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# DOUBLE-SIDED STS-CLT CONNECTION FOR A MODULARIZED BUILDING SYSTEM

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**Abstract:** Cross laminated timber (CLT) is a lumber-based engineered wood product characterized by supreme mechanical performance, CNC fabrication capability, and panelized building system, making CLT a good building material for volumetric modular construction. However, most of the connections used in the CLT are transferred from the light- or heavy-frame wood construction with deficient stiffness and strength characteristics which can only provide vertical or horizontal connectivity. This study focused on the development of a CLT connection comprised of self-tapping screw (STS), and steel plate that could offer both vertical and horizontal connectivity. Three types of double-sided STS arrangement were investigated: Type 1 was the traditional 45° inserted STS parallel-to-grain, Type 2 was the 45° horizontally inserted perpendicular-to-grain on the opposite direction of each side of the steel plate, and Type 3 was a combination of Type 1 and Type 2. It was found the Type 3 was the most efficient connection in terms of strength and ductility. Type 3 resulted in an increase in the peak load and ductility by 28% and 33%, respectively compared to Type 1. It was concluded that the proposed connection arrangement was promising for both vertical and horizontal connectivity with adequate stiffness and strength.

**Keywords: Cross-laminated timber (CLT); self-tapping screw (STS); STS-CLT connection; vertical and horizontal connectivity, initial stiffness, peak load, ductility**

## 1. INTRODUCTION

CLT is a lumber-based engineered wood product having high resistance to the in-plane shear and tension and is a good candidate for volumetric modular construction with low carbon footprint, however most of the connections being used in CLT construction nowadays are transferred from the traditional light-frame structure (FPInnovations 2019; Gong 2021; Mohammad et al. 2018). Those connections consisting of screws and steel brackets usually could both be damaged in service, with limited stiffness and strength being not compatible with the superior mechanical performance of CLT (Benedetti et al. 2019; D'Arenzo et al. 2018; Li et al. 2020). The hold-down of the CLT modular was regarded to be the most critical connection, which was expected to provide both vertical and horizontal connectivity, instead of resisting tension and shear on separate connections so as to mitigate the demand of the other structural components. ISO-certified corner fittings were standardized industrial products which could provide both horizontal and vertical connectivity with strength much higher than most of the CLT connections on the market (Lew, Sadek, and Anderson 2000; Simpson Strong Tie 2024; Rothoblaas 2022).

Therefore, the CLT connections are the bottleneck in enabling the ISO-certified connections to fully realize its potential of strength on a CLT modular. A CLT connection that could provide comparable horizontal and vertical connectivity with ISO-certified corner fitting would make the design and assembly of a robust CLT modular possible with ease of installation and dismounting.

STS and “thick” steel plates used on CLT (“thick” meaning the failure of the connection would be dominated by the STSs, not the steel, and the steel would be re-usable) are a great combination of developing a hold-down connection promising to be used in CLT modular and be compatible to the high strength of ISO-certified corner fitting in both vertical and horizontal loading directions. STS is a fastener that features high withdrawal resistance, ease of installation, and the reusable steel plate would make the post-failure repair possible (Blass and Bejtka 2001; Li et al. 2020). STS inserted at 90° perpendicular-to-grain and inserted at an angle of 45° parallel-to-grain are the two representative arrangements of STSs. It was reported that when STS installed 45° parallel-to-grain and loaded laterally, it may provide higher stiffness, and strength, yet lower ductility than that of the STS installed at 90° perpendicular-to-grain (Brown et al. 2021; Hossain et al. 2019; Krauss et al. 2023; Wright et al. 2021). A combination of both 45° parallel-to-grain and 90° perpendicular-to-grain inserted STSs in one connection was promising to enable the connection to have the advantage of both arrangements of STS, stiffness primarily contributed by the 45° inserted STS parallel-to-grain and ductility primarily contributed by the 90° inserted STS perpendicular-to-grain (Brown et al. 2021; Hossain et al. 2019; Krauss et al. 2023; Wright et al. 2021).

The purpose of this study was to investigate the potential of CLT connection made of simple, readily available materials, such as STS and steel plate, to provide both vertical and horizontal connectivity with adequate stiffness, strength, and ductility.

