Mechanical behaviour of in-plane shear connections between CLT wall panels

Tom Joyce[1], Marco Ballerini[2], Ian Smith[1]

[1] University of New Brunswick, Fredericton, Canada
[2] University of Trento, Trento, Italy

1 Introduction

The use of timber in building construction has recently increased due to the development of a new timber panel product known as cross laminated timber (CLT, or X-lam). The high strength and stiffness properties of this new material mean that it can be used in many different situations, including for floors and walls, and this allows for the realization of timber buildings of solid construction. Other benefits, such as the potential for rapid and low cost construction, are generating interest for this material in areas with a tradition for light-frame timber construction and are spreading the use of wood to areas that customarily prefer massive building construction (for instance, southern European countries).

CLT panels have very high in-plane stiffness and as such remain elastic when in service. In order to dissipate energy the connections must be designed to achieve a high degree of ductility. In platform construction with massive CLT plate elements this ductility can be obtained only in connections between CLT panels, for instance in wall-to-wall connections and hold-downs [1]. In structures that make use of CLT for rigid building cores or shear walls the ductility can be achieved in the connections between the elements of the gravity load-resisting frame.

In order to better understand the performance of wall-to-wall connections a study was initiated to investigate the static and dynamic properties of common connections. The study is divided into two parts: first an experimental program is investigating the behaviour of connections subjected to tensile and in-plane shear forces; and second, numerical models will be used to find the forces acting on wall-to-wall connections.

2 Test program and procedures

Two connections were investigated, double spline and angled screws (Fig. 1), and two fastener variations each were considered (Table 1). The monotonic tests were carried out with displacement controlled ramping at a loading rate of 0.05 mm/s. Specimens were tested until a load equal to 50% of the peak load was reached on the post-peak branch of the load-slip curve and five repetitions were made for each connection. Two cyclic tests were conducted for each connection using a non-reversed modification of the procedure outlined in EN12512 [2]. Displacement at yielding was calculated with the same standard on the basis of the results of the monotonic tests.

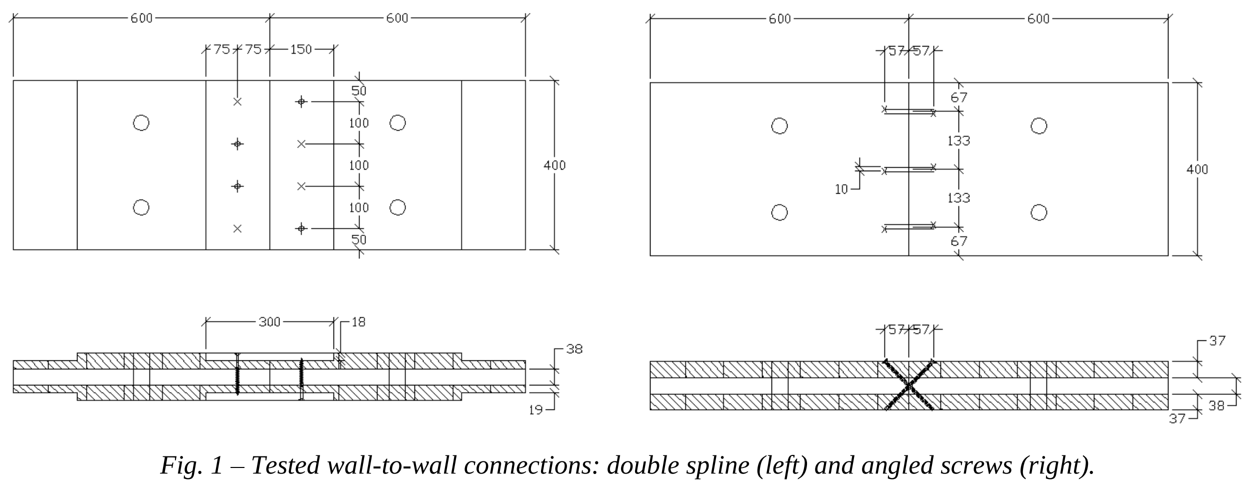


Fig. 1 – Tested wall-to-wall connections: double spline (left) and angled screws (right).

Table 1 – Details of tested wall-to-wall connections.

