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# Ecological Peculiarities and Problems of Glued Timber Structures Reinforcement

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## 1. Introduction

The environmental benefits of timber, as a structural material, are undeniable (Pavlenko & Shkarovskiy 2018). Glued timber structures (GTSs) are superior to products from lumber in some strength and stiffness characteristics, but they also have a number of disadvantages. Therefore, the correct calculation of the elements of building structures from GTSs is so important.

A lot of works are devoted to the problems of wooden structures reinforcement. In most cases, they give recommendations for extending the service life of traditional solid wood, modern GTSs only begin. This is due to many reasons: tested with practice (Kiryutina 2016). The problems of localization of defects of modern:

- the brevity of their "biography",
- insufficiency of studying the stress-strain state (SSS), not only the nodes of conjugation of elements, but also the elements themselves,
- the lack of generally accepted approaches to assessing their strength, and the most important is the presence of different opinions on the parameters of structures made of materials with an increased degree of anisotropy in comparison with solid timber (Serov 2015, Glukhikh & Chernykh 2013).

## 2. Analysis of the existing situation

A thorough study of the nature of the occurrence of defects and signs of timber destruction in modern GTSs (Serov & Mironova 2013) makes it possible to more accurately assess the causes of their limit state. As a result of such studies, it was found that there exists such a geometrical location of inclined areas in which the ratio of the normal stresses to the strength characteristics of the material is greatest (Serov 2000, Serov et al. 1999). Therefore, the concept of homogeneity of SSS as applied to glued wood can be interpreted more widely than generally accepted. When assessing the strength of the GTSs, considering them along the cross sections is not enough. Should be taken into account the gradient of stresses along inclined areas located not in one cross section, but in their totality (1):

$$\omega_1 = \omega_{max} = \frac{\sigma_1}{R_\alpha} \quad (1)$$

where:
$\omega_1$ – relative value of the stresses of the corresponding area,
$\sigma_1$ – limit strength of wood in the direction of the main stresses,
$R_\alpha$ – calculated resistance of timber at an angle α to the timber fibers.

In the transition from one elementary stress area to another, a gradient of the orientation angle also arises in the dangerous region. The presence of such an area, the size of which is comparable with the cross sections of the GTSs elements, leads to the achievement of the ultimate limite state of the structure, despite the small value of stresses arising in the directions of the axes of symmetry of the material. The destruction in glued timber in this case occurs at areas of minimum relative strength. An example is the nature of the fracture of specimens subjected to uniaxial tension, i.e. the absence of a gap perpendicular to maximum stresses (Serov 2015).

The assertion that all defects of solid timber structures are eliminated in the GTSs is incorrect. On the contrary, new specific “paradoxes” and problems arose. Even in the bent glued frames of Getzer’s company splintering cracks and breaks appeared on beveled edges. Studies have shown that even with a smooth cutting of the glued blocks to form the tapering of GTS elements, additional tangential and normal stresses could arise in them stretching the timber across the fibers. Cracks also appeared in bent-glued beams, the occurrence of which can be explained by calculations according to the formulas of “bent beam” (Serov et al. 1999). Stresses stretching the timber across the fibers are small in the absolute value, but they are large in comparison with the corresponding resistance of glued wood, the degree of anisotropy of which is much higher than that of the solid one.

The resistance increased along the fibers due to the removal of large defects and gluing of the boards along the length of the toothed spike, dispersing the remaining small knots in the glued bag, increasing the homogeneity of the material, and so on. Across the fibers, on the contrary, the characteristics decreased as a consequence of gluing layers with unavoidable cut fibers through the plastic. This happens when sawing always saves logs, cutting a thin layer, as well as knots, which are then glued to adjacent layers almost across the fibers (Byzov & Melekhov 2016).

## 3. Defects in the GTSs caused by design errors

In modern GTSs with undercutting and benches already at the design stage there is the inevitability of cleavage cracks, i.e. in fact, strengthening of such structures is required even before external loads are applied. A vivid example is a bent glued frame with a ledge in the crossbar. Cracks arising in the places of such ledges can reach the support node in the column (Fig. 1). In other words, an attempt to improve these designs from a technological point of view transferred these glued laminated bent frames (GLBFs) from some of the most reliable and long-span frames to unreliable ones.

In addition to such frames, in structures of powerful glutinous blocks, sometimes knots are laid which were designed more than half a century ago for TSs, but which did not receive application, and are also not suitable for GTSs.

In some GTSs developed in the last decade and approved as model ones, the inevitability of the occurrence of cracks was a priori laid. References in publications on the poor quality of adhesives, on technological flaws did not reveal the essence of misses. Examples include MDA-type arches, glued frames of the GLBF type (Fig. 3).

