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Comparison of glulam post-to-beam connections reinforced by two different dowel-type fasteners

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HIGHLIGHTS

- A new type of bolted connection reinforced by plain round rods is designed.
- The moment resistance performance and seismic behavior are investigated.
- The reinforcing effects of plain round rod and self-tapping screw are compared.

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ABSTRACT

In this paper, the performance improvement of glulam post-to-beam connections reinforced by plain round rods (PRRs) and self-tapping screws (STSs) were compared. Five non-reinforced post-to-beam bolted connections, five PRR-reinforcing connections and five STS-reinforcing connections were experimentally investigated under monotonic and low frequency cyclic loading. Their stiffness, ductility, moment resistance capacity, failure modes and seismic behavior were analyzed. The findings indicated that both of these two reinforcements could mitigate wood splitting, and change the failure mode from brittle failure to ductile failure. The maximum moment and failure rotation of PRR-reinforcing connection were increased by 29% and 6% respectively, compared with those of non-reinforced connection. In addition, those of STS-reinforcing connection increased by 86% and 145% respectively. Furthermore, the comparison of PRR-reinforcing and STS-reinforcing connections indicated that the connection ductility reinforced by self-tapping screws enhanced more significantly; 106% higher than that of PRR-reinforcing connection. Moreover, under the low frequency cyclic loading, PRR-reinforcing and STS-reinforcing connections dissipated more energy (336% and 641% respectively) with a lower stiffness degeneration rate and a higher equivalent viscous damping ratio than those of non-reinforced connection. Besides, the dissipation energy and equivalent viscous damping ratio of STS-reinforcing connection were larger than those of PRR-reinforcing connection.

1. Introduction

In modern glulam structures, bolted connections with slotted-steel plate are commonly used as post-to-beam connections [1,2]. Due to the low tensile strength perpendicular-to-wood-grain and shear strength parallel-to-wood-grain, the moment resistance capacity of bolted glulam connections is limited [3]. Thus, in practical design codes, such as NDS-2005 [4], CSA-O86-01 [5], and Eurocode 5 [6], this type of connection is supposed to only transmit shear force and axial force, and the moment resistance capacity is ignored. However, the vertical load on the beam or lateral load such as wind and seismic load will lead to moment at the post-to-beam connections. Meanwhile, it produces tensile stress perpendicular to the grain and shear stress parallel to the grain in the timber near the bolt hole, which results into cracks in the zone. Thereby, unexpected brittle failures such as splitting and plug shear will occur, which will weaken the ductility and energy dissipation capacity of the whole structure [7,8]. Therefore, it is important to improve the lateral resistance behavior of post-to-beam connections for the structure safety and economical efficiency.

So far, several reinforcement methods to enhance the moment resistance capacity of post-to-beam bolted connections have been proposed. Rodd et al. [9], Leijten et al. [10], and Araki et al. [11] conducted tests and finite element analysis on the timber connection with steel tube inserted. Their research indicated that the stiffness, ductility and energy dissipation capacity of tube connection

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were superior to solid fastener connections, and the thinner tube wall could avoid brittle failure of connection and improve the energy dissipation capacity. He et al. [12] proposed a pre-stressed tube bolted joint with slotted-in steel plate to improve the performance of post-to-beam connections, and test results proved that pre-stressed tube joints outperformed the traditional bolted connections in load bearing capacity and slip modulus. Research efforts were also made regarding improving the capacity of wood in the connection zone, such as using serrated surfaces on the connection surfaces, or using locally cross-laminated glulam within the bolting area. Idota et al. [13] carried out monotonic loading tests for joints using serrated surface and cyclic loading test for portal frames, and found that the proposed serrated joint had higher stiffness and strength in comparison with bolted joints. Wang et al. [14] investigated the rotational behavior of bolted post-to-beam glulam connections with locally cross-laminated glulam members. The experimental results indicated that the cross-laminated technique led to a more ductile failure mode and higher moment-resisting capacity, ductility, and energy dissipation, in comparison with the non-reinforced connections. In addition, some investigations have indicated that using fiber-based materials as reinforcement was effective in mitigating the brittle failure and improving the connection performance [15–17]. Using dowel-type fasteners as reinforcement is an effective method to eliminate wood splitting and improve the connection behavior as well. Recent experimental researches on STS-reinforcing connections (connections reinforced by self-tapping screws perpendicular to the grain), have shown that both the moment resistance capacity and ductility of STS-reinforcing connections were significantly superior to those of non-reinforced connections [18–21]. Furthermore, a similar concept using plain round rods (PRRs) as reinforcement has been proposed. Analogous to STS-reinforcing connections, the PRRs are placed perpendicular to the bolt axis and to the grain direction around the bolt holes. This reinforcement is achieved through the tight clamping force of washers and nuts. Although studies on different types of reinforced connections were conducted, the reinforcing effects of the different reinforcements were seldom compared. Piazza et al. [22] conducted tests and analysis to evaluate the ability of current procedures to mechanically characterize a joint's behavior as a function of different kinds of connector – traditional dowel-type systems or innovative self-tapping screws inserted with different inclinations with respect to the shear plane. On the basis of analysis results, some robust procedures were proposed.

