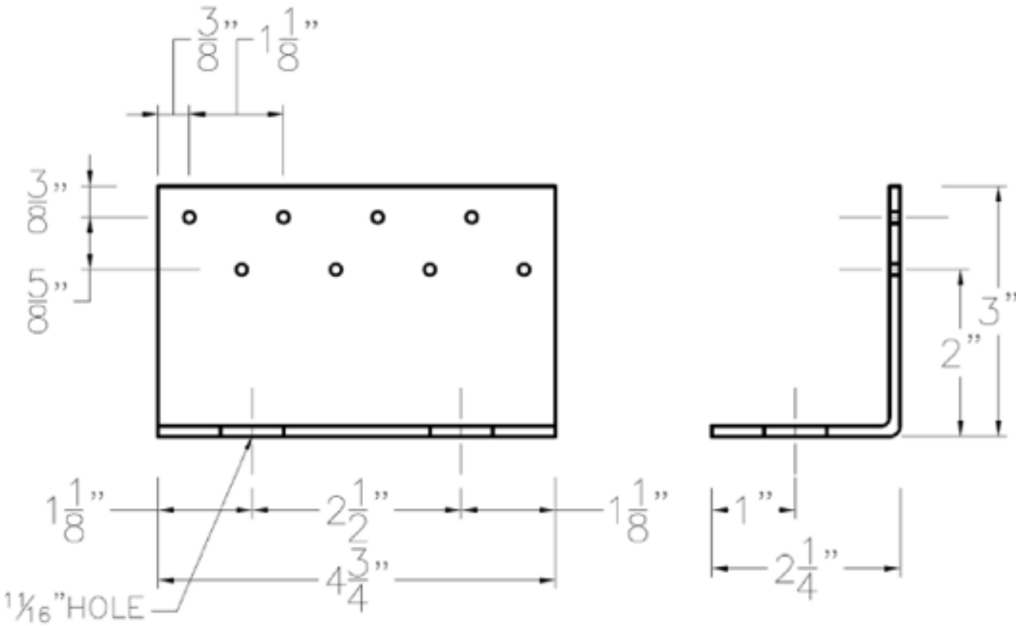
2021 SDPWS – CLT Shear Wall requirements

Panel to Panel Connection



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

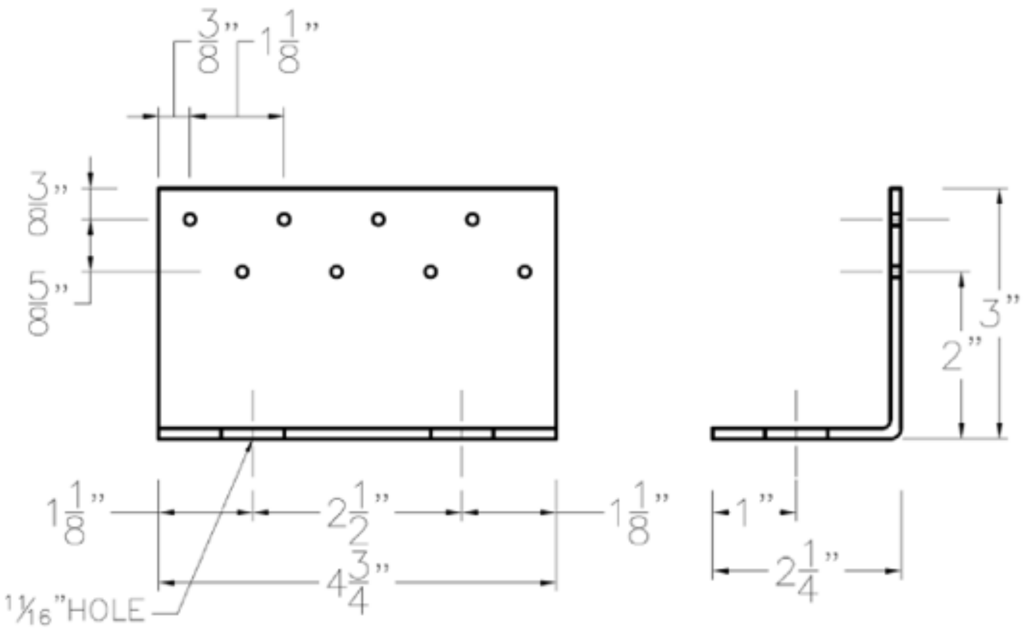
Panel to Platform Connection



Same steel plate material and nails plus
(2) 5/8” Ø bolts or lag screws to roof, floor or foundation

