

# Features of preliminary stresses in wooden constructions

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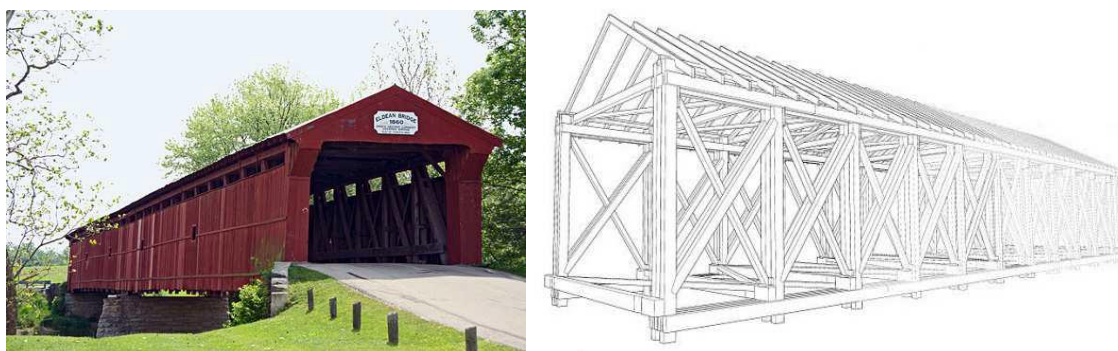
**Abstract.** Unlike reinforced concrete and metal, prestressing is used much less frequently in wood. Wood began to apply in 1860 and continued to be used in prestressed structures. But at the same time it faced some problems. To minimize the impact of these factors it is recommended to take the following measures: 1) To use special knots with the most increased contact surface for prevention of wood deformation in them. For such a node, the author of this article received a patent for a utility model; 2) carefully control the humidity and prevent it from changing during operation; 3) prestress is set with some margin due to the rheological properties of wood, or during operation to increase it

## 1. Introduction

The prestressing significantly increases the bearing capacity of construction. It is highly widespread in reinforced concrete structures due to the fact that it minimizes the creep of concrete. Nowadays most factory-produced reinforced concrete has a prestressing. Similarly, in metal structures, strut beams are very widely used.

## 2. Examples of prestressing in constructions

In 1860, a wooden bridge was built (Elden Bridge) using Long farms (Figure 1) [7]. In the Long's drawings, the structural elements and additional braces were installed in the farm and held by compressive forces. It was realized using wedges located at different points on the farm panels.



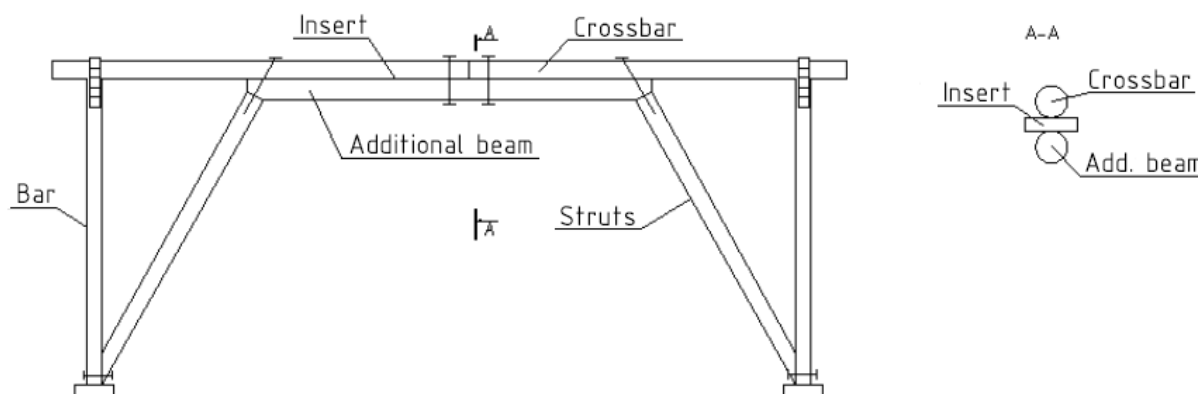
**Figure 1.** Elden Bridge built in 1860



Long described the wedges as  $\frac{3}{4}$  inches thick at the end,  $\frac{1}{4}$  inches thick at the back, and one foot in length. The preliminary compression of the braces caused the appearance of the corresponding states of prestressing in the uprights and belts. In 2002, this bridge was calculated with simulated prestressing from wedges, which revealed that prestressing allowed the redistribution of forces in the bridge structures to increase the reliability of the structure and reduced the deflection of the bridge by 81%.

