Stress-strain condition of reinforced timber structures with artificially created weakenings

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Abstract. About 20% of the world's timber grows in Russia, but the huge forest-raw material potential is used inefficiently. The forest industry is modestly represented and the Russian economy brings minimal income. In recent decades, more serious requirements have been placed on building structures, but the quality of lumber has been steadily declining throughout the world. The modern woodworking industry improves the quality of lumber by removing unacceptable wood defects, followed by end gluing of boards to a “mustache” or “toothed joint”. Of all types of joints of wooden elements, the notched adhesive or “toothed joint” provides the best use of their bearing capacity, since it causes less weakening of the cross-section of the elements, which is characteristic of other methods of joining (nailing, bolting, etc.). But along with this, the results of numerous tests showed that in conditions of mass production, the main place of destruction is the “toothed joint” or gear joints (about 50%) in the layers of the structures of the stretched zone. The presence in the most stressed layers of the stretched zone of the bent glued elements of the gear joints leads, as a rule, to the destruction of the elements precisely because of these weaknesses. As a result, there is a need for a more detailed and in-depth study of the effect of artificially created weakenings on the work of wooden structures. One of the methods for improving the performance of structures made of low-grade wood is their reinforcement. The purpose of the research is to determine the degree of influence of some artificially created types of attenuation on the stress-strain state of reinforced wooden beams. The main research methods: mathematical calculations, computer modeling in the PC "COSMOS / M", experiment. The experimental design technique is given [27]. The results are presented in the form of graphs and tables. The main conclusions made after the work: deformability in reinforced beams is 15-20% lower than in unreinforced ones; the destruction of reinforced beams with a weakened cross section occurs without a sharp collapse, due to the supporting effect of the reinforcement in the stretched zone and the reliable connection of the reinforcement with the wood, which provides an adhesive joint up to the destruction of the wood. The safety factor of reinforced wooden structures varies from 3.00 to 5.00.

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1 Introduction

Wood is a natural building material, characterized by its environmental friendliness, renewability and widespread, because the forest area is about 1/3 of the surface of the earth. But at the same time, the use of wood is limited due to its low resistance to fire, decay, anisotropy, the presence of natural defects, etc. [8]. In addition, the limited use of wood in construction is associated with ever-decreasing volumes of whole industrial timber. The way out of this situation is the use of glued wood: the glued bag is much less susceptible to fire and biodeterioration, it is known that of all types of joints of wooden elements, the adhesive joint provides the best use of their bearing capacity, since it does not cause weakening of the cross-section of the elements characteristic of other connection methods (nailing, bolting, etc.). However, wood defects have a great influence on the gluing process, the quality of the adhesive joint and the structure as a whole. Numerous studies of glued structures have very clearly shown that when testing structures for bending, the main cause of destruction is wood defects. To improve the quality and strength properties of wood, splicing along the length with the cutting of unacceptable defects is used. The most common connection method is a gear spike. At Russian enterprises, gear joints are used, with various parameters on which not only the strength of adhesive joints, but also the productivity of the equipment depends [6]. GOST 19414 - 90 regulates the parameters of the most acceptable compounds. But with the in-line production of glued structures at the enterprise, the strength of the layers that determine the structure of the adhesive element is markedly reduced. The destruction of the beams occurs along the lower stretched layer, which is natural, because the gear connection occupies the entire cross-sectional area of the element. It has been established that the nature of fracture during the long and short-term action of the load is the same: fracture begins with the formation of cracks that occur in the wood at one of the weakening angles in the tenon dull area [3]. However, in practice, it is almost impossible to reduce blunting to a minimum due to a sharp decrease in the wear resistance of the cutting tool. In real building structures, adhesive joints are in a difficult stress state. The uneven distribution of stresses over the area of the adhesive joint depends on the stiffness of the materials being joined, the elastic-plastic properties of the adhesive, the thickness of the adhesive layer and the elements to be joined, and many other factors, all this must be taken into account to avoid manufacturing defects.

To reduce the influence of wood defects of natural origin, as well as artificially created (gear joints), steel reinforcement was used on the strength and bearing capacity of structures. Reinforcement makes it possible to reduce the cross-sectional height of wooden elements by 25 - 30%, reduce wood consumption by 30 - 40%, reduce installation weight by 15 - 25%, cost by 12 - 18%, and also makes it possible to use 3 types of wood, due to perception reinforcement of a significant part of the load [16]. Moreover, over time, the value of the share of perceived load in the reinforcement from the current bending moment only increases [29].

