LOCALLY REINFORCED LAMINATED TIMBER WITH GLASS FIBER GLUED-IN BETWEEN THE TIMBER LAYERS

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Abstract
Research of truss girder joint based on the steel pipe placed in bottom and top cord and steel rods glued-in web member, requires local reinforcing of laminated timber in the zone of steel pipe. In this paper the reinforcing of wooden laminated element at the connection areas will be point out. Tests on 120mm width, 200mm high and 1000mm long specimens loaded perpendicular to the grain through a steel tube 50mm in diameter will be carried out. Experimental results obtained by reinforcing laminated timber will be compared with no reinforcing timber. Parallel with the results of laboratory experiments, results of numerical models will be presented. Numerical models with material and geometric nonlinearities were made with Abaqus /Standard for both series, reinforced and no reinforced timber.

1 Joints in timber structures

Joints are among the weakest points in timber structures. Due to their weaker mechanical properties and brittle fracture on tension perpendicular to grain and shear longitudinal to grain, joints reduce the timber structure capacities. Approximately 80% of all damages in timber structures have been observed in the area of joints [1].
Joints in timber structures can be divided, according to force transfer method, into three categories [2]:

a. carpentry joints
b. glued joints
c. joints with mechanical fasteners

Joints by means of fasteners are among the most frequent in timber structures. The category includes screws, dowels, threaded fasteners, nails, cramps and shear studs. As said above, the major drawback of timber joints is low tensile resistance of timber perpendicular to grain and brittle fracture. To avoid brittle fracture and to ensure the ductility of joints in timber structures, minimum distances of the fastener from the edge of the element and minimum distances between the fasteners have been set out [3].
Small diameter screws will ensure higher ductility of the joint, but due to their low resistance to bending, the joints made by small diameter fasteners will have low rigidity and resistance. By increasing their cross section of the screw, the resistance of the joint is increased proportionally, but in order to keep the ductility – the geometry of the joint needs to be increased. Increased joint geometry, i.e. distance between the screws and distance from the

edge of the beam requires the increase of all elements and leads to increased timber consumption in the structures [4].

2 Concept of fast-assembly connection

Fast assembly connection concept is based on a large diameter fastener and local reinforcement on the place of timber element connection. Figure 1. presents the structure of a connection used for the test by the introduction of force perpendicularly to grain. The timber element which the force is introduced into has been adopted in the presented connection 120mm width.

Timber reinforcement process on the point of connection is conducted in the process of lamella gluing and does not require specific change in the gluing technology. The quantity of fabric in the timber element and the timber reinforcement ratio depends on the requirements of the joint in terms of resistance, ductility and rigidity.

At the cross point of the axes of the joint elements, the timber glulam element has a horizontal hole of 50 mm diameter. The main element of the joint, steel pipe of outer diameter 49 mm is installed into the hole. The fastener is the screw connecting the pipe with the agent or element introducing the force into the connection.

Screw M-16 class 12.9 is installed through a pre-drilled hole in the timber element with rated diameter exceeding by 2 mm the outer diameter of a profiled washer. The hole for the screw is drilled in such a way that the axis crosses the axis of a 50 mm diameter hole and that the angle it closes with the grain corresponds to that of the force introduced into the connection.

The other half of the connection consists of an element introducing the force into the connection. Introduction of the force into the connection may be resolved through a timber element with glued steel bar or directly from steel bar. Whether glued or direct, the bar at its end is mounted into the added bushing.

The bushing has two threads, outer and inner. The inner thread is used from one side for the installation of the bar and from the other side for the installation of the screw. If the bars are glued, the external thread is done on the added bushing. Through the outer tread on the added bushing, the steel bar is installed into the timber element and its structural support at the spot during the gluing process.

3 Experimental research

Timber laminated elements are made of 32 mm lamina at the plants of HOJA d.d. of Slovenia. Small samples in size 12×20×100 [cm] used for experimental research have been made out of four laminas glued with melamine glue. Elements intended for experimental research of glass fibre fabric reinforced joints were reinforced by insertion of the fabric between the laminas in the gluing process.

According to the mechanical features of the timber used for laminas, manufactured laminated elements are in class GL24h according to EC5 regulations.

The fabric used for reinforcement of timber samples on the joint spot has been selected from the production range of Kelteks d.o.o. The fabric is branded RT (Roving fabric) – 900 K 2/2.

Technical characteristics of the fabric claimed by the manufacturer are fine yarn for warp and woof 2400 tex, warp density 18 threads/10cm and woof density 19 threads/10cm. The type of weave is twill 2/2. Fabric weight is 900±5% g/m^2.

All steel elements are made of steel of high yielding limit. Steel pipe is made of steel with yielding limit 355 N/mm^2, and the threading bar and added bushings are made of steel with yielding limit 750 N/mm^2. The main fastening element is screw M-16 class 12.9, installed from the lower side of the cord, passing through the steel pipe ø 50mm, and mounted in bushing via thread. The threaded bar glued into the truss web has quality equivalent to screw class 8.8, and at the external end it has a bushing in which the screw enters.

Figure 2 shows testing of reinforced specimen on Shimatzu AG-300 machine (1) with applied load perpendicular to the grain. Figure 3. below shows the scheme of border conditions of the tested sample with the introduction of the force perpendicular to the grain.

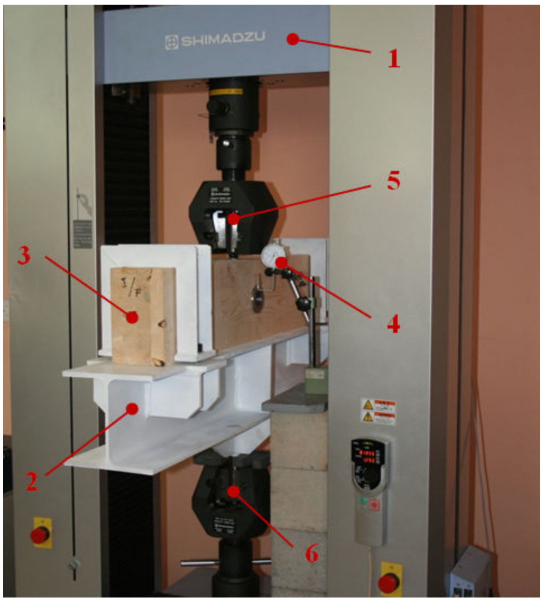


Figure 1. Sample testing with force perpendicular to grain

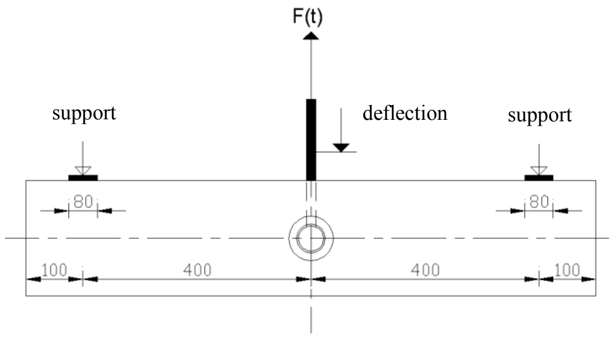


Figure 2. Scheme of sample testing with force perpendicular to grain

The force was introduced into the element through the screw of the principal joint element of the observed connection. The screw is mounted into the steel bushing with inside thread and the bushing is seized with the top mobile jaws (5) of the testing machine.
The force was introduced with the control of force increase up to the full yield of the connection. In the course of the test, deformation was monitored depending on the applied force on the cutting machine jaws and by means of a micro-clock measuring the relative screw displacement. Force increase in the course of the testing was 5.0 kN/min under load and 10.0 kN/min at relaxation of load. Sample relaxation was done at 25.0 kN force and for reinforced samples at the force of 25.0 kN, 50.0 kN and 75.0 kN, in the course of relaxation, the force was reduced to 10.0 kN and then increased again by 5.0 kN/min increments.
The samples were divided into two groups, non-reinforced and reinforced samples. The testing on the non-reinforced samples was conducted on two elements, A and B, and the testing on the reinforced samples on four elements marked C to F.

3.1 Experimental test results

Results obtained on samples by experimental tests are presented in table 1. for reinforced samples and in table 2. for non-reinforced samples. The processing of the results and the obtaining of characteristic sizes were conducted according to the procedure set out by CEN (European Committee for Standardisation).
CEN defines the procedure for determination of mechanical characteristics of the joints in timber structures through the following standards:

a) for testing of joints by static force EN 26891
b) for testing of joints by variable force EN 12512

The foregoing rules provide no guidance, however, for determination of ductility of the joints under static force [5]. For that reason, considering that in this paper we describe the testing of the joints under static force, guidance from EN 12512 has been taken for determination of ductility.

Method 1/6 consists of the definition of the elastic range with a line determined with two points, corresponding to 10% and 40% maximum force. After the definition of the first line and the angle closed by that line with the horizontal axis ("X" axis) of the coordinate system, the other line is placed with 1/6 inclination of the first line in such a way as to be tangent to the operating curve. The cross point of the two lines determines the yielding limit.

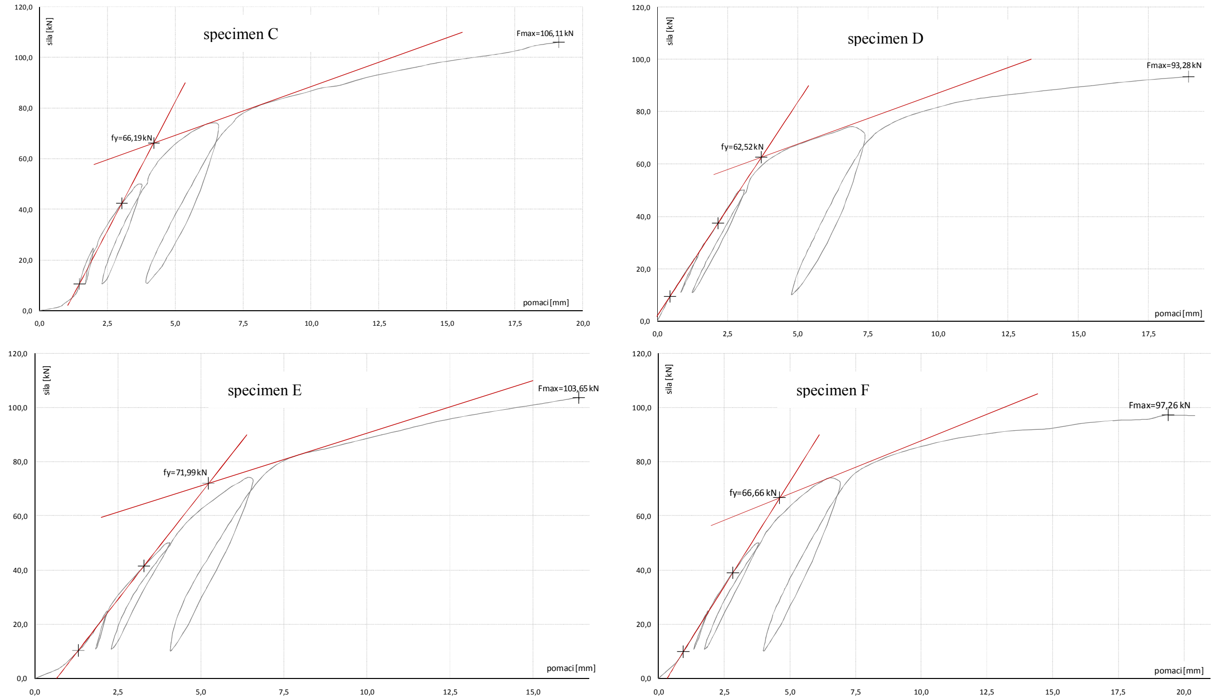


Table 1. Graphic presentation of results – series I, samples C-F

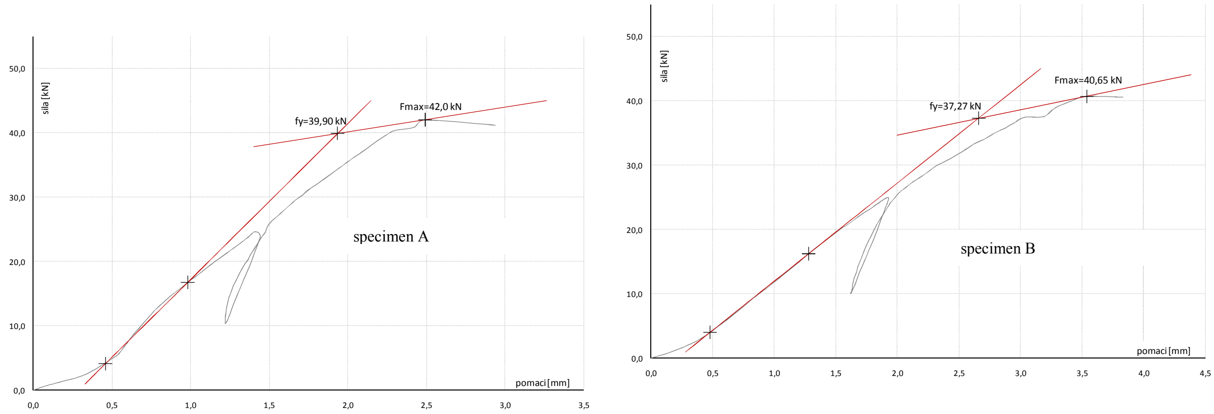


Table 2. Graphic presentation of results – series I, samples A and B

Two values to be observed with the yielding limit and strength for the obtained results of the experimental and numeric research are ductility and rigidity of the joints.

Ductility may be described as capacity of the structure to keep the resistance out of elastic area with large deformations before the fracture. Ductility is expressed as a relation between the displacement in the points of yield and rigidity [2].

$$d = \frac{\delta_u}{\delta_y} \tag{1}$$

In rigidity, we discern between two rigidities, the initial rigidity k_i and characteristic rigidity k_s. Characteristic rigidity is calculated as 2/3 initial rigidity, and is determined from the inclination of the line marked with 10% and 40% maximum force according to the expression:

$$k_s = \frac{0{,}4 \cdot F_u - 0{,}1 \cdot F_u}{\delta_{0,4} - \delta_{0,1}} \quad (2)$$

The classification and processing of the results have led to mechanical characteristics of the joint. By use of method 1/6, as described in this paper, the average force of the reinforced samples F_{max}= 100.08 kN and average yielding limit F_y= 66.84 kN have been obtained. For non-reinforced samples, values of characteristic forces are F_{max}= 41.33 kN and F_y = 38.58 kN. Ductility of the joints according to the obtained results is d = 4.25 for reinforced samples and d= 1.31 for non-reinforced ones. Analysis of results has shown characteristic rigidity of the fabric reinforced joints at k_s = 16.98 kN/mm and that for non-reinforced samples at k_s=19.73 kN/mm.

4 Numerical models

The joint has been subject to numerical analysis by ABAQUS/CAE ver.6.10 software. Volume finite elements C3D8 have been used defined through eight nodes. Glulam part of the joint was modelled as two symmetric halves, joined by cohesion interaction of the two surfaces at the point where the opening and widening of the crack is expected (middle of the sample).

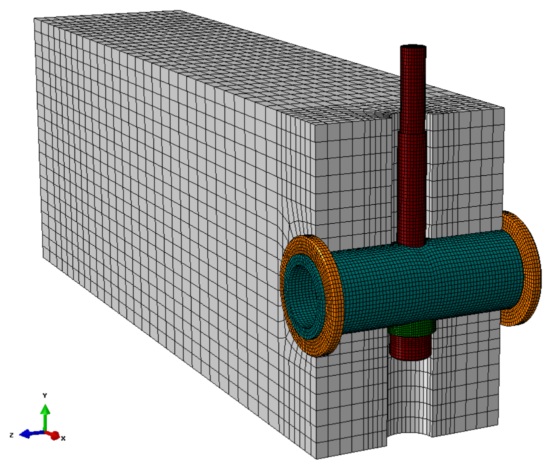


Figure 3. A half of the numerical model without reinforcement

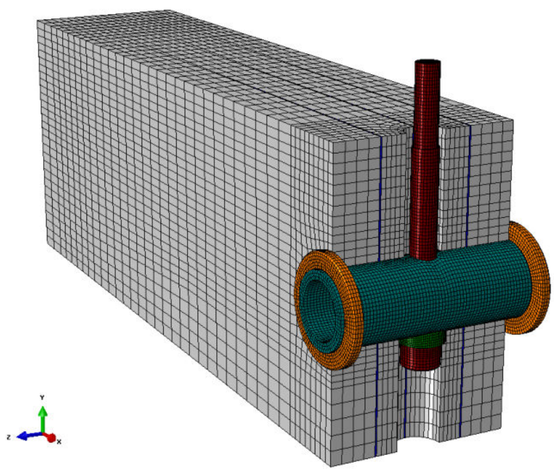


Figure 4. A half of the numerical model with reinforcement

The numerical models of fabric reinforced joints required the modelling of a slot in the timber for the fabric. The slots for the fabric in the wood are made at 1 mm width, 400 mm length and at full height of the wooden element, fig. 4.

The slot made in the wood was filled with the fabric modelled with 1 mm thickness. The reason for making the fabric thicker is that with less thick fabric, it would be hard to fulfil the minimum recommended ratios between the sides of the finite element.

For the modelling of contact surfaces, absolute rigidity to normal stress and the possibility of tangential sliding of two surfaces with the friction ratio were used. Friction ratio applied to steel-steel contact is taken as 0.2, and that for wood-steel contact is 0.25 [6].

The numerical analyses of connection models were conducted with the included geometrical non-linearity to increase the accuracy, considering major deformations and their influence to final results.

Non-linear numerical analyses have been conducted with included geometrical and material non-linearity. Newton method with automatic increment control was used for force control. Maximum force increment was limited to 0.25 t provided that the initial increment was placed at 0.1 t. Force increment for all numerical models was given on linear basis with 1 kN increment in time unit t.

Load modelling was conducted by means of screw pressure perpendicular to the screw cross section. The pressure per screw surface is 6.49612, which corresponds to force of 1000.0 N on the surface of the screw of 153.9 mm^2. Force increment in time in the numerical model was led by amplitude depending on time as set out above.

Elasticity and shear modules for each specific direction [7] and Poisson's ratios [8] are presented in Table 3.

The issue of numerical modelling of timber was already studied and described in some papers [6, 9-11]. Abaqus/CEA enables the creation of a series of subroutines for description of problems other than those in the standard package. In this paper, for modelling timber mechanical properties UMAT subroutines was used.

The other problem in detailed numerical description of timber behaviour is tension perpendicular to grain and opening of a crack. Opening of a crack in a material or adhesive is one of the problems described and used in timber studies [12-14]. In this paper, cohesion elements and the cohesion interaction between the two surfaces have been used for modelling of the yield of timber, fabric and adhesive due to tensile and shear stresses.

Yielding limits for each direction and pre-mark of tension have been set for the observed timber class GL 24 h (table 3). Timber characteristics are such that the wood may be observed as an elasto- plastic material with reinforcement. Tangential module has been adopted for the plastic area under pressure at 50% value of the elastic range, which after the increase of stresses over the strength, moves to 10%, and for tensile area 10% value of the module for the elastic area has been adopted [13].

Testing of fabric samples in direction of warp and woof has determined mechanical characteristics converted to avoid prohibited ratio of finite element sides, which corresponded to the thickness of finite elements of 1.0 mm. Mechanical characteristics are presented in the table 4. below. The working diagram of the fabric is set as elasto-plastic material with reinforcement. It should be noted that the fabric as material has no shear modulus and the shear modulus of melamine adhesive in which the fabric is placed is taken as that value.

For the modelling of steel elements, mechanical characteristics presented in table 5 are taken. Steel is modelled as elasto-plastic material with reinforcement, provided that for determination of the tangential elasticity module, relative deformation condition of 0.2% was taken.

Elastic modulus	Shear modulus	Poisson's ratio	Yield strength in compression	Yield strength in tension
E_L=11500 N/mm^2	G_{LR}=600 N/mm^2	ν_{LR} = 0.42	f_{yLc}= 24.0 N/mm^2	f_{yLt}= 16.5 N/mm^2
E_T= 450 N/mm^2	G_{RT}=60 N/mm^2	ν_{RT} = 0.5	f_{yTc}= 2.9 N/mm^2	f_{yTt}= 0.4 N/mm^2
E_R= 600 N/mm^2	G_{LT}=650 N/mm^2	ν_{LT} = 0.48	f_{yRc}= 2.9 N/mm^2	f_{yRt}= 0.4 N/mm^2

Table 3. Mechanical characteristics of timber

Elastic modulus	Shear modulus	Poisson's ratio	Yield strength in compression	Yield strength in tension
E_L=4571 N/mm^2	G_{LR}=760.8 N/mm^2	ν_{LR} = 0.38	f_{yLc}= 160.0 N/mm^2	f_{yLt}= 160.0 N/mm^2
E_T= 4571 N/mm^2	G_{RT}=760.8 N/mm^2	ν_{RT} = 0.38	f_{yTc}= 160.0 N/mm^2	f_{yTt}= 160.0 N/mm^2

Table 4. Mechanical characteristics of fabric

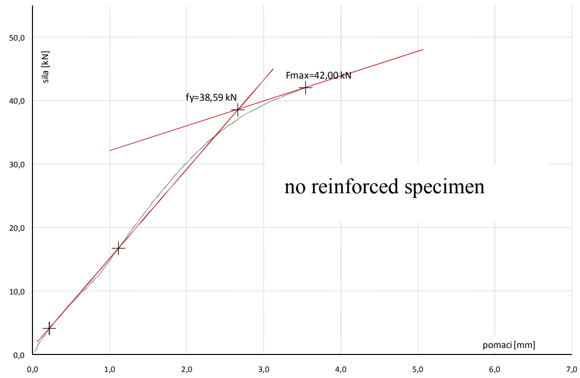
Elastic modulus	Shear modulus	Poisson's ratio	Yield strength	Ultimate strength
E360 E=210000 N/mm^2	G_{LR}=80769 N/mm^2	ν_{LR} = 0.3	f_{yLc}= 355.0 N/mm^2	f_{yLt}= 670.0 N/mm^2
42CrMo4 E=210000 N/mm^2	G_{LR}=80769 N/mm^2	ν_{LR} = 0.3	f_{yLc}= 750.0 N/mm^2	f_{yLt}= 1000.0 N/mm^2
Bolt E=210000 N/mm^2	G_{LR}=80769 N/mm^2	ν_{LR} = 0.3	f_{yLc}=1080.0 N/mm^2	f_{yLt}= 1200.0 N/mm^2

Table 5. Mechanical characteristics of steel parts

4.1 Numerical analysis results

Results obtained on numerical models for reinforced and non-reinforced samples are presented in table 6. The results have been processed according to method 1/6 as well as for experimental studies as visible on the graph.

Characteristic sizes of forces obtained by numerical models are: for fabric reinforced joint F_{max}= 92.0 kN and F_y= 79.24 kN, and for non-reinforced joint: F_{max}= 42.0 kN and F_y= 38.59 kN.



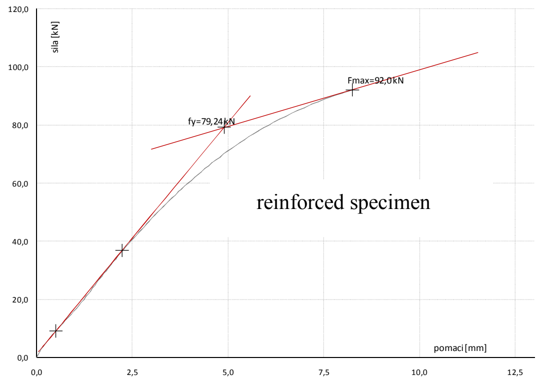


Table 6. Results of numerical models

Ductility of joints according to the obtained results is d= 1.68 for a reinforced joint and d= 1.33 for a non-reinforced joint. Characteristic rigidity of fabric reinforced joints was obtained by the analysis of results at the value of k_s= 15.92 kN/mm, and k_s= 14.23 kN/mm for non-reinforced joints.

5 Conclusion

The paper presents the testing of installed fast-assembly joints for timber truss structures. The studies on non-reinforced and local reinforced samples have provided the results of behaviour of such joints. The studies have been conducted to obtain knowledge about joints with large hole diameter as the former studies so far have been insignificant.

The results obtained on the tested samples show multiple increases in ductility and resistance of a local reinforced joint compared to a non-reinforced joint. Joint reinforcement by means of fabric between the laminas has proven to be a very good solution with multiple increase of the resistance of the joint to tensile force perpendicular to grain. Further, ductility of local

reinforced joints compared to those non-reinforced has been increased 3.24 times, which makes local reinforced joints medium ductile joints according to Eurocode 8 [2].
Numerical models have provided results with relatively small deviations compared to the experimental research. The major deficiency of the numerical models is modelling of mechanical characteristics of timber in compression. Considering that the timber in compression above strength has a negative elasticity module (descending line of the working diagram), which is difficult to set by finite element method, there is a difference in the deformation of the experimental results and the numerical models. The difference in the deformation provides deviations in ductility and yielding limits.

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