ASPECT
STRUCTURAL ENGINEERS

Mass Timber Connections: Building Structural Design Skills

DUNCAN BOURKE
Associate, P.Eng
duncan@aspectengineers.com

"The Wood Products Council" is a Registered Provider with The American Institute of Architects Continuing Education Systems (AIA/CES), Provider #G516.

Credit(s) earned on completion of this course will be reported to AIA CES for AIA members. Certificates of Completion for both AIA members and non-AIA members are available upon request.

This course is registered with AIA CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product.

Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

Description

For engineers new to mass timber design, connections can pose a particular challenge. This course focuses on connection design principles and analysis techniques unique to mass timber products such as cross-laminated timber, glued-laminated timber and nail-laminated timber. The session will focus on design options for connection solutions ranging from commodity fasteners, pre-engineered wood products and custom-designed connections. Discussion will also include a review of timber mechanics and load transfer, as well as considerations such as tolerances, fabrication, durability, fire and shrinkage that are relevant to structural design.

Disclaimer

While the presenters have tried to be as accurate as possible, they cannot be held responsible for the designs of others that might be based on the material presented in this workshop. The material covered in this workshop is intended for the use of professional personnel who are competent to evaluate the significance and limitations of its content and recommendations and who will accept the responsibility for its application. The presenters and the sponsoring organizations disclaim any and all responsibility for the applications of the stated principles & values and for the accuracy of any of the material presented in the workshop.

Learning Objectives

1. Review the timber mechanics that are relevant to mass timber design including, grain orientation and dimensional stability and define how loads are transferred in timber connections.
2. Consider practical aspects of design that are not traditionally in the scope of a structural design for other materials but may be relevant for mass timber such as tolerances, fabrication, durability, fire, and shrinkage.
3. Explore connection solutions available including commodity fasteners, pre-engineered products and custom designed connections.
4. Learn about cutting edge connection technologies and resources for learning more.

Agenda

Introduction

1. Mass Timber Maturity
2. Basics of Connection Design
3. Practical Considerations
4. Design Solutions
5. Next Generation of Connections

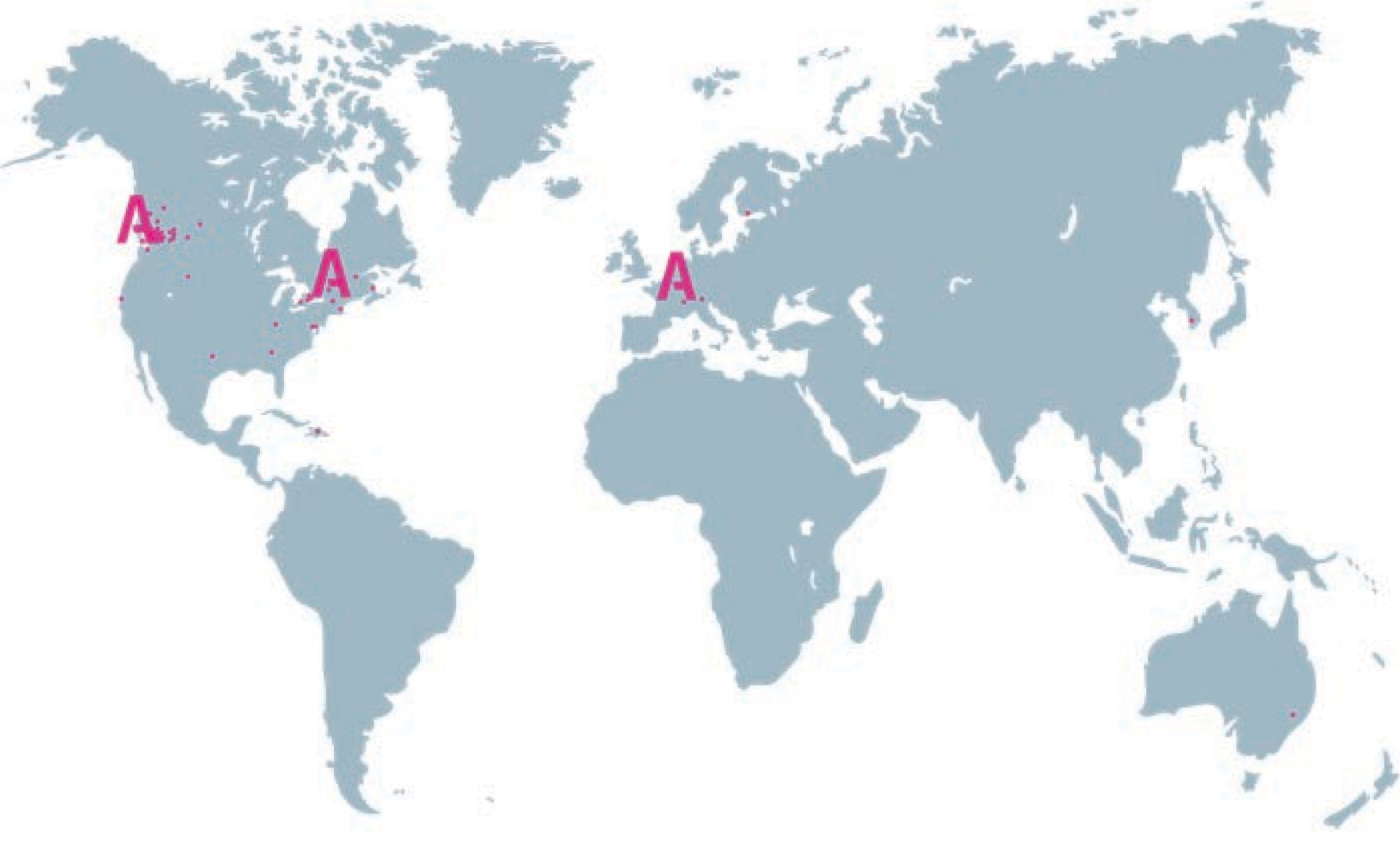
3 Things to remember

- Appreciate the difference between Behavior and Strength
- Small Ø are better than large (t/d=5)
- NEVER use traditional lag screws again

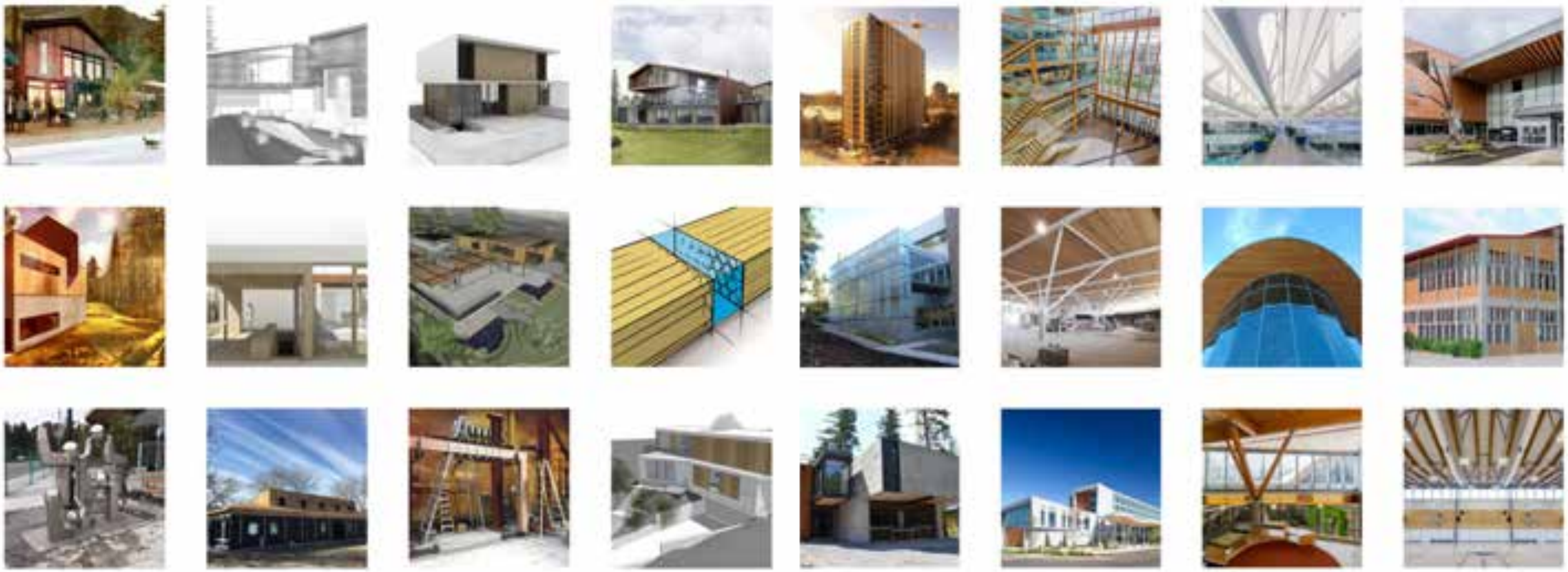
Introduction

Our Office Locations

Our Projects



What We Do



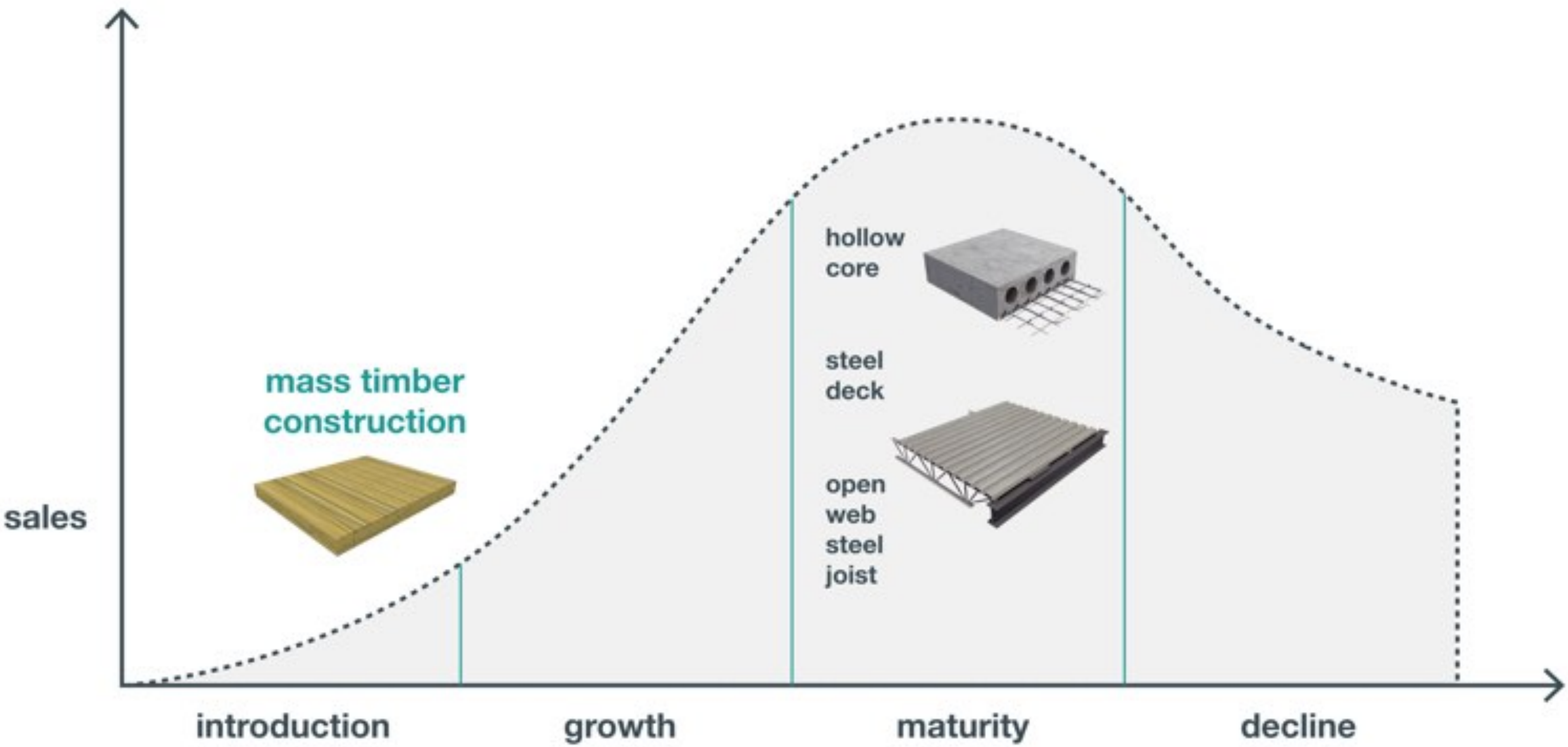
How We Think

"Engineers are good at solving problems.

The trick is to make sure to solve the right problems and not the first one that is encountered along the way"

1.0 Mass Timber Maturity

Where We Are At



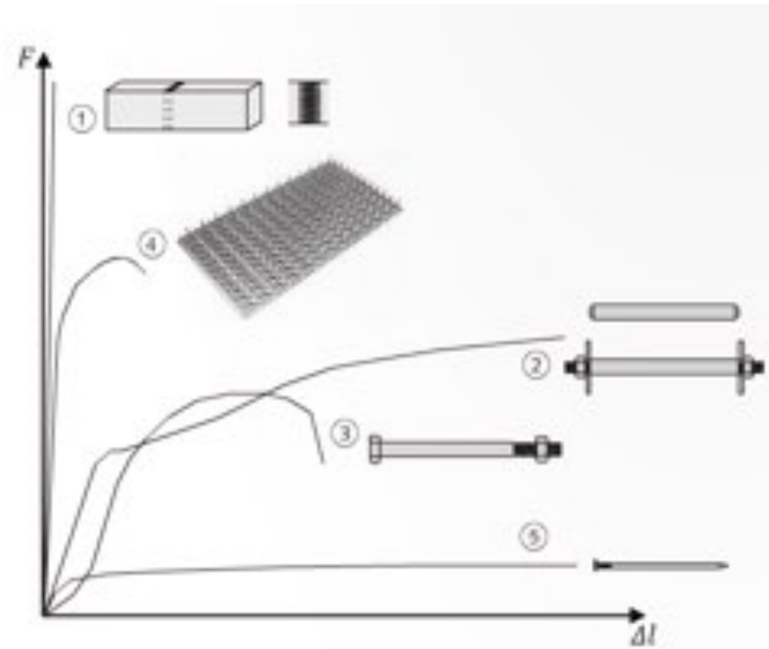
2.0 Basics of Connection Design

Connection Design Depends On:

- Nature of the forces and their magnitude
- Practicality
- Production
- Geometry
- Environmental conditions
- Aesthetics
- Cost
- Fire performance

2.1 Environment

2.2 Connection Stiffness



1. Glued Connection
2. Tight Fit Dowel / Bolt Φ = 16 mm
3. Through Bolts Φ = 19 mm
4. Truss Plate 10'000 mm^2
5. Nail Φ = 4.4 mm

