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CARRYING CAPACITY OF ROUND TIMBER BOLTED JOINTS WITH STEEL PLATES UNDER STATIC AND CYCLIC LOADING

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Abstract: *Aim of this article is in presentation of results of static and dynamic tests of round timber bolted connections with slotted – in steel plates. Round timber joints static tests in tension were made on pressure machine EU100 in laboratory of the Faculty of Civil Engineering VSB-TU Ostrava. Results of laboratory tests have been statistically evaluated and completed by graphical records of deformation response on loading. Round timber joints multicyclic dynamic (fatigue) tests in tension were made on pulsator INSTRON in laboratory of ITAM CAS Prague.*

Keywords: ***Round timber, bolt, joint, carrying capacity, static, dynamic, multicycle, fatigue.***

1. Introduction

Nowadays timber constructions made of round timber become increasingly popular. It concerns footbridges, bridges, watchtowers (the tallest round timber watchtower in central Europe was built at Lázně Bohdaneč in 2011, tower height is almost 53 m – Fig. 1, 2 and (Straka, B., Šmak, M., 2011)) or playground equipment. If these constructions are designed with truss supporting system, element connections are often made of bolts with slotted-in steel plates (gusset plates).

Fig. 1: Watchtower near Lázně Bohdaneč made of round timber

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Fig. 2: Watchtower near Lázně Bohdaneč – round timber bolted joints with slotted-in plates

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

It is necessary to know the response of the construction and their 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 joint was chosen: bolted joint with slotted - in steel plates subject 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 deformation of a single tension – up to the failure of connection. Carrying capacity and deformation of connections under static loading was measured in this test, results were compared with the calculation of carrying capacity according to 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 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 connections have been tested under multicyclic loading on pulsator INSTRON at laboratory of ITAM CAS Prague.

2. Description of the static test samples

It was necessary to adapt dimensions of the test samples by possibilities of equipment in laboratory of the Faculty of Civil Engineering at VŠB - Technical University of Ostrava. Spruce round timber with diameter 120 *mm* and sample length 450 *mm* was used. The bolts made of HS (High Strength Steel) steel category 8.8 (f_y = 640 *MPa*, f_u = 800 *MPa*) with diameter 20 *mm* were used. Connection plates made of steel S235 with thickness of 8 *mm* and width of 70 *mm* were used. Holes for bolts in steel plates have diameter of 22 *mm*. Holes for bolts with diameter 20 *mm* were made in the round timber. Nine test samples were produced reasonably (Figure 3 and 4-A). Tensile tests were conducted on the press EU100 with a recording system (Figure 4-B).

Fig. 3: Round timber tested samples

A several nondestructive tests were carried out before start of static tests in the press. Aim of these tests was to determine the quality of the round timber material, particularly its moisture and density. Test samples were weighed on a laboratory scale, their moisture and dimensions were measured (Figure 5-A). Apparent density and mass density was determinated on the base on measured values. The average moisture was 11,3 %. Average value of apparent density reached 542 kg/m^3. Average thickness of annual rings was 1,24 *mm*, it confirms the relatively high measured density values and the quality of the tested round timber. Average penetration depth measured with penetration device PILODYN 6J (Figure 5-B) was 10,9 *mm*, this corresponds to mass density of round timber 430 kg/m^3 (according to the relations in (Kuklík, P., Kuklíková, A., 2000)).

Fig. 4-A/B: Tested sample in the press (A - left), the press EU 100 with sample (B - right)

Fig. 5-A/B: Humidity measuring of sample (A – left), density testing with PILODYN 6J (B –right)

3. Course of static tests

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

Diagram of increasing of tension force during time is in Fig. 6. Fig. 7 shows relation between displacement (eg. elongation) of the joint and tension force working on the joint.

