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Changing the Stress State of the Track Superstructure while Strengthening the Subgrade

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Abstract. Strengthening the subgrade with the help of various technologies significantly affects the stress state of the track superstructure. The strengthening of the subgrade with piles, leads to an abrupt stiffening of the track superstructure, which is problematic for its normal operation. Two finite element models were created to determine the change in the stress state of the track superstructure when strengthening the subgrade. They fully reflect the geometric, deformation and power characteristics of a real subgrade, which is strengthened by piles. Individual finite elements of the models are provided with the deformation characteristics of the steel rails, reinforced concrete sleepers, soil subgrade, ballast and soil-cement material of piles. The authors carried out the calculation of stress state of the track superstructure for two finite element models. Results are obtained and analyzed to help in choosing the most effective option for strengthening the subgrade.

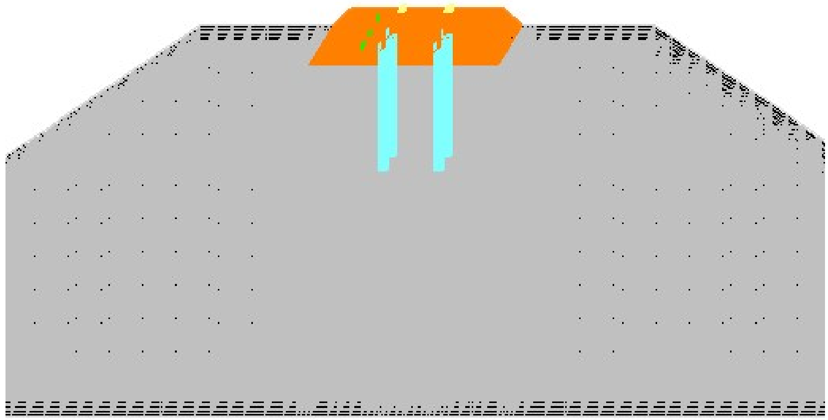
Introduction

At the current stage, among the many issues in transport improving traffic safety is relevant. It depends on many factors including the interaction of parts in the "rolling stock – track superstructure – subgrade" system. A comprehensive analysis of these parts involves the research of the stress state when the rolling stock operations, taking into account the features of the track superstructure (TS) [1]. For example, geometrical irregularities and rails unevenness [1,2], their geometric position in the plane (circular and transition curves) [1,3], parameters of TS [4], etc. Since the rolling stock operation is characterized by significant dynamic loads [5,6], they, in turn, move in the form of impacts on the "track superstructure – subgrade" system.

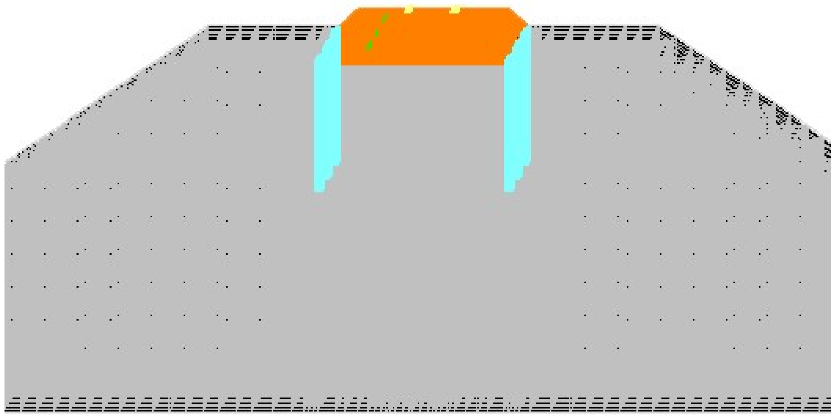
Physical modelling is an important part of the researches that provides possibilities to correct theoretical foundations [7–10]. A number of methods are existing for solving the problem of straightening of the subgrade in transport [11–15]. One of which there is strengthening the subgrade by various technologies, which significantly affects the stress state of the track superstructure.

