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DETERMINING THE LOADING OF A CONTAINER FOR GRAIN TRANSPORTATION UNDER OPERATING CONDITIONS

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The object of this study is the processes of perception and redistribution of loads in the structure of a container for grain transportation under operating conditions. The task to address is to provide the railroad industry with vehicles for grain transportation by modernizing universal containers.

To upgrade the universal container for grain transportation, a 1CC container was selected as a prototype. In order to adapt this container for grain transportation, it is proposed to install three standard-diameter loading hatches on the roof. It is planned to make an unloading hatch in the end wall 1/3 of the height of the lower strapping. To substantiate the proposed solution, the strength of the container was calculated under the following loading scenarios: transporting the container as part of a railroad train; lifting by the upper corner fittings; unloading the container. The calculation results showed that the strength of the container is ensured under all the considered loading schemes.

A special feature of the results is that the provision of the railroad industry with vehicles for grain transportation is achieved not by designing new structures but by modernizing existing ones.

The field of practical application of the research results is railroad transport. The conditions for the practical use of the results are the application of low-alloy steel to fabricate the components of the container structure.

The results of the study will help compile recommendations for the modernization and design of container structures, as well as to improve the efficiency of container transportation, including international traffic

Keywords: railroad transport, container, container modernization, container load, container strength, container transportation

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1. Introduction

The transport industry is a key component of the successful development of the economies of European countries [1]. For a long time, it has ensured the uninterrupted process of passenger [2] and freight transportation [3]. A significant share of transportation is accounted for by rail transport [4]. To ensure the efficiency of rail transport, it is important to equip it with vehicles with improved technical and economic characteristics [5].

One of the most common types of cargo transported by rail in international traffic is grain. Hopper cars are most often used for its transportation by rail. The lack of hopper cars in operation has led to the use of containers for these purposes, which is also explained by their mobility and ease of maintenance. At the same time, the container fleet is currently formed mostly by universal containers, which are designed for the transportation of a wide range of cargo. The construction of new types of containers intended for the transportation of bulk cargo (bulk container), including grain, requires significant capital investments. Therefore, it is advisable to study the possibility of designing containers for grain transportation based on existing structures. This could improve not only the efficiency of grain transportation along international routes but also the foreign-trade economic indicators of the countries involved in the transportation process. In this regard, the issue of modernization of universal containers for their adaptation to grain transportation becomes relevant.

2. Literature review and problem statement

Currently, a fairly large variety of containers used in operation differ not only in design but also in the principle of technological processing. Therefore, the issues of container design are relevant. For example, in work [6], in order to reduce the lateral loads acting on the container in operation, it was proposed to introduce sandwich panels as components of its design. This contributes not only to improving the strength of the container but also the safety of the cargo transported in it. The results of determining the dynamic loading and strength of the container were reported, which confirmed the feasibility of the proposed solutions. However, the authors did not consider the possibility of using that container for the transportation of bulk cargo, including grain cargo. This can be explained by the fact that they set the task, first of all, to justify the use of sandwich panels in the container design. Therefore, they focused on a conditional type of cargo.

Paper [7] highlights the features of the container loading under some operational schemes. The authors determined the dynamic loads acting on the container and then took them into account in strength calculations. The results of the calculation made it possible to determine the most loaded components of the container. However, the authors did not propose any solutions to improve its design in order to increase the efficiency of its use. This may be due to the fact that the authors planned to conduct research on improving the design of the container some time later. The features of the calculation for the strength of a container of standard size 1AA were carried out in work [8]. The authors focused their attention on determining the strength of the container floor. At the same time, its movement through a tunnel of a certain radius was considered. The calculations made it possible to compile recommendations for the safe operation of the container along a given route. At the same time, the authors did not pay attention to the issues of structural improvement of the container to improve the efficiency of its operation. This can be explained by the fact that the authors set the task of ensuring the safety of container transportation precisely along the given route and therefore limited themselves to the relevant recommendations.

In paper [9], in order to reduce the container's tare, it is proposed to manufacture it from a composite material. By reducing the container's tare, an increase in its load-bearing capacity is also achieved, so the authors of the work chose this direction of improving the container design. The results of the calculation of the container's strength proved the feasibility of using a composite material for its manufacture. However, the serial introduction of such containers is constrained by the high cost of their manufacture.

The selection of a rational material for the manufacture of a container for fruit and vegetable products from the point of view of the quality characteristics of the transported cargo is carried out in [10]. The results of analysis conducted by the authors revealed that the most appropriate is the use of plastic containers for the transportation of fruit and vegetable products. At the same time, the authors limited themselves only to the selection of a rational material for the container's execution and did not study the features of its loading in operation. Perhaps this can be explained by the fact that they planned to conduct such studies at the next stage of their work.

In paper [11], the authors proposed a container design with a floor made of sandwich panels. Such an improvement of the container is justified by its perception of constant cyclic loads. The use of sandwich panels as floor components also contributes to improving the safety of the cargo transported in it. A set of theoretical calculations on the strength of the container structure is reported, which confirmed the feasibility of its improvement. However, the authors did not consider the possibility of transporting grain in such a container since they set the goal of designing a universal container structure.

The features of calculating the strength of a container for transporting fruit and vegetable products are highlighted in [12]. In this case, the authors proposed structural solutions in the container aimed at improving its operation. These solutions are justified by modern requirements for containers of similar designs. The calculations confirmed the feasibility of the proposed improvement. At the same time, the authors did not study the possibility of implementing the proposed solutions for the design of a container for transporting grain. This is explained by the fact that they set the goal of improving the specified container model, which is also quite popular in operation.

In [13], the authors highlight the features of the design of a composite container for transporting bulk cargo. A comparative analysis of the use of this container in comparison with other designs is reported. The feasibility of using a composite container from the point of view of saving costs for the transportation process is proven. But the work did not analyze the loading of the proposed container design, which does not make it possible to assess its advantages in comparison with existing designs in terms of strength. Perhaps the authors planned to consider such a problem at the next stages of research in this area.

Our review of the literature [6–13] proves that improving container designs is a rather important task. But so far, due attention has not been paid to the issues of designing and modernizing containers for grain transportation, which is a rather important aspect of the development of the economy of European countries. Therefore, it is necessary to conduct research in this area.

3. The aim and objectives of the study

The purpose of our study is to determine the characteristics of loading the container structure for grain transportation during operational modes. This will contribute to increasing the efficiency of grain transportation, as well as to technological advancements in the design of container structures for grain transportation.

The stated goal was achieved by solving the following tasks:

– to calculate the strength of the container when it is transported as part of a railroad train;

– to calculate the strength of the container when it is lifted by the upper corner fittings;

– to calculate the strength of the container when it is unloaded.

4. The study materials and methods

The object of our study is the processes of perception and redistribution of loads in the design of a container for grain transportation under operational conditions.

The main hypothesis of the study assumes that the modernization of a universal container of standard size 1CC contributes to the possibility of its use for grain transportation.

For the modernization of a universal container for grain transportation, a container of standard size 1CC was chosen as a prototype. The spatial model of the container is shown in Fig. 1.

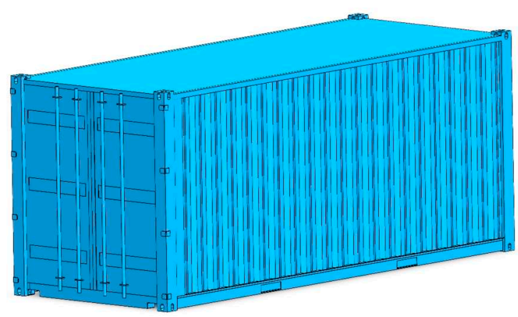

Fig. 1. Spatial model of a 1CC size container

Loading of this container is carried out through the end doors, which in the closed state form the end wall. Mechanized equipment can be used for loading/unloading of the container. In order to adapt this container to the transportation of grain, it is proposed to install three loading hatches of standard diameter on the roof. It is planned to make an unloading hatch in the end wall at a height of 1/3 from the lower strapping (Fig. 2).

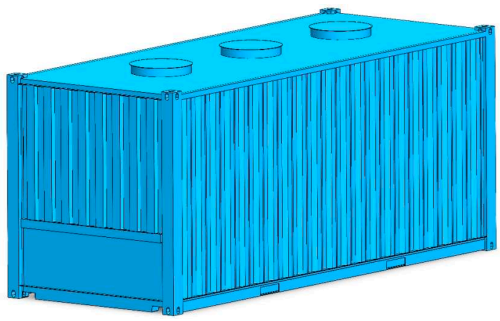

Fig. 2. Spatial container model

To substantiate the proposed modernization, a calculation was performed of the container strength under the main loading modes:

– transportation of the container as part of a railroad train;
– lifting by the upper corner fittings;
– unloading of the container.

