Stress-strain state of wooden beams with external reinforcement

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Abstract. The stress-strain state of wood-composite beams was studied numerically. Numerical studies were performed on wood-composite floor beams with a cross-section size of 100x240 mm and a length of 4.8 m. It was experimentally proved that the deformability of wood-glued beams is reduced by 1.8...2.1 times, compared to conventional wooden beams. For wooden beams in the elastic design stage, the limiter is the calculation of the 2nd group of limit States (for stiffness), for composite beams, the calculation of the 1st group of limit States (for strength. The calculation proved that the deformability of wood composite beams is reduced by 1.8...2.1 times, compared to conventional wooden beams. The high efficiency of the finite element method calculation for evaluating the criteria of load-bearing capacity of wood-composite beams up to their destruction is proved.

1. Introduction
The widespread use of wood composite structures is hindered by a number of reasons, in particular, insufficient knowledge of the rheological properties of wood, the behavior of rebar and wood in load-bearing structures [1,2]. The development of reinforced wooden structures [3] is carried out using conventional reinforcement and prestressed. The first method of reinforcement [4,5] is more widely used, since it gives a positive effect with relatively small labor costs and capital investments. In structures with prestressed reinforcement, the deformability of structures is reduced from two to eight times compared to non-reinforced structures and the strength is significantly less than that of conventional reinforced structures [6] with the same percentage of reinforcement. In addition, pre-stress reinforcement creates additional shear stress in wood, which together with the stresses arising from the action of external loads, leading to premature achievement of the maximum values of shear forces in the wood primarnoj zone, and further to the destruction from the action of shear forces.

Research of reinforced wooden structures [7...11] and the study of their stress-strain state under short-term and long-term loads required the development of methods for calculating such structures taking into account the features of the stress-strain state of structures, heterogeneity and materials in a complex structure, creep of wood and glue, etc.

The first developments in the field of calculating wood-composite structures [12] were proposed By V. Yu.Shchuko. The calculation of wood composite structures was based on the given geometric characteristics of the section, as well as taking into account the elastic-plastic work of wood based on
the diagram "Belyankin-Prager". At the same time, the hypothesis of flat cross-sections and the compatibility of the steel-wood adhesive joint at all stages of construction work were discussed [13].

Since the calculations are numerically introduced graphs of actual wood work, taking into account the non-linearity, multi-modularity, anisotropy and creep of wood, the accuracy of the results obtained is much higher than the results of the engineering method of calculation. Numerical calculations based on the characteristics of wood properties allow for more economical design [14] and are applicable for calculating the structure at all stages of work. Therefore, research in the field of improving honey calculation of wood-composite structures [15..17] is an actual scientific task.

The object of research was wood-composite beam structures.

The subject of research is the stress-strain state under the action of static loads.

The purpose of the study is to improve wood-glued composite structures by providing scientifically based strength, stiffness and performance characteristics.

At the same time the tasks were set:

1. To conduct numerical studies of the work of wood-glued structures and the influence of the nature of reinforcement on the stress-strain state (VAT), taking into account anisotropy, effects of multi-modularity and nonlinear deformation of wood.
2. Evaluate the load-bearing capacity and deformability of composite wood-glued beams.
3. Develop recommendations for improving wood composite structures aimed at reducing material consumption and increasing their economic efficiency.

2. Methods

Both linear and nonlinear calculations of an ordinary beam without amplification were performed [18]. The calculation of beams with various amplification options is performed only in a non-linear setting that takes into account the real (actual) operation of the structure [19]. Non-linearity in the software package is taken into account when setting the final elements (plates) of stiffness.

The effectiveness of reinforced elements and structures is largely determined by the methods used to calculate the strength and deformability, determine the relative and absolute cross-section dimensions, and select the number of rebars.

There are methods for calculating building structures that allow us to assess their load-bearing capacity and deformability with sufficient accuracy at any stage of work. However, the calculation of reinforced wooden structures and elements in most cases is carried out only under the assumption of elastic work of materials, which does not correspond to the actual work of elements beyond the elastic limit. When loading reinforced wooden elements with an external load before destruction, three characteristic and successive stages of the stress-strain state are clearly manifested: conditionally elastic, elastic-plastic, and destruction [20].

