RESEARCH OF DYNAMIC LOADING CAPACITY AND STRENGTH OF CONTAINER WHEN TRANSPORTED ON OPEN WAGON

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Abstract. Container transportation is currently the most promising type of combined transportation. This is justified by the mobility of containers, which allow the possibility of their transporting by almost all modes of transport. A significant share of container transportation falls on railway transport. Flat wagons are most often used for it. In connection with the intensification of container transportation by railway transport, open wagons have begun to be used for their transportation. To ensure the safety of container transportation in open wagons, it is important to study their loads. In this regard, the presented article highlights the features of the research conducted to determine the dynamic loading and strength of a container when transported on an open wagon. To determine the dynamic load acting on the container, mathematical modelling was performed. For this purpose, a mathematical model was formed. It describes the longitudinal loading of the container during transportation on an open wagon. The determined dynamic load value was considered when calculating the strength of the container. Two schemes of its loads were considered: the absence of pressure of the transported cargo on the end wall, as well as its presence. The strength calculation was performed using the finite element method, which is implemented in the SolidWorks simulation software. The calculation results showed that the strength of the container is not observed under the considered loading modes. The conducted studies will be useful developments in creating new technologies for container transportation and they will contribute to increasing the efficiency of container transportation operations.

Keywords: ISO container, dynamic load, loading modelling, strength, container transportation.

Introduction

The development of foreign economic relations between the Eurasian countries largely depends on the coordinated functioning of the transport industry, one of the most important components of which is railway transport [1-3]. The need to improve the efficiency of rail transport in international traffic has led to the introduction of container transportation [4; 5]. Containers are mostly transported by rail in flat wagons. The lack of flat wagons has led to the use of open wagons to transport containers. Because containers can easily be placed in a roofless open wagon, there is a need to equip the open wagon with fitting stops or other fastening equipment to secure the containers. It should be noted that due to operating conditions, containers and open wagons may be damaged during transportation, thus necessitating unscheduled repairs. Therefore, to improve the efficiency of rail transport operations, it is important to develop practices regarding the situational adaptation of open wagons for container transportation together with considering other dynamics effects acting on wagon bogies, a wagon body as well as on a railway track [6-9]. The issue of situational adaptation of rail transport for container transportation is covered in many publications. For example, the article [10] deals with the use of a special detachable module that functions as an intermediate adapter between the body and the container and can be used for containers transported in open wagons. The paper highlights the features of determining the dynamic load and strength of an open wagon, taking into account the proposed detachable module for fastening containers. However, the authors did not study the load on the container fixed to the detachable module. In order to adapt a wagon for containers, measures to modernize the open wagon are proposed in [11]. They include the installation of fitting stops (stationary or folding) on the wagon; this solution was substantiated. The study was carried out on the example of a flat wagon. However, the strength of the container, taking into account its fixation on the flat wagon, was not determined. Study [12] is devoted to determining the container load under operating conditions. The authors carried out mathematical modelling of the dynamic load of the container. The obtained values of dynamic loads were taken into account in the strength calculations of the container in Ansys software. The peculiarities of calculating the floor strength of a 40-foot container in the Abaqus/CAE v 6.1 software package are described in [13]. Recommendations for safe operation of this container are also proposed. However, the authors of [12; 13] did not study the dynamic load and strength of the container when transported in an open wagon. To adapt the flat wagon to transport a wide range of goods, the design of a detachable module of the FLAT RACK type is proposed in [14]. The justification of its design is given and the prospects of using such a module in operation are also described. However, the authors did not determine the strength of the containers when they are fixed to this detachable module. The features of developing a container intended for transporting fruit and vegetable products are covered in [15]. All structural improvements are proved by the results of the strength calculation of this container. The authors took into account the main loading diagrams of the container in operation, but the specifics of container loading when the container was transported in an open wagon were not taken into account. The analysis of literature sources has shown that the issues of determining the dynamic load and strength of a container transported in an open wagon are yet to be studied. The purpose of the article is to present the results of a study of the longitudinal dynamic load and the strength of a container when transported in an open wagon. To achieve this purpose, the following objectives are set:

- to determine the longitudinal load of a container when transported in an open wagon; and
- to study the strength of a container when transported in an open wagon.

