Automated calculation method effect values in load securing elements fixed on a rolling stock

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Abstract. The article presents a method for the automated calculation of the magnitude of the efforts in the means of securing cargo fixed to the rolling stock in accordance with the Technical Conditions for Stowing and Securing Cargo in Wagons and Containers - a regulatory document of JSC Russian Railways (hereinafter referred to as TU). The method provides for all possible factors of the influence of the forces acting on the transported cargo as a result of its movement from the point of loading to the point of unloading, including the necessary technological operations performed along the route, using the example of a cargo with a flat base using the capabilities of the computing environment. The obtained research results are supposed to be used by shippers in the development of the optimal method for placing and securing transported goods on the rolling stock. The automated calculation method will allow obtaining the predicted value of the cargo shift value both along and across the car from the total effect of longitudinal, transverse and vertical forces acting on the cargo along the way. These values make it possible to optimally determine the place of installation of thrust bars on the car floor, depending on the geometric parameters of the transported cargo and the chosen method of fastening it to the rolling stock.

1. Introduction

Today the safety of the transportation process is the most significant requirement for the organization of railway transportation. On the one hand, this type of transport is used to move a huge number of people; on the other hand, railways are a strategically important transport system for the country, on the smooth operation of which the economic condition of many, many industries, and the economy as a whole, depends.

Any "contingency" situation can provoke serious problems for entire sectors of the economy, not to mention individual enterprises or citizens. Therefore, ensuring the safety and continuity of the transportation process in all areas of activity is a multipurpose task of the railway transport system (RTS). Increasing requirements of ZDTS clients to the quality and the list of services provided determines the need to use advanced world technologies. In the short term, in order to reduce the distance between major regional centers, it is planned to develop high-speed traffic and increase the speed of passenger trains to 160-200 km / h. The main condition for the organization of traffic with the smooth
The operation of the railway system is to observe the safety of train passage. Unimpeded and safe passage of trains can be called quality execution of the train schedule.

The management of the Russian Railways has adopted and is successfully implementing a draft of a new concept for improving traffic safety in the field of transportation, based on the use of multifunctional integrated systems for regulating train traffic [1]. The transition to the use of technical safety equipment in the Russian railway transport system based on the latest information technologies - satellite navigation, digital radio channel, centralized route management and diagnostics of technical means - will allow the devices distributed along the tracks with their safety functions to be transferred to railway stations and train locomotives. This will significantly increase the level of safety of the transportation process and the customer focus of the industry. Since the introduction of modern security systems improves not only protection against hazardous situations, but also reduces system failures and failures, which makes it possible to increase the speed of trains, increase the throughput of railway facilities, and reduce the number of unscheduled repairs of technical equipment. That is, this time, the solution of security issues in the railway transport system was treated comprehensively.

2. Elimination of the negative impact of the human factor on traffic safety by automating production processes

The normal functioning of railway transport systems is possible only through coordinated and efficient work of groups of subsystems: infrastructure, commercial, freight, shunting and train, which are peculiar technological processes with specific features for each of them. Each of the subsystems has its own operating technology, its own technical equipment, fixed assets, specially trained technical personnel. Common things to all subsystems and the system as a whole are:

- subject of labor - transportation of goods (passengers);
- goal to generate income and profit;
- tasks ensuring the safety of functioning in order to reduce non-productive costs and the safety of fixed assets of the railway transport system and each of its subsystems.

All subsystems are interconnected by internal links and enter into technical, technological, financial and economic relations, without which the normal course of the transportation process is impossible. Clear and uninterrupted operation of the system, elimination of cases of risks, achievement of the goal and solution of the assigned tasks can be achieved only through close interaction of subsystems with each other, compliance with the requirements of regulatory documents, compliance with norms and standards of work.

In order to identify the causes most dependent on the occurrence of risk cases, it is advisable, first of all, to analyze the activities of the cargo subsystem. It is the control of the procedure for accepting cargo for transportation that is fundamental in organizing the transportation process, since the safety of the functioning of the railway transport system as a whole and its individual subsystems largely depends on the correct preparation of cargo and rolling stock in the transportation process [2, 3].

According to the reporting data of the Transportation Management Department of the Russian Railways Holding, the industry has been continuously increasing its traffic volumes in recent years. This has a positive effect on the financial and economic performance, but along with the growth in traffic volumes, the number of traffic safety risks associated with disorders of loading of goods loaded in wagons and containers. To identify the main factual causes of security violations in the railway transport system associated with violations of the loading disorder of goods loaded in wagons and containers, to improve the quality of the transportation process, providing a systematic approach to determine the root causes of this problem, based on data on the state of safety on Russian railways in 2010-2019 [1, 4], the Ishikawa diagram is constructed (figure 1).

