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Method of Railroad Sub-Ballast of Native Soils Construction.

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ABSTRACT

The proved fact is nonconformity of a large number of European and Russian railways to modern requirements imposed for passing of speed and heavy traffic. In order to provide the road stability, the supporting subgrade must not lose its strength, water resistance and freeze resistance during the operation of the railway under the influence of heavy loads. A possibility of construction of a protective sub-ballast layer and top subgrade of a mixture of native soils with the addition of binders and “Dorzin” stabilizer was considered. After mixing with additives and packing the soil becomes a waterproof and freeze resistant soil-concrete of M100 brand. Depending on the amount of a binder added we may receive a soil-concrete with a modulus of deformation of 180 MPa to 600 MPa. The required thickness and strength of the structural layers was obtained by calculation of finite-element models of the road. The analysis of the performed calculations of rail-track stress-strain state showed that when there is a protective sub-ballast layer and reinforced top subgrade of the soil-concrete with the stabilizer “Dorzin”, vertical deformation of the rails are within a suitable range for heavy and high-speed trains.

Keywords: Railways, sub-ballast protective layer, subgrade, stabilizer, soil-concrete, modulus of deformation, finite-element models of the track, effective rail deflection.

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INTRODUCTION

Rail networks of many European countries, including Russia, consist of long-ago built lines, the state and the parameters of which are far from modern standards.

At the stage of development of transport infrastructure under conditions of high-speed train and heavy train traffic it is necessary to have an accurate idea about the technical condition of all components of the track, starting from the ballast and ending with the subgrade. During the implementation of the program Innotrack in five countries of the European Union 15 railway sections were measured, the purpose of these measurements was to assess the state of the track [1, 2].Specific problems were identified, among them:

- Czech Republic – recurrent significant vertical roughness, caused mainly by the poor state of subgrade upper layers;
- France - the poor state of drainage;
- Germany - progressive roughness of the permanent way, and the poor state of subfoundations and ditch cuts;
- Spain – in is necessary to strengthen sub-ballast layers of subgrade and to achieve uniformity of the parameters of transition zones of different structures;
- Sweden – it is necessary to strengthen subfoundations on considerably long sections of the track.

The causes for rapid track geometric parameters degradation at heavy loads most often are insufficient rigidity of subgrade and presence of weak soils under the ballast body [1, 3].

MAIN PART

According to the Strategy of development of railway transport up to 2030 in the Russian Federation it is planned to reconstruct the subgrade and the engineering structures on all basic directions of the network and bring them to a state corresponding to axial loads of 250-300 kN/axle and perspective linear loads of 105 kN/m (in comparison with the existing linear loads of 40-60 kN/m). Russian railways also have all the deformations typical for European railways. Perspective change-over to high-speed train and heavy-train traffic place extra high demands on the stability of the track.
To provide the track stability its design must have stable bonds between all the elements and a certain safety margin of every element. Gradual stress softening from the rail to the subgrade base should take place, all track elements should work together, and the main area of the subgrade should be strong enough all year round. Let's consider the way these requirements are fulfilled at currently operated railway track forms of JSC "RZD". Table 1 shows the actual and the desired distribution of elasticity modules of the railway track main elements.

Table 1 Elasticity modules of the railway track main elements

Name of track element	Elasticity modulus actual, MPa	Elasticity module Required, MPa
Rails	210000	210000
Ferro-concrete sleepers	30000	30000
Crushed stone ballast	500	500
Sand bed	30	500 (sub-ballast layer)
Top of subgrade	10…30	200
Subgrade	10…40	10…40

Operated in Russia railway track has a sharp variation of elasticity modules at the place of contact of the crushed stone layer and the sand bed. Crushed stone particles easily penetrate into the sandy bed, and therefore there occur residual deformation. In the period of seasonal dampening of the main site soil the soil becomes softer, this significantly reduce the strength, and dipping of the ballast into the soil takes place forming depressions and twists of the track, ballast tanks and beds (see Fig. 1). Alignment of the track is performed by increasing the ballast layer.

