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CALCULATION OF THE BALLAST RESISTANCE TO TRANSVERSE DISPLACEMENTS OF SLEEPERS DURING HIGH-SPEED TRAIN MOVEMENT

Abdukhamid Abdujabarov Khalilovich,
T.F.D., Professor
Tashkent State Transport University

Begmatov Pardaboy Abdurahimovich,
Doctoral Student
Tashkent State Transport University

Matkarimov Abdurashid Khayitmat o'g'li,
T.F.N., Docent
Tashkent State Transport University

ABSTRACT:

Based on the generalization of experimental data, an algorithm for calculating the resistance of the ballast to the transverse displacements of the sleeper under the action of vertical and lateral loads is developed. One of the factors that counteract the deformations of the rail-sleeper grid in the horizontal plane is the resistance of the ballast to the shear of the sleepers. The quasi-static forces of the resistance of crushed stone ballast to the displacement of a sleeper with a concave support part and a geotextile gasket from the shear value and vertical load are determined. As well as determining the energy dissipation in various elements of the track structure by the shift of the operated track, at which the energy dissipation coefficients for the movements of the rail head, lining and sleeper from the load on the rail were determined.

Keywords: ballast prism, rail-sleeper grid, sleepers.

INTRODUCTION:

When calculating the strength of a railway track, stresses and deformations in the ballast prism and on the main platform of the roadbed are determined under the influence of passing trains, or such loads and train speeds that the stresses and deformations in these elements of the track will not exceed the permissible ones. These values are also determined during the feasibility study of the construction of the upper structure of the track [1].

In today's day of increasing the stability and durability of the railway track with high-speed train traffic, the requirements taking into account the real conditions of Uzbekistan are relevant. All this leads to the need to create constructive solutions to ensure the reliability of the roadbed and the ballast layer.

Stress-strain state of the ballast layer and the roadbed according to the results of research by M. F. Verigo, A. M. Golavanchikov, S. N. Popova, V. V. Kuznetsova, and others. [1, 2, 3, 4]. They were clarified when reinforcing with geotextile, which provides these structures with stability during high-Speed train traffic.

When external vibration influences on the ballast prism, the most vulnerable node is the slopes from which its destruction begins, and geotextile reinforcement ensures its stability, which positively affects the stable operation of the entire structure. Edge stresses that occur in the cantilever part of the ballast prism, where the slopes are located, are significantly reduced by geotextile laying. [5].

RESULTS AND DISCUSSION:

One of the factors that counteract the deformation of the rail-sleeper grid in the horizontal plane is the resistance of the ballast to the shear of the sleepers. According to the results of the track laboratory of the Swedish state railway, the ballast prism accounts for 60% of the total resistance to transverse movements of the track [6]. The main factors affecting the shear resistance of sleepers are the vertical load on the sleeper and the degree of compaction of the ballast [7].

When processing experimental data, the dependence of the quasi-static resistance force of crushed stone ballast to the displacement of a sleeper with a concave support part and a geotextile gasket on the shear value and vertical load is obtained:

$$F = (a + b\nu)\sqrt[5]{\Delta}\, f\, d \qquad (1)$$

here: F –the value of the quasi-static component of the ballast resistance, kN;
ν – vertical load on the sleeper, kN;
Δ – the displacement of the sleepers under the action of external forces, mm;
a, b – factors that take into account the type and state of the ballast are proposed in [3].
f – coefficient that takes into account the effect on the strengthening of the ballast from geotextile laying, (f=1.1);
d – coefficient that takes into account the concavity of the support part of the sleeper, (d=1.05).

Coefficient – a characterizes the resistance of the ballast at the ends and side walls of the sleeper, b – characterizes the resistance depending on the value of the vertical load.

The initial degree of the root simplifies the formalization of the calculation process when taking into account the direction of the reaction of the ballast prism depending on the direction of the sleeper displacement.

The large steepness of the power dependence in the region of small offset values avoids the use of a constant component in this empirical formula (1). The viscous properties of the ballast are taken into account by introducing into the expression for the total resistance $R_б$ except for the quasi static term which is proportional to the first power of the sleeper displacement velocity:

$$R_б = F + K_б\, \dot{y}\, e \qquad (2)$$

here: $K_б$ – coefficient of viscous friction in the ballast, which depends on the vertical load;
y – the amount of disturbance to sleepers, mm;
e – coefficient that takes into account the change in the viscosity of the ballast from the use of geotextile gaskets, (e=1,2).

In the course of experiments, we used a method for determining the elastic and dissipative components of the ballast reaction in the vertical and transverse directions under the rolling stock [8].

