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Moment resisting on-site splice of large glulam elements by use of mechanically coupled long threaded rods

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ABSTRACT

Large spans of modern timber bridges can be achieved by use of glulam arches with network hanger configuration. Since transportation and production limit the length of timber elements, the glulam arches must be spliced on bridge site. However, it is difficult to obtain practical moment resisting on-site splicing of massive glulam elements featuring flexural rigidity by the available timber splicing techniques. Consequently, the arches are often designed as trusses containing a large number of connections, which are costly and present a risk of decay development. In the present paper, a novel splicing technique suitable for large massive timber sections is presented. The flexural rigidity of the joint is obtained by the utilisation of long threaded rods having large withdrawal stiffness. Fast and easy on-site assembly is facilitated by mechanical coupling of the rods. The rods are oriented with a small inclination to grain, which prevents potential development of shrinkage cracks along the rods. Experimental and numerical methods were used to investigate the flexural joint characteristics. The joint prototypes featured large rotational stiffness without initial slip. As a basis for practical joint design, analytical relations are proposed for estimating the rotational stiffness, the moment capacity and the capacity under combined bending and normal force.

1. Introduction

Feasibility studies of glulam arch bridges with network hanger configuration have shown excellent structural properties for bridges with massive glulam arches spanning up to 100–120 m [1,2]. Since the timber arches cannot be produced and transported in one piece, the timber elements must be spliced on bridge site. In order to maintain the stability of the arches, it is crucial to incorporate flexural rigidity in the splice connections [3–5].

Fig. 1 shows the recently erected network arch bridge Steibrua in Norway [6]. With a span of 88 m, the bridge is currently the longest single-span timber road bridge in the world. However, due to the lack of rotationally stiff splicing solution for large timber elements, the arches of Steibrua are formed as hybrid timber-steel trusses. This is probably not the most optimal solution since the trusses contain a large number of connections, which are expensive and vulnerable to decay developments. A more durable and cheaper solution could be achieved by the use of massive glulam arches, necessitating on-site splice joints with sufficient rotational stiffness.

The pros and cons of different splice connection techniques in timber engineering are discussed in [7]. Recent research on steel rods glued into timber has demonstrated that connections featuring large stiffness and capacity can be achieved by using high strength epoxy adhesives [8–11]. However, for large joints, multiple rods are necessary, and the brittleness of the adhesives can lead to a progressive failure in a group of rods [12]. Therefore, design provisions for ductile failure are necessary [13–17]. The main shortcoming associated with the application of glued-in rods is the production. Experience from reviewers of failed joints revealed inadequately mixed and incorrectly applied epoxy on site. Nowadays, the production is limited to a climate controlled environment with quality control and skilled personnel [12].

The difficulties connected to gluing of rods are avoided by using long threaded rods, which are simply driven into pre-drilled holes in timber. Large rotational stiffness and moment capacity of spliced timber beams was achieved in [18] by using commonly available long threaded rods (SFS WB-T-20). The rods were inserted parallel to the grain in the opposed parts of timber beams, and the mutual splicing of the rods was carried out by grout-filled steel couplers (similar to systems used for reinforced pre-cast concrete). The parallel to grain orientation of the threaded rods enables effective force transfer in the axial direction and allows the utilisation of the high withdrawal stiffness of rods parallel to the grain. On the other hand, the development of shrinkage cracks (in the grain direction) in close proximity to the threaded rods can lead to loss of capacity. In addition, the gluing

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Fig. 1. Steibrua, Norway – Network arch bridge with glulam arches [6].

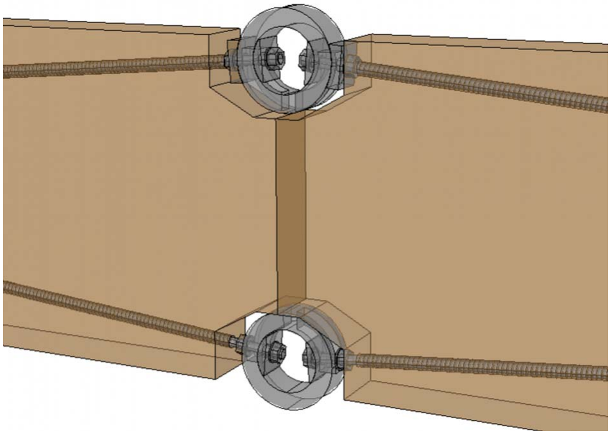

Fig. 2. Principle layout of the splice joint with inclined mechanically coupled long threaded rods.

operation on site implies quality control issues, and curing of the glue affects the final setting time of the joint.

