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ROUND TIMBER BOLTED JOINTS EXPOSED TO STATIC AND DYNAMIC LOADING

Antonín Lokaj, Kristýna Klajmonová
Všb-Technical University of Ostrava, Faculty of Civil Engineering Department of Building Structures
Ostrava, Czech Republic

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ABSTRACT

The Aim of this article is a presentation of the results of static and dynamic tests of round timber bolted connections with slotted – in steel plates. Round timber joints static tests in tension were carried out on a pressure machine EU100 in the laboratory of the Faculty of Civil Engineering VŠB-TU Ostrava. The results of the laboratory tests have been statistically evaluated and completed by the graphical records of deformation response to loading. Round timber joints multicyclic dynamic (fatigue) tests in tension were carried out on a pulsator INSTRON in the laboratory of The Institute of Theoretical and Applied Mechanics AS CR in Prague and in the laboratory of Transport Research Institute in Žilina, Slovakia. Possibilities of reinforcing statically loaded joints are also presented

KEYWORDS: Round timber, bolt, joint, carrying capacity, reinforcement.

INTRODUCTION

Timber constructions made of round timber are becoming increasingly popular nowadays.

It encompasses footbridges, bridges, watchtowers (the highest round timber watchtower in central Europe was built in Lázně Bohdaneč in 2011; the tower is almost 53 m high – Fig. 1. (Straka and Šmak 2011)) or playground equipment. If these constructions are designed with a load supporting truss system, element connections are often made from bolts with slotted-in steel plates (gusset plates). As the element connections are the weakest part of structures, mechanical reinforcement possibilities of round timber bolted joints were also researched and tested. All these static tests were performed on the laboratory equipment of the Faculty of Civil Engineering at VŠB-TU Ostrava.

Fig. 1: Watchtower near Lázně Bohdaneč – round timber bolted joints with slotted-in plates.

The issue of timber-to-timber joints and steel-to-timber joints is solved by means of bolts in the current European standards for design of timber structures (Eurocode 5, 2004), but these standards cover only connections from squared timber (Blesák et al., 2012, Lokaj and Klajmonová, 2013a). Connections from round timber don`t have sufficient support in existing Eurocodes. Problem is also in determining cyclically loaded round timber joints (fatigue loading in wood e.g. (Malo et al. 2002) and (Smith et al. 2003)) or their combination with steel components. Static carrying capacity of bolted joints of round timber was explored by the researchers in Great Britain, at the Czech Technical University in Prague (Kuklík 2005) and in other research centres. Bolted joints of steel beams and glulam elements tests results are showed in Lokaj et al. (2010).

It is necessary to know the response of a construction and its connections to static and dynamic loading for reliable structural design of constructions (such as bridges, footbridges, towers or watchtowers) which are subjected to dynamic loading. In the first phase, the most common type of a joint was chosen: A bolted joint with slotted - in steel plates subjected to axial tension. Test samples were produced then. Samples bolt connections of round timber elements with slotted - in steel plates were tested for carrying capacity and the deformation of single tension – up to the failure of a connection. Carrying capacity and the deformation of connections under static loading were measured in this test, and the results were compared with the calculation of carrying capacity according to the current applicable European standard for design of timber structures – Eurocode 5 (indicating relations for steel-to-timber joint of squared timber). These tests were performed on the laboratory equipment of the Faculty of Civil Engineering at VŠB - Technical University of Ostrava. Based on these tests results, intensity of dynamic loading has been set, and the connections have been tested under multicyclic loading on a pulsator INSTRON in the laboratory of The Institute of Theoretical and Applied Mechanics AS CR in Prague, and in laboratory of Transport Research Institute in Žilina, Slovakia.

MATERIAL AND METHODS

Description of the static test samples

Spruce round timber with a diameter of 120 mm and a sample length of 450 mm was used. Bolts made of high strength steel of a category 8.8 (f_y = 640 MPa, f_u = 800 MPa) with a diameter of 20 mm were used. Connection plates made of steel S235 with a thickness of 8 mm and width of 70 mm were used. The holes for bolts in steel plates had a diameter of 22 mm. Holes for bolts with a diameter of 20 mm were made in the round timber. Forty-seven unreinforced test samples were produced reasonably. The tensile tests were conducted on the press EU100 with a recording system (Fig. 2).

