



STUDY OF THE STRENGTH OF AN OPEN WAGON STRUCTURE FOR LONG CARGO TRANSPORTATION

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Abstract

The article highlights the features of a modernized open wagon design, which is intended for long cargo transportation. There is presented a method of strength analysis of its supporting structure when it is subjected to the longitudinal loads. Mathematical modelling was performed to determine the numerical values of the longitudinal loads acting on the open wagon structure while running as a component of a trainset. The strength of a supporting structure of the open wagon was determined using the finite element method. The von Mises criterion was chosen as a calculation criterion. It was established that the strength of the supporting structure of the analyzed open wagon is maintained. In this case, the maximum stresses were recorded in the places of interaction of the backbone beam with the center pivots. The resulting stresses are lower by 15% than the permissible stresses. This proves the rationality of the designed structural solutions of the proposed open wagon. The maximum displacements occur in the middle part of the body, which is explained by the scheme of its fastening and loading. The solved open wagon can also be used for the transportation of other types of cargo, for example, packaged goods or containers. In this case, the supporting structure of the open wagon should be supplemented with appropriate fastening elements. The results presented in this research will be useful recommendations for creating new open wagon designs or modernizing existing ones.

Keywords: railway transport, open wagon, modernization, dynamic loads, long cargo transportation

1 Introduction

Ensuring the efficient functioning of the national economy requires reliable and stable functioning of the railway industry [1]. One of the most common cargoes transported by railways is long cargo. Flat wagons are usually used for long cargo transportation [2]. The shortage of flat wagons led to use of open wagons for transportation of such cargo (figure 1). Loading long cargo to open wagons requires using additional components, which are wooden posts. They are fixed to the side wall at height (figure 2) [3]. The wooden posts interact with each other using horizontal boards that are nailed to them (figure 3).

When preparatory operations are completed, the body is loaded with long cargo. Grabs or other lifting and transport equipment are used. When transporting long cargo in an open wagon, its end wall does not perceive longitudinal loads. After all, the friction forces between the floor and the long cargo, as well as between individual logs of the long cargo, are greater than the inertia forces acting on the body. Therefore, the end wall creates an additional sprung mass of the wagon body, which is about 500 kg, i.e. 1 t per one open wagon.



Figure 1 An open wagon loaded with long cargo (timber)



Figure 2 Attaching a wooden post to the side wall of the body: a) attaching the post to the upper body strapping, b) attaching the post to the lower part of the side wall



Figure 3 A placement of wooden posts in an open wagon body: a) an inside view, b) a side view

Therefore, it is advisable to modernize the design of an open wagon for its more effective involvement in the transportation of long cargo. An analysis of literary sources about the study topic proved that the issue of long cargo transportation by railways is relevant. For example, the research [4] highlights the study of the loading the flat wagon structure designed for long cargo transportation. The conducted research allowed to formulate recommendations on adjusting theoretical models for determining the loading of a flat wagon. However, the authors did not consider the possibility of involving open wagons for long cargo transportation. The authors of study presented in [5] proposed measures to modernize flat wagons for the possibility of long cargo transportation. Vertical racks were installed on the wagon for this purpose. The calculation results proved the effectiveness of such modernization. However, the authors did not consider the issue of modernizing open wagons for the transportation of long cargo. The research [6] proposed a solution for situational adaptation of open wagons containers transportation. It consists in placing fitting stops on the floor of an open wagon. The theoretical justification for such modernization is given. However, the issues of situational adaptation of open wagons for long cargo transportation were not studied. A new design of an open wagon was proposed in [7]. Its peculiarity consists in, that its wall cladding is formed by sandwich panels. This allowed to improve the strength of the open wagon body under the operational loads. If necessary, the sandwich panels can be dismantled and replaced with new ones. A similar solution is also highlighted in the study [8]. However, it was considered with the aim of improving the technical maintenance and repair of the wagon. At the same time, the authors of these works did not study the possibility of long cargo transportation in open wagons.

The introduction of new materials into the design of an open wagon body to improve its strength was considered in the research [9]. It was conducted on an example of the side walls of the body. The results of this implementation confirmed its feasibility. However, the authors did not consider the load of side walls by long cargo. The same drawback is also found in work [10], which highlights a new design of an open wagon with improved characteristics. The wagon has a lower center of gravity, which contributes to better stability. This would also contribute to improving the safety of long cargo transportation. The analysis of literary sources shows that the issue of long cargo transportation in open wagons has not been given due attention. Therefore, the goal of the presented research is set to determine the strength of an open wagon when transporting long cargo. The implementation of this goal was carried out by solving the following tasks:

- to propose modernization of an open wagon long cargo transportation
- to analyze the strength of the open wagon body structure.

2 Materials and methods of research

The main hypothesis of this study is that the modernization of a universal open wagon body will increase the efficiency of long cargo transportation by railways. Therefore, a modernization of a universal open wagon design is proposed to enable its for long cargo transportation. This modernization consists of dismantling the end doors (walls) and installing transverse belts that connect the corner posts to each other. The body is equipped with binding rings into which vertical posts are installed to secure the cargo from the inside. When loading the wagon with long cargo, it is secured with cables. If necessary, the open wagon can also be used for the transportation of other types of cargo, e.g. unit loads or containers. In this case, the supporting structure of the open wagon must be supplemented with appropriate fastening elements. Appropriate calculations were performed to substantiate such a modernization. The open wagon model 12-757 was chosen as a prototype. The proposed modernization of this open wagon is depicted in figure 4a.

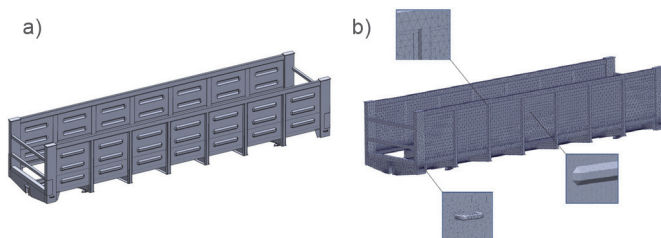


Figure 4 a) A spatial model of the modernized open wagon body, b) a finite element model of the modernized open wagon body

Strength analyses were performed using the finite element method in the SolidWorks simulation software. The Mises criterion was used [11, 12]. This choice is justified by the fact that the structural material is low-alloy steel 09G2S, which has linear isotropic properties [13, 14]. The finite element model of the modernized open wagon structure is formed by tetrahedra [15-18] and it has 576, 637 elements with number of nodes of 1, 123, 955 nodes (figure 4b). The maximum element size was 80 mm and the minimum was 16 mm. These model parameters were determined by graph-analytical calculations with sensitivity testing [19]. In the further development of this work, it is planned to conduct experimental studies, which results will allow to additionally check the quality of the finite element model creation and, if necessary, to make its corrections.

At the next stage of the study, a calculation model of the supporting structure of the open wagon was formed. The wagon is loaded during its operation due to several factors, such as track irregularities, loading and unloading and others [20, 21]. The following loads were considered (figure 5): vertical P_v , which was calculated considering the full use of the open wagon's carrying capacity; the load transmitted to the open wagon's uprights P_{st} ; the longitudinal force P_{pr} , equals to the value of 1.0 MN and it was applied to the automatic coupler along the running direction; the force P_p as reaction to the force P_{pr} and it was applied to the rear stop located on the opposite side of the supporting structure along the running direction. The load transferred to the racks of the P_{st} open wagon was calculated according to the "Local technical conditions for the placement and fastening of round lumber 3.0, 4.0, 6.0 on a specialized platform of model 13-9997":

$$P_{st} = \frac{\Delta F_n}{L_{st}} \quad (1)$$

ΔF_n [kN]– the transverse inertia force from the load; L_{st} [m]– a height of the rack;

The transverse inertia force from the load can be calculated as follows:

$$\Delta F_n = n \cdot (F_n + W) - F_{pr}^n \quad (2)$$

n – a coefficient set at the design stage of the wagon; F_n – the inertial load from the cargo and centrifugal force; W - the wind load; F_{pr}^n – the friction force in the lateral direction. The permissible stresses of the steel grade for the mode of the wagon movement in the train (the 3rd design mode) are taken equal to 210 MPa [22]. An analogue of this standard is the European standard [23]. Rigid connections were installed on a bogie thrust bearings, which simulated the support of the body on a bogie [24, 25].

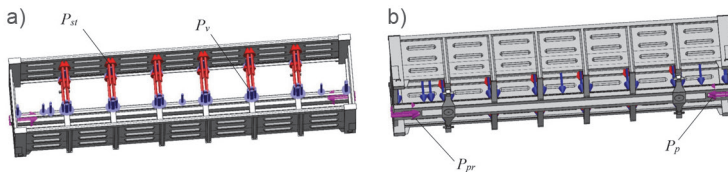


Figure 5 A diagram of forces acting on the open wagon structure: a) the vertical and lateral forces, b) the longitudinal forces

3 Results and discussion

The calculations showed that the backbone beams are the most loaded areas of the body structure (figure 6). The dislocation of stresses is observed in the areas of their interaction with the pivot beams, which is explained by the body fastening scheme.

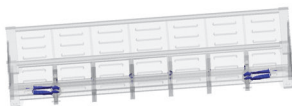


Figure 6 Areas with concentration of the greatest stresses

The greatest stresses in the structure of the modernized open wagon were 174.2 MPa (figure 7). These stresses were about 135 MPa in the upper part of the interaction zones of the backbone and pivot beams, as it is depicted in figure 7a. The largest deflections of the structure of the modernized open wagon under the defined loads were indicated in the upper strapping of the side walls and these values were of 3.6 mm, as it is shown in figure 8. This distribution of deflections is explained by the fact that the side wall of the open wagon structure is subjected to the load distributed along its length, and its fastening is carried out to the lower strapping of the body. The maximal displacements were detected in the middle part of the spine beam of 3.5 mm. The numerical analyses showed that the strength of the modernized open wagon body design is preserved. This allows to conclude that the decisions made during the design of the open wagon body were rational. The advantage of this study compared to works [1-7] is that the proposed solution of increasing the efficiency of long-length cargo transportation by rail does not require significant capital investments. If necessary, the wagon design can be returned to its original one. Additionally, the proposed modernization is also appropriate for the case of container transportation in an open wagon.

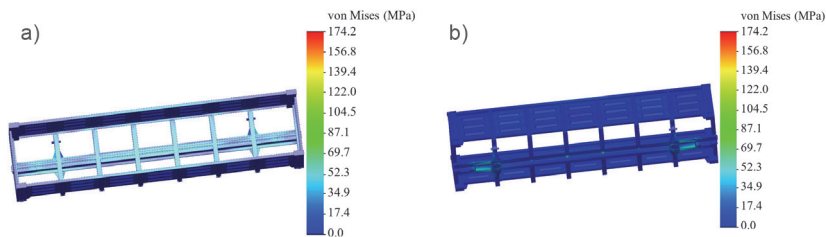


Figure 7 A distribution of stresses in the modernized body structure: a) a view 1, b) a view 2

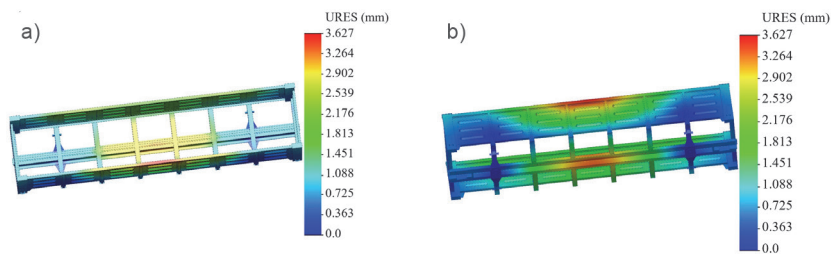


Figure 8 Deflections of the modernized body structure under the defined loads: a) a view 1, b) a view 2

The limits of this study are obvious in building a spatial model of the open wagon. The authors did not consider its possible operational wear. It means that the model was built considering the nominal parameters. A promising direction of this work is the study of loading the open wagon during rail-ferry transportation. After all, during sea transportation, the side walls of the open wagon are subjected to loads that exceed the operational ones. This is planned to be carried out in the subsequent stages of future research in this direction.

4 Conclusion

It was proposed to modernize an open wagon body to enable long cargo transportation. This modernization consists in dismantling the end doors and installing lateral belts that connect the corner posts to each other. This solution helps to reduce the sprung mass of the wagon body by more than 1 t. This allows to increase its load capacity by the same amount. The body is equipped with tie-down rings to secure the cargo from the inside.

They are installed in vertical posts. When loading the body with long cargo, it is secured with cables. Strength analyses of the modernized open wagon body structure were performed. It was established that the greatest stresses in the wagon body structure were 174.2 MPa. They are lower by 17% than the permissible ones. In the upper part of the interaction zones of the backbone and pivot beams, these stresses were about 135 MPa. The largest deflections in the structure were recorded in the upper strapping of the side walls, and they amounted to the value of 3.6 mm. The conducted studies will be useful recommendations when creating new open wagon designs or modernizing existing ones.

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