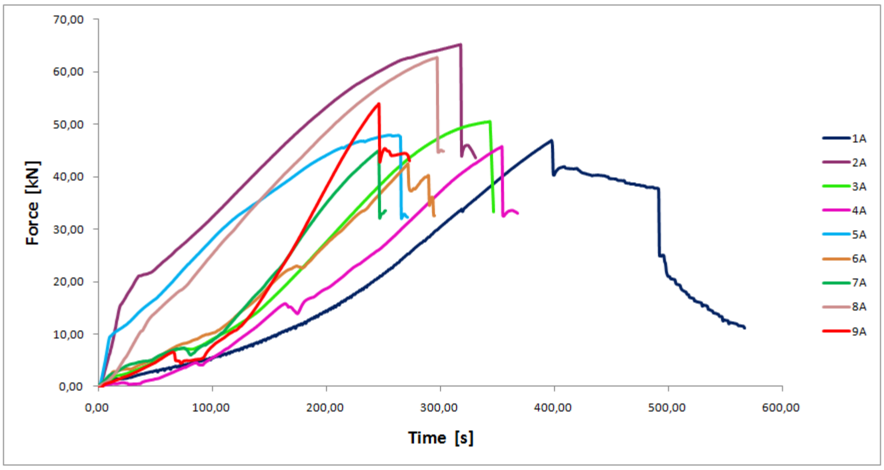

Fig. 6: Tension force increasing in the joint during time

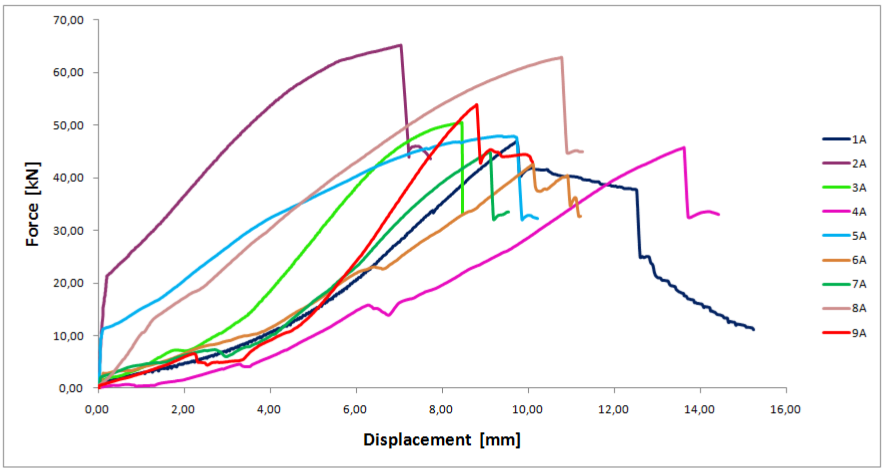

Fig. 7: Relation between tension force in the joint and displacement of the joint

The weakest part of the joint should be steel bolt, according to relations for double shear joints steel to timber type with steel plate inside, even if this bolt is made of high strength steel. Failure of the joint should have been caused by achievement of plastic carrying capacity of bolt in bending and by appearing of plastic hinge. Deceleration of increasing of the force during testing time can be observed in Fig. 6 and a similar clearly deceleration of increasing of the force in relation to increasing of displacement can be observed in Fig. 7. It indicates plastic deformation of the bolt. All testing samples collapsed by disruption of the sample (Fig. 8). Disruption of the sample was caused by exceeding of timber strength in tension perpendicular to the grains, but a block shear collapse was not observed. Fracture of the bolt was not observed in any test.

