Scientific Justification for the Structural Design of a Universal Railway Container Frame and Reinforcing Elements

Alyona Lovska[1], Juraj Gerlici[1], Mykhailo Pavliuchenkov[2,3] and Ján Dižo[1,*]

[1] University of Žilina, Faculty of Mechanical Engineering, Department of Transport and Handling Machines, Univerzitná 8215/1, 010 26 Žilina, Slovakia; {juraj.gerlici,alyona.lovska,jan.dizo}@fstroj.uniza.sk

[2] O.M. Beketov National University of Urban Economy in Kharkiv, Department of Theoretical and Structural Mechanics, Marshala Bazhanova str. 17, 61002 Kharkiv, Ukraine; pavliuchenkov@ukr.net

[3] Sumy National Agrarian University, Department of Building Structures, Faculty of Civil Engineering, 160 Herasyma Kondratieva Street, 40000 Sumy, Ukraine

*Corresponding author

Abstract: Freight railway transport represents a key part of intermodal transport systems. It ensures the long-range transportation of goods by land, in transport units, for varying distances. Containers are the standard transport units used for intermodal transport. Requirements for reliable and safe transport leads to new design solutions. The presented research is focused on the innovative design of a container structure. Structural solutions of a universal container frame were proposed to increase the efficiency of container transportation. A feature of these solutions is the introduction of reinforcing elements into the structure, which reduces the force factors in the highest load areas of the structure. These elements are made in the form of a fork and provide unloading of the longitudinal beams of the frame, during operation. In order to substantiate the proposed solutions, appropriate calculations of the container frame, as a rod system, have been carried out. The most rational variant of the container frame was selected. The frame's profile was determined, and the strength calculation was carried out using FEM (Finite Element Method). Two load cases were analyzed: one load case for the longitudinal load, where the maximal stresses were up to the value of 165.4 MPa and the other for lifting the container, where the maximal stresses were up to 138.4 MPa. The results of the numerical calculations have proven the feasibility of the proposed solutions.

Keywords: railway transport; container transportation; container design; FEM; design improvement

1 Introduction

Railways ensure the transport of huge amounts of goods (as well as passengers) worldwide [1-3]. Europe is known for its strong efforts to reduce the harmful effects of transport on the environment [4-6]. These efforts are supported by such transport systems, which represent effective and economical ways to move large quantities of goods, with the simultaneous use of ecologically friendly power sources [7]. Intermodal transport, with containers, is a perspective mode to transport the material with minimization of operation, loading and unloading the transported units [8-10]. The containers, combined with freight flat wagons, are one of the most environmentally friendly ways of transporting goods. Railway transport has several advantages compared to road land transport, mainly due to lower rolling resistance [11-14], drag and higher vertical load per axle [15-18]. Moreover, railway tracks are able to withstand higher vertical loads [19] [20]. Furthermore, an advantage is the possibility of setting up long trainsets [21-23], which can be moved in long, even very long distances.

As mentioned above, container transport is one of the most popular types of cargo transportation, from various modes of transport. This is explained by their mobility and the absence of the need to reload cargo operations at special points. Currently, a wide variety of containers are used, which differ not only by their design and processing principle, but also by their load capacity (Fig. 1).

a) b)

Figure 1

Universal containers: a) a size 1AA [24], b) a size 1CC [25]

Simultaneously, the process of container transportation containers by various types of vehicles is accompanied by loads of different natures to their structure [26-28]. This can lead damage of their structure, during operation.

Regarding the damage, the main modes of container loads in operation were studied, and it was established that the most unfavorable load schemes occur during railway transportation, namely during a shunting collision of flat wagons [29-32], which are loaded by containers. In this operating mode, the longitudinal force of 3.5 MN acts on the rear stop of an autocoupler. Therefore, the container experiences significant dynamic loads that can cause damage. Most of this damage is on the longitudinal beams of the frame, namely, the areas of their interaction with the fittings. In such a situation, there is a risk of damage to the container, collapse of the cargo on the route, as well as the safety threat of the train. Therefore, the container's design needs to be improved to ensure its strength under operational conditions.

To identify existing developments in container improvements, an analysis of scientific publications on the topic of the study was conducted. For example, in article [33], the authors proposed a design of a universal container in which sandwich panels form wall cladding. It is noted that such an implementation contributes to improving the safety of transported cargo by reducing the magnitude of the dynamic loads acting on the container during operation. The results of the conducted modeling of the container load confirmed that such a solution is justified. However, implementing containers in the proposed design is financially constrained since it requires significant capital investments. A similar drawback is also found in publication [34], where the Authors proposed the implementation of sandwich components as the container floor covering and the end walls.

A container design with a frame formed by closed profiles is proposed in the research [35]. This solution is justified by increasing the moment of resistance of the frame components when perceiving the operational loads. The calculations showed that the stresses in the design of such a container are less than those in the design of the prototype. However, the authors of the work did not propose solutions to reduce the loading of the container in the concentration areas with the highest stresses. The authors of the publication [36] proposed a container design for fruit and vegetable cargo. The work justifies such a design with appropriate strength calculations. However, the work does not consider the longitudinal loading of the container and does not indicate any structural solutions for the possibility of its reduction. A similar drawback is also found in the publication [37], which proposes a container design for transporting fruit and vegetable cargo.

The study of the influence of container flexibility on the strength of its structure during rail transportation is highlighted in the work [38]. Based on the calculations, requirements for the safe operation of the container were formulated. The peculiarities of the container loading during its water transportation were investigated in the study [39]. The conducted studies also allowed the form requirements for the safety of container transportation along the studied route. However, no structural solutions were proposed to improve its structure in the research presented in the works [38] [39].

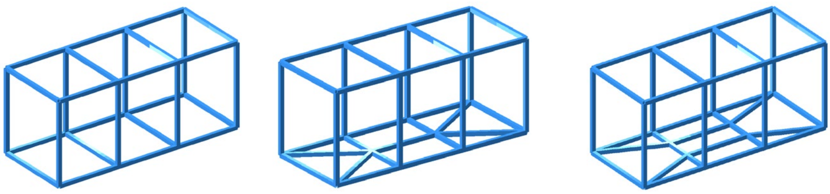
The literature review of publications [33-39] shows that the issue of improving the container frame to improve its strength in operation has not been given the needed attention. Therefore, it is necessary to conduct research in this scientific direction.

The purpose of the presented research is to scientifically substantiate the structural design of the frame of a universal container with reinforcing elements in the frame. This will help reduce the damage they cause during operation and, accordingly, reduce maintenance costs. To achieve the stated goal, the following tasks were defined:

- Determine the force factors in the container frame, taking into account various structural options for its execution
- Select the profile of the container frame and calculate its strength under operational loads

2 Materials and Methods

It is proposed to improve its design to ensure the container's durability during operation. It is planned to install additional elements to the lower part of the container frame, which will relieve the most loaded areas of its design (Fig. 2b, Fig. 2c). At the same time, Fig. 2a shows the initial version of the container design without reinforcing elements in the frame.



a) b) c)

Figure 2

Container frame design options: a) an option 1; b) an option 2; c) an option 3

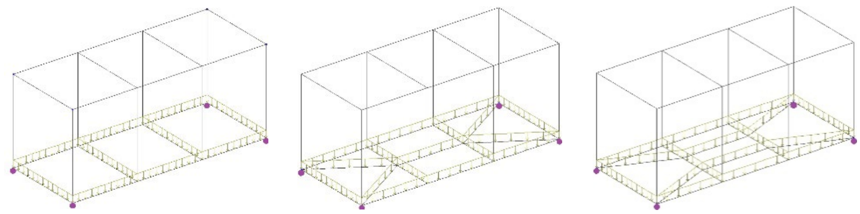
Reinforcing elements of the frame are presented in the form of a fork, the end parts of which perceive part of the load from the fittings and transfer it to its middle part. The frame was calculated as a rod system in the PC software complex "LIRA – CAD" to substantiate the proposed solution. The calculation was carried out using an example of a container with a standard size of 1CC.

The purpose of this calculation was to determine the force factors that arise in the frame during the most loaded modes of operation of the container:

- The effect of the vertical loads on the container frame when it is lifted by the upper fittings
- The effect of the longitudinal load on the container frame placed on a flat wagon during a shunting collision

The rod systems of the container frame were fixed by the corner fittings. When studying the vertical load of all three variants of the container, the fastening was carried out by the upper fittings and the longitudinal loads were defined to the lower ones. The supports of all three models are defined in lower corners as it is depicted in Fig. 3 by purple color. The maximal load corresponding to the container mass of 24 t was considered. It was considered from the side of the vehicle movement.

A sliding support was used on the opposite side. For the case of the container perceiving vertical loads, calculation schemes were formed, as shown in Fig. 3.



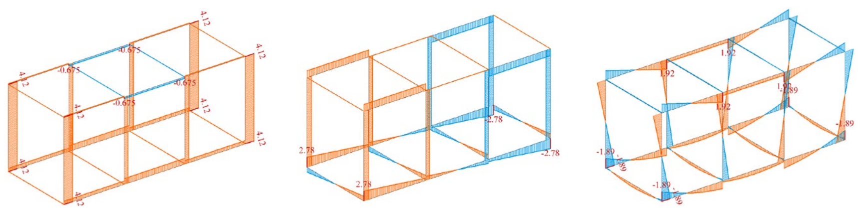
a) b) c)

Figure 3

Design schemes of the frame when it perceives vertical loads: a) option 1; b) option 2; c) option 3

3 Research Results and Discussion

The diagrams of force factors acting on the container frame when it perceives vertical loads were obtained based on the calculations performed using the options of the PC "LIRA – CAD" software. The orange color indicates a positive value of the force factors, and the blue color indicates a negative one. The vertical load applied to the container frame was considered 240 kN, i.e., it corresponds to the container's gross weight with the given size. Therefore, the maximum longitudinal forces arise in the container's vertical uprights for the container's structural design according to option 1, and they are numbered to the value of 41.2 kN (Fig. 4a).



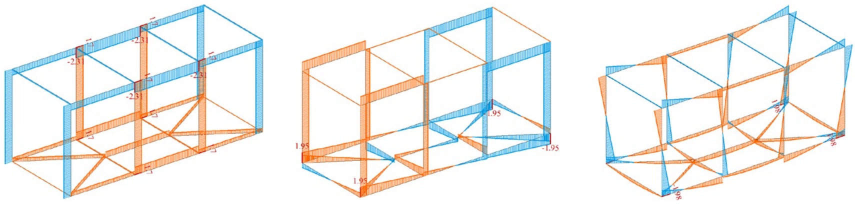
a) b) c)

Figure 4

Diagrams of the force factors acting on the container frame when it perceives the vertical loads (the option 1): a) a diagram of the longitudinal forces; b) a diagram of the transverse forces; c) a diagram of the bending moments

The maximum transverse forces in the container frame arise in the longitudinal beams of the container. This can be seen in Fig. 4b. These forces have an alternating character. In the center of the longitudinal beams, these forces are equal to zero and increase to the end parts to the value of 27.8 kN. Bending moments also arise in the frame. This is depicted in Fig. 4c. Their maximum values are recorded in the upper strapping and numbered to the value of 19.2 kN·m. This bending moment also has an alternating character for each section of the frame. As it can be seen, the given load is symmetrical.

The results of the calculation of the container frame according to option 2 are shown in Fig. 5. The maximum values of longitudinal forces are observed in the middle part of the upper strapping of the container, and they have the value of 23.1 kN (Fig. 5a). This zone of the frame works in compression. Therefore, the longitudinal forces have a negative value. The maximum transverse forces in the container frame are observed in the lower corner parts, equal to 19.5 kN (Fig. 5b). These forces have an alternating character.



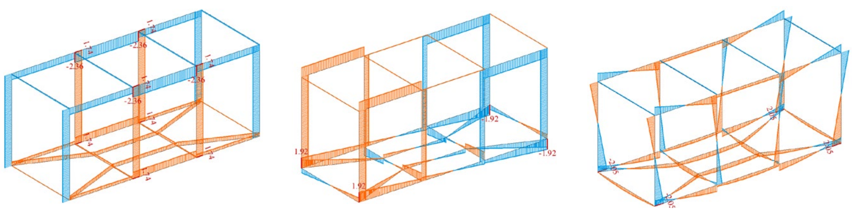
a) b) c)

Figure 5

Diagrams of the force factors acting on the container frame when it perceives the vertical loads (the option 2): a) a diagram of the longitudinal forces; b) a diagram of the transverse forces; c) a diagram of the bending moments

Regarding the maximum bending moment, it can be concluded that it occurs in the vertical uprights of the corner parts of the frame, which is equal to the value of 19.8 kN·m (Fig. 5c). This moment has an alternating character.

Finally, Fig. 6 shows the results of calculating the force factors in the container frame according to option 3.



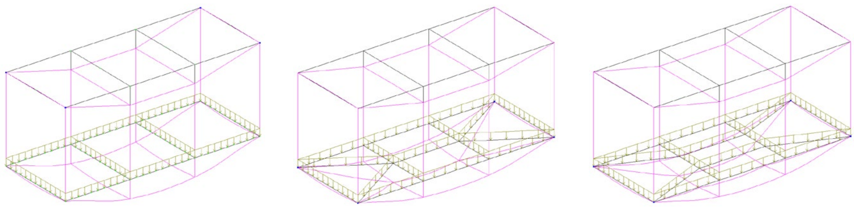
a) b) c)

Figure 6

Diagrams of the force factors acting on the container frame when it perceives the vertical loads (the option 3): a) a diagram of the longitudinal forces; b) a diagram of the transverse forces; c) a diagram of the bending moments

Therefore, when the container perceives the vertical loads, the maximum value of the longitudinal forces is traced along the middle part of the upper strapping. They equal to the value of 23.6 kN (Fig. 6a). The maximum transverse forces occur in the end parts of the braces, namely the zones of their interaction with the fittings, and they are 19.2 kN (Fig. 6b). These forces have an alternating character similar to the previous cases. The maximum value of the bending moment occurs in the container's corners and is equal to the value of 20.5 kN m. (Fig. 6c).

A diagram of the movements of the container components when they are subjected to the vertical loads is depicted in Fig. 7. At the same time, the maximum movements occur in the strapping for all three variants of the container's structural design. This can be explained by its’ design peculiarity and the applying load scheme.

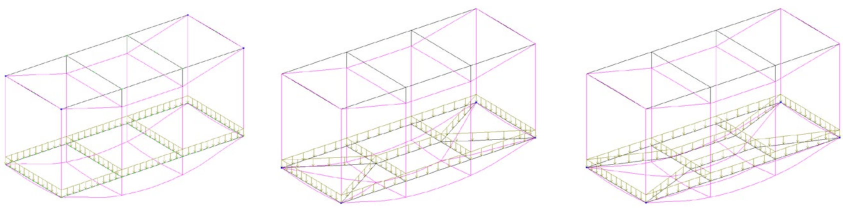


a) b) c)

Figure 7

Deformation of frame structures when they perceive the vertical loads (an enlarged scale):
a) the option 1; b) the option 2; c) the option 3

The container was calculated in the following research stage when it perceives longitudinal loads. The calculated schemes of the frame are shown in Fig. 8. It was taken into account that longitudinal loads are perceived by the longitudinal beams of the lower part of the frame.



a) b) c)

Figure 8

Design schemes of the frame when it perceives longitudinal loads: a) option 1; b) option 2; c) option 3

A mathematical model of the dynamic load of the container was carried out to determine the value of longitudinal loads, provided that it is placed on a flat wagon. In this case, the mathematical model formed in the previous work of the authors [35] was used:

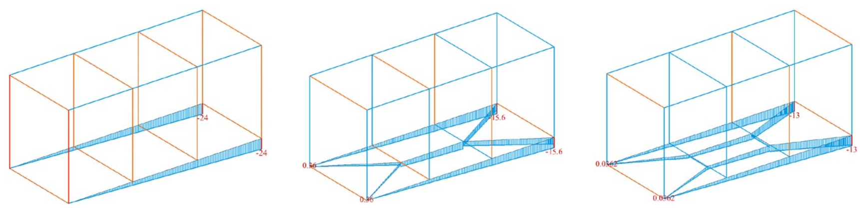
$$\begin{cases} M_{FW} \cdot \ddot{q}_1 = P - \sum_{i=1}^{n} [F_{FR} \cdot sign(\dot{q}_1 - \dot{q}_2)] \\ M_C \cdot \ddot{q}_2 = [F_{FR} \cdot sign(\dot{q}_1 - \dot{q}_2)] \end{cases} \quad (1)$$

where M_{FW}, M_C are inertia coefficients that characterize the mass of the flat wagon frame and the container, respectively; P is the force acting on the stops of the flat wagon automatic coupling device; F_{FR} is the friction force between the flat wagon frame and the container.

It was considered that the magnitude of the longitudinal force, acting on the automatic coupling device's stops is 2.5 MN [40]. Based on the solution of this mathematical model, the acceleration acting on the container was about the value of 20 m/s^2. The achieved value corresponds to the maximal permissible value of 20 m/s^2 [41]. This acceleration was considered when determining the magnitude of the longitudinal load acting on the container. This load was 480 kN.

The longitudinal forces arise in the container (Fig. 9), taking into account the application of the longitudinal load to the beams of the container frame. The maximum value of the longitudinal force in the frame design, made according to Option 1, it is concentrated in the longitudinal beams, which are located along the wagon running direction (Fig. 9a). This force is 240 kN, and it is distributed according to the law of the triangle. The beam works in compression, so the value of this force is negative. In the container frame, made according to Option 2, the maximum value of the longitudinal force is also observed in the longitudinal beams, and it is equal to the value of 156 kN (Fig. 9b). These forces are less than 35% of those occurring in the container frame, due to the use of a fork, made according to Option 1.

The maximum value of the longitudinal force in the container frame made according to Option 3 is also recorded in the longitudinal beams, which is 130 kN. This can be seen in Fig. 9c. The obtained value of the longitudinal force is lower almost by 46% over those that occurred in the frame of the container made according to the Option 1 and lower by 13% than those occurred in the container frame made according to the Option 2.



a) b) c)

Figure 9

Diagrams of the longitudinal forces acting on the container frame when it receives the longitudinal loads: a) option 1; b) option 2; c) option 3

Fig. 10 shows the container frame components' displacement diagrams when subjected to longitudinal forces. The largest displacements for all three frame designs are in the vertical uprights and transverse beams of the upper part of the frame.

According to the results of the calculations, it can be concluded that the smallest force factors arise in the container frame made according to option 3 (Table 1).

Table 1
Force factors acting on the frame of an improved container design

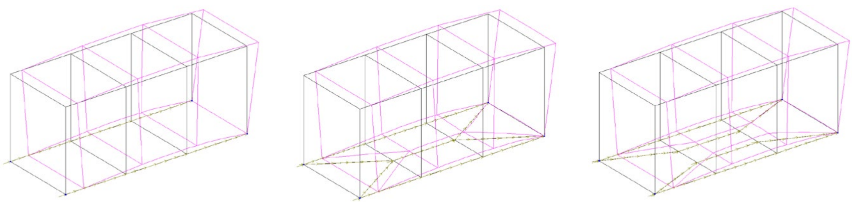
Variant of a container	Vertical loads due to:			Longitudinal load due to:
	Longitudinal force [kN]	Lateral force [kN]	Bending moment [kN·m]	Bending moment [kN·m]
1	41.2	27.8	19.2	240
2	23.1	19.5	19.8	156
3	23.6	19.2	20.5	130

The mass of the frame made according to the 1st vvariant is about 950 kg, the 2nd version is about 1080 kg and the finally, the 3rd version is about 1100 kg.

At the next stage of the calculation, the profile of the beams of the frame of this container was selected. When the structure operates in a "tension-compression" mode, the profile of the frame was selected according to the area A:

$$A = \frac{F}{[\sigma]} \quad (2)$$

where F is the force acting on the container frame; $[\sigma]$ is the value of the allowable stress of the frame material.



a) b) c)

Figure 10
Deformation of frame structures when they perceive the longitudinal loads (an enlarged scale):
a) option 1; b) option 2; c) option 3

In the case of the bending moment M acting on the frame structure, the selection of the execution profile is carried out according to the moment of resistance W of the section:

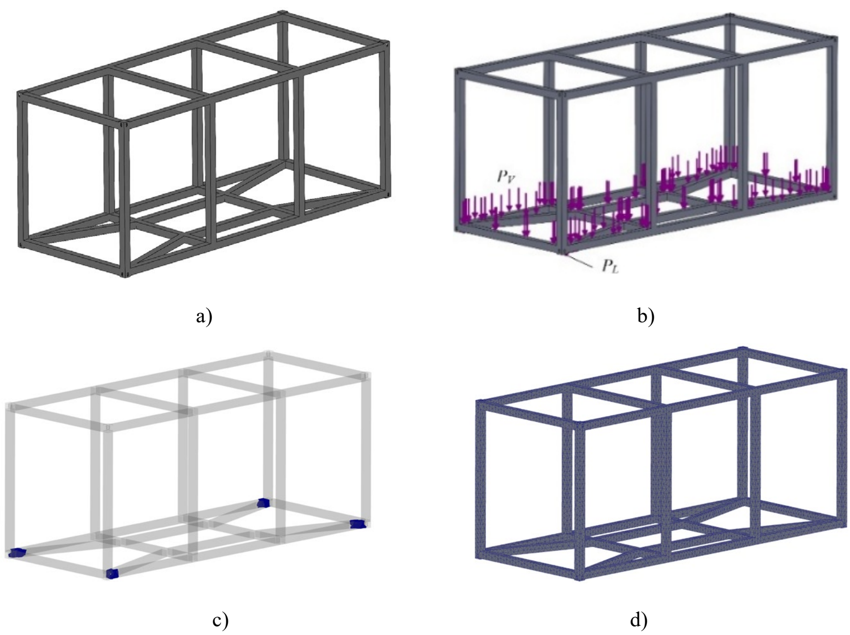
$$W = \frac{M}{[\sigma]} \quad (3)$$

Based on the calculations, a rectangular pipe with the cross-section dimensions of 180×180 mm with the following parameters $W = 162.8$ cm^3, $A = 4.5$ cm^2 and a mass of 1 linear meter $m = 24.39$ kg was selected as the frame profile.

Considering the selected profile of the container frame, its spatial model was built in SolidWorks software, which is shown in Fig. 11. Simulation computations of the strength of the container frame were performed using the finite element method in SolidWorks simulation software [42-44] based on this model.

When creating a finite element model, tetrahedra were used [45]. The number of elements in the model was 51708 and was determined graphically. The number of nodes is 16824. The design scheme of the container is shown in Fig. 12. It includes a vertical load P_v, as well as a longitudinal P_p, applied to the container fittings in front of the train. The vertical load acting on the container includes a load due to the container's weight and the weight of the cargo transported in it. In this case, the container's weight was applied, considering the options for the SolidWorks Simulation software package.