In this paper, the performance improvements of glulam post-to-beam bolted connections reinforced by two different dowel-type fasteners (plain round rods and self-tapping screws) perpendicular to the grain were compared. Both monotonic and low frequency cyclic loading tests of non-reinforced connections, PRR-reinforcing connections, and STS-reinforcing connections were conducted. The stiffness, ductility, moment resistance capacity, failure modes, and seismic behavior of connections were investigated. Based on the experimental investigation, a better understanding of connections reinforced by the two dowel-type fasteners was achieved. Moreover, a suggestion on reasonable selection of the reinforced methods in practice was supplied.

2. Experimentation description

In order to compare the reinforcing effect of plain round rods and self-tapping screws, a group of non-reinforced connections named N, a group of connections reinforced by plain round rods (PRR-reinforcing connections) named S_1, and a group of connections reinforced by self-tapping screws (STS-reinforcing connections) named S_2 were designed. All the specimens were with the same materials and same dimensions. There were five replicates in each group. Three of them were tested under monotonic loading and the other two were tested under low frequency cyclic loading.

2.1. Materials

The materials considered in this study included the following:

- Glulam used for the beam and column was glued by No. 2 North American visually graded Spruce-pine-fir dimension lumber with an average moisture content of 14.58% and an air-dry density of 408 kg/m^3.
- Bolts with a diameter of 24 mm and a strength grade of 8.8 were used as fasteners. They had a nominal tensile strength of 800 MPa conforming to the Chinese code of mechanical properties of fasteners bolts, screws, and studs [23].
- Mild carbon steel Q235B, with a nominal yielding strength of 235 MPa, as specified in the Chinese code of notations for designations of iron and steel [24], were used as the inserted steel plate. The thickness of the plate is 10 mm.
- The continuously threaded self-tapping screws produced by Germanic WURTH company (Product number: 0165310300)were used as reinforcements in the STS-reinforcing connections, with a length of 300 mm and a diameter of 10 mm, as shown in Fig. 1. The material of self-tapping screws is ASTM A29 steel, with the tensile strength of 400 MPa according to the product specification.
- The plain round rods, used as reinforcements in the PRR-reinforcing connections, were 300 mm long and 10 mm in diameter, with a 260 mm-long unthreaded portion in the middle and a 20 mm-long thread portion at both ends, as presented in Fig. 2. The material of plain round rods is mild carbon steel, with a strength grade of 4.8. According to the Chinese code of mechanical properties of fasteners bolts, screws, and studs, the nominal tensile strength of the plain round rods is 400 MPa.

2.2. Specimen design

The details of specimens are shown in Fig. 3. The beam members were 300 mm × 200 mm in cross section and 850 mm in length, and the column members were 300 mm × 250 mm in cross section and 1100 mm in length. The timber members and steel plates were predrilled before assembly. The bolt holes were 2 mm larger in diameter than the bolts. The edge distance, end distance, and bolt spacing were determined by the Chinese technical code of glued laminated timber structures [25]. The glulam members were slotted with a width of 12 mm. PRR-reinforcing connections (R1) and STS-reinforcing connections (R2) were reinforced at the same position with the same number of reinforcement dowel-type fasteners, as shown in Fig. 3(b).To avoid the failing of the connection zone on the column occurring before that on the beam, there are more bolts and reinforcements on the column than on the beam. The attention is focused on the failure of the beam. The predrilled holes for plain round rods in timber members were 12 mm in diameter. The plain round rods were anchored to the wood members through the nuts and washers. The washer used in the test is the standard flat wash for the 10 mm-diameter PRR, with an 11 mm-inner-diameter, a 20 mm-outer-diameter, and a 2 mm-thickness. Fig. 4 demonstrates the configuration of connections reinforced by plain round rod.

2.3. Loading device and data measurement

The test loading device and the distribution of the displacement measurement devices are given in Fig. 5. To facilitate loading, the connection specimens were rotated 90°.The column member was fixed on the floor. Blocks and anchor bolts were used to prevent the specimen from sliding. The top end of the beam member

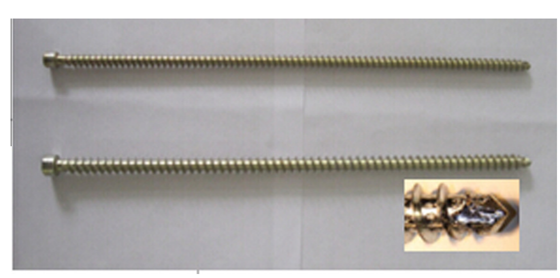

Fig. 1. Self-tapping screw.

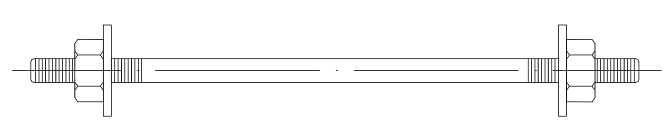

Fig. 2. Plain round rod.