Experimental Evaluation of Railway Crew Impact on Tension Rails

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Abstract—**Due to constantly growing requirement increase in capacity of the existing network railroads of the Republic of Kazakhstan and (especially areas bordering with Russian Federation and China), the relevant issue is to improve the safety of operation of freight trains of increased mass and length. Putting into operation of heavy trains – the complex task connected with use of more powerful locomotives, increase in axial loadings, reconstruction of traveling infrastructure and power supply, improvement of technology of transportation process. In addition, increasing the speed of train traffic with increasing traffic density requires increasing strength and compliance paths. Technical policy of Joint-Stock Company "National Company" "Kazakhstan Railways" in Kazakhstan aims to complete the transition to a continuous path on a concrete base. This paper presents the results of measurements of the edge strains and stresses in the rail web in the center of the sleeper box outer rail of the filament curve of radius R = 380 m, obtained during testing of freight wagons and locomotive on the section of the railway line Almaty-Shu. The results of measurements of edge stresses and tension in the neck of a rail in a curve radius R = 380 m, obtained during the tests on the effect of the locomotive CKD6e-2108, freight cars 12-9941 and 12-9920, on the section of the Almaty-Shu railway line are presented. The dependences of stresses in the edges of the sole and in the neck of the rail on the speed of the test rolling stock are obtained. The possibility of increasing the weight norms of freight trains without the cost of reconstruction of the track infrastructure is substantiated by introducing a fleet of modernized freight cars with an axle load of 245 kN (25 tons).**

Index Terms—**railway track, stresses, lateral forces, rolling, experimental**

I. Introduction

On the Railways of countries added to the world fleet of rolling stock increased carrying capacity. Great transit potential causes growth of demand increase throughput of existing railway network of the Republic of Kazakhstan [1]. For regions bordering the Russian Federation and China, the issue of ensuring safety operation of freight trains increased mass and length is relevant [2]. The commissioning of heavy trains is a complex task related use of more powerful locomotives, increased axle loads, reconstruction of track infrastructure and power supply, and improvement of the technology of the transportation process [3]. In addition, an increase speed of train traffic with increasing traffic density requires increasing strength and stability of the road [4]. The technical policy of JSC "NC" "Kazakhstan Railways" in Kazakhstan is aimed to complete transition to a seamless path on a reinforced concrete foundation [5]. The use of reinforced concrete sleepers and heavy-type rails along with strengthening of strength and reliability path causes an increase modulus elasticity of under-rail base and the rigidity of path, as compared to wooden sleepers [6]. The accuracy and correctness of the accepted experimental methods for evaluating the force impacts of wheels on the rail track is of paramount importance for analyzing safety of the use of freight component trains [7]. The edge stresses caused by bending and torsion rail from the vertical and horizontal impact of rolling stock, are critical parameters which determine the strength of the rail. It is known the half sum vertical edge stresses characterizes impact of path and the half - horizontal (lateral force). They also characterize nature impact of the moments of forces on application of lateral loads and the displacement of the position conditioned center of the contact spot wheel and the railhead [8]. This paper presents the results of measurements of edge stresses and tension in the rail web center of a sleeper box of an external rail thread with a curve of radius R = 380 m, obtained during testing of freight trains and diesel locomotives on the Almaty-Shu railway line [9-11]. The presence of malfunctions of the rolling stock, namely: slides, uneven rolling, wheels on wheels, wheel diameter, type of spring suspension, the difference bases of the side frames, the size of the gaps in axle slots and the overestimation friction wedges relative to the supporting surface of the bolster and also path faults: in joints and welding places of rails, saddles wavy wear and other factors significantly impair the interaction of the elements of track and rolling stock [12].

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The solution of the entire complex of this multivariate problem in this study was not considered. Measuring was conducted in accordance with requirements [13] through a strain-gaugeo instrumentation-calculable complex (see Fig. 1) consisting of certificated and attorneys of facilities measuring of leading world producers [14-17]. A complex allows to produce the precision (high-fidelity) measuring of tensions and relative deformations in the elements of way and flight structures of bridges from influence of rolling stock simultaneously in 16 sections at length of measuring highway a to 500 m. The accuracy class of the measuring equipment is 0.1 the error of the measurement results given in this study was in the range from 0.33 to 1%.

II. MATERIALS AND METHODS

The complex is tested on the number of objects of JSC "NC" "Kazakhstan Railways" and showed good results in the evaluation efficiency of strengthening of structures railway bridges of composite material [1], and determining the impact of the dynamic effects of rolling stock on a railway track and the superstructure of the bridges [2]. Before the tests, a road-measuring car passed through the site. Based on the results of measurements service responsible for the state of way issued an act on the readiness of the path to testing and permissible speeds of traffic on the site (see Fig. 1). The railway track on this section is contained with tolerances for the widening plus 4 mm, for a narrowing of minus 2 mm; The deviations geometry of the track gauge do not exceed the first degree in accordance with [3].

Figure 1. Tens metric measuring and computing complex for measuring relative deformations and stresses in structures: 1 – measuring modules (16 pieces); 2 – semi-industrial laptop; 3 – sinusoidal inverter; 4 – intermodulation connection cable; 5– connecting cable between the measuring module and the primary transducer (strain gage); 6 – accumulator battery.

