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GREEN TECHNOLOGIES IN THE DESIGN OF SINGLE-STOREY FRAMEWORKS

Purpose. Analysis of the effectiveness of long-span structural systems based on glued laminated timber for a single-storey frame of a public building.

Methodology. The study used a set of research methods, including scientific analysis and synthesis of available technical information on the use of modern wood products for the design of load-bearing frames of buildings with large spans. Computer modelling methods based on the numerical method of structural mechanics – the finite element method – were also used. The analysis of the structural options was performed using the finite element method using the SCAD (Ukraine) design and computing complex. A separate area of work involved design development, which included methods of engineering assessment of the accuracy and reliability of the results obtained, as well as the execution of design documentation.

Findings. For the considered structural variants of the equipment compartment frame covering, stress-strain state patterns, as well as natural frequency spectra and vibration modes, were obtained. The structural variant of the frame recommended for practical implementation is based on the set of technical and economic indicators involves the use of an arched covering system. It is also shown that the use of biocomposite glued beams opens up reserves for reducing the material consumption of the structure by preliminary estimates up to 25 %.

Originality. The conducted research studies allowed estimating in complex the static and dynamic load-bearing capacity of a large-span frame using glued laminated timber. The high efficiency of the combined frame system, especially in the case of biocomposite timber, has been proven. The obtained frequency spectrum is discrete and lies in the lower frequency range of 1.5–5.0 Hz.

Practical value. The use of glued and biocomposite timber beams for load-bearing elements of single-storey frames opens up a direction of green technologies for specialized buildings, such as a Fire Station. In combination with modern finishing materials such as fire-resistant wood wool, this allows increasing the operational qualities of wooden structures.

Keywords: *wood, glued laminated timber, biocomposite laminated timber, load-bearing framework, equipment compartment*

Introduction. One of the newest and most promising areas of building construction is green construction. Its implementation allows one not only to increase the efficiency of construction, but also to reduce its potential negative impact on the environment. As a separate direction, green construction has emerged from the direction of safe construction, continuing and developing its basic ideas and principles [1, 2]. This trend is currently gaining popularity in Asian countries, in particular in China [3, 4], where harmony with nature has always been a cornerstone principle of the worldview.

Analysing the available professional literature [5, 6], the following aspects of green construction should be highlighted:

1. Architectural aspect, which involves:

1. Choosing the location of the facility in an area with improved environmental conditions. As a rule, these are areas outside of large cities, as well as areas with a low degree of change in natural and climatic conditions during the day, season or year.

2. Harmonisation of the external and internal design of the facility with the environment, landscape and transport routes.

3. Selection of an energy-efficient facility layout that will help minimise energy consumption by the facil-

ity occupants for its maintenance and improvement of the quality of its operation.

4. Use of natural and environmentally friendly building materials that can not only have a positive impact on the health of the facility residents, but also improve their psycho-emotional state.

5. Safe interaction with the environment due to the absence of harmful waste and negative impacts from the facility.

***2. Constructive aspect*,** which involves:

1. Rational design solution that reduces material costs for its creation and reduces the level of hazard from its use.

2. Ensuring the appropriate level of protection of structural elements from the negative impact of the external environment to increase the durability and service life of the object.

***3. Economic aspect*,** which involves:

1. Application of automated and computerized systems for managing energy consumption and energy supply of functional systems of the facility.

The most successful modern examples of the practical implementation of the direction of green construction are the following (Fig. 1):

a) vegetation on facade surfaces (aspects 1–2, 1–5);

b) vegetation on roofs (aspects 1–2, 1–3, 1–4, 1–5);

c) ecological roofing (aspects 1–2, 1–4, 1–5);

d) structures on trees (aspects 1–5, 1–3, 1–4, 1–5).

Such examples cover mainly the architectural aspect of green construction. The implementation of the constructive aspect requires a calculation justification and is associated with the complexity of conducting multivariate calculations to determine the most efficient option.

Literature review. The development and implementation of the architectural aspect of green construction in construction practice involves the use of wood as the most natural and environmentally friendly building material. Another positive aspect of using wood for various building structures, especially those intended for human use, such as public or residential buildings, is its rather low thermal conductivity. At the household level, people often describe this as the effect that wood seems to "radiate heat". Staying in rooms decorated with wooden elements or made of wooden structural elements gives the impression of "warmth". At the same time, being in similar rooms made of, for example, steel structures leaves the impression of "radiation of cold" or "the presence of cold that seems to penetrate to the bones".

This is an additional factor that contributes to the widespread use of wood for load-bearing elements of building structures, despite the progressive development of steel and reinforced concrete structures [7, 8]. Researchers' interest in this building material is not waning, and research and development of both new types of wood products [9] and new types of connections for wood elements [10] continue. One of these types of products is glued laminated timber. The conducted studies have shown its rather high mechanical characteristics compared to traditional types of wood products [11, 12]. Special improved types of connections for glued laminated timber elements are also being developed [13].

Therefore, modern engineers are increasingly trying to use this structural element for more and more types of building structures [14, 15]. Fire stations are one of such construction facilities. It seems that nature itself imposes certain restrictions in this case, because the concepts of "fire" and "wood" have always been incompatible [16, 17]. However, modern advances in materials science, such as the development of wood wool type material with extremely low fire resistance [18], make the impossible possible – the use of such boards avoids problems with fire protection.

