MyTiCon Timber Connectors White Paper

Structural Screw Technology in Tall Wood Buildings

WOOD you like to CONNECT?

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What is presented in this White Paper with proposed design methods?

For the past two years Tall Wood Buildings have been one of the hottest topics in North American timber construction. Glulam manufacturing, machining and production, machining of engineered wood products such as Cross Laminated Timber (CLT), Laminated Veneer Lumber (LVL) and Laminated Strand Lumber (LSL) have advanced to a level where Tall Wood Buildings finally seem realistic in North America. Realising tall wood building poses many challenges to the industry. Among these challenges is connecting timber elements most cost efficiently. To design efficient timber connection systems for tall wood buildings one must understand the performance of each timber connection and how the behaviour of a single connection affects the performance of a structural system.

Since many of the required connection assemblies for tall wood have not yet been tested with North American timber products and very little design guidelines have been published, engineers are challenged to predict connection performances.

A master and PhD research project at the University of British Columbia (UBC) was launched in early 2014 and has now produced the first preliminary results on CLT connection system performances.

This White Paper summarizes the conducted initial tests and their respective preliminary results. Furthermore, preliminary design procedures (in LSD) to predict the performance of the respective connection systems are proposed and evaluated. The proposed design procedures and results shall be verified by a design professional in any case before applied in a structure. Proposed design capacities only consider the design of the fasteners. Timber element design checks are not included and must be verified by a qualified design professional.

CLT panel to beam and panel to panel connection with SWG ASSY® screws

Panel to beam connections can be established utilizing a variety of connectors and connector arrangements. Depending on the purpose of the connection or expected system performances, three major connection types can be distinguished using either partial thread or full thread screws.

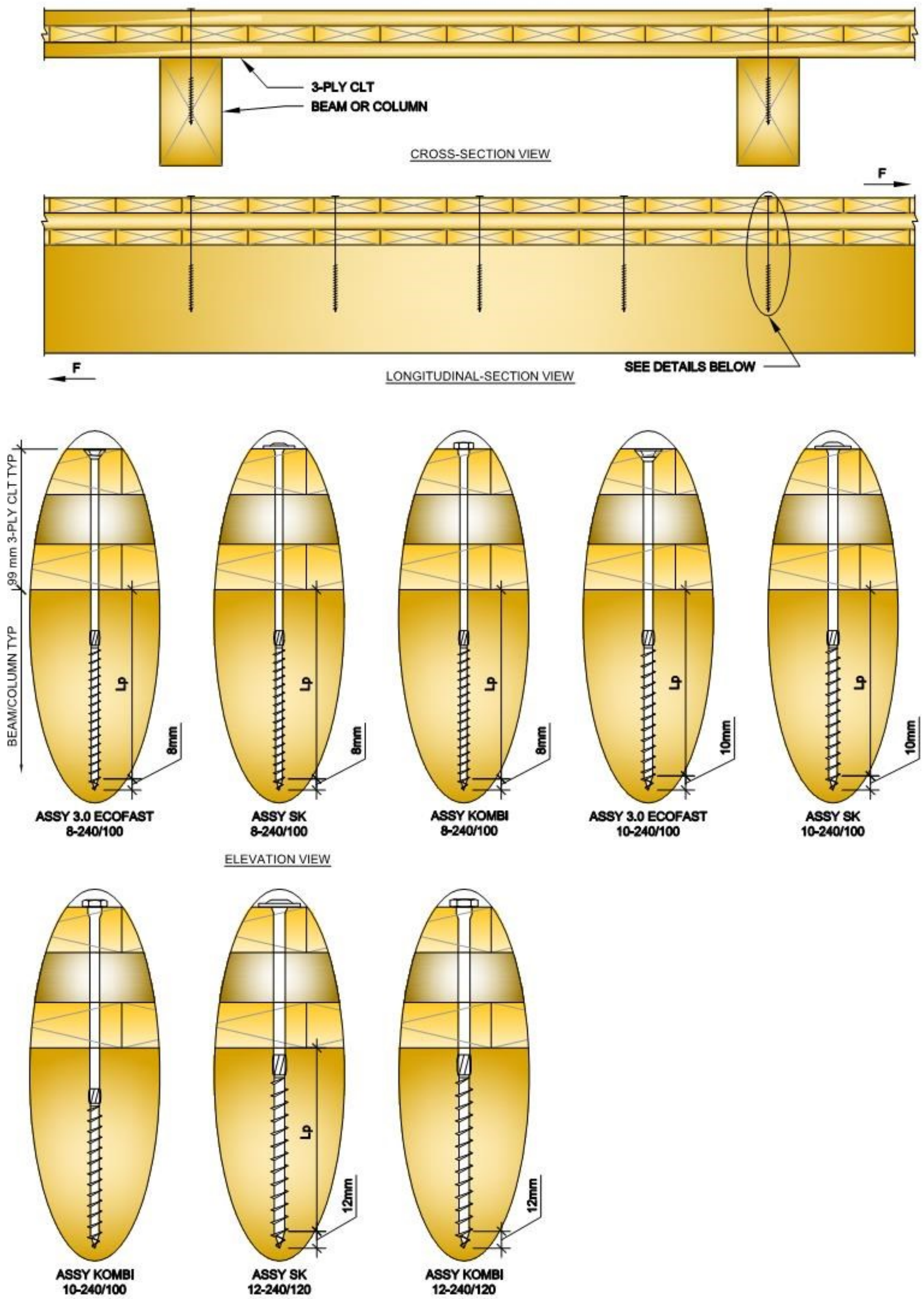
Option #1: partial thread screws perpendicular to the panel plane

Option #2: full thread screws arranged at a 45° angle to the panel plane

Option #3: full thread screws arranged cross wise at a 45° angle to the panel plane in panel to panel connection

Proposed DESIGN OPTION #1 - partial thread screw arranged at 90°	
Conditions of connection and connection requirements	The panel to beam connection is to be designed for 30kN/m under standard term loading. Loading condition: Two directional load parallel to beam axis D-Fir glulam main member and Canadian S-P-F CLT side member connection with SWG ASSY KOMBI 10mm x 220mm @ 90° angle. Note: Gap, check or split width in CLT panel shall not exceed the minor thread diameter of the screw.
Geometry	**b** = beam width 215mm **h** = beam depth 380mm $\mathbf{h_{CLT}}$ = 99mm (3-Ply CLT by Structurlam) Min panel thickness 99mm **—>** 10d = 10* 10 = 100mm ≈ 99mm
*Spacing, end and edge distance requirements in **CLT side member** [2]*	Screw spacing parallel = 4* d = 40mm Loaded end distance = 6* d = 60mm Unloaded edge distance = 2.5* d = 25mm
*Spacing, end and edge distance requirements in **glulam main member** [1]*	Screw spacing parallel = 10.5* d = 105mm Loaded end distance = 15* d = 150mm Unloaded edge distance = 7*d = 70mm Spacing perpendicular to grain = 7* d = 70mm
Effective embedment length	$\mathbf{L_{p,1}}$ = side member = 99mm $\mathbf{L_{p,2}}$ = main member = 220mm - 99mm - 10mm = 111mm Note: Effective thread embedment is reduced by 1xd where d = screw diameter screw in angle α = 90°
Shear resistance design Pr [1], [4]	d_F = 7.2mm (shank diameter of screw)—> f_1 = 95.6* $d^{-0.5}$ * $G^{1.05}$ = 14.32 N/mm² —> f_2 = 50G* (1-0.01d_f) = 22.73N/mm² —> t_1 = 99mm —> t_2 = 111mm —> f_y = 942 N/mm² Computing through Johansen Yield Theory failure modes (a) through (f) (a) = 10.2kN —> (b) = 19.8kN —> (c) = 3.9kN —> (d) = 4.4kN —> (e) = 6.0kN —> **(f) = 3.8kN** K_D = 1.0 —> K_{SF} = 1.0 —> K_t =1.0 —> ϕ =0.6 —> J_{pl} = 1.0 —> J_G ≈ 0.82
Design shear resistance	3.8kN* 0.6* 1000mm/120mm* 1*1*1*1 *0.82= 15.58kN
Required effective number of fasteners	30kN / 15.58kN = 1.92 ≈ 2 rows @70mm from edge each side @ 120mm o.c. staggered
Lateral deformation estimate of screw joint [6]	K_p = (5.04*G-0.29)*J_y K_{SF} J_G —> K_Q = (5.04*G-0.29)*J_Q K_{SF} J_G —> cross layers of CLT consideration with average of K_p and K_Q Δ= P/ ((K_p + K_Q)/2)*d_F*t_2*n_f = 1.16mm G=0.42; J_Y =1; J_Q=0.97 (7.2mm shank diameter); d_F =7.2; n_f = 1000/120*2= 20; P= 30kN
Connection specification	Use 2 rows of SWG ASSY Kombi 10x220. Fasteners spaced 120mm o.c.. Stagger screws with 25mm offset away from beam edge

CLT panel to beam connection example with SWG ASSY® screws @90°



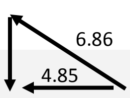
CLT panel to beam and panel to panel connection with SWG ASSY® screws

Panel to beam connections can be established utilizing a variety of connectors and connector arrangements. Depending on the purpose of the connection or expected system performances, three major connection types can be distinguished using either partial thread or full thread screws.

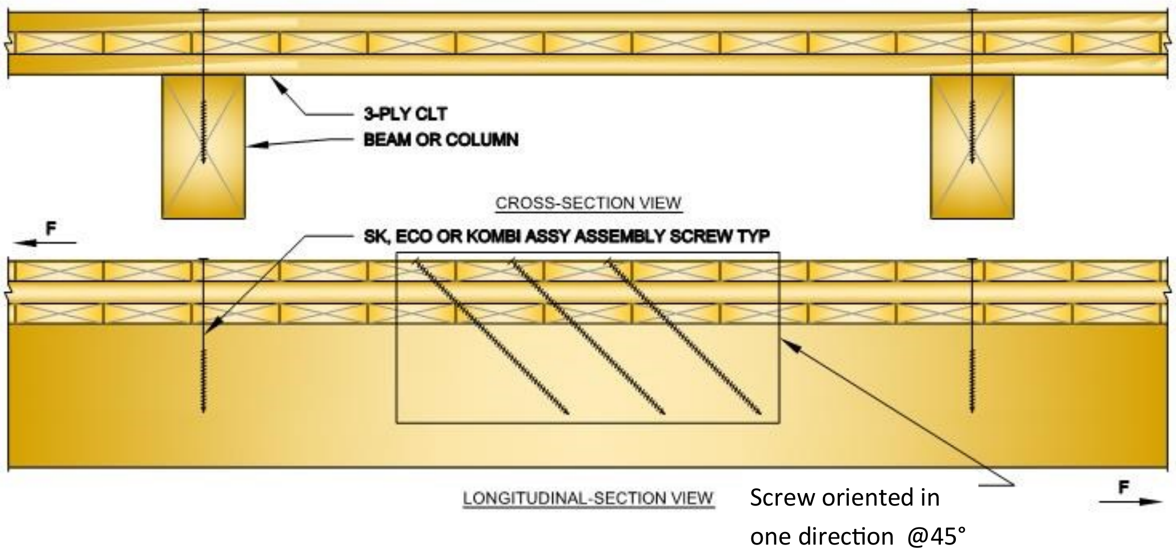
Option #1: partial thread screws perpendicular to the panel plane