Zhadanov V.I., Dmitriev P.A. and Tisevich E.V. developed [8] an improved glued wooden construction. Its advantage is that rods equal in length to the width of the pile are glued into the drilled holes of the pressed pile, taking into account its reduction due to pressure from the compression. Uniform prestressing along the entire length of the pile is ensured by the pitch of the rods from 300 to 500 mm.

A prestressed frame was developed (Figure 2) under the supervision of V. N. Golovach [9] (Belarusian Polytechnic Institute). This frame has the following design: an additional beam, supported by braces, is laid under the crossbar resting on the uprights.



**Figure 2.** Prestressed wooden frame

### 3. Factors in wooden constructions affecting prestressing

However, all the above examples of prestressing in wooden constructions encountered the following features of wood as a structural material:

- High anisotropy. The strength and deformability of wood along and across the fibers differ by a factor of 5-10 (according to [1]). In this regard, the strains along the fibers are significantly lower than the tensile strength; wood begins to undergo plastic deformations across the fibers. This phenomenon is known as “press down” of wood in knots;
- Deformation in knots. The flexibility of nodal joints under the action of deformations from compression-tension is characterized by the stiffness coefficient  $C$ , which is calculated using the following formula:

$$C = P / \delta \quad (1),$$

where  $P$  is the compression-tension force;  $\delta$  - linear deformation.

The calculation of the average bending stiffness coefficient  $C$  when the angle  $\alpha$  (the angle between the direction of the force and the axis of symmetry of the cross section) varies from 0 to 90; produced by the transition from linear to angular deformation:

$$C = M / \theta \quad (2)$$

where  $M$  is the bending moment;  $\theta$  is the angular deformation. In this case, the error caused by edge deformations is not taken into account due to the smallness of edge deformations compared with the deformations of bonds due to bending and crushing of wood.

$$\delta = \delta_{cr} + \delta_y \quad (3),$$

where  $\delta_{cr}$  – deformation caused by crackage in nodal connection;  $\delta_e$  – deformation of the elastic characteristics of the nodal element;

- The effect of wood humidity. The increase in humidity in wooden construction leads to a decrease in elastic characteristics (Young's modulus, shear modulus, etc.) in accordance with the following formula [2]:

$$E_{12} = \frac{E_W}{1 - a(W - 12)} \quad (4)$$

When humidity changes, the elastic modulus changes up to 2 or more times. Strength characteristics of wood depend on humidity accordance with the following formula:

$$B_{12} = B_W(1 + a(W - 12)) \quad (5),$$

where  $E_{12}$  – the elastic modulus at 12% humidity,  $E_W$  the elastic modulus at  $W$  humidity,  $B_{12}$  is the strength characteristic at 12% humidity,  $B_W$  is the strength characteristic at  $W$  humidity,  $a$  – the correction coefficient for various types of stress state,  $a = 0.05$  during compression,  $a = 0.04$  during bending and  $a = 0.03$  during chipping. This formula is valid in the range of sample humidity from 8% to 23%.

Thus, with the increase of humidity, the fluidity of wood and the loss of prestressing effect are also observed. The wood in constructions is dried to 12% humidity. Then, during operation, it is exposed to short-term (daily) and long-term (seasonal) changes in relative humidity. However, at the same time, short-term changes in humidity affect only the surface layers with a thickness of not more than 10 - 15 mm. In order to protect against long-term changes, it is recommended to cover wood with a protective layer of coatings, as well as to prevent significant long-term changes in humidity using ventilation and heating.

- Rheological properties of wood. Wood consists of components with different elastic properties, resulting in a redistribution of internal stresses between the constituent parts of material. As a result, the stress state and deformation of structural elements change over time.

