UDC 629.463.03:629.015
DOI: 10.15587/1729-4061.2025.321858

DETERMINING THE LOADING OF AN IMPROVED TANK CONTAINER FOR 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
Arsen Muradian
PhD, Associate Professor*
Hanna Barsukova
PhD, Associate Professor**
Oleksandr Yurchenko
Senior Lecturer**
Oleksii Demydiukov
PhD Student*
*Department of Port Operation
and Cargo Handling Technology
Odesa National Maritime University
Mechnikova str., 34, Odesa, Ukraine, 65029
**Department of Energy and Electrical Engineering Systems
Sumy National Agrarian University
H. Kondratieva str., 160, Sumy, Ukraine, 40021

The object of this study is the processes of perception and redistribution of longitudinal loads in the structure of a tank container placed on a flat wagon during a shunting collision. In this paper, the task was solved to ensure the strength of the tank container during rail transportation.

In order to identify the stress concentration in the tank container, mathematical modeling of its longitudinal load under the condition of being placed on a flat wagon during a shunting collision was carried out. The resulting accelerations were taken into account when calculating the strength of the tank container. It was established that the maximum stresses occur in the zone of interaction of the paw with the vertical rack and amount to 938.2 MPa, which is significantly higher than the allowable ones. It has been proposed to improve the tank container by introducing reinforcing elements into its structure. The results of the strength calculation proved the feasibility of the proposed improvement. The maximum stresses in the tank container are about 215 MPa. Also, as part of the research, a modal analysis of the improved tank container was carried out. It was established that the safety of transportation of a tank container by rail transport from the point of view of modal analysis is ensured.

A special feature of the results is that the strength of the tank container was improved by strengthening its frame as the most loaded element of the structure.

The field of practical application of the findings is railroad transport. The conditions for the practical use of the results are the placement of braces of the reinforcing element of the frame at an angle of 45° to the horizontal.

The results of this study will contribute to new technological advancements in the design of modern structures of tank containers, as well as to improving the efficiency of operation of container transportation

Keywords: rail transport, tank container, tank container design improvement, tank container strength, modal analysis

Received 04.11.2024
Received in revised form 26.12.2024
Accepted 16.01.2025
Published 26.02.2025

How to Cite: *Lovska, A., Muradian, A., Barsukova, H., Yurchenko, O., Demydiukov, O. (2025). Determining the loading of an improved tank container for railroad transportation. Eastern-European Journal of Enterprise Technologies, 1 (7 (133)), 90–98. https://doi.org/10.15587/1729-4061.2025.321858*

1. Introduction

For a long time now, the railroad industry has been providing a reliable segment of freight traffic between European countries. Currently, all types of cargo from various branches of the economy are transported by railroad [1–3]. Bulk cargoes are quite common among such cargoes. Transportation of bulk cargoes by railroad is carried out by tank cars.

Tank containers were used to increase the mobility of bulk cargo transportation by rail. Currently, a large number of tank containers are in operation owing to their design features and processing technology. The possibility of transportation by different types of transport also leads to quite different loading schemes of tank containers in operation [4]. Analysis of existing regulatory documents on design and calculation of tank containers revealed that the most unfavorable mode of their loading is the shunting collision that occurs during rail transportation [5]. In this case, longitudinal forces caused by inertial forces, as well as reactive forces in the areas of interaction of fittings with fitting stops, act on the tank container. In the case of exceeding the dynamic forces acting on the tank container above the vertical component of the gross weight, it moves in the longitudinal plane and there is an impact interaction of the fittings against the fitting stops [6]. This can lead to their mutual damage, which makes it necessary to carry out unscheduled types of vehicle repairs. A similar situation on the route of a tank container as part of a train is quite dangerous from the point of view of ecology. Taking this into account, the issue of improvements to tank container structures in order to prolong their durability during operation is quite relevant.

2. Literature review and problem statement

The issues of improvements to tank containers are quite common and are covered in a considerable number of publications. So, for example, the peculiarities of the structural and functional analysis of tank container structures are considered in [7]. The purpose of the analysis was to identify potential directions for improvement of tank containers to improve their technical and economic parameters. The author provides a relevant analysis but does not propose specific improvements to their designs. This can be explained by the fact that the author did not determine the most loaded zones of tank container structures in operation.

Paper [8] gives an analysis of the stress-strain state of a tank container. The most heavily loaded areas of its structure, as well as the deflection of its components, were determined. As a further area of research, the reduction of the tare of the tank container is indicated. However, the work does not highlight the ways to achieve this goal. The reason for this may be that the reduction of the tare of the tank container can be achieved not only by optimizing the design but also by introducing advanced materials. It is possible that the authors at this stage of research have not yet chosen a way to reduce the tank container's tare.

The study of the stress state of a tank container for the transportation of food products is reported in [9]. Analysis of the results made it possible to establish that the most loaded node of the tank container structure is the node of interaction of the jar with the frame. Frequencies of self-oscillations of the tank container were detected. A direction to improve the design of the tank container not only from the point of view of its strength but also to reduce the tare is proposed. Along with this, the authors did not investigate the case of loading of its structure during a shunting collision when carrying out the corresponding calculations of the tank container. This can be explained by the fact that, perhaps, the design of the tank container in question is not suitable for operation under the given mode.

Work [10] highlights the peculiarities of determining the strength of a tank container under operational loads. In this case, to improve the strength of the tank container, three options for improving its design are proposed. The conducted strength calculations confirmed the expediency of using each of the improvement options. The authors indicated further ways of development of this research. However, mathematical modeling of the dynamic load of tank containers was not carried out in the work, and the normative values of the loads were taken into account when carrying out strength calculations. This can be explained by the fact that the authors considered the case of the tank container's perception of the maximum permissible load in accordance with the load standards, that is, excessive load modes were not taken into account.

