UDC 621.869.888
DOI: 10.15587/1729-4061.2025.329840

DETERMINING THE LOAD ON A CONTAINER WITH A TRUSS FRAME DURING RAILROAD TRANSPORTATION

Alyona Lovska
Corresponding author
Doctor of Technical Sciences, Professor
Department of Wagon Engineering and Product Quality
Ukrainian State University of Railway Transport
Feuerbakh sq., 7, Kharkiv, Ukraine, 61050
E-mail: alyonaLovskaya.vagons@gmail.com
Oksana Zharova
PhD, Associate Professor
Department of Advanced Mathematics and Systems Modelling
Odesa Polytechnic National University
Shevchenko ave., 1, Odesa, Ukraine, 65044
Arsen Muradian
PhD, Associate Professor
Department of Port Operation and Cargo Handling Technology*
Valeriia Kyryllova
PhD, Associate Professor
Department of Fleet Operation and
Maritime Transportation Technology*
Yevhen Pelypenko
PhD, Associate Professor
Department of Car and Tractor Industry
National Technical University «Kharkiv Polytechnic Institute»
Kyrpychova str., 2, Kharkiv, Ukraine, 61002
*Odessa National Maritime University
Mechnikova str., 34, Odesa, Ukraine, 65029

The object of this study is the processes of perception and redistribution of loads in the structure of a container with a truss frame during railroad transportation. The task addressed is to ensure the strength of the container walls under operational loads.

To provide for the strength of the container walls, it is proposed to increase the rigidity of the frame. In this case, it is assumed to install braces between the corner and vertical posts, as well as a reinforcing horizontal belt between the vertical posts.

To substantiate the proposed improvement, a calculation of the container strength was performed. Two modes of its loading were taken into account: lateral loading and vertical loading. The calculation results showed that the stresses in the container structure under the considered loading modes do not exceed the permissible ones. At the same time, the maximum stresses when the container perceives lateral loads are almost 12% lower than those that operate in a typical structure, and when perceiving vertical loads – by 5%.

In addition, a modal analysis of the container was performed as part of the study. The results of the calculation showed that the safety of its transportation from the point of view of modal analysis is observed.

A feature of the results of this study is that ensuring the strength of the container is achieved not by using high-cost materials in its design but by introducing truss components into the frame.

The scope of practical application of the research results is railroad transport. The conditions for practical use of the results are the fabrication of truss components from the same material as the container frame.

The results of the study could also contribute to compiling the recommendations for the design of new and modernization of existing containers

Keywords: railroad transport, universal container, container improvement, truss structure, container strength, container transportation

Received 26.02.2025
Received in revised form 25.04.2025
Accepted 06.05.2025
Published 27.06.2025

How to Cite: *Lovska, A., Zharova, O., Muradian, A., Kyryllova, V., Pelypenko, Y. (2025). Determining the load on a container with a truss frame during railroad transportation. Eastern-European Journal of Enterprise Technologies, 3 (7 (135)), 6–13. https://doi.org/10.15587/1729-4061.2025.329840*

1. Introduction

Container transportation is one of the most promising types of cargo transportation in international traffic. Due to the mobility of the structure, it is possible to transport them by various modes of transport [1, 2]. At the same time, the absence of the need to reload cargo when transporting it by various modes of transport ensures high competitiveness of containers compared to other types of transport.

The process of transporting containers is accompanied by the action of a fairly wide range of loads on their structure. This situation causes damage to containers on the way. The most frequent damage to containers can include deformation and rupture of the skin. This is explained not only by the action of significant transverse forces on the container structure during transportation but also by the unreliability of cargo fastenings in it. The consequence of these container damages can be a violation of the safety of cargo transportation, as well as environmental safety. In this regard, to increase the efficiency of container cargo transportation, it is important to devise solutions aimed at improving the strength of containers under operational loads. Therefore, research on improving containers is quite important and relevant.

2. Literature review and problem statement

The issue of improving the strength of the container side walls by introducing a sandwich panel cladding is covered in [3]. The work not only proposes a solution that will help reduce the loading of the container during its transportation but also provides the appropriate scientific justification for such a solution. However, the introduction of sandwich components into the container design requires significant capital investments. In addition, maintenance and repair of such containers in operation requires the establishment of an appropriate technical base.

In [4], the results of theoretical and experimental studies of the rigidity of the container structure with side openings are reported. In this case, the authors used the Abaqus software package (France), which implements the finite element method. The results were confirmed by experimental studies. At the same time, the authors did not propose solutions to improve the container design in order to improve its strength under operational loads. This can be explained by the fact that the authors did not set such a task as their goal.

The design features of a container made of carbon fiber are described in paper [5]. It is proven that the use of this material helps reduce the container's packaging by 80 % compared to existing analogs. The author of the work provides the relevant results of the calculation of the strength of the specified container design, which confirmed the feasibility of such an improvement. However, this container design has the same disadvantages as the one described in work [3].

In [6], in order to improve the strength of the container floor, as well as the safety of the cargo transported in it, it was proposed to manufacture the floor from sandwich panels. Mathematical modeling of the vertical loading of the container during railroad transportation was carried out. The results from solving the mathematical model were used in calculating the container for strength. The feasibility of using sandwich panels as components of the container floor was proven. However, no solutions were proposed to improve the strength of the container side walls. This can be explained by the fact that the work not only considered the problem of improving the strength of the container but also the safety of the cargo transported in it.

Paper [7] considers improving the operational properties of a container for the transportation of fruit and vegetable produce. In order to ensure natural ventilation of the container, and accordingly, the safety of the cargo transported in it, it is proposed to equip it with ventilation windows. The results of the calculation of the strength of such a container under operational loads are reported. It was established that the maximum stresses in its structure do not exceed the permissible values. However, the authors of the work did not study solutions to improve the strength of the container side walls.

In [8], the causes of container damage during operation, namely during loading and unloading operations, are highlighted. The research was conducted on the example of the Klaipeda seaport (Lithuania). The need to ensure the safety of containers at the current stage of containerization of cargo transportation is proven. However, the authors did not propose solutions to ensure the safety of containers during rail transportation. Perhaps this can be explained by the fact that the authors set the goal of studying the safety of containers during loading and unloading operations in ports.

Paper [9] highlights the design features of a specialized container, as well as its strength calculation. The calculation of the strength of the container was carried out under the main modes of its loading in operation. However, the case of loading this container during rail transportation was not considered. Perhaps the authors planned to solve this problem in their subsequent publications.

Analysis of the structural integrity of containers lost during transportation at sea is reported in [10]. The authors present the features of finite element analysis of the strength of the container structure when interacting with the water environment. Technical solutions are proposed for removing containers from water to prevent environmental safety. However, the authors limited themselves to studying only this mode of loading the container. This can be explained by the fact that they set themselves just such a task.

Features of building a cargo container model and studying its strength using the Abaqus/CAE software product (France) are highlighted in work [11]. Strength studies were conducted to substantiate the possibility of using the container as a residential module. The results showed that the strength of the container is maintained under the considered loading scheme. However, the issues of container loading during transportation were not studied.

Improving the strength of containers can also be achieved by introducing new materials into their design. For example, in [12], the features of the use of composite materials in structures for various purposes are highlighted. The justification for the use of composite material patches in structural repairs is given. However, the issues of introducing such materials and technologies into container structures were left out of consideration.

In [13], the process of designing a wagon body from extruded aluminum panels based on structural optimization was considered. The proposed technical solutions were confirmed by comprehensive calculations on the strength of the wagon body. However, the possibility of such implementation was not investigated using the example of modular vehicles, in particular containers.

The feasibility of using magnesium alloys in the load-bearing structures of vehicles was considered in paper [14]. The purpose of such implementation is not only to improve the strength of vehicles but also to reduce their packaging. The studies confirmed the feasibility of the proposed implementation. However, similar to [13], the authors limited themselves to considering the load-bearing structures of wagons.

Our review of the literature [3–14] proves that the issue of improving the frame of containers to ensure their strength under operational loads requires further research and separate solution. Available scientific work on this topic does not fully cover the specified problem.

3. The aim and objectives of the study

The purpose of our study is to identify the loading on a container with a truss frame during rail transportation. This will contribute to improving the strength of containers in operation and, accordingly, to reducing the costs of their maintenance.

To implement the stated goal, the following tasks were set:

– to calculate the strength of the container when perceiving lateral loads;

– to calculate the strength of the container when perceiving vertical loads.

4. The study materials and methods

The object of our study is the processes of perception and redistribution of loads in the structure of a container with a truss frame during railroad transportation.

The main hypothesis of the study assumes that designing a container frame with truss components could contribute to improving its strength during operation.

To ensure the strength of the container walls during operation, it is proposed to increase the rigidity of its frame (Fig. 1). In this case, it is planned to install braces between the corner and vertical posts, as well as a reinforcing horizontal belt between the vertical posts. This belt runs at a height of 1/3 from the lower strapping of the frame.

The same reinforcing horizontal belt is installed on the end wall. To substantiate the proposed improvement, a calculation of the container strength was performed. The spatial model of the container was built using the SolidWorks (France) software (Fig. 2).

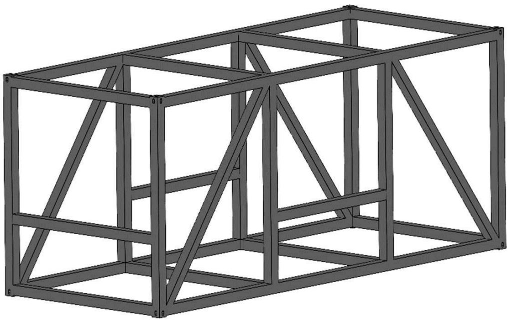

Fig. 1. Container frame

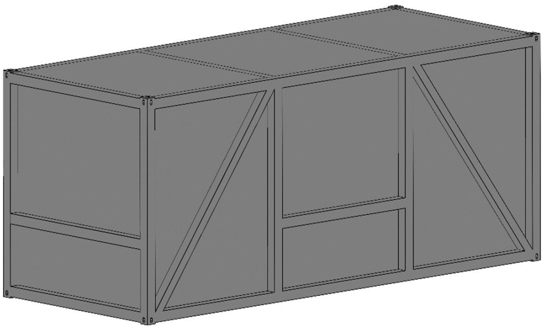

Fig. 2. Spatial container model

To calculate the strength of the container, the finite element method was used, as the most common method for calculating vehicles currently used in their design [15–17]. The implementation of this method was carried out in SolidWorks Simulation (France). The finite element model was built using tetrahedra [18–20]. This type of element was chosen due to the fact that the mesh was constructed on a solid body (Fig. 3). The number of mesh elements was determined graph-analytically [21, 22]. Taking this into account, the model has 77090 elements with a maximum size of 120 mm and a minimum of 24 mm, as well as 141251 nodes. The number of Jacobian points was 16.

