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Analysis of Strength Characteristics of Adhesive-Board Reinforced Beams

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Abstract: This article presents a comparative analysis of the strength characteristics of glued-board reinforced beams for the first and second groups of limit states, considering both the reinforcement configuration and the reinforcement material. The main thesis is that the use of the SCAD calculation and graphic complex is effective for determining the rational configuration of reinforcement and the choice of reinforcement material, which enables an increase in the strength characteristics of wooden structures. This article examines how reinforcement configuration and properties influence the performance of glued laminated timber beams, offering a more comprehensive understanding of their performance characteristics. The work aims to determine the rational configuration of reinforcement and reinforcement material based on the strength of the first and second groups of limit states, as well as to minimize the mass of the structure.

Keywords: glued-to-board beams, strength, SCAD, stress-strain state, first and second groups of limit states, reinforcement

1. Introduction

Wood is widely used as a construction material in various industries. Its introduction into construction, transport, energy, and other areas is steadily growing, as are the requirements for its strength and deformation properties (Abu-Hasan et al. 2018a, Veselov et al. 2019). Increasing the natural strength characteristics of elements in wooden structures (WS) and glued wooden structures (GWS) is achieved using various methods (Kulish & Nakashidze 1974).

The choice of a rational method for increasing natural strength characteristics depends on many parameters and is made through a system analysis of factors that take into account the force impact on structural elements and a technical and economic comparison. In some cases, the most advantageous is the use of internal rod reinforcement (Temnev et al. 2020).

The authors of the article provide an analysis of the strength characteristics of glued-board reinforced beams in the SCAD calculation and graphic complex (Abu-Hasan et al. 2018c, Sycheva et al. 2016). Several configurations of glued laminated timber beams are used in the analysis, as shown in Fig. 1.

The calculation is carried out under the same operating conditions of glued-to-board beams, which will allow them to be compared according to the following parameters (Abu-Hasan & Egorov 2018, Svatovskaya et al. 2007):

- Beam mass,
- Section utilization factor,
- Maximum values of normal stress in the section,
- Maximum vertical movements.

These parameters are decisive for assessing the bearing capacity for the first and second groups of limit states, and also make it possible to determine the most effective configuration based on the condition of ensuring strength with a lower mass of structures (Arleninov & Becker 2015).

2. Research Methodology

The calculations were performed using the SCAD calculation and graphic complex, which employs the finite element method (Starchukov et al. 2017). To compare the selected configurations, a calculation scheme was modeled using rod elements. For the joint operation of plank elements in a package, a tool is used – combining displacements, while the rods are preliminarily divided into equal sections of 150 mm, in the near-support sections, we take the division of 40 mm (Egorov et al. 2018-1, Solovieva et al. 2017-2). The calculation scheme is shown in Fig. 2. The beam clamping is hinged.