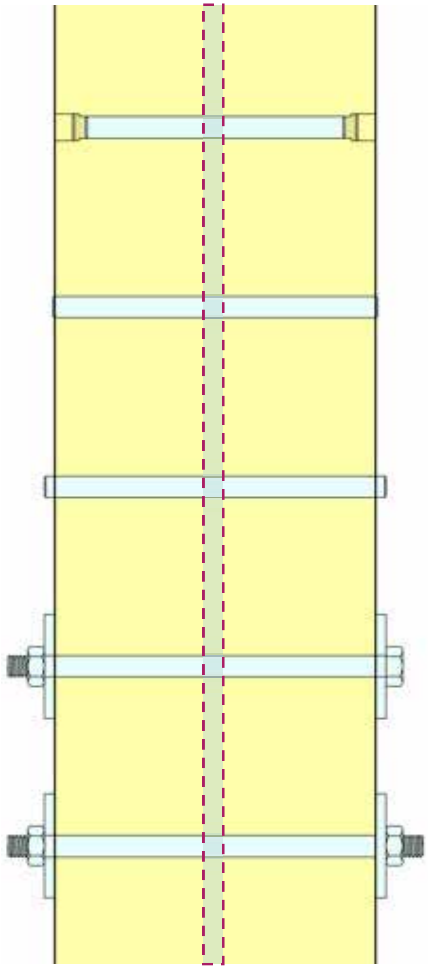
→ Behavior vs. Strength

2.3 Bolt vs. Tight Fit Dowels

Through Bolt

Tight Fit Bolt

2.3 Bolt vs. Tight Fit Dowels



Tight Fit Dowel with Plug

Tight Fit Dowel flush

Tight Fit Dowel with projection

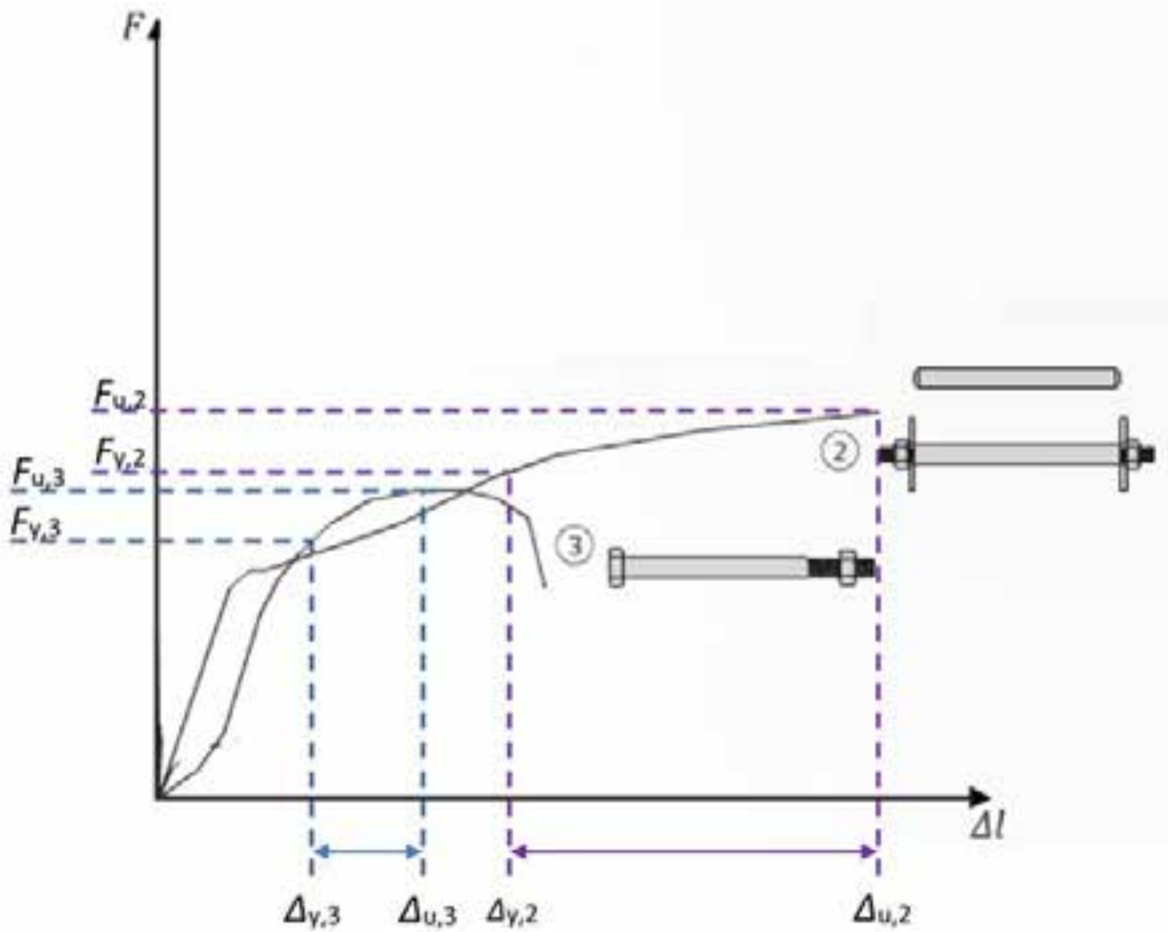
Through Bolt

Tight Fit Bolt

2.3 Bolt vs. Tight Fit Dowels

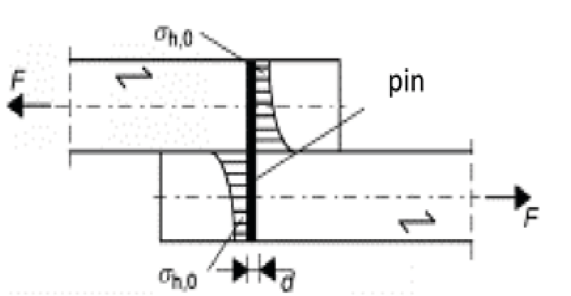
	Size of hole in Wood	Size of hole in Steel	Use of Connection
Tight Fit Dowel/Bolt	Same size as pin/bolt diameter	Up to 1/32" larger than pin/bolt diameter	Typically used for engineered connections without additional load transfers (i.e. w/o bearing plates for example).
Through Bolt	Up to 1/16" larger than bolt diameter	Up to 1/16" larger than pin/bolt diameter	Typically used in connections where the bolt serves as a positioning aid. Traditional heavy timber buildings may also feature such a connection. This type of connection should be avoided in heavily loaded connections or if part of the SFRS.

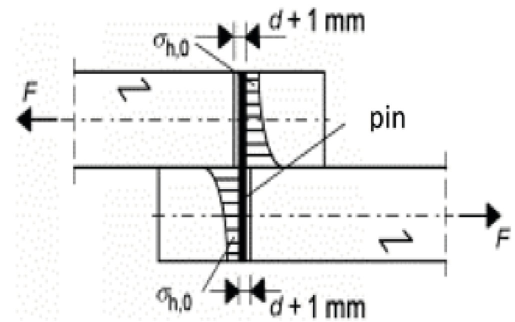
2.3 Bolt vs. Tight Fit Dowels

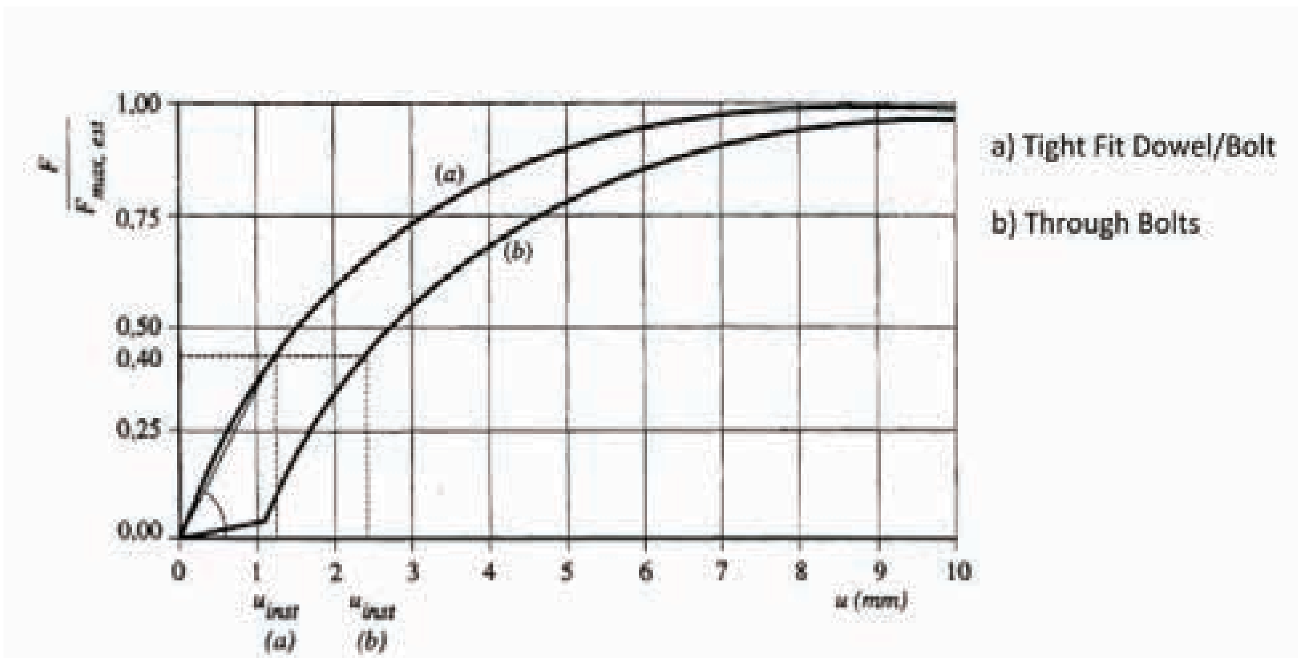


* NDS HAS 75% CAP FOR DRIFT PINS…

2.3 Bolt vs. Tight Fit Dowels

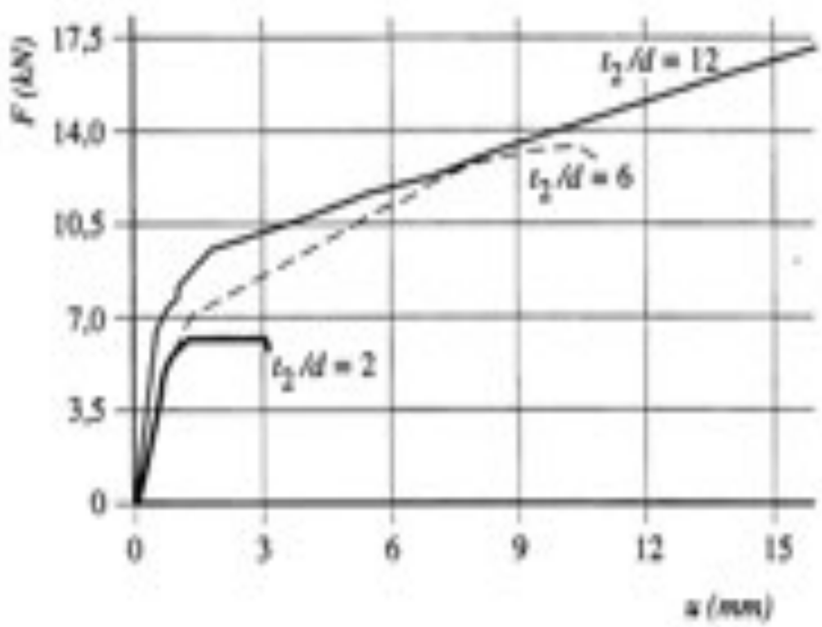






Fu = Ultimate Strength   Fy = Yield Strength

2.4 Bolts / Dowels - Slenderness



$$\lambda = \frac{t}{d}$$

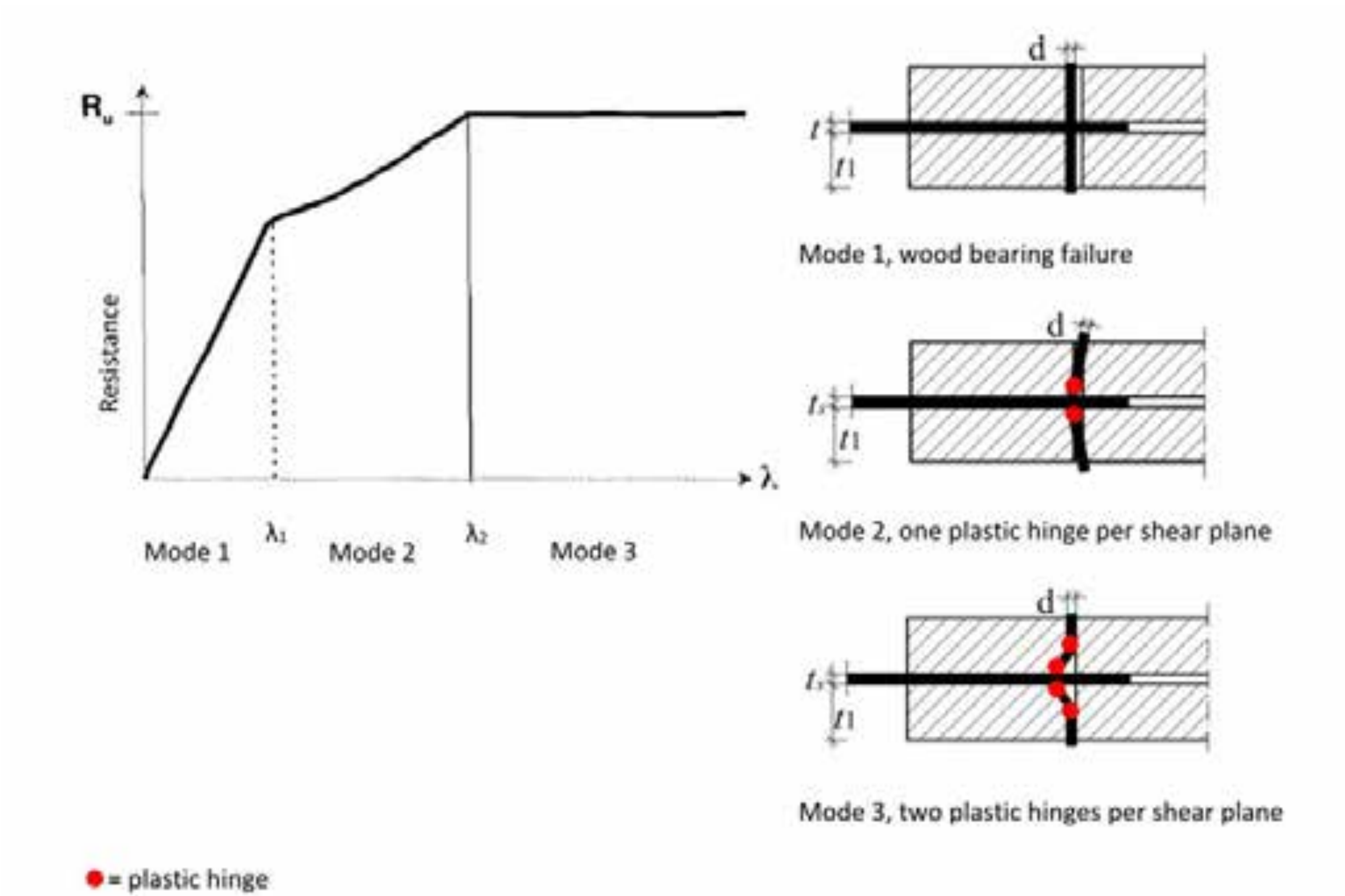
Where;