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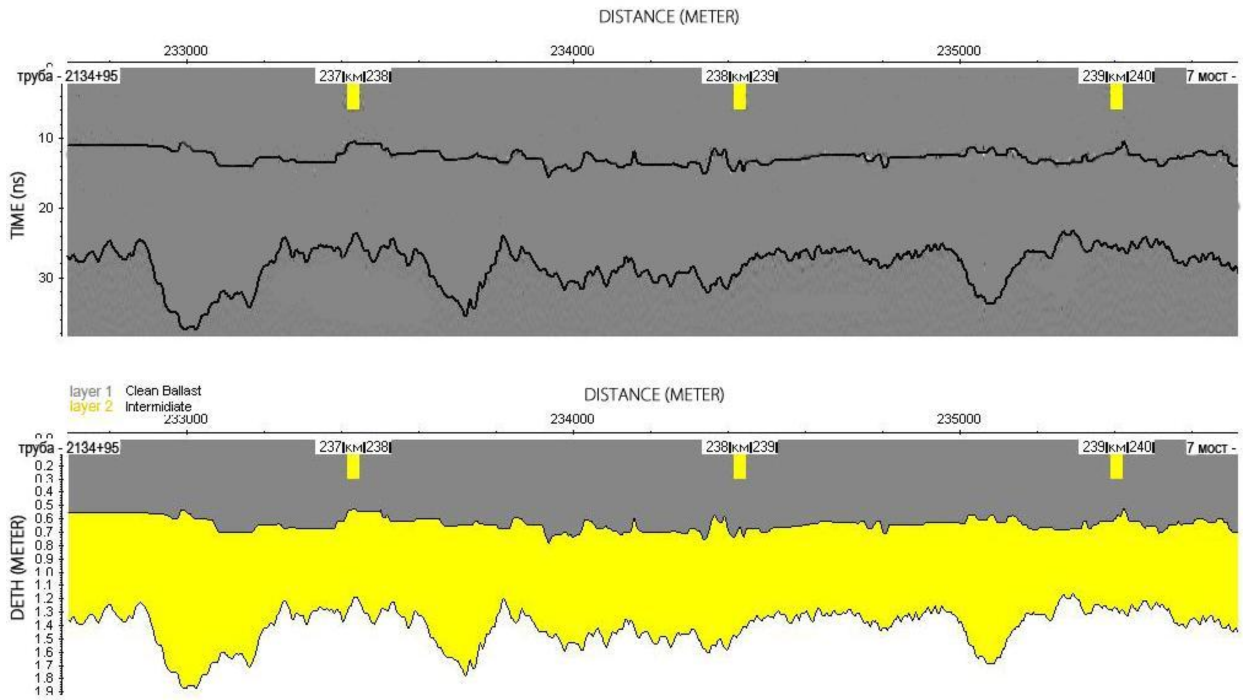


Figure 1: Deformation of the subgrade top of loamy soils while in operation (sand bed under crushed stone is shown in yellow)

In future proof designs of a low-maintenance track the elasticity modules reduce smoothly without any jumps (the right-hand side of Table. 1). Residual deformations between crushed stone and sand are removed by a strong sub-ballast layer and a durable waterproof top layer of the subgrade primary area. In this case, the crushed stone does not penetrate into the sub-ballast layer, which is resting on the stable, waterproof and freeze resistant top of the subgrade.

High-speed passenger trains traffic and interchange of vehicles with axial load of 250-300 kN/axle require construction of a subballast protective layer on the sub-ballast main area according to [4, 5, 6]. In most advanced European countries (Germany, France, Great Britain) application of the protective layer is standard and is formalized in technical regulations. Laying a protective layer on the subballast it is possible to achieve track stability. If no improvement of the road foundation will be carried out, then:

- High costs for maintenance work for the purpose of track alignment arise;
- Service life of all permanent-way materials is reduced;
- Interference of operating conditions arises as a result of the speed limitation.

Laying of a layer of hot asphalt concrete on the subgrade as a sub-ballast layer is a standard practice of railway construction in the United States [7]. There is a positive experience of asphalt concrete use for strengthening of sub-ballast zone in Russia [8]. Under a layer of asphalt concrete soil moisture of the subgrade top decreases and its strength increases in the course of time. In railways construction in Russia a protection layers of sand and gravel mixtures shown in Fig. 2 are mainly used. These mixtures drain water and the subgrade top under them becomes moist, losing its strength, which leads to deformation of clayey soils under high loads. Stability of the subgrade top and hence the track as a whole, as a rule, is not achieved.