In order to determine the strength of the container during rail transportation, the loading mode when moving as part of a railroad train was considered – a jerk. This mode takes into account the effect on the front stops of the auto coupler of a longitudinal force of 2.5 MN in accordance with DSTU 7598:2014. Freight cars. General requirements for calculations and design of new and modernized 1520 mm gauge cars (non-self-propelled). The international analog of this standard is "EN 12663-2. Railroad applications – structural requirements of railroad vehicle bodies – Part 2: Freight cars".

The calculation was carried out using the finite element method in the SolidWorks Simulation software package (France). The design scheme of the container is shown in Fig. 3. It was taken into account that the container is subjected to a vertical load P_v, which takes into account its carrying capacity. The container's natural weight was taken into account using the options of the SolidWorks Simulation software package, provided that the structure is made of steel grade 09G2S. The bulk cargo expansion pressure P_p was applied to the side walls of the container, and P_w to the end walls. Inertia forces P_f were applied to the front fittings of the container in the direction of movement of the platform car.

The determination of the active, i.e., static, pressure of the bulk cargo expansion on the container walls is carried out using the well-known formula:

$$P_a = \gamma \cdot g \cdot H \cdot \mathrm{tg}^2\left(\frac{\pi}{4} - \frac{\phi}{2}\right), \quad (1)$$

where γ – density of the bulk cargo; H – height of the side wall; g – acceleration of gravity; φ – angle of natural slope of the cargo.

The pressure of the unevenly distributed load applied to the end wall is determined as follows:

$$P_w = P_a + P_{ps}, \quad (2)$$

where P_{ps} – passive cargo pressure.

Passive cargo pressure is determined from formula (1), but in it the square of the tangent of the difference of two angles is replaced by the square of the tangent of their sum and taking into account the coefficient of vertical dynamics, as well as the angle of natural slope.

To determine the inertia forces P_f acting on the fitting stops, mathematical modeling of the longitudinal dynamics of a platform car loaded with two containers was carried out. The calculation scheme of the platform car is shown in Fig. 4.

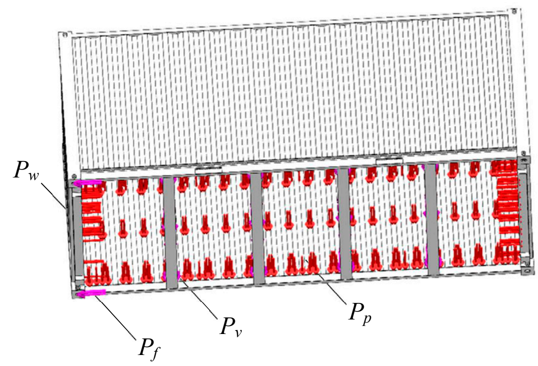

Fig. 3. Container design diagram

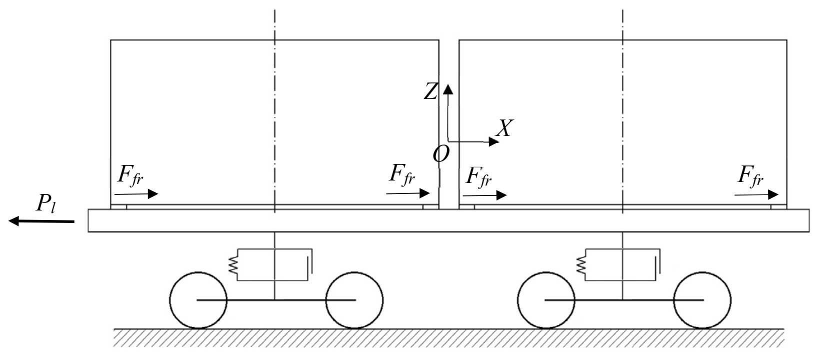

Fig. 4. Calculation diagram of a platform car loaded with two containers

When constructing the mathematical model, it was taken into account that containers placed on the frame of a platform car have a degree of freedom in the longitudinal plane, due to the presence of technological gaps between the fitting stops and fittings.