## 2. MATERIAL AND METHODS

Rothoblaas VGS 11*150mm STS and VGU 1145 washer were used for the joint tests (Rothoblaas 2023). Two customized over-designed steel plates were fabricated and used in the tests for locating the STSs and exerting the tensile force. The in-house made black spruce (*Picea mariana*) CLT was used. In total three types of double-sided connections were fabricated, and they were named as Type 1, Type 2, and Type 3. Type 1 used two 45° inserted STS parallel-to-grain of the major layer of the CLT, providing adequate stiffness and strength vertically; Type 2 used two 45° inserted STS perpendicular-to-grain of the major layer of the CLT on the opposite direction of each side, offering adequate stiffness and strength in shear and ductility in tension. Type 3 was a combination of Type 1 and Type 2, which was designed to combine the advantages of Type 1 and Type 2 in one connection that could be functional in tension and shear with comparable stiffness and strength. The facial dimensions of the CLT used in connection specimens were 271*191mm for Types 1 and 2, and 274*381mm for Type 3 (Figure 1). The thickness of each lamination was 36mm.

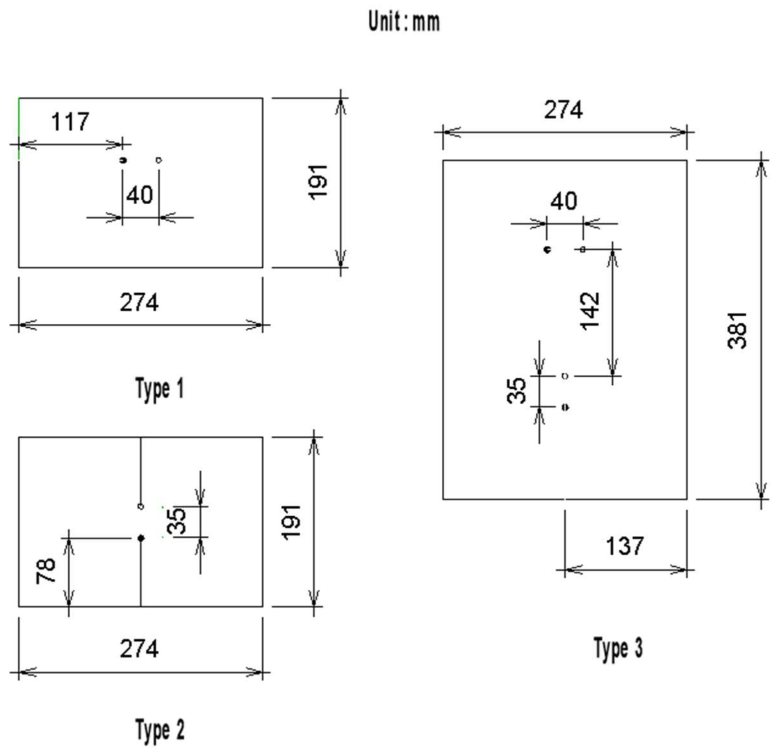


Figure 1 Dimensions in mm of CLT and locations of STS in Type 1, Type 2 and Type 3 (Hollow circles are the locations of the STS on the opposite side).

Figure 2 shows that Type 3 specimen was restrained by the red steel plate and the steel rods. The force was applied by the actuator so that the STSs were loaded analogous to the hold-down tensile scenario. The test was monotonic, quasi-static deformation-controlled and the loading speed used was 5mm/min. Two LVDTs were installed on the side face of the specimen to measure the relative movement of the connection during test. The initial stiffness ($K_{initial}$), peak load ($P_{peak}$), and ductility ($D_u$) were calculated after testing.


Figure 2 Type 3 setup with LVDTs.

**3. Results and Discussions**

Figure 3 illustrates three sample load-deformation curves representing three types of specimens. The inclusion of Type 2 to Type 1 (forming Type 3) did not improve the initial stiffness (Figure *3*, Table *1*). On the contrary, Type 3 stiffness was reduced by 12% compared to Type 1. This might be caused by the interaction between Type 1 and Type 2 from the deficient spacing between them, however this needs to be further investigated. Type 3 shows the highest peak load and comparable high initial stiffness (Figure *3*). The average peak load of Type 3 was 60.12 kN, which was increased by 28% compared to that of Type 1, suggesting that Type 2 also could be helpful in the improvement of the load resistance rather than only the ductility. The ductility of Type 1 improved 34% by combining Type 1 and Type 2 (Figure *3*, Table *1*) which was analogous to the mix-angled double-sided STS connection benefited from the 90° inserted perpendicular-to-grain STS which was in agreement with Wright & Li, (2021).

