Working capability of composite wood-rubcon (rubber concrete) reinforced bridge beams under static loads

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Abstract. The results of experimental studies of the performance of bent composite wood-rubcon reinforced bridge beams under static loads are presented and the bearing capacity of composite wood-rubcon reinforced bridge beams is determined. A method for calculating wood-rubcon reinforced composite bridge beams is proposed.

1 Introduction

Wood is one of the first effective building materials from which man built housing, bridges and other structures. The main advantages of wood include light weight, ease of transportation and handling, chemical resistance, high mechanical strength, low sound and heat conductivity and, finally, frost resistance. The effectiveness of the use of wood-rubcon composite bridge beams can be increased by reinforcing the stretched area of the beams, which increases their strength and rigidity [1-8].

At present, wood with large diameters has become scarce, from which bridge and transverse beams were made, as well as sleepers. The direction of work associated with the reinforcement of the tensile zone of wooden composite bridge beams is an urgent task, as it makes it possible to work with wood of small diameters [9-12].

With the introduction of new double-layer wood-rubcon reinforced structures, it becomes necessary to experimentally and theoretically study the operation of wood-rubcon reinforced structures under static loads .

The purpose of the work was to determine the strength and deformability of wood-rubcon reinforced composite bridge beams with transverse bending, to determine theoretical and experimental deflections and to compare experimental data with the results of theoretical calculations and to analyze the causes of possible deviations.

Scientific novelty of the work:

- the experimental and theoretical bearing capacity of wood-rubcon reinforced composite bridge beams has been determined;
- an analysis was made of the efficiency of compounds of wood with rubcon under static loads.

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2 Production of wood-rubcon reinforced composite bridge beams

Structurally, the wood-rubcon reinforced composite bridge beams consist of two layers, the first upper layer includes wooden beams (1) with the frame (2) (Figure 1.), then the second lower layer is made of rubcon (3) (Figure 2). Interlayer contact is reinforced with steel cage frames (Figures 3, 4). After laying the rubcon layer, the double-layer element is placed in a dry heating chamber, where the process of vulcanization occurs at a temperature 120±5°C.

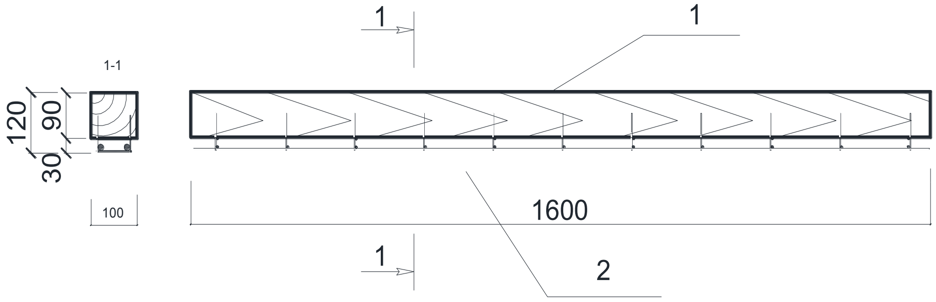

Fig. 1. Wooden beam with steel cage frame. Where:1- wooden beam, 2- steel cage frame (SNKR-1).

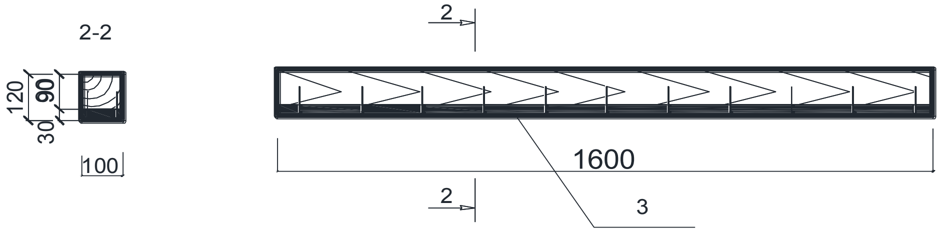

Fig. 2. A wood-rubcon reinforced composite bridge beam. Where: 3-rubcon.

