FINITE ELEMENT MODELING OF THE UNIT FOR FASTENING PIPES ON RAILWAY FLATCARS

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Abstract. *Steel pipes of large diameter should be fastened to the flatcar during transporting to prevent the damage of the edges prepared for welding. The pipes have low specific weight compared to the occupied volume, so the rolling stock gauge should be used more effectively at tubes placement. The work deals with stress-strain state modeling of the self-aligning devices for fixing pipes on the flatcar. The purpose is to create a structure ensuring the strength conditions fulfillment for the pipes edges so that stresses don't exceed the yield stress values. To solve this problem it was developed the finite element model of the unit for fastening pipes consisted of three bodies: the hook, insert and transported pipe fragment. The peculiarity of the model is the presence of four contact pairs, wherein the state of one of them is inherently uncertain and depends on the external forces application and on the operating conditions of the remained contacts. Computational results for different friction coefficients between the parts demonstrated that the existing structure of the fastening parts causes plastic deformations of the pipe material. A variant of the design improvement allowing to ensure the reduction of stresses was suggested.*

1 INTRODUCTION

Nowadays the range of goods transported by railway transport is being expanded and there is a need to improve both the railway cars constructions and ways of loads' placing and fastening on the rolling stock. It is clear that it is very expensive to equip the rolling stock by sufficient number of specialized wagons for each cargo. Therefore it is necessary to develop new means of goods fastening to reduce the physical impact on the railway car and the cargo.

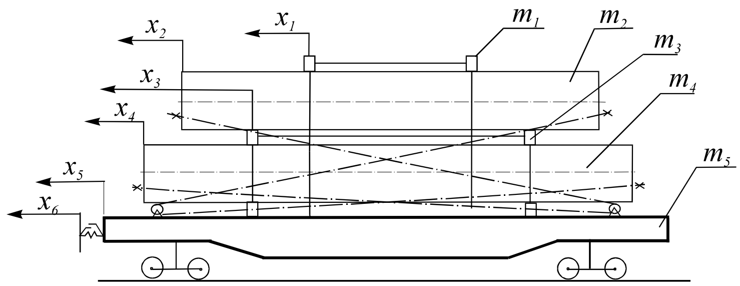
Numerous studies show that the main reason leading to the damage of cargo as well as flatcars is the wrong operation mode of the railway rolling stock at sorting operations [1]. In paper [2] it is noted that the lack of cargo fastening can lead to the final consequence of many fault states is a derailment. That is why it is necessary to reduce the dynamic forces acting on the flatcar and on the cargo by the additional cargo suspension relative to the flatcar in the longitudinal direction and to equip the flatcar respectively.

The analysis of earlier investigations showed that there is a significant number of studies on the safety increase of cargo placement and fastening. In the book [3] the number of ways of cargo placement and fastening on railway transport and examples of calculations for different schemes are presented. In CIS countries placement and fastening of cargo on the open rolling stock is regulated by the Technical conditions [4]. If the way of placement and fastening of some cargo isn't mentioned in [4], the shipper shall make the calculations. At the same time, the developed documentation must be experimentally tested in the conditions of railway cars impact.

In the literature we found only a few articles devoted to the above-mentioned problem and considering deformations of cargo and fastening means. In [5, 6] it were proposed the correlation coefficients for spatial systems of forces acting cargo and influencing the elastic tension forces in the means of cargo fixing. In paper [7] for theory of solid cargo fastening there has been investigated a case when the cargo is in motion in relation to the wagon floor with acceleration. There have been set out the results of analytical investigation of cargo shift in dynamics and accordingly elongation and tension in flexible fastening elements under the action of plane force system. It has been established that the longitudinal force perceived by the flexible fastening elements in value is smaller than the force obtained when inertia in relative motion (at rest) is not taken into account. Hence, the cargo shift lengthwise the wagon in this case will be smaller. This, in its turn, will affect the decrease of elongation value and consequently the decrease of the effort of every flexible element, thus increasing their load-carrying capacity. However, the strength calculations for fastening devices elements were not considered in these works.

