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Research of the strength of the bearing structure of the flat wagon body from round pipes during transportation on the railway ferry

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Abstract. The dynamic loading of the bearing structure of the flat wagon from round pipes was investigated during transportation on the railway ferry. The main types of movements of the railway ferry with wagons located on its decks are taken into account. The research has been carried out on the strength of the bearing structure of the flat wagon by the finite element method. The coefficient of the reserve for the fatigue strength of the bearing structure is calculated, taking into account the action of cyclic loads in the conditions of sea disturbance.

1 Formulation of the problem

The active competition of railway transport with other modes of transport, both on the internal market of goods transportation and through international transport corridors, causes the necessity of providing the transport industry with wagons of the new generation. The construction of such wagons at the present stage of development should ensure that they can be used not only for railways, but also for international rail and water connections [1-9]. Therefore, the issue of designing and putting into operation of fundamentally new structures of wagons with improved technical and economic indicators and an expanded spectrum of functional capabilities is a topical issue.

2 Analysis of recent research

The issue of designing the rolling stock for the carriage of heavy goods is considered in [4]. Dynamics and strength research was carried out using modern software tools such as ProMechanica and CosmosWorks. When designing the bearing structure of the transporter, research was conducted on the possibility of its execution from various types of materials.

Comparison of analytical stress analysis and numerical calculation of mobile work machine part is considered in [5].

The study of the dynamics of a railway wagon with an open loading platform is given in [7]. The calculation is carried out in the software environment of MSC Adams. Investigation of stability against the rollover of a wagon was carried out when it is entered into a curve with a radius of 250 m, taking into account different speeds of motion.

Determination of dynamic parameters of wagons during transportation on a railway ferry in works is not carried out.

The structural features of the wagon for intermodal transportation are considered in [8]. The wagon has a reduced middle part, and the presence of the back part makes it possible to load / unload the vehicle on / off it with a scooter. An analysis of the design of a new-generation flat wagon is given in [9]. The feature of a flat wagon is the possibility of adjusting the useful length depending on the dimensions of the cargo being transported.

In the designs of the flat wagons considered, there are no nodes for fixing of chain binders for the purpose of transportation on railway ferries.

Studies on the expediency of using round pipes as elements of bearing systems of flat wagons are given in [10]. On the basis of theoretical studies of the stress-strain state of the bearing structure of the flat wagon model 13-401, the reserves of the strength of its components were determined and the use of a round section pipe frame as a bearing element was proposed. The study of the dynamics of the improved bearing structure of the flat wagon in the work is not carried out.

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Features of creation of ideal bearing structures of railway vehicles with optimal technical and economic indicators are covered in [11, 12]. The question of studying the dynamic loading of bearing structures of wagons during transportation on railway ferries in the considered works was not investigated.

Illumination of the features of the study of the structural strength of the flat wagon from round pipes when transporting on a railway ferry.

To achieve this purpose, the dynamic loading of the bearing structure of the flat wagon of round pipes was investigated during transportation on the railway ferry. The main types of movements of the railway ferry with wagons located on its decks are taken into account: forward movements relative to the vertical axis, angular displacements around the transverse axis, and angular displacements around the longitudinal axis. The solution of differential equations is carried out by the Runge–Kutta method. The research has been carried out on the strength of the bearing structure of the flat wagon by the finite element method implemented in the CosmosWorks software environment. The coefficient of the reserve for the fatigue strength of the bearing structure of the flat wagon during transportation on the railway ferry is calculated, taking into account the action of cyclic loads in the conditions of sea disturbance.

3 Presentation of the main material

The structural features of a new generation flat wagon, bearing elements of which are made of pipes of circular cross section, are given in [10]. For the possibility of transportation of a flat wagon on a railway ferry, it is proposed to install on its bolster beams the nodes for fixing the chain binders (Figure 1) [13].

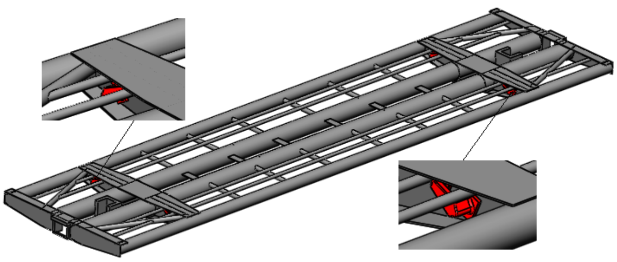

Fig. 1. Improved bearing structure of a flat wagon with nodes for fixing relative to the decks of the railway ferry.

The study of the dynamic loading of the bearing structure of the flat wagon was carried out using the mathematical model presented in [13, 14].

The main types of movements of a railway ferry with wagons located on its decks are taken into account: forward movements relative to the vertical axis Z (1), angular displacements around the transverse axis Y (2), angular displacements around the longitudinal axis X (3).

The diagram of the movements of the flat wagon fixed to the deck of the railway ferry is shown in Figure 2.

$$D' \cdot \ddot{q}_1 + \Lambda_z \cdot \dot{q}_1 = \Lambda_z \cdot \dot{F}(t); \quad (1)$$

$$I_\varphi \cdot \ddot{q}_2 + \left(\Lambda_\varphi \cdot \frac{L}{2} \right) \dot{q}_2 = p' \cdot \frac{h}{2} + \Lambda_\varphi \cdot \frac{L}{2} \cdot \dot{F}(t); \quad (2)$$

$$I_\theta \cdot \ddot{q}_3 + \left(\Lambda_\theta \cdot \frac{B}{2} \right) \dot{q}_3 = p' \cdot \frac{h}{2} + \Lambda_\theta \cdot \frac{B}{2} \cdot \dot{F}(t), \quad (3)$$

where $q_1 = z$, $q_2 = \varphi$, $q_3 = \theta$ – generalized coordinates corresponding to: z – the displacement of the body relative to the vertical axis passing through its center of mass, φ – the angular displacement around the transverse axis, θ – the angular displacement around the longitudinal axis. The origin of the coordinate system is located at the center of the mass of the railway ferry.

D' – massive water extrusion, L, B – the length and width of the railway ferry; h – the height of the board of the railway ferry; Λ_i – coefficient of resistance fluctuations; p' – wind load; and $F(t)$ – the law of the force of efforts that disturbs the movement of a railway ferry with the bodies of cars located on its decks.

The resistance coefficient of movement of a railway ferry is determined by the following formula:

$$\Lambda_i = \int_{-L/2}^{L/2} \rho \omega T^2 \overline{\Lambda}_i dL, \quad (4)$$

where Λ_i – dimensionless damping factor, which is determined by the graphical dependencies of the reference literature, in accordance with the characteristics of the railway ferry [15].

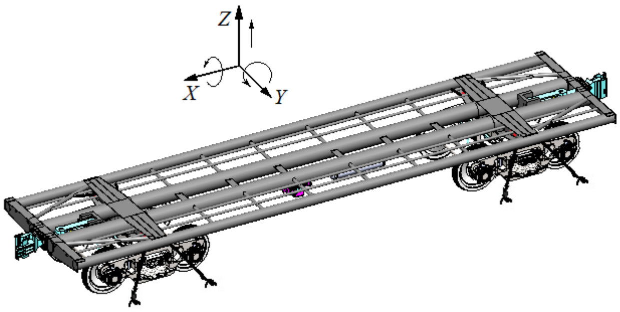

Fig. 2. Scheme of movement of a flat wagon during fluctuations of a railway ferry.

The model takes into account that the wagon is rigidly fixed relative to the deck and carries with it the movement, that is, it does not have its own degree of freedom. The impact of sea waves on the building of a railway ferry with wagons placed on its board was not taken into account. It is taken into account that the railway ferry is loaded with flat wagons using their full load-carrying capacity.

The research was conducted for the case of the carriage of wagons on the ferry "Heroes of Shipka" by the Black Sea.

The solution of differential equations (1-3) was carried out in the software environment of Mathcad [16, 17] by the Runge-Kutta method.

It was established that when moving the railway ferry in the vertical direction, the maximum accelerations act on the flat wagons located on the upper deck and make up 0.82 g, with angular displacement around the transverse axis for the extreme of the open stern of the wagon - 0,1 g, with the angular displacement around the longitudinal the axis for the extreme from the bulwark of the wagon - 0,23g.

The resulting numerical values of acceleration are taken into account when calculating the strength of the bearing structure of the flat wagon. The strength study was conducted using the finite element method implemented in the CosmosWorks software environment.