The stress-strain state of the reinforced element at the first stage of operation is estimated using material resistance formulas with sufficient accuracy for practical purposes. To assess the stress-strain state and the ultimate load-bearing capacity at the second and third stages of work, methods are used that take into account the elastic-plastic work of materials [21,22].

Wood was described as a finite element, designed to determine the plane stress state of plates loaded in their plane. The plate is considered only in the isotropic version, taking into account the physical nonlinearity of the material. The armature was described as a flat 2-node single-axis end element having, respectively, 2 or 3 translational degrees of freedom in each node.

The beams were loaded with concentrated loads, the points of application of which are located at a distance of 0.5 m from each other. The load was applied in stages, the values of which were assumed to be equal to 1/10 of the destructive load [23,24].

The method of reinforcement proposed by the authors consists in strengthening the compressed or stretched zones of beams with rigid external reinforcement in the form of a channel and gluing inclined rod reinforcement in the body of the beam. – this is in another section, not here. Numerical studies were carried out on wooden floor beams with standard cross-section dimensions of 100x240
mm and a length of 4.8 m. the Material is pine. Reinforcement was taken from rebar rods of class A-III diameter 12 mm. The number 12 of the rolling channel was taken along the width of the beam.

Construction, and a cross-sectional view of one of the options for strengthening wood beams with location of channel gain in the upper compressed zone and the reinforcement along the main compressive stresses, given in the form of graphical material figure 1.

Figure 1. Construction and cross section of the reinforced floor beam B-1.

The numerical experiment of the structure under study was performed taking into account the actual work of wood [25...30], using the diagram of the work "compression-tension" obtained when testing standard samples of wood. In this case, the boundary values of wood work are:
- calculated compressive (tensile) resistance of wood-130 kg/cm2;
- the limit of compressive strength of 400 kg/cm2;
- tensile strength-1000 kg/cm2.

Marking beams:
- B-0/1-wooden beam in linear calculation;
- B-0/2-wooden beam in non-linear calculation;
- B-1-composite beam with an external reinforcement arrangement on top, glued reinforcement on the main compressive stresses;
- B-2-composite beam with the location of the external reinforcement from the bottom, glued reinforcement on the main tensile stresses;
- B-3-composite beam with the location of external reinforcement on top, glued reinforcement on the main tensile stresses;
- B-4-composite beam with the location of the external armature from below, the glued armature on the main compressive stresses.

3. Results and discussion
Based on the results of numerical research, the following conclusions are obtained about the nature of destruction, strength and deformability of wood and reinforcement elements of wood-composite beams.

Composite beams (B-1...B-4) reach the maximum deflection when working in the elastic stage at loads of 745...905 kg/m, wooden beams (B-0/2) at 425 kg/m.

The maximum permissible load is 750 kg/m for beams with a channel at the top (B-1 and B-3) and 760 kg/m and 745 kg/m for beams with a channel at the bottom (B-2 and B-4, respectively). Thus, the additional load on the beams after the reinforcement will be 320...335 kg/m.

Destruction of wood occurs at loads of 1450...1500 kg/m on the stretched zone of wood. The nature of the destruction of composite beams with the channel arrangement on top does not change, it also occurs along the stretched beams at loads of 2715...2950 kg/m (beams B-3 and B-1, respectively), and when the channel is located below the compressed zone at loads of 2710...2815 kg/m (beams B-2 and B-4, respectively).

The results of calculating wood-composite beams represent the stress and strain values for all finite elements of all groups (plate and rod). They are represented graphically in the form of constructed diagrams (figure 2.1...2.8).

The numerical testing of beams allows us to most accurately approximate the operation of wood-composite beams to real operating conditions. Thus, proper planning of experiments and strict adherence to the techniques of numerical investigation allow to reveal the peculiarities of the stress-
strain state of beams and transition to the limit state and fracture of beams and determination of the failure load.

Figure 2.1. Load-deflection diagram

Figure 2.2. Diagram of the load – tensile strain in the wood

Figure 2.3. Diagram of stress – compressive strain in the wood
Figure 2.4. Diagram load-tangential stresses in wood

Figure 2.5. Diagram load-normal stresses in the channel

Figure 2.6. Diagram load-tangent stresses in the channel

Figure 2.7. Diagram of the load voltage in terminals
The results obtained using the FEM should be carefully evaluated in the light of experimental data and General engineering considerations. To be more confident in the results of the FEM calculations, it is desirable to vary the model using different numbers of elements or alternative types of elements. For some types of elements, this task can be solved by the program itself. The software package implements H- and P-methods for modifying the grid, which allow you to automatically get a given level of accuracy of results.

