Loading on the carrying structure of a flat wagon when transporting firing military equipment Loading on the carrying structure of a flat wagon when transporting firing military eq...

Article *in* IOP Conference Series Materials Science and Engineering · December 2020

DOI: 10.1088/1757-899X/1002/1/012012

3 authors:

O. V. Fomin
State University of Infrastructure and Technologies, Kyiv, Ukraine
252 PUBLICATIONS **1,538** CITATIONS
SEE PROFILE

Glib Vatulia
O.M. Beketov National University of Urban Economy in Kharkiv
76 PUBLICATIONS **473** CITATIONS
SEE PROFILE

Alyona Lovska
Ukrainian State University of Railway Transport
220 PUBLICATIONS **1,315** CITATIONS
SEE PROFILE

PAPER • OPEN ACCESS

Loading on the carrying structure of a flat wagon when transporting firing military equipment

Loading on the carrying structure of a flat wagon when transporting firing military equipment

O Fomin[1], G Vatulia[2] and A Lovska[3,4]

[1] Department of Cars and Carriage Facilities, State University of Infrastructure and Technologies, Kyrylivska str., 9, Kyiv, Ukraine, 04071
[2] Department of Structural Mechanics and Hydraulics, Ukrainian State University of Railway Transport, Feuerbach sq., 7, Kharkiv, Ukraine, 61050
[3] Department of Wagons, Ukrainian State University of Railway Transport, Feuerbach sq., 7, Kharkiv, Ukraine, 61050

[4] E-mail: alyonalovskaya.vagons@gmail.com

Abstract. The study deals with research through mathematic modeling of the dynamic loading on the carrying structure of a flat wagon in transportation of military equipment conducting fire. A 13-401 flat wagon loaded with a tank with combat load of 55 tons was taken as the prototype. The mathematical model was solved in MathCad software. It was established that the maximum acceleration on the carrying structure of a flat wagon in the horizontal plane was about 40 m/sec^2, and in the vertical plane – about 10 m/sec^2. The values obtained were considered in strength calculation for a flat wagon. The calculation was made using the finite element method in CosmosWorks software. It was established that the maximum equivalent stresses in the carrying structure of a flat wagon exceeded the admissible values twice. The results of the study will encourage engineers to design carrying structures of flat wagons intended for transporting military equipment firing in motion

1. Introduction

Prospects in the technical and economic development of European countries, as well as enhancing their national defense and security require higher efficiency of the rolling stock of railway transport, as a leading industry of the transportation system. Therefore, there is a need to implement highly efficient interoperable railway equipment in operation. In order to ensure their defense prospective European countries have to solve the problem of formation of special fleet of wagons to transport military equipment.

It is known that one of the most widely spread types of wagons for transportation of military equipment are flat wagons (figure 1 [1, 2]).

There are several ways to fix military equipment on a flat wagon:

- standard multiple-thread fixtures (1st method);
- metal lugs (2nd method);
- wooden support beams and bracing (standard) wires (3rd method);
- metal support brake shoes and wooden pads (4th method);
- wooden support beams and pads (5th method);
- tension cables and screw cramps (6th method).

All those methods, except the 5th one, are used for transporting equipment as part of military trains, including guarded ones [3]. Special railway cars for transportation of military equipment and research into the possibility to fire in motion are of considerable importance for ensuring national defense.

Figure 1. Flat wagons loaded with military equipment.

Calculation of capacity indexes for a flat wagon under transportation of containers and loading/unloading with the ACTS system was conducted in [4, 5].The strength calculation was conducted in the static setting in Nastran software. Numerical values of the designed loads on a flat wagon were taken according to the PNEN12663 and BN – 77/3532 – 40 Standards.

The structural features of a flat wagon for intermodal transportation are presented in [6]. The study outlines the general technological requirements in terms of organization of intermodal transportation and their advantages. Study [7] substantiates the efficiency of flat wagons for transportation of containers, including tank containers produced by Transmash (Russia).The loading capacity of a flat wagon is 73 tons and it can transport 1CC, 1C and 1CX containers. However, they do not study the possibility to transport military equipment firing in motion by flat wagons.

Research into the dynamics of a rail wagon with open charging floors is given in [8].The calculation is made in MSC Adams software. The study deals with research into the stability of a wagon against swinging-over along 250-m curves at different traffic speeds.

