Strengthening of the operated wooden floor beams with external rigid reinforcement

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Abstract. Reinforced wooden floor beams with rigid reinforcement were studied from a rolling channel fixed to the body of the beam by means of obliquely glued reinforcing rods. The experimental study of four variants of reinforced solid-wood beams was performed on a unique stationary stand using an eight-point loading scheme that simulates a load evenly distributed over the beam span. When reinforcing beams by the proposed method, the load-bearing capacity increases by 47 ... 66%, and the deformability decreases by 54...62%, depending on the location of the rigid reinforcement (top or bottom of the beam) and the inclination of the glued rods (according to the main compressive or tensile stresses). When the reinforcement elements are placed on top of the beams, their load-bearing capacity is on average 18% higher than at the bottom. It is experimentally proved that the destruction of reinforced beams is fragile, which in turn excludes the possibility of their collapse from chipping and splitting in the supporting sections. Research has proved the high efficiency of using the developed method of reinforcement during major repairs and strengthening of buildings in use.

1. Introduction

Wooden beam structures are widely used in construction [1]. They are used in the construction of public, industrial, agricultural and warehouse buildings [2].

Along with the new construction of floors, in buildings and structures with the use of wooden structures as their physical and moral wear, there is a need to modernize the existing structures of buildings. Most often, it is associated with the repair and strengthening of floor structures [3]. Inter-floor and attic floors of residential and public buildings erected before the 60s of the twentieth century were solved mainly by the beam type using wooden structures [4]. Wooden beams were the supporting structures that accepted the constant and temporary load [5] of such overlaps [6, 7].

During the operational period, building floor structures become unsuitable for further operation as a result of changes in temperature and humidity conditions [8] and the life of harmful wood-destroying insects, mechanical damage [9], changes in the requirements of rules and regulations, and many other factors, and to extend the service life requires their strengthening. Often strengthening of structures is necessary when changing the functional purpose of premises associated with an increase in the value of the time load.
Being in periodically changing temperature and humidity conditions, elements of wooden structures during operation change their humidity, rot. Destruction of wood elements is usually accompanied by cracking and stratification of wood [10]. Rotting contributes to contamination of structures during operation. If they are not repaired in time, the wooden structures may collapse.

When examining wooden structures, it should be taken into account that on the surface of the elements, destruction develops at very high humidity of wood [11], in the absence of ventilation. The most vulnerable places for destruction of wooden structures are the support nodes and fasteners (Figure 1).

![Figure 1. Destroyed sections of wood elements: a) wooden rafters; b) wooden beam](image)

At various times, well-known scientists were engaged in the problems of operation, determining the strength, durability and stability of wooden structures, evaluating the technical capabilities of wood, as well as improving the efficiency of using raw materials.

Wood used in the construction of wooden buildings is often subjected to adverse operational effects [12]. In changing conditions of temperature and humidity conditions, organic material is bio regulated by microorganisms, rot and wood destruction occur, which leads to a loss of operational reliability of elements of wooden structures as a whole.

The main factors that reduce the operational reliability of wooden beams [13] include: untimely maintenance of current and major repairs, the effect of aggressive media, non-compliance with temperature and humidity conditions. The most vulnerable zones of destruction of wooden structures are the support areas [14].

Currently, various methods of restoration and strengthening of wooden structures are used, based mainly on selective replacement of affected areas of structures with solid wood or metal [15].

Various construction materials are used abroad and in our country to restore load-bearing wooden structures that have defects or have insufficient load-bearing capacity and unacceptable deformability [16]. Metal is traditionally used to strengthen wooden structures containing certain defects [17, 18]. One of the most common methods is that a defective section of a wooden structure or its element is replaced with a prosthesis made of steel [19, 20]. The following methods of restoring the ends of wooden beams using metal are widely used, of course, in many cases in combination with other materials:

1. The device of end prostheses in the form of paired side plates made of channels on steel bolts and a yoke [21].
2. The device of prostheses in the form of wooden paired side plates on bolts, nails or dowels; the installation of steel welded rod prostheses, impaled on the cut end of the beam [22].
3. The device of prostheses in the form of a bar of healthy wood, spliced with the cut end of the beam using special connecting elements [23], welded from steel profiles and steel bolts.
4. Support of the cut end of the beam on a bracket, welded from steel profiles and fixed in the wall.
In General, the accumulated research experience in the field of metal-reinforced wooden structures that work with bending [24] and compression with bending, indicates that their design properties are quite high and that this method of strengthening is promising. Reinforcement can increase the load-bearing capacity of wooden structures by 1.5-3.5 times [25].

