STUDY OF LOADING OF AN IMPROVED CONTAINER DESIGN DURING TRANSPORTATION BY RAILWAY

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ABSTRACT

The object of research: The object of research is the processes of occurrence, perception and redistribution of loads in the design of a container with a frame made of square pipes and lining made of smooth sheets.

Investigated problem. Under operating conditions, damage to containers may occur due to the loads acting on them during transportation by various modes of transport. One of the most determining among such loads are dynamic loads, which are experienced not only by the container structure, but also by the cargo placed in it. As a result, there may be damage to the structure of the container, as well as to the cargo, which necessitates additional costs, both for the repair of containers and for reimbursement of expenses for damage to the transported cargo. In addition, this situation is unfavorable from an environmental point of view. In this regard, there is a need to conduct research to improve the design of a universal container in order to reduce its load, as well as increase operational efficiency.

The main scientific results. A scientific substantiation of the use of square pipes as components of the frame of a universal container has been carried out.

The area of practical use of research results. The sphere of practical use of the obtained results is the engineering industry, in particular railway transport.

Innovative technological product. The concept of a universal container with a frame made of square pipes and a lining made of smooth sheets.

Scope of the innovative technological product. The developments proposed as part of the study will be useful recommendations for creating innovative vehicle designs, including modular ones.

1. Introduction

1. 1. The object of research

The object of research is the processes of occurrence, perception and redistribution of loads in the design of a container with a frame made of square pipes and lining made of smooth sheets.

1. 2. Problem description

It is known that the container is the most common transport unit. This can be explained by the fact that it has significant mobility. In this connection, transportation of containers is carried out by all types of transport. At the same time, the mobility of the container determines its perception of various loads, which are typical for specific types of transport carrying out its transportation.

In this regard, under operating conditions, damage to containers may occur due to operational loads. One of the most determining among operational loads are dynamic ones. These loads affect not only the design of the container, but also the cargo placed in it. As a result, damage to the container structure as well as the cargo may occur. This situation necessitates additional costs, respectively, for the repair of containers and compensation for damage to the transported cargo. In this regard, there is a need to conduct research to improve the design of the container in order to reduce its load during operation.

Research devoted to the improvement of containers is very relevant, this is confirmed by a significant number of them. For example, article [1] reflects the design features of a container for transporting fruits and vegetables. The proposed design solutions are confirmed by appropriate strength calculations for the main operational schemes for accepting loads by the container. The corresponding calculation protocols are presented, which illustrate the stressed state of the container. It is important to say that when designing this container design, the authors did not propose solutions to ensure the strength of its structure.

The study [2] also proposed a similar container design for the transportation and storage of fruits and vegetables. The results of container strength calculations using the finite element method are presented. The work also specifies the requirements for the operating conditions of this container. But, as in work [1], the authors did not propose solutions aimed at improving the strength characteristics of the container.

Features of designing an ISO container are discussed in publication [3]. The basic loading diagrams of the container are presented, as well as the calculation of the resistance of its structure to operational loads. However, the authors of this work have not proposed solutions aimed at increasing the rigidity of the frame under operating loads.

Article [4] provides a justification for the use of flexible connections in container fittings to reduce its dynamic load in operation. The following ductile connections are considered: elastic-frictional, viscous, and elastic-viscous. The results of mathematical modeling of the dynamic loading of a container with these types of flexible connections in fittings are presented. The author also presents the results of calculations for the strength of the container, taking into account the proposed improvement of its design. However, the researcher limited itself to improving the fittings themselves, and not the container frame.

In order to reduce the dynamic loads acting on the container during operation, work [5] proposed the use of sandwich panels as its walls. A scientific rationale for this decision is given. At the same time, the team of authors studied the strength of the sandwich panel itself. This work does not pay attention to determining the strength of the container structure as a whole.

In [6], the authors conducted a study of the longitudinal loading of a container with walls made of sandwich panels placed on a flat wagon during a shunting collision. It has been proven that the use of such panels helps to reduce the stresses that arise in the container structure compared to the standard one. However, this work does not propose solutions aimed at reducing the load on the container frame under operational loads.

