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Research Article

Investigation of container strength when fixed in an open wagon equipped with pneumatic bags

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Abstract: Ensuring the efficiency of railway transport in international traffic needs the development of combined transport systems. Container transportation is the most relevant among them. Containers are usually transported by rail on platform wagons. Along with this, the lack of platform wagons in operation makes it necessary to use other types of wagons for container transportation, such as open wagons. The fastening of containers in open wagons is carried out using pneumatic bags. To study the effectiveness of applying such a fastening scheme, the load of the container during transportation in an open wagon was determined. The conducted research will contribute to creating recommendations for improving rail transport operations' efficiency.

Keywords: transport mechanics; container; dynamic load; container strength; container transportation

I. Introduction

The increase in the operational efficiency of the transport industry led to the introduction of modular vehicles. Containers used in operation are one of the most common among them. This is explained by the possibility of their transportation by almost all modes of transport: rail, road, water and air [1-3]. A significant share of container transportation is accounted for the rail transport. Transportation of containers by railway is carried out on platform wagons [4-6]. The lack of platform wagons in operation makes it necessary to use other types of wagons for container transportation, for example, open wagons [7-9]. Along with this, using open wagons for container transportation requires the provision of a reliable scheme of their interaction, which would ensure their proper protection against movement during transportation.

To ensure proper fastening of containers in the longitudinal plane, pneumatic bags are found to be used there, and they are installed between the end walls of the open wagon and the container (**Fig. 1**). Usually, such pneumatic bags have standard dimensions and characteristics.

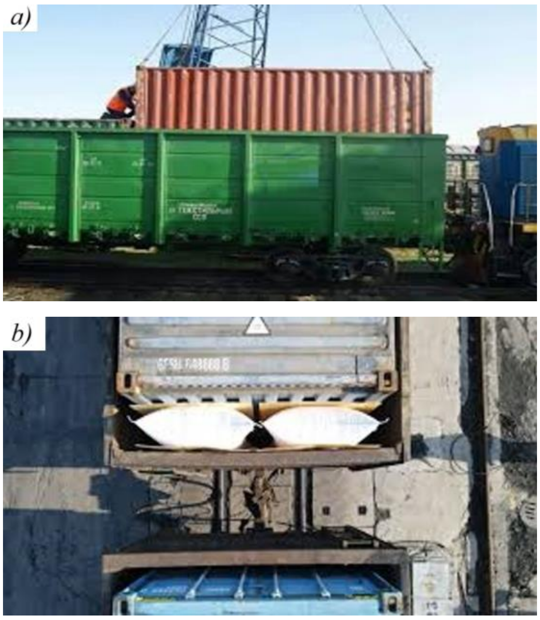

Figure 1. *Transportation of containers: a) loading a container, b) fastening a container*

To study the effectiveness of pneumatic bags for fastening containers in an open wagon, it is necessary to determine their load in the conditions of operational modes. Therefore, studies devoted to determining the load of a container when it is fixed in an open wagon employing pneumatic bags are relevant.

Many publications are devoted to the issue of container transportation by rail. Thus, the analysis of the main indicators of the strength of the load-bearing structure of an open wagon when transporting containers in it is described in the publication [10]. The longitudinal dynamics of an open wagon loaded with two containers were investigated. It was considered that their interaction is carried out through fitting stops, which are welded to the floor of the open wagon. The performed calculations showed that the transportation of containers using the specified fastening scheme is permissible. However, such a fastening scheme is ineffective in the conditions of over-normalized regimes. The design of a removable module of a Flat Rack type is proposed in the research [11] for an adaptation of wagons to transportation of containers. The results of the strength calculation of the removable module under the condition of its use on a platform wagon are presented. The calculation results proved the feasibility of the proposed design of the removable module.

Along with this, the authors did not investigate the possibility of its use for fastening containers in open wagons. Features of the modernization of the supporting structure of the wagon for the possibility of transporting containers on it are highlighted in the work [12]. The author's team presents the results of experimental studies of the strength of the wagon frame during a shunting collision. It was established that the proposed modernization is expedient. The features of the modernization of a freight wagon for the transportation of containers are covered in the article [13]. The authors proposed using a removable frame for placing 20-foot and 40-foot containers. It has been proven that the proposed solutions for using such a frame are effective. However, the studies [12, 13] were conducted on a platform wagon example. The paper [14] provides the solutions for the situational adaptation of open wagons to the transportation of containers. A special removable module for securing containers in an open wagon is proposed. However, when considering using such a module, the authors did not pay attention to the strength of the load-bearing structure of an open wagon and a container. The article [15] highlights the features of calculating the strength of the floor of a 40-foot container during its transportation by water transport. Recommendations for safe operation of this type of container. However, these solutions are ineffective when transporting it by rail, particularly in open wagons.

The analysis of literature sources proves that the issues of studying the load of containers during transportation by rail transport are relevant and require further research.

Regarding this, the goal of the presented research was to study the strength of a container when it is fixed in an open wagon with the help of pneumatic bags.

II. Presentation of the Primary Research Material

Mathematical modelling was conducted to determine the efficiency of pneumatic bags for fastening containers in an open wagon. A mathematical model (1) [16] was used for this purpose. The model characterizes the load of the container in the longitudinal plane placed on the platform wagon during a shunting maneuver [17].

As part of this study, a specified model was refined by considering the force from a pneumatic bag on a container. It is assumed that the pneumatic bag is entirely distributed relative to the end wall of the container. It is considered that the container is supported and fastened in the open wagon through

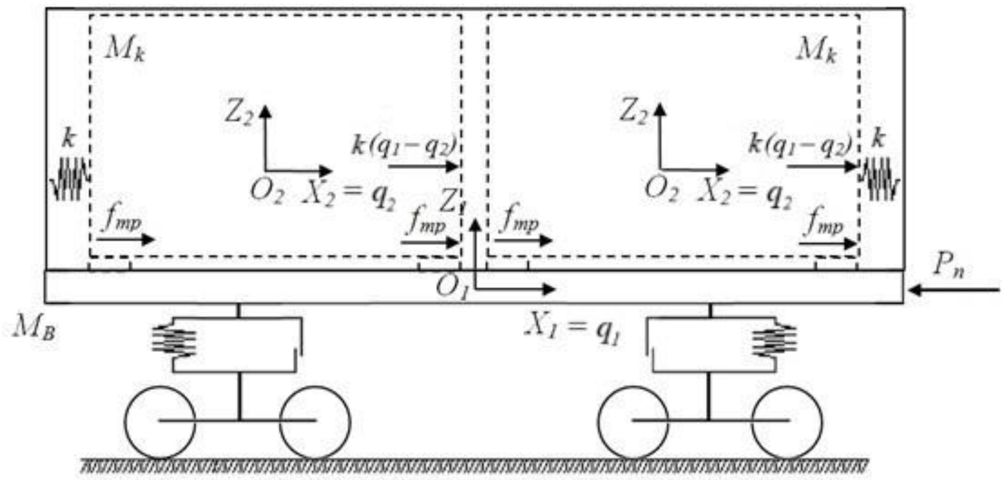

Figure 2. *A calculation diagram of an open wagon loaded by containers*

fittings that interact with the fitting stops. Due to a technological gap, frictional forces arise between the horizontal surfaces of fittings and fitting stops.

The container is loaded with conditional cargo using the full carrying capacity. The movement of the cargo in the container was not considered. There is no gap between the pneumatic bag and the container wall. The model did not consider the previous static compression of the pneumatic bag. The calculation diagram of an open wagon loaded by containers is shown in **Fig. 2**.

A mathematical model describing a container's dynamic load when transported in an open wagon has the following form (see Eq. (1)).

$$\begin{cases} M_B \cdot \ddot{q}_1 = \\ = P_n - \sum_{i=1}^{n} \left[f_{mp} \cdot \operatorname{sign}(\dot{q}_1 - \dot{q}_2) + k \cdot (q_1 - q_2) \right] \\ M_k \cdot \ddot{q}_2 = \\ = f_{mp} \cdot \operatorname{sign}(\dot{q}_1 - \dot{q}_2) + k \cdot (q_1 - q_2), \end{cases} \quad (1)$$

where M_B is the wagon body mass, M_k is the container mass, P_n is the magnitude of the longitudinal force acting in an automatic coupler (the value of 3.5 MN is considered [23]), P is the stiffness of pneumatic bags, f_{mp} is the friction force (the value of 0.15, i.e. steel – steel couple is considered) between fitting stops and fittings, q_1, q_2 are generalized coordinates, at which, they are identical with the longitudinal axes X_1 (for the wagon body) and X_2 (for the containers). Both containers have the same coordinate system, because it is assumed that any motion is allowed between them (rigid coupling is assumed between them).