The mathematical model that characterizes the longitudinal loading of containers placed on a platform car takes the form:

$$\begin{cases} M_W^{gm} \cdot \ddot{q}_1 = P_l - \sum_{i=1}^{n}\left(F_{fr} \cdot \mathrm{sign}\left(\dot{q}_1 - \dot{q}_2\right)\right), \\ M_c \cdot \ddot{q}_2 = \left(F_{fr} \cdot \mathrm{sign}\left(\dot{q}_1 - \dot{q}_2\right)\right), \end{cases} \quad (3)$$

where M_W^{gm} – gross mass of the platform car; P_l – magnitude of the longitudinal force acting on the auto coupler; n – number of containers placed on the platform car; F_{fr} – friction force between fitting stops and fittings; M_c – container mass; q_1, q_2 – coordinates that determine the movement, respectively, of the platform car and the container relative to the longitudinal axis.

The mathematical model (3) was solved using the Mathcad software package (USA) [14–16]. In this case, a standard procedure was applied. The equations that form the mathematical model (3) were reduced to the normal Cauchy form. After that, they were integrated using the Runge-Kutta method [17–19]. That is:

$$T(t,y)=\begin{bmatrix} y_3 \\ y_4 \\ \dfrac{P_l-\sum\limits_{i=1}^{n}\left(F_{fr}\cdot\operatorname{sign}\left(y_3-y_4\right)\right)}{M_W^{gm}} \\ \dfrac{\left(F_{fr}\cdot\operatorname{sign}\left(y_3-y_4\right)\right)}{M_c} \end{bmatrix}, \tag{4}$$

$$Z=rkfixed\left(Y0,tn,tk,n,T\right).$$

In this case:

$$y_1=q_1,\quad y_2=q_2,\quad y_3=\dot{y}_1,\quad y_4=\dot{y}_2.$$

To determine the generalized accelerations, the arrays $ddq_{j,i}$ were formed:

$$ddq_{j,1}=\frac{P_l-\sum\limits_{i=1}^{n}\left(F_{fr}\cdot\operatorname{sign}\left(y_3-y_4\right)\right)}{M_W^{gm}}, \tag{5}$$

$$ddq_{j,2}=\frac{\left(F_{fr}\cdot\operatorname{sign}\left(y_3-y_4\right)\right)}{M_c}. \tag{6}$$

The initial conditions are set to zero. The calculation results have established that the acceleration acting on the containers is about 27 m/s^2.

This acceleration is taken into account when calculating the strength of the container, namely, when taking into account the forces P_f and P_w in the calculation model shown in Fig. 3.

5. Results of determining the loading of a container for grain transportation under operational modes

5. 1. Results of determining the loading of a container when it moves in a train

To determine the loading of a container when it moves in a train, its finite element model was formed. The model was built using tetrahedra [20–22]. The mesh was formed on the basis of mixed curvature [23–25] and has 1,027,293 elements and 1,838,877 nodes. The maximum element size was 60 mm, and the minimum was 3 mm. The number of Jacobian points for a high-quality mesh was 16 units.

The container was fixed to fittings [26–28]. The results of its calculation for strength when transported in a train are shown in Fig. 5, 6. The maximum stresses occur in the middle part of the horizontal beam for fastening the unloading hatch and are 121.4 MPa (Fig. 5). These stresses are lower than the permissible ones, which for the specified mode are taken equal to 210 MPa.

The maximum displacements are recorded in the side wall and are 1.8 mm (Fig. 6).

Therefore, the strength of the container under the applied load regime of its design is maintained.

