Non Split Wooden Beam Reinforced with Composite Reinforcement

Mikhail Lukin, Mikhail Sergeev(✉), and Mikhail Lisyatnikov

Vladimir State University named after Alexander Grigorievich and Nikolai Grigorievich Stoletovs, Institute of Architecture Construction and Energy Engineering, Gorky Street 87, Vladimir 600000, Russia

sergeevmichael@inbox.ru

Abstract. The object of research is multi-span wooden beams reinforced with fiberglass rods in a stretched zone. The purpose of the study is to study the stress-strain state of multi-span wooden beams reinforced with fiberglass reinforcement. Studies of single-span wooden structures with fiberglass reinforcement have shown positive results, including under prolonged loads and with the use of pre-stress. At the same time, multi-span wood-glued beams using fiberglass rods as a reinforcing material are an experimental design and today their work is poorly studied, which makes this task relevant.

The research was carried out on 3 variants of beam structures, two of which are wood-composite, one – solid wood, given as a standard. Taking into account the scheme of operation, composite rods are located both at the bottom of the section – in spans, and at the top – on supports. Depending on the coefficient of reinforcement, the strength of beams reinforced with fiberglass rods in stretched zones increases by 32–37%, and the deformability decreases in the range of 15–19% compared to standard wooden beams. Based on the results obtained, we can conclude that the considered method of strengthening wooden beams is appropriate and effective.

Keywords: Wood composite · Fiberglass reinforcement · Rational reinforcement

1 Introduction

Rational use of wood in the manufacture of new types of structures and their elements provides for the strengthening of nodes and interfaces with the use of new materials and technical solutions based on the latest achievements of science and technology. A significant role in the improvement of wooden structures was made by the appearance and development of epoxy resins. The development of wooden structures tends to create systems, types, elements and types of connections that would save wood, while increasing the load-bearing capacity, and best take into account its physical and mechanical features. The main feature that characterizes progress in the field of wooden structures is the focus on glued [1–5] and composite [6–10] wooden structures. The development and distribution of glued wooden structures is inextricably linked with the success in the

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production of synthetic polymer materials, since adhesives based on them are the best for gluing wood [7, 8]. One of the priority areas is the creation of lightweight composite bendable structures based on wood. These include reinforced [9–12], glued plywood [13, 14], and other beam structures. The use of composites can significantly reduce the impact of various defects in the structure of wood – knots, slants, etc., use low-grade wood, which is usually not used, and expand the scope of composite beam structures not only in new construction, but also in the reconstruction of significant historical objects [15–20].

Nowadays glued wooden structures are mainly used in the construction of gyms, swimming pools, stadiums and bridges. Taking into account the requirements of fire regulations, they are also used for industrial buildings, especially for warehouses and buildings with a chemically aggressive environment, the use of metal and reinforced concrete in which is associated with high costs for their anti-corrosion protection. In the structure under study, fiberglass reinforcement is used as a reinforcing material. In comparison with reinforcing elements made of metal, fiberglass products are not exposed to chemically active media, however, this type of reinforcement requires more careful protection from heating during a fire. Studies of single-span wooden structures with fiberglass reinforcement have shown positive results, including under prolonged loads and with the use of pre-stress. At the same time, multi-span wood-glued beams using fiberglass rods as a reinforcing material are an experimental design and today their work is poorly studied, which makes this task relevant.

The scientific novelty of the article consists in the study of multi-span continuous composite beams with reinforcing elements made of fiberglass reinforcement, which can be used both in new construction and in the reconstruction of buildings. The object of research is multi-span wooden beams reinforced with fiberglass rods in a stretched zone. The subject of the study is the stress-strain state (SSS) of multi-span wood-composite beams of the proposed type. The purpose of the study is to study the stress-strain state of multi-span wooden beams reinforced with fiberglass reinforcement.

To achieve this objective, tasks were identified: to analyze world experience of research related to improving the bearing capacity of wooden beams by the use of fiberglass reinforcement and other composite materials; to carry out theoretical research derivatising beams with the rationale adopted by anisotropic physical and mathematical models of wood and a reinforcing material; to perform the stress-strain state of structures designed on the basis of experimental results.

The scientific novelty of the work consists of: a method for increasing the load-bearing capacity of continuous wooden beams by rational reinforcement of the stretched zone with composite rods; a numerical model that takes into account the physical nonlinearity of materials, including wood reinforcement; results of theoretical and experimental studies of wood-composite beams.

