STEEL TO CLT LATERAL CONNECTIONS

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ABSTRACT

This white paper reviews the results of recent lateral load testing of ASSY® screws used to fasten steel plates to CLT. Test results are compared to design values calculated according to NDS 2018 and CSA O86 with the intent to asses the current design approach. Due in part to the reinforcing property of CLT against splitting, and the high strength and plastic capacities of ASSY® screws, high factors of safety are achieved.

CLT LATERAL CONNECTION

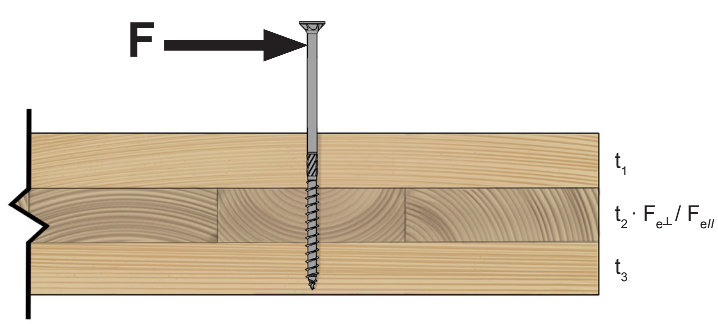
In North America, the interest in CLT continues to grow as it offers speed and ease of construction making it an attractive design element over more conventional materials. Structures that use CLT can exploit its high strength properties and rapid construction to surpass six stories, which is generally agreed as the limit to light-frame construction. As buildings grow taller, it is natural that design loads in connections increase too. Steel plate connections are often designed to transmit high intensity loads requiring capacity for energy dissipation, so understanding their performance is critical.

Lateral connection design for unidirectional wood products such as glulam is well-established: NDS 2018 and CSA O86 use some variation of the European Yield Model (referred to as the “Yield Limit Equations” in the NDS and “Johansen yield theory” in EC5). Provisions for CLT were added to the NDS in 2015, and CSA O86 in the 2016 supplement.

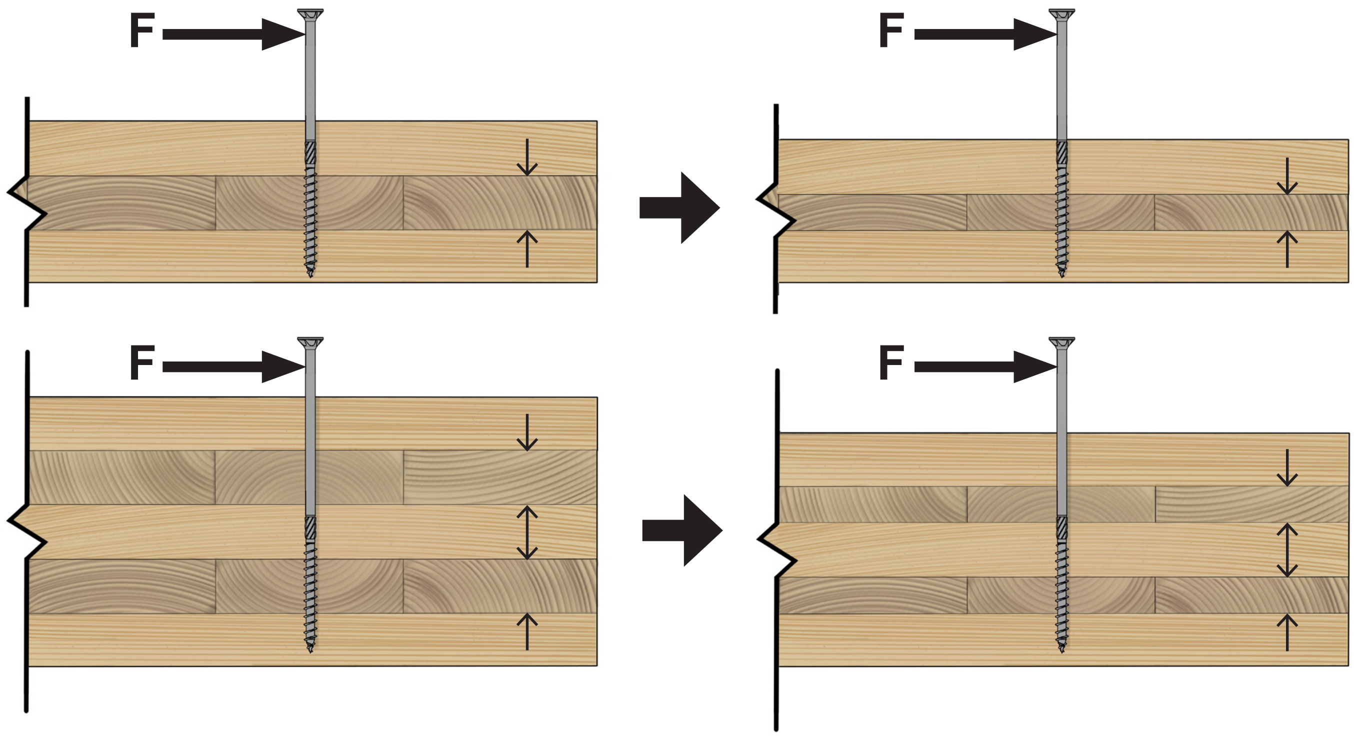
While provisions for lateral connection design with CLT deal with strength reductions over unidirectional timber products, these reductions are generally small and CLT still offers high connection performance. While crossing laminations can reduce dowel bearing strength (embedment strength), the crossing layers also reinforce against splitting effects with sufficient fastener anchorage, which means that highly ductile connections can be designed using slender, self tapping screws in the wide face of the panel.