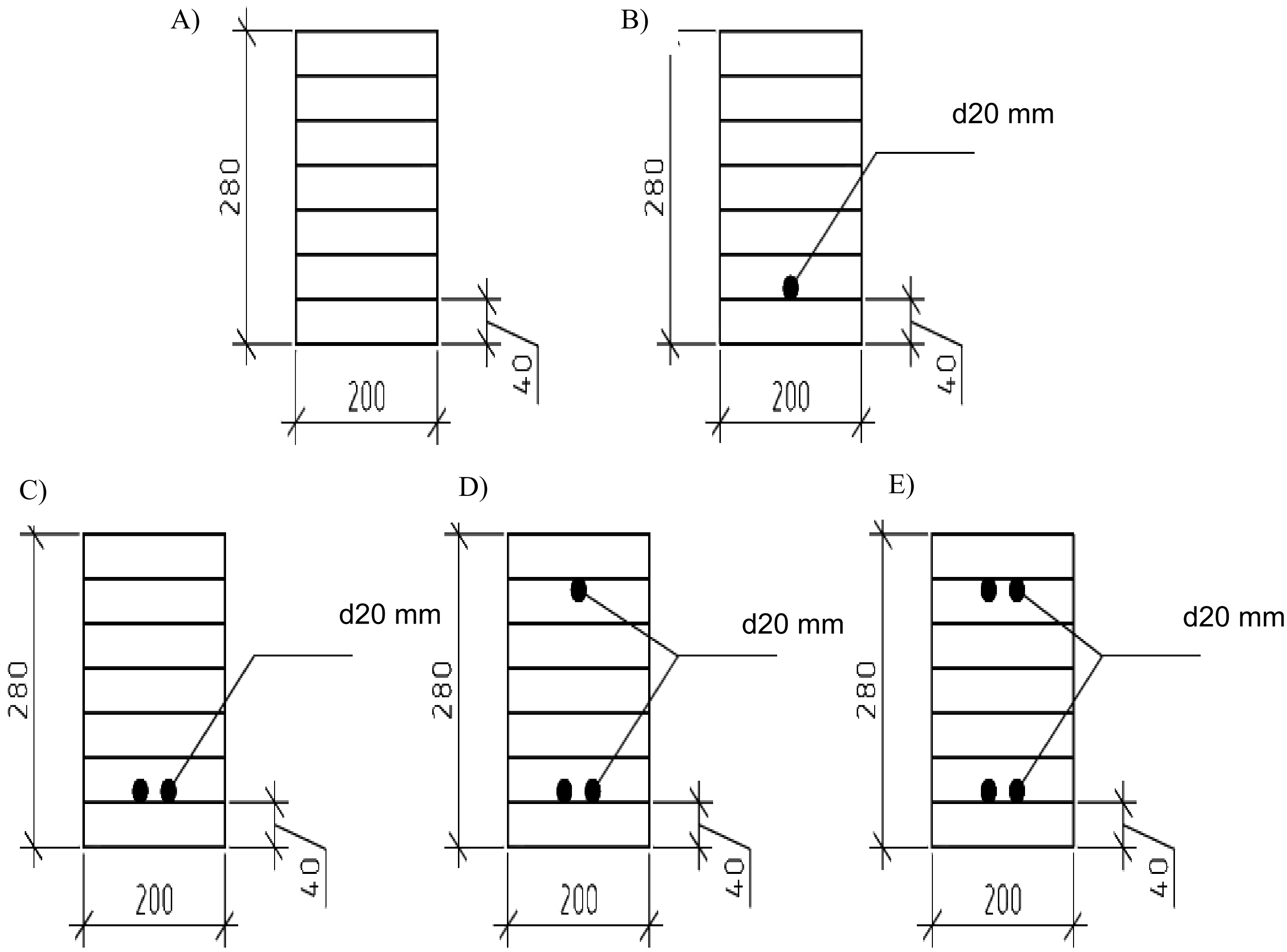


Fig. 1. Configurations of glued-to-laminated beams for calculations: A – No reinforcement, B – Reinforcement with 1 rod, C – Reinforcement with 2 rods, D – Reinforcement with 3 rods, E – Reinforcement with 4 rods

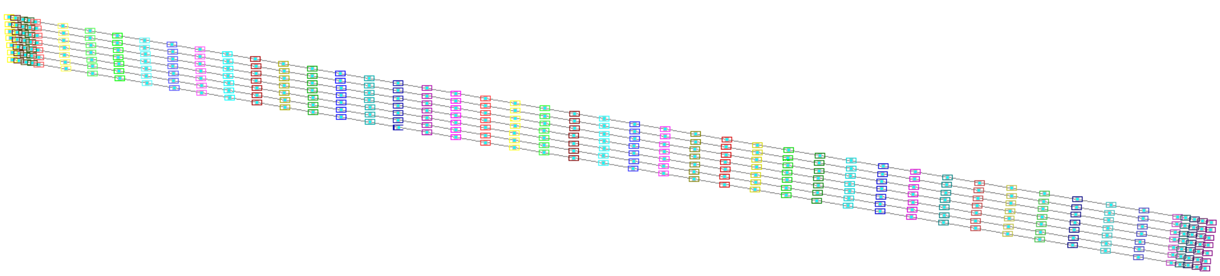


Fig. 2. Calculation scheme in SCAD

The analysis considers loads from dead weight (applied automatically). The load application diagram is shown in Fig. 3.

