This paper reports determining the basic strength indicators for the removable roof of a railroad gondola. It has been established that the typical roof design has a significant margin of safety in the components of the supporting structure. In order to reduce the roof material intensity, the reserves of its strength have been determined and optimized based on the criterion for minimal material intensity. Pipes of square cross-section have been proposed for using as the components of the roof frame.

When taking into consideration the proposed measures, it becomes possible to reduce the mass of the frame of the removable roof for a railroad gondola by almost 15 % compared to the typical design. At the same time, to apply the roof on different types of gondolas, its cantilevered parts can move in a longitudinal plane. It is possible to use deflectors on the removable roof. The roof can be attached to the body in a regular way. It is also possible to fix it using shog-connections.

To substantiate the proposed solution, the strength of the improved structure of the removable roof was determined. It was established that the maximum equivalent stresses in the load-bearing structure of the removable roof did not exceed permissible ones. To define the indicators of removable roof dynamics, its dynamic loading was investigated. The calculation was performed in a flat coordinate system. The oscillations in bouncing and galloping were taken into consideration as the most common types of a railroad car oscillations when running on a rail track. The mathematical model of dynamic loading was solved in the Mathcad software package (Boston, USA). The study has shown that the acceleration of the body in the center of masses is 0.4 g and is within the permissible limits. At the same time, the ride of a railroad car is excellent.

The study reported here would contribute to the improvement of the efficiency of railroad transportation

Keywords: transport mechanics, railroad gondola, removable roof, roof strength, stressed state, dynamic load

UDC 629.463.65

DOI: 10.15587/1729-4061.2021.237157

JUSTIFICATION OF THE USE OF SQUARE PIPES IN THE FRAME OF THE REMOVABLE ROOF OF THE OPEN WAGON

Oleksij Fomin
Corresponding author
Doctor of Technical Sciences, Professor
Department of Cars and Carriage Facilities
State University of Infrastructure and Technologies
Kyrylivska str., 9, Kyiv, Ukraine, 04071
E-mail: fomin1985@ukr.net

Alyona Lovska
Doctor of Technical Sciences, Associate Professor
Department of Wagon Engineering
and Product Quality
Ukrainian State University of Railway Transport
Feierbakha sq., 7, Kharkiv, Ukraine, 61050

Received date 13.04.2021
Accepted date 09.07.2021
Published date 10.08.2021

How to Cite: *Fomin, O., Lovska, A. (2021). Substantiating the use of pipes of square cross-section in the frame of the removable roof for a railroad gondola. Eastern-European Journal of Enterprise Technologies, 4 (7 (112)), 18–25. doi: https://doi.org/10.15587/1729-4061.2021.237157*

1. Introduction

The accelerated pace of integration of Euro-Asian states into the system of international transport corridors predetermines the need to improve the efficiency of railroad cars utilization in international traffic.

To ensure a timely transportation process, it is important to have an appropriate type of rolling stock for the transportation of the specified range of cargoes.

The study of statistics of cargo transportation in international traffic through the territory of Euro-Asian states suggests that the most common among them are bulk, loose, and piecewise. The latter need protection from precipitation during transportation.

The replenishment rate of the Ukrzaliznytsya railroad car fleet in recent years is insignificant. This predetermines the need to implement new technical solutions aimed at improving the load-bearing structures of car bodies.

The efficiency of railroad gondolas utilization that are the most common type of cars can be improved by using a removable roof on them. Such a solution would allow the transportation of not only bulk and loose cargoes in them but also those that need protection from precipitation.

One of the first designs of railroad cars with a roof that can be opened for loading a body with cargo was developed in 1955–1958. The roof opening drive was manual or electric.

In 1970, the «Altai Railroad Car Building Plant» also designed a car structure with a roof that opened in the transverse plane and was equipped with enlarged doorways, which allowed loading and unloading the car along the entire length of the body. That enabled a wider mechanization of loading and unloading operations when performing them both through the roof and through the doorway [1].

The existence of a removable roof increases the tare of the car. Thus, its spring mass increases. That affects the indicators of the movement of the car and its dynamic load. To expand the functionality of the car while providing for appropriate movement indicators, it is important to minimize the tare of a removable roof.

Therefore, it is important to conduct appropriate research in this area in order to adapt the load-bearing structures of railroad cars to the transportation of cargoes that need protection from precipitation.

2. Literature review and problem statement

Measures to improve the load-bearing structure of a railroad gondola in order to increase traffic safety in the transportation of cargoes whose height exceeds the upper dimensions are described in work [2]. A variant of the rod in an extendable rack is offered. However, that design is not adapted to the possibility of perception of significant loads that occur in operation.

The study of the strength of the load-bearing structure of a railroad gondola is reported in [3]. The authors provide the results from determining the fatigue durability of a welded body structure. They also proposed measures to improve the efficiency of railroad gondola operation.

In work [4], the strength of the bearing structure of the Zans-type car was determined. The car has an improved design and enhanced technical and economic characteristics. The strength calculation was implemented by the method of finite elements. The calculation results confirmed the expediency of solutions adopted in the design. It is important to say that the design of such a car structure does not provide for an increase in its universalization.

Work [5] determined the strength of the load-bearing structure of a freight car. The fields of dislocation of maximum equivalent stresses were defined taking into consideration operational loads. At the same time, the design of this type of car is specialized and it cannot be used to transport a wide range of cargoes.

