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Moment resisting splice of timber beams using long threaded rods and grout-filled couplers – Experimental results and predictive models

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HIGHLIGHTS

- A novel rotationally stiff on-site splice timber joint is presented.
- Long threaded rods are used as main fasteners in moment resisting joint.
- Predictive models for the rotational stiffness and the strength are proposed.
- Experimental and numerical methods were used.

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ABSTRACT

In order to achieve larger spans of timber arch bridges, glulam massive timber sections must be spliced on-site by moment resisting and rotationally stiff joints. In this paper, a novel timber splice connection utilizing long threaded rods and grout-filled couplers is presented. Flexural characteristics of the splice joint were investigated by full-scale experimental tests and 3D finite element models. An analytical model is proposed for determining the moment capacity and the rotational stiffness of the splice connection. The experimentally measured efficiency of the splice connection with regard to moment capacity and rotational stiffness was 69% and 66%, respectively.

1. Introduction

The development of glued laminated timber (glulam) allows for production of timber elements with nearly unlimited cross-sectional dimensions. However, production and transportation impose limitations on the length of timber elements. The maximum length of glulam elements is in a range of 30–40 m for straight elements, and approximately 20–30 m for curved elements in dependence on the radius of curvature and means of impregnation [1,2]. In order to obtain larger spans, it is necessary to splice the timber elements on site. Feasibility studies of glulam arches with network hanger configuration have shown that it is possible to achieve timber bridges with spans in a range of 100–120 m [3,4]. In order to maintain stability and reduce buckling problems of the timber arches, it is crucial to incorporate flexural rigidity in splice connections.

The pros and cons of different splice connection techniques in timber engineering are discussed in [5]. Recent research on self-tapping screws and long threaded rods has demonstrated the capability of these axially loaded fasteners to achieve effective connections by utilizing their high axial withdrawal capacity and stiffness. Currently, self-tapping screws and long threaded rods are mostly used as reinforcement of timber beams [6] or as connectors in a shear or axially loaded lap connections [7]. However, the performance of long threaded rods in moment resisting connections remains to be revealed. The present investigation deals with the application of long threaded rods as the main fasteners in timber splice connections subjected to bending moments. Grout-filled steel couplers (similar to systems used for reinforced pre-cast concrete) are used to connect the long threaded rods inserted in the two parts of the timber beam. The main objective of the investigation is to determine the flexural characteristics of the splice connection. Prototype splice connections were produced and investigated by full-scale experimental tests. Complementary experimental investigations were carried out to 1) identify

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withdrawal properties of the grouted rod splice, and 2) to establish the contact stiffness of two mutually compressed mating timber end faces. The numerical simulations performed by finite element models enabled a deeper insight into the mechanical behaviour of the tested connections. Based on the findings from both the experimental and the numerical investigations, analytical relations are proposed for determining the rotational stiffness and the moment capacity intended for practical design.

2. Problem definition

The present splice connection is intended for large glulam sections with special focus on timber network arch bridges. The dominating internal force in such structures is compression transferred by the contact of timber end faces. Shear force can be transferred via shear keys. The design philosophy is based on utilizing high withdrawal stiffness and virtually non-existing initial slip of threaded rods to achieve rotationally stiff joints that can transfer the moderate bending moments. By providing sufficient effective length, the failure mode is driven by yielding of the steel rods. This enables a more reliable prediction of the structural properties and increased ductility of the joint. Since both the threaded rods and the steel couplers are embedded in the timber, the connection is durable, fire resistant and aesthetic. Both the threaded rods and the couplers can be pre-assembled prior to transport of the timber sections; this eases the mounting process on site. It should be noted, however, that the final setting time is affected by the curing of the glue, and the gluing operation on site implies quality control issues.

The main concern regarding implementation of splice joints in glulam arches is the required rotational stiffness of the joints. The flexural characteristics of this splice connection were studied using prototype splices of timber beams. The principal layout of the prototype beam splice connection is presented in Fig. 1.

3. Experimental tests

3.1. Tensile test of the rod splice

Tensile testing of the rod splice was carried out in order to verify sufficient strength and to determine the withdrawal stiffness of the system of rods and grout-filled couplers. In total, 6 tensile tests were conducted. In 3 of these tests, the relative displacements of the rods were monitored by two displacement transducers (confer Fig. 2). The mean value of these two measurements from each test was used to determine the deformation characteristics. Load was applied according to the loading procedure given in EN 26891:1991 [8].