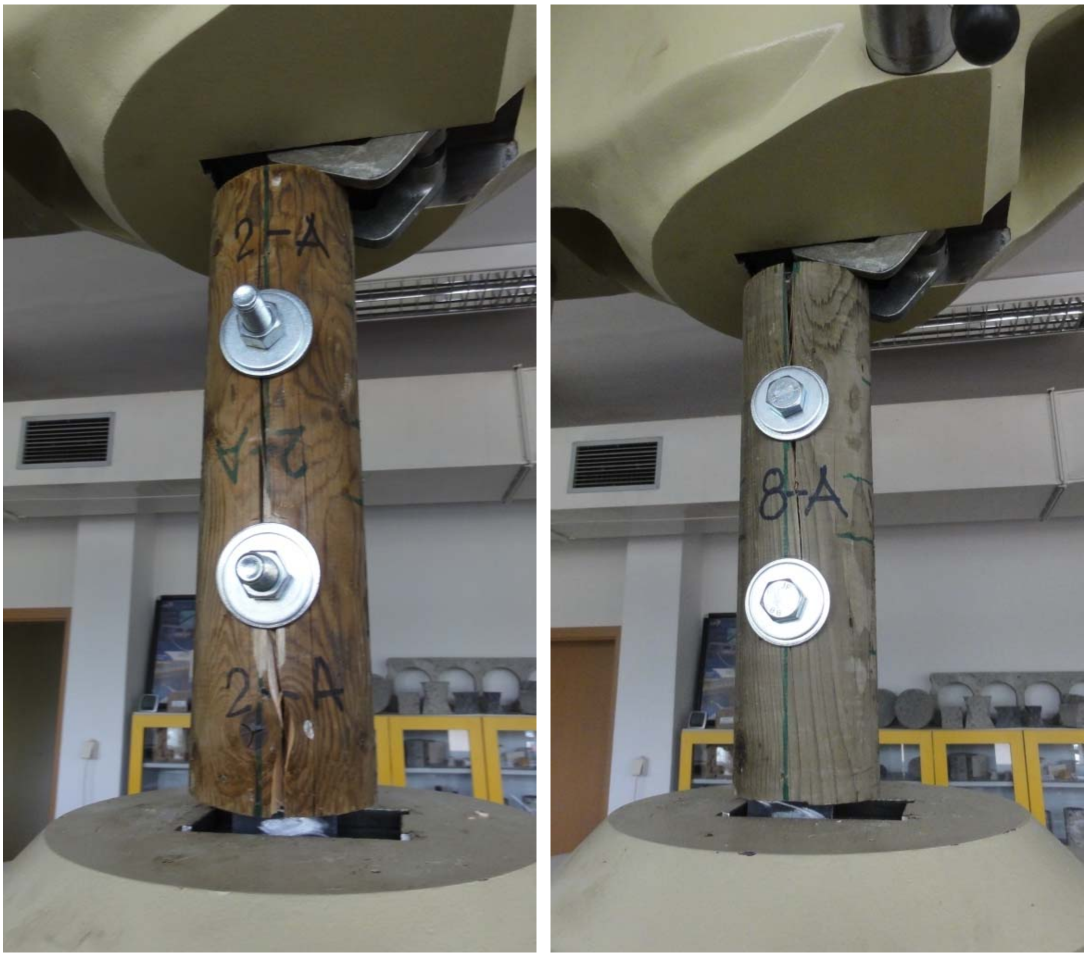

Fig. 8: Failure of statically testing samples in the press EU100

4. Static tests results

Results of the joints carrying capacity obtained from laboratory tests and values calculated by Eurocode 5 with actual values of timber density are shown in Tab. 1. It cannot be possible to explicit conclusions due to limited number of samples, but response of all tested connection samples to loading shows some similar signs. After initial displacement of the joint (displacement about 5 *mm*), which was caused by different diameter of bolt and a hole in steel plate, than follows almost linear phase of "working diagram" of the joint up to 80 % of maximal carrying capacity. Audible cracking was observed over this border and "plastic" phase of the joint displacement occured, e.g. displacement of the joint was increasing more than adequate increasing of force (see Fig. 6). Rapid disruption of timber element in the area between bolt and the end of round timber occured in final phase (Fig. 7). Although joints carrying capacity of all tests shows relatively large variability (from 43 *kN* to 65 *kN*), we are able to conclude, that measured joints carrying capacity values are relatively well corresponding with values calculated according to Eurocode 5 with actual values of round timber density.