Researches of the stress state of the track superstructure

In order to determine the influence of the subgrade straightening on the stress state of the track superstructure two finite-element models were built using a professional complex SCAD. They correspond to the strengthening of the subgrade by soil-cement piles. Option 1 – piles are located near a rail (Fig. 1, a); Option 2 – piles are located near the ballast section (Fig. 1, b).



a)



b)

Fig. 1: Finite-element models of the subgrade: a) Option 1; b) Option 2

The models fully reflect the geometric, deformation and power characteristics of a real subgrade which is strengthened by piles [13,16,17]. At the same time, the individual finite elements are given the deformation characteristics of steel rails, reinforced concrete of sleepers, soil of the subgrade, crushed stone of ballast and soil-cement material of piles.

The total number of model nodes is 28 203 pcs. (about 85 thousand degrees of freedom, the task is considered to be large-sized), the number of finite elements is 31 572 pcs. The finite elements in the model are accepted as compatible ones, that is, all nodes of neighboring elements coincide, which positively affects the accuracy of the solution. The finite elements of the "prism" and "tetrahedron" types were taken from the SCAD complex library (license number is F755B84 (KMBKB RA 4810)). These are isoparametric elements with a maximum size of 0.2×0.2×0.2 m (there are elements with a size of 0.25×0.25×0.25 m, not more than 5…7% of the total number of finite elements in the model). Model dimensions: length (base) is 40.6 m, width is 1.64 m, height is 11.1 m (6 m of which is the height of the subgrade).

The finite elements of the model were provided with the corresponding stress-strain properties: 1) the basis of the subgrade is loam, specific gravity γ=1.9 t/m^3, modulus of elasticity

E=25 MPa, Poisson's ratio ν=0.3; 2) ballast section is crushed stone, specific gravity γ=2.2 t/m^3, modulus of elasticity E=150 MPa, Poisson's ratio ν=0.2; 3) a rail is steel, specific gravity γ=7.7 t/m^3, modulus of elasticity E=2.1 GPa, Poisson's ratio ν=0.2; 4) a pile – specific gravity γ=2.3 t/m^3, modulus E=200 MPa, Poisson's ratio ν=0.2; 5) a sleeper is reinforced concrete, specific gravity γ=2.5 t/m^3, modulus of elasticity E=0.4 GPa, Poisson's ratio ν=0.2.

Boundary conditions are imposed on the model: below is the ban in displacement along all three axes x, y and z, on the sides of the base is the ban on x and y axes, on the transverse sides of the model is the ban on y axis (flat deformation condition). The top and slopes of the model are free from boundary conditions.

The train was accepted as a model load, the axle pressure was assumed to be equal to the normative pressure from the train P=23.5 t per axle. The load was applied to the finite element node that simulates the rail, the nature of the action is the point contact.

For the two finite-element models the stress state of the track superstructure was calculated along the x (horizontal) and z (vertical) axes in the place of a sleeper and in the place between sleepers. As an example, we present the characteristic results of the performed calculations (Fig. 2–5).

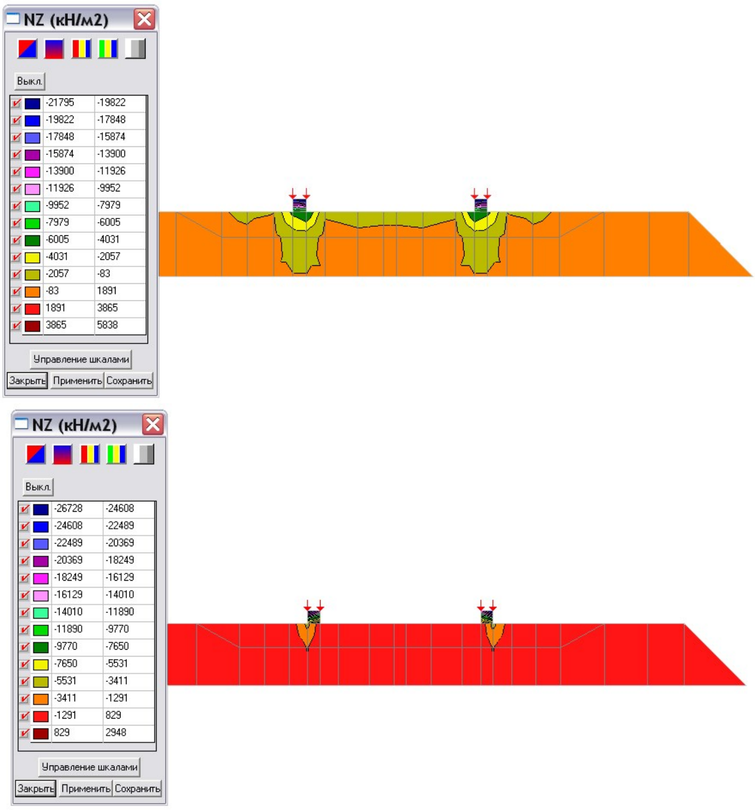


Fig. 2: Isolines and isofields of vertical normal stresses in the fragment of models (Option 1)