Materials and methods

In order to determine the stress state of the container when it is transported in an open wagon, including its fastening to the fittings, the relevant calculations were made. For this purpose, a spatial model of a 1CC container was built (Fig. 1). Graphics work was made in SolidWorks Simulation.

Fig. 1. **Spatial model of the container**

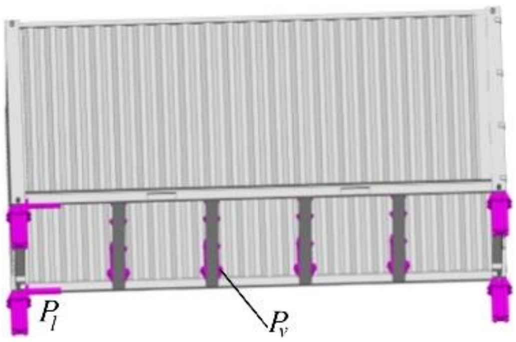

Fig. 2. **Design diagram of the container**

The stress state of the container was determined using the finite element method in SolidWorks Simulation. When building the design model, it was taken into account that the container bears the following loads: the vertical static P_v, applied to the cross bearers, and the longitudinal dynamic P_l, applied to the fittings in the areas of their interaction with fitting stops (Fig. 2). To determine the longitudinal dynamic load acting on the container fittings, mathematical modelling of its dynamic load was carried out. The design diagram is shown in Fig. 3. The longitudinal load of the container during its transportation in an open wagon was taken into account, when considering the gaps between fittings and fitting stops. The design mode 'jerk' of the car's movement was studied. In this case, the value of the longitudinal force on the front stops of the automatic coupler was assumed to be 2.5 MN [16]. A mathematical model that describes the dynamic load of a container when it is transported in an open wagon has the form [14]:

$$\begin{cases} M_W \cdot \ddot{q}_1 = P_l - \sum_{i=1}^{n} \left(F_{fr} \cdot sign(\dot{q}_1 - \dot{q}_2) + C_f \cdot (q_1 - q_2) \right), \\ M_c \cdot \ddot{q}_2 = \left(F_{fr} \cdot sign(\dot{q}_1 - \dot{q}_2) + C_f \cdot (q_1 - q_2) \right), \end{cases} \quad (1)$$

where M_W – gross weight of the open wagon, kg;

P_l – longitudinal force acting on the front stops of the automatic coupler, N;

n – number of containers placed in the open wagon, pcs;

F_{fr} – frictional force between the fitting stops and container fittings, N;

M_c – gross weight of the container, kg;

C_f – stiffness of the connection between fittings and fitting stops, N·m^{-1};

q_1, q_2 – coordinates that determine the displacements of the open wagon and the container relative to the longitudinal axis, respectively.