The roughness's on the rolling surface of T1 rails of type P65 in the experimental section (see Fig. 2) with the welded track structure did not exceed permissible values specified in [4]. The tests of freight cars were carried out in empty and laden condition, in accordance with the requirements of [5]. The experimental train consisted of a diesel locomotive CKD6e-2108 (maximum static load 23 tons per axle), freight gondola cars 12-9941 (static axle load 23.5 tons) and 19-9920 (static axle load 25.0 tons), an electric locomotive VL80s (axial load 24.0 tons).

Figure 2. Preparatory work in the experimental site.

In the measuring section of the route was carried out "Shuttle" method [6] controlled from cabin of diesel locomotive and electric locomotive in the daytime. Direct course made the motion of Shu in Almaty, back – from Almaty to Shu. When driving a straight course moving the unit experienced trains are located as follows: 6-axle diesel locomotive CKD6e-2108, empty gondola 12-9920 loaded gondola 12-9920, 12-9941 loaded wagon, empty wagon 12-9941, 8-axle electric locomotive VL80c (see Fig. 3). When reversing, mobile units located, respectively, on contrary, that is, without reformation of rolling stock. In Fig. 3 shows a diagram of the location of mobile units experienced train depending on the direction of movement in the forward and backward stroke [7].

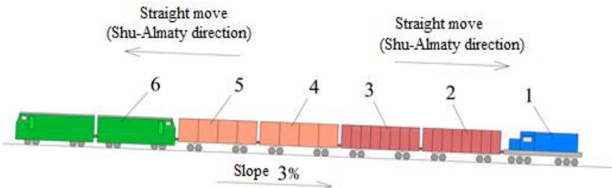


Figure 3. The scheme an experimental train: 1 – diesel locomotive CKD6e-2108; 2 – empty gondola car 12-9920; loaded gondola car 12-9920; 3 – loaded gondola car 12-9941; empty gondola car 12-9941; 4 – electric locomotive VL80^c.

III. EQUIPMENT SECTIONS OF THE TRACK FOR TESTING SENSORS

The places of sticker's sensors are selected according to the results of measurements of path, based on the state of the path in areas with the greatest deviation in plan and profile. Also, when selecting track links for equipment, strain gauges are guided by the dynamic indicators of a diesel locomotive and gondola cars when passing the test section [8]. The locomotive and open wagons with an allowable speed are rolled in a straight line and along curves. Strain gages are installed on the links with the most unfavorable indicators of frame forces and vertical dynamics coefficients. Dynamic stresses in the outer and inner edges of the rail sole in straight and curved sections track, on the front reach of the frame rails and thrust rail conversion curve, on the outer edge sole of curved wit in normalized cross-sections of turnouts are measured using strain gauges [9]. The number of measuring sections on the rail in straight and curved sections must be at least 12. Stresses in the outer edges of sole front outreach of the rail turnout switch are measured in two sections, on the thrust rail conversion curve in five sections. Stresses in the outer edge sole of a curved wit of a turnout are determined in sections with a width head of wit 20, 30, 50 and 70 mm. To measure the lateral forces transmitted from the wheels to the rail head, strain gauges are glued to rail neck from the outside and inside. The strain gages are arranged vertically so that moments of resistance of horizontal sections passing through the sticker points of the center of the grating strain gages are equal. This is achieved by selecting the same thickness of the necks of the rails along the axis of the strain gages. In addition, the strain sensitivity of the strain gages should be the same. The arrangement of strain gages on the rail neck and their connection are shown in Fig. 4.

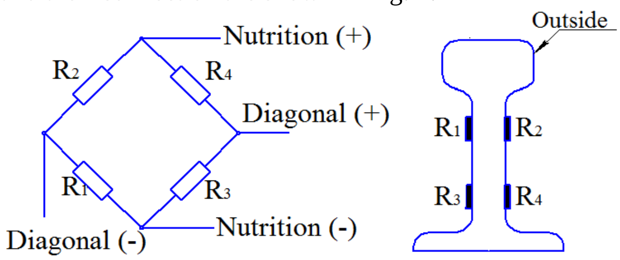


Figure 4. Layout of strain gages on the rail neck and their connection for measuring lateral forces.

Schemes for measuring lateral forces are graduated by means of a special calibration device and a force measuring sensor. Calibration is done prior to testing. Lateral forces are measured in the same sections as the edge stresses at the bottom of the rail, i.e., in no less than 12 sections. The sequence of tests in straight and curved sections and turnouts is decided on-line during the tests. Trips on test sections of the track are performed with a stepwise increase in speed and lateral acceleration in curves [10]. Before moving to the next higher speed, preliminary express analysis of the experimental information is performed. Tests with the registration of dynamic processes in the upper structure of the track are carried out at a specially allocated time for this purpose "window".