Based on the regression analysis, it was established [63] that under constant loading, the deformation process obeys a single regularity:

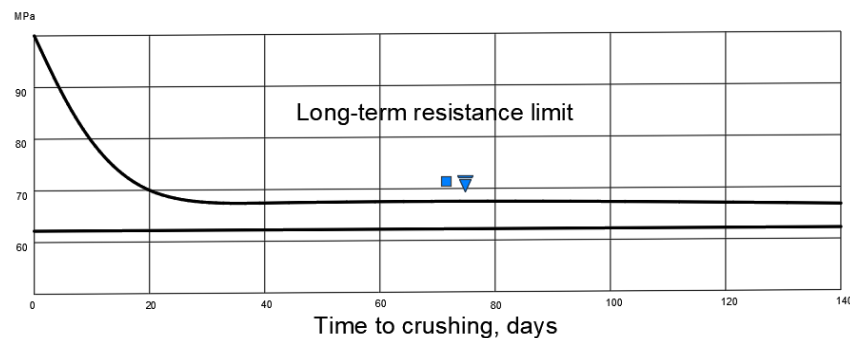
$$\delta(t) = \delta_1[1 + \varphi(t)] \quad (6)$$

where  $\delta_1$  – the deformation of a material at the initial moment of loading, determined experimentally and depending on the type and material, level of loading, temperature and humidity operating conditions and technological factors;  $\varphi(t)$  – the creep characteristic of a material, which is the ratio of creep to  $\delta_1$ .

The value of  $\varphi(t)$  is determined using the following equation:

$$\varphi(t) = \varphi_\infty(1 - e^{-\gamma t}) \quad (7)$$

where  $\varphi_\infty$  – ultimate creep characteristic of a material at the moment of its deformation stabilization,  $\gamma$  – coefficient characterizing the rate of development of creep strain in time ( $t$ , days). The strength of wood during long-term application of the load is reduced to 1.5 times in accordance with the following diagram (Figure 3).



**Figure 3.** Changes in the strength of wood over time

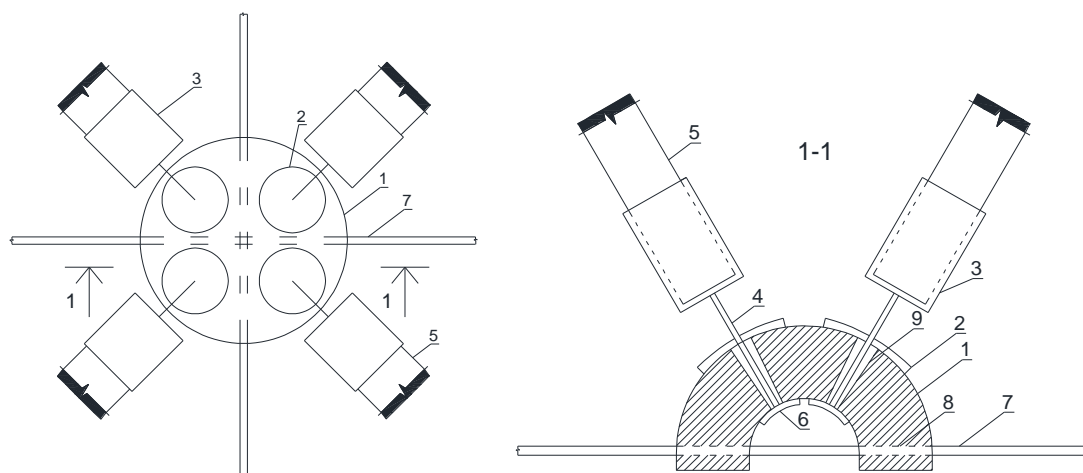
Wood deformations also increase over time. This affects the fact that the maximum value of prestressing must be assigned taking into account the maximum long-term deformations.

The above mentioned factors greatly complicate the task of prestressing wooden structures.

#### 4. The measures to reduce the impact of negative factors

In order to reduce the impact of these negative factors, it is necessary to:

1. To maximize the area of contact surfaces in the nodes in order to prevent "wear in" of wood. The example of such a node is shown in Figure 4 provided in the research work [3]. As it is proved by the experiments in the research work [3], with this nodal design the effect of node compliance and wood anisotropy did not exceed 5%.
2. To keep firm humidity control; to prevent humidity changes during the operation of the structure, or to adjust prestressing taking into account humidity changes.
3. To set the levels of prestressing taking into account the possible deformability over time.