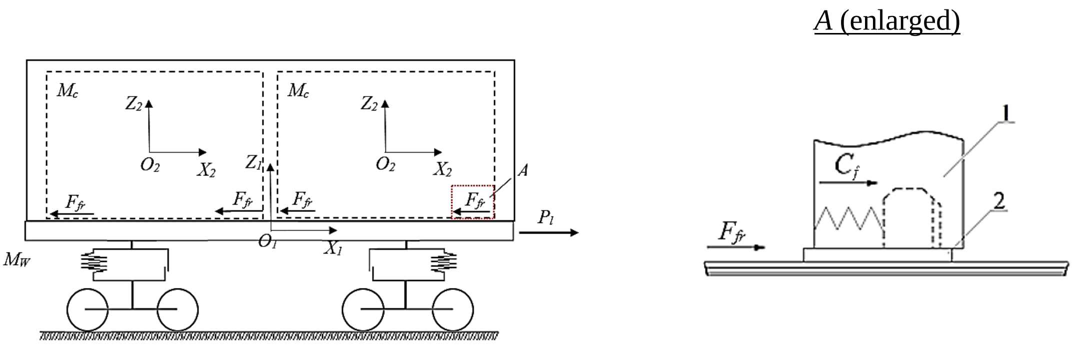

Fig. 3. **Design diagram of the container:** 1 – container fitting, 2 – fitting stop located in the open wagon, *Ffr* is the frictional force that occurs between the fitting and the fitting stop, Cf is the stiffness of the connection between the fitting and the fitting stop

The stiffness of the connection between the fitting and the fitting stop was determined from:

$$C_f = \frac{P}{f} \tag{2}$$

where P – force acting on the fitting stop N;
f – displacements that occur in the fitting stop, m.

In order to determine the displacements that occur in the fitting stop, its strength was calculated using the finite element method. The design diagram of the fitting stop is shown in Fig. 3. The fitting stop was fastened to its support part, i.e. from the side adjacent to the open wagon. The longitudinal force P and the vertical force P'_v, caused by the weight of the container, were considered. The numerical value of the longitudinal force was determined by the known dependence of the resistance of materials, which is used when determining the stresses in the test sample under the longitudinal force:

$$\sigma = \frac{P}{A} \tag{3}$$

where A – surface area subject to the longitudinal force (A = 0.002 m^2), m^2;
σ – stresses that occur in the test sample; MPa.

Hence, provided that $\sigma = [\sigma]$, then:

$$P = A \cdot [\sigma] \tag{4}$$

where $[\sigma]$ – permissible stresses for the material of the fitting stop (low-alloy steel grade 09G2D), MPa.

For the design mode III and considering the material of the fitting stop, $[\sigma]$ was taken to be 195 MPa [16].

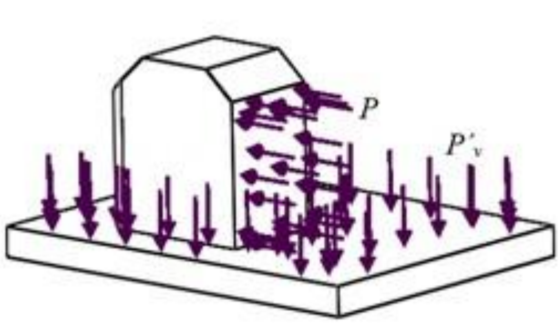

Fig. 3. **Design diagram of the fitting stop**

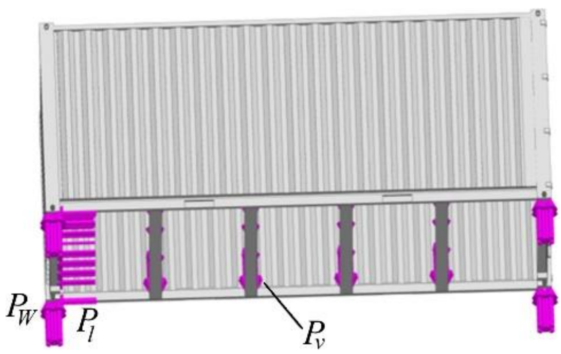

Fig. 4. **Design diagram of the container when the end wall is subjected to a longitudinal load**

Based on the calculations, the force *P* acting on the fitting stop was about 390 kN. This force was considered when calculating the strength of the fitting stop. The finite element model was formed by tetrahedra. The optimal number was determined graphically [17 – 19] and amounted to 2,706. The number of nodes was 768. The maximum element size of the finite element model was 15 mm, the minimum was 5 mm.

Results and discussion

Based on the calculations, the displacements in the fitting stop were 0.24 mm (Fig. 5).