The study of the strength of a tank container of an improved design during rail transportation is carried out in [11]. A structural feature of the tank container is the presence of flexible connections in the lower corner fittings and the production of the jar from composite material. The results of the strength calculation proved the capability of the proposed structural improvements. However, with a number of advantages of this design, it also has a significant drawback – the high cost of production, which, under conditions of serial production, causes the need for significant capital investments.

Paper [12] highlights the specificity of determining the strength of a heavy-duty tank container during rail transportation. In this case, the authors used experiment and numerical simulation. The impact of the technological gap on the load of the tank container at different speeds of collisions was determined. Solutions for improving the design of the tank container are proposed, but the results of their implementation are not given. This, perhaps, can be explained by the fact that the authors planned to conduct such research as part of subsequent work.

The specificity of determining the strength of a 40-foot tank container for the transportation of liquefied natural gas are carried out by the authors of paper [13]. In this case, the authors used the finite element method, which was implemented in the Ansys Mechanical program. The results of the calculations showed that the fatigue strength of the tank container is observed. However, in this case, the mode of shunting collision of the tank container was not investigated as the most unfavorable case of its load in operation. Perhaps this can be explained by the fact that this type of tank container is not allowed to be lowered from the slides during the shunting collision of platform wagons.

Work [14] reports the results of strength analysis of a tank container of standard size 1 AA according to ISO under the main operating modes of loads. The dependence of the strength of the tank container on the force factors acting on it is determined. In this case, the authors did not propose any solutions to improve its design. This can be explained by the fact that the authors set themselves the task of determining the most loaded areas of the tank container structure in operation.

New methods for designing and calculating tank containers were proposed by the authors of work [15]. A feature of the highlighted method is taking into account the fluctuations of the free surface of the liquid and its interaction with the walls of the jar. This makes it possible to accurately describe the process of dynamic loading of a tank container under operational conditions. The accuracy of the proposed method is confirmed by theoretical, simulation and experimental comparisons of the results of modeling the dynamic load of the tank container. However, the authors did not propose solutions for its improvement. Apparently, this is explained by the fact that the main task for the authors was to determine the load capacity of the tank container structure under operational conditions.

Paper [16] gives a procedure for determining the dynamic characteristics of a tank container for vegetable oils during collisions. The authors used the method of electrical strain measurement. The results of its application made it possible to detect the accelerations acting on the tank container. It was established that the obtained acceleration significantly exceeds the normative values. This proved the need for further research on improving the designs of tank containers. However, such solutions are not given in the work. Perhaps the authors planned to consider them in the framework of subsequent studies.

Our review of the literature [7–16] proves that the issues of improving tank containers to ensure their durability in operation were solved by introducing the latest materials into their construction, dissipative connections, etc. But such improvements require significant capital investment. Some researchers in their works focused on determining the load of tank containers in operation. That made it possible to formulate recommendations regarding the conditions of their safe operation. However, no solutions aimed at improving containers under the most unfavorable operating mode of loading (shunting collision)? were offered. Therefore, there is a need to conduct further research in this area.

3. The aim and objectives of the study

The purpose of our study is to determine the characteristics of the longitudinal load on a tank container placed on a flat wagon during a shunting collision. This will make it possible to determine the most loaded areas of the tank container structure and propose solutions for its improvement.

To achieve the goal, the following tasks are set:

– to investigate the longitudinal load on a typical structure of a tank container during a shunting collision;

– to propose a solution to improve the design of the tank container and investigate its load capacity during a shunting collision.

4. The study materials and methods

The object of our study is the processes of perception and redistribution of longitudinal loads in the structure of a tank container placed on a flat wagon during a shunting collision.

The main hypothesis of the study assumes that the use of braces in the frame of the tank container could contribute to reducing the load on the interaction node of the lower corner fittings with the paws of the tank container.

When conducting the research, it was assumed that the pressure from the transported cargo on the walls of the tank container is evenly distributed. A simplification of the study is that the structure of the tank container is monolithic, that is, it does not take into account the presence of welding seams between its components.

To study the strength of a tank container with a jar support on paws, appropriate calculations were performed. Tank container TK25 was chosen as the prototype. Graphic works on constructing a spatial model were reproduced in SolidWorks (France) (Fig. 1).

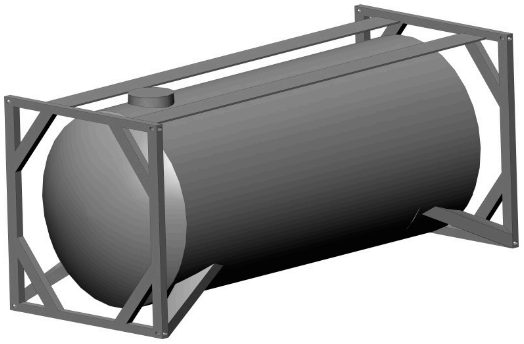


Fig. 1. Spatial model of a tank container

The strength calculation was carried out using the finite element method in SolidWorks Simulation (France). When constructing a finite-element model of a tank container, tetrahedra were used (Fig. 2). Their optimal number was calculated graph-analytically [17, 18]. Taking this into account, the model has 170406 elements with a maximum size of 120 mm and a minimum of 24 mm. The number of nodes was 56409.

When devising the calculation scheme, it was taken into account that the following loads act on the tank container (Fig. 3):

– vertical static load P_v;

– horizontal force acting on the bottom of the jar P_a;

– pressure from the bulk cargo on the jar P_c;

– reactions in the fitting stops P_f to the action of horizontal loads perceived by the tank container.