The large-diameter pipes are widely used in the industry. To increase the better flatcar capacity use it is expedient to transport pipes placed in several tiers (fig. 1). Incomplete use of the flatcar capacity and the usage of single-use tiedown means are the special features of large diameter pipes transporting on the open rolling stock in accordance with the Technical requirements.

a)



b)

Figure 1. A flatcar with pipes: real fastening (a) and normative scheme (b)

For the pipelines construction steel tubes with ends prepared for welding are used. Therefore, at their transporting pipes must be fixed to a vehicle without damaging the edges of end faces. For this purpose the self-aligning devices can be used for fixing pipes on the flatcar. These devices include a hook of a special form of which rests on the pipe by a cylindrical insert. The hook is connected to the cable, which is attached to the other end of the flatcar (fig. 2).

a) 

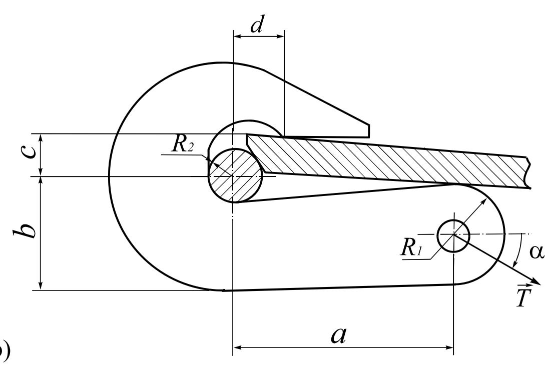
b) 

Figure 2. Self-aligning devices for fixing pipes: photo (a) and scheme (b)

The peculiarity of the device is the presence of four contact pairs, wherein the state of one of them is inherently uncertain and depends on the external forces application and on the operating conditions of the remained contacts. A large number of studies, for example [8, 9], were devoted to the contact interaction analysis for the bodies of complex shapes. Previously developed techniques of contact problems solving are applied to solve problems of cargo safe fastening on a railway flatcar. The work purpose is to create a structure ensuring the strength conditions fulfillment for the pipes edges so that stresses don’t exceed the yield stress values.

2 DETERMINATION OF INITIAL DATA FOR FINITE ELEMENT MODELING

A flatcar loaded by pipes is a mechanical system with several degrees of freedom (fig. 1b). To find the values of forces acting the hooks by the cables there were carried out calculations for the impact process between the moving railcar with the motionless "wall", consisted of three loaded railcars. To create a mathematical model the traditional technique, described for example, in [10, 11, 12], was used.

Pipes were considered as solid bodies. It was assumed that the elements of pipe longitudinal fastening elements, transverse strapping elements and intermediate supports have elastic properties and linear characteristics. All frictional forces were applied in the longitudinal vertical plane. Elements of cross-fasteneres and intermediate supports were combined in separate blocks with corresponding masses m_i. Thus, there was considered the system with 6 degrees of freedom taking into account all made assumptions about the car and cargo movement [13].

The numerical calculations were carried out by MathCAD package means for the following initial data: velocity of moving railcar-motionless cars impact of 5 km/h, each pipe mass of 6800 kg, flatcar mass of 21000 kg, motionless car mass of 84000 kg, friction coefficient of 0.35 and elastic stiffness coefficient of fastening elements of 2 MN/m. As a result of the numerical solution of differential equations it was found that forces in elastic fixation elements of the top tier of pipes are equal to 41.5 kN; forces in elastic fixation elements of the bottom tier of pipes – 42.5 kN. The obtained values of forces were further used as an input data for the finite element modeling of the fastening details unit.

3 FINITE ELEMENT MODEL OF THE ANALYZED SYSTEM

To determine the stress-strain state of the construction by the finite element analysis ANSYS software package was applied. The model of the fastening elements unit included three parts: hook, insert and the transported tube. The presence of inserts (fig. 2) allows the hooks to self-align on the ends of the pipes. This helps to prevent the pipe edges damage, which takes place in the case of the hook-pipe direct contact.

There were considered the following model element characteristics: a Young's modulus of $E = 2 \cdot 10^{11}$ Pa, $\nu = 0.2$. Calculations were made for the real non-linear relationships between stresses and strains of the pipe material of K42 strength class (fig. 3). To analyze the stress-strain state of the device there were performed simulations for the following dimensions (fig. 2b): c = 14 mm, b = 80 mm, d = 12 mm, a = 95 mm, R_1 = 35 mm, R_2 = 10 mm, applied force T was equal to 43 kN, $\alpha = 20^\circ$.

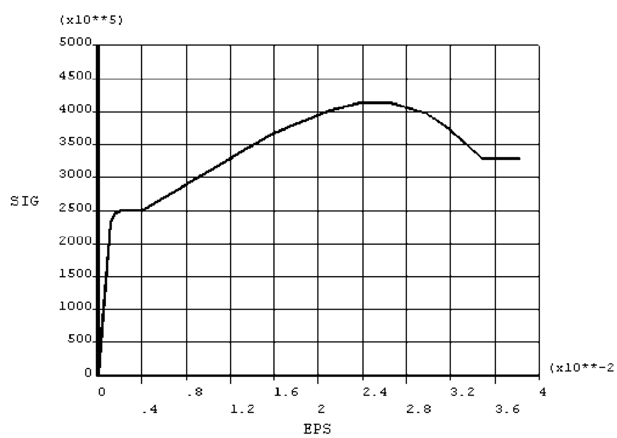
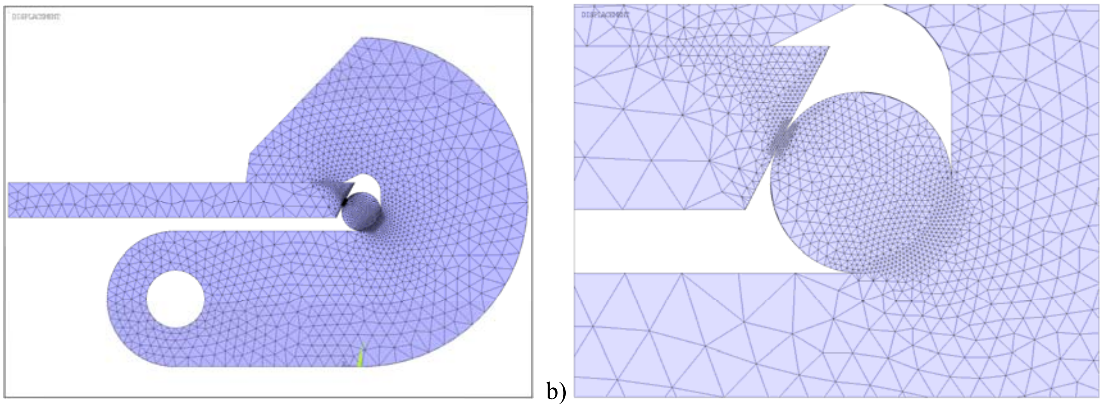


Figure 3. Diagram for the pipe material stretching

To achieve the required accuracy of the calculations the contact area was meshed into small finite elements, so the simulations took a long time. That is why it was created the half-model of real construction due to the symmetry of the construction. Also, it was created 4 contact pairs. Under different conditions of transportation for example, in dry or rainy weather the friction coefficient values between the bodies can change. Therefore, the calculation is performed for the friction coefficient values f from 0.06 to 0.4.To create finite element mesh there were used such elements as SOLID285, TARGE170, CONTA174. In the contact area the size of finite element edge was taken as 0.5 mm. As a result it was received the finite element model shown in Fig. 3. The total number of model elements was equal to 470799.

