PECULIARITIES OF DESIGNING THE FRAME OF A UNIVERSAL CONTAINER MADE OF RECTANGULAR PIPES

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Resume

The features of designing the frame of a universal container made of square pipes are presented in this paper. The two frame loading schemes are taken into account: the effect of vertical loading on the container frame when it is lifted by the upper corner fittings (I loading mode); the effect of longitudinal loading on the frame during transportation by the rail transport (II loading mode). Mathematical modeling was performed to determine the longitudinal loading acting on the container in the II loading mode. The determined acceleration is taken into account when constructing the schemes of force factors that arise in the frame. The strength of the frame was calculated using the finite element method, which was implemented in SolidWorks Simulation. The conducted research could contribute to creation of recommendations and developments regarding the design of modern structures of modular vehicles.

Article info

Received 10 November 2023
Accepted 10 January 2024
Online 26 January 2024

Keywords:

container
container frame
container loading
container strength
container transportation

Available online: https://doi.org/10.26552/com.C.2024.016

ISSN 1335-4205 (print version)
ISSN 2585-7878 (online version)

1 Introduction

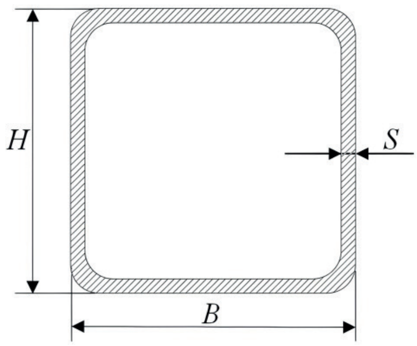
Container transportation has long been one of the most successful symbioses of transport interaction. Due to the mobility of their design, containers are transported by all types of transport [1-3]. One of the most common logistics schemes is the transportation of containers by rail transport with subsequent transshipment onto the decks of railway vessels. In this case, the transshipment of containers from one type of transport to another is carried out with the help of lifting and transporting equipment - spreaders, fork-lift trucks, etc. Containers can be damaged as a result of loading and unloading operations. Such damages include a rupture of the cladding, deformation of the frame elements, broken welds, etc. These damages not only cause the need for additional capital costs for the operation of containers, in particular for repairs, but can also cause damage to the cargo placed in them. In addition, such damages threaten the traffic safety of vehicles transporting such containers. In this regard, there is a need to create modern container designs with improved technical properties, including operational ones.

2 Analysis of recent research and publications

Currently, there is a large number of developments on design of the modern container structures. Some of them are considered hereon. For example, in work [4], an analysis of the stresses occurring in the structure of the container during its transportation by water transport is carried out. A 40-foot container of standard size 1AA is taken into account. The calculation results made it possible to formulate the main requirements for operation of such a container.

Authors of publication [5] also analyzed the strength of the universal container, however, in the case of transporting it by rail. They obtained the dependence of the influence of the container's own movements on its strength. It must be said that the works [4-5] do not propose solutions for improving the container, which would enable the enhancement of its operational properties.

The creation of a new design of a specialized container is covered in publication [6]. The container is intended for transportation of fruit and vegetable products. The authors not only highlighted the features



H - height; B - width; S - wall thickness

Figure 1 *Pipe section*

of its design, but also performed the strength calculation. The paper also mentions the prospects for operation of such a container. Similar studies are also covered in work [7], where a design of a container for fruit and vegetable products is also proposed.

Peculiarities of designing a container, according to the ISO standard size, are considered in the work [8]. The main loading patterns of the container in operation are analyzed. The influence of operational loadings on the strength qualities of the container was studied. Further prospects for creation of modern container designs have been determined. Along with this, the authors of works [6-8] did not propose solutions for improving the design of the container frame, as its most loaded component.

To reduce the dynamic loading of the container during transportation by rail, works [9-10] proposed to make its walls from sandwich panels with a layer of energy-absorbing material. These panels are supposed to be attached to the frame. To justify such an implementation, the simulation of the container loading (longitudinal and lateral) and the calculation of strength of its structure were carried out. The obtained results proved the effectiveness of the proposed improvement. At the same time, the authors' team did not pay attention to the improvement of the container's frame.

