TRANSNAV
http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 18 Number 1 March 2024
DOI: 10.12716/1001.18.01.21

Investigation Into the Dynamic Load of the Container with Sandwich Panel Walls when Transported by Train Ferry

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ABSTRACT: The article presents the results of the study into the dynamic load of the container during its transportation by the train ferry. The peculiarity of the container is that its walls are made of sandwich panels. Such a solution will help to reduce the dynamic loads acting on the container at operating load modes, including when transported by sea as part of combined trains.
To determine the dynamic loads acting on the container, a mathematical model was build that took into account the angular displacements around the longitudinal axis of the system "train ferry – flat wagon – container – freight". The calculations were made for the train ferry Geroi Plevny. The mathematical model was solved in MathCad. It was found that the value of acceleration acting on the container of the proposed design during transportation by sea was 4.3% lower than that acting on the container of a typical design.
The acceleration value obtained, as a component of the dynamic load, was taken into account to determine the stability coefficient of the container in a typical diagram of its interaction with the flat wagon. The roll angle of the train ferry, at which the stability of the container placed on the flat wagon is ensured, was also calculated.
The results of the study will contribute to the database of recommendations for the design of modern container structures and their safe operation in international rail and water traffic.

1 INTRODUCTION

The development of a competitive environment between individual sectors of the transport system necessitates the development and implementation of solutions aimed at maintaining the leading position of railway transport in the segment of total freight turnover [1-3]. One of the possible solutions to achieve this goal is the introduction of combined transport systems, in particular container systems, as the most common and highly demanded for international traffic [4, 5].

To increase the efficiency of container transportation, it is important to create modern container designs with improved technical properties. When designing such containers, it is necessary to take into account the loads that can act on them not only during transportation by rail, road, air and sea, but also during transportation as part of combined trains by train ferries (Figure 1). This type of combined transport was developed during the commissioning of the New Silk Road transport corridor, which connected Ukraine with China and provided the possibility of transporting combined transport by train ferries (Figure 2).

Therefore, the issue of creating new container designs adapted to transportation by train ferries, as part of combined trains requires further research.

a)

b)

Figure 1. Train ferries
a) Heroes of Shipka;
b) Heroes of Sevastopol and Heroes of Odessa

a)

b)

Figure 2. Transportation of containers by train ferries
a) Greifswald;
b) Heroes of Sevastopol

2 ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The issues of improving containers to increase their efficiency are covered in the scientific works of many Ukrainian and foreign scientists. For example, in [6] the authors present the design features of ISO containers. Possible load diagrams of their bearing structures in operation are considered. A solution for possible ways to improve containers to ensure their durability in operation is proposed.

The study into the load of the 1AA high-capacity container is covered in [7]. The stress state of the container was analysed. The zones of concentration of the highest load of its structure were determined. This made it possible to formulate requirements aimed at ensuring the safety of its operation.

At the same time, the authors of these works did not investigate the strength of the proposed container structures during transportation by train ferries.

The study of the dynamic load of the container is carried out in [8]. The authors determined the inertial loads acting on the container and calculated its strength under the action of these loads. It was found that the strength indicators of the container model under study were provided. At the same time, the authors did not propose measures to improve the efficiency of containers.

Publication [9], which highlights the prospects for the use of removable bodies that operate on the principle of containers, is of scientific interest. It presents the requirements that modern removable body designs must meet. However, the authors did not discuss the possibility of their transportation by train ferries as part of combined trains.

The dynamic load of vehicles during transportation by train ferries is determined in [10]. Mathematical models that allow estimating the dynamic load acting on vehicles during the rolling motion of the vessel are presented. However, the issue of the dynamic load of containers during transportation by sea was not studied in this work.

Article [11] proposes the design of a FLAT RACK container, the peculiarity of which is the flexible bonds in the fittings, as well as the fact that all the components of its frame are made of rectangular profiles. This solution helps to reduce its load in operation in comparison with typical designs of containers of this type.

The design features of the container for fruit and vegetable products are highlighted in [12]. The proposed design solutions were confirmed by the corresponding strength calculations for the main operational load schemes of the container.

At the same time, these container designs were not tested for strength when transported by train ferries as part of combined trains.

The analysis of literary sources [6 – 12] allows us to conclude that the issues of improving containers in order to enhance their operational properties are quite relevant; at the same time they need further research and development.

The objective of the study is to highlight the results of determining the dynamic load of the container with sandwich panel walls when transported by the train ferry as part of the combined train. To achieve this objective the following tasks were set:

- to conduct mathematical modelling of the dynamic load of the container; and
- to determine the roll angle of the train ferry, which ensures the container stability.

3 PRESENTATION OF THE MAIN MATERIAL OF THE ARTICLE

To reduce the dynamic loads that act on the container during operating modes, including when transported by sea, it is proposed to manufacture its walls in the form of sandwich panels. In this case, the sandwich panel consists of two metal sheets with an energy-absorbing layer between them (Figure 3).

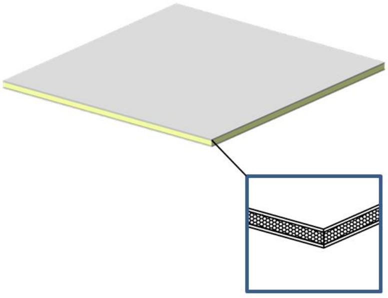

Figure 3. Sandwich panel

To determine the possibility of transporting a container of the proposed design as part of a combined train by a train ferry, mathematical modelling was carried out. The design scheme of the container placed on the flat wagon and fixed on the train ferry deck is shown in Figure 4.

It was taken into account that the system under study has four degrees of freedom characterized by angular movements around the longitudinal axis of the train ferry, flat wagon, container and freight placed in it, respectively. When making calculations, the freight was considered as conditional, using the full load capacity of the container. The energy-absorbing material in the container walls was modelled with an elastic-viscous connection with a coefficient of viscous resistance of 20 kN·s/m and a stiffness coefficient of 15 kN/m. These parameters were determined on the basis of previous studies of the authors.

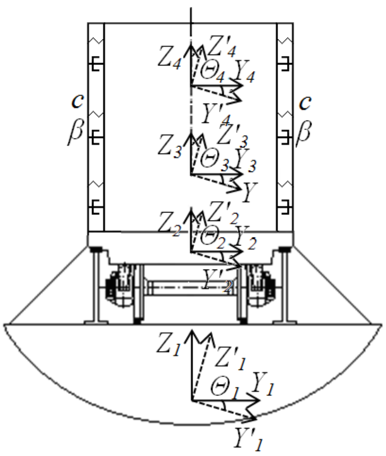

Figure 4. Design diagram of the container placed on the flat wagon

When building the mathematical model, the friction forces between the following components of the system were not taken into account: centre bowl – centre plate, jack – bolster, freight – container, etc.

The mathematical model looked as follows

$$\begin{cases} I_{TF}\cdot\ddot{q}_1+\left(\Lambda_\theta\cdot\dfrac{B}{2}\right)\dot{q}_1=P(t), \\ I^{\theta}_{FW}\cdot\ddot{q}_2=p'_{FW}\cdot\dfrac{h_{FW}}{2}+M^{D}_{FW}+M^{C}_{FW}, \\ I^{\theta}_{C}\cdot\ddot{q}_3=p'_{C}\cdot\dfrac{h_{C}}{2}+M^{FW}_{C}+M^{C}_{C} \\ I^{\theta}_{C}\cdot\ddot{q}_4=-\beta\cdot h_C\cdot\dot{q}_3-c\cdot h_C\cdot q_3+M'^{C}_{C}, \end{cases} \tag{1}$$

$$P(t)=p'_{TF}\cdot\frac{h}{2}+\Lambda_\theta\cdot\frac{B}{2}\cdot\dot{F}(t), \tag{2}$$

where
I_{TF} – the moment of inertia of the train ferry;
$\Delta\theta$ – the coefficient of resistance to oscillations;
B – the breadth of the train ferry;
h – the side height;
p'_{TF} – the wind load on the above-water projection;
$F(t)$ – the law of disturbing force (sea wave);
I_{FW}^{θ}– the moment of inertia of the flat wagon;
h_{FW} – the height of the side surface of the flat wagon;
$p'_{ВПФ}$ – the wind load on the side surface of the flat wagon;
M_{FW}^{D} – the moment of forces arising between the flat wagon and the train ferry deck;
M_{FW}^{C} – the moment of forces arising be-tween the flat wagon and containers;
I_C^{θ} – the moment of inertia of the container;
h_C – the height of the side surface of the container;
p'_C – the wind load on the side surface of the container;
M_C^{FW} – the moment of forces arising between the container and the flat wagon;
M_C^{C} – the moment of forces arising between the container and the freight;
M_C^{θ} – the moment of inertia be-tween the freight and the container;
M'^{C}_{C} – the moment of forces arising between the freight and the container;
β – the coefficient of viscous resistance of the energy-absorbing material;
c – the stiffness of the energy-absorbing material.

The motion of the wave was described by a trochoidal curve. System of differential equations (1) was solved in MathCad [13 – 16]. For this, the transition from systems of second-order differential equations to systems of first-order differential equations was carried out, followed by the use of standard algorithms for solving systems using the rkfixed Mathcad function [17, 18].

The generalized accelerations were calculated in the array $ddq_{j,i}$:

$$ddq_{j,1} = \frac{p'_{TF} \cdot \frac{h}{2} + \Lambda_\theta \cdot \frac{B}{2} \cdot \dot{F}(t) - \left(\Lambda_\theta \cdot \frac{B}{2} \right) \dot{y}_1}{\left(\frac{D}{12 \cdot g} (B^2 + 4 z_g{}^2) \right)}, \tag{3}$$

$$ddq_{j,2} = \frac{p'_{FW} \cdot \frac{h_{FW}}{2} + M^D_{FW} + M^C_{FW}}{I^\theta_{FW}}, \tag{4}$$

$$ddq_{j,3} = \frac{p'_C \cdot \frac{h_C}{2} + M^{FW}_C + M^C_C}{I^\theta_C}, \tag{5}$$

$$ddq_{j,4} = \frac{-\beta \cdot h_C \cdot \dot{q}_3 - c \cdot h_C \cdot q_3 + M'^C_C}{I^\theta_C}. \tag{6}$$

Based on the calculation, it was found that the greatest acceleration values occur at the wave angles relative to the train ferry body $\chi = 60°$ and $\chi = 120°$. At the same time, the maximum acceleration of the container relative to the standard place on the deck was about 2.3 m/s² (Figure 5). The numerical acceleration value was indicated without the component of free fall acceleration.

The total acceleration value was determined as

$$\ddot{\theta}_{tot} = \ddot{\theta}_a + g \cdot \sin\theta, \tag{7}$$

where
$\ddot{\theta}_a$ – the acceleration that acts relative to the standard place of the flat wagon with containers on the deck;
g – the free fall acceleration;
θ – the roll angle of the train ferry.

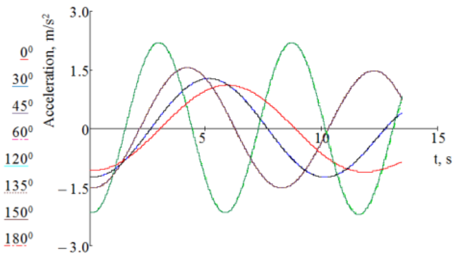

Figure 5. Accelerations on the container transported by the train ferry

By taking into account the hydro-meteorological characteristics of the sea and the above-water projection of the train ferry, the roll angle value was 12.2°. The value of roll angle was calculated for the case of static action of the wind on the above-water projection of the train ferry. The calculation was made for a train ferry of the Geroi Plevny type when moving by the Black Sea.

Taking this into account, the total acceleration acting on the container was 4.4 m/s² (0.45 g). The resulting acceleration value was 4.3% lower than that acting on the container of a typical design.

The accelerations were calculated for the other roll angles of the train ferry (Figure 6).

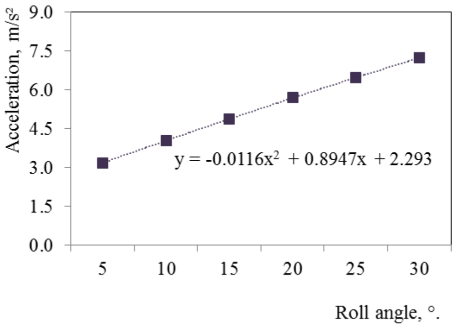

Figure 6. Dependence of accelerations to the container on the roll angle of the train ferry

The obtained accelerations were taken into account when determining the stability coefficient of the container placed on the flat wagon. The calculation was made according to the methodology given in the previous works of the authors. The results of the calculation are given in Figure 7.

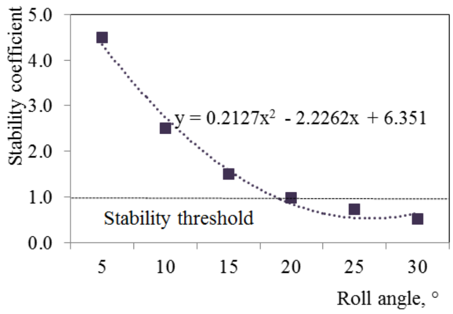

Figure 7. Dependence of the stability coefficient of the container on the roll angle

By analysing the dependence shown in Fig. 7, it can be concluded that the stability of the container is ensured at roll angles up to 17°.

The results of the study will contribute to the database of recommendations for the design of modern container structures and their safe operation in international traffic.

4 CONCLUSIONS

1. Mathematical modelling of the dynamic load of the container with sandwich panel walls during transportation as part of the combined train by the train ferry was carried out. The largest acceleration values occur at the wave angles relative to the train ferry body $\chi = 60°$ and $\chi = 120°$. The maximum acceleration of the container relative to the standard place on the deck is about 2.3 m/s². In this case, the total acceleration that acts on the container is 4.4 m/s2 (0.45 g). The resulting acceleration value is 4.3% lower than that acting on the container of a typical design.
2. The admissible roll angle of the train ferry in terms of ensuring the stability of the container was determined. The results of the calculations show that the stability of the container is ensured at roll angles up to 17°. At the same time, the stability coefficient of the container is 1.
The results of the study will contribute to the database of recommendations for the design of

modern container structures and their safe operation in international rail and water traffic.

ACKNOWLEDGEMENTS

This contribution was elaborated within execution of the projects VEGA 1/0513/22. Investigation of the properties of railway brake components in simulated operating conditions on a flywheel brake stand; KEGA 036ŽU-4/2021. Implementation of modern methods of computer and experimental analysis of the properties of vehicle components in the education of designers of future means of transport.

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