STRENGTH ASSESSMENT OF AN IMPROVED DESIGN OF A TANK CONTAINER UNDER OPERATING CONDITIONS

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Resume

The publication presents the results of research into the strength of an improved tank container. The tare of a tank container can be reduced through application of composite material for the tank. In this case its mass can be 46% lower than that of a metal tank. The strength of the tank was calculated by computer simulation. The maximum stress occurs in its lower part and is about 295 MPa.

The dynamic loading of a tank can be reduced by application of elastic elements in the fittings of a tank container. The reduction in dynamic load is achieved by the elastic friction forces generated in the fittings. The results of mathematical modelling of the tank container dynamics proved the effectiveness of this solution.

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1 Introduction

One of the most mobile transport facilities widely used for combined transportation is containers. This is by a reason, that they can be transported by almost all types of transport: rail, road, air and sea. In case of railway transport, containers are the most often transported on a flat car (Figure 1 [1]).

At present the use of tank containers is increasing due to higher volume of liquid freight transported along international transport corridors (Figure 2 [2-3]).

The demand for inter-modal tank containers is increasingly growing. There is a need for development and introduction of innovative tank containers with improved characteristics. The designing of such structures for tank containers requires the introduction of measures for their better strength during operational modes which will provide ecological compatibility [4-7] of combined transportation and lower maintenance costs.

2 Analysis of recent research and publications

The issue of the dynamic loading and the strength of tank containers was studied by many researchers. Study [8] presents the study of the loading to a tank container on the flat car during a shunting impact. The calculation of the accelerations to a tank container included a technological gap between fixed fittings and container fittings. The longitudinal forces on the flat wagon were approximately 2.2 - 2.8 MN according to the tank container load.

However, the maximum longitudinal force on the flatcar during shunting is 3.5 MN [9]. Therefore, improved values of accelerations to a tank container in operation can be obtained by means of additional research.

Studies [10-11] have presented the results of optimization of the tank car structures and substantiated development and introduction of tank containers as transport means into operation. They designed improved


a) b)

Figure 1 *Placement of containers on a flat car*
a) dry bulk containers; b) tank containers


a) b)

Figure 2 *Tank container*
a) model T11-254 / T11-254.2; b) model T14-254

tank container structures. The strength model of a tank container included the normative loading values given in [9]. The study into the strength of tank container with improved operational loading values (compliance of freight, displacements of container fittings relative to fixed fitting, etc.) was not included.

The strength calculation for a tank car in operational loading are described in article [12]. The authors used the ABAQUS calculation tool. The case of static loading on the tank container structure according to ISO 1496-3 [13] was included in the calculation.

Study [14] presents the calculation of the dynamic of a tank container transported by road or rail transport. This study was used for the research into an advanced tank container structure. Besides, these studies do not give the engineering solutions to reduction of the loading on the tank container structure.

The issue of how the structural solution for tank containers impacts their loading in operation is studied in [15]. The work caclulated the stress strain state of a tank container. The authors substantiated the structural solution for a hatch in the tank.

However this tank container structure does not include elements intended for reduction of the loading at operational loading modes.

Study [16] presents the research into the strength of a tank container. The authors analyzed how the finite element mesh influences the stresses of a tank container. However, the authors did not provide solutions for improvements in the bearing structure of a tank container for improved strength in operational modes.

The analysis of literature [8-16] shows that there is a possibility for further developments and improvements of the tank containers in order to provide their strength and higher operational efficiency.

3 The aim and main objectives of the article

The objective of the publication is research into the loading of the tank container with the tank of composite material and improved container fittings. The given objective can be achieved by means of the following tasks:

- determine the strength of the tank of a container of composite material; and
- study the longitudinal loading on the structure of a tank container on the flat car during a shunting impact.

4 Presentation of the main content of the article

In their previous studies the researchers developed the method to reduce the material capacity of tank container by improving its frame through replacing the rectangular cross-section, used in the standard structure, for the circular pipes which provide both strength conditions and operational reliability (Figure 3).