An analysis of the stresses arising in the structure of a container during its transportation by water transport is carried out in publication [7]. The research was carried out on the example of a 40-foot container of size 1AA. The calculation results made it possible to formulate the basic requirements for the operation of such a container. At the same time, no attention was paid to the issue of calculating its strength during transportation by rail.

The review of literature sources [1–7] allows to conclude that the issues of improving containers are very relevant. At the same time, to improve the efficiency of container transportation, these issues need further development.

In this regard, the purpose of the article is to highlight the results of a study of the loading of a container concept with a frame made of square pipes and a lining made of smooth sheets. To achieve this goal, the following tasks are identified:

– determine the geometric parameters of the container frame profile;

– carry out a strength calculation of a container with a frame made of square pipes and a lining made of smooth sheets.

2. Materials and Methods

To ensure the strength of the container under operating conditions, it is proposed to manufacture its frame from square pipes (**Fig. 1**). It is also assumed that the walls of the container will be formed by smooth sheets.

This solution will increase the moment of resistance of the container compared to the standard design.

To determine the geometric parameters of the pipes, a calculation was carried out in the Lyra – CAD software [8]. The container is considered as a rod structure with fastening at the corners, i.e. for fittings. The calculation was carried out for two loading schemes:

– perception by the system of vertical load P_v (**Fig. 2**);

– perception by the system of longitudinal load P_l (**Fig. 3**).

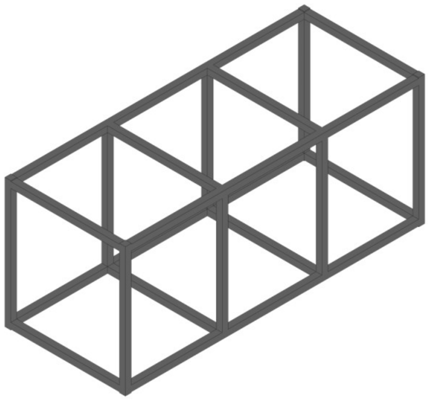

Fig. 1. Container frame made of square pipes

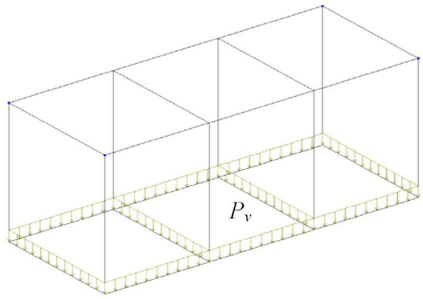

Fig. 2. Design diagram of the container (I design diagram)

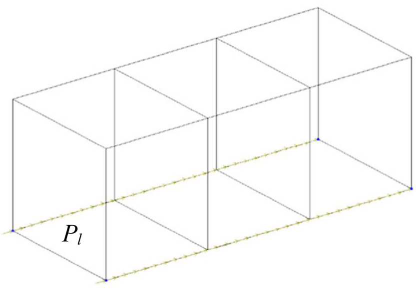

Fig. 3. Design diagram of the container (II design diagram)

From the obtained diagrams of the distribution of force factors, the geometric dimensions of the container's profile were determined. When the structure accepted a bending moment, the selection of the profile was carried out through the moment of resistance, namely [9, 10]:

$$W = \frac{M}{[\sigma]}, \tag{1}$$

where M – the value of the bending moment acting in the frame section; $[\sigma]$ – permissible stresses of the container manufacturing material (it is taken into account that the frame consists of steel grade 09G2S, for which $[\sigma]$=210 MPa).

In the case where the structure perceives longitudinal force, the selection was carried out based on the cross-sectional area [9, 10]:

$$A=\frac{F}{[\sigma]}, \tag{2}$$

where F – the value of the longitudinal force acting on the section.