Tab. 1: Results of the joints carrying capacity obtained from static laboratory tests and calculation

	$F_{V,Rk,1}$ [kN]	$F_{V,Rk,2}$ [kN]	$F_{V,Rk,3}$ [kN]	$\mathbf{F_{V,Rd,CAL}}$ [kN]	$\mathbf{F_{V,Rd,TEST}}$ [kN]
μ	35,54	32,03	49,64	**49,28**	**50,29**
SD	0,96	0,52	0,71	**0,80**	**5,95**
V [%]	2,71	1,63	1,44	**1,63**	**11,82**

Where:

$F_{V,Rk,I}$ are characteristic values of double shear joint (steel to timber) in one shear for particular way of failure calculated according to Eurocode 5;

$F_{V,Rd,CAL}$ is design value of double shear joint (steel to timber) calculated for k_{mod} = 1,0 and γ_M = 1,3;

$F_{V,Rd,TEST}$ is design value of double shear joint (steel to timber) obtained from laboratory tests;

μ is mean value of corresponding variable;

SD is standard deviation of corresponding variable;

V is variation coefficient of corresponding variable.

There was made numerical model of the round timber bolted joint with slotted – in steel plates loaded by tension force to discover extreme stresses in timber and also steel parts of joint. Results of the numerical modelling can be seen in Fig. 9 and 10.