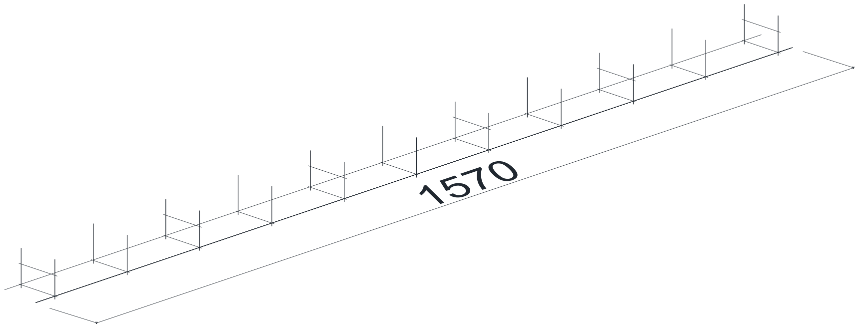

Fig. 3. Isometry of a steel cage frame (SNKR-1).

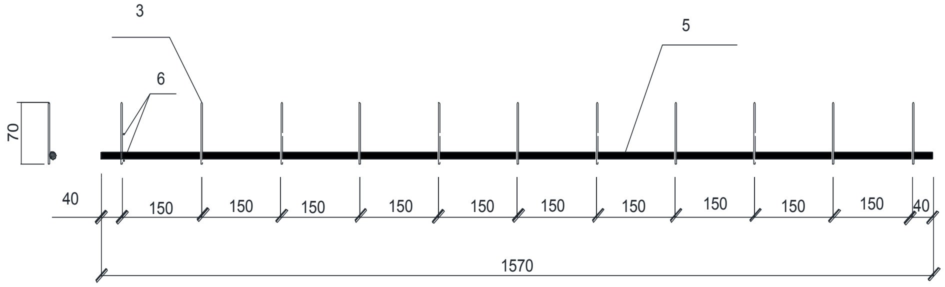

Fig. 4. Steel cage frame. Where: 4- steel pins, 5- longitudinal working reinforcing bar, 6- tenon.

In order to reduce the loads on wooden composite bridge beams during testing, the width and height of the cross section and the length of the experimental samples were halved, which did not lead to a change in the operation of composite bridge beams, since all natural defects are manifested at a width of 100 mm [13].

Samples for testing wood-rubcon reinforced composite bridge beams (fig. 5). Samples for obtaining the calculated characteristics of rubcon (Figure 6) [14-17].

Fig. 5. General view of a wood-rubcon reinforced composite bridge beam.

Fig. 6. Samples for obtaining the calculated characteristics of rubcon.

3 Experimental and theoretical studies of the operation of wood-rubcon reinforced composite bridge beams under static loads

The purpose of the work was to check the resistance of joints of wood-rubcon reinforced composite bridge beams under static loads. To achieve this goal in the laboratory for testing building constructions of Center for Collective Use (CCU) named after. prof. Yu.M. Borisov, of the Voronezh State Technical University, samples of wood-rubcon reinforced composite bridge beams were tested under static loads (fig. 7, 8).

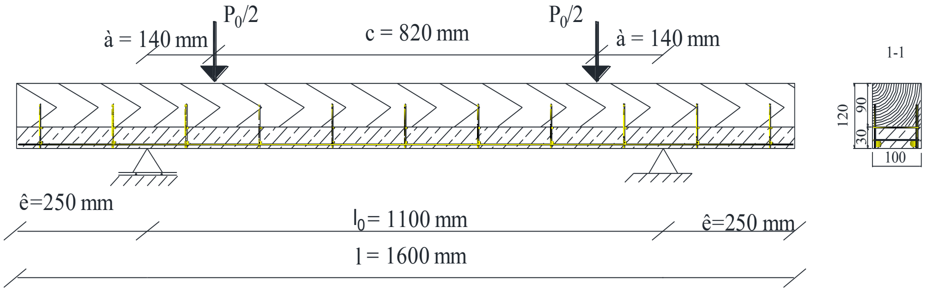

Fig. 7. Design scheme of wood-rubcon reinforced composite bridge beams.