Since this study is aimed at improving the strength of the container side walls, the calculation was carried out when the container perceives lateral loads. It was taken into account that the container experiences a vertical load P_v taking into account the use of the total load capacity (Fig. 4).

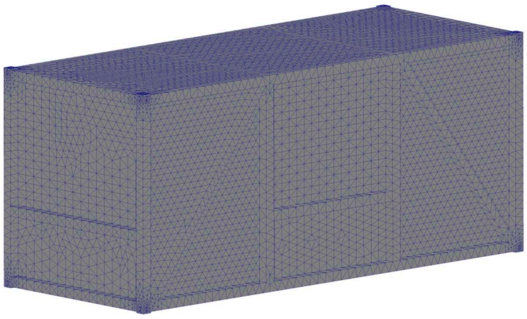

Fig. 3. Finite-element container model

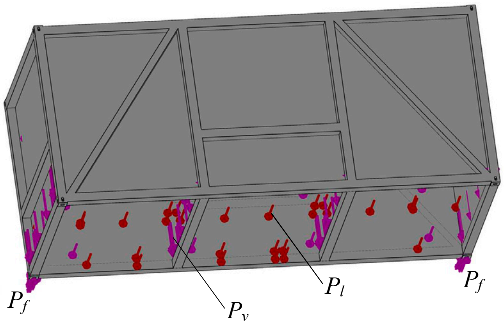

Fig. 4. Container design scheme

The side wall of the container is subjected to a lateral load P_l, which includes centrifugal force and wind load. These forces were calculated using the formulas given in the regulatory document, namely, DSTU 7598:2014. Freight railroad wagons. General requirements for calculations and design of new and modernized 1520 mm gauge railroad wagons (non-self-propelled). The foreign analog of this standard is "EN 12663-2. Railroad applications – structural requirements of railroad vehicle bodies – Part 2: Freight railroad wagons".

The centrifugal force P_{cf} was determined from the formula

$$P_{cf}=\frac{P_{gw}\cdot V^2}{g\cdot R}, \qquad (1)$$

where P_{gw} is the gross weight of the container; V is the speed of the railroad wagon loaded with the container; g is the acceleration of gravity; R is the radius of the curve into which the railroad wagon loaded with the container fits.

The wind load was calculated as follows

$$P_w=w\cdot S, \qquad (2)$$

where w is the intensity of the wind load on the side wall of the container; S is the area of the side wall of the container.

Reactions P_f to the action of the specified loads were applied to the container fittings, which are located along the length of the side wall on its loading side. The container construction material was designated as steel grade 09G2S with a strength class of 345 MPa. This type of material was chosen due to the fact that it is the most common for the manufacture of load-bearing structures of railroad vehicles. The permissible stresses for steel grade 09G2S in the studied design modes were taken equal to 210 MPa. Due to the fact that steel is an isotropic material, the Mises criterion was used as the design criterion. The container was fixed to the fittings. In this case, a rigid connection was used [23, 24]. This type of connection was chosen under the following assumption: the container fittings rest against the fitting stops of the flat wagon, i.e., the container has no degree of freedom in the longitudinal plane.

To study the vertical loading of a container, as one of the most common types of loading of its structure during transportation by rail, appropriate calculations were carried out. The oscillations of jumping and galloping were studied. It was taken into account that the containers are transported by a flat wagon of the model 13–4012 on bogies 18–100 with a spring suspension stiffness of 8000 kN/m. In this case, there are two containers on the flat wagon, which have the same cargo loading. The containers do not have their own degree of freedom in the vertical plane and move together with the flat wagon. The mathematical model was solved in the Mathcad software package (USA) using the Runge-Kutta method [25–28]. The following initial conditions were taken into account: the initial displacement is taken equal to 0.004 m, and the initial velocity is 0 [29–33]. The calculation was carried out at a speed of the flat wagon of 80 km/h. The obtained acceleration was taken into account when calculating the strength of the container.

To study the natural frequencies of vibrations of the container, a modal analysis of its structure was carried out. For this purpose, the options of the SolidWorks Simulation software package were used.

5. Results of determining the loading on a container with a truss frame during railroad transportation

5. 1. Results of determining the loading on a container when perceiving lateral loads

Taking into account the formed calculation scheme shown in Fig. 4, the strength of the container was calculated. The results of our calculations are shown in Fig. 5–7. The maximum stresses were recorded in the zones of interaction of the vertical uprights of the container with the longitudinal beams of the frame (Fig. 5, 6). These stresses amounted to 158.1 MPa. They are lower than the permissible ones. It should also be noted that the obtained stresses are almost 12% lower than those operating in a typical design.