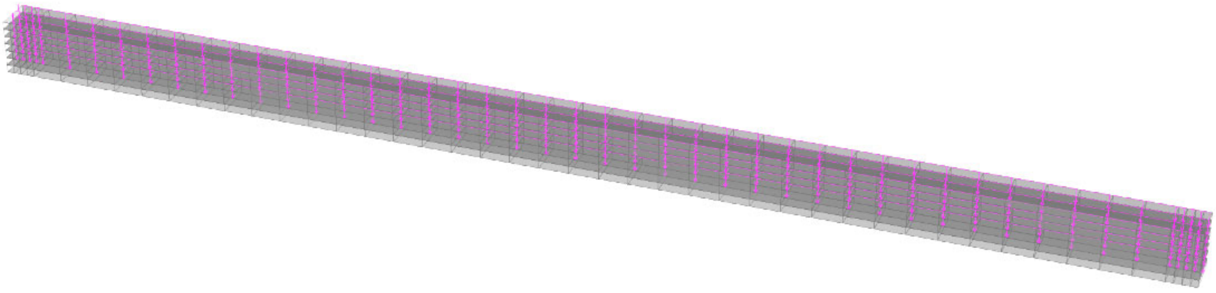


Fig. 3. Loads from own weight

For calculations for the first and second groups of limit states, calculated combinations of forces and displacements are assigned (Fig. 4).

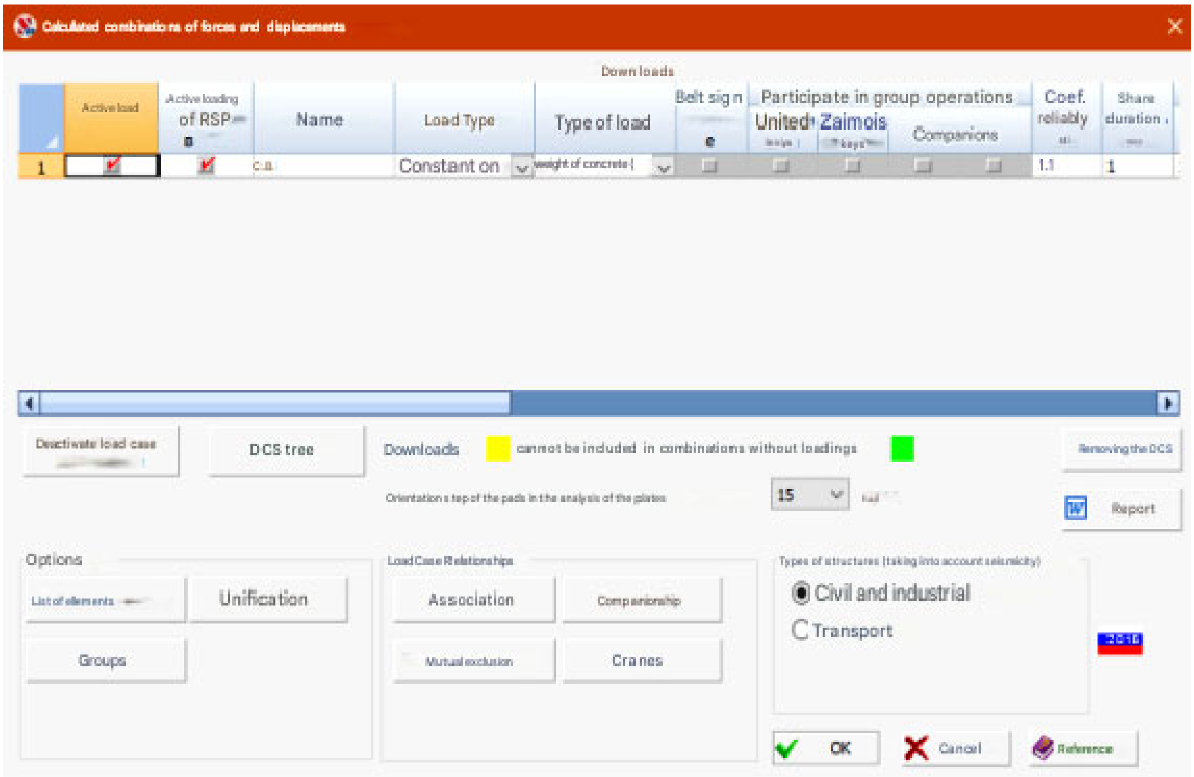


Fig. 4. Calculated combinations of forces and displacements

The calculations were based on the mechanical properties of grade 1 pine wood when used in laminated timber construction (Egorov et al. 2018-2).

The calculation parameters are illustrated in Fig. 5. The multi-frontal method enables the calculation of spatial elements of buildings for statics, dynamics, and stability (Solovieva et al. 2017).

After the static calculation, the values of maximum normal stresses in the cross-section of the glued-board beam were determined, and an examination of the cross-section was carried out; for this purpose, the value of the critical factor is used. If this value falls within the range of 0 to 1, the checked section ensures the bearing capacity for both the first and second groups of limit states.

The values of critical factors are determined according to the following criteria (8):

- flexibility of the element in the XOY plane,
- strength of an element under the action of a bending moment My,
- strength under transverse force Qz,
- stability of plane deformation.

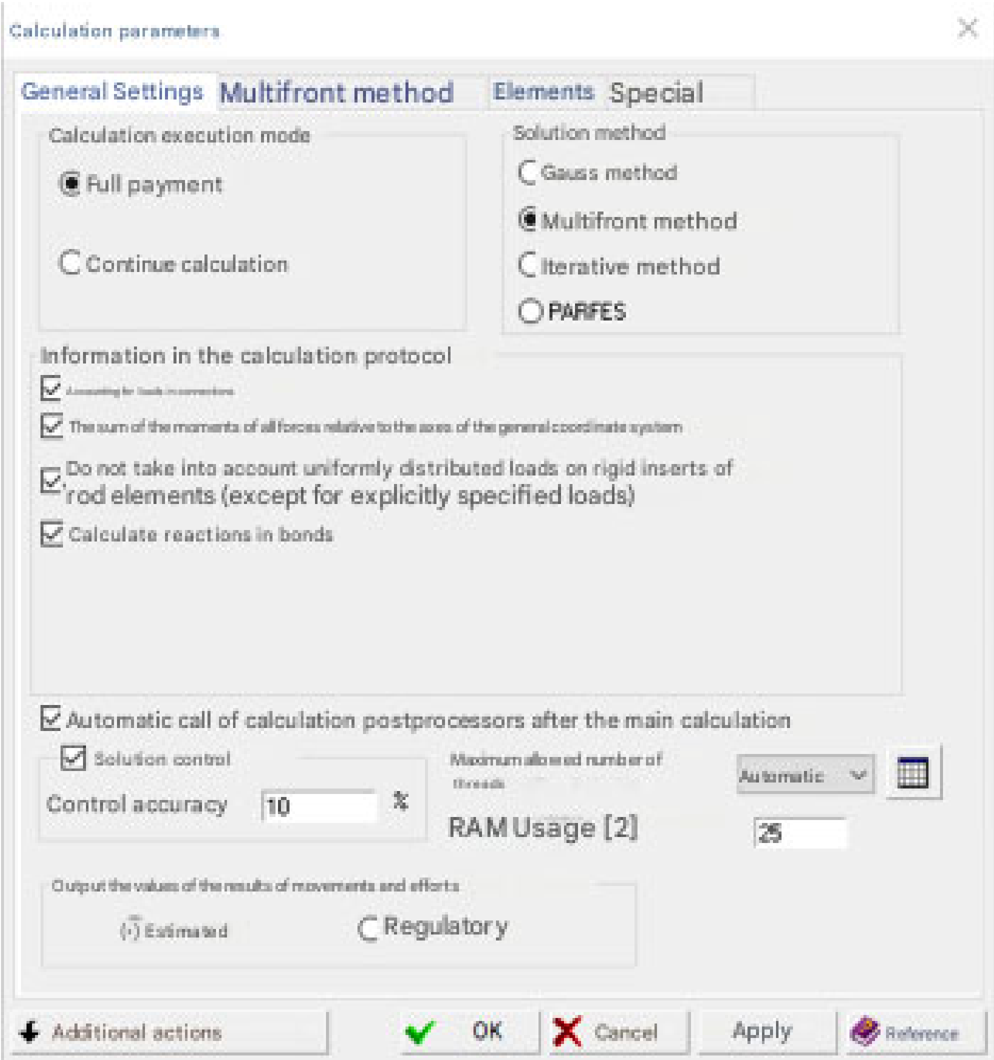


Fig. 5. Calculation parameters

The values of critical factors are shown in Figures 6 to 11.