2 Materials and Methods

Currently existing methods for calculating wooden structures allow us to estimate their load-bearing capacity and deformability with sufficient accuracy for any cross-sections and at any stage of work. When loading wooden structures with an external load, three characteristic and sequential stages of the stress-strain state are clearly manifested: conditionally elastic, elastic - plastic, and the stage of destruction.

The stage of conditional elastic work is characterized by the amount of deformations that do not exceed the limit values of elastic deformations of wood and rebar. When unloading reinforced elements at this stage, there are no residual deformations or they are so insignificant that they can be ignored. Due to the fact that even at low stresses, the linear relationship between stresses and deformations of wood is somewhat violated, the first stage of the stress-strain state can only be considered as conditionally elastic. The stage of elastic-plastic work is characterized by the appearance of noticeable plastic deformations in the compressed wood fibers, and then in the compressed reinforcement. In the compressed part of the section, a plastic zone is formed, spreading with increasing load into the depth of the section. There is a redistribution of forces, as a result of which the neutral layer is shifted towards the stretched fibers. Deformations of stretched wood fibers increase to the value of the proportionality limit. When the element is unloaded at this stage, significant residual deformations appear. The failure stage is characterized by a significant increase in the deformability of the reinforced element with a small increase in the load. Plastic deformations get the maximum development. The element is destroyed, the nature of which depends on the type of reinforcement.

As an experimental design, a multi-span beam made of wood with reinforcement in stretched zones with fiberglass reinforcement according to GOST 31938-2012 “composite polymer reinforcement for reinforcing concrete structures” was adopted. As rods for reinforcement, ask type reinforcement (glass composite) is used, with the following characteristics: tensile strength 1300 MPa; elastic modulus-64000 MPa. Wood for calculations has the following characteristics: density 500 kg/m3; modulus of elasticity – 11000 MPa.

Taking into account the scheme of operation, composite rods are located both at the bottom of the section – in spans, and at the top – on supports. As a reference beam, the VAT analysis of an unreinforced beam of a similar cross-section was performed. The research was carried out on 3 variants of beam structures, two of which are wood-composite, one – solid wood, given as a standard. Accepted marking of beam structures (Fig. 1):

1) DB series – all-wood beams accepted as blanks and reference, with three spans of 1.5 m, 40 × 80 (b × h) mm cross-section;
2) BK-1 series – beams reinforced in the lower zone of the span and the upper zone of the support with reinforced fiberglass rods F8 mm, with three spans of 1.5 m, with a cross section of 40 × 80 (b × h) mm;
3) BK-2 series – beams reinforced in the lower zone of the span and the upper zone of the support with reinforced fiberglass rods F10 mm, with three spans of 1.5 m, with a cross section of 40 × 80 (b × h) mm.

The numerical experiment is performed on the cross-section dimensions corresponding to the dimensions of the beam model, which are available for further field tests. At the first stage of research, the use of ED-20 epoxy resin with a PEP hardener without modifications is assumed as an adhesive composition.