Determination of the stress-deformation state of the container body with a variable volume is carried out in work [11]. The calculation was carried out in the ANSYS software. Experimental studies were carried out on the lateral skew of the container at insignificant loads to check the adequacy of the obtained results.

The study of the stress-deformed state of the container body when it is lifted by a crane and moved by a drag is carried out in the publication [12]. The theoretical determination of strength indicators was carried out in the WinMachine ARM software package. The experimental study of strength was carried out using the method of electrical strain measurement.

The determination of the dynamic load of the container under operational load modes was carried out in work [13]. The obtained values of dynamic loads are taken into account when calculating the strength of the container in the Ansys software.

However, solutions for improving the supporting structure of the container and its technical and economic indicators are not given in these works.

The literary review of sources [4-13] proves that the creation of modern container designs is a very relevant issue, but it needs further development.

The purpose of this study was to highlight the features of creating a frame of a universal container from square pipes. To achieve this goal, the authors set the following tasks:

- to determine the force factors that occur in the structure of the container frame during operational loading modes;
- to choose the profile of the container frame execution and calculate its strength.

3 The proposal of the new container frame design

To reduce the damage to the container during the operational modes, it is suggested to make its frame from the closed profiles - square pipes (Figure 1) [14]. When designing this container, the requirements of the international standard ISO 668 "Series 1 cargo containers. Classification, dimensions and nominal characteristics" were taken into account.

To justify the expediency of such an implementation, a frame scheme is proposed, which is shown in Figure 2. The study was carried out on the example of a 24-ton container (1CC).

To determine the parameters of the frame pipes, the corresponding calculations were carried out in the Lira - SAPR. Lira - SAPR is a multifunctional software complex designed for the design and calculation of machine-building and construction structures for various purposes. Calculations in the program are performed for both static and dynamic effects. The finite element method is the basis of calculations in this software. Various available modules can be connected to select and to check cross-sections of steel and reinforced concrete structures, model of soil, calculation of bridges