Dynamic loading on a flat wagon transporting military equipment is not considered.

Dynamic loading on a flat wagon in operational modes is defined in [9, 10].The studies present mathematical models which characterize the most unfavorable loading modes of carrying structures of flat wagons. However, loading on wagons, while transporting military equipment, is not determined in the studies.

The objective of the study is research into loading on the carrying structure of a flat wagon transporting firing military equipment conducting fire. To achieve the objective the following tasks were set:

- mathematical modeling of dynamic loads on the carrying structure of a flat wagon transporting firing military equipment;
- strength characteristics of the carrying structure of a flat wagon transporting firing military equipment.

2. Mathematical modeling of dynamic loads on the carrying structure of a flat wagon with a tank firing from it

A mathematical model was built to study the possibility to transport a military tank and conduct fire in motion. The study used the mathematical model given in [11].The model was improved with an additional degree of freedom – oscillations in the longitudinal plane. Therefore, the study deals with the movement of a flat wagon loaded with a military tank in longitudinal and vertical planes. The design diagram is presented in figure 2.The calculation was made in the plane coordinates. The firing process while the wagon was passing over a joint track irregularity has been considered.

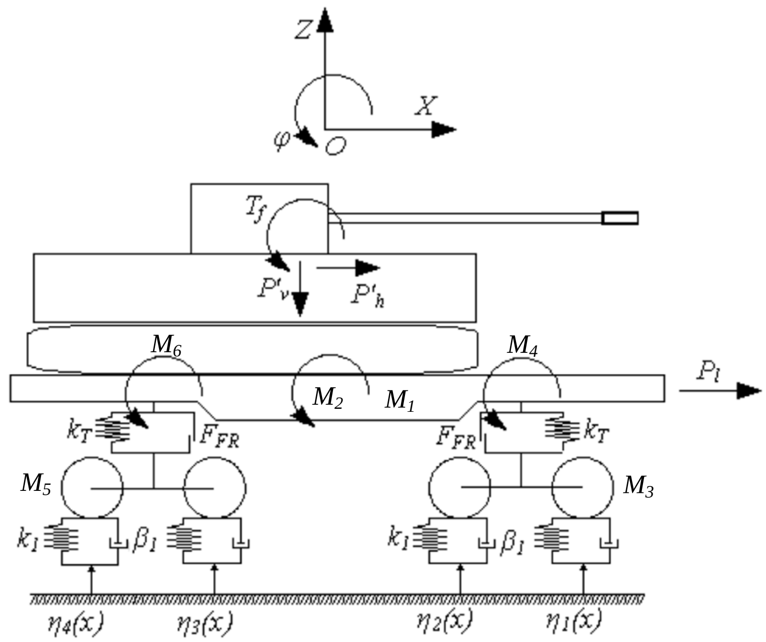

Figure 2. Design diagram of a flat wagon loaded with a military tank.

The equation of motion for the design model is as follows:

$$M_1 \frac{d^2}{dt^2} q_1 + M' \frac{d^2}{dt^2} q_3 = P_l + P'_h; \quad (1)$$

$$M_1 \frac{d^2}{dt^2} q_2 + C_{2,2} q_2 + C_{2,5} q_5 + C_{2,8} q_8 = -F_{FR} \left(sign\left(\frac{d}{dt}\delta_1\right) + sign\left(\frac{d}{dt}\delta_2\right) \right) + P'_v; \quad (2)$$

$$M_2 \frac{d^2}{dt^2} q_3 + C_{3,3} q_3 + C_{3,5} q_5 + C_{3,8} q_8 = F_{FR} l \left(sign\left(\frac{d}{dt}\delta_1\right) + sign\left(\frac{d}{dt}\delta_2\right) \right) + T_f; \quad (3)$$

$$M_3 \frac{d^2}{dt^2} q_4 = 0; \quad (4)$$

$$M_3 \frac{d^2}{dt^2} q_5 + C_{5,2} q_2 + C_{5,3} q_3 + C_{5,5} q_5 + B_{5,5} \frac{d}{dt} q_5 = F_{FR} sign\left(\frac{d}{dt}\delta_1\right) + k_1(\eta_1 + \eta_2) + \beta_1 \left(\frac{d}{dt}\eta_1 + \frac{d}{dt}\eta_2\right); \quad (5)$$