Connection	Series Name	Diameter and Length	Threaded Length	Fastener Spacing
Double	J1 T 08	08x100	60	100
Spline	J1 T 10	10x100	60	100
Angled	J2 T PT 08	08x160	80	133
Screws	J2 T FT 08	08x160	150	133

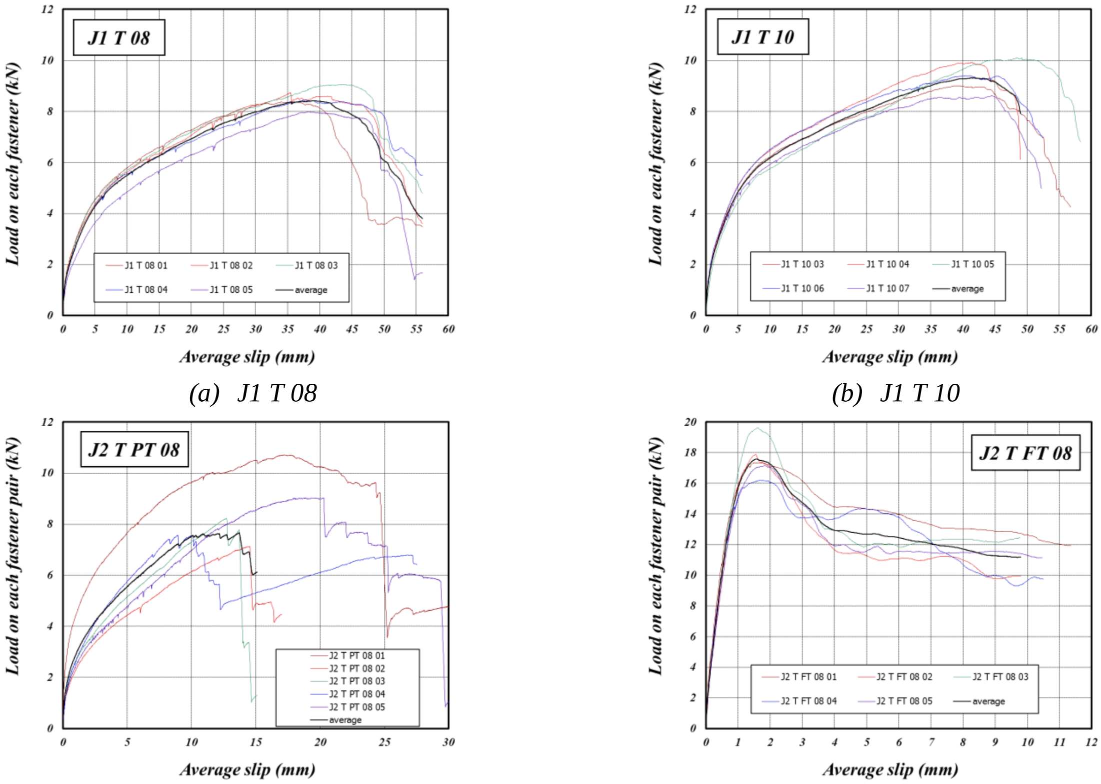
The CLT used was 3-layer pre-commercial Nordic X-Lam with a thickness of 112mm. The average density was 461 kg/m^{3}at a moisture content of 10.2%.For the double spline connections the boundaries of the panels were notched to enclose 18mm thick Douglas Fir plywood splines. Tests were conducted using a 250kN MTS universal machine operated by an external MTS controller and with an automatic data acquisition system. Two LVDTs were used on the sides of the specimens to measure the displacement of the ends of the connections.

3 Results

The main results of the monotonic tests are shown in Fig. 2 and summarized in Table 2. The peak measured load has been divided by the number of shear planes for the double spline connections (4 planes) and by the number of fastener pairs for the angled screws (3 pairs). The data shows a low degree of scatter for all of the connections except the partially threaded angled screws (J2 T PT 08).

In the angled screws connection the fasteners are partially loaded axially. This results in a stiffer connection performance, with average elastic stiffness values (as per [3]) of 6830 and 68000kN/mm for the partially and fully threaded screw connections as compared with 4490 and 5020kN/mm for the 8 and 10 mm diameter double spline connections, respectively.

The failure of the double spline connections was found to be due to the formation of a plastic hinge in the CLT element (EYM failure mode IIa [4]). The failures occurred concurrently with pull-through of the screw head through the plywood. For the angled screw the failure was found to be due to splitting of the outer lamination of the CLT due to the forces acting perpendicular to the grain generated by the penetration of the screw head. For all cases the failure occurred on the head-side of the CLT elements. This effect was reduced



(a) J1 T 08 *(b) J1 T 10*

(c) J2 T PT 08 *(d) J2 T FT 08*

Fig. 2 –Load-slip response of monotonic tensile tests and computed average curves.

when fully threaded screws were used, as the threading through the head-side CLT element provided additional embedment resistance through mechanical adhesion. Sometimes a partial withdrawal of the point-side of the screws with considerable bending was observed.

