Commissioning of the freight wagons with increased axle loads is a guarantee of the further development of railways of the Republic of Uzbekistan

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Abstract. The aim of the study is to select rational axle loads of the rolling stock and establish the conditions for their circulation on the railways of the Republic of Uzbekistan. In this work, research has been carried out to assess the indicators of the stress-strain state of rail track elements from the action of the rolling stock with various axial loads. The dynamic loads from the rolling stock wheel on the rail, tensile stresses at the edges of the rail foot, in wooden sleepers (rubber under-rail pads on reinforced concrete) under the linings, in the ballast under the sleeper, as well as stresses at the main area of the roadbed, were determined. The obtained results of studies on the determination and assessment of the loading of the elements of the permanent way and sub-grade bed under the condition of not exceeding their standard values made it possible to establish the permissible speeds of movement of freight wagons with increased axle loads of 25 and 27 tf on the railways of the Republic of Uzbekistan, depending on the design of the track and the thickness of the ballast layer, which will increase the running and carrying capacity of the most loaded sections of the railway network, reduce operating costs, increase the volume of freight traffic by rail, which will create conditions for the further development of national rail transport in the implementation of export and transit potential.

1 Introduction

The possibility of introducing into operation of freight wagons with increased axle loads and arranging their circulation on the railways, depending on the structure of the permanent way, is determined by assessing the indicators of the impact of the rolling stock on the track. Various techniques have been developed to assess this impact [1-3]. However, their application is difficult due to insufficient knowledge of the quantitative assessment of the main factors affecting this interaction.

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2 Methods

Currently, to determine the indicators of the impact of the rolling stock on the track on the railways of the CIS countries, including in the Republic of Uzbekistan, the "Methodology for assessing the impact of the rolling stock on the track according to the conditions of ensuring its reliability" is mainly used [4].

According to the Methodology [4] and GOST R 55050-2012 [5], the main factors influencing the loading indicators of the elements of the permanent way and the sub-grade bed include the axial load of the rolling stock; track characteristics and design: type of rail, sleepers, ballast, modulus of elasticity of the rail base, thickness of the ballast layer, the distance between the axles of sleepers and others; bogie design: mass of unsprung parts, static deflection of spring suspension, the distance between the centers of the axles of wheel pairs, wheel diameter and others; train speed.

To select rational axle loads of the rolling stock and establish the conditions for their circulation on the railways of the Republic of Uzbekistan according to the approved Methodology [4], studies have been carried out to assess the indicators of the stress-strain state of rail track elements.

Based on the analysis of the characteristics of the structures of the main, station and access roads, which are included in the balance of JSC "O'zbekiston temir yo'llari", the following track designs were selected for research [6-10]:

- rails R65 and R50 types, laid on reinforced concrete sleepers (RCS) with a profile of sleepers 1840 pcs/km on crushed stone ballast (Cs);
- R65 rails, laid on wooden sleepers of the first (I) type with a sleep pattern of 1600 and 1840 pcs/km on crushed stone ballast;
- rails R65 and R50 types, laid on wooden sleepers of the second type with a profile of sleepers 1600 and 1840 pcs/km on gravel ballast (Gr);
- R50 rails, laid on wooden sleepers of the second (II) type with a sleep pattern of 1600 and 1840 pcs/km on crushed stone ballast.

Also, the studies considered the above track designs on curved sections with a radius of 350 m with a sleep pattern of 2000 pcs/km.

Because the share of tracks with R75 and R43 rails on the country's railways is so small (no more than 2.5 %), the design studies of tracks with these rails were not considered. Also, tracks with sand ballast were not considered since their share in the total length of tracks does not exceed 1.0 % (about 70 km) and are mainly available on non-public tracks, where train speeds are limited to 25-40 km/h [11, 12].

According to [13, 14], in the studies, variable values of the thickness of the ballast layer under the sleeper were taken, taking into account the ballast cushion of sand with a thickness of 20 cm:

- on crushed stone ballast: 45, 50 and 55 cm;
- on gravel ballast: 30, 35 and 40 cm.