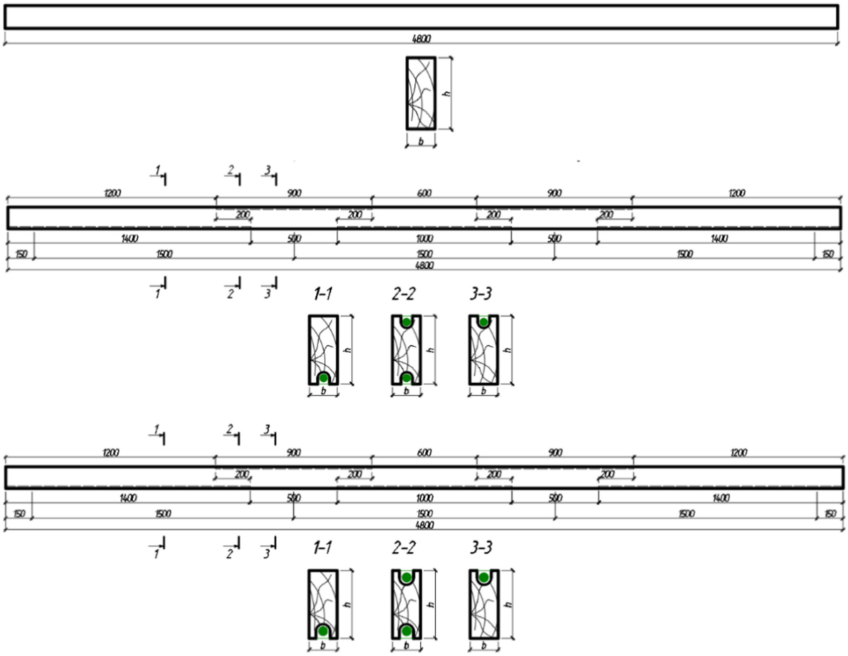

Fig. 1. A series of beams for the experiment

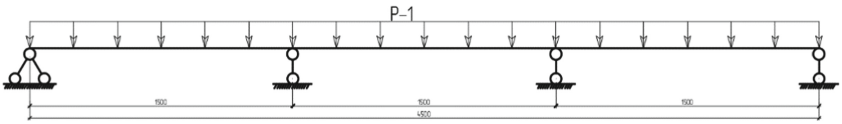

Fig. 2. A design scheme of the beam

A vertical evenly distributed load was applied to the beam over all spans in steps 1/10 of the destructive one. When performing a linear calculation in the LIRA 10.10 PC, the first load was copied to the subsequent ones with a load conversion with a coefficient corresponding to the load sequence number. When performing a non - linear calculation, the load accumulated from load to load. The number of iterations is set to 300. cross-sections corresponding to the dimensions of the model beams that are available for further field tests. At the first stage of research, the use of ED-20 epoxy resin with a PEP hardener without modifications is assumed as an adhesive composition.

3 Results and Discussion

As a result of computer modeling, it is established that the destruction of composite beams is plastic in nature, it can be stated that the destruction begins with crumpling in the compressed zone, after which stress concentrations are formed in the stretched zone in the places of defects. There is no separation of fiberglass rods from wood. The destruction of composite beams occurs only in normal cross-sections. This eliminates the possibility of destruction of reinforced beams from chipping and splitting in the supporting sections, i.e. provides reliable operation of structures for the action of shear forces in the support sections, thereby increasing the reliability of the structure against collapse.

The design scheme of the structure is adopted in the form of a three-span pivotally supported beam, with spans of 1.5 m, loaded with a uniformly distributed load along the entire length.

Isofields of stresses and displacements based on the results of numerical calculation for half of the beam structure (1.5 spans) are shown in Figs. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14.

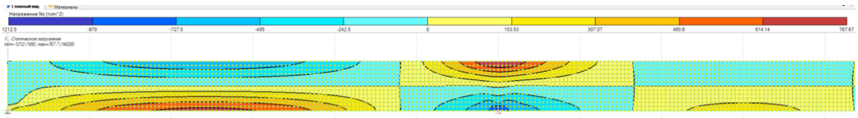

Fig. 3. Isofields of normal stresses σx, MPa for a wooden beam (half the length)

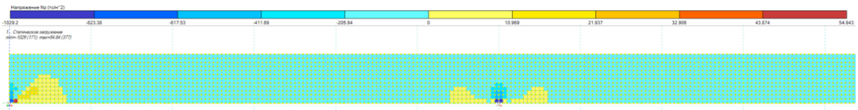

Fig. 4. Isofields of normal stresses σz, MPa for a wooden beam (half the length)

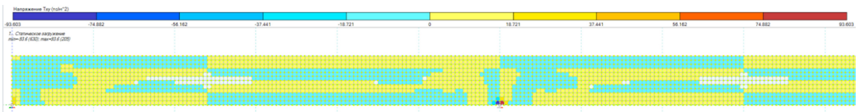

Fig. 5. Tangential stresses τxy MPa for a wooden beam (half the length)

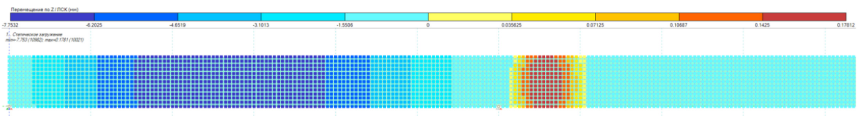

Fig. 6. Vertical movements z, mm for a wooden beam (half the length)

Unlike wooden beams, the strength of composite beams with rational reinforcement of stretched zones increases by 32–37%, and the deformability decreases by 15–19%, depending on the diameter of the reinforcement used.