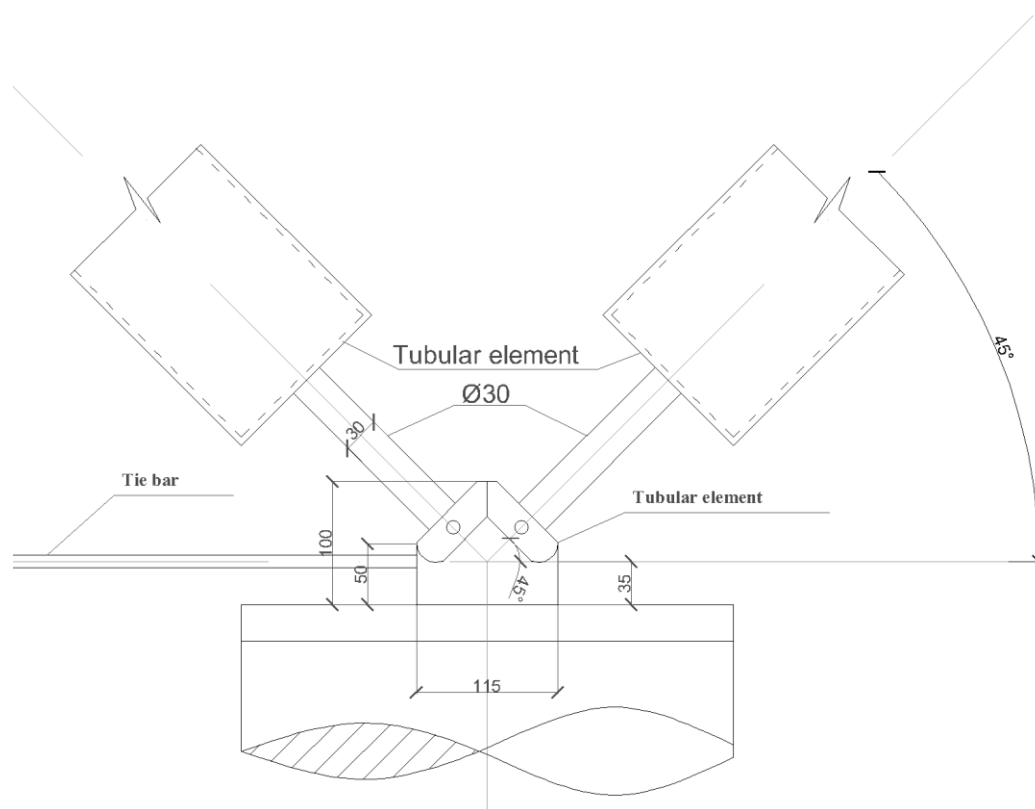
**Figure 4.** Pin joint of metal lower belt and wooden braces: 1-nodal element of spherical shape, 2, 6-spherical seat washer, 3 tips in the form of holders for rod elements of braces, 4-connectors transmitting forces from braces to bearing nodal element, 5- braces of metal-wooden construction, 7-metal element of belt, 8, 9 - conical holes allowing rotation of the braces around the center of nodal element

This node consists of a hemisphere, sliders rest on its inner and outer surface and braces elements rest on the sliders. The sliders have the possibility of some sliding along the surface of the sphere. The elements of the lower zone are directly attached to the hemisphere by welding or end elements

according to the “Marches” nod. The strength of the nodal joint is ensured by the spherical shape of the nodal element, since the ball works well in compression. Also, the connection of the sliders with the braces is carried out with the help of the end elements according to the “Marches” type. If plywood pipes are used as braces, then the connection with the sliders is carried out using the thread on which the pipes are screwed.

The use of a similar unit (Figure 4) is also rational when connecting wooden elements of the upper belt and wooden elements of the lattice of braces of metal-wooden constructions.

The supporting node of the metal-wooden construction, in which tie bars are attached to it, is shown in Figure 5. This node, based on the Kislovodsk system, was made with some changes. The axis of the braces and tie bars converge at one point. The nodal element is a truncated polyhedron.



**Figure 5.** The supporting node of the metal-wooden construction

## 5. Conclusion

Thus, taking into account all the above mentioned recommendations, it is quite possible to apply prestressing for a material such as wood.

## References

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