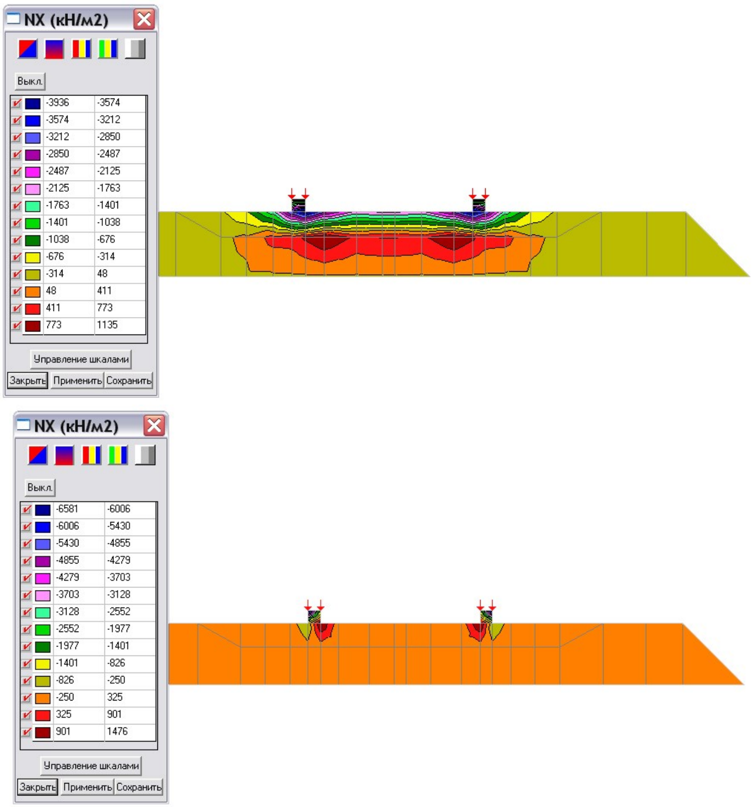


Fig. 3: Isolines and isofields of horizontal normal stresses in the fragment of models (Option 1)

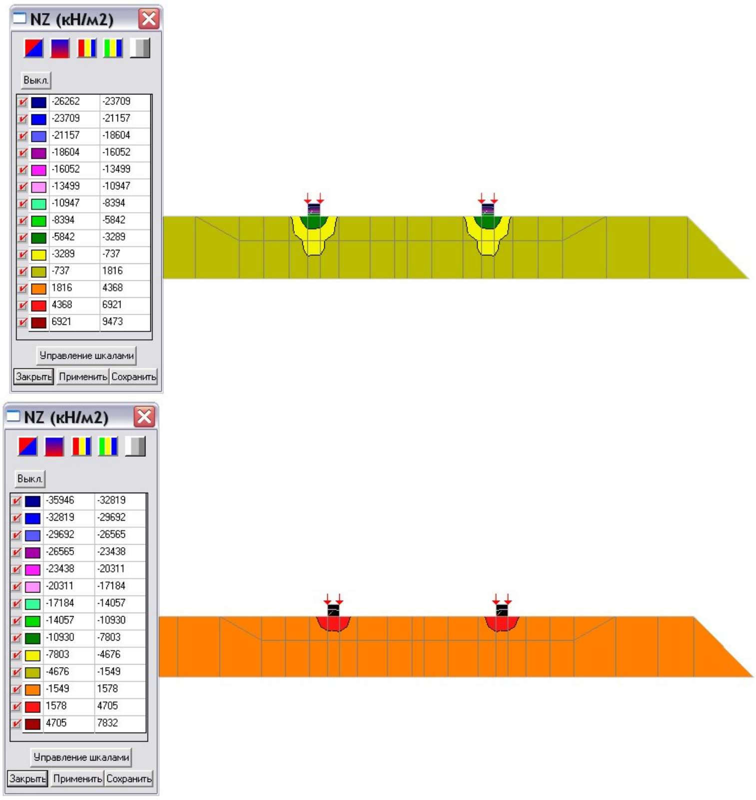


Fig. 4: Isolines and isofields of vertical normal stresses in the fragment of models (Option 2)

