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RESEARCH OF THE STRENGTH OF THE BODY OF A COVERED WAGON WHEN IT IS FASTENED WITH A NEW DEVICE ON THE DECK OF A RAILWAY FERRY

SKÚMANIE PEVNOSTI SKRINE UZAVRETÉHO VOZŇA PRI JEHO UPEVNENÍ POMOCOU NOVÉHO ZARIADENIA NA PALUBE ŽELEZNIČNÉHO TRAJEKTU

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1 INTRODUCTION

The efficiency of functioning of the transport industry necessitates the introduction of modern vehicles. Since the main segment of the transportation process is allocated to rail transport, the creation of modern wagon designs must be subject to special requirements. This applies in particular to their load-bearing structures. When designing the load-bearing structures of modern wagons, it is necessary to take into account the specified values of loads that can act on them not only when operating on main tracks, but also in combined railway-ferry transportation. This direction is quite relevant for many European countries that have access to international traffic through water areas of the seas.

Covered wagons are one of the most common types of wagons that have found use in the international rail-water service. To ensure the stability of covered wagons on railway ferries, they are fixed with multi-turn means. It is important to say that due to the lack of technical adaptation of the load-bearing structure of the wagon to interact with multi-turn means, they are damaged.

This circumstance can contribute to the disruption of the stability of the wagon on deck and the steadiness of the railway ferry, and, accordingly, the environmental sustainability of transportation.

Therefore, to ensure the safety of transportation of covered wagons by sea, it is important to adapt them technically to secure fixing on the decks. This will help provide the

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safety of transportation of wagons by sea, reduce the cost of unscheduled kinds of repairs, ensure environmental sustainability of railway-ferry services, as well as increase the efficiency of their operation.

2 ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

In work [1] the analysis of technology of modernization of freight wagons is carried out. It is proposed to make the wagon body from composite panels, and perform the paint coating with anti-corrosion materials. However, this paper does not substantiate the modernization of wagons in order to ensure the reliability of their attachment to the decks of railway ferries.

Issues of optimization of load-bearing structures of freight wagons are considered in article [2]. To reduce the material consumption of the load-bearing structure of the wagon, the authors proposed to use aluminum panels in the body. It is noted that this solution also helps to reduce the dynamic loading of the wagon due to the presence of flexible connections in them. However, the issue of reducing the dynamic loading of the wagon frame is not paid attention to in the work.

The study of fatigue strength of the gondola car body in operating modes is carried out in publications [3, 4]. The results of the research have shown that the method of predicting the fatigue strength of the body, based on hybrid modelling of dynamics and finite element analysis is possible. It is important to say that the task of determining the dynamic loading of the wagon body when transported by railway ferry is not set in these works.

Improvement of the load-bearing structure of the wagon frame to ensure strength in operating modes is implemented in work [5]. The peculiarities of calculation of strength of the improved load-bearing structure of the wagon with the help of computer simulation are highlighted. However, this design of the wagon is not adapted to transportation by railway ferry.

The results of calculation of strength of the load-bearing structure of the covered wagon are given in article [6]. The calculation is realized by the finite element method. At the same time, when conducting strength calculations the authors did not take into account the loads that may affect the load-bearing structure of the wagon when transported by railway ferry.

The issues of reducing the dynamic loading of the load-bearing structures of wagons by using flexible connections in them are covered in works [7, 8]. The results of the conducted research established that the use of energy-absorbing materials in the components of the load-bearing structures of wagons is appropriate. However, the authors did not pay attention to the issues of introduction of flexible connections between the wagon body and the deck of the railway ferry.

Analysis of scientific publications [1 – 8] allows us to conclude that the issues of improving the load-bearing structures of covered wagons to ensure the reliability of their attachment to railway ferries are relevant and need research.