These loads are specified in the normative document DSTU ISO 1496-3:2013 Cargo containers of series 1. Technical requirements and test methods. Part 3. Tank containers for liquids, gases, and bulk goods under pressure. Foreign analog of this standard: “ISO 1496-3:1995+ISO 1496-3:1995/Amd 1:2006 Series 1 freight containers. Specification and testing. Part 3: Tank containers for liquids, gases, and pressurized dry bulk”.

To determine the dynamic load acting on the tank container, mathematical modeling of its longitudinal load was carried out using the model given in [19]. However, it is taken into account that the tank container does not have its natural movements in the vertical plane. The movement of cargo in the jar was modeled by mathematical pendulums.

The Runge-Kutta method [20, 21] was used to solve the mathematical model. It was implemented in the Mathcad software package [22, 23]. The initial conditions are set to zero [24, 25].

When calculating the strength of the tank container, it was attached to the fittings. The construction material is low-alloy steel 09G2S [26]. Permissible stresses acting in the design of the tank container were assumed equal to 310.5 MPa, in accordance with DSTU 7598:2014. Freight cars. General requirements for calculations and design of new and modernized cars of 1520 mm gauge (non-self-propelled). Foreign analog of this standard: “EN 12663-2. Railroad applications – structural requirements of railroad vehicle bodies – Part 2: Freight cars”.

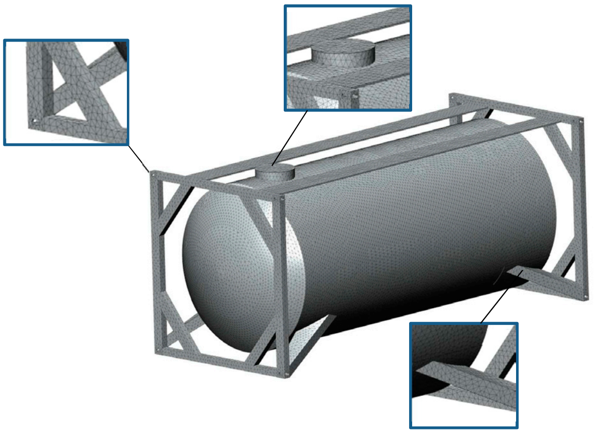


Fig. 2. Finite element model of a tank container

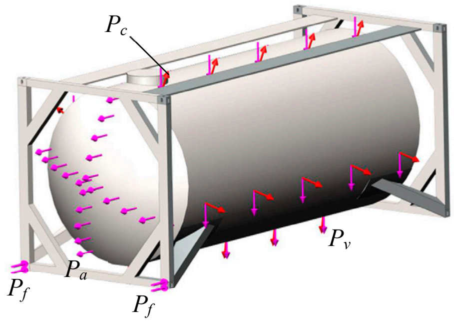


Fig. 3. Calculation diagram of a tank container

5. Results of determining the longitudinal load on a tank container placed on a flat wagon during a shunting collision

5. 1. Results of determining the longitudinal load on a typical structure of a tank container

To determine the dynamic load acting on a tank container placed on a flat wagon during a shunting collision, a calculation model was built, which is shown in Fig. 4. It is taken into account that the tank container is placed on a 13-401 model flat wagon.

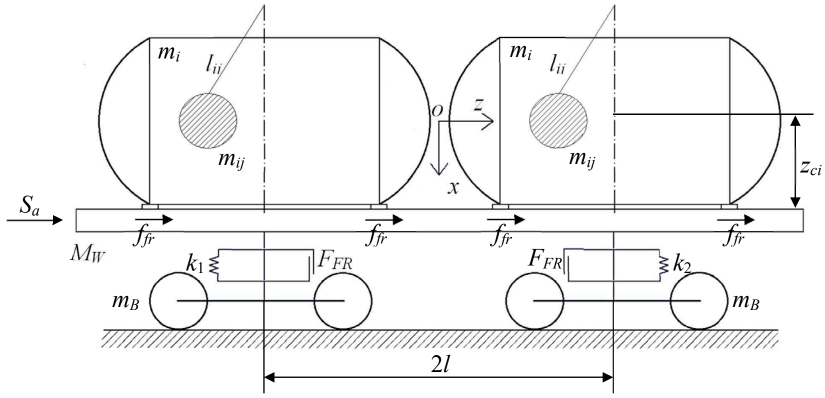


Fig. 4. Calculation diagram of a flat wagon loaded with tank containers

The tank container was considered as an attached mass relative to the frame of the flat wagon, which has flexibility in the longitudinal direction due to the presence of gaps between the fitting stops and fittings [27]. It is taken into account that the tank containers placed on the flat wagon have the same jar loading with bulk cargo:

$$\left(M_W + 2\cdot m_B + \frac{n\cdot I}{r^2}\right)\cdot\ddot{x}_W + M_W\cdot h\cdot\ddot{\varphi}_W = \\ = S_a - \sum_{i=1}^{2}\left(f_{fr}\cdot sign\cdot\left(x_W - x_i\right)'\right), \tag{1}$$

$$I_W\cdot\ddot{\varphi}_W + M_W\cdot h\cdot\ddot{x}_W - g\cdot\varphi_W\cdot M_W\cdot h = \\ = l\cdot F_{FR}\left(sign\dot{\Delta}_1 - sign\dot{\Delta}_2\right) + l\left(k_1\cdot\Delta_1 - k_2\cdot\Delta_2\right), \tag{2}$$

$$M_W\cdot\ddot{z}_W = k_1\cdot\Delta_1 + k_2\cdot\Delta_2 - F_{FR}\left(sign\dot{\Delta}_1 - sign\dot{\Delta}_2\right), \tag{3}$$