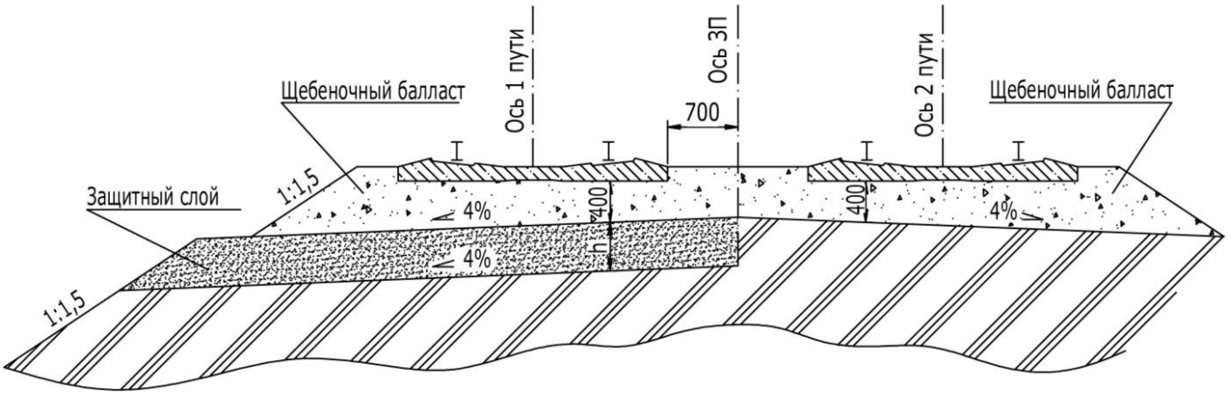


Fig. 2 Cross-section Sub-ballast barrier under the first path on the double-track section

/Защитный слой – protective layer
Щебеночный балласт – broken stone ballast
Ось 1 пути – 1st track centerline
Ось 3П – 3rd track centerline
Ость 2 пути 2nd track centerline/

Fig. 2 Cross-section of sub-ballast protective layer under the first track on the double-track line
Most part of the territory of Russia has no solid stone materials and when constructing and repairing railways crushed stone, gravel and sand delivered from remote mountainous parts of the country are used. Significant costs for transportation of these materials cause an increase in the total cost of the work. Therefore in order to construct the subgrade protective layer it is economically advantageous to use a mixture of native soils or man-made materials [9] with addition of binders and stabilizers.

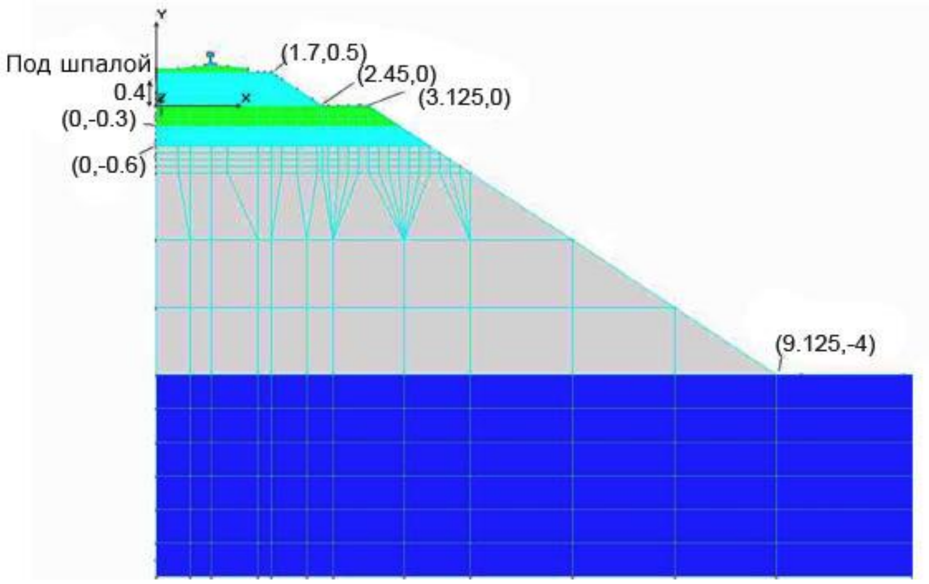
The most widely used in Russia are clay soils of different genesis. The main deterrent of their broad application in road construction is the change of physical and mechanical characteristics for the worse in case of moistening. But a mixture of these soils with stabilizers and a small amount of binders changes the soils properties, making them hydrophobic and freeze proof.

