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Experimental test of coupling effect on CLT angle bracket connections

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ABSTRACT

In this paper, the coupling effect of axial and lateral loading on Cross Laminated Timber (CLT) angle bracket connections is investigated through experimental tests. Monotonic and cyclic tests of the connections were carried out in shear, with different levels of constant force applied in tension simultaneously. Specimens subject to four different levels of tension forces were tested and the results were analyzed in terms of key mechanical characteristics of those connections including strength, stiffness, ductility, strength/stiffness degradation, equivalent viscous damping and energy dissipation. The results show that shear and tension for angle brackets are strongly coupled. Co-existent of tension force reduces the lateral strength and stiffness capacity of the connection significantly. Under complex loading, the gap between nail and wood embedment mitigates and the friction increases, resulting in the reduction of pinching effect; hence, the energy dissipation capacity drops under larger deformation. The study gives a better understanding of hysteretic behavior of angle bracket connections for CLT where rocking motions occur, and provides reliable data for future numerical analysis of CLT structures.

1. Introduction

Cross Laminated Timber (CLT) is an attractive structural material with relatively high dimensional stability and load capacity; therefore, its use is expanding as walls and floors in massive timber structural systems. Much research on both the component level and structural level has recently been carried out to study its structural behavior. A series of experimental tests on the structural performance of CLT walls were carried out at the University of Ljubljana, Slovenia, including monotonic and cyclic tests of CLT walls with different anchorage details [1], CLT walls different vertical load and boundary conditions [2], and CLT walls with openings [3]. IVALSA Institute of the National Research Council at San Michelel all'Adige (Trento, Italy) carried out the SOFIE project to investigate the performance and capacities of the X-LAM system, known as CLT structures now. The project included a series of lateral resistance performance test of cross-laminated wooden panels [4], a shaking table test of a three-storey CLT building [5], and a seismic test on a 7-storey X-lam building on the E-Defense 3D shaking table in Japan [6]. In Canada, FPInnovations, the University of British Columbia, and University of New Brunswick, conducted a set experimental research on the structural performance of CLT walls [7–10]. In the United States, a NEES CLT Planning project is ongoing to develop seismically resilient tall Cross Laminated Timber (CLT) systems [11–14].

There are some other notable experimental efforts on CLT structural behavior in Germany [15], Japan [16], Italy [17], and Chile [18]. Those studies show that most deformation in CLT structures happens at metal connectors instead of the wood, dominated by rocking and slip mechanisms. A typical design assumption is that, angle brackets will slip under loading and only take the shear force along the CLT wall. Under such assumptions, former researchers tested CLT connections loaded in one direction [19,20]; experimental performance of hold down, bracket, and a half-lap joint connection under cyclic loading was investigated [21]; experiments were undertaken to evaluate how the structural characteristics of steel angle bracket connectors vary across a range of mass produced and special connectors under shear loading [22]. These connectors were tested in shear and withdrawal directions to capture the main features of the behavior of these CLT connections.

In those researches, rocking and slip mechanisms were considered interacting independently. However, recent study has shown that those two mechanisms are acting jointly on the connectors. Under complex stress conditions, the shear behavior and axial behavior of angle brackets are coupled, which was neglected in previous simplified methods [23,24]. This paper presents the results of the monotonic and cyclic tests of CLT angle bracket connections under shear loading, with four levels of different constant tension forces applied.

2. Experimental tests

This experiment aims to investigate the coupling effect of tension

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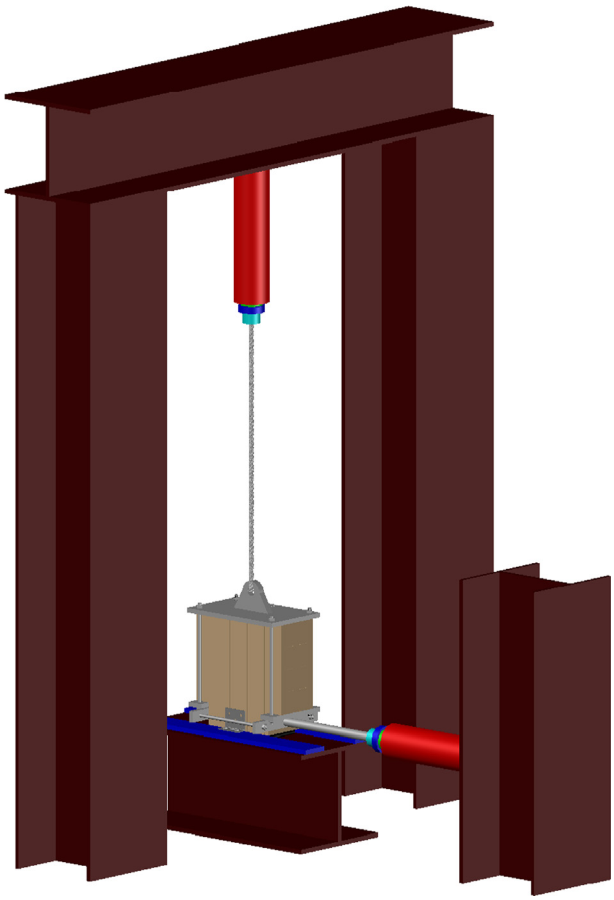

Fig. 1. 3D schematic drawing of the set-up.