In the squeezed-bending elements of TSs with small spans, the transmission of longitudinal forces (N) with the eccentricity (e) at the nodes was justified, since the support SSS did not go to the beyond. With the increase in spans and cross sections of GTS elements, similar methods of reducing bending moments in the middle of their length proved to be irrational. For example, in the MD with a span of more than 12 m cracks have already appeared from normal working loads. The pre-node sections of the glued blocks represented samples for gluing of enormous dimensions.

Analysis of the SSS even of standard samples leads to the conclusion that they had been cracked along main successively placed stretched areas in the form of shearing with cleavage. If we also take into account transverse forces in the MDA, from which normal stresses arise stretching the timber across the fibers (Serov 2015), then the appearance of cracks outside the stamp is inevitable (see Figure 4). Equally illiterate from the engineering point of view is the solution of the cornice unit in the glued timber frames (GTFs)). In 1970, the head of the German firm, Erwin Dimter, showed the Muscovites a colorful movie about the production of frames made from rectilinear elusive elements by gluing blocks onto a toothed spike, cut through the entire section of the diagonal direction. The simplest technology attracted not only officials, but also some specialists. First, the GTFs were used in experimental construction, and after 2 years they became standard. But the SSS of broken rods turned out to be prohibitive, especially in the stretched zone. Formally, the distributive α in the diagonal section of the broken rod can be represented in the form of a curved rod of GTS with a curvature radius tending to zero. Most often, such nodes are calculated according to the Henri Navier formula with the coefficients (Serov et al. 2011), which does not correspond to the actual SSS. And yet, despite the aspiration to zero α in the outgoing corner of the stretched edge of the diagonal section, the cracks originate in the stretched zone and sometimes reach the support (Fig. 5a and 5b).

**Fig. 1.** Fragments with cracks passing in the GLBF from the ledge in the crossbar to the support

**Fig. 2.** The nature of the defects of GLBFs with a ledge in the crossbar during operation

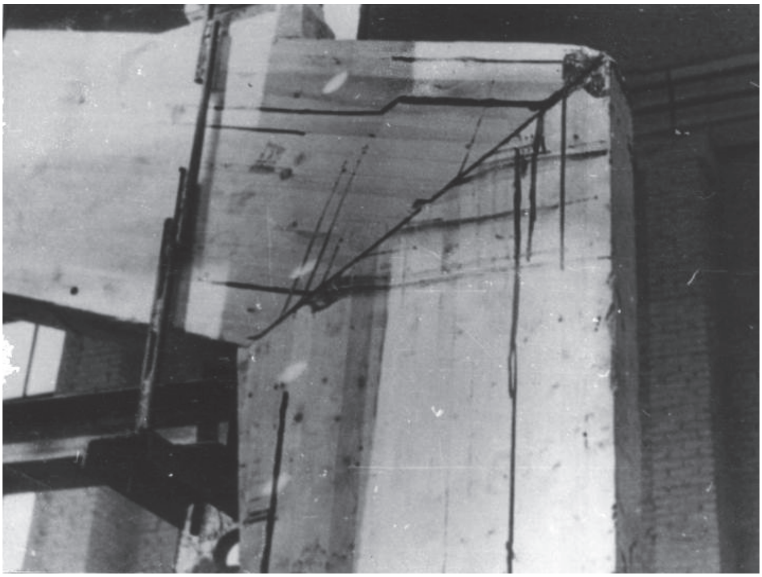

**Fig. 3.** The nature of glued timber frames destruction in the stretched zone of the cornice unit with short posts

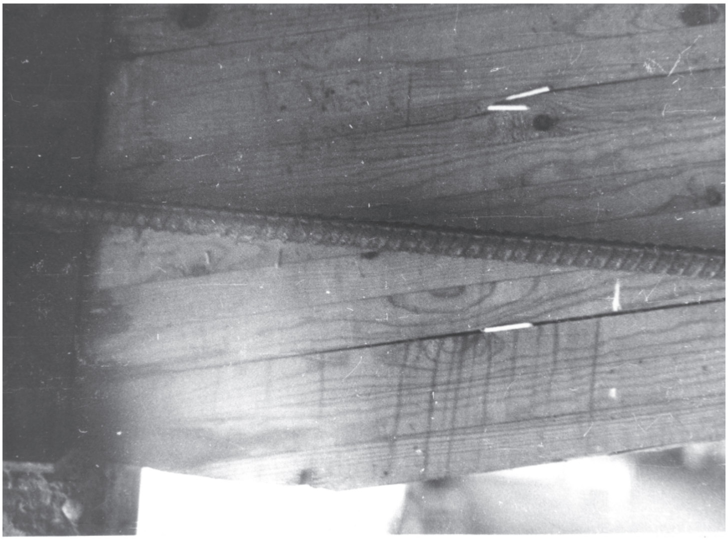

**Fig. 4.** Cracks in the pre-support zones of glued MDA blocks (marked with matches) when the sloping section leaves the support platform