The solution for this system of equations of motion was carried out using the MathCad software [18, 19], with initial conditions set close to zero [20]. The system of equations (1) was solved using the "rkfixed" function integrated in the MathCad software. It gives velocities to individual element of the solved mechanical system. During the calculation iteration process, the acceleration shown in Fig. 3 were obtained. The air bags stiffness value

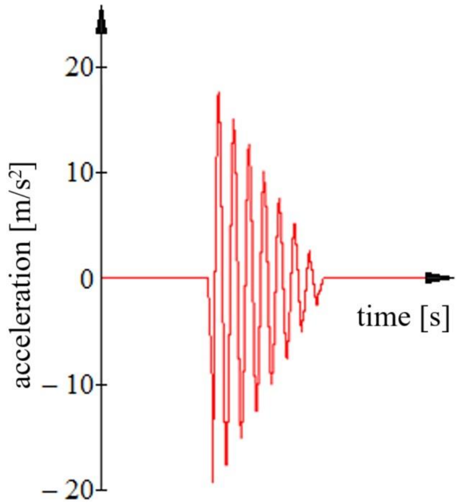

Figure 3. *Accelerations acting on a container*

was obtained by means of this iteration process.

The calculation results established that to maintain container accelerations up to 20 m/s^2, the stiffness of the pneumatic bag should be at least 2500 kN/m (**Fig. 3**).

It is important to note, that this stiffness value should be even more important in conditions of over-normalized operating modes.

A calculation was made in SolidWorks Simulation to determine the container's strength, considering its fastening by means of pneumatic bags in the open wagon [21, 22]. The calculation diagram of the container is shown in **Fig. 4**.

This scheme considers the effect of the longitudinal load P_p on the end wall. The vertical load P_v was applied to the container's lower frame using the container's full carrying capacity, and the friction force f_{mp} was applied to the horizontal parts