The use of biocomposite materials is also a separate state-of-the-art area [19]. On their basis, it is possible to develop a "biocomposite laminated timber" modified with a biocomposite mass based on chopped wood fermented by xylotrophic fungi. According to preliminary estimates, the strength of such a material can be increased to 50 MPa in bending, and the stiffness will increase to 25,000 MPa. Additional advantages over conventional laminated timber include no shrinkage, relatively stable low humidity, which prevents the development of bacteria and fungi and at the same time increases durability.

Unsolved aspects of the problem. Existing structural systems of wooden frames of one-story buildings are oriented on the traditional structural elements made of wood – beams with an inclined upper belt, metal-wood trusses, plywood panels. At the same time, the low load-bearing capacity of such elements limits both the dimensions of the building structure and its architectural expressiveness.

At the same time, wooden glued beams, thanks to their improved characteristics, open up new opportunities for creating more flexible systems in structural solutions. However, their practical implementation remains questionable, as it is limited by the lack of theoretical and experimental developments aimed at implementing new approaches to designing wooden frames from glued beams.

The purpose of the article. The aim of the study is to analyse the efficiency of using wood laminated timber and their modification in the form of biocomposite laminated timber in the frameworks of one-storey buildings. The research object is the combined steel-wood one-storey framework of the equipment compartment of the Fire station. The real object was chosen to concretise the analysis results and avoid excessive abstraction.

The overall geometric dimensions in the plan of the equipment compartment in the axes are 27.12 by 24.87 m, which ensures the free location of 8 fire engines of the main type – Fig. 1. The total height of the compartment to the bottom of the roof framing structures should be at least 7 m, which ensures free movement of fire vehicles.

To achieve that aim, the following tasks were formulated and solved during the research:

1) to develop a fundamental design solution for the supporting frame of the hardware compartment based on the use of glued wooden beams;

2) to propose design variants for the hardware compartment covering system taking into account the possibility of maximum release of internal space;

3) to analyze the operation of the developed design variants for the supporting frame with different coating systems;

4) to determine the most effective design variant for the supporting frame from the proposed ones based on a set of technical and economic indicators;

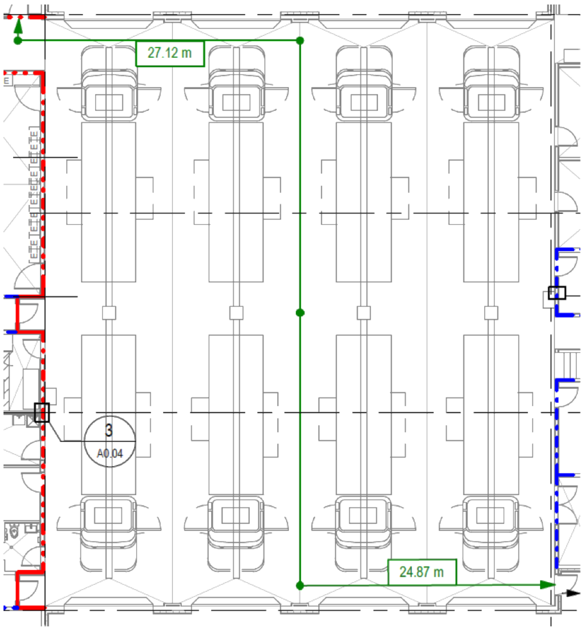

Fig. 1. Principle planning concept of equipment compartment

5) to analyze the possibilities of replacing glued wooden beams with biocomposite beams.

The consistent solution of these tasks in the course of the conducted research allows one not only to determine the limits for the use of glued laminated timber for the frames of one-story public buildings, but also to outline the most successful ways of using its bearing capacity. Also, such research will serve another utilitarian function – increasing the degree of reliability and durability of the frames of the type under consideration, because predicting their working for different operating conditions is an important separate task. In this case the dynamic analysis of the bearing frame, which opens up prospects for countering special influences, such as seismic or explosive, is particular relevance.

Description of the research methodology. One of the main tasks when planning the equipment compartments of Fire stations is to create a space free of intermediate supports. This makes it possible to improve the conditions for the manoeuvring of fire vehicles during entry/exit from the equipment compartment. In contrast to the traditional concept of placing firefighting equipment in special boxes of small capacity, this concept is considered more modern and progressive. In addition, the frame design scheme for the arrangement of load-bearing structures will correspond to this concept.

The basis of the framework structure is a roof framing supported by a system of vertical columns. The columns are located around the perimeter of the framework and along the centre line and are made of steel. Additional systems of horizontal strapping elements, also made of steel, are installed along the perimeter of the framework. The roof framing is made of glued laminated timber and has increased stiffness, which ensures the stiffness of the entire framework. This ideological construction of the one-storey framework is aimed at withstanding both traditional natural and climatic loads (snow, wind, rain) and seismic impacts due to the flexibility of the columns [20].

The following design variants of the equipment compartment roof framing were considered:

1. Beam system with two intermediate supports (variant No. 1).
2. Beam system with one intermediate support (variant No. 2).
3. Beam-girder system without intermediate supports (variant No. 3).
4. Arch system without intermediate supports (variant No. 4).