IV. Results and Discussion

In Fig. 5 presents the plots of the measured maximum edge stress from the effects laden gondola 12-9920 in the speed range from 25 to 80 km/h On the outer edge of the foot rail the highest value (106 MPa) recorded during the passage of the composition at a speed of 40 km/h from Almaty to Shu (reverse), the lowest is 63 MPa, at the same speed, but the composition took place from the Shu in Almaty [11]. On the inner edge of the foot rail the highest value (75 MPa) was also observed at a speed of 40 km/h during the return stroke (Almaty-Shu), but the lowest (55 MPa) recorded at 80 km/h as in direct and reverse motion. It should be noted that at a speed of 25 km/h, on the inner edge of the foot rail, the quantitative magnitude of the voltage in the direct (58 MPa) and the reverse (62 MPa) the passage of the experienced staff at least slightly, but higher than the recorded minimum, maximum stresses measured at a speed of 80 km/h.

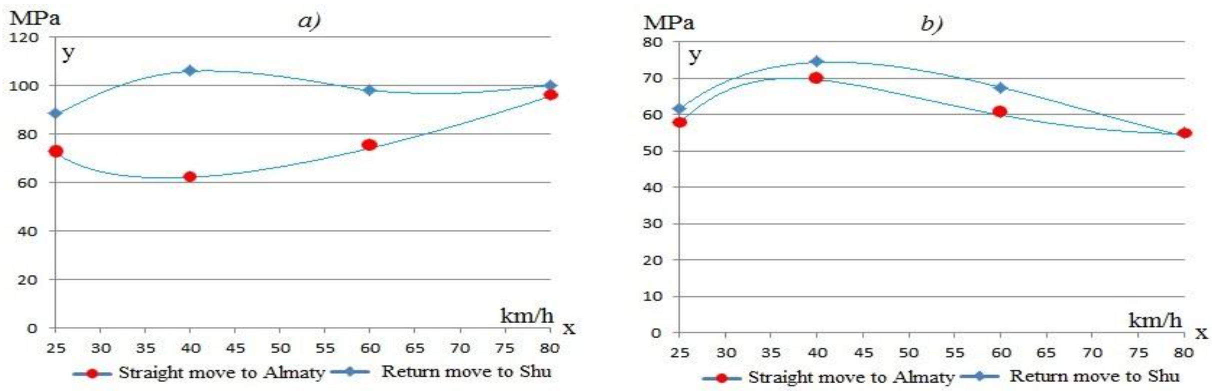


Figure 5. The maximum stresses from the impact of a laden gondola car 12-9920: a) – outer edge of the rail sole, b) - inner edge of rail sole.

Several times, both in terms quantitative values of the intensity and nature of the curves, graphs, results for the passage of the laden gondola 12-9941 (see Fig. 6). The maximum value of the stress in the outer edge of the rail sole (103 MPa) was also observed at a crew speed of 40 km / h during the return pass [12]. Taking into account that the difference between the axial loads is 6%, and the difference between the stress values (106 and 103 MPa) is only 2.8%, it can be concluded that the gondola 12-9920 exerts on the path of early impact than the gondola 12-9941. In Fig. 7 graph shows observed maximum edge stresses under the influence of empty gondola 12-9920. In this case, the highest stresses (34 MPa in the outer edge of the direct course and 26 MPa at the inner edge of the return stroke) is fixed at 60 km/h (in the case of a loaded gondola car is 40 km/h). Moreover, the increasing speed of carriage up to 80 km/h (regardless of direction) leads to a decrease in stresses in the outer edge to 27, in the interior up to 21 MPa. The curve of stresses in the edges of the rail base obtained by passage through the measuring section is empty gondola 12-9941, shown in Fig. 8. The highest stress values in the outer (40 MPa at a speed of 40 km/h) and the inner (32 MPa at a speed of 80 km/h) the edges of the foot rail was observed during the return stroke of the rolling stock [13]. The smallest voltage value (23 MPa at the outer edge during the forward pass, 24 MPa in the reverse passage in the inner edge) is fixed at the speed of 25 km/h.

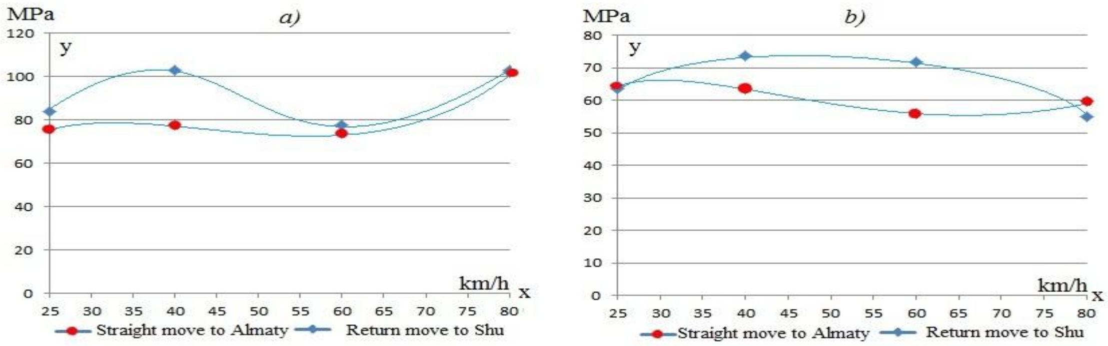


Figure 6. The maximum stresses from the effect of a laden gondola car 12-9941: a) – outer edge of the rail sole; b) - inner edge of rail sole.

