RIGIDNESS OF COMBINED REINFORCED GLUED WOOD BEAMS

[a]SVYATOSLAV S. GOMON, [b]MYKOLA POLISHCHUK, [c]SVIATOSLAV HOMON, [d]PETRO GOMON, [e]OLEG VERESHKO, [f]YULIIA MELNYK, [g]INNA BOYARSKA

[a-d]National University of Water and Environmental Engineering, 11, Soborna Str., 33000, Rivne, Ukraine
[e-g]Lutsk National Technical University, 75, Lvivska Str., 43018, Lutsk, Ukraine
email: [a]slavagomon@ukr.net, [b]m.v.polishchuk@nuwm.edu.ua, [c]homonsviatoslav@ukr.net, [d]p.s.homon@nuwm.edu.ua, [e]olegboremel@gmail.com, [f]melnykjulka@gmail.com, [g]boiarska_inna@ukr.net

Abstract: The operation of glued wood beams with combined reinforcement is investigated. The beam's construction provides for the reinforcement of the compressed zone with steel rod reinforcement and the stretched zone with external tape reinforcement made of high-strength composite materials. Thus, due to the reinforcement, an attempt was made to increase the reinforced wooden elements' stiffness and load-bearing capacity on the transverse bend. Based on experimental research, the graphs of deflections showing the rigidity change between not reinforced and reinforced samples are constructed. The data on the bearing capacity of the tested samples are given.

Keywords: Composite reinforcement, Glued wood, Load-bearing capacity, Rigidity, Steel reinforcement.

1 Introduction

Due to its strength, beauty, ease of processing, and installation, wood has long been in demand as an essential building material. The use of glued wood in the construction, which is made by joining individual boards, pressed in layers under pressure, minimizes the impact of natural defects and shortcomings, such as knots, stratification, rot, etc.

Wood has sufficient tensile and compressive strength, even compared to the strength of conventional concrete. However, high strength is usually accompanied by low rigidity, so the design is usually controlled by the limitations of the deflections of structures [7, 8, 13]. Increasing the stiffness without increasing the height of wooden elements saves a lot of space, prevents folds in the compressed zone [1, 11, 12], and saves material. It is the reinforcement of the glued wood beam that contributes to this. The introduction of a more rigid material (steel reinforcement) in the compressed cross-sectional area affects the increase in the beams' overall stiffness, which in turn leads to a decrease in deflections.

Reinforcement of glued wooden beams using steel reinforcement is better known and researched [2, 11, 19, 21]. The most effective is considered to be double reinforcement, in which the reinforcement is located in the compressed and stretched areas of the beams.

Over the last few decades, there has been significant progress in using composite materials in construction. Due to its high strength, high corrosion resistance, lightweight, composite reinforcement easily competes, and in some cases, has advantages over traditional steel reinforcement. It is delivered in rods, rods, cables, tapes, and a cloth. Composite reinforcement is intended for use mainly in concrete structures, significantly when they are reinforced, but also provides for the use of wooden and metal structures.

In many foreign countries, composite materials for the reinforcement of wooden elements are not new. In Ukraine, we are just beginning to more thoroughly study the joint work of such materials with wooden structures, and we already have some experience in this direction [4, 6, 9, 10, 14, 20].

A more known is a glued wooden beam containing steel rod reinforcement in the grooves of the compressed and stretched zone [16].

This paper proposes a variant of reinforcement that does not require the installation of reinforcement inside the stretched zone and thus does not weaken the most loaded stretched wood fibers due to the cutting of the boards in order to arrange the grooves. Instead, a high-strength composite carbon fiber tape is glued outside the stretched beam zone, thus giving the structure additional strength and the steel reinforcement of the compressed zone - additional rigidity [9, 10, 14].

1.1 The Purpose and Objectives of the Study

Our goal was to investigate the operation of glued wood beams, which were reinforced with different types of reinforcement in compressed and stretched areas, and to compare the change in stiffness with non-reinforced samples.

To achieve this goal, tasks were set, which included the manufacture of glued wood beams (non-reinforced, with compressed zone reinforcement and combined reinforcement), experimental research, data processing, and conclusions on changes in the stiffness of the test specimens when working on transverse bending.

2 Materials and Methods

Several series of glued beams were made for testing (Table 1). All of them were 3000 mm long and 100 x 150 mm in cross-sectional dimensions.