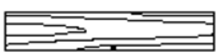
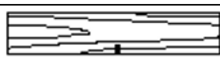
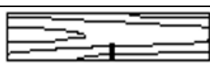
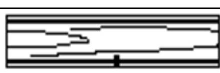
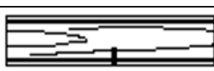
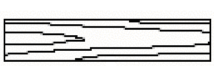
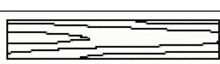
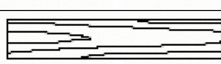
2 Materials and methods

Technical and economic considerations given in [19] show that when conducting experimental studies it is advisable to perform on models of reinforced beams designed according to the principle of complete geometric similarity. At the same time, the materials of models and real structures should be assumed the same, which makes it possible to obtain similarities in stiffness in self-similar wooden reinforced beams, and the adopted type of simulation makes it possible to preserve the physical phenomena that occur in full-scale structures during loading in the model.

The experiment included studies of the work of beams with artificially created attenuation. the beam B-0 was also taken as a basis, having dimensions: span l = 1.8 m, section height h = 125 mm, which is h / l = 1 / 14.4, section width b = 30 mm, the ratio of the strain gauge base to the height of the model, in this case, is 0.16.

Technological weaknesses in the structures were modeled as artificially created weaknesses - cuts located in the middle of the span, in the stretched zone, over the entire width of the beam section. This attenuation of the cross-section of the beams models the possible attenuation of the cross-sections when applying glued wood to the notched joint. Weakening height: 1.0 cm, 2.0 cm, 3.0 cm when comparing wood of the 3rd grade with wood of the 1st and 2nd grade, equal to 0.09 h, 0.19 h, 0.32 h, where h is the section height beams [16], attenuation width 2 mm. Beams were both reinforced and unreinforced. The beams were reinforced with rods of class AIII (A400) [7] with a diameter of 8 mm, which is μ = 0.027 in two other series of beams. Reinforcement was carried out with reinforcing rods of class AIII (A400) [7], which were glued into grooves of a rectangular cross section using an epoxy-sand compound [7, 8].

Table 1. Marking and parameters of wooden beams with a span of 1.8 m.

Series	**Attenuation pattern**	**Geom. characteristics**			**Attenuation** $\frac{Fw}{F}$ **/%**	**reinforcing rods class A - III ∅/μ. mm/%**	E_w**. MPa**
		L. mm	h×b. mm	h_w xb mm^2			
B 1-1		1800	125x30	115x30	0.92/8	0	10730
B 2-2		1800	125x30	103x30	0.84/16	0	10620
B 3-3		1800	125x30	95x30	0.75/25	0	9475
B- 1		1800	125x30	115x30	0.92/8	2∅8/2.8	9310
B - 2		1800	125x30	103x30	0.84/16	2∅8/3.0	10150
B - 3		1800	125x30	95x30	0.77/23	2∅8/3.1	10390
control beams							
B 1-1*		1800	125x30	115x30	0.92/8	0	11020
B2-2*		1800	123x30	103x30	0.84/16	0	10810
B 3-3*		1800	125x30	95x30	0.76/24	0	9226

According to [10], the work of the beams was studied in two stages: At the first stage, the stress-strain state of reinforced and unreinforced beams with artificially created attenuation was studied, the nature of failure was determined depending on the design parameters and the nature of the attenuation in the wooden beams.

At the second stage, the integral modulus of elasticity of the beam without reinforcement was determined, which, unlike the calculated modulus of elasticity, takes into account the heterogeneity of wood, defects, at this stage, the beam blanks were selected for similar indicators.

The load was applied in the third span; such a decision was made in order to get a clean bend.

Experimental studies of structures with a span of 1.80 m were carried out on a test bench (Fig. 1, 2). The distribution beam provided the correct load sharing in half and its transfer to the test structure. The stability of the beams from the plane was provided by vertical struts attached to the reactive beam.

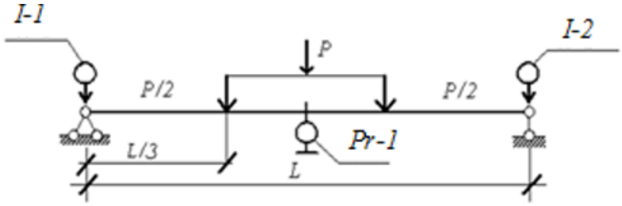


Fig. 1. The arrangement of devices. Pr-1 deflection meter of the PAO-6 brand, I-1, I-2 - indicators of the sentry type.

Fig. 2. Test rig with reinforced wooden beam B-2.

3 Results

As can be seen from table 2, the effect of attenuation is reduced in the reinforced beams - the value of the breaking load increases from 1.8 to 4 times, and the value of the calculated load from 40% to 68%. The deformability of reinforced beams is lower by 20-55%, this is due to the supporting effect of reinforcement in the stretched zone.

When comparing the methods for studying beams (Table 3 and Table 4), it turned out that the convergence of the results is 5-10%. Based on this, we can conclude that all three methods are sufficiently accurate.

It should be noted that in the zone of attenuation (sawing) of the beams, stress concentration was noted, the stress concentration coefficient is 1.1-1.3, since the fibers along with the attenuation perceive the load of the cut fibers.