t = member thickness

d = dowel or bolt diameter

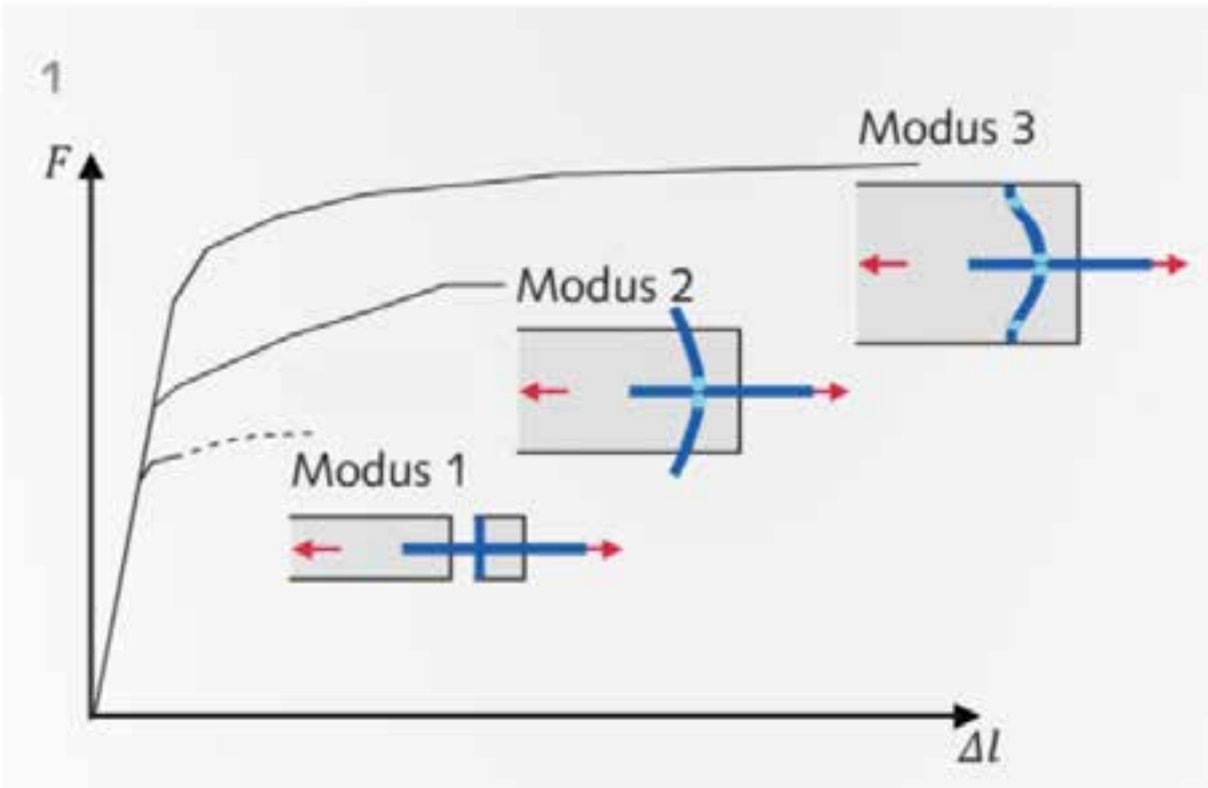
→ Behavior vs. Strength

2.5 Bolts / Dowels – Failure Mode



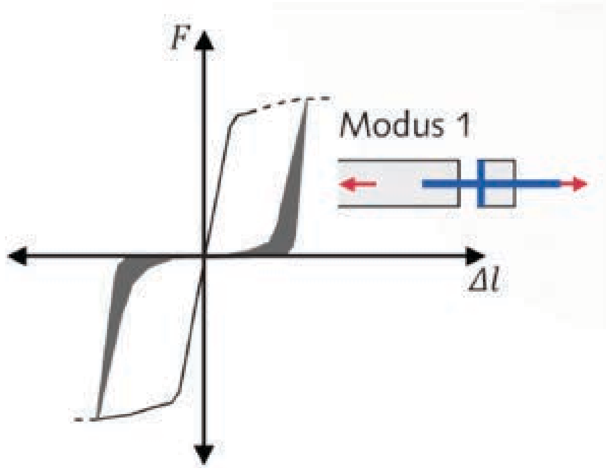
NOTE: THESE MODES DO NOT CORRESPOND TO THE NDS. THEY ARE BASED ON THE RESEARCH PAPERS QUOTED

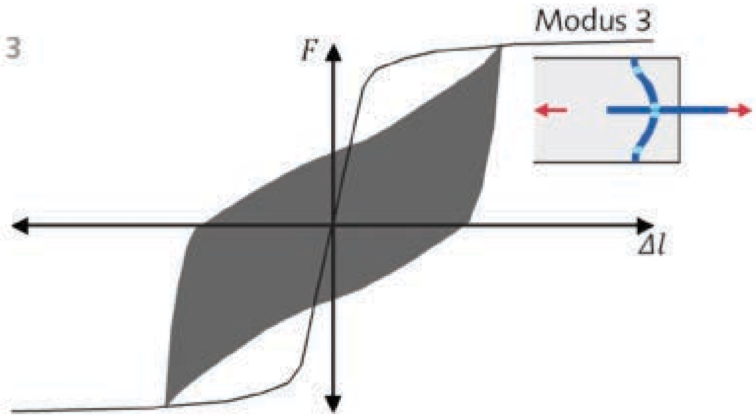
2.5 Bolts / Dowels – Failure Mode



NOTE: THESE MODES DO NOT CORRESPOND TO THE NDS. THEY ARE BASED ON THE RESEAERCH PAPERS QUOTED

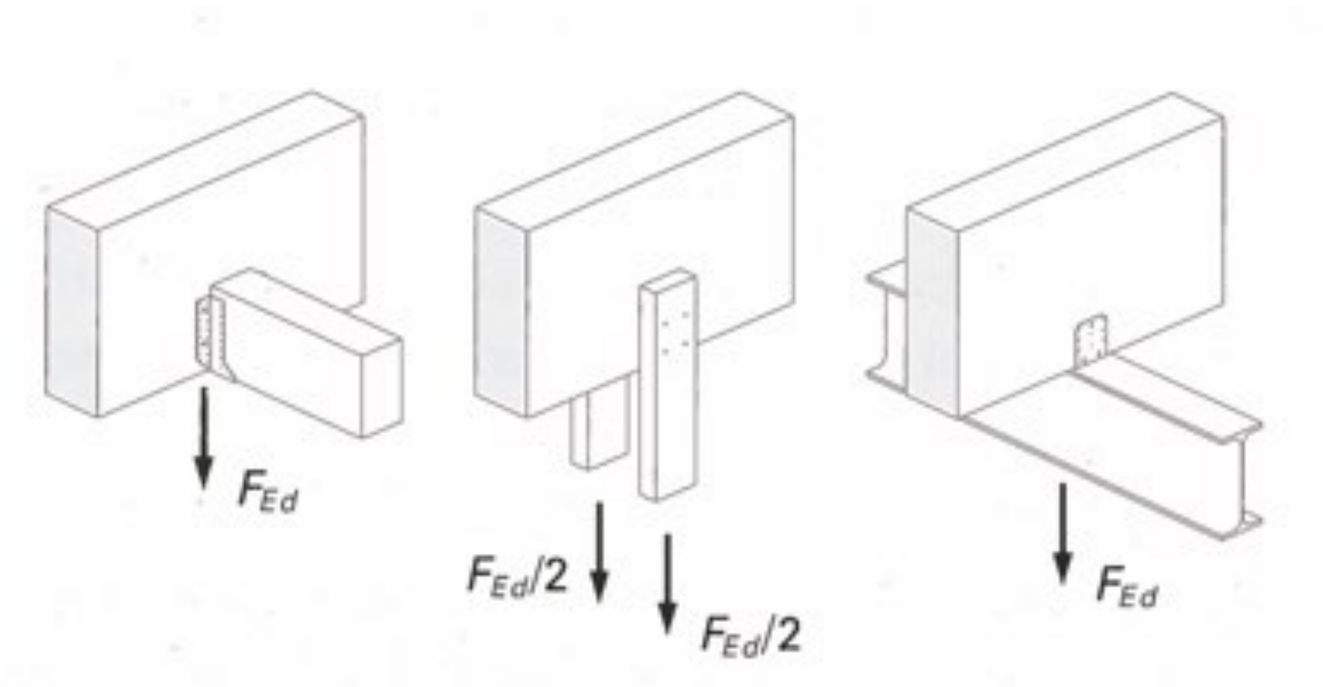
2.6 Bolts / Dowels – Seismic Design





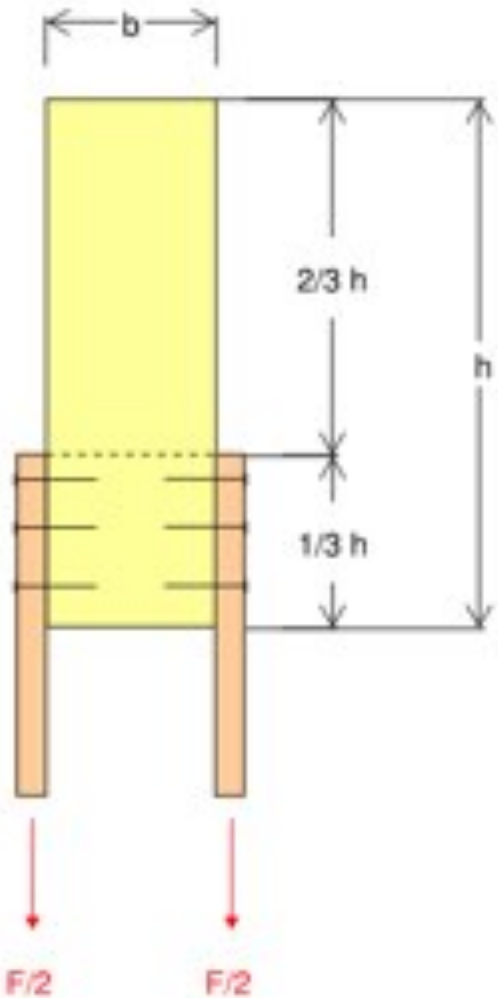
NOTE: THESE MODES DO NOT CORRESPOND TO THE NDS. THEY ARE BASED ON THE RESEAERCH PAPERS QUOTED

2.8 Tension Perpendicular



Bad connection geometries!

2.8 Tension Perpendicular

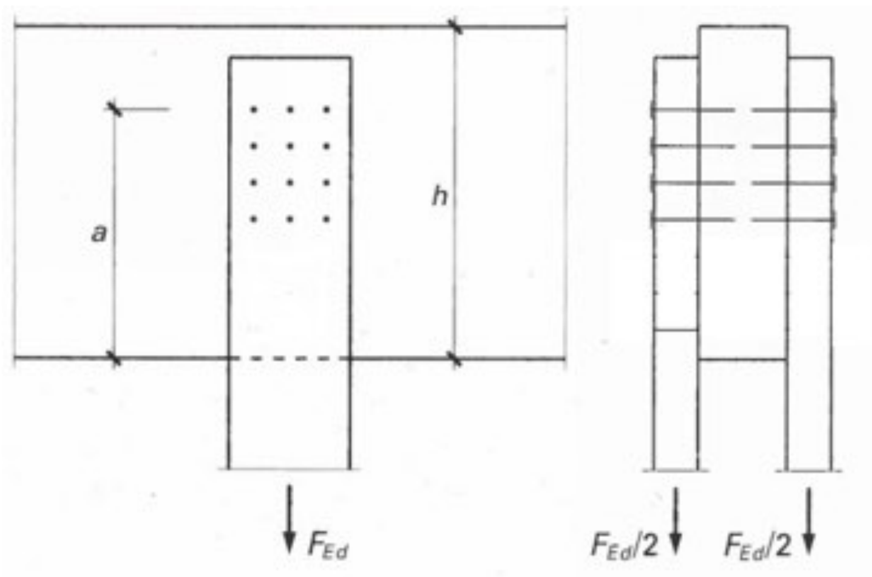


Upper portion is 8! times stiffer

But both portions need to deflect the same amount

2.8 Tension Perpendicular

2.8 Tension Perpendicular



In general, if a/h ≥ 0.7, the effect of tension perpendicular can be ignored. This should be the preferred approach to any connection

2.9 Movement

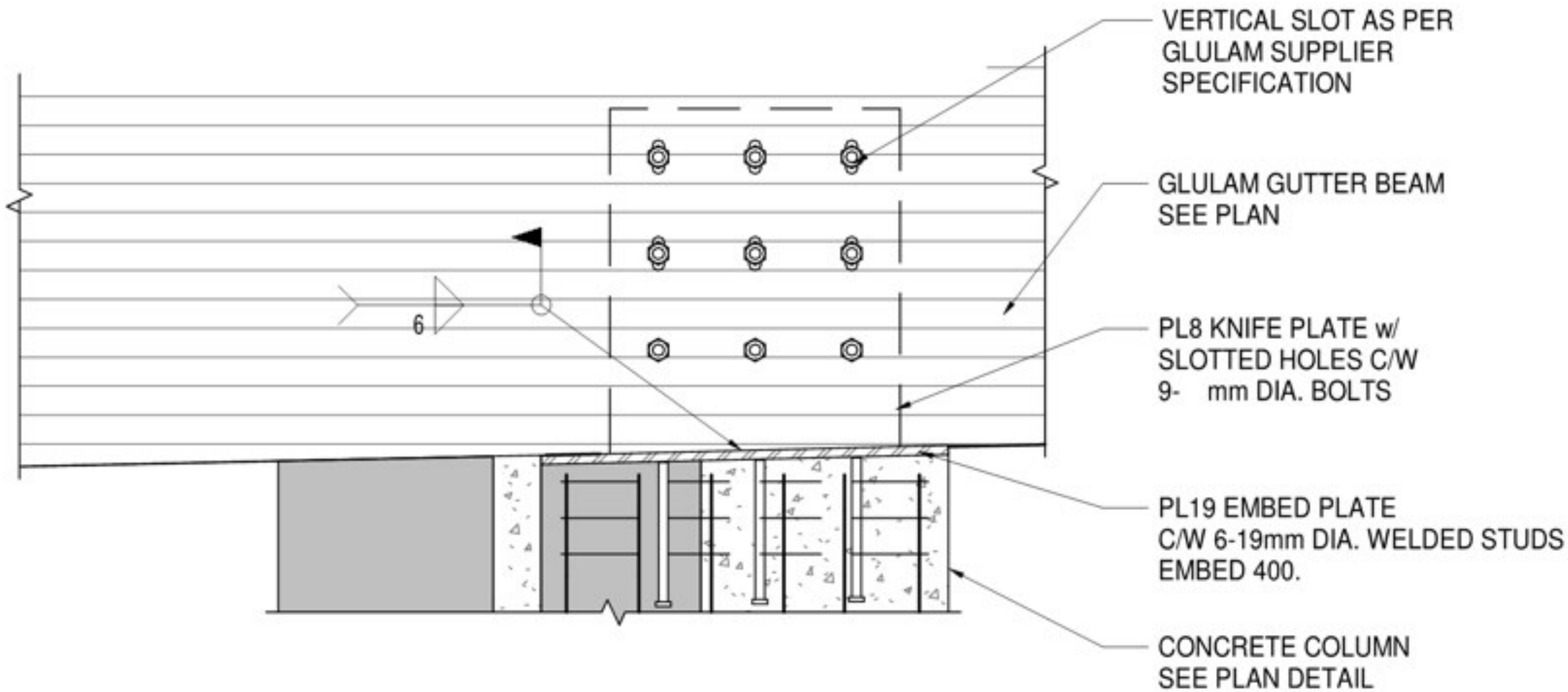
shrinkage

Be realistic about actual fluctuation of EMC

It takes quite a while for larger cross sections to equalize throughout the cross section

swelling

2.9 Movement



VERTICAL SLOT AS PER GLULAM SUPPLIER SPECIFICATION
GLULAM GUTTER BEAM SEE PLAN
6
PL8 KNIFE PLATE w/ SLOTTED HOLES C/W 9- mm DIA. BOLTS
PL19 EMBED PLATE C/W 6-19mm DIA. WELDED STUDS EMBED 400.
CONCRETE COLUMN SEE PLAN DETAIL