Table 1: Volume of samples for experimental research

Series number	Marking	Reinforcement	Number of samples
I	GB-A	unreinforced	1
	GB-B	unreinforced	1
II	GRB-12A	2Ø12 A500C + Sika Carbo DurS-512	1
	GRB-12B	2Ø12 A500C + Sika Carbo DurS-512 + Sika Wrap-230 C	1
III	GRB-16A	2Ø16 A500C + Sika Carbo DurS-512	1
	GRB-16B	2Ø16 A500C + Sika Carbo DurS-512 + Sika Wrap-230 C	1
IV	GRB-12C	2Ø12 A500C	1

The first series of GB glued beams consisted of two beams (GB-A and GB-B), tested with a single short-term load to determine the deflections and compare them with the corresponding reinforced beams.

The beams of the second series GRB (GRB and GRB-12B) were reinforced in the compressed area with steel reinforcement in the form of two rods with a diameter of 12 mm class A500C and composite tape Sika Carbo Dur S-512, glued on the outside of the stretched area. The second series's two beams differed in that the composite tape in the GRB-12B sample was also anchored to prevent its premature separation. Sika Wrap-230 C carbon fiber fabric was used for anchoring, glued around the beam's perimeter in the supporting sections of the beam.

Reinforced beams of the third series GRB-16A and GRB-16B, were made similarly to the second series, with the only difference that in the compressed zone, steel armature with a diameter of 16 mm was used.

Another wooden beam of the fourth series GRB-12C was also tested, which contained steel reinforcement in the form of two rods of class A500C with a diameter of 12 mm only in the compressed zone.

Manufacturing and testing of all samples were carried out in the Department of Industrial, Civil Engineering, and Civil Engineering NUVGP Rivne laboratory. Beams are made of pine boards 25 mm thick. Each non-reinforced beam was formed and glued simultaneously, while reinforced beams were made in several stages.

First, the steel reinforcement was glued into the pre-made grooves of the penultimate board of the upper compressed zone with epoxy glue. Next, on a special stand under pressure, a package of boards was glued using resorcinol glue. After the glue has completely hardened, the composite tape reinforcement was glued with Sika Dur-30 glue specially designed for it from the outside of the future stretched zone of the beam.

Sika Carbo Dur S-512 composite tape 1.2 mm thick and 50 mm wide is supplied. However, due to its high strength, it was decided to divide it in half along its entire length, thus obtaining a width of 25 mm.

After gluing the tape for its anchoring, Sika Wrap-230C was additionally glued in two beams GRB-12B and GRB-16B, using the corresponding Sika Dur-330 glue. Since it is forbidden to bend the canvas at an acute angle, chamfers with a radius of at least 20 mm were made in its gluing places, in the corners of the beams. The scheme of reinforcement of beams by steel and composite reinforcement is shown in Figure 1.

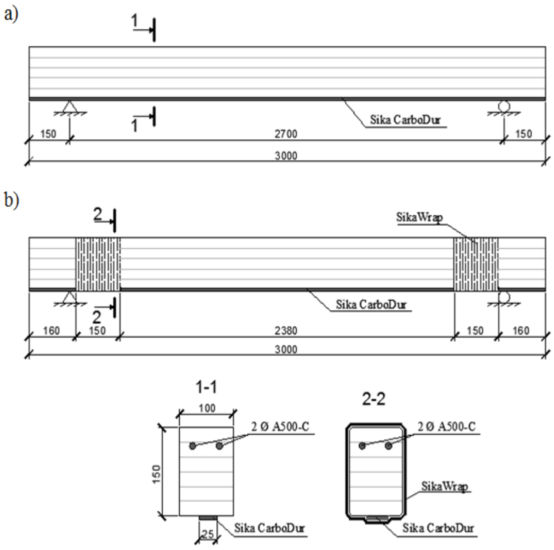

Figure 1 – Scheme of reinforcement of beams from glued wood with steel and composite reinforcement: a) without additional anchoring of composite tape; b) with additional anchoring of the tape

Beams prepared for testing were mounted on hinged and fixed supports. The load was applied to the samples using a hydraulic jack, and its level was monitored using a ring dynamometer. The force from the jack in the form of two concentrated forces was transmitted to the structure through a metal traverse in thirds of the span. According to the requirements, the test was performed with a single load in stages of 5-10% of the expected destructive load [3, 5, 17]. At each stage, the shutter speed was 5-7 minutes, during which samples were taken from all devices placed on the test beam.

Metal and wooden pads were installed on the supports at the load transfer points from the beam to the beam and at the beam support points, which reduced the concentration of local stresses and prevented the wood from crumpling across the fibers.

When testing the experimental beams for transverse bending and placement of measuring instruments, the scheme of installation is shown in Figure 2.