3 PURPOSE AND MAIN OBJECTIVES OF THE STUDY

The purpose of the study is to determine the loading of the covered wagon when fixing it with viscous ties to the deck to ensure the environmental sustainability of railway-ferry transportations. To achieve this goal, the following tasks are defined:

- to determine the strength of the load-bearing structure of the covered wagon with a typical scheme of its fastening on the deck of the railway ferry;
- to investigate the dynamic loading of the load-bearing structure of the covered wagon when fixed with viscous ties on the deck of the railway ferry;

- to determine the strength of the load-bearing structure of the covered wagon when fixed with viscous ties on the deck of the railway ferry.

4 DETERMINATION OF THE STRENGTH OF THE LOAD-BEARING STRUCTURE OF THE COVERED WAGON WITH A TYPICAL SCHEME OF ITS FASTENING ON THE DECK OF THE RAILWAY FERRY

To determine the indicators of strength of the load-bearing structure of the covered wagon when transported on the railway ferry, model 11-217 was chosen as a basic one (***fig. 1***).

Fig. 1 *Covered wagon of model 11-217*

Obr. 1 *Krytý vozeň vzor 11-217*

In this case, one of the most unfavorable variants of its fixing on the deck is considered (***fig. 2***).

Fig. 2 *Scheme of fixing the covered wagon on the deck of the railway ferry*

Obr. 2 *Schéma upevnenia krytého vozňa na paluba železničného trajektu*

The spatial model of the load-bearing structure of the covered wagon is built in the SolidWorks software package and is shown in ***fig. 3***. The construction of the model takes into account the elements of the body, which interact rigidly with each other, i.e. the model did not take into consideration the movable self-sealing doors.

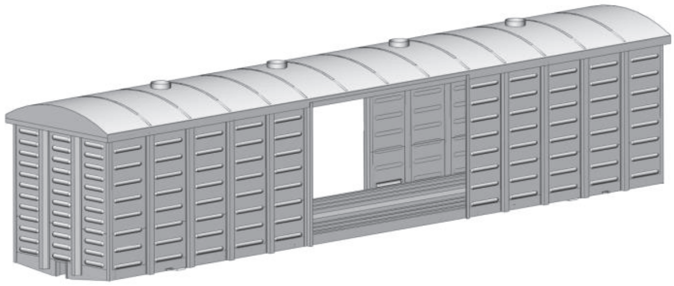

Fig. 3 *Spatial model of the load-bearing structure of the covered wagon*

Obr. 3 *Priestorový model nosnej konštrukcie krytého vozňa*

The calculation of strength was performed using the finite element method in the environment of the SolidWorks Simulation software package [9, 10]. In carrying out the calculations, the case of the on-board rocking of the railway ferry was taken into account, as the most unfavorable mode of loading of the load-bearing structures of wagons during transportation by sea.

When creating the calculation scheme, it is assumed that the wagon is loaded with a conditional cargo using full carrying capacity. When compiling the calculation scheme, it is taken into account that the wagon is subject to vertical static load P_v^{st}, dynamic load P_d, wind load P_v, as well as the force of tension of the chain ties P_{ch}. Due to the spatial arrangement of chain ties, this force was broken down into components taking into account the angles of placement of the tie in space (***fig. 4***). Fastening of the model was realized in the areas where it rests on the carts and support surfaces of mechanical jacks. The construction material is steel of grade 09G2C with the value of yield strength of 345 MPa and tensile strength of 490 MPa [11, 12].

The finite element model of the load-bearing structure of the covered wagon is shown in ***fig. 5***.

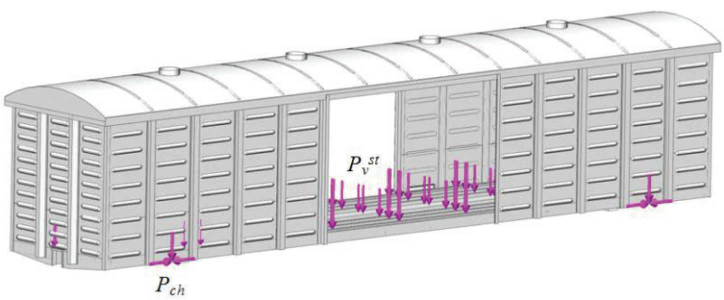

Fig. 4 *Calculation scheme of the load-bearing structure of the covered wagon body*