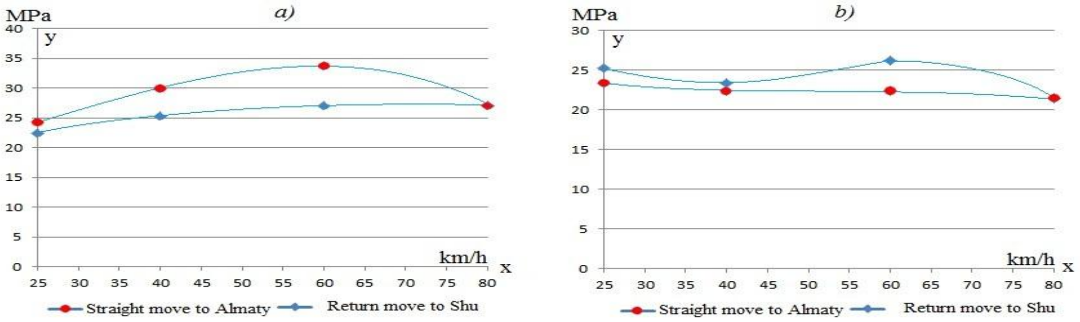


Figure 7. The maximum voltage from the action of an empty gondola car 12-9920: a) – outer edge of the rail sole, b) - inner edge of rail sole.

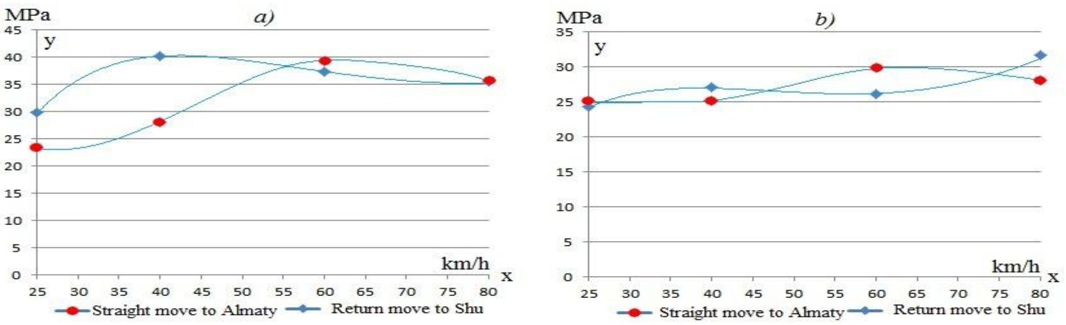


Figure 8. The maximum voltage from the action of an empty gondola car 12-9941: a) – outer edge of the rail sole, b) - inner edge of rail sole.

In Fig. 9 graph shows the maximum observed edge stresses that occur when passing through the measurement cross section of the shunting locomotive CKD-6e. In the outer edge, the dependence is practically linear. The greatest value in the outer edge (107 MPa with forward and reverse travel) is fixed at a speed of 80 km / h, the smallest (56 MPa at the back pass) - at a speed of 25 km / h. In the inner edge, a maximum (53 MPa) is observed at a speed of 40 km / h and a minimum (44 MPa) at a speed of 60 km / h. with the return pass. At speeds of 25 and 80 km / h, the voltages (50 MPa) are equivalent, both in the forward and reverse motion of the crew. At a speed of 40 km / h, the voltage at the reverse travel of the rolling stock (from Almaty to Shu) corresponded to the stresses at speeds of 25 and 80 km / h and was equal to 50 MPa.

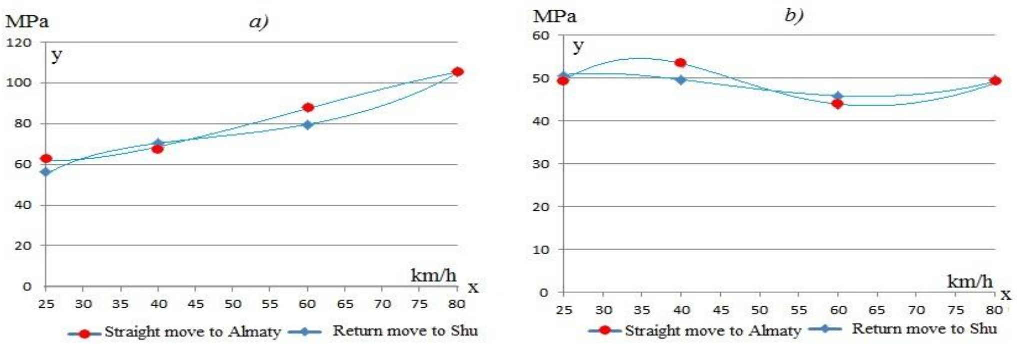


Figure 9. The maximum stresses due to the effect of the locomotive CKD-6e: a) – outer edge of the rail sole, b) - inner edge of rail sole.

From the analysis of graphs shown in Fig. 10 representing the relationships observed maximum edge stresses when passing through the measuring cross-section electric locomotive VL-80, it follows that in the speed range from 40 to 80 km/h, in the outer edge of the foot rail there is a sharp jump voltage from 100 to 192 MPa at a live course. And at the speed of 25 km/h, the voltage (110 MPa) higher than the voltage (100 MPa) corresponding to a speed of 40 km/h During the return stroke, the voltage increases less sharply, from 100 MPa at the speed of 25 km/h to 156 MPa at 80 km/h.