3.2. Experimental determination of the stiffness at the interface of two mutually compressed mating timber end faces

The contact stiffness at the interface of two mutually compressed mating timber end faces was determined experimentally.

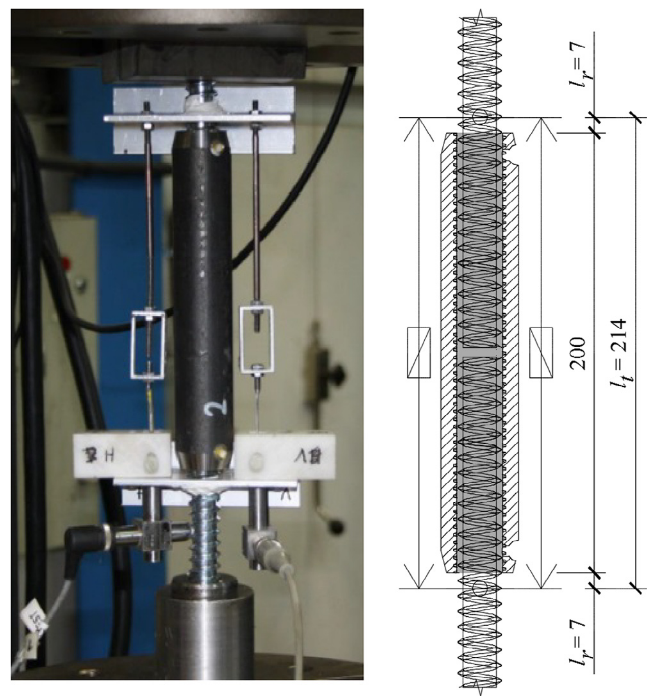

Fig. 2. Test set-up of tensile test of the rod splice (dimensions given in mm).

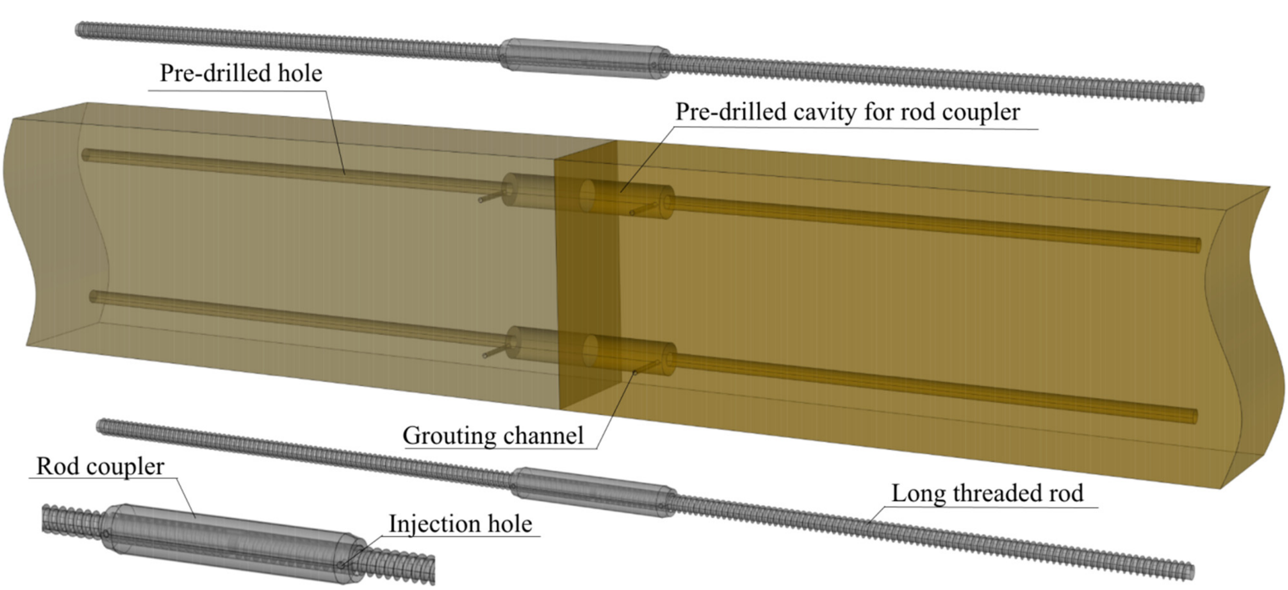

Fig. 1. Principal layout of splice connection with long threaded rods and grout-filled couplers.