$$\left(m_i + \sum_{j=1}^{k} m_{ij}\right)\cdot\ddot{x}_i + \left(m_i\cdot z_{ci} + \sum_{j=1}^{k} m_{ij}\cdot c_{ij}\right)\cdot\ddot{\varphi}_i - \\ -\sum_{j=1}^{k} m_{ij}\cdot l_{ij}\cdot\ddot{\xi}_{ij} = \left(f_{fr}\cdot sign\cdot\left(x_W - x_i\right)'\right), \tag{4}$$

$$\left(I_{\theta i} + \sum_{j=1}^{k} m_{ij}\cdot c_{ij}^2\right)\cdot\ddot{\varphi}_i + \left(m_i\cdot z_{ci} + \sum_{j=1}^{k} m_{ij}\cdot c_{ij}\right)\cdot\ddot{x}_i + \\ +\sum_{j=1}^{k} m_{ij}\cdot c_{ij}\cdot l_{ij}\cdot\ddot{\xi}_{ij} - g\cdot\left(m_i\cdot z_{ci} + \sum_{j=1}^{k} m_{ij}\cdot c_{ij}\right)\times \\ \times\left(\varphi_W - \varphi_i\right) = 0, \tag{5}$$

$$\left(m_i + \sum_{j=1}^{k} m_{ij}\right)\cdot\ddot{z}_W = 0, \tag{6}$$

$$I_{ij}\cdot\ddot{\xi}_{ij} - m_{ij}\cdot l_{ij}\cdot\ddot{x}_{ij} - m_{ij}\cdot c_{ij}\cdot l_{ij}\cdot\ddot{\varphi}_i + g\cdot m_{ij}\cdot l_{ij}\cdot\ddot{\xi}_{ij} = 0, \tag{7}$$

where:

$$\Delta_1 = z_W - l\cdot\varphi_W,\quad \Delta_2 = z_W + l\cdot\varphi_W,$$

where M_W – mass of the flat wagon frame; S_a – impact force on the auto coupling (3.5 MN); I_W – longitudinal moment of inertia of the flat wagon; f_{fr} – force of dry friction; m_B – mass of the bogies of the flat wagon; I – moment of inertia of the wheelset; r – wheel radius of the wheelset; n – axis of the chassis; l – 1/2 of the base of the flat wagon; F_{FR} – force of dry friction in the spring assembly of the chassis; k_1, k_2 – spring stiffness of spring suspension of running parts; k – the number of cycles of load fluctuations; m_i – mass of the body, which is equivalent to the i-th tank container; m_{ij} – mass of the j-th pendulum in the i-th jar; z_{ci} – height of the center of gravity of the tank container; c_{ij} – distance from the plane z_i=0 to the fixation point of the j-th pendulum in the i-th jar; l_{ij} – length of the j-th pendulum; I_θ – moment of inertia (reduced) of the i-th tank container with bulk cargo that does not move in the jar; I_{ij} – moment of inertia of the pendulum; x, φ, z – coordinates characterizing the longitudinal, angular around the longitudinal axis and vertical movement of the flat wagon, respectively; x_i, φ_i – coordinates characterizing the longitudinal and angular movement of the tank container around the longitudinal axis, respectively; ξ_{ij} – value of the angle of deviation of the jth pendulum from the vertical axis.

Our calculations showed that in the absence of gaps between fittings and fitting stops, the acceleration of the tank container is about 40 m/s^2. If there is a gap between fittings and fitting stops of 30 mm, the acceleration of the tank container is about 300 m/s^2.

This acceleration value is taken into account when calculating the strength of the tank container. Based on the calculations, the main strength indicators of the tank container were obtained (Fig. 5, 6). Therefore, the maximum stresses occur in the zone of interaction of the paw with the vertical rack and amount to 938.2 MPa (Fig. 5). The obtained stresses are higher than permissible.

The maximum movements occur in the middle part of the bottom of the jar of the tank container and amount to 11.4 mm (Fig. 6).

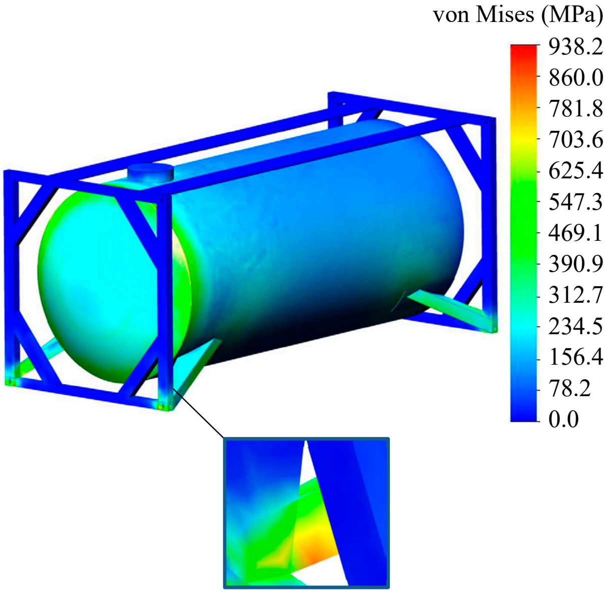


Fig. 5. The stressed state of the tank container

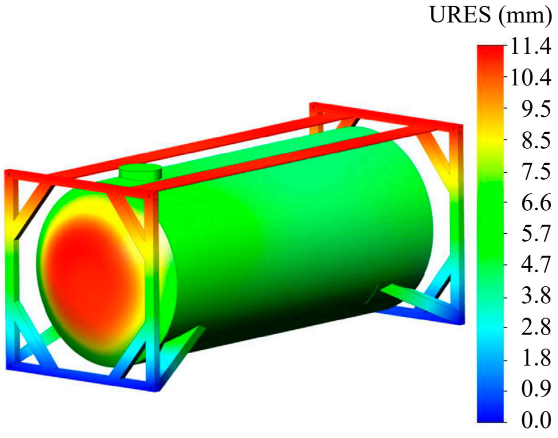


Fig. 6. Movement in the nodes of the tank container

This distribution of movement fields can be explained by the schemes of applying loads to the jar, as well as its fastening.

5. 2. Results of improving the structure of the tank container and determining its load during a shunting collision

In order to ensure the strength of the tank container, it is proposed to improve its frame by introducing reinforcing elements into the structure (Fig. 7).

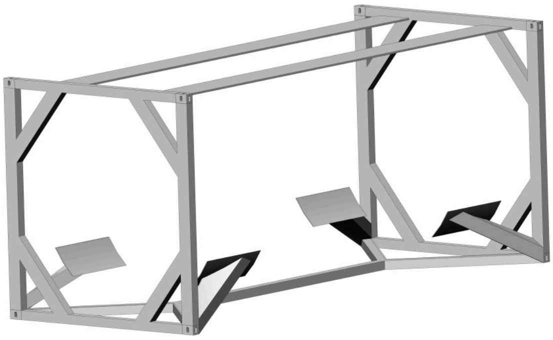


Fig. 7. Tank container frame

The reinforcing element is made in the form of a fork, the end parts of which (braces) are placed at an angle α=45° to the horizontal (Fig. 8). The nodes of interaction of the braces on the left and right sides of the tank container are connected by a longitudinal belt. This element is made of the same profile as the frame belts.

The spatial model of the tank container is shown in Fig. 9.

To determine the expediency of such an improvement, a calculation of the strength of the tank container, as well as its modal analysis, was carried out.

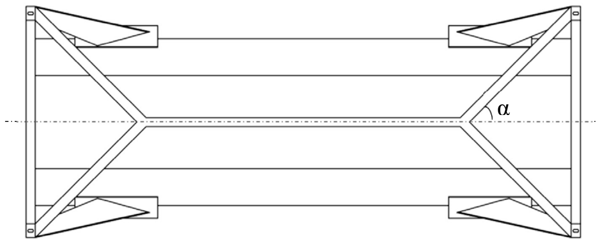


Fig. 8. Tank container frame (bottom view)

When constructing the finite-element model, tetrahedra were used, the number of which was 182,213, and the number of nodes was 60,189 (Fig. 10). The maximum size of the element was 120 mm, and the minimum – 24 mm.

The calculation scheme of the tank container, its fixing scheme, and construction material are identical to those used in the calculation of the typical structure of the tank container.

The calculation results are shown in Fig. 11, 12. The maximum stresses recorded in the hole zone are 215 MPa (Fig. 11), which is below the permissible level.

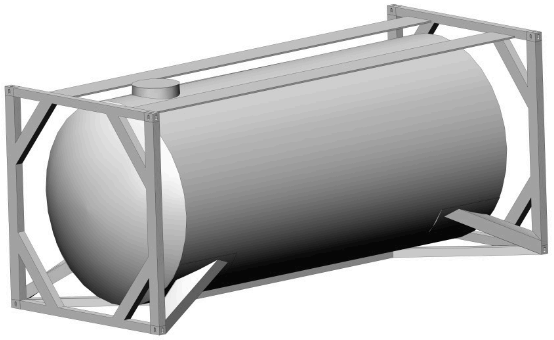


Fig. 9. Spatial model of the improved structure of the tank container

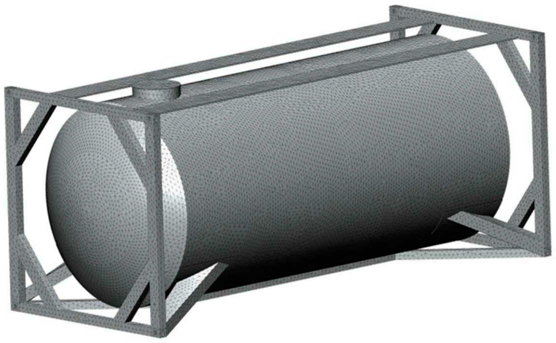


Fig. 10. Finite element model of the improved structure of the tank container

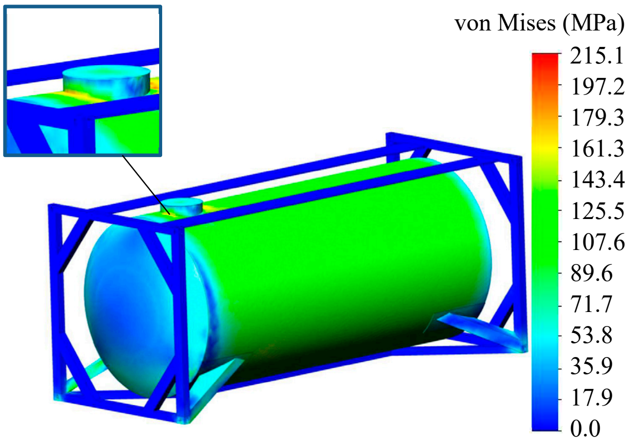


Fig. 11. The stressed state of the improved structure of the tank container

The maximum displacements occur in the lower part of the jar and amount to 2.6 mm (Fig. 13). In this case, their dislocation is observed closer to the cantilever part of the jar from the side of the longitudinal force on the flat wagon (Fig. 14). The displacement values were recorded along the horizontal axis passing through the lower part of the jar.

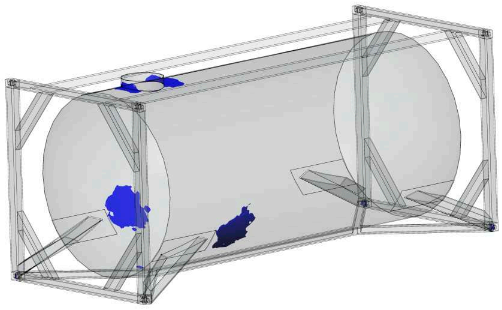


Fig. 12. The most loaded areas of the tank container

In order to determine the safety of transportation of a tank container, a modal analysis of its design was carried out. In this case, we applied the calculation scheme shown in Fig. 3.

