Optimizing the Load-Bearing Capacity of Cross Timber Beams Using Different Types of Timber

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Abstract. This article examines the operation of structures made of solid wooden beams and composite glued beams of two types, consisting of different types of wood. The object of the study was a beam structure, which is a homogeneous slab resting along a contour of constant stiffness under the action of an external load. The calculation of structures made of glued beams of rectangular cross-section has been performed. The calculation is based on the finite element method, analysis of the main methods and approaches for the optimal design of spatial structural structures. The main unknowns are the displacements and rotations of the nodes of the design scheme, based on this, the idealization of the structure is embodied in a form adapted to the use of this method: this system is presented in the form of a certain set of bodies of a standard type, which is attached to the nodes.

1. Introduction

The researches in the software package of the work of structures with orthogonal and diagonal arrangement of beams, used materials, solid wood beams and glued composite beams, assessment of the bearing capacity and deformability. Assessment of the stress-strain state. Structures of bending elements of a composite section. Analysis and comparison of the results obtained [1-2].

Timber structures are lightweight structures, the use of which is one of the most important directions in construction on the way of increasing and increasing the efficiency of the speed of construction production [3-4].

Wooden structures are lightweight, reliable and durable. With the help of glued timber structures, buildings are erected with coverings of both large and small spans. Relatively small houses, public and industrial facilities are designed from solid timber [5-6].

Cross-beam structure (CBS) is a cage, consisting of beams, working together, intersecting in two or three directions of glued wood or glue-veneer elements. The angle between the beams in the plan can be 45, 60, or 90° [7-8].

The beams can be used both single and paired.

By positioning the beams in the coating plane at different angles to each other, you can ensure that they will perceive forces that act in two or three directions, that is, the entire coating will work as a spatial one.

2. Statement of research tasks

The positive qualities of structures made of prefabricated glued wooden elements include:

— architectural: architectural and aesthetic expressiveness, contributing to the creation of a
modern interior with good acoustics; the possibility of using cross-beam structures for buildings with different configurations in the plan;

- structural: large spatial rigidity, which contributes to an increase in the span of the coating, the rejection of stiffness bonds; the ability to increase the ratio of the height of the beams to the width without the risk of loss of stability of the elements; multi-connectivity of the system, which increases the degree of reliability of the structure in case of local damage; regularity and uniformity of structural elements; a significant reduction in the material consumption of the fence due to the contour support of the coating panels;

- technological: the simplicity of the structural form of the beam elements and, as a result, the possibility of manufacturing them on automated lines; the possibility of rational use of narrow-gauge and short-gauge material; a high degree of factory readiness of the coating [9-10].

Systems of cross beams made of prefabricated glued wooden elements can be manufactured on any equipment designed for the production of straight glued wooden structures.

Cross-beam structures are used for overlapping triangular, rectangular, square (at B / L≤1.5), as well as more complex configurations in terms of rooms with spans not exceeding 30 m. The orientation of the load – bearing elements in the cross-beam structure relative to the plan can be triangular, diagonal, or orthogonal (figure 1).

3. Problem statement
The support of the cross-beam structure can be carried out on the walls as well as on the columns. Cross-beam structures can include contour elements in the form of load-bearing beams or rely directly on racks, the pitch of which in this case coincides with the size of the cells. Supports of cross-beam structures can be located inside it or along the outline of the plan. The supports can also be arranged in a mixed way. For larger spans, it is recommended that the plan be divided into squares by a grid of columns supported by more rigid contour beams [11-12].

![Figure 1. Diagrams of cross-beam structures of different configurations in the plan with different orientation of elements:
1, 2 - with an orthogonal and diagonal arrangement of beams above a square room in the plan; 3-
inscribed in a circle with beams of three directions;
4 – The same, triangular in the plan; 5-with orthogonal beams octagonal in the plan; 6-hexagonal in
the plan with beams of three directions with an intra-contour placement of racks.](image)

Cross-beam structures are effective load-bearing structures for covering and overlapping buildings. They have a fairly wide scope of practical use and are of particular interest for use in modern construction, both structurally and architecturally [13-14].

4. Theoretical part
The experience of implementation and application in the practice of construction of beam structures revealed problematic points in their work. One of the most important is the imperfection of the design features of rigid beam coupling units in the structure.