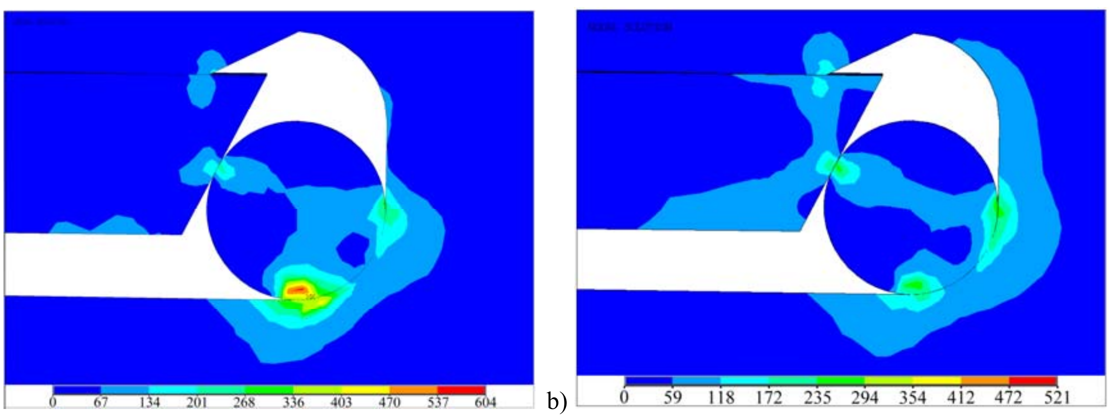


a) b)

Figure 4. Finite element model: a – full model; b – elements contact areas

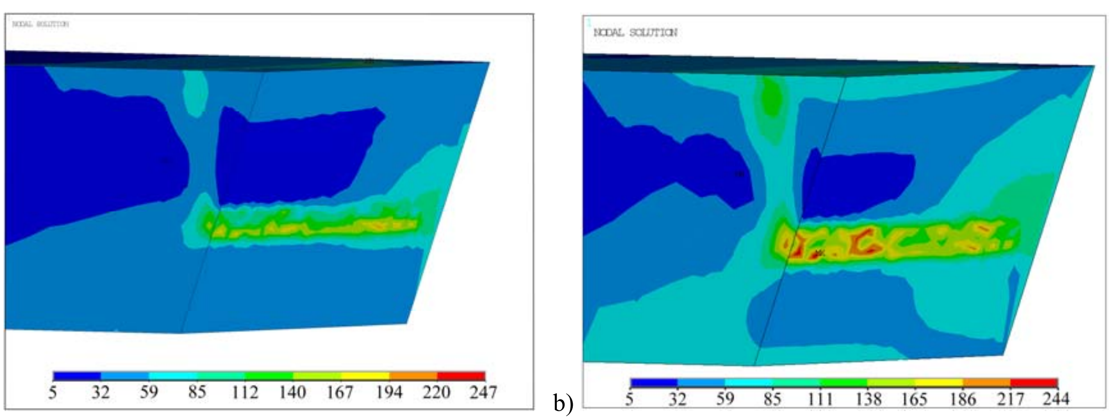
4 SIMULATION RESULTS AND THEIR DISCUSSION

During simulations there were calculated the values of stresses and strains in the most loaded places of the fastening unit parts. Figure 5 is a diagram showing the distribution of equivalent von Mises stresses in the pipe-fastening device element contact region for two values of the friction coefficient. The results show that the maximal stresses appear in the insert. They are much higher than the material yield strength. It should be noted that at simulations the insert was considered as an elastic body, so the actual stresses in it are smaller than obtained by calculations. At the same time, the stresses in the pipe don't exceed the material yield strength (fig. 6).



a) b)

Figure 5. Equivalent von Mises stresses (MPa) in the contact area of the pipe and fastening for the different values of friction coefficient: a) $f = 0.4$; b) $f = 0.06$



a) b)

Figure 6. Equivalent von Mises stresses (MPa) in the insert-pipe contact point for the different values of friction coefficient: a) $f = 0.4$; b) $f = 0.06$

The obtained maximal stresses-force *T* dependence for different friction coefficients between fastening device elements demonstrates insignificant decrease of stresses at friction coefficient value increase (fig. 7).