The new structure of a frame of container is calculated for loading mentioned in [9]. It was found that the improved structure of the frame is 354 kg lighter than that of its existing analogue, which together with their massive state produces a considerable economic effect.

The tank container tare can also be decreased if the tank is made of composite material. The mass can be reduced by 46 % in comparison with a metal tank. The substantiation of this solution was made with the computer modelling of the strength of the tank. The graphic work for the tank container have been made in SolidWorks (Figure 4).

The model included several pads mounted in the

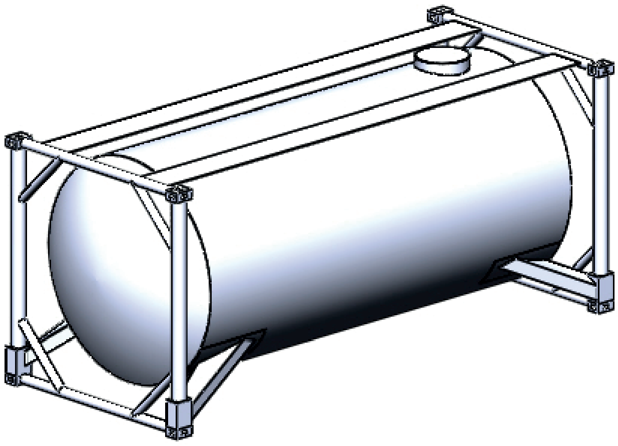

Figure 3 *Spatial model of an improved tank container*

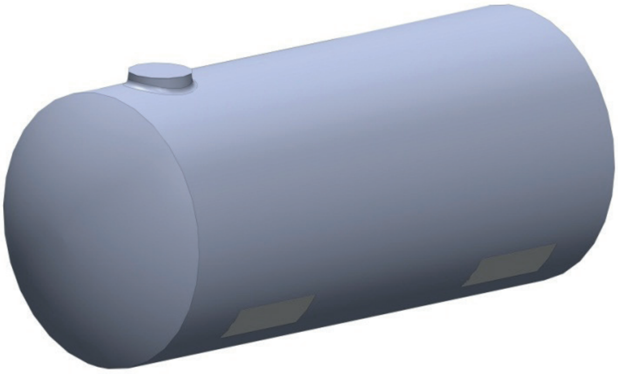

Figure 4 *Model of the tank*

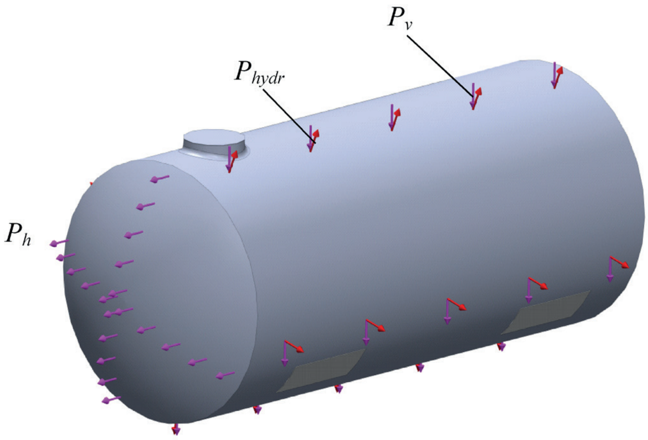

Figure 5 *Design diagram of the tank*

area where the tank rested on the frame with the geometry identical to the padding sheets.

The strength calculation was made with the FEM in SolidWorks Simulation [17-20].

It was taken into account that the tank was made of a composite with linear elastic orthotropic characteristics [21-22]. The limit strength along the fiber was 1100-1300 MPa and across the fiber - 650 MPa. The number of layers in the material was taken equal to 2. The strength calculation for the tank was made as if for a thin shell. The model was secured in the areas of support of the tank on the padding sheets. The model was rigidly fixed.

The FEM was built with tetrahedrons [23-24], the optimum of which was calculated with FAM [25-27].

