Comparison of behaviour of laterally loaded round and squared timber bolted joints

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ABSTRACT. In the current European standards for design of timber structures, the issue of timber-to-timber joint type is addressed only to squared timber, which makes the pinpointing of the round timber bolted joints load carrying capacity near-unfeasible due to the insufficient support in the current standards. There have been made series of tests of round timber joints in different inclinations of the loading force and also the reference tests of squared timber joints to compare the behaviour of this type of joints. Mechanical behaviour of the round and the squared timber bolted joints was tested in the laboratory of the Faculty of Civil Engineering in Ostrava. This paper presents results of static tests in tension at an angle of 0°, 90° and 60° to the grain of squared and round timber bolted joints. Load carrying capacity was determined according to the applicable standards and theories of fracture mechanics. The test results of laboratory tests were then compared with the results of theoretical calculations.

KEYWORDS. Round timber; Bolt; Joint; Load carrying capacity.

OPEN ACCESS

Citation: Labudkova, J., Cajka, R., Numerical analyses of interaction of steel-fibre reinforced concrete slab model with subsoil, Frattura ed Integrità Strutturale, 39 (2017) 56-61.

Received: 11.07.2016
Accepted: 14.09.2016
Published: 01.01.2017

INTRODUCTION

The strength of wood varies depending on the force direction relative to the orientation of the grains. The highest value reaches the tensile strength parallel to the grains, the average value indicates 120 N·mm^{-2}. This high strength is mainly due to the shape of cells and fibrous cell wall structure. Tensile strength perpendicular to the grain is, on the other hand, the smallest strength of wood at all. The average tensile strength perpendicular to the grain is in the range between 2 N·mm^{-2} and 5 N·mm^{-2}. This corresponds to 1/20 of the tensile strength of the wood parallel to the grain [1]. Low value of tensile strength perpendicular to the grain is caused by orientation of the binding forces. Hydrogen bonds and van der Waals forces connect grains in the transverse direction. The tensile stress of timber perpendicular to the grain is desirable in use in the support structure.

This paper focuses on the behaviour of round timber bolted joints. In the current European standards for the design of timber structures [2], the issue of timber-to-timber joint type is addressed only to squared timber, which makes the pinpointing of the round timber bolted joints load carrying capacity near-unfeasible due to the insufficient support in the current standards. To compare the behaviour of this type of connections, a series of laboratory static tests in different inclinations of the loading force to the grain has been made. The reference tests of squared timber joints were also carried out [3]. Mechanical behaviour of the round and the squared timber bolted joints were tested in the laboratory of the Faculty of Civil Engineering in Ostrava.

Samples type	Value	Tension orientation at an angle to the grain								
		0°			60°			90°		
		$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Round timber	Number of samples		12			12			12	
	Density (kg·m^{-3})	**412.6**	42.1	10.2	**405.9**	26.4	6.5	**414.9**	46.2	11.1
	Moisture (%)	**11.6**	1.1	9.4	**11.3**	1.0	8,9	**11.4**	1.1	9.6
Squared timber	Number of samples		9			10			12	
	Density (kg·m^{-3})	**426.8**	13.77	3.2	**443.6**	14.6	3.3	**454.4**	50.1	11.0
	Moisture (%)	**11.2**	0.6	5.3	**12.2**	0.5	4.1	**11.6**	0.5	4.3

Table 1: Characteristics of tested wood ($\bar{x}$ is the arithmetical average; SD is the standard deviation; CV is the coefficient of variation).

The special steel element for testing was prepared (Fig. 1). In order for the load direction to be perpendicular (or at an angle 60°) to the grain, the samples were subjected to a simple tensile test with the loading force being increased gradually. The test parameters were invariable for all samples.

Each round timber sample subjected to a simple tension test had the same test parameters. The tension force on samples loaded parallel to the grain was increased gradually. The selected rate of displacement of the press jaws was optimal. Each specimen failure occurred in time boundary of 300 ± 120 sec. It corresponds to the current European standard.

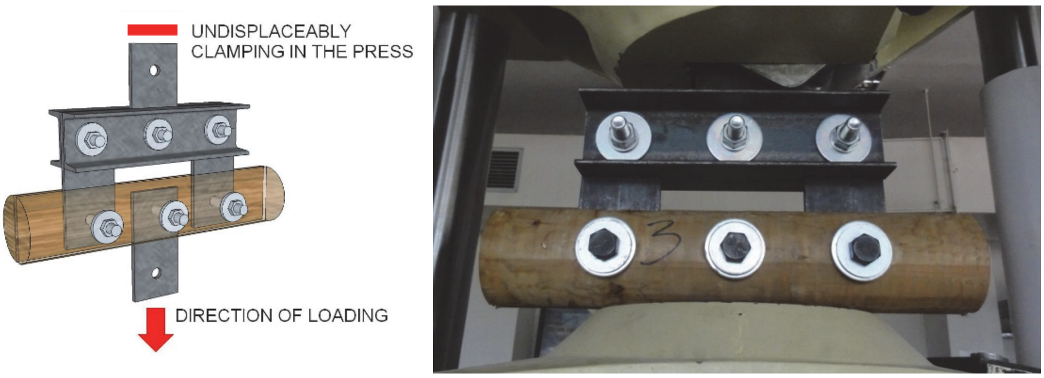

Figure 1: Steel product for testing in tension perpendicular to the grain and sample in press machine.

MATERIAL AND TEST METHOD

As spruce wood is the most common type of timber, it was used as samples for testing. A few non-destructive tests were carried out before the onset of the static tests in the press, [4, 5]. Dimensions of the test samples were adjusted to the equipment possibilities of the laboratory at the Faculty of Civil Engineering. Thus, the specimen length was 450 mm (for tests in tension at an angle of 0°) and 560 mm (for tests in tension at an angle of 60°and 90°), respectively, and the specimen diameter was 120 mm. The bolts of high strength steel (category 8.8) were used. The diameter of the bolts was 20 mm. The connection plates were made of steel S235 with thickness of 8 mm, length of 290 mm and width of 80 mm. The diameter of holes in steel plates was 22 mm and diameter in timber elements was 20 mm. The distance between holes and the free end in timber was 140 mm, in steel 50 mm [6]. The squared timber was used with the cross section of 60×120 mm, the other geometry of joint was the same as in the case of round specimens.

CALCULATION OF THE LOAD CARRYING CAPACITY OF JOINT

For comparison with applicable European standards [2] there was carried out a numerical calculation of the joint resistance. The investigated joint is of the double-shear dowel type with an embedded steel sheet, which forms the central element of the joint. Failure mechanisms for the investigated type of joint are shown in Fig. 2.

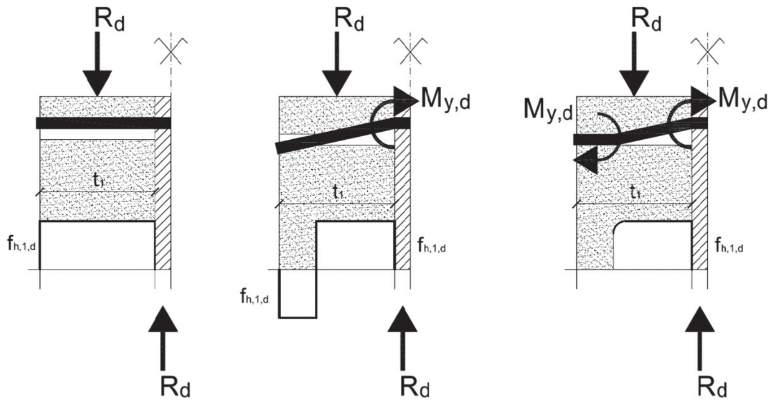

Figure 2: Failure mechanisms of double-shear dowel type steel to timber joint.

According to Johansen's theory [7] that underlies Eurocode 5, the characteristic load carrying capacity of one coupling element in one cut at the steel-to-timber connection, where the steel plate is the middle joint element, is determined by expression:

$$F_{v,Rk} = min\begin{Bmatrix} f_{h,k} \cdot t_1 \cdot d \\ f_{h,k} \cdot t_1 \cdot d\left[\sqrt{2+\dfrac{4M_{y,Rk}}{f_{h,k}\cdot d\cdot t_1^2}}-1\right] \\ 2,3\sqrt{M_{y,Rk}\cdot f_{h,k}\cdot d} \end{Bmatrix} \tag{1}$$

where:

$F_{v,Rk}$ is the characteristic load-carrying capacity per shear plane per fastener (N) without rope effect,
$f_{h,k}$ is the characteristic embedment strength of timber member (N·mm^{-2}),
t_1 is the timber or board thickness or penetration depth (mm),
d is the fastener diameter (mm),
$M_{y,Rk}$ is the characteristic fastener yield moment (N·mm).

Relationships mentioned above are based on the theory of Johansen [7], which the calculation of dowel type joints in Eurocode 5 is based. This theory is underscored by a series of laboratory measurements [8]. Johansen's theory is based on the assumption that the load carrying capacity of the fastener is limited by the load capacity in bearing walls of the bolt hole in at least one of the constituent elements, or simultaneous occurrence of the embedment strength and plastic hinge in the dowel.

The mechanism of failure depends on the geometry of the connection and the properties of the construction materials, particularly on a plastic torque of dowel and tensile deformation of the wall of dowel hole in the case of timber or wood-based material [9, 10].
From equations for determining the load carrying capacity of the connecting means it is evident that calculation for determining the load carrying capacity of connections depends on characteristics of wood density and thickness of the timber embedding the bolt. The decisive parameter is the diameter of the bolt and the material embedment strength [11].

RESULTS

The test results of bolt connections of the squared and round timber with embedded steel plates laterally loaded at different angles to the grain give similar values of resistance, which are higher than the load capacity determined according to the Eurocode 5. It means that the equations for determining the resistance of joints Eurocode 5, which were derived for squared timber, can be applied to the joints of round timber.

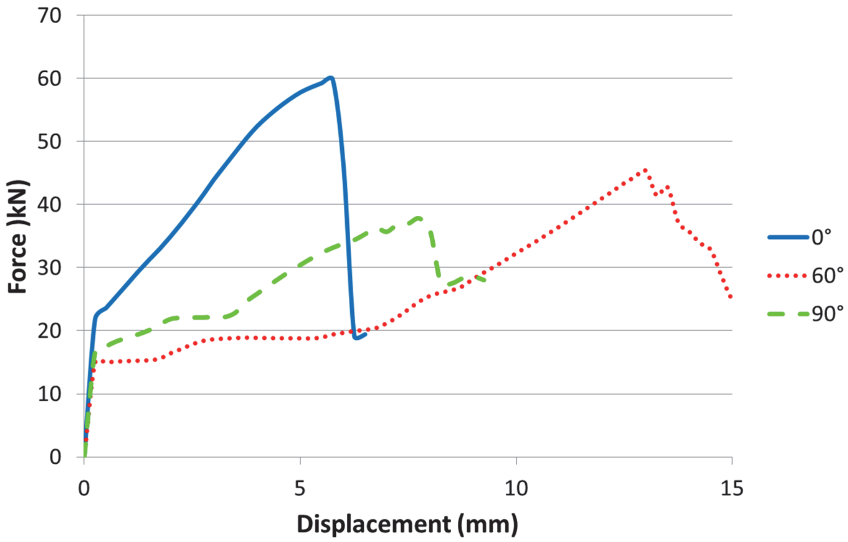

Figure 3: Comparison of the test records of squared timber samples loaded in tension at different angles.

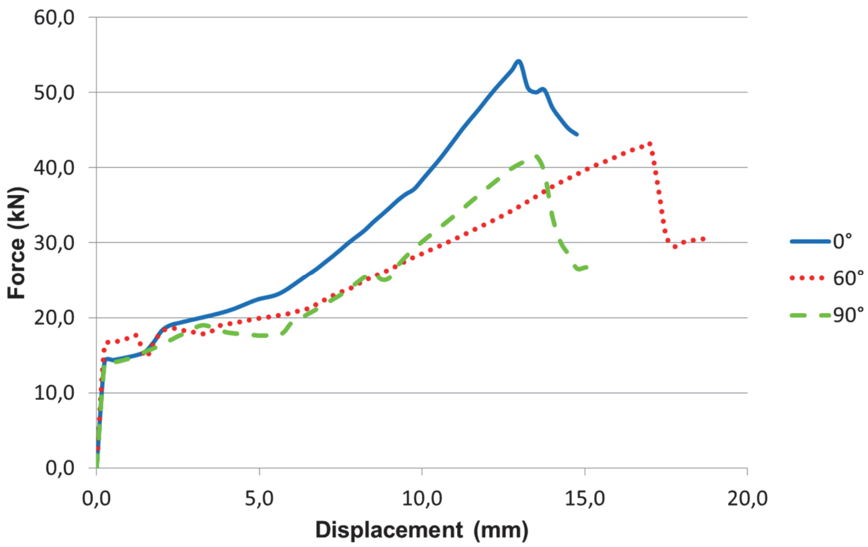

Figure 4: Comparison of the test records of round timber samples loaded in tension at different angles.

From the course of deformation of the round timber joints and squared timber joints it is evident that resistance and stiffness at different angles reaches comparable values. Only squared timber joints samples exposed to force parallel to the grain exhibit less deformation than the corresponding round timber joints. Connections with squared timber also have significant plastic deformations prior to the collapse of the joints, in contrast to round timber joints. Different behaviours during testing at different angles of the loading force to the grain are shown in Fig. 3 and 4. Summary of the test results of round timber and squared timber samples subjected loading force at different angles to the grain are shown in Tab.2.

Samples type	Value	Loading force orientation at an angle to the grain								
			0°			**60°**			**90°**	
		$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Round timber	Density (kg·m^{-3})	**412.6**	42.1	10.2	**405.9**	26.4	6.5	**414.9**	46.2	11.1
	Capacity from test (kN)	**64.9**	6.3	9.7	**41.7**	4.8	11.5	**40.6**	5.0	12.5
	EC5 (kN)		**38.7**			**30.8**			**28.5**	
Squared timber	Density (kg·m^{-3})	**426.8**	13.77	3.2	**443.6**	14.6	3.3	**454.4**	50.1	11.0
	Capacity from test (kN)	**57.7**	5.1	8.8	**49.7**	2.9	5.8	**32.5**	3.6	11.1
	EC5 (kN)		**39.3**			**32.8**			**31.4**	

Table 2: Summary of the carrying capacity test results and the calculated values of load carrying capacity according to EC5 ($\bar{x}$ is the arithmetical average; SD is the standard deviation; CV is the coefficient of variation).

Figure 5: Damaged round timber samples loaded in tension at different angles.

Figure 6: Damaged squared timber samples loaded in tension at different angles.

Conclusions

The test results of bolt connections of squared and round timber with embedded steel plates loaded at different angles to the grain give similar values of resistance, which is higher than the load capacity determined according to the Eurocode 5. It means that the equations for determining the resistance of joints according to Eurocode 5, which were derived for squared timber, can be applied to the joints of round timber. Fracture destruction is principal especially for wood joints with higher density. That fact was confirmed in the static tests.

Acknowledgement

This outcome has been achieved with funds of Conceptual development of science, research and innovation assigned to VŠB - Technical University of Ostrava by Ministry of Education Youth and Sports of the Czech Republic in 2016 (No. IP2216611).

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