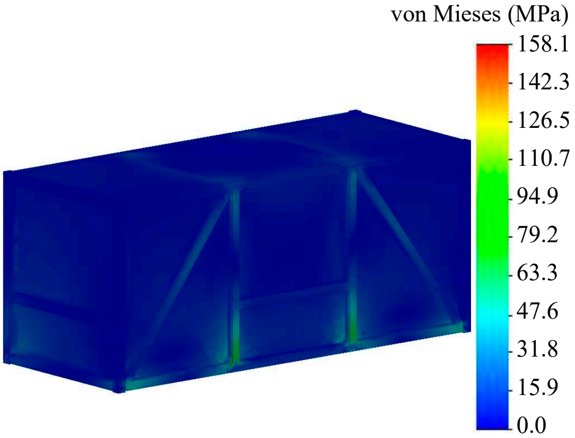

Fig. 5. Container stress state

The maximum displacements were recorded in the transverse beams of the container frame – 3.15 mm (Fig. 7).

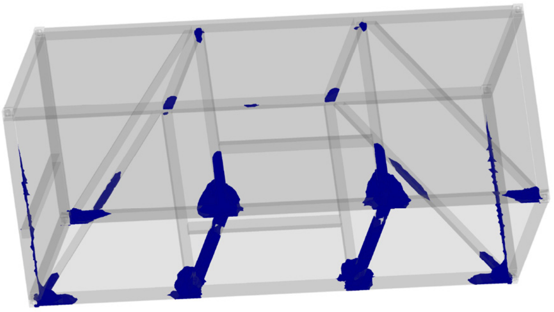

Fig. 6. The most loaded areas of the container

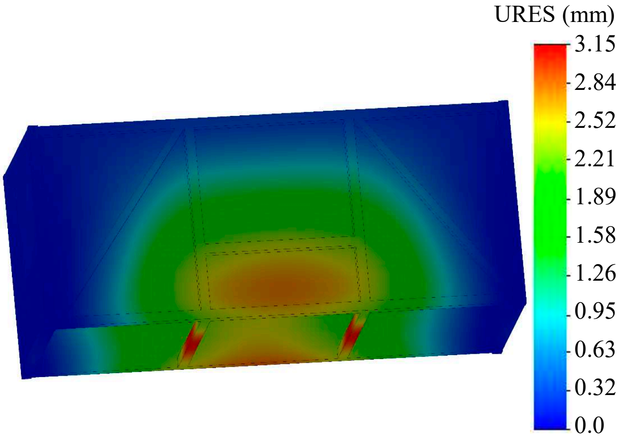

Fig. 7. Movement in container structure nodes

This distribution of displacements can be explained by the fact that the end parts of these beams interact with the longitudinal beams, and the middle part of the transverse beams has a degree of freedom in the vertical plane.

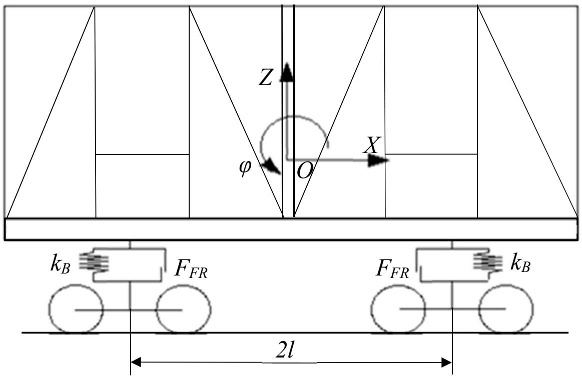

Fig. 8. Calculation diagram of a flat wagon with containers

5. 2. Results of determining the loading on a container when perceiving vertical loads

To determine the vertical accelerations acting on the container during transportation by rail, a calculation scheme was built, shown in Fig. 8.

The equation of motion of a flat wagon with containers can be written as:

$$\begin{cases} M\cdot\dfrac{d^2}{dt^2}q_1+2k_B\cdot q_1= \\ =-F_{FR}\cdot\left(\begin{array}{l}\operatorname{sign}\left(\dfrac{d}{dt}\delta_1\right)+\\ +\operatorname{sign}\left(\dfrac{d}{dt}\delta_2\right)\end{array}\right), \\ I\cdot\dfrac{d^2}{dt^2}q_2+\left(2\cdot l^2\cdot k_B\right)\cdot q_2= \\ =F_{FR}\cdot l\cdot\left(\begin{array}{l}\operatorname{sign}\left(\dfrac{d}{dt}\delta_1\right)+\\ +\operatorname{sign}\left(\dfrac{d}{dt}\delta_2\right)\end{array}\right), \end{cases} \qquad (3)$$

where M is the mass of the frame of the flat wagon with containers placed on it during jumping vibrations; I is the moment of inertia of the frame of the flat wagon with containers placed on it during galloping vibrations; k_B is the stiffness of the springs of the spring suspension of the bogie; F_{FR} is the friction force acting in the spring suspension; δ_i is the deformations occurring in the spring suspension.

Based on our calculations, it was established that the acceleration acting on the containers is about 1.2 m/s^2.

This acceleration was taken into account when determining the strength of the container as a component of the vertical load acting on it during railroad transportation. The design scheme of the container is shown in Fig. 9. This scheme takes into account that the container is subjected to a vertical load P_v, which includes vertical static and dynamic loads, as well as the pressure of the bulk cargo expansion on its walls.