2021 SDPWS – CLT Shear Wall requirements

Panel to Platform Connection



Nominal shear capacity of connector

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 $G = 0.35$
$= 1.0 – 2\,(0.42\text{-}G)$	for $0.42 > G > 0.35$

Nominal unit shear capacity:

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

2021 SDPWS – CLT Shear Wall requirements

(platform and balloon-framed)

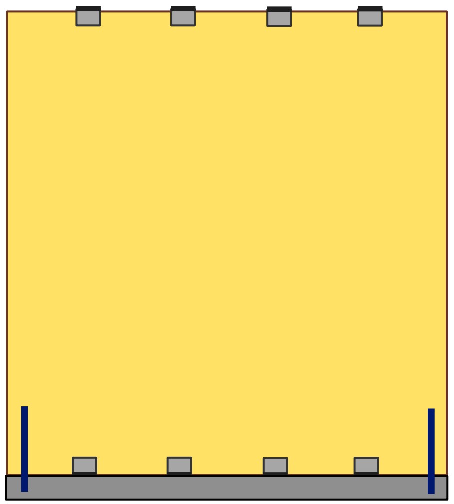
CLT Shear Walls

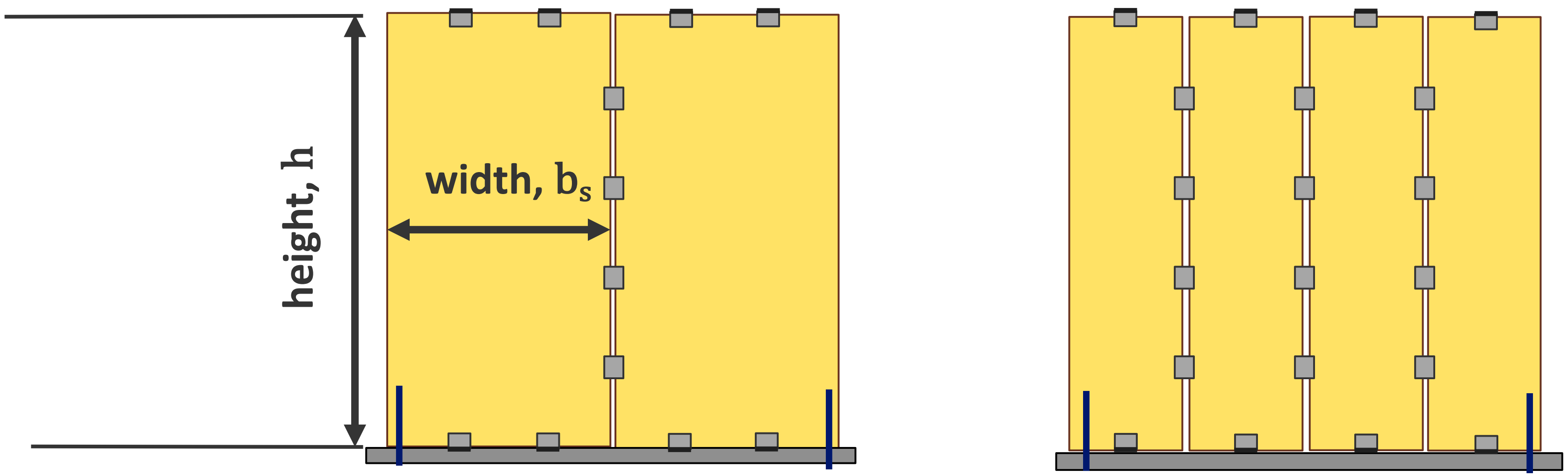
not meeting Appendix B

(platform-framed only)

CLT Shear Walls

meeting Appendix B





Seismic Design Category
A or B only
(SDPWS Section 4.6.3)