As the analysis of the risks threatening traffic safety associated with violations of the disruption of loading of goods loaded in wagons and containers shows, the role of the human factor can be seen in the cause of almost each of them. Therefore, considering the priority tasks in the field of traffic safety, it is necessary to pay attention to the work of people.
The new concept of improving traffic safety in the field of organizing transportation is focused on solving a number of tasks, the main of which is to eliminate the negative impact of the human factor on traffic safety by automating management processes and introducing additional control over the actions of operating personnel and users of railway services.

Coordinated development and improvement of existing technical means of security in certain areas of activity, taking into account the complex application of new systems and technologies in specific areas or sections of railways, the use of modern information technologies in the development of new technical means, creation of conditions for a comprehensive solution of transport security issues when accepting cargo to transportation are the main strategic tasks of the railway transport system.

3. The method of automated calculation of the magnitude of the forces in the means of securing the cargo fixed on the rolling stock

The article proposes a method for automated calculation of the magnitude of efforts in the elements of securing cargo fixed on the rolling stock in accordance with the Technical Conditions for Stowing and Securing Cargo in Wagons and Containers - a regulatory document of JSC Russian Railways (hereinafter - TU) [4, 5]. The method provides for all possible factors of influence of the forces acting on the cargo as a result of its movement from the point of loading to the point of unloading. This includes the necessary technological operations performed along the route, using the example of a cargo with a flat base using the capabilities of the computing environment.

The compiled system of equations [6-8], taking into account the nature of the change in the friction force, is easily realizable in a computing environment. The use of it makes it possible to compile calculation programs for the direct determination of the forces in the means of securing the transported
cargo, the normal reaction of the connection and the coordinate of the point of its application, the values of the load displacement along the transverse the axis of the car, rotation around the vertical axis [9-11].

The approach proposed by the authors to the preparation of initial data is one of the crucial stages of computational experiments. This subsequently simplifies the compilation of a mathematical model and its implementation in an electronic environment, the use of which makes it possible to automate the calculation to determine the forces in the means of securing goods transported in wagons and containers. At the same time, in the mathematical model, the forces in the fastening means are taken into account only by positive signs, regardless of the direction of the projection of these forces relative to the adopted coordinate axes. All this is already taken into account automatically, and, observing the generally accepted rules of signs, external forces and moments acting on the system "transported cargo-securing means-rolling stock" with a flat base [12-14].

The approach developed using the basic provisions of general mechanics to describe the equilibrium conditions of the system "transported cargo-securing means-rolling stock" made it possible to compose a generalized mathematical model of this system using the example of transportation of cargo having a flat base, in the form of equations. This made it possible to use a computing environment to determine predictive values of the magnitude of the forces in the load securing braces at different values of the coefficient of friction, longitudinal, transverse and vertical accelerations, arising wind loads [2, 15-16].

The obtained research results are supposed to be used by shippers in the development of the optimal method for placing and securing transported goods on the rolling stock. The automated calculation method will allow obtaining the predicted value of the cargo shift value both along and across the car from the total effect of longitudinal, transverse and vertical forces acting on the cargo along the way [9, 17, 18]. The obtained values make it possible to optimally determine the place of installation of thrust bars on the car floor, depending on the geometric parameters of the transported cargo and the chosen method of fastening it to the rolling stock. This, in turn, will make it possible to analytically substantiate the installation locations of the fastening elements in the form of thrust bars with joint fastening cargo with guy wires, straps and stubborn bars. In addition, in an automated way, calculations can be performed to determine the number of fasteners to secure these thrust bars [9, 19].

Figure 2 shows, for example, the design model required to determine the required number of fasteners to secure the thrust bar on the car floor.

Figure 2 has the following notation:

- $R_x$ - force acting from the side of the cargo on a thrust bar along the carriage, kN;
- $H$ - distance from the car floor to the point of application of the force $R_x$, m;
- $x$ or $y$ - distance between the ends of the load and the thrust bar, m, with $0 \leq x$ or $y \leq 0.04$;
- $A$ - point of intersection of the plane of the car floor and the axis of the nail;
- $b$ and $h$ - width and height of the bar, m;
- $\delta$ - thickness of the car floor, m;
$L$ - nail length, m,

$b_{\text{floor}}$ - width of one carriage floor board, m.

