



A STUDY OF THE STRENGTH OF THE LOAD-BEARING STRUCTURE OF A BOX WAGON WITH CORRUGATED CLADDING SHEETS

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Abstract – The study is based on the assumption that the strength of the load-bearing structure of a box wagon can be improved by using corrugated sheets. It can reduce the tare of the load-bearing structure of the box wagon in comparison with that of the typical design by 2.3%. To substantiate the proposed improvement, the strength of the load-bearing structure of the box wagon is calculated using the finite element method. A spatial model of the load-bearing structure of the box wagon is constructed in SolidWorks. The von Mises criterion is used as the design criterion in the calculations. The results demonstrate that the proposed solution reduces stresses in the cladding by 8.6% compared to the typical design. The conducted studies will help improve the strength of the load-bearing structures of a box wagon and reduce its maintenance cost.

Keywords – box wagon, design improvements, corrugated cladding sheets, structural strength, railway transport.

1. INTRODUCTION

Rail transport is the most important sector of the transport system, which is responsible for transporting passengers and freight, including goods of strategic importance. Railways carry a wide and varied range of goods, among which are those that require protection from the elements, which are transported primarily in box wagons.

The box wagon walls are usually made of stamped metal sheets that may have various types of damage (deformations, cracks, tears, etc.) caused by the operational load conditions. Such damage requires unscheduled repairs to the wagons, and, consequently, incurs maintenance costs. Furthermore, the train that includes a wagon with such damage can pose a threat to the rail operation safety. It is therefore necessary to improve the cladding of a box wagon in order to enhance their operational efficiency.

In order to study the current state of the research into the improvements of load-bearing structures in box wagons, a review of recent scientific publications has been carried out. In [1], it is proposed that the tare weight of a box wagon can be reduced by improving its roof through constructing it as a triangular arch.

This solution reduces the tare weight of the wagon body by 1.8% compared with that of the typical design. The calculations of the dynamic and strength characteristics of the proposed wagon body with the roof confirm the effectiveness of this solution. However, the authors do not consider the issue of improving the cladding of such a wagon.

The design improvements to the body of the BCNHL box wagon are described in [2]. The authors propose changes to the door opening geometry in order to facilitate loading/unloading operations by using mechanised equipment. However, limited attention has been given to enhancing the structural strength of the wagon body cladding during operation.

In [3], the strength of a box wagon's body walls is improved through the use of sandwich panels, comprising two smooth metal sheets with an energy-absorbing material core. The strength calculations demonstrate the feasibility of this solution. However, efficiency can be improved by modifying the configuration of the sheets within the sandwich panel.

A similar shortcoming is also found in [4, 5], where the strength of the cladding of a wagon is improved by using materials with better strength and

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mass characteristics. Although such materials offer several advantages over steel, they require significant capital investment and the availability of the necessary technical infrastructure for wagon repair and maintenance.

The analysis of scientific publications has shown that at present the issue of improving the cladding of box wagons has yet to be addressed, which requires therefore relevant research in this area.

The purpose of the study is to substantiate the use of corrugated sheets for cladding for the box wagon body. To achieve this purpose, the following tasks were set:

- to construct a three-dimensional model of the load-bearing structure of a box wagon with corrugated

cladding sheets, and

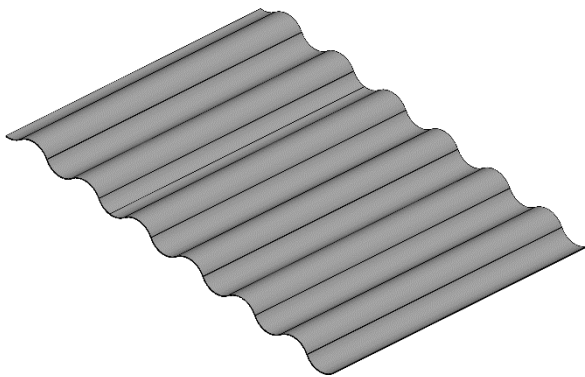
- to calculate the strength of the load-bearing structure of a box wagon.

2. MATERIALS AND METHODS OF RESEARCH

The box wagon is intended for transporting goods that need protection from the elements.

There is a range of specialised wagons on the basis of the general-purpose wagons.

It was proposed to improve the strength of the box wagon by using corrugated sheets as its cladding (Fig. 1).



a)



b)

Fig.1. The damage to the cladding of a box wagon: a) deformation of the third cladding sheet from the corner post; b) deformation of the outermost cladding sheet from the corner post

A corrugated sheet has a number of advantages over a smooth sheet. Thus, it provides higher structural strength due to the wavy layers which divide the material into several parts, thus reducing the probability of tearing. Corrugated sheets also possess shock-absorbing properties, which protect the packaged cargo from vibration loads. Furthermore, their use reduces the overall structural weight.

To confirm this hypothesis, a spatial model of the box wagon body was developed, featuring cladding made of corrugated sheets. The spatial model was constructed in SolidWorks (Fig. 2), and the strength was calculated in SolidWorks Simulation.

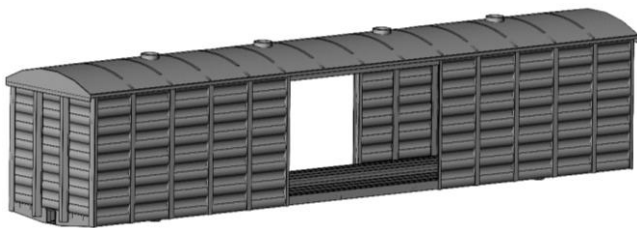


Fig.2. The spatial model of the load-bearing structure of the box wagon

The spatial model of the load-bearing structure of the box wagon included the elements rigidly interacted with each other. Since the double-leaf doors had hinged interaction with the body, they were not included in the model.

The thickness of the cladding sheet was assumed to be 2 mm. It was determined by the optimization model developed in the previous studies of the authors. Importantly, the use of corrugated sheets can also reduce the tare of the load-bearing structure of the box wagon compared to that of the typical design by 2.3%.

The strength of the load-bearing structure of the box wagon was calculated using the finite element method. As far as the load-bearing structure of the wagon was made of low-alloy steel 09G2S, the von Mises criterion was used in the calculations. For this steel grade, the permissible stresses are 310.5 MPa for design mode I and 210 MPa for design mode III of wagon operation [6].

The finite-element model of the load-bearing structure of the box wagon was formed by tetrahedra (Fig. 3). The number of elements was determined graphically and analytically by performing a mesh sensitivity analysis. Thus, the model had 222,372 elements, and 72,316 nodes. The maximum size of the

element in the model was 12.5 mm, and the minimum size was 0.625 mm. The mesh was refined in the areas of rounding using the software package options.

The structural design scheme of the load-bearing structure of the box wagon included the effect of the vertical load P_v (Fig. 4).

The walls of the body were subject to the pressure P_p from the bulk cargo (grain). The longitudinal force P_l , which was equal to 3.5 MN, was applied to the rear draft lugs. This force was balanced by the reaction R applied on the opposite side of the wagon. The support of the body on the bogies was represented by rigid elements placed at the centre plates.

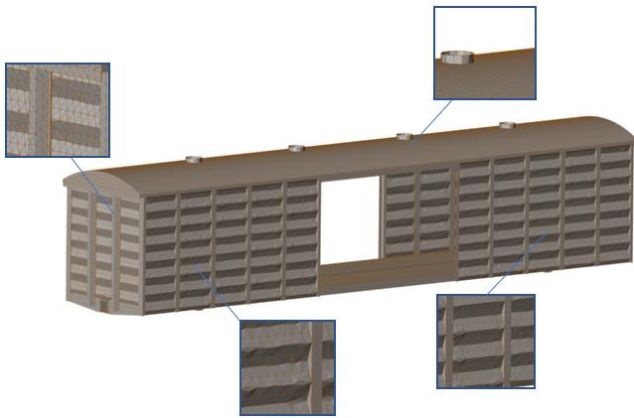


Fig. 3. The finite element model of the load-bearing structure of the box wagon

The pressure from the bulk cargo P_p was calculated by the formula

$$P_p = \gamma \cdot g \cdot H \cdot tg^2 \left(\frac{\pi}{4} - \frac{\varphi}{2} \right), \quad (1)$$

where γ is the density of bulk cargo, t/m^3 ; H is the height of the side wall, m; φ is the critical angle of repose of the cargo, rad; g is the free fall acceleration, m/s^2 .

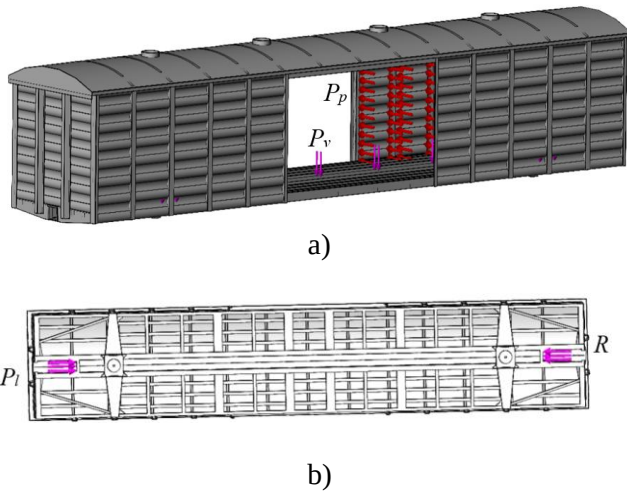


Fig. 4. The structural design scheme of the load-bearing structure of the box wagon: a) vertical and transverse forces; b) longitudinal forces

3. RESULTS AND DISCUSSION

The design model built was used to calculate the strength of the load-bearing structure of the box wagon. The results are shown in Fig. 5 – 7. The maximum stresses were recorded in the centre sill of the frame between centre plates and bolsters (Fig. 5). These stresses amounted to 304.4 MPa (Fig. 6) and were lower than permissible. In the cladding, the maximum stresses were 128.3 MPa; they were 8.6% lower than those emerging in the cladding of the typical design.

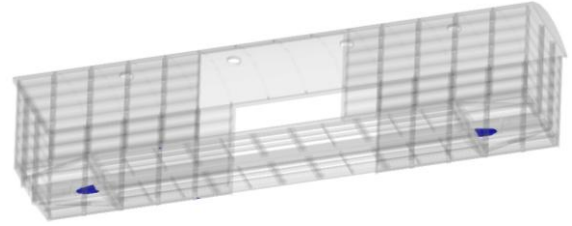


Fig. 5. The zones with highest stresses

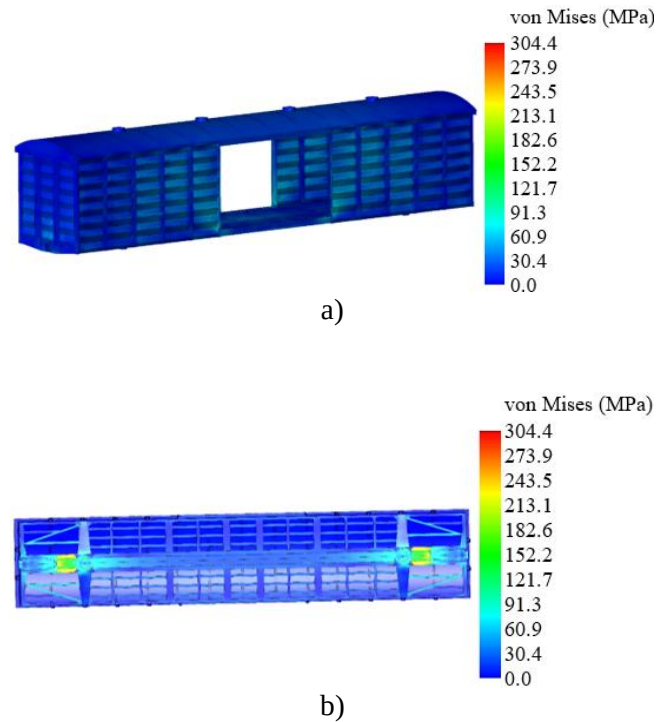


Fig. 6. The stress state of the load-bearing structure of the box wagon: a) view 1; b) view 2

The maximum displacements occurred in the middle part of the box wagon frame; they were 3.4 mm (Fig. 7).

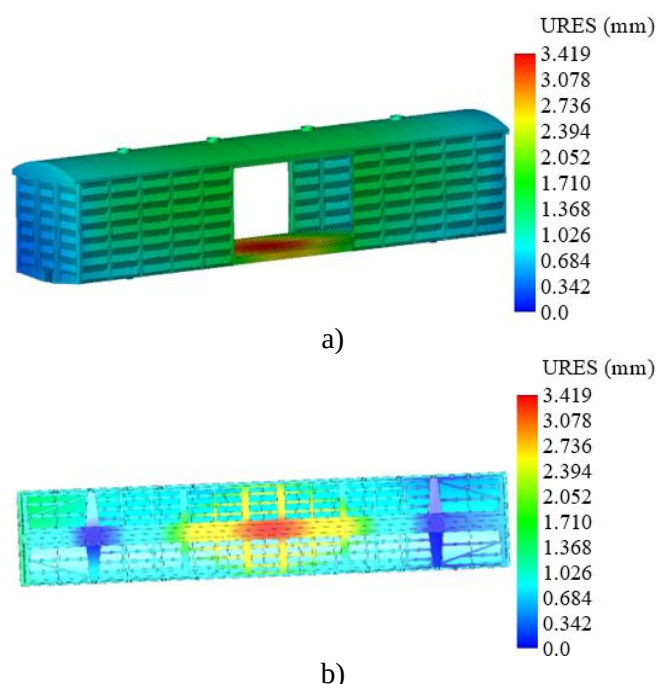


Fig. 7. The displacements in the units of the load-bearing structure of the box wagon:
a) view 1; b) view 2

The proposed solution is effective in reducing the load on the box wagon's cladding sheets and is suitable for both new designs and the modernization of existing rolling stock.

A further area of the research in the field can be the fatigue strength of the load-bearing structure of a box wagon with corrugated cladding sheets. Optimizing the geometry of cladding sheets (corrugation pitch, width, length, etc.) is also of high importance, as well as exploring the possibility of using sandwich panels with corrugated sheets for wagon wall cladding. All these issues will be considered in further research.

The research conducted will help improve the strength of the load-bearing structures of box wagons and reduce their maintenance cost.

4. CONCLUSION

In order to substantiate the use of corrugated sheets as cladding for the box wagon body, a three-dimensional model of the wagon has been developed

and a strength analysis has been carried out. The peculiarity of the model built is that it includes only structural elements rigidly interacted with each other.

The strength of the load-bearing structure of the box wagon has been calculated. The highest stresses are concentrated in the centre sill, namely, in the area between the centre plates and the bolsters. The stresses amount to 304.4 MPa, which does not exceed the permissible values. The maximum stresses in the cladding are 128.3 MPa; they are 8.6% lower than those in the typical design. The maximum displacements (3.4 mm) are in the box wagon frame. The strength calculations have demonstrated the effectiveness of the proposed solution.

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