CURRENT PROBLEMS IN RAIL VEHICLES

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ANALYSIS OF THE STRENGTH OF AN OPEN WAGON BODY WHEN IT IS LIFTED TO CHANGE BOGIES AT A RAILWAY FERRY STATION

ANALÝZA PEVNOSTI OTVORENÉHO VOZŇA PRI JEHO ZDVIHNUTÍ ZA ÚČELOM VÝMENY PODVOZKOV NA ŽELEZNIČNEJ TRAJEKTOVEJ STANICI

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Abstract

The presented research highlights the analysis of the strength of an open wagon body when it is lifted to change bogies in the conditions of a railway ferry station. It has been established that the strength of the open wagon body structure withstands the loads arising during its lifting by a handling machine. There were analysed the places, where a transport equipment interacts with the towing brackets, which are welded to the corner posts of the wagon body. The conducted research will contribute to the creation of recommendations for the design of modern freight wagon structures and increasing the efficiency of the operation in railway-ferry stations.

Keywords

an open wagon, lifting and transport operations, open wagon body strength, open wagon body load, railway ferry transportation

Abstrakt

Predložený výskum sa zameriava na analýzu pevnosti otvorenej skrine vozňa pri jej zdvíhaní za účelom výmeny podvozkov v podmienkach železničnej trajektovej stanice. Bolo zistené, že pevnosť konštrukcie otvorenej skrine vozňa odoláva zaťaženiam vznikajúcim pri jej zdvíhaní manipulačným strojom. Boli analyzované miesta, kde dopravné zariadenie interaguje s ťažnými konzolami, ktoré sú privarené k rohovým stĺpikom skrine vozňa. Vykonaný výskum prispeje k vytvoreniu odporúčaní pre návrh moderných konštrukcií nákladných vozňov a zvýšenie efektívnosti prevádzky v železnično-trajektových komplexoch.

Klíčová slova

otvorený vagón, zdvíhacie a prepravné operácie, pevnosť otvoreného vagóna, zaťaženie otvoreného vagóna, železnično-trajektová preprava

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1 INTRODUCTION

The possibility of European countries entering international communication led to a creation and successful operation of railway ferry transportation [1-5]. Currently, the largest European railway ferry routes pass through the waters of the Baltic and Black Seas. Particular attention should be paid to the railway ferry crossing connecting Ukraine with Bulgaria. It is served by railway ferries of the "Heroes of Shipka" type, which are designed for 108 wagons. The railway ferries are depicted in Fig. 1 and Fig. 2.

a) b)

Fig. 1 Railway ferries: a) Greifswald; b) Heroes of Odessa

a) b)

Fig. 2 Placement of wagons on the decks of railway ferries: a) Heroes of Plevna; b) Heroes of Odessa

The peculiarity of this crossing is that there is a special point in Varna for changing wagons from a 1520 mm track gauge to a 1435 mm track gauge [6] (Fig. 3). Lifting and transport machines are used to change wagon bodies to other type of bogies (Fig. 4). In this case, this machine includes equipment, which is attached to the structural components of the wagon body. Then, the wagon body is lifted.

