TFEC
• TIMBER FRAME •
ENGINEERING COUNCIL

Bulletin No. 2016-5

First Release:	January 2016	**Revised:**	
Prepared by:	Thomas Tannert[1]		
Title:	Design of Rounded Dovetail Joints		

Abstract

Rounded Dovetail Joints (RDJ) are a viable connection concept that can be successfully applied in heavy timber construction in North America given appropriate design guidelines. Experimental and numerical research provided input data to develop design guidance. This Technical Bulletin covers the fundamentals and gives some practical advice on reinforcing RDJ.

Introduction

Rounded Dovetail Joints (RDJs), named after the rounded shape similar to a dovetail, as illustrated in Figure 1 (left), are a versatile concept for connecting structural timber members, with the most common application being the joist-to-beam connection. A variety of dovetail configurations were employed throughout Europe and Asia with their design usually governed by practical considerations. High labor costs and inefficiencies due to overly conservative designs rendered these joints uncompetitive. Developments in CNC wood processing machines re-established the cost effectiveness for carpentry type wood-to-wood joints. While RDJs were originally adapted to be CNC produced, new hand-routing systems allow small scale companies to produce and use RDJs.

A number of experimental studies on RDJs indicated that geometric features, summarized in Figure 1 (right), govern the load transfer mechanism in the joints [1-7]. These studies highlight the fact that failure of RDJs under shear loading is typically brittle, as illustrated in Figure 2, and occurs in the elastic range of the load-deformation curve. The influence of manufacturing parameters, including moisture content, was investigated demonstrating that joints manufactured and tested with low and constant moisture content outperform those manufactured and tested under other conditions.

[1] Assistant Professor, Civil Engineering and Wood Science, University of British Columbia, Vancouver BC V6T1Z4

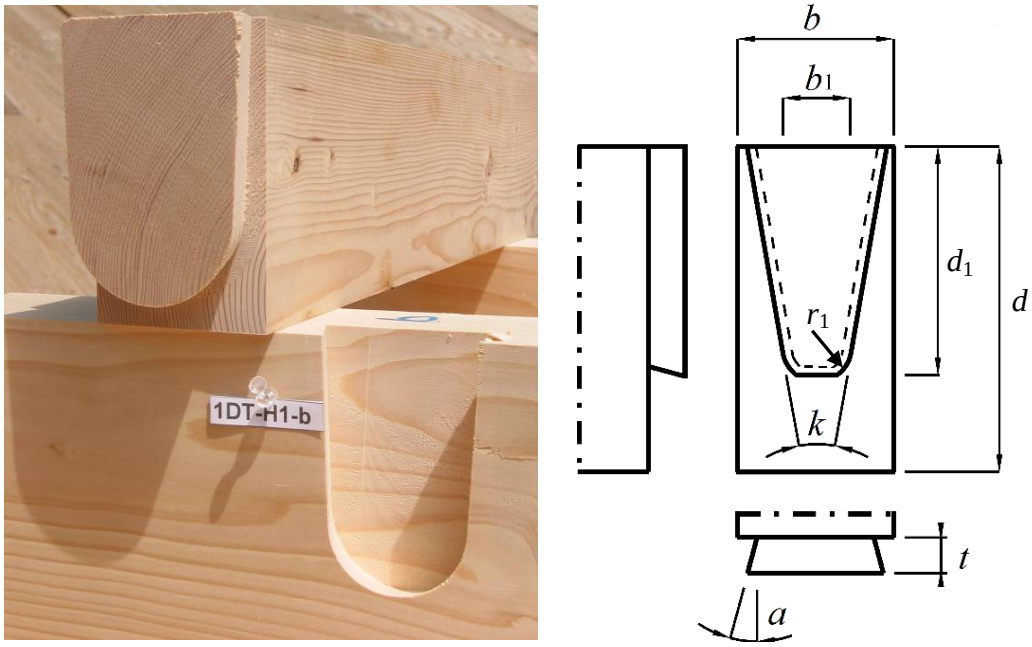

Figure 1 – Rounded Dovetail Joint: photo (left) and geometric parameters (right)

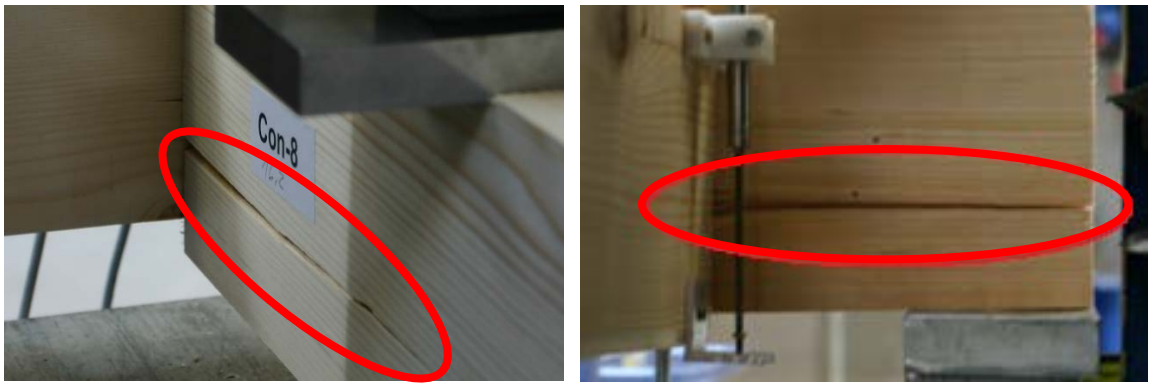

Figure 2 – Brittle failure Rounded Dovetail Joint: joist (left) and main beam (right)

Minimum distances for spacing RDJ need to be considered [4]:

- Main beam width for joints on one side: t + 2 in;
- Main beam width for joints on both sides: 2·t + 4 in;
- Distance between two joist connecting to one main beam: 20 in;
- Distance between RDJ and main beam end: 20 in.

Design of Rounded Dovetail Joints

The joists of RDJs behave similar to end notched beams - both details represent situations where brittle fracture via crack propagation is an issue. The allowable load of the dovetail joist member can be estimated by reducing the allowable shear stresses acting on the dovetail area:

$$V'_{r,J} = \frac{2}{3} \cdot A_1 \cdot F'_V \cdot k_V \tag{1}$$

where: $V'_{r,J}$ = allowable load for joist, lbf

A_1 = dovetail area, in^2

F'_V = shear strength parallel to grain, psi,

k_V = reduction factor due to stress concentration

Individual manufacturers obtained product approvals, one of them, “baukunst philipphaus” [8], provides a simplified calculation of the effective dovetail area, A_1, as follows:

$$A_1 = b_1 \cdot (d_1 - r_1) \tag{2}$$

where: b_1 = dovetail width, in

r_1 = dovetail radius, in,

d_1 = dovetail height, in

As can be seen from equation 2, neither the dovetail angle, *k*, the flange angle, *a*, nor the flange length, *t*, have any direct impact on the allowable load for the joist. Commonly as a result of the cutting tool geometry, *a* and *t* are approx. 15º and 2 in, respectively, and *k* results from the ratio of *b* to b_1.

Analytical approaches based on linear elastic fracture mechanics are now given in design standards such as Eurocode 5 [9]. For simplicity, the NDS approach for end notches [10] that computes k_V as the ratio of dovetail height, d_1, to beam height, *d*, can be used:

$$k_V = \left[\frac{d_1}{d} \right]^2 \tag{3}$$

As design criterion for the main beam, an empirical formula that estimates the design load based on the expected location of the crack that develops on the mortise base can be used:

$$V'_{r,M} = 514 \cdot \left(d_M - d_1 + \frac{b_1}{2} \right) \tag{4}$$

where: $V'_{r,M}$ = allowable load for main beam, lbf

d_M = main beam height, in

Reinforcing Rounded Dovetail Joints

Depending on connection accuracy, small loads are sufficient to cause significant initial alignment behaviour of RDJ, see Figure 4. Therefore joints should be tight fitting and manufactured using timber that has a moisture content close to the equilibrium moisture content that the timber will achieve in use. Further, significant relative vertical deformation between members may occur at loads as low as 30% of the joint capacity. As a consequence, reinforcements are a promising possibility to improve the structural performance of RDJs. Self-tapping screws (STS) do usually not require pre-drilling and are therefore faster to install than traditional lag screws or wood screws, making them a cost efficient connector appropriate for many timber structures [11]. STS with continuous threads are hardened to produce a high yield moment, tensile, and torsional strength. The cutting thread and surface coating are designed to avoid the need for pre-drilling, thereby ensuring easy assembly.

In one project [6], three reinforcement methods for RDJs (d = 10.8 in; b = 4.9 in; d_1 = 8.0 in; b_1 = 2.0 in) using STS with continuous threads and a diameter of 1/3 in were evaluated:

- R1: joist reinforcement with STS at an angle of 90^0 between the screw axis and the wood grain of the joist (Layout 1 in Figure 3; blue curves in Figure 4 left);
- R2: reinforcement of joist and main beam with STS at an angle of 55^0 between the screw axis and the wood grain of the joist (Layout 2 in Figure 3; green curves in Figure 4 left);
- R3: reinforcement of joist and main beam with angled STS crossing each other (Layout 3 in Figure 3; red curves in Figure 4 left).

All three reinforcement methods significantly increased RDJ capacity compared to non-reinforced RDJ (black curves in Figure 4 left), and stiffness was significantly higher when main beam and the joist were reinforced with STS and ductility was slightly higher, see Figure 4 left.

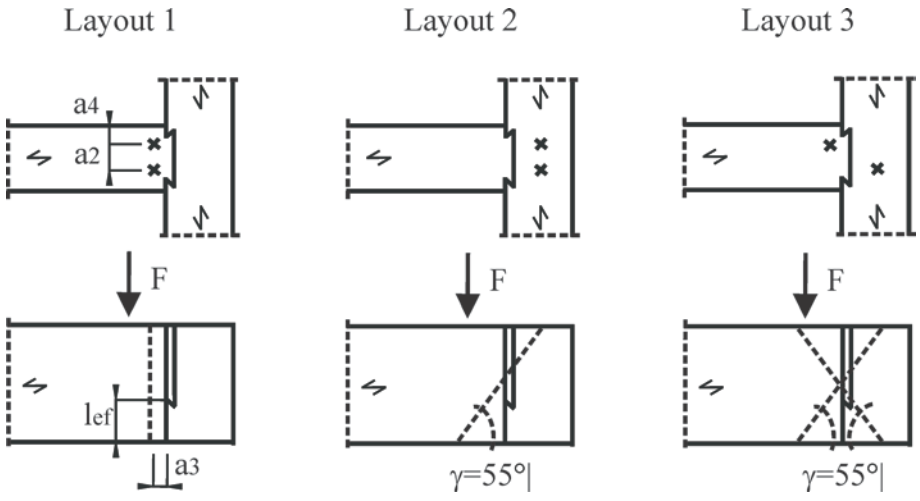

Figure 3 – Layouts of RDJ reinforcements

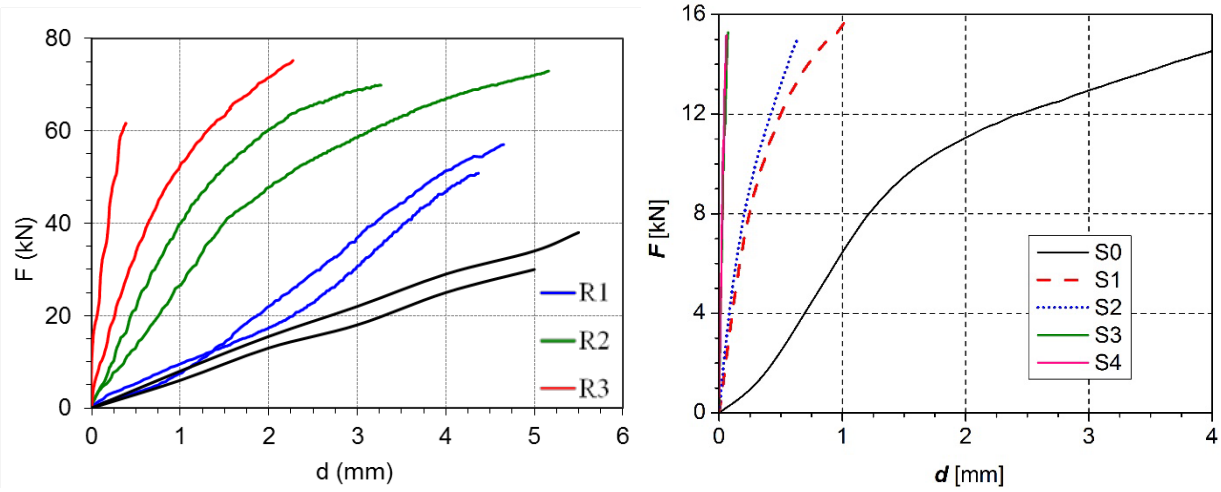

Figure 4 – Load-deformation curves illustrating reinforcement effects

Subsequent work from Switzerland [7] studied further reinforcement methods on smaller RDJs (d = 4.7 in; b = 3.1 in; d_1 = 3.1 in; b_1 = 2.0 in) to improve their stiffness:

- S1: oversizing the tenon width by approx. 1/10 in to create a tighter initial fit;
- S2: reinforcement of joist and main beam with STS (STS with continuous threads and a diameter of 1/4 in placed at an angle of 45°were used);
- S3: reinforcement with an adhesive layer (a stiff and brittle two-component epoxy – SikaDur330 – was used) between joist and beam; and
- S4: reinforcement with a combination of self-tapping screws and adhesive layer.

The research allowed drawing the following conclusions, as illustrated by the average load-deformation curves in Figure 4 right:

- The structural performance of these joints can be significantly improved by simple and economic means of reinforcements.
- The relative vertical joint deformation can be decreased by oversizing the tenon by approx. 1/10 in to create a tight fitting joint, or by the use of STS. Within the parameters investigated, these methods did not increase joint capacity.
- Applying an adhesive layer further increases the joint stiffness and eliminated the relative vertical displacement between joist and beam
- A combination of both methods (adhesive layer and STS) did not provide further improvements compared to the adhesive layer by itself.

References

[1] Kreuzinger H, Spengler R. 1999. Zum Tragverhalten von maschinell abgebundenen Zapfenverbindungen aus Konstruktionsvollholz zwischen Haupt- und Nebenträger. Report LKI 7313, Technische Universität München, Germany.

[2] Hochstrate M. 2000. Untersuchungen zum Tragverhalten von CNC gefertigten Schwalbenschwanzverbindungen. Diploma Thesis, FH Hildesheim, Germany.

[3] Bobacz D. 2002. In CNC-Technik gefertigte zimmermannsmäßige Verbindungsmittel – Untersuchung des Schwalbenschwanzzapfens. Thesis, Universität für Bodenkultur, Vienna, Austria.

[4] Werner H. 2002. Queranschlüsse mit Schwalben-schwanz-Zapfenverbindungen, Vorschlag für die Bemessung. Verband-High-Tech-Abbund. Stuttgart, Germany.

[5] Dietsch P. 2005. Development of a finite-element model for parameter studies of a dovetail joint. Thesis, Technische Universität München, Germany.

[6] Tannert T. 2008. Structural performance of rounded dovetail connections. Thesis, The University of British Columbia, Vancouver, Canada.

[7] Tannert T, Keller N, Frei R, Vallée T. 2012. Improved Performance of Rounded Dovetail Joints. World Conference on Timber Engineering, Auckland, New Zealand.

[8] Allgemeine Bauaufsichtliche Zulassung Z-9.1-649. 2008. Dovetec Schwalbenschwanz-zapfen-Verbindung in Bauteilen. Deutsches Institut für Bautechnik, Berlin, Germany.

[9] EN 1995-1-1. 2008. Eurocode 5: Design of Timber Structures – Part 1-1: General – Common Rules and Rules for Buildings. CEN European Committee for Standardization, Brussels, Belgium.

[10] NDS 2015. National Design Specifications for Wood. American Wood Council, Leesburg, Virginia.

[11] Dietsch P, Brandner R. 2015. Self-tapping screws and threaded rods as reinforcement for structural timber elements – A state of-the-art report. Constr Build Mater, 97: 78–89.