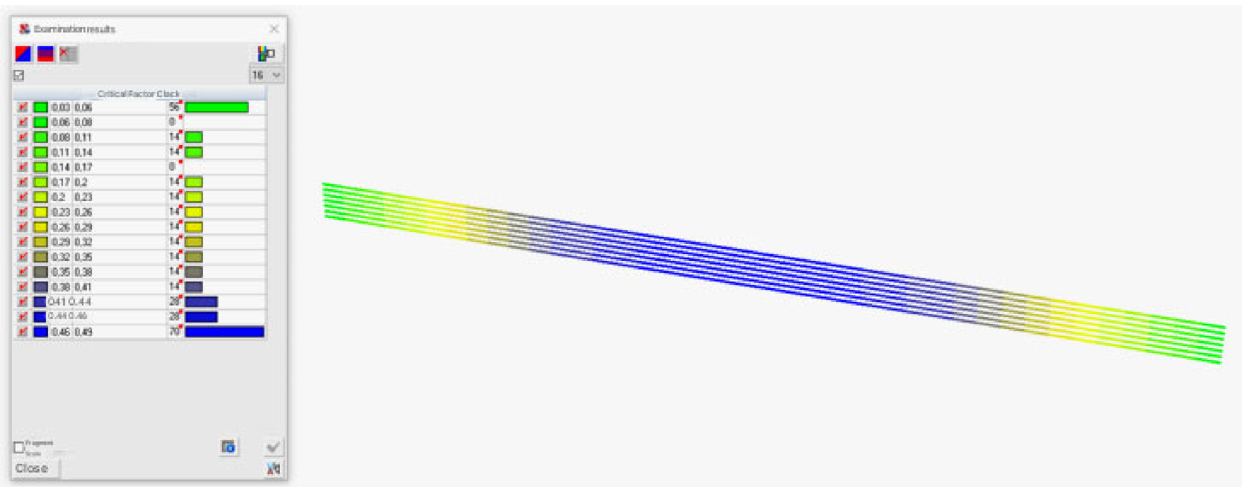


Fig. 6. Critical factor values: beam without reinforcement

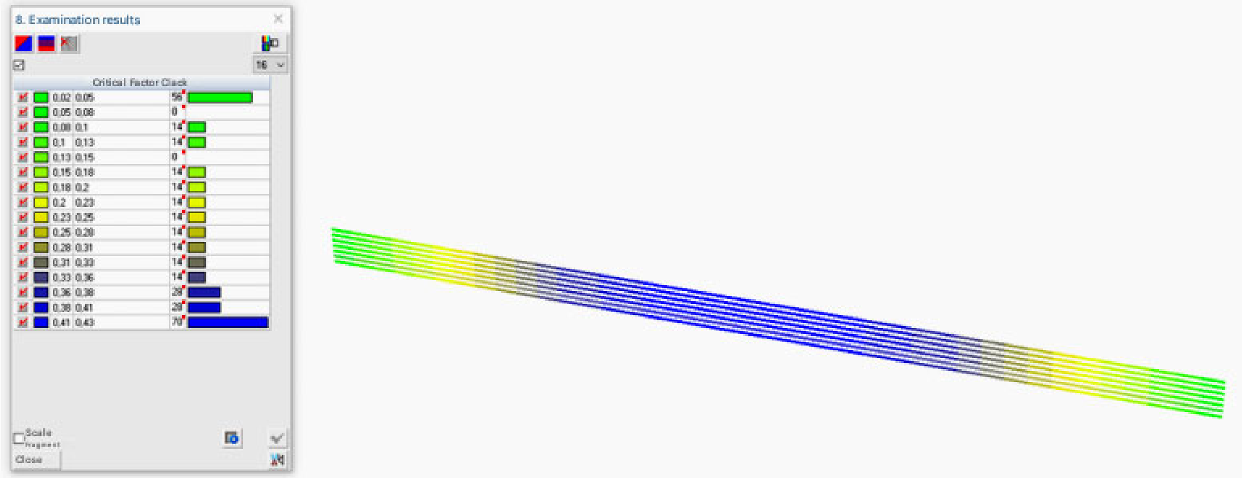


Fig. 7. Critical factor values: beam with one steel reinforcement bar

Even with the installation of one steel reinforcement rod, a significant reduction in the critical factor can be observed (Abu-Khasan et al. 2018-2). At the same time, the maximum values of normal stresses decreased from 540 t/m² to 475 t/m², representing a 12% decrease.