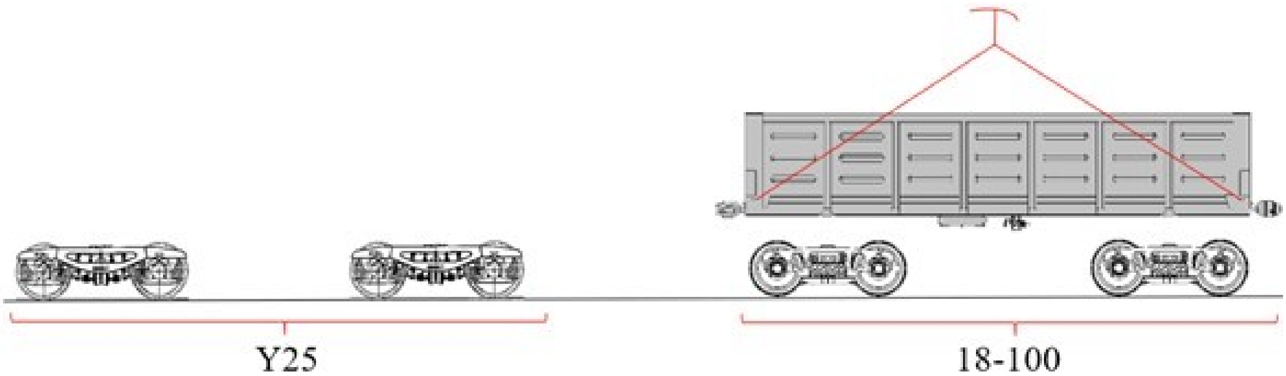
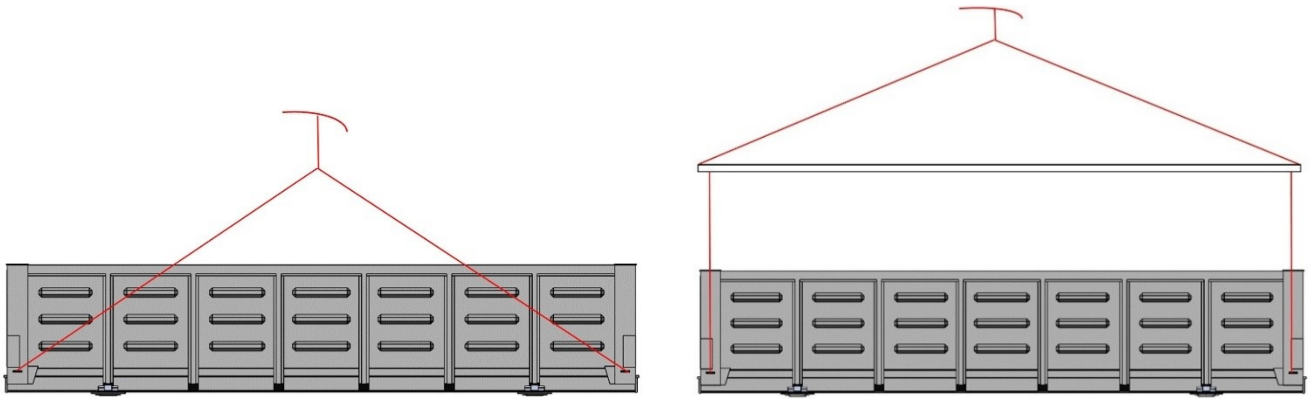


Fig. 3 A scheme of changing the wagon body from 18-100 model bogies to Y25 bogies

It is important to note, that analysis of the wagon body strength when it interacts with fastening equipment is important from the safety point of view during handling and transporting operation. Therefore, this study is devoted to determining the strength of a wagon body when it is lifted to change bogies in the conditions of a railway ferry station.



a) b)

Fig. 4 Schemes of securing the body during lifting: a) angular fastening of cables; b) vertical fastening of cables

The issues of ensuring the strength of wagon bodies during operation in international railway ferry transportation are relevant. The prospects for the functioning railway ferry transportation are analysed in work [7]. The technology of transporting wagons by railway ferries without bogies is considered. The advantages of this technology in comparison with known ones are presented. At the same time, the authors did not conduct a study of the wagon body strength when loading or unloading them on/from a ferry using such technology.

The features of securing wagons on railway ferries decks are investigated in expert works [8, 9]. Requirements for the placement of wagon securing means relative to the deck are given. However, the features of the wagon loading during lifting and transport operations are not specified.

Research of the strength of an open wagon body when transported by a railway ferry was conducted in the scientific paper [10]. In this case, the finite element method implemented in the SolidWorks Simulation software was applied for the research. The calculation results were confirmed by experimental studies of the wagon body strength. The disadvantage of this work is that it is limited to determining the strength of an open wagon body during its transportation by a railway ferry. The authors team did not consider its loading during lifting and transport operations.

The features of the loads of an open wagon body during its loading onto a railway ferry by coasting are highlighted in the work [11]. The accelerations acting on an open wagon body when passing through the joints zone of the railway ferry tracks and the deck are determined. However, the author did not study the loading of the open wagon body during lifting and transport operations in the conditions of the railway ferry station.

The issue of studying the strength of vehicles during railway ferry transportation is covered in the article [12]. At the same time, the most unfavourable type of railway ferry vibrations was considered. It is side swaying. Based on the conducted research, requirements were formulated for the safety of rail vehicle transportation by the railway ferry. However, the author did not pay attention to the issues of determining the loading of wagons during handling, i.e. lifting and transport operations.

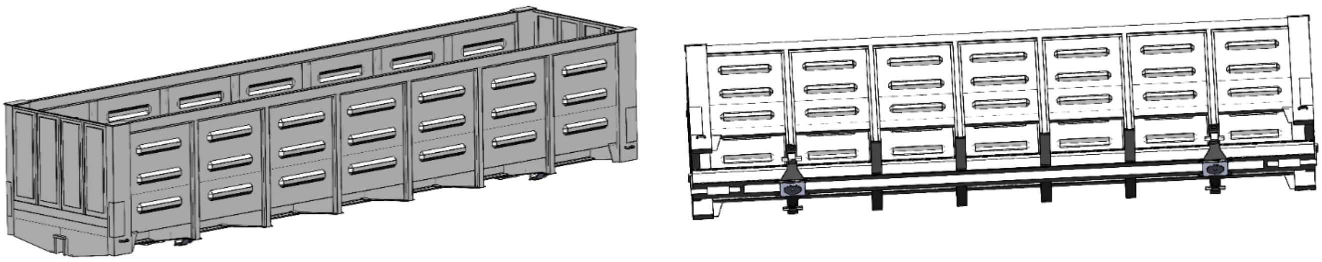
The conducted analysis of literature sources proves that the issue of determining the loading of the open wagon body during its lifting for changing bogies in the conditions of the railway ferry station was not investigated properly. This requires conducting research in the specified direction.

Hence, the purpose of the presented research article is to analyse the strength of the open wagon body during its lifting to change bogies in the conditions of the railway ferry station. The following tasks were formulated to achieve this goal:

- to create of a calculation diagram of the open wagon body when it is lifted by the towing brackets,
- to calculate the strength of the open wagon body.

2 MATERIALS AND METHODS

The study was conducted on the example of an open wagon, a model 12-757. A spatial model of the open wagon was created in SolidWorks software (Fig. 5). Structural elements that rigidly interact with each other were taken into account in the created model. Therefore, hatch covers are absent in the model because they have a hinged connection with the body. The model does not take into account the presence of welded seams or riveted joints and it is created as a monolithic structure. The calculation scheme of the open wagon is shown in Fig. 6. It considers the effect on the open wagon body of the following loads: the vertical static load P_V, pressure caused by the transported cargo on the side and end walls P_S. A wind load P_W was also applied to the outer surface of the side wall. Appropriate calculations were performed using the finite element method is implemented in the SolidWorks Simulation software [13, 14] to study the strength of an open wagon body during its lifting. The Mises criterion (the 4th energy theory) was applied.



a) b)

Fig. 5 Spatial model of the open wagon body: a) a top view; b) a bottom view

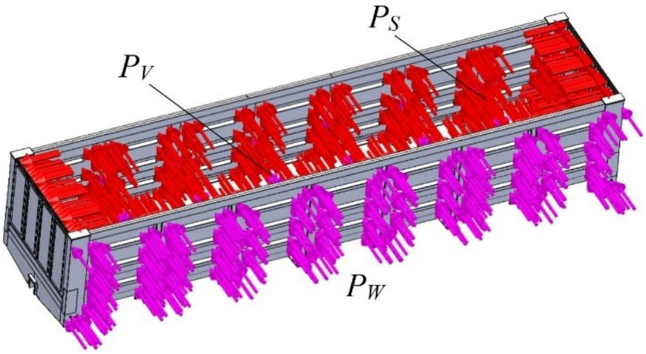


Fig. 6 A calculation diagram of the open wagon body

When calculating the design of a small weight of the open wagon body, it is provided using the options of the software package. The vertical static load P_V monitors the weight of the cargo in the open wagon, namely the value of 69.0 t (690 kN). This force was applied to the body frame.

There was considered in the calculation, that the open wagon body is loaded with crushed stone. The pressure from the load on the walls was determined using the formula [15]:

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

where γ is cargo density [kg/m^3], H is body wall height [m], g is gravitational acceleration [m/s^2] and φ is an angle of repose of cargo [°].

The pressure on the side walls of the body was 6.9 kPa, and on the end walls 61.2 kPa. The pressure was applied to the side walls according to the law of a triangle with a maximum at the base. Further, the pressure was applied according to the law of a trapezoid, also with a maximum at the base. In this case, the standards set out in document [15] were considered, because the type of the studied open wagon is designed for operation on a 1520 mm railway track. However, it can also be operated on a 1435 mm railway track considering the use of an adapter between the body center plate and the bogie center plate. This is due to the fact that a flat center plate is used on 1520 mm railway track, and on 1435 mm railway track bogies a spherical one is used.

The wind load [16] is calculated using the following formula:

$$P_{\mathrm{W}} = p \cdot S, \tag{2}$$

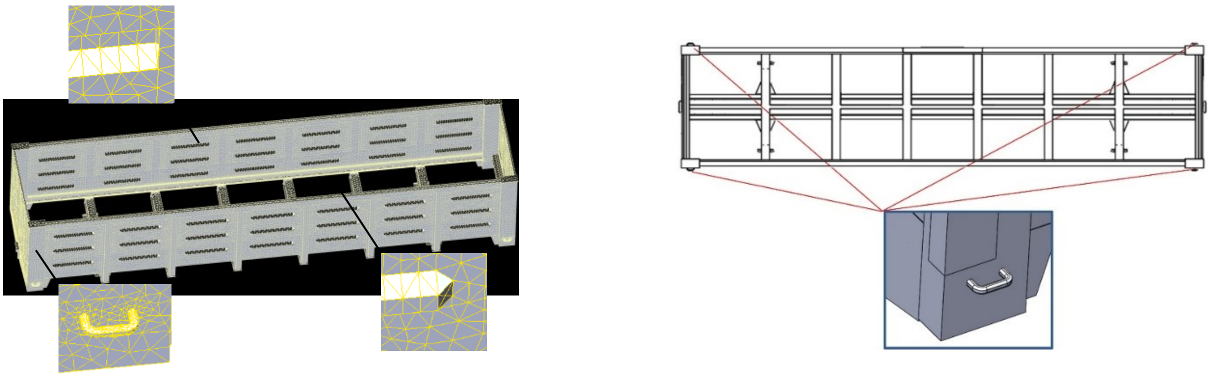
where p is wind pressure [MPa] and S is body side wall area [mm^2].

The magnitude of this force is 6.1 kN. It was applied to the outer side surface of the open wagon body.

When performing calculations, dynamic loads acting on the open wagon body and caused by its possible rocking were not considered. That is, the calculation was performed statically.

The finite element model of the body is formed by isoparametric tetrahedra elements (Fig. 7a). Their number is calculated by means of the graph-analytical method. Taking this into account, the model has 153,157 nodes and 469,910 finite elements with a maximum size of 80 mm and a minimum size of 16 mm.

The model was secured by consoles for pulling up the wagon during shunting operations (Fig. 7b). A rigid connection was considered in the calculation scheme. The wagon body material is steel marked as 09G2S. The permissible stresses for this type of steel under the given loading regime are taken to be 210 MPa [15].



a) b)

Fig. 7 The open wagon body: a) a finite element model, b) a placement of a console on the open wagon body for pulling up the wagon during shunting operations

3 RESULTS AND DISCUSSION

Firstly, the calculation was carried out for the body lifting scheme shown in Fig. 4a. Based on the performed calculations, the stress and displacement distribution fields in the open wagon body structure were obtained and they are depicted in Fig. 8 to Fig. 10.

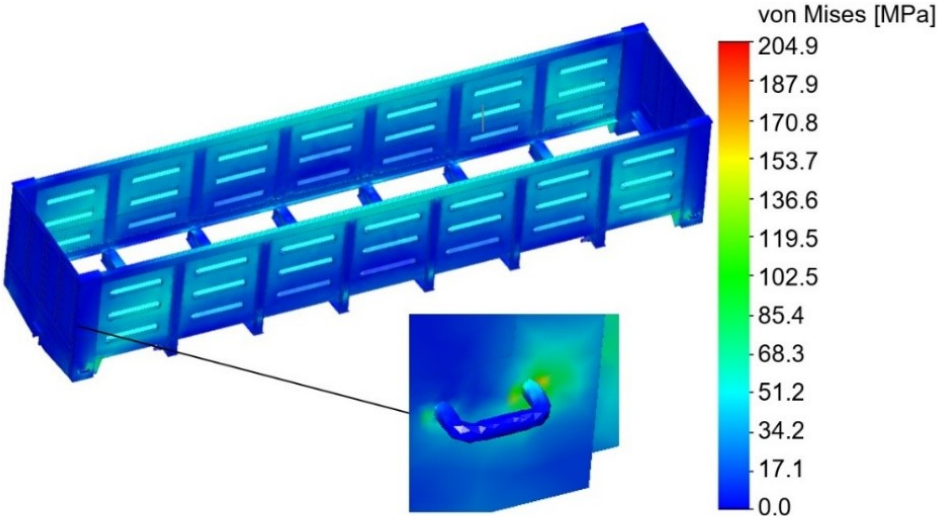


Fig. 8 A distribution of stresses in the open wagon body structure

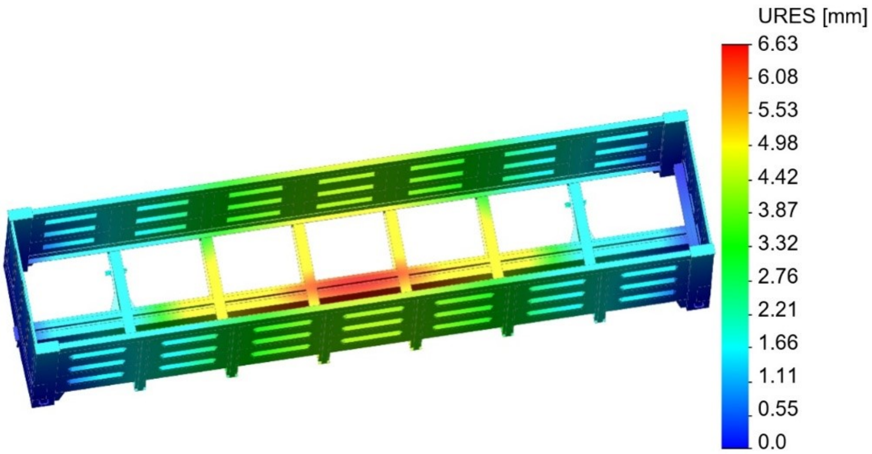
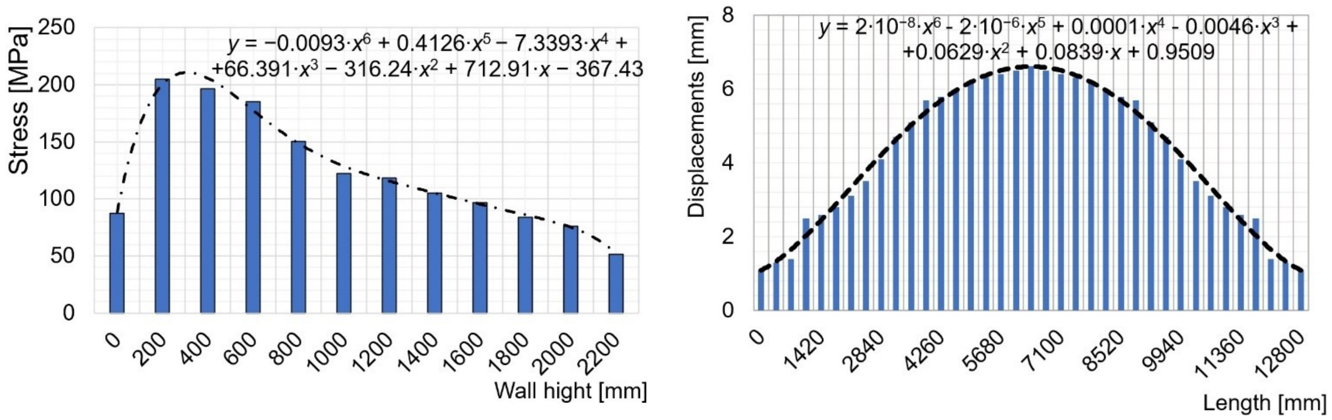


Fig. 9 Deflections in the nodes of the open wagon body structure



a) b)

Fig. 10 A distribution of stresses and deflections along the length of the open wagon body elements: a) A distribution of stresses along the height of the corner post of the open wagon body, b) A distribution of deflections along the length of the backbone beam of open wagon body

It was found out that the maximum stresses in the open wagon body structure occur in the zone of interaction of the console with the corner post and are 205 MPa (Fig. 8). The resulting stresses are 2.4% lower than the permissible ones. The distribution of stresses along the height of the corner post is shown in Fig. 10a. It can be concluded analyzing this figure, that the maximum stresses occur in the area of attachment of the bracket to the corner post. Along the height of the post, these stresses decrease.

