Investigation of glued in bars strength and deformability indexes within framework of research of wood reinforcement with cable reinforcement

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Abstract. The increasing demand for the low-height housing construction frame technology keeps current the issue of saving timber in building construction. The method of reinforcing beams with reinforcing steel is a promising direction of research in the field of ensuring the gain in strength and the cost indexes reduction of structures. In 2017 as a graduate student of the Department of building structures of VlSU Koscheev A.A. proposed for the investigation a new type of reinforcing wooden beams by the steel cable reinforcement in solid wood along the original curvilinear trajectory. As of today, a number of numerical investigations in this area was carried out and the process of the full-scale experimental investigations was launched. This research article is devoted to the first cycle of the experimental analysis in this area: investigation of the influence of the steel wire rope strength characteristics on the behaviour of the adhesive interlayer of the epoxy composition when conducting tensile tests – pulling out a straight bar from the solid wood. On the basis of the data obtained, conclusions on the applicability of the rope reinforcement in solid wood constructions were drawn and the main directions for further research were determined.

1. Introduction

Every year wood-frame low-rise construction projects are becoming more and more popular. Wood consumption is growing due to the increased demand so considering the fact that the first-grade wood is mainly used in load-bearing structures, the world reserves of sound wood decrease every year. [1-4] A decrease in the amount of resources inevitably leads to an increase in the cost of wood that makes the leading scientific schools all over the world look for new ways to increase the strength indexes of wooden structures[5-7] that allows to reduce material consumption of structures and to ensure the cost-effectiveness for the ultimate customer[8,9].

The Department of Building Structures of Vladimir State University has been engaged in the modernization of wood beam structures for many years. Progress in the investigation of the use of the steel ribbed bar reinforcement in wooden structures has been achieved[10-16]. With a foundation of the conducted research it has been possible to study the issues of gluing in reinforcement into solid wood, to investigate the behavior of the glue joints under loads, to solve the problems of the stress concentrators occurrence on the support zones of wooden floor beams and floorings. Based on the achievements of the school of wooden reinforced constructions that was founded on the results of the
fundamental research of Professor Shuko V. Yu.[16-20], in 2017 a post-graduate student of the department proposed to up-level the known methods of reinforcing wood with hot-rolled steel ribbed bar by replacing it with a zink coated regular or double regular steel lay of LC-O type. Rational proposals have been based on the higher strength indexes of steel cables over the reinforcement with the comparable cross section along with the lower material consumption.

Reinforcement with cable reinforcement has been proposed to be used in floor beams and floorings, in the tension side since steel cable works only under tensile stresses[21]. The following main provisions of the new type of reinforcement representing the scientific novelty have been ascertained:

1. Use of the steel wire rope instead of the steel ribbed bar (Figure 1)

![Figure 1. Choice of the reinforcing material.](image1)

2. The use of the U-shaped milling groove for fixing the reinforcement, made through the use of the U-shaped slot-milling cutter, CNC milling cutter or manual milling machine with a Trend guide. In the case of milling a curvilinear trajectory it has been proposed to use templates along which the support bearing of the corner-rounding milling cutter will move (figure 2).

![Figure 2. The shape of the groove in the cross section and the form of the cutter.](image2)

Anchoring along the original trajectory. Let us make clear the essence of this matter: reinforcement has been located in the tensioned zone, in order to ensure the anchoring of the reinforcing material and activating of more solid wood than in the classic linear reinforcement[22], it has been proposed to mill slots along the s-shaped curved trajectory (figure 3,4).
These solutions will make it possible to reduce the cross-sectional area of the beam structures that will lead to savings of wood and steel during the construction of floorings and coverings. It has been planned to use the multicomponent adhesive compound based on epoxy resin with the PEPA hardener and plasticizer[23-25].

2. Materials and methods
To study the proposed method of wooden beams reinforcing, numerical studies have been carried out - deflections and deformations on the basis of the calculations by means of the SCAD program have been obtained. Various forms of reinforcing material arrangement i. e. different types of trajectories have been investigated. Reinforcement along the S-shaped 1-line trajectory with steel wire rope reinforcement has been considered to be the most advantageous from among all the options. This option is characterized by the highest rate of reinforcement efficiency among those investigated, i. e. the strength properties of the reinforcing material have been used the most effectively, herewith ensuring the decrease in the deformation indexes in comparison with the unreinforced structure by 2.81 times (figure 5).

Figure 3. The proposed form of anchoring on the support zone and the demonstration model of the reinforcement on the bottom surface of the beam.

Figure 4. Geometric characteristics of reinforcement in the anchoring zone

Figure 5. Analysis of the stress - strain state of beams with various types of reinforcement on the basis of the numerical investigations. Isopole stresses.
It has been decided to investigate the effect of the decrease of the glued in wood wire rope cross section on the adhesive interlayer under the action of tensile stresses as the first cycle of the full-scale tests on the basis of the data of the numerical studies.

Samples of various glued in solid wood bars have been made for this tests. The process of making samples has consisted in the following:

1. Cutting and milling of wooden blanks has been performed by means of the Makita 3612C manual milling machine and the U-shaped slot-milling cutter of 12 mm in diameter. Milling has been performed at 30,000 rpm to ensure the high quality of the inner surface of the groove. The groove has been made 15 mm deep to ensure the complete overlapping of the reinforcing material by the epoxy adhesive (Figure 6).

2. Preparations for gluing in the reinforcing material, involving a steel ribbed bar of 10 mm in diameter and a zink coated double regular steel lay of LC-O type of 10 mm in diameter, have been made. Then the bars have been cut, cleaned and treated by the degreaser and acetone (Figure 7).

3. Gluing in the reinforcing bars into a groove and clearing of the wooden dust residues has been made. Mixing and preparation of the adhesive composition of the epoxy resin ED-20 and hardener has been carried out using electronic scales with a measurement accuracy of up to 1 gr (Figure 8).
After preparation of the experimental samples, tensile tests have been carried out on a tensile machine. Software, instrumental, photo and video reporting of the emerging deformations and fracture behavior has been made in the process of the testing.

3. Results and discussions
On the basis of the conducted tests, analysis of the nature of the deformations and tensile strength has been performed. The nature of the deformations obtained during the tests has shown that the samples destruction occurs in the base material, i. e. in the wood. These conclusions have been made by reason of the nature of the resulting damage – there are wood fibres on the adhesive interlayer (Figure 9,10). This mode of failure is indicative of the admissible operation of the glue joint in the case of using steel wire rope in the solid wood.

Figure 9. The mode of failure of the sample with steel ribbed bar

Figure 10. The mode of failure of the sample with galvanized steel wire rope.

In a point of fact, if we analyze the tensile force at which the sample has been destroyed, we can conclude that the glued in the wood steel wire rope has exhibited a 19.26% higher strength performance that is indicative of the reasonability of the further research aimed at the investigation of the curvilinear form of the steel wire rope reinforcement of wood (table 1).

| The name of the reinforcing material | The average value of the tensile strength of the sample strength limit (on the basis of 3 samples in the series of tests) | Relative change of strength indicators,% |
|--------------------------------------|-------------------------------------------------------------------------------------------------|-----------------------------------------|
| Galvanized steel wire rope d = 10 mm | 22.730 kN                                                                                      | 119.26 %                                |
| Steel reinforcement A 300 d = 10 mm  | 19.058 kN                                                                                      | 100 %                                   |
4. Conclusions
The conducted tests allow for the conclusion of the possibility of using steel wire rope reinforcement in wooden floor beams and floorings. The experiment has shown that the lateral deformation of the steel wire rope by the action of the tensile stresses does not lead to the failure of the adhesive interlayer. Moreover, the relatively high linear elongation during the deformation and the fiberlike structure of the steel wire rope has led to the improvement of the adhesive properties of the contact surface which leads to more uniform deformations along the entire length of the gluing in groove, due to which a large solid wood surface is activated. In the author's opinion this is exactly the reason of 20% gain in strength.

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