The elements in the mesh was 13065, and nodes - 38714. The calculation diagram is given in Figure 5.

The pressure to the tank P_h was determined to the formula [9]:

$$P_h = N \cdot \frac{m_v}{m_{br}} \cdot \frac{1}{F}, \tag{1}$$

where:
N - impact force to a coupler, MN; m_v - mass of freight in the tank, kg; m_{br} - gross mass of a container, kg; F - area of the internal cross section of the tank, m^2.

Petrol was taken as liquid freight.

The hydrostatic pressure was determined by formula:

$$P_{hydr} = \rho \cdot g \cdot h, \tag{2}$$

where:
ρ - density of liquid freight, kg/m^3; h - height of the freight distribution in the tank, m; g - acceleration of gravity, m/s^2.

The maximum stresses in the tank of a tank container occur in its bottom part and amount to about 295 MPa (Figure 6), which is 8% lower than in the standard structure.

Distribution of the stresses by the length of the cylindrical (bottom) part of the tank is given in Figure 7.

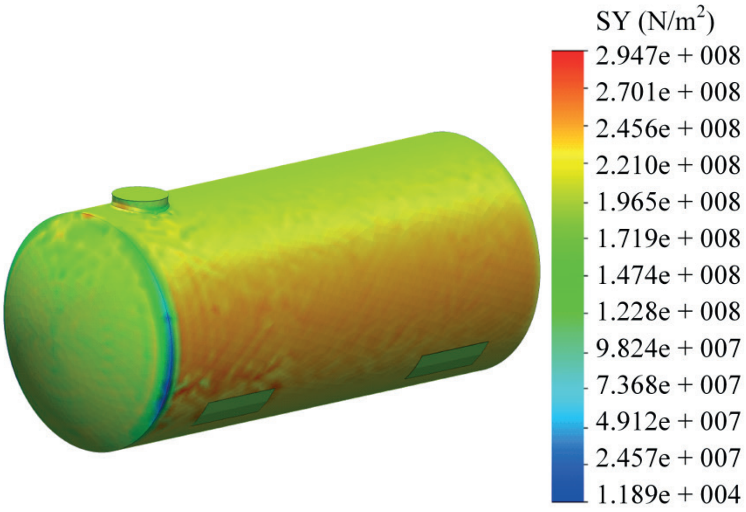

Figure 6 *Stress state of the tank*

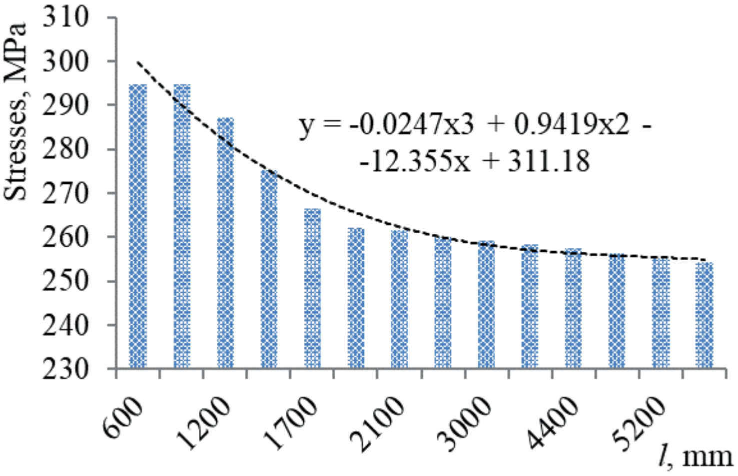

Figure 7 *Distribution of the stresses by the length of the cylindrical (bottom) part of the tank*