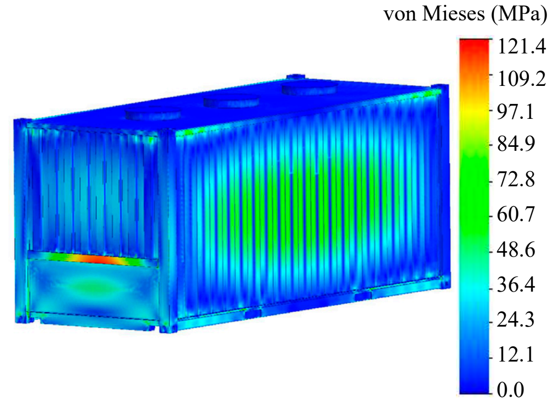

Fig. 5. The stressed state of the container when it is transported in a train

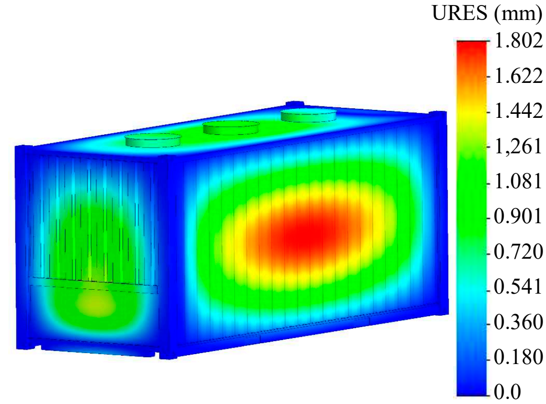

Fig. 6. Movement in the nodes of a container when it is transported in a train

5. 2. Results of determining the container load when lifting it by the upper corner fittings

At the next stage of the study, the strength of the container was determined when lifting it by the upper corner fittings. The calculation scheme of the container is shown in Fig. 7. It was taken into account that the container is lifted by slings, which are placed at an angle of 45° to the horizontal. Therefore, the load transmitted from the slings to the container was decomposed into two components: vertical P_v and horizontal P_h. The calculation scheme also takes into account the vertical load, as well as the pressure of the bulk cargo expansion on the walls of the container (not shown in Fig. 7). The calculation results are shown in Fig. 8, 9.

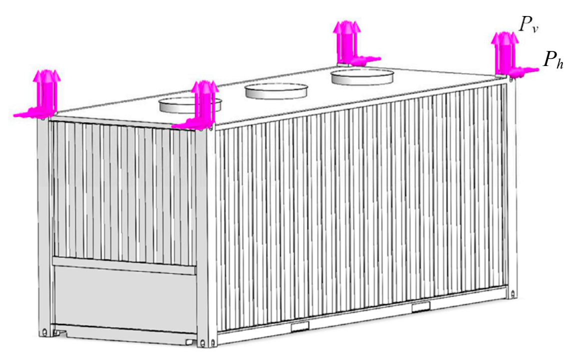

Fig. 7. Calculation diagram of the container when lifting it by the upper corner fittings

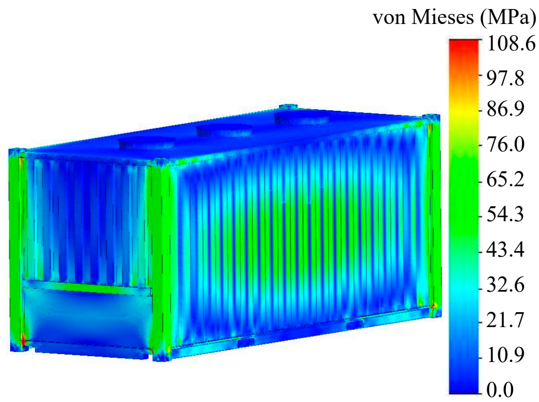

Fig. 8. The stressed state of the container when it is lifted by the upper corner fittings

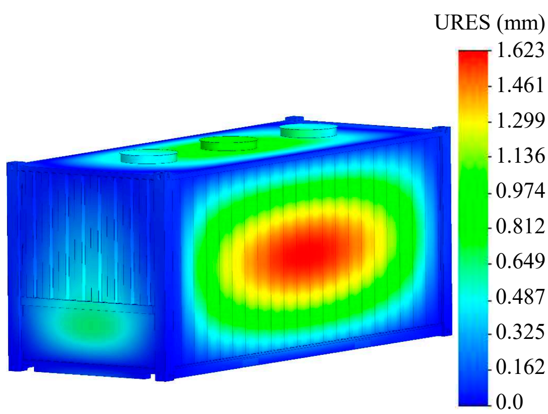

Fig. 9. Movement in the container nodes when lifting it by the upper corner fittings

Therefore, the maximum stresses when lifting the container by the upper corner fittings arise in the zones of interaction of the corner posts with the cross beams and are 108.6 MPa (Fig. 7). These stresses do not exceed the permissible ones.