CLT Lateral Design in the United States

For fasteners with D ≥ ¼”, the NDS models dowel bearing strength as stronger when loaded parallel to the grain. In order to accommodate crossing grain directions in CLT, the dowel bearing strength is adjusted through an “effective dowel bearing length.” When large diameter fasteners are loaded in the direction parallel to the grain at the wide panel face, the segments of the dowel bearing length passing through plies loaded perpendicular to the grain are reduced in size proportional to their reduced dowel bearing strength relative to the strong direction. The concept is illustrated below:



The following figures illustrate the concept of effective dowel bearing lengths for 3-ply and 5-ply CLT panels by reducing the thickness of the crossing plies:



The NDS advises against installing fasteners into gaps between adjacent lamellas in the wide panel face as a best practice, but otherwise, no further adjustments are necessary. Reference lateral design values (Z) approximate the nominal proportional limit, and will typically limit joint slip to < 0.015 inch (ASCE, 1995). According to Foliente and Smith (2004), a minimum factor of safety of 3.5 can be expected for softwood like SPF.

CLT Lateral Design in Canada

The Canadian provisions for CLT are based on a European study concerning the embedment strength of CLT with fasteners installed in the wide panel face. The study consisted of 620 tests, with fasteners of various sizes deliberately positioned in solid sections of CLT as well as directly in the gaps between lamellas, and loaded in varying directions relative to the surface grain (Blass & Uibel, 2007). The analysis showed that, once calibrated to CSA O86, the embedment strength for CLT could be modeled by applying a J_x factor of 0.9 to embedment strength equations for unidirectional timber.

Currently, lateral connection design using self tapping screws is carried out in accordance with Cl.12.6.6 for lag screws, which penalizes design strengths rather severely with a resistance factor of $\phi = 0.6$. Older editions of CSA O86 (pre-1994) included both a factored lateral strength resistance check (against factored loads) and a lateral slip resistance check (against specified loads). The slip limit was calibrated to limit movement at the joints to approximately 0.8mm. Beginning in 1994, CSA O86 removed slip check requirements for lag screws, leaving it instead to the designer to decide on an acceptable degree joint movement.

STEEL TO CLT CONNECTION TESTING

Steel to CLT shear connection testing was performed at the University of Alberta. The CLT specimens had a nominal dimension of 15.75in x 7.87in x 7.24in (400 mm x 200 mm x 184 mm). H-block test specimens were made by fastening two steel plates of 5/16” (8mm) thickness onto both of the panel faces of the CLT. Four ASSY® screws were used in each plate. Both 5/16” (8mm) and 1/2” (12mm) partially threaded and fully threaded screws were tested across four test series. The test consisted in loading the CLT element such that the fasteners were loaded parallel to the grain at the panel surface.

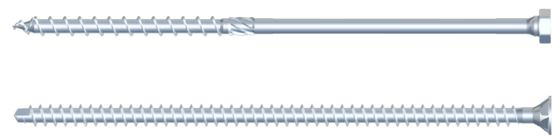


Figure 1. [top] ASSY Kombi screws; [bottom] ASSY VG CSK screws

Table 1. Screws Used in Lateral Connection Tests.

Name of the Configuration	Type of Fastener		Diameter (D)		Length	
	Screw Name	Thread Type	in	[mm]	in	[mm]
CLT-8PT	ASSY Kombi	Partially Threaded	5/16”	[8]	5-1/2”	[140]
CLT-12PT	ASSY Kombi	Partially Threaded	1/2”	[12]	5-1/2”	[140]
CLT-8FT	ASSY VG CSK	Fully Threaded	5/16”	[8]	5-1/2”	[140]
CLT-12FT	ASSY VG CSK	Fully Threaded	1/2”	[12]	5-1/2”	[140]

The CLT samples were composed of 5 plies of 1.45” (36.8mm) SPF lumber (spruce-pine-fir). The holes in the steel plates were sharp-edged holes with a diameter equal to D+1mm for the Kombi screws. For the VG CSK screws, the plates were machined to accept the shape of the countersunk head. The detailed specimen layout for Kombi and VG CSK screws is shown below:

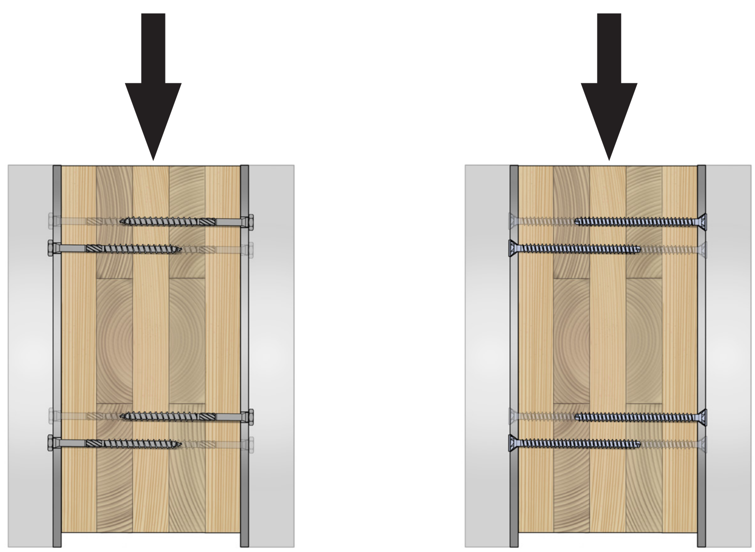


Figure 1. [left] Steel-CLT H-block test with 8 ASSY® Kombi screws; [right] Steel-CLT H-block test with 8 ASSY® VG CSK screws.

USA: Adjusted Lateral Design Value (Z')

Design of a steel to CLT H-Block connection using 8 ASSY® Kombi 5/16" x 5-1/2" according to NDS 2018 (Allowable Stress Design):

$$Z' = Z \cdot n_F \cdot n_R \cdot C'$$

Z	Reference lateral resistance value	337 [lbs]
n_F	Number of effective fasteners in a row; $n_F = n^{0.9}$	$2^{0.9}$
n_R	Number of rows in the connection	4
C_D	Load duration factor	1.6

$$Z' = 4{,}025 \text{ [lbs]}$$

Table 2. Adjusted Lateral Design Value for the Test Specimens.