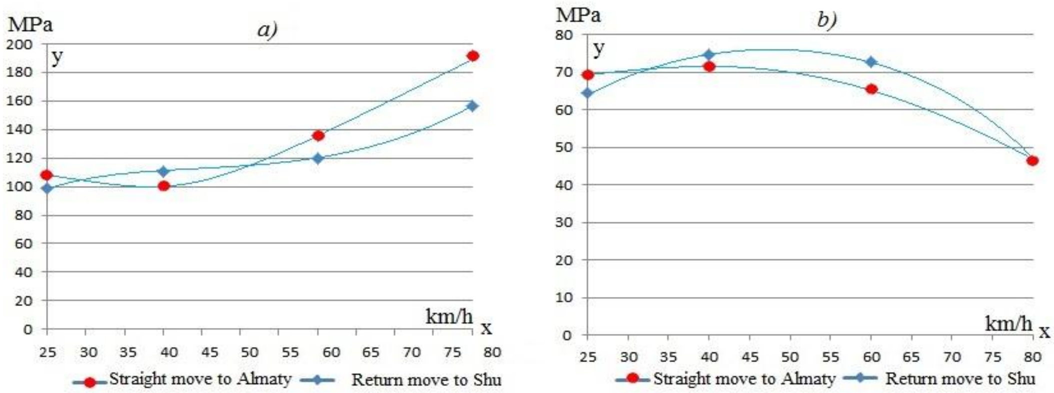


Figure 10. The maximum voltage from the action of an electric locomotive VL-80s: a) – outer edge of the rail sole, b) - inner edge of rail sole.

In the inner edge of the foot rail in forward, with increasing speed of the composition from 25 to 40 km/h, an increase in voltage from 69 to 72 MPa, while further increasing the speed from 40 to 80 km/h there is a drop in stresses up to 47 MPa. This is due to the known effect of obtrusive wheel due to a partial separation from the rail with increasing speed. This is especially true for empty cars [14]. Running in reverse, with increasing speed of the composition from 25 to 40 km/h, the voltage increased from 64 to 75 MPa, at a speed of 60 km/h reduced to 73 MPa and with increasing speed up to 80 km/h falling to 47 MPa. The reason for the sharp jump in voltage from 110 to 192 MPA at the forward stroke of the locomotive VL80c with increasing speed from 40 to 80 km/h due to, most likely a significant deterioration of this locomotive in connection with a long service life. The spread between the value of the stress at 30% at speed of 40 km/h at forward and reverse motion of the same locomotive VL80c can be explained by the additional stress during movement on the rise of 3‰ during the back to the side of Shu. Dynamic effects on the rail experienced trains illustrate the diagram below stresses in the outer (Fig. 11) and the inner (Fig. 12) the edges of the foot rail [15]. The train passed at a speed of 60 km/h from Almaty to Shu (reverse). It is seen that the empty gondolas 12-9920 have on the rail a smaller force than the gondolas 12-9941. The impact 12-9920 loaded wagons with greater axle load is almost equivalent to the effects laden gondolas 12-9941. This fact (the above measurement results of the edge stresses under the influence of empty and loaded gondolas also confirm this) you can explain the improved characteristics for suspension of the gondola 12-9920, due to the use of truck model ZK1, which excludes:

- rushing longitudinal side frames relative to each other, resulting in a decrease in the intensity of the wagging of the truck, improves the smoothness of the car;
- a pendular oscillation of the frames about their own longitudinal axes, the result is uniform transfer of loads on the elements of the axle unit, which eliminates the distortions of the bearings.

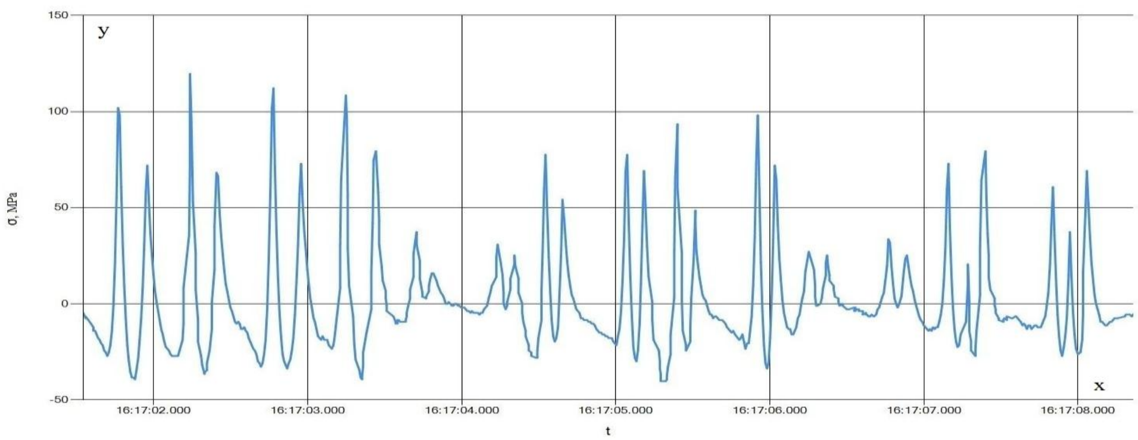


Figure 11. Diagram of stresses in the outer edge of the rail sole (reverse stroke).

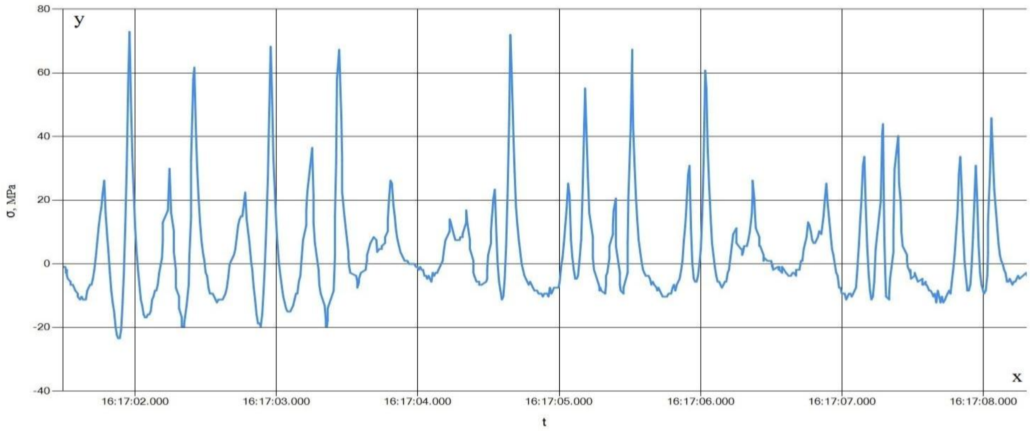
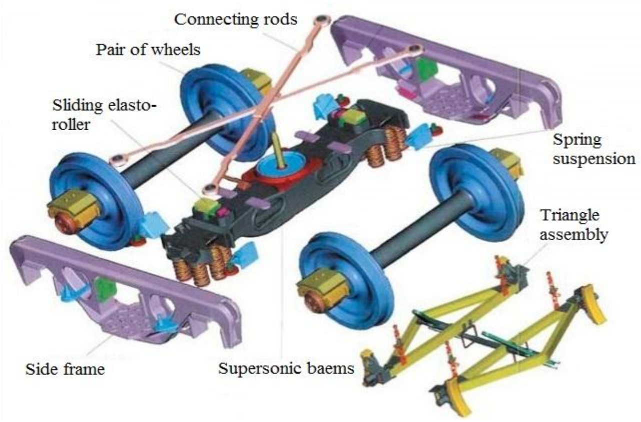
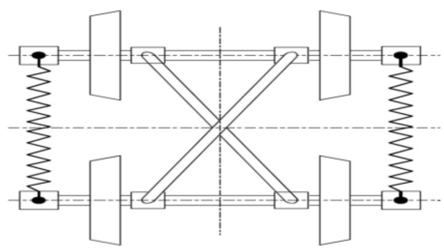


Figure 12. Diagram of stresses in the inner edge of the rail sole (reverse stroke).



a.



b.

Figure 13. Truck model ZK1: general structure (a), scheme (b).

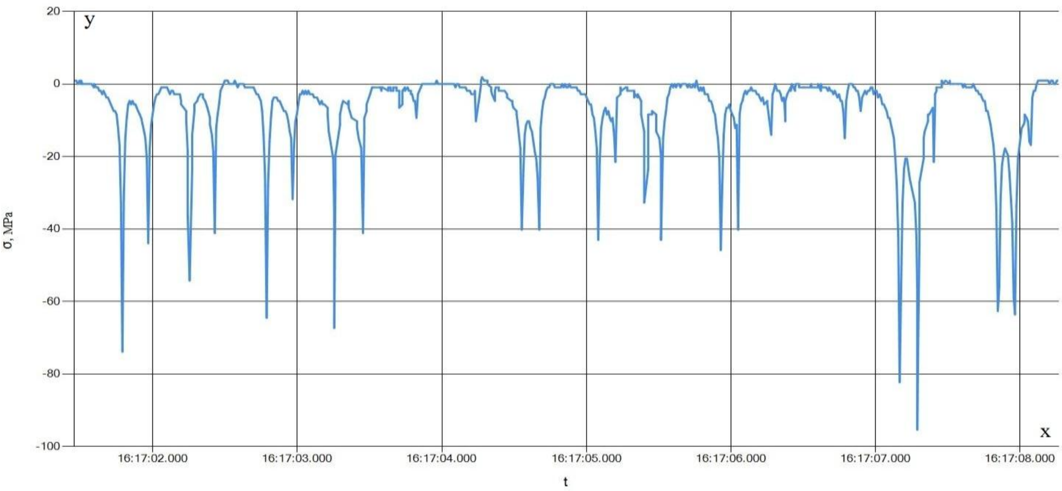


Figure 14. Diagram of stresses in the neck of the rail (reverse stroke).

