IDENTIFYING FEATURES OF DETERMINING STRENGTH OF CONTAINER WHEN TRANSPORTED BY SEA

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Resume

The presented research is aimed at assessment of issues relating to strength of a universal container of the standard size of 1CC while it is transported on the sea by a railway ferry. Further it is considered that the container is located on a flat wagon at which, it is fixed to the upper deck of a railway ferry. Three load scenarios were considered in the research. Each of these scenarios are characterized by loaded conditions defined in the study. The structure of the investigated container was modelled in a commercial simulation software. The dynamic loads acting to the container structure for all three considered schemes, were carried out using mathematical modelling. The finite element method was applied to the numerical analyses of strength of the container structure. It was revealed by means of simulation computations, that the maximal stress in the container structure was of 102.4 MPa within the permissible limits and the maximal displacements of 4.5 mm were achieved.

Available online: https://doi.org/10.26552/com.C.2026.034

Article info

Received 10 April 2026
Accepted 13 May 2026
Online 10 June 2026

Keywords:

strength analysis
container
mathematical model
railway ferry
container

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

1 Introduction

Combined transport has an irreplaceable place in development of the economies in many European countries. It is a part of intermodal transportation system. At least two kinds of transport are included within combined transport [1-2]. It is usually a combination of road and railway transport [3-5]. Sea transport is also often included in the intermodal transportation chain of goods [6]. Railway transport has an advantage in comparison with road transport, that it has lower aerodynamic resistance [7], lower rolling resistance [8-10] and it is possible to achieve higher axle load [11]. Containers are the most common type of intermodal transportation unit used for this kind of transport [12-13]. The possibility of some of them entering international transportation system through sea areas contributed to the emergence of railway ferry transportation. Currently, not only railway wagons are transported by sea, but also combined trains, that is, flat wagons on which containers or tank containers are placed (Figure 1).

This type of transportation is quite promising because it reduces the time of loading and unloading operations in the conditions of railway-ferry complexes. At the same time, it is needed to perform research to ensure the safety of transportation of combined transport trains on railway ferries by sea [16-17] of containers relative to the frames of flat wagons. This will allow to form some recommendations on safety of operation of railway-ferry transportation. Analysis of the structural features and prospects for the operation of containers is covered in a considerable number of publications. For example, tank container designs are analysed in the article [18]. Stainless steel is used as the material of the container's supporting structure. Solutions of improving the thermal insulation of the container are proposed in this study. However, the issue of loading the container structure during sea transport is not addressed in that research.

Research presented in contributions [19-20] are focused on a study of strength and improvements of

(a)

(b)

Figure 1 *Rail-ferry transportation of combined transport trains: a) boarding a railway ferry [14]; b) accommodation on a railway ferry [15]*

a container, a tank type. Strength characteristics are also analysed and included in these contributions. Standard values of the loads were considered in the created computational model of the tank container in its strength analyses. These loads were adopted from a normative document [21]. The achieved values of the stresses were presented in a scale stress distribution in its structure. It is obvious from the studied research, that the loads, which can rise during transportation of a railway ferry were not defined within boundary conditions. Further, the study included in a contribution [22] was aimed at an identification of a process of heat transfer in a tank container. The authors applied to the model principles of heat transfer, which are included in a theory of cylindrical vessels. The study has a deficiency, that the load of tank container was not analysed in a case of transportation by a railway ferry. It means, that this phenomenon should be further studied. Myamlin et al. presented in the study [23] optimization of a design of a tank container. The main purpose of the study was to improve its design to be able to transport light oil products. However, the loads arising in the mutual interaction of the railway ferry and tank container while sailing on the sea are neither included this study. The authors team Föhr et al in the project [24] presented new solutions of design of tank containers. The main purpose of the project was to design a tank container for extreme cold weather conditions with the temperature of -30°C and lower. These conditions correspond to Nordic conditions during winter season. Despite of the deep study, the container structure was not designed for the loads, which are tank containers exposed during sailing on the sea by a railway ferry.

