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Peculiarities of computer modeling of strength of body bearing construction of gondola car during transportation by ferry-bridge

Alena Lovska

Dr.-Ing.,
Senior lector of Carriage department
Ukrainian State Academy of railway transport

Abstract
The article shows the results of researches of gondola car body strength taking into account its design innovation for the transportation by ferry-bridge. There developed strength model of bearing construction of gondola car body, which takes into account the forces affecting it in conditions of angular displacement towards the axis of elongation of ferry-bridge (heel). The results obtained allowed to conclude that gondola car body strength taking into account suggested measures concerning its construction improvement during shipping are provided. This allows to increase effectiveness of railway-ferry transportation of cars by ship and also to provide protection of their bearing constructions during interaction with reinforcing tools towards the deck.
Key words: GONDOLA CAR, CAR DYNAMICS, STRENGTH, STRAIN-STRESS STATE, ADAPTATION OF CONSTRUCTION, COMBINED RAILWAY FERRY TRANSPORT, RAILWAY FERRY SERVICE.

Problem statement

Heightened rates of Ukrainian integration into the system of international travel corridors causes the necessity to create combined transport systems, where one of the most successful ones are railway ferry traffic. Car motion by ferry-bridge (FB) by sea in conditions of its heaving is accompanied by appearance and action of forces on the bearing construction of gondola car bodies, which differ from exploitation ones towards main-line trackage.

Investigation of maintenance conditions of cars during their transportation by FB on the Black Sea showed that there takes place damage of elements of bearing construction of the body, which is conditioned by affection of loads exceeding exploitation ones against main-line trackage and also technical inadaptability to reliable interaction with multiway fastener towards the deck.

Analysis of latest researches

There are a lot of scientific works of Omsk Institute, which are devoted to strength analysis of gondola car bodies made of aluminum alloys taking into account material nonlinearity of material. Herein there used generalized method of forces [1]. But there is no focus on the determination of stresses in car body elements during their transportation by FB.

The question concerning possibility of service life extension of gondola cars is considered in [2]. There was developed methodology of technical diagnosis of gondola cars, on the assumption of which there suggested determination of the final service lifetime of gondola cars on the base of strength, stiffness and remaining lifetime analysis.

It is necessary to mark that the presented in the work finite-element model (FEM) of the gondola car body does not consider the possibility of loading, affecting it trough the reinforcing tools relatively the decks of FB taking into account combined railway-ferry interaction.

Recommendations concerning usage of software for estimation of efficiency of railway transport objects are given in [3]. In connection with the fact that while usage of modern methods for stress calculation there absent recommendations concerning necessary degree of discretization of zones of certain objects, it is suggested to work out new methods of calculation and results analysis. FEM of elements of gondola car bodies are given.

D.G. Beyn (Bryansk city) was engaged into investigation of optimization of car bodies of open type [4]. His work gives refined analysis of stress state and structure parametric optimization of side walls. For stress calculation in body liner there suggested modified laminar- beam model.
It is significant that the forces, which will affect the body during their transportation by sea by FB were not considered.

Calculation method of gondola car body as combined laminar-beam system is given in [5]. Authors fulfilled calculation of body elements for strength with the usage of software.

To determine reaction matrix coefficients under displacement method there applied elastic theory. On the base of the program there was fulfilled a range of calculation concerning 8-wheel gondola cars.

To the questions concerning car bodies strength during combined interaction with other types of transport are not paid attention.

Investigation of strain stress state of draw-bar of gondola car taking into account fitting of assemblies of fixation of chain tie hooks is given in [6]. On the base of fulfilled researches there was concluded that stress in construction does not exceed allowed one, this proves the possibility of its improvement with the aim to adopt it to interaction with multiway FB fastener. It is important to note that draw-bar is the constructional element of car frame, which works in conjunction with other frame elements,that is why to achieve more accurate result it is necessary to investigate gondola care body strength in general.

Aim of the article

To throw light on the peculiarities of computer modeling of strength of bearing construction of gondola car body during FB transportation.