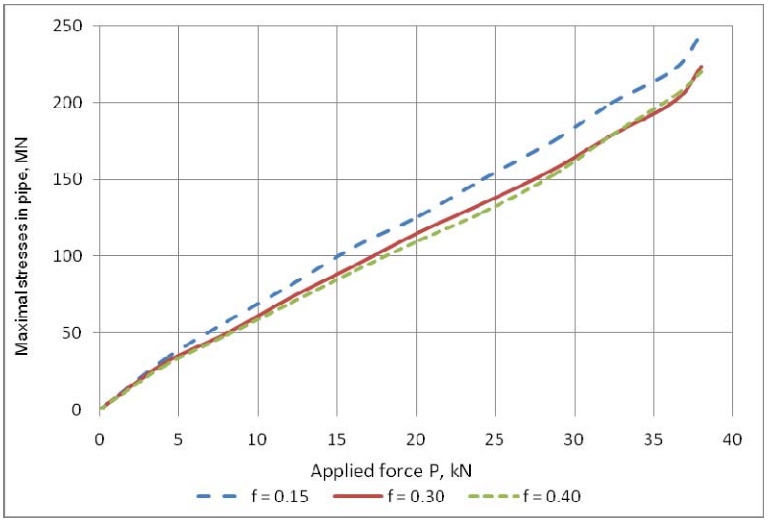


Figure 7. The dependence of the maximal stresses in the pipe on the applied force *T*

The analysis also showed that in spite of the identical configuration of the contact area at different friction coefficient values there are differences in features of the pipe-insert contact region (fig. 8). If friction coefficient value is higher than 0.18, sticking appears, if values of friction coefficients are small there is a sliding along all contact surface.

a) b)

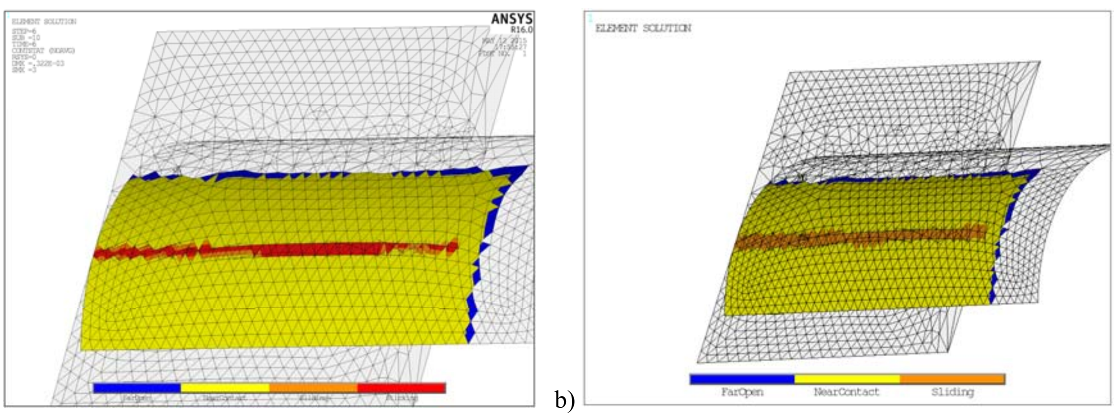


Figure 8. The insert-pipe contact status for the different values of friction coefficient: a) *f* = 0.4; b) *f* = 0.06

Overall, the computational results show that the stresses in the contact area of pipe with the insert is very close to the yield stresses of the material, so the proposed device can be used for pipes of lower strength class. Therefore it is suggested to change the form of the insert to increase its contact area with the end of the pipe.

5 CONCLUSIONS

Thus, in the work progress there was proposed a method of calculation and simulation of numerical-analytical computations of self-aligning devices for pipes fixing to railway platforms with taking into account the features of contact interaction between the components of cargo-fastening contact. The finite element model initial data was based on real non-linear relationships between stresses and strains of the pipe and fastening device material. Carried out simulations allowed to obtain the values of stresses and strains in the most loaded places of fastening elements and to suggest a new rational configuration of the insert between the pipe and fixing element.

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