The frame material was selected from steel grade 09G2S, which, for the given operating mode, has permissible stresses of 210 MPa [40]. The model was fixed to the fittings [46] [47].



a) b)

c) d)

Figure 11

Schemes of the container: a) a spatial model of the container frame; b) a design diagram of a container when it perceives the longitudinal loads; c) the most loaded areas of the container frame; d) a finite element model of the frame of the container

The calculation results are shown in Fig. 13 to Fig. 15. The maximum stresses in the frame were recorded in the zone of interaction of the longitudinal beams with the fittings (Fig. 14). These stresses were 165.4 MPa, and they were lower than the permissible values, by 21.2%.

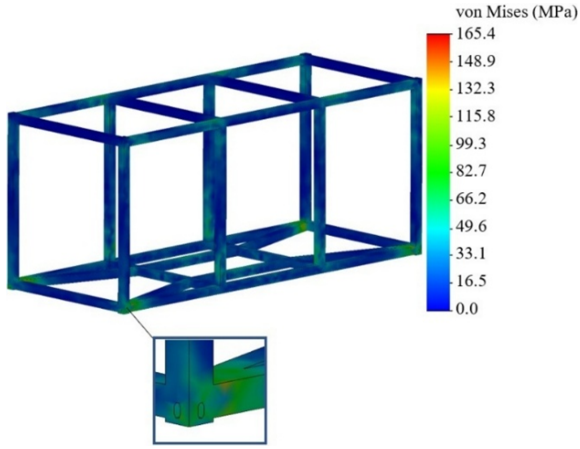


Figure 13
A distribution of stresses in the container frame structure

The maximum displacement occurs in the middle part of the fork, which is about 3 mm (Fig. 15). This stress dislocation is explained by applying loads to the container frame and fastening it.

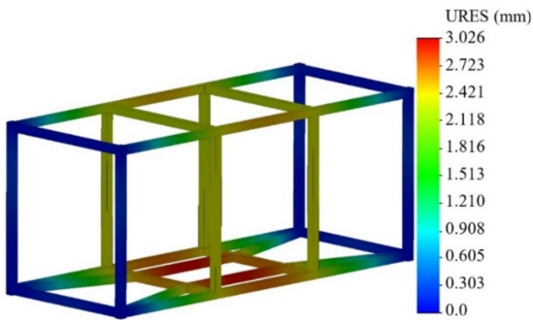


Figure 15
Displacements in the nodes of the container frame structure

The calculation was also carried out to lift the container by the upper fittings. The calculation results also ensured the strength of the container frame for this design mode. The maximum stresses in the frame were 138.4 MPa and concentrated in the racks. The maximum displacement was recorded in the middle part of the fork, which was 2.9 mm.

The limitation of this study is that when calculating the strength of the container frame, the authors did not consider the presence of welds between its individual components.

The further development of this study will be the optimization of the container shell and the study of its loading under other design modes.

Conclusions

Determining force factors in container frames, considering various structural variants of its execution, was completed. Two calculation schemes of the frame loads were taken into account: the first as the vertical loads on the frame, when it is lifted by the upper fittings and the second as the longitudinal load on the frame placed on the flat wagon during shunting collision.

The calculations showed that Option 2 is the most rational of the considered variants of the structural design execution of the container frame. The value of the longitudinal force in such a frame is lower, by almost 46%, than those that occurred in the container frame made according to Option 1 and lower by 13% over the container frames made according to Option 2.

The profile of the container frame was selected, and its strength under operational loads was calculated. It was found that maximum stresses occur in the frame when it has longitudinal loads. These stresses arise in the zone of interaction of the longitudinal beams with the fittings, and their values are 165.4 MPa. These stresses are 21.2% lower than the permissible values. The maximum displacement shows in the middle section of the fork, which is about 3 mm.

In the case of lifting the container by the upper fittings, the maximum stresses in the frame are concentrated in the racks and they are 138.4 MPa. The maximum displacement is found in the fork's middle section and is 2.9 mm.

The work conducted contribute to the creation of recommendations for the design and modernization of containers, with improved the technical, economic and operational characteristics.

Acknowledgements

This research was also supported by the Slovak Research and Development Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic VEGA 1/0308/24 "Research of dynamic properties of rail vehicles mechanical systems with flexible components when running on a track. This publication was supported by the Cultural and Educational Grant Agency of the Ministry of Education of the Slovak Republic in the project KEGA 031ŽU-4/2023: Development of key competencies of the graduate of the study program Vehicles and Engines.

"Funded by the EU NextGenerationEU through the Recovery and Resilience Plan for Slovakia under the project No. 09I03-03-V01-00131."