Conducting research in this direction is currently an urgent scientific and practical task. The object of the study was exploited beam structures with destructed zones of wood. The subject of the study was the complex stress-strain state of reinforced beams. The purpose of the study is to improve methods of strengthening wooden structures by providing scientifically based strength, stiffness and performance characteristics. At the same time the tasks were set:

1. Carry out a system analysis in the context of the problem of increasing the effectiveness of strengthening wooden structures.
2. To develop a technical solution for strengthening of load-bearing wooden structures using reinforcement and polymer adhesives.
3. To conduct theoretical studies of reinforced 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.
4. Perform experimental studies and evaluate the load-bearing capacity and deformability of reinforced wooden structures.

Based on the results of the study, the necessary conclusions about the nature of destruction [26,27], the strength and deformability of real reinforced wooden beams [28...30] were obtained.

2. Methods
The method of reinforcement proposed by the authors of the article consists in strengthening the compressed zone of beams with rigid external reinforcement in the form of a channel and gluing inclined rod reinforcement into the body of the beam.

The main elements of reinforcement are rolled in the form of a metal channel and reinforcing rods [38]. The wooden cross-section of the studied beams is 100x240 mm. the Length is 4.8 m, the calculated span is 4.5 m.

The channel is installed either in the upper (compressed) or lower (stretched) zone of the beam, the number of rolled products is selected by the width of the cross-section of the beam (No. 12). Fixing of steel channel to beam body is performed by tilting the glued reinforcing bar class A400 periodic profile with a diameter of 10 mm. the Location is on the main tensile or compressive stresses at an angle of 450 with the step of 300 mm along the beam length.

The research was carried out on 4 variants of reinforced beams (Figure 2).

Marking beams:
- B-0-operated (reinforced) wooden beam;
- B-1-reinforced beam with the location of external reinforcement on top, glued reinforcement for the main compressive stresses (option 1);
- B-2-reinforced beam with the location of external reinforcement from the bottom, glued reinforcement on the main tensile stress (option 2);
- B-3-reinforced beam with the location of external reinforcement on top, glued reinforcement on the main tensile stress (option 3);
- B-4-reinforced beam with the location of external reinforcement from the bottom, glued reinforcement for the main compressive stresses (option 4).

Technical and economic considerations and the geometric dimensions of the experimental installation show that the solution of the above research tasks is advisable to perform on full-scale beams. The full-scale construction is tested, which makes it possible to preserve all the physical phenomena that occur in structures during loading. 3 models were accepted for each series of beams.
To study the stress-strain state of reinforced beams with a design span of 4.5 m, an eight-point loading scheme was adopted, which simulates the operating load with sufficient accuracy—evenly distributed over the span.

The installation for testing beams is a powerful stationary stand. It consists of a jet beam on which there are supports for the tested beams and transfer shafts with a diameter of 300 mm. Loading of the test sample occurs using platforms that are attached to the transfer shafts. Through the transfer shafts, the load increases by 7 times and is transmitted to the beam by clamps with wooden linings. The load from the beam is transmitted to the supports through metal distribution plates fixed in the support sections of the lower belt. These plates provide the strength of wood to crumple in the supporting sections of structures. To ensure the stability of the beam, additional struts were installed, rigidly connected to the jet beam.

**Figure 2. Options for strengthening wooden floor beams**

For conducting experimental studies of beams, the method of tensometry was chosen, since it alone gives a quantitative picture of displacements and stresses, and not a qualitative one. A qualitative picture of the stress distribution was obtained using the FEM. The experimental base of Vladimir State University has equipment for conducting strain measurements (digital strain gauge complex SIIT-3M). This method has been tested and a large number of tests have been carried out using strain gauge equipment.

The layout of the measuring devices on the beam is shown in figure 3.