Numerical modelling based on the finite element method was used to analyse the performance of the load-bearing framework [21, 22]. The practical implementation of the analysis was carried out on the basis of the design and computing complex SCAD (Ukraine). The complex has a construction orientation and is specially designed for the analysis of building structures, including those under complex loading conditions [23]. Among the main advantages of its calculation module is the ability to generate calculated force combinations, which makes it possible to guarantee the worst case scenario of the loading effect.

The constructed finite-element models for the considered variants of the equipment compartment framework are shown in Fig. 2.

Presentation of the main material and scientific results.

1. Classic wooden glued timber. Based on the results of computer modelling, the stiffness characteristics of the main load-bearing elements of the framework were determined to maximise the use of the load-bearing capacity of the elements (Table 1). The cross-sections for laminated wood timbers were taken in accordance with the Canadian product range [24], as the world's leading country in the production of this type of product (material – Douglas fir and larch). The cross-sections for the steel elements were also selected according to the assortment of the same country, which makes it possible to "harmonize" the structure. We chose 350 W steel, which is becoming almost the main steel used in the manufacture of modern building structures in the world [25].

The calculated mass and estimated indicators for the analysed design variants are presented in Table 2. The cost of only the material is given, excluding processing and manufacturing costs.

As can be seen from the obtained data of the computer analysis, the least material-intensive is design variant No. 2; however, it does not fully meet the condition of freeing up the internal space of the equipment compartment. From this point of view, design variant No. 4 is more effective, which at the same time has increased architectural expressiveness due to the curvilinear outline of the roofing surface. Therefore, it is this variant that can be recommended as the final one for single-storey frameworks of the considered type.

The analysis of the stress-strain state of the design variants of the equipment compartment deserves special attention.

The obtained deformation patterns of the equipment compartment load-bearing framework under the main loads are shown in Fig. 3. For all the considered structural variants, the deformation pattern turned out to be quite typical in terms of quality. The central load-bearing element (longitudinal beam) has a deflection only in

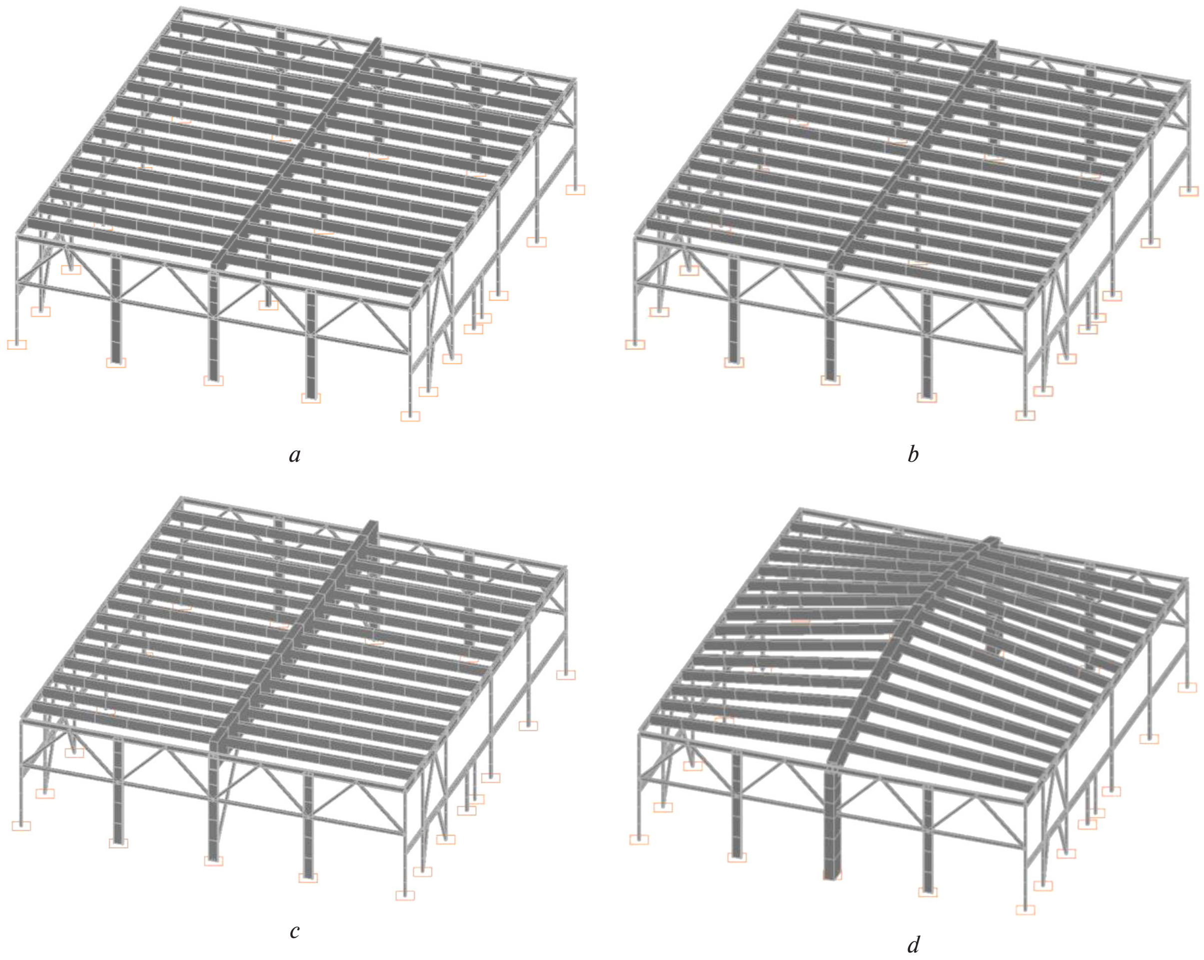

Fig. 2. Calculation model of the equipment compartment framework:
a – variant No. 1; b – variant No. 2; c – variant No. 3; d – variant No. 4