The maximum displacements are recorded in the side walls. They are equal to 1.6 mm. That is, with the applied loading mode, the strength of the container is maintained.

5. 3. Results of determining the loading of the container during its unloading

In addition, the study considered the case of the loading of the container during its unloading. It was taken into account that the container is unloaded "floating" (Fig. 10).

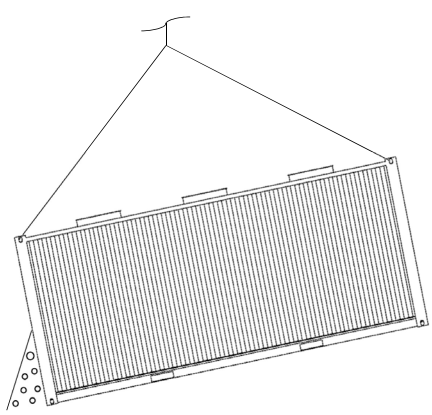

Fig. 10. Container unloading scheme

The calculation of the container strength was carried out at an angle of inclination to the horizontal α=45°. It was taken into account that the container was tilted to the specified angle, and after that the process of its unloading began.

The calculated diagram of the container is shown in Fig. 11. The designations of the loads on it is identical to those used in the diagrams shown in Fig. 3, 7.

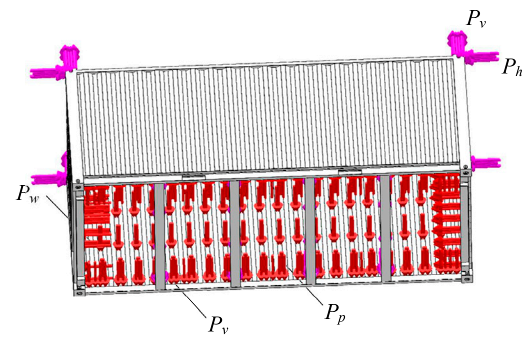

Fig. 11. Calculation diagram of a container during its unloading

The calculation results are shown in Fig. 12, 13.

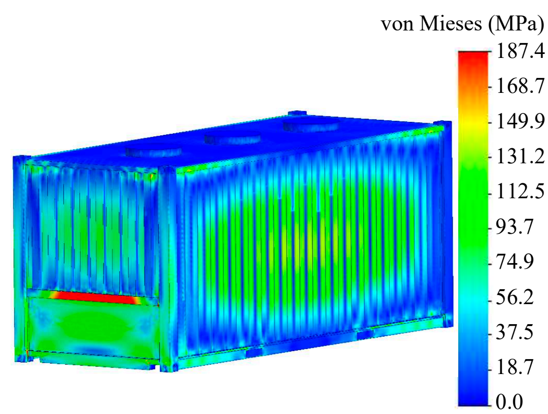

Fig. 12. The stressed state of the container during its unloading

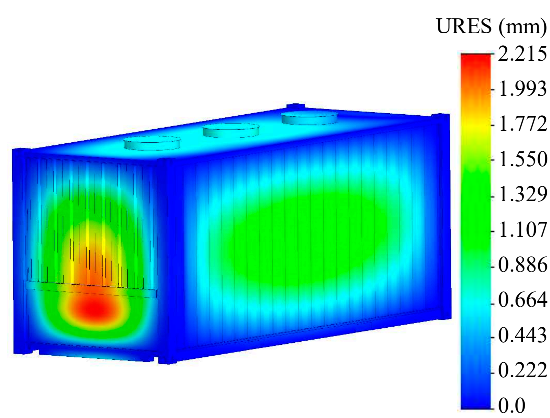

Fig. 13. Movement in the nodes of the container during its unloading

The maximum stresses occur in the horizontal beam for fastening the unloading hatch and are 187.4 MPa (Fig. 11), which is lower than the permissible ones. The maximum displacements are also recorded in the horizontal beam – 2.2 mm. That is, the strength of the container is maintained.

6. Discussion of results based on determining the loading of a container for grain transportation under operational conditions

To enable the use of universal containers for grain transportation, their modernization is proposed. The study was conducted on the example of a universal container of standard size 1CC (Fig. 1). The modernization involves the installation of three loading hatches on the roof of the container (Fig. 2). It is also planned to make an unloading hatch in the end wall at a height of 1/3 from the lower strapping.