A few nondestructive tests were carried out before the start of the static tests in the press. Aim of these tests was to determine the quality of a round timber material, particularly its moisture and density. The test samples were weighed on a laboratory scale, their moisture and dimensions were measured. A mass density was determinated based on the measured values. The average moisture was 12.4 %. The average value of an apparent density reached 487 $kg.m^{-3}$. The average thickness of the annual rings was 3.21 mm; it confirms the relatively high measured density values and the quality of the tested round timber.

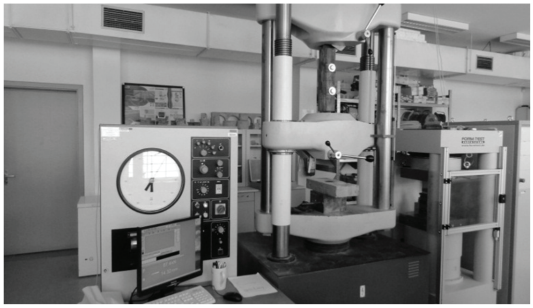

Fig. 2: Tested sample in the press EU100 with a sample.

Course of the static tests

The testing was proceeded in a press EU100, while the tension force was increased gradually. The chosen rate of the displacement of the jaws of the press seems to be optimal, because the failure of all the tested samples appeared in a time-boundary of 300±120 sec, which corresponds to the interval of laboratory tests for short–time strength according to the current European standards for timber structure Eurocode 5 (2004).

Reinforcement design

In case of a sample failure, the upcoming samples are reinforced (Klajmonová and Lokaj 2013b). The reinforcement design was based on the first series test results. The main purpose of a sample reinforcing is to delay the occurrence of a failure. For decreasing the probability of a crack occurrence during sample testing, reinforcement should be in the direction perpendicular to the grain (Smith et al. 2003). Five different approaches to the sample reinforcement were tested - applying the modified washers, applying the common wood screws, using BOVA plates and application of steel bands (see Fig. 3).

Modified washers. For the modified washers approach, the washers were made of steel plate with a thickness 6 mm, category S235. The dimensions of these plates were 60 mm to 100 mm. Holes with a diameter of 22 mm were used. The washers were rounded to fit tightly to the round timber sample, and the wood in the area of a bolt was clamped tightly as well.

BOVA plates. This is a steel plate with a thickness of 2 mm and dimensions of 40 to 120 mm, provided with holes for nails. The plate was fastened to a sample with four nails.

One screw. For the common wood screws approach, the tested screws had a diameter of 5 mm and the length of 90 mm. One screw was located under each bolt (in the direction of loading). The screws were oriented perpendicular to the grain.

Two screws. The principle of reinforcement with two screws is similar to the one with just one screw. For the common wood screws approach, the tested screws had a diameter of 5 mm and the length of 90 mm. Two screws were opposite each other and located under each bolt (in the direction of loading). The screws were oriented perpendicular to the grain.

Steel band. The last method is to tighten the end of the samples with a steel band. The band has a thickness of 0.9 mm and width 9 mm.

Fig. 3: Half - models of reinforced samples.

Dynamic multicyclic tests of bolted joints

Dynamic tests on similar testing samples were prepared on the basis of the results of static tests of bolted joints carrying capacity. The dynamic tests were carried out on a pulsator devices (see Fig. 4 and Lokaj and Klajmonová 2013b). The magnitude of the tension forces was between 80 and 140 % of the average static carrying capacity of the joints. The various numbers of loading cycles (3 – 120000) was achieved. The frequency was 3 or 4 Hz.

Fig. 4: Pulsator INSTRON in ITAM CAS Prague (left), Pulsator in TRI Žilina (right).

RESULTS

The weakest part of a unreinforced joint should be a steel bolt, according to the relations for a double shear joints steel-to-timber type with a steel plate inside, even if this bolt is made of high strength steel. The failure of the joint should have been caused by achieving the plastic carrying capacity of a bolt in bending and by occurrence of a plastic hinge. The deceleration of increasing of the force in relation to the increasing of a/the displacement can be observed on Fig. 5. It indicates the plastic deformation of the bolt. All the testing samples collapsed by the disruption (splitting) of the sample (Fig. 6). The disruption of the sample was caused by exceeding the timber strength in tension perpendicular to the grains, but a block shear collapse was not observed. The fracture of the bolt was not observed in any test. Values of the unreinforced bolted joints carrying capacity can be seen on Tab. 1.

It cannot be possible to draw conclusions due to the limited number of samples, but the response of all the tested connection samples to the loading shows some similar signs. After the initial displacement of the joint (displacement about 5 mm), which was caused by the different diameter of a bolt and a hole in a steel plate, the nearly linear phase of the "working diagram" of the joint follows up to 80 % of maximal carrying capacity. Audible cracking was observed over this border and the "plastic" phase of a joint displacement occured, e.g. the displacement of a joint was increasing more than an adequate force increase (see Fig. 5). The rapid disruption of a timber element in the area between the bolt and the end of the round timber occured in the final phase. Although joints carrying capacity of all the tests shows relatively large variability (from 43 kN to 111 kN).

Tab. 1: Values of carrying capacity and density for unreinforced samples tested in static tension.

	Carrying capacity (kN)	Density ($kg.m^{-3}$)
Mean	67.26	487.11
Stnd. deviation	15.33	88.32
Coef. of variation (%)	22.80	18.13

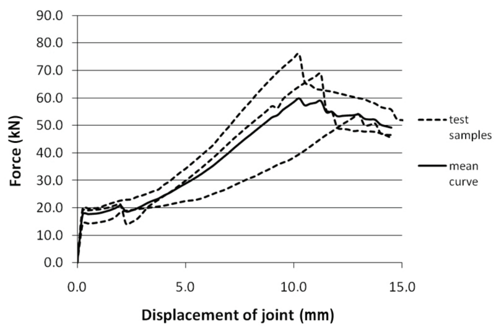

Fig. 5: Tension force increase in the joint during time; the curves are shown for samples having a density of 400 ± 20 $kg.m^{-3}$

Fig. 6: The failure of statically tested samples in the press EU100.

There were numerical models made of the round timber bolted joint with slotted – in steel plates loaded strained by the tension force to discover the extreme stresses in the timber and also the steel parts of the joint. The results of the numerical modelling can be seen on Fig. 7.

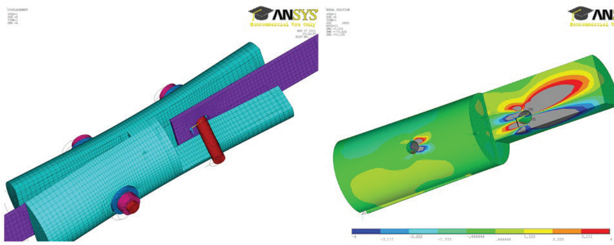

Fig. 7: Numerical model of round timber bolted joint with slotted-in steel plate loaded by tension force (stresses in timber parts)

Results of laboratory tests of carrying capacity of reinforced round timber joints showed relatively large differences by type of reinforcement.

The average value of carrying capacity of samples with modified washers was 81.9 kN. Cracking and subsequent growth were decreased. The samples with BOVA plates were damaged due to splitting. The average value of carrying capacity of these samples was 74.5 kN. During testing samples with two screws, no failure due to a crack occurrence was observed. The displacement was increased up to the failure. Most observed failures were caused by the plug shear (Blass and Schädle, 2011). The average value of carrying capacity of these samples was 92.5 kN. The samples tighted by steel band were disrupted due to the band snap and the wood split under the bolt. The average value of carrying capacity of these samples was 83.6 kN.

The chart vividly shows that the highest reinforcement effectiveness was achieved by using two screws.