A General view of the experimental installation with the test beam is shown in figure 4.

The reinforcement proposed for beams increases their load-bearing capacity by 47 ... 66% and reduces deformability by 54 ... 62% compared to conventional solid wood beams. This allows both to maintain and exceed the design load-bearing capacity of the operated beams.
Figure 3. The layout of measuring devices: P-1 - deflector mark 6-PAO; T-1 - guckenberger strain gauges; I-1, I-2 - hour-type indicators.

Figure 4. General view of the experimental installation with the test beam

It has been experimentally confirmed that the destruction of reinforced beams occurs brittle and only in normal cross sections. This eliminates the possibility of destruction of reinforced beams from chipping and splitting in the supporting sections, i.e. it ensures the reliability of structures for the action of shear forces in the support sections, thereby increasing the reliability of the structure against collapse.
3. Results and discussion
The calculated linear load was determined from the condition of strength of normal cross sections using the results of numerical studies and amounted to 1520 kg/m for solid wood beams and 2380 kg/m for reinforced beams.

The destruction of beams of the B-0 series occurred at an average load of 1480 kg/m, which differs from the theoretical value of the destructive load by 3%, and began in a stretched zone in the area of the defect in the form of a knot. After that, the compressed wood fibers lost their stability with the formation of a plastic fold. No deformations were observed in the support area of the beams.

The destruction of beams of the B-1 and B-3 series occurred at a load of 2550 kg/m and 2600 kg/m, respectively, due to the destruction of stretched fibers in the area of the defect in the form of a knot. The destruction of beams of the B-2 and B-4 series occurred at a load of 2220 kg/m and 2200 kg/m due to the loss of stability of the compressed fibers with the formation of a plastic fold. Amplification of the compressed zone is more efficient due to the faster integration of amplification elements into the work.

Based on the test results, the graphs shown in figures 5.1...5.6 are constructed.

The conducted research aimed at studying the strength and deformative characteristics of operated wooden beams reinforced with external reinforcement has shown the possibility of using this type of reinforcement.

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**Figure 5.1.** Diagram of load-deflection

**Figure 5.2.** Diagram of the load – tensile strain in the wood
Figure 5.3. Diagram of stress – compressive strain in the wood

Figure 5.4. Diagram load-normal stresses in the channel

Figure 5.5. Diagram load-tangent stresses in the channel
Figure 5.6. Diagram load -normal stresses in the rods

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The results of the experiment form a number of important conclusions that are necessary for further research of this type of amplification.

Symmetrical reinforcement of beams was not considered due to the General increase in the cost of structures, and as a result of the inexpediency of using such a solution.

4. Conclusions

Quantitative estimates of strength and deformation parameters of reinforced solid-wood beams were obtained experimentally.

Based on the results of the research, the following main conclusions can be formulated:

1. When reinforcing beams from above, the load-bearing capacity is 18% greater than when reinforcing from below.

2. The reinforcement proposed for operational beams increases their load-bearing capacity by 47 ... 66% and reduces deformability by 54 ... 62%.

3. The conducted research has shown the possibility of using the developed method of strengthening beams during major repairs and reconstruction of buildings.

4. The Developed method expands the scope of application of steel elements when carrying out works on strengthening of wooden structures.

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 vol 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. Vyss. Uchebnynkh 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 Int. J. Appl. Eng. Res. 10

[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] Karelskiy 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 patch plates with toothed-plate connectors J. Ind. Pollut. Control

[17] Gorpinchenko V M, Pogoreltsev A A and Echinadosyan 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.

[18] Turkovskij S B and Pogoreltsev A A 2001 Wooden structures with rigid joints in structures with corrosive medium Promyshlennoe i Grazhdanskoie Stroit.

[19] Turkovskij S B, Pogoreltsev A A and Eknadosyantsev I L 2003 Selection of design scheme of lens-shaped trusses from adhesive wood Stroit. Mater.

[20] Preobrazhenskaya I P, Pogoreltsev 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. Uchebnykh Zaved. Seriya Teknol. Tekst. Promyshlennosti*

[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 Matveevskiy A 2016 Physical and mechanical properties of the cement stone based on biocidal Portland cement with active mineral additive *Solid State Phenomena*