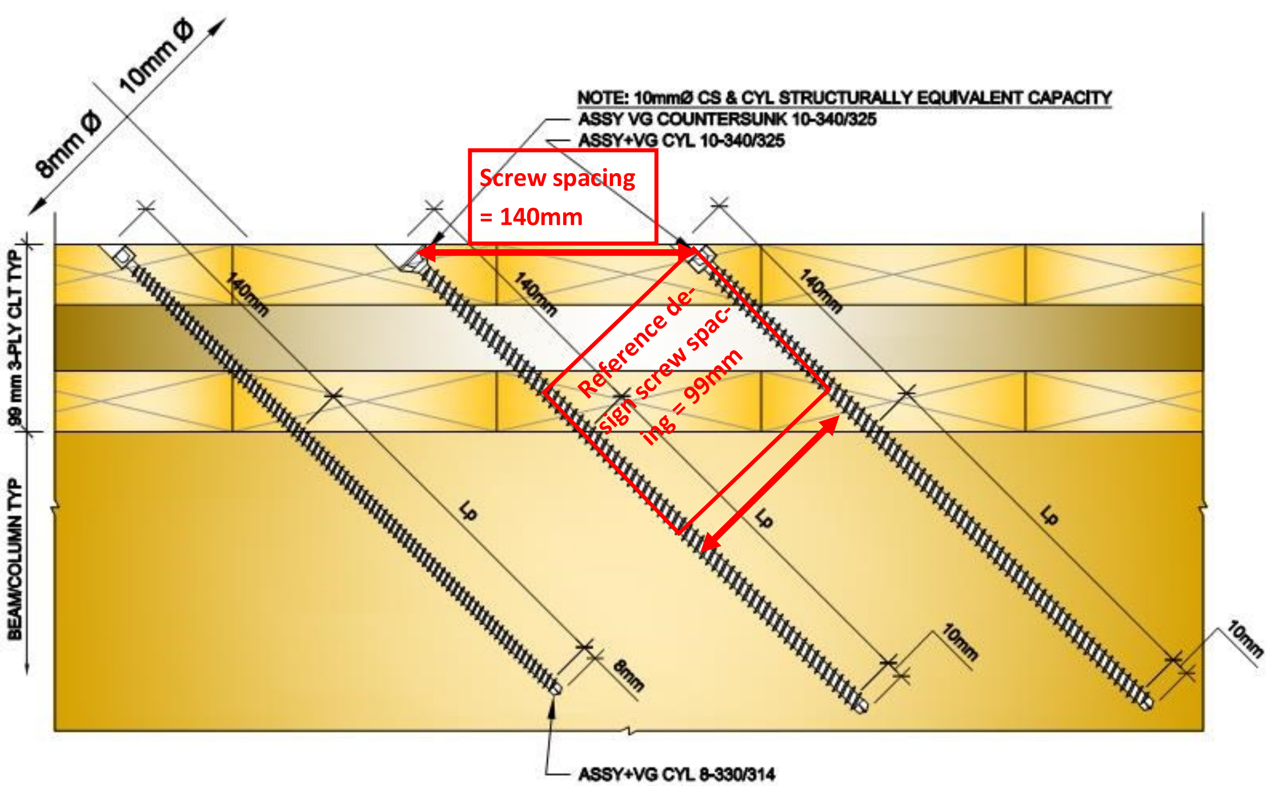
Option #2: full thread screws arranged at a 45° angle to the panel plane

Option #3: full thread screws arranged cross wise at a 45° angle to the panel plane in panel to panel connection

Proposed DESIGN OPTION #2 - full thread screw arranged at 45°	
Conditions of connection and connection requirements	The panel to beam connection is to be designed for 50kN/m under standard term loading. Loading condition: **One directional load.** D-Fir glulam main member and Canadian S-P-F CLT side member connection with SWG ASSY VG CYL 8mm x 330mm @ 45° angle and ASSY SK 8x300 assembly screw to assure panel firmly bearing on beam Note: Gap, check or split width in CLT panel shall not exceed the minor thread diameter of the screw.
Geometry	**b** = beam width 130mm **h** = beam depth 300mm $\mathbf{h_{CLT}}$ = 99mm (3-Ply CLT planed by Structurlam) Min panel thickness 99mm **—>** 10d = 10* 8 = 80mm < 99
*Spacing, end and edge distance requirements in **CLT side member** [2]*	Screw spacing parallel = 4* d = 32mm (measured perpendicular to fastener axis) Loaded end distance = 6* d = 48mm Unloaded edge distance = 2.5* d = 20mm
*Spacing, end and edge distance requirements in **glulam main member** [1]*	Screw spacing parallel = 7.5* d = 60mm (measured perpendicular to fastener axis) Loaded end distance = 7.5* d = 60mm Unloaded edge distance = 2.5* d = 20mm Spacing perpendicular to grain = 2.5* d = 20mm
Effective thread embedment length	$\mathbf{L_{p,1}}$ = side member = (99mm/cos α) - 8mm = 132mm $\mathbf{L_{p,2}}$ = main member = 330mm - 140mm-8mm = 182mm Note: Effective thread embedment is reduced by 1*d where d = screw diameter screw in angle α = 45°
Withdrawal resistance [1]	$\mathbf{Pr'w}_{side}$ = 1.04kN* (132mm/20mm) = 6.86 [kN] side member controls design $\mathbf{Pr'w}_{main}$ = 1.37kN* (182mm/20mm) = 12.46 [kN]
Tensile resistance check screw [1]	15.12 kN > 6.86 kN 
Design shear resistance per screw	F = 4.85kN
Required effective number of fasteners per meter of connection	50kN / 4.85kN = 10.3 effective screws required **—>** considering an effective number of screws $n_{eff} = n^{0.9}$ as per [3] use $14^{0.9}$ = 10.7 > 10.3
Serviceability limit state connection stiffness estimate [5]	$K_{ser} = 780 * d^{0.2} * L_{p,i}^{0.4}$ = 8335 N/mm Est. connection stiffness along screw axis = 10.7*8335 N/mm = 89.18kN/mm Est. connection stiffness parallel to shear plane = 89.18*cos45°= 63.06kN/mm Note: only applicable to axially loaded full thread SWG ASSY VG screws
Connection specification	Use 2 rows of 7 SWG ASSY VG per meter @ 140mm o.c and one row ASSY SK @500 mm o.c.

CLT panel to beam connection example with SWG ASSY® screws @45°





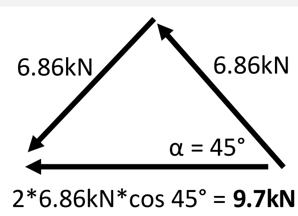
CLT panel to beam and panel to panel connection with SWG ASSY® screws

Panel to beam connections can be established utilizing a variety of connectors and connector arrangements. Depending on the purpose of the connection or expected system performances, three major connection types can be distinguished using either partial thread or full thread screws.

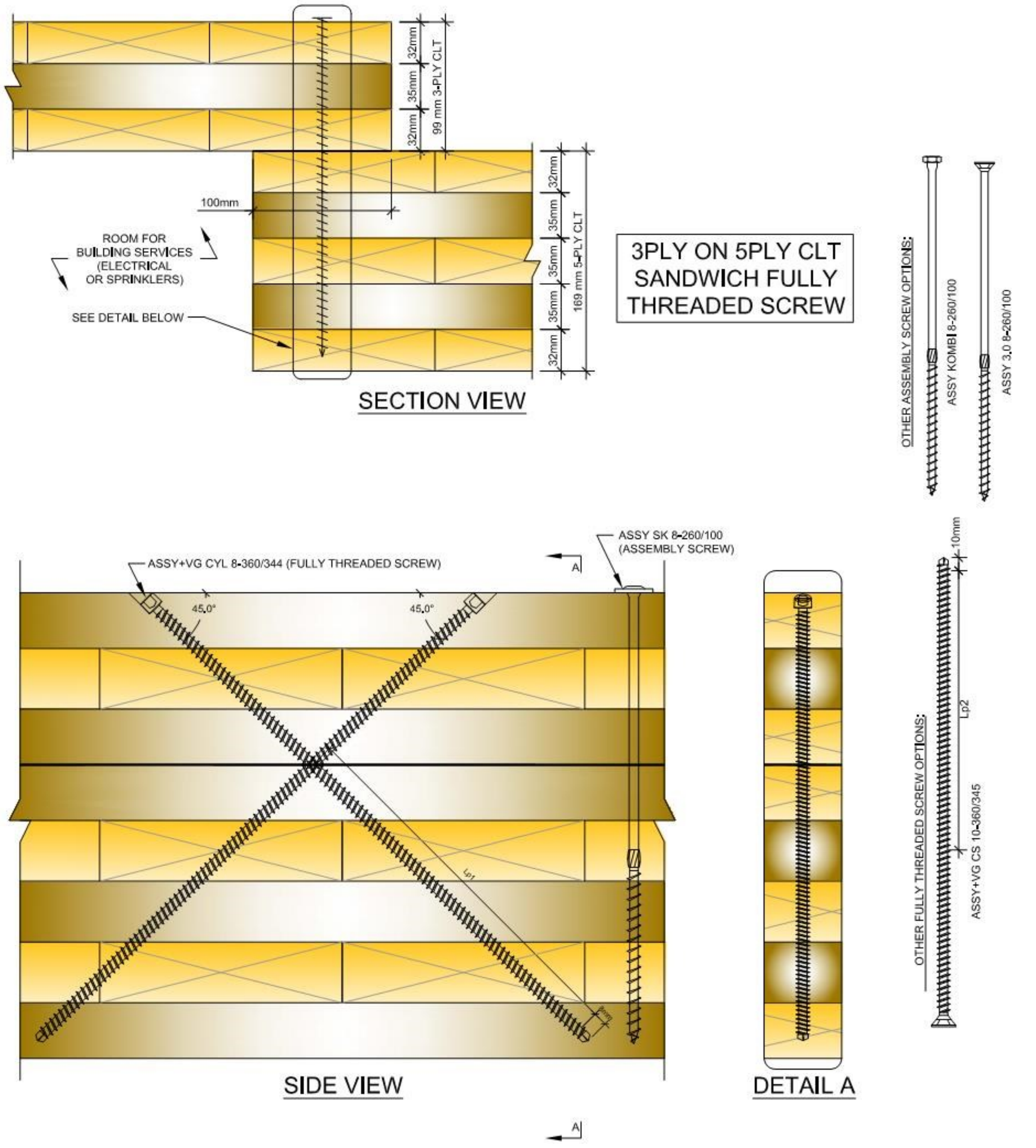
Option #1: partial thread screws perpendicular to the panel plane

Option #2: full thread screws arranged at a 45° angle to the panel plane

Option #3: full thread screws arranged cross wise at a 45° angle to the panel plane in panel to panel connection

Proposed DESIGN OPTION #3 - full thread screw arranged at 45° cross wise	
Conditions of connection and connection requirements	The panel to panel connection is to be designed for 100kN/m under standard term loading. Loading condition: **Two directional load** 3-Ply S-P-F CLT side member connected to 5-Ply S-P-F CLT main member with SWG ASSY VG CYL 8mm x 360mm @ 45° angle. Note: Gap, check or split width in CLT panel shall not exceed the minor thread diameter of the screw.
Geometry	**b** = width overlap 100mm $\mathbf{h_{CLT}}$ = depth 3-Ply CLT = 99mm, 5-PLY CLT = 169mm (CLT by Structurlam) Min panel thickness 99mm **—>** 10d = 10* 8 = 80mm < 99
*Spacing, end and edge distance requirements in **CLT side and CLT main member** [2]*	Screw spacing parallel = 4* d = 32mm Screw spacing perpendicular = 2.5* d = 20mm Loaded end distance = 6* d = 48mm Unloaded edge distance = 2.5* d = 20mm
Effective thread embedment length	$\mathbf{L_{p,1}}$ = side member = (99mm/cos α) - 8mm = 132mm $\mathbf{L_{p,2}}$ = main member = 360mm - 140mm-8mm = 212mm Note: Effective thread embedment is reduced by 1*d where d = screw diameter screw in angle α = 45°
Withdrawal resistance [1]	$\mathbf{Pr'w_{side}}$ = 1.04kN* (132mm/20mm) = 6.86 [kN] side member controls design $\mathbf{Pr'w_{main}}$ = 1.04kN* (212mm/20mm) = 11.02 [kN]
Tensile resistance check screw [1]	15.12 kN > 6.86 kN
Design shear resistance per screw cross	 Required effective number of fasteners per meter of connection: 100kN / 9.7kN = 10.3 effective screw crosses required Select 14 screw crosses to account for potential group effect **—>** $14^{0.9}$ = 10.7 **—> 10.7 > 10.3**
Serviceability limit state connection stiffness estimate [5]	$K_{ser} = 780 * d^{0.2} * L_{p,i}^{0.4}$ = 8335 N/mm Estimated connection stiffness parallel to shear plane per screw cross with screws at 45° = 2*8335N/mm*cos45°= 11787N/mm Estimated connection stiffness parallel to shear plane with 10.7 effective screws i.e. effective screw crosses = 10.7*11.78kN/mm = 126.05kN/mm Note: only applicable to axially loaded SWG ASSY VG full thread screws
Connection specification	Use 14 screw crosses (14 SWG ASSY VG 8mm x 360mm per meter @45° in each direction)@70mm o.c. spacing. Min. 25mm spacing between rows. Apply one partial thread ASSY 8mm x 260mm assembly screw @500mm o.c.