Unit	5/16" screws		1/2" screws	
	Kombi	VG CSK	Kombi	VG CSK
lbs	4,025	3,153	7,381	5,876
[kN]	[17.90]	[14.03]	[32.83]	[26.14]

Note: Design value in accordance with NDS 2018 adjusted for short term loading

Canada: Factored Lateral Strength Resistance (N_r)

Design of a steel to CLT H-Block connection using 8 ASSY® Kombi 5/16" x 5-1/2" according to CSA O86 (Limit State Design):

$$N_r = N'_r \cdot n_F \cdot n_R \cdot J' \cdot K'$$

N'_r	Basic factored lateral resistance value (incorporating $J_x = 0.9$)	2.203 [kN]
n_F	Number of effective fasteners in a row; $n_F = n^{0.9}$	$2^{0.9}$
n_R	Number of rows in the connection	4
K_D	Load duration factor	1.15

$$N_r = 18.91 \text{ [kN]}$$

Table 3. Factored Lateral Strength Resistance for the Test Specimens.

Unit	5/16" [8 mm] screws		1/2" [12 mm] screws	
	Kombi	VG CSK	Kombi	VG CSK
lbs	4,251	3,172	8,919	6,727
[kN]	[18.91]	[14.11]	[39.68]	[29.92]

Note: Design value in accordance with CSA O86 factored for short term loading

The reduction factor, $J_x = 0.9$, only applies to the embedment strength in the main member. Therefore, total reduction in connection strength for CLT over unidirectional wood is actually less than 10% (in this case, roughly 5%).

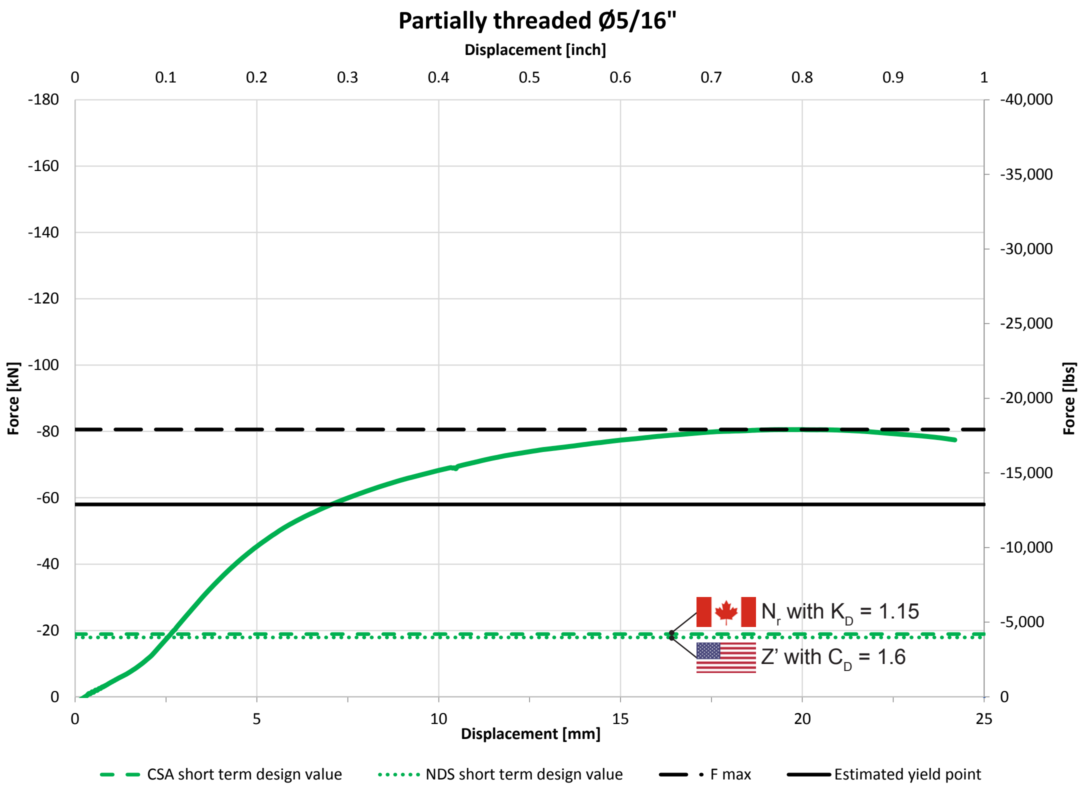
TEST RESULTS

Shear failure of the screws at the heads governed the ultimate failure modes in all cases, but not before large displacements were attained. Any surviving screw heads were removed with a power tool to separate the CLT and steel plates. CLT specimens were then cut open to reveal the deformed shape of the fasteners and bending angles were measured.

