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DETERMINATION OF CARRYING CAPACITY OF STEEL-TIMBER JOINTS WITH STEEL RODS GLUED-IN PARALLEL TO GRAIN

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ABSTRACT

The issue of behavior and deformation of joints of wooden structures is an integral part of the design of timber structures in its entirety. In this article the attention is therefore devoted to joints of timber structures. For testing there were selected joints with glued-in steel rods. These joints are currently, due to the frequent requirement for invisibility of joints in structures, at the forefront of interest. The content of this paper is therefore testing of these joints and determination of their carrying capacity and describing the type of deformation under load. These tests were carried out on a pressure machine EU100 in the laboratory of the Faculty of Civil Engineering VSB-TU Ostrava. The results of the laboratory tests have been statistically evaluated and accompanied by the graphical records of deformation response to loading. Comparison of test carrying capacity results with values determined from calculation according to the current applicable European standard for design of timber structures and numerical modeling are also presented.

KEYWORDS: Timber, joint, carrying capacity, glued-in steel rod.

INTRODUCTION

The Czech Republic has always been country with sufficiency of structural wood (spruce, beech, oak) and therefore in history wood was mainly in forested regions the basic building material. In the course of last century the huge development of new building materials and procedures happened (reinforced concrete, panel construction), which forced out wood as building material.

Thanks to new wave of "ecological thinking" renewability and affordability of wood is now coming out the increase of timber usage in civil engineering especially in housing constructions, creation of new houses as well as reconstructions.

And because it can be stated: "Structure is bearable only as its weakest part" it is needed to design and proceed joints of timber structures that they are not the weakest part of the structure.

Not only in reconstruction of historical buildings, where the great emphasis is placed on maintaining of the original appearance of the structure, i.e. without the possibility of using visible fasteners, as well as in construction of new wooden structures, where is preferred aesthetics is an attempt to hide the fasteners. For this reason there are commonly used longitudinally and transverse joints with glued-in steel rods.

To the issue of carrying capacity and performance of joints of timber structures with glued-in steel rods are dedicated some specialists from all around the world (Gustafsson et al. 2001; Aicher et al. 1999; Guan 1998) and also from the Czech Republic (Vašek and Mikeš 1998). Behaviour and bearing capacity of these joints is documented, and their design is supported by normative regulations Eurocode (2006) and ČSN 73 1702 (2007).

But there are numerous parameters influencing the carrying capacity and behavior of joints with-glued in steel rods. These parameters can be divided into 3 base groups:

- wood (density, moisture content, ….),
- steel (diameter, gluing depth, distance between, rods, …),
- adhesive.

From the reason of these numerous parameters affecting the carrying capacity, there is still much to discover in the field joint with glued-in steel rods into timber elements.

The aim of this research are longitudinal joints with one steel rods glued-in parallel to grain of solid wood element The results obtained from the laboratory testing are compared with results from numerical modeling in ANSYS program and will be used in the future to refine models in this program in order to faithfully describe the actual behavior of these joints under load.

MATERIAL AND METHODS

Description of the static test samples

For testing was assembled set, comprising 15 test samples. To determine the real behavior and carrying capacity of joints were assembled for testing samples of structural dimensions. Squared timber with dimensions 200x200 mm made of solid spruce wood of strength class C30 (see Fig. 1).

Into the timber element was glued-in 1 rod parallel to grain to a depth 160 mm with diameter of 16 mm. Material of the threaded rod – steel 8.8. (f_u = 800 MPa) .

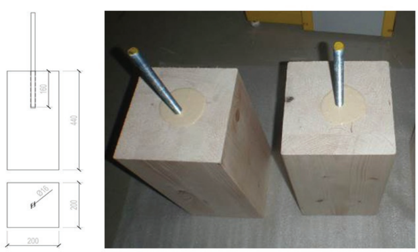

Fig. 1: Test sample geometry.

For gluing-in of steel rod was used the bio component epoxy adhesive XEPOX with low viscosity and high wetting power. The test samples were conditioned prior to destructive testing in standard ambient temperature 20±2°C and relative moisture content 65±5 %. To determine the test samples moisture was used moisture detector.

Course of the static tests

The testing was proceeded on a pressure machine EU100 at laboratories of Faculty of Civil Engineering, VSB-TU Ostrava, while the tension force in axis of glued-in steel rods 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 structures – Eurocode 5 (2006).

The test sample fixing to the hydraulic press is shown in the Fig. 2. The sample was loaded with increase of deformation within the specified time so the resulting carrying capacity wasn´t significantly affected by the speed of loading.

Fig. 2: Test sample and its fixing in hydraulic press – tension parallel to the grain.

Calculation of carrying capacity according to Eurocode 5 and ČSN 73 1702

Design value of withdrawal strength of one glued-in steel rod is possible to determine according to formula given in ČSN 73 1702 (2007):

$$R_{ax,d} = \min\left\{f_{y,d}\, A_{ef}; \pi\, d\, l_{ad}\, f_{k,1,d}\right\} \tag{1}$$

where: $f_{y,d}$ - design value of steel rod yield strength,
A_{ef} - loaded rod cross-section,
l_{ad} - glued-in depth of steel rod,
$f_{k,1,d}$ - design value of gluing strength.

For steel rods glued parallel to the grain and tensioned is to assess at the end of the steel rod the tensile stress in the wood. As an effective sectional area of the wood it may be considered at most the area of 36 d^2 for one steel rod ČSN 73 1702 (2007).

$$\sigma_{t,0,d} = \frac{N_{Ed}(R_{ax,d})}{A} \le f_{t,0,d} \Rightarrow R_{ax,d} = f_{t,0,d}\, A \tag{2}$$

Numerical modelling

In the Fig. 3 on the left is drawn finite element network of the tested joint. The network was compressed in the area of anchor rods. The model was calculated geometrically and materially nonlinearly considering the contact surfaces in the contact area of timber prisms. The wooden part of the structure was considered as orthotropic. Prisms on the edges of the test sample were supports against tensile forces from the hydraulic press.

In the Fig. 3 on the right is shown overall deformation of the joint. The value of the deformation is drawn for maximal reached force in numerical model which is 76.40 kN.

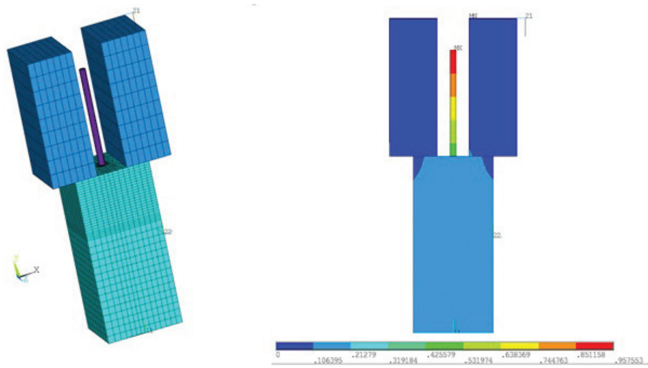

Fig. 3: Finite element network of the tested joint.

RESULTS AND DISCUSSION

Laboratory testing

Typical damage of the test sample is pulling out of the steel bar with around glued mass of wood (see Fig. 4). The value of tension force in damage ranged between 53 - 78 kN with the mean value of all test samples 63.27 kN.

In damage has separated the epoxy package with bonded wood mass from the surrounding layers of the wood element. Breach apparently occurred primarily in the area of bonding due to exceeding the shear stress. The shear stress for longitudinal and transverse axis (longitudinal and radial or tangential direction) reaches the range of 4-10 MPa.

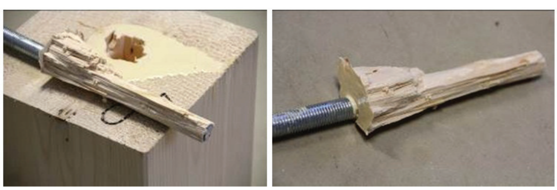

Fig. 4: Tension parallel to the grain – test sample damage

Calculation of carrying capacity according to Eurocode 5 and ČSN 73 1702

Based on values substituted into formulas (1) and (2) according to the EC5 it is evident that decided value of withdrawal strength of glued-in steel. The design value calculated for elements with tested dimensions is 22.3 kN.

Numerical modelling

In Fig. 5 on the left there are shown tensile stresses for achieved force at value of approximately 76.40 kN. When this force is achieved in the area of joint tensile stress in the fiber direction is at a local peak of around + 24 MPa in the bottom area of glued anchor. This tension is not on the limit of the physical resistance of wood.

Fig. 5 on the right shows a glued-in steel rod and its stress according von Mises at nodes in the middle of threaded steel rod. The stress is drawn for force about 76.40 kN. The stress on the steel member is still in the elastic area of the rod. It is evident, how uniform is stress in the area of gluing and from the point of gluing-in into the wood element parallel to the grain linearly decreases to almost zero. The maximal stress on the steel rod is 414 MPa. The results confirm that for this type of joint decides the resistance of timber. Steel anchoring element is in the elastic area.

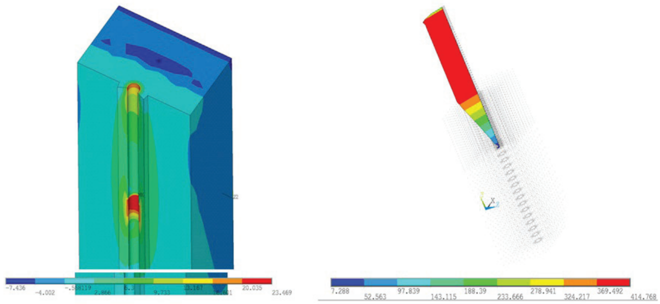

Fig. 5: Tension Sx and von Mises stress for the force F=76.40 kN.

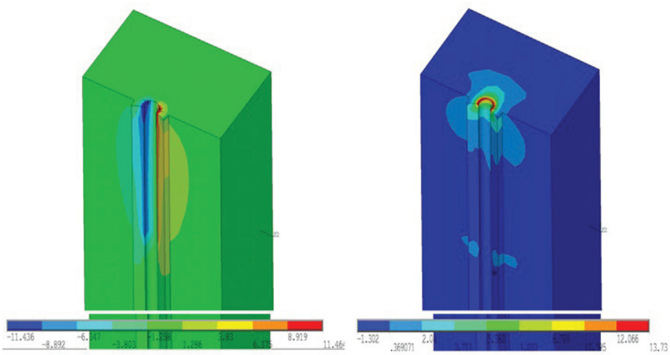

Fig. 6: Shear Sxy and tension Sy stress for the force F=76.40 kN.

In Fig. 6 on the left are shown shear stresses for achieved force at value of approximately 76.40 kN. When this force is achieved in the area of joint shear stress in the fiber direction is at a local peak of around + 11.47 MPa in the upper area of glued anchor. This stress is on the limit of the physical resistance of wood.

In Fig. 6 on the right are shown shown tensile stresses for achieved force at value of approximately 76.40 kN. When this force is achieved in the area of the joint top the tensile stress perpendicular to the grain is in local extreme around ± 13.74 MPa in the upper part of the glued anchor. This stress is roughly beyond physical load timber strength perpendicular to the grain. This is a significant numerical extreme.

In the real experiment, the wood is cracking in this area, but the loss of carrying capacity doesn´t occur because it is dependent on the shear stress in the area of glued anchor.

Comparison of results

The table below (see Tab. 1) shows resulting values of carrying capacity of joints with one steel rod glued-in parallel to the grain, for laboratory testing, numerical modelling and calculation according to EC5 and ČSN 73 1702.

Tab. 1: The carrying capacity results.

The carrying capacity of the joint	kN
Calculation according to EC5 – design value	22.30
Laboratory tests – mean value	63.27
ANSYS	76.40

In Fig. 7 is graph of deformation curves of laboratory testing and numerical modelling with drawn mean values of laboratory testing, numerical modelling and calculation according to EC5 and ČSN 73 1702. The deformation curve ANSYS is numericaly obtained value for adjustment of material constants according to values from previous experiments (Klajmonová and Lokaj 2013; Straka and Šmak 2011).

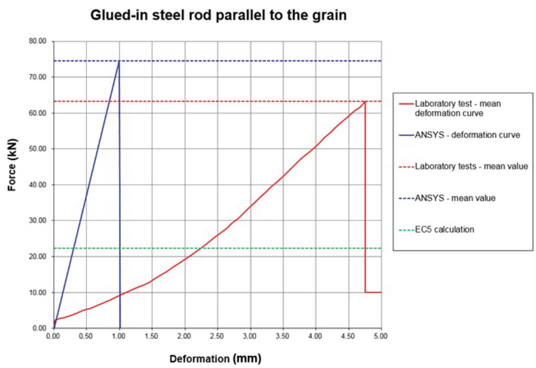

Fig. 7: Glued-in steel rod parallel to grain – results.

Typical damage of the test sample with one steel threaded rod in the cross-section is pulling out of the steel rod with around glued mass of wood. The failure type of test samples with one glued-in steel rod corresponds with results from previous research on test samples from beech LVL material (Stepinac 2014) and solid wood material (Chans et al. 2013).

The obtained results show that the resulting value achieved from the numerical model corresponds fairly well with the values obtained experimentally (Lokaj and Klajmonová 2014; Lokaj and Klajmonová 2013; Vašek and Vyhnálek 2006).

CONCLUSIONS

The carrying capacity values obtained from the experiment are within 53 to 78 kN for single rod glued parallel to the grain. Grown wood is a natural material with a greater dispersion of stiffness and strength characteristics. Therefore, each experiment has a different behavior and carrying capacity. Factor affecting the carrying capacity is also the quality of gluing-in the steel rod into the timber.

Differences in stiffness of the numerical model and experiments are caused by slips in the press and in the joints in the test sample. The numerical model was modeled for an ideal clamping without slippage caused by mechanical anchoring to the surrounding structure of the press.

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