References

[1] Kučera, P. & Heřmánková, A. (2024) The use of automation in rail transport to ensure interchanges in regional passenger transport. Communications - Scientific Letters of the University of Žilina 26(4), D82-D91

[2] Petrović, A. D., Banić, M., Simonović, M., Stamenković, D., Miltenović, A., Adamović, G. & Rangelov, D. (2022) Integration of computer vision and convolutional neural networks in the system for detection of rail track and signals on the railway. Applied Sciences 12(12), 6045

[3] Fischer, S. & Kocsis Szürke, S. (2023) Detection process of energy loss in electric railway vehicles. Facta Universitatis, Series: Mechanical Engineering 21(1), 81-99

[4] Tomaschek, T. A. & Selmeczy, A. M. (2023) Mobility Data for a Safer and Greener Transport. Acta Technica Jaurinensis 16(4), 129-142

[5] Fischer, S., Hermán, S., Sysyn, M., Kurhan, D. & Kocsis Szürke, S. (2025) Quantitative analysis and optimization of energy efficiency in electric multiple units. Facta Universitatis, Series: Mechanical Engineering

[6] Rybicka, I., Stopka, O., Luptak, V., Chovancova, M. & Drozdziel, P. (2018) Application of the methodology related to the emission standard to specific railway line in comparison with parallel road transport: a case study. MATEC Web of Conferences 244, 03002

[7] S. Kocsis Szürke, G. Kovács, M. Sysyn, J. Liu, S. Fischer. Numerical optimization of battery heat management of electric vehicles. Journal of Applied and Computational Mechanics 9 (4) (2023), pp. 1076-1092

[8] Di Gialleonardo, E., Melzi, S., Trevisi, D. (2023) Freight trains for intermodal transportation: optimisation of payload distribution for reducing longitudinal coupling forces. Vehicle System Dynamics 61(10), 2532-2550

[9] Nehring, K., Lasota, M., Zabielska, A. & Jachimowski, R. (2023) A multifaceted approach to assessing intermodal transport. Scientific J. of Silesian University of Technology. Series Transport 121, 141-165

[10] Macioszek, E. (2023) Analysis of the rail cargo transport volume in Poland in 2010-2021. Scientific Journal of Silesian University of Technology. Series Transport 119, 125-140

[11] E. Mikhailov, S. Semenov, S. Sapronova, V. Tkachenko, On the issue of wheel flange sliding along the rail. Lecture Notes in Intelligent Transportation and Infrastructure Part F1380 (2020), pp. 377-385

[12] S. Fischer. Investigation of the settlement behavior of ballasted railway tracks due to dynamic loading. Spectrum of Mechanical Engineering and Operational Research 2 (1) (2025), pp. 24-46

[13] Matej, J., Seńko, J., Caban, J., Szyca, M. & Gołębiewski, H. (2024) Influence of unsupported sleepers on flange climb derailment of two freight wagons. Open Engineering 14(1), 20220544

[14] Kou, L., Sysyn, M. & Liu, J. (2024) Influence of crossing wear on rolling contact fatigue damage of frog rail. Facta Universitatis, Series: Mechanical Engineering 22(1), 25-44

[15] Bosso, N., Magelli, M., Trinchero, R. & Zampieri, N. (2023) Application of machine learning techniques to build digital twins for long train dynamics simulations. Vehicle System Dynamics 62(1), 21-40

[16] S. Fischer, D. Harangozó, D. Németh, B. Kocsis, M. Sysyn, D. Kurhan, A. Brautigam. Investigation of heat-affected zones of thermite rail welding. Facta Universitatis, Series: Mechanical Engineering 22 (4) (2024), 689-710

[17] Konowrocki, R. & Chojnacki, A. (2020) Analysis of rail vehicles' operational reliability in the aspect of safety against derailment based on various methods of determining the assessment criterion. Eksploatacja i Niezawodnosc 22(1), 73-85

[18] Dimitrovova, Z. (2022) Two-layer model of the railway track: analysis of the critical velocity and instability of two moving proximate masses. International Journal of Mechanical Sciences 217, 1-25

[19] Jover, V., & Fischer, S. (2022) Statistical analysis of track geometry parameters on tramway line No. 1 in Budapest. The Baltic Journal of Road and Bridge Engineering, 17(2), 75-106

[20] Ézsiás, L., Tompa, R., & Fischer, S. (2024) Investigation of the possible correlations between specific characteristics of crushed stone aggregates. Spectrum of Mechanical Engineering and Operational Research, 1(1), 10-26

[21] Kurhan, D. & Kovalskyi, D. (2025) Quasi-static methods for determining the calculated wheel load on the railway track. Acta Technica Jaurinensis 18(1), 38-45

[22] Juricka, M., Fojtl, L., Rusnáková, S. & Juříčková, E. (2020) Acoustic characteristics of composite structures used in train. Manufacturing Technology 20(3), 335-341

[23] Banić, M., Pavlović, I. R., Miltenović, A., Simonović, M., Mladenović, M., Jovanović, D. & Rackov, M. (2022) Prediction of dynamic response of vibration isolated railway obstacle detection system. Acta Polytechnica Hungarica 19(3), 51-64