CLT panel to panel connection example with SWG ASSY® screws @45° cross wise



CLT panel to beam connection with SWG ASSY® screws @ 45°

Fmax = maximum recorded force during test

Displ. Fmax = recorded displacement at Fmax

0.4 Fmax, 0.7 Fmax = recorded force at 40% of predicted ultimate capacity and respectively 70%

Displ. 0.4 Fmax, 0.7 Fmax = recorded displacement at respective force level

Stiffness ultimate = calculated stiffness at Fmax

Stiffness 0.4 Fmax, 0.7 Fmax = calculate stiffness at respective load level

Design value = Capacity as per outlined design example procedure proposal

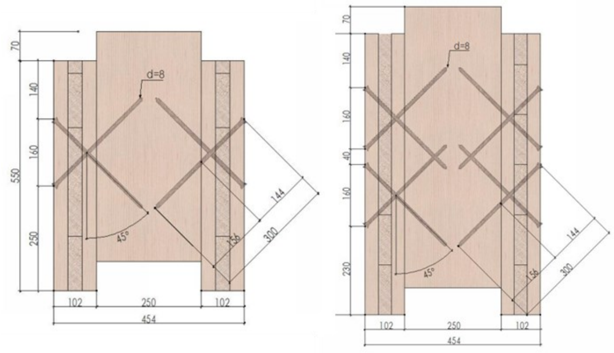
Over-strength factor = Tested capacity/ design capacity

Table 1: Proposed connection design values vs obtained test values—Panel to beam connection with 45° screws

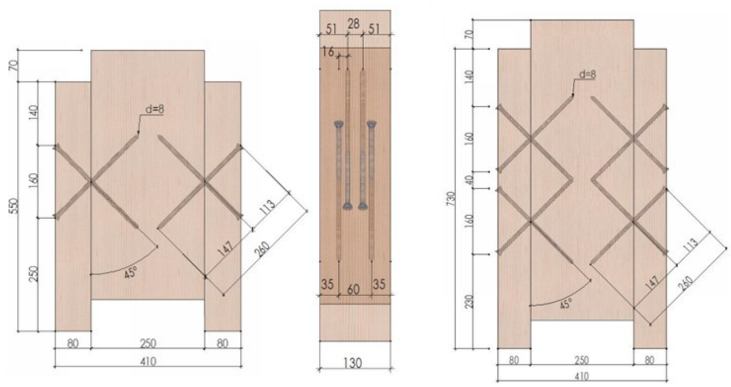
Design values vs Test values
Note: Values without bracket consider KD = 1.15 for shorty term loading (Values in brackets are standard term loading i.e. K_D= 1.0)

Specimen	Fmax [kN]	Displ. Fmax [mm]	0.4 Fmax [kN]	Displ. 0.4 Fmax [mm]	0.7 F max [kN]	Displ. 0.7 Fmax [mm]	Stiffness ultimate [kN/mm]	Stiffness 0.4 Fmax [kN/ mm]	Stiff-ness 0.7 Fmax [kN/ mm]	Design value [kN]	Over-strength	Predicted stiffness [kN/mm]
CLT to GL 8 - 8x300 FT@45°	143.6	3.48	57.5	1.58	100.5	2.41	37.6	36.39	41.7	≈44.62 (≈38.8)	3.21 (3.7)	≈47.1
CLT to GL 16 - 8x300 FT@45°	268	2.2	107.5	0.77	187.6	1.21	121.8	139.61	155.04	≈89.24 (≈77.6)	3.0 (3.45)	≈94.3
GL to GL 8 – 8x260 FT@45°	154.6	3.8	61.83	1.54	108	2.34	40.68	40.14	46.15	≈46.8 (≈40.7)	3.3 (3.79)	≈43.0
GL to GL 16 – 8x260 FT@45°	245	1.6	98	0.55	171	0.81	153.12	178.12	211.11	≈93.66 (≈81.45)	2.61 (3.0)	≈86.0

Note: Results listed in this table are average measurements out of 5 tests obtained from the positive load cycle. FT= **F**ull **T**hread screw
A load duration factor of K_D = 1.15 and 1.0 is considered. **Dynamic loading was applied to all specimen. No dynamic reduction factors are applied to design values or stiffness values**



CLT to Glulam connection



Glulam to Glulam connection

CLT panel to beam connection with SWG ASSY® screws @ 30°

Fmax = maximum recorded force during test

Displ. F max = recorded displacement at Fmax

0.4 F max, 0.7 F max = recorded force at 40% of predicted ultimate capacity and respectively 70%

Displ. 0.4 F max, 0.7 F max = recorded displacement at respective force level

Stiffness ultimate = calculated stiffness at F max

Stiffness 0.4Fmax, 0.7Fmax = calculate stiffness at respective load level

Design value = Capacity as per outlined design example procedure

Over-strength factor = Tested capacity/ design capacity

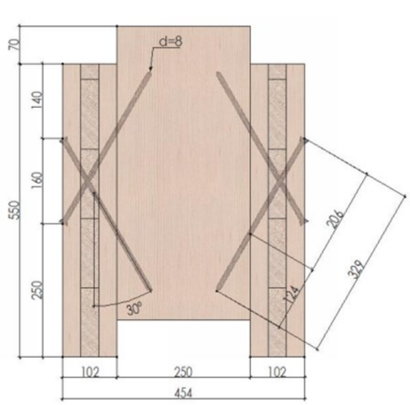
Table 2: Proposed connection design values vs obtained test values—Panel to beam connection with 30° screws

Design values vs Test values

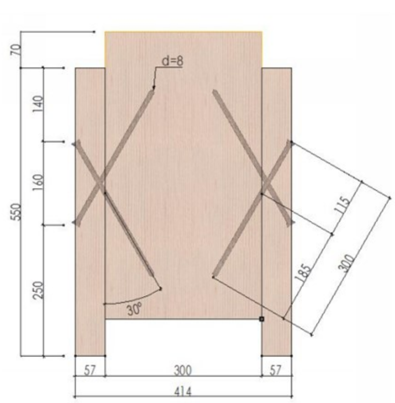
Note: Values without bracket consider KD = 1.15 for short term loading (Values in brackets are standard term loading i.e. K_D= 1.0)

Specimen	Fmax [kN]	Displ. Fmax [mm]	0.4 Fmax [kN]	Displ. 0.4 Fmax [mm]	0.7 Fmax [kN]	Displ. 0.7 Fmax [mm]	Stiffness ultimate [kN/mm]	Stiffness 0.4 Fmax [kN/mm]	Stiff-ness 0.7 Fmax [kN/mm]	Design value [kN]	Over-strength	Predicted stiffness [kN/mm]
CLT to GL 8 - 8x330 FT@30°	172.6	3.01	69.04	1.22	120.82	1.87	57.34	56.59	64.60	≈59.15 (≈51.43)	2.91 (3.35)	≈56.32
GL to GL 8 – 8x300 FT@30°	200.8	3.22	80.33	1.26	140.57	1.97	62.36	63.75	71.35	≈54.56 (≈47.44)	3.66 (4.23)	≈57.7

Note: Results listed in this table are average measurements out of 5 test obtained from the positive load cycle. FT= **F**ull **T**hread screw
A load duration factor of K_D = 1.15 and 1.0 is considered. **Dynamic loading was applied to all specimen. No dynamic reduction factors are applied to design values or stiffness values**



Glulam to Glulam connection



CLT to Glulam connection

CLT panel to panel connection with SWG ASSY® screws

Panel to panel connections can be established utilizing a variety of connectors and connector arrangements. Depending on the purpose of the connection or expected system performances three major connection types can be distinguished using either partial thread or full thread screws. A variety of connection combinations are also possible.

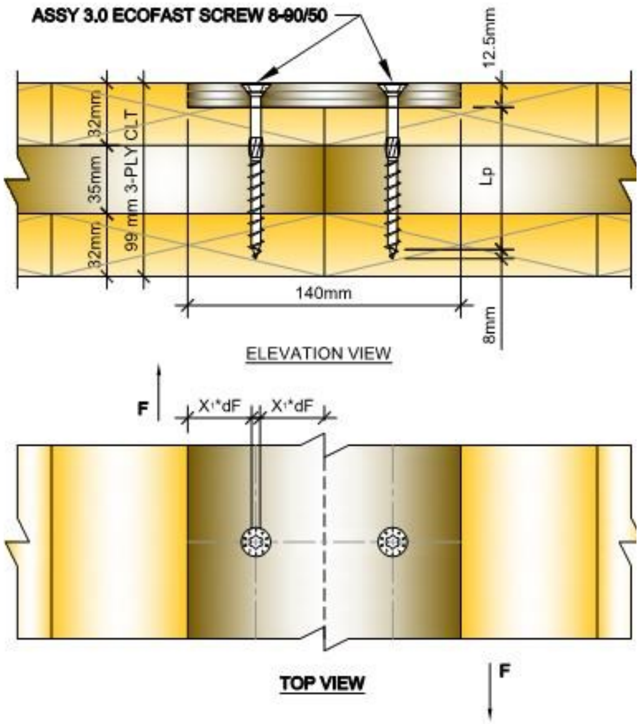
Option #4: partial thread screws perpendicular to the panel plane in surface spline joint

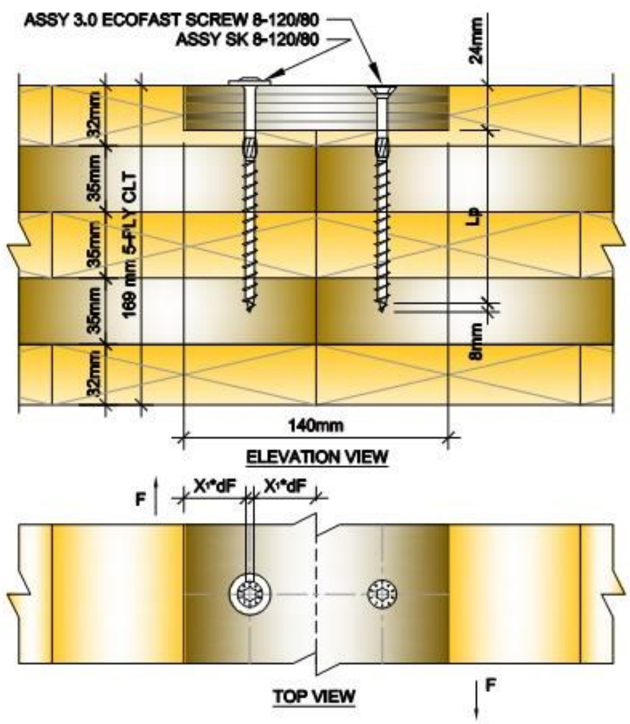
Option #5: partial thread screws perpendicular to the panel plane in lap-joint

Option #6: full thread screws arranged cross wise at a 45° angle to the panel plane in lap-joint

Proposed DESIGN OPTION #4 - **partial thread screws perpendicular to the panel plane in surface spline joint**	
Conditions of connection and connection requirements	The panel to panel connection is to be designed for 20kN/m under standard term loading. Loading condition: Two directional load parallel to panel spline. Plywood side member and Canadian S-P-F CLT main member connection with SWG ASSY 3.0 Eco 8mm x 90mm @ 90° angle. Note: Fasteners shall not be installed into cracks, checks, or gaps.
Geometry	**t** = plywood thickness 19mm **b** = plywood width 176mm $\mathbf{h_{CLT}}$ = 105mm (3-Ply CLT planed by Structurlam) Min panel thickness 105mm **—>** 10d = 10* 8 = 80mm < 105mm
Spacing, end and edge distance requirements in ***plywood side member*** *[2]*	Screw spacing parallel = 4* d = 32mm Loaded end distance = 6* d = 48mm Unloaded edge distance = 2.5* d = 20mm Spacing perpendicular to grain = 2.5* d = 20mm Note: *Spacing, end and edge distance requirements in* CLT was considered to be applicable for plywood
Spacing, end and edge distance requirements in ***CLT main member*** *[2]*	Screw spacing parallel = 4* d = 32mm Loaded end distance = 6* d = 48mm Unloaded edge distance = 2.5* d = 20mm Spacing perpendicular to grain = 2.5* d = 20mm
Effective embedment length	$\mathbf{L_{p,1}}$ = side member = 19mm $\mathbf{L_{p,2}}$ = main member = 90mm - 8mm-19mm= 63mm Note: Effective thread embedment is reduced by 1xd where d = screw diameter screw in angle α = 90°
Shear resistance design Pr [1], [4]	d_F = 5.8mm (shank diameter of screw)—> f_1 = 104G* (1-0.1d_f) = 18.35 N/mm^2 —> f_2 = 95.6*$d_f^{-0.5}G^{1.05}$= 15.96N/mm^2 —> t_1 = 19mm —> t_2 = 53mm —> f_y = 1015 N/mm^2 Computing through Johansen Yield Theory failure modes (a) through (f) (a) = 2.02kN —> (b) = 6.03kN —> (d) = 1.68N —> (e) = 2.66kN —> **(f) = 1.61kN** —> (g) = 2.56kN K_D , K_{sf} , K_t = 1.0 —> ϕ =0.6 —> J_{pl} = 1 —> J_G = 0.81
Design shear resistance	1.61kN* 0.6* 1000mm/32mm* 1*1*1*0.81 = 24.45kN
Required effective fasteners per meter	20kN / 24.45kN = 0.81 ≈ 1 row @ 32mm o.c.
Lateral connection deformation estimate [6]	K_p = (5.04*G-0.29)*J_y K_{SF} J_G —> K_Q = (5.04*G-0.29)*J_Q K_{SF} J_G —> cross layers of CLT consideration with average of K_p and K_Q Δ= P/ ((K_p + K_Q)/2)*d_F*t_2*n_f = 1.18mm G=0.42; J_Y =1; J_Q =0.97 (5.8mm shank diameter); d_F =5.8; n_f = 1000/64*2= 32; P= 20kN
Connection specification	Use 2 rows of SWG ASSY Eco 8x90 (32pc total each side) @ 64mm o.c. Offset rows with 20mm spacing perpendicular to panel face.

