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# Influence of cracks on the mechanical performance of dowel type glulam bolted joints

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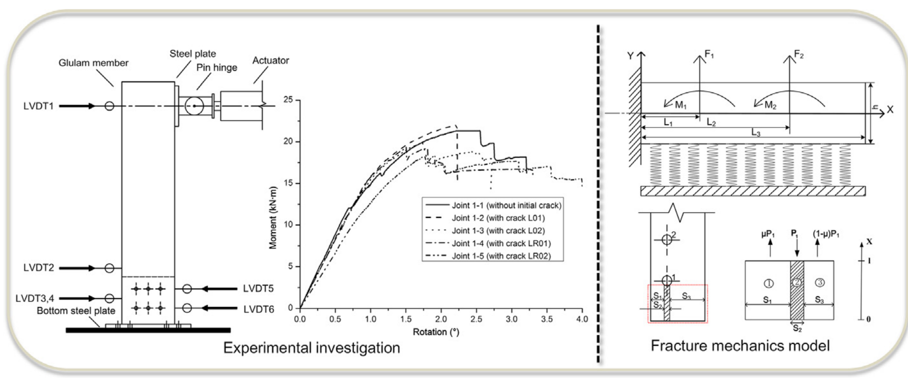
## HIGHLIGHTS

- The effect of cracks on behavior of bolted joints is experimentally investigated.
- Different parameters and crack patterns are included in the experimental research.
- An analytical method is proposed to predict the capacity of cracked glulam joints.

## GRAPHICAL ABSTRACT

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## ABSTRACT

Cracks are easily observed in glulam bolted joints due to the high moisture transport rate in the area and constraint stresses caused by the presence of steel fasteners. The purpose of this research is to explore to what extent initial cracks affect the mechanical performance of bolted glulam joints. Experiments were conducted on full-scale specimens with different bolt diameters, bolt layouts, and combinations of different crack patterns (e.g. crack length, location, etc.) were considered. This paper presents the failure modes and the reduction in several mechanical parameters of cracked glulam joints. It is found that initial cracks have a significant effect on the mechanical behavior of the joints. The cracks lead to a reduction up to 52% in the stiffness and a reduction up to 61% in the ductility ratio of the joints, respectively. In addition, an analytical method based on the yield theory and fracture mechanics was proposed to predict the load carrying capacity of the cracked glulam joints, and the proposed model was further verified by the experimental results.



## 1. Introduction

As a hygroscopic material, wood can absorb and desorb moisture from the surrounding air when exposed to variable climates [1]. High moisture gradients will be developed in the wood sections with fast humidity changes. Due to these gradients and uneven or restrained shrinkage and swelling strains, moisture induced stresses will be further created in timber elements, which may lead to cracks in timber structures [2–4]. Bolted joints with slotted-in steel plates are widely used in timber structures, while the joints are more sensitive to variable climate conditions due to several factors [4]. First, exposed end and slots of the joints enlarge the interface to moisture transport. Further, constraint stress can be induced easily in the joint area because the moisture induced deformation is restrained by the steel fasteners. As a

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result, longitudinal cracks have been commonly observed in these timber joints [5].

Cracks in timber structures may have a significant influence on the mechanical behavior of timber elements or joints. At present, most performed researches have emphasized on structural behavior of glulam beams with openings, cracks or notches [6–11]. Due to the large surface of exposed end in inverted double-tapered glulam beams, the effect of initial cracks has been investigated by two fracture mechanics models [12]. In the case of steel-to-timber joints, several investigations have been conducted on quantifying the influence of moisture induced stresses [2–4,13–15]. These research results indicated that the stresses have a negative effect on the load carrying capacity of tension-loaded joints. Moment-resisting joint is a key part in timber structures to transfer internal forces between timber elements such as beams and columns [16]. Bolted steel-to-timber joints are commonly observed due to its elegant appearance, and the mechanical behavior of such joints has been extensively studied [17–20]. With high longitudinal shear stress and perpendicular-to-grain tensile stress produced near the fasteners, premature brittle failure modes such as plug shear and splitting are commonly encountered in these joints. It has been reported that such brittle failure will weaken the performance and ductility of the joints [17]. In that case, initial cracks may do harm to the mechanical behavior of bolted timber joints, and the cracks will lead to the occurrence of brittle failure modes. However, few researches have been conducted to investigate the effect of initial cracks on timber joints.

This paper evaluates the mechanical performance of bolted joints with initial cracks. Monotonic loading tests were conducted on twenty full-scale specimens to investigate the influence of initial cracks on the performance of moment-resisting joints with two different bolt diameters and bolt layouts. Combinations of different crack patterns (e.g. crack length, location, etc.) are considered. The experimental results are analyzed and presented, and the ultimate capacity of the moment-resisting joints is analytically calculated based on the yield theory [21] and a quasi non-linear fracture mechanics model [22]. The analytical method can consider both brittle failure and bolt yielding occurring at the joint area. Finally, comparison between the analytical and the experimental results is presented in support of the effectiveness of the proposed analytical model.