$$M_4 \frac{d^2}{dt^2} q_6 + C_{6,6} q_6 + B_{6,6} \frac{d}{dt} q_6 = -k_1(\eta_1 - \eta_2) - \beta_1 a \left(\frac{d}{dt}\eta_1 - \frac{d}{dt}\eta_2\right); \quad (6)$$

$$M_5 \frac{d^2}{dt^2} q_7 = 0; \tag{7}$$

$$M_5 \frac{d^2}{dt^2} q_8 + C_{8,2} q_2 + C_{8,3} q_3 + C_{8,8} q_8 + B_{8,8} \frac{d}{dt} q_8 = F_{FR} sign\left(\frac{d}{dt}\delta_2\right) + k_1(\eta_3 + \eta_4) + \beta_1\left(\frac{d}{dt}\eta_3 + \frac{d}{dt}\eta_4\right); \tag{8}$$

$$M_6 \frac{d^2}{dt^2} q_9 + C_{9,9} q_9 + B_{9,9} \frac{d}{dt} q_9 = -k_1 a(\eta_3 - \eta_4) - \beta_1 a\left(\frac{d}{dt}\eta_3 - \frac{d}{dt}\eta_4\right), \tag{9}$$

where M_1, M_2 – weight and moment of inertia of the flat wagon supporting structure respectively; M_3, M_4 – weight and moment of inertia of the first bogie in the direction of travel respectively; M_5, M_6 – weight and moment of inertia of the second bogie in the direction of travel respectively; C_{ij} – elasticity characteristic of the vibration system elements; B_{ij} – pattern density function; a – half bogie wheelbase; q_i – specified coordinates corresponding to translational displacements relative to the longitudinal and vertical axes and angular displacements around the vertical axis; k_T – spring suspension rigidity; k_1 – rigidity of track; β_1 – damping factor; $\eta_i(x)$ – function that describes the track irregularity; δ_i – deformation of elastic elements of spring suspension; F_{FR} – absolute friction force in a spring complex; P_l – longitudinal loading on the automatic coupling supports; P_v', P_h' – loads on the carrying structure in vertical and horizontal planes in firing, respectively; T_f– moment on the carrying structure of a flat wagon with a tank firing from it.

Here the first equation characterizes a longitudinal displacement of the body, the second one – a vertical displacement of the body, the third – an angular, the forth, the fifth, and the sixth equations – displacements of the first body, respectively, and the seventh, eighth and ninth – displacements of the second body.

The matrix of elastic coefficients looks like:

$$C = \begin{vmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2k_T & 0 & 0 & -k_T & 0 & 0 & -k_T & 0 \\ 0 & 0 & 2k_T l^2 & 0 & k_T l & 0 & 0 & k_T l & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -k_T & k_T l & 0 & k_T + 2k_1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 2k_1 a^2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -k_T & k_T l & 0 & 0 & 0 & 0 & k_T + 2k_1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2k_1 a^2 \end{vmatrix} \tag{10}$$

and the matrix of dissipative coefficients has the form:

$$B = \begin{vmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2\beta_1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 2\beta_1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2\beta_1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2\beta_1 \end{vmatrix}. \tag{11}$$

The initial displacement and speeds were taken to be equal to zero. The input parameters of the model were technical characteristics of the carrying structure of a flat wagon, spring suspension, perturbation action, and engineering characteristics of a tank (table 1). The duration of the shock pulse action on a wagon from rail irregularity was taken to be equal to 0.1 sec at the speed 80 km/h. The calculation considered spring suspension parameters of an 18-100 bogie. There is a rule in artillery science that 3% out of the muzzle energy of a missile is consumed by the mechanical recoil energy [12].Therefore, on the basis of the work the authors obtained the loading on the carrying structure of a flat wagon transporting a tank firing from it. The rate of fire of a tank was taken to be 12 rds/min. The model considered one round in 5 sec.

Table 1. The input parameters of the model.

