TEST RESULTS OF CONNECTIONS OF TIMBER STRUCTURES

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Abstract - The paper outlines the results of static tests of bolted connections of rectangular cross-section timber with inserted steel plates. The tested specimens were subjected to tension parallel to the grain, where the load-deformation diagram of the connections was recorded. Fifteen specimens of three different distances between the fastener and the loaded end were tested. The results of the tests were statistically evaluated, complemented with graphical records of the load-deformation curves and compared with the calculations according to the valid standard for design of timber structures.

Keywords - Bolt, Connection, Structure, Test, Timber

I. INTRODUCTION

For reliable and safe design of timber structures, it is necessary to know the response of these structures and especially their connections to a static load. Connections in timber structures are often the most critical in dimensioning of a structure and are frequently crucial for the serviceability and durability of the whole structure. It is therefore desirable to pay close attention to their design.

The contemporary European standard for the design of timber structures deals with timber-to-timber or steel-to-timber connections using mechanical fasteners such as bolts, dowels, nails, screws, etc. The edge and end distances and spacings for fasteners in the connections are only given as the minimum recommended. Therefore, static tests of bolted connections of rectangular cross-section timber with inserted steel plates were performed. Several variants of connections with different distances between the fastener and the loaded end were chosen for the tests in order to prove if the real load-carrying capacity is influenced by the distance. The specimens were subjected to tension parallel to the grain, carried out to failure of the connections.

II. DESCRIPTION OF MATERIALS FOR TEST SPECIMENS

Specimens for tension tests parallel to the grain were made of rectangular cross-section timber with cross-sectional dimensions of twice 60x120 mm. The specimens consisted of two equal parts due to easier production of final specimens (placement of steel plates). All specimens were made of spruce timber of C24 strength class. Specimens of three different lengths were tested (see Fig. 1) - 400 mm (designation H1), 480 mm (designation H2), 560 mm (designation H3). The circular holes in the timber members for placing fasteners had a diameter of 20 mm.

High tensile bolts grade 8.8 (f_y = 640 MPa, f_u = 800 MPa) with a diameter of 20 mm were used as fasteners. The bolts were placed at three different distances from the loaded end - 140 mm (= 7x bolt diameter), 180 mm (= 9x bolt diameter), 220 mm (= 11x bolt diameter). The axial spacing between two bolts in one specimen was 120 mm.

The steel plates were made of structural steel grade S235J0, their thickness was 10 mm. The dimensions of the steel plates also varied depending on the distance between the fastener and the loaded end. The protruding part of the plates for clamping the plates into the jaws of the testing machine was 180 mm long (see Fig. 2). The plates were provided with circular holes with a diameter of 22 mm for placing bolts (a clearance of 2 mm was left).

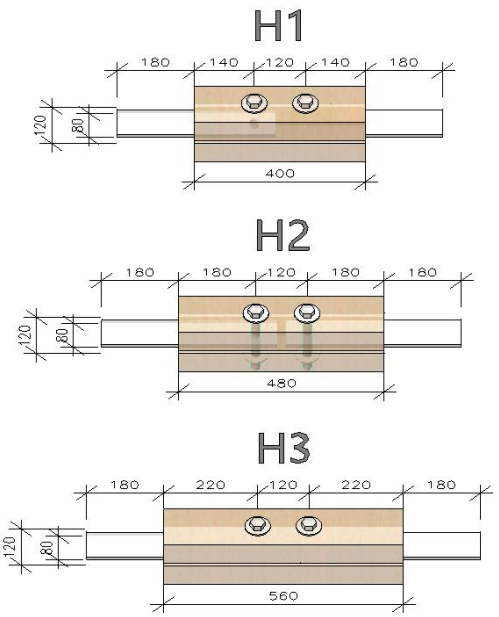


Fig. 1 - Types of specimens for parallel to the grain tension test

III. METHODS OF TESTING

A. Description of the testing machine

The experiments were performed using LabTest 6.1200 electromechanical testing machine from

LABORTECH (see Fig. 2), which allows not only static tension and compression testing, but also dynamic testing. The maximum force that the electrohydraulic cylinders of the testing machine can exert is 1200 kN, which seemed sufficient for the tested connections to failure. The test speed of the testing machine ranges from 0.0005 to 250 mm / min. The specimens are clamped into jaws, the surface of which is treated with special serrations for better adhesion. The machine is controlled by simple software.

B. Description of the course of the testing

Several non-destructive tests were carried out before the main testing to determine the quality of used timber material, its moisture content and its density. The test specimens were weighed on a laboratory scale and their dimensions and moisture content were measured. Based on these data, the bulk density of the specimens and the density derived therefrom were determined according to [3]. The measurement of the moisture content was performed using a capacitive material moisture meter according to [4].

The test specimens were clamped into the jaws of the testing machine so that the tested connection was subjected to an axial tensile load with possible additional effects from imperfections. The arrangement and loading of the test specimens was designed to correspond to the actual state of connections in real supporting structures. The aim was not to simulate ideal conditions, but to verify the behavior of the connection under standard conditions. For this reason, the bolts were also tightened by the hand using a spanner.

The tensile load was generated by electrohydraulic cylinders with a capacity of 1200 kN. During the test, continuous recording of the time, the tensile force and the deformation of the connection in the longitudinal direction was performed.

The course of loading was carried out in accordance with the standard for the testing of connections of timber structures with mechanical fasteners [2], where the following loading procedure is prescribed:

1. Estimation of the maximum force F_{est} for the tested connection based on experience, calculation or pre-tests
2. Loading of the specimen to the level of 40% of the estimated maximum force $0.4 \cdot F_{est}$, then waiting on that level of the load for 30 seconds
3. Decrease of the loading to the level of 10 % of the estimated maximum force $0.1 \cdot F_{est}$, then waiting on that level of the load for 30 seconds
4. Continuous loading to failure of the specimen

The loading speed is chosen constant in mm/min or kN/min. The total testing time of one specimen was about 10 to 15 minutes.

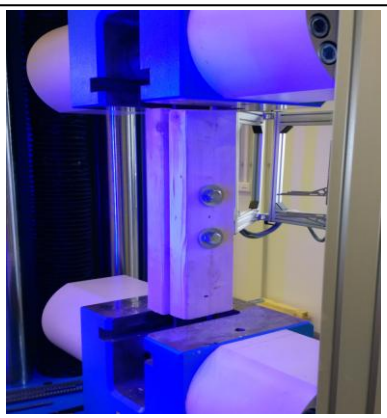


Fig. 2 - A specimen clamped in the jaws of the testing machine



Fig. 3 - A specimen after failure

IV. RESULTS

For this paper, three types of bolt connections of rectangular cross-section timber with inserted steel plates were tested. Five specimens were used for each type, in total fifteen specimens were tested. Tables 1, 2, 3 show statistically evaluated values of bulk density and moisture content of used timber material, maximum failure forces and values of the initial slip modulus and slip modulus (for more [2]) for all the types (H1, H2, H3). Graph 1 shows the load-deformation curves of the H3 specimens. The graph shows the initial loading at 40% of the estimated maximum force, the subsequent unloading at 10% of the estimated maximum force and the loading to failure. It is also possible to see the actual maximum force and the corresponding deformation at failure. According to Eurocode 5 [1], it is considered a double shear steel-to-timber connection (for a steel plate of any thickness as a central member). The characteristic value of the load-carrying capacity without the contribution from the rope effect of the given type of the connection according to the above mentioned standard is $F_{v,Rk}$ = 46528 N.

In order to calculate the load-carrying capacity, the necessary input values for timber of C24 strength class and bolt M20 grade 8.8 were used.

H1	ρ [kg/m^3] Bulk density	w [%] Moisture content	F_{max} [N] Maximum force	k_i [N/mm] Initial slip modulus	k_s [N/mm] Slip modulus
Average value	417	12,7	65835	5915	7271
Sample standard deviaton	15,0	0,2	4343	230	482
Coefficient of variation	3,59%	1,94%	6,60%	3,89%	6,62%
5% quantile value	380	-	55151	-	-

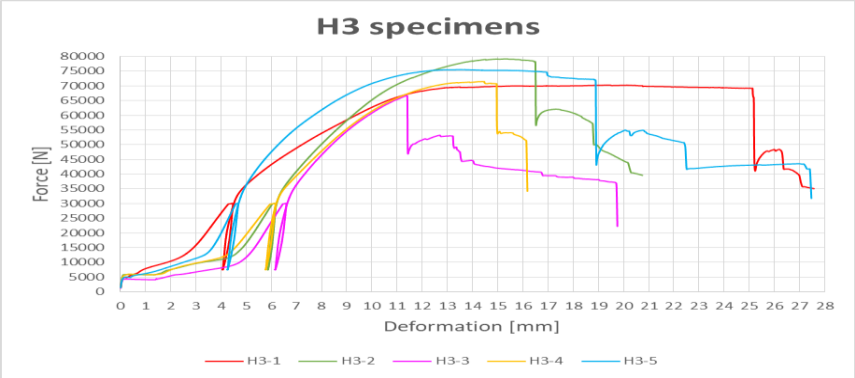
Table 1 - Values of bulk density, moisture content and slip moduli for H1

H2	ρ [kg/m^3] Bulk density	w [%] Moisture content	F_{max} [N] Maximum force	k_i [N/mm] Initial slip modulus	k_s [N/mm] Slip modulus
Average value	407	12,6	75427	5931	5644
Sample standard deviaton	20,4	0,6	8263	2046	1412
Coefficient of variation	5,01%	4,44%	10,95%	34,50%	25,02%
5% quantile value	357	-	55101	-	-

Table 2 - Values of bulk density, moisture content and slip moduli for H2

H3	ρ [kg/m^3] Bulk density	w [%] Moisture content	F_{max} [N] Maximum force	k_i [N/mm] Initial slip modulus	k_s [N/mm] Slip modulus
Average value	414	13,0	72625	5530	6446
Sample standard deviaton	20,6	1,0	4838	1021	1005
Coefficient of variation	4,98%	7,40%	6,66%	18,47%	15,60%
5% quantile value	363	-	60724	-	-

Table 3 - Values of bulk density, moisture content and slip moduli for H3



Graph 1 - Load-deformation curves of H3 specimens

V. DISCUSSION OF THE RESULTS

From the beginning of the loading, plastic deformation of holes in timber members occurred until the failure of the tested specimens caused by tension perpendicular to the grain. The failure always occurred by splitting the timber under the bolt, when the tensile strength perpendicular to the grain was exceeded and cross links between individual fibers in timber were broken (see Fig. 3). This phenomenon is attributed to the fact that the timber in tension has little plasticity and is broken by a brittle fracture.

As can be seen in Graph 1, the specimen with the most significant initial slip was broken first (specimen H3-3). This is probably due to the fact that in the initial phase of loading the timber has exhausted all its plasticity in the compression, and in the final phase a brittle tensile failure soon occurred. In contrast, the specimen with the least significant initial slip shows a considerable plasticity margin in the final phase of loading (specimen H3-1).

The evaluated characteristic values of load-carrying capacity for all types of specimens are higher than the values calculated according to the standard Eurocode 5. The highest characteristic value of the load-carrying capacity was found in specimens of type H3 (the greatest distance between the bolt and the loaded end). For H1 and H2 specimens, the characteristic values are very similar. Therefore, it is not possible to draw a conclusion from the evaluation of the test results that there is a significant influence of the distance between the fastener and the loaded end on the characteristic load-carrying capacity of the connection. In addition, this is complicated by the small amount of tested specimens, which considerably affects the statistical evaluation of specimens with higher coefficient of variation (especially specimens of type H2).

VI. CONCLUSION

Experimental testing is the most appropriate way of verifying structural details of timber structures. Therefore, tests of bolted connections of rectangular cross-section timber with inserted steel plates of different distances between the fastener and the loaded end were performed. For a more objective, more comprehensive conclusion about the behavior of these connections and the verification of the tests already carried out, it is necessary to carry out another series of tests in the coming period.

Connections with inserted steel plates are also widely used in exterior timber structures that are subject to significant temperature and moisture content changes. Besides, these structures are predominantly loaded by wind having the characteristics of an alternating dynamic load. On the basis of these facts, the future research of this issue also offers the possibility to complete the experiments with dynamic tests and tests using specimens with different moisture content of timber members.

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