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

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

Panel aspect ratios
$h/b_s = 4$

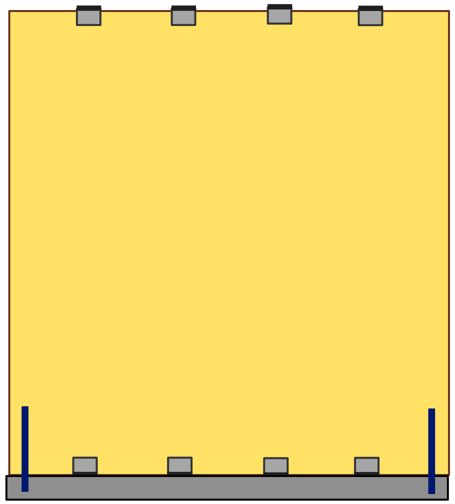
What “R” value can I use?

2021 SDPWS – "R" Values for CLT Shear Walls

(platform and balloon framed)

CLT Shear Walls

not meeting Appendix B



"R" = 1.5

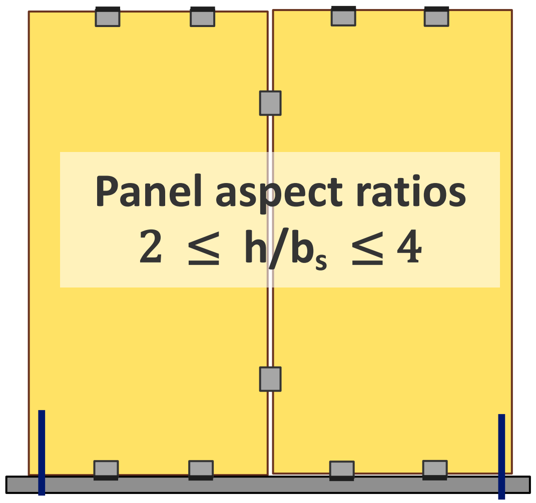
$C_d = 1.5$ $\Omega_o = 2.5$

(SDPWS Section 4.6.3)

(platform-framed only)

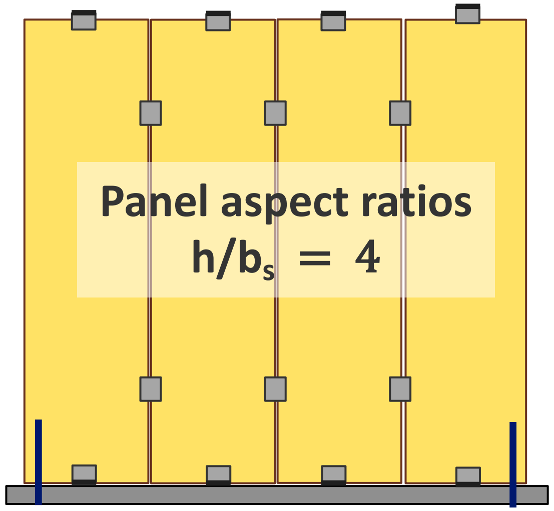
CLT Shear Walls

meeting Appendix B



"R" = 3.0*

$C_d = 3.0$ $\Omega_o = 3.0$



"R" = 4.0*

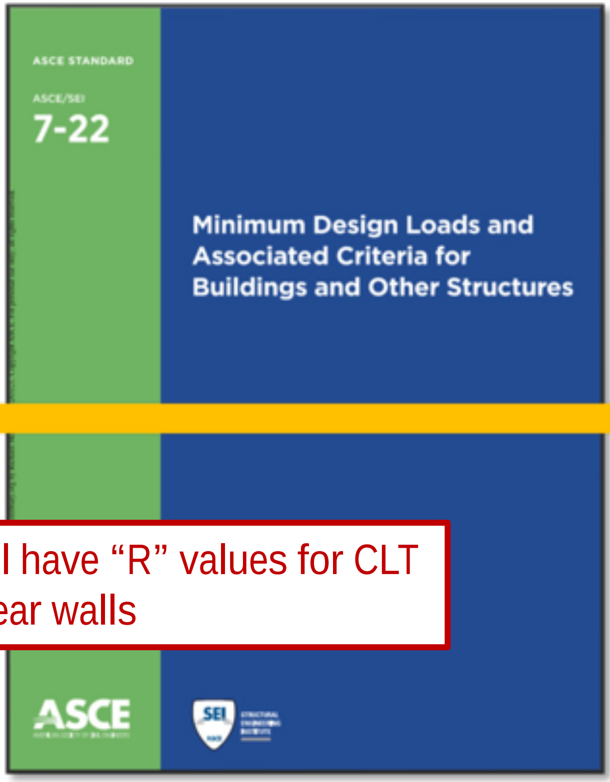
$C_d = 4.0$ $\Omega_o = 3.0$

* ASCE 7-22

CLT in the 2024 IBC (Lateral)

