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Material Laboratory Testing of the Sub-Ballast Protective Layer with Binding Agents

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ABSTRACT

The importance of the reinforcement of the subgrade and particularly of its main platform is conditioned by the increase in train axle load.

The analysis of the results of testing of the strength and deformation characteristics of recycled ballast material during improved with binding agents with the addition of polymer stabilizers has been conducted to assess the applicability of soil consolidation technology when arranging a sub-ballast protective layer.

Laboratory testing has allowed to obtain the dependences of compressive strength and bending stretch on the percentage of Portland cement and polymer stabilizer, and to assess the decrease in material properties when exposed to an aggressive environment.

The testing has resulted in selection of optimal composition of cement and stabilizer for a given granulometric composition of sub-ballast protective layer and allowed to reveal main advantages of the use of soil stabilizer as compared with the samples with the use of cement only.

Keywords: railway transport, sub-ballast protective layer, deformation modulus, binding agents, stabilizers, plate loading tests, elementary test samples.

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INTRODUCTION

One of the key approaches to the solution of tasks of the growth in performance of railways with the increase in the volume and speed of cargo delivery is associated with the operation of the trains with increased axle loads, e.g., of up to 27 tf on the network of Russian Railways. This in turn involves ensuring the stability of the position of the rail track, depending on the condition of the subgrade. Considering that, for in many cases, the subgrade was built more than a hundred years ago and was designed for significantly lower loads, increasing them can cause deformation of the subgrade in places where its load-bearing capacity is insufficient. Therefore, it is important to strengthen the subgrade, and, first, its main platform.

Existing technologies for strengthening the main platform of the subgrade when carrying out work on reconstruction or major repairs of the track, which have proven themselves positively in Russia and abroad, involve the installation of the sub-ballast protective layer (SPL) made from crushed stone-sand-gravel mixtures (hereinafter referred to as CSSGM), thanks to what the track receives an increased stablity [1–6]. The advantage of this technology is the ability to perform it without removing the rail-sleeper grid during deep cleaning of ballast. However, the widespread implementation of this technology is hampered by several factors including:

– Large thickness of SPL, which leads to a slowdown in the pace of work during technological traffic intervals and to an increase in cost.

– High cost of CSSGM material.

– The need to deliver CSSGM to the work site.

To reduce the thickness of SPL while ensuring its required reinforcement characteristics, geogrid reinforcement is used. The possibility of reducing the thickness of SPL when using geogrids is justified by scientific research [5; 6] and in Russia is enshrined in a regulatory document[1]. But the need to deliver a new CSSGM material and the associated disadvantages still remain, so one of the promising options for constructing a SPL is the use of local materials, which can be the accumulated thick volume of ballast materials. However, according to research conducted at Russian University of Transport[2], the deformation modulus of the mixture of old ballast materials itself is no more than 65 MPa, and, therefore, it is impossible to achieve a deformation modulus at the top of SPL above this value. According to [2], to ensure at the level of the main platform of the subgrade the required value of the deformation modulus, which according to[1] should be of 80 MPa, the deformation modulus of SPL material should be about 150–200 MPa.

In this regard, it is proposed to consider the possibility of arranging SPL using old ballast materials obtained during their cleaning with improving their characteristics to the required values by treating them with binders with the addition of a polymer stabilizer. This technology will reduce the time it takes to complete the work by eliminating the operations of removing the ballast layer and eliminating the need for delivery of new CSSGM materials, as well as by reducing the thickness of SPL itself.

Currently, road construction widely uses cement additives and polymer-mineral compositions to strengthen the main platform and foundations [7; 8], which, according to research [9], allows:

– Reducing the thickness of the structural layer.

– Reducing material consumption and time for production and delivery of materials.

– Using production waste instead of its disposal.

The use of stabilizers is due to an increase in the crack resistance of the structure and resistance to aggressive environments [10].

PROBLEM STATEMENT

The objective of the work was to select, under laboratory conditions, the correct amount of Portland cement and stabilizer additives to be added to the recycled old ballast to obtain deformation characteristics required for SPL material.

The initial SPL material for laboratory research was taken from among ballast treated products previously received at Moscow Railway and used in studies conducted at RUT (MIIT)[2].

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[1] Instructions for the installation of sub-ballast protective layers during the reconstruction (modernisation) of the railway track, approved by the order of JSC Russian Railways dated December 12, 2012, No. 2544r. [Electronic resource]: https://base. garant.ru/406652845/. Last accessed 23.12.2023.

[2] Technical specifications for the material of the protective layer using products from cutting out old ballast with crushed stone cleaning complexes. Scientific and technical report. Stage No. 1 «Laboratory test results.» Topic leader E. S. Ashpiz. Moscow, MIIT 2021, 111 p.

Pic. 1. Holder for making samples [authors' photo].

The granulometric composition of this material is shown in Table 1.

Various amounts of Portland cement and polymer stabilizers were added to this material, and samples were prepared for laboratory testing to determine the deformation modulus depending on its composition.

To assess the effect of humidity on the strength properties of the material, tests after water absorption were planned as well.

TEST TECHNIQUES

The tests were carried out through two stages. At the first stage, the amount of cement was selected for the material with the selected granulometric composition (see Table 1). To select the amount of cement, elementary samples were made, which were a cylinder with a height of 60 mm and a diameter of 101 mm. The samples were mixed with 2 %, 3 % and 4 % of Portland cement (calculated per weight of the soil) and with water until optimal humidity was achieved. Next, the mixture was placed in a special holder (Pic. 1), where it was subjected to vibration on a vibrating table to better fill the voids formed during the laying process, after which the mixture was compacted by a press under a load of 24 tons. After compaction, the samples were extracted from the holder and left to gain strength for seven days. A total of 18 samples were made: six per each percentage of cement. After gaining strength, the samples were subject to compression test to determine the deformation modulus of the material of the fixed sub-ballast protective layer, including after water absorption, according to the technique[3] simulating the laying of the sub-ballast protective layer respectively in dry weather and under conditions of high humidity. The composition that had shown the most optimal characteristics was accepted for further research on the selection of a stabilizer.

Table 1

Granulometric composition (particle size distribution) of SPL material used to produce samples

Fraction, mm	Percentage
25–30	2,04
20–25	18,57
12,5–20	18,57
10–12,5	6,40
7,5–10	9,13
5–7,5	7,24
2,5–5	8,43
1,25–2,5	4,52
1–1,25	0,72
0,63–1	9,56
0,315–0,63	7,15
0,16–0,315	5,99
< 0,16	1,69

At the second stage, with the selected cement content, the rational content of the stabilizer (for which the Nicoflok additive was chosen) was identified, which allows further work (for example, track ballasting) to be carried out immediately after compaction of the mixture, thus minimising the time for laying the protective layer.

Nicoflok belongs to the group of redispersible polymer powders (RPP), which give mineral-based materials greater impact strength, reduce the fragility of the material and increase resistance to aggressive environments, and slