

## **EXPERIMENTAL TESTS OF TIMBER CONNECTIONS WITH GLUED-IN RODS IN BENDING**

VLADIMÍR DUCHOŇ, TOMÁŠ KLAS, ORSOLYA KATONA  
JÁN BRODNIANSKY, LUBOŠ BALCIERÁK, JAROSLAV SANDANUS, KRISTIAN SÓGEL  
SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA, FACULTY OF CIVIL ENGINEERING  
DEPARTMENT OF STEEL AND TIMBER STRUCTURES  
BRATISLAVA, SLOVAK REPUBLIC

(RECEIVED APRIL 2016)

### **ABSTRACT**

The article deals with research of joints with glued-in threaded rods. The introduction provides a brief presentation of the issue. The first part focuses on axially loaded glued-in threaded rods. The second part explains the behaviour of joints with glued-in rods loaded by bending moment. Theoretical analysis was performed on models based on the finite element method. Verification of theoretical results was realized by practical experiments. Tensile tests were carried out on timber blocks with glued-in bars to verify the depth of affixing. Furthermore, the resistance in bending was confirmed on actual beams with glued-in bars in the middle of the span. Results and the follow-up work are summarized in the conclusion.

**KEYWORDS:** Timber, glued-in rods, epoxy, polyurethane, wood, rotation.

### **INTRODUCTION**

Owing to the advantages of timber itself, the advantages of timber structures made this material increasingly popular in the design of supporting structures of buildings in the last years. The most important part of these structures is the quality of produced joints, which are able to resist not only axial and lateral forces, but also torsion and bending moment. Joints with glued-in rods are an example of such a connection. In the course of designing these connections, their rotational stiffness and the curve expressing the dependence between rotation and bending moments are considered (Vašek 2011). The use of these connections is applied not only in the design of new structures, but also in the rehabilitation of the original timber elements (Reinprecht 1996). In addition to the steel threaded rods, rods made of carbon (Lorenzis et al. 2005), aramid, or glass fibers (Broughton and Hutchinson 2001) bonded with a resin-based binder, and concrete (Lokaj and Agel 2014) are also used. The interaction of rods with timber elements is achieved by epoxy or polyurethane adhesives.

## MATERIAL AND METHODS

Experimental analysis of glued-in threaded rods was divided into two phases of tests and is based on theoretical analyses that were solved by finite element method (Duchon 2015). In order to determine the required minimum bonding length of rods in the timber element, tensile tests of glued-in threaded rods were carried out in the first phase. In the second stage, the real joints of timber beams connected by glued-in threaded rods in mid-span were examined.

The first part of experimental analysis concerned axially loaded glued-in threaded rods. The aim of the tests was to determine the optimal length of bonding into solid timber, the behaviour of different adhesives, and identifying their tensile strength. Within the experimental analysis, following components were used to prepare the specimens: KVH elements (Konstruktions Voll Holz - from Germany) with dimensions 140x140x500 mm, steel threaded rods with a diameter of 12 and 14 mm, and two different types of two-component adhesives. The first, CARBO RESIN adhesive, was epoxy-based, and the second, NEOPUR 2744, was a polyurethane-based adhesive. Later, the new HILTI HIT-RE 500 adhesive with excellent mechanical qualities characterized by simple application by a dispensing gun was used. This adhesive was also two-component and its chemical composition was epoxy-based. Preliminary bonding length of the rods was set on the grounds of studies (Mikeš 2001; Mikolášek et al. 2015) and the European standards (STN EN 1995-2 2005) dealing with these issues.

The experiment was realized with the use of several types of specimens varying in the type of adhesive used, diameter of steel threaded rods, and the bonding length of the rods into the timber elements. The total number of specimens was 45. The first 16 specimens were prepared to determine the necessary bonding length of rods into the timber and the behaviour of different types of adhesives. After the testing of these 16 specimens, certain types of specimens was selected (specimens with insufficient length of bonding were rejected) and another 24 specimens were prepared to verify the achieved results. At the end, 5 additional specimens using HILTI HIT-RE 500 adhesive were tested. Wood moisture ranged from 9 to 11 %. The density of timber was about 400 kg.m<sup>-3</sup>. Tensile test was realised by means of universal hydraulic testing machine with a load bearing capacity of approximately 100 kN (Fig. 1).



Fig. 1: Universal hydraulic testing machine with a specimen (left), force transducer and inductive deformation sensor (right).

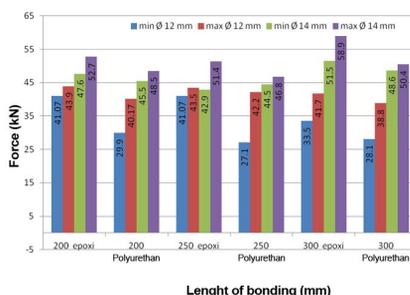


Fig. 2: Results evaluation of specimens with CARBO RESIN adhesive and NEOPUR 2744 adhesive.

The universal hydraulic testing machine consisted of two arms by which the tension loading was introduced into the specimens. Force transducer and inductive deformation sensor were installed on the upper arm (Fig. 1). The lower arm was static and acted as the support for the

specimen. Delivery metal sheets were used on both sides of the arm. The lower delivery sheet had a hole with the diameter of 5 cm in order to prevent influencing the stressed area at the beginning of the element. The measured values were recorded only after the entire assembly settled. Individual tests were carried out until failure. The specimens were mechanically dismantled in order to verify the character and details of damage.

The resulting graph of achieved resistances (Fig. 2) shows the minimum and maximum values of selected types of specimens. The measurement was performed three times for each specimen. Different types of adhesives were characterized by significantly different results and the nature of the damage. Specimens in which epoxy adhesive were used showed better resistance in comparison with the specimens with polyurethane adhesive. Specimens with the polyurethane adhesive also achieved high level of resistance. However, they were characterized by extensive spread of results. In case of specimens with epoxy adhesive, about the damage occurred in the form of either a breach of the steel bars, or damage of wood fibres by shear. In case of samples with polyurethane adhesive, the damage occurred to a greater extent in the connection with the damage of adhesive itself by shear, by bonding strength, or possibly by damage of the wood fibres in the surroundings of the drill hole. Breaching of steel rods remained exceptional. Based on the assumptions and results obtained, it was found that tensile stresses occurred in the close surroundings of the hole in the wood fibres. After exceeding the tensile strength of the fibres the resistance was secured by means of shear strength between the fibres. Because of this, the bonding length of rods into the timber is determinative for the resistance of the joint.

Mechanical dismantling of the specimens after the experiment clarified the results in detail (Fig. 3). It was found that the following facts significantly affect the resistance: The direction of wood fibres, the presence of bulges and knots, and the quality of adhesion between timber and steel threaded rod. For specimens in which the wooden fibres were parallel with the axis of the hole, a thin film was torn off from the timber in several cases. In some cases, a combined rupture of tearing off the thin wooden film from the wood fibres and also the adhesive occurred. It is very important to carefully transfer the bonding of rods in a way securing that presence air bubbles, which would reduce the effective area of affixing where shear stress occurs, is avoided.

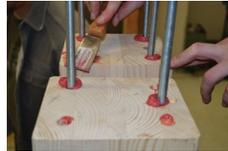


Fig. 3: Mechanical dismantling of the specimens bonded by CARBO RESIN adhesive. Fig. 4: Preparation of tested beams.

The realized tests confirmed the results that have been achieved abroad (Blass and Laskewitz 2001; Riberholt et al. 1991). However, they slightly differ from the available methods of computation (Mikeš 2001). In cases where epoxy-based adhesives were used, breakage of the steel threaded rods was the dominant form of damage. Polyurethane-based adhesives are characterized by lower resistance. In these cases, the damage of the adhesive was more common. Based on the results achieved, tests were realized on the simple beams that will constitute lengthening timber elements which can be used either for new structures, or for renovations of degraded parts of already existing elements.

Within the second phase of the experimental analysis, 10 beams with measurements 150x180x3200 mm divided in the middle of their span were prepared (Fig. 4). Their mutual

connections were realized with the use of glued-in threaded rods. With the aim to install the rods with the strength class 8.8, three holes were prepared in the area of the tensile zone. Two holes for rods of strength class 4.6 were placed in the pressure zone. All of these drilled holes had a diameter of 14 and a depth of 200 mm. For bonding of glued-in threaded rods into the timber elements, HILTI HIT-RE 500 adhesive was used. The glue was applied with the use of automatic dispensing gun. Taking into account the number of specimens, this way of application was considered to be the most suitable. Mechanical properties of this adhesive were verified through five tensile tests. In these tests, the highest tensile strength of 86.2 kN was reached. At this stress level, damage of the adhesive by shear occurred. One half of the prepared beams were made of solid timber and the second half was made of glued laminated timber. During the gluing process, the beams were balanced by means of guiding steel profiles and stabilized by wooden dowels. It was very important to avoid the formation of gaps in the compression zone that would unfavourably affect the curve that expresses a slight rotation of the joint. In cases where gaps occurred due to uneven faces of the beams, these gaps were filled with the glue.

The loading assembly was prepared according to EN 408 2013 (Fig. 5). Axial distance of supports was 3 m and the load was applied by concentrated forces in thirds of span. The supports were designed to allow a slight rotation. For the purpose of load application, universal hydraulic testing machine was installed into a steel frame and steel beam with a cross-section formed by two profiles U200 (Fig. 6) was used. The reached load level was measured by a force transducer. With the aim to determine the local and global modulus of elasticity and deflection of beams, deformations were recorded at three points on each side of the tested beam (Fig. 7). Deformations expressing slight rotation of the joint were measured at the bottom, tensile-stressed side and on the top, compressed side of the beam. Deformations were measured by inductive deformation sensors. On the bottom and lateral side of the beam, strain gauges for measurement of strain were glued. Their function was to measure the strain from which the stress generated in timber beams at the place of joint was derived.

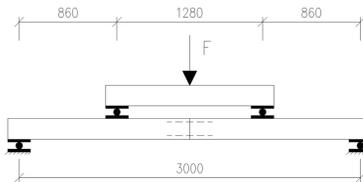


Fig. 5: Loading assembly under the STN EN 408. Fig. 6: Loading assembly.

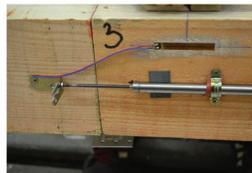


Fig. 7: Inductive deformation sensors and the strain gauges.

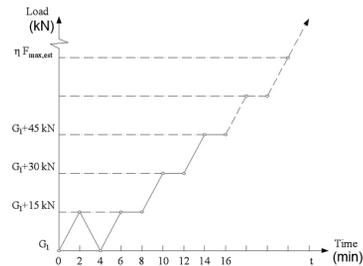


Fig. 8: Diagram of loading procedure under the STN EN 380 1998.

The process and individual steps of loading were applied in accordance with STN EN 380 1998 (Fig. 8). The first load step was conducted up to the level of load 15 kN. During this step, the assembly settled and the load was then reset. The size of the following steps was 15 kN with a time span of 120 seconds. Beams were loaded until failure.

## RESULTS AND DISCUSSION

Measured values were recorded and evaluated by means of graphs and tables that clearly describe the obtained results. All beams had almost identical results, even though in some cases they were affected by the boundary conditions which depended on the quality of joint realization and on non-homogeneous structure of timber. Particularly specimens N01, N02, and N08 were significantly affected by these boundary conditions. N01 specimen contained a dried crack that was situated in an area of tension rods. As a result, the bearing capacity of joint was reduced and a deformation and slight rotation of the joint took place in a different way. In case of N02 specimen, the whole timber block around the tension area of the joint was damaged by shear. This situation was caused by non-homogeneous composition of timber in this zone. By mistake, the specimen N08 contained one rod without the adhesive and a smaller maximum load was thus reached. Nevertheless, the resultant tensile forces showed that the rod resistance remained almost similar to the other specimens.

The resultant forces in the tension rods were approximately the same as the values obtained in the first stage of the experimental analysis. The achieved loads, forces in rods, and deformation parameters are listed in the Tab. 1. The curve expressing interdependence between the bending moment and rotation is shown in the Fig. 9.

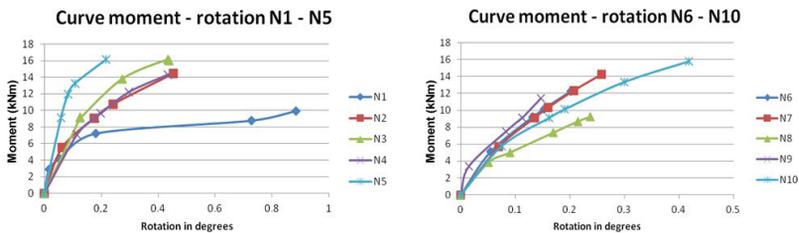


Fig. 9: Graphs expressing interdependence between the bending moments and slight rotation.

Tab. 1: Overview of the load and deformations measured.

Specim. No.	Material	Load achieved (kN)	Strength in one tension rod (kN)	Deflection of the beam (mm)	Compaction of the joint (mm)	Opening of the joint (mm)
N01	Solid timber	19.06	25.41	29.55	1.63	1.47
N02	Solid timber	32.98	43.97	32.39	1.04	0.71
N03	Solid timber	40.00	53.33	36.23	0.61	1.21
N04	Solid timber	37.36	49.40	42.15	0.95	1.07
N05	Solid timber	40.42	53.89	34.51	0.57	0.75
N06	GLT	29.56	39.41	17.80	0.33	0.56
N07	GLT	34.12	45.49	21.90	0.36	0.88
N08	GLT	19.24	38.48	12.03	0.41	0.37

N09	GLT	28.60	38.13	16.75	0.28	0.50
N10	GLT	34.96	46.61	24.87	0.78	0.85

The inductive deformation sensors that were placed on the tension and compression side of the cross-section allowed to express deformation parameters of joints, thus helping to render the neutral axis and identify the height of the cross-section's compression zone (Fig. 10). The figures below show that the height of the compression zones varied irregularly depending on the quality of designed joints and structure of the timber. Threaded rods had only insignificant share in the resulting deformations. The overall deformation of the beam consisted of deflection of the beam and joint rotation (Fig. 11).

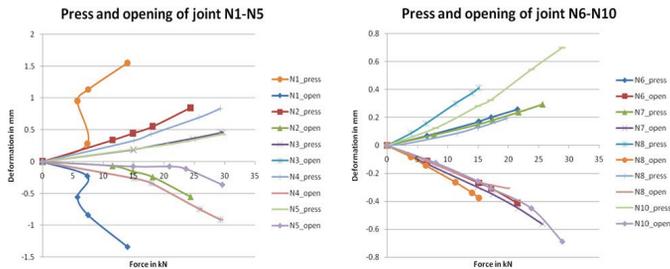


Fig. 10: Graphs indicating compaction and opening of joints.

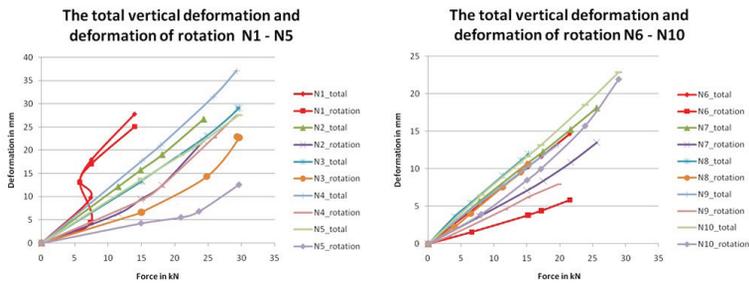


Fig. 11: Graphs expressing total deformation and deformation caused by joint rotation.

### CONCLUSIONS

The obtained results are similar to those achieved in the previous work where the finite elements method was used for calculations. However, the experimental analysis helped to clarify the differences between the resistances of tested specimens. For the elements of glued laminated timber, which is characterized by a more regular material structure, lower resistance was measured in comparison to solid timber. These values correspond to the numerical model which was solved without the non-homogeneous structure of timber.

Based on the obtained results, it is assumed that the resistance of timber element is crucial especially around the gaps. At the same time, tensile strength parallel to the grains and the shear resistance parallel to the fibres can be counted into the resistance of timber elements. It is assumed that after exceeding the tensile strength, the resistance of timber elements will be formed only by shear resistance parallel to the fibres. Therefore, it is important to design the minimum depth of bonding. These assumptions do not apply in case where non-homogeneous properties

of timber occur, because in this situation a more complex stresses distribution in timber elements occurs. Owing to more complicated structure of solid timber, this type of timber achieved higher resistance than glued laminated timber with a relatively regular structure. A very important factor, which significantly influences the rotation stiffness of a joint, is the quality of its design and the presence of dried cracks. In cases where distribution of deformations was affected in this way, larger deformations were measured.

Joints with glued-in threaded rods are characterized by high loading capacity and more favourable architectural appearance. Their ability to withstand bending and torque moments puts them to the foreground in the design of timber structures in many aspects of this issue.

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VLADIMÍR DUCHON\*, TOMÁŠ KLAS, ORSOLYA KATONA,  
JÁN BRODNIANSKY, LUBOŠ BALCIERÁK, JAROSLAV SANDANUS  
KRISTIAN SÓGEL  
SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA  
FACULTY OF CIVIL ENGINEERING  
DEPARTMENT OF STEEL AND TIMBER STRUCTURES  
RADLINSKÉHO 11  
81368 BRATISLAVA  
SLOVAK REPUBLIC  
PHONE: +421 2 592 74 372  
Corresponding author: rvladimirduchon@gmail.com