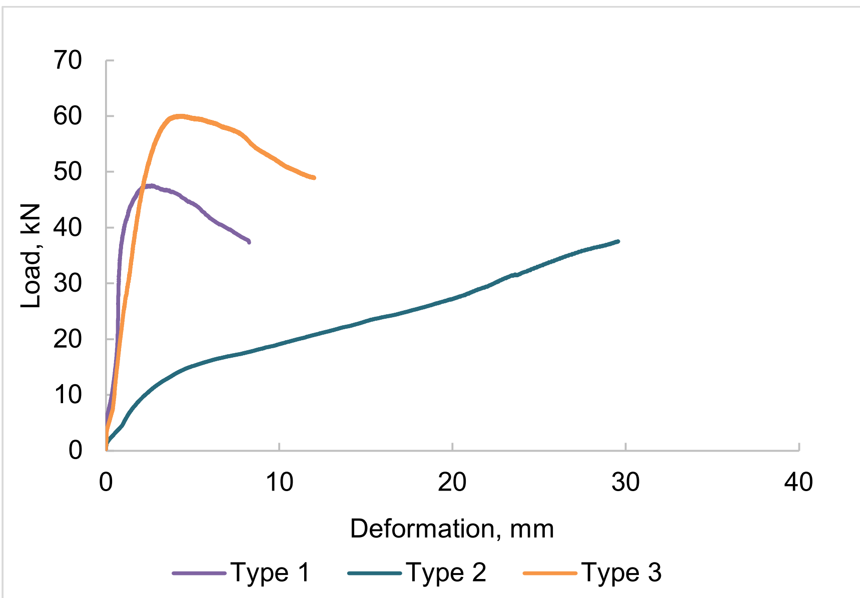


Figure 3 Typical load-deformation curves of three types of joint specimens tested.

Table 1 Summary of the test results of three types of connections, STD is standard deviation and COV is coefficient of variance.

| Series | $K_{initial}$ | | | $P_{peak}$ | | | $D_u$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean (kN/mm) | STD (kN/mm) | COV | Mean (kN) | STD (kN) | COV | Mean | STD | COV |
| Type 1 | 21.37 | 7.88 | 37% | 47 | 2.98 | 6% | 3.99 | 1.31 | 33% |
| Type 2 | 3.62 | 0.5 | 14% | 39.87 | 2.71 | 7% | 9.74 | 2.04 | 21% |
| Type 3 | 18.78 | 5.66 | 30% | 60.12 | 8.53 | 14% | 5.32 | 2.39 | 45% |

When examining the failure modes, two plastic hinges could be observed from the cross section of failed Type 2, suggesting its relatively high capacity of energy dissipation and displacement accommodation (Figure 4). No significant wood crushing or STS yielding observed in either Type 1 or Type 3, indicating their potential for post-failure repair (Figure 4).

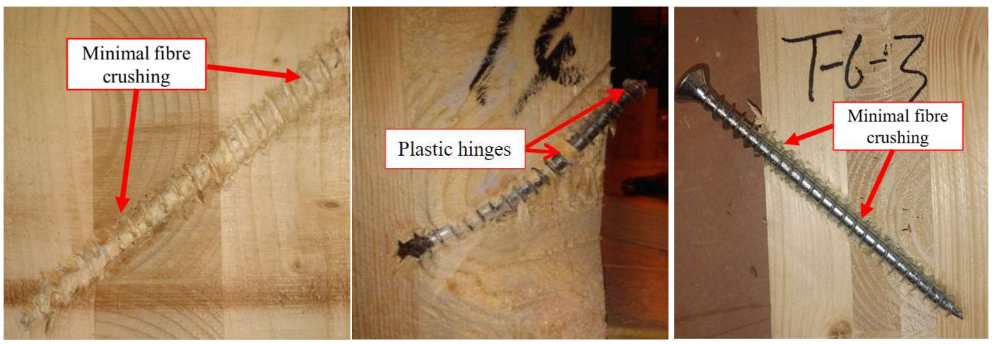


Figure 4 Left, Type 1, Middle, Type 2, Right, Type 3

## 4. Conclusions

Based on the above results and discussions, it could be concluded that:

- The introducing of Type 2 to Type 1 could help increase peak load and ductility by 28% and 33% respectively compared to Type 1, while the stiffness of Type 3 remained comparable to Type 1 (18.78kN/mm versus 21.31kN/mm).
- Type 2 could be promising in offering energy dissipation due to the presence of two plastic hinges.
- Type 3 is promising to offer comparable tension and shear resistance in CLT modular and potentially, facilitate post-failure repair.
- It is recommended to do further investigations of Type 3 to examine group effect.

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