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A component method for moment-resistant glulam beam–column connections with glued-in steel rods

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ABSTRACT

This paper presents an analytical method of the determination of the moment resistance, initial stiffness and the rotation capacity of glulam beam–column connections with glued-in rods. The methodology is based on the component method and is implemented using appropriate mechanical models. As a simplified component of the steel box sections, the substitute T-stub in the model is well verified by the experimental results, whether with or without the transverse web stiffeners. On the basis of the mechanical properties of the individual components such as initial stiffness, load resistance and a further force–deformation relationship, the moment–rotation curves of the entire joint can be obtained. The proposed model is evaluated against the experimental results, which shows good agreement between the two.

1. Introduction

Wood is renewable and sustainable, and it also has the lowest energy consumption and the lowest carbon dioxide emission among many building materials. Thus it is one of the world's most environmentally friendly building materials. Connection is critical for structural timber or steel design. And the ductility and energy dissipation behavior usually depends on the connections for timber structures, since timber elements are regarded as behaving elastically [1,2]. The capability to dissipate energy of ductile connections provides some benefits, such as the integration to the earthquake analysis and in addition to increase the robustness of the structure [3].

A possible solution for the ductile moment-resistant connection is glued-in steel rods connection. Some attractive properties presented by this kind of connections include high strength, high stiffness, and aesthetic appearance. Furthermore it can provide a higher adaptability of geometrically complex connections. The use of this technology began in Denmark about 1980. A great number of research has been carried out on pull-out behavior of glued-in rods joints [4–8] and a comprehensive review of early efforts involving it can be found in the literature [9]. Also some research was carried out on moment-resistant behavior of timber connections with glued-in rods [10–20], which is the focus of this paper.

1.1. Moment-resistant timber connections with glued-in rods

Buchanan and Fairweather [10] executed an experimental investigation on moment-resisting glulam beam–column connections using glued-in rods with and without steel brackets (see Fig. 1). Test results showed that brittle splitting fracture of glulam column occurred in connections using glued-in rods in both beam and column of the connection without steel brackets. As providing some un-bonding length of each rod at beam–column interface, the excellent hysteresis loops showed good ductile behavior almost similar to that of a steel structure. Nevertheless it is inconvenient for the in-situ gluing process due to the requirement of some special conditions [12]. Buchanan and Fairweather [10] therefore designed another group of specimens with steel connecting brackets. Then under a capacity design, it could ensure that the ultimate fracture would be the ductile failure of steel brackets rather than that of wood, adhesives, or other non-ductile component. Moreover, the addition of the steel component allows a practical application and easy assembly of this kind of structures [13].

By the cyclic tests on the ductile moment-resisting glulam timber connections with glued-in rods, Fairweather [14] obtained the best results for glulam members with glued-in rods epoxied into the end-grain of glulam beams and bolted to ductile steel connect-

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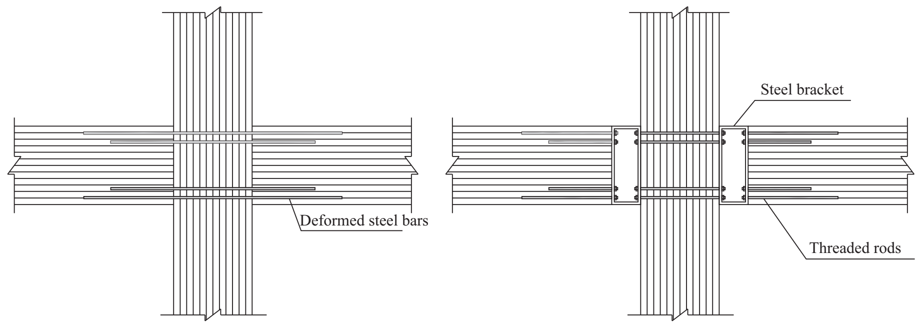

Fig. 1. Moment-resisting glulam beam–column connections using glued-in rods [10].

ing brackets. Furthermore this ductile damage to the brackets allows inspection and replacement after an earthquake.