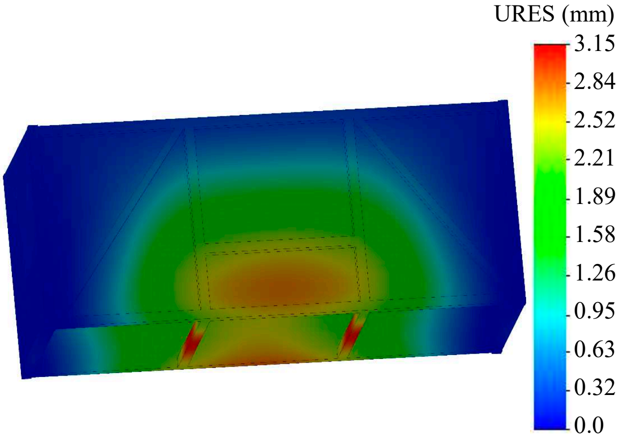

Fig. 9. Container design diagram

The features of constructing a finite element model are identical to those considered in the study of the lateral loading of the container. The calculation results are shown in Fig. 10–12. The maximum stresses were recorded in the zones of interaction of the transverse beams with the longitudinal ones and amounted to 163.1 MPa (Fig. 10, 11). These stresses do not exceed the permissible ones and are 5% lower than those operating in a typical design.

The maximum displacements occur in the middle parts of the cross beams and are 3.54 mm (Fig. 12).

In the study we also paid attention to determining the natural frequencies of vibrations of the container of the proposed design during railroad transportation. For this purpose, a model analysis was conducted. The calculation was carried out using the scheme shown in Fig. 9. In this case, the options of the SolidWorks Simulation software package were used. The calculation results are shown in Fig. 13. As an example, the shapes and frequencies of the first six vibrations of the container are given.

The safety of container transportation was assessed by the first natural frequency of oscillations, which should be at least 8 Hz. Analyzing the results obtained, it can be concluded that the safety of transportation from the point of view of modal analysis is ensured.