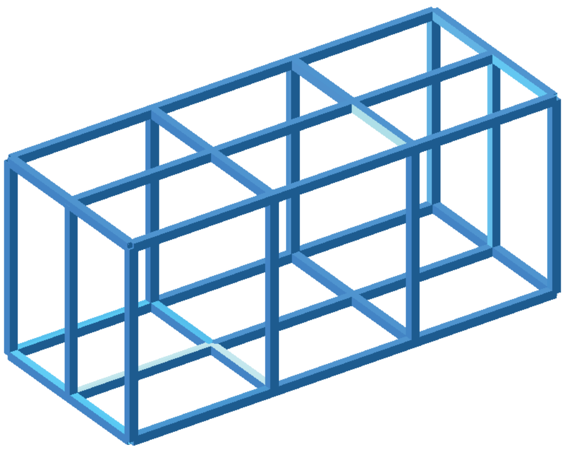


Figure 2 *Container frame*

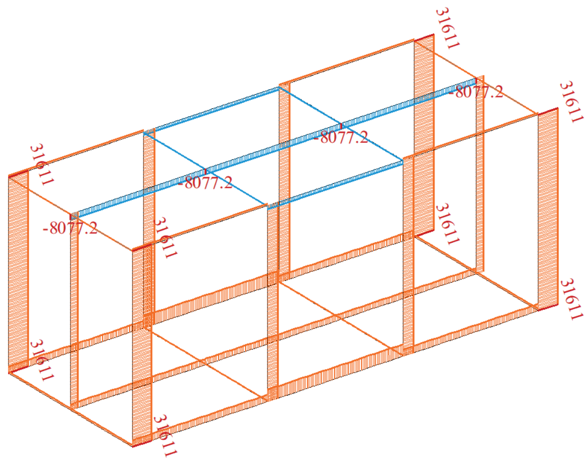


Figure 4 *Scheme of the longitudinal forces acting in the frame (N)*

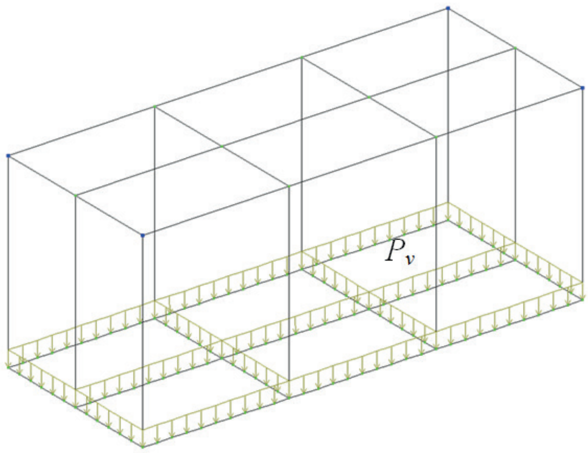


Figure 3 *Calculation scheme of the frame for the I loading mode*

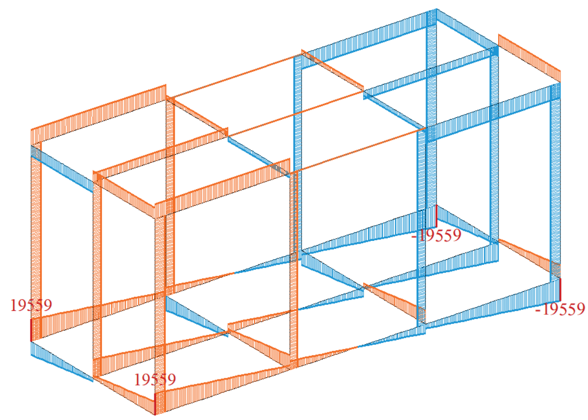


Figure 5 *Scheme of the lateral forces acting in the frame (N)*

and behavior of buildings during the installation period, etc. [15].

In this case, the frame is considered as a rod system. Two frame loading schemes are taken into account:

- vertical loading of the frame when it is lifted by the upper corner fittings (I loading mode);
- longitudinal loading of the frame during the transportation by rail transport (II loading mode).

The calculation scheme of the frame when it is lifted by the upper corner fittings is shown in Figure 3.

The fact that the container frame is secured by the upper corner fittings is taken into account. The vertical loading P_v is transferred to the lower part of the frame, which is intended for placing floor boards. It is also taken into account that the vertical load P_v is determined by the weight of the transported cargo and the container's own weight, i.e. gross weight of the container. In this case, the conditional load was considered using the full carrying capacity of the container. Taking this into account, the schemes of longitudinal (Figure 4) and lateral forces (Figure 5) acting in the frame, as well as the scheme of bending moments (Figure 6) were obtained. Here, in Figures 4 - 6, "extension" is indicated in orange, and "compression" is indicated in blue.

The analysis of a scheme shown in Figure 4 leads to the fact, that the longitudinal forces in individual sections of the frame are constant. This is explained by the fact that the elements in individual sections were considered as one whole rod that experiences a given type of internal force (tension or compression).

Therefore, the maximum value of the longitudinal force occurs in the vertical struts and equals 31.6 kN. This is due to the fact that they act as an intermediate adapter between the anchor point and the area of application of force to the container frame.

The maximum value of the lateral force occurs in the intermediate vertical struts. Its value is 19.6 kN.

These struts connect the bottom part of the container frame with the lower one. Therefore, in the case of loading the lower part of the frame, the maximum values of this force occur here.

The maximum value of the bending moment also occurs in the intermediate vertical struts and equals 13.6 kNm. The scheme of frame movements under the action of vertical loading is shown in Figure 7.

At the same time, the longitudinal beams of the

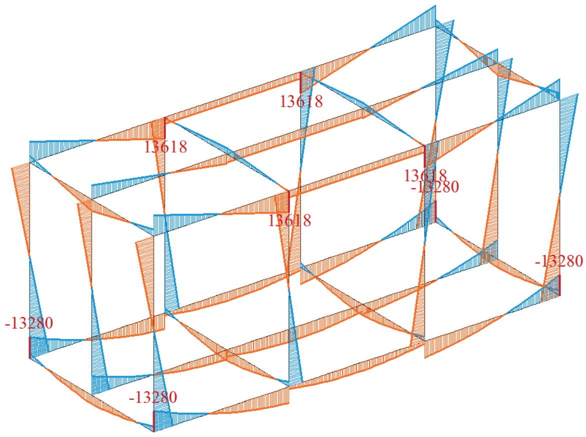


***Figure 6** Scheme of the bending moments acting in the frame (N m)*

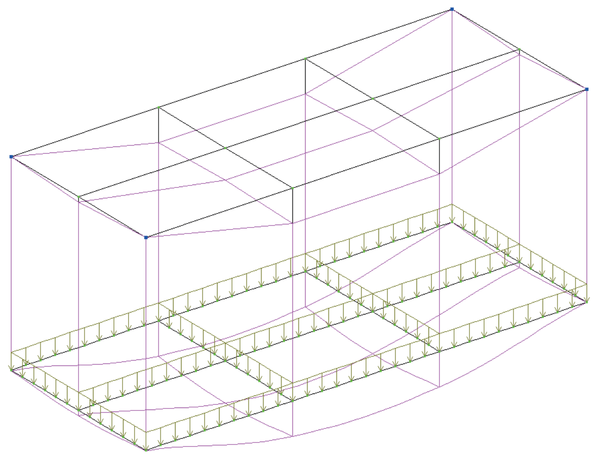


***Figure 7** Scheme of the frame movements under the action of vertical loading*

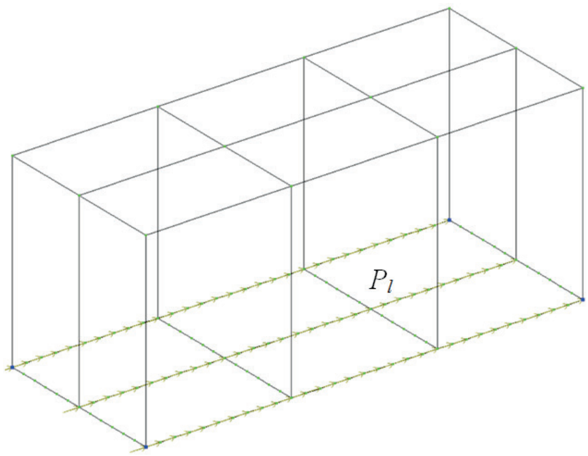


***Figure 8** Calculation scheme of the frame for the II loading mode*

upper and lower parts of the frame experience the largest movements. This is due to the fact that an evenly distributed loading is applied to the beams that form the lower part of the frame.

In addition, as part of the study, the calculation of the container frame under longitudinal loading was carried out, taking into account its transportation by rail transport (on a flat wagon as a part of a train). The calculation scheme of the frame is shown in Figure 8.

In this case, the longitudinal loading P_l was applied to the beams forming the lower part of the frame, namely to the longitudinal beams. This scheme is explained by the fact that the load on the lower frame of the container when transported by a flat wagon is transferred from the corner fittings, which interact with the fitting stops. The movement of cargo relative to the container was not taken into account. The frame was secured in corner fittings.

To determine the amount of the longitudinal force, a mathematical model, formed in the previous work of the authors [16], was used. However, this model was further developed to determine the longitudinal loading of a container placed on a flat wagon when a longitudinal force is applied to it. In view of this, the model has the following form:

$$\begin{cases} M_{FW} \cdot \ddot{q}_1 = P - \sum_{i=1}^{n} (F_{FR} \cdot sign(\dot{q}_1 - \dot{q}_2)), \\ M_c \cdot \ddot{q}_2 = (F_{FR} \cdot sign(\dot{q}_1 - \dot{q}_2)), \end{cases} \tag{1}$$

here M_{FW}, M_C - inertial coefficients, which characterize, respectively, the mass of the frame of the flat wagon and the container; P - force acting on the stops of the automatic coupling device of the flat wagon; F_{FR} - frictional force between the frame of the flat wagon and the containers; q_1 and q_2 - generalized coordinates characterizing the movement of a flat wagon and a container, respectively.

The calculation was carried out under the condition that a longitudinal force of 2.5 MN [17] is applied to the stops of the automatic coupling. It was considered that this force acts in the form of a "jerk" with a constant value.

It is important to note that it is necessary to take into account the value of forces that are characteristic of their operating conditions in the case of using this model

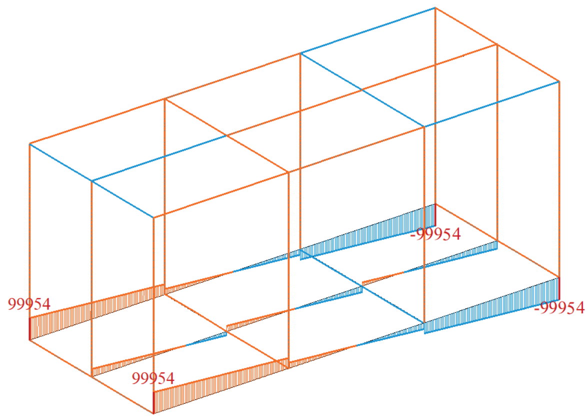


Figure 9 *Scheme of the longitudinal forces acting in the frame (N)*

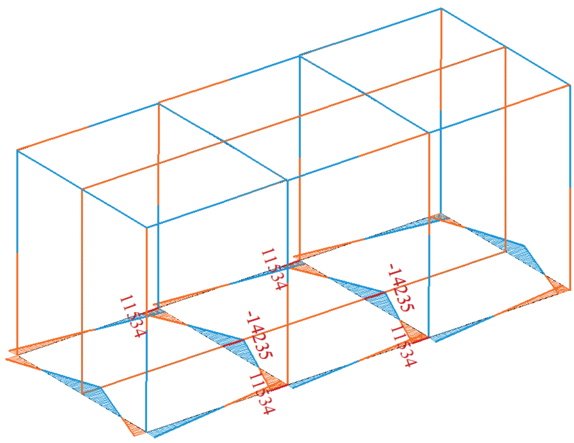


Figure 11 *Scheme of the bending moments acting in the frame (Nm)*

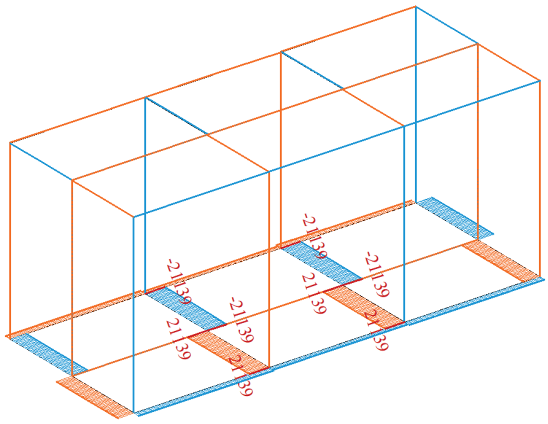


Figure 10 *Scheme of the lateral forces acting in the frame (N)*

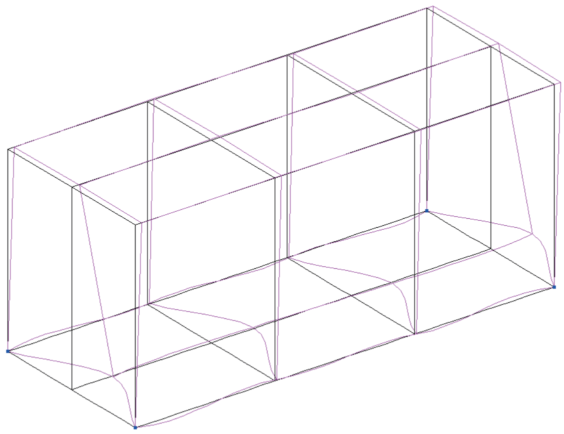


Figure 12 *Scheme of the frame movements when a longitudinal force is applied to it*

for a 1435 mm gauge car equipped with a screw tie.

