

# EDGE CONNECTIONS FOR CLT PLATES: IN-PLANE SHEAR TESTS ON HALF-LAPPED AND SINGLE-SPLINE JOINTS

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**ABSTRACT:** A crucial aspect of fully realising the potential of cross-laminated-timber (CLT) as a structural material is ability to interconnect it to similar and dissimilar materials. This paper primarily reports in-plane shear tests on half-lapped and single-spline joints that make edge-to-edge connections between CLT panels using screws. A novel aspect of the study is investigation of how placing washers under screw heads alters stiffness and strengths of joints. Subsidiary axial load tests on screws assisted explanation of the shear joint results. Conclusions include the importance of accounting for large displacement effects on how screws transfer forces across joint-planes, and need to improve current generation joint design methods so that they account for effects of eccentricities that result from construction arrangement and detailing decision.

**KEYWORDS:** Connections, Cross-Laminated-Timber, Lateral load, Self-Tapping Screws, Shear, Washers, Withdrawal

## 1 INTRODUCTION

CLT products have particular characteristics that need to be considered when addressing design and construction of joints in them. As the name implies, CLT has pieces of lumber placed in layers that cross-reinforce one another, with adjacent layer faces bonded using mechanical fasteners or adhesives. This overcomes what has proven to be the primary weakness of most other types of EWP, and that has limited their usage as general purpose structural materials. To activate toughening against splitting caused by laterally loaded fasteners, it necessary that fasteners penetrate sufficiently deeply into CLT to be anchored into at least lamination that cross-reinforces a face lamination. Proprietary self-tapping screws are a common choice of fastener because they are available in suitably large lengths and their threads cause them to anchor properly in CLT. Preferences also commonly favour use of relatively small diameter self-tapping screws (~ 10mm) because that mitigates proneness to intra-lamination splitting when lateral forces on screws makes them embed into CLT.

The lateral load resistance of dowel-type fasteners (nails, screws, plain dowels, bolts, etc.) is widely taken to be adequately explained by the European Yield Model (EYM). Various timber design codes use the EYM to predict the yield load ( $P_y$ ) as the basis of design strengths of joints, while others supplement those capacities with an allowance for rope effect resistance which develops at high

deformation of joints. When the rope effect is included the estimated strength approximates the maximum load ( $P_m$ ).

This paper discusses and interprets tests on half-lapped and single-spline CLT connections made using self-tapping screws. Specimens were subjected to in-plane shear forces that simulated force flows that would occur in edge-to-edge CLT plate connections within CLT slabs that perform diaphragm or shear wall functions. Supplementary screw withdrawal and pull through tests were carried out to facilitate explanation of the shear force test results.

## 2 METHOD

Shear force test specimens were designed to simulate antisymmetric lapped joints and non-symmetric single-spline joints as occur in connections in CLT slabs. As shown in Figure 1 the panel element on the left side of a specimen was pushed down relative to the piece on the right side, with the apparatus constraining other distortions. The CLT used was 180mm thick Nordic X-Lam manufactured in Canada, having five equal thickness laminations and an average density of 513kg/m<sup>3</sup>. The self-tapping screws used had nominal shank diameters of 6mm, were 160mm long and thread to 70mm from the tip. The splice elements in single-spline tests were 19mm thick Douglas fir plywood. For each type of joint two fasteners situations were considered, with those being use of only self-tapping screws and use of self-tapping screws with washers placed under their heads. Washers used were flat shaped steel with a thickness of 3mm, and having outer and inner diameters of 19mm and 7mm respectively.

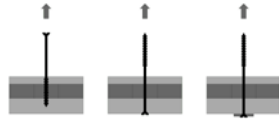
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Figure 2 shows axial load tests carried out with intent that they represent behaviours of self-tapping screws subjected to longitudinal shearing surface forces similar to those developed due to initial eccentricities or large deformations in joints/connections.



**Figure 1:** Shear test apparatus

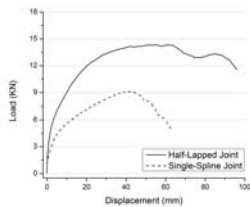


**Figure 2:** Axial test configurations

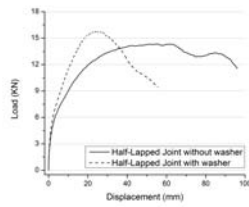
### 3 PRIMARY RESULTS

Test data were analysed to determine engineering parameters that quantify the stiffness, strength, ductility, and energy absorption characteristics of joints or screws.

Figure 3 shows average load versus deformation responses of half-lapped and single-spline joints without washers inserted under screw heads. In rough terms, half-lapped CLT plate edge-to-edge joints were 50% superior to single-spline joints subjected to shear flows. This is attributed to combined effects of using relatively thin plywood as the head-side member and eccentricities that complicate force flows in single-spline joints.



**Figure 3:** Average load-displacement curves for shear tests: half-lapped and single-spline joints without washers



**Figure 4:** Effect of washers on average load-displacement responses of half-lapped joints

Examination of plastically deformed screws from failed joint specimens revealed that half-lapped and single-spline joints failed by type IV and type III mechanisms respectively when there were no washers. This agreed with the EYM theory, but does not mean that that type of design level model accurately predicts observed joint capacities. Comparisons of Eurocode 5 EYM equation predictions with test results indicated substantial discrepancies exist in predictions of either  $P_y$  or  $P_m$ .

Figure 4 compares average load-displacement responses for half-lapped joints with and without washers placed under the heads of screws. Addition of washers had only slight effect on initial stiffness of a joint, increased strength, and decreases the post-yield point ductility. However adding washers did not create a non-ductile response. Inclusion of washers changed the deformation and failure mechanisms after the response exceeded the small

deformation regime. Figure 5 shows examples of residual deformations in lapped-joint specimens with and without washers placed under screw heads. In both instances the failure mechanism involved plastic bending deformation of the screw on either side of the joint plane. The greatest bending distortion occurred in either instance on the side of the joint where the screws were most effectively anchored into the CLT. When there were no washers the anchoring was most effective on the point-side of the joint, and therefore development of axial forces in screws was controlled by pull-through resistance of the head-side portions of screws. By contrast, when there were washers the screws were anchored most effectively on the head-side of the joint, with development of axial forces in screws controlled by withdrawal resistance of threaded portions of screws. This is entirely consistent with results of axial load tests on screws.



a) without washers      b) with washers

**Figure 5:** Residual deformations in half-lapped joints

Adding washers also significantly altered the responses of single-spline joints, with the reasons once again relating to alteration of the axial load response of screws. Plus in that instance there was alteration of deformation and failure mechanisms. Also again, significant discrepancies existed between EYM model predictions and test results.

As discussed in the full length version of this paper, data and observations from axial load tests on screws were consistent with and helped explain findings from shear tests.

### 4 CONCLUSIONS

Primary conclusions from the presently reported study are:

- Half-lapped self-tapping joints are about 50% stronger and stiffer than single-spline joints when acting as plate edge-to-edge in-plane shear connections in CLT slabs.
- Placing washers in under heads of self-tapping screws can significantly increase the capacities of either half-lapped or single-spline shear joints in CLT slabs.
- It is important to consider eccentricities that affect the behaviour of shear joints in CLT slabs, as can occur for example when single-spline connections are employed.
- Some inadequacies exist in contemporary European Yield Model type methods for calculating design capacities of self-tapping screw joints in CLT.