After selecting the geometric parameters of the frame execution profile, its spatial model was created in the SolidWorks software package. It is taken into account that the walls of the container consist of smooth sheets. The thickness of these sheets was determined using the Bubnov-Galerkin method:

$$\delta=\sqrt{\frac{P\cdot 96\cdot\left(b^2+\mu\cdot a^2\right)\cdot a^2\cdot b^2}{\sigma\cdot\pi^4\cdot\left(a^2+b^2\right)}}, \tag{3}$$

where P – the force acting on the plate (steel sheet); a and b – the width and height of the slab, respectively; μ – Poisson's ratio; σ – permissible stresses of the slab head material.

Next, the strength of the proposed container design was calculated using the finite element method implemented in SolidWorks Simulation.

3. Results and Discussions

In accordance with the design diagram of the container frame shown in **Fig. 2**, using the options of the Lyra – CAD software, diagrams of longitudinal forces (**Fig. 4**), transverse forces (**Fig. 5**) and bending moments (**Fig. 6**) were obtained. Red color in **Fig. 3–5** characterizes "extension", and blue – "compression".

The greatest value of the longitudinal force occurs in the vertical posts and is 4.12 kN. The maximum value of the transverse force was recorded in the longitudinal beams is 2.78 kN. From the diagram of bending moments, it is possible to conclude that the maximum value of the bending moment occurs in the upper longitudinal beams of the frame and is 1.92 kN m. This distribution of force factors can be explained by the fact that the container is secured to the corner fittings, and the load is applied to the lower part frame. Based on these values of the force factors, the geometric parameters of the pipe were selected – a pipe with a height and width of 60 mm, a wall thickness of 5 mm. In this case, the selection was carried out through the moment of resistance, since if it is carried out through the area, then the pipe has smaller geometric characteristics and insufficient fatigue strength. It is important to say that when selecting the profile, a safety factor of 1.8 was taken into account in accordance with DSTU 7598:2014. Freight wagons. General requirements for calculations and design of new and modernized wagons of 1520 mm gauge (non-self-propelled).

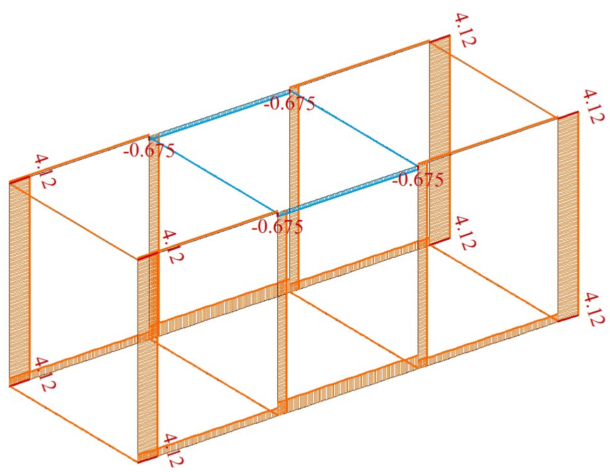

Fig. 4. Diagram of longitudinal forces, kN (I design diagram)

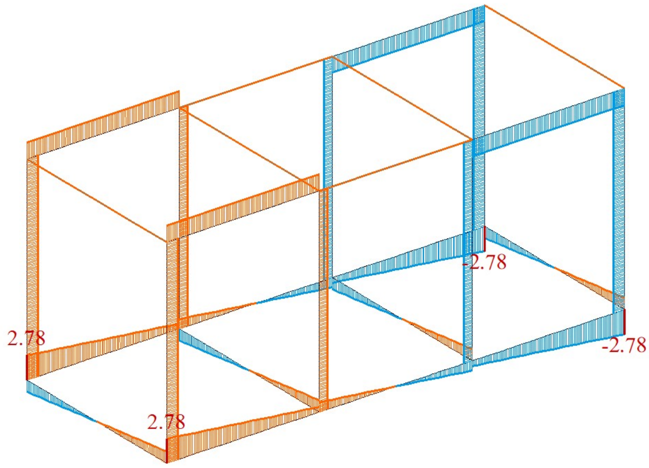

Fig. 5. Diagram of transverse forces, kN (I design diagram)