Methods for calculating cross-beam structures need to be refined, taking into account the actual operation of the entire structural system and the nodal interfaces of the elements [15-16].

In this work, a number of scientific experimental and theoretical studies are carried out, the
analysis and comparison of beam structures from different beams is carried out, and the stress-strain state of beam structures with orthogonal and diagonal arrangement of the load-bearing elements of the beams is evaluated [17-18].

The design scheme of the structure is defined as a general system, the main unknowns of which, as well as its deformations, are represented by linear displacements of nodal points along the X, Y, Z axes and rotations around these axes. The movements of the nodes of the computational scheme are limited by external links that prohibit some of these movements, the points of adjacency of the finite element to the nodes have the same movements with the specified nodes.

For rod elements, the presence of forces is possible: N – longitudinal force, Mк – torque output, Qz – cutting force in the direction of the axis Z, My – bending moment with a vector along the axis Y, Qy – force in the direction of the axis Y, Rz – elastic base rebound, Mz – bending moment relative to the axis Z. The positive directions of the moments are shown in the figure 2.

![Figure 2. Positive directions of moments in the calculation in the ROBOT software package.](image)

5. Practical relevance
The stage of choosing a design scheme is an important process, it is important to choose one that reflects the actual operation of the cross-beam structure.

The structures were designed for the loaded action: \( \text{gсв} \) – load from the self-weight of the beams in the structure; \( q=1,86 \text{ kН/m}^2 \) – evenly distributed load on the structure.

The calculations are made in order to compare the maximum bending moments that occur in the elements of the structure from the specified loads.

The design scheme of cross-beam structures in the ROBOT software package is given in the form of a general spatial-rod model, which is located in the XOY plane, consisting of rods rigidly conjugated to each other at the nodes (figure 3), the hinge support of the structure on the racks is set by superimposing connections in the direction of the axes X, Y, Z.

![Figure 3. Visualization of the design model of a beam structure in the ROBOT program using the example of an orthogonal-diagonal scheme.](image)
The self-weight load on the structure will be set using the “Self-weight” function in a separate “Loads” tab. To simulate uniform loading of a load distributed over the area of the structure (see figure 4), the coating was introduced by forming a mesh of finite elements on a plane, taking into account the fact that beam structures made of wooden elements, as a rule, cannot have a monolithic conjugation with the elements of the coating, this condition is implemented by the designation of overlays with a thickness of 1 mm. In this case, the coating performs only the functions of transferring the load to the structure, and at the same time will not participate in its overall work [19-20].

![Figure 4. Schemes of loading an orthogonal and diagonal system of beams.](image)

The static calculation is performed in the calculation and graphic complex ROBOT, tensile forces in it are given with a (-) sign, compressive ones with a (+) sign.

Three beam options were investigated. The first option is a solid beam. The second option is a glued beam made of different types of wood, birch and oak (figure 5). Elastic modulus – 18 300/14 300 MPa. Poisson's ratio – 0,45/0,41. Shear modulus – 1510/1380 M. The third option is a glued beam (figure. 6) using pine, birch, oak.. Elastic modulus – 12 100/18 300/14 300 MPa. Poisson's ratio – 0,41/0,45/0,41. Shear modulus – 1210/1510/1380 MPa.

![Figure 5. Glued beam using birch and oak species.](image)
Figure 6. Glued beam using species pine, birch, oak.

Table 1. Section of structural elements.