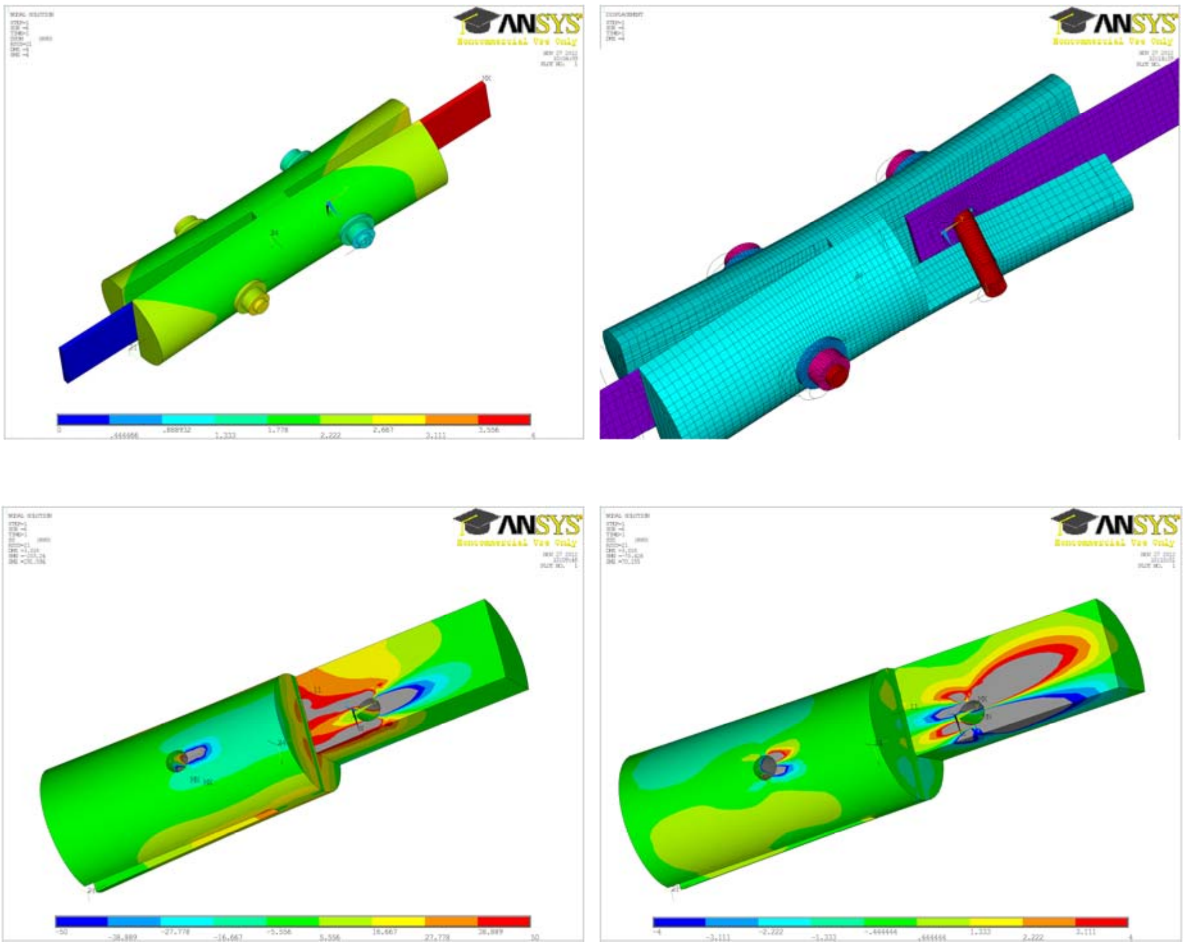

Fig. 9: Numerical model of round timber bolted joint with slotted-in steel plate loaded by tension force (stresses in timber parts)

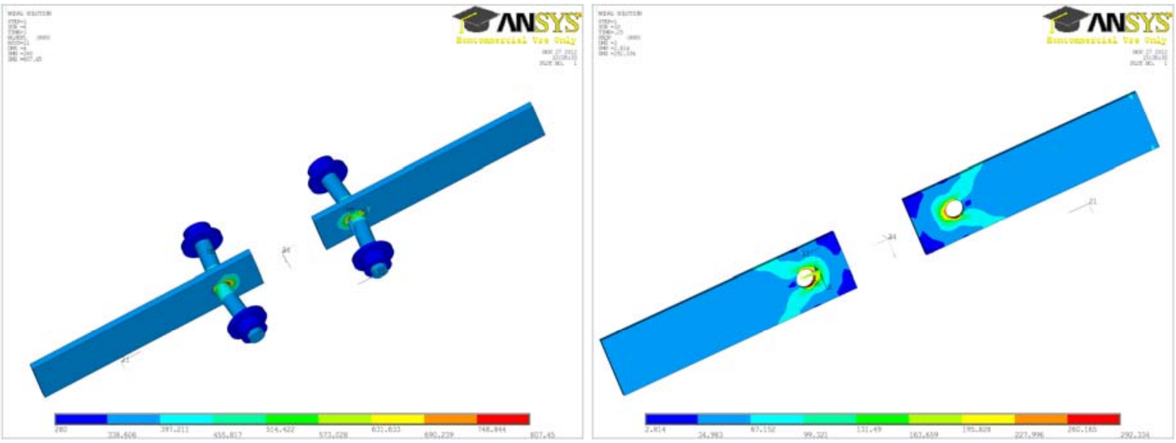

Fig. 10: Numerical model of round timber bolted joint with slotted-in steel plate loaded by tension force (stresses in steel parts)

Fig. 11: Embedment of hole in steel plate of the joint

Fig. 11 shows embedment – deformation of slotted-in steel plate which is well corresponding with numerical model in Fig. 10 - above.

5. Dynamic multicyclic tests of bolted joints

Dynamic tests on similar testing samples had been prepared on the base of results of static tests of bolted joints carrying capacity. The dynamic tests were carried out on pulsator device – INSTRON (Fig. 12A, B) in laboratory of ITAM CAS Prague. Length of samples was 700 *mm*, diameter of round timber was 120 *mm*, diameter of bolts was 20 *mm* (Fig. 12A). Pulsator INSTRON allows loading test samples by tension forces 0 to max. 100 *kN* with frequency up to 5 *Hz*. Only 14 samples there were tested due to limited financial and time possibilities. Magnitude of tension forces was between 80 % and 140 % of average static carrying capacity of the joints. Frequency was 3 or 4 *Hz*. There were achieved various number of loading cycles (3 – 120000). Tension forces and related displacement of joint were recorded and hysteresis curve can be seen in Fig. 13.