When creating a finite-element model, isoparametric tetrahedrons was used, the optimal number of which was determined by the graph-analytical method. The number of elements of the grid was 3056795, the nodes - 849631, the maximum dimension of the element - 15 mm, the minimum - 3 mm, the maximum aspect ratio of the elements - 584,93 the percentage of elements with a side relation of less than 3 - 89,3, more than 10 - 0,228. The minimum number of elements in the circle was 8, the ratio of increase in the size of the element - 1.6.

The model of the structural strength of the flat wagon at angular displacements relative to the longitudinal axis, as in the case of the greatest loading of the bearing structure, is shown in Figure 3.

When compiling the strength model, the following loads are taken into account: vertical static P_v^{st} and dynamic load, as well as loads that act on the body of the wagon through the chain binders P_{chb}. Since the chain binders have a spatial arrangement, the forces that will be transmitted to the supporting structure through them are decomposed into three components, taking into account the angles of their placement in space.

The fixing of the model was carried out in the areas of buckling of the bearing structure of the flat wagon on the bogies, as well as the supporting surfaces of mechanical stop-jacks. Steel grade 09G2S was used as the material of the bearing structure of the flat wagon.

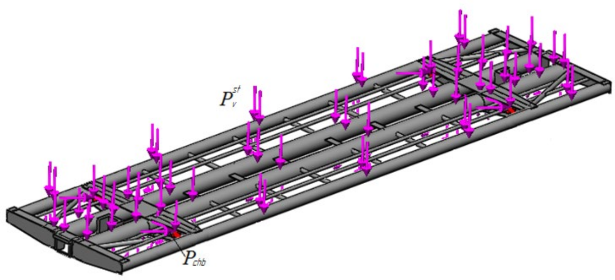

Fig. 3. Model of strength of the bearing structure of the flat wagon.

The results of the calculation are shown in Figures 4, 5. The conducted studies allowed us to conclude that the maximum equivalent stresses arise in the zones of interaction of the bolster beams with the ridge beam and make up about 280 MPa, that is, they do not exceed the permissible values [18, 19]. The distribution of maximum equivalent stresses along the length of the ridge of the flat wagon is shown in Figure 6.

Maximum displacements arise in the middle part of the main longitudinal beam of the frame by placing the chain binders that are tensioned at the angular displacement of the bearing structure of the flat wagon and make up 27.7 mm (Figure 7). The maximum deformations were $3{,}19 \cdot 10^{-3}$.

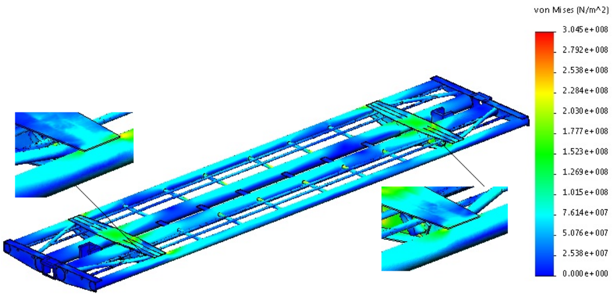

Fig. 4. The stressed state of the bearing structure of the flat wagon at angular movements around the longitudinal axis (top view).

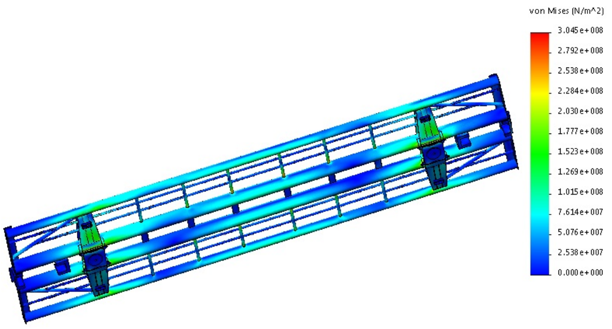

Fig. 5. The stressed state of the bearing structure of the flat wagon at angular movements around the longitudinal axis (bottom view).

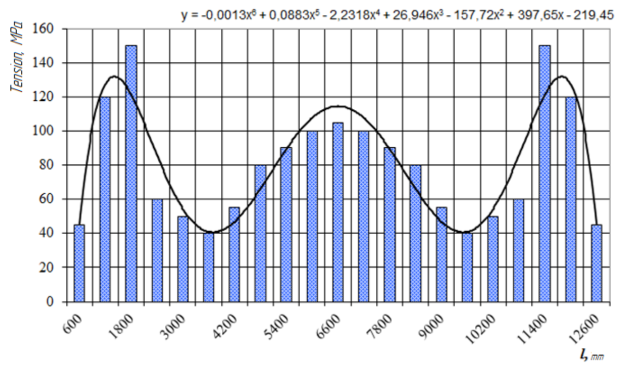

Fig. 6. Distribution of maximum equivalent stresses over the length of the ridge beam of the flat wagon.

The results of calculations at other schemes of displacements of the flat wagon allowed to conclude that the maximum equivalent stresses in the bearing structure do not exceed the permissible values.

To ensure the strength of the bearing structure of the flat wagon under the influence of cyclic loads in conditions of sea disturbance, the calculation of the reserve factor for fatigue strength was performed. The calculation is carried out according to the method shown in [20]. At the same time, the coefficient of reserve for

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fatigue strength in a multifaceted tense state is determined:

$$n = \sigma_{-1} / \sigma_{equ} \cdot K_m \qquad (5)$$

where σ_{-1} – limit of endurance; σ_{equ} – equivalent stresses; K_m – a coefficient that takes into account the characteristics of the material.

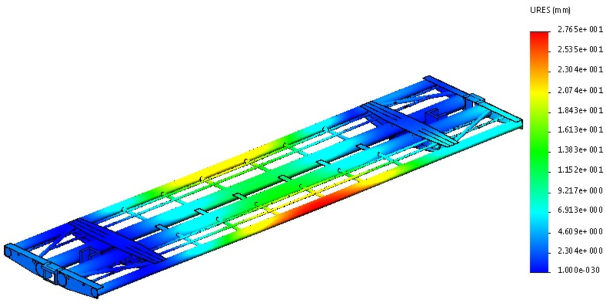

Fig. 7. Moving in the nodes of the bearing structure of the flat wagon.

$$K_m = \frac{1-R}{2}\left[\frac{1}{n_{-1}\cdot\varepsilon_\sigma} + \left(\frac{1}{\beta} - \beta\right)\frac{1}{\alpha_\sigma}\right]\frac{1}{\beta_y} + \frac{1+R}{2\alpha_\sigma}\psi_\sigma, \qquad (6)$$

where R – coefficient of asymmetry of the cycle of stresses; n_{-1} – coefficient, which characterizes the sensitivity of the material to stress concentration; ε_σ – scale factor; β – coefficient of surface quality; β_y – coefficient of strengthening the surface; α_σ – theoretical concentration of stresses; ψ_σ – coefficient taking into account the influence of the asymmetry of the cycle.

The calculations made allow us to conclude that the coefficient of reserve for fatigue strength is $n \approx 1.7$, that is, within the limits of permissible [18, 19].

Conclusions

1. In order to increase the efficiency of combined transport, the construction of a new generation of flat wagon has been proposed. The peculiarity of the flat wagon is that its load-bearing elements are made of round pipes, which allows reducing the carriage tare compared with the prototype wagon by almost 5%. For the possibility of carriage a flat wagon on a railway ferry, it is proposed to set up the nodes on the bolster beams for chain binders fixing;
2. The maximal accelerations, acting on the supporting structure of the flat wagon of round pipes, are determined at transportation on the railway ferry. When moving the railway ferry in the vertical direction for the flat wagon, placed on the upper deck, the maximum acceleration value is 0.82 g, with the angular displacement around the transverse axis for the extreme of the open stern of the wagon - 0,1 g, with the angular displacement around the longitudinal the axis for the extreme from the bulwark of the wagon – 0.23 g.
3. Researches on the strength of the bearing structure of the flat wagon during transportation on the railway ferry allowed to conclude that the maximum equivalent stresses do not exceed the permissible and make up about 280 MPa;
4. Conducted calculation of the reserve factor for the fatigue strength of the bearing structure of the flat wagon during transportation on the railway ferry. The results of the calculation showed that the value of the reserve factor for fatigue strength is within the permissible limit;
5. The conducted researches will allow to increase efficiency of operation of flat wagons through international transport corridors.

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