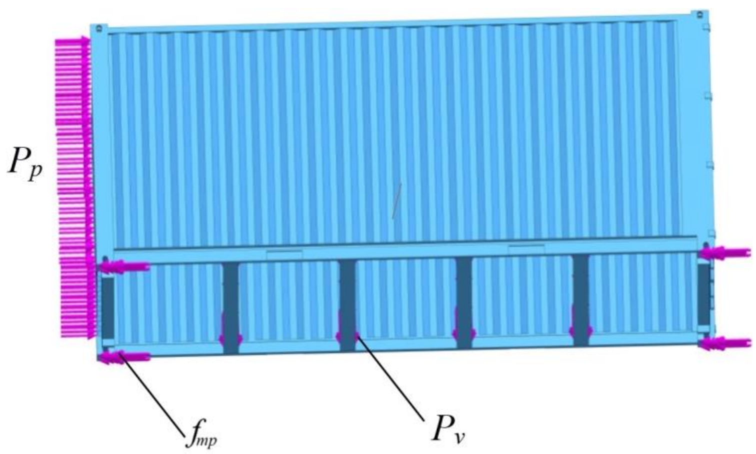

Figure 4. *A calculation scheme of a container*

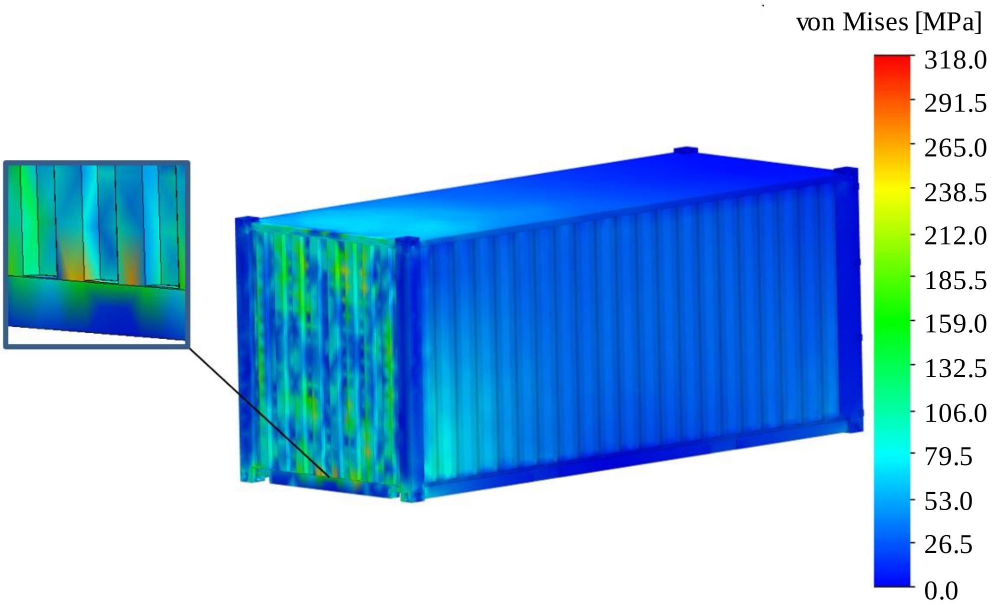

Figure 5. *A stress distribution in the container structure*

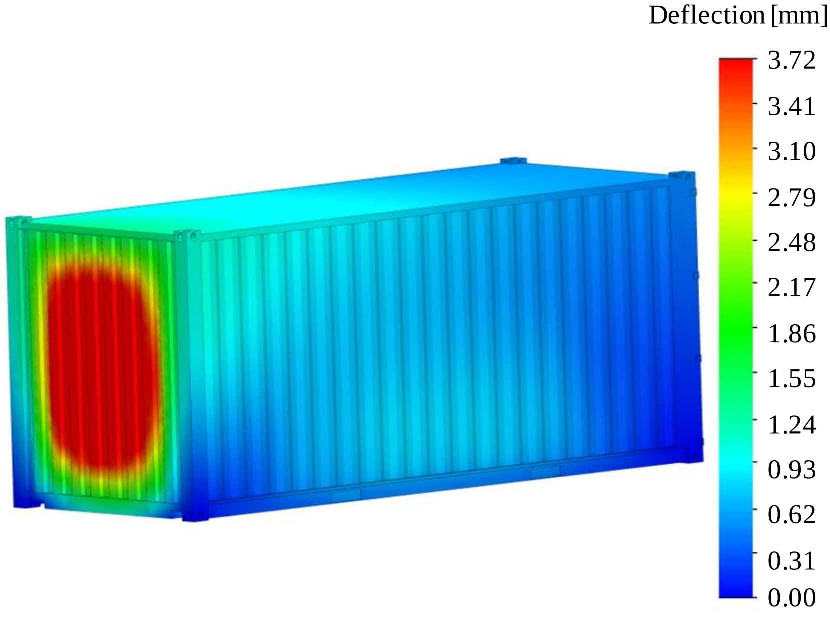

Figure 6. *Deflections calculated in the container structure*

of the fitting stops. The construction material is 09G2S steel. The permissible strength of the used material is of 310.5 MPa [23].

III. RESULTS OF THE STRENGTH ANALYSIS OF THE CONTAINER

The finite element model of the container is formed by tetrahedral elements. Their optimal number was determined by the graphic-analytical method [24]. The calculation results are shown in **Fig. 5** and **Fig. 6**.

The maximum stresses in the container were identified in the area where the cladding adhered to the end beam of the container and mounted. It is also detailed in **Fig. 5**.

These values were up to 318.0 MPa. The maximum deflections detected in the end wall occur at its center and are equal to the value of 3.7 mm, as seen in **Fig. 6**. The calculation results allow to conclude that the strength of the container under the applied loads is not ensured.

The research proved that applying the pneumatic bags led to an excessive load on the container in the open wagon. Future research will focus on improving the proposed idea through improving the structure. Subsequently, strength analyses will be performed to determine whether using pneumatic bags is possible.

IV. Conclusion

Mathematical modeling of the longitudinal load of a container placed in an open wagon was carried out. It was established that to maintain container accelerations within 20 m/s^2, the stiffness of the pneumatic bag should be at least 2,500 kN/m.

The strength of the container is calculated when it is fixed in the open wagon with the help of pneumatic bags. The maximum stresses in the container were identified in the area where the cladding adhered to the end beam of the container and amounted to the value of 318.0 MPa. The maximum deflections in the end wall occur at its center. These deflections were numbered to the value of 3.7 mm. Based on the calculation results, it is possible to conclude that the required strength of the container under the acting loads has not been met. Therefore, the issue of improving the scheme of securing containers in open wagons requires further research.

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Author Contributions

A. Lovska: Conceptualization, Methodology, Software, Writing – original draft preparation, visualization.

J. Gerlici: Formal analysis, Investigation, Supervision, Validation.

J. Dižo: Writing – original draft preparation, Project administration, Data curation.

P. Rukavishnykov: Resources, Formal analysis, Visualisation.

Disclosure Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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