CLT panel to panel surface spline connection example with SWG ASSY® screws





CLT panel to panel connection with SWG ASSY® screws

Panel to panel connections can be established utilizing a variety of connectors and connector arrangements. Depending on the purpose of the connection or expected system performances three major connection types can be distinguished using either partial thread or full thread screws. A variety of connection combinations are also possible.

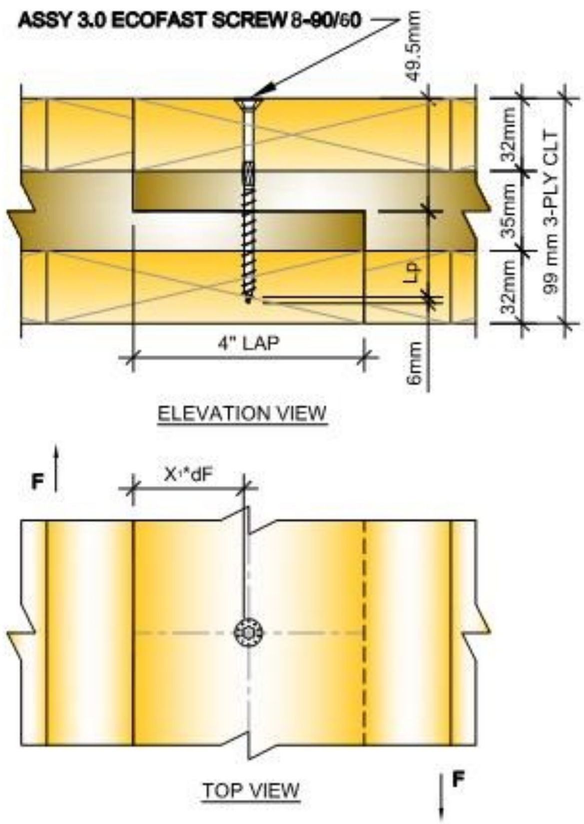
Option #4: partial thread screws perpendicular to the panel plane in surface spline joint

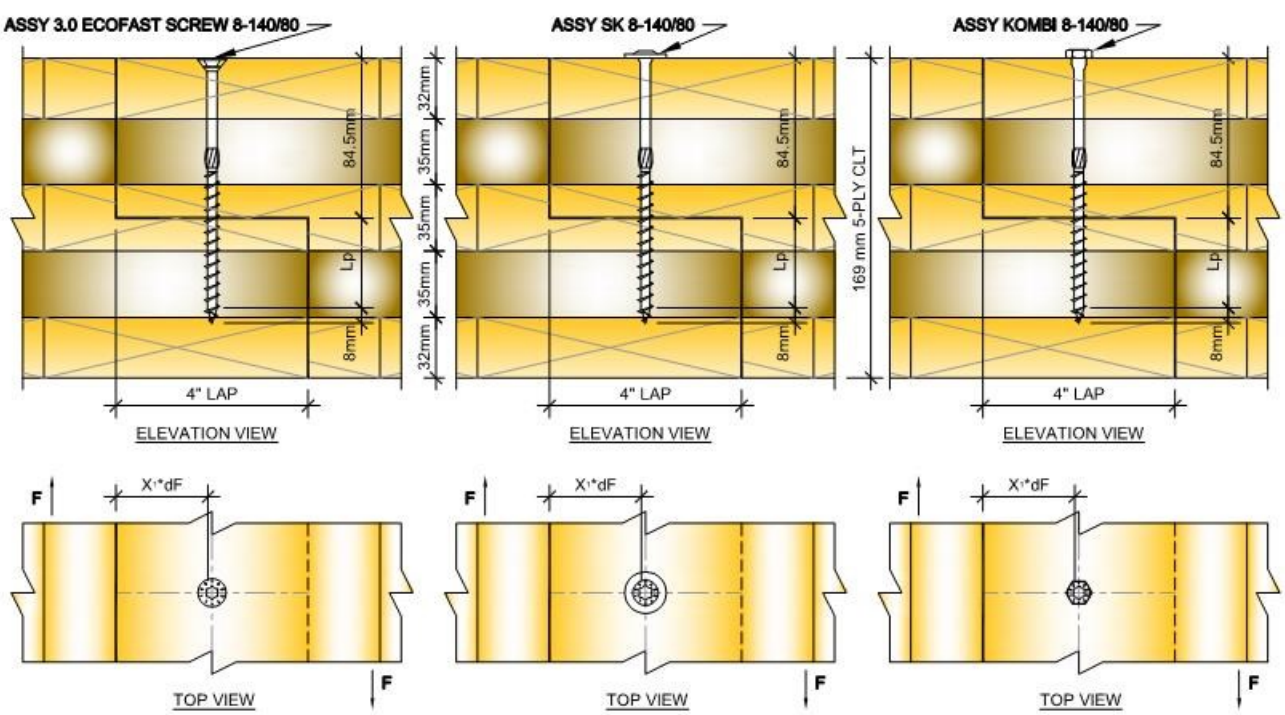
Option #5: partial thread screws perpendicular to the panel plane in lap-joint

Option #6: full thread screws arranged cross wise at a 45° angle to the panel plane in lap-joint

Proposed DESIGN OPTION #5 - **partial thread screws perpendicular to the panel plane in lap-joint**	
Conditions of connection and connection requirements	The panel to panel connection is to be designed for 25kN/m under standard term loading. Loading condition: Two directional load parallel to panel lap joint. Canadian S-P-F CLT side member and Canadian S-P-F CLT main member connection with SWG ASSY 3.0 Eco 8mm x 90mm @ 90° angle. Note: Fasteners shall not be installed into cracks, checks, or gaps.
Geometry	**t** = lap thickness 52.5mm **b** = lap width 80mm $\mathbf{h_{CLT}}$ = 99mm (3-Ply CLT planed by Structurlam) Min panel thickness 99mm **—>** 10d = 10* 8 = 80mm < 99mm
*Spacing, end and edge distance requirements in **CLT side and CLT main member** [2]*	Screw spacing parallel = 4* d = 32mm Loaded end distance = 6* d = 48mm Unloaded edge distance = 2.5* d = 20mm Spacing perpendicular to grain = 2.5* d = 20mm
Effective embedment length	$\mathbf{L_{p,1}}$ = side member = 49.5mm $\mathbf{L_{p,2}}$ = main member = 90mm - 8mm-49.5mm= 32.5mm Note: Effective thread embedment is reduced by 1xd where d = screw diameter screw in angle α = 90°
Shear resistance design Pr [1], [4]	d_F = 5.8mm (shank diameter of screw)—> $f_1 = f_2 = 95.6{*}d_f^{-0.5}G^{1.05}$= 15.96N/mm^2 —> t_1 = 52.5mm —> t_2 = 29.5mm —> f_y = 1015 N/mm^2 Computing through Johansen Yield Theory failure modes (a) through (f) (a) = 4.5N —> (b) = 3.7kN —> (d) = 2.1N —> (e) = 1.9kN —> **(f) = 1.6kN** —> (g) = 2.47kN K_D, K_{sf} , K_t = 1.0 —> ϕ = 0.6 —>J_{pl} = 0.7—> J_G = 0.85
Design shear resistance	1.6kN* 0.6* 1000mm/32mm* 1*1*1*0.85 *0.7 = 17.85kN
Required effective fasteners per meter	25kN / 17.85kN = 1.4 ≈ 2 rows @ 62mm o.c.
Lateral connection deformation estimate [6]	$K_p = (5.04{*}G-0.29){*}J_y K_{SF} J_G$ —> $K_Q = (5.04{*}G-0.29){*}J_Q K_{SF} J_G$ —> cross layers of CLT consideration with average of K_p and K_Q $\Delta = P/((K_p + K_Q)/2){*}d_F{*}t_2{*}n_f$ = 2.7mm Note: deformation exceed suggested maximum of ≈ 1mm to prevent permanent deformation G=0.42; J_Y =1; J_Q=0.97 (5.8mm shank diameter); d_F =5.8; n_f = 1000/62*2= 32; P= 25kN
Connection specification	Use 2 rows of SWG ASSY Eco 8x90 @ 62mm o.c. Stagger rows with 20mm offset

CLT panel to panel half lap connection example with SWG ASSY® screws





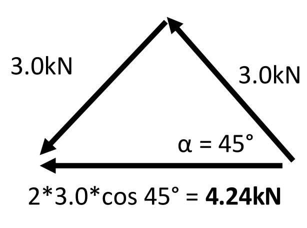
CLT panel to beam and panel to panel connection with SWG ASSY® screws

Panel to panel connections can be established utilizing a variety of connectors and connector arrangements. Depending on the purpose of the connection or expected system performances three major connection types can be distinguished using either partial thread or full thread screws. A variety of connection combinations are also possible.

Option #4: partial thread screws perpendicular to the panel plane in surface spline joint

Option #5: partial thread screws perpendicular to the panel plane in lap-joint

Option #6: full thread screws arranged cross wise at a 45° angle to the panel plane in lap-joint

Proposed DESIGN OPTION #6 - full thread screw arranged at 45° cross wise in half lap joint	
Conditions of connection and connection requirements	The panel to panel connection is to be designed for 40kN/m under standard term loading. Loading condition: Two directional load parallel to panel lap joint. Canadian S-P-F CLT side member and Canadian S-P-F CLT main member connection with SWG ASSY VG 8mm x 140mm @ 45° angle. Note: Fasteners shall not be installed into cracks, checks, or gaps.
Geometry	**t** = lap thickness 52.5mm **b** = lap width 80mm $\mathbf{h_{CLT}}$ = 105mm (3-Ply CLT planed by Structurlam) Min panel thickness 105mm —> 10d = 10* 8 = 80mm < 105mm
*Spacing, end and edge distance requirements in **CLT side and CLT main member** [2]*	Screw spacing parallel = 4* d = 32mm Screw spacing perpendicular = 2.5* d = 20mm Loaded end distance = 6* d = 48mm Unloaded edge distance = 2.5* d = 20mm
Effective thread embedment length	$\mathbf{L_{p,1}}$ = side member = (52.5mm/cos α) - 8mm = 66.25mm $\mathbf{L_{p,2}}$ = main member = 140mm - 74.25mm-8mm = 57.8mm Note: Effective thread embedment is reduced by 1*d where d = screw diameter screw in angle α = 45°
Withdrawal resistance [1]	$\mathbf{Pr'w_{side}}$ = 1.04kN* (66.25mm/20mm) = 3.45 [kN] $\mathbf{Pr'w_{main}}$ = 1.04kN* (57.8mm/20mm) = 3.0 [kN] main member controls design
Tensile resistance check screw [1]	15.12 kN > 3.0 kN
Design shear resistance per screw cross	 Required effective number of screw crosses 40kN / 4.24kN = 9.43 screw crosses Select 13 screw crosses to account for potential group factor —> $13^{0.9}$ = 10.05 —> **10.05 > 9.43**
Serviceability limit state connection stiffness estimate [5]	$K_{ser} = 780 * d^{0.2} * L_{p,i}^{0.4}$ = 5617 N/mm Estimated connection stiffness along shear plane per screw cross with screws at 45° = 2*5617*cos45°= 7943N/mm Estimated connection stiffness parallel to shear plane with 10.05 effective screw crosses = 10.05*7943kN/mm = 83.4kN/mm Note: only applicable to axially loaded SWG ASSY VG full thread screws
Connection specification	Use 13 screw crosses (13 SWG ASSY VG per meter @45° in each direction @50mm o.c. spacing between screws of opposite orientation min. 20mm

