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MODELING RHEOLOGICAL BEHAVIOR OF THE BOLTED JOINTS USED IN WOOD CONSTRUCTIONS

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Abstract:

Wooden buildings are subjected to both short term and long term variable loads. The wood is better able to withstand high loads in a short period of time than for a longer period of time. The stress duration refers to the loss of strength, which must be considered as a phenomenon in its own right. Joints are the main areas in which the energy can be dissipated by the possibility of using the plastic capacity of those parts of the structure. The deformability is observed mainly when used mechanical clips in joints. One of the limits of the energy dissipation is wood breaking in the joint area. In assessing the mechanical properties of a wooden element, the regularity of growth, the presence, arrangement and dimensions of any knots or other defects must be taken into account. All these have influence upon the elastic-plastic properties of wood, showing continuous deformation under load (creep).

This paper presents the results of numerical and experimental modeling of the rheological behavior of the wood joints in case of using simple rod and Bulldog rod stud type. In the first part of the study, the rod joint subjected to tensile stresses was modeled with FEM analysis, determining the displacement and the maximum stresses. In the second stage, the joints were subjected to tensile stresses and the curves stresses – displacement and energy of deformation were extracted, then another set of specimens were subjected to tensile stresses, while being monitored the values of the climatic parameters and displacement values.

Key words: *rheological behaviour; bolted joint; wood construction; finite element model.*

INTRODUCTION

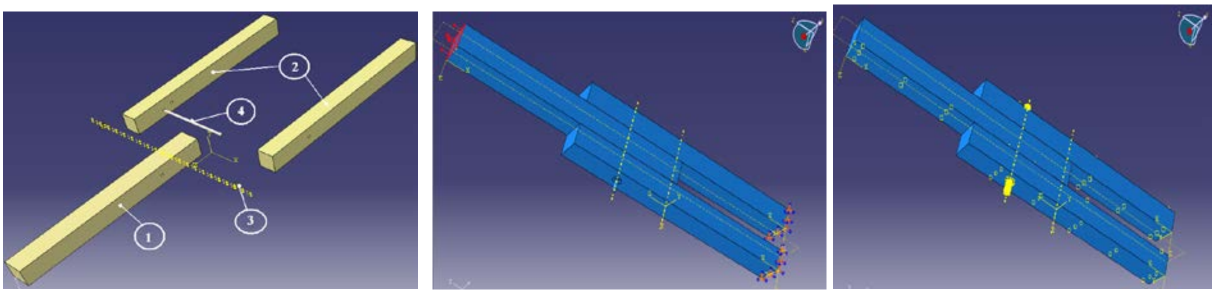
So far, not enough studies have been conducted to describe, both theoretically and experimentally, the exact behavior of the wood joints for long periods of time. At present, the experimental studies have been limited to the analysis of the properties of the solid wood as such and not to the analysis of the structures made of wood, in joints respectively (Breyer *et al*. 2006). These joints have been only staticaly tested, under laboratory conditions, for short periods of time (Hwang & Komatsu 2002).

The behavior of the joints in time, under long-term stresses, subjected to the environmental factors (humidity, temperature) and to the intensity and the duration of the forces applied to them was not investigated so far, fact which can lead to the loss of stability and often to the shortening of life of the timber constructions (Agahayere 2007, Moutée 2006, Barbero,1998, Chaplain 1994).

The paper presents the numerical and the experimental analysis of the behavior in time in case of simple rod joints and Bulldog stud rod joints used for wooden constructions, considering the following factors of influence: species of wood, humidity, temperature, the nature and the size of the applied stresses. Thus, the proportion of elastic deformations (instantaneous and delayed) and plastic ones for the same species of wood and stresses depends directly to the humidity (U), temperature (T), the nature and the size of the applied stresses (σ) to wood (Dateş 2009, 2008, Lăzărescu 2004, Curtu 1993).

FINITE ELEMENT METHOD USED TO SIMULATE THE BEHAVIOR TO THE TENSILE STRESSES

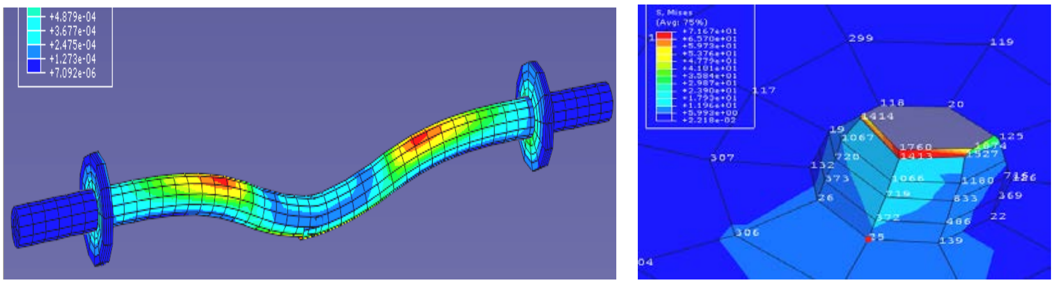
In order to observe the behavior of the cylindrical rods joints to the tensile stresses, the finite element modelling with ABAQUS software have been chosen (Fig. 1). The cylindrical rod joint having a 6mm rod diameter, being subjected to a force of 5kN was modelled. The side parts of the joint elements were considered to be embedded. (Fig. 1). The components of the assembly have been discretized into finite elements C3D8R type (8 knots). The applied load was considered into the longitudinal direction of the fibers. The values of the material constants were as follows: for wood (Curtu, Ghelmeziu 1984): E_1=14300*MPa;* E_2=620*MP;* E_3=420*MPa;* G_{12}=6500*MPa;* G_{13}=4160*MPa;* G_{23}=3470*MPa;* ν_{12}=0,25; ν_{13}=0,48; ν_{23}=0,411; for steel: the Young's modulus was $E=2\cdot10^5$MPa and the Poisson's ratio was ν=0,3. The coefficient of friction between the elements was considered equal to 0.2. For the wooden elements, the direction of fibers was parallel to their length. The loading force was applied in the same direction.



a. **b.** **c.**

Fig. 1

***The components of the assembly*: *a - 1- central element (434x40x50mm), 2 - side elements (434x35x50mm), 3 - nut, 4 - metal rod of Ø6mm;* b *– loading scheme and support conditions; c - contacts and interactions between the joint elements*.**



a. **b.**

Fig. 2

Deformations and stresses for rod joint: a – rod deformations distribution, ε; b - Von Mises stresses distribution, in the vecinity of the hole, on the side element.

The highest stresses and displacements occured in the metal rod and at the contact between the rod and the wood. A comparative analysis of the elements shows that the highest stresses occured on the side parts and not on the central ones, where, in return, greater displacement occured (Fig. 2).

It was considered necessary, in the second stage, to introduce Bulldog stud type connectors between the wooden elements of the analyzed assembly, in order to optimize its strength and stiffness (Fig. 3). The finite element analysis upon the joints where Bulldog rod stud type was used, has been imposed then (Fig. 4).

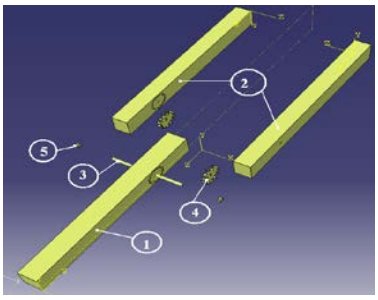


Fig. 3
Components of the assembly: 1 - central element (434x40x50mm), 2 - side elements (434x35x50mm), 3 - metal rod of Ø6 mm, 4 - Bulldog rod stud, 5 – nut.

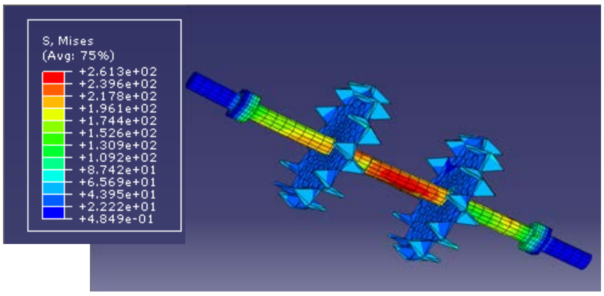


Fig. 4
Von Mises stresses distributed on the rod surface.

Comparing the two types of joints, it appears that the stresses are lower when using Buldog studs, whilest the displacements were higher in case of simple rod joints and the differences were higher in this case, too.

The results of the maximum stresses and displacements recorded by finite element modeling are shown in Table 1.

Table 1

Maximum stresses and displacements recorded by finite element modeling

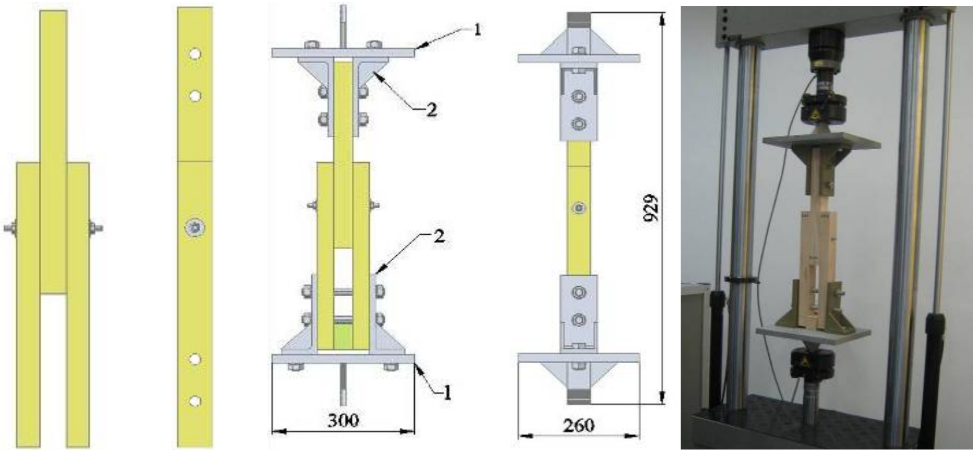
	Simple rod joint		**Stud rod joint**	
	Maximum stresses [*MPa*]	Maximum displacements [*mm*]	Maximum stresses [*MPa*]	Maximum displacements [*mm*]
Central element	64,1098	0,1794	27,7739	0,0991
Side element	70,1851	0,1261	76,5602	0,0493
Metal rod	290,562	0,256	261,293	0,0667

BEHAVIOR OF WOODEN JOINTS WITH CYLINDRICAL RODS SUBJECTED TO TENSILE STRAINS

Static Testing

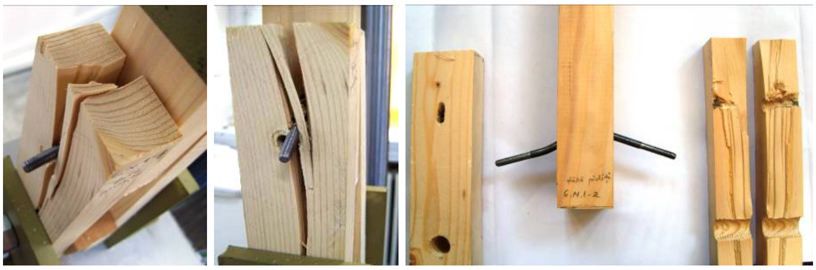
In order to establish the time behavior of bolt wooden joints when subjected to tensile strains, first the breaking strength under laboratory conditions intended to be achieved. The studied joint is shown in Fig. 5, consisting of three wooden elements and a metal rod bolt type. In order to conduct the tests in the laboratory conditions, the downsizing 1:2 scale of specimens has been imposed. The tested joints were made of spruce wood. In order to measure the moisture content of the specimens, an apparatus with electromagnetic waves has been used. The jointed elements had recorded at the first experimental tests a moisture content percentage in the range between 10.2 to 21.9%. The experimental tests have followed the influence of the rod diameter variation and of the mosture content upon the mechanical strength of the joint. For this type of joints, a M6 X 110mm threaded rod, standard nuts and washers for wood joints were chosen.

The tested joint was fixed on the tensile - compressive mechanical testing machine and subjected to the tensile strains up to the maximum breaking strength of the assembly. For the joints where rod of 6mm diameter was used, the fracture occurred in the longitudinal direction of wood for one structure whilst the rod deformations recorded for all tested structures (Fig. 6). The influence of the type of joint and of the moisture content on the tensile strength was thus determined.



a. b.

Fig. 5
Experimental set-up:
a – sample tested to tensile strains and and the fixture; b - Tensile testing machine.



a. b. c.

Fig. 6
The joint fractures.

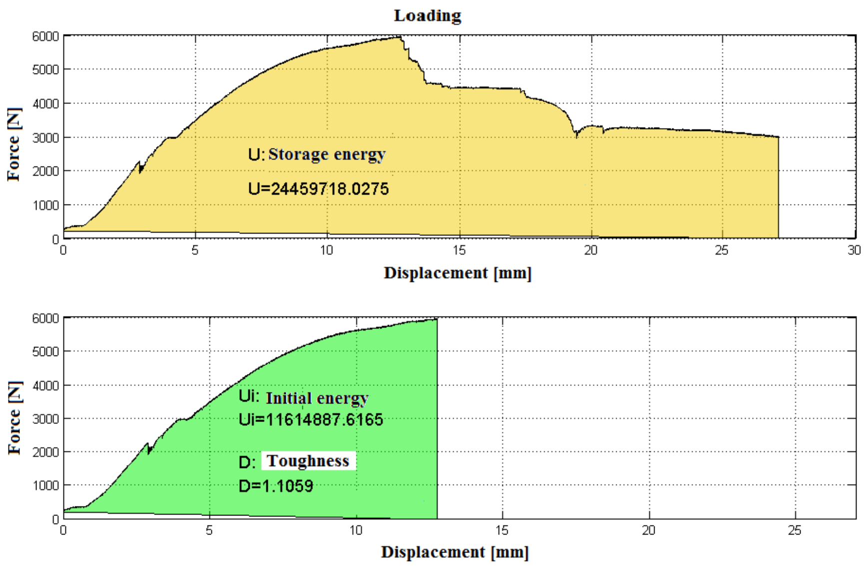


Fig. 7
The loading curve: a - The total absorbed energy; b - the initial energy and the tenacity of the simple rod joint, Φ 6mm, without nut.

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Rheological testing

In order to time study the behavior of metal rods (bolts) wood joints under continuous loads, the testing stand presented in Fig. 8 was designed and built.

Fig. 8
Testing stand; components.

The tests followed the time evolution of joint displacements under the continuous load. The joints were fixed on the device frame made of steel and a disk holder made of steel was attached at the free end, with the possibility of attaching new discs in order to increase the load. The weight of the disc holder is Q_1 = 300*N*, and the second one is Q_2 = 250*N.* After the deformation of the joints became constant, a third disc was attached with a weight of 300*N*, reaching a weight of 900N at the end of the experimental program.

The deformations recorded by the gauge with an accuracy of 0.01mm and the influence of the temperature (T) and of the relative humidity of the air (φ) in the environment *were periodically documented*. The total test period was 202 days, with a period of 12 hours for the measurement of displacement, temperature and relative humidity of air.

At the end of the tests the following issues were determined: the evolution and behavior of the displacements occured during the test performance, changes of the relative humidity of air and of the environment temperature, the speed of the joint displacements.

The evolution of deformations in time are presented in figures 9 and 10 for the Φ6 unthreaded rod joints, as function of temperature (T) and relative humidity of air (φ) of the environment, for 202 days long. The two tested stages are separated; for the first set of tests Qtot = 600*N,* and for the second one Qtot = 900*N*.

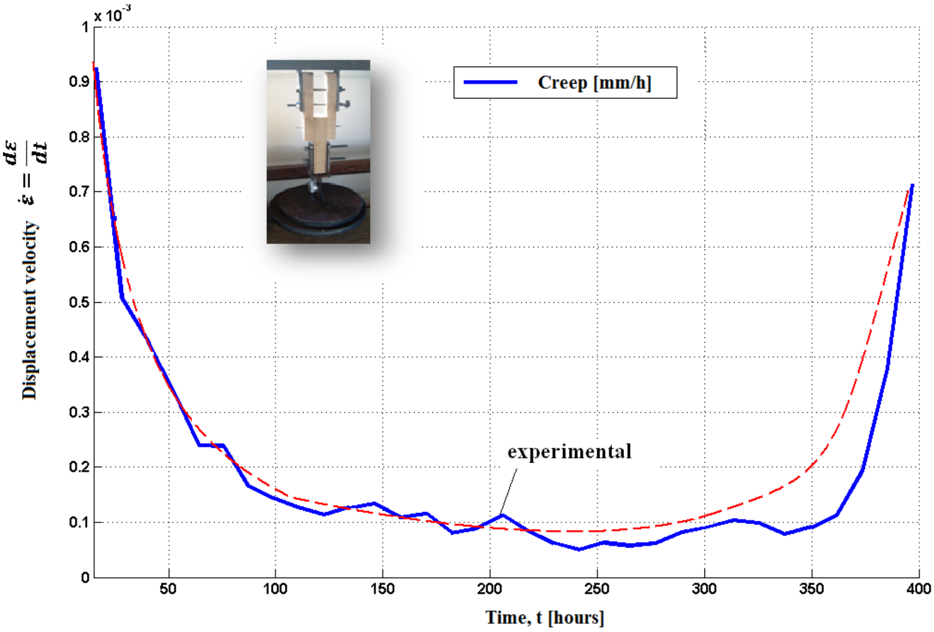

Fig. 9
The deformation speed calculated and experimentally determined for the Φ6 rod joint, under a load of 600N.

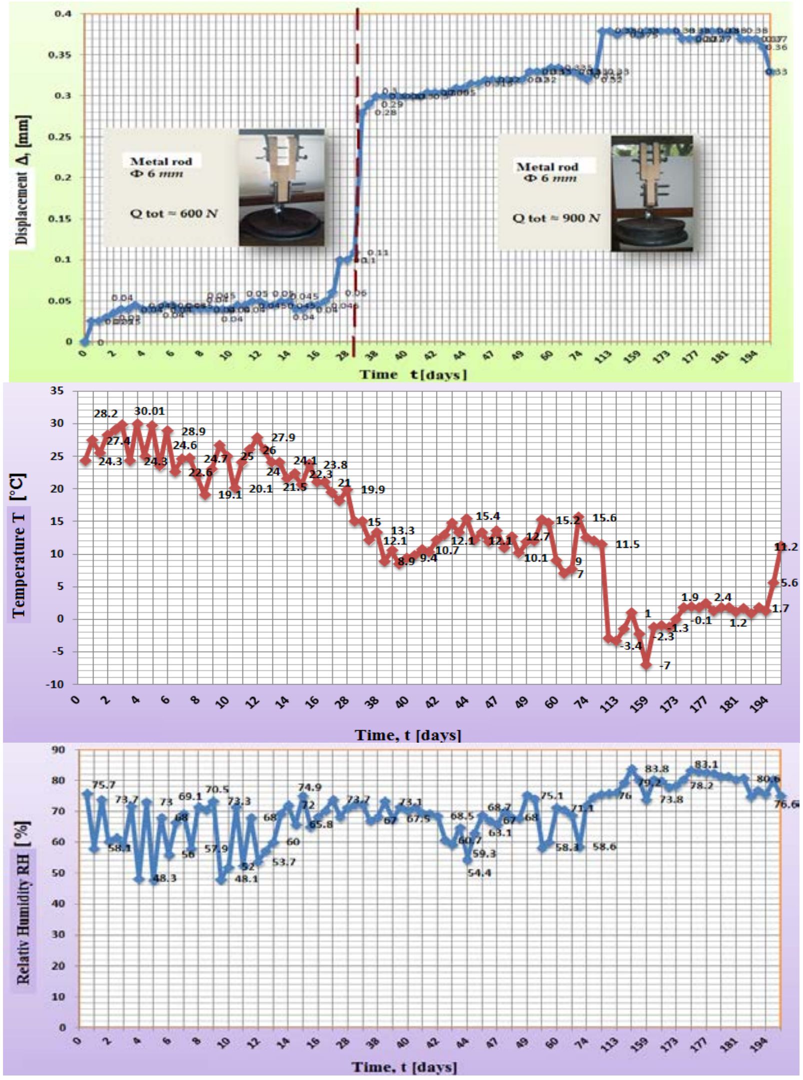

Fig.10

Evolution in time of the deformation for Φ6 unthreaded rod joint, as function of temperature (T) and relative humidity of air (φ) of the environment, for a load of 600 N, and 900 N respectively.

RESULTS AND DISCUSSION

Table 2 shows the deformation energy and the tenacity rate, calculated for the simple, threaded and Buldog stud joints. The two elements were calculated as function of the maximum breaking force and the moisture content of the wood.

Table 2

The deformation energy and the tenacity rate calculated for the representative joints

Type of rod	Moisture content [%]	Maximum breaking force [*kN*]	Total displacement [*mm*]	Total absorbed energy; U [*N·mm*]	Breaking initiating force; Ui [*N·mm*]	Tenacity rate; D
Ø 6 simple	9,4 - 10	8,4	38	$2{,}827 \cdot 10^{8}$	$2{,}778 \cdot 10^{8}$	0,0177
Ø 6 simple, without nut	9,4 – 9,7	6	27	$0{,}2445 \cdot 10^{8}$	$0{,}1161 \cdot 10^{8}$	1,1059
Ø 6 threaded, stud	9,1 – 9,7	12,8	50	$1{,}414 \cdot 10^{8}$	$1{,}139 \cdot 10^{8}$	0,24123

General behavior of the joints under the load was similar for the all three rod diameters. The differences were given by the change of diameter and have been highlighted by the way of rupture and the maximum breaking force. For the second set of experimental tests (bolt joints and Bulldog stud type), the fracture occurred differently from those in the first set (bolt joints without Bulldog stud type). Thus, if on the first set the fracture has occurred in the central part of the joint and at least in one of the side elements, in the second set, the fracture occurred only in the side elements of the assembly. Strong snatching fibers have observed, especially when using Bulldog studs type and most evident on the side members in the shearing areas, due to the deformation of the metal rod. By overlapping the load-displacement diagrams it can be observed that with the increasing of the rod diameter, the maximum breaking force increases and the displacements are smaller. Large displacements occurred at the minimum diameter and a lower breaking force was recorded. When reaching maximum breaking force, the highest displacement was recorded for the 6mm diameter rod, the threaded one and the Bulldog stud type (Fig.11 and 12).

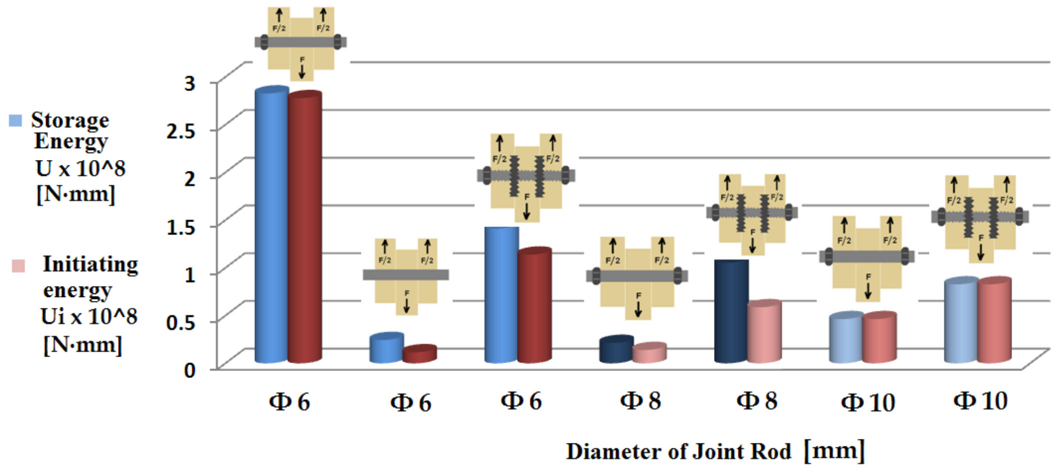

Fig. 11
The comparison between the total absorbed energy of the specimen and the initiating energy for the studied joints.

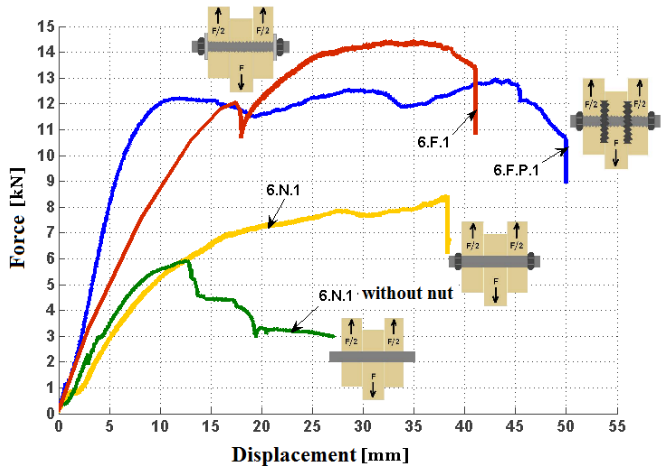

Fig. 12
The influence of the rod type (simple and threaded) and of the Bulldog studs, upon the correlation force-displacement, for a 6mm diameter.

The environment temperature has varied between -7°*C* and +30,01°*C*. The relative humidity of the air has varied between 47,8% and 83,8%. The low temperatures and the increasing relative humidity of the air in winter time had driven to the sudden changes of deformations for all three diameters of the rods. The highest deformation speed was recorded for the 10*mm* diameter rod joint, and the lowest one for 6*mm* diameter. In the same trend, the maximum displacements were recorded for the 10*mm* diameter rod joint, and the lowest one for 8*mm* diameter. The deformations/displacements were small, not visible, both for wooden parts and metal rods. Compared with the laboratory testing, time testing broght higher differences of the values, for the same load; the laboratory results had higher values that in case of time testing. The average of the displacements was the smallest one for the rod diameter of 10mm, whilst the lowest values beeing recorded for the diameter of 8mm. The 10*mm* rod joint had a sudden change of deformation, due to the correlation of slow change of temperature and relative humidity of the air with the possible defects of the

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material, more numerous in case of 10mm rod diameter. In case of 6 and 8*mm* rod joints the speed of changing the behavior in time was that described in the literature, explained by a primary running, where the deformation speed $\dot{\varepsilon} = \frac{d\varepsilon}{dt}$ has decreased, a secondary running, when the deformation speed remained constant for a long period of time and the tertiary deformation speed, which accelerates in time (Fig. 13). The deformation speed was lower for the 900 *N* load compared with the 600*N* load.

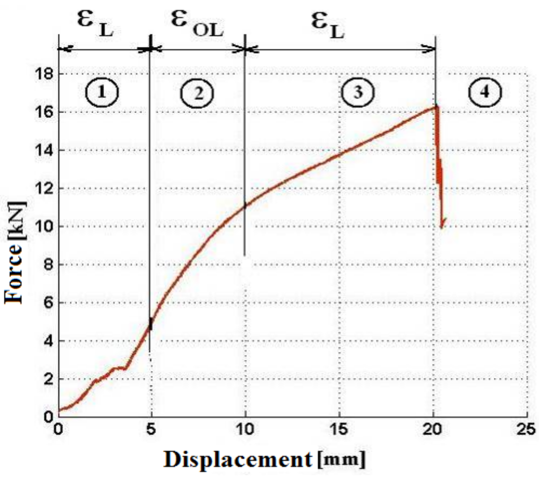

Fig. 13
Running phenomena of wood bolt and unthreaded rod joint, 6mm diameter: ε_L - wood deformation, ε_{OL} – rod deformation.

Four running stages were recorded, as shown in (Fig. 14): stage 1: specimen loading and elastic deformation in wood, rigid rod; stage 2: full load, plastic deformation of wood and initial elastic deformation of rod transforming into plastic one; stage 3: residual deformations both for wooden and metal elements; fracture of wooden elements; stage 4: deformation of the assembly reaching the maximum force: fracture of side elements of the joint, rod plastic deformation and a residual deformation of the central part, without fracture.

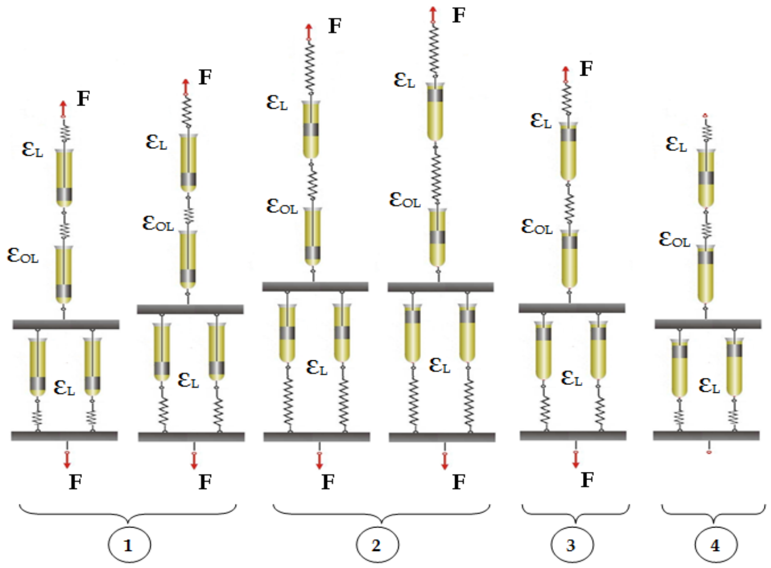

Fig. 14
The order of deformations, as rheological models of wood bolt, 6mm diameter unthreaded rod joint: ε_L - wood deformation; ε_{OL} – rod deformation; 1,2,3,4 – running stages.

CONCLUSION

With the increasing of loading (the relationship between the applied stresses and the limit breaking strength for the short time tests) and of the applied bending stress in the conditions of changing the relative humidity and the temperature of the environment (similar to the changes in case of real buildings), the size of residual deformations (ie the rate between the maximum deflection f_{pi} and the size of opening, *l*) increases linearly. The increased deformation of the wooden parts in the condition of increasing the load and the stresses is determined also by the reduction of the modulus of elasticity at a time, after a certain time of maintaining the load. The lower tenacity rate was recorded for the 6mm simple rod joint and the highest value was recorded for the assembly without nuts on the rod. By overlapping the load-displacement diagrams it can be observed that the breaking force increases for the 6 mm diameter of the rod up to the diameter of 8mm, and then decreases. The force increases with the increasing of diameter, the crushing surface being higher in this case, and then decreases, because when increasing the diameter, it weakens the section subjected to bending strain. By overlapping the load-displacement diagrams it can be observed that with the increasing of the rod diameter, the maximum breaking force increases and the displacements are smaller. Large displacements occurred at the minimum diameter and low breaking forces were recorded in this case.

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