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Stability Study of Tank Containers Placed on a Roll-Trailer During Transportation by Railway Ferry

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ABSTRACT: The article presents the results of determining the dynamic load of the load-bearing structure of the tank container placed on a roll-trailer during transportation by railway ferry. For this purpose, a mathematical model was developed, which takes into account the dynamic loading of the tank container during angular displacements of the railway ferry. It is taken into account that the roll trailer is rigidly fixed on the deck, and the tank container and the liquid cargo in the boiler have their own degrees of freedom. The obtained accelerations are taken into account when calculating the stability of the tank container on the roll trailer. Thus the stability of the tank container is provided at lurch angles to 240. The carried-out researches will allow increasing safety of transportations of tank-containers on railway ferries by the sea, and also the efficiency of functioning of combined transportations in the international communication.

1 INTRODUCTION

The growth of liquid cargo transportation through international transport corridors leads to the commissioning of tank containers. The demand for tank containers in the transportation process is due to their mobility as vehicles and intermodality. Trade flows should be regarded as a key driver of demand and development for container services in seaports [20]. In work [12] the influence of global container market development on global logistics supply chains has been estimated.

Recently, the efficiency of the operation of tank containers has also been traced on railway ferry routes as part of combined transport trains. At the same time, the transportation of tank containers can also be carried out on roll trailers.

It is important to note that the process of loading the carrying structures of tank containers during transportation by rail ferries by sea differs significantly from the operation relative to main lines. As a result of the action of loads that are inherent in these operating conditions, the stability of tank containers relative to vehicles may be disturbed. This situation endangers safety to damage the stability of the railway ferry and its traffic safety.

In this regard, to ensure the safety of the navigation of tank containers by sea, it is necessary to study their stability during oscillations of a railway ferry.

Determination of the dynamic loading of a tank container under operating conditions of loading was carried out in [24]. The obtained values of dynamic loads were taken into account when calculating the strength of the tank container in the Ansys software environment. However, the work does not pay attention to the study of the dynamic loading of a tank container during transportation on a railway ferry.

The results of determining the stress state of the tank container are given in [1]. The work is carried out to determine the deviations of the frame and the boiler under operating load conditions.

The study of the strength of the T11 tank container under operating load conditions is carried out in [18]. The paper analyses the effect of the density of a finite element mesh on the accuracy of calculating the stress-strain state of a tank container, and also carries out field studies of its strength under shock loads.

It is important to say that the strength calculations did not take into account the loads that can act on the tank container when transported by railway ferry.

The specifics of calculating the strength of the carrying structure of a tank container for transporting food products are highlighted in [15]. Strength analysis was carried out using the finite element method [5, 15, 23]. Recommendations for the design of tank containers of this type are given [15].

The results of optimization of the supporting structure of the tank container are given in [21]. Improvement of the design of the tank container for the transportation of light oil products.

However, when carrying out strength calculations, no account was taken of the loads that may act on the carrying structure of a tank container when transported on a roll-trailer by a railway ferry.

The study of the dynamic loading and strength of a tank container during transportation as part of a combined train on a rail ferry is carried out in [9, 10]. Recommendations for the safe operation of tank containers are given.

At the same time, no attention was paid to the study of the dynamic loading and stability of the tank container during transportation on a roll-trailer by rail ferry.

The purpose of the article is to highlight the features of the dynamic loading and stability of a tank container placed on a roll-trailer during transportation by a railway ferry. To achieve this goal, the following tasks have been set:

– to determine the dynamic loading of a tank container placed on a roll-trailer during transportation by a rail ferry.
– to determine the stability of a tank container placed on a roll-trailer during transportation by a rail ferry.

2 PRESENTATION OF THE MAIN MATERIAL OF THE ARTICLE

To determine the dynamic loading of a tank container placed on a roll-trailer during transportation by a railway ferry, a mathematical model was created (1), созданная авторами статьи,which takes into account the movement of the system "railway ferry - tank container - liquid cargo" during angular displacements relative to the longitudinal axis (Fig. 1).

The model takes into account that the roll-trailer, on which the tank container is located, is rigidly fixed to the deck of the railway ferry and moves along with it. It is important to say that the design diagram shown in Fig. 1 and model (1) were developed by the authors of the article.

The calculations were carried out to the Greifswald railway ferry moving along the Black Sea. As a prototype, a tank container of 1CC standard size was chosen, which is placed on a roll-trailer 6.09 m long and with a carrying capacity of 20 tons.

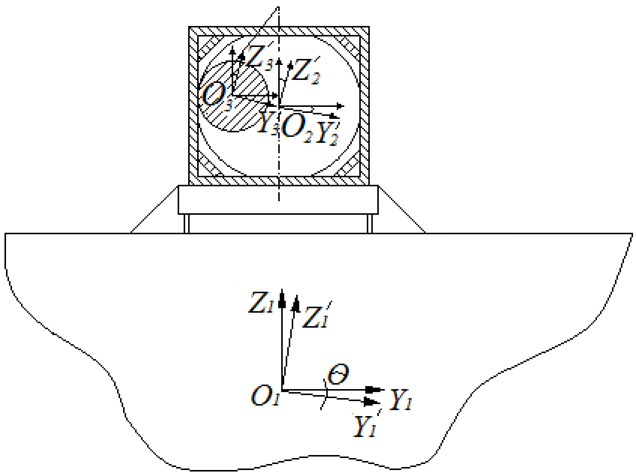

Figure 1. Diagram of displacements of a tank container with a liquid cargo during oscillations of a railway ferry

The shock effect of sea waves on the body of the railway ferry was not taken into account. When compiling the model, the trochoidal law of motion of the disturbing action [17, 19] (sea wave) on the railway ferry and the dissipative component, which arises during oscillations of the railway ferry under sea rolling conditions, as well as the heading angles of the sea wave concerning the body of the railway ferry (χ = 0° - 180° [4]) and wind load acting on its surface projection.

$$\begin{cases} \left(\frac{D}{12\cdot g}\left(B^2+4z_g^2\right)\right)\ddot{q}+\left(\Lambda_\theta\cdot\frac{B}{2}\right)\dot{q}=p'\cdot\frac{h}{2}+\Lambda_\theta\cdot\frac{B}{2}\cdot\dot{F}(t), \\ \left(I_{\theta i}+\sum_{j=1}^{k}m_{ij}\cdot c_{ij}^2\right)\cdot\ddot{\theta}_2+\sum_{j=1}^{k}m_{ij}\cdot c_{ij}\cdot l_{ij}\cdot\ddot{\theta}_3-g\left(m_i\cdot z_{ci}+\sum_{j=1}^{k}m_{ij}\cdot c_{ij}\right)\cdot\theta_2 \\ I_{ij}\cdot\ddot{\theta}_3-m_{ij}\cdot c_{ij}\cdot l_{ij}\cdot\ddot{\theta}_2+g\cdot m_{ij}\cdot l_{ij}\cdot\theta_3=0, \end{cases} \quad (1)$$

where $q_1 = \theta_1$, $q_2 = \theta_2$, $q_3 = \theta_3$ – generalized coordinates corresponding to the angular displacement relative to the longitudinal axis, respectively, of the railway ferry, tank container and liquid cargo. The origin of the coordinate system is at the centre of mass of the rail ferry.

D - weight of displaced water; B - width; h - board height; $\Lambda\theta$ is the coefficient of resistance to vibrations; z_g - coordinate of the gravity centre; p' - wind load; $F(t)$ - law of the force action that excites the movement of the railway ferry with the wagons placed on its decks; I_{ij} - moment of inertia of the pendulum; m_{ij} - the pendulum mass in the tank wagon boiler; c_{ij} - the distance from the plane z_i=0 to the fixation point of the pendulum in the tank wagon boiler; l_{ij} - the pendulum length; I_θ - the reduced moment of inertia of the liquid tank wagon boiler, does not participate in the movement relative to the boiler; z_{ci} - the centre height of tank wagon gravity; m_i - body weight equivalent to the tank wagon boiler of a part of the liquid cargo does not participate in the movement relative to the boiler, F_k - moment of forces between tank container and roll trailer.

The movement of the liquid cargo in the boiler of the tank container is described by the oscillations of a mathematical pendulum [2]. The determination of the hydrodynamic characteristics of the liquid cargo was carried out according to the methodology given in [14]. Gasoline was adopted as a liquid cargo. The determination of the hydrodynamic characteristics of the liquid cargo was carried out taking into account the maximum permissible load of the tank container boiler - 95% of its total capacity.

The calculation of the mathematical model was carried out in the MathCad software package [6–8, 25]. In this case, the initial displacements and speeds are set equal to zero [11, 16, 25]. The Runge-Kutta method [3, 13, 22] was used as a calculation method.

The total acceleration value includes the acceleration that acts concerning the nominal position of the tank container placed on the roll trailer, as well as the horizontal component of the gravitational acceleration due to the roll angle of the rail ferry. It is taken into account that the lurch of the rail ferry is caused by wind loads on the surface of the rail ferry. With the value of wind pressure P = 1.47 kPa [27], the resulting lurch angle θ = 18.80. The results obtained by the authors of the article are shown in Fig. 2. From the side of the ordinate axis, the heading angles of the wave concerning the body of the railway ferry are taken out. In this case, the acceleration values are about 0.46g.

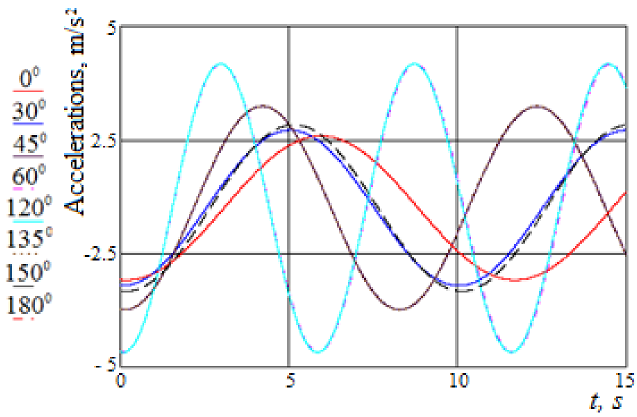

Figure 2. Acceleration of a tank container placed on a roll trailer

The obtained accelerations were taken into account when determining the stability of a tank container on a roll-trailer during transportation by a rail ferry. The design scheme created by the authors of the article is shown in Fig. 3.

In this case, the equilibrium condition has the form [10, 26]:

$$k_c = \frac{M_{res}}{M_o} \geq 1, \tag{3}$$

where M_{res} - the value of the restoring torque; M_o - the value of the overturning moment.

At the same time, the article authors have derived analytical dependencies for determining the overturning (4) and restoring (5) moments.

$$M_o = p_k' \cdot \frac{h_k}{2} + M_{gr} \cdot \left(g \cdot \sin\theta + \ddot{\theta}_2\right) \cdot \frac{h_k}{2}, \tag{4}$$

$$M_{res} = P_{gr} \cdot \cos\theta \cdot \frac{B_k}{2} + n_f \cdot \left(M_{gr} \cdot \left(g \cdot \sin\theta + \ddot{q}_k\right)\right) \cdot \frac{h_f}{2}, \tag{5}$$

where M_{gr} is the gross mass of the tank container; P_{gr} - gross weight of the tank container; V_s - the width of the tank container; n_f is the number of fitting stops on which the tank container is supported during angular displacements relative to the longitudinal axis; h_f - the height of the stop fittings.

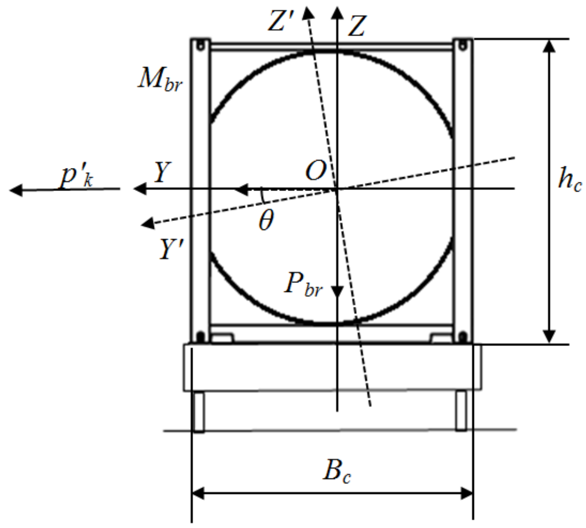

Figure 3. Calculated diagram of a tank container

Based on the studies carried out, the dependence of the stability coefficient of a tank container on a roll-trailer on the lurch angle of a railway ferry was obtained (Fig. 4). The stability threshold is set when the values of the restoring and overturning moments are equal to each other.

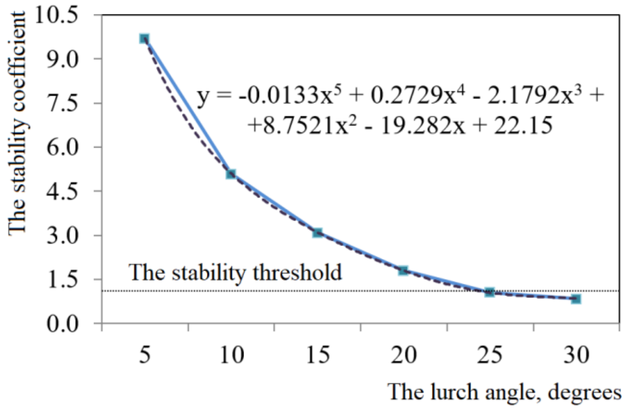

Figure 4. Dependence of the stability coefficient of a tank container on a roll-trailer from the lurch angle of a railway ferry

It was found that the stability of a tank container on a roll-trailer, taking into account the typical scheme of interaction (fitting stops - fittings), is ensured at lurch angles up to 240.

3 CONCLUSIONS

1. The dynamic loading of a tank container placed on a roll-trailer during transportation by a railway ferry has been determined. For this, a mathematical model has been created that takes into account the movement of the railway ferry around the longitudinal axis. It was found that in the absence of movements of the roll-trailer relative to the deck and the presence of movements of the tank-container on the roll-trailer, the maximum accelerations acting on the tank-container are equal to 0.46g.
2. The stability of the tank container placed on a roll-trailer during transportation by rail is determined. It was found that the stability of a tank container on a roll-trailer, taking into account the typical interaction scheme, is ensured at lurch angles up to 240.

To ensure the safety of combined transport in international traffic, it is important to clarify the regulatory documents, which indicate the loads acting on vehicles. At the same time, it is necessary to note additional conditions for loading tank containers when transported on roll trailers by rail ferries. The results obtained can contribute to the creation of recommendations for the design of tank containers.

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