The solution of the mathematical model was carried out by the method of variation of arbitrary constants, with initial conditions close to zero [18-19]. Based on the calculations, it was established that the longitudinal acceleration acting on the container is about 20 m/s^2.

This value of acceleration is taken into account when constructing the loading scheme of the container frame in the II loading mode. The calculation results are shown in Figures 9 - 11. Analyzing the data of the scheme, one can conclude that the maximum value of the longitudinal force occurs in the bottom part of the frame and equals 100 kN (Figure 9). This can be explained by the fact that it was secured by the lower corner fittings. The maximum value of the lateral force was recorded in the longitudinal beams and amounted to 21.1 kN (Figure 10). This is explained by the same argument as for the situation with longitudinal forces. The maximum bending moment occurs in the bottom part of the frame and is equal to 14.2 kNm (Figure 11).

The scheme of the frame movements in the II calculation mode is shown in Figure 12.

At the same time, the lateral beams of the lower part of the frame experience maximum displacement. This circumstance is caused by the fact that it is fixed by the lower corner fittings, and the longitudinal force is applied to the lateral beams.

Based on the obtained results, the moment of resistance of the section of the container frame execution profile was determined. In this case, the following dependency was used [20]:

$$W = \frac{M}{[\sigma]}, \tag{2}$$

here M - value of the maximum bending moment acting in the section of the frame; [σ] - allowable stresses for the material of the frame execution (steel grade 09G2S, [σ] = 210 MPa [13]).

It should be noted that grade 09G2S steel is standard for the manufacture of containers.

The cross-sectional area of the frame execution profile was considered, as well. In this case [20]

$$A = \frac{F}{[\sigma]}, \tag{3}$$

here F - value of the longitudinal force acting in the frame.