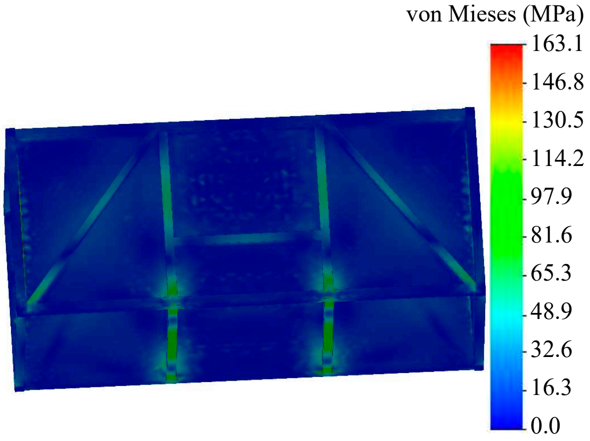

Fig. 10. Container stress state

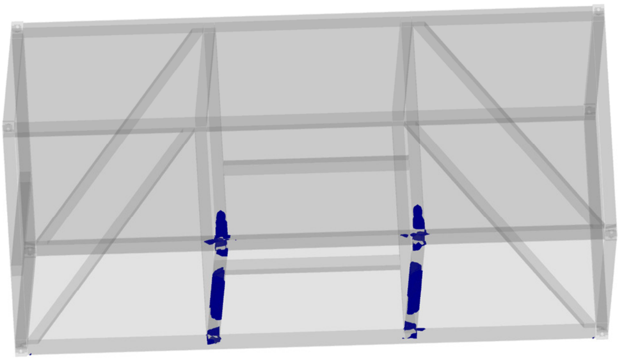

Fig. 11. The most loaded areas of the container

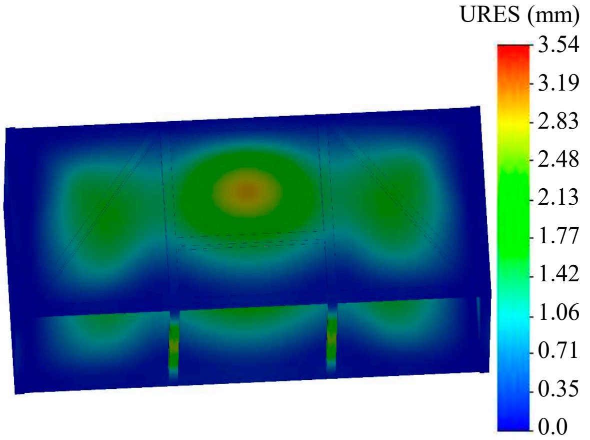

Fig. 12. Movement in container nodes

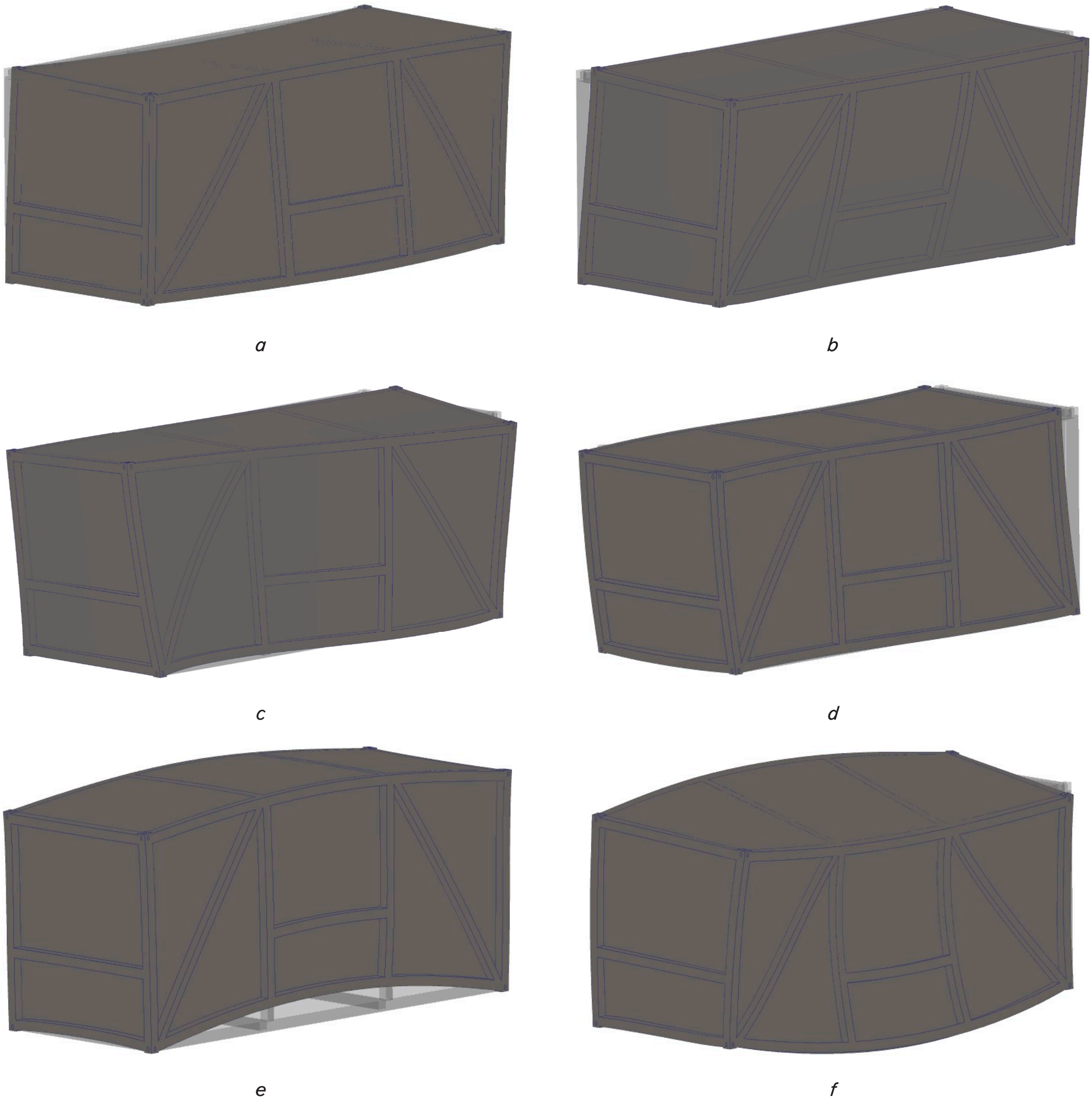

Fig. 13. Certain modes of container oscillations: *a* – first mode at frequency $\nu = 58.8$ Hz; *b* – second mode at frequency $\nu = 90$ Hz; *c* – third mode at frequency $\nu = 134.4$ Hz; *d* – fourth mode at frequency $\nu = 135.7$ Hz; *e* – fifth mode at frequency $\nu = 142.9$ Hz; *f* – sixth mode at frequency $\nu = 162.1$ Hz

6. Discussion of results based on determining the loading on a container with a truss frame during railroad transportation

In order to ensure the strength of the container walls during operation, it is proposed to strengthen its frame (Fig. 1). This solution involves making the side wall of the frame from a truss structure, which consists of vertical uprights, braces, and a horizontal belt.

To substantiate the proposed solution, a calculation was performed of the container's strength when it perceives lateral and vertical loads. It was established that when the container perceives lateral loads, the maximum stresses in its structure arise in the zones of interaction of the vertical uprights with the longitudinal beams of the frame (Fig. 5, 6). These stresses amounted to 158.1 MPa and are lower than the permissible ones. The obtained stresses are almost 12% lower than those operating in a typical design. The maximum displacements were recorded in the transverse beams of the container frame – 3.15 mm (Fig. 7).

To determine the vertical loading on the container, mathematical modeling of its loading under the conditions of transportation on a flat wagon was carried out (Fig. 8). Based on our calculations, it was established that the acceleration acting on the containers is about 1.2 m/s^2. The determined acceleration value was taken into account in the calculations for the strength of the container. It was established that the maximum stresses arise in the zones of interaction of the transverse beams with the longitudinal ones and amounted to 163.1 MPa (Fig. 10, 11). These stresses do not exceed the permissible ones and are 5% lower than those acting in a typical design. The maximum displacements occur in the middle parts of the transverse beams and are 3.54 mm (Fig. 12).

The structural solutions proposed in our work to improve the container have certain advantages compared to the known ones. For example, unlike [1, 4], the proposed improvement does not require significant capital investments for implementation, and the container resource can be maintained with the existing repair base. This solution has the same advantage in comparison with [3]. Unlike works [2, 5, 6], we have proposed a solution to improve the container design, which could help improve its durability during operation. Unlike [7–9], our work has investigated the durability of the container during its transportation as the most unfavorable case of its loading during operation. Compared with [12–14], this study proposed solutions aimed directly at improving the durability of containers as the most common means of transport in international traffic.

The proposed solutions for improving containers are appropriate both when designing new containers and when modernizing already operated ones.