CLT panel to panel connection with SWG ASSY® screws @ 90°

Fmax = maximum recorded force during test, Displ. Fmax = recorded displacement at Fmax,

0.4 Fmax, 0.7 Fmax = recorded force at 40% of predicted ultimate capacity and respectively 70%

Displ. 0.4Fmax, 0.7 Fmax = recorded displacement at respective force level, Stiffness ultimate = calculated stiffness at Fmax

Stiffness 0.4 Fmax, 0.7 Fmax = calculate stiffness at respective load level, Design value = Capacity as per outlined design example procedure

Over-strength factor = Tested capacity/ design capacity

SS=Surface Spline, LJ=Lap Joint, BJ=Butt Joint, 3p = 3 pieces of panel, nR= n rows of screws per each side of shear planes (n=1 and 2),

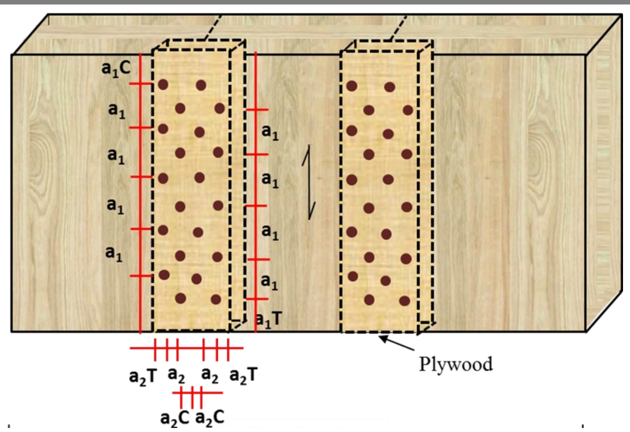
8S= Spacing of the screws is 8 times the diameter of the screw, 45= Angle between the screw axis and the CLT plane

Table 3: Proposed design values vs obtained test values—CLT panel to panel connections with three members

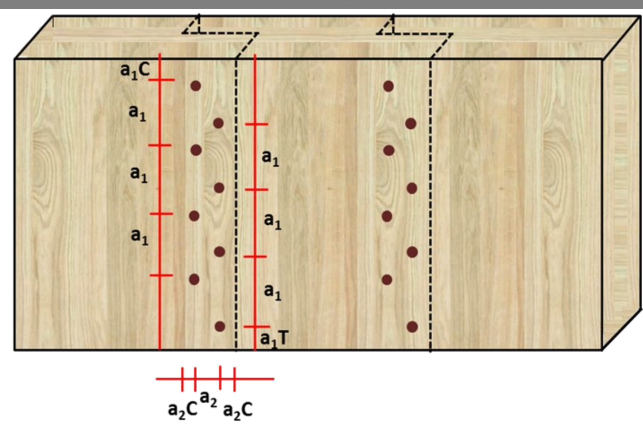
Design values vs Test values
Note: Values consider K_D = 1.15 for shorty term loading

Specimen 3-Ply CLT	# of screws	Fmax [kN]	Displ. Fmax [mm]	0.4 Fmax [kN]	Displ. 0.4 Fmax [mm]	0.7 Fmax [kN]	Displ. 0.7 Fmax [mm]	Stiffness ultimate [kN/ mm]	Stiffness 0.4 Fmax [kN/mm]	Stiffness 0.7 Fmax [kN/mm]	Design value [kN]	Over-strength	Predicted displace-ment[1] [mm]
SS_3p_3ply_1R_8S 3/4” plywood spline	10	20.35	34.2	8.14	3.3	14.25	9	0.6	2.47	1.58	≈7.75	2.63	**≈1.7**
SS_3p_3ply_2R_8S 3/4” plywood spline	20	34.10	22.3	13.64	3	23.87	8.7	1.53	4.55	2.74	≈15.49	2.20	**≈1.7**
SS_3p_5ply_1R_8S 1” plywood spline	10	30.80	47.7	12.32	6.4	21.56	18.6	0.65	1.93	1.16	≈9.79	3.15	**≈1.7**
SS_3p_5ply_2R_8S 1” plywood spline	20	45..95	33	18.32	4.8	32.17	12.2	1.39	3.83	2.64	≈19.57	2.35	**≈1.7**
LJ_3p_3ply_1R_8S	5	25.65	23.5	10.26	1.3	17.96	8.7	1.09	7.89	2.06	≈*2.78	9.22	≈2.1
LJ_3p_5ply_1R_8S	5	53.40	43.3	21.36	2.6	37.38	12.5	1.23	8.22	2.99	≈7.13	7.49	≈2.5
LJ_3p_3ply_2R_45	8	43.40	2.6	17.36	**0.03	30.38	**0.32	16.69	578.67	94.94	≈19.62	2.21	≈0.63
LJ_3p_5ply_2R_45	6	59.19	3	23.66	**0.11	41.41	**0.74	19.72	215.09	55.95	≈24.60	2.40	≈0.84
BJ_3p_3ply_2R_8S	4	47.40	1.8	18.96	**0.1	33.18	**0.2	26.33	189.60	165.90	-	-	-

Note: Results listed in this table are average measurements out of 6 tests. FT= **F**ull **T**hread screw
A load duration factor of K_D = 1.15 is considered
[1] Predicted displacement (estimate) based on CSA 086 section A.12.6.6.3 and the Design Value from table 3 above in kN
*J_{pl} factor of J_{pl} = 0.625 for reduced fastener penetration into main member heavily impacts design value
** Testing with 3 members indicated very small displacements during testing and must be verified with further analysis



CLT panel to panel surface spline joint



CLT panel to panel half lap joint

CLT panel to panel connection with SWG ASSY® screws @ 90° and 45°

Fmax = maximum recorded force during test, Displ. Fmax = recorded displacement at Fmax,

0.4 Fmax, 0.7 Fmax = recorded force at 40% of predicted ultimate capacity and respectively 70%

Displ. 0.4 Fmax, 0.7 Fmax = recorded displacement at respective force level, Stiffness ultimate = calculated stiffness at Fmax

Stiffness 0.4Fmax, 0.7Fmax = calculate stiffness at respective load level, Design value = Capacity as per outlined design example procedure

Over-strength factor = Tested capacity/ design capacity

SS=Surface Spline, LJ=Lap Joint, BJ=Butt Joint, 3p = 3 pieces of panel, nR= n rows of screws per each side of shear planes (n=1 and 2),

8S= Spacing of the screws is 8 times the diameter of the screw, 45= Angle between the screw axis and the CLT plane

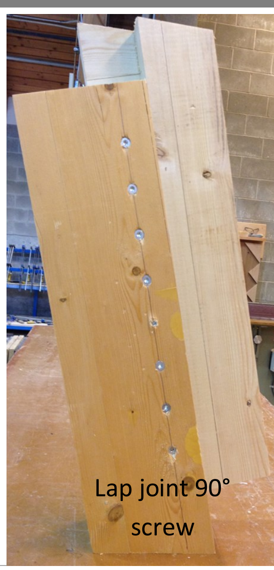
Table 4: Proposed design values vs obtained test values—CLT panel to panel connections with two members

Design values vs Test values
Note: Values consider K_D = 1.15 for shorty term loading

Specimen 3-Ply CLT	# of screws	Fmax [kN]	Displ. Fmax [mm]	0.4 Fmax [kN]	Displ. 0.4 Fmax [mm]	0.7 Fmax [kN]	Displ. 0.7 Fmax [mm]	Stiffness ultimate [kN/ mm]	Stiffness 0.4 Fmax [kN/mm]	Stiffness 0.7 Fmax [kN/mm]	Design value [kN]	Over-strength	Predicted displace-ment[1] [mm]
SS_2p_3ply_1R_90 3/4" plywood spline	16	50.46	47.60	20.18	5.00	35.32	11.50	1.06	4.04	3.07	≈12.39	4.07	≈1.73
SS_2p_5ply_1R_90 1" plywood spline	16	84.50	56.30	33.80	6.33	59.15	24.50	1.50	5.34	2.41	≈15.66	5.40	≈1.75
LJ_2p_3ply_1R_90	8	54.12	26.50	21.65	4.17	37.88	12.25	2.04	5.19	3.09	≈*4.92	11.01	≈2.45
LJ_2p_5ply_1R_90	8	85.59	54.70	34.23	4.67	59.91	13.83	1.56	7.33	4.33	≈12.00	7.13	≈2.62
LJ_2p_3ply_1R_45	12	84.71	5.40	33.88	0.40	59.30	1.07	15.69	84.71	55.42	≈24.46	3.46	≈0.58
LJ_2p_5ply_1R_45	10	126.56	4.40	50.62	0.80	88.59	1.87	28.76	63.28	47.38	≈31.77	3.98	≈0.74
LJ_2p_3ply_1R_45-90	8	52.21	19.50	20.89	**0.52	36.55	1.63	2.68	40.17	22.42	≈9.10	5.74	≈0.58
LJ_2p_5ply_1R_45-90	8	71.84	3.00	28.73	**0.38	50.29	0.82	23.95	75.62	61.32	≈13.93	5.16	≈0.74
BJ_2p_3ply_1R_33/45	8	62.77	5.80	25.11	**0.62	43.94	1.67	10.82	40.50	26.31	-	-	-

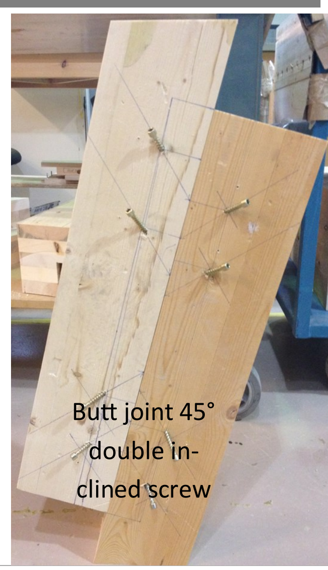
Note: Results listed in this table are average measurements out of 6 tests. FT= **F**ull **T**hread screw
A load duration factor of K_D = 1.15 is considered.
[1] Predicted displacement (estimate) based on CSA 086 section A.12.6.6.3 and the Design Value from table 4 above
*J_{pl} factor of J_{pl} = 0.625 for reduced fastener penetration into main member heavily impacts design value
** Testing with 3 members indicated very small displacements during testing and must be verified with further analysis