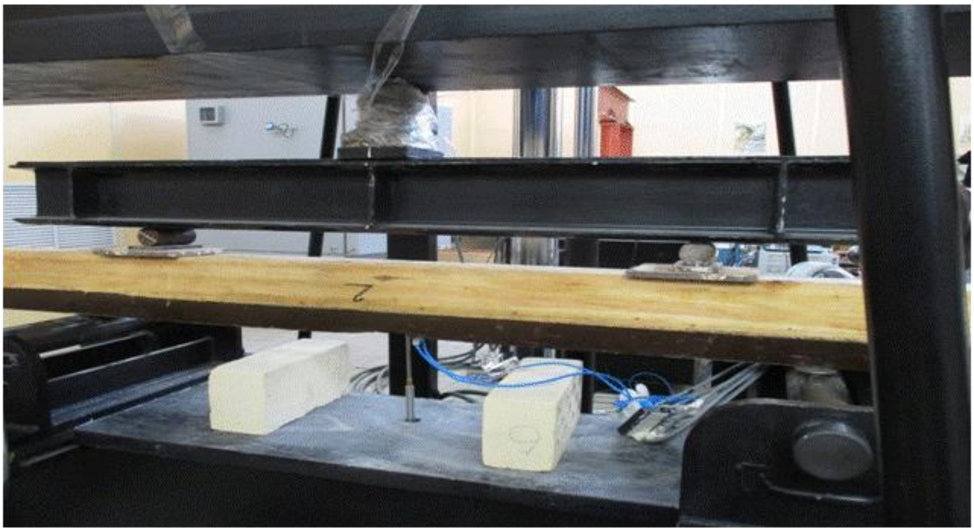

Fig. 8. Loading scheme of wood-rubcon reinforced composite bridge beams.

3.1 Determination of actual dimensions of wood-rubcon reinforced composite bridge beams

The following materials were used for the manufacture of wood-rubcon reinforced composite bridge beams:

- wood - pine grade I;
- rubcon;
- reinforcing bar of class A-300.

Initial data:

- wood moisture - 20%;
- cross-sectional height of a wood-rubcon reinforced composite bridge beam, h=120 mm;
- width of the cross-section of a wood-rubcon reinforced composite bridge beam, b=100 mm;
- height of the cross section of the 1st layer of wood, h_d=90 mm;
- cross-sectional height of the 2nd layer of rubcon, h_k=30 mm;
- beam length, l=1600 mm;
- design beam span, l_p=1100 mm.

3.2 Determination of the design characteristics of the material of a wood-rubcon reinforced composite bridge beam

Design bending resistance of wood (R^{p}) equals:

$$R^{\text{p}} = R^{A} \cdot m_{lt} \cdot \Pi m_{i}, \tag{1}$$

where R^{A} - the design resistance of wood, MPa, shown in table 3 [18], with a humidity of 12% for loading mode A, according to table 4 [18] in constructions of the 2nd class of functional purpose, according to Appendix B [18], with a service life of not more than 50 years;
m_{lt} - coefficient of long-term strength corresponding to the mode of loading duration (table 4) [2];

Πm_i- the product of the coefficients of the working conditions [18].

$$R^A = 24MPa;\ m_{lt} = 0{,}66;\ \Pi m_i = 1{,}0.$$

$$R^{\text{p}} = 24 \cdot 0{,}66 \cdot 1{,}0 = 15{,}84\ MPa \tag{2}$$

E_{w} - wood elastic modulus, E_{w}=10 000 MPa [18];
G_{w} wood shear design modulus, G_{w} =500 MPa [18];
E_{r} - calculated elastic modulus of rubcon, E_{r}=19500 MPa [19];
E_{s} - design modulus of elasticity of reinforcing bar, E_{s}=240 000 MPa.

3.3 Determination of the geometric characteristics of the cross section of a wood-rubcon reinforced composite bridge beam

1) F_{wr} - reduced cross-sectional area of a wood-rubcon reinforced composite bridge beam is determined by the formula

$$F_{wr} = F_w + F_r \cdot n_r + n_s \cdot A_s = 0{,}009 + 0{,}003 \cdot 1{,}95 + 24 \cdot 0{,}000308 = 0{,}0151\ \text{m}^2, \tag{3}$$

where F_w - cross-sectional area of the 1st layer of a wood-rubcon reinforced composite bridge beam $F_w = b \cdot h_w = 0{,}1 \cdot 0{,}090 = 0{,}009$ m^2;
F_r - Cross-sectional area of the 2nd layer of a wood-rubcon reinforced composite bridge beam from rubcon

$$F_r = b \cdot h_r = 0{,}1 \cdot 0{,}030 = 0{,}003\ \text{m}^2;$$

n_r - coefficient taking into account the ratio of the elastic modulus of the rubcon with the wood