When the yield is reached, the plastic displacement of the sleeper begins, which does not cause a further increase in the resistance forces. For crushed stone and gravel ballast, the value of the residual displacement – $\delta_т$ depends on the maximum values of the sleeper displacements and is determined by the expression – (Fig. 1).

$$\delta_т = \begin{cases} 0,\text{ для } |\max(y_n - y_{on})| \le 0{,}3\text{ мм} \\ 0{,}35\,[\max(y_n - y_{on}) - 0{,}3\,\mathrm{sign}\max(y_n - y_{on})]\text{ для } 0{,}3\Delta|\max(y_n - y_{on})| \le \\ \max(y_n - y_{on}) - 0{,}9\,\mathrm{sign}\max(y_n - y_{on}),\text{ для } 1\Delta\,|\max(y_n - y_{on})| \end{cases}$$
$2\text{ мм} \qquad (3)$

here all quantities have the dimension of mm.
y_{on} – starting point of reference for sleeper offsets;
y_n – the value of the sleeper offset from the zero position achieved in this – n loading cycle;

$\max(y_n - y_{on})$ – the maximum offset, that is, the amplitude of the n – cycle offset.

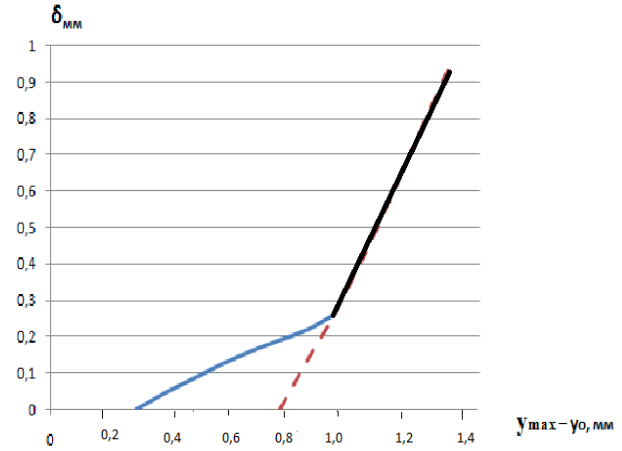

FIGURE 1. Dependence of the residual displacement of the sleeper on the maximum value of the cross slide.

When the shear force decreases, the sleeper under the action of the elastic component of the ballast resistance force returns to a position different from the original one by the value – δ_T. The initial position of the sleeper was – y_{on}, then before the start of the n+1 loading cycle, the new reference point for determining the value of the ballast drag force is:

$$y_{on+1} = y_{on} + \delta_T;$$
(4)

The value of the ballast resistance force under loading in the (n+1) cycle is equal to:

$$F^T_{n+1} = (a + bv)\sqrt[5]{y - y_{on+1}};$$
(5)

here the index (+) corresponds to an increase in the sleeper offset, that is, the condition is met:

$$\text{sign}(y - y_{on-1}) = \text{sign}\,\dot{y};$$

The presence of friction forces in the path, which depend not only on the speed of trains, but also on the displacement of sleepers, the unloading branch of the quasi-static cycle differs significantly from the load one [5]. Characteristic of the unloading process is a sharp initial decline in the value of the return force. Further, the curve of the return force dependence on the displacement becomes more gentle crossing the abscissa axis at the point – y_{on+1} – Fig. 2.

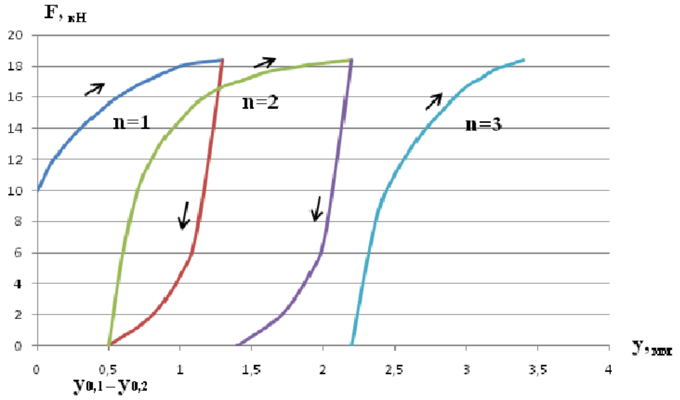

FIGURE 2. Nature of the force–displacement curves under cyclic loading of the sleeper (vertical load 27 kN).