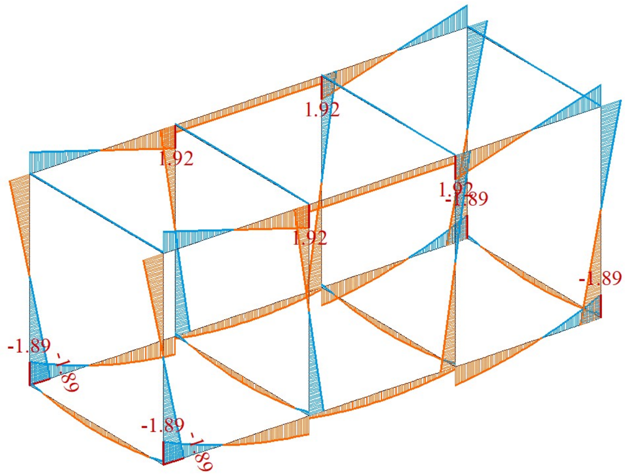

Fig. 6. Diagram of bending moments, kN m (I design diagram)

Taking into account the calculations carried out in accordance with the design diagram shown in **Fig. 3**, the values of longitudinal forces (**Fig. 7**), transverse forces (**Fig. 8**) and bending moments (**Fig. 9**) were obtained.

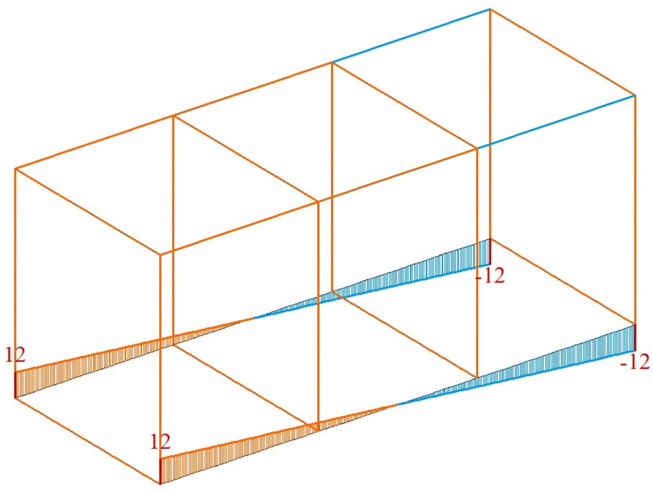

Fig. 7. Diagram of longitudinal forces, kN (II design scheme)

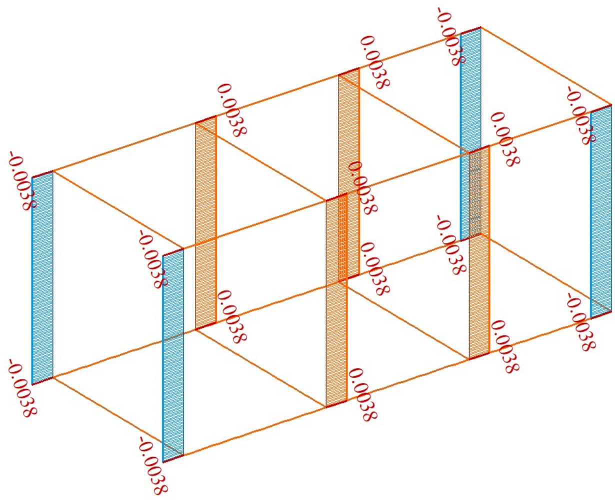

Fig. 8. Diagram of transverse forces, kN (II design scheme)