The studies considered that the rolling stock is formed of freight wagons with improved indicators of dynamic impact on the track. The impact on the track of freight wagons on bogies 18-9855 with an axle load of 25 tf, wagons on bogies 18-6863 with an axle load of 27 tf and serial freight wagons on bogies 18-100 with an axle load of 23.5 tf (table 1) was evaluated.

Table 1. Basic technical characteristics of the wagons crew part [15, 16].

Parameters	Bogie model		
	18-100	18-9855	18-6863
Axle loading (tf)	23.5	25.0	27.0
Weight of the unsprung parts referred to the wheel (kgf)	995	1035	1140
Static deflection of the spring suspension (mm)	48	51	70
The distance between the centers of the axles of the wheelsets of the vehicle bogie (cm)	185	185	187
Wheel diameter on a rolling circle (cm)	95		

3 Results and Discussion

The dynamic load from the wheel of the rolling stock on the rail following the Methodology [4] is determined by the expression

$$P_{din}^{\max} = P_{st} + 0.75 \cdot k_d \cdot (P_{st} - q) + 2.5 \cdot S, \quad (1)$$

where P_{st} is the static load from the wheel to the rail; k_d is the coefficient of dynamic addition of the sprung parts; q is the weight of the unsprung parts referred to the wheel; S is the average deviation of the dynamic vertical load of the wheel on the rail.

The value of the coefficient of dynamic addition of the sprung parts k_d is determined experimentally and in the absence of experimental data – by calculation. As a result of the analysis, it was stated that the experimental values of the coefficient of dynamic addition of sprung parts k_d obtained during running dynamic tests of freight wagons on straight sections of the track, in comparison with the calculated ones according to empirical formulas on the Methodology [4, formula (5)] and according to GOST 33211-2014 [17, formula (4.12)], is less than calculated (figure 1, *a*, *b*).

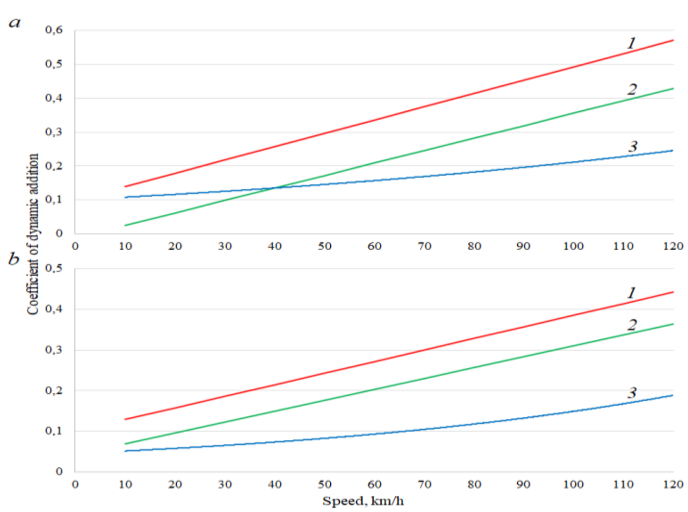

Fig.1. Dependence of the coefficient of dynamic addition of sprung parts of a freight wagon with an axle load of 25 tf (*a*) and 27 tf (*b*) on the speed of rolling stock: 1 is calculation according to the Methodology [4]; 2 is calculation according to GOST 33211-2014 [17]; 3 is experiment.

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Dependences obtained by expression (1) and experimental values of dynamic loads on a typical track structure (with R65 rails laid on reinforced concrete sleepers with a sleep pattern in straight track sections 1840 pcs/km on crushed stone ballast) on the speed of rolling stock on straight sections are shown in figure 2.