Now with CLT shear wall and diaphragm requirements

2021 SDPWS



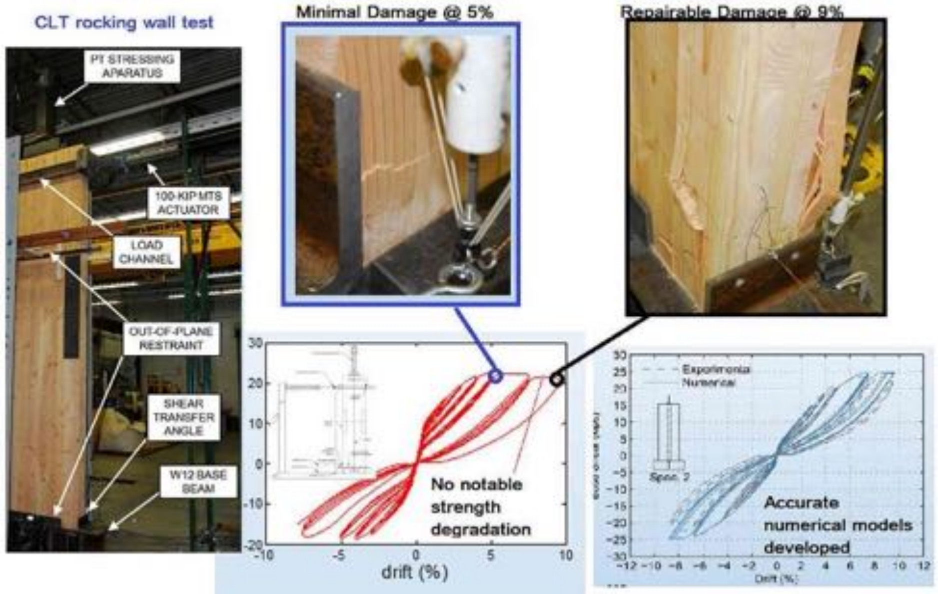
Will have "R" values for CLT shear walls

ASCE/SEI 7-22

2024 IBC

CLT lateral systems will be fully recognized in the 2024 International Building Code