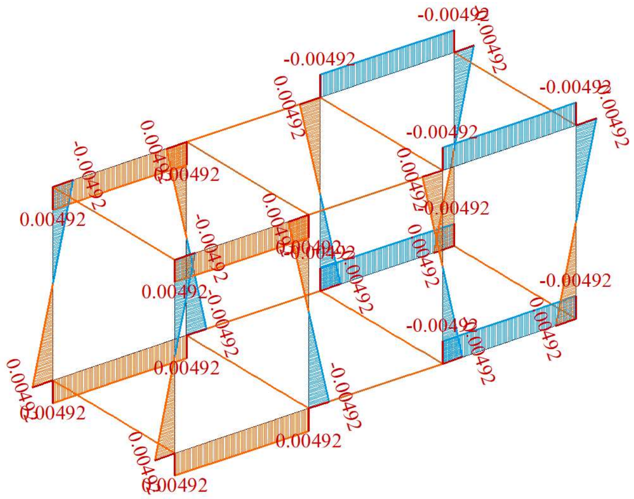

Fig. 9. Diagram of bending moments, kN m (II design scheme)

From the given diagrams it is clear that the maximum value of the longitudinal force is 12 kN and occurs in the longitudinal beams. The highest value of lateral force was recorded in the vertical posts. However, its value is very small and close to zero. The same can be said about the bending moment. This can be explained by the fact that only the longitudinal beam moves between the fittings, which is why these force factors are so insignificant.

Based on the obtained value of the longitudinal force, a frame profile was selected – a pipe with a height and width of 20 mm, a wall thickness of 2 mm. However, the results of profile selection according to the first design scheme were taken into account as determining ones.

To confirm the obtained results, a strength calculation was carried out for a container with a frame made of square pipes and a lining made of a smooth sheet, the thickness of which is 1.5 mm (**Fig. 10**).

Tetrahedra were used to create the finite element model. The optimal number of grid elements was determined graphically [11]. Taking this into account, the mesh is formed by 100824 elements and 32006 nodes. When carrying out calculations, the loading schemes shown in **Fig. 2**, **3**. Based on the calculations carried out, diagrams of the stressed state of the container were obtained for two design schemes for accepting the load. **Fig. 11** shows the stressed state of the container under design scheme 1. In this case, the maximum stresses arise in the transverse beams of the frame and amount to 200.8 MPa, which is below the permissible values by almost 4.4 %. The maximum movements also occur in the transverse beams and amount to 3.7 mm.

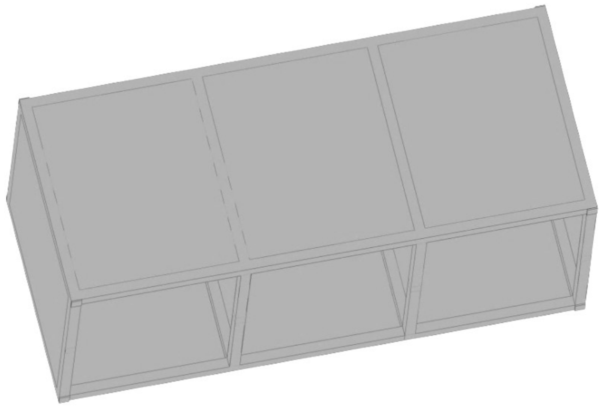

Fig. 10. Container with a frame made of square pipes

In the second design scheme, the maximum stresses in the container were 154 MPa and they arise in the corner fittings. The maximum movements also occur in the transverse beams and are equal to 3.5 mm. Taking into account the combination of vertical and longitudinal loads on the container, the maximum stresses were 205.7 MPa, and the displacements were 3.7 mm. Consequently, the strength of the container with the considered fastening schemes is ensured.

A limitation of this study is that the calculations did not take into account the technological gaps between the fittings and fitting stops. This limitation is valid for the case when the friction force between the fittings and fitting stops exceeds the dynamic load acting on the container.

The disadvantage of this study is that the authors limited themselves to only two design schemes of the container in operation. At subsequent stages, it is necessary to consider other container loading schemes.