The maximum displacements that occur in the frame are 6.6 mm (Fig. 9). They are concentrated in the middle part of the backbone beam of the open wagon body structure (Fig. 10b). This dislocation of stresses is explained by the scheme of fastening and loading of the open wagon body.

The calculation was also performed for the body lifting scheme shown in Fig. 4b. The calculation results are shown in Fig. 11, 12. The maximum stresses also take place in the interaction zone of the bracket with the corner post and are 208.8 MPa, i.e. they do not exceed the permissible ones. The maximum deflections are recorded in the central part of the center beam and are equal to 6.71 mm. The achieved stresses at this stage are not compared with the experimental ones. A similar issue will be considered in subsequent works of the authors. The study also paid attention to the issue of the strength of the towing bracket as a separate element of the body structure. For this purpose, a spatial model of the bracket was created (Fig. 13).

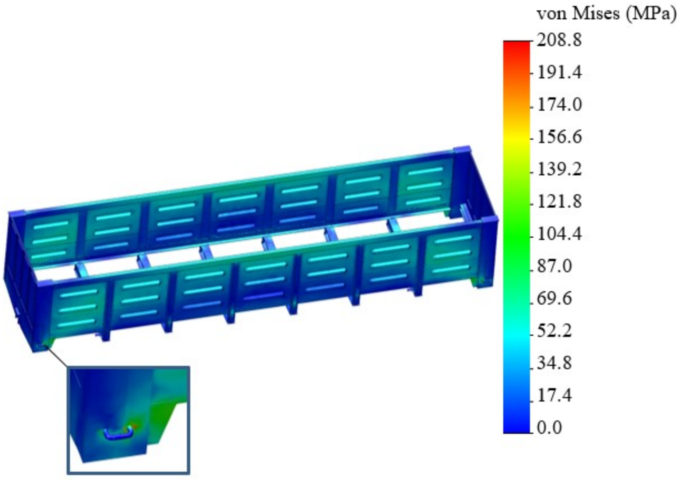


Fig. 11 Stress state of the open wagon body

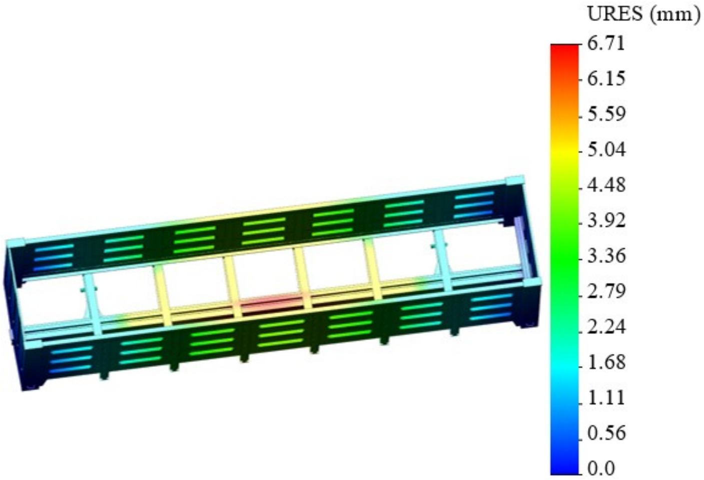


Fig. 12 Deflections in the nodes of the open wagon body

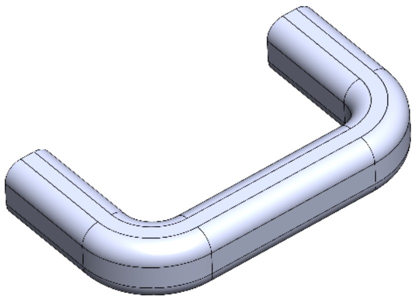


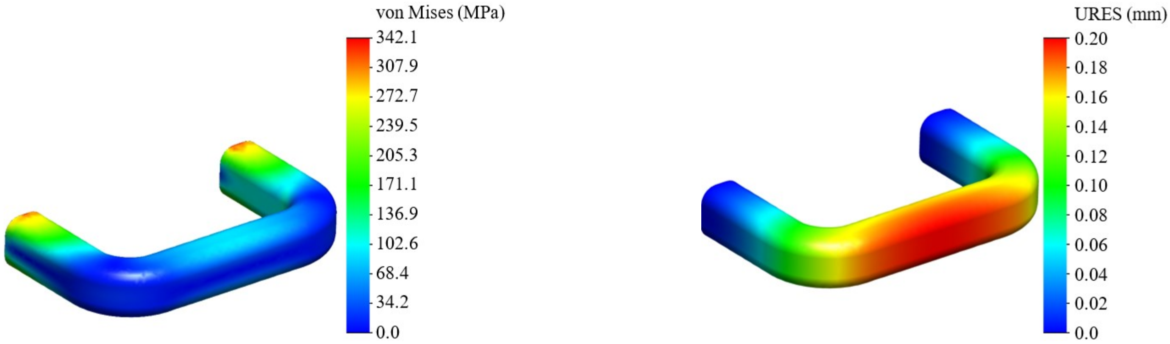
Fig. 13 A spatial model of the towing bracket

The calculation scheme of the bracket is shown in Fig. 14a. In this case, the case of loading the bracket with only a vertical load was considered, i.e. the body lifting scheme shown in Fig. 4b was considered. The finite element model of the bracket is formed by tetrahedrons (Fig. 14b). Their number is 9538, with the number of nodes being 14,862. The tetrahedrons are the same size of 6.4 mm. The bracket was fixed in the zones of its interaction with the corner post. Rigid fastening was used.

The results of the bracket calculation are shown in Fig. 15. The maximum stresses in the bracket were 342.1 MPa (Fig. 15a). They occur in the area of interaction of the bracket with the corner post. These stresses are higher than those obtained for the case of loading the bracket as part of the open wagon body structure. This can be explained by the bracket fastening scheme, namely the use of rigid fastening. At the same time, given the fact that in reality the bracket is designed to perceive