Stress–Strain State of a Wood-Glued Three-Span Beam with Layer-By-Layer Modification

M. Sergeev, **A. Lukina**, **N. Zdralovic**, and **D. Reva**

Abstract One of the priority areas of research is the creation of lightweight composite bendable structures based on wood. Composite multi-span wood-glued beams with the proposed reinforcement scheme are an experimental design and to date their operation is poorly studied. The essence of the proposed design is to form a glued beam in which fiberglass is placed in the adhesive seam between the boards. To perform the calculations, we set the model of a beam with three spans. The load is assumed to be evenly distributed over the entire length of the beam. A comparison of the structure to assess its rationality was carried out with an unreinforced glued beam with the same design scheme. In the course of the study, it was found that, in contrast to glued beams, the strength of composite beams with layer-by-layer modification increases by 14–17%, and the deformability decreases by 4–7%. The destruction of the beams occurs along normal sections, which eliminates the possibility of chipping and splitting in the supporting sections, i.e. ensures the reliability of the structures for the action of shear forces in the supporting sections, thereby increasing the reliability of the structure against collapse.

Keywords Composite beam · Layer-by-layer modification · Three-span beam

1 Introduction

Glued wooden structures in our time are used mainly in the construction of large sports facilities and in some cases in the construction of bridges. Taking into account the requirements of fire protection standards, they are also used for

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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. One of the important advantages of wooden structures is the aesthetic component, which plays an increasingly important role in the selection of future building structures [1–5].

The scientific novelty of the article lies in the study of layer-by-layer modified glued beams, the use of which is possible both in new construction and in reconstruction. Composite wood-glued beams are an experimental design and to date their work is poorly studied [6–9].

The scientific nature of the article is traced in the study of the stress–strain state of glued beams with layer-by-layer reinforcement with fiberglass by studying the results of a numerical experiment performed in a computational complex.

2   Methods

The study is based on a glued multi-span beam, in which a layer of fiberglass is glued between each board in the package. The epoxy resin ED-20 modified by the addition of carbon nanotubes is used as an adhesive. The compound with the inclusion of carbon nanotubes allows to achieve a higher conversion, and, consequently, to obtain a more regular and frequent grid of chemical cross-links than in the original systems. Such pre-cured compositions will have a higher glass transition temperature, a higher elastic modulus, a greater tensile strain and, as a result, a higher ultimate strength. The strength of the ED-20 epoxy matrix containing carbon nanotubes increases by 6–8% during cold curing [10–13].

As a design scheme for the numerical experiment and further testing of the models, a three-span continuous beam with a single layer of fiberglass reinforcement in each seam between the boards in the beam package is adopted. The cross section of the beam for numerical modeling and further experimental research is 80×160 (h) mm. Boards for the set of cross-sections are accepted for 19 mm, in the amount of 8 pieces, which eventually allows you to dial a cross-section with a height of 160 mm. Thus, the number of layers of fiberglass is 7.

The reinforcement coefficient is set experimentally, at the first stage laying one layer of fiberglass between each plate of the recruited package of boards. In the future, the reinforcement coefficient can be varied by increasing the number of layers of fiberglass. Sizing with tape is made along the entire length of the beams without breaking (Fig. 1).

To compare the results and evaluate the feasibility of the proposed design, we will take a beam of a similar cross-section as a reference, but without layer-by-layer reinforcement with fiberglass.

Modern methods of calculating wooden structures allow us to accurately assess both the load-bearing capacity and deformability for any cross-sections and at any stage of work. When loading wood structures with an external load, three
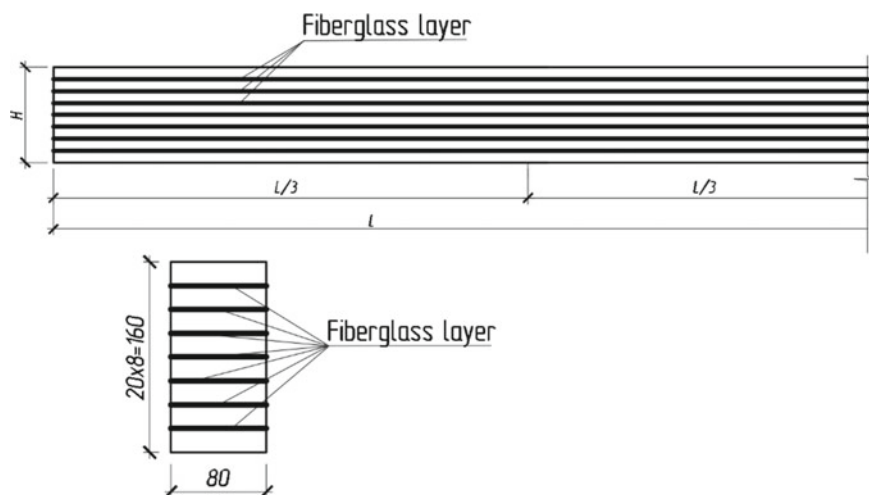
Fig. 1 Diagram of the beam in question

characteristic and successive stages of the stress–strain state are clearly manifested: conditionally elastic, elastic–plastic, and destruction.

The design and calculation of composite beam structures in the normative literature is carried out under the assumption of the elastic work of materials using the coefficients of reduction to wood of the geometric characteristics of the cross-sections of these beams [14–21]. This calculation method is applied and uses a number of assumptions, which in turn allow us to obtain compact mathematical expressions for finding the required parameters.

The finite element method is used to calculate structures in the elastic–plastic and plastic stages of the stress–strain state, as well as to visualize transient physical processes in structural elements at various loading stages. Reliable calculation results are obtained using a physically nonlinear model with the use of actual deformation diagrams of the materials used and taking into account the duration of the applied loads [21–30].

The analysis of the stress–strain state (SSS) of structures was carried out sequentially at the conditionally elastic stage, then at the elastic–plastic stage, and at the failure stage using the finite element method in the Lira software package. The calculation is carried out by the method of successive loads in the linear and physically-nonlinear formulation of the problem.

The design scheme of the structure is adopted in the form of a pivotally supported continuous three-span beam. The spans are taken at 2.0 m, the beam is loaded with a uniformly distributed load along the entire length. For the possibility of further full-scale tests on the models, a numerical experiment is performed on the cross-section sizes corresponding to the dimensions of the model beams that are available for full-scale tests.
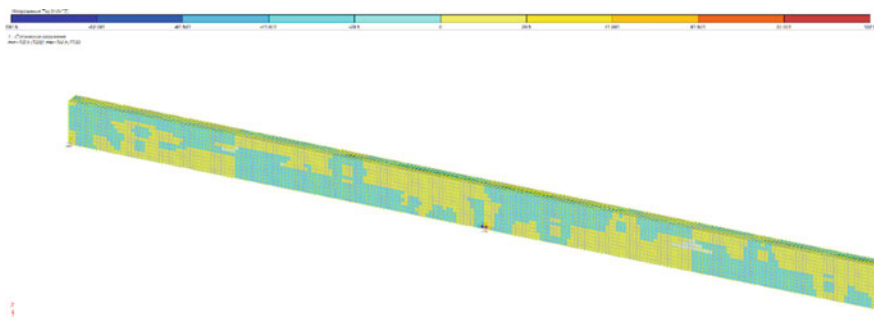
Isofields of stresses and displacements based on the results of numerical calculation for half of the span of a composite beam structure are shown in Figs. 2, 3 and 4.
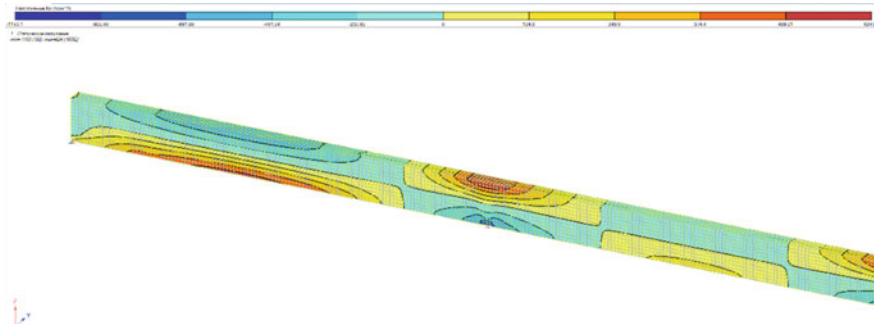
Fig. 2 Normal stress isofield σ_x, MPa for a layer-by-layer modified beam (half length)
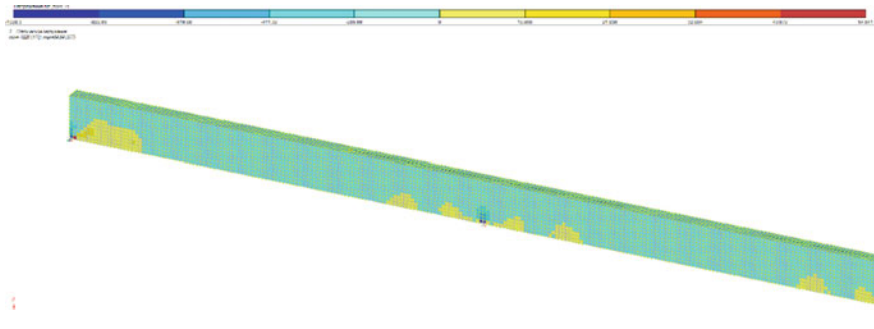
Fig. 3 Normal stress isofield σ_z, MPa for a layer-by-layer modified beam (half length)

Fig. 4 Isofields of tangent stresses τ_{xy} MPa for a layer-by-layer modified beam (half length)

3   Results and Discussion

As a result of modeling, it is established that the destruction of layer-by-layer modified 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. The separation of fiberglass from wood and its rupture does not occur. The destruction of composite beams occurs only in normal cross-sections, which eliminates the possibility of destruction of the proposed structure of beams from chipping and splitting in the supporting areas, i.e. provides reliable operation of structures under the action of shear forces in the support sections, thereby increasing the reliability of the structure against collapse.

In contrast to simple glued beams, the strength of layer-by-layer modified composite beams increases by 14–17%, and the deformability decreases by 4–7%.

The reliability of the results obtained is ensured by the correctness of the tasks set, the use of hypotheses and assumptions accepted in structural mechanics; modern research tools using a certified tool base; methods of conducting numerical experiments using computational programs.

4   Conclusion

By evaluating structural and technological indicators such as cross-sectional dimensions and mounting weight, it is possible to evaluate the effectiveness of load-bearing building structures, as well as by technical and economic indicators, expressed in this case in the level of consumption of basic materials, factory cost, the cost of structures in the case, the reduced costs and operational suitability. The effectiveness of composite wooden structures, namely, the proposed structure can be attributed to them, in comparison with traditional ones, is beyond doubt: reducing the cross-section of reinforced elements allows you to reduce the total volume of the structure and, as a result, the cost of enclosing structures and heating, reducing the size and weight of the elements makes it possible to more effectively solve the issues of storage, transportation and installation of structures.

Based on the results obtained during the numerical study, it can be argued about the feasibility and effectiveness of the considered method of strengthening wooden beams. According to the conducted numerical experiment, it was found that, in contrast to simple glued beams, the strength of composite beams with layer-by-layer modification increases by 14–17%, and the deformability decreases by 4–7%.

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