the vertical plane. The transverse supporting elements of the roof framing (transverse beams) are also deformed in the vertical plane. The deformation of the columns is approximately one order of magnitude less than that of the elements of the roof framing.

In the course of the dynamic analysis of the framework structure, the authors' work and approaches, described in work [25] were used. The development of dynamic models was done almost identically to the methods developed in works [26, 27]. In this case, the main practical method for increasing the validity and reliability of residual results was to monitor the analysis of the accumulative mass system. This made it possible to estimate the contribution of every nature mode to the resulting total mode of oscillation. The minimum marginal contribution of modal masses along the horizontal lateral and transverse axes was chosen to be equal to 90 %. In this case, it was necessary to obtain 50 first natural frequencies and modes of oscillation. Data on the distribution of modal masses according to the oscillation modes for design variant No. 1 are presented in Table 3. In this table, the axes are: axe X – the transverse direction of the frame of the equipment compartment, axe Y – the lateral direction to the frame of the equip-

Table 1

Cross sections of the load-bearing elements of the equipment compartment frame

Load-bearing element	Design variant No.			
	1	2	3	4
Longitudinal beam	█ 1140 × 365	█ 1140 × 365	█ 1900 × 540	█ 1140 × 640
Transverse beams	█ 646 × 265	█ 646 × 265	█ 646 × 265	█ 646 × 265
Central column	□ HSS254 × 254 × 9.5	□ HSS254 × 254 × 9.5	–	–
Edge column	I W530 × 92	I W530 × 92	I W610 × 101	I W610 × 101
Spandrel girder	I W460 × 97	I W460 × 97	I W460 × 97	I W460 × 97
Symbols of element cross-section: █ – solid rectangular; □ – square tube; I – I-beam				

Table 2

Technical and economic indicators of design variants of the equipment compartment

Indicator	Design variant No.			
	1	2	3	4
Roof framing weight (wood), *t*	38.8	38.8	46.4	43.2
Framework weight (steel), *t*	20.1	19.6	21.2	23.4
Total weight, *t*	58.9	58.4	67.6	66.6
Cost (wood), USD	69,000	69,000	82,000	77,000
Cost (steel), USD	18,700	18,300	19,800	21,800
Total cost, USD	87,700	87,300	101,800	98,800

ment compartment, axe Z – vertical direction to the frame of the equipment compartment.

From the data presented in Table 3, it can be seen that the accumulation of mass is generated even more unevenly. The main contribution to the resulting values comes from the lower oscillation modes, specifically modes 1–16. Higher forms add an insignificant amount, which is gradually summed up to the lower values. Also, along the vertical axis Z, the accumulation of masess is not observed, which confirms the very high rigidity of the structure in the vertical direction – the support system ensures the stability of the structure of the frame.

The obtained form of deformation of the load-bearing framework of the equipment compartment due to seismic load is presented in Fig. 4. For all the considered design variants, it represents oscillations in the transverse direction of the framework and is additionally accompanied by vertical oscillations of the roof framing, therefore the pattern is given only for design variant No. 4. The obtained frequency spectrum of natural oscillations of the equipment compartment framework is given in Table 4. Table 5 shows generalized data regarding the deformed state of the load-bearing framework. The detailed data on the stress state of load-bearing frame are presented in Table 6.

The most problematic places are the nodal zones of the connection of the roof framing elements with the columns. The design of these zones should be given primary attention, since they determine the level of bearing capacity of the single-storey frame of the equipment compartment as a whole.

2. Biocomposite wooden glued laminated timber. The possibility of using a biocomposite glued timber was considered for the final selected structural variant of the load-bearing frame of the equipment compartment. According to the finite-element analysis, this makes it possible to reduce the cross-sections of the roof framing elements – for the main arch to 1,084 × 315 mm, and for the supporting beams to 494 × 265 mm. At the same time, the total weight of the roof framing decreased to 27.8 tons, and the total weight of the load-bearing framework to 51.3 tons. This reduction in weight by more than 15 tons also leads to a decrease in the cost of the framework by more than 20,000 USD. Therefore, the prospects of using biocomposite glued timbers are quite significant.