Name of the parameter	Value
CARRYING STRUCTURE OF A FLAT WAGON	
mass, t	11.5
moment of inertia, t·m^2	198.2
half base, m	4.86
BOGIE	
mass, t	4.3
moment of inertia, t·m^2	3.0
half base, m	0.925
rigidity of spring suspension of one bogie, kN/m	8000
coefficient of relative friction	0.1
TRACK CHARACTERISTICS	
damping factor, kN·sec/m	200
rigidity, kN/m	100000
amplitude of inequality, m	0.01
distance between the inequalities, m	25
TANK	
mass, t	55
length of the body with a gun, m	10.8
muzzle energy, mJ	24

Differential equations (1) – (9) were reduced to standard Cauchy problems. Then they were integrated by the Runge-Kutta method [13, 14]. On the basis of the calculation the authors defined the accelerations on a flat wagon during fire from the tank at various fire angles in horizontal and vertical planes. Besides, they considered the most unfavorable loading on the carrying structure of a flat wagon, particularly, movement over a joint track irregularity with simultaneous firing. The peak value of acceleration was about 40 m/sec^2. The maximum acceleration affected the carrying structure of a flat wagon at a fire angle of 30°. The pattern of change in accelerations on the carrying structure of a flat wagon at a fire angle of 30° is given in figures 3 and 4.

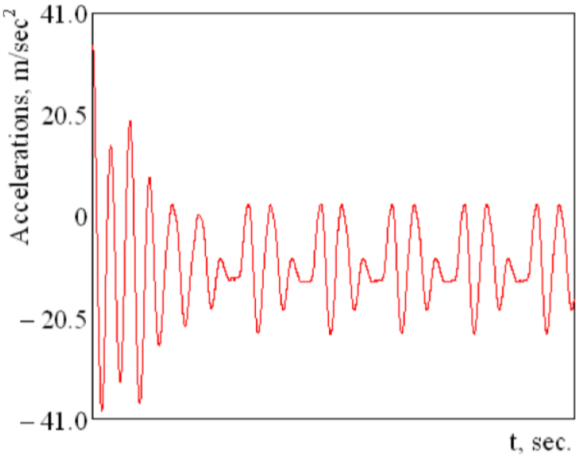

Figure 3. Accelerations in the mass center of the carrying structure of a flat wagon (the gun is at an angle of 30° relative to the longitudinal axle of a wagon) in the horizontal plane.

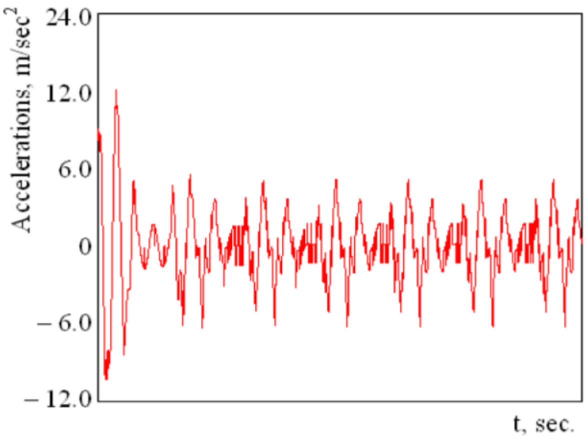

Figure 4. Accelerations in the mass center of the carrying structure of a flat wagon (the gun is at an angle of 30° relative to the longitudinal axle of a wagon) in the vertical plane.

3. Strength characteristics of the carrying structure of a flat wagon with a tank firing

The accelerations obtained were taken into account when determining strength values of the carrying structure of a flat wagon. The calculation was made for a 13-401 flat wagon. For modeling loads on the carrying structure of a flat wagon from a tank, the flat wagon was equipped with pads imitating the support part of caterpillar tracks (figure 5). The calculation was conducted with the finite element method in CosmosWorks software (figure 6). Spatial tetrahedrons were used as finite elements for the continuous model. The optimal number of elements was calculated with the graphical analytical method [15, 16]. The model consisted of 114,459 units and 353,604 elements. The maximum size of an element was 235.62 mm, and the minimum – 47.12 mm. The percentage of elements with a side ratio less than three was 24.7, and more than ten – 31. The minimum number of elements in the circle was 9, and a gain ratio of the size of an element was 1.8.