4. Conclusions
Based on the results of the work performed for the purpose of analyzing the stress-strain state of wood-composite beams using the FE calculation method, the following conclusions can be drawn:

1. The deformability of wood-composite beams is reduced by 1.8...2.1 times, compared to conventional wooden ones.

2. For wooden beams in the elastic design stage, the limiter is the calculation of the 2nd group of limit States (for stiffness), for composite beams, the calculation of the 1st group of limit States (for strength).

3. Normal stresses reach their maximum value in the channel wall in the middle of the span of the composite beam. The graphs "load-stress in the channel" are linear. The most favorable work is observed in the channel when it is located in the lower zone of the beams.

4. Normal stresses in the rods are less when their location is taken by the main compressive stresses when amplified in the compressed zone and by the main tensile stresses when amplified in the stretched zone, but the location of the rods does not play a significant role in the distribution of tangential stresses, the difference is within 1...2%.

5. Rods experience a complex stress-strain state of "compression with a bend" when they are located on the main compressive stresses and "stretching with a bend" when they are located on the main tensile forces. Maximum stresses occur in the second inclined rod from the support.

6. Rods better perceive the load when they are located in the upper compressed zone of the beams. The best work of the rods is observed in the beam when the rods are arranged according to the main compressive stresses.

7. The greatest local stresses occur under the most stressed rods in the "wood-channel" contact zone. The best work of wood is observed in beams, when the rods are arranged according to the main compressive stresses.

8. It is proposed to use calculation systems to identify all the features of the work of wood-composite beams at all stages of its operation, up to destruction.

References
[1] Koshcheev A A, Lisyatnikov M S and Roshchina S I 2019 Technical- and- economic efficiency of reinforced wooden structures IOP Conference Series: Materials Science and Engineering DOI: 10.1088/1757-899X/698/2/022005
[2] Roschina S, Gribanov A, Lukin M, Lisyatnikov M and Strekalkin A 2018 Calculation of wooden beams reinforced with polymeric composites with modification of the wood compression area *MATEC Web of Conferences* **251** DOI: 10.1051 / matecconf / 201825104029

[3] Kuzina E and Rimshin V 2019 Strengthening of Concrete Beams with the Use of Carbon Fiber *Advances in Intelligent Systems and Computing*

[4] Roschina S I, Lukin M V, Lisyatnikov M S and Sergeyev M S 2017 Reconstruction of coating by a single-stage adjustment of a lind-fitting factory in the city of vyazniki *Izv. Vyssh. Uchebnych Zaved. Seriya Teknol. Tekst. Promyshlennosti* **370**

[5] Varlamov A, Rimshin V and Tverskoi S 2019 A method for assessing the stress-strain state of reinforced concrete structures E3S Web of Conferences

[6] Roschina S I, Lukin M V, Lukina A V, Sergeyev M S and Lisyatnikov M S 2015 Experimental research on pressed-bending reinforced timberwork *Izv. Vyssh. Uchebnych Zaved. Seriya Teknol. Tekst. Promyshlennosti* **370**

[7] Naychuk A Y 2013 Estimation of load-bearing capacity and stiffness of timber beams with through-thickness cracks *Advanced Materials Research*

[8] Varenik K A, Varenik A S, Sanzharovskiy R S and Labudin B V. 2019 Wood moisture accounting in creep equations *IOP Conference Series: Materials Science and Engineering*

[9] Kuzina E, Rimshin V and Neverov A 2019 Reserves and exposure assessment of reinforced concrete structures safety while reducing its power resistance E3S Web of Conferences

[10] Gribanov A S, Rimshin V I and Roschina S I 2019 Experimental investigations of composite wooden beams with local wood modification *IOP Conference Series: Materials Science and Engineering* DOI: 10.1088/1757-899X/687/3/033039

[11] Karelskii A V., Zhuravleva T P and Labudin B V. 2015 Load-to-failure bending test of wood composite beams connected by gang nail *Mag. Civ. Eng.*