Spline joint



Lap joint 90° screw

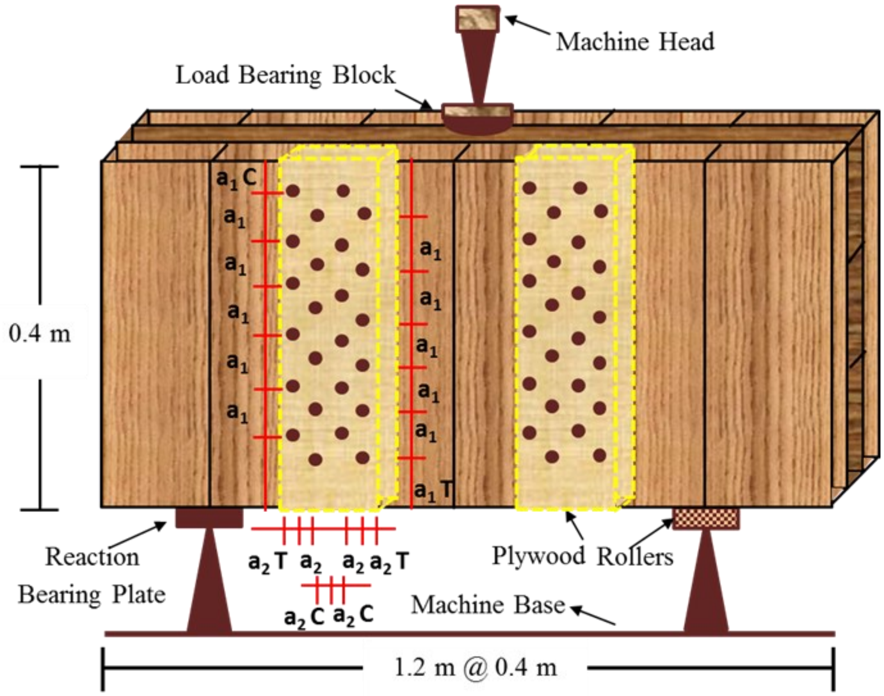
Lap joint 45° screw



Butt joint 45° double in-clined screw

Appendix A

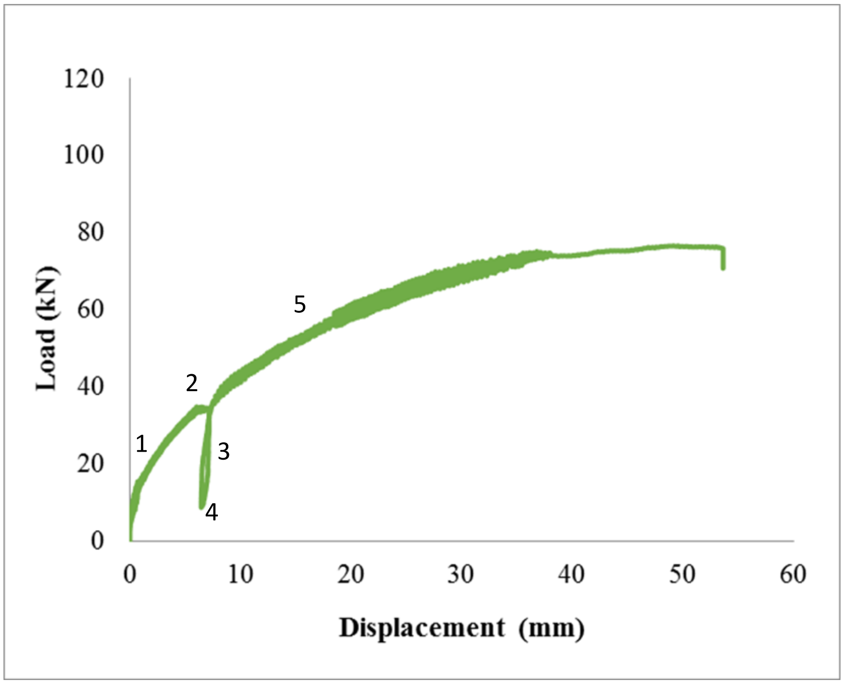
Loading procedure connection testing with 3 CLT members



- Loading under displacement control
- Failure is assumed after the load dropped below 80% of the maximum load recorded in respective specimen
- Data on actuator load and displacement of CLT center piece was recorded

Appendix B

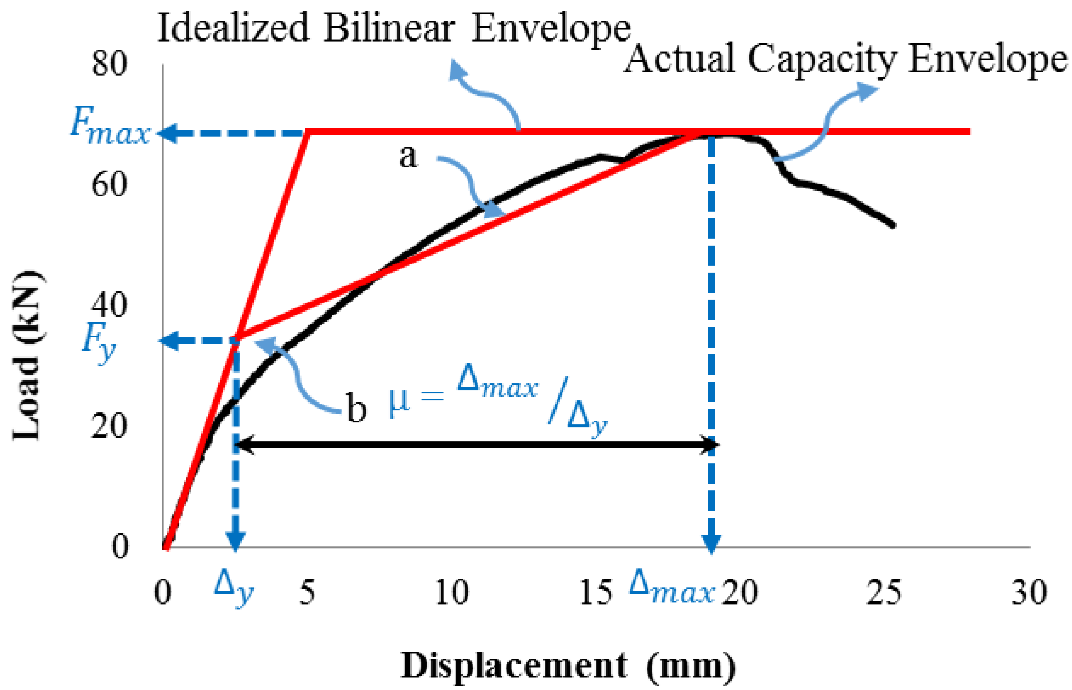
Loading procedure connection testing with 2 CLT members



1. Loading up to 40% of expected peak load
2. Holding load for 30 seconds
3. Unloading down to 10% of expected peak load
4. Holding load for 30 seconds
5. Loading of connection until failure occurs. Failure is assumed after load dropped below 80% of the maximum recorded load in respective specimen

Appendix C

Assumptions for ductility estimate according to FEMA 356 (2000)



Appendix D

Typical average load displacement curves out of 6 tests with 3 CLT members

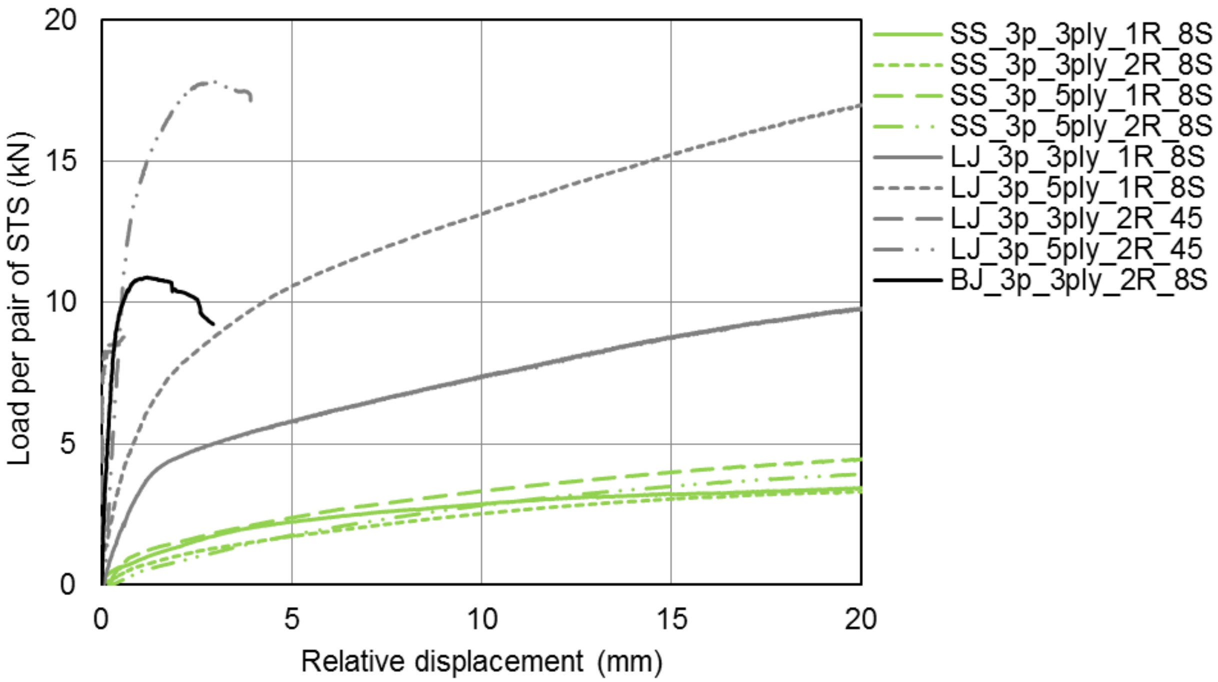


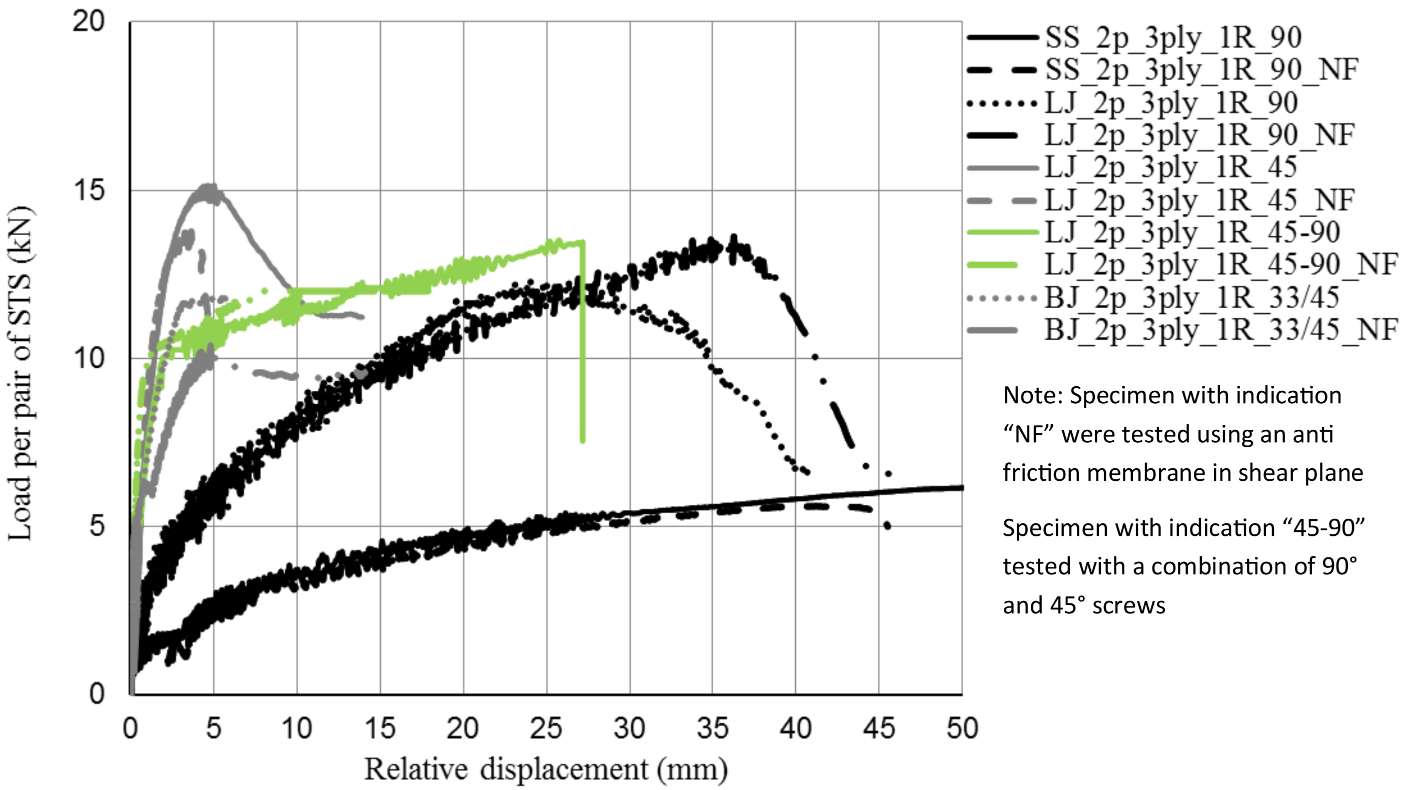
Table 5: Preliminary *test results for 3-Ply CLT and 5-Ply CLT connections consisting out of 3 members*