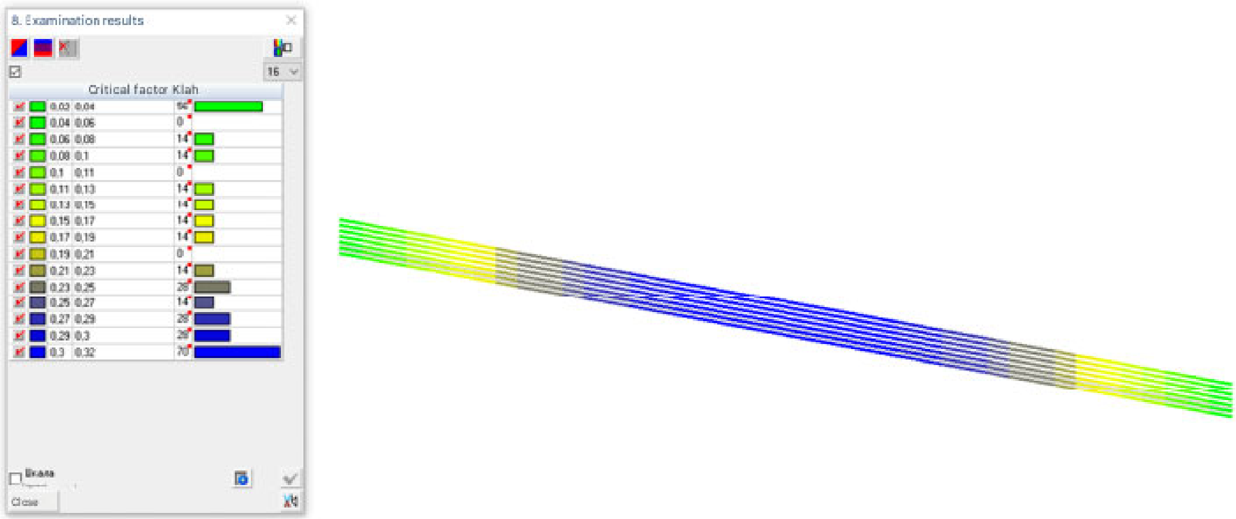


Fig. 8. Critical factor values: beam with two steel reinforcement bars

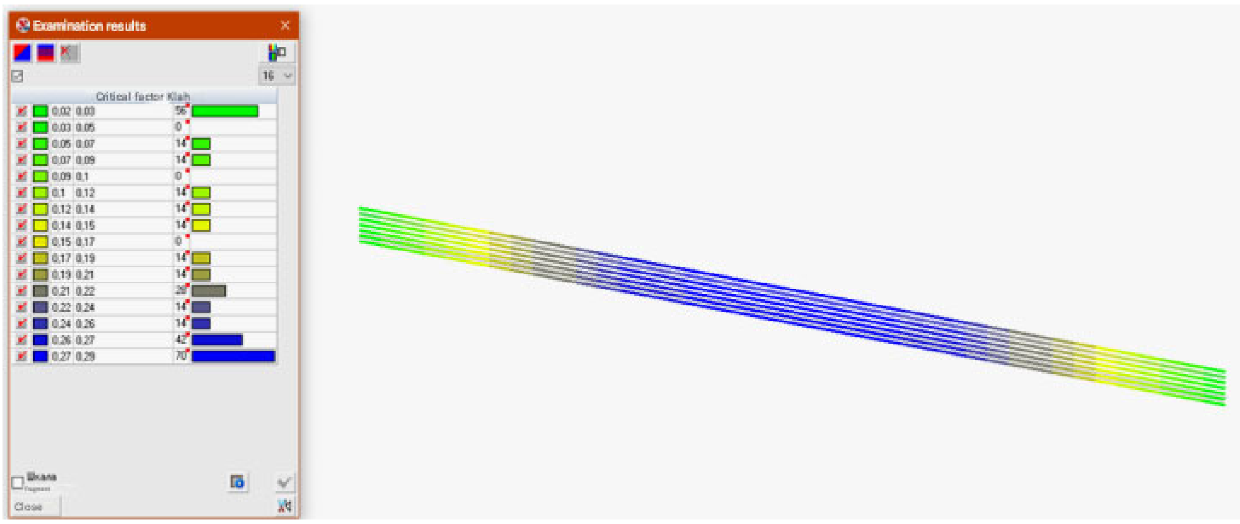


Fig. 9. Critical factor values: beam with three steel reinforcement bars

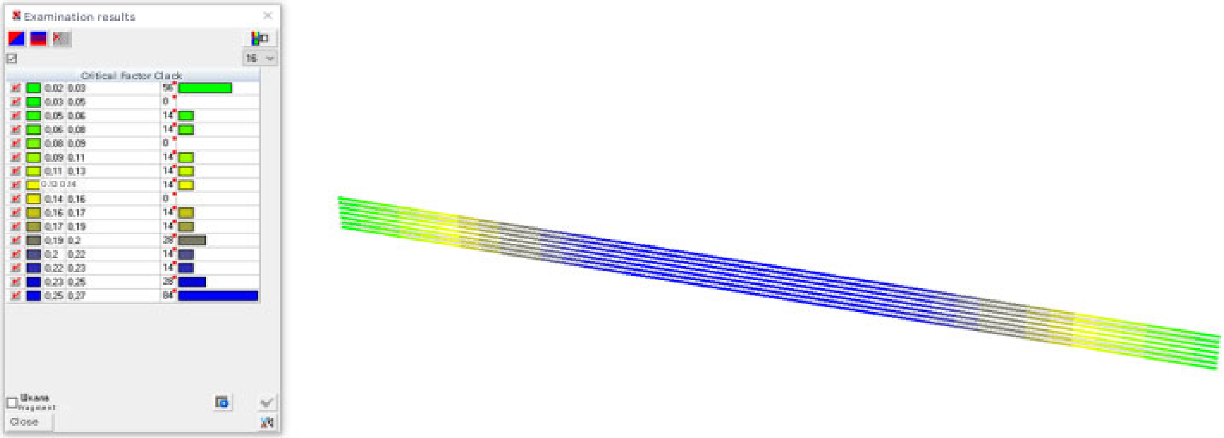


Fig. 10. Critical factor values: beam with four steel reinforcement bars

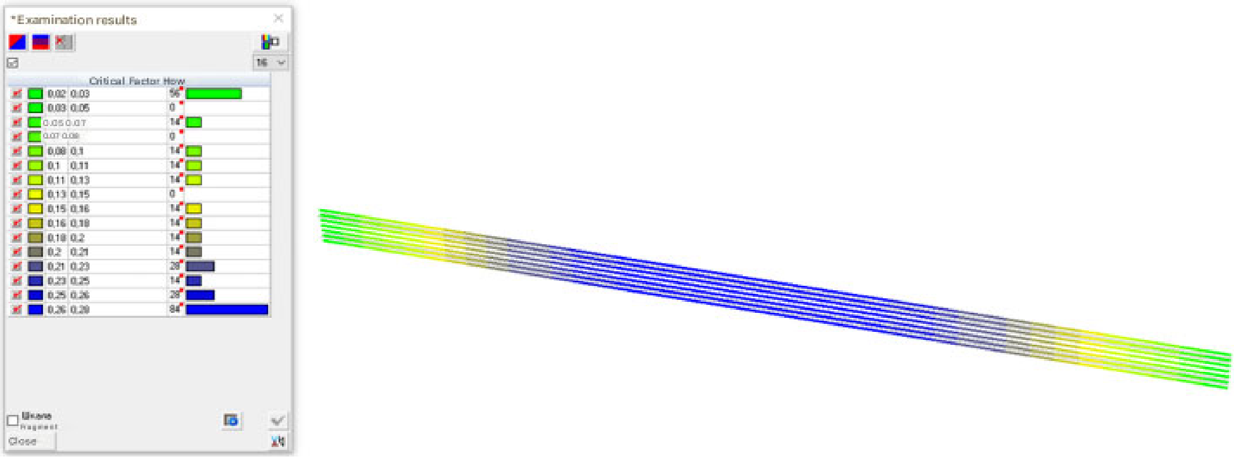


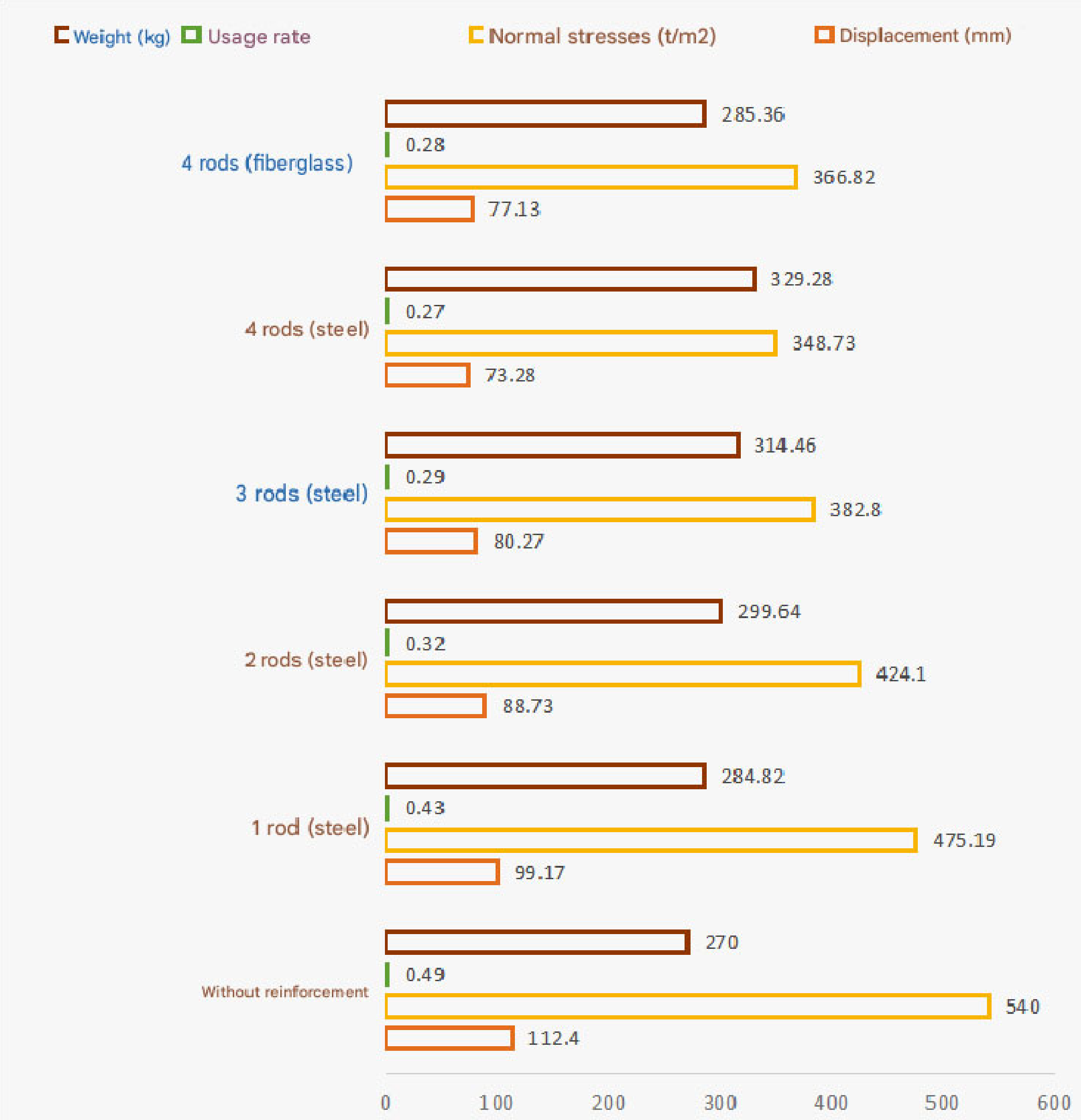
Fig. 11. Critical factor values: beam with four fiberglass reinforcement rods

Simultaneously with the utilization factor, an analysis was conducted to examine the changes in displacement, normal stress, and the mass of the structure. The calculation results are given in Table 1.

Table 1. Calculation results

Beam	Displacements, mm	Normal stress, t/m^2	Utilization rate	Weight, kg