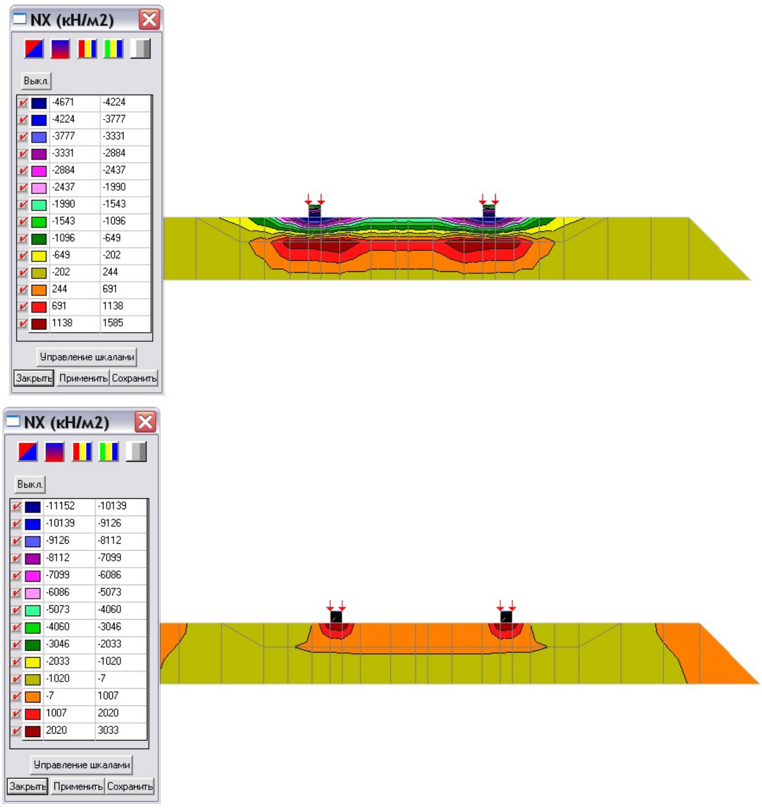


Fig. 5: Isolines and isofields of horizontal normal stresses in the fragment of models (Option 2)

The distribution patterns of normal vertical stresses (Fig. 2 – 3) in the ballast section reach -3400 … -4000 kPa (mean value is 1700 kPa) and -4600 … -5800 kPa (mean value is 1800 kPa) according to Options 1 and 2, which is significantly less than the strength of the ballast material.

The obtained results showed that the horizontal stresses in the TS have the following maximum values (Fig. 4–5): Option 1 is -3936 kPa for finding the load in the place of a sleeper and – -6581 kPa in the place between sleepers; Option 2 is -4671 kPa for finding the load in the place of a sleeper and – -11152 kPa in the place between sleepers, which are on the surface of rails and sleepers, they do not cause any overstresses.

Conclusions

The system of soil-cement piles, which is analyzed in the finite element analysis, introduces a significant positive fluctuation into the "TS – the subgrade" system. This is expressed in the significant heterogeneity of the stress state around the piles, which take on a significant part of the impact of the rolling stock.

Both of the proposed options for strengthening the subgrade are such that have a positive effect on the subsystems of the overall "TS – subgrade" system. In each of the options of strengthening there is a clear decrease in a stress state, which indicates an increase in the load capacity of the subgrade.

After analyzing the obtained results, the most effective (from the stress state viewpoint) location of the subgrade strengthening piles was chosen. This is the Option 1 (piles are located near the rail). As a following step the tuning of the FEA model of "TS – subgrade" system by measurement of the properties of crushed stone, subgrade soil, and soil-cement piles is planned. In the future work the influence of subgrade strengthening also on the dynamic characteristics of the rolling stock will be investigated.

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