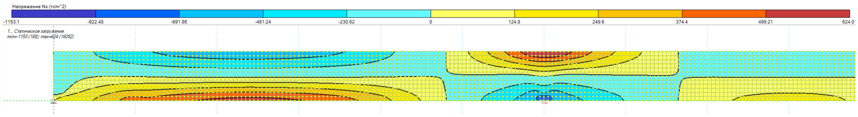

Fig. 7. Isofields of normal stresses σx, MPa for a reinforced beam in linear calculation (half the length)

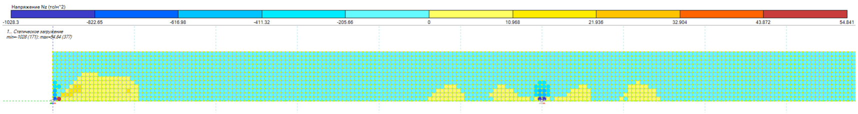

Fig. 8. Isofields of normal stresses σz MPa of a reinforced beam in linear calculation (half of the length)

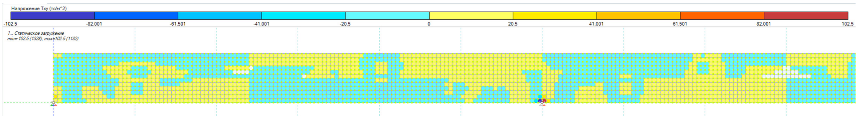

Fig. 9. Tangential stresses τxy MPa for a reinforced beam in a linear calculation (half the length)

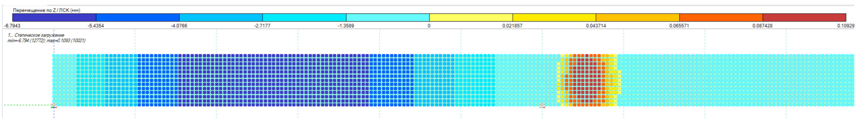

Fig. 10. Vertical displacements z, mm for a reinforced beam in linear calculation (half the length)

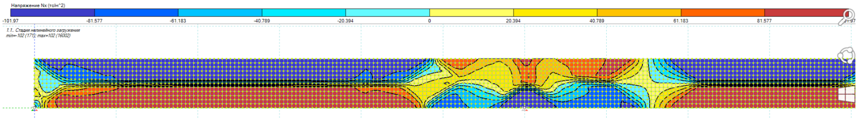

Fig. 11. Isofields of normal stresses σx, MPa for a reinforced beam in non-linear calculation (half the length)

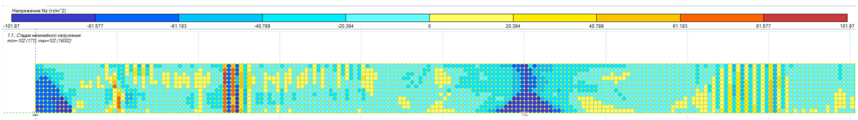

Fig. 12. Isofields of normal stresses σz MPa for a reinforced beam in non-linear calculation (half the length)

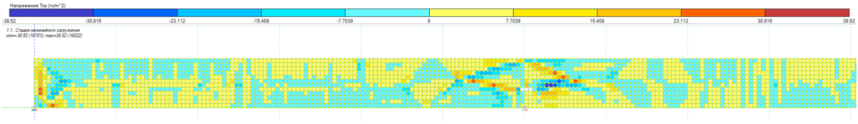

Fig. 13. Tangential stresses τxy MPa for a reinforced beam in non-linear calculation (half the length)

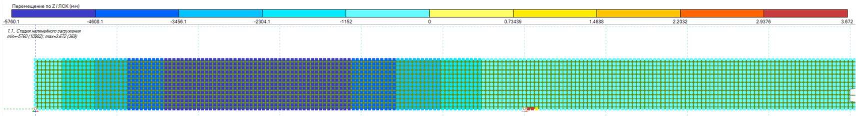

Fig. 14. Vertical displacements z, mm for a reinforced beam in non-linear calculation (half the length)

4 Conclusion

The main indicators of the effectiveness of load-bearing building structures are both structural and technological indicators: cross-section dimensions and installation weight, and technical and economic indicators: consumption of basic materials, factory cost, cost of structures in operation, reduced costs, operational suitability, etc. The efficiency of the composite wooden structures compared to traditional no doubt: reducing the cross-section of strengthened elements (especially height) to reduce building volume and therefore the cost of building envelope and heating; reducing the width of the cross section of the elements enables the use of the abundant lumber width 130 × 150 mm; reducing the size and weight of the elements makes it possible to more efficiently solve the issues of storage, transportation and installation.

In the course of the work, the analysis of the world experience of research connected with the use of fiberglass reinforcement in wooden structures was carried out. According to the results, it is established that multi-span structures with reinforced fiberglass rods are currently poorly studied.

The numerical experiment was performed on models of beams available for further field tests. Depending on the coefficient of reinforcement, the strength of beams reinforced with fiberglass rods in stretched zones increases by 32–37%, and the deformability decreases in the range of 15–19% compared to standard wooden beams. Based on the results obtained, we can conclude that the considered method of strengthening wooden beams is appropriate and effective.

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