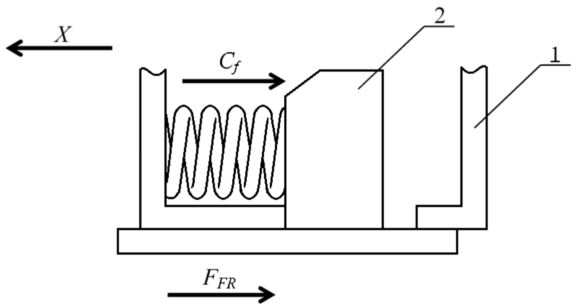

Figure 8 *Diagram of interaction container and flat car*
1 - container; 2 - flat car;
C_f - stiffness of the fitting spring, kN/m; F_{FR} - friction force, kN

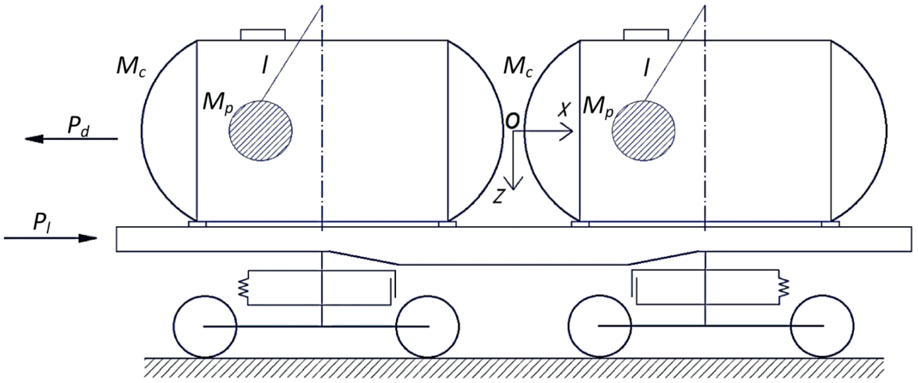

Figure 9 *Action of the longitudinal force to a flat car*

The maximum stresses occur on the side of the hatch and decrease along the tank length.

The loading of the tank can also be reduced by application of elastic elements in the tank container fittings (Figure 8).

The solution was substantiated through the mathematic modelling of the dynamic of a tank container. The calculation included the shunting impact of a flat car (Figure 9).

The accelerations of a tank container were studies through the mathematical model:

$$\begin{cases} M_{FC}^{gr} \cdot \ddot{q}_1 = P - \sum\limits_{i=1}^{n} \begin{pmatrix} F_{FR} \cdot sign(\dot{q}_1 - \dot{q}_2) + \\ + C_f(q_1 - q_2) \end{pmatrix}, \\ M_c \cdot \ddot{q}_2 = \sum\limits_{i=1}^{n} \begin{pmatrix} F_{FR} \cdot sign(\dot{q}_1 - \dot{q}_2) + \\ + C_f(q_1 - q_2) + M_P \cdot l \cdot q_3 \end{pmatrix}, \\ I_P \cdot \ddot{q}_3 = M_P \cdot l \cdot \ddot{q}_2 - g \cdot M_P \cdot l \cdot q_3, \end{cases} \tag{3}$$

where:
M_{FC}^{gr} - gross mass of a flat car, t; P_l - longitudinal force, kN; F_{FR} - friction force, kN; M_c - mass of a tank container, t; l_f - stiffness of elastic elements, kN/m; M_P - mass of a pendulum simulating the displacements of liquid freight in a tank container, t; l - length of a pendulum rod, m; I_P - inertia moment of a pendulum, t · m^2; q_1, q_2, q_3 - coordinates corresponding to displacements of flat car, tank container and freight relative to the longitudinal axle.

The movement of the liquid bulk cargo was described by a set of mathematical pendulums [8]. The value of the longitudinal impact force acting on the flat car was assumed to be 3.5 MN [9].

The hydrodynamic characteristics of the liquid bulk cargo were determined according to the method given in [28]. Petrol was taken into account as a liquid cargo. The hydrodynamic characteristics of the liquid cargo were made with the maximum admissible load of the tank container according to [29]. Based on the calculations performed in accordance with [28], the value of I_p = 250 t · m^2 was obtained.