Statement of base material

To provide stiffness of bearing constructions of gondola car body during their FB transportation, at the department "Cars" Ukrdazt (Kharkow) there was developed special unit for fixation of bodies towards the deck (fig. 1), [6].

a) front elevation

b) side elevation

Figure 1. Arrangement of units for fixation of cars towards decks on draw-bars of gondola cars

Space model of gondola car was built for investigation of its body bearing construction strength. Herein position of intensive diaphragms was fulfilled to provide stiffness of cross section of draw-bar at the level of units of fixation of chain ties. Calculation is fulfilled on the example of general-purpose gondola car, model 12-757, constructed by “Kryukovsky railway car building works”, JSC with the application of finite elements method. During development of strength computer model there considered the elements, which interact hard together.

In connection with the fact that hatch doors are connected with body frame not hard but pivotally and fulfill the function of elements, which transfer a load to the hard connected frame elements, they were not considered in the model.

During model development axial forces, conditioned by probable movements of body by means of automatic coupling device, were not considered

Model of gondola car body strength in conditions of FB rolling motion, as the case of the greatest load of car bearing construction (fig.2), considers the following loads: vertical static p_v, wind p_w, arch action of bulk load p_a, inertial loading and loadings, which affect the car body through chain ties p_t. Due to space arrangement of chain tie, the strain, which will be transferred to the bearing construction of gondola car body by means of it, was dissolved (fig. 3). Real areas of loads application to the units of fixation of chain ties were simulated by means of arrangement of special elements – plates, configuration of which is identic to the shape of contact area of hook interaction. This allowed to simulate with maximum approximation fixation of gondola car body towards the deck. Numerical values of loads, which affect the bearing construction of gondola car body in conditions of FB rolling motion are given in the table 1. During determination of loads on the car body it is considered that heel is caused by static action of the wind on the abovewater projection of FB with car body, placed towards its top deck. In respect with real hydrometeorological characteristics of Black Sea the angle of roll was 12.2^0.

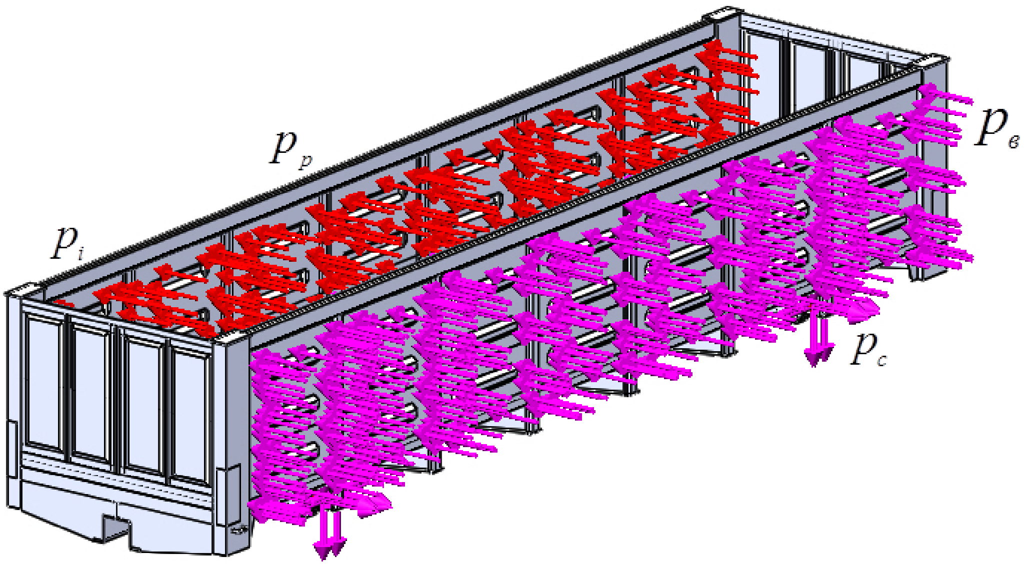


Figure 2. Strength model of gondola car body

In the zones of gondola car body bearing on the bogie center plates, side bearing and support jacks there were settled additional couplings.