| Rod          | Section | Material | Lay  | Laz  | Raito | Load   |
|--------------|---------|----------|------|------|-------|--------|
| **Group: 1 Belts** |         |          |      |      |       |        |
| BALK 75x150  |          | Oak      | 195.96 | 391.93 | 1.06  |        |
| BALK 75x160  |          | Oak      | 183.71 | 391.92 | 0.99  | 1 EXP.1|
| BALK 75x175  |          | Oak      | 168.00 | 392.00 | 0.90  |        |
| BEAM 200x200 |          | Oak      | 146.97 | 146.97 | 0.29  |        |
| BEAM 200x225 |          | Oak      | 130.64 | 146.97 | 0.26  | 1 EXP.1|
| **Group: 2 Racks** |        |          |      |      |       |        |
| 218 Simple rod_218 | BALK 50x100 | Oak    | 103.92 | 207.81 | 0.57  | 1 EXP.1|
| 218 Simple rod_218 | BALK 50x115 | Oak    | 90.37  | 207.84 | 0.50  | 1 EXP.1|
| 218 Simple rod_218 | BEAM 200x200 | Oak    | 51.96  | 51.96  | 0.07  |        |
| 218 Simple rod_218 | BEAM 200x225 | Oak    | 46.19  | 51.96  | 0.06  | 1 EXP.1|
| **Group: 3 Braces** |        |          |      |      |       |        |
| 1813 Simple rod_1813 | BALK 63x200 | Oak    | 90.00  | 285.73 | 1.06  |        |
| 1813 Simple rod_1813 | BALK 63x225 | Oak    | 80.01  | 285.78 | 0.94  | 1 EXP.1|
| 1813 Simple rod_1813 | BALK 63x250 | Oak    | 72.00  | 285.72 | 0.85  |        |
| 1813 Simple rod_1813 | BEAM 200x200 | Oak    | 90.00  | 90.00  | 0.33  |        |
| 1813 Simple rod_1813 | BEAM 200x225 | Oak    | 80.00  | 90.00  | 0.30  | 1 EXP.1|

Load - applied to the surface of the coating, equivalent to 1.86 kPa.
Static calculation is performed in the calculation and graphic complex ROBOT. The selection of the optimal cross-section of structures for the first group of limiting states, using the computational-graphic complex Robot, is presented in Table 1. From table 1 it can be seen that the most optimal is the cross-section of the beam with the dimensions: Belts - 75x160 mm, Racks - 50x100 mm, Bracing - 63x225 mm. Figure 7 shows the deformations of the structure under the action of the applied force.

![Deformation of the structure under the applied load](image)

**Figure 7.** Deformation of the structure under the applied load.

Figure 9 shows a diagram of determining the forces and displacements of a cross-bar system with an orthogonal scheme: a) from solid wood, b) from a composite beam using birch and oak species, c) from a composite beam using pine, birch and oak species.

![Cross-bar system with an orthogonal scheme](image)

The weight of this structure – 56 441 kg. The weight of this structure – 54 112 kg. The weight of this structure – 51 029 kg.

**Figure 8.** Cross-bar system with an orthogonal scheme: a) from solid wood, b) from a composite beam using birch and oak species, c) from a composite beam using pine, birch and oak species.

Figure 9 shows a diagram for determining the forces and displacements of a cross-bar system with a diagonal scheme: a) from solid wood, b) from a composite beam using birch and oak species, c) from a composite beam using pine, birch and oak species.
The weight of this structure – 37 800 kg.
The weight of this structure – 34 176 kg.
The weight of this structure – 31 726 kg.

Figure 9. Cross-bar system with a diagonal scheme: a) from solid wood, b) from a composite beam using birch and oak species, c) from a composite beam using pine, birch and oak species.

The results of the maximum stresses and displacements are presented in table 2.

| Construction 1 | Nx(-) (кН) | Nx(+) (кН) | Displacement (см) | weight (кг) | Max. straining (МПа) |
|----------------|-----------|-----------|-------------------|-------------|----------------------|
| Solid wood     | -559,8    | 400,6     | -10,2             | 56 441      | 21,75                |
| Beam 1         | -558,6    | 399,9     | -9,4              | 54 112      | 21,7                 |
| Beam 2         | -556,7    | 398,5     | -9,5              | 51 029      | 21,6                 |

| Construction 2 | Nx(-) | Nx(+) | Displacement | weight | Max. straining |
|----------------|-------|-------|--------------|--------|----------------|
| Solid wood     | -320,2| 273,7 | -15,1        | 37 800 | 26,21          |
| Beam 1         | -325,3| 278,3 | -14,3        | 34 176 | 25,94          |
| Beam 2         | -326,1| 279,3 | -14,3        | 31 726 | 24,3           |

6. Conclusion
By changing the cross-bar system from orthogonal to diagonal, you can significantly reduce the forces on the structure, reduce weight and strain (displacement), but at the same time increase the maximum torque acting on the structure by 18%. From this we can conclude that based on the effort, movement of the structure and weight it is more profitable to use a diagonal rod system. The work of the structure is influenced by the materials used (solid wood, beam 2 (oak, birch), beam 3 (oak, pine, birch)), so beam 3 is more profitable to use than solid wood and beam 2 in terms of weight, maximum moments and movement of the structure.

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