2.10 Summary

- Direct load path
- Respect Wood Movement (and design for it!)
- Bolts / Dowels to have ductile failure modes
- Careful with tension perpendicular
- Avoid horizontal wood in the vertical load path
- Old school bearing type connections often economical
- Design with fabrication and installation in mind → next chapter

3.0 Practical Considerations

3.1 Equipment

- Hand Tools

3.1 Equipment

- CNC

3.2 Installers

3.3 Overview

Practical Considerations for Connection Designs		Origin of Issue					Where to address the Issue				
		Design	Fabrication	Transportation	Installation	Use	Design	Fabrication	Transportation	Installation	Use
Supply Capabilities	CNC machining vs Hand-framing of wood members		x				x				
Supply Capabilities	Welding / machining of custom steel pieces		x		x		x				
Shrinkage	Movement (or restricted movement) of wood due to fluctuation of moisture content					x	x				
Tolerances	Missing tolerance level in standards		x		x		x				
Tolerances	Member size not as per specs, assembly of members doesn't fit		x		x		x	x			
Tolerances	Interface to other materials (steel and concrete) doesn't fit. Steel and concrete have much larger tolerances		x		x		x	x			
Fire Resistance	Charring of wood, reduction of cross section, heat transfer					x	x	x		x	
Fire Resistance	Exposed connectors					x	x	x		x	

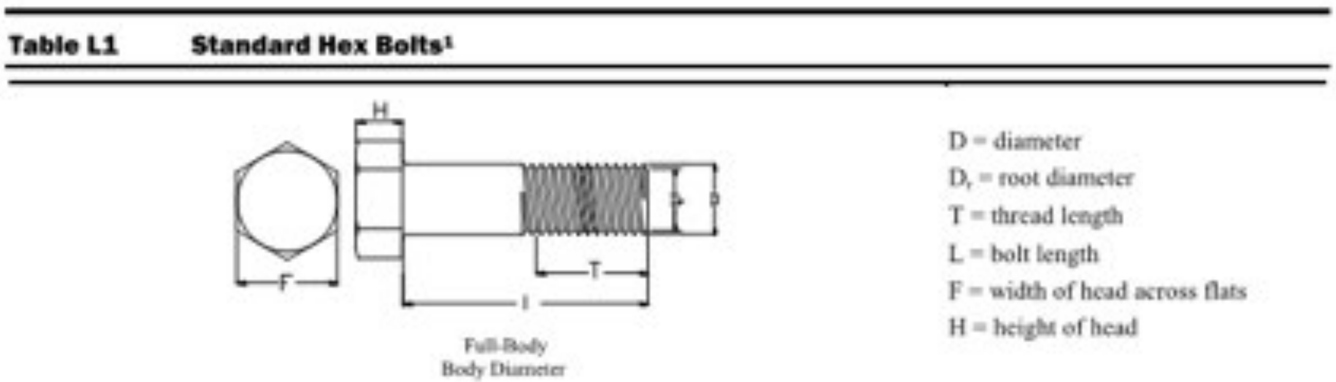
3.3 Overview

Practical Considerations for Connection Designs		Origin of Issue					Where to address the Issue				
		Design	Fabrication	Transportation	Installation	Use	Design	Fabrication	Transportation	Installation	Use
Local Workforce	Installation strategy needs to respect labor skill sets available.				x		x				
Site Conditions	Crane type and locations may impact member length and require add'l splices.			x	x		x				
Speed of installation	Maximize site production, limited crane time available				x		x				
Speed of installation	Connection types		x		x		x				
AHJ	AHJ is not familiar with the type of construction	x					x				
AHJ	AHJ does not facilitate the use of alternate connectors	x					x				
Drift Compatibility	Connections need to accommodate lateral movement	x				x	x			x	
Detail Complexity	Multiple members framing coming together	x					x				

4.0 Design Solutions

4.1 Commodity (NDS Dowel-Type)

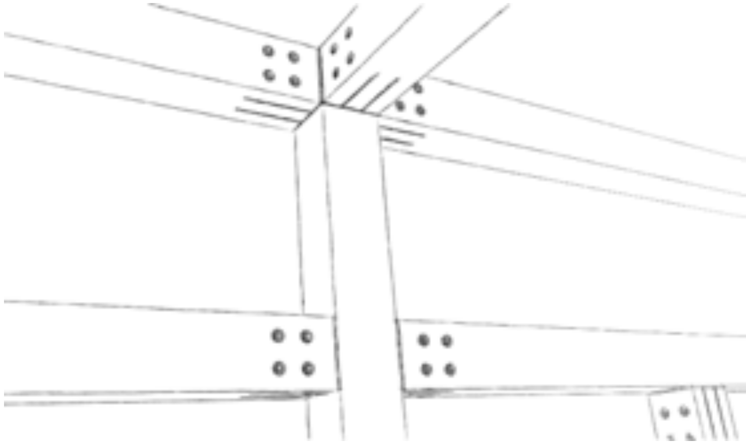
4.1.1 Standard Hex Bolts



Applications	Pros	Cons
• Direct beam to beam connections (in shear) • Beam to beam or beam to column connections via knife or side plates • Nominal connectors for plate saddles/bearing connections	• Readily Available • Skilled trades not required for installation • Can keep bolt heads exposed for architecturally expressive exposed old-school heavy timber connections • Can be used for timber connection to any material (concrete, steel, masonry)	• Connections are naturally exposed • Both sides of connection must be accessible • Bolt head/nut and washer must be perpendicular to connected surfaces (or shimmed or notched/recessed to suit)

4.1 Commodity (NDS Dowel-Type)

4.1.1 Standard Hex Bolts

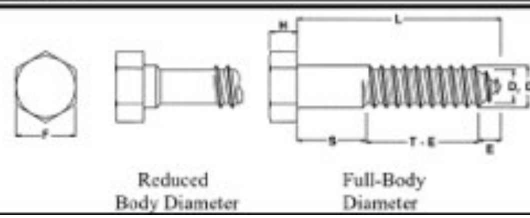


4.1 Commodity (NDS Dowel-Type)

4.1.2 Standard Hex Lag Screws

Table L2 Standard Hex Lag Screws[1]

D = diameter
D_r = root diameter
S = unthreaded body length
T = minimum thread length[2]



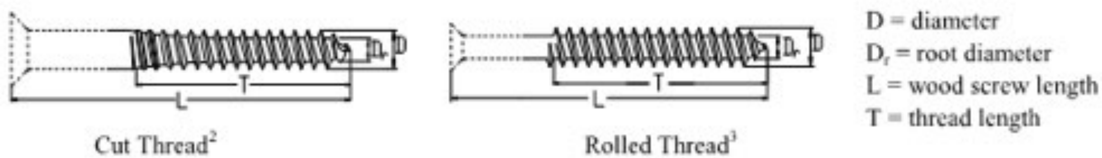
E = length of tapered tip
L = lag screw length
N = number of threads/inch
F = width of head across flats
H = height of head

Applications	Pros	Cons
• Direct beam to beam connections (in shear) • Beam to beam or beam to column connections via side plates • Nominal connectors for plate saddles/bearing connections where only one side is accessible	• Readily Available • Can keep bolt heads exposed for architecturally expressive old-school exposed heavy timber connections • Only one side of connection needs to be accessible • May be loaded in tension/withdrawal (but please avoid it)	• Very time consuming to install (skill needed) • Connections are naturally exposed • Lag screw head must be perpendicular to side member surface

4.1 Commodity (NDS Dowel-Type)

4.1.3 Standard Wood Screws

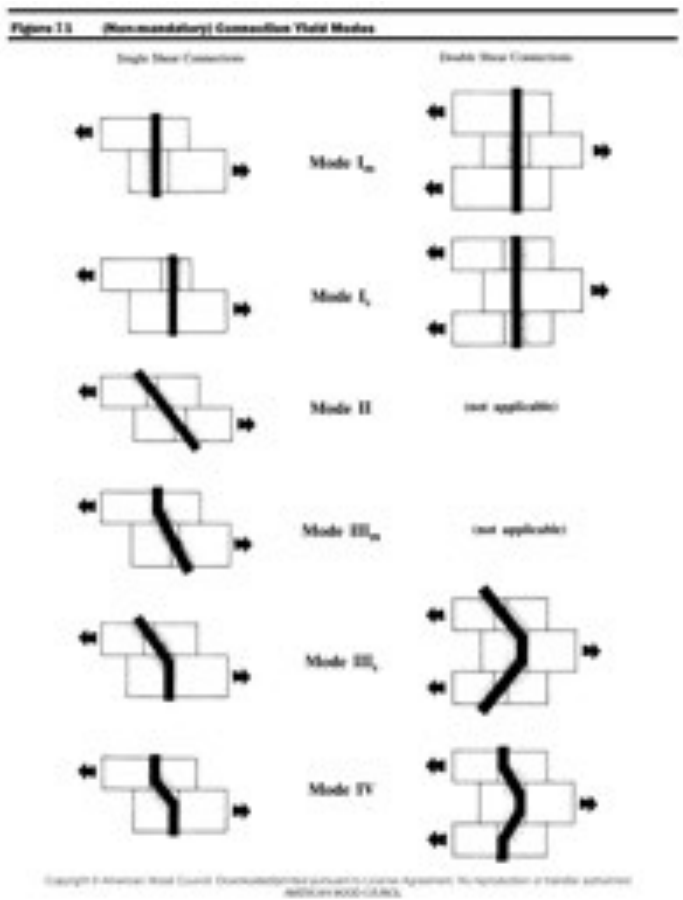
Table L3 Standard Wood Screws[1,5]



Applications	Pros	Cons
• Light wood frame connections (side members <1 ½”) • Loading permitted in shear and tension/withdrawal	• Readily Available • Relatively quick to install with a power drill • Skilled trades not required • Variable head sizes and shapes – can be flush or recessed if required • Small heads = low connection visibility • May be installed at an angle to the surface (with reduction factor) • Only one side of connection needs to be exposed • Predrilling not required	• Design diameter varies. Important to clearly specify screws. • Relatively short standard lengths available • Small resistances

4.1 Commodity (NDS Dowel-Type)

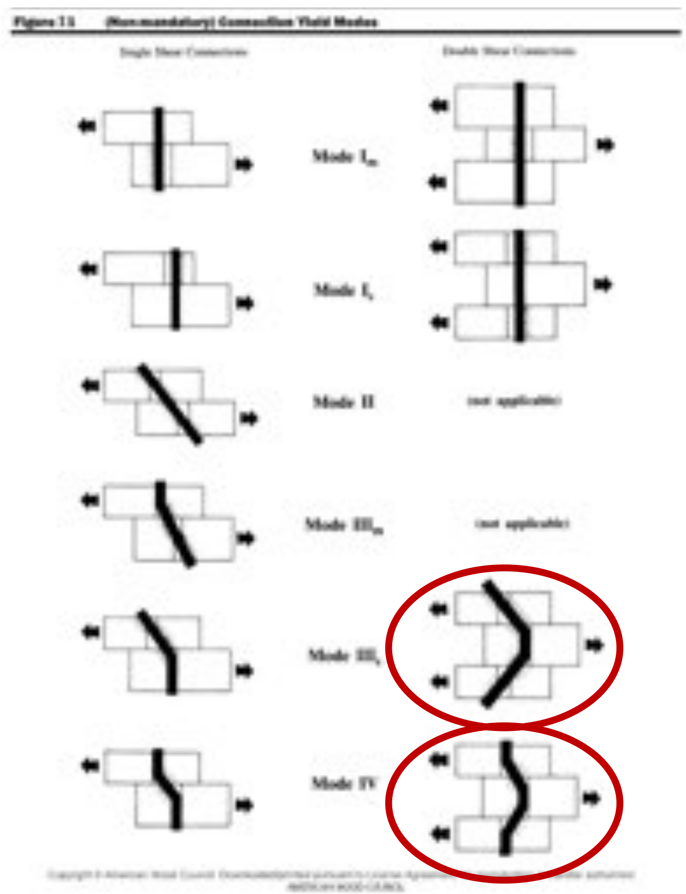
4.1.4 General – Failure Modes



Credit: AWC/NDS

4.1 Commodity (NDS Dowel-Type)

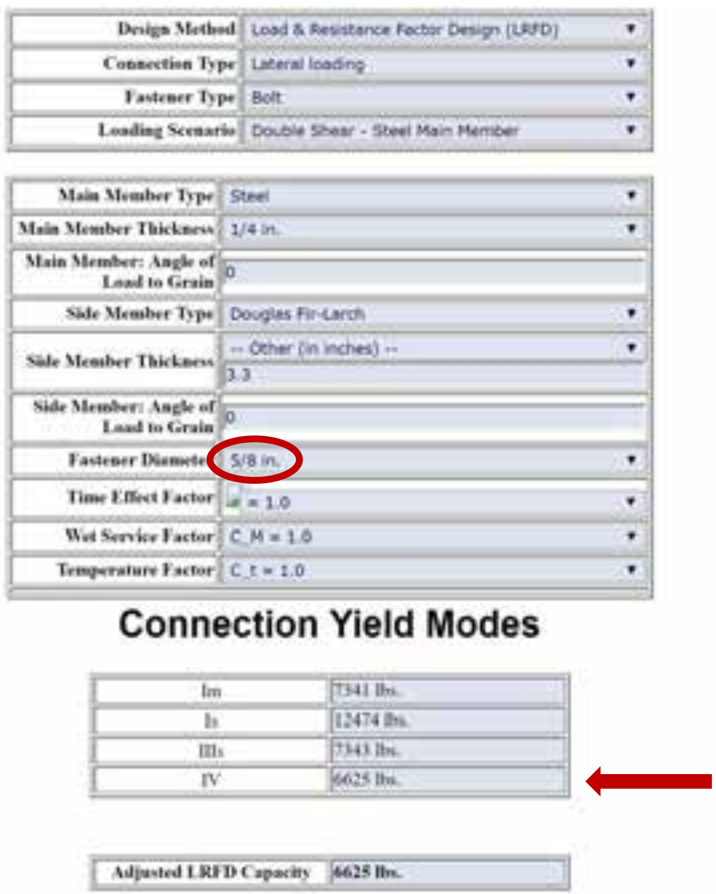
4.1.4 General – Failure Modes



Credit: AWC/NDS

4.1 Commodity (NDS Dowel-Type)

4.1.4 General – 6-3/4” D.Fir-L Glulam



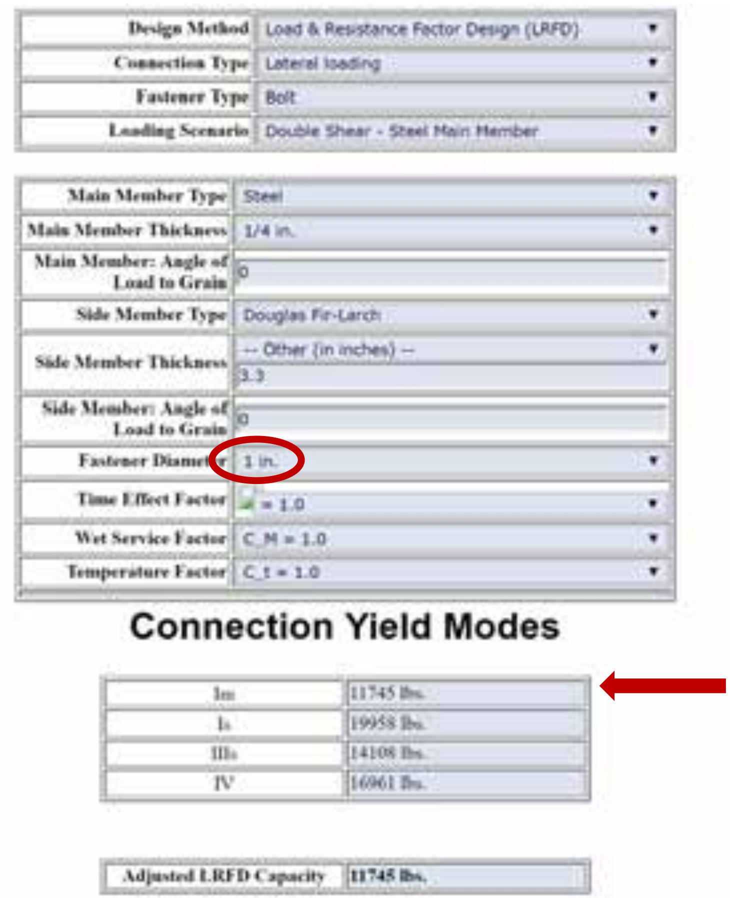
Design Method	Load & Resistance Factor Design (LRFD)
Connection Type	Lateral loading
Fastener Type	Bolt
Loading Scenario	Double Shear - Steel Main Member

Main Member Type	Steel
Main Member Thickness	1/4 in.
Main Member: Angle of Load to Grain	0
Side Member Type	Douglas Fir-Larch
Side Member Thickness	-- Other (in inches) -- 3.3
Side Member: Angle of Load to Grain	0
Fastener Diameter	5/8 in.
Time Effect Factor	= 1.0
Wet Service Factor	C_M = 1.0
Temperature Factor	C_t = 1.0

Connection Yield Modes

Im	7341 lbs.
Is	12474 lbs.
IIIs	7343 lbs.
IV	6625 lbs.

Adjusted LRFD Capacity	6625 lbs.



Design Method	Load & Resistance Factor Design (LRFD)
Connection Type	Lateral loading
Fastener Type	Bolt
Loading Scenario	Double Shear - Steel Main Member

Main Member Type	Steel
Main Member Thickness	1/4 in.
Main Member: Angle of Load to Grain	0
Side Member Type	Douglas Fir-Larch
Side Member Thickness	-- Other (in inches) -- 3.3
Side Member: Angle of Load to Grain	0
Fastener Diameter	1 in.
Time Effect Factor	= 1.0
Wet Service Factor	C_M = 1.0
Temperature Factor	C_t = 1.0

Connection Yield Modes

Im	11745 lbs.
Is	19958 lbs.
IIIs	14108 lbs.
IV	16961 lbs.

Adjusted LRFD Capacity	11745 lbs.

Reference: http://www.awc.org/codes-standards/calculators-software/connectioncalc

4.1 Commodity (NDS Dowel-Type)

4.1.4 General – 6-3/4” D.Fir-L Glulam

Based on 4d spacings as per NDS:

5/8” = 1 fastener every 2.5” = 2650lbs/inch

1” = 1 fastener every 4” = 2936lbs/inch

1” bolt only 10% better but brittle failure mode

→ Behavior vs. Strength

4.2 Pre-Engineered / Proprietary

4.2.1 Screws

Lag Screws

Self Tapping Screw

4.2 Pre-Engineered / Proprietary

4.2.1 Screws

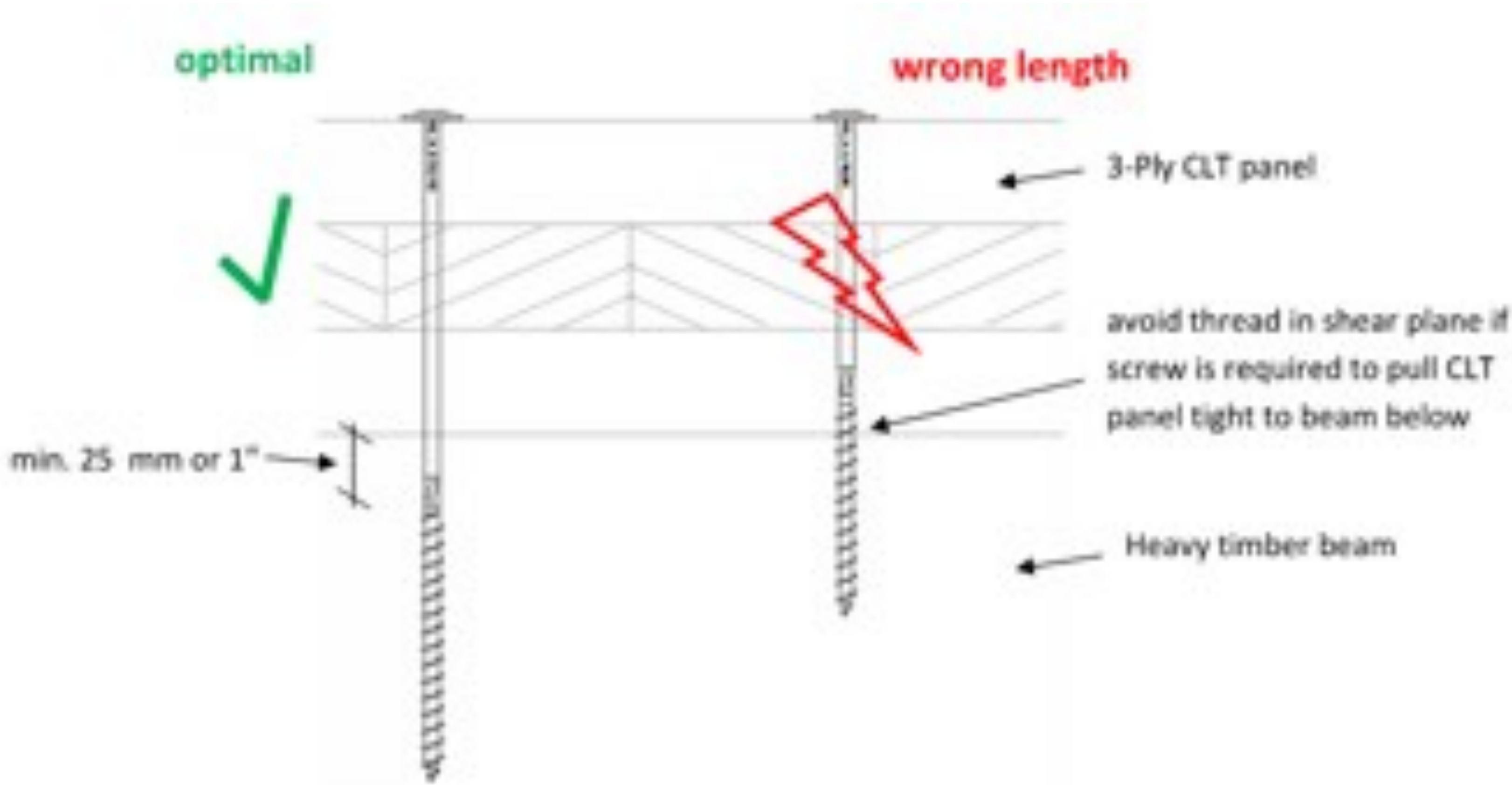
Washer Head (partially threaded screws only)	
Hex Head (partially threaded screws only)	
Countersunk Head (partially and fully threaded screws)	  
Cylindrical Head (fully threaded screws only)	

4.2 Pre-Engineered / Proprietary

4.2.1 Screws

4.2 Pre-Engineered / Proprietary

4.2.1 Screws



Credit: MyTiCon

4.2 Pre-Engineered / Proprietary

4.2.1 Screws

https://www.youtube.com/watch?v=jewbqmxWM_4&feature=youtu.be

Credit: MyTiCon

4.2 Pre-Engineered / Proprietary

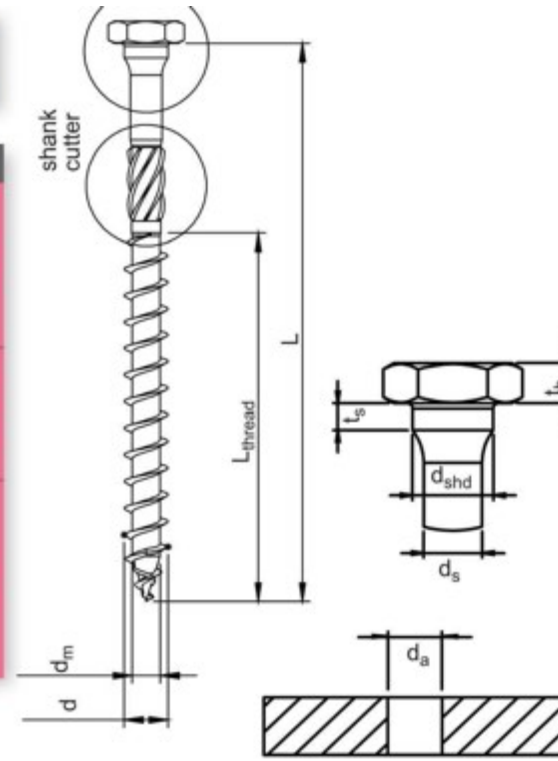
4.2.1 Screws

Specs metric [Specs imperial]

d	L		L_{Thread}		L_{TIP}	d_{Head}	d_{min}	d_s	d_a	d_{shd}	t_h	t_s	Bit
	60	[2-3/8]	40	[1-1/2]									
	80	[3-1/8]	50	[2]									
8 [5/16]	100	[4]	60	[2-3/8]	8 [5/16]	12 [1/2]	5,3 [0,208]	5,8 [0,228]	9 [0,354]	7,8 [0,307]	4,5 [0,177]	3,5 [0,137]	AW® 40 / 12 mm socket
	120-200[1]	[4-3/4 – 7-7/8[2]]	80	[3-1/8]									
	220-300[1]	[8-5/8 – 12[2]]	100	[4]									
	140	[5-1/2]	80	[3-1/8]									
10 [3/8]	160-300[1]	[6-1/4–12[2]]	100	[4]	10 [3/8]	15 [9/16]	6,3 [0,248]	7,2 [0,283]	11 [0,433]	9,8 [0,385]	5 [0,196]	3,75 [0,147]	AW® 40 / 15 mm socket
	320-400[1]	[12-5/8–15-3/4[2]]	120	[4-3/4]									
	440-520[3]	[17-3/4 – 20-1/2][4]	120	[4-3/4]									
	100	[4]	60	[2-3/8]									
	120	[4-3/4]	80	[3-1/8]									
12 [1/2]	140	[5-1/2]	80	[3-1/8]	12 [1/2]	17 [0,66]	7,2 [0,283]	8,2 [0,322]	13 [0,511]	11,8 [0,464]	5,5 [0,216]	4 [0,157]	AW® 40 / 17 mm socket
	160-200[1]	[6-1/4 – 7-7/8][2]	100	[4]									
	220-360[1]	[8-5/8 – 14-1/8][2]	120	4-3/4]									
	380-600[1]	[15 – 23-5/8][2]	145	[5-3/4]									

[1] in 20 mm increments | [2] in 3/4 increments | [3] in 40 mm increments | [4] in 1-1/2 increments

Note: • values listed in the table above are average measurements between upper and lower tolerance boundary
• values in the table are average measurements to the nearest imperial size



Credit: MyTiCon

4.2 Pre-Engineered / Proprietary

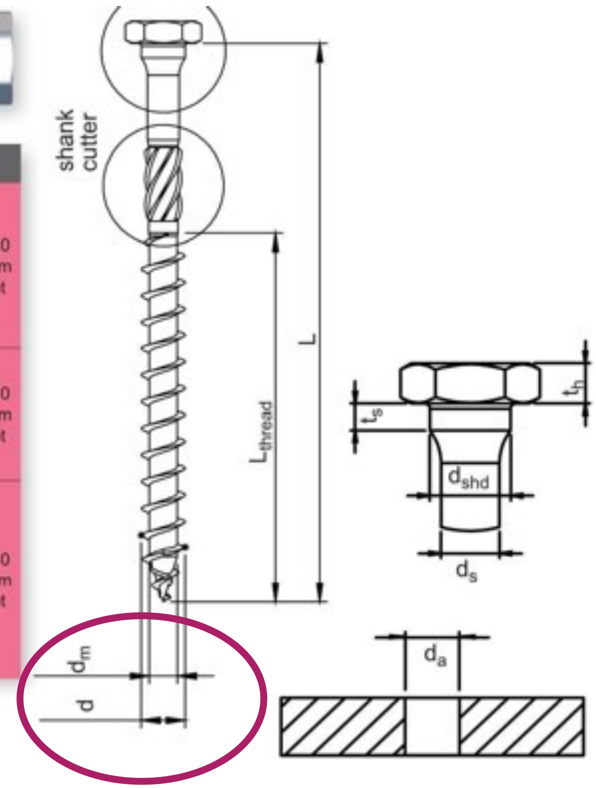
4.2.1 Screws

Specs metric [Specs imperial]

d	L		L_{Thread}		L_{TIP}	d_{Head}	d_{min}	d_s	d_a	d_{shd}	t_h	t_s	Bit
8 [5/16]	60	[2-3/8]	40	[1-1/2]	8 [5/16]	12 [1/2]	5,3 [0,208]	5,8 [0,228]	9 [0,354]	7,8 [0,307]	4,5 [0,177]	3,5 [0,137]	AW® 40 / 12 mm socket
	80	[3-1/8]	50	[2]									
	100	[4]	60	[2-3/8]									
	120-200[1]	[4-3/4 – 7-7/8[2]]	80	[3-1/8]									
	220-300[1]	[8-5/8 – 12[2]]	100	[4]									
10 [3/8]	140	[5-1/2]	80	[3-1/8]	10 [3/8]	15 [9/16]	6,3 [0,248]	7,2 [0,283]	11 [0,433]	9,8 [0,385]	5 [0,196]	3,75 [0,147]	AW® 40 / 15 mm socket
	160-300[1]	[6-1/4–12[2]]	100	[4]									
	320-400[1]	[12-5/8–15-3/4[2]]	120	[4-3/4]									
	440-520[3]	[17-3/4 – 20-1/2][4]	120	[4-3/4]									
12 [1/2]	100	[4]	60	[2-3/8]	12 [1/2]	17 [0,66]	7,2 [0,283]	8,2 [0,322]	13 [0,511]	11,8 [0,464]	5,5 [0,216]	4 [0,157]	AW® 40 / 17 mm socket
	120	[4-3/4]	80	[3-1/8]									
	140	[5-1/2]	80	[3-1/8]									
	160-200[1]	[6-1/4 – 7-7/8][2]	100	[4]									
	220-360[1]	[8-5/8 – 14-1/8][2]	120	4-3/4]									
	380-600[1]	[15 – 23-5/8][2]	145	[5-3/4]									

[1] in 20 mm increments | [2] in 3/4 increments | [3] in 40 mm increments | [4] in 1-1/2 increments

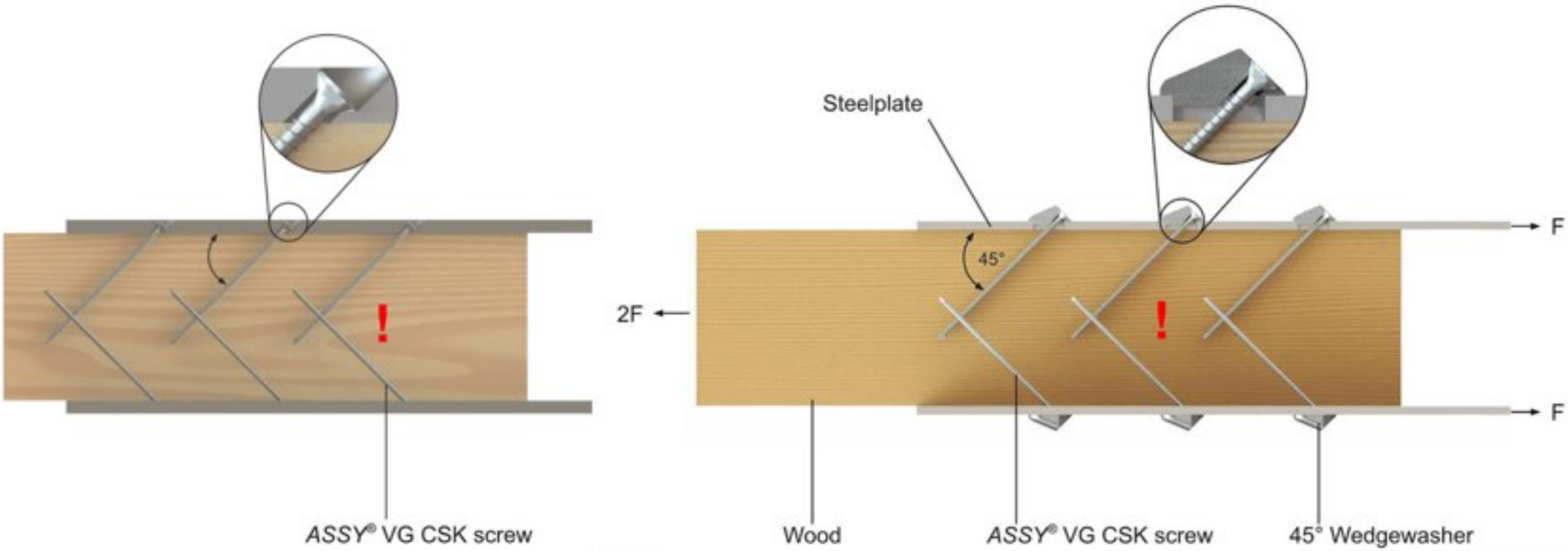
Note: • values listed in the table above are average measurements between upper and lower tolerance boundary
• values in the table are average measurements to the nearest imperial size



Credit: MyTiCon

4.2 Pre-Engineered / Proprietary

4.2.1 Screws



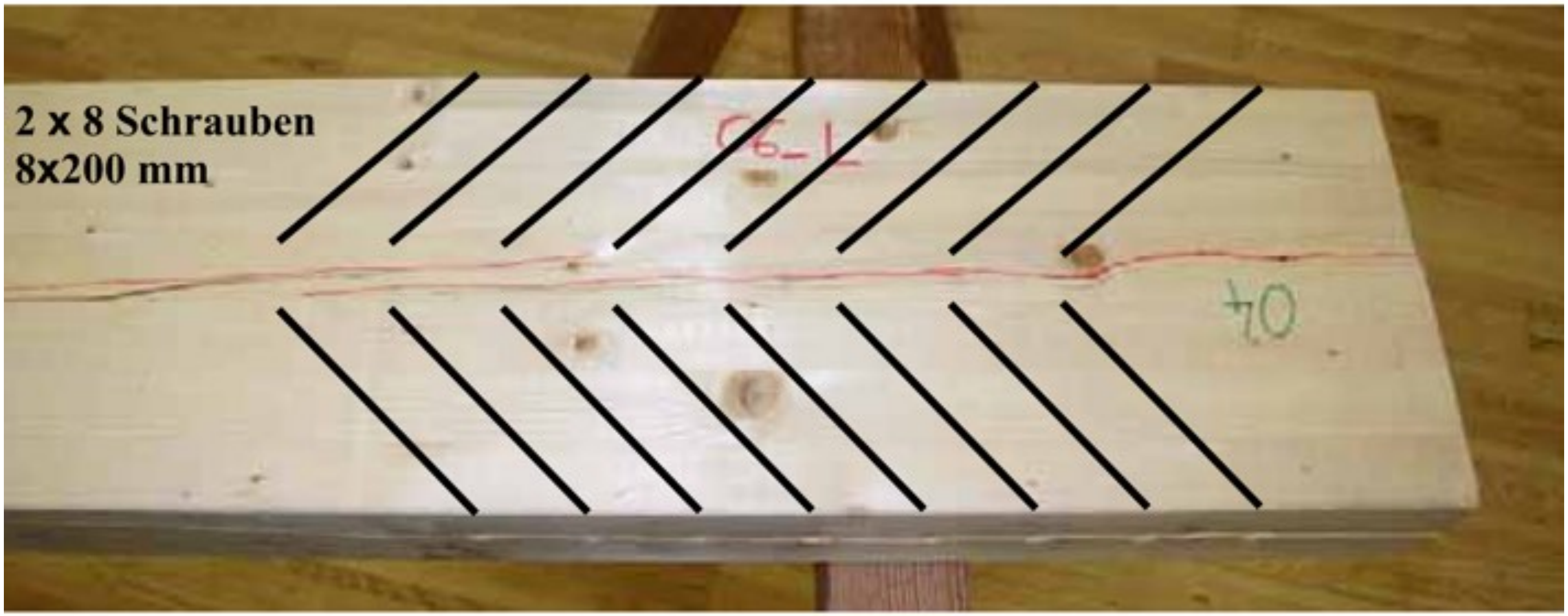
Credit: MyTiCon

4.2 Pre-Engineered / Proprietary

4.2.1 Screws

4.2 Pre-Engineered / Proprietary

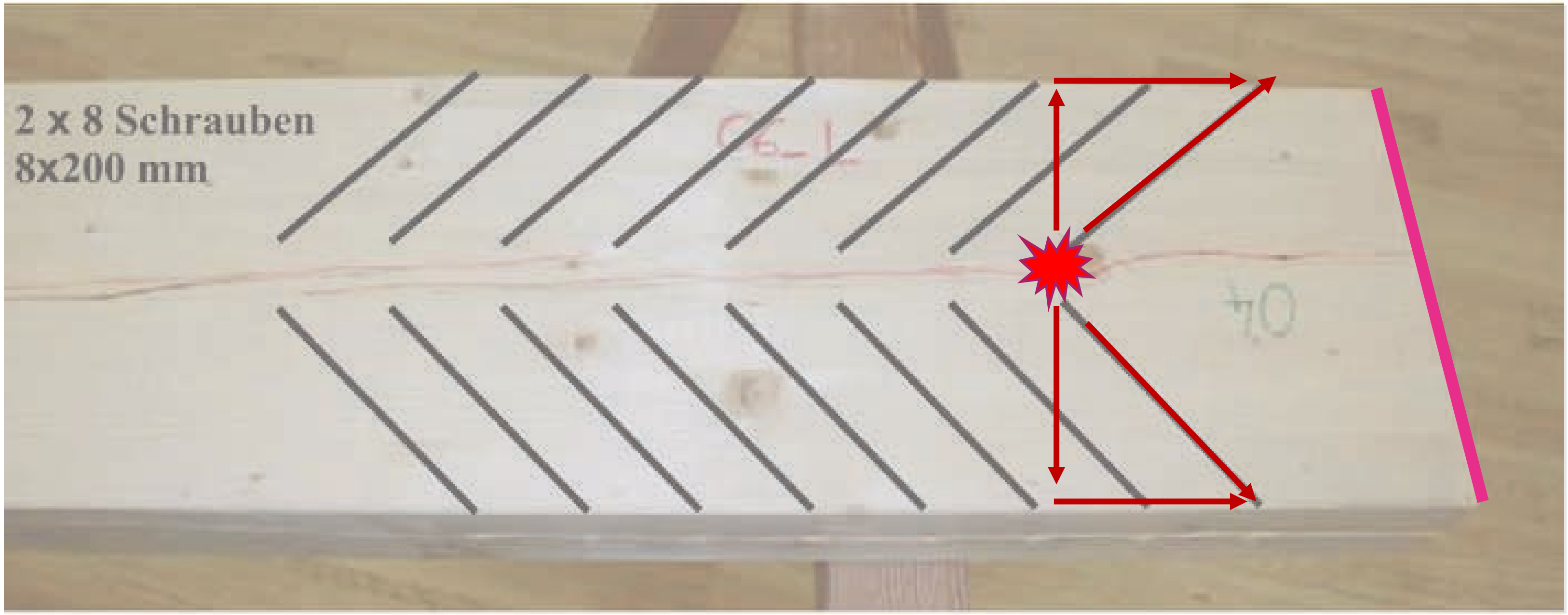
4.2.1 Screws



Reference: Grazer Holzbau-Fachtagung 2007: Traglast von auf Zugbeanspruchten Schraubenverbindungen mit Stahlblechen
https://www.tugraz.at/fileadmin/user_upload/Institute/LIGNUM/Downloads/Unterlagen/06_GraHFT_07_tagungsband.pdf

4.2 Pre-Engineered / Proprietary

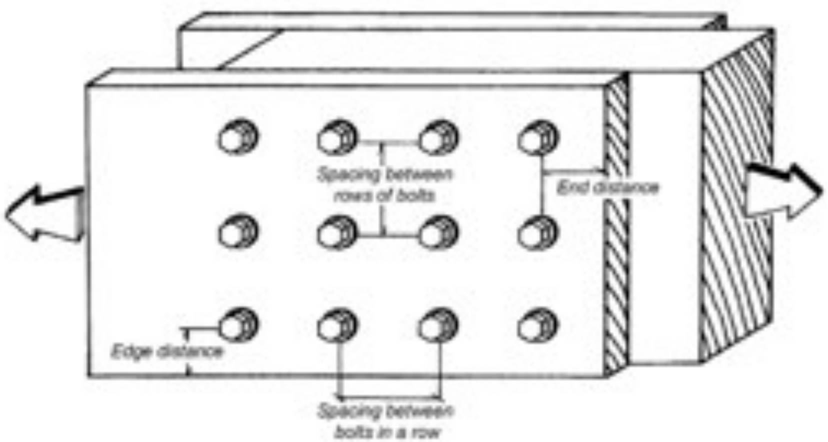
4.2.1 Screws



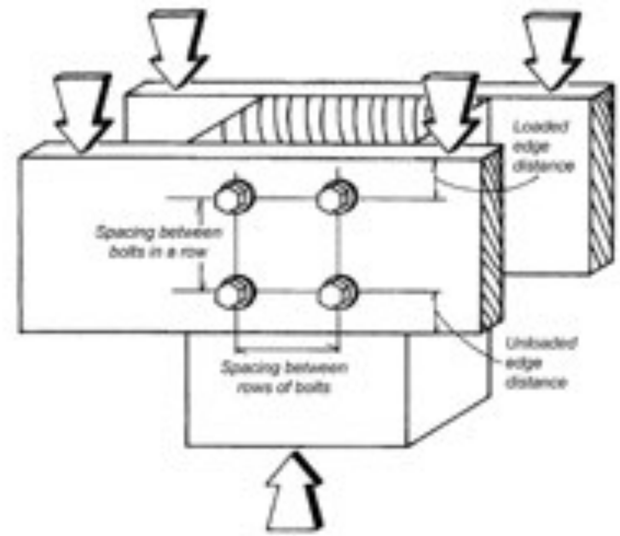
Reference: Grazer Holzbau-Fachtagung 2007: Traglast von auf Zugbeanspruchten Schraubenverbindungen mit Stahlblechen
https://www.tugraz.at/fileadmin/user_upload/Institute/LIGNUM/Downloads/Unterlagen/06_GraHFT_07_tagungsband.pdf

4.2 Pre-Engineered / Proprietary

4.2.1 Screws



Parallel to grain loading in all wood members ($Z_{\parallel}$)



Perpendicular to grain loading in the side member and parallel to grain loading in the main member ($Z_{s\perp}$)

Follow the approvals for spacings!

Group Factors….!?
($n_{ef} = n^{0.9}$)

Credit: AWC/NDS

4.2 Pre-Engineered / Proprietary

4.2.2 Brackets

(Simpson ABR 105)

(RothoBlaas Titan)

4.2 Pre-Engineered / Proprietary

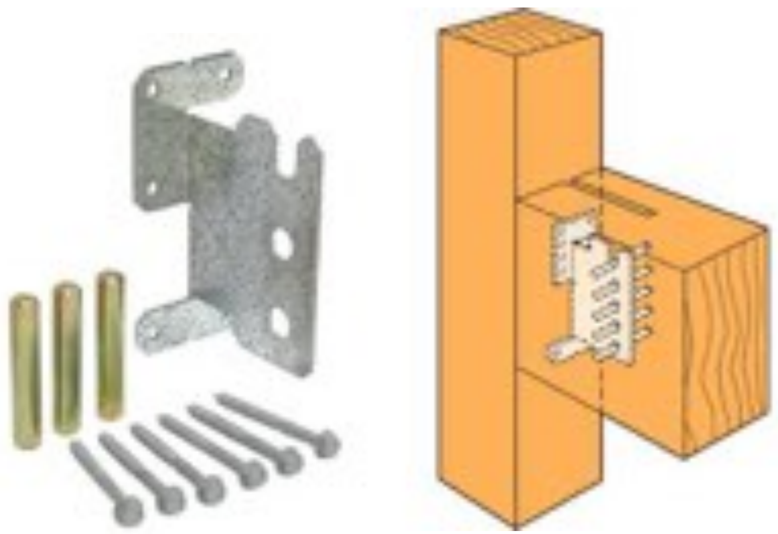
4.2.2 Brackets/Hold-downs

(Rothoblaas X-RAD)

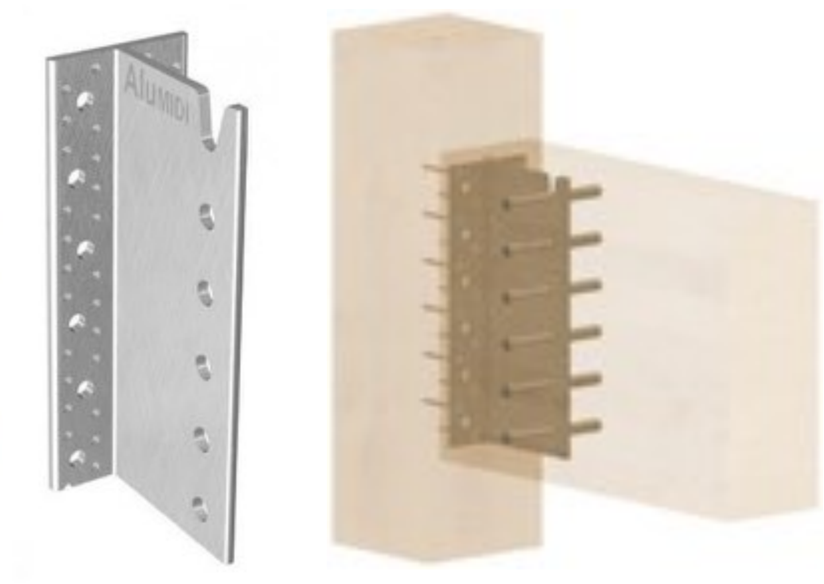
(RothoBlaas WHT)

4.2 Pre-Engineered / Proprietary

4.2.3 Hangers



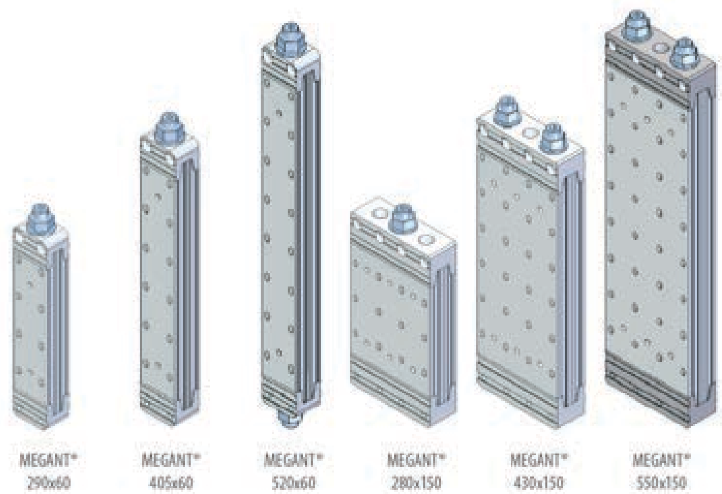
(Simpson CJT1)

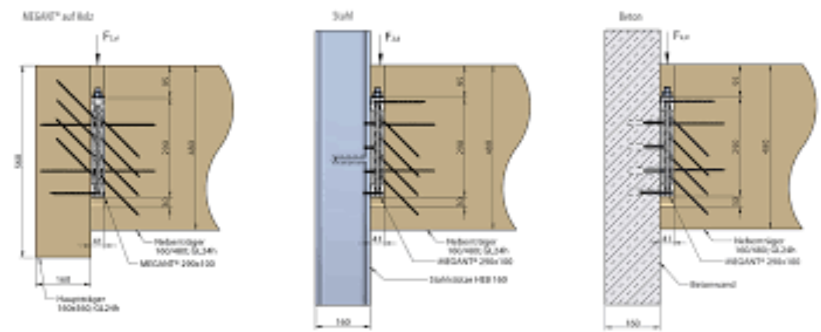


(RothoBlaas AluMaxi)

4.2 Pre-Engineered / Proprietary

4.2.3 Hangers

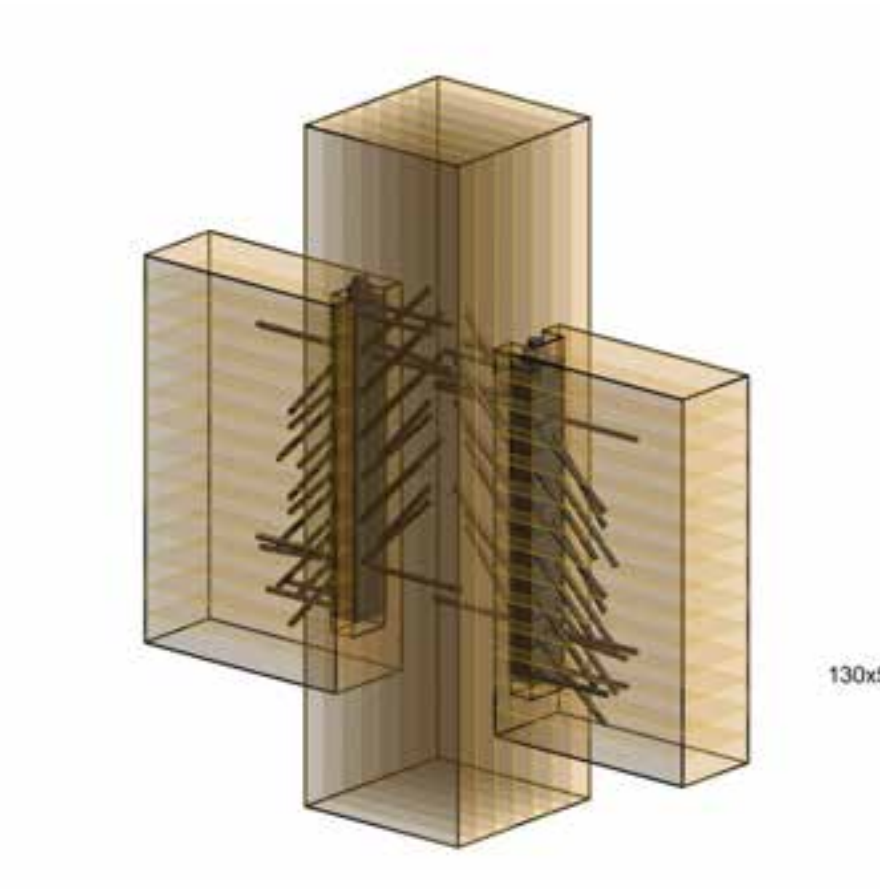


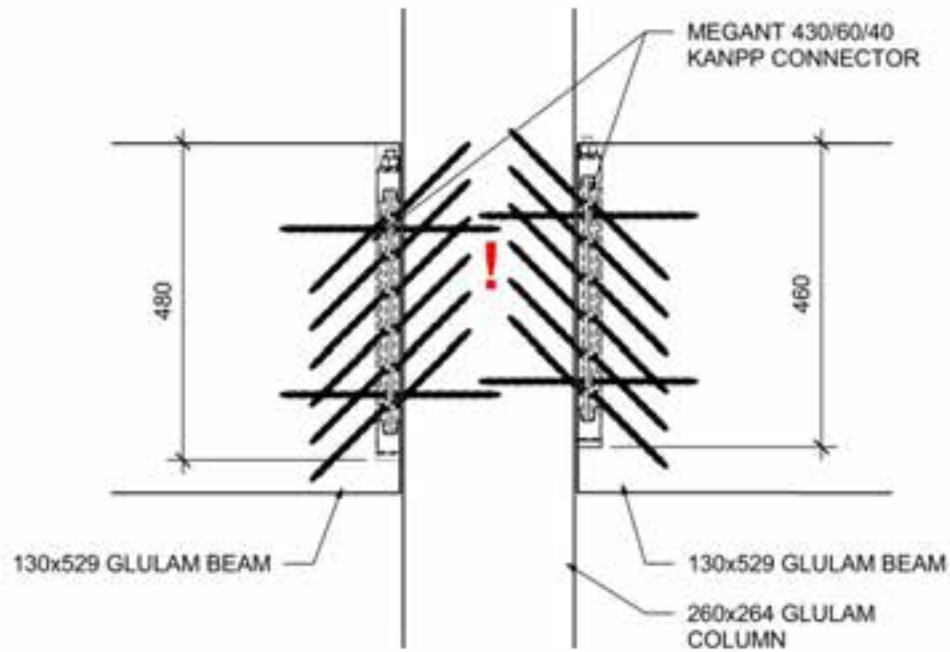


(Knapp Megant)

4.2 Pre-Engineered / Proprietary

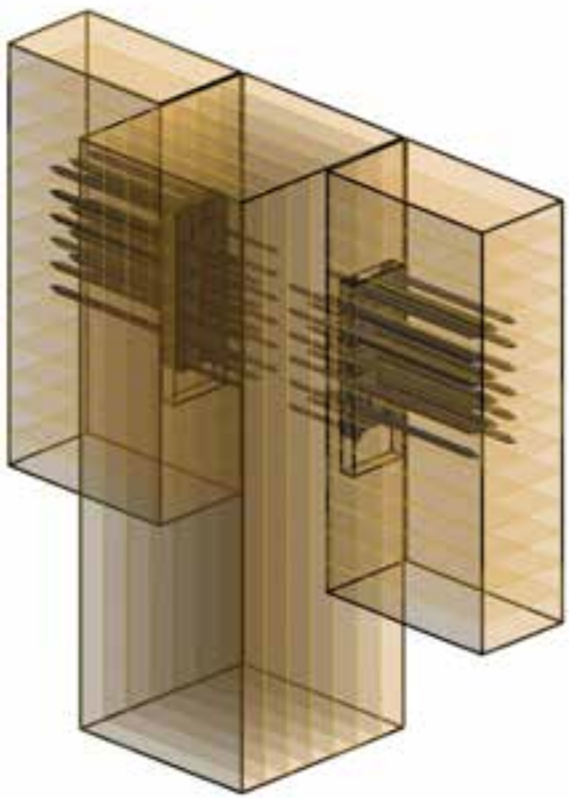
4.2.3 Hangers

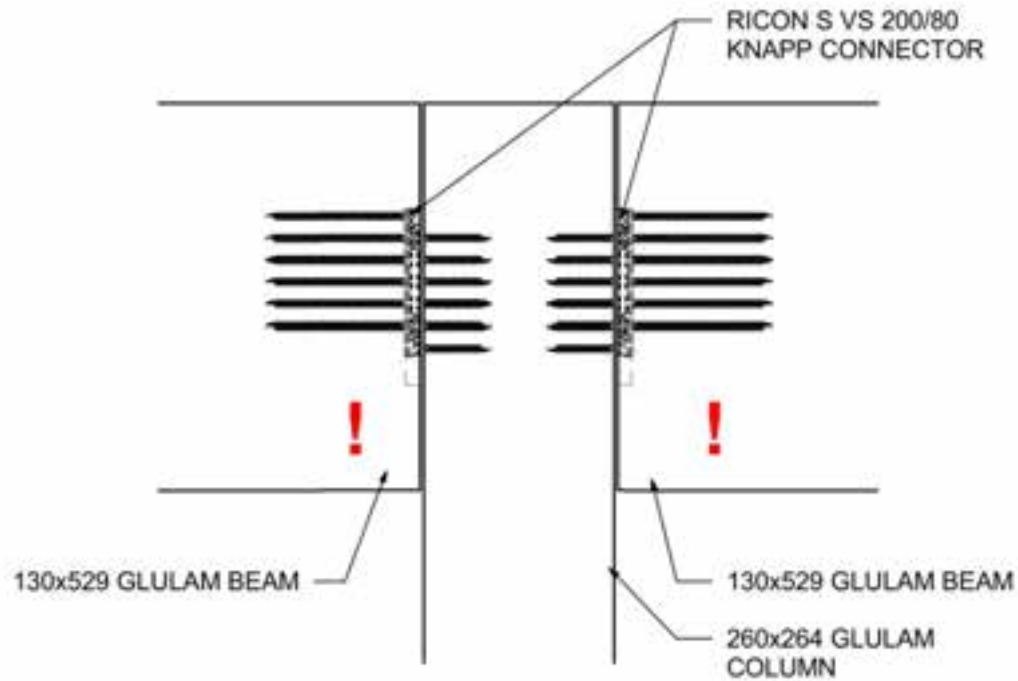




4.2 Pre-Engineered / Proprietary

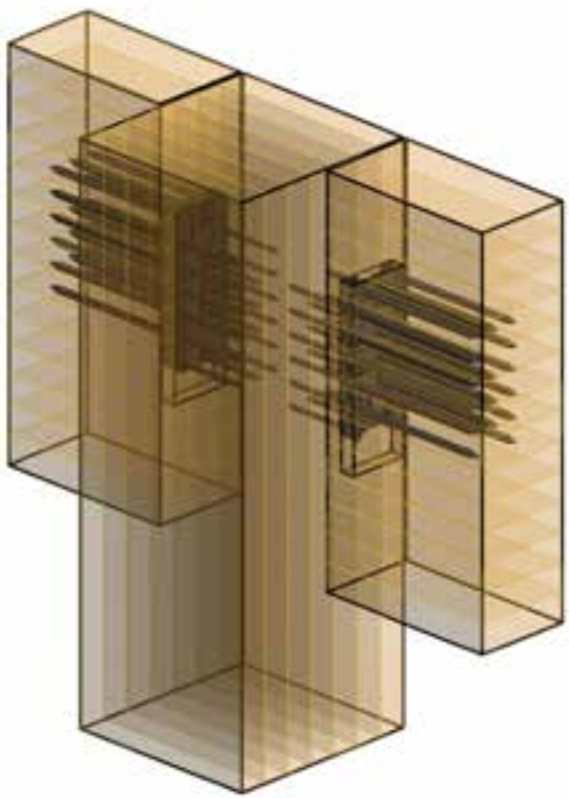
4.2.3 Hangers

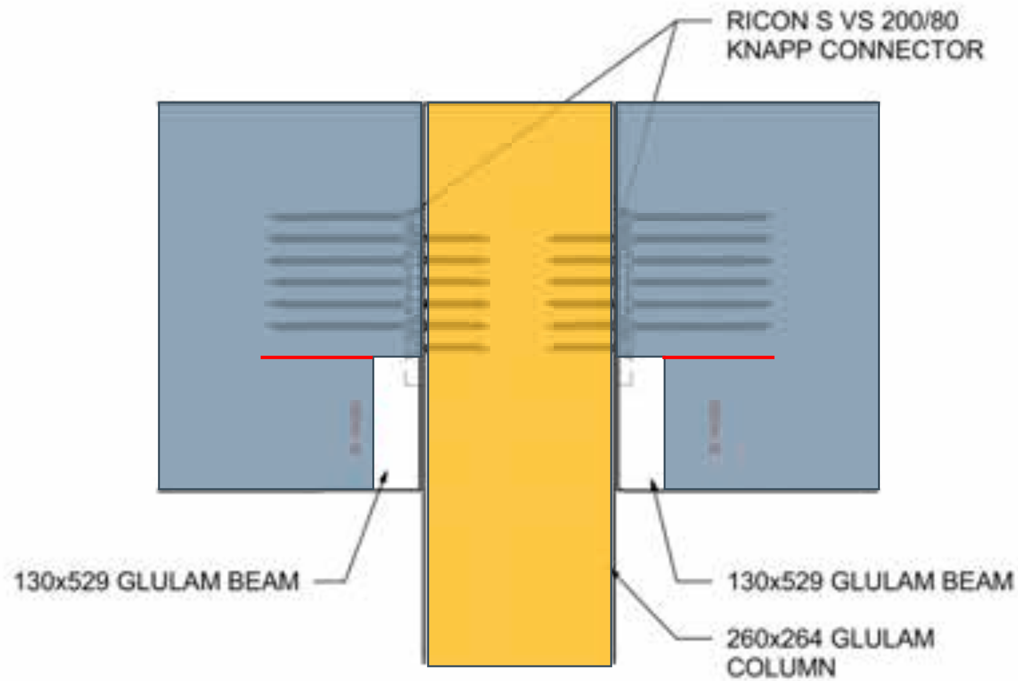




4.2 Pre-Engineered / Proprietary

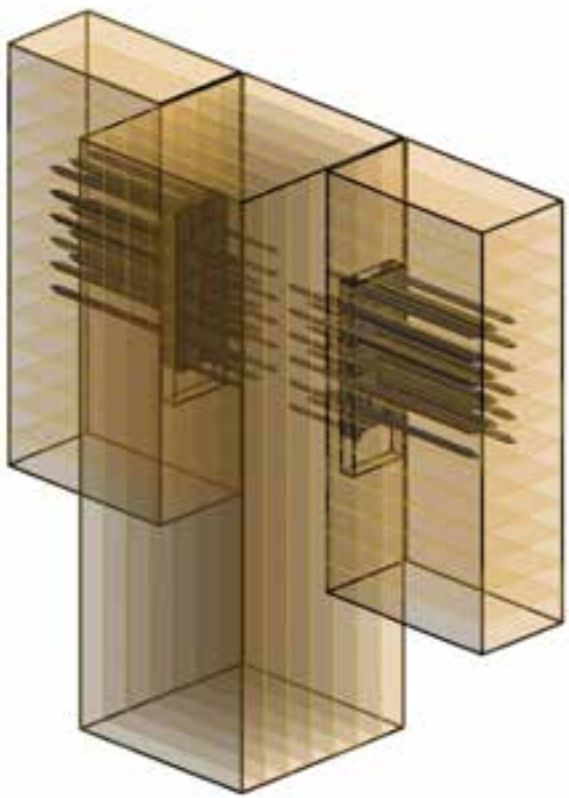
4.2.3 Hangers

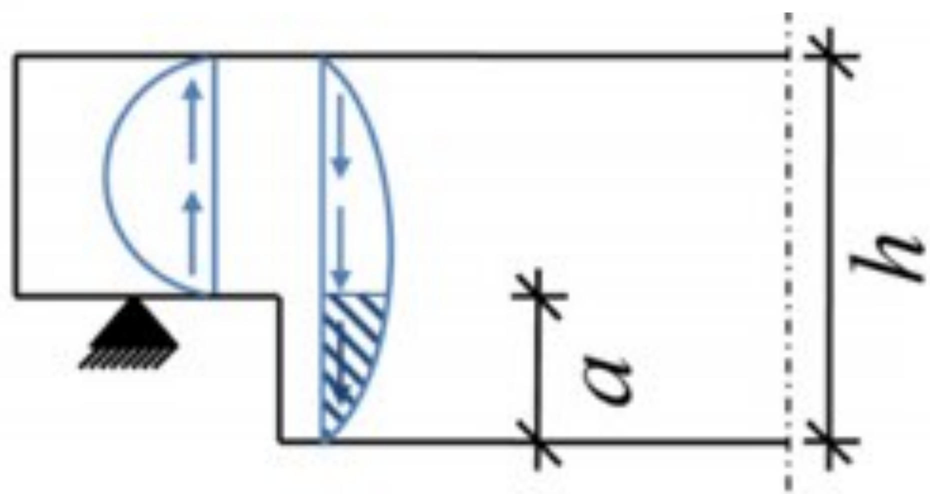




4.2 Pre-Engineered / Proprietary

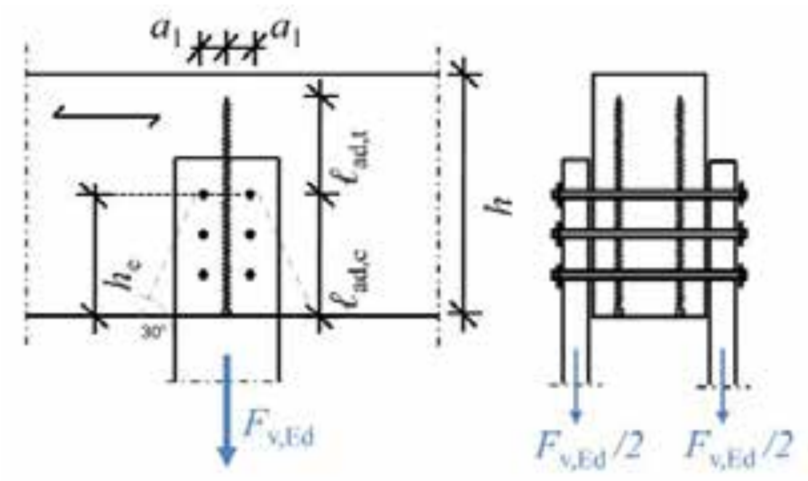
4.2.3 Hangers





4.3 Custom

4.3.1 Reinforcing



$F_{t,90,d} = [1-3 * (h_e/h)^2 + 2 * (h_e/h)^3] * F_{v,Ed}$

with:

$F_{t,90,d}$ = design tension perpendicular to grain
$F_{v,Ed}$ = design connection force

The reinforcing is to be designed for Ft,90,d.

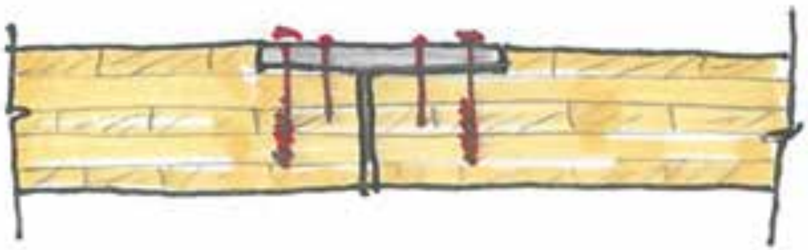
Embedment length for design lad = min $\{l_{ad,c}; l_{ad,t}\}$.

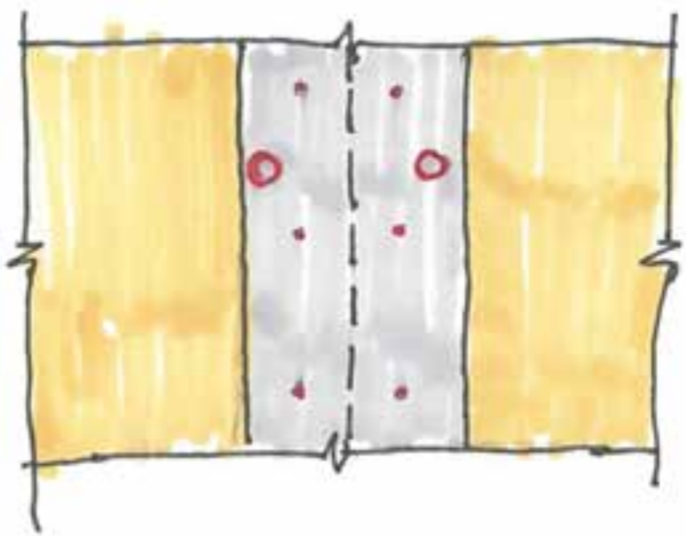
$l_{ad,t}$ should extend at least up to 70% of the beam height.

Reinforcement should be placed within an area based on 30° measured from the top of the connection.

4.3 Custom

4.3.2 CLT to CLT Surface Spline





- Washer head screws to pull panel flush
- Nails to transfer in-plane shear loads
- Out of plane shear loads to be taken by washer head screw and plywood bending or provide pairs of fully threaded screws (high heads)
- ¾” plywood, 5 $^3/_4$ strip. 4’ plywood sheet will yield 8 strips with minimal waste

4.3 Custom

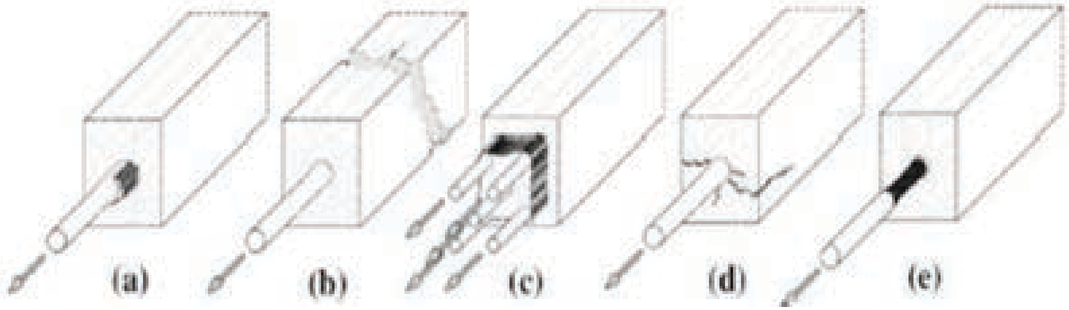
4.3.3 Hold-down connection

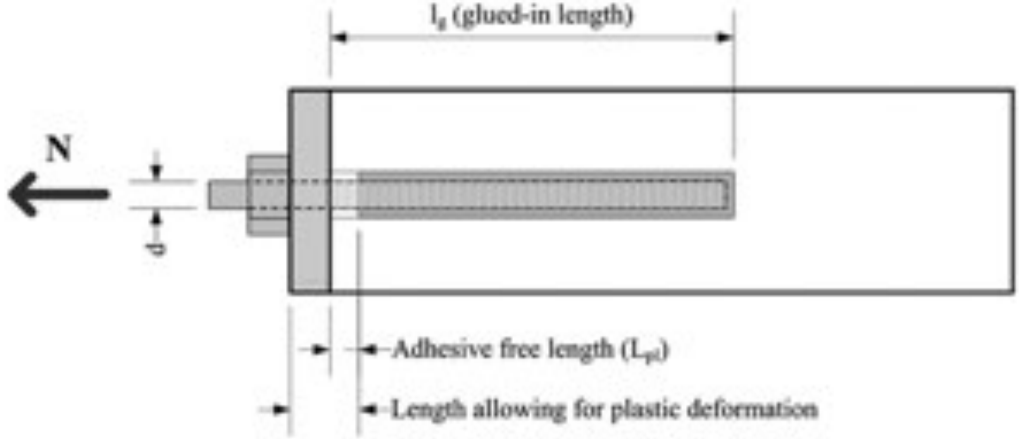
- CLT Hold-down connection
- Internal knife plate
- 6mm self-drilling screws
- Strong, but ductile connection
- Shop-installed with special equipment

5.0 Next Generation

5.1 Adhesive Connections

5.1.1 Glued in Rods



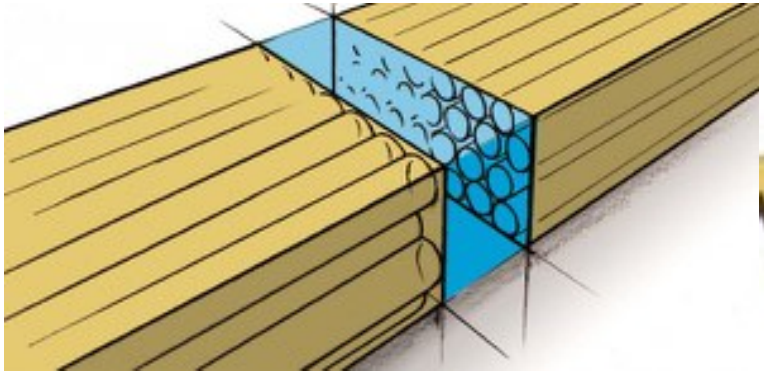


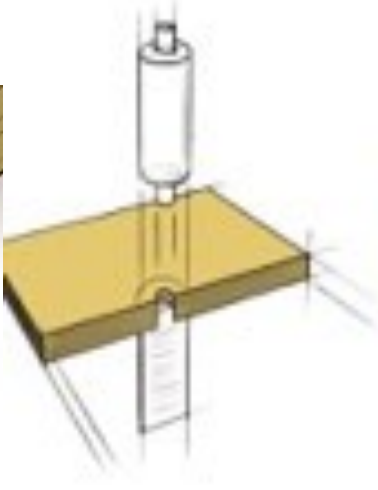
5.1 Adhesive Connections

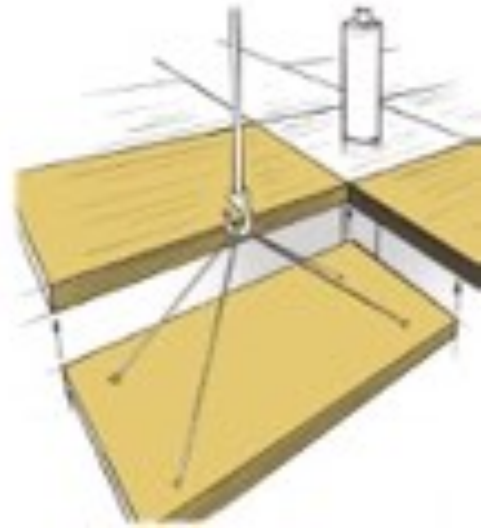
5.1.2 HSK

5.1 Adhesive Connections

5.1.3 TS3.0 – Glued Butt Joints

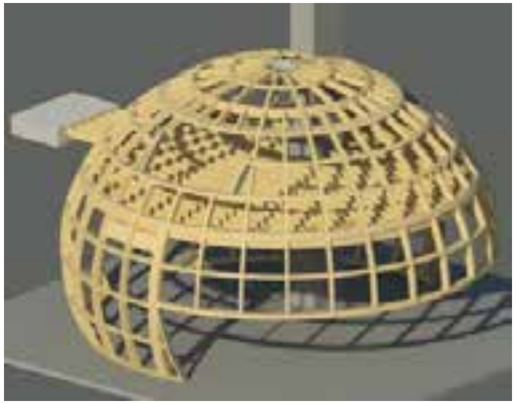




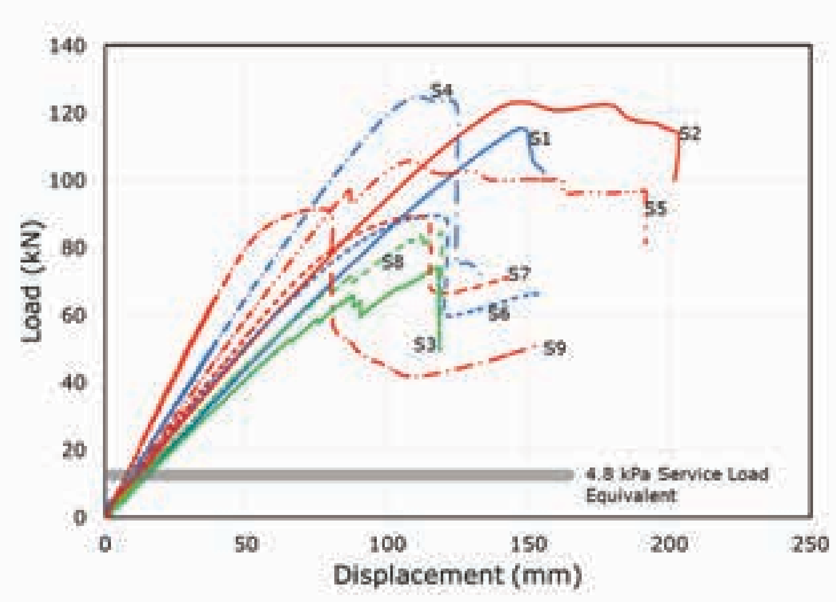


5.1 Adhesive Connections

5.1.4 Glued and screwed



5.2 Timber-Concrete Composite Systems



Further Resources

Further Resources

Load-carrying behaviour of steel-to-timber dowel connections; Adrian Mischler, Helmut Prion, Frank Lam
https://pdfs.semanticscholar.org/bd4b/a80168b8d48ab053ca29960ddb4842136041.pdf

Grazer Holzbau-Fachtagung 2007: Traglast von auf Zugbeanspruchten Schraubenverbindungen mit Stahlbleche; H. Krenn, G. Schickhofer
https://www.tugraz.at/fileadmin/user_upload/Institute/LIGNUM/Downloads/Unterlagen/06_GraHFT_07_tagungsband.pdf

Self-tapping screws and threaded rods as reinforcement for structural timber elements – A state-of-the-art report; Philipp Dietsch, Reinhard Brandner

EN 1995 design of timber structures (Eurocode 5)

→ See also supplier specific documents and white papers

Questions?

This concludes the American Institute of Architects Continuing Education Course.

Duncan Bourke
duncan@aspectengineers.com