To substantiate such modernization, a calculation was performed of the strength of the container under the following load schemes:

– transportation of the container as part of a railroad train;
– lifting by the upper corner fittings;
– unloading the container.

In order to determine the dynamic loads acting on the container when it moves in a train, mathematical modeling was performed. For this purpose, a mathematical model (3) was formed. The results of solving it allowed us to determine the acceleration and take it into account in calculations for the strength of the container.

It was established that when transporting a container in a railroad train, the maximum stresses arise in the middle part of the horizontal beam for fastening the unloading hatch and are 121.4 MPa (Fig. 5). It is important to say that these stresses are lower than the permissible ones. At the same time, the maximum displacements are recorded in the side wall and are equal to 1.8 mm (Fig. 6). This distribution of displacement fields is explained by the fact that the wall is fixed along the perimeter, and a distributed load acts on its area.

When lifting the container by the upper corner fittings, the maximum stresses occur in the zones of interaction of the corner posts with the cross beams and are 108.6 MPa (Fig. 8). These stresses also do not exceed the permissible values. The maximum displacements are recorded in the side walls of the container and are equal to 1.6 mm (Fig. 9). This is explained by the same argument as for the previous container loading scheme.

When unloading the container, the maximum stresses in its structure arise in the horizontal beam for fastening the unloading hatch. These stresses amounted to 187.4 MPa (Fig. 12). Therefore, these stresses are lower than the permissible ones. The maximum displacements were also recorded in the horizontal beam and are equal to 2.2 mm (Fig. 13). This is explained by the action of the inertia forces of the bulk cargo on the end wall. Therefore, with this loading scheme, the strength of the container is also ensured.

It must be said that the solutions proposed in the work can be implemented not only when upgrading existing container structures but also when designing new ones.

The results of this study have certain advantages compared to the known ones. For example, unlike works [1–7], we have proposed and substantiated the design of a container for transporting a specific cargo, which is quite common in transportation. Unlike work [2], we have proposed measures that could help improve the efficiency of container operation. In comparison with the results of work [3], within the framework of this work, an improvement of the container design is proposed, with the possibility of its operation not only in domestic traffic of countries but also in international traffic. Unlike work [4], the proposed solutions for improving the container do not require the use of high-cost materials in its design. In comparison with the results of works [5, 8], the proposed solutions have been justified by theoretical calculations of the container strength under certain operating load conditions.

The limitation of this study is that we did not examine the case of cargo, grain, sticking together, and the impact of such a phenomenon on the container unloading process.

The disadvantage of this study is that when calculating the strength, the nominal dimensions of the container were taken into account. That is, if we are talking about modernization, then the container that is subject to such modernization may have wear of the structural components. But such wear was not taken into account when calculating. Also, as a disadvantage of this study, it can be noted that the calculation model of the container does not take into account welds, that is, it is considered as a monolithic structure.

Prospect for advancing this study worth noting is to determine the loading of the container during transportation by other types of vehicles.

The results of the study will contribute to compiling recommendations for modernization and design of container structures, as well as increasing the efficiency of container transportation, including international traffic.

7. Conclusions

1. The strength of the container has been calculated when it was transported in a railroad train. To determine the dynamic load acting on the container, mathematical modeling was performed. It was established that the acceleration acting on the containers placed on the platform car is about 27 m/s^2. Taking into account this acceleration value, the maximum stresses arising in the container structure were 121.4 MPa, which is lower than the permissible ones. These stresses are concentrated in the middle part of the horizontal beam for fastening the unloading hatch. The maximum displacements were recorded in the side wall of the container and are 1.8 mm.

2. The strength of the container has been calculated when it was lifted by the upper corner fittings. It was established that the maximum stresses arise in the zones of interaction of the corner posts of the container with the cross beams and are 108.6 MPa. The resulting stresses do not exceed the permissible ones. The maximum displacements were recorded in the side walls and were 1.6 mm.

3. The strength of the container during unloading has been calculated. Under this mode, the maximum stresses arise in the horizontal beam for fastening the unloading hatch. These stresses are 187.4 MPa, which is lower than the permissible ones. The maximum displacements were also recorded in the horizontal beam for fastening the unloading hatch and were 2.2 mm.

So, with the considered load schemes, the strength of the modernized container design is maintained.

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.

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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.

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