$$n_r = E_{\text{r}}/E_{\text{w}} = 19500/10000 = 1{,}95;$$

n_s - coefficient taking into account the ratio of the elastic modulus of reinforcing rod with a wood

$$n_s = E_{\text{s}}/E_{\text{w}} = 240000/10000 = 24;$$

A_s - cross-sectional area of reinforcing rod A_s = 0,000308 m^2
2) S_{wr} - reduced static moment of a wood-rubcon reinforced composite bridge beam is determined by the formula:

$$S_{wr} = S_w + F_r \cdot z_{c2} \cdot n_r + n_s \cdot A_s \cdot z_{c3} = 0{,}000101+0{,}000351+0{,}000406=0{,}000858\ \text{m}^3, \tag{4}$$

where S_w - static moment of the 1st layer. $S_w = b \cdot \frac{h_w^2}{8} = 0{,}1 \cdot \frac{0{,}09^2}{8} = 0{,}00010$ m^3;
z_{c2} - distance from the center of gravity of 1 layer of wood to the center of gravity of the rubcon layer.

$$z_{c2} = \frac{h_w}{2} + \frac{h_r}{2} = \frac{90}{2} + \frac{30}{2} = 60\ mm = 0{,}06\ m;$$

z_{c3} - distance from the center of gravity of 1 layer of wood to the center of gravity of the reinforcing bar.

$$z_{c3}=\frac{h_w}{2}+h_r-\mathrm{a}=\frac{90}{2}+30-20=55\,mm=0{,}055\,m.$$

3) I_{wr} - the reduced moment of inertia of the wood-rubcon reinforced composite bridge beam is determined by the formula

$$I_{wr}=I_w+I_r+A_r\cdot {z_{c2}}^2\cdot n_r+n_s\cdot A_s\cdot {z_{c3}}^2= \\ =0{,}00000607+0{,}000000225+0{,}0000052+0{,}0000055=0{,}000017\ \mathrm{m}^4, \tag{5}$$

where I_w- moment of inertia of the 1st layer of the beam,

$$I_w=b\cdot\frac{h_w^3}{12}=0{,}1\cdot\frac{0{,}090^3}{12}=0{,}0000607\ \mathrm{m}^4.$$

4) W_{wr} - the reduced moment of resistance of a wood-rubcon reinforced composite bridge beam is determined by the formula

$$W_{wr}=\frac{2\cdot I_{wr}}{h}=\frac{2\cdot 0{,}000017}{0{,}12}=0{,}00028\ \ \mathrm{m}^3 \tag{6}$$

3.4 Determination of the bearing capacity of a wood-rubcon reinforced composite bridge beam

3.4.1 Determination of the bearing capacity of a wood-rubcon reinforced composite bridge beam from the calculated normal bending stresses

$$\sigma=\frac{\mathrm{M}}{W_{\mathrm{wr}}}=\frac{P\cdot 0{,}140}{2\cdot W_{wr}}\leq R^{\mathrm{p}}, \tag{7}$$

where $M=\frac{P}{2}\cdot 0{,}140$; P - design load.

From formula (7), we assume that the voltage is equal to the rated resistance and we determine the rated load

$$P=\frac{R^{\mathrm{p}}\cdot 2\cdot W_{\mathrm{wr}}}{0{,}140}=\frac{15{,}84\cdot 1000\cdot 2\cdot 0{,}00028}{0{,}140}=63{,}36\ \ \mathrm{kN} \tag{8}$$

3.4.2 Determination of the bearing capacity of a wood-rubcon reinforced composite bridge beam from the estimated tangential stresses in bending

$$\tau=\frac{Q\cdot S}{I\cdot b}=\frac{3Q}{2F}\leq R_{\mathrm{c}}\ , \tag{9}$$

where $\mathrm{Q}=\frac{P}{2}$, then $\tau=\frac{3P}{4F}\leq R_{\mathrm{c}}$

From formula (9), we assume that the shear stress is equal to the design resistance when shearing and determine the design load

$$P=\frac{4F\cdot R_{\mathrm{c}}}{3}=\frac{4\cdot 0{,}151\cdot 1{,}78\cdot 1000}{3}=35{,}83\ \ \mathrm{kN} \tag{10}$$