At the same time, the advantage of this study compared to the works [1, 2] is that the proposed container design is universal and can be used to transport a wide range of goods. In contrast to the works [3, 4], the authors proposed solutions aimed at improving the container frame as its supporting structure. Unlike the results of [5, 6], the proposed improvement will not cause difficulties during maintenance and repairs in operation. In comparison with the results of work [7], this study examines the most loaded mode of container operation – transportation by rail.

As a further development of this work, it is important to note the need to calculate the container under various operating conditions. Also, an important step is to take into account the above-standard loading conditions of the container (gaps between fittings and fitting stops, transportation by rail ferries as part of combined trains, etc.) when calculating the strength. In addition, the authors plan to consider the possibility of using filler in the container frame. This will further reduce its operational load.

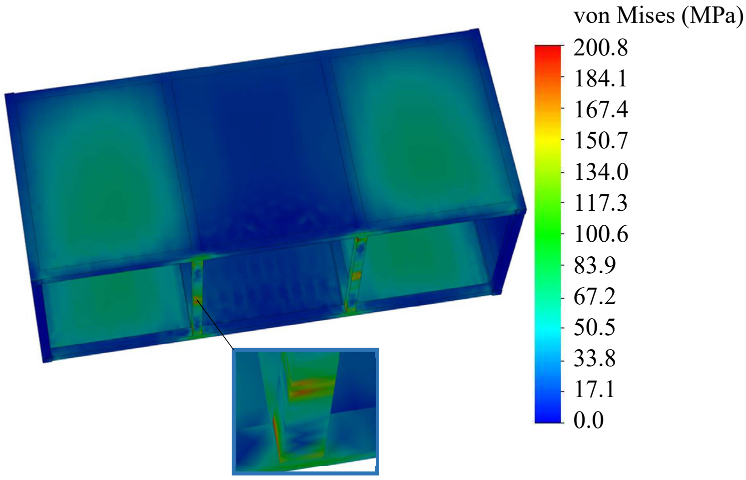

Fig. 11. Stressed state of the container (I design diagram)

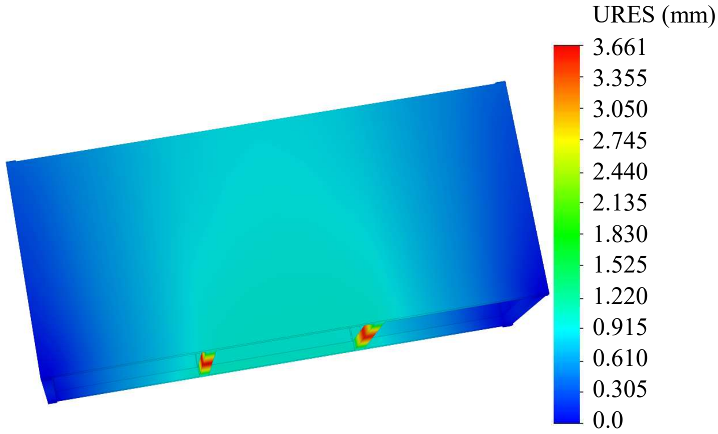

Fig. 12. Movements in container nodes (I design diagram)

The developments proposed as part of the study will be useful recommendations for creating innovative vehicle designs, including modular ones.

4. Conclusions

1. The geometric parameters of the container frame profile have been determined. In this case, the calculation has been carried out when the container absorbed vertical loads, as well as longitudinal ones. The calculation results have been shown that the maximum force factors occur when vertical loads are applied to the container. At the same time, the greatest value of the longitudinal force occurs in the vertical posts and amounts to 4.12 kN. The maximum value of the transverse force was recorded in the longitudinal beams – 2.78 kN. The maximum value of the bending moment occurs in the upper longitudinal beams of the frame and is 1.92 kN m. Based on these values of the force factors, the geometric parameters of the pipe have been selected – a pipe with a height and width of 60 mm, a wall thickness of 5 mm.

In the second design mode, the value of the longitudinal force is 12 kN and occurs in the longitudinal beams. At the same time, the values of transverse forces and bending moments are close to zero.

