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Improved performance of reinforced rounded dovetail joints

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HIGHLIGHTS

- Rounded Dovetail Joints (RDJ) are a viable option to connect timber members.
- Structural performance of hand- and machine routed joints is similar.
- Design equation for RDJ yields conservative predictions.
- RDJ performance can be improved through reinforcements.

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ABSTRACT

The paper presents experimental investigations on different methods to increase the stiffness of Rounded Dovetail Joints (RDJs). Departing from a reference geometry, the specific methods were (i) oversizing the dovetail tenon part for a tighter fit; (ii) reinforcement with self-tapping screws; (iii) reinforcement with an adhesive layer; and (iv) a combination of adhesive layer and self-tapping screws. The specimens from the reinforced test series were compared to regular RDJ specimens and to beam to joist connections by means of self-tapping screws only. It was demonstrated that all methods significantly increased the joint stiffness of RDJs. Furthermore, the research showed that there is no difference in structural performance between hand-routed joints and CNC-routed joints, and that a previously suggested design equation for RDJs yields conservative predictions when compared to the experimentally obtained 5th percentile values.

1. Introduction

1.1. Timber joints

In timber engineering, three main methods to connect load bearing timber structures can be distinguished: (i) mechanical fasteners, (ii) adhesively bonding; and (iii) direct contact. Substantial research on connections with laterally loaded dowel-type fasteners (e.g. bolts, drift pins, nails, and screws) with regard to their geometrical disposition and the corresponding failure modes has been carried out e.g. [1–4]. The work showed that such joints are potentially ductile due to the nonlinear embedment behaviour of the wood in compression, and the bending of the steel fasteners; brittle failure mechanisms can be avoided by large fastener spacing or by using reinforcement methods [4]. Mechanical fasteners represent the most common connection method and most contemporary timber design standards such as EN 1995 [5] cover their design in much detail.

The second category, adhesive bonding, provides a durable and structurally efficient approach provided that the connections are adequately designed, the work is done by skilled personnel, and strict quality control during manufacturing is exercised [6,7]. Adhesively bonded joints often outperform joints achieved by mechanical fasteners; specifically, they exhibit higher stiffness. The use of adhesive bonding is described as a development with the potential to “free timber of the metal needed presently to make joints” [8].

The third category, direct contact in wood-to-wood joints, represents the most traditional connection method for timber structures already known in antiquity [9]. Until the middle of the 20th century, carpentry type joints, including dovetails, were commonly used with their design and manufacturing based on the skills of experienced wood workers. Both in Europe and Asia, a variety of dovetail configurations were employed [10–12] but high labor costs and conservative designs approaches rendered them uncompetitive. An increase of interest in heavy-timber-frame buildings occurred in the late 20th century [13] and the advent of modern computer-numerically-controlled (CNC) heavy timber machinery has re-established the cost effectiveness of

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wood-to-wood connections and led to a small-scale revival [14–16]. Most research on such joints, however, focused on their performance with respect reinforcing historical structures [17–20].

Besides the three main connection categories, it is conceptually possible to combine these and achieve a "hybrid" connection [21–24]. The concept of adding an adhesive layer to mechanical fasteners seems elegant; bolts can be considered as back-up system, carry loads originating from different directions, help ensure the fire resistance, and might avoid problems related to the long-term performance [21]. The description of the load transfer in hybrid joints is complex when there is a mismatch in stiffness [22] and additional strength can only be achieved for properly designed combinations. Current timber design standards such as EN 1995 [5] do not account for the cumulative contributions of fasteners with different stiffness and usually discard hybrid combinations.

1.2. Rounded Dovetail Joints

Rounded Dovetail Joints (RDJs) consist, similar to mortise and tenon joints, of a female and a male part with a rounded shape similar to a dovetail, see Fig. 1a. These joints are versatile for connecting structural timber members, most commonly they connect a joist to a main beam. While RDJs were initially adapted to be produced with CNC equipment, low-cost hand-routing systems allow small scale companies to produce RDJs [25]. A series of experimental studies on RDJs indicated that the geometry, summarized in Fig. 2b, governs their load transfer mechanism and capacity [14–16,26–36]. "These studies highlight the fact that failure of RDJs under shear loading is typically brittle, governed by the joist, and occurs in the elastic range of the load-deformation curve" [36]. Furthermore, the influence of several manufacturing parameters, including the impact of moisture content (MC) during manufacturing and testing, was investigated [16]. The research demonstrated that RDJs produced and tested with constant and low MC exhibit higher stiffness when compared to those produced and tested under different moisture conditions.