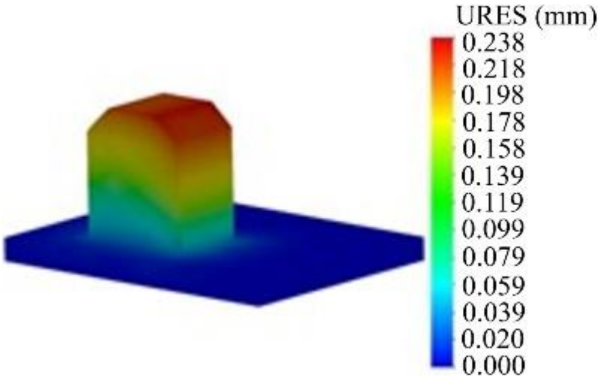

Fig. 5. **Displacements in the fitting stop units**

The calculations show that the maximum displacements occur in the upper part of the fitting pin. Therefore, the stiffness of the connection between the fitting and fitting stop is 1 638 655.46 $kN \cdot m^{-1}$.

The resulting stiffness was taken into account when solving differential equations (1) in MathCad by means of the Runge-Kutta method [20, 21]. The initial conditions were set to zero [22, 23]. It was found that the acceleration acting on the container is about 40 $m \cdot s^{-2}$.

The next stage of the study included the strength calculation of the container according to the design model shown in Fig. 2. The model was fastened to the fittings. The material of the container was steel 09G2S. It was assumed in the calculation that the freight in the container did not have its own degree of freedom and did not affect the container walls. The results of calculation are shown in Fig. 6, 7.

The maximum stresses occur in the container fittings and amount to about 350 MPa (Fig. 6). The maximum displacements occur in the cross bearer of the container and amount to about 1 mm (Fig. 7). Analysing the results, it can be concluded that the strength of the container is not ensured [16].

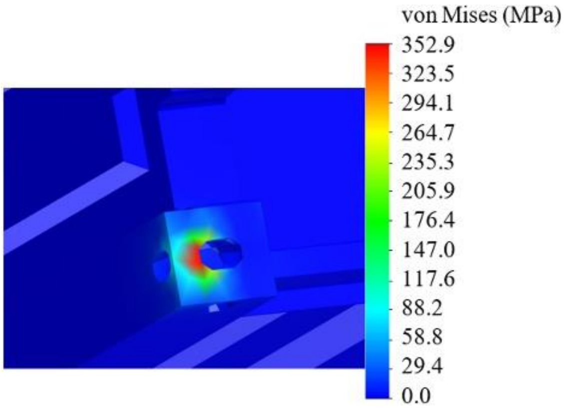

Fig. 6. **Stress state of a container fitting**

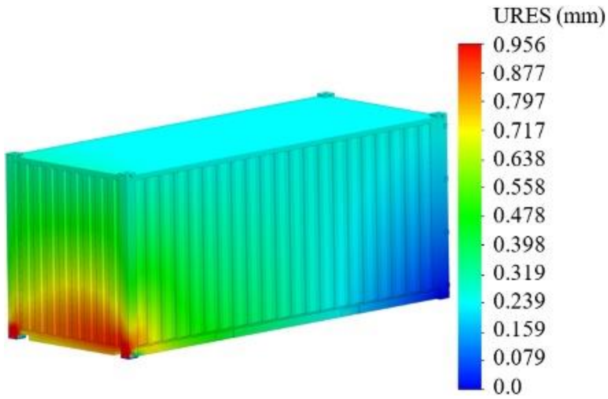

Fig. 7. **Displacements in the container units**

The strength of the container was also calculated for the case of a longitudinal force from the load on the end wall of the container. The design diagram of the container is shown in Fig. 4. The load P_T acting on the end wall was determined taking into account the acceleration obtained from the mathematical model (1).

The results of calculation are shown in Fig. 8, 9. The maximum stresses occur in the fittings and amount to 364.8 MPa (Fig. 8). The maximum displacements occur in the middle of the end wall and are 4.2 mm (Fig. 9). The calculations show that the strength of the container is not ensured [16].