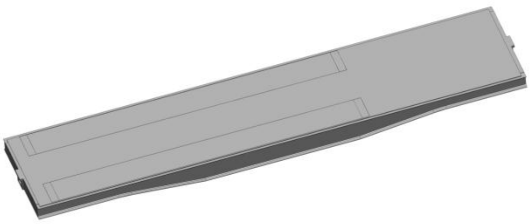

Figure 5. Spatial model of the carrying structure of a flat wagon.

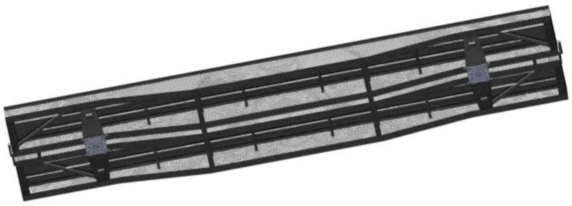

Figure 6. Finite element model of the carrying structure of a flat wagon.

The design diagram of the carrying structure of a flat wagon is given in figure 7. The design diagram takes into account that the longitudinal loading P_l 2.5 MN impacted the frontal supports of the automatic coupling device. The vertical load P_v from the gross weight of the tank and load P_f in the fixation areas impacted the carrying structure of a flat wagon. Due to the angular location of fixation elements, load P_f was decomposed. The model was fixed in the areas where it rested on the gear parts. Steel 09G2S was used as structural material for a flat wagon.

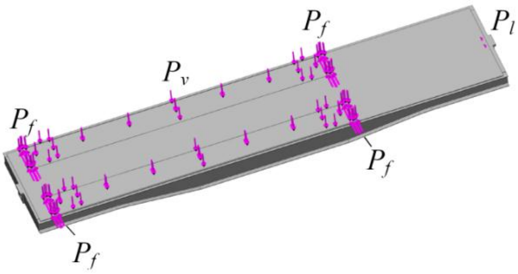

Figure 7. Design diagram of the carrying structure of a flat wagon.

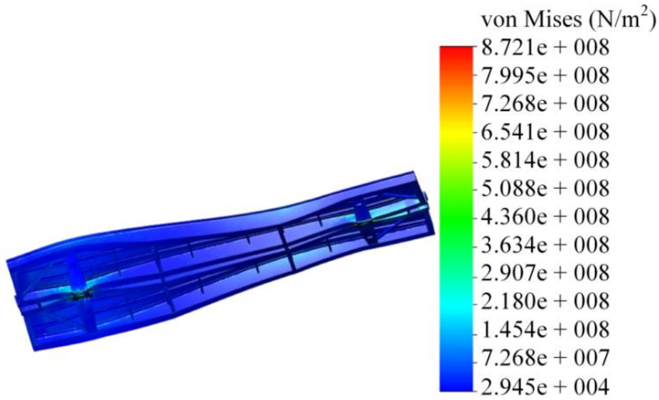

Figure 8. Stress strain behavior of the carrying structure of a flat wagon (deformation scale 50:1).

On the basis of the calculation the authors defined the basic strength parameters of the carrying structure of a flat wagon. The maximum equivalent stresses emerged in the areas where the carrying structure of the flat wagon rested on the bogies. Numerical values of the maximum equivalent stresses were about 870 MPa (figure 8). The maximum equivalent stresses exceeded the admissible values twice [17 – 19]. The maximum displacements were about 27.3 mm. The maximum deformations were $1.15 \cdot 10^{-2}$. Therefore, it is not possible for a flat wagon to carry a tank that is firing.

4. Conclusions

- The authors conducted the mathematical modeling of dynamic loads on the carrying structure of a flat wagon while conducting fire. Besides, they considered the most unfavorable loading on the carrying structure of a flat wagon, particularly, movement over a joint track irregularity with simultaneous firing. The peak acceleration on the carrying structure of a flat wagon in the horizontal plane was about 40 m/sec^2, and in the vertical plane – about 10 m/sec^2.
- The study defined the strength characteristics of the carrying structure of a flat wagon with a tank firing from it. The calculation was conducted with the finite element method in CosmosWorks software. The maximum equivalent stresses emerged in areas where the carrying structure of a flat wagon rested on the bogies and they were about 870 MPa; the maximum displacements were 27.3 mm, and the maximum deformations were $1.15 \cdot 10^{-2}$.