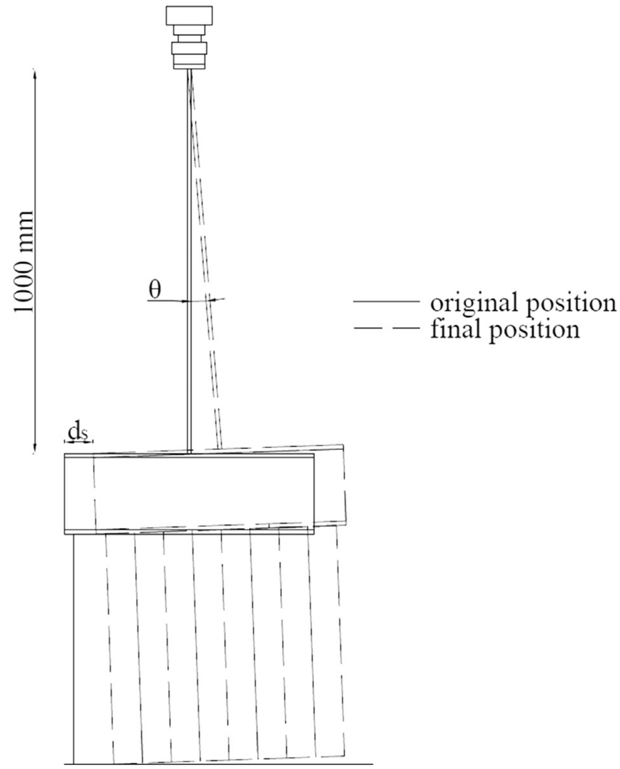

Fig. 2. Deformation of the cable due to lateral displacement of the specimen.

and shear forces on angle brackets used in CLT structures. This section describes the setup, specimens and test procedures.

2.1. Description of the setup

The experiment was conducted for typical commercially available CLT angle bracket connections. Steel base-panel connections were tested, representing the wall panels to foundations connection. The connection tests were performed under bi-axial monotonic and cyclic loading, shear and tension. Fig. 1 presents the configurations of the angle bracket connection tests.

During the bi-axial loading, the specimen will slip due to the shear force, resulting that the tension force will be loaded eccentrically. A long steel cable (1 m) was used to connect the load cell for tension and the specimen (Fig. 2). With a horizontal displacement d_s of the specimen, the angle between the cable and the vertical direction θ would not exceed 5°, which minimizes the eccentricity effect. Thus, the tension load (F_T) can be considered as vertical all along the test. The shear force (F_S) induced a turning moment since it was located above the bottom of the specimen. Fig. 3 shows the mechanism for calculating the forces at the angle brackets.

As shown in Fig. 4(a), the specimen was fixed to the steel base by angle brackets, using 3 M12 bolts on each side. Two actuators were acting on the specimen, denoted as LC1 and LC2. LC1 was connected to the steel components constrained on the top of the CLT specimen by the steel cable, providing a constant tension load. LC2 was connected to the steel components constrained at the bottom of the specimen by steel plates, delivering monotonic and cyclic shear loads. Steel rollers were placed between the specimen and the steel base to prevent friction.

Fig. 4(b) shows one specimen fully set up for experiment. On each side of the specimen, one linear voltage displacement transducer (LVDT) was installed to measure the vertical displacement of the specimen. During the test of 40 kN vertical load, such complex loading and slightly eccentricity of the specimen can cause out-of-plane movement. This was avoided by two rigid "L" shaped steel plates connected to the specimen with rollers. Fig. 4(c) shows how the bi-axial loading acted on the angle bracket connector: at the beginning of each test, a vertical tension load was applied to the connector, after the target tension load was reached, the monotonic or cyclic shear load was delivered horizontally while maintaining the target tension load.

2.2. Specimens characteristics

For the CLT panels, 5-layer panels made of graded No. 1/2 SPF lumber with a thickness of 169 mm were used. The dimensions of each CLT specimen are 450 mm × 600 mm and the layout is shown in Fig. 5(a). The specimens had a moisture content of 12% and they were stored and tested under controlled conditions at 50% RH and 20 °C. AE 116 (angle bracket) were tested using 11 annular-ringed nail 4 × 60 mm and 3 12 mm diameter bolts (8.8 grade). The photo and configuration for AE 116 connector are shown in Fig. 5(b).

2.3. Test procedure

All shear tests were conducted using a reverse cyclic procedure with predefined yield values which varied from configuration to configuration, depending on experimental yield values obtained from monotonic tests.

Constant tension load was first applied and maintained to the specimens up to the target value with the vertical actuator under load control. Subsequently, monotonic or cyclic lateral displacement was applied. Monotonic tests were carried out under displacement control at a loading rate of 0.2 mm/s. Cyclic tests followed a modified procedure based on EN 12512 (CEN 2006) [25] for cyclic testing of joints made with mechanical fasteners (Fig. 6), with input displacement rate 0.8 mm/s so that a duration of each test did not exceed the time limit of