In this paper, a novel splicing solution is presented, which overcomes the aforementioned shortcomings by the use of slightly inclined long threaded rods with a metric threaded part at one end. A principle layout of the joint is shown in Fig. 2. Inserting the rods with a small inclination to the grain avoids the risk of failure due to the occurrence of shrinkage cracks since the rods cross several "layers" of wood. The mechanical joint of the rods allows easy and fast on-site mounting without the need of special tools. In order to transmit the normal force acting in the arch, mutual contact of the mating timber end faces is assured by tightening the rods in the couplers. The shear force can be transmitted through shear keys. A reliable prediction of the structural properties and ductile behaviour is achieved by design provisions enforcing a failure mode driven by yielding of the steel rods.

The key prerequisite regarding splicing of massive glulam arches is a sufficient and predictable rotational stiffness of the splice joints. Therefore, the main objective of the present work is to determine the flexural characteristics of the proposed splicing technique by the use of experimental testing on full-scale prototype joints and numerical models. In order to allow for practical design of the joint, analytical relations are here proposed for the determination of the rotational stiffness, the moment capacity and the combined capacity for bending moment and normal force.

2. Materials and methods

2.1. Analytical prediction of flexural joint characteristics

2.1.1. Rotational stiffness

An analytical model for the determination of the rotational stiffness of a splice joint using long threaded rods inserted parallel to the grain was derived in [18]. However, due to the inclination of the rods in the proposed splicing solution, a lateral force component is present at the rod-ends. A modification of the model accounting for the lateral deformations of the rods is presented in the following, with input parameters specified in the Appendix A. The model parameters are shown in Fig. 3. Here, h and b are the height and the width of the cross-section respectively, a_0 is the height of wood in compression, a_i is a coordinate along z-axis of the i-th rod row determined from the upper edge of wood in compression (with reference to Fig. 3, a_i is negative for the rods in compression), h_t is the height of timber end faces in mutual contact, θ represents the relative rotation of the end timber faces, γ is the rod-to-

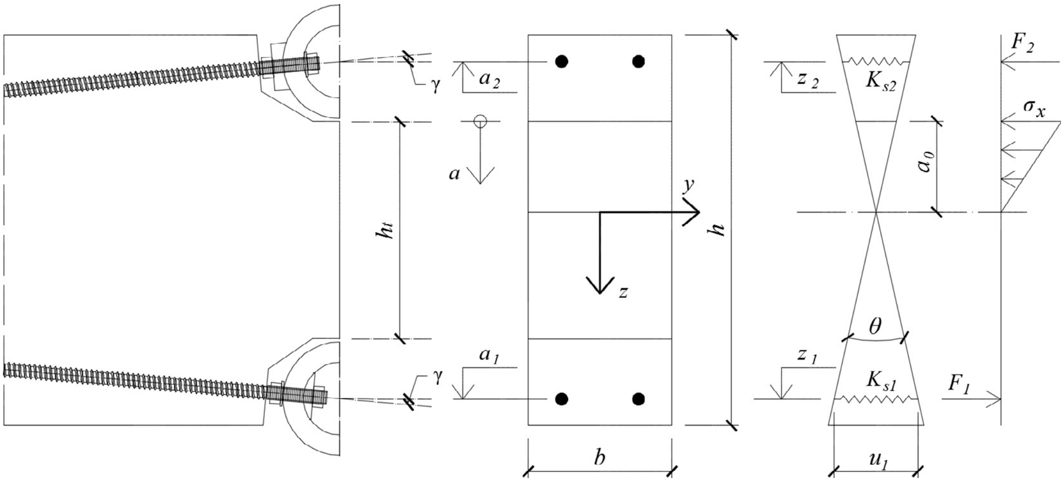

Fig. 3. Analytical model nomenclature.