Fig. 12 - A/B: Pulsator INSTRON (A - left), joint failure in block shear (B - right)

Fig. 13: Recording of tension forces and displacement of joint

There are demonstrated results of the dynamic tests in Fig. 14. There can be seen trend of the relationship between carrying capacity of the joint loaded by dynamic forces (F_{dyn}) and carrying capacity of the joint loaded statically (F_{stat}) – F_{rel} - in dependence of number of loading cycles:

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

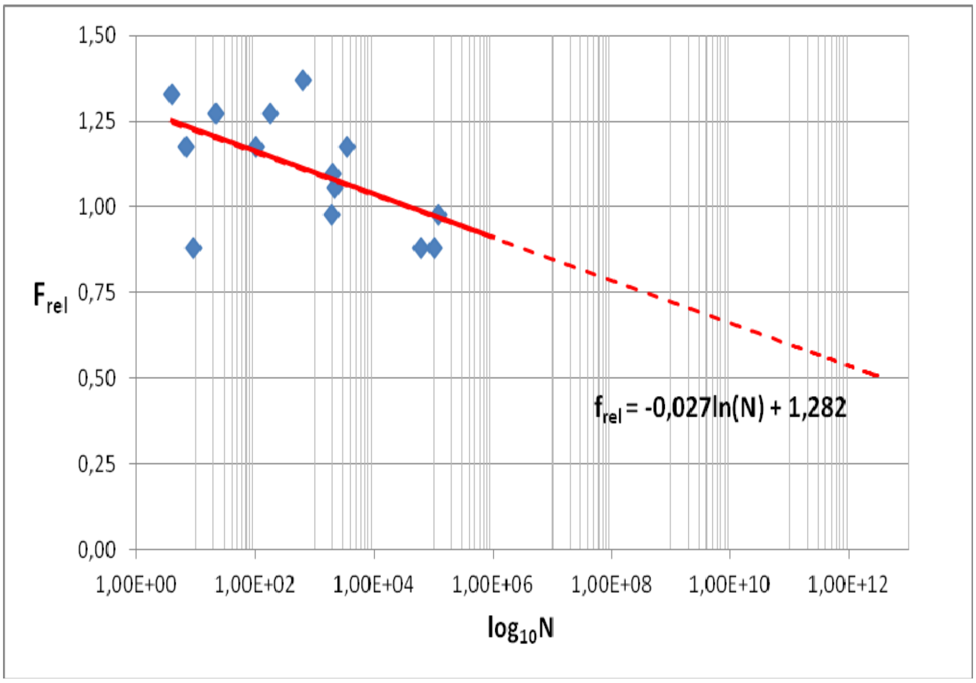

Fig. 14: Results of dynamic loading round timber joints tests

Fig. 15: Failure of the fatigue loaded joint in tension by block shear of the round timber

6. Conclusion

The results of static testing of round timber bolted joints with slotted-in steel plates indicate well corresponding with calculated values according to Eurocode 5, in spite of relatively large dispersion of 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 (Vavrušová et al., 2012) or (Lokaj, A., Vavrušová, K., 2011).

During dynamic testing (by multicycling passing loading) smaller part (one third) of tested samples failed in different way in opposite to static tests – by block shear (see Fig. 12B and Fig. 15). In several first cycles small plastic zone in timber element under bolt can be observed and it protected round timber element from rapid development of initial crack.

Due to high dispersion of carrying capacity of round timber bolted joints with slotted - in plates is suitable to consider of using some fully probabilistic method e.g. (Lokaj, A., Marek, P., 2009), (Janas, P. et al., 2009) or (Krejsa, M. et al., 2013) for design and assessment of this type of joints.

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