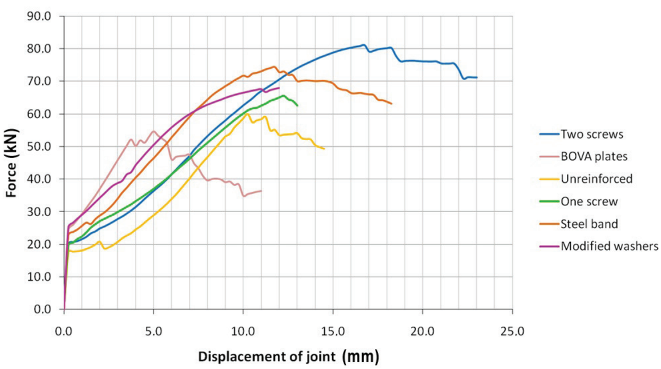

Fig. 8: Comparison of effectiveness of particular ways of reinforcing round timber bolted joints with a density of about 400 kg.m^{-3}.

Tab. 2 and Fig. 8 imply that reinforcing by means of the modified washers and BOVA plates demonstrates the highest increase in carrying capacity. In terms of implementation simplicity, reinforcing using two screws appears to be the most effectual. The least effectual reinforcement is bandaging with a steel band. Reinforcing of the connection demonstrated higher effectiveness when wood of lower density was employed (value about kg·m^{-3}); by contrast, when using wood with the density of about 550 kg·m^{-3} the efect of the reincorcement was minimal.

Tab. 2: Comparison of carrying capacity of various reinforcement methods.

		One screw		Two screws		BOVA plates		Modified waschers		Steel band	
		Density (kg.m^{-3})	Force (kN)	Density (kg.m^{-3})	Force (kN)	Density (kg.m^{-3})	Force (kN)	Density (kg.m^{-3})	Force (kN)	Density (kg.m^{-3})	Force (kN)
Unreinforced samples	Mean	440.8	73.9	463.1	82.9	419.3	66.3	447.2	65.2	439.7	78.5
	Stnd. deviation	57.4	17.1	72.3	17.1	52.3	14.4	43.5	6.6	75.5	18.5
	Coef. of variation	13.0	23.1	15.6	20.6	12.5	21.7	9.7	10.1	17.2	23.6
Reinforced samples	Mean	444.6	82.4	479.7	92.5	448.5	74.5	453.9	81.9	438.1	83.6
	Stnd. deviation	66.6	18.3	72.6	14.3	59.6	15.9	52.3	13.1	75.1	15.7
	Coef. of variation	15.0	22.2	15.1	15.4	13.3	21.4	11.5	16.0	17.1	18.8
INCREASING	Mean	12.3		13.6		17.7		22.4		7.7	
	Stnd. deviation	11.5		17.0		36.2		6.2		9.0	
	Coef. of variation	93.3		125.4		204.3		27.7		117.5	

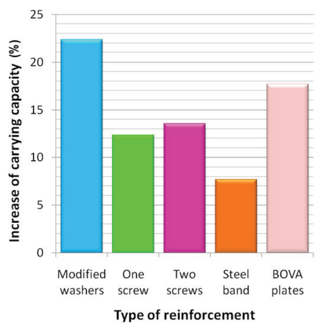

Fig. 9: Comparison of effectivity of reinforcement methods.

In Fig. 10 and 11 the ways of the reinforced round timber bolted joints failures caused by tension are apparent. The most typical failure mode was splitting, only in few cases appeared plug shear collapse (mainly at samples reinforced with screws). The samples are reinforced with steel bands and BOVA plates (Fig. 10), BOVA plates, one screw and modified washers (Fig. 11).

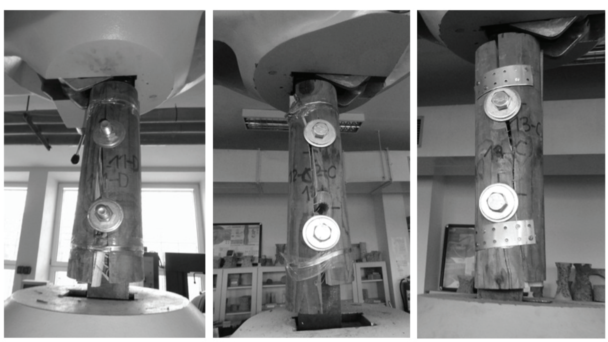

Fig. 10: Failures of reinforced joints with steel bands (left) and BOVA plates (right).