2. The strength of a container with a frame made of square pipes and a lining made of smooth sheets has been calculated. With design scheme I, the maximum stresses arise in the transverse beams of the frame and amount to 200.8 MPa, which is below the permissible values by almost 4.4 %. The maximum movements also occur in the transverse beams and amount to 3.7 mm.

In the second design scheme, the maximum stresses in the container are 154 MPa and they arise in the corner fittings. The maximum movements also occur in the transverse beams and are equal to 3.5 mm.

Also taken into account is the scheme of combining vertical and longitudinal loads on the container. In this case, the maximum stresses were 205.7 MPa, and the displacements were 3.7 mm. The calculations carried out allow to conclude that with the considered fastening schemes, the strength of the container is ensured.

Conflict of interest

The authors declare that there is no conflict of interest in relation to this paper, as well as the published research results, including the financial aspects of conducting the research, obtaining and using its results, as well as any non-financial personal relationships.

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Data availability

Data will be made available on reasonable request.

Use of artificial intelligence

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

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References

[1] Khadjimukhametova, M. A., Merganov, A. M. (2020). Development of the Design and Conditions of Operation of Containers for Transportation of Fruit and Vegetable Products. International Journal of Recent Technology and Engineering (IJRTE), 8 (5), 252–256. doi: https://doi.org/10.35940/ijrte.e4856.018520

[2] Ibragimov, N. N., Rakhimov, R. V., Khadzhimukhamedova, M. A. (2015). Razrabotka konstruktcii konteinera dlia perevozki plodoovoshchnoi produktcii. Molodoi uchenyi, 21 (101), 168–173.

[3] Giriunas, K., Sezen, H., Dupaix, R. B. (2012). Evaluation, modeling, and analysis of shipping container building structures. Engineering Structures, 43, 48–57. doi: https://doi.org/10.1016/j.engstruct.2012.05.001

[4] Lovska, A. O. (2019). Determination of loading for a container located on a flat wagon under visco-elastic interaction between fittings and fitting stops. Collection of Scientific Works of the Ukrainian State University of Railway Transport, 184 (184). doi: https://doi.org/10.18664/1994-7852.184.2019.171446

[5] Vatulia, G. L., Lovska, A. O., Myamlin, S. S., Krasnokutskyi, Ye. S. (2022). Substantiation of the Design Features of Sandwich Panels for Container Wall Lining. Science and Transport Progress, 1 (101), 55–63. doi: https://doi.org/10.15802/stp2023/280009

[6] Vatulia, G., Lovska, A., Myamlin, S., Stanovska, I., Holofieieva, M., Horobets, V. et al. (2023). Revealing the effect of structural components made of sandwich panels on loading the container transported by railroad. Eastern-European Journal of Enterprise Technologies, 1 (7 (121)), 48–56. doi: https://doi.org/10.15587/1729-4061.2023.272316

[7] Rzeczycki, A., Wisnicki, B. (2016). Strength analysis of shipping container floor with gooseneck tunnel under heavy cargo load. Solid State Phenomena, 252, 81–90. doi: https://doi.org/10.4028/www.scientific.net/ssp.252.81

[8] Barabash, M. S., Soroka M. M., Surianinov, M. H. (2018). Neliniina budivelna mekhanika z PK Lira-Sapr. Moscow, 234.

[9] Shvabiuk, V. I. (2016). Opir materialiv. Kyiv: Znannia, 407.

[10] Kutsenko, A., Bondar, M., Chausov, M. (2019). Prykladna mekhanika (opir materialiv). Kyiv: Aspekt-Polihraf, 530.

[11] Fomin, O., Lovska, A., Daki, O., Bohomia, V., Tymoshchuk, O., Tkachenko, V. (2019). Determining the dynamic loading on an open-top wagon with a two-pipe girder beam. Eastern-European Journal of Enterprise Technologies, 3 (7 (99)), 18–25. doi: https://doi.org/10.15587/1729-4061.2019.166329