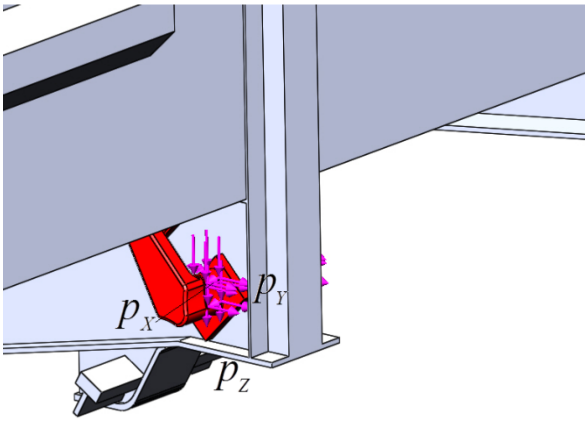


Figure 3. The scheme of stress application from chain tie on the fusing unit

Table 1. Forces affecting gondola car body in conditions of heaving

Forces affecting gondola car body					Stress components from chain ties, kN								
					Inertia efforts, kN			Wind effort, kN			Efforts from tension of chain ties kN		
Vertical steady-state force, kN	Inertia efforts, kN	Wind effort , kN	Arch action efforts, kPa	Efforts from tension of chain ties, kN	XY	YZ	XZ	XY	YZ	XZ	XY	YZ	XZ
p_z=811	175	9.4	15.5 -1.02	54	p_x=31 p_y=31	p_y=22 p_z=38	p_x=21.9 p_z=38	p_x=1,7 p_y=1.7	p_y=1.2 p_z=2,04	p_x=2.04 p_z=1,2	p_x=27 p_y=47	p_y=27 p_z=47	p_x=27 p_z=47

During creation of FEM (fig. 4) there were used isoparametric tetrahedrons, optimal amount of which is determined by graphic analytic method. Amount of grid element was 288 951, units - 94664, maximum dimension of element – 120 mm, minimum – 24 mm, maximum aspect ratio of elements – 571,21, the rate of elements with aspect ratio less than 3-16, more than 10-36.6.

Developed FEM of gondola car body allows to make calculations for strength not only under common conditions of car exploitation, but also on FB, taking into account various conditions of construction loads.

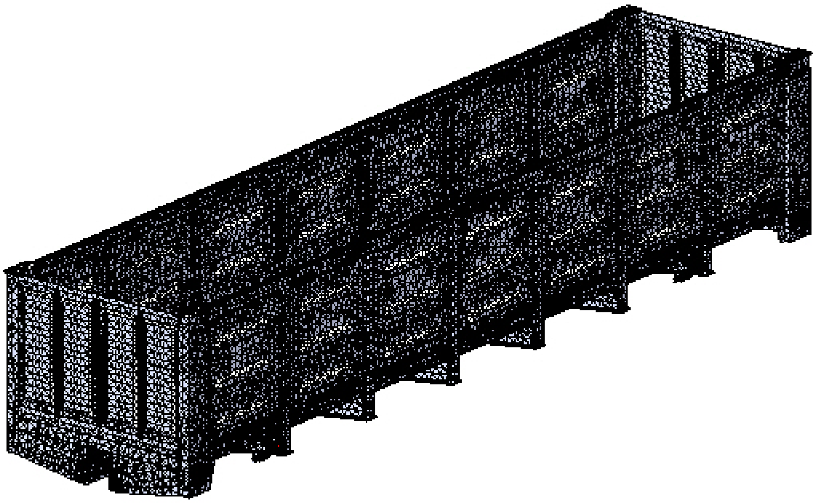
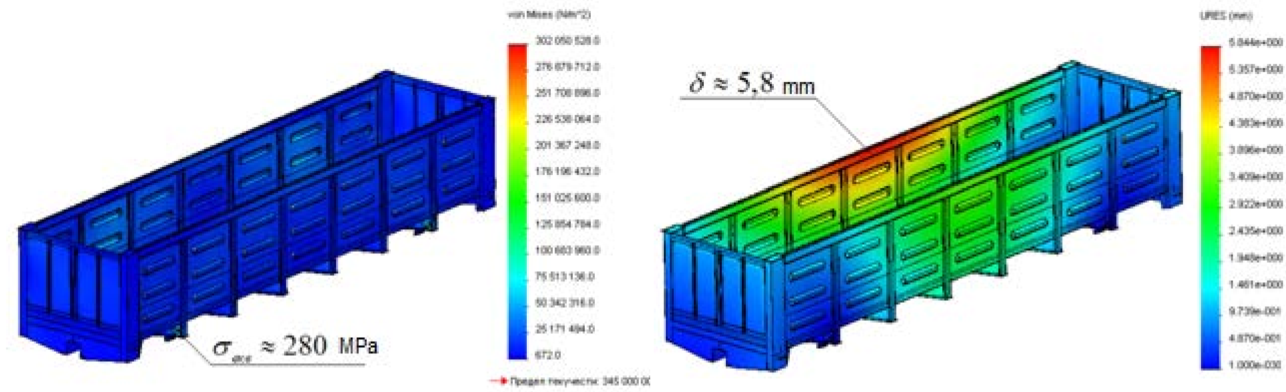


Figure 4. Finite-element model of gondola car body

Calculation results of fulfilled researches, given in the figure 5, allow to conclude that maximum equivalent stresses appear in radial part of assembly to fix chain tie and make almost 280 MPa. Stress in vertical sheet of draw-bar is within the limits of 176 MPa and does not exceed allowed ones for steel grade of body metalware. Maximum displacement arises in the middle part of body side wall of gondola car from the side of its inclination during heel and makes 5.8 mm.



a) stress condition; b) motions in the construction units

Figure 5. Calculation results for strength of bearing construction of gondola car body

To investigate fatigue strength of bearing construction of gondola car body during its transportation by FB in conditions of heaving there was fulfilled calculations for fatigue within CosmosWorks software. Study base here was 10 cycles. The results obtained allowed to conclude that in respect with cyclicity of loads of gondola car body its stiffness is provided.

With the aim of determination of project life service of bearing construction of gondola car body in respect with adaptation measures to the FB transportation, there was used methodology used in [7]:

$$T_n = \frac{\left(\sigma_{-1W}/[n]\right)^m \cdot N_0}{B \cdot f_e \cdot \sigma_r^m},$$

where σ_{-1w} - average value of workpiece endurance strength, MPa;

n – allowable coefficient of resistance;

m - exponent of power of fatigue curve;

N_0 – testing base;

B – coefficient, which characterizes the time of object continuous work in seconds;

f_e - effective frequency of dynamic stress, c^{-1};

σ_r – range of equivalent dynamic stress, MPa.

There accepted the following parameters during calculations: average value of endurance strength of bearing construction of gondola car body was determined by 0.5 σ_T of material (steel grade 09Mn2Cu, 09Mn2Si) and was 172.5 MPa; testing base – 10^7 cycles (recommended testing base for steel); continuous work time of bearing construction of car body was $1{,}5 \cdot 10^6$ s (determined on the base of real rotation of FB); effective frequency of dynamic stresses is determined on the base of parameters of disturbing effect (water wave) and for waves with the period 9 s was 0.1 hz; allowable coefficient of resistance equals 2; exponent of power of fatigue curve for welding construction is equal to 4; range of equivalent dynamic stresses is determined on the base of fulfilled calculations of (SSS) of bearing construction of gondola car body and was 176.2 MPa.

On the base of fulfilled calculations design lifetime of bearing construction of gondola car body taking into account its constant exploitation on FB was about 30 years, and the unit for fixation of chain tie about 6 years.

It is necessary to point out that got lifetime of the unit for fixation will be of great importance as its loading is fulfilled under the condition of FB running into a gale, under normal exploitation conditions (calm movement or calm wave conditions) it will be loaded only from tension force of chain tie, which will be about 54 kN.
Specified service life may be increased by observation of corresponding maintenance systems and diagnosing.

Conclusions

To provide strength of bearing construction of car bodies during their transportation on FB, it is necessary to fulfill engineering and design of strain-stress state (SSS) of body in conditions of carriage works taking into account the loads, which affect them during FB transportation. Herein it is recommended to take into account refined calculation models of car bodies strength, which consider their loads on FB.
Investigation of SSS of bearing construction of gondola car body taking into account its fixation towards FB deck for special units allowed to conclude that its strength is provided. Suggested measures concerning improvement of bearing construction of gondola car body during FB transportation in conditions of confused sea allowed to provide their strength and increase save of motion of combined transport.

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