Table 2. The main results of experimental and theoretical research of beams.

№	Series of beams	Cross-section		Reduced section		Load P. kN	Strain ε×10⁻⁴				Deflections. mm	Breaking load. kN
							wood		reinforcing rods			
		h. mm	b. mm	h_w. mm	b_w. mm		compression	tensile	compression	tensile		
non-reinforced beams												
1	B 1-1	125.0	30.0	115.0	30.0	3.17	-	-	-	-	4.3	10.0
2	B 2-2	125.0		103.0		2.94	-	-	-	-	5.66	9.0
3	B 3-3	125.0		95.0		1.89	-	-	-	-	4.75	6.2
control beams												
4	B 1-1*	125.0	30.0	115.0	30.0	3.5	-	-	-	-	5.21	12.0
5	B 2-2*	123.0		103.0		2.78	-	-	-	-	5.22	11.4
6	B 3-3*	125.0		95.0		1.49	-	-	-	-	4.64	8.6
reinforced beams												
7	B-1	125.0	30.0	115.0	30.0	5.865	4.76	3.00	5.82	5.95	3.37	27.0
8	B-2	125.0		103.0		5.355	5.21	3.24	6.67	6.18	4.13	21.0
9	B-3	125.0		95.0		4.675	5.82	3.53	7.19	6.27	3.87	25.0

Table 3. Non-reinforced beams research results.

Series of beams	Factors	Deflections. mm	Modulus of elasticity $Ex10^5$. Pa
non-reinforced. naturally weakened	Theory	5.11	1.0
	"Cosmos/M"	5.08	1.0
	Experiment	5.02	1.035
non-reinforced. with artificial weakening	Theory	5.29	1.0
	"Cosmos/M"	5.16	1.0
	Experiment	4.9	1.028

Table 4. The main results of studies of reinforced beams.

Series of beams	Factors	Normal stress. MPa				Relative strain. εx10⁻⁴				Deflections. mm	Modulus of elasticity. $Ex10^5$. MPa
		wood		reinforcing rods		wood		reinforcing rods			
		compression	tensile	compression	tensile	compression	tensile	compression	tensile		
reinforced. d_a = 8mm	Theory	7.08	7.08	135.56	135.56	7.08	7.08	6.79	6.79	4.007	1.0
	"Cos-mos/M"	6.28	9.0	119.83	125.00	5.43	3.78	6.61	6.47	4.063	1.0

	Experiment	5.41	8.18	113.66	121.35	4.93	3.26	6.56	6.14	3.791	0.995

4 Discussions

It has been experimentally confirmed that the influence of technological (toothed spikes) weakenings when applying reinforcement in load-bearing and enclosing structures is noticeably reduced, wood consumption is reduced by reducing the cross section, and without reducing the design load of the structures. Reinforcement allows you to compensate for the effect of attenuation of the cross section of structures on its strength and deformability. This fact makes it possible to efficiently use reinforced solid wood structures of 3-grade wood (girders and edges of slabs of coatings) in construction to replace existing structures of lumber of 2 grades and makes it possible not only to reduce the consumption of wood, but also to reduce the cost of the structures themselves.

Reinforcing reinforcement is one of the cheapest means of increasing the strength and deformability of wooden structures; in recent years, special attention has been paid to improving the indicated characteristics of wood with carbon fiber materials. In the works of a number of scientists [1, 9, 21, 26, 31, 32, 34-37] it is noted that these types of amplification lead to a decrease in stress concentration and increase the strength characteristics of reinforced structures.

5 Conclusion

The results of experimental and theoretical studies of the operation of reinforced wooden beams, with technological weakening of the cross section, allowed us to draw the following conclusions:

Weakening of the cross section significantly reduces the strength and deformability of wooden structures. Reinforcement compensates for the effect of attenuation, while the structures increase strength and reliability against collapse compared to unreinforced.

The equal strength of reinforced structures with weakened sections is achieved by increasing the coefficient of reinforcement by 10 - 30% compared with reinforced structures without weakening.

In reinforced wooden beams with weakening in the stretched zone (at the place of weakening), a significant concentration of stresses is observed. The stress concentration coefficient is 1.1 - 1.3, which must be taken into account when designing.

The deformability in reinforced beams is 15 - 20% lower than in unreinforced beams. When the reinforced beams with a weakened cross-section are destroyed, the collapse does not occur due to the supporting effect of the reinforcement in the stretched zone and the reliable connection of the reinforcement with the wood, which provides an adhesive joint up to the destruction of the wood.

When using 3 grades of wood and increasing the reinforcement coefficient by 10-30%, the effect of attenuation is compensated: in the reinforced beams, the values of deflection are much lower than in unreinforced beams and this difference averages about 30%. the design load in the reinforced beams increases, on average, by 50% compared with unreinforced.

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