In the work [25], the analysis of the influence of insulating materials on the energy properties of a transport container is highlighted. From the energy efficiency point of view, the optimal territorial zone of Europe for use of containers was identified. However, in this case, the container was considered not as a means of transport, but as a building module with a stationary position. That is, the authors did not pay attention to the issue of using such a container in the transport process.

A study of the structural integrity of containers lost during transportation by the sea was conducted in the publication [26]. The authors presented the features of finite element analysis of the stress distribution in a container structure when interacting with the aquatic environment. Technical solutions are proposed for the removal of containers from the water to prevent environmental safety. However, the authors limited the research to study only this load mode of a container. This can be explained by the fact that the research was focused exactly on this task.

It was possible to revealed by the overview of the available recent studies of tank containers [18-26], that the structures of tank containers were not analysed in these studies from their strength point of view. Though, the supporting structure of the container is subjected to different loads during sea sailing than during transport bay railways. It was a motivation to perform this presented research with the goal of strength assessment of a container while sailing on a railway ferry. The following two main tasks were defined to achieve the estimated goal of the research:

- To determine the dynamic load, which the container is exposed while transported by a wagon to,
- To analyse strength of the container under the loads, which the container is exposed while transported on a wagon by a railway ferry on the sea to.

The scientific novelty of this research consists in the study of container loading during its transportation as a part of a combined sea train. Previously, such issues had received little attention, as this type of transportation emerged in 2017 with the opening of the New Silk Road corridor, linking Ukraine with China, bypassing Russia.

2 Materials and methods

The presented research was performed by means of a mathematical model of the assessed container. The created computational model was applied to identify the main dynamical loads, which the container is exposed while transported by a combined train to. Determination of suitable boundary conditions in the computational model was required to the detailed study of container strength. In this case, three different loading conditions, or scenarios were defined, which allowed to simulate behaviour of the container in a flat wagon. They are namely as follows (Figure 2):

1. Mutual displacements of the container and the flat wagon were not allowed during oscillations regarding to the initial position (Figure 2a). A flat wagon with loaded by is considered as a mass attached to the ferry deck and completely repeats the trajectory of the railway ferry (the first load mode);
2. Displacements of the flat wagon were allowed regarding to the railway ferry during oscillations. However, the mutual displacements of the container and the flat wagon frame were constrained (the second load mode), (Figure 2b);
3. Mutual displacements of the flat wagon regarding to the railway ferry deck as well as the container regarding to the flat wagon frame were allowed (the third load mode) (Figure 2c).

The calculations were aimed at investigation of roll movement of railway ferry. Hence, the achieved results correspond to this.

Accelerations arisen due to the container movement on the railway ferry are an important factor, which affects the container behaviour and subsequently also the wanted results. Therefore, the values of accelerations, which act on the container, were calculated by means of the mathematical models. These models were adopted from the research presented in [27]. Based on the revealed results, the total value of acceleration (i.e. the acceleration magnitude) is of 0.25g for the first loading scenario. It means that this value of acceleration is valid for the absence of the mutual displacements of the flat wagon and the container regarding to the initial position. This value is identified farthest from the container bulwark. Further, the total value of acceleration for the second load scenarios is of 0.3g and it is also identified the farthest from the container bulwark. The maximal values of accelerations were found out for the third load scenarios. Namely, the acceleration value of 0.4g was achieved again the farthest from the container bulwark

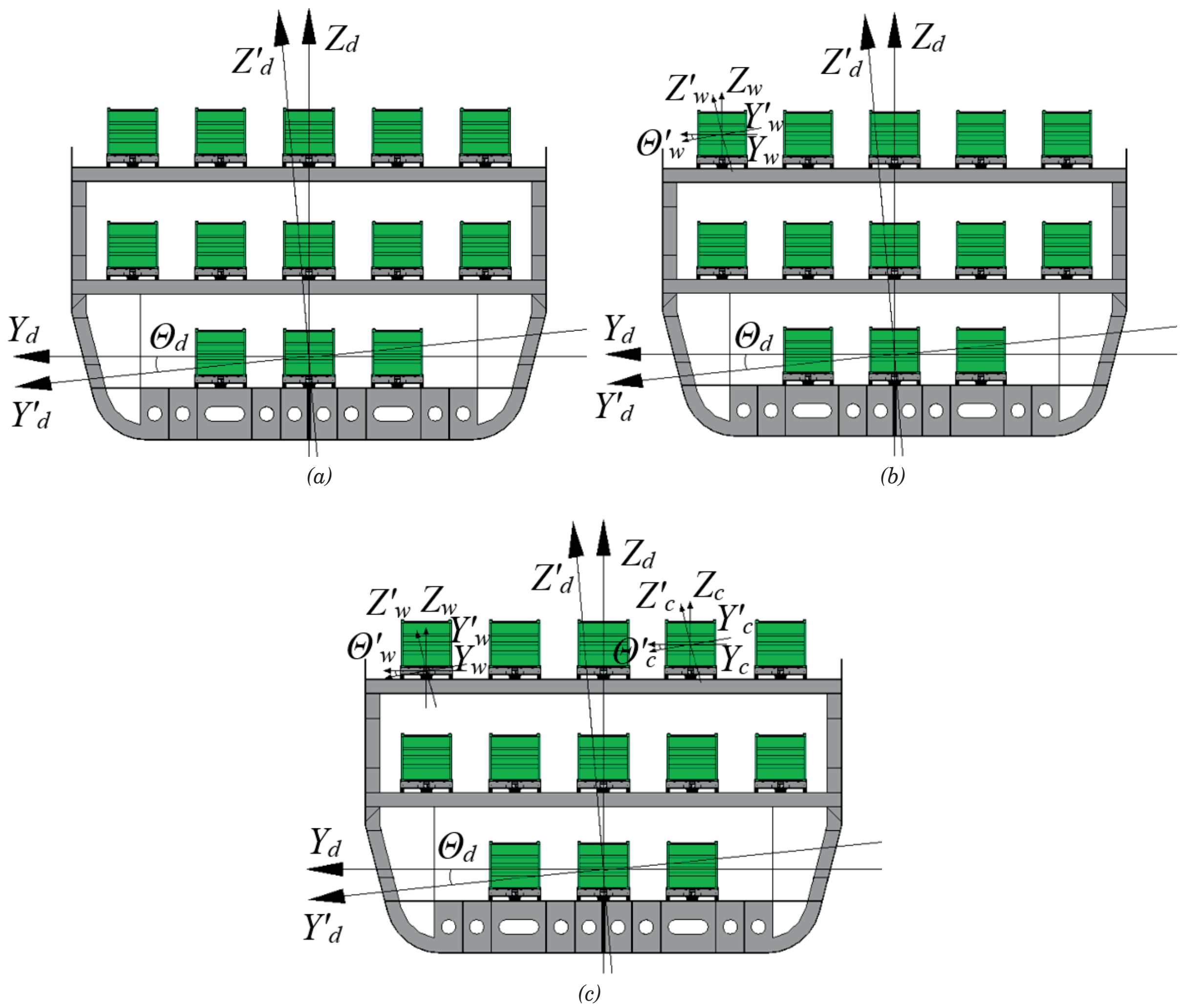


Figure 2 *A calculation scheme for studying angular displacements relative to the longitudinal axis of a flat wagon loaded by containers placed on a railway ferry: a) the first load mode; b) the second load mode; c) the third load mode*

and the acceleration value of 0.48g on the container placed on the wagon. Then, these values of acceleration were input to the mathematical model in order to analyse strength state of the container.

The research was conducted considering a 1 CC container with a gross weight of 24 tons. In the designation of this container, the letters "CC" indicated the container's technical characteristics are identified for the dimensions according to the international ISO standard as follows:

1 - container type, intended for international transport;
C - the container's length is indicated by the first letter, in this case, the length is of 6.058 m;
C - the container's height is indicated by the second letter, in this case, the height is of 2.591 m.

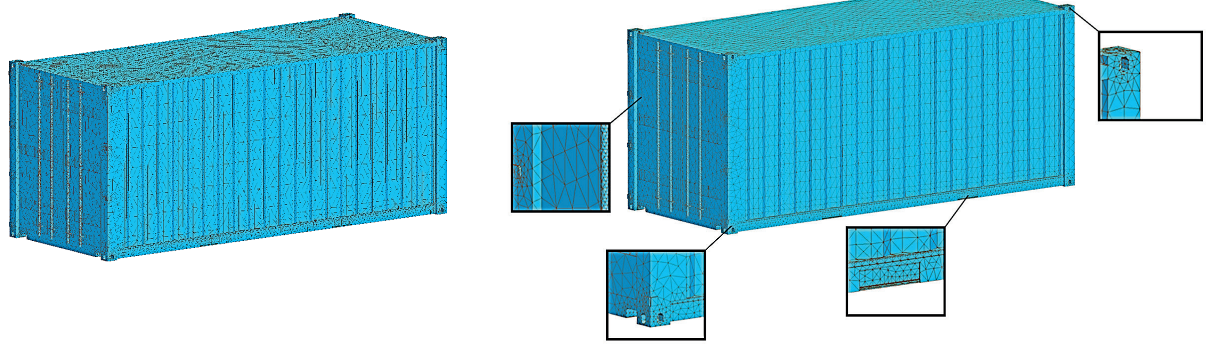
A three-dimensional model of the solved container was modelled in the Solid Works software (abbr. SW) and it is depicted in Figure 3a. The finite element method was used to perform the strength analyses of the container. The finite-element model (FE model) was also set-up in the SW software, at which, tetrahedral elements [28-30] were included in the FE-model mesh. The finished FE model of the container can be seen in Figure 3b together with details of the FE mesh in the selected locations. The sensitivity analysis of the FE mesh was also performed. The number of nodes in the FE mesh was of 39,789 and the resulting number of FE elements was of 123,139.

A calculation scheme of the solved container structure is depicted in Figure 4, where it is possible to mention marking the acting forces to individual selected locations. These forces are different to each other depending on their character and behaviour as well as on their effect to the container structure. There are designated three forces, namely the dynamic force P_d, vertical reactions P_s^v and the horizontal reactions P_s^h. These reactions forces arise under the dynamic load action and they are manifested in the fitting stops. The fitting stops are mounting points of the container on a transport means, in this case on a freight flat wagon. Further, ties as structural units of the container were installed to the fittings surfaces in a horizontal direction, where they are able to transmit the force effects.

Moreover, a proper definition of material characteristics is an important point of numerical calculations. In is considered, that the container could be made of low-alloyed steel with the permissible stress of 310.5 MPa [31]. Then, the following known condition should be met:

$$\sigma_{cal} \leq \sigma_{per}, \tag{1}$$

where σ_{cal} [MPa] is the calculated stress in the container and σ_{per} [MPa] is the permissible stress of the used



(a) (b)

Figure 3 *The designed container: a) a 3-D model; b) a finite element model*

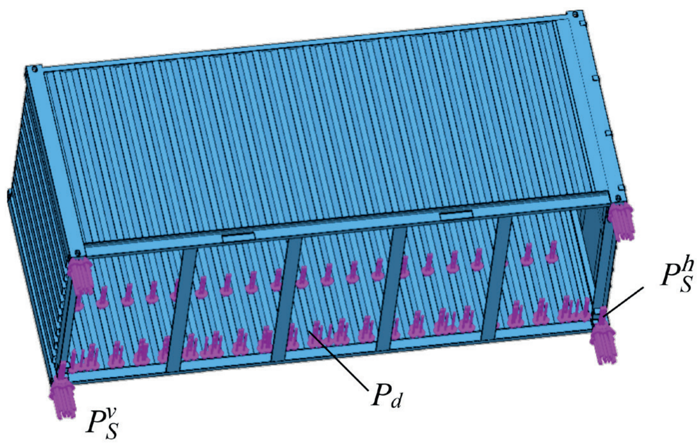


Figure 4 *A calculation diagram of the container*

material and it is a tabular value. As the container structure is exposed to the dynamic load, it is necessary to consider the dynamic coefficient. In this case, the dynamic coefficient of k_{dyn} = 1.5 was included in calculation. Then, the maximal permissible stress of the material will be reduced to the value given by the following formulation:

$$\sigma_{per}^{dyn} = \sigma_{per} \cdot k_{dyn} . \tag{2}$$

Further, the container is made by welding technology, i.e. it is a welded structure. Therefore, the welding coefficient of the material should be considered. Welding causes reducing the permissible stress of the material and the welding coefficient k_w is considered of 0.8. Thus, the maximal permissible stress of the material considering the dynamic coefficient together with the welding coefficient will be as follows:

$$\sigma_{per}^{dyn,w} = \sigma_{per}^{dyn} \cdot k_w . \tag{3}$$

The resulting calculated value of the maximal permissible stress of the material will be $\sigma_{per}^{dyn,w} = 165.6$ MPa. The achieved stresses in the container structure under all three load scenarios will be compared with this value.

3 Results of research and discussion

Achieved results of the numerical calculations of the container structure are included in this section includes. These results are loaded for the defined three load scenarios. The numerical values of the stresses on the structure as well as the displacements in nodes are listed in Table 1. It should be noted, that the stresses in the container structure were calculated based on the von-Misses hypothesis, i.e. equivalent stresses were compared with the permissible stress $\sigma_{per}^{dyn,w}$ [31]. The maximal equivalent stresses were identified in the container structure for the third load mode, at which, a scheme with a distribution of stresses are depicted in Figure 5.

It was found out, that the maximal identified value of stress in the container structure was of 102.4 MPa. It can be seen, that this stress is distributed in a close area of the fitting stop of the container. Further, stress of 57.5 MPa for the first load mode and to stress of 69.3 MPa for the second load mode are calculated for the loads of the container based on the first load mode and the second load mode, These values stresses in the container structure are lower as in the original design. It is obvious, that the first and second load modes are more favourable to the container structure then the third load mode.

Further, it was identified, that the maximal displacements of the container structure were achieved also for the third load mode and this value was of 4.5 mm. The maximal values of displacements for the first load mode and for the second load mode were of 2.4 mm and of 2.8 mm, respectively. The maximal displacements were of 4.5 mm (Figure 6). Hence, the conditions of strength of the container structure were met, because the maximal value of the equivalent stress for all