## 2. Materials and methods

Two configurations of moment-resisting joints (i.e. Joint 1 and Joint 2) are included in the test. The joints were designed according to the Chinese technical code of glulam structures [23]. Glulam members with same geometrical dimensions (i.e. 1200 in length and 260 × 130 mm in cross section) and slotted-in steel plates with a thickness of 10 mm were prepared for all the specimens. The glulam members were manufactured with the same batch of spruce-pine-fir (SPF) lumber. The mean density and moisture content were measured as 399 kg/m$^3$ and 14.5%, respectively. The standard deviations of density and moisture content are 15 kg/m$^3$ and 1.4%, respectively. The steel plates were made of mild steel, which had a nominal yield stress of 235 MPa as given in [24]. Bolts with a strength grade of 8.8 were used to connect the glulam members to the steel plates. Their nominal value of tensile strength can reach 800 MPa according to [25]. Joint 1 includes six bolts with 16 mm in diameter, while joint 2 has nine bolts with 12 mm in diameter. The spacing, end and edge distances in Joint 1 and Joint 2 with bolts of different diameters are determined to meet the minimum required values defined in the code [23]. Considering manufacturing tolerance, the bolt holes were predrilled with a diameter 2 mm larger than the bolt diameter and an 11 mm slot was cut for the 10 mm steel plates to ease assembly. 20 mm-thick bottom steel plates and six bolts with 20 mm in diameter were used to fasten the specimens to the structural ground.

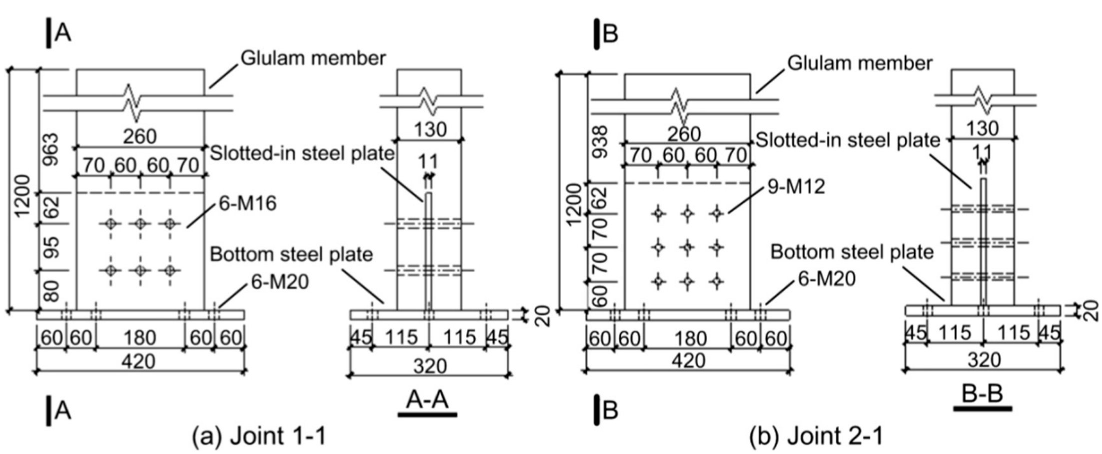


**Fig. 1.** Configurations of Joint 1-1 and Joint 2-1 (dimensions are in millimeter).

**Table 1**
Specimen configurations.

| Joint Notation | Species | Lumber Grade | Bolt diameter (mm) | Bolt Grade | Crack Notation | Crack Length (mm) | Crack Depth (mm) | Crack Location |
|---|---|---|---|---|---|---|---|---|
| Joint 1-1 | S-P-F | No. 2 | 16 | 8.8 | – | – | – | – |
| Joint 1-2 | S-P-F | No. 2 | 16 | 8.8 | J1-L01 | 71 | 59.5 | LBC |
| Joint 1-3 | S-P-F | No. 2 | 16 | 8.8 | J1-L02 | 148 | 59.5 | LBC |
| Joint 1-4 | S-P-F | No. 2 | 16 | 8.8 | J1-LR1 | 71 | 59.5 | LRBC |
| Joint 1-5 | S-P-F | No. 2 | 16 | 8.8 | J1-LR2 | 148 | 59.5 | LRBC |
| Joint 2-1 | S-P-F | No. 2 | 12 | 8.8 | – | – | – | – |
| Joint 2-2 | S-P-F | No. 2 | 12 | 8.8 | J2-L02 | 109 | 59.5 | LBC |
| Joint 2-3 | S-P-F | No. 2 | 12 | 8.8 | J2-M02 | 109 | 59.5 | MBC |
| Joint 2-4 | S-P-F | No. 2 | 12 | 8.8 | J2-LR2 | 109 | 59.5 | LRBC |
| Joint 2-5 | S-P-F | No. 2 | 12 | 8.8 | J2-MR2 | 109 | 59.5 | MRBC |

*Note:* S-P-F stands for spruce-pine-fir; Crack was initialized along the grain direction in length and out-of-plane direction in depth from the front surface of the glulam specimens to the inner slot; LBC and MBC indicate that the initial crack is along the left and middle bolt line, respectively; LRBC means that there are two initial cracks along the left and right bolt line, respectively; and MRBC means that there are two initial cracks along the middle and right bolt line, respectively.