The potential expected effect of using the research results is to increase the efficiency of container transportation by reducing the costs of their maintenance. The research results could also contribute to compiling the recommendations for the design of new and modernizing existing containers.

The main limitation of this study is that the formed finite element model of the container does not take into account welds.

The disadvantage of our study is that when calculating the strength of the container, it was considered as a monolithic structure. That is, it was assumed that all structural elements interact rigidly with each other.

A promising area for further research is to determine the strength of the container under other calculation schemes of its structural loads. We also plan to carry out a study on optimizing the geometry of the container skin sheets.

7. Conclusions

1. The container strength was calculated when perceiving lateral loads. It was established that the maximum stresses arise in the zones of interaction of the vertical uprights of the container with the longitudinal beams of the frame. These stresses amounted to 158.1 MPa and are almost 12% lower than those operating in a typical design. The maximum displacements were recorded in the transverse beams of the container frame – 3.15 mm.

2. The container strength was calculated when perceiving vertical loads. For this purpose, mathematical modeling of the dynamic loading of the container in the vertical plane was carried out. Based on our calculations, it was established that the acceleration acting on the containers is about 1.2 m/s^2. The obtained acceleration value was taken into account when calculating the container strength. The maximum stresses were recorded in the zones of interaction of the transverse beams with the longitudinal ones and amounted to 163.1 MPa. These stresses do not exceed the permissible ones and are 5% lower than those in a typical design. The maximum displacements occur in the middle parts of the cross beams and are 3.54 mm.

A modal analysis of the container during its transportation by rail was performed. The results of our calculation showed that the safety of its transportation from the point of view of modal analysis is observed.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

Funding

The study was conducted without financial support.

Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

References

1. Gerlici, J., Lovska, A., Vatulia, G., Pavliuchenkov, M., Kravchenko, O., Solčanský, S. (2023). Situational Adaptation of the Open Wagon Body to Container Transportation. Applied Sciences, 13 (15), 8605. https://doi.org/10.3390/app13158605
2. Lee, C.-Y., Song, D.-P. (2017). Ocean container transport in global supply chains: Overview and research opportunities. Transportation Research Part B: Methodological, 95, 442–474. https://doi.org/10.1016/j.trb.2016.05.001
3. Vatulia, G. L., Lovska, A. O., Krasnokutskyi, Y. S. (2023). Research into the transverse loading of the container with sandwich-panel walls when transported by rail. IOP Conference Series: Earth and Environmental Science, 1254 (1), 012140. https://doi.org/10.1088/1755-1315/1254/1/012140
4. Zha, X., Zuo, Y. (2016). Theoretical and experimental studies on in-plane stiffness of container structure with holes. Advances in Mechanical Engineering, 8 (6). https://doi.org/10.1177/1687814016651372
5. Yildiz, T. (2019). Design and Analysis of a Lightweight Composite Shipping Container Made of Carbon Fiber Laminates. Logistics, 3 (3), 18. https://doi.org/10.3390/logistics3030018
6. Lovska, A., Stanovska, I., Kyryllova, V., Okorokov, A., Vernigora, R. (2024). Determining the vertical load on a container with a floor made of sandwich panels transported by a flat wagon. Eastern-European Journal of Enterprise Technologies, 6 (7 (132)), 36–44. https://doi.org/10.15587/1729-4061.2024.315059