The quasi-static component of the relationship between the forces of the ballast and the displacement of the sleeper, with a decrease in the magnitude of the external impact, is equal to:

$$F_n = (a + bv)\sqrt[5]{\frac{\max y_n - y_{on}}{\max y_n + y_{on}}}\left(\sqrt[5]{\max y_n - y_{on}} - \sqrt[5]{\max y_n - y}\right); \qquad (6)$$

here: F_n – is the quasi – static component of the forces of interaction between the sleeper and the ballast in the b n – cycle when moving to the equilibrium position (sign $y \neq$ sign(y-y_{on}));

max y_n – the maximum value of the sleeper displacement in the loading cycle;

y_{on} – coordinate of the sleeper at the beginning of the loading cycle;

y_{on}= y_{on}+ δ_T – the intersection point of the cycle discharge line with the abscissa axis.

A consequence of the nonlinear nature of the loading and unloading dependences is the energy dissipation of the ballast during loading, which is determined by the absorption coefficient:

$$\psi = \frac{\Delta W}{W};$$
(7)

here: ΔW – part of the energy absorbed in one cycle;

W – is the potential energy of the cycle corresponding to the strain amplitude for the same cycle.

To determine the energy dissipation in various elements of the track structure, experiments were conducted on the shift of the operated track, in which the coefficients of energy dissipation for the movements of the rail head, lining and sleeper from the load on the rail were determined – Fig. 3.

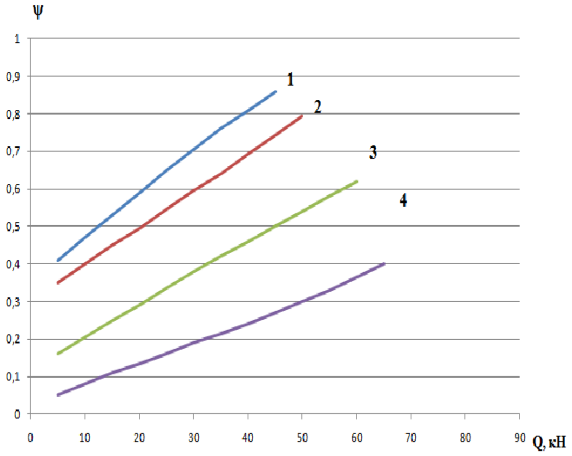

FIGURE 3. The power dissipation calculated:
1 – for sleepers with a concave support part;
2 – for normal sleepers;
3 – for lining made of fluoropolymer – F4;
4 – for the rail head.

Processing the experimental results for the steady state of crushed stone ballast allowed us to determine the coefficients:

$$a=9, \qquad b=0,6;$$

a an empirical formula for calculating the force of resistance to the displacement of sleepers in crushed stone ballast under the action of vertical and horizontal loads:

$$F = (9 + 0,6\sqrt[5]{\Delta}; \qquad (8)$$

here the forces are expressed in kN, and the displacement – Δ – in millimeters.

Figure 4 shows the dependence of the value of the shear force on the vertical load, obtained as a result of processing data from experiments at the test site [10].

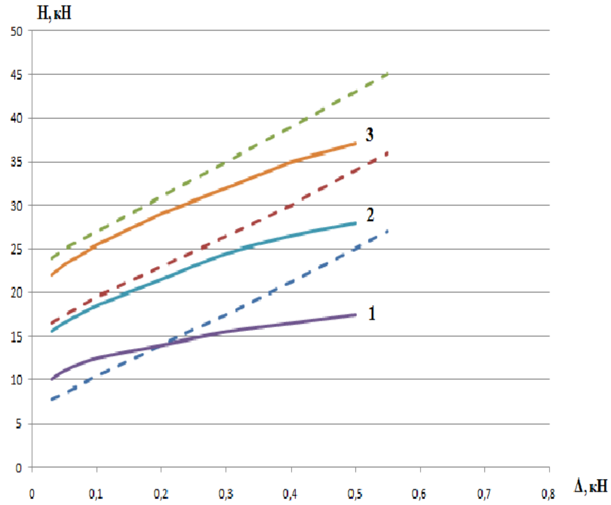

FIGURE 4. Dependence of the shear force on the vertical load – ν: 1– ν =20 kN; 2– ν =40 kN; 3– ν =60 kN;

——–the curve obtained by calculation.

-------- – the curve obtained from the experiment.

Figure 4 shows a sufficient convergence of the empirical dependence with the experimental data, which shows the reliability of the obtained scientific research.

CONCLUSION:

1.The formula for the quasi-static resistance force of crushed stone ballast to the displacement of a sleeper with a concave support part and a geotextile gasket is clarified;

2.Clarified the viscous properties of the ballast from the use of geotextile gaskets;

3.The dependence of the residual displacement of the sleeper on the maximum value of the cross slide is established;

4.Updated the power dissipation of the ballast during loading:

a) for sleepers with a concave support surface;
b) for ordinary sleepers;
c) for the rail head;
d) if the strip of fluoroplastic's

5.The dependence of the shear force at different vertical loads is clarified.

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