The joist members of RDJs behave similar to end notched beams, both represent details where brittle failure modes associated with crack propagation are an issue. The allowable load $V_{\mathrm{r,J}}$ of a notch or the joist of a RDJ can be estimated by reducing the allowable shear stresses acting on the dovetail area [38]:

$$V_{\mathrm{r,J}} = \frac{2}{3} \cdot A_1 \cdot f_{\mathrm{S}} \cdot k_{\mathrm{V}} \qquad (1)$$

where A_1 is the dovetail area, f_{S} the shear strength, and k_{V} the reduction factor that accounts for stress concentrations. Individual manufacturers obtained product approvals [37] that provide a simplified and conservative calculation for A_1:

$$A_1 = b_1 \cdot (h_1 - r_1) \qquad (2)$$

where b_1 is the dovetail width, h_1 the dovetail height, and r_1 the dovetail.

In early design proposals for end-notched beams, the reduction factor k_{V} was set equal to the ratio of notch height h_1 to beam height h. The US timber design standard NDS [39] computes k_{V} for end notches as the square of the ratio of h_1 to h. Analytical approaches based on linear elastic fracture mechanics were developed [38] and closed-form equations are now included in many

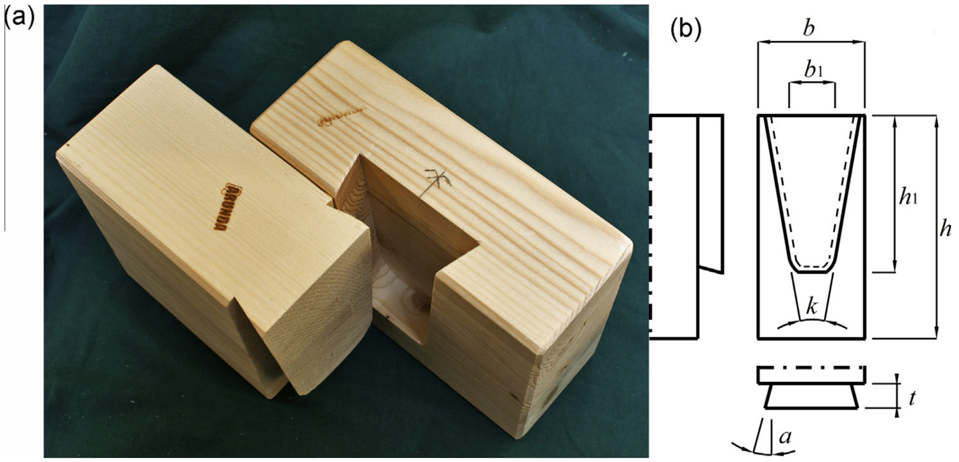

Fig. 1. RDJ: (a) picture; (b) definition of geometry parameters.

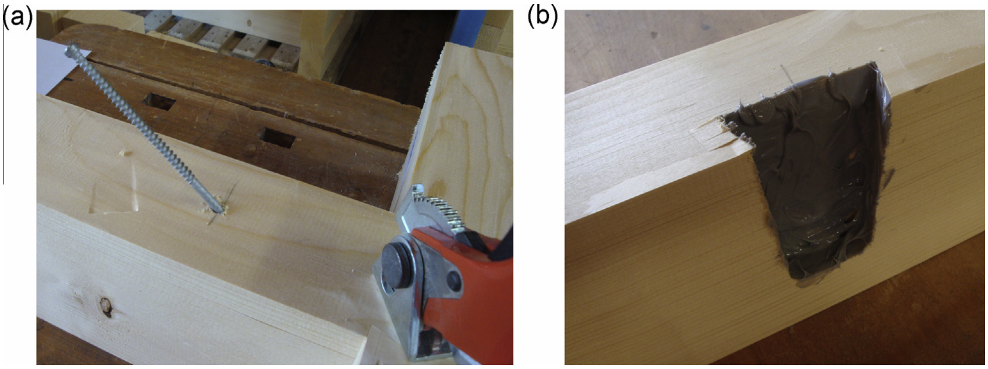

Fig. 2. Detail showing reinforced RDJ: (a) use of STS; (b) use of adhesive layer.