On the basis of experimental evaluation, Buchanan et al. [15] suggested that yielding of steel connecting brackets is preferred to yielding of the epoxied rods for ductile seismic design. However, the problem is that tension perpendicular to grain stresses would occur due to the shrinkage of the timber while the beams are bolted to rigid steel brackets at high moisture content. And therefore some measures must to be taken, e.g. by providing transverse steel rods, to prevent the splitting or shear failure at the beam end.

Vašek and Vyhnálek [13] provided the steel component by steel box section to the glued-in rod beam–column connections. Furthermore, to prevent the wood splitting failure at the beam end, a vertical connecting rod was introduced between the upper and the lower steel tube. The test work showed a quite positive result in which the strength of connections was similar to that of glulam beam.

Fragiacomo and Batchelar [17,18] provided a design process and long-term experimental investigation on timber frame moment joints with glued-in steel rods. The design method for the connections was based on the use of the transformed section method at the beam–column interface so as to evaluate the stress distribution in the rods and timber. Also the failure type, ductile or brittle, could easily be assessed. However, it was difficult to calculate the stiffness of rotational spring due to the shortage of information about it.

1.2. Component method

To investigate the moment-resistant timber joint M–ϕ curve or its characteristic properties of strength, initial rotational stiffness and rotational capacity, the suitable design model is necessary. A possible solution is the introduction of the component method [21,22], which is successfully used in steel and steel–concrete composite connections, into moment-resistant timber connections. The originality of the component method is that it considers any joint as a set of "individual basic components" [21]. Each component is represented by an extensional spring, which is independent and can be connected to other springs or to rigid elements [23]. Once the individual constitutive components are identified and characterized, the overall behavior of the connection can be modelled through the so-called assembly procedures [24].

Moment-resistant timber connections were investigated using the component method mentioned above in the literatures [13,19,20,24,25]. By using the component method, Tomasi et al. [19] and Andreolli et al. [20]. carried out detail investigation on ductile moment-resistant timber connections with the combination of glued-in rods and steel connecting studs. It was discovered that the method could well predict the joint response in terms of failure mode, ultimate resistance, stiffness, and rotation capacity.

1.3. Objectives of the study

The objective of this research was to develop and validate a theoretical model based on the component method and to predict the strength and stiffness properties of moment-resistant glulam beam–column connections with glued-in rods.

2. Theoretical model

2.1. Model methodology

In accordance with Jaspart [21] and EN 1993-1-8 [22], a design moment–rotation characteristic should define the following three main structural properties: (a) moment resistance $M_{j,Rd}$; (b) initial rotational stiffness $S_{j,ini}$; and (c) rotation capacity (maximum rotation at failure) ϕ_{Cd}.

Essentially, the application of the component method requires the following steps:

- identification of the active components for the studied joint;
- evaluation of the mechanical characteristics of each individual basic component (specific characteristics—design strength, initial stiffness, etc.);
- "assembly" of the components into a mechanical model made up of extensional springs and rigid links.

2.2. Basic components of the joint

In the connection shown in Fig. 2(a), which is theoretically and experimentally evaluated in this paper, several separate steel box sections are connected with glued-in rods or glued-in steel tube to glulam beam end and with connecting bolts to glulam column. The steel box section of the middle one combined with glued-in steel tube was designed to mainly transfer the shear force and to prevent shear failure of the connection, while the other two steel box sections with glued-in rods were used to transmit the bending moment.

As to the assembling of the connections, the rods and steel tube were firstly glued into the holes at the beam end. After the solidification of glue, the glulam beam was connected with glulam column using steel box sections and bolts.

The basic components were depicted in Fig. 2(a) and (b), while the naming of each component was provided in Table 1.

The T-stub concept was introduced into the context of the resistance of end plate connections by Zoetemeijer [26] and adopted in EN 1993-1-8 [22] for both end plate and steel column flange in bending. To simplify the calculating model of this investigation, the steel box section with a transverse web stiffener was transformed into two kind of equivalent T-stubs, as shown in Fig. 3, in