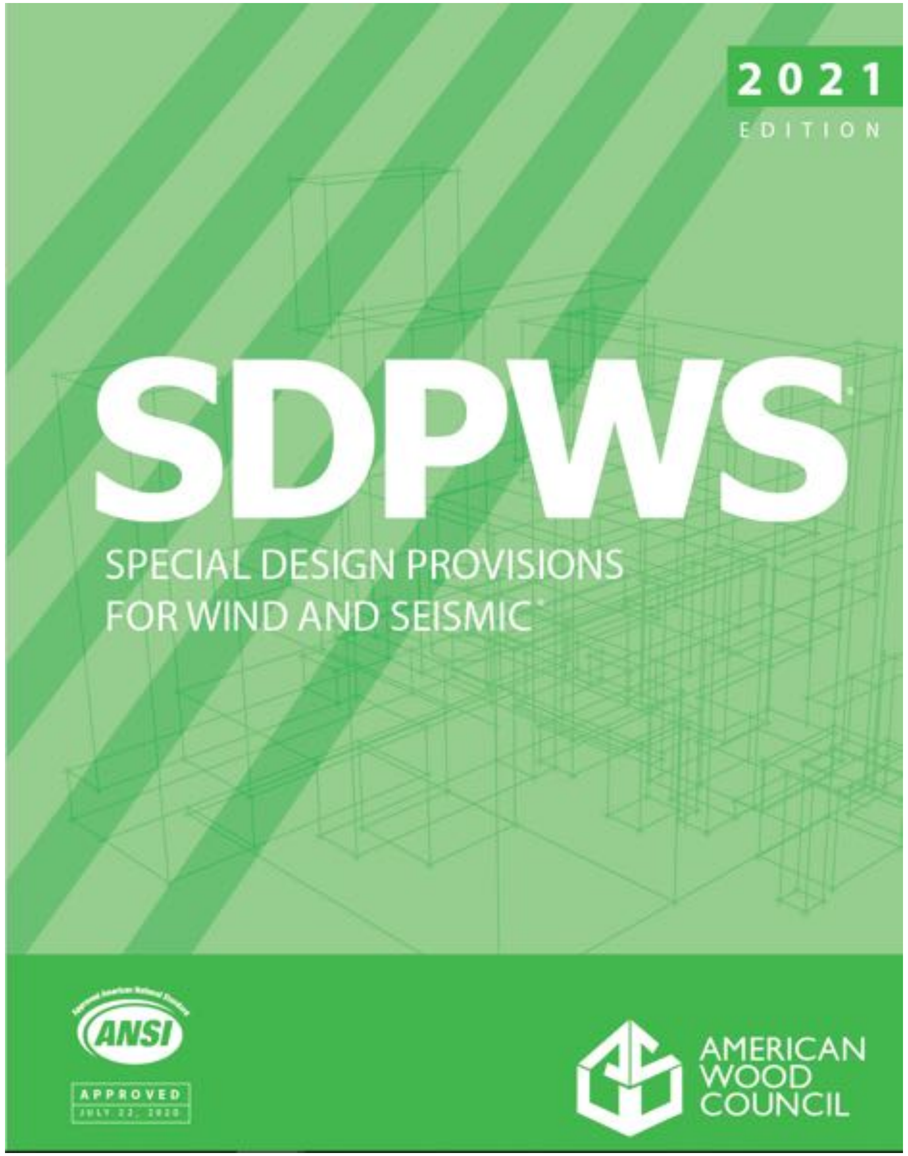
CLT Post-Tensioned Rocking Shear Wall System Tests