3.4.3 Determination of the bearing capacity of a wood-rubcon reinforced composite bridge beam from the stiffness condition

The standard deflection of the beam is 1/170 span, hence

$$\frac{f}{l} = \frac{P\cdot \mathrm{a}^3\cdot l_\mathrm{p}}{24\cdot \mathrm{E}_w\cdot I_{wr}\cdot \gamma_f}\cdot\left(3\cdot\frac{l_\mathrm{p}^2}{\mathrm{a}^2}-4\right), \tag{11}$$

where γ_f = 1,1 - reliability factor

$$P = \frac{48\cdot \mathrm{E}_w\cdot I_{wr}\cdot \gamma_f\cdot l_\mathrm{p}}{\left(3\cdot\frac{l_\mathrm{p}^2}{\mathrm{a}^2}-4\right)\cdot \mathrm{a}^3} = \frac{48\cdot 10^7\cdot 0{,}000017\cdot 1{,}1\cdot 1\cdot 1{,}1}{\left(\frac{3\cdot 1{,}1^2}{0{,}140^2}-4\right)\cdot 170\cdot (0{,}140)^3} = 32{,}50\ \text{kN} \tag{12}$$

The calculated load is equal to the minimum calculated by the formulae (8), (10), (12).

Destructive load is determined by multiplying the design load value by the material safety factor $\gamma_м$ = 1,15, then

$$P_{destr.d} = P\cdot\gamma_м = 32{,}50\cdot 1{,}15 = 37{,}38\ \text{kN}$$

3.4. Drawing up a design diagram of a wood-rubcon reinforced composite bridge beam and determining the forces

Design scheme. The design scheme (Figure 9) of a wood-rubcon reinforced composite bridge beam is taken in the form of a single-span beam on two supports.

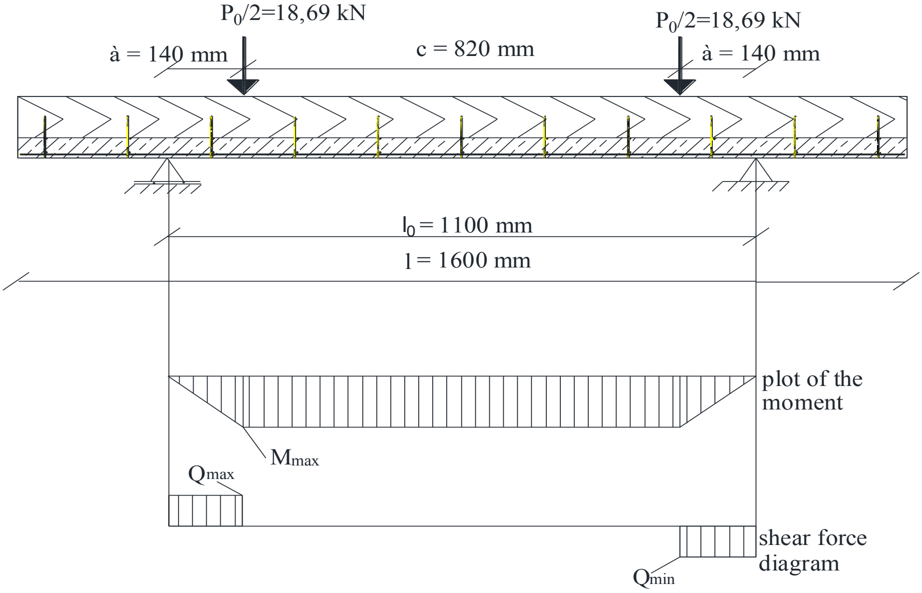

Fig. 9. Design scheme of a wood-rubcon reinforced composite bridge beam.