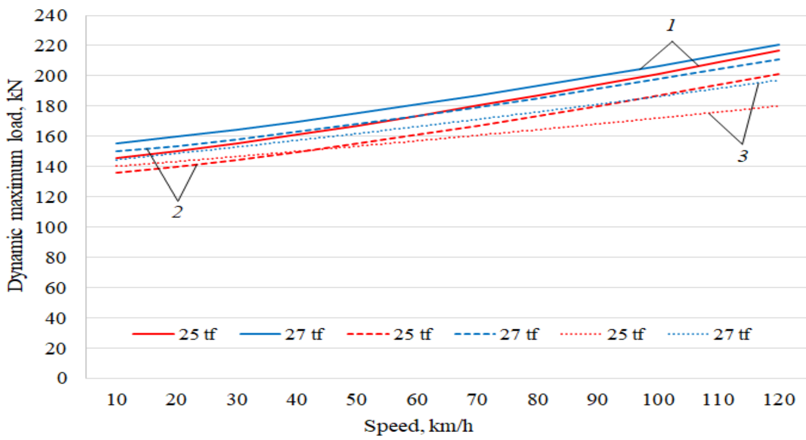


Fig. 2. Dependence of the dynamic maximum loads on the speed of the rolling stock with axial loads of 25 and 27 tf: 1 is according to the calculated values k_d according to the Methodology [4]; 2 is according to the calculated values k_d according to GOST 33211-2014 [17]; 3 are experimental values

According to the research results, it was found out that the experimental values of the dynamic maximum loads from the wheels on the rails are less than the calculated ones. Therefore, in the future, the load indicators of the track elements were calculated with the loads obtained by the calculation formula, according to the Methodology [4], which will ensure the safety margin of the track elements.
As an assessment criteria for the force impact of the rolling stock on the track in accordance with the Methodology [4] and GOST R 55050-2012 [5], the indicators given in table 2 were taken.

Table 2. Evaluation criteria for track strength

Criteria	Unit of measurement	According to GOST R 55050-2012 [5]
[σ_k] – allowable tensile stresses in the edges of the rail foot	MPa	240
[σ_{sl}] – permissible collapse stresses in wooden sleepers (pads on reinforced concrete) under pads		2.2
[σ_b] – allowable compressive stress in the ballast under the sleeper		0.5/03* (*for track with gravel ballast)
[σ_h] – allowable compressive stresses on the main site of the subgrade		0.08

The assessment of the impact of freight wagons with increased axle loads on the track was made by comparing the data obtained from the results of stress calculations with their permissible values according to GOST R 55050-2012 [5], as well as with those obtained during operation on the railway network of freight wagons on bogies of traditional design (models 18-100) with an axle load of 23.5 tf.

Tensile stresses in the edges of the rail foot are considered to be the determining parameter of the rail strength, which, following the Methodology [4], are calculated by the formula:

$$\sigma_k = f \cdot \sigma_0. \tag{2}$$

Here *f* is the coefficient of transition from axial stresses in the rail foot to edge stresses; σ_0 is maximum stresses in the rail foot from its bending under the action of the moment *M*, which are determined by the expression,

$$\sigma_0 = \frac{M}{W} = \frac{P_{din}^{\max} + \sum \mu_i P_{av}}{4kW},$$

where *W* is the moment of resistance to bending of the rail to the axis passing in the plane of its foot; *k* is coefficient taking into account the relative stiffness of the rail base and the rail; μ_i is ordinates of the line of influence of bending moments of the rail in the sections of the railway track; P_{av} is the average value of the vertical force from the wheel to the rail.

The calculation results obtained by formula (2) are shown in figure 3. It can be seen that the highest values of edge stresses in the rail foot in all considered track structures, except for R50(6)2000(II)Cs and R50(6)2000(II)Gr, do not exceed the established permissible values of 240 MPa according to GOST R 55050-2012 [5] when operating freight wagons with an axle load of up to 27 tf at a speed of 90 km/h, which meets the requirements of the Rules for the technical operation of railways of the Republic of Uzbekistan (RTO) [12]. On tracks with type II wooden sleepers R50(6)2000(II)Cs and R50(6)2000(II)Gr for not exceeding the established allowable values of 240 MPa following GOST R 55050-2012 (figure 3) when operating freight wagons with the axle with a load of 27 tf, it is necessary to limit the speed to 80 km/h.