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

CLT Diaphragm Design

2021 Special Design Provisions for Wind and Seismic

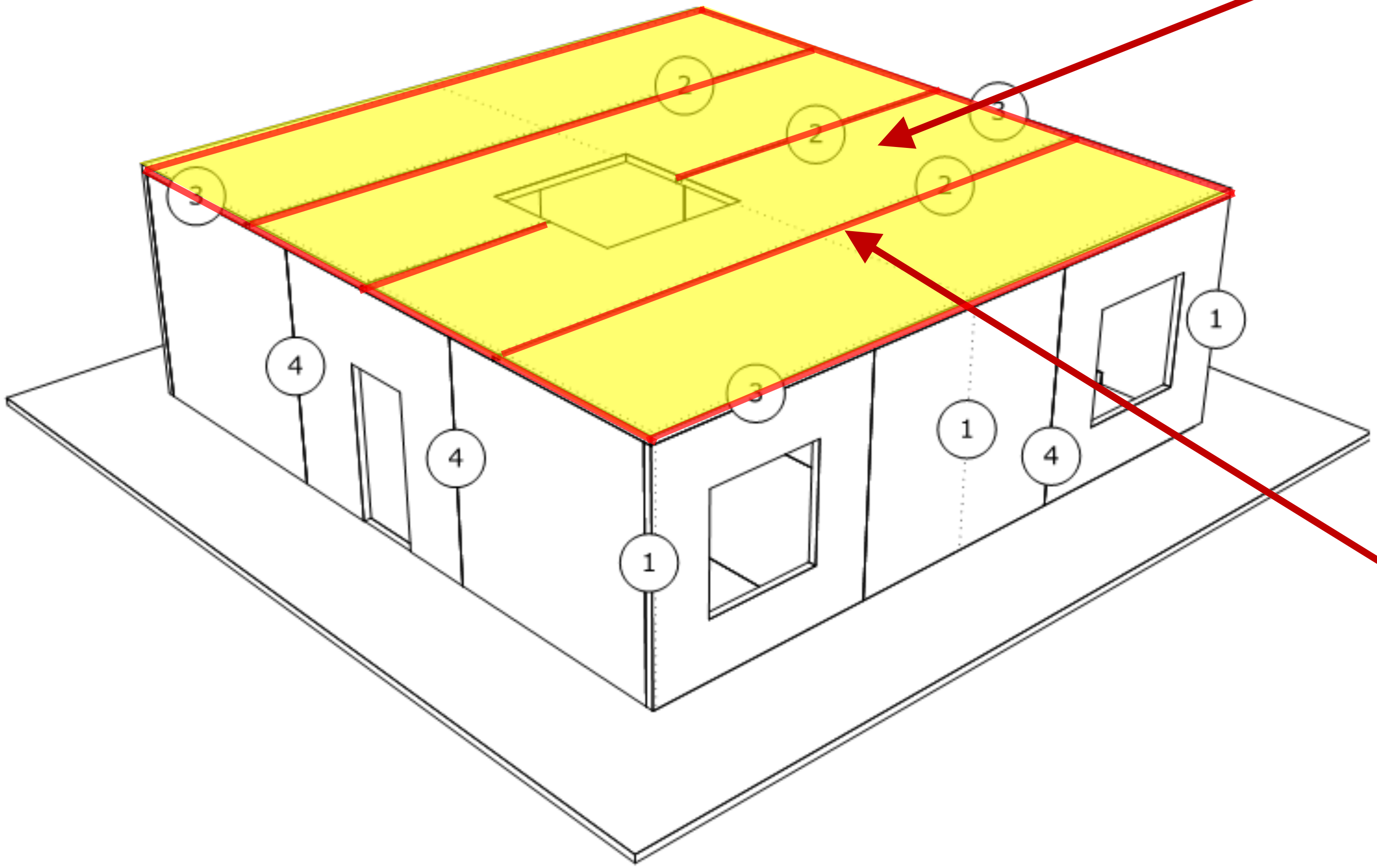


Top Changes Relevant to CLT Lateral Systems:

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

View for free at awc.org

CLT Diaphragms



Strength of CLT should never govern

Strength of connections (covered by NDS and proprietary fastener Evaluation Reports) governs design

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 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.

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

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_s, 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$_s$ 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.

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 Transfer Connection Design

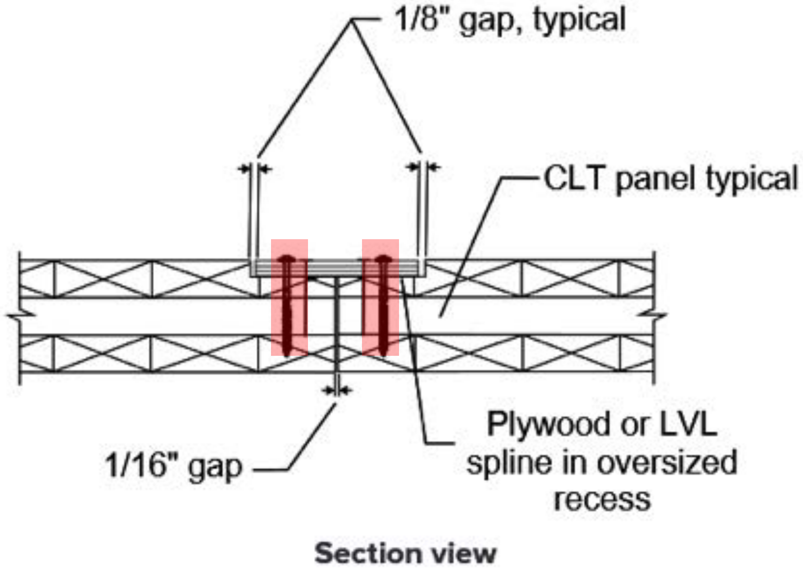
Nominal capacity of CLT diaphragm shear transfer connection fastener:

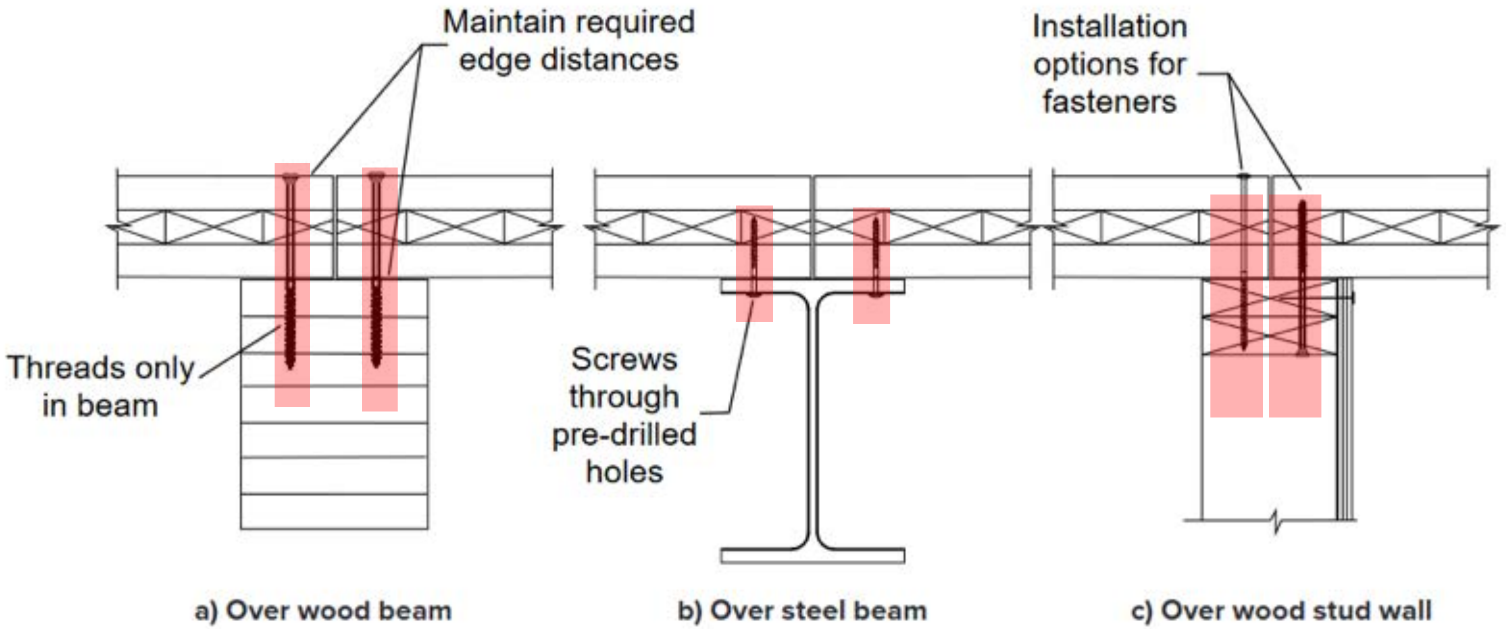
$$Z_n = 4.5\, Z^*$$

Where Z^* is reference lateral capacity Z from NDS multiplied by all applicable factors *except* C_D, K_F, ϕ, $\lambda = 1.0$

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

CLT Diaphragm Shear Transfer Connections





Diaphragm **shear transfer connections** at CLT panel edges:

- Use dowel-type fasteners in shear (nails, screws, bolts)
- Yield **Mode IIIs or IV** per NDS 12.3.1 must control capacity

Other CLT 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_s, 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.

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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.

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.

Other CLT Diaphragm Components

Amplified Diaphragm Design Forces ≤ Design Capacity

$$\gamma \cdot v \leq v'$$

v = wind or seismic force demand

$v' =$ Adjusted capacity calculated per the NDS *not 4.5 Z**

$\gamma =$ 2.0 for wood and steel components, except:

1.5 wood members resisting wind loads

1.5 chord splice connections controlled by Mode IIIs or IV (seismic)

1.0 chord splice connections controlled by Mode IIIs or IV (wind)

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

Additional Resources

Additional Resources

Available from woodworks.org

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

WOODWORKS WOOD PRODUCTS COUNCIL

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 factor, Ω_D, or multiplying by a resistance factor, ϕ_D, for LRFD design as summarized in Table 1. For sheathed wood-frame diaphragms, the SDPWS