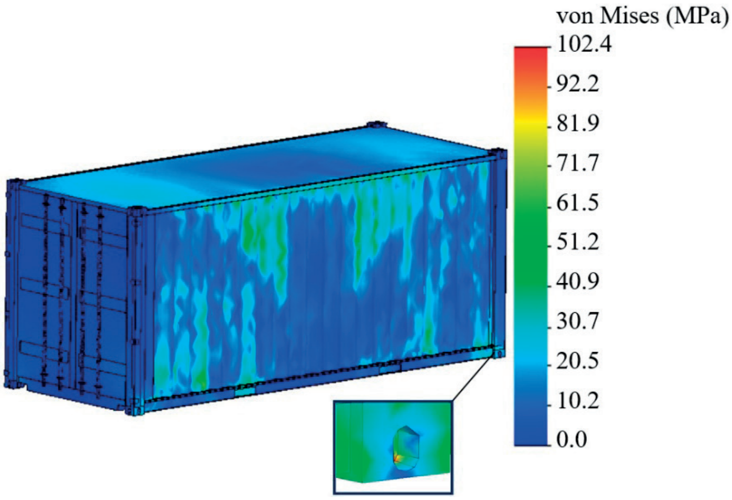


Figure 5 *Stress distribution fields in the container*

Table 1 *Container strength indicators during transportation by rail ferry*

Strength indicator	Load mode		
	First	Second	Third
Strength [MPa]	57.5	69.3	102.4
Displacement in nodes [mm]	2.4	2.8	4.5

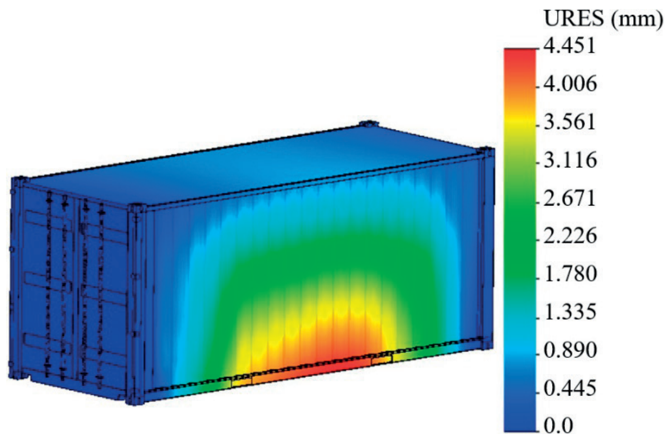


Figure 6 *Distribution of displacement fields in the container*

three load modes as well as in the entire structure did not exceed the maximal permissible value of $\sigma_{per}^{dyn,w}$. Determination of the refined values of accelerations acting to the container structure was allowed based on the achieved results of the performed numerical calculations. The achieved values of accelerations were considered for analysis of the container strength.

The development of this research consists in calculation of the equilibrium stability of a container, which is placed on a flat wagon. This direction of research is very important, because not only the safety of the cargo transported in containers, but also the safety of the functioning of railway ferry transportation depends on it. Future research in this direction will be aimed at development of more advanced models of transport units. It will be considered, that new modern technologies can be applied for production of chosen parts of containers [32-34]. The efforts will be aimed at improvement of dynamic properties of transport means under the operational loads [35-37] to obtain a reliable, effective and safe containers and other types of transport units.

4 Conclusions

The following results and findings are concluded based on the performed research of strength analysis of the container structure under the defined three load scenarios:

A study was conducted on the dynamic load on containers during their rail-ferry transportation. It was established that the maximum acceleration values occur when there are movements of the flat wagon regarding to the railway ferry deck and to the containers regarding to the flat wagon frame. For the flat wagon, they are about 0.4·g, and for the containers placed on it, about 0.48g;

Simulation computations were performed in order to analyse strength of the container structure. It was established that the maximal value of the equivalent stresses did not exceed the permissible value for the reduced stress for the defined material at which these stresses were achieved for the third load scenario. The maximal stresses were of 102.4 MPa and the maximum displacements were of 4.5 mm.

It is recommended at the design stage of modern container structures to consider the loads that may act to them and when transported as part of combined transport trains by the sea.

The conducted studies can be applied to increase the safety of cargo transportation by combined trains by the sea, by selecting optimal, and from the point of view of force action, regular places on the deck. For example, when pitching on board, such places are those that are further away from the bulwark.

The results of the research will be useful for the development of new container structures, as well as for the improved efficiency of intermodal transportation within international transport corridors.

Acknowledgements

This publication was supported by the project KEGA 024ZU-4/2024 and the project VEGA 1/0308/24.

This contribution was elaborated within execution of the project “New generation of freight railway wagons” (Project code in ITMS2014+: 313010P922), based on support of the operational program Research and innovation financed from the European Regional Development Fund.

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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