Fig. 11: Failures of reinforced joints with BOVA plates (left), one screw (middle) and modified washers (right).

The results of the dynamic tests on the unreinforced samples are demonstrated on Fig. 12. The results of the dynamic tests on the reinforced samples are demonstrated on Fig. 13. The trend of a relation between the carrying capacity of a joint loaded by dynamic forces (F_{dyn}) and the carrying capacity of a joint loaded statically (F_{stat}) – F_{rel} can be seen - depending on the number of loading cycles:

$$F_{rel} = \frac{F_{dyn}}{F_{stat}} \tag{1}$$

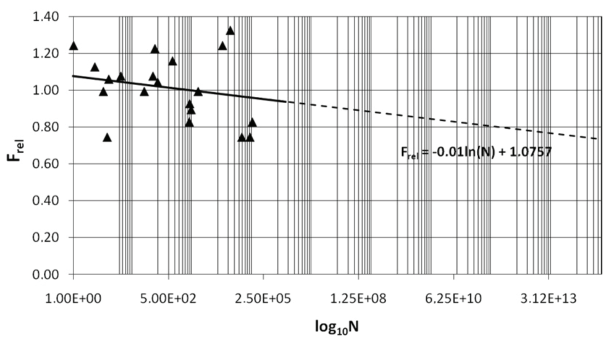

Fig. 12: Results of dynamic loading unreinforced round timber joints tests.

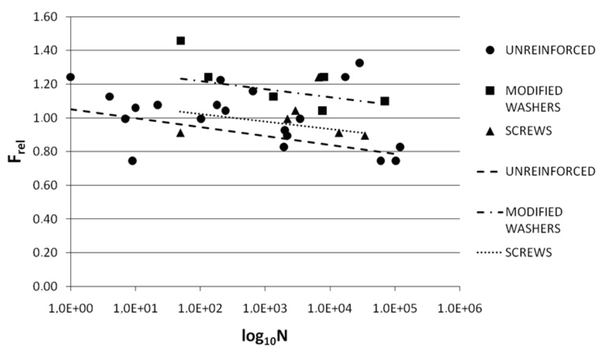

Fig. 13: Results of dynamic loading reinforced round timber joints tests.

DISCUSSION

The results of static testing of round timber bolted joints with slotted-in steel plates indicate well a correspondence with the calculated values according to Eurocode 5, in spite of the relatively large dispersion of the measured values. This high dispersion has many reasons, e.g. variability of mechanical properties of timber, natural defects of timber, growth conditions of wood, quality of manufacturing, etc. – see (Lokaj et al. 2013). Given the simplicity and the cost involved in its implemention, the reinforcement using a pair of two screws appears to be the most suitable. The reinforcement of this connection leads to the increase of carrying capacity, but, in addition, even bigger asset of this reinforcement lies in the increase of safety. Unreinforced connections, after a fracture has developed therein, lose the ability to carry a load (see Fig. 5). By way of contrast, connections which are reinforced feature some sort of a residual carrying capacity even after having reached their maximal carrying capacity; albeit at the cost of huge deformation (see Fig. 8)

During the dynamic testing (by multicycling passing loading), a smaller part (one third) of the tested samples failed in a different way in contrast to the static tests – by plug shear. In several first cycles a small plastic zone in timber element under the bolt can be observed, which protected the round timber element from the rapid development of initial crack.

Due to the high dispersion of carrying capacity of round timber bolted joints with slotted - in plates, it is pertinent to consider using some a probabilistic method e.g. (Lokaj and Marek 2009) or (Krejsa et al. 2013, Křivý et al. 2013) for the design and assessment of this type of joints.

CONCLUSIONS

Based on the results of static and dynamic round timber bolted joints tests, reinforcement of the bolted joints significantly increased joint carrying capacity and reliability. Among used reinforcement methods, the most significant increase of joint capacity and reliability was observed on samples reinforced with modified washers and using two screws.

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Antonín Lokaj, Kristýna Klajmonová
Všb-Technical University of Ostrava
Faculty of Civil Engineering
Department of Building Structures
17. Listopadu 15/2172
708 33 Ostrava
Czech Republic
Correspondig author: antonin.lokaj@vsb.cz