Equation (3) was solved in MathCad [30-34]. To do this, it was reduced to the Cauchy form and then integrated using the Runge-Kutta method. In this case, one can write:

$$F(t,y) = \begin{bmatrix} y_2 \\ y_4 \\ y_6 \\ \dfrac{P_l - \sum\limits_{i=1}^{n} \begin{pmatrix} F_{FR} \cdot sign(y_2 - y_4) + \\ + C_f(y_1 - y_3) \end{pmatrix}}{M_{FC}^{gr}} \\ \dfrac{\sum\limits_{i=1}^{n} \begin{pmatrix} F_{FR} \cdot sign(y_2 - y_4) + \\ + C_f(y_1 - y_3) + M_P \cdot l \cdot y_5 \end{pmatrix}}{M_c} \\ \dfrac{M_P \cdot l \cdot \dot{y}_4 - g \cdot M_P \cdot l \cdot y_5}{I_P} \end{bmatrix}, \tag{4}$$

$$Z = rkfixed(Y0, tn, tk, n, F).$$

where:
Y0 - the vector with initial conditions, *tn, tk* - initial and final integration variables, *n’* - number of steps, *F* - the symbolic vector.

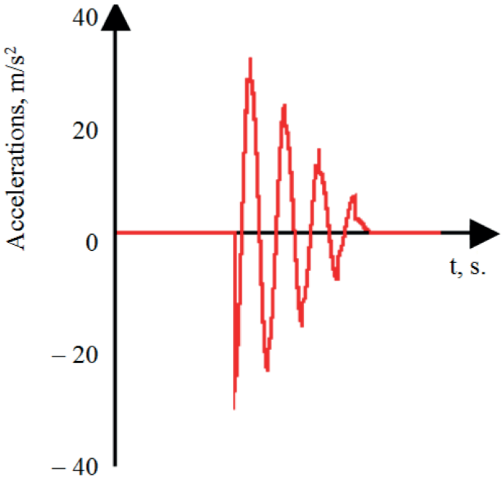

Figure 10 *Accelerations to the tank container*

The generalised accelerations acting on the components of the mechanical system were calculated in the array $ddq_{j,i}$:

$$ddq_{j,1} = \frac{P_l - \sum_{i=1}^{n} \begin{pmatrix} F_{FR} \cdot sign(y_2 - y_4) + \\ + C_f (y_1 - y_3) \end{pmatrix}}{M_{FC}^{gr}}, \tag{5}$$

$$ddq_{j,2} = \frac{\sum_{i=1}^{n} \begin{pmatrix} F_{FR} \cdot sign(y_2 - y_4) + \\ + C_f (y_1 - y_3) + M_p \cdot l \cdot y_5 \end{pmatrix}}{M_c}, \tag{6}$$

$$ddq_{j,3} = \frac{M_P \cdot l \cdot \dot{y}_4 - g \cdot M_P \cdot l \cdot y_5}{I_P}. \tag{7}$$

On the basis of the calculation the authors obtained the accelerations of an improved tank container structure (Figure 10).

This value of acceleration was about 40 m/s² ($\approx$4g), thus it was within the allowable values.

5 Conclusions

The study deals with calculation of the strength of a tank container made of composite material and fittings with elastic-friction bonding. The use of composite materials will reduce the weight of the boiler by 46% compared with metal. The use of elastic-friction bonds in the fittings will reduce the dynamic load of the tank container during the operational regimes.

To investigate the strength of the tank container boiler, calculations were made using the finite element method. The stresses in the tank occur in its bottom part and amount to about 295 MPa, which is 8% lower than that of the standard structure.

The longitudinal loading on the improved container located on the car during a shunting impact was studied. It was found that the accelerations to a container were about 40 m/s² (4g); the calculation included the elastic-frictional connections in the fittings; they do not exceed the allowable values. The total rigidity of the elastic elements for one tank container must be within a range of 426 - 535 kN/m.

This study will contribute to the development of tank containers with better technical and operational characteristics, higher operational efficiency and improved environmental friendliness of container transport.

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Conflicts of interest

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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