On the basis of our analysis, frequencies and forms of self-oscillations of the tank container were obtained (Fig. 15).

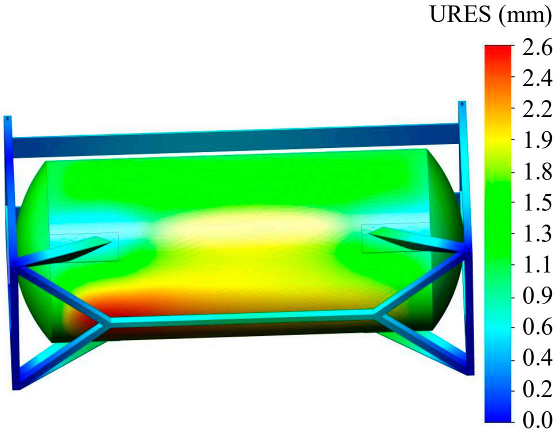


Fig. 13. Movement in the nodes of the improved structure of the tank container

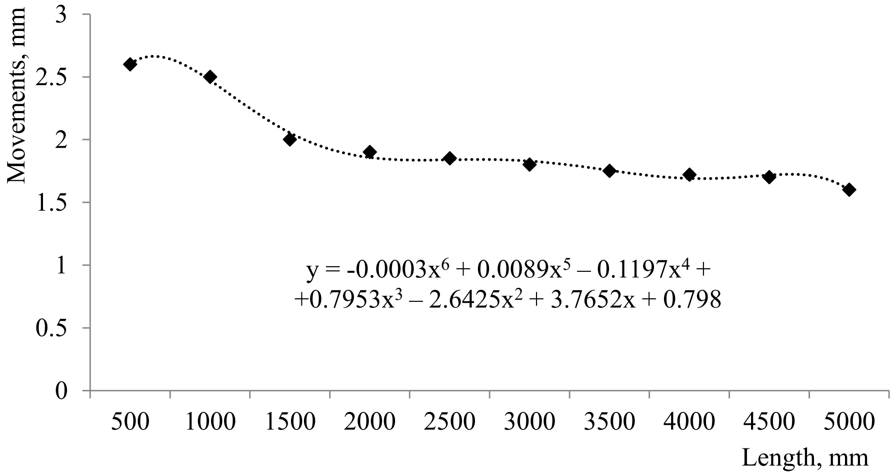
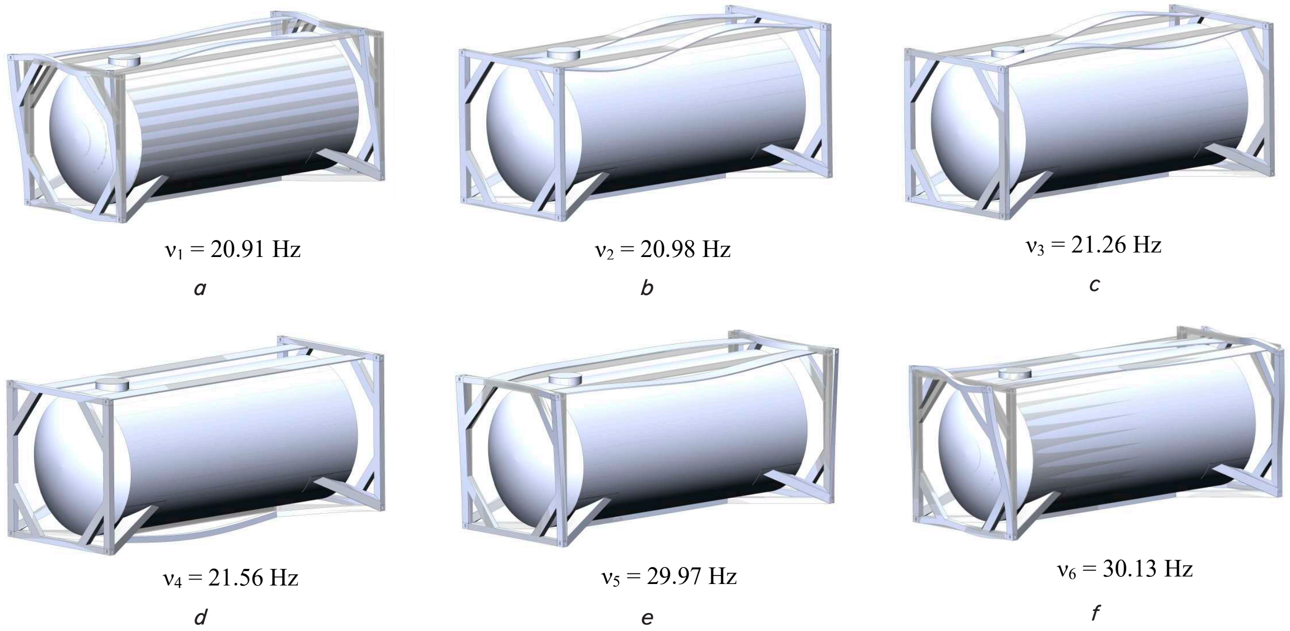


Fig. 14. Distribution of movements along the length of the jar



$\nu_1 = 20.91$ Hz

a

$\nu_2 = 20.98$ Hz

b

$\nu_3 = 21.26$ Hz

c

$\nu_4 = 21.56$ Hz

d

$\nu_5 = 29.97$ Hz

e

$\nu_6 = 30.13$ Hz

f

Fig. 15. Forms and frequencies of oscillations of the tank container (at a scale of 15:1): *a* – the first mode; *b* – the second mode; *c* – the third mode; *d* – the fourth mode; *e* – the fifth mode; *f* – the sixth mode

The safety of transportation of the tank container was assessed by the first natural frequency of oscillations. According to the calculations, it takes a value of 20.91 Hz (Fig. 15, *a*). That is, transportation safety from the point of view of modal analysis is observed since this frequency is more than permissible.