Series	F_{max} [1] (kN)	F @ 5mm displ.[1] (kN)	Yield load F_Y [1] (kN)	Displ. @ F_{max} [2] (mm)	Displ. @ yield Δ_y (mm)	Ductility μ (-)
SS_3p_3ply_1R_8S	4.1	2.7	2.7	34.2	4.9	7.0
SS_3p_3ply_2R_8S	3.4	2.9	2.0	22.3	3.7	6.1
LJ_3p_3ply_1R_8S	10.3	6.1	6.4	23.5	5.1	5.5
LJ_3p_3ply_2R_45	10.8	-	8.8	2.6	0.8	4.2
BJ_3p_3ply_2R_8S	11.9	-	10.6	1.8	0.4	4.9
SS_3p_5ply_1R_8S	6.2	2.7	3.6	47.7	8.6	5.7
SS_3p_5ply_1R_8S	4.6	1.7	2.8	33.0	7.0	4.9
LJ_3p_5ply_1R_8S	21.4	10.5	14.3	43.3	8.3	5.4
LJ_3p_5ply_2R_45	19.7	-	17	3.0	1.5	2.5

Note: [1] calculated forces per one pair of screws, [2] Connection deformation at ultimate load

Appendix E

Typical average load displacement curves out of 6 tests with 2 member 3-Ply CLT



Note: Specimen with indication "NF" were tested using an anti friction membrane in shear plane

Specimen with indication "45-90" tested with a combination of 90° and 45° screws

Table 6: Preliminary test results for 3-Ply CLT connections consisting out of 2 members

Series	F_{max} [1] (kN)	F @ 5mm displ. [1] (kN)	Yield load F_Y [1] (kN)	Displ. @ F_{max} [2] (mm)	Displ. @ yield Δ_y (mm)	Ductility μ (-)
SS_2p_3ply_1R_90	6.3	2.5	4.5	47.6	12.1	4.0
SS_2p_3ply_1R_90_NF	6.2	2.5	4.3	54.0	11.7	4.7
LJ_2p_3ply_1R_90	13.5	5.8	8.7	26.5	9.8	2.7
LJ_2p_3ply_1R_90_NF	13.6	6.0	8.3	30.5	8.5	3.6
LJ_2p_3ply_1R_45	14.1	11.2	12.0	5.4	1.5	3.5
LJ_2p_3ply_1R_45_NF	14	11	10.8	5.7	1.8	3.0
LJ_2p_3ply_1R_45-90	13.1	11.3	11.0	19.5	2.4	8.1
LJ_2p_3ply_1R_45-90_NF	13.0	11.2	10.5	7.8	2.0	4.3
BJ_2p_3ply_1R_33/45	15.7	14.0	11.5	5.8	2.0	2.9
BJ_2p_3ply_1R_33/45_NF	14.2	12.5	12.0	6.3	3.1	2.1

Note: [1] calculated forces per one pair of screws, [2] Connection deformation at ultimate load

Appendix F

Typical average load displacement curves out of 6 tests with 2 member 5-Ply CLT

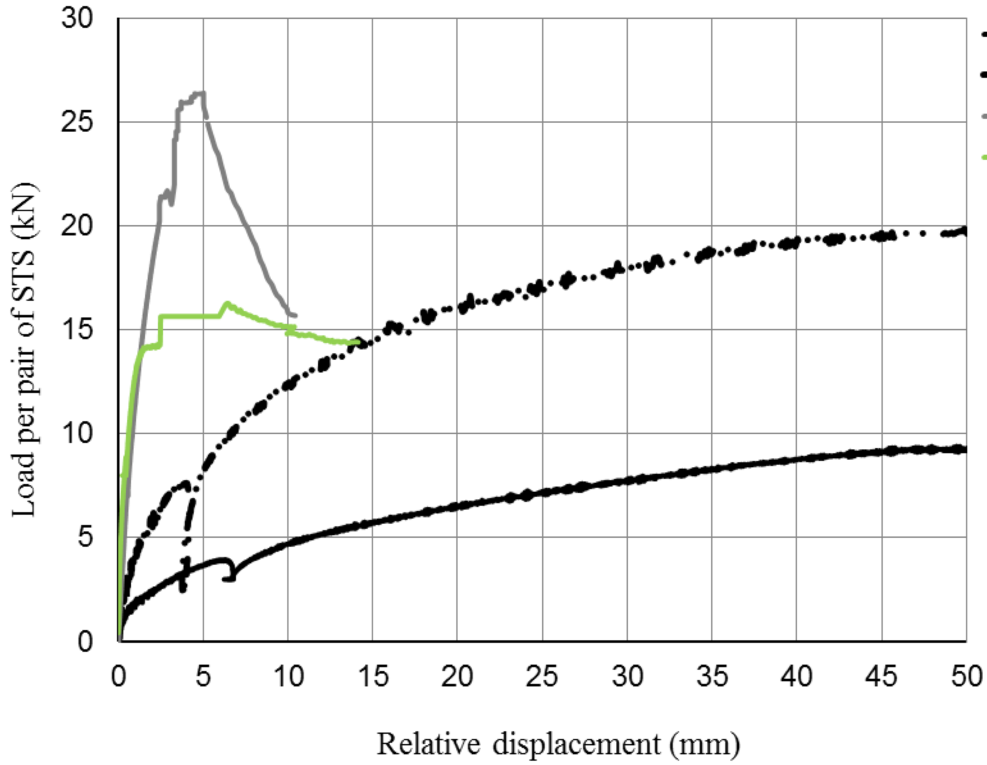


Table 7: Preliminary *test results for 5-Ply CLT connections consisting out of 2 members*

Series	F_{max} [1] (kN)	F @ 5mm displ.[1] (kN)	Yield load F_Y (kN)	Displ. @ F_{max} [2] (mm)	Displ. @ yield Δ_y (mm)	Ductility μ (-)
SS_2p_5ply_1R_90	10.6	3.6	7	56.3	12.0	4.3
LJ_2p_5ply_1R_90	21.4	8.4	14.8	54.7	11.8	4.7
LJ_2p_5ply_1R_45	25.3	23	19.2	4.4	1.8	2.6
LJ_2p_5ply_1R_45-90	18	16.6	15.4	3.0	2.5	2.5

Note: [1] calculated forces per one pair of screws, [2] Connection deformation at ultimate load

Appendix G

Typical average ultimate load displacement curves out of 6 tests with 3 CLT members

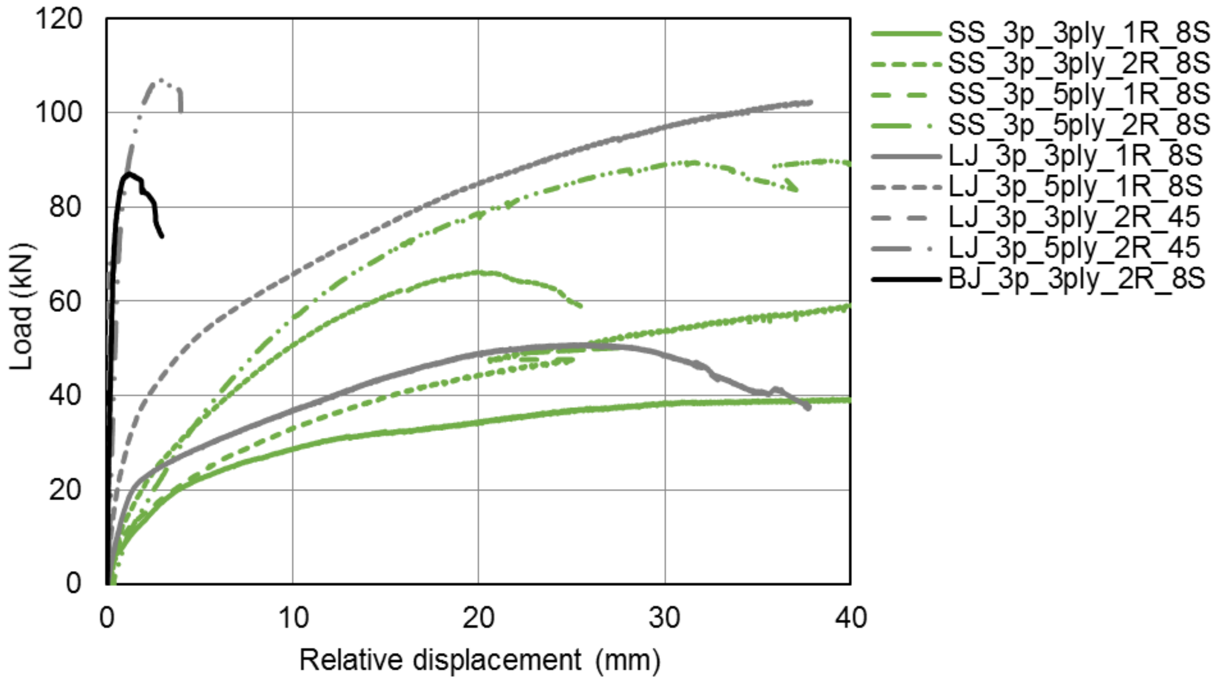


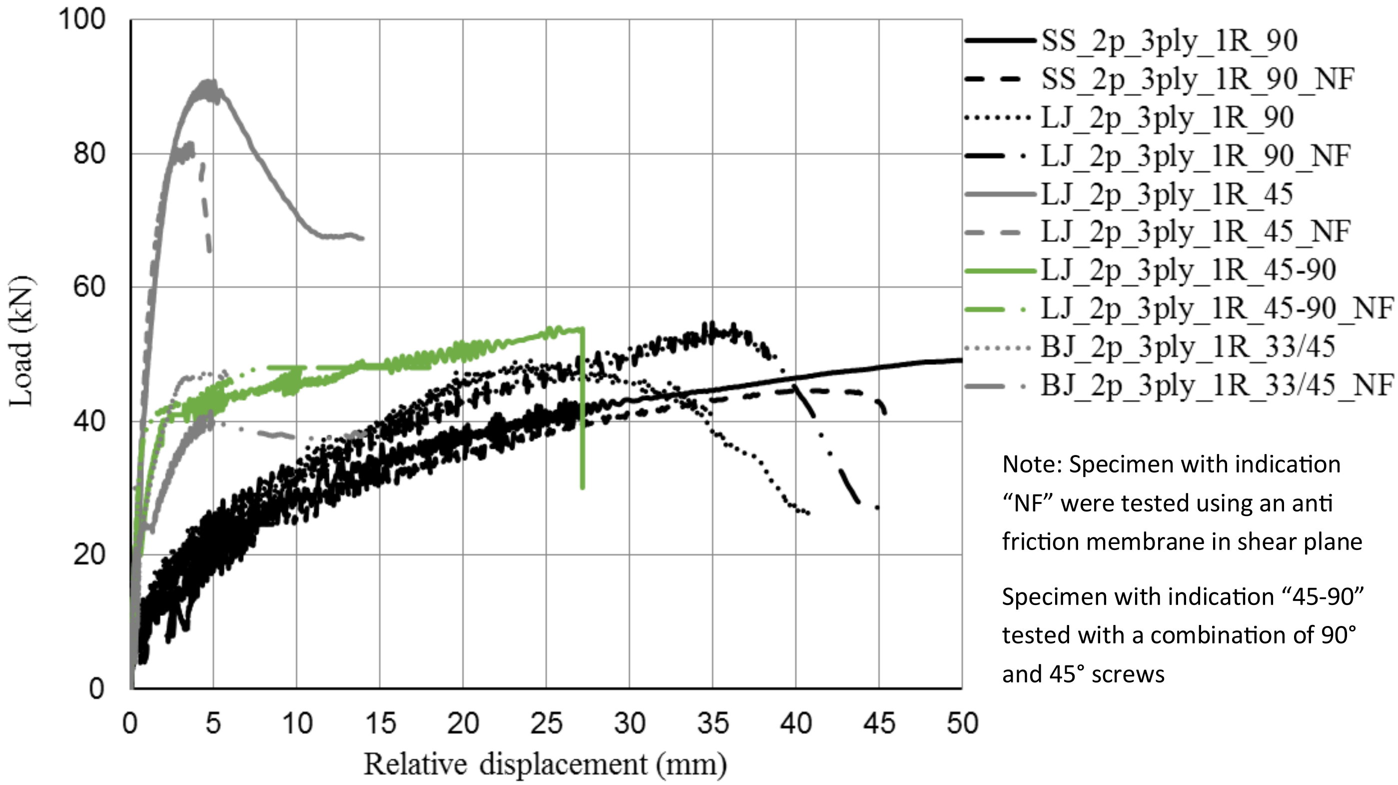
Table 8: Preliminary test results for 3-Ply CLT and 5-Ply CLT connections consisting out of 3 members

Series	F_{max} [1] (kN)	F @ 5mm displ.[1] (kN)	Yield load F_Y [1] (kN)	Displ. @ F_{max} [2] (mm)	Displ. @ yield Δ_y (mm)	Ductility μ (-)
SS_3p_3ply_1R_8S	40.7	22.8	27.2	34.2	4.9	7.0
SS_3p_3ply_2R_8S	68.2	34.7	40.0	22.3	3.7	6.1
LJ_3p_3ply_1R_8S	51.3	30.3	32.0	23.5	5.1	5.5
LJ_3p_3ply_2R_45	86.8	-	70.7	2.6	0.8	4.2
BJ_3p_3ply_2R_8S	94.8	-	85.0	1.8	0.4	4.9
SS_3p_5ply_1R_8S	61.6	26.7	35.7	47.7	8.6	5.7
SS_3p_5ply_1R_8S	91.9	34.7	56.7	33.0	7.0	4.9
LJ_3p_5ply_1R_8S	106.8	52.7	71.7	43.3	8.3	5.4
LJ_3p_5ply_2R_45	118.3	-	102.0	3.0	1.5	2.5

Note: [1] calculated forces per one pair of screws, [2] Connection deformation at ultimate load

Appendix H

Typical average ultimate load displacement curves out of 6 tests with 2 member 3-Ply



Note: Specimen with indication "NF" were tested using an anti friction membrane in shear plane

Specimen with indication "45-90" tested with a combination of 90° and 45° screws

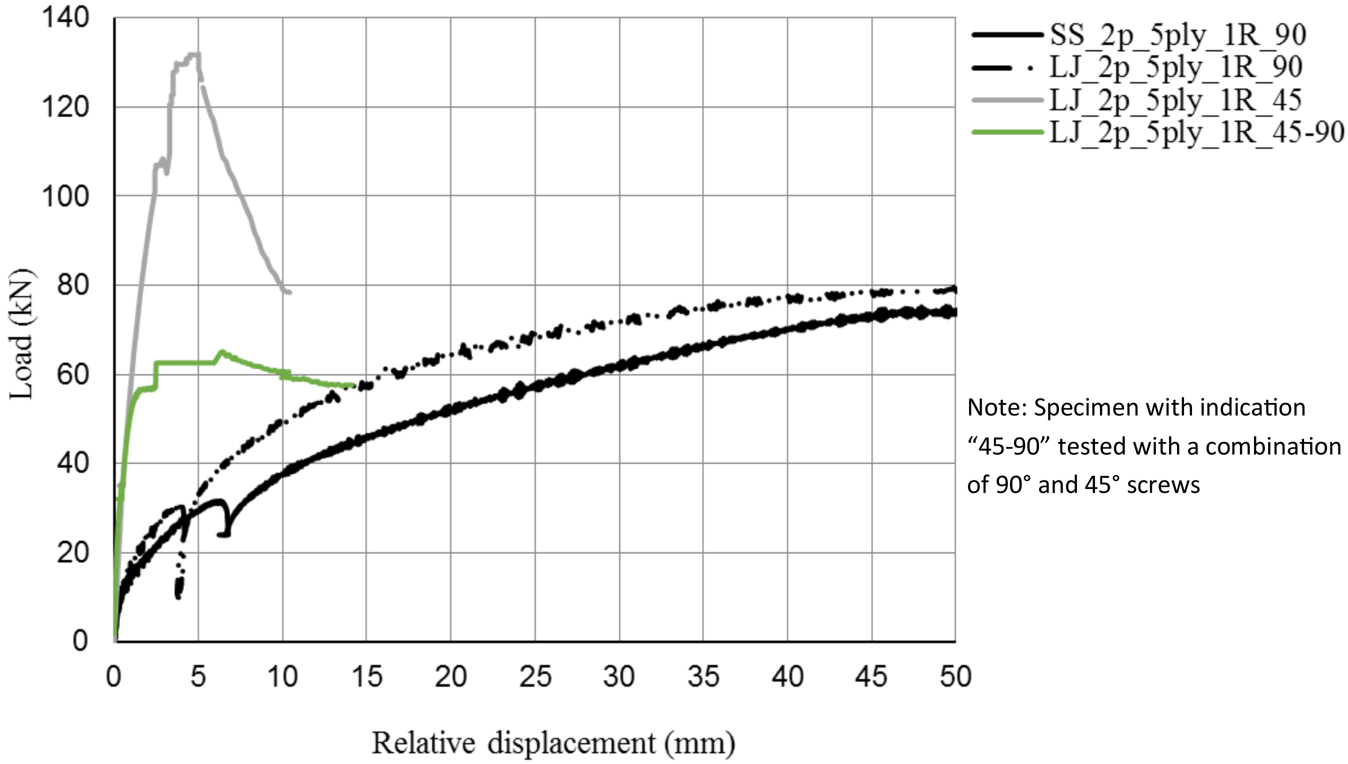
Table 9: Preliminary test results for 3-Ply CLT connections consisting out of 2 members

Series	F_{max} [1] (kN)	F @ 5mm displ.[1] (kN)	Yield load F_Y [1] (kN)	Displ. @ F_{max} [2] (mm)	Displ. @ yield Δ_y (mm)	Ductility μ (-)
SS_2p_3ply_1R_90	50.5	20.2	36.0	47.6	12.1	4.0
SS_2p_3ply_1R_90_NF	49.8	19.7	34.3	54.0	11.7	4.7
LJ_2p_3ply_1R_90	54.1	23.3	34.7	26.5	9.8	2.7
LJ_2p_3ply_1R_90_NF	54.5	24.0	33.0	30.5	8.5	3.6
LJ_2p_3ply_1R_45	84.7	67.0	72.0	5.4	1.5	3.5
LJ_2p_3ply_1R_45_NF	84.2	66.0	65.0	5.7	1.8	3.0
LJ_2p_3ply_1R_45-90	52.2	45.3	44.0	19.5	2.4	8.1
LJ_2p_3ply_1R_45-90_NF	52.1	44.7	42.0	7.8	2.0	4.3
BJ_2p_3ply_1R_33/45	60.2	56.0	46.0	5.8	2.0	2.9
BJ_2p_3ply_1R_33/45_NF	56.9	50.0	48.0	6.3	3.1	2.1

Note: [1] calculated forces per one pair of screws, [2] Connection deformation at ultimate load

Appendix I

Typical average ultimate load displacement curves out of 6 tests with 3 member 5-Ply



Note: Specimen with indication "45-90" tested with a combination of 90° and 45° screws

Table 10: Preliminary *test results for 5-Ply CLT connections consisting out of 2 members*

Series	F_{max} [1] (kN)	F @ 5mm displ. [1] (kN)	Yield load F_Y (kN)	Displ. @ F_{max} [2] (mm)	Displ. @ yield Δ_y (mm)	Ductility μ (-)
SS_2p_5ply_1R_90	84.5	28.5	56.0	56.3	12.0	4.3
LJ_2p_5ply_1R_90	85.6	33.7	59.0	54.7	11.8	4.7
LJ_2p_5ply_1R_45	126.6	115.2	95.8	4.4	1.8	2.6
LJ_2p_5ply_1R_45-90	71.8	66.3	61.7	3.0	2.5	2.5

Note: [1] calculated forces per one pair of screws, [2] Connection deformation at ultimate load

Design tables for SWG ASSY® VG screws

Table 11: Assumed *factored withdrawal resistance of SWG ASSY® VG screws in kN per 20 mm of thread penetration*

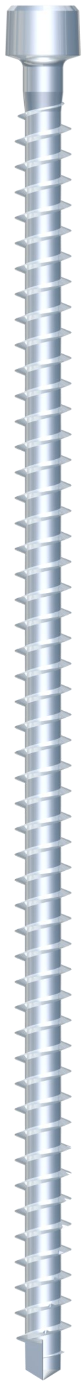
Factored withdrawal resistance * $P'_{rw,\alpha}$ per 20 mm of thread penetration in kN (only applicable to SWG ASSY® VG screws)							
Screw diameter in mm	**Mean oven dry relative density**						**Factored tensile resistance in kN**
	0.35	**0.42**	**0.44**	**0.46**	**0.49**	**0.50 (PSL)**	
	α ** = 90°						
6	0.63	0.91	0.97	1.06	1.20	0.70	**9.04**
8	0.85	1.22	1.29	1.41	1.60	0.94	**15.12**
10	1.06	1.52	1.61	1.76	2.00	1.17	**19.2**
12	1.27	1.83	1.94	2.12	2.40	1.41	**24**
	α ** = 45°						
6	0.54	0.78	0.83	0.91	1.03	0.60	**9.04**
8	0.73	1.04	1.11	1.21	1.37	0.80	**15.12**
10	0.91	1.31	1.38	1.51	1.71	1.00	**19.2**
12	1.09	1.57	1.66	1.81	2.06	1.21	**24**
α ** = 30°							
6	0.51	0.73	0.77	0.85	0.96	0.56	**9.04**
8	0.68	0.98	1.03	1.13	1.28	0.75	**15.12**
10	0.85	1.22	1.29	1.41	1.60	0.94	**19.2**
12	1.02	1.46	1.55	1.69	1.92	1.12	**24**

Note: * assumed resistance as per [1]
** α: angle between wood grain and screw axis

SWG ASSY® VG Cyl. (full thread)

Table 12: SWG ASSY® VG Cyl screw specifications

Major Ø	Length	Thread Length	L_t	Head Ø	Minor Ø	Bit
mm						
6	**70**	63	6	8	3.8	AW 30
	80	73				
	100	93				
	120	113				
	140	133				
	160	153				
	180	173				
	200	193				
8	**160 to 300 in 20 mm increments**	144 to 284 in 20 mm increments	8	10	5	AW 40
	330	314				
	360	344				
	380	364				
	430	414				
	480	464				
	530	514				
	580	564				
10	**140 to 280 in 20 mm increments**	125 to 265 in 20 mm increments	10	13.4	6.2	AW 50
	300	280				
	320 to 400 in 20 mm increments	305 to 380 in 20 mm increments				
	430	415				
	480	456				
	530	506				
	580	556				
	and longer	and longer				



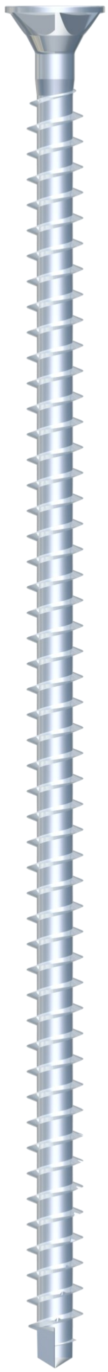
Note: values listed in the table above are average measurements between upper and lower tolerance boundary

SWG ASSY® VG CSK (full thread)

Table 13: SWG ASSY® VG CSK screw specifications

Major Ø	Length	Thread Length	L_t	Head Ø	Minor Ø	Bit
mm						
8	**120**	103	8	14.8	5	AW 40
	140	123				
	160	143				
	180	163				
	200	183				
	220	203				
	240	223				
	260	243				
	280	263				
	300	283				
10	**140 to 400 in 20 mm increments**	125 to 385 in 20 mm increments	10	19.6	6.2	AW 50
	430	415				
	480	465				
	530	512				
	580	562				
	650 to 800 in 50 mm increments	632 to 782 in 50 mm increments				
12	**220**	205	12	22.1	7.1	AW 50
	380	365				
	480	465				
	600	585				

Note: values listed in the table above are average measurements between upper and lower tolerance boundary



References

[1] CCMC report 'CCMC 13677-R'

[2] CLT Connection Design Guide CSA by MyTiCon Timber Connectors Inc.

[3] Eurocode 5—DIN EN 1995-1-1:2010-12: *8.7.2(8) Axially loaded screws*

[4] FPI CLT Design Workshop handout Toronto Canada

[5] European Technical Approval ETA-11/0190

[6] CSA 086 2015 section A.12.6.6.3

[7] FEMA 356. (2000). *Prestandard and commentary for the seismic rehabilitation of buildings*. Federal Emergency Management Agency, Washington, D.C.

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