For a specific load with the accepted number of securing means, the predicted value of the load shift can be determined using the capabilities of the presented computing environment. Computational experiments to determine the forces in the fasteners of the transported cargo, the values of the shifts of the cargo along and across the carriage are performed in the following sequence:

- input of initial data, which include: technical and operational characteristics of the rolling stock selected for transportation; geometric parameters of fastening means, cargo, carriage; coefficient of friction of the contacting surfaces of the cargo and the floor of the car; efforts of preliminary spins of fastening means;
- direct calculation of efforts in the fastening means, predicted values of possible shifts of the load along and across the car.

The source and other related data for the example copied from the layout document are shown in Figure 3.

\[
\begin{align*}
\text{Cargo parameters} \\
M := 60 \cdot 10^3 & \quad \text{weight of cargo, kg} \\
h := 2.1 & \quad \text{cargo height, m} \\
b := 2 & \quad \text{width of cargo, m} \\
l := 9.1 & \quad \text{length of cargo, m} \\
b_{\text{br}} := 2.87 & \quad \text{transverse distance between brackets, m} \\
f := 0.55 & \quad \text{adhesion coefficient of friction (reinforced concrete on wood)} \\
\text{TOL} := 10^{-5} & \quad \text{g := 9.81}
\end{align*}
\]

\[
\begin{align*}
\text{Parameters of flexible fasteners} \\
E := 1 \cdot 10^7 & \quad \text{modulus of elasticity of flexible fastening elements, taking into account the wiring line, kN/m}^2 \\
d := 0.006 & \quad \text{wire diameter of flexible fastening element, m} \\
n := 8 & \quad \text{number of threads in flexible fastening elements, pcs} \\
A := \frac{d^2}{4} & \quad \text{cross-sectional area of the wire of the flexible fastening element, m}^2 \\
S_0 := 2.05 \cdot 10^{-4} & \quad \text{initial tension of flexible fastening element, kN}
\end{align*}
\]

**Figure 3.** Initial and other related data for computational experiments.

Below are the results of computational experiments to determine the forces acting on the side of the transported load on the thrust bar and the required number of fasteners of the thrust bar required to hold the load against shear when the longitudinal and transverse forces are applied to the system "bar - fastener - car floor".

4. **Results of computational experiments**
The calculation of the movement of the transported cargo, depending on the time it is on the route, is shown in Figure 4. Analysis of the dependences of the displacement of the load on time shows that the displacement of the load from the action of the portable inertial force of the load and the wind load increases with time.
The results of calculating the force acting from the load on the thrust bar are shown in Figure 5. The analysis of the obtained results shows that the force acting from the side of the transported cargo on the bar, depending on the movement of the cargo, decreases in a linearly decreasing manner, which is logical. Since this increases the restoring force of the load securing means and the friction force, the impact of the wind load is taken into account in the calculations.

![Graph of force vs. time](image)

**Figure 5.** Graphical dependence of the force acting on the side of the transported cargo on the bar when moving the cargo.

The results of computational experiments to determine the number of fasteners required to secure the thrust bar, depending on its location in the car, are shown in Figure 6. The analysis of the given dependencies shows that the number of fasteners required securing the thrust bar, given the initial data, decreases in proportion to the increase in the distance to the transported cargo. In addition, the number of fasteners is significantly influenced by such physical and mechanical characteristics of wood as tensile strength and elastic modulus, which largely depends on the degree of its moisture content, i.e. on the climatic conditions in which the cargo is transported.

![Graph of force vs. displacement](image)

**Figure 6.** Graphical dependence of the number of fasteners required to secure the thrust bar on the distance to the cargo.
Analysis of the graphical dependences of the force of impact on the bar shows that with the given initial data, the load hits the bar located at a given distance of 40 mm with a force of 193.57 kN (19.4 tf). When installing a thrust bar close to the end of the transported cargo, a force equal to 322.66 kN (32.3 tf) acts on it, which is 1.6 times more than the standard value established by the technical conditions. From the action of a force of such magnitude, a breakdown of the stubborn bar occurs, a violation of the entire securing system of the transported cargo, the probability of a risk event increases.

5. Conclusion

The continuous increase in the volume of work at railway stations makes it necessary to improve the technology and means of automating the processes of accepting cargo for transportation, as well as improving the quality of operational management of operational work in all technological links. The systems of automation of control processes developed to achieve the set goals should provide high reliability, accelerated response, locality, relative independence and "survivability" as part of a general automated control system for technological processes in railway transport systems.

The automated approach developed based on the use of the basic provisions of general mechanics made it possible to determine the force acting from the side of the load on a thrust bar located at a certain distance from the end of the load. This is the basis for calculations to determine the number of fasteners of this bar that retains the load from shear. The results of computational experiments showed the possibility of automatically calculating the required number of fasteners depending on the geometric parameters of the transported cargo, the size of the bar, fasteners and the car floor.

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