Truck ZK1 consists of cast notched the box girders with four technological openings and cast side frames with technological Windows (Fig. 13). For a more rigid connection between the sides frames, bolster beam and spring sets, side frames diagonally connected to each other by means of two cross-bonded elastic elements (anchor links). The design articulation of a truck bolster with the side frames ensures the Squareness of the shape of the bogie. The benefit is the alignment of wheel set axles when the truck traffic [16]. For ease of fit in the curves of the track sections these carts have 11 mm transverse stroke of the wheel pair relative to the sidewall. To reduce the yaw of the truck slipping in the nodes of the applied rubber adapters. Truck model ZK1 is designed for an axial load of 245 kN (25t) and speed 120 km/h. In Fig. 14 diagram shows the measured stresses in the neck of the rail, and Figs. 16-19 – the distribution of the calculated vertical normal stresses in the rail are calculated using the finite element method (FEM). It is obvious that the measured voltage is comparable with the calculated stresses. The findings (see above) from the results of experimental studies require establishing the limits of applicability of the Schlumpf method as a means to restore forces from a wheel to a rail. For this purpose, design finite element models of a loaded vertical rail have been developed. (F_Z = 120 kN) and side (F_Y = 45 kN) concentrated forces in various combinations in sections above the support and between the supports. The stress-strain states (SSS) of the rail were studied at various positions point of application of vertical force to its head: along the axis of the rail and with an offset from the axis by d = 24.5 mm. The stress values were recorded at the control points on the rail neck [17], corresponding to the places where the strain gauges were installed to determine the lateral forces from the wheel to the rail according to GOST 55050-2012. The sectional diagram of the rail with the location point's application of concentrated forces and control points is shown in Fig. 15.

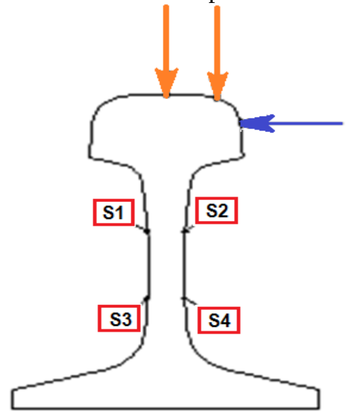


Figure 15. Scheme of the section of the rail with the location of the point's application of concentrated forces and control points.

In Figs. 16 - 19 show the distribution of normal vertical stresses in a rail for various design schemes.

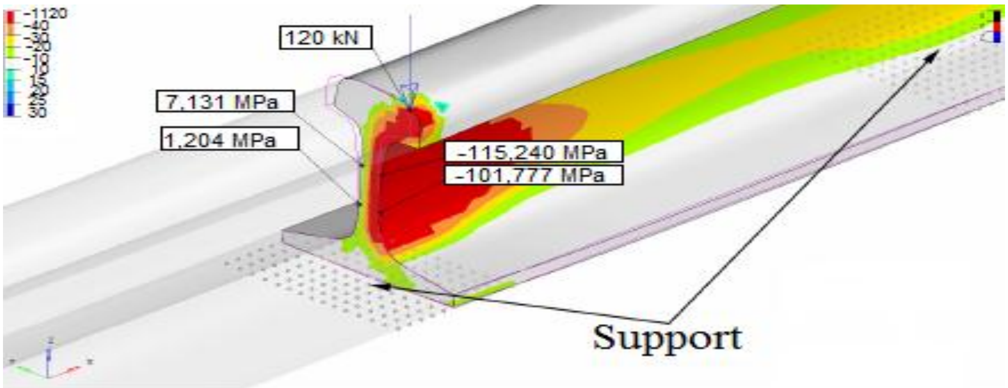


Figure 16. Distribution of normal vertical stresses in a rail, MPa. Vertical force 120 kN offset, lateral force 0 kN, loads above the support.

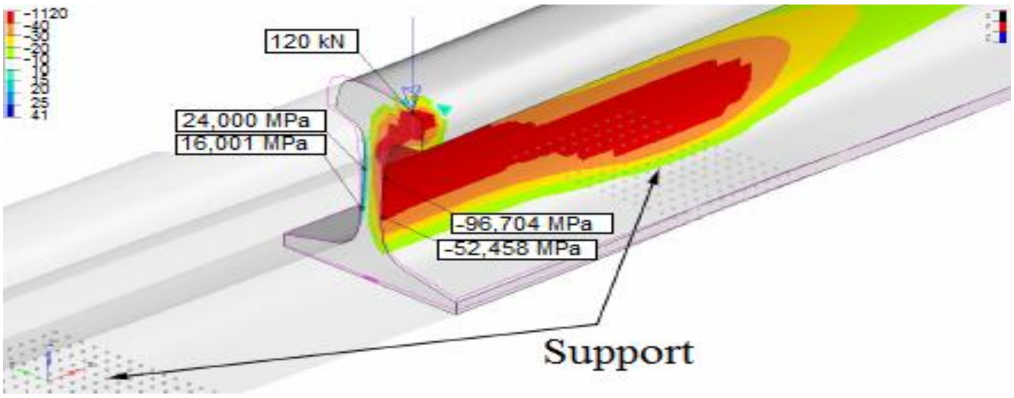


Figure 17. Distribution of normal vertical stresses in a rail, MPa. Vertical force 120 kN offset, lateral force 0 kN, loads between supports.