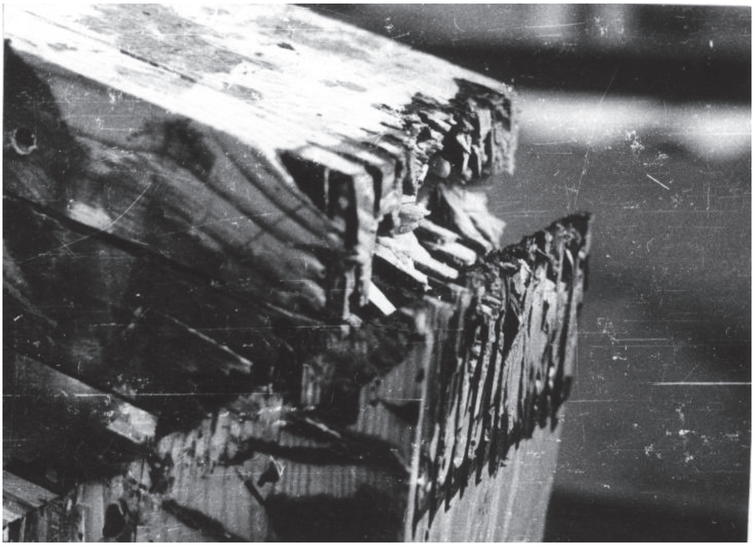

**Fig. 5a.** The nature of glued laminated timber frames or (GLTFs) destruction in the stretched zone of the cornice unit

**Fig. 5b.** The nature of glued laminated timber frames or (GLTFs) destruction in the stretched zone of the cornice unit

## 4. Features of reinforcing GTSs

The main feature of reinforcement of the large-span GTSs is their two-stage operation. First, it is necessary to "heal" the resulting cracks, and then eliminate the possibility of their formation in the above-mentioned hazardous areas during subsequent operation (Arkaev et al. 2012).

At the first stage, even an "increase" in crack opening is desirable. For this purpose a GTS is fully unloaded, up to the "exclusion" of support reactions and the SSS zone with a crack. After that – on the contrary, the beam is supported from below and reinforcement of the structure is done.

At full unloading the sloping holes are drilled in steps of 300 mm along the cracks, through which the glue is injected by injectors. To reduce glue losses, the cracks are glued from both sides with a transparent tape. The injection is carried out until the glue is squeezed out of the cracks. Only after that, the GTS is supported or pressed. Extract under stress is carried out prior to polymerization of the glue (up to collapsible strength). At the end of this exposure, the actual GTS reinforcement is performed either by glued or screwed rods in the direction of the trajectory of the principal tensile stresses (realization of the string principle).

We can use the beams of Grand Menshikov Palace in Oranienbaum, Solombala Factory and the Arch of Sports Palace in Arkhangelsk, as well as the arches of the Dobrynya Shopping Center in Petrozavodsk as examples of TS and

GTS reinforcement with the implementation of the string principle (Serov & Naychuk 2010).

In 1977, when analyzing the results of the semi-arch test for the future Sports Palace in Arkhangelsk for the Olympics-80, we found the root cause of the emergence of a main crack that spread from the end of the semi-arch at the mobile support at 13.6 m with a half-32.76 m. It turned out that under short-term control load the marginal normal stresses exceeded the calculated resistance by 2.25 times, the tangential stresses by 2.01 times, and the main tensile stresses in the support zone by approximately 3.5 times. To solve the problem, we proposed the reinforcement of the arched zones of arches in the direction of dangerous principal tensile stresses by gluing three steel bars of the periodic profile Ø = 20 mm into pre-drilled holes in the prong zones with a pitch of 500 mm. As a result, hardening of the arched zones of the arches in the manufacturing process, localization of local dangerous tearing stresses, approaching the curve of the strong resistance of glued wood to the tension at an angle to the fibers faster than others took place (Naychuk 2016). This eliminated the risk of cracks in the arches under working loads and impacts. The structures have been successfully used from 1980 to the present. When they were inspected in 1983 and 1988, only two arches revealed surface cracks in the area of installation of the air heaters.