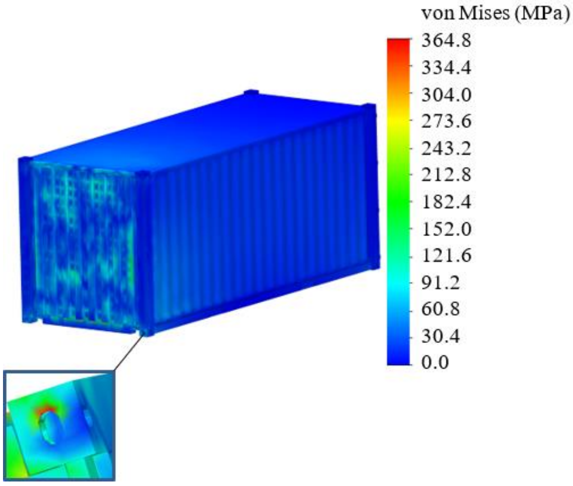

Fig. 8. **Stress state of the container when the end wall is subject to a longitudinal load**

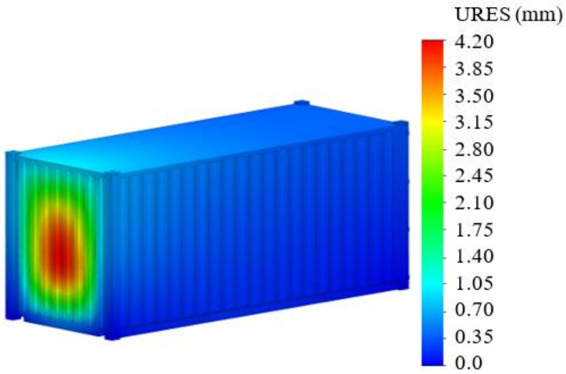

Fig. 9. **Displacements in the container units when the end wall is subject to a longitudinal load**

Conclusions

1. The longitudinal dynamic load of a container when transported in an open wagon is determined. The system of differential equations is solved using the Runge-Kutta method in MathCad. It is found that the acceleration acting on the container is about 40 $m \cdot s^{-2}$.
2. The strength of a container when transported in an open wagon is studied. Two loading diagrams of the container are taken into account: with the pressure of the transported freight on the end wall, and without it. The calculation results show that without the load pressure on the end wall of the container, the maximum stresses occur in the container fittings and amount to about 350 MPa. The maximum displacements occur in the cross bearer of the container and amount to about 1 mm.
3. If the freight in the container acts on the end wall of the container, the maximum stresses also occur in the fittings and amount to 364.8 MPa. Here, the maximum displacements occur in the middle of the end wall and amount to 4.2 mm. The results of the calculation show that the strength of the container is not ensured when transported in an open wagon.
4. The research will be useful for those developing new container transport technologies and can help improve the efficiency of container transport operations.

Acknowledgements

This publication was prepared thanks to support from the Cultural and Educational Grant Agency of the Ministry of Education of the Slovak Republic within the project KEGA 031ZU-4/2023: Development of key competencies of the graduate of the study program Vehicles and Engines; from the Slovak Research and Development Agency of the Ministry of Education, Science, Research and Sport in the project and VEGA 1/0513/22 "Investigation of the properties of railway brake components in simulated operating conditions on a flywheel brake stand" funded by the EU NextGenerationEU through the Recovery and Resilience Plan for Slovakia under the project No. 09I03-03-V01-00131.

Author contributions

Conceptualization, A.L..; methodology, A.L. and J.G.; software, J.D..; validation, A.L. and P.R.; formal analysis, J.D. and P.R..; investigation, A.L., J.G., J.D. and P.R.; data curation, A.L., J.G. an J.D.; writing – original draft preparation, J.D.; writing – review and editing, A.L. and J.D.; visualization, J.G., P.R..; project administration, A.L.; funding acquisition, J.D. All authors have read and agreed to the published version of the manuscript.

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