The features of optimization and improvement of the load-bearing structures of cars are described in [6]. At the same time, these improvements are focused on extending the service life of the car. The authors also proposed a new system of technical diagnostics of the car.

A set of theoretical studies into the optimization of the load-bearing structure of the freight car was carried out in work [7]. The calculation was carried out using a finite element method. The «BOXN25» railroad gondola was used as a prototype car. However, those measures do not provide for the possibility of transporting cargoes that need protection from precipitation.

A study into the strength of the removable roof of a railroad gondola is reported in [8]. The main modes of roof loading in operation were taken into consideration. The authors proposed measures to improve the roof structure. However, they did not optimize the structural components of the frame to reduce its mass.

In [9], the car load-bearing structure was improved to increase the efficiency of operation in international traffic [9]. The authors report the results from modeling the dynamic load and strength of the car bearing structure, which confirm the feasibility of the proposed technical solutions. At the same time, they did not pay attention to the issues of expanding the functionality of the car to adapt it for the transportation of cargoes that need protection from the environment.

In [10], the authors substantiated the improvement of the supporting structure of the car in order to reduce the load during operation. They provided the mathematical models that make it possible to determine the dynamic load on the car bearing structure under the most adverse operating modes. However, the proposed improvement measures do not allow this type of car to be used to transport cargoes requiring protection from precipitation.

Our review of the scientific literature leads to a conclusion about the expediency of a study into expanding the functionality of the use of gondola cars. That could contribute to the adaptation of their load-bearing structures to the transportation of a wider range of cargoes. In addition, such a study would make it possible to devise recommendations for improving the efficiency of railroad transport utilization.

3. The aim and objectives of the study

The aim of this study is to determine the features of improvement and optimization of the removable roof of railroad gondolas in order to improve the efficiency of their operation.

To accomplish the aim, the following tasks have been set:

– to determine the strength reserves of the removable roof of a typical structure;

– to calculate the strength of the improved structure of the removable roof;

– to determine the strength of the bolt connection between the roof and the upper tying of a railroad gondola body;

– to determine the dynamic load of the load-bearing structure of a railroad gondola with a removable roof.

4. Materials and methods to study the strength and dynamic load of the load-bearing structure of a railroad gondola with a removable roof

To optimize the load-bearing structure of the removable roof of a railroad gondola, we used the method of optimization in terms of its strength reserves. In order to determine the strength reserves of the removable roof of a typical structure, its spatial model was built. That employed the SolidWorks Simulation software package (France). The strength calculation was performed using a finite element method.

When constructing a finite-element model of the removable roof, isoparametric tetrahedra were taken into consideration. The optimal number of the model elements was determined by the graphic-analytical method. The number of nodes in the model was 41,839, of elements – 126,643. The maximum size of the element was 100 mm, and the minimum – 20 mm. The percentage of the elements with an aspect ratio of less than three was 0.122, larger than ten – 63.3. The minimum number of elements in the circle was 22, the ratio of increase in the size of elements – 1.8. The model was fixed along the perimeter of the roof in the area of interaction with the upper tying of the body of a gondola.

Based on the results of our calculations, the optimal profile for the removable roof has been found in terms of the minimum material intensity.

To test the strength of the improved load-bearing structure of the removable roof for a gondola, we performed a calculation. A finite element method was employed, implemented in the SolidWorks Simulation software package.

When constructing a finite-element model, isoparametric tetrahedra were taken into consideration. The optimal number of model elements was determined by the graphic-analytical method. The number of nodes in the model was 42,534, elements –137,547. The maximum size of the element was

100 mm, and the minimum – 20 mm. The percentage of elements with an apex ratio of less than three was 0.138, larger than ten – 65.6. The minimum number of elements in the circle was 22, the ratio of increase in the size of elements – 1.8. The model was fixed along the perimeter of the roof in the area of interaction with the upper tying of the body of a gondola.

To ensure the reliability of the interaction between the removable roof and the upper tying of the body of a gondola, we calculated a bolt connection. The calculation of the bolt connection was carried out according to the classical method of resistance of materials.

To determine the basic indicators of the dynamics of the supporting body structure of a gondola, equipped with a removable roof, mathematical modeling was carried out. In this case, the differential equations of motion were solved by reducing them to the normal Cauchy form. They then were solved using the Runge-Kutta method. That employed the Mathcad software package. The initial movements and speeds were set to zero.

5. The results of studying the strength and dynamic load of the bearing structure of a railroad gondola with a removable roof

5. 1. Determining the strength reserves of the removable roof of typical structure

The spatial model of the removable roof of a gondola is shown in Fig. 1.

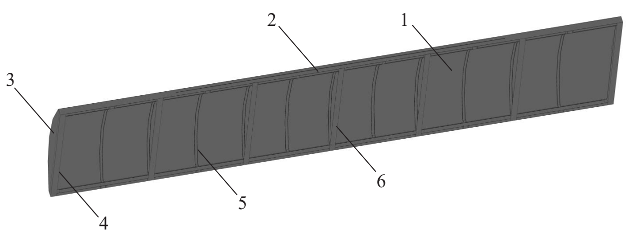

Fig. 1. Spatial model of the removable roof: 1 – cladding; 2 – side longitudinal beam; 3 – end sheet of cladding; 4 – end transverse beam; 5 – transverse arc; 6 – intermediate transverse beam

According to regulatory documents, the roof is calculated for strength under the action of two forces, 1 kN each, distributed over the site of 0.25×0.25 m, and added at a distance of 0.5 m from each other in any part of the roof. The roof is additionally calculated under estimation mode III (as the most dangerous) and when a crane lifts it e [11, 12].

When calculating under estimation mode III, the following combination of loads acting on the roof is accepted:

– the strength of roof weight;

– the vertical dynamic force, which is determined by multiplying the strength of the roof weight by the coefficient of the vertical dynamics.

It is also necessary to take into consideration the assessment of the strength of the roof under the effect of snow load.

The estimation scheme of the roof under the action of two forces, 1 kN each, distributed over the site of 0.25×0.25 m, and added at a distance of 0.5 m from each other, is shown in Fig. 2. The results from calculating the roof are shown in Fig. 3.

The maximum equivalent stresses occur in the middle roof arc and are about 80 MPa, that is, they do not exceed permissible ones [11, 12]. Maximum displacements in the structural nodes occur in the middle part of the roof – 1.3 mm. Consequently, the load-bearing structural elements have a significant reserve of strength.

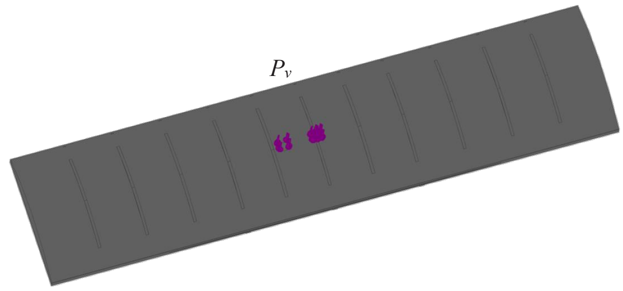

Fig. 2. Estimation scheme of the removable roof

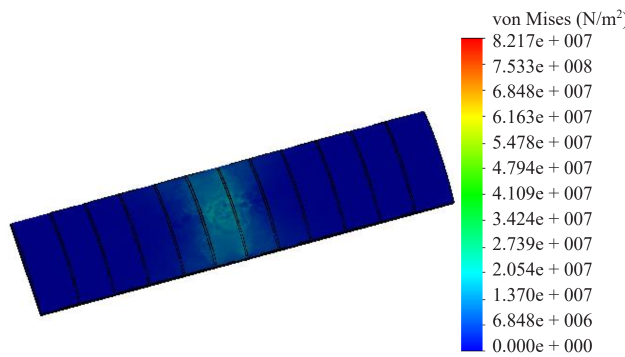

Fig. 3. The stressed state of the removable roof

To reduce the mass of the removable roof of a gondola, its optimization was carried out according to the reserve of strength of the load-bearing elements [13–15]. The calculation results are given in Table 1.

The objective function is:

$$B_r \rightarrow \min, \tag{1}$$

where m_r is the roof weight, kg.

Optimization model limitations are:

1. Geometric dimensions of a railroad gondola.

2. Estimated stresses should be less than permissible ones [11, 12]:

$$\sigma_{eq} < [\sigma], \tag{2}$$

where σ_{eq} is the equivalent stresses in a structure, MPa; $[\sigma]$ is the permissible strains, MPa.

A promising direction for achieving the set goal is the introduction of pipes as load-bearing elements of the roof [16–18], which ensure a decrease in the overall metal intensity of the structure while meeting the conditions of strength (Fig. 4).

Based on our calculations, a spatial model of the removable roof for a gondola was built (Fig. 5).

Taking into consideration the proposed measures, it becomes possible to reduce the mass of the frame of the removable roof for a gondola by almost 15 % compared to the typical structure. The arrangement of the removable roof on the body of a gondola is shown in Fig. 6.

At the same time, in order to use the roof on different types of gondolas, its cantilever parts can move in a longitudinal plane (Fig. 7).

Table 1

Determining the optimal parameters for the cross-sections of elements of the removable roof

Roof frame element	n	σ_{eq}, MPa	I_x, cm^4	I_y, cm^4	W_x, cm^3	W_y, cm^3	$[W_x]$, cm^3	$[W_y]$, cm^3	Pipe optimal parameter			1 m pipe weight, kg
									W, cm^3	h, mm	S, mm	
Arc	2.6	92.6	10.2	10.2	5.1	5.1	1.96	1.96	2.18	30	2.5	2.07
Side longitudinal beam	3.1	78.3	97.26	621.29	12.16	155.32	3.93	50.1	4.17	35	4.0	3.67
End transverse beam	3.2	75.4	97.26	621.29	12.16	155.32	3.93	50.1	4.17	35	4.0	3.67
Intermediate transverse beam	2.8	87.3	10.2	10.2	5.1	5.1	1.96	1.96	2.18	30	2.5	2.07

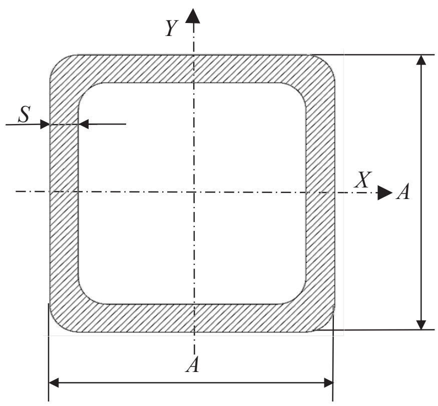

Fig. 4. Square pipe cross-section

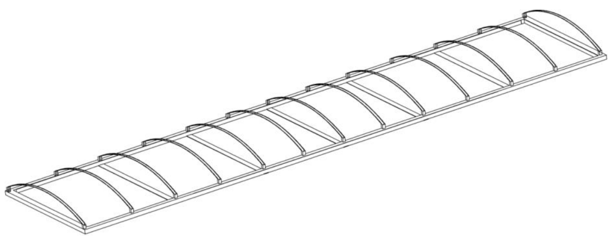

Fig. 5. Frame of the optimized structure of the removable roof

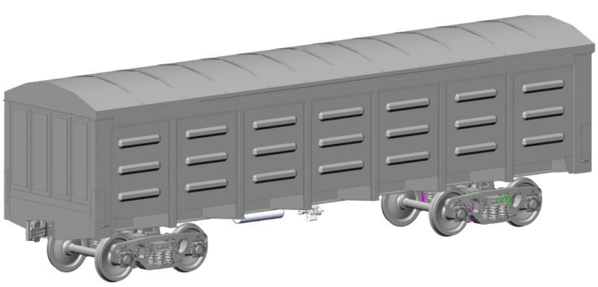

Fig. 6. Railroad gondola with a removable roof

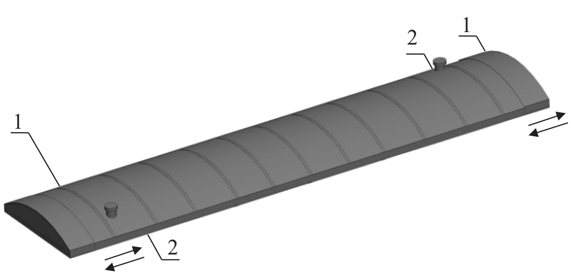

Fig. 7. Gondola removable roof with improved structure: 1 – moving parts of the roof; 2 – deflectors

In this case, deflectors are arranged on stationary parts of the roof. The roof is attached to the body in a regular way. It is possible to fix it with the help of shog-connections.

5. 2. Calculating the strength of the improved structure of the removable roof

The results of our calculation of the removable roof strength are shown in Fig. 8, 9. In this case, the maximum equivalent stresses occur in the middle part of the roof and are about 230 MPa, that is, they do not exceed permissible ones [11, 12]. The maximum displacements in the structural nodes occur in the middle part of the roof – 1.8 mm. The maximum deformations were $9.31 \cdot 10^{-6}$.

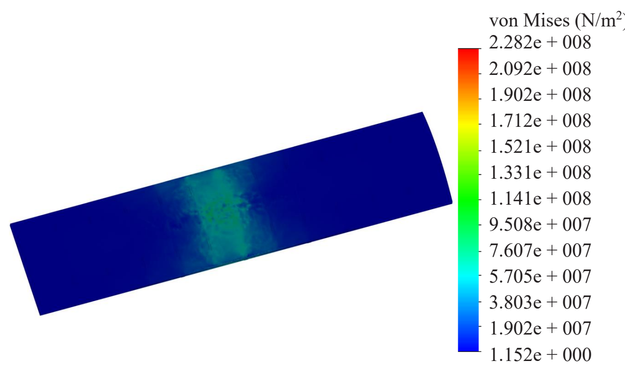

Fig. 8. The stressed state of the removable roof

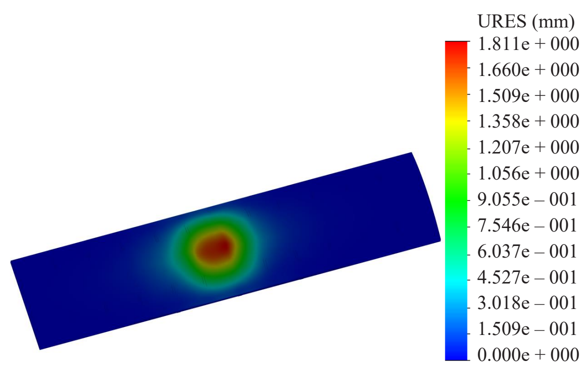

Fig. 9. Displacements in the nodes of the removable roof

The maximum equivalent stresses of the removable roof under estimation mode III arise in its middle part. The numerical values of stresses were about 230 MPa, that is, they do not exceed permissible ones [11, 12]. The maximum movements in the structural nodes occur in the middle part of the roof – 1.8 mm.

The maximum equivalent stresses when lifting a removable roof with slings occur in the roof fastening zones and are about 120 MPa, that is, they do not exceed permissible ones [11, 12]. The maximum movements in the structure's nodes occur in the areas of fixing the roof – 1.65 mm.

In addition, the removable roof of a gondola is designed for the effect of snow load. The maximum equivalent stresses occur in the middle part of the roof and are about 104.1 MPa, that is, they do not exceed permissible ones [11, 12]. The maximum movements in the structural nodes occur in the middle part of the roof – 1.31 mm.

Our calculations allow us to conclude that the proposed measures are justified and appropriate.

5. 3. Determining the strength of the bolt connection of the roof with the upper tying of a gondola body

To ensure the reliability of the roof mounting to the body of a gondola, the bolt connection was calculated. The roof is attached to the upper tying of the longitudinal walls by bolts M12x90.

The roof is attached to the end wall with bolts M12x65. After tightening the bolt joint, the nut is welded to prevent self-unscrewing.

In this case, an event was taken into consideration where the roof is loaded by the longitudinal force that occurs when the car is hit, as a case of the greatest load of its structure during operation. The bolt connection would be exposed to the longitudinal force Q, due to the longitudinal force of inertia of the car body when hit, and the vertical effort N, due to the natural roof weight (Fig. 10).

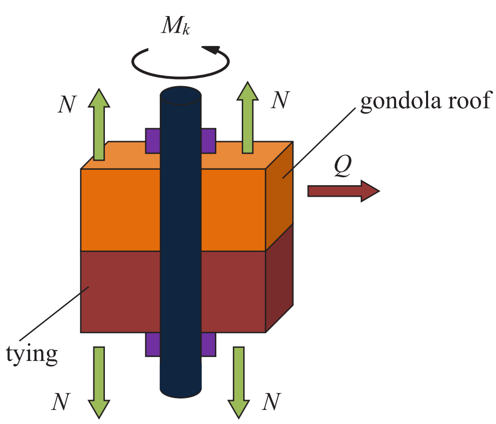

Fig. 10. Estimation scheme of the bolt fastening of the roof to the upper tying of the body of a gondola

Since the bolts are welded after screwing, then when the longitudinal force is in effect, in addition to the above forces, forces arising from the torsion deformation would affect them.

Then, the condition of strength takes the following form [19]:

$$N_{red} = \sqrt{\left(N_N + N_{M,\max}\right)^2 + N_Q^2} \le N_{b,\min}, \qquad (3)$$

where N_N is the longitudinal force acting on the bolt connection; $N_{M,\max}$ is the highest possible load in the bolt connection; N_Q is the transverse force acting on the bolt connection; $N_{b,\min}$ is the bearing capacity of the bolt.

When the cutting force Q is in effect, it is simplified to believe that the efforts in the bolts are distributed evenly. Thus, the effort acting on one bolt is determined as:

$$N_Q = \frac{Q}{n}, \qquad (4)$$

where n is the number of bolts in a connection.

The force N_N is calculated similarly to N_Q.

$$N_N = \frac{N}{n}. \qquad (5)$$

The maximum load $N_{M,\max}$ due to the effect of the moment M on the bolt connection is determined as:

$$N_{M,\max} = \frac{M \cdot l_{\max}}{m \sum_{i=1}^{k} l_i^2}, \qquad (6)$$

where l_i is the distance between the pairs of bolts placed symmetrically relative to the center of gravity of the connection; $l_{\max}$ is the maximum distance between bolt pairs; m is the number of bolt pairs.

We accept that the maximum longitudinal force of inertia is 4.0 g. The vertical load N_N is equal to 210.21 N. It is taken into consideration that the roof weight is 1.2 tons. The roof is attached to the upper tying of a gondola by 56 bolts with a diameter of 12 mm. The transverse load N_Q, perceived by the bolts interacting at the end of the roof with the upper tying (the most loaded during roof bolts at shunting), would equal 8,857.14 N.

Taking into consideration the fact that the distance between the roof bolts is 0.375 m, then $N_{M,\max}$=3,489.8 N. Hence, taking into consideration the area of the cross-section of the bolt (S=113.04 mm^2), we have N_{red}=138.75 N/mm^2, at $N_{b,\min}$=122 N/mm^2. That is, the condition of strength is not met. Therefore, the use of standard bolts used to attach the roof to the body is impractical.

To ensure the reliability of fastening the roof to the upper tying of the body of a gondola, it is proposed to use bolts that have a higher bearing capacity, namely, M12x95, thread step – 1.75, strength class – 5.8.

5. 4. Determining the dynamic load on the bearing structure of a railroad gondola with a removable roof

To determine the accelerations that affect the body of a gondola, we have applied a mathematical from [20]. However, it was refined. The model takes into consideration the movement of the load-bearing body structure, and not the car in general. The estimation scheme is shown in Fig. 11.

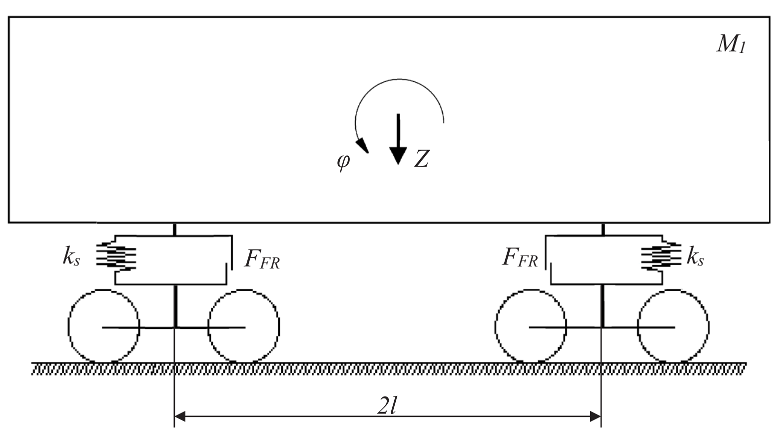

Fig. 11. Estimation scheme of a gondola

The mathematical model is below. The study was carried out in a flat coordinate system. The oscillations in bouncing and galloping were taken into consideration as the most common types of car oscillations during operation.

$$\begin{cases} M_1 \cdot \dfrac{d^2}{dt^2} q_1 + C_{1,1} \cdot q_1 = \\ = -F_{FR} \cdot \left(\operatorname{sign}\left(\dfrac{d}{dt} \delta_1 \right) + \operatorname{sign}\left(\dfrac{d}{dt} \delta_2 \right) \right), \\ M_2 \cdot \dfrac{d^2}{dt^2} q_2 + C_{2,2} \cdot q_2 = \\ = F_{FR} \cdot l \cdot \left(\operatorname{sign}\left(\dfrac{d}{dt} \delta_1 \right) - \operatorname{sign}\left(\dfrac{d}{dt} \delta_2 \right) \right), \end{cases} \tag{7}$$

where M_1, M_2 are, respectively, the mass and moment of inertia of the body relative to the vertical axis; q_{1-2} are the generalized coordinates corresponding to the translational and angular displacements relative to the vertical axis; $C_{1.1-2.2}$ are the nonzero elements of the matrix of elastic coefficients; k_s is the rigidity of spring suspension; F_{FR} is a dry friction force that acts in the suspension of the bogie; l is the half of the base of the car; $\delta_{1,2}$ is the deformations of the elastic elements of spring suspension.

The matrix of elastic coefficients takes the form:

$$C = \begin{vmatrix} 2 \cdot k_S & 0 \\ 0 & 2 \cdot l^2 \cdot k_S \end{vmatrix}. \tag{8}$$

The deformations of elastic elements in a spring suspension (from the position of equilibrium) were determined from the following expressions:

$$\delta_1 = z - l\varphi; \;\; \delta_2 = z + l\varphi. \tag{9}$$

The force of dry friction acting in the suspension of the bogie is determined as:

$$F_{FR} = P \cdot \varphi_{FR}, \tag{10}$$

where P_B is the load force of the bogie by the body of a car; φ_{FR} is the coefficient of relative friction of spring suspension.

When solving the mathematical model, the mass of the load-bearing body structure was taken into consideration accounting for the removable roof. The system of differential equations (7) was solved using the Mathcad software package [21–23] in the form:

$$Q(t,y) = \begin{vmatrix} C_3 \\ C_4 \\ \dfrac{-F_{FR} \cdot \left(\operatorname{sign}\left(\dfrac{d}{dt} \delta_1 \right) + \operatorname{sign}\left(\dfrac{d}{dt} \delta_2 \right) \right) - C_{1,1} \cdot y_1}{M_1} \\ \dfrac{F_{FR} \cdot l \cdot \left(\operatorname{sign}\left(\dfrac{d}{dt} \delta_1 \right) - \operatorname{sign}\left(\dfrac{d}{dt} \delta_2 \right) \right) - C_{2,2} \cdot y_2}{M_2} \end{vmatrix}, \tag{11}$$

$$Z = rkfixed\left(Y0, tn, tk, n', Q\right).$$

In this case, $y_1 = q_1$, $y_2 = q_2$, $y_3 = \dot{q}_1$, $y_4 = \dot{q}_2$.

The initial movements and speeds were set to zero [24–26]:

$$Y0 = \begin{vmatrix} 0 \\ 0 \\ 0 \\ 0 \end{vmatrix}. \tag{12}$$

The results of the calculation of the mathematical model are shown in Fig. 12.

The acceleration of the body in the center of masses in terms of g is equal to 0.4 and is within the permissible limits, according to [11, 12]. The assessment of the car ride is excellent.

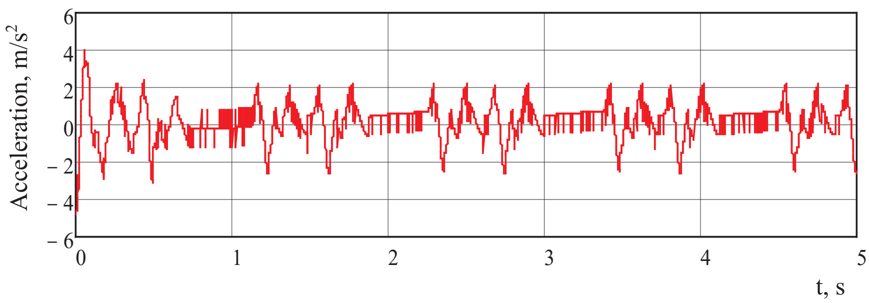

Fig. 12. Acceleration of the body of a gondola in the center of masses

6. Discussion of results of improving the removable roof for a railroad gondola

To improve the efficiency of using railroad gondolas, it is proposed to apply a removable roof. This solution contributes to the possibility of transportation of cargoes that need protection from precipitation.

We have determined the strength reserves of a typical roof of a car. It was established that under the main operating modes of the load there is a significant unused margin of safety in the bearing elements of the frame (Fig. 3). Given this, it has been proposed to optimize the roof of a car according to the criterion of minimum material intensity. Our calculations have made it possible to choose a more optimal profile of the roof components from the point of view of minimal material intensity.

Taking into consideration the proposed measures, it becomes possible to reduce the mass of the frame of the removable roof by almost 15 % compared to the typical design (Fig. 5). At the same time, in order to use the roof on different types of railroad gondolas, its cantilever parts can move in a longitudinal plane (Fig. 7). The results of our strength calculation have confirmed the feasibility of the solutions adopted during the design. The strength of the bolt connection of the roof with the upper tying of a railroad gondola body has been determined.

To determine the dynamic load of a railroad gondola with a removable roof, a calculation was performed. The limitation of the estimation model is that it takes into consideration the movement of the supporting structure in the vertical plane. Our study has shown that the acceleration of the body in the center of masses is 0.4 g and is within the permissible limits. At the same time, the assessment of car ride is excellent (Fig. 11).

In the further research into this area, it is important to experimentally determine the load on a removable roof. This could be done using a similarity method involving electrical tensometry.

Our study would contribute to the improvement of the efficiency of railroad transport.

7. Conclusions

1. The reserves of strength of the roof of a typical structure have been determined. It was established that under the most unfavorable roof load scheme, the maximum equivalent stresses occur in the middle arc and are about 80 MPa. Therefore, there is a significant unused margin of safety in the load-bearing elements of the frame. Given this, the frame of the removable roof was optimized according to the criterion of the minimum material intensity. The introduction of pipes as load-bearing elements of the roof has been proposed, which reduce the overall metal intensity of the structure while the conditions of strength are met. Taking into consideration the proposed measures, it becomes possible to reduce the mass of the frame of the removable roof of a gondola by almost 15 % compared to the typical design.

2. The strength of the improved structure of the removable roof has been calculated. The calculation was performed by a finite element method. The maximum equivalent stresses occur in the middle part of the roof and are about 230 MPa, that is, they do not exceed permissible ones. The maximum movements in the structural nodes occur in the middle part of the roof – 1.8 mm. Therefore, the strength of the load-bearing structure of the removable roof is ensured.

3. The strength of the bolt connection between the roof and the upper tying of a gondola body has been determined. It was established that taking into consideration the use of typical bolts for fixing the roof to the body, the strength of the connection is not ensured.

To ensure the reliability of fastening the roof to the upper tying of the body of a gondola, it is proposed to use bolts that have a higher bearing capacity, namely, M12x95, thread step – 1.75, strength class – 5.8.

4. The dynamic load on the bearing structure of a gondola with a removable roof has been determined. The study was carried out in a vertical plane. The oscillations related to the car bouncing and galloping were taken into consideration.

The acceleration of the body in the center of masses is 0.4 in terms of *g*; it is within the permissible limits. The assessment of car ride is excellent.

Acknowledgments

This paper was prepared within the framework of the project «Development of conceptual frameworks for restoring the efficient operation of obsolete freight cars». Project registration No: 2020.02/0122, financed by the National Research Foundation of Ukraine from the state budget.

References

1. Vagony s raskryvayuscheysya kryshey. Available at: http://scaletrainsclub.com/board/viewtopic.php?t=1916
2. Reidemeister, A., Muradian, L., Shaposhnyk, V., Shykunov, O., Kyryl'chuk, O., Kalashnyk, V. (2020). Improvement of the open wagon for cargoes which imply loading with a «hat.» IOP Conference Series: Materials Science and Engineering, 985, 012034. doi: https://doi.org/10.1088/1757-899x/985/1/012034
3. Antipin, D. Y., Racin, D. Y., Shorokhov, S. G. (2016). Justification of a Rational Design of the Pivot Center of the Open-top Wagon Frame by means of Computer Simulation. Procedia Engineering, 150, 150–154. doi: https://doi.org/10.1016/j.proeng.2016.06.738
4. Šťastniak, P., Moravčík, M., Smetanka, L. (2019). Investigation of strength conditions of the new wagon prototype type Zans. MATEC Web of Conferences, 254, 02037. doi: https://doi.org/10.1051/matecconf/201925402037
5. Slavchev, S., Stoilov, V., Purgic, S. (2015). Static strength analysis of the body of a wagon, series Zans. Journal of the Balkan Tribological Association, 21 (1), 49–57. Available at: https://www.semanticscholar.org/paper/STATIC-STRENGTH-ANALYSIS-OF-THE-BODY-OF-A-WAGON%2C-Stoilov-Purgi%C4%87/633c5cf68afdd73c979ef9a2c4f505deb600988c
6. Płaczek, M., Wróbel, A., Buchacz, A. (2016). A concept of technology for freight wagons modernization. IOP Conference Series: Materials Science and Engineering, 161, 012107. doi: https://doi.org/10.1088/1757-899x/161/1/012107
7. Harak, S. S., Sharma, S. C., Harsha, S. P. (2014). Structural Dynamic Analysis of Freight Railway Wagon Using Finite Element Method. Procedia Materials Science, 6, 1891–1898. doi: https://doi.org/10.1016/j.mspro.2014.07.221
8. Kiril'chuk, O. A., Shatunova, D. A. (2016). Issledovanie prochnosti konstruktsii semnoy kryshi dlya poluvagonov. Vagonnyy park, 5-6 (110-111), 50–53. Available at: http://eadnurt.diit.edu.ua/jspui/handle/123456789/9413
9. Fomin, O., Lovska, A. (2020). Improvements in passenger car body for higher stability of train ferry. Engineering Science and Technology, an International Journal, 23 (6), 1455–1465. doi: https://doi.org/10.1016/j.jestch.2020.08.010
10. Fomin, O. V., Lovska, A. O., Plakhtii, O. A., Nerubatskyi, V. P. (2017). The influence of implementation of circular pipes in load-bearing structures of bodies of freight cars on their physico-mechanical properties. Scientific Bulletin of National Mining University, 6, 89–96. Available at: http://www.irbis-nbuv.gov.ua/cgi-bin/irbis_nbuv/cgiirbis_64.exe?I21DBN=LINK&P21DBN=UJRN&Z21ID=&S21REF=10&S21CNR=20&S21STN=1&S21FMT=ASP_meta&C21COM=S&2_S21P03=FILA=&2_S21STR=Nvngu_2017_6_15
11. DSTU 7598:2014. Freight Wagons. General reguirements to calculation and designing of the new and modernized 1520 mm gauge wagons (non-self-propelled) (2015). Kyiv.
12. GOST 33211-2014. Freight wagons. Requirements to structural strength and dynamic qualities (2016). Moscow.
13. Fomin, O., Lovska, A., Masliyev, V., Tsymbaliuk, A., Burlutski, O. (2019). Determining strength indicators for the bearing structure of a covered wagon's body made from round pipes when transported by a railroad ferry. Eastern-European Journal of Enterprise Technologies, 1 (7 (97)), 33–40. doi: http://doi.org/10.15587/1729-4061.2019.154282