Stabilizers are classified as organic, chemical and synthetic, but they all have the same principle of impact on soil. The positive impact of stabilizers on clayey soil is connected to the partial decomposition of water into ions H + and OH-, ion exchange, plasticizing and hydrophobizated effect. Due to the water decomposition and active ion exchange the thickness of water films on the surface of ground units decreases, the electrostatic potential barrier in soil conglomerate system become destroyed. As a result, organic ions contained in the stabilizer penetrate into crystal lattice of clay minerals and squeezed out H + and OH- ions, and metal cations, which promotes a more stable bond between crystals packets. As a result of these processes aggregation of soil takes place, its optimum moisture content reduces, density, strength and water resistance increase [10].

Most of the territory of Russia is devoid of solid stone materials and the construction and repair of railways used crushed stone, gravel and sand to be delivered from remote mountainous parts of the country. Significant costs for the transportation of materials cause an increase in the total cost of the work. Therefore, the device of the protective layer of subgrade economically advantageous to use a mixture of local soil, or man-made materials with additives 9 binders and stabilizers.

Stabilizers also reduce the strains required for soil compaction, which makes it possible to achieve any necessary compaction at a smaller quantity of roller passes. If to provide an adequate strength, water and freeze resistance it is not enough to use one stabilizer, it is recommended to apply for additional introduction of inorganic binders such as cement in the range of 3 - 8% of the soil weight. It is possible to strengthen soils not only in special installations, but by mixing on the road as well. The mix-on-the road method allows to work in any hard to reach (including for installation and operation of mixing plants) places. There is a varied machines and equipment fleet for mixing of different soils and industrial wastes with binders (organic, nonorganic and complex); these machines ensure proper dosing of binders, uniformity of mixture stirring and required density of the material in a constructive layer.

The efficiency of obtaining of soil-concretes on the basis of clay materials was theoretically substantiated and experimentally proved by the researches of BSTU named after V.G. Shoukhov. To strengthen upper 0.2-0.3 m of soil of the subgrade by a mixture of ionic stabilizers and binders, according [11] it is required 80% of clay soil, 4% of Portland cement, 0.05% of enzyme preparation "Dorzin" and water. To stabilize 1 m^2 of the subgrade it is required about 20 kg of additives. After mixing with additives and packing the soil becomes a water-tight freeze proof (of F25 brand) road bed – the soil-concrete of M100 brand. Depending on the quantity of added binder by the method of soil stabilization it is possible to obtain a soil-concrete with a deformation modulus of 180 MPa to 600 MPa. If the subgrade stabilized soil (at a depth of 0.15-0.20 m) withstands strain of 5-10 MPa, the residual deformations of this layer cased by stresses on the bottom of the ballast up to 0.1 MPa will be excluded. The subballast layer requires the soil mixture strength of at least 450-500 MPa (similar to the elasticity modulus the crushed stone layer). It is possible to produce soil mixtures with elasticity modulus of up to 800-900 MPa. The required thickness and strength of the sub-ballast layer of soil mixtures can be obtained by calculation of finite element models of the track [12], Fig. 3.



/Под шпалой – under a sleeper/

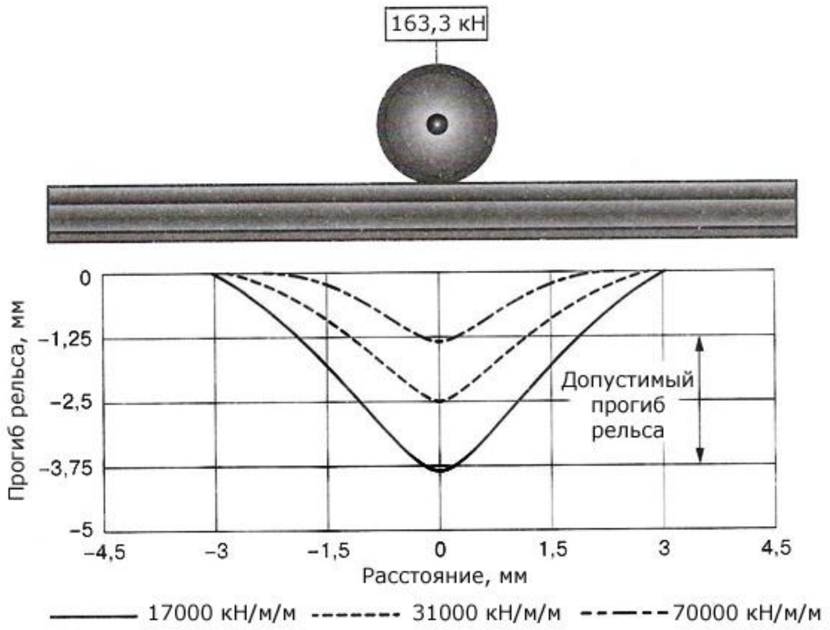
Figure 3 Finite element model of an embankment with a sub-ballast layer

Fig. 3 shows a sub-ballast layer of a mixture of native soil with a deformation modulus of 500 MPa and thickness of 0.3 m and a stabilized top subgrade layer with a deformation modulus of 200 MPa and thickness of 0.3 m. The embankment is composed of native soil with a deformation modulus of 10 MPa.

A vertical force equal to 220 kN is applied from every wheel to a rail. This corresponds to an axial load of 300 kN/axle with a dynamic factor equal to 1.45. For comparison, let's take the traditional design of a railway track without any sub-ballast layer.

CONCLUSION

The criterion is to achieve the effective rail deflection, shown in Fig. 4 according to [13] under vertical load of 163.3 kN.



Rail de Bow – rail deflection
Distance, NM – distance, nm
Déviation admissible du rail – allowable rail deflection
кН/м/н – kN/m/n/

Figure 4 Rail deflection depending on the tack rigidity

When making a sub-ballast layer of a mixture of native soil and binders under a layer of broken stone 0.3 m thick and stabilizing the subgrade top of 0.30 m the calculated rail shrinkage is 3.5 mm.

When making a sub-ballast layer 0.6 m thick with a deformation modulus of 500 MPa, the maximum vertical rail shrinkage will be 2.44 mm, which meets the requirements of track stiffness in case of heavy train traffic (Table. 2).

Table 2: Rail shrinkage in the center of a wagon wheel, mm

Deformation modulus embankment soil, MPa	Standard variant	Variant with sub-ballast layer (500 MPa) and stabilized subgrade top (200 MPa)	Variant with sub-ballast layer (500 MPa) and stabilized subgrade top (500 MPa)
10	8,4	6,0	3,5
20	6,0	5,0	3,0
30	5,0	4,0	2,6
40	4,5	3,5	2,4

In case of a high-speed traffic of trains with an axle load of 140 kN/axle the rail deflection under a wheel will be about 1.2 mm, which is close to the technical requirements. A sub-ballast layer of native clay soils allows to reduce the rail deflection at a lower layer thickness in comparison with the standards of Austria (Table. 3).

Table 3 Parameters of variants of a protective layer for Austrian railways

Variant No.	Soil deformation modulus in MPa in case of the variant application	Protective layer thickness, m	Alternate layouts of geosynthetic materials
1	At least 30	0,40	Geotextile at the bottom
2	20 to 30	0,40	Reinforced geotextile at the bottom
3	10 to 20	0,45	Geogrid in the middle + geotextile at the bottom
4	Less then 10	0,45	Geogrid in the middle + reinforced geotextile at the bottom

In case of a low mass of the embankment (soil modulus of deformation is 10 MPa) when the thickness of the stabilized soil layer is 0.6 m embankments can be made by the method of soil stabilization for heavy trains traffic with axle loads of 300 kN/axle. If we compare the cost of 1 m^2 of a traditional sand and gravel sub-ballast layer with a layer of a mix of hot asphalt concrete and stable local clay soil (Table. 4), the advantages of the stabilization soil are evident.

Table 4: Cost of construction of 1 m^2 of a sub-ballast layer in rubles (including cost of materials)

Variant	Стоимость 1 $м^2$ укрепления, руб.
Sand and gravel mix with a layer thickness of 0.6 m and a deformation modulus of 400 MPa	2760
Asphalt concrete mixture with a layer thickness of 0.2 m and a deformation modulus of 3200 MPa	3300
A mixture of native soil with a binder and a stabilizer with a layer thickness of 0.6 m and a deformation modulus of 500 MPa	1250

SUMMARY

The proposed method of sub-ballast layer construction according to the innovative technology of strengthening of a mixture of native soil with binders and stabilizers is cost effective and technically appropriate. At the same time, as the analysis of the conducted calculations of the railway track stress-strain state showed vertical deformations of rails are within the allowable for heavy and high-speed train traffic range. It is expedient to change the typical railway roadbed cross-sections, providing subgrade soil stabilization to a depth of 0.3 m with a deformation modulus of at least 200 MPa.

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