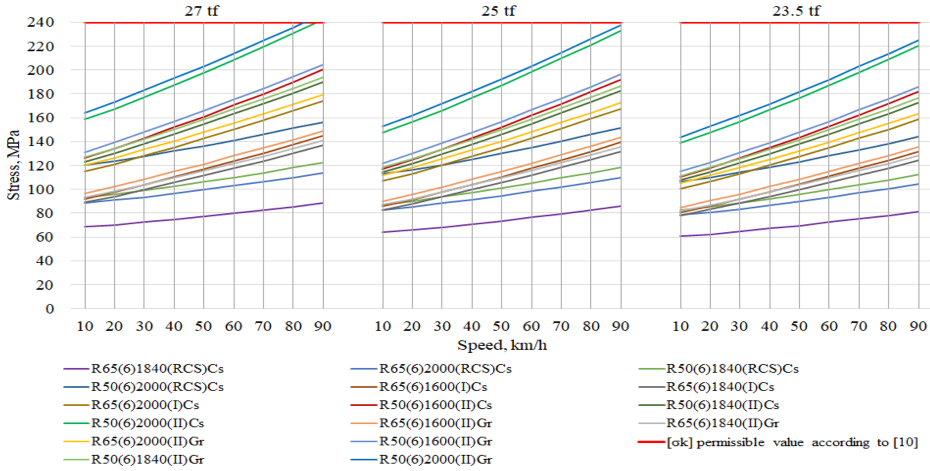


Fig. 3. Dependence of the maximum stresses arising in the edges of the rail foot from the speed of the rolling stock.

The stresses in wooden sleepers (rubber under-rail pads on reinforced concrete) under pads following the Methodology [4] are determined by the formula:

$$\sigma_{sl} = \frac{kl_{sl}}{2\omega}(P_{din}^{\max} + \sum \eta_i P_{av}), \tag{3}$$

where l_{sl} is the distance between the axles of adjacent sleepers; ω is area of under-rail pad; η_i is ordinates of the line of influence of rail deflections in track profile.

The dependences of the maximum stresses in wooden sleepers (rubber under-rail pads on reinforced concrete) from the speed of the rolling stock, obtained by formula (3), are shown in figure 4.

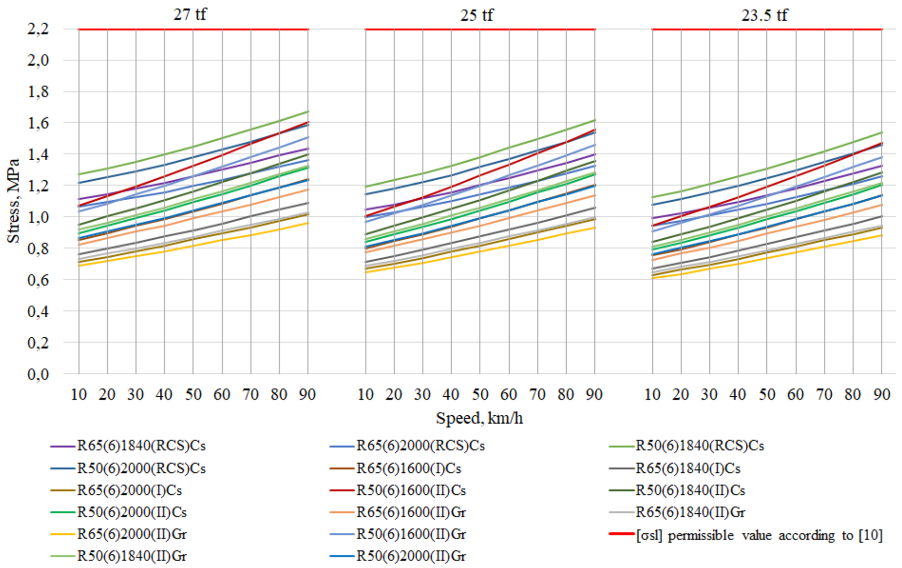


Fig.4. Dependence of the maximum stresses arising in wooden sleepers (rubber under-rail pads on reinforced concrete) from the speed of the rolling stock.

It has been determined that the maximum stresses arising in wooden sleepers (rubber under-rail pads on reinforced concrete) under the lining in all considered rail track structures do not exceed the established allowable values of 2.2 MPa according to GOST R 55050-2012 [5] when operating freight wagons with an axle load of up to 27 tf vehicle with the speed of 90 km/h, which meets the requirements of the RTO [12].

The maximum stresses in the ballast under the sleeper in accordance with the Methodology [4] is determined by the expression

$$\sigma_b = \frac{Q}{\Omega} = \frac{kl_{sl}}{2\Omega}(P_{din}^{\max} + \sum \eta_i P_{av}), \tag{4}$$

where Q is the maximum effort on the sleeper; Ω is the area of the half-sleeper, taking into account the correction for its bending, cm^2.

Figure 5 shows the calculation results obtained by formula (4). It was determined that the maximum stresses arising in the ballast under the sleeper in all the track structures under consideration, except for the R50(6)1600(II)Gr track design, do not exceed the established permissible values of 0.5 MPa (0.3 MPa for a track with gravel ballast) according to GOST R 55050-2012 [5] when operating freight wagons with an increased axle load of up to 27 tf at a speed of up to 90 km/h, which meets the requirements of the RTO [12]. On tracks with the R50 (6)1600(II)Gr structure for not exceeding the stresses arising in the gravel ballast under the sleeper, the established permissible values of 0.3 MPa following GOST R 55050-2012 [5] when operating freight wagons with an axle load of up to 27 tf the vehicle must reduce the speed of movement to 80 km/h (figure 5, *b*).

a

b

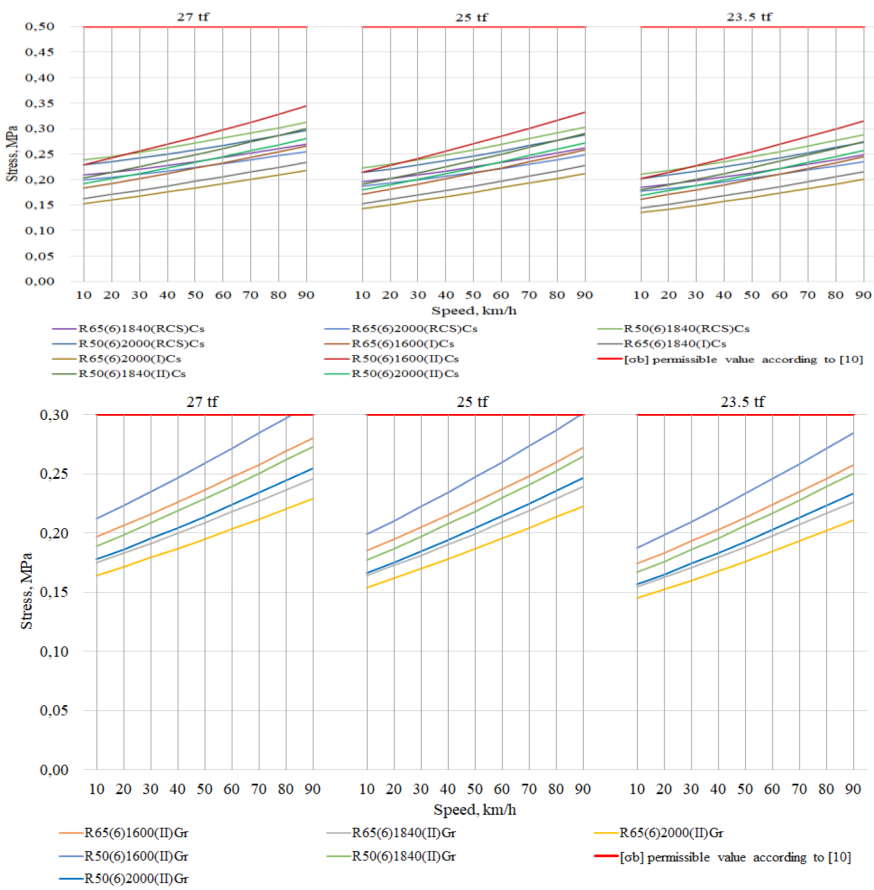


Fig.5. Dependence of the maximum stresses arising in the ballast under the sleeper on the speed of the rolling stock: *a* is for crushed stone ballast; *b* is for gravel ballast.

Normal stresses σ_h in the main area of the subgrade bed at a depth h from the foot of the sleeper in the rail zone along the calculated vertical in accordance with the Methodology [4] are determined by the expression

$$\sigma_h = \sigma_{h1} + \sigma_{h2} + \sigma_{h3}\,. \tag{5}$$

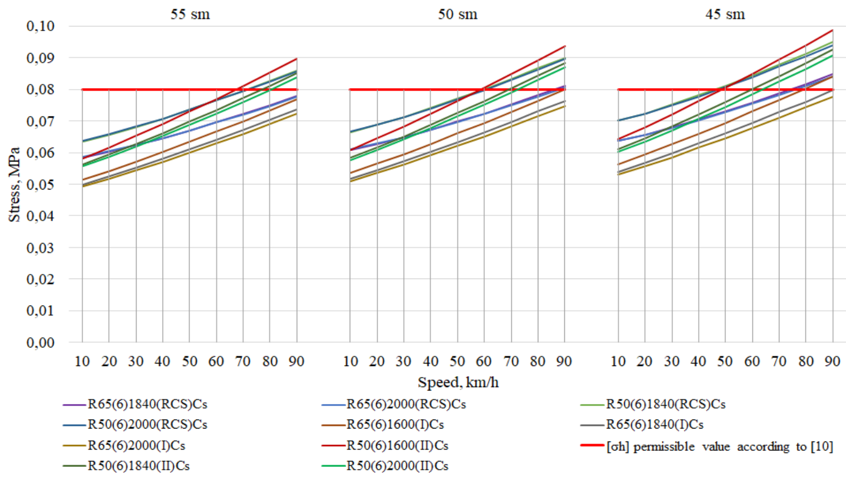
Here σ_{h1} and σ_{h3} are stresses from the impact of the 1st and 3rd sleepers, respectively, lying on both sides of the second (calculated) sleeper; σ_{h2} is stresses from the impact of the second sleeper in the profile of the track under the design wheel

$$\sigma_{h2} = \sigma_b z\left[2.55C_2 + (0.635C_1 - 1.275C_2)m\right]$$

where z is a coefficient that takes into account the uneven distribution of pressure along the sleeper and the spatial distribution of the load; m is the transition coefficient from the pressure on the ballast averaged over the width of the sleeper to the pressure under the axis of the sleeper; C_1, C_2 are coefficients that take into account the width of the sleepers bed and the depth of the ballast layer; σ_b is the stress in ballast under the calculated (second) sleeper, averaged over the width of the sleeper.

The calculation results obtained by expression (5) are shown in figure 6.

a



b

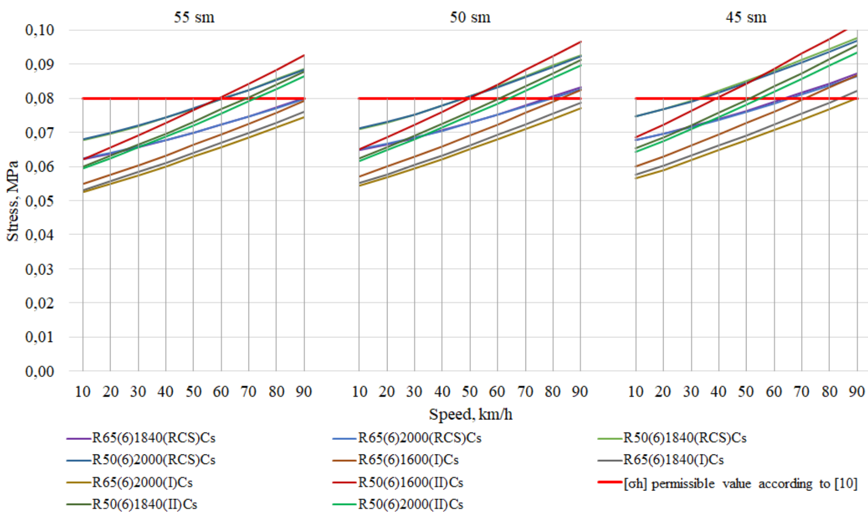


Fig. 6. Dependence of the maximum stresses arising in the main area of the roadbed on the speed of the rolling stock with axial loads of 25 tf (*a*) and 27 tf (*b*) on crushed stone ballast.

The results of the research showed that the stresses in the main area of the sub-grade bed on the main tracks of the railways of the Republic of Uzbekistan, where the track mainly has a structure with rails of the R65 type and heavier, laid on reinforced concrete sleepers and type I wooden sleepers with a sleeper pattern of 1840 pcs/km and more on crushed stone ballast with the thickness of at least 55 cm, taking into account a ballast cushion of sand with the thickness of 20 cm (R65(6)1840(RCS)Cs, R65(6)2000(RCS)Cs, R65(6)1840(I)Cs and R65(6)2000(I)Cs), do not exceed the established allowed values of 0.08 MPa according to GOST R 55050-2012 [5] when operating freight wagons with an axle load of up to 27 tf at a speed of up to 90 km / h, which meets the requirements of the RTO [12]. At the same time, on tracks with R50 rails (R50(6)1840(RCS)Cs and R50(6)2000(RCS)Cs) with a ballast layer thickness of at least 55 cm in order not to exceed the stresses arising in the main area of the sub-grade bed, the permissible values 0.08 MPa following GOST R 55050-2012 when operating freight wagons with an axle load of 25 tf, it is necessary to limit the speed of movement to 70 km/h, and when operating wagons with an axle load of 27 tf – to 60 km/h (figure 6).

It was found that on the station and access tracks included in the balance of JSC "O'zbekiston temir yo'llari" for the operation of freight wagons with an axle load of 25 tf at a speed of up to 40 km/h, according to [11, 12], on tracks with R50 rails laid on reinforced concrete sleepers (R50(6)1840(RCS)Cs and R50(6)2000(RCS)Cs), the thickness of crushed stone ballast must be at least 45 cm, and for wagons with an axle load of 27 tf – at least 50 cm.

4 Conclusions

Thus, the performed research to determine and assess the loading of the elements of the permanent way and sub-grade bed according to the condition of not exceeding their standard values made it possible to establish the permissible speeds of movement of the freight wagons with increased axial loads of 25 and 27 tf on the country's railways, depending on the track design and the thickness of the ballast layer. At the same time, it was stated that the existing structure of the main tracks of the railways of the Republic of Uzbekistan with rails of the R65 type and heavier, laid on reinforced concrete sleepers with a sleeper pattern of 1840 pcs/km or more on crushed stone ballast with a thickness of at least 55 cm, taking into account a ballast cushion of sand with a thickness of 20 cm, has sufficient strength and allows, without overstressing the elements of the permanent way and sub-grade bed, to operate freight rolling stock with increased axial loads up to 27 tf at a speed of up to 90 km/h, which meets the requirements of the RTO [12].

To improve the accuracy of measurements of the rolling stock's force impact on the track, it is proposed to apply the method of piecewise continuous registration of vertical and lateral forces from the interaction of the wheel with the rail by measuring the stresses in two sections of the rail [18-21].

Thus, the introduction of the considered rolling stock on the railways of the Republic of Uzbekistan will increase the carrying and throughput capacity of the most loaded sections of the railway network [22, 23], reduce operating costs, increase the volume of freight traffic by rail, which will create conditions for the further development of national railway transport in the implementation of export and transit potentials of the Republic of Uzbekistan.

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