The research confirmed that the flat wagon does not have the needed strength to ensure safe transportation and simultaneous gun firing. The results of the study will encourage engineers to design carrying structures of flat wagons intended for transportation of military equipment firing in motion.

Acknowledgments

The research was conducted under a project for young researchers "Innovative approaches in designing resource-saving rail car structures based on refined dynamic loading and functional-adaptive flash-concepts", supported by the State Budget of Ukraine since 2020.

References

[1] 2017 New wagon certified at Uralvagonzavodhttps: //vsenovostint.ru/2017/04/11/novyiy-vagon-platformu-sertifitsirovali-na-uvz/ (In Russian)
[2] 2019 T-34 tanks in Irkutsk: echelon with 30 military weapons visited the capital of Eastern Siberia https://irkutsk.bezformata.com/listnews/tanki-t-34-v-irkutske-eshelon-s-30-boevimi/72165957/ (In Russian)
[3] 1987 Manual on the transport of troops by rail, sea, river and air transport (Cham: Moscow Military publication) p 124 (In Russian)

[4] Chlus K and Krason W 2011 Dynamic analysis of railway platform chassis model *Journal of KONES Powertrain and Transport* **182** pp 93–100
[5] Chlus K and Krason W 2012 Numerical standard tests of railway carriage platform *Journal of KONES Powertrain and Transport* **193** pp 59–64
[6] Nader M, Sala M, Korzeb J and Kostrzewski A 2014 Kolejowy wagon transportowy jako nowatorskie, innowacyjne rozwiązanie konstrukcyjne do przewozu naczep siodłowych i zestawów drogowych dla transportu intermodalnego *Logistyka* **4** pp 2272–9
[7] 2015 Switching over to the home platform *J. for partners Transmashholding* **3 09** pp 22–3
[8] Niezgoda T and Krason W and Stankiewicz M 2012 Simulations of motion of prototype railway wagon with rotatable loading floor carried out in MSC Adams software *Journal of KONES Powertrain and* Transport **194** pp 495–502
[9] Fomin O, Lovska A, Kulbovskyi I, Holub H, Kozarchuk I and Kharuta V 2019 Determining the dynamic loading on a semi-wagon when fixing it with a viscous coupling to a ferry deck *Eastern-European Journal of Enterprise Technologies* **8 2/7**(98) pp 6–12
[10] Lovskaya A and Rybin A 2016 The study of dynamic load on a wagon-platform at a shunting collision *Eastern-European Journal of Enterprise Technologies* **3** pp 4–8
[11] Domin Yu V and Chernyak G Yu 2003 Basics of carriage dynamics (Cham: Kiyiv KUETT) p 269 (In Ukrainian)
[12] Zelenskij E P, Smolyar B S and Belokur M N 1990 Textbook sergeant rocket troops and artillery (Cham: Moskow Military publication) p 227 (In Russian)
[13] Fomin O, Lovska A, Píštěk V and Kučera P 2020 Research of stability of containers in the combined trains during transportation by railroad ferry *MM Science Journal* **March** pp 3728–33
[14] Fomin O, Kulbovsky I, Sorochinska E, Sapronova S and Bambura O 2017 Experimental confirmation of the theory of implementation of the coupled design of center girder of the hopper wagons for iron ore pellets *Eastern-European Journal of Enterprise* Technologies **5 1**(89) pp 11–8
[15] Vatulia G, Falendysh A, Orel Y and Pavliuchenkov M 2017 Structural improvements in a tank wagon with modern software packages *Procedia Engineering* **187** pp 301–7
[16] Kitov Y, Verevicheva M, Vatulia G, Orel Y and Deryzemlia S 2017 Design solutions for structures with optimal internal stress distribution *MATEC Web of Conf.* **133**(1–3) 03001
[17] DSTU 7598:2014 2014 Freight wagons. General requirements for the calculation and design of new and upgraded rail wagons 1520 mm (non-self-propelled) p 162 (In Ukrainian)
[18] GOST 33211-2014 2014 Freight wagons. Requirements for strength and dynamic qualities p 54 (In Russian)
[19] DIN EN 12663-2-2010 2010 Railway applications – Structural requirements of railway vehicle bodies – Part 2: Freight wagons p 54