Obr. 4 *Výpočtová schéma nosnej konštrukcie krytej skrine vozňa*

The optimal number of grid elements is determined using the graph-analytical method. The number of grid elements is 637520, nodes – 225092. The maximum size of the grid element is 100.0 mm, the minimum size – 20.0 mm, the maximum ratio of the sides of the elements – 525.19, the percentage of elements with the sides ratio of less than 3 – 11.1, more than ten – 46.7. The minimum number of elements in the circle is 22, the ratio of increasing the size of the element is 1.8, the coefficient of simplification of the model in the areas of location of rounding-offs and openings is 0.4.

The results of the calculation are shown in ***fig. 5*** *and* ***fig. 6***.

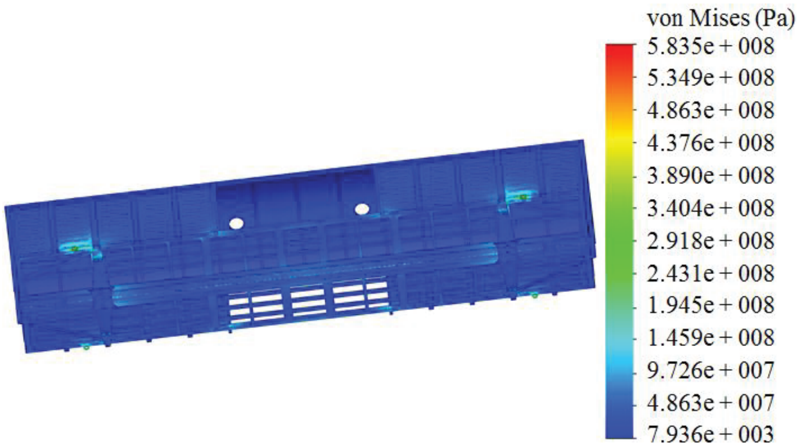

Fig. 5 *Stress state of the load-bearing structure of the covered wagon*

Obr. 5 *Napätosť nosnej konštrukcie krytého vozňa*

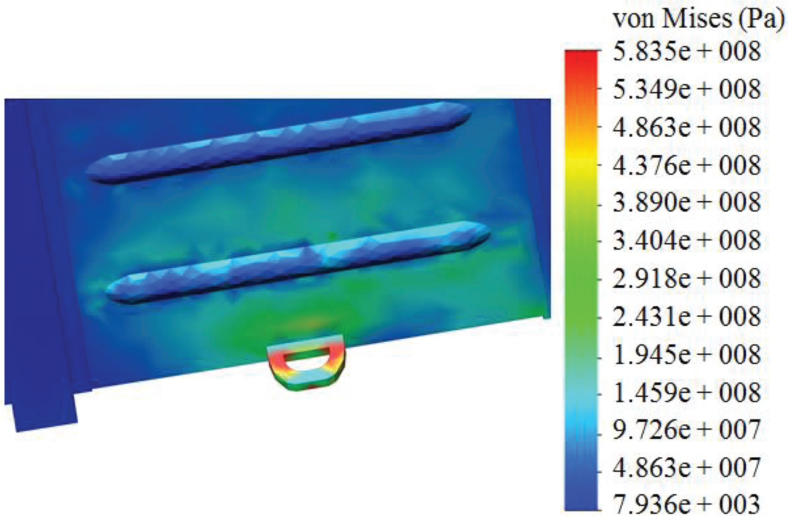

Fig. 6 *Stress state of the load-bearing structure of the covered wagon in the area of location f the towing bracket*

Obr. 6 *Napätosť nosnej konštrukcie krytého vozňa v oblasti umiestnenia ťažného zariadenia*

Based on the conducted calculations, it is established that the maximum equivalent stresses in the load-bearing structure of the covered wagon are about 580 MPa, so they exceed the allowable values [11, 12].

To ensure the reliability of securing and safety of wagon transportation by sea, a unit for interaction with chain ties has been developed [13]. In order to mitigate the effects of loads from the chain ties on the wagon body, it is proposed to set not a rigid connection between them (***fig. 7***), but a viscous one, by means of installing a special device – a damper between the body and the deck.

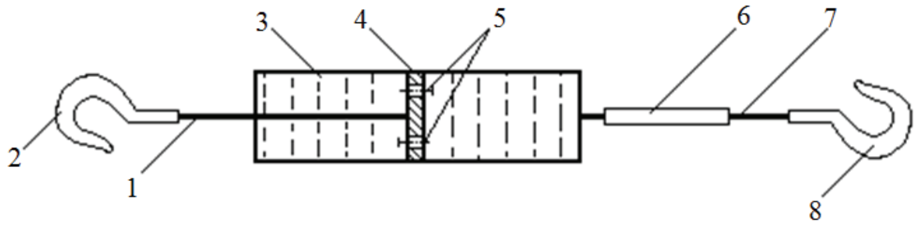

Fig. 7 *Device for fixing the wagon on the deck of the railway ferry*
1 – rod; 2 – hook for fastening the body; 3 – shell; 4 – piston;
5 – throttle opening; 6 – adapter with thread tapping; 7 – rigid rod; 8 – hook for fastening to the deck rim

Obr. 7 *Zariadenie na upevnenie vozňa na palube železničného prievozu*
1 – tyč; 2 – háčik na upevnenie tela; 3 – škrupina; 4 – piest;
5 – otvorenie škrtiacej klapky; 6 – adaptér so závitom; 7 – tuhá tyč; 8 – háčik na upevnenie na okraj paluby

The device for fixing the wagon on the deck of the railway ferry consists of rigid rod 1 at the end of which there is hook 2 for fastening to the wagon body. The acting part of the device is a hydraulic damper, which includes shell 3. Inside the shell there is piston 4 with throttle openings 5. The lower part of the device consists of adapter 6 with thread tapping for adjusting the length of the device, rigid rod 7 and hook 8 for fastening to the deck rim.

5 STUDY OF THE DYNAMIC LOADING OF THE LOAD-BEARING STRUCTURE OF THE COVERED WAGON WHEN FIXED WITH VISCOUS TIES ON THE DECK OF THE RAILWAY FERRY

In order to determine the acceleration of the load-bearing structure of the covered wagon fixed on the deck with the help of the proposed device, mathematical modelling is performed. For this purpose, a mathematical model of fluctuations of the railway ferry with the wagons placed on it is made (***fig. 8***). The case of on-board rocking of the railway ferry is taken into account.

Here the system of differential equations has the form

$$\begin{cases} \frac{D}{12 \cdot g} \cdot \left(B^2 + 4 \cdot z_g^2\right) \cdot \ddot{q}_1 + \left(L_q \cdot \frac{B}{2}\right) \cdot \dot{q}_1 = p' \cdot \frac{h}{2} + L_q \cdot \frac{B}{2} \cdot \dot{F}(t), \\ I_k \cdot \ddot{q}_2 + b \cdot \frac{B}{2} \cdot \dot{q}_2 = p_k \cdot \frac{h_k}{2} + F_b, \end{cases} \quad (1)$$

where q_1, q_2 are generalized coordinates corresponding to the angular displacement around the longitudinal axis X of the railway ferry and the wagon body, respectively.

For the railway ferry:

D – weight displacement; B – width; h - board height; Λ_θ – coefficient of resistance to oscillations; z_g – coordinate of the center of gravity; p' – wind load; $F(t)$ – law of action of force causing the movement of the railway ferry with wagon bodies placed on its decks.

For the body of the covered wagon:

I_k – moment of inertia relative to the longitudinal axis; β – coefficient of viscous resistance of the element; $в_k$ – body width; p_k – wind load on the side wall; h_k – height of the side wall; F_β – moment of forces occuring between the body and the deck.

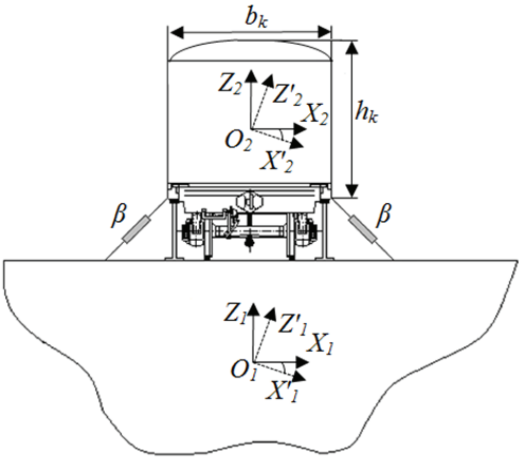

Fig. 8 *Calculation scheme for determining the dynamic loading of the covered wagon*

Obr. 8 *Výpočtová schéma na určenie dynamického zaťaženia krytého vozňa*

Calculations were made for the railway ferry "Heroes of Shipka" when it is moving through the water area of the Black Sea. The input parameters to model (1) are the technical characteristics of the railway ferry, the covered wagon, as well as hydrometeorological characteristics of the water area of the sea.

The solving of the system of differential equations (1) was performed in the environment of the Mathcad software package [14 – 16] using Runge-Kutta method. The initial conditions are assumed to be equal to zero.

Fig. 9 shows the accelerations acting on the load-bearing structure of the covered wagon, taking into account the typical scheme of fastening on the deck, as well as the one using viscous ties. In this case, the acceleration acting on the load-bearing structure of the covered wagon, given the typical fastening scheme is 1.78 m/s^2.

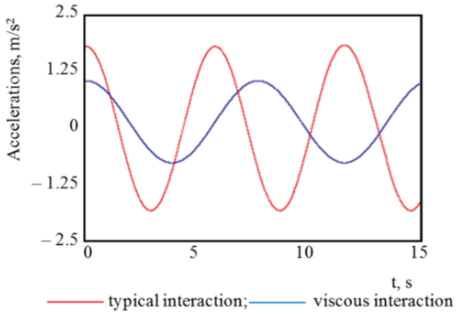

Fig. 9 *Accelerations acting on the load-bearing structure of the covered wagon when transported by railway ferry*

Obr. 9 *Zrýchlenia pôsobiace na nosnú konštrukciu krytého vozňa pri preprave železničným trajektom*

Accelerations are given for the course angle of the wave χ = 0° relative to the hull of the railway ferry. Taking into account the fixing of the wagon with viscous ties, the acceleration acting on the load-bearing structure was 1.25 m/s^2. Therefore, when using viscous ties to secure the wagon on the deck, it is possible to reduce the amounts of accelerations acting on its load-bearing structure by 30 %.

It is important to note that in this case the working fluid that will create a viscous resistance between the body and the deck must have a viscosity coefficient from 1.8 kN•s/m to 4.2 kN•s/m.

6 DETERMINATION OF THE STRENGTH OF THE LOAD-BEARING STRUCTURE OF THE COVERED WAGON WHEN FIXED WITH VISCOUS TIES ON THE DECK OF THE RAILWAY FERRY

To determine the strength indicators of the load-bearing structure of the covered wagon, taking into account the obtained accelerations, a calculation was performed. The spatial model of the load-bearing structure of the covered wagon based on the improvement is shown in ***fig. 10***.

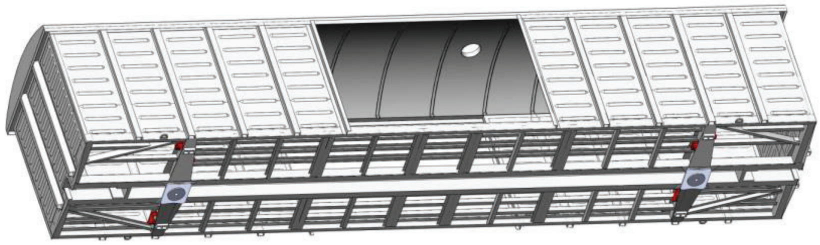

Fig. 10 *Load-bearing structure of the covered wagon with units for fastening on the deck*

Obr. 10 *Nosná konštrukcia krytého vozňa s jednotkami na upevnenie na palube*

While creating a finite element model, isoparametric tetrahedra were used [17 – 19], the optimal number of which was determined by the graph-analytical method [20]. The number of elements of the grid is 876083, nodes – 314193, the maximum size of the element - 80 mm, the minimum size – 16 mm, the maximum ratio of the sides of the elements – 1609.9, the percentage of elements with the sides ratio of less than 3 – 12.6, more than 10 – 40.5. The ratio of the increase of elements in the grid – 1.9. Number of elements in the circle – 22. The calculation scheme of the load-bearing structure of the covered wagon is shown in ***fig. 11***.

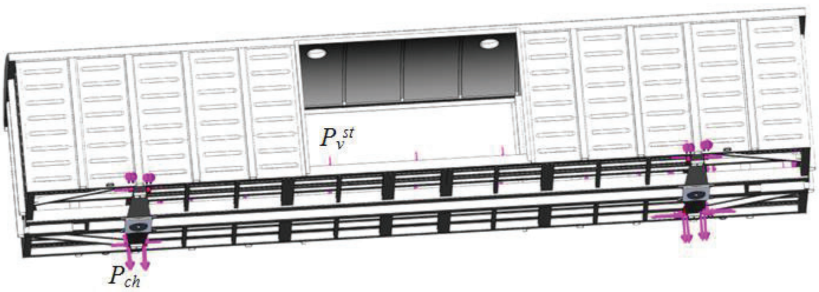

Fig. 11 *Calculation scheme of the load-bearing structure of the covered wagon*

Obr. 11 *Výpočtová schéma nosnej konštrukcie krytého vozňa*

The results of the calculations are shown in ***fig. 12, 13***.

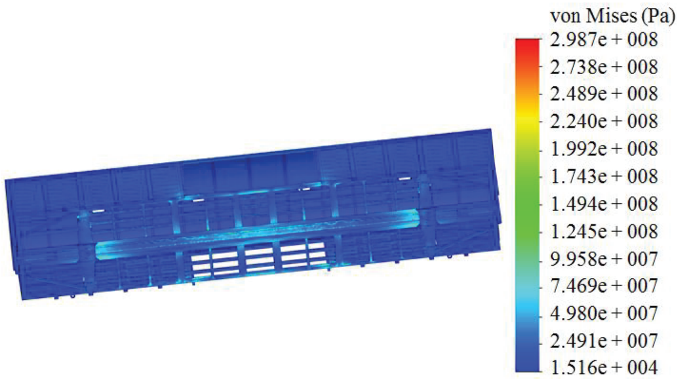

Fig. 12 *Stress state of the load-bearing structure of the covered wagon*

Obr. 12 *Napätosť nosnej konštrukcie krytého vozňa*

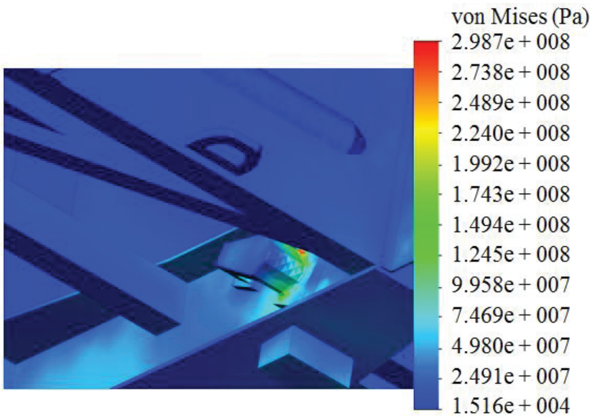

Fig. 13 *Stress state of the load-bearing structure of the covered wagon in the area of the fastening unit location*

Obr.13 *Napätosť nosnej konštrukcie krytého vozňa v oblasti umiestnenia upevňovacej jednotky*

Based on the conducted calculations, it is established that the maximum equivalent stresses in the load-bearing structure of the covered wagon are about 298 MPa. Therefore, taking into account the new scheme of fixing the covered wagon on the deck, the maximum equivalent stresses in the elements of the load-bearing structure do not exceed the allowable [11, 12] and are 51% lower than in the typical scheme of fastening.