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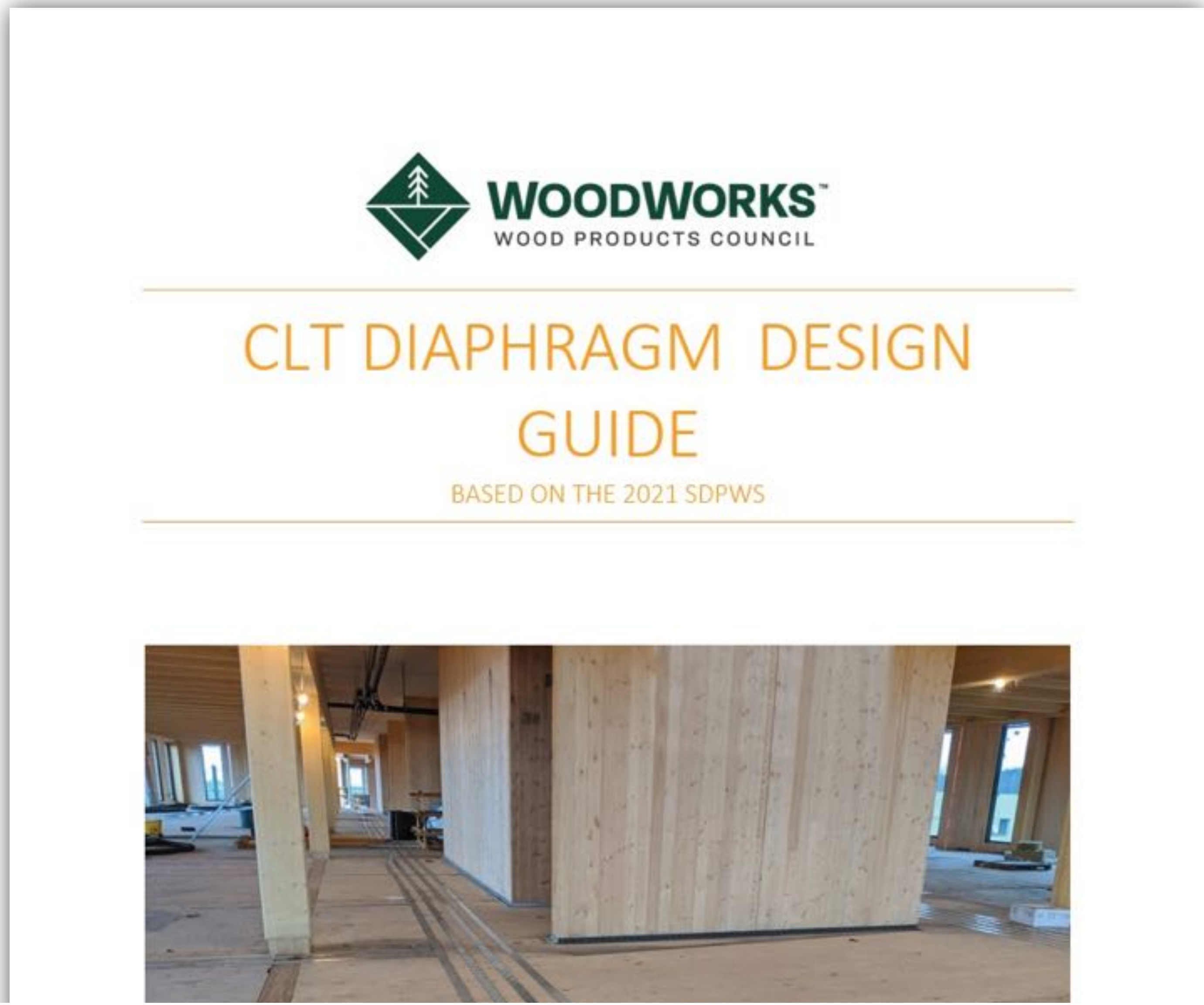
Additional Resources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CLT DIAPHRAGM DESIGN GUIDE

BASED ON THE 2021 SDPWS

Under Development By:

WOODWORKS WOOD PRODUCTS COUNCIL

Holmes Structures

kpff

SWINERTON MASS TIMBER

Funded By:

U.S. Endowment for Forestry and Communities

USDA

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