6. Discussion of results based on determining the load on the improved tank container during rail transportation

To identify the load of a typical design of a tank container with a jar support on paws, mathematical modeling of its load was carried out. The study was carried out under the condition of placing a tank container on a flat wagon during a shunting collision (Fig. 4). It was established that in the case when the gap between the fitting stop and the fitting is equal to 30 mm, the acceleration per tank container is about 300 m/s^2. The resulting calculations were used to determine the strength of the tank container. It was found that the maximum stresses occur in the zone of interaction of the paw with the vertical rack and amount to 938.2 MPa (Fig. 5). These stresses exceed the allowable by almost three times. In this case, the maximum movements occur in the middle part of the bottom of the jar of the tank container and amount to 11.4 mm (Fig. 6).

To ensure the strength of the tank container frame, it is proposed to introduce reinforcing elements into its structure (Fig. 7). These elements are made in the form of a fork, the braces of which are placed at an angle α=45° to the horizontal (Fig. 8). The nodes of interaction of the braces on the left and right sides of the tank container are connected by a longitudinal belt. To justify the proposed improvement, a calculation was performed on the strength of the tank container. It was established that the maximum stresses occur in the hole zone and amount to 215 MPa (Fig. 11), which is lower than permissible. The maximum displacements occur in the lower part of the jar and amount to 2.6 mm (Fig. 13). Therefore, the strength of the tank container is assured. Also, as part of the research, the frequencies and forms of self-oscillations of the tank container were determined. The calculation results showed that the safety of operation of the tank container is ensured because the first natural frequency of oscillations exceeds 8 Hz (Fig. 15).

This improvement can be implemented not only when creating new designs of tank containers but also during their modernization.

The results of our research have certain advantages in comparison with known ones. For example, in contrast to works [7, 8, 12], the authors not only proposed solutions for improving the tank container but also provided their corresponding scientific justification. In this study, the most unfavorable case of loading a tank container in operation, as opposed to work, is considered [9, 13]. In order to determine the dynamic loads on the tank container, mathematical modeling was carried out, and the normative values of accelerations laid down in the relevant documents were not used, in contrast to work [10].

In comparison with the design improvement specified in [11], the proposed implementation is economically more profitable because high-cost materials are not used. In contrast to works [14–16], we have not only identified the load of a typical design of a tank container but also provided solutions for its improvement.

As a limitation of this study, it can be noted that when determining the load on a tank container, its nominal dimensions were taken into account, that is, operational wear was not taken into account.

The shortcoming of this research is that when modeling the dynamic loading of a tank container, it is assumed that the impact on the car coupling of the flat wagon is absolutely hard.

The prospect for further research is determining the load capacity of the improved tank container when transported by other types of transport since it is a mobile transport unit.

The results of this study will contribute to technological advancements in the design of modern structures of tank containers, as well as to increasing the efficiency of operation of container transportation.

7. Conclusions

1. The longitudinal load on a typical structure of a tank container during a shunting collision has been studied. Mathematical modeling was performed to determine the dynamic load on a tank container placed on a flat wagon during a shunting collision. It was established that in the absence of gaps between the fitting stops and the fittings, the acceleration acting on the tank container is about 40 m/s^2. The maximum accelerations are obtained for the case when the gap between the fitting stop and the fitting is 30 mm. In this case, the acceleration is about 300 m/s^2. The results of calculating the strength of the tank container showed that the maximum stresses occur in the zone of interaction of the paw with the vertical rack and amount to 938.2 MPa. These stresses are higher than permissible. The maximum movements occur in the middle part of the bottom of the tank container jar and are 11.4 mm.

2. A solution has been proposed to improve the tank container by introducing reinforcing elements into its structure. The reinforcing element is made in the form of a fork, the end parts of which are placed at an angle α=45° to the horizontal.

The longitudinal load on the improved structure of the tank container during a shunting collision has been investigated. The maximum stresses were recorded in the hole zone and amounted to 215 MPa. The obtained stresses are lower than permissible. The maximum movements occur in the lower part of the jar and amount to 2.6 mm.

A modal analysis of the tank container was carried out. It has been established that the safety of the movement from the point of view of the results of the modal analysis is ensured since the first natural frequency of oscillation exceeds 8 Hz.

Acknowledgments

This paper was prepared as part of the scholarship work of the Verkhovna Rada of Ukraine for young scientists – doctors of sciences “Effective constructive solutions to railway rolling stock for transportation of strategic cargoes” (No.DR 0124U003906).