The maximum bending moment is determined by the formula:

$$M = \frac{P_{destr.d}}{2}\cdot a = \frac{37{,}38}{2}\cdot 0{,}140 = 2{,}61\ \text{kN·m}, \tag{13}$$

where a - the distance from the axes of support of the beam to the place of application of the load, equal to 140 mm

$$Q = \frac{P_{destr.d}}{2} = \frac{37{,}38}{2} = 18{,}69\ \text{kN} \tag{14}$$

3.5 Verification of a wood-rubcon reinforced composite bridge beam according to groups I and II of the limiting state

a) Checking beam according to the I ultimate state of strength:

$$\sigma = \frac{\mathrm{M}}{W\mathrm{wr}} \leq \mathrm{R^p}, \tag{15}$$

where $\mathrm{R^p}$ - design bending resistance, MPa [2]; M - maximum bending moment.

$$\sigma = \frac{M}{W\mathrm{wr}} = \frac{2{,}61}{0{,}00028} = 9{,}32\ \mathrm{MPa} \leq \mathrm{R^p} = 15{,}84\ \mathrm{MPa}$$

b) Checking the beam according to the II limit state for deflection:

$$f = \frac{f_0}{k}\left[1 + C\left(\frac{h}{l}\right)^2\right] \leq [f_u], \tag{16}$$

where h - maximum section height; l - span of beam; k - a coefficient taking into account the influence of variability of the height of the section, taken equal to 1 for a beam of constant cross section; C - coefficient taking into account the influence of shear deformation from shear force, determined by the formula C = 15,4 + 3,8·β =19,2, where β=1; $f_u = \frac{1}{170}\ l$ - ultimate deflection /10 /; f_0 - beam deflection, determined by the formula

$$f_0 = \frac{P_0 \cdot \mathrm{a}^3 \cdot \mathrm{l_p^2}}{48\mathrm{E}_w \cdot I_{wr} \cdot \gamma_f} \cdot \left(3 \cdot \frac{\mathrm{l_p^2}}{\mathrm{a}^2} - 4\right) = \frac{37{,}38 \cdot 0{,}14^3 \cdot 1{,}1\ 2}{48 \cdot 10000 \cdot 1000 \cdot 0{,}000017 \cdot 1{,}1} \cdot \left(3 \cdot \frac{1{,}1^2}{0{,}14^2} - 4\right) = 0{,}0022$$

$$f = \frac{0{,}0022}{1}\left[1 + 19{,}2\left(\frac{0{,}12}{1{,}1}\right)^2\right] = 0{,}0027\ m \leq \left[f_u = \frac{1}{170}\ 1{,}1 = 0{,}0064\ m\right]$$

4 Test procedure for a wood-rubcon reinforced composite bridge beam under short-term loads

4.1 Test results of a wood-rubcon reinforced composite bridge beam

The loading scheme and arrangement of devices (fig. 10, 11) corresponded to the test conditions. The load on each of the two simultaneously loaded beams was 37.38 kN and was determined when calibrating the lever plants of the second order using the model dynamometer DOSM-3-5. The loading of the sample is carried out in steps. The magnitude of the step is $0{,}25 \cdot \mathrm{P_{test}}$.

Tests of wooden reinforced composite bridge bars were carried out at the Voronezh State Technical University in the laboratory for testing building constructions of the CCU named after prof. Yu.M. Borisov.

Fig. 10. Loading scheme of a wood-rubcon reinforced composite bridge beam.