7 CONCLUSION

1. The strength of the load-bearing structure of the covered wagon in case of the typical scheme of its fixing on the deck of the railway ferry is determined. It is established that the maximum equivalent stresses in the load-bearing structure of the covered wagon are about 580 MPa and occur in the towing brackets with the help of which the wagon is fixed. Thus, the maximum equivalent stresses exceed the allowable values.

2. The dynamic loading of the load-bearing structure of the covered wagon fixed with viscous ties on the deck of the railway ferry was studied. The acceleration acting on the load-bearing structure of the covered wagon, given the typical scheme of interaction with the deck, was 1.78 m/s^2. Taking into account the fixing of the wagon with viscous ties, the

acceleration acting on the load-bearing structure was 1.25 m/s^2. Therefore, when using viscous ties to secure the wagon on the deck, it is possible to reduce the amounts of accelerations acting on its load-bearing structure by 30%.

3. The strength of the load-bearing structure of the covered wagon when fixed with viscous ties on the deck of the railway ferry was determined. It is established that the maximum equivalent stresses in the load-bearing structure of the covered wagon are about 298 MPa. Therefore, taking into account the new scheme of fastening the covered wagon on the deck, the maximum equivalent stresses in the elements of the load-bearing structure do not exceed the allowable ones and are 51% lower than in the typical scheme of fastening.

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Summary

Determination of strength of the load-bearing structure of a covered wagon with a typical scheme of fastening on the deck of the railway ferry is carried out. It is established that the maximum equivalent stresses in the load-bearing structure of the wagon exceed the allowable values. To mitigate the effects of chain tie loads on the wagon body, it is proposed not to make a rigid connection between them, but a viscous one, by installing a special device – a damper between the body and the deck. It is established that in this case it is possible to reduce the values of accelerations acting on the load-bearing structure of the covered wagon by 30% compared to the typical fastening scheme. The maximum equivalent stresses in the load-bearing structure of the covered wagon, taking into account the use of viscous ties, were about 298 MPa, i.e. they do not exceed the allowable ones and are 51% lower than in the typical scheme of fastening the wagon.

The conducted research will promote ensuring the safety of transportation of wagons by the sea, reduction of expenses for unscheduled kinds of repairs, environmental sustainability of railway-ferry transportations, as well as increase of efficiency of their operation.

Resumé

Vykonáva sa stanovenie pevnosti nosnej konštrukcie krytého vozňa s typickou schémou upevnenia na palube železničného prievozu. Zistilo sa, že maximálne ekvivalentné napätia v nosnej konštrukcii vozňa presahujú prípustné hodnoty. Na zmiernenie účinkov zaťaženia reťazou na skriňu vozňa sa navrhuje, aby sa medzi nimi nevytvorilo pevné spojenie, ale viskózne, a to inštaláciou špeciálneho zariadenia - tlmiča medzi skriňu a palubu. Zistilo sa, že v tomto prípade je možné znížiť hodnoty zrýchlení pôsobiacich na nosnú konštrukciu krytého vozňa o 30 % v porovnaní s typickou schémou upevnenia. Maximálne ekvivalentné napätia v nosnej konštrukcii krytého vozňa, berúc do úvahy použitie viskóznych väzieb, boli asi 298 MPa, t.j. neprekračujú prípustné napätia a sú o 51 % nižšie ako pri typickej schéme upevnenia. vozeň.

Uskutočnený výskum podporí zaistenie bezpečnosti prepravy vozňov po mori, zníženie nákladov na neplánované druhy opráv, environmentálnu udržateľnosť železnično-trajektových prepráv, ako aj zvýšenie efektívnosti ich prevádzky.