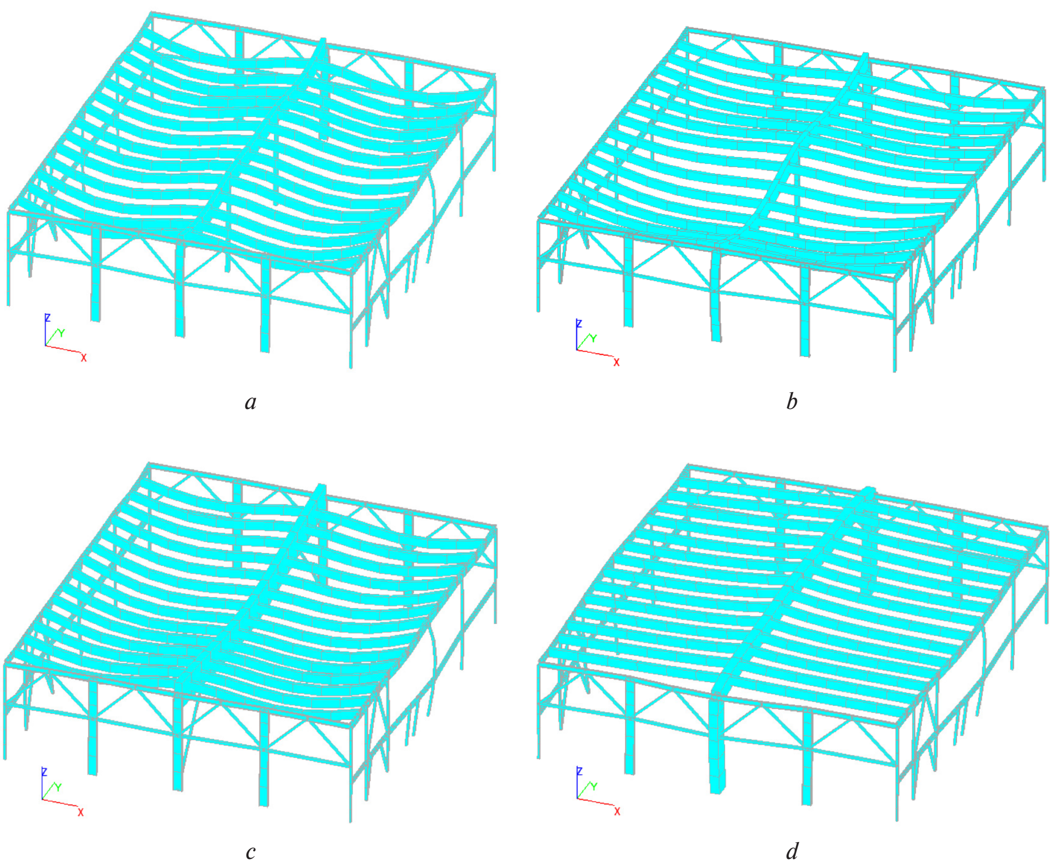

Fig. 3. Deformation pattern of the equipment compartment framework (main loads):
a – variant No. 1; b – variant No. 2; c – variant No. 3; d – variant No. 4

Table 3

Distribution of modal masses by the oscillation modes

Mode	Modal masses according axes, %			Modal coefficients on directions					
	X	*Y*	*Z*	*X*	*Y*	*Z*	U_X	U_Y	U_Z
1	75.52	0.01	0	210.991	2.818	–0.009	–1,919.659	145,510.399	–288,761.440
2	0.02	64.07	0	–3.194	194.341	–0.008	–133,120.145	–2,154.784	240,661.893
3	0	0	0	1.298	–0.497	0.042	402.227	1,832.230	–178,639.298
4	0	0	0	0.015	0.233	0.015	–1.237	–309.183	31,746.669
5	0	0	0	–0.772	–0.173	0.003	142.147	–1,034.145	–25,031.261
6	0	0.06	0	–0.063	5.842	0.564	47.748	–543.875	7,028.474
7	0	0.78	0	0.443	21.429	–0.247	–4936.622	490.936	26,720.510
8	9.36	0	0	–74.281	–0.156	–0.362	–401.122	–49,139.685	100,550.616
9	3.64	0	0	46.350	–0.184	–0.856	–1,111.804	19,759.099	–70,716.151
10	0.08	0	0	6.983	–1.320	0.440	1,373.287	–6,022.928	–1,112.684
11	0	0.05	0	1.218	5.345	–0.926	–4,779.706	–5,095.041	69,090.225
12	1.22	0	0	26.763	0.412	1.004	754.748	6,647.449	–52,850.363
13	0.03	0.25	0	–4.424	–12.027	0.299	8,198.160	–7,231.343	–174,171.083
14	0	0.25	0	–0.870	12.160	1.240	–6,977.060	–6,983.382	95,798.987
15	0	1.21	0	–2.174	–26.724	0.210	18,071.081	–2,834.826	–57,450.742
16	0.03	21.61	0	–4.382	112.878	0.024	–76,863.721	–3,112.594	115,014.145
17	0.27	0.24	0	–12.729	–11.874	0.895	9,470.938	–14,676.674	14,428.976
18	0.22	0.11	0	11.315	8.162	–0.262	–6,181.096	7,826.191	–12,991.394
19	0.18	0.09	0	10.226	7.376	0.065	–4,853.149	5,008.684	–10,216.881
20	0.11	0.03	0	–7.949	–4.097	0.085	3,700.812	–3,258.080	3,190.950
21	2.84	0	0	–40.901	–1.143	–0.066	494.287	–18,511.648	56,675.071
22	0.56	0	0	18.127	–1.012	–0.260	–734.031	8,373.429	–34,779.036
23	1.45	0	0	29.255	2.107	–0.122	–1,193.755	12,813.429	–51,850.493
24	0.14	0	0	–9.047	–1.347	–0.025	594.943	–3,959.340	16,242.315
25	0.52	0	0	17.428	1.723	0.045	–760.280	7,439.327	–30,547.791
26	0.02	0	0	–3.049	–0.256	–0.059	–429.573	–1,378.968	4,872.895
27	0.24	0	0	11.991	0.410	–0.287	–1,244.714	5,462.743	–21,870.828
28	0.26	0.01	0	–12.285	2.500	–0.239	–2,651.720	–5,214.588	18,236.440
29	0.14	0.01	0	8.933	–2.91	0.265	1,938.215	3,579.059	–13,739.910
30	0.11	0.01	0	7.936	2.891	–0.647	–3,647.040	4,211.922	–10,096.188
31	0.45	0	0	–16.291	1.500	0.128	–2,243.588	–7,404.011	11,774.809
32	0.18	0.02	0	10.290	–3.297	0.032	566.979	4,705.499	–9,580.365
33	0	0	0	–1.466	1.996	–0.710	–2,423.491	241.480	676.025
34	0.07	0	0	6.224	0.143	–1.725	–2,039.661	4,950.520	–1,030.763
35	0.01	0.32	0.02	2.891	13.738	3.044	–799.311	–2,247.413	13,632.159
36	0.02	0.49	0	3.034	–17.005	0.092	4,876.181	1,099.949	–24,860.943
37	0	0.66	0	–0.337	19.724	–0.208	–6,726.072	39.400	19,122.914
38	0	1.39	0	1.103	28.652	–0.766	–10,375.891	1,500.389	31,854.379
39	0	0.22	0	0.748	11.488	–0.461	–4,308.832	844.138	18,686.958
40	0.02	0.13	0	3.380	–8.845	0.488	3,502.910	837.787	–9,165.409
41	0.06	0.05	0	6.182	5.225	–0.265	–2,293.322	3,059.340	980.263
42	0.09	0	0	7.284	–1.670	0.090	728.364	2,892.594	–11,119.344
43	0	0.01	0	–2.281	–2.592	0.087	1,180.746	–997.254	7,420.404
44	0.01	0	0	–2.433	2.091	0.154	–460.034	–1,076.493	14,490.276
45	0	0.02	0	0.415	3.311	–0.121	–1,368.896	260.580	3,984.996
46	0.01	0	0	–2.737	0.822	–0.034	–246.182	–944.747	3,880.257
47	0	0	0	–0.014	–2.207	–0.001	1,110.905	–178.614	–4,154.865
48	0	0	0	–0.203	2.165	–0.253	–1,319.117	–399.224	11,131.705
49	0.05	0	0	–5.429	–0.301	–1.864	–2,071.989	–95.036	–24,924.922
50	0	0.01	0.01	0.165	–2.585	–2.786	–2,859.930	25,572.352	369.851
Sum	**97.91**	**92.13**	**0.03**						

Table 4

Intrinsic frequency spectrum of the load-bearing framework of the equipment compartment

Intrinsic frequency, Hz	Design variant No			
	1	2	3	4
1	1.47	1.45	1.43	1.53
2	1.70	1.66	3.32	2.46
3	3.00	2.99	3.41	3.62
4	3.32	3.32	3.45	3.75
5	3.42	3.42	3.69	3.82
6	3.76	3.76	3.82	3.86
7	3.95	3.95	4.97	4.00
8	4.76	4.75	5.39	4.60

Table 5

Deformed state of the load-bearing framework of the equipment compartment

Indicator	Design variant No.			
	1	2	3	4
Displacement due to main load, mm				
along the *X* axis	4.7	6.8	7.2	29.9
along the *Y* axis	3.5	8.4	1.8	19.0
along the *Z* axis	16.7	36.8	25.3	85.1
(acceptable *Z*)	50.0	50.0	116.2	116.2
Displacement due to seismic load, mm				
along the *X* axis	97.9	99.9	92.9	80.1
along the *Y* axis	14.8	15.5	12.3	13.9
along the *Z* axis	2.5	2.3	1.9	1.8

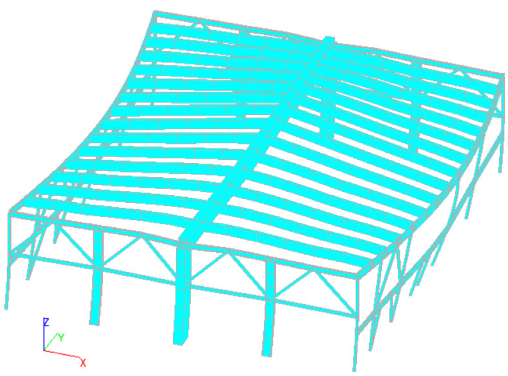

Fig. 4. Deformation pattern of the equipment compartment framework (seismic load) for variant No. 4

Conclusions. In the course of the presented research, the four most common design schemes of the single-span, single-storey framework of the equipment compartment of the Fire station for 8 vehicles were analysed. The framework structure uses one of the directions of modern green technologies in construction – a combination of wood and steel. The combined design of the framework involves the implementation of a roof framing made of wooden glued laminated timber, which creates increased stiffness, and vertical supports-columns made of steel profiles, which contributes to the flexibility of the framework when subjected to seismic loads. The dynamic spectrum of such a framework is quite sparse and has a lower natural frequency of about 1.5 Hz.

The most effective in terms of a set of technical and economic indicators was the design variant of the framework using an arched roofing system. It allows one to completely free up the internal space of the equipment compartment for the possibility of manoeuvring fire equipment. The weight of such a framework is on average 10 % higher than that of a design variant with one intermediate vertical support.

The use of biocomposite glued laminated timber makes it possible to reduce the material consumption of the framework by up to 25 %. This is undoubtedly a very promising direction in the use of green technologies in the design of single-storey building frames.

References.

1. Travush, V., Emelianov, S., Kolchunov, V., & Bulgakov, A. (2016). Mechanical safety and survivability of buildings and building structures under different loading types and impacts. *Procedia Engineering*, *164*, 416-424. https://doi.org/10.1016/j.proeng.2016.11.639

2. Jkhsi, Sh. (2020). Evaluation of risk and safety in building structures under construction. *International Journal of Advanced Engineering Sciences and Applications*, *1*(4), 24-28. https://doi.org/10.47346/ijaesa.v1i4.43

3. Zheng, Z., Su, Yi., Liu, J., Zhou, Zh., & Wang, X. (2024). Optimization study on stakeholder capability configuration in green construction. *Buildings*, *14*, 3135. https://doi.org/10.3390/buildings14103135

4. Wang, J., Wang, Ji., Liu, B., & Gu, H. (2024). Research on the evaluation and analysis method of green construction of substation project. *E3S Web of Conferences*, *561*, 02003. https://doi.org/10.1051/e3sconf/202456102003

5. Pati, V.A., Wadalkar, Sh., Kale, V., Sawant, R., & Joshi, D.A. (2024). Optimizing sustainable construction costs: A Green Building Approach for Residential Development. *E3S Web of Conferences*, *559*, 04034. https://doi.org/10.1051/e3sconf/202455904034

6. Sviatohorov, I. (2024). Application of geotechnical structures in "green construction". *Environmental safety and nature management*, *2*(50), 36-47. https://doi.org/10.32347/2411-4049.2024.2.36-47

7. Tienthavorn, T. (2024). Exploring sustainable conservation: A case study on the transformation of knockdown wooden houses in Thailand. *Journal of Architectural/Planning Research and Studies*, *22*(1), 268705. https://doi.org/10.56261/jars.v22.268705

8. Kossakowski, P.G. (2024). New Advances in Strengthening of Structural Timber. *Materials*, *17*(11), 2545. https://doi.org/10.3390/ma17112545

9. Dmytrenko, A., Dmytrenko, T., Derkach, T., & Klochko, L. (2018). Experimental investigation and computer-generated simulation of reinforced double-tee girders with a wall of oriented standard board. *International Journal of Engineering & Technology*, *7*(4.8), 115-119. https://doi.org/10.14419/ijet.v7i4.8.27224

10. Dezhin, M., & Ibragimov, A. (2024). Development of constructive solutions for interfaces of wooden beams and CLT. *E3S Web of Conferences*, *533*, 02003. https://doi.org/10.1051/e3sconf/202453302003

11. Das, A.K., Islam, Md. N., Ghosh, C.K., & Ghosh, R.K. (2023). Physical and mechanical properties of Albizia procera glulam beam. *Heliyon*, *9*, e18383. https://doi.org/10.1016/j.heliyon.2023.e18383

12. Wei, P.X., Wang, B.J., Li, H., Wang, L.B., Peng, S., & Zhang, L. (2019). A comparative study of compression behaviors of cross-laminated timber and glued-laminated timber columns. *Construction and Building Materials*, *222*(20), 86-95. https://doi.org/10.1016/j.conbuildmat.2019.06.139

13. Dezhin, M., & Ibragimov, A. (2023). Improving the reliability of the joints of wooden elements on metal linings. *E3S Web of Conferences*, *402*, 10005. https://doi.org/10.1051/e3sconf/202340210005

14. Faria, D.L., Cruz, T.M., Dias, M.C., Mendes, M.C., & Guimaraes, J.B. (2020). Physical and mechanical behavior of glulam beams produced with rubberwood treated with preservatives. *Ciência e Agrotecnologia*, *44*, 012020. https://doi.org/10.1590/1413-7054202044012020

15. Bergamin, R.V., Mascia, N.T., Dodadon, B.F., & Trautwein, L.M. (2020). Experimental investigation of glued-laminated timber beams with Vectran-FRP reinforcement. *Engineering Structures*, *202*(1), 109818. https://doi.org/10.1016/j.engstruct.2019.109818

16. Martynov, V., Myasnikov, D., & Roshchina, S. (2024). Investigation of the strength and deformability of glued wooden beams with lamellas made of thermally damaged (Pinus sylvestris L.) wood based on experimental planning. *Forestry Engineering Journal, 14*(1), 170-189. https://doi.org/10.34220/issn.2222-7962/2024.1/10

17. Sotiriadis, K., Guzii, S., Mácová, P., Viani, A., Dvořák, K., & Drdacky, M. (2019). Thermal behavior of an intumescent alkaline aluminosilicate composite material for fire protection of structural elements. *Journal of Materials in Civil Engineering*, *6*(31), 237-248. https://doi.org/10.1061/(ASCE)MT.1943-5533.0002702

18. Tsapko, Yu., Bondarenko, O., Tsapko, O., Gorbachova, A., Mazurchuk, S., & Zherebchuk, D. (2023). Functional assignment of technological accessories for woodworking. *Ways to Improve Construction Efficiency*, *51*, 206-217. https://doi.org/10.32347/2707-501x.2023.51(1).206-217

19. Kashytskyi, V. P., Sadova, O. L., Zabolotnyi, O. V., Malets, V. M., & Mazurok, V. S. (2022). Development of biocomposites filled with products of recycling of secondary raw materials of plant origin. *Visnyk of Vinnytsia Polytechnical Institute*, *1*, 95-102. https://doi.org/10.31649/1997-9266-2022-160-1-95-102

20. Bannikov, D. O., Radkevich, A. V., & Nikiforova, N. A. (2019). Features of the design of steel frame structures in India for seismic areas. *Materials Science Forum*, *968*, 348-354. https://doi.org/10.4028/www.scientific.net/MSF.968.348

21. Bofang, Z. (2018). *The finite element method: fundamentals and applications in civil, hydraulic, mechanical and aeronautical engineering*. Singapore: John Wiley & Sons Singapore Pte. Ltd. https://doi.org/10.1002/9781119107323

22. Zienkiewicz, O. C., Taylor, R. L., & Fox, D. D. (2014). *The finite element method for solid and structural mechanic*. 7th edition. Elsevier LTD. Retrieved from URL: https://www.sciencedirect.com/book/9781856176347/the-finite-element-method-for-solid-and-structural-mechanics

23. Fialko, S., & Karpilovskyi, V. (2018). Time history analysis formulation in SCAD FEA software. *Journal of Measurements in Engineering*, *6*, 4, 173-180. https://doi.org/10.21595/jme.2018.20408

24. Hezentsvei, Y., & Bannikov, D. (2020). Effectiveness evaluation of steel strength improvement for pyramidal-prismatic bunkers. *EUREKA, Physics and Engineering*, *2020*(2), 30-38. https://doi.org/10.21303/2461-4262.2020.001146

25. Bannikov, D., Tiutkin, O., Hezentsvei, Y., & Muntian, A. (2024). Controlling the dynamic characteristics of steel bunker containers for bulk materials. *IOP Conference Series: Earth and Environmental Science*, *1348*(1), 012002. https://doi.org/10.1088/1755-1315/1348/1/012002

26. Bannikov, D., & Yakovliev, S. (2020). Development of dynamic integral evaluation method of technical state of one-section electric locomotive body. *Eastern-European Journal of Enterprise Technologies*, *1*(7-103), 57-64. https://doi.org/10.15587/1729-4061.2020.192468

27. Bannikov, D., Radkevich, A., & Muntian, A. (2020). Modernization of the buffer beam of PE2U traction unit electric locomotive. *IOP Conference Series: Materials Science and Engineering*, *985*(1), 012035. https://doi.org/10.1088/1757-899X/985/1/012035

«Зелені» технології у проєктуванні одноповерхових каркасів

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Мета. Аналіз ефективності великопрольотних конструктивних систем на основі клеєного деревного бруса для одноповерхового каркасу громадської будівлі.

Методика. У роботі використовувався комплекс методів дослідження, що включає науковий аналіз і синтез наявної технічної інформації стосовно застосування сучасних виробів із деревини для проєктування несучих каркасів будівель із великим прольотами. Також застосовувалися методи комп'ютерного моделювання на базі чисельного методу будівельної механіки – методу скінченних елементів. Аналіз роботи конструктивних варіантів проводився із використанням проєктно-обчислювального комплексу SCAD (Україна). Окремим напрямом у роботі були конструкторські розробки, що включали методи інженерної оцінки точності й достовірності отриманих результатів, а також виконання конструкторської документації.

Результати. Для розглянутих конструктивних варіантів покриття каркасу апаратного відсіку отримані картини напружено-деформованого стану, а також спектри власних частот і форм коливань. Рекомендований до практичної реалізації за сукупністю техніко-економічних показників конструктивний варіант каркасу передбачає використання аркової системи покриття. Також показано, що застосування біокомпозитного клеєного бруса відкриває резерви для зниження матеріаломісткості конструкції за попередніми оцінками до 25 %.

Наукова новизна. Проведені дослідження дозволили комплексно оцінити статичну й динамічну несучу здатність великопрольотного каркасу із використанням клеєного брусу. Доведена висока ефективність застосування комбінованої системи каркасу, особливо у випадку біокомпозитного брусу. Отриманий частотний спектр при цьому є дискретним і лежить у діапазоні нижніх частот 1,5–5,0 Гц.

Практична значимість. Використання для несучих елементів одноповерхових каркасів клеєного й біокомпозитного деревних брусів відкриває напрям «зелених» технологій для будівель спеціалізованого призначення, таких як Пожежна станція. У сукупності із сучасними оздоблювальними матеріалами типу вогнестійкої деревної шерсті це дозволяє підвищити експлуатаційні якості дерев'яних конструкцій.

Ключові слова: *деревина, клеєний деревний брус, біокопозитний деревний брус, несучий каркас, апаратний відсік*

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