Without reinforcement	112.40	540.00	0.49	270.00
1 rod (steel)	99.17	475.19	0.43	284.82
2 rods (steel)	88.73	424.10	0.32	299.64
3 rods (steel)	80.27	382.80	0.29	314.46
4 rods (steel)	73.28	348.73	0.27	329.28
4 rods (fiberglass)	77.13	366.82	0.28	285.36

For greater clarity, the calculation results for all configurations of reinforced glued-board beams are summarized in Fig. 12.



	Without reinforcement	1 rod (steel)	2 rods (steel)	3 rods (steel)	4 rods (steel)	4 rods (steklopl.)
Weight (kg)	270	284.82	299.64	314.46	329.28	285.36
Usage rate	0.49	0.43	0.32	0.29	0.27	0.28
Normal stresses (t/m2)	540	475.19	424.1	382.8	348.73	366.82
Displacement (mm)	112.4	99.17	88.73	80.27	73.28	77.13

Fig. 12. Calculation results for all configurations of reinforced glued-board beams

3. Conclusion

Based on the calculation results, it can be concluded that reinforcement of glued-board beams is an effective method for increasing the rigidity and strength of this type of structure, so when reinforcing with four steel reinforcement bars, vertical movements were reduced by **-34%**, and the section utilization factor was reduced by **-44%**. However, when reinforcing, the beam mass increased by **18%**.

When using fiberglass reinforcement, the values of vertical displacements compared to an unreinforced beam were reduced by **-31%**, the utilization factor of the cross-section was reduced by **-44%**, while the weight increased by only **5%**.

Thus, the use of fiberglass reinforcement is the most effective way to increase the rigidity and strength of glued-board beams.

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