14. Lovska, A. A. (2015). Peculiarities of computer modeling of strength of body bearing construction of gondola car during transportation by ferry-bridge. Metallurgical and Mining Industry, 1, 49–54. Available at: https://www.semanticscholar.org/paper/Peculiarities-of-computer-modeling-of-strength-of-Lovska/b86e05254031bcd026118d57f8504a58686d9905
15. Bychkov, A. S., Kondratiev, A. V. (2019). Criterion-Based Assessment of Performance Improvement for Aircraft Structural Parts with Thermal Spray Coatings. Journal of Superhard Materials, 41 (1), 53–59. doi: https://doi.org/10.3103/s1063457619010088
16. Kondratiev, A., Gaidachuk, V., Nabokina, T., Tsaritsynskyi, A. (2020). New Possibilities of Creating the Efficient Dimensionally Stable Composite Honeycomb Structures for Space Applications. Advances in Intelligent Systems and Computing, 45–59. doi: https://doi.org/10.1007/978-3-030-37618-5_5
17. Vatulia, G. L., Lobiak, O. V., Deryzemlia, S. V., Verevicheva, M. A., Orel, Y. F. (2019). Rationalization of cross-sections of the composite reinforced concrete span structure of bridges with a monolithic reinforced concrete roadway slab. IOP Conference Series: Materials Science and Engineering, 664, 012014. doi: https://doi.org/10.1088/1757-899x/664/1/012014
18. Vatulia, G., Komagorova, S., Pavliuchenkov, M. (2018). Optimization of the truss beam. Verification of the calculation results. MATEC Web of Conferences, 230, 02037. doi: https://doi.org/10.1051/matecconf/201823002037
19. Semenov, V. S., Karimova, R. H. (2008). Raschet i konstruirovanie soedineniy stal'nyh stroitel'nyh konstruktsiy. Bishkek: KRSU, 80.
20. Domin, Yu. V., Cherniak, H. Yu. (2003). Osnovy dynamiky vahoniv. Kyiv: KUETT, 269.
21. Goolak, S., Gerlici, J., Tkachenko, V., Sapronova, S., Lack, T., Kravchenko, K. (2019). Determination of Parameters of Asynchronous Electric Machines with Asymmetrical Windings of Electric Locomotives. Communications - Scientific Letters of the University of Zilina, 21 (2), 24–31. doi: https://doi.org/10.26552/com.c.2019.2.24-31
22. Goolak, S., Gubarevych, O., Yermolenko, E., Slobodyanyuk, M., Gorobchenko, O. (2020). Mathematical modeling of an induction motor for vehicles. Eastern-European Journal of Enterprise Technologies, 2 (2 (104)), 25–34. doi: https://doi.org/10.15587/1729-4061.2020.199559
23. Kliuiev, S. (2018). Experimental study of the method of locomotive wheelrail angle of attack control using acoustic emission. Eastern-European Journal of Enterprise Technologies, 2 (9 (92)), 69–75. doi: https://doi.org/10.15587/1729-4061.2018.122131
24. Klimenko, I., Kalivoda, J., Neduzha, L. (2020). Influence of Parameters of Electric Locomotive on its Critical Speed. Lecture Notes in Intelligent Transportation and Infrastructure, 531–540. doi: https://doi.org/10.1007/978-3-030-38666-5_56
25. Fomin, O., Lovska, A., Píštěk, V., Kučera, P. (2019). Dynamic load effect on the transportation safety of tank containers as part of combined trains on railway ferries. Vibroengineering PROCEDIA, 29, 124–129. doi: https://doi.org/10.21595/vp.2019.21138
26. Vatulia, G., Lobiak, A., Chernogil, V., Novikova, M. (2019). Simulation of Performance of CFST Elements Containing Differentiated Profile Tubes Filled with Reinforced Concrete. Materials Science Forum, 968, 281–287. doi: https://doi.org/10.4028/www.scientific.net/msf.968.281