It must be said that according to the results of

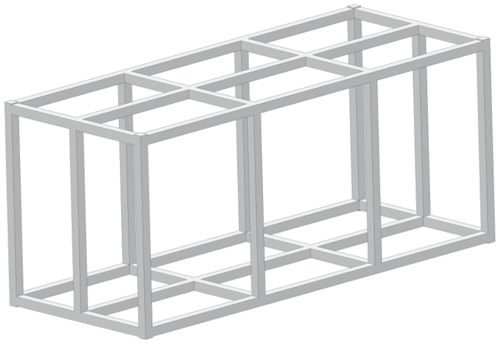


***Figure 13** the 3-D model of the container frame*

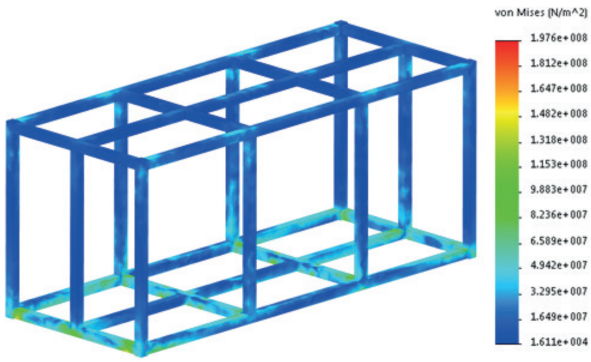


***Figure 14** Stressed state of the container frame*

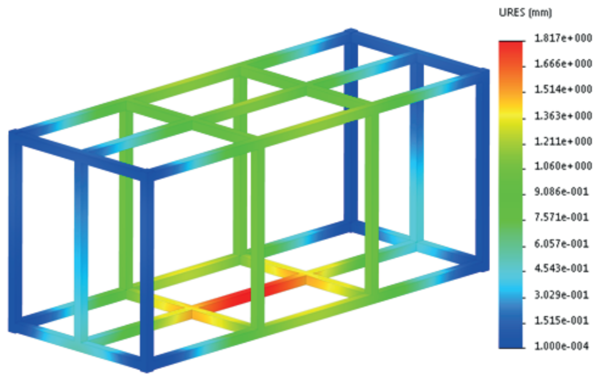


***Figure 15** Displacements in the nodes of the container frame*

calculations, the selection of the section parameters of the frame was carried out according to Equation (2), since here the value of the moment of resistance, from the point of view of ensuring the strength of the frame execution profile, is more important. Taking into account the conducted calculations, it was established that the profile of the frame execution is a square pipe with the following parameters: $H = B = 120$ mm, $S = 4$ mm, $W = 67.05$ cm^3. Based on the specified parameters, the mass of the container frame will amount to about 500 kg.

At the next stage of the research, a spatial model of the container frame was built (Figure 13) and its FEM analysis was carried out in SolidWorks Simulation [21-22].

The results of the calculation of the container's strength under the II loading mode are shown in Figures 14 and 15.

The maximum stresses occur in the lateral beam and amount to 197.6 MPa (Figure 14), that is, they are lower than permissible. The maximum displacements occur in the middle part of the longitudinal beam and amount to 1.8 mm (Figure 15). Therefore, the strength of the container frame under operational loadings is ensured [17].

4 Conclusions

1. The force factors that take place in the structure of the container frame during the operational loading modes are determined. At the same time, the two schemes are considered: the effect of the vertical loading on the frame of the container when it is lifted by the upper corner fittings (I loading mode) and the effect of the longitudinal loading on the frame during the transportation by rail transport (II loading mode). It was found that the maximum value of the longitudinal force in the I mode occurs in vertical struts and equals 31.6 kN. The maximum value of the lateral force is recorded in the intermediate vertical struts and equals 19.6 kN. The maximum value of the bending moment also occurs in the intermediate vertical struts and is equal to 13.6 kN m.
To determine the longitudinal force acting on the frame of the container, mathematical modeling of its dynamic loading when placed on a flat wagon was carried out. It was established that the longitudinal acceleration acting on the container is about 20 m/s^2. In view of this, the calculation of the container frame in the II mode was carried out. The maximum value of the longitudinal force occurs in the bottom part of the frame and equals 100 kN. The maximum value of the lateral force was recorded in the longitudinal beams and amounted to 21.1 kN. The maximum bending moment occurs in the bottom part of the frame and is equal to 11.5 kNm.
2. The profile of the container frame execution was selected - a square pipe with parameters:

$H = B = 120$ mm, $S = 4$ mm, $W = 67.05$ cm^3. Here, the mass of the container frame was about 500 kg. The strength of the container frame was calculated. The calculation results showed that the maximum stresses occur in the lateral beam and amount to 197.6 MPa. The maximum displacements occur in the middle part of the longitudinal beam and amount to 1.8 mm. Therefore, the strength of the container frame under the considered operational loadings is ensured.

The conducted research could contribute to creation of recommendations and developments in the sphere of designing modern structures of vehicles of a modular type.

Acknowledgment

This publication was prepared thanks to support from the Cultural and Educational Grant Agency of the Ministry of Education of the Slovak Republic in the project KEGA 031ZU-4/2023: Development of key competencies of the graduate of the study program Vehicles and Engines; from the Slovak Research and Development Agency of the Ministry of Education, Science, Research and Sport in the project and VEGA 1/0513/22 "Investigation of the properties of railway brake components in simulated operating conditions on a flywheel brake stand; funding by the EU NextGenerationEU through the Recovery and Resilience Plan for Slovakia under the project No. 09I03-03-V01-00131; Funding by the EU NextGenerationEU through the Recovery and Resilience Plan for Slovakia under the project No. 09I03-03-V01-00129.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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