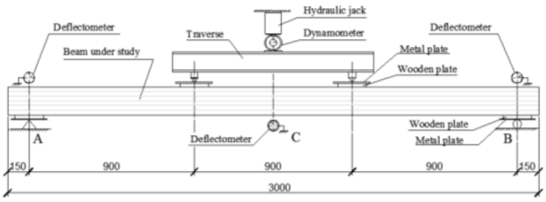

Figure 2 – The scheme of the experimental installation when testing beams from glued wood

6-PAO prognometers were used to determine the deflections of the beams. They were installed in the middle of the span and above the supports to determine the supports' beam's subsidence. When more than 80% of the expected destructive load was reached, the instruments were removed to prevent damage in the possible destruction of the test specimens. The general view of the beam under load is shown in Figure 3.

Figure 3 – General view of the reinforced beam under load

3 Results and Discussion

Based on experimental studies, graphs of maximum deflections of beams in the middle of the span depending on the bending moment were constructed. The value of deflections at the appropriate degree of the load was determined by the formula (1)

$$w = w_C - (w_A + w_B)/2 \quad (1)$$

where w_A – subsidence of the beam on the support A, mm; w_B – subsidence of the beam on the support B, mm; w_C – deflection in the middle of the span, mm.

The maximum allowable deflection is 1/150×*l* according to [20], where *l* is the span of the beam. For our samples, the maximum deflection will be:

$$w_{fin} = l/150 = 2700/150 = 18 \text{ мм} \quad (2)$$

The graph of deflections under the short-term loading of the tested beams is shown in Figure 4.

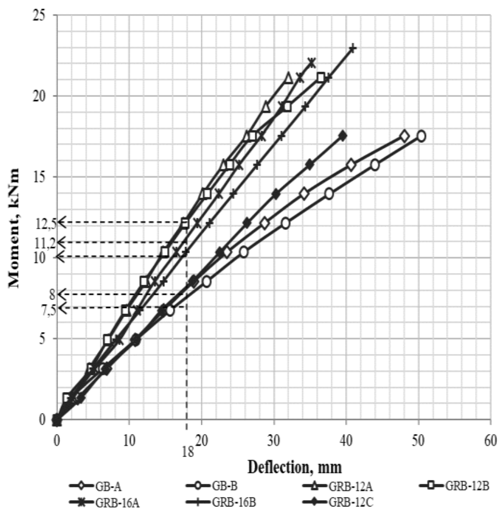

Figure 4 – Graph of deflections of the studied beams

The graph shows that the maximum deflection of 18 mm for non-reinforced beams and GRB-12C beams with reinforcement only in the compressed zone was achieved at lower loads, in particular, for the GB-B sample at 7.5 kNm, for GB-A and GRB-12C at 8 kNm. Simultaneously, the second series samples with steel reinforcement with a diameter of 12 mm in the compressed zone and composite tape in the stretched zone showed the most significant rigidity. The maximum deflection for both GRB-12A and GRB-12B beams was achieved at 12.5 kNm. Regarding the beams of the third series with reinforcement with a diameter of 16 mm in the compressed zone, they reached the deflection limit value at slightly lower values of bending moment than the samples of the second series GRB-12A and GRB-12B at 10.4 kNm. However, despite this, the load-bearing capacity of the beams of the third series was the largest. The values of the destructive loads of all tested samples are given in Table 2.

Table 2: Destructive loads of the studied beams of glued wood:

Series	I		II		III		IV
Sample name	GB-A	GB-B	GRB-12A	GRB-12B	GRB-16A	GRB-16B	GRB-12C
Destructive moment, M, kNm	23,85	22,05	26,55	31,05	32,85	33,75	22,95

Further reduction of deflection limits at higher bending moment values can be achieved by applying a prestress of Sika Carbo DurS-512 carbon tape in the glued beam's stretched area [15], which causes the initial bending of the element before the process.

4 Conclusion

As a result of the conducted research, the data on the change of rigidity of beams from glued wood due to the combined reinforcement were received. The deflections of non-reinforced and reinforced beams are compared with steel rod reinforcement glued to the compressed zone's grooves and composite carbon fiber tape glued to the outside of the stretched zone. It was found that the stiffness changes with increasing diameter of steel reinforcement in the compressed zone and in the sample containing reinforcement only in this zone. It was found that the reinforcement of only the compressed zone of the beams does not significantly affect the increase in stiffness because the maximum deflection was achieved at the same load values as for non-reinforced samples of glued wood. At the same time, the reinforcement of the compressed and stretched zone gives noticeable results. Therefore, for samples GRB-16A, GRB-16B with a reinforcement diameter of 16 mm in the compressed zone, the deflection's value was achieved at a load, on average, 39% greater than for non-reinforced beams. However, it should be noted that the total bearing capacity of these samples was the largest. Samples with 12 mm reinforcement in the compressed zone showed the greatest rigidity. For them, the maximum deflection was achieved under load, which is 61% more than the average value for non-reinforced samples. The obtained results allow us to state that the proposed reinforcement significantly increases the stiffness and load-bearing capacity of glued beams.

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