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. Dižo, J., Blatnický, M. (2019). Investigation of ride properties of a three-wheeled electric vehicle in terms of driving safety. Transportation Research Procedia, 40, 663–670. https://doi.org/10.1016/j.trpro.2019.07.094
2. Vatulia, G., Lovska, A., Pavliuchenkov, M., Nerubatskyi, V., Okorokov, A., Hordiienko, D. et al. (2022). Determining patterns of vertical load on the prototype of a removable module for long-size cargoes. Eastern-European Journal of Enterprise Technologies, 6 (7 (120)), 21–29. https://doi.org/10.15587/1729-4061.2022.266855
3. 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
4. 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
5. O'Connell, P. (2012). Improving operational and public safety in shunting operations through active hazard ID. International Conference "Railway safety". London. Available at: https://international-railway-safety-council.com/wp-content/uploads/2017/09/oconnell-improving-operational-public-safety-in-shunting-operations-through-active-hazard-id.pdf
6. Semko, Zh. O. (2022). Vymohy normatyvnykh dokumentiv do konteineriv, yaki pryznacheni dlia transportuvannia vantazhiv zaliznychnym transportom. Zbirnyk naukovykh prats «Reikovyi rukhomyi sklad», 24, 61–83. Available at: https://ukrndiv.com.ua/wp-content/uploads/2022/07/6.pdf
7. Kovalenko, V. (2017). Structural and functional analysis of tank containers. Metallurgical and Mining Industry, 1, 26–31.
8. Bhattacharyya, R., Hazra, A. (2013). A study on stress analysis of ISO tank container. Proceedings of 58th Congress of ISTAM. Available at: https://www.researchgate.net/publication/316320046_A_study_on_stress_analysis_of_ISO_tank_container
9. Liguori, A., Formato, A., Pellegrino, A., Villecco, F. (2021). Study of Tank Containers for Foodstuffs. Machines, 9 (2), 44. https://doi.org/10.3390/machines9020044
10. Wang, Z., Qian, C., Wu, Z. (2023). Stress Analysis and Structural Improvement of LNG Tank Container Frames under Impact from Railway Transport Vehicles. Applied Sciences, 13 (24), 13335. https://doi.org/10.3390/app132413335
11. Panchenko, S., Gerlici, J., Vatulia, G., Lovska, A., Rybin, A., Kravchenko, O. (2023). Strength Assessment of an Improved Design of a Tank Container under Operating Conditions. Communications - Scientific Letters of the University of Zilina, 25 (3), B186–B193. https://doi.org/10.26552/com.c.2023.047
12. Wang, Z., Qian, C., Li, W. (2023). Study on Impact Process of a Large LNG Tank Container for Trains. Applied Sciences, 13 (3), 1351. https://doi.org/10.3390/app13031351
13. Lee, D.-Y., Jo, J.-S., Nyongesa, A. J., Lee, W.-J. (2023). Fatigue Analysis of a 40 ft LNG ISO Tank Container. Materials, 16 (1), 428. https://doi.org/10.3390/ma16010428
14. Wang, Z., Qian, C. (2020). Strength analysis of LNG tank container for trains under inertial force. Journal of Physics: Conference Series, 1549 (3), 032107. https://doi.org/10.1088/1742-6596/1549/3/032107
15. Zhao, C., Zhao, S., Xie, S., He, M., Li, X., Li, Y. (2024). New methods and applications of structural dynamics modeling for railway freight liquid tank. Advances in Mechanical Engineering, 16 (11). https://doi.org/10.1177/16878132241274441
16. Tretiak, E. V., Rechkalov, V. S., Murchkov, S. V. (2020). Protsedura otrymannia dynamichnykh kharakterystyk pid chas spivudarian tank-konteinera dlia transportuvannia roslynnykh oliy. Zbirnyk naukovykh prats «Reikovyi rukhomyi sklad», 21, 44–57.
17. 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
18. Dveirin, O. Z., Andreev, O. V., Kondrat'ev, A. V., Haidachuk, V. Ye. (2021). Stressed State in the Vicinity of a Hole in Mechanical Joint of Composite Parts. International Applied Mechanics, 57 (2), 234–247. https://doi.org/10.1007/s10778-021-01076-4
19. Bogomaz, G. I., Mekhov, D. D., Pilipchenko, O. P., Chernomashenceva, YU. G. (1992). Nagruzhennost' kontejnerov-cistern, raspolozhennyh na zheleznodorozhnoy platforme, pri udarah v avtoscepku. Zbirnyk naukovykh prats «Dynamika ta keruvannia rukhom mekhanichnykh system», 87–95.
20. Andrunyk, V. A., Vysotska, V. A., Pasichnyk, V. V., Chyrun, L. V. (2018). Chyselni metody v kompiuternykh naukakh. Vol. 2. Lviv, 536. Available at: https://library.kre.dp.ua/Books/2-4%20kurs/%D0%90%D0%BB%D0%B3%D0%BE%D1%80%D0%B8%D1%82%D0%BC%D0%B8%20%D1%96%20%D0%BC%D0%B5%D1%82%D0%BE%D0%B4%D0%B8%20%D0%BE%D0%B1%D1%87%D0%B8%D1%81%D0%BB%D0%B5%D0%BD%D1%8C/Andrunik_Chiselni_metodi_v_KN_2018_536.pdf

21. Honcharov, O. A., Vasylieva, L. V., Yunda, A. M. (2020). Chyselni metody rozviazannia prykladnykh zadach. Sumy, 142. Available at: https://essuir.sumdu.edu.ua/bitstream-download/123456789/79378/3/Honcharov_chyselni_metody.pdf;jsessionid=918A997CF26B8A8B64BDC7C279EF2773
22. Bohach, I. V., Krakovetskyi, O. Yu., Kylyk, L. V. (2020). Chyselni metody rozviazannia dyferentsialnykh rivnian zasobamy MathCad. Vinnytsia, 106. Available at: http://pdf.lib.vntu.edu.ua/books/IRVC/Bogach_2020_106.pdf
23. 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
24. 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
25. Dižo, J., Harušinec, J., Blatnický, M. (2015). Multibody System of a Rail Vehicle Bogie with a Flexible Body. Manufacturing Technology, 15 (5), 781–788. https://doi.org/10.21062/ujep/x.2015/a/1213-2489/mt/15/5/781
26. 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
27. Lovska, A. O. (2016). Doslidzhennia mitsnosti nesuchoi konstruktsiyi konteinera-tsysterny, rozmishchenoho na vahoni-platformi pry manevrovomu spivudarianni. Zbirnyk naukovykh prats DETUT: Seriya «Transportni systemy i tekhnolohiyi», 28, 90–98.