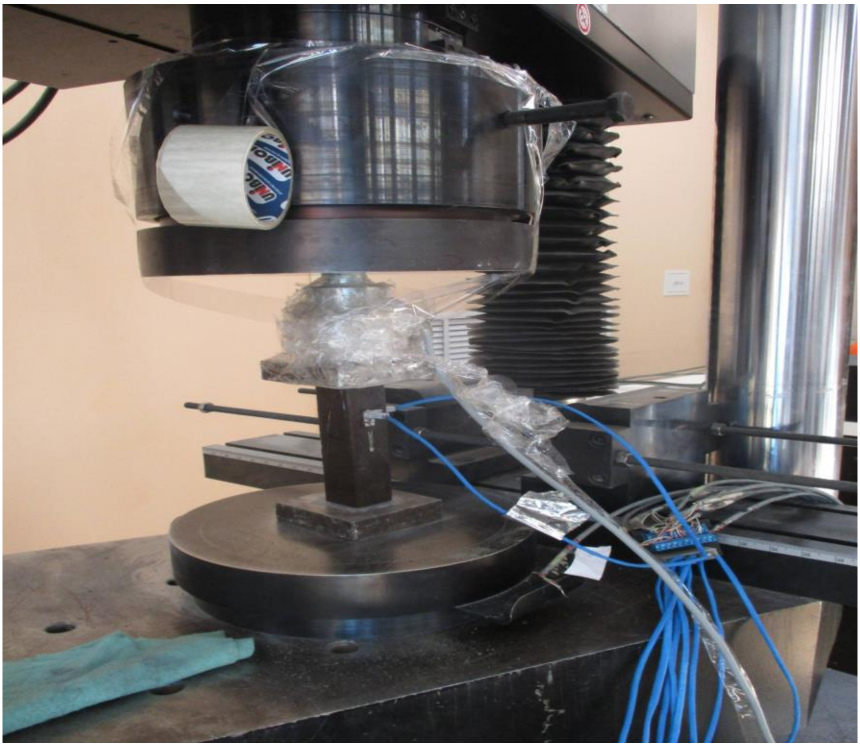

Fig. 11. Test pattern of rubcon concrete sample for deformation.

Deformation graphs are shown in the Figure 12. The maximum deflections were 6.201 mm at load 37,68 kN.

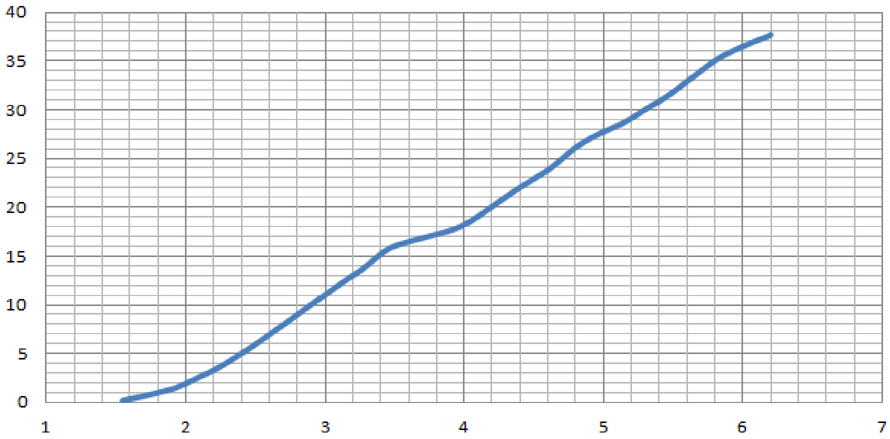

Fig. 12. Deformation of a wood-rubcon reinforced composite bridge beam.

To obtain the calculated characteristics of the rubcon, prism samples were made with a dimension size of 40 mm × 40 mm × 160 mm [19] (Figure 6). We tested them for compressive strength. We plotted the graph of the relationship between stress and strain (Figure 13).

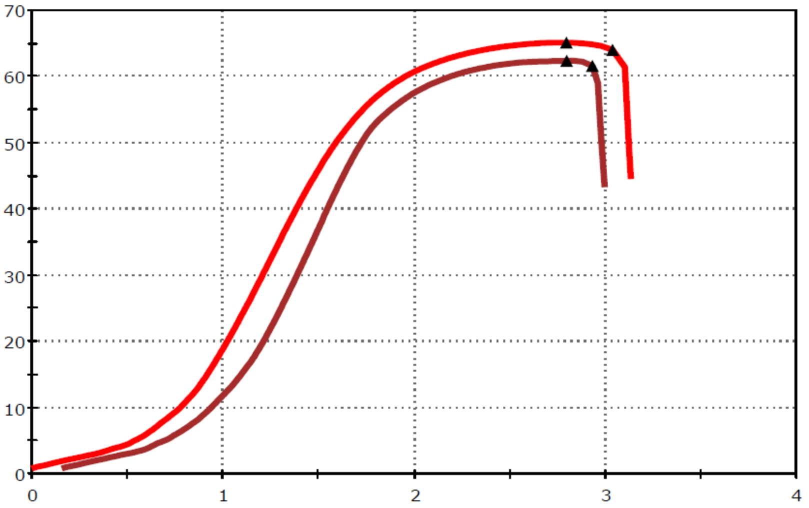

Fig. 13. Graph of the relationship between load and deformation.

5 Conclusions

1. For the first time, experimental data have been obtained on the performance of wood-rubcon reinforced composite bridge beams.
2. An optimal methodology has been developed for experimental studies of wood-rubcon reinforced composite bridge beams.
3. An experimental deflection of wood-rubcon reinforced composite bridge beams was obtained.
4. A method for calculating wood-rubcon reinforced composite bridge beams has been developed.

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