7. Rahimov, R. V., Khadjimukhametova, M. A., Rakhmatov, Z. X. (2016). Development of improved technical means for transportation fruits and vegetables. European Science Review, 1-2, 175–177. https://doi.org/10.20534/esr-16-1.2-175-177
8. Jakovlev, S., Eglynas, T., Jusis, M., Jankunas, V., Voznak, M. (2025). Mitigating Container Damage and Enhancing Operational Efficiency in Global Containerisation. Sensors, 25 (7), 2019. https://doi.org/10.3390/s25072019
9. Cheng, K. J., Lees, C. H., Peng, C. C. (2024). Design and structural analysis of high payload C1 container. Journal of Physics: Conference Series, 2878(1), 012012. https://doi.org/10.1088/1742-6596/2878/1/012012
10. Oterkus, S., Wang, B., Oterkus, E., Galadima, Y. K., Cocard, M., Stefanos, S. et al. (2022). Structural Integrity Analysis of Containers Lost at Sea Using Finite Element Method. Sustainable Marine Structures, 4 (2), 11–17. https://doi.org/10.36956/sms.v4i2.505
11. Ling, P. C. H., Tan, C. S. (2019). Numerical Simulation of ISO Freight Container Using Finite Element Modelling. Proceedings of AICCE'19, 463–469. https://doi.org/10.1007/978-3-030-32816-0_31
12. Kondratiev, A., Píštěk, V., Smovziuk, L., Shevtsova, M., Fomina, A., Kučera, P., Prokop, A. (2021). Effects of the Temperature-Time Regime of Curing of Composite Patch on Repair Process Efficiency. Polymers, 13 (24), 4342. https://doi.org/10.3390/polym13244342
13. Lee, H.-A., Jung, S.-B., Jang, H.-H., Shin, D.-H., Lee, J. U., Kim, K. W., Park, G.-J. (2015). Structural-optimization-based design process for the body of a railway vehicle made from extruded aluminum panels. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 230 (4), 1283–1296. https://doi.org/10.1177/0954409715593971
14. Lee, W. G., Kim, J.-S., Sun, S.-J., Lim, J.-Y. (2016). The next generation material for lightweight railway car body structures: Magnesium alloys. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 232 (1), 25–42. https://doi.org/10.1177/0954409716646140
15. Koziar, M. M., Feshchuk, Yu. V., Parfeniuk, O. V. (2018). Kompiuterna hrafika: SolidWorks. Kherson: Oldi-plius, 252.
16. Pustiulha, S. I., Samostian, V. R., Klak, Yu. V. (2018). Inzhenerna hrafika v SolidWorks. Lutsk: Vezha, 172.
17. Gerlici, J., Lovska, A., Kozáková, K. (2025). Research into the Longitudinal Loading of an Improved Load-Bearing Structure of a Flat Car for Container Transportation. Designs, 9 (1), 12. https://doi.org/10.3390/designs9010012
18. Golovanevskiy, V., Kondratiev, A. (2021). Elastic Properties of Steel-Cord Rubber Conveyor Belt. Experimental Techniques, 45 (2), 217–226. https://doi.org/10.1007/s40799-021-00439-3
19. Panchenko, S., Gerlici, J., Vatulia, G., Lovska, A., Ravlyuk, V., Harusinec, J. (2023). Studying the load of composite brake pads under high-temperature impact from the rolling surface of wheels. EUREKA: Physics and Engineering, 4, 155–167. https://doi.org/10.21303/2461-4262.2023.002994
20. Koshel, O., Sapronova, S., Kara, S. (2023). Revealing patterns in the stressed-strained state of load-bearing structures in special rolling stock to further improve them. Eastern-European Journal of Enterprise Technologies, 4 (7 (124)), 30–42. https://doi.org/10.15587/1729-4061.2023.285894
21. Gerlici, J., Lovska, A. (2024). Study of the Strength of the Open Wagon Hatch Door with Rectangular Corrugations under Static Loads. Communications - Scientific Letters of the University of Zilina, 26 (3), B216–B225. https://doi.org/10.26552/com.c.2024.039
22. Gerlici, J., Lovska, A., Pavliuchenkov, M. (2024). Study of the Dynamics and Strength of the Detachable Module for Long Cargoes under Asymmetric Loading Diagrams. Applied Sciences, 14 (8), 3211. https://doi.org/10.3390/app14083211
23. Gerlici, J., Lovska, A., Pavliuchenkov, M., Harušinec, J. (2024). Investigation of the Strength and Dynamic Load on a Wagon Covered with Tarpaulin for 1520 mm Gauge Lines. Applied Sciences, 14 (15), 6810. https://doi.org/10.3390/app14156810
24. Stoilov, V., Slavchev, S., Maznichki, V., Purgic, S. (2023). Method for Theoretical Assessment of Safety against Derailment of New Freight Wagons. Applied Sciences, 13 (23), 12698. https://doi.org/10.3390/app132312698
25. Lovska, A., Gerlici, J., Dižo, J., Ishchuk, V. (2023). The Strength of Rail Vehicles Transported by a Ferry Considering the Influence of Sea Waves on Its Hull. Sensors, 24 (1), 183. https://doi.org/10.3390/s24010183
26. Dižo, J., Blatnický, M., Harušinec, J., Suchánek, A. (2022). Assessment of Dynamics of a Rail Vehicle in Terms of Running Properties While Moving on a Real Track Model. Symmetry, 14 (3), 536. https://doi.org/10.3390/sym14030536
27. Soukup, J., Skočilas, J., Skočilasová, B., Dižo, J. (2017). Vertical Vibration of Two Axle Railway Vehicle. Procedia Engineering, 177, 25–32. https://doi.org/10.1016/j.proeng.2017.02.178
28. Goolak, S., Sapronova, S., Tkachenko, V., Riabov, I., Batrak, Y. (2020). Improvement of the model of power losses in the pulsed current traction motor in an electric locomotive. Eastern-European Journal of Enterprise Technologies, 6 (5 (108)), 38–46. https://doi.org/10.15587/1729-4061.2020.218542
29. Domin, Yu. V., Cherniak, H. Yu. (2003). Osnovy dynamiky vahoniv. Kyiv: KUETT, 269.
30. Goolak, S., Tkachenko, V., Bureika, G., Vaičiūnas, G. (2021). Method of spectral analysis of traction current of ac electric locomotives. Transport, 35 (6), 658–668. https://doi.org/10.3846/transport.2020.14242
31. Goolak, S., Liubarskyi, B., Sapronova, S., Tkachenko, V., Riabov, Ie. (2021). Refined Model of Asynchronous Traction Electric Motor of Electric Locomotive. The proceedings of the 25th International Scientific Conference Transport Means 2021 - Sustainability: Research and Solutions. Kaunas, 455–460.
32. Steišūnas, S., Dižo, J., Bureika, G., Žuraulis, V. (2017). Examination of Vertical Dynamics of Passenger Car with Wheel Flat Considering Suspension Parameters. Procedia Engineering, 187, 235–241. https://doi.org/10.1016/j.proeng.2017.04.370
33. Dizo, J., Blatnicky, M. (2019). Evaluation of Vibrational Properties of a Three-wheeled Vehicle in Terms of Comfort. Manufacturing Technology, 19 (2), 197–203. https://doi.org/10.21062/ujep/269.2019/a/1213-2489/mt/19/2/197