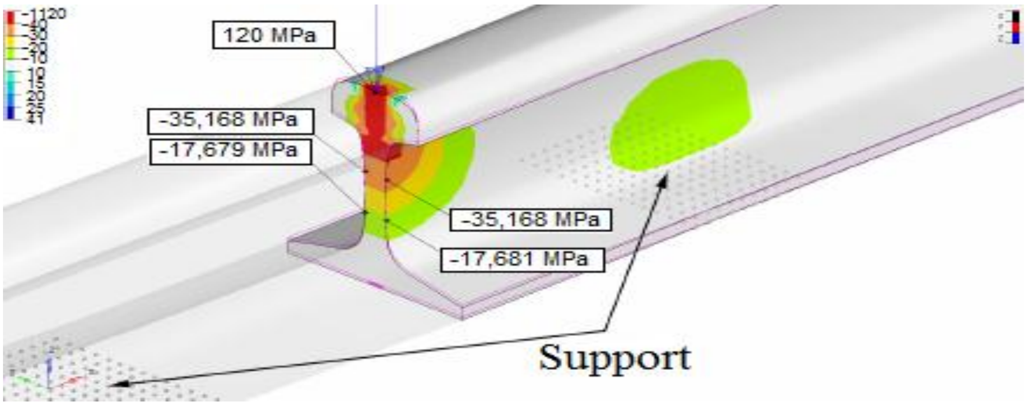


Figure 18. Distribution of normal vertical stresses in a rail, MPa. Vertical force 120 kN along the rail axis, lateral force 0 kN, loads between supports.

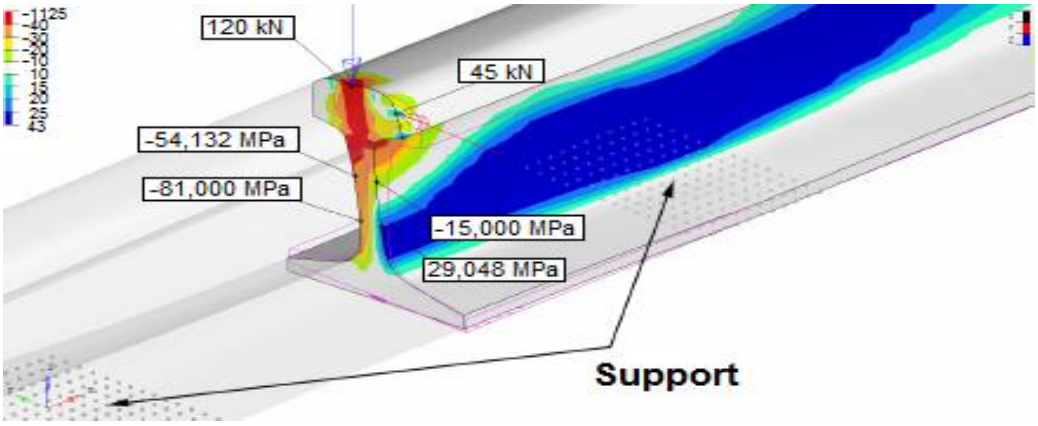


Figure 19. Distribution of normal vertical stresses in the rail (MPa), Vertical force 120 kN, lateral force 45 kN, loads between supports.

V. Conclusion

Analysis of graphs of the maximum measured edge stress from the effects laden gondola 12-9920 in the speed range from 25 to 80 km/h showed that on the outer edge of the foot rail the highest value (106 MPa) recorded during the passage of the composition at a speed of 40 km/h from Almaty to Shu (reverse), the lowest is 63 MPa, at the same speed, but the composition took place from the Shu in Almaty. On the inner edge of the foot rail the highest value (75 MPa) was also observed at a speed of 40 km/h during the return stroke (Almaty-Shu), but the lowest (55 MPa) recorded at 80 km/h as in direct and reverse motion. The maximum value of the voltage when passing the loaded gondola car 12-9941 from the outer edge of the foot rail (103 MPa) was also observed when speed of carriage 40 km/h during the return passage. Given that the difference between axial loads of gondola cars model 12-9920 and 12-9941 is 6% and the difference between the voltage (106 and 103 MPa) at only 2.8%. The experimental data on the values of the edge stresses in the sole and stresses in the neck of the rail suggest that the effect of gondola cars with a greater axial load of 12-9920 (25 tons) but with improved spring suspension is preferable to gondolas 12-9941 (23, 5 tons). Increasing the weight norms of freight trains is a very topical issue. The conducted measurements showed that it is quite possible without excessive influence on the railway track and accordingly expenses for reconstruction of the infrastructure, when modernized freight gondola cars with axle load of 245 kN (25 tons) are used on the network of the roads of JSC "NC" "Kazakhstan Railways".

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Author Contributions

Co-authors brought the following contributions for the development of the paper. Prof. Musayev J. developed the theoretical basics of tension rails. ass. Prof. Kvashnin M. developed the kinematic scheme for the railway crew. Dr. Zhauyt A. made mathematical model and numerical check of the system. ass. Prof. Zhunisbekov S. analyzed and calculated the parameters for the virtual model of the railway. Doctoral student Azilkiyasheva M. developed the virtual model of the proposed railway within UM software. Simulation and numerical check of the virtual model have been done by Doctoral student Murzakayeva M.

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