longitudinal loads, i.e. pulling the wagon during maneuvers, it can be considered that this loading scheme is above the standard for it. Therefore, it is proposed to accept the yield stress of the material, which is 345 MPa, as the permissible stresses. Taking this into account, the obtained stresses are lower than the permissible ones. The maximum displacements in the nodes are recorded in the central part of the bracket, but they are very insignificant, i. e. less than 1 mm (Fig. 15b).

(a) (b)

Fig. 14 A calculation scheme of the bracket (a); a finite element model of the bracket (b)



(a) (b)

Fig. 15 Stress state of the bracket (a); deflections in the bracket nodes (b)

The limitation of this study is that the symmetrical placement of the cargo in the open wagon body was considered. That is, its uneven distribution relative to the body was not considered, which may affect its loading when lifting to change bogies. Therefore, the next stage of the development of this study is the influence of the asymmetry of the body loading on its strength when lifting to change bogies.

The conducted studies will contribute to the creation of recommendations for the design of modern car structures and increasing the efficiency of railway ferry stations.

4 CONCLUSIONS

A calculation scheme of the open wagon body when it is lifted by the console has been created. It has been considered that the following loads act on the car body: vertical static, as well as pressure from the cargo on the side and end walls. The body was secured by the towing brackets. The strength of the open wagon body structure has been calculated. At the same time, the maximum stresses were recorded in the zones of interaction of the console with the corner posts and amounted to 208.8 MPa. The resulting stresses are lower than the permissible. Therefore, the strength of the open wagon body structure when it is lifted by the console is maintained. The maximum displacements were 6.6 mm and occur in the middle part of the backbone beam of the open wagon boy structure.

The study also examined the strength of the towing bracket when taking on the vertical loads. The calculation results showed that the maximum stress in the bracket was 342.1 MPa, and the deflections in the nodes were 0.2 mm.

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