Table 2 – Summary of monotonic test results.

Series	Stiffness			Peak Capacity		Allowable Capacity		Yielding		Ductility Ratio
	K_I	K_{II}	K_{III}	F_{max}	Δ_{max}	P_{allow}	Δ_{allow}	P_y	Δ_y	
	N/mm	N/mm	N/mm	kN	mm	kN	mm	kN	mm	
J1 T 08	3.93	0.67	0.14	8.42	39.05	7.97*	30.0*	4.29	3.66	8.2
J1 T 10	5.16	0.64	0.12	9.31	41.35	8.58*	30.0*	4.80	3.56	8.4
J2 T PT 08	14.38	0.83	0.44	7.63	12.06	7.63	12.06	4.02	1.51	9.9
J2 T FT 08	103.5	48.5	15.8	17.58	1.57	17.58	1.57	14.66	0.65	5.2

Two cyclic tests have been performed for the double spline connection for each screw diameter and the recorded load-slip curves are reported in Fig. 3 together with the average response of the monotonic tests. The results show strong agreement with the monotonic tests and a clear pinching effect at high displacements. The equivalent viscous damping for large displacements was found to be similar for both screw diameters considered, with ratios of 20% and 10% for the first and second cycles, respectively. At displacements nearer to yielding the equivalent viscous damping of the 8mm screws was found to be greater, with ratios of 21% and 15% for the first two cycles, compared to that of the 10mm screws, where values of 19% and 11% were found.

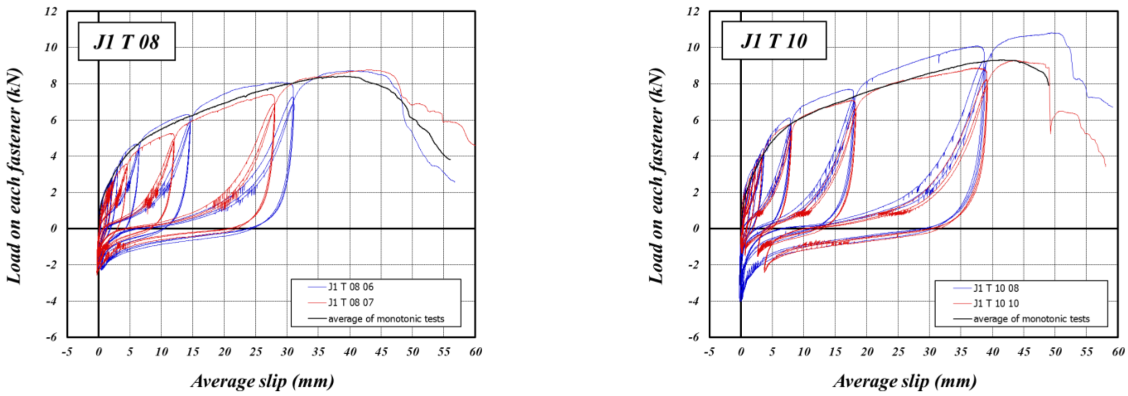


Fig. 3 –Load-slip response of cyclic tensile tests for specimens J1 T 08 (left) and J1 T 10 (right) with the corresponding backbone curves.

4 Conclusions

The main preliminary results of an on-going research on the structural behaviour of wall-to-wall connections in CLT construction have been presented. The tensile tests that have been performed up to now show good behaviour of the double spline connections and poorer behaviour of connections with angled screws. The ductility of the double spline connections was found to be high; however in situations where the elastic stiffness is importance the fully threaded angled screws option provides a significantly higher stiffness than any of the other options investigated.

References

[1] Sandhaas, C.; Boukes, J.; van de Kuilen, J. W. G.; Ceccotti, A.: *Analysis of X-lam Panel-to-Panel Connections Under Monotonic and Cyclic Loading*. Paper 42-12-2, CIB W18 Meeting 42, Dübendorf. Switzerland, 2009.

[2] EN 12512: 2001, *Timber structures – Test methods – Cyclic testing of joints made with mechanical fasteners*, CEN, 2001, Brussels, Belgium.

[3] EN 26891: 1991, *Timber structures – Joints made with mechanical fasteners – General principles for the determination of strength and deformation characteristics*, CEN, 1991, Brussels, Belgium.

[4] UNI EN 1995 1-1: 2009, *Eurocode 5: Design of timber structures – Part 1-1: General – Common rules and rules for buildings*. CEN, 2009, Brussels, Belgium.