[24] Container. Available online: https://container.in.ua/morski-kontejnery/ (accessed on 27 May 2025)

[25] Green cargo container shipping freight twenty feet 3D rendering. Available online: https://www.freepik.com/premium-photo/green-cargo-container-shipping-freight-twenty-feet-3d-rendering_37908881.htm (accessed on 27 May 2025)

[26] Gerlici, J., Lovska, A., Vatulia, G., Pavliuchenkov, M., Kravchenko, O. & Solcansky, S. (2023) Situational adaptation of the open wagon body to container transportation. Applied Sciences 13(15), 8605

[27] Zub, E., Tkachenko, V., Sapronova, S. & Syvakivskiy, S. (2024) Determining the influ-ence of wheelset arrangement in the model 18-100

bogies on the level of steering efforts in the wheel-rail flange contacts. Eastern-European Journal of Enterprise Technologies 3(7(129)), 38-46

[28] Vatulia, G. L., Lovska, A. O. & Krasnokutskyi, Ye. S. (2023) Research into the transverse loading of the container with sandwich-panel walls when transported by rail. IOP Conf. Series: Earth and Environmental Science 1254, 012140

[29] Szczepański, E., Gołębiowski, P. & Kondracka, B. (2023) Evaluation of the technological process of wagon processing at shunting stations using the simulation model. Scientific Journal of Silesian University of Technology. Series Transport 120, 249-267

[30] Šťastniak, P. & Moravčík, M. (2017) Freight bogie prototype properties analysis by means of simulation computations. Manufacturing Technology 17(3), 27-28

[31] Nozhenko, V., Kovtanets, M., Sergienko, O., Prosvirova, O., Kovtanets, T., Boyko, G. & Semenov, S. (2021) Method for determining the linear velocity of a locomotive development. Proceedings of the 25th International Scientific Conference Transport Means, Kaunas, Virtual, 6-8 October 2021, pp. 994-997

[32] Opala, M., Korzeb, J., Koziak, S. & Melnik, R. (2021) Evaluation of stress and fatigue of rail vehicle suspension component. Energies 14(12), 3410

[33] Lovska, A., Stanovska, I., Kyryllova, V., Okorokov, A. & Vernigora, R. (2025) Determining the vertical load on a container with a floor made of sandwich panels transported by a flat wagon. Eastern-European Journal of Enterprise Technologies 6/7(132), 36-44

[34] Vatulia, G., Lovska, A., Myamlin, S., Stanovska, I., Holofieieva, M., Horobets, V., Nerubatskyi, V. & Krasnokutskyi, Y. (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

[35] Gerlici, J, Lovska, A., Pavliuchenkov, M. & Kravchenko, O. (2024) Peculiarities of designing the frame of a universal container made of rectangular pipes. Communications – Scientific Letters of the University of Zilina 26(2), B72-B79

[36] 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 8(5), 2277-3878

[37] Ibragimov, N. N., Rahimov, R. V. & Khadzhimukhamedova, M. A. (2015) Development of the design of a container for the transportation of fruit and vegetable products. Young Scientist 21(101), 168-173

[38] Nikitchenko, A., Artiukh, V., Shevchenko, D. & Prakash, R. (2016) Evaluation of Interaction Between Flat Wagons and Container at Dynamic Coupling of Flat Wagons. MATEC Web of Conferences 7, 04008

[39] Rzeczycki, A. & Wisnicki, B. (2016) Strength analysis of shipping container floor with gooseneck tunnel under heavy cargo load. Solid State Phenomena 252, 81-90

[40] DSTU 7598:2014. Freight wagons. General requirements for calculations and design of new and modernized 1520 mm gauge wagons (non-self-propelled) Kyiv, 2015, p. 250

[41] DSTU ISO 1496-1:2013 Freight containers, series 1. Technical requirements and test methods. Part 1. General purpose universal containers. Kyiv, 2013, p. 28

[42] Kozyar, M. M., Feshchuk Y. V. & Parfenyuk O. V. (2018) Computer Graphics: SolidWorks: Textbook. Kherson: Oldi-plus, p. 252

[43] Gerlici, J., Lovska, A. & Kozáková, K. (2025) Research into the longitudinal loading of an improved load-bearing structure of a flat car for container transportation. Designs 9(1), 12

[44] Gzaiel, M., Triki, E. & Barkaoui, A. (2024) Experimental study and numerical simulation of cutting and tearing of silicone rubber using extended finite element method. Journal of Applied and Computational Mechanics 10(3), 465-478

[45] 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

[46] 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

[47] Liguori, A., Formato, A., Pellegrino, A. & Villecco, F. (2021) Study of tank containers for foodstuffs. Machines 9(2), 44