[12] Roschina S, Sergeyev M, Lukin M and Strekalkin A 2018 Reconstruction of Fixed Fertilizer Folders in the Vladimir Region *IOP Conference Series: Materials Science and Engineering* vol 463 DOI: 10.1088/1757-899X/463/4/042011

[13] Telichenko V, Rimshin V, Eremeev V and Kurbatov V 2018 Mathematical modeling of groundwaters pressure distribution in the underground structures by cylindrical form zone *MATEC Web of Conferences*

[14] Merkulov S, Polyakova N, Rimshin V, Kuzina E and Neverov A 2019 Construction building systems protection under emergency exposure E3S Web of Conferences

[15] Kuzina E, Rimshin V and Neverov A 2019 Residual resource of power resistance during building structures deformation E3S Web of Conferences

[16] Telichenko V I, Rimshin V I, Karelskii A V, Labudin B V and Kurbatov V L 2017 Strengthening technology of timber trusses by plate plates with toothed-plate connectors *J. Ind. Pollut. Control*

[17] Gorpinchenko V M, Pogorelt'sev A A and Ecknadosyan I L 2005 Large-scale tests provided for a block, consisting of two wooden lens-type roof trusses of the sports complex “Strogino” *Promyshlennoe i Grazhdanskoe Stroit.*

[18] Turkovskij S B and Pogorelt'sev A A 2001 Wooden structures with rigid joints in structures with corrosive medium *Promyshlennoe i Grazhdanskoe Stroit.*

[19] Turkovskij S B, Pogorelt'sev A A and Eknados'yan I L 2003 Selection of design scheme of lens-shaped trusses from adhesive wood *Stroit. Mater.*

[20] Preobrazhenskaya I P, Pogorelt'sev A A and Turkovskij S B 2003 Development of design and construction of potassium chloride storehouse with framework from prefabricated wood frames with size of 63 m *Stroit. Mater.*

[21] Labudin B V., Popov E V and Nikitina T A 2019 Notes for calculated resistance to tension for laminated wood *IOP Conference Series: Materials Science and Engineering*

[22] Labudin B V., Popov E V and Sopilov V V. 2019 Stability of compressed sheathings of wood composite plate-ribbed structures *IOP Conference Series: Materials Science and Engineering*
[23] Labudin B, Popov E, Stolypin D and Sopilov V 2019 The wood composite ribbed panels on mechanical joints *E3S Web of Conferences*

[24] Rimshin V, Labudin B, Morozov V, Orlov A, Kazarian A and Kazaryan V 2019 Calculation of Shear Stability of Conjugation of the Main Pillars with the Foundation in Wooden Frame Buildings *Advances in Intelligent Systems and Computing*

[25] Roshchina S, Lukin M, Lisyatnikov M and Koscheev A 2018 The phenomenon for the wood creep in the reinforced glued wooden structures *MATEC Web of Conferences* 245 DOI: 10.1051/matecconf/201824503020

[26] Gorpinchenko V M, Pogoreltsev A A and Ecknadosyan I L 2005 Large-scale tests provided for a block, consisting of two wooden lens-type roof trusses of the sports complex “Strogino” *Promyshlennoe i Grazhdanskoie Stroit.*

[27] Rimshin V and Truntov P 2020 Calculation and Strengthening of Reinforced Concrete Floor Slab by Composite Materials *Advances in Intelligent Systems and Computing*

[28] Rimshin V I, Pudova A A and Shubin L I 2018 Evaluation of efficiency of use of photoelectric systems at operation of a residential house *Izv. Vyssh. Uchebn. Zaved. Seriya Teknol. Tekst. Promyshlennost*

[29] Krishan A L, Rimshin V I, Astafeva M A and Troshkina E A 2019 Calculation of Limit Axial Deformations of the Concrete Core of Compressed Tube-Reinforced Concrete Elements *Zhilishchnoe Stroit.*

[30] Erofeev V, Kalashnikov V, Karpushin S, Rodin A, Smirnov V, Smirnova O, Moroz M, Rimshin V, Tretiakov I and Matvievskiy A 2016 Physical and mechanical properties of the cement stone based on biocidal Portland cement with active mineral additive *Solid State Phenomena*