In 1977 at the Department of the LISI House of Culture, we together with V.D. Popov tested two series of glued laminated beams with pre-support zone reinforcement in various ways and without (Popov & Serov 1978). In the foreign press, works about such kind of reinforcement appeared two or three years later (Serov 2015). It was considered that the most effective and technologically accessible method of plywood strips reinforcement on glue, however, a method for pasting rods into drilled holes. At the same time, the co-work of differently modular materials, which react to changes in the temperature and humidity of the medium in a different way, but with a rigid interface between them, casts doubt on the relation to this method of strengthening as commonly accepted.

From our point of view, there are two approaches for GTS reinforcement improvement:

1) its non-metallic manufacturing from timber or other materials close in properties to timber,
2) providing not rigid – adhesive interrelation of the reinforcement element with wood, but mechanical damping – "tracking", for the indicated deformations of the intensified zones of GTSs and kept long under operating temperature and humidity conditions.

Among the disadvantages of reinforcement by gluing the rods is also the requirement to perform it under factory conditions (the arches of the Sport Palace were reinforced directly at the factory – when gluing the semi-arches). With variable temperature and humidity conditions, it is more reliable to carry out the screwing of a new generation of screws rather than gluing.

## 5. Conclusions

Reinforcement of glued laminated beams and other structures with cracks is recommended not only in cases where it is necessary to increase the resistance of beams to the main tensile stresses in areas located in the bearing zones, but also at the points of inflection of the glued bent beams, where glue is usually "forced" to work for tension across the fibers (Figure 3).

Unfortunately, we have to state that so far, many specialists continue to consider the need for reinforcement in the presence of the GTS pre-support zones, the overstretching shear stresses and the danger of structural failure from shear.

Long research of our scientific school SPbGASU persuades us that this is only a "visual deception". Timber even in uniaxially loaded laboratory samples, and even more so in the GWSs, is destructed by normal stresses acting at an angle to the fibers.

Therefore, in each specific case, it is necessary to value the SSS taking into account all its components and the load-bearing capacity for a particular criterion of destruction (Serov 1999).

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## Abstract

Long evolution of solid timber structures has developed sufficiently reliable engineering solutions and methods of timber structures reinforcement. The experience of mass production and application of new glued timber structures has shown that the simple transfer of traditional methods of calculation and design to modern structures is not always correct. The design and reinforcement of modern are still being developed. Graphical representation of the fields of operating normal stresses and wood resistance fields show that even with simple uniaxial stretching along the fibers the limiting state initially arises not at the direction of the principal axes of symmetry but at an angle to the fibers. The current trends in management, diagnostics, design and reconstruction of buildings show that almost all problems of preserving wooden and other structures in ordinary reconstructed objects, as well as in architectural, historical and cultural monuments are based on the competence level of the personnel not only in the restoration industry, but in construction industry too.

**Keywords:**
bearing capacity of timber structures, glued timber structure reinforcement,
stress gradient, stress – strain state (SSS)

## Właściwości ekologiczne i problemy wzmocnienia konstrukcji z drewna klejonego

## Streszczenie

Długotrwała ewolucja konstrukcji z litego drewna rozwinęła znacząco niezawodne rozwiązania inżynieryjne i metody wzmacniania konstrukcji drewnianych. Doświadczenie w masowej produkcji i stosowania konstrukcji z drewna klejonego wykazało, że proste przeniesienie tradycyjnych metod obliczania i projektowania na nowoczesne konstrukcje nie zawsze jest poprawne. Projektowanie i wzmocnienie nowoczesnych konstrukcji są wciąż rozwijane. Graficzne przedstawienie obszarów występowania normalnych naprężeń i obszarów oporu drewna pokazuje, że nawet przy prostym jednoosiowym rozciągnięciu wzdłuż włókien stan graniczny pojawia się początkowo nie w kierunku głównych osi symetrii, ale pod kątem w stosunku do włókien. Obecne trendy w zarządzaniu, diagnostyce, projektowaniu i rekonstrukcji obiektów budowlanych pokazują, że prawie wszystkie problemy związane z konserwacją konstrukcji drewnianych i innych rekonstruowanych w zwykłych obiektach, a także w zabytkach architektonicznych, historycznych i kulturowych opierają się na poziomie kompetencji personelu nie tylko w branży restauratorskiej, ale także w budownictwie.

**Słowa kluczowe:**
wytrzymałość konstrukcji z drewna klejonego, wzmocnienie konstrukcji z drewna, gradient naprężeń, stan tensorowo-odkształceniowy