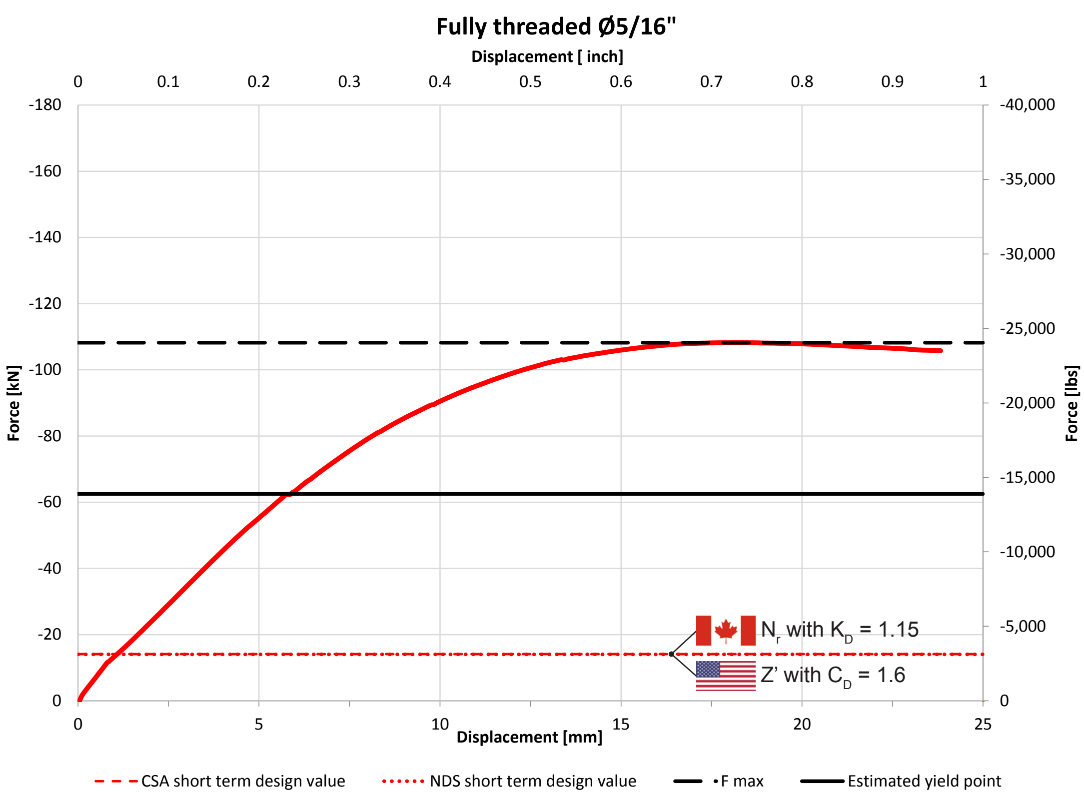
It should also be noted that because self tapping screws have a wider thread diameter than a smooth shank diameter, they may not bear evenly against the inner surfaces of the holes in some cases involving especially thick steel plates. Kombi screws provide a bearing surface under the head equal to the nominal diameter which makes them especially suitable for conventionally sized steel plate connections. The conical receiving holes in the steel plates for the ASSY® VG CSK countersunk head screws also likely provided increased bearing area. In the analysis, the 5% offset method is used to determine the estimated yield point.

Figure 2. H-block test specimen. [Picture provided by University of Alberta research team].

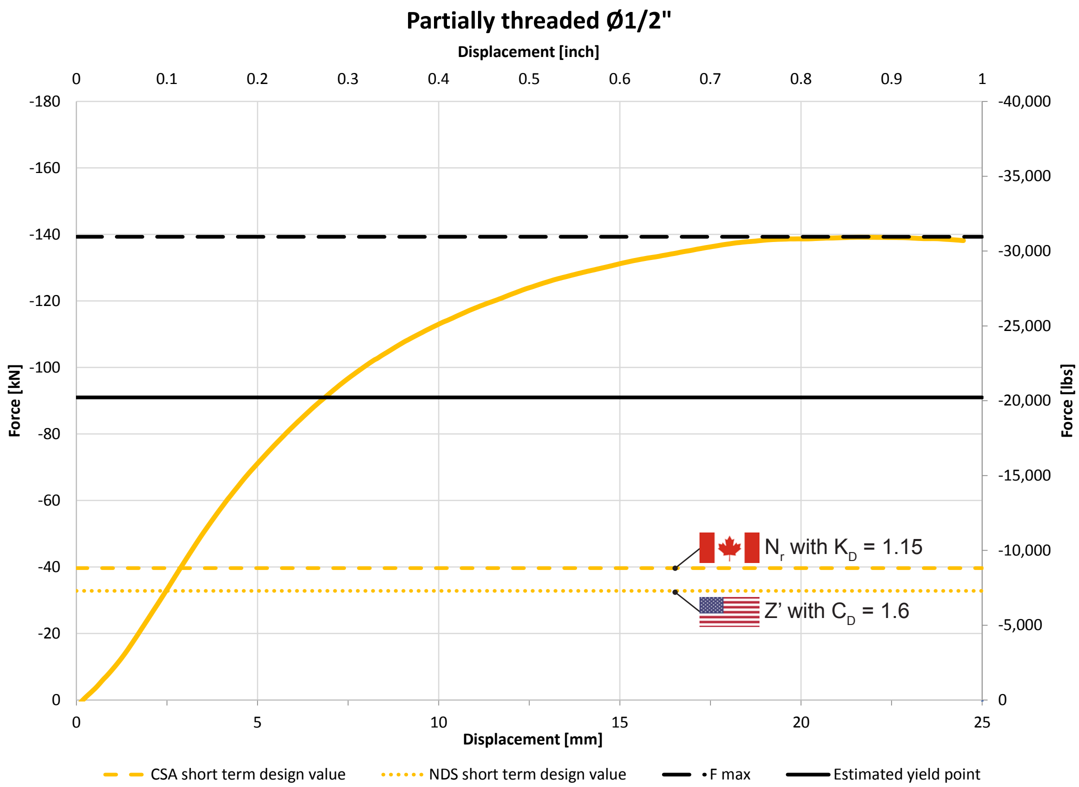
Figure 3. Cutaway of the test specimen to reveal the deformed shape of the ASSY® screws and localized embedment failure (left: Kombi; right: VG CSK) after testing to failure. [Pictures provided by University of Alberta research team].



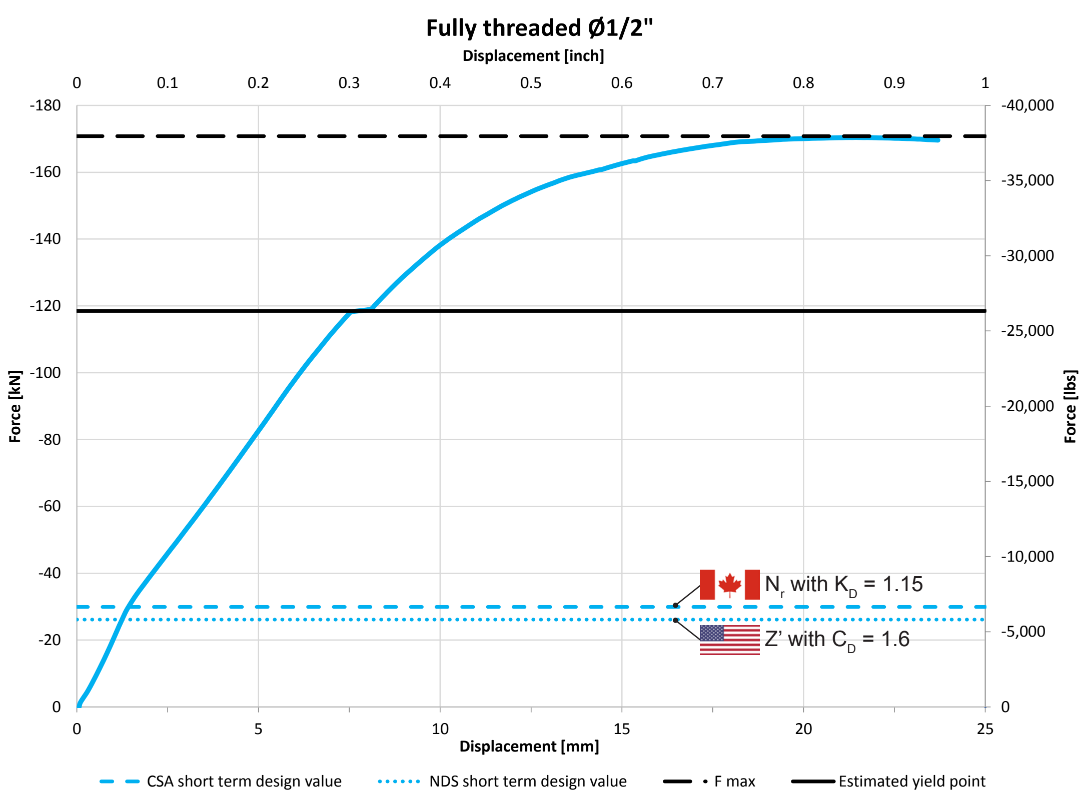
Graph 1. **Recorded average load displacement curves for test specimens using ASSY® Kombi 5/16" x 5-1/2".**



Graph 2. **Recorded average load displacement curves for test specimens using ASSY® VG CSK 5/16" x 5-1/2".**



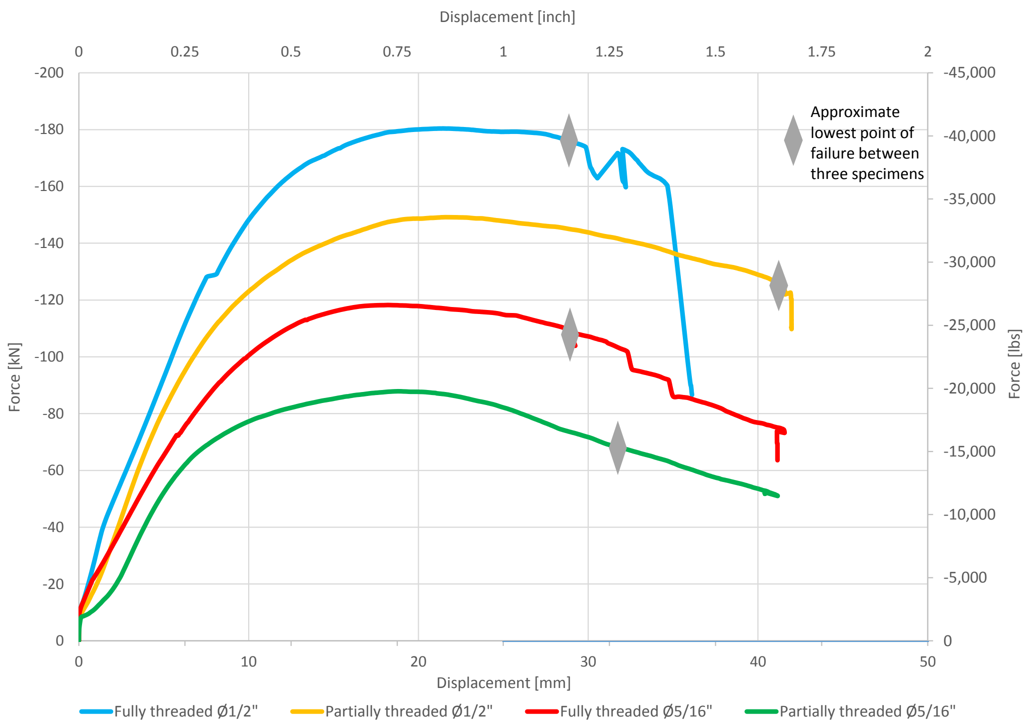
Graph 3. **Recorded average load displacement curves for test specimens using ASSY® Kombi 1/2” x 5-1/2”.**



Graph 4. **Recorded average load displacement curves for test specimens using ASSY® VG CSK 1/2” x 5-1/2”.**

ANALYSIS

The screw length was kept constant at 5-1/2" (140mm) for all test series. With the screw diameter increasing from 5/16" inch to 1/2" inch, the capacity and strength values increased respectively by 65% and 67% with partially-threaded screws and by 53% and 48% with fully-threaded screws. Since capacities did not drop off substantially beyond F_{max}, ductility can be considered as the ratio between displacement at F_{ult} to displacement at the yield load. Both fully threaded and partially threaded screws showed moderate to high ductility.



Graph 5. **Complete load dispacement curves (average) showing approximate first specimen failure.**

For all test series, formation of two plastic hinges was observed in the fasteners, corresponding to failure mode IV in NDS 2018 and failure mode (f) in CSA O86, as seen in Figure 4, below:

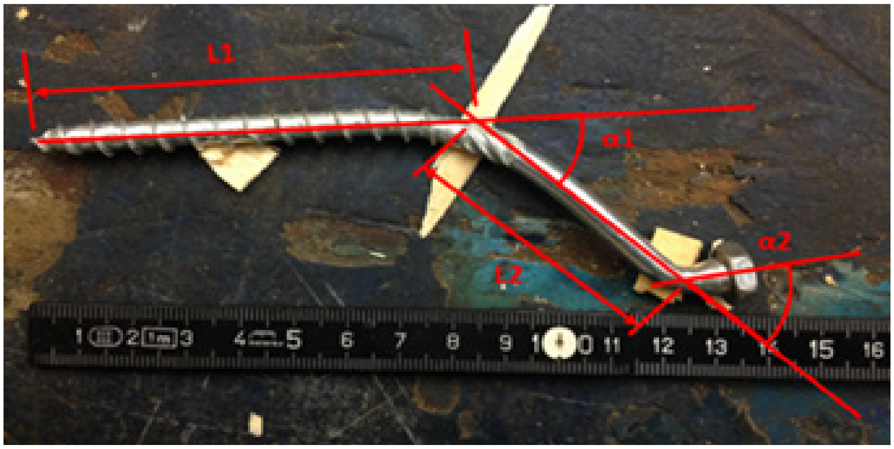


Figure 4. **5/16" (8mm) Kombi screw exhibiting type IV (f) failure mode with two plastic hinges upon recovery from test specimen. [Picture provided by University of Alberta research team].**

The table below shows the average plastic deformation of each type of fasteners, expressed as the magnitude and location of the plastic hinge in the main member portion of the fastener. At large bending angles, a greater area of the fastener cross section develops its plastic yield strength, which contributes additional connection strength (specified bending yield strengths account for the fact the plastic capacity of a fastener in bending is only partially developed).

Additionally, the axial tension component along the shear plane could be estimated using parameter α1, see figure 4. The parameter α2 is not shown in the tables as the removal process tended to damage the head around this second plastic hinge. It is worth noting that during testing, the bending angle would have been even greater as any elastic bending would have relaxed upon unloading.

Table 4. Average Measured Fastener Deformations.

	5/16" screws				1/2" screws			
	Kombi		VG CSK		Kombi		VG CSK	
α1	38.95°		30.3°		17.25°		16.85°	
L1	3.04"	[77.3 mm]	3.09"	[78.6 mm]	2.88"	[73.2 mm]	3.15"	[80.05 mm]
L2	2.06"	[52.2 mm]	1.74"	[44.1 mm]	2.05"	[52.15 mm]	1.74"	[44.25 mm]

The factor of safety is calculated as the ratio between the mean maximum tested load and the reference lateral design value (Z) as calculated according to NDS 2018:

Table 5. Factor of Safety (Allowable Stress Design*).

Connection type	Fmax lbs	Z lbs	Factor of safety
CLT-8PT	13,034	2,516	7.2
CLT-12PT	20,457	4,613	6.8
CLT-8FT	14,051	1,971	12.3
CLT-12FT	38,397	3,672	10.5

*not applicable to Canada

Neither the NDS nor CSA O86 consider strength contributions of friction or axial tensioning components in the design provisions. For failure modes including fastener rotation or yielding, a force component is generated along the fastener in the axial direction, as illustrated in Figure 5. This axial effect pulls the members together, generating a normal force at the connection interface which is assumed to increase connection strength through friction. As the fastener inclines further, the force component of the axial strength of the fastener can also contribute substantially to the maximum connection strength. The increase in connection strength due to axial effects is referred to as the "rope effect."

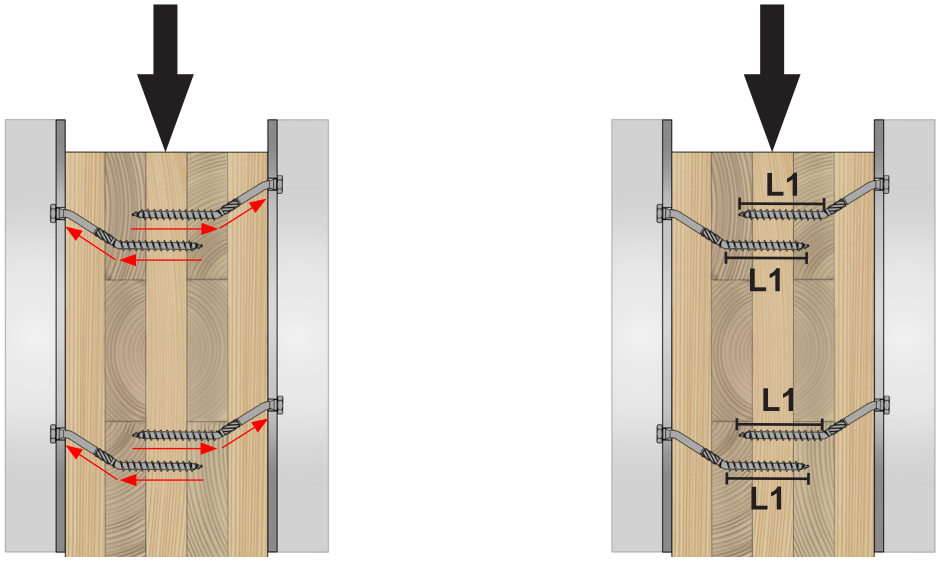


Figure 5. **[left] Illustration of the rope effect in a yielded fastener; [right] Undeformed section of the fasteners.**

The lateral load carrying capacity for screws presented in EC5 contains a correction term accounting for the strength contribution of the rope effect in certain failure modes where yielding of fasteners is governing. The rope effect term is designed to incorporate only the contribution of the friction, as the strength contribution from the tension force components along the shear plane are relevant only at significant deformations and/or fastener inclination. Although the rope effect is added to yield modes involving fastener rotation or yielding, derivation of the rope effect term takes the fastener in the undeformed state. A general coefficient of friction assumed as 0.25 for both steel to wood and wood to wood connections (Hilson, 2017). The format for including the rope effect is as follows:

$$\text{Lateral resistance} = \min \begin{cases} \text{Johansen yield load} + 0.25\ \text{withdrawal resistance} \\ 2 \cdot \text{Johansen yield load} \end{cases}$$

According to the European test standard ISO 6891, "*Timber structures. Joints made with mechanical fasteners*", the maximum connection strength is recorded over 15mm [0.6"] of joint displacement. Following this procedure, Hansen (2002) showed that it is possible to approximately double the design strength capacity of connections using laterally loaded self tapping screws by considering the friction effect at displacements of 15mm [0.6"]. However, Hansen also mentions that displacements this large would not be suitable for many design purposes as they would exceed serviceability limit states intended to limit inter-storey drift and damage to surface materials, for instance. Nonetheless, as mass timber buildings continue to be built taller and taller, there is an increasing need to provide ductility in these structural systems. For structures composed of rigid CLT panels, this ductility must come from the connections. Connections employing slender, laterally loaded self-tapping screws with high axial strengths are a proven solution for adding ductility and reserve strength to tall timber structural systems.

An example of the suggested lateral connection design in North America following the allowance for the rope effect shown above is included on the following pages.

USA: Adjusted Lateral Design Value (Z') Incorporating Rope Effect (0.25 · W')

Design of a steel to CLT H-Block connection using 8 ASSY® Kombi 5/16" x 5-1/2" according to NDS 2018 (Allowable Stress Design):

$$0.25 \cdot W' = 0.25 \cdot W_{90} \cdot R_{\alpha} \cdot L_{eff} \cdot n_F \cdot C'$$

W_{90}	Perpendicular to grain reference withdrawal design value	185 [lbs]
R_{α}	Angle to grain reduction factor for withdrawal	1
L_{eff}	Effective length of embedment: $L_{Thread} - L_{Tip}$	2.183 [in]
n_F	Number of effective fasteners in a row: $n_F = n^{0.9}$	$2^{0.9}$
n_R	Number of rows in the connection	4
C_D	Load duration factor	1.6

$$0.25 \cdot W' = 1{,}552 \text{ [lbs]}$$

min { 0.25 · W' + Z' = **5,577 [lbs]** ; 2 · Z' = 8,050 [lbs] }

Table 6. Adjusted Lateral Design Value Incorporating Rope Effect.

Unit	5/16" [8 mm] screws				1/2" [12 mm] screws			
	Kombi		VG CSK		Kombi		VG CSK	
	Z'	Z' + Rope	Z'	Z' + Rope	Z'	Z' + Rope	Z'	Z' + Rope
lbs	4,025	5,577	3,153	5,775	7,381	9,041	5,876	8,644
[kN]	[17.90]	[24.81]	[14.03]	[25.69]	[32.83]	[40.22]	[26.14]	[38.45]

Note: Design value in accordance with NDS 2018 adjusted for short term loading

Canada: Factored Lateral Strength Resistance (N_r) Incorporating Rope Effect (0.25 · P_{rw})

Design of a steel to CLT H-Block connection using 8 ASSY® Kombi 5/16" x 5-1/2" according to CSA O86 (Limit State Design):

$$0.25 \cdot P_{rw} = 0.25 \cdot P'_{rw,90} \cdot R_{\alpha} \cdot L_{eff} \cdot n_F \cdot J' \cdot K'$$

$P'_{rw,90}$	Basic factored withdrawal resistance value	61 [N]
R_{α}	Angle to grain reduction factor for withdrawal	1
L_{eff}	Effective length of embedment: $L_{Thread} - L_{Tip}$	72 [mm]
n_F	Number of effective fasteners in a row: $n_F = n^{0.9}$	$2^{0.9}$
n_R	Number of rows in the connection	4
J_X	Reduction factor for the use of CLT	0.9
K_D	Load duration factor	1.15

$$0.25 \cdot Prw = 8.48 \text{ [kN]}$$

Min {0.25 · Prw + Nr = **27.39 [kN]** ;2 · Nr = 37.82 [kN]}

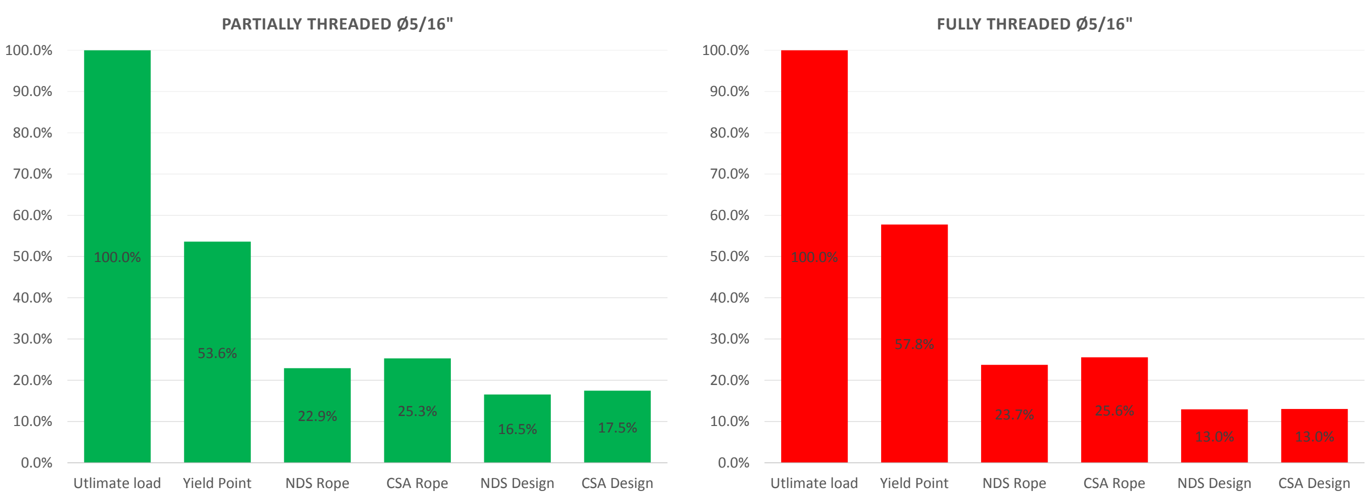
Table 7. Factored Lateral Strength Resistance Incorporating Rope Effect.

Unit	5/16” [8 mm] screws				1/2” [12 mm] screws			
	Kombi		VG CSK		Kombi		VG CSK	
	Nr	Nr + Rope	Nr	Nr + Rope	Nr	Nr + Rope	Nr	Nr + Rope
lbs	4,251	6,158	3,172	6,216	8,919	11,605	6,727	11,189
[kN]	[18.91]	[27.39]	[14.11]	[27.65]	[39.68]	[51.62]	[29.92]	[49.77]

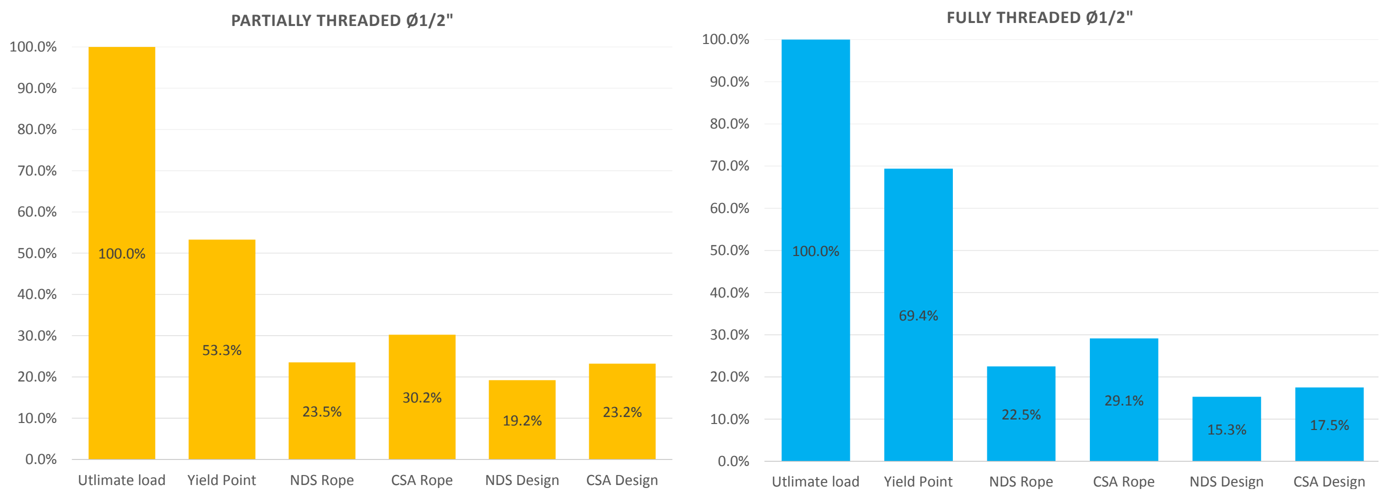
Note: Design value in accordance with CSA O86 factored for short term loading

The graphs below show that even incorporating the rope effect following respective provisions for lateral and withdrawal design, there are still large factors of safety in the design values. In the NDS, lateral design values are designed to limit slip and provide a sufficient factor of safety. Table 5 shows that high factors of safety are achieved. In Canada, the lateral design of self-tapping screws is penalized by a resistance factor 0.6 (assigned to lag screws), while a resistance factor of 0.8 is assigned to bolts, nails, and standard wood screws (reflecting ductile failure modes). Lateral connection testing with self-tapping screws, however, consistently demonstrates their potential for ductile failures.

Furthermore, since slender, laterally loaded fasteners in the panel face of CLT demonstrate an appreciated ability to redistribute loads through yielding, there is a case for setting the number of effective fasteners equal to the actual number of fasteners in the connection (n_F = n). Finally, self-tapping screws could perhaps be assigned an “effective diameter” to account for the strength contribution of the large thread wings.



Graph 6. Comparison between average ultimate value, elastic limit, improved design value and design value for 5/16” screws.



Graph 7. Comparison between average ultimate value, elastic limit, improved design value and design value for 1/2" screws.

CONCLUSION

These twelve tests show that self tapping screws can provide high strength, ductile connections in CLT with steel plates. The results further indicate that there is considerable reserve strength beyond what is calculated using North American design procedures. Because NDS 2018, CSA O86, and EC5 are calibrated differently, designers should be aware of the differences between them when comparing design values and procedures.

References

ASTM D5764-97a: Standard test method for evaluating dowel-bearing strength of wood and wood-based products. (2007). West Conshohocken, PA: ASTM International.

ASTM F1575-03: Standard test method for determining bending yield moment of nails. (2003). West Conshohocken, PA: ASTM International.

Blass, H. J., & Uibel, T. (2007). Tragfähigkeit von stiftförmigen Verbindungsmitteln in Brettsperrholz. Karlsruhe: Univ.-Verl. Karlsruhe.

Foliente, G. & Smith, I. (2004). Development of limit states design method for joints with dowel type fasteners—Literature review. Melbourne, Victoria: Forrest and Wood Products Research and Development Corporation.

Hilson, B., (2017). Johansen model. In Blass, H. & Sandhaas, C. (Ed.), Timber Engineering (pp347-364). KIT Scientific Publishing.

ISO. (1983). Timber structures-joints made with mechanical fasteners-general principles for the determination of strength and deformation characteristics. Standard ISO 6891. Internaiton al Organization for Standardization. Geneva, Switzerland.

Task Committee on Fasteners of the Committee on Wood, & ASCE Manuals and report on engineering practice ; 84. (1995). Mechanical connections in wood structures. New York: ASCE.

Hansen, K. F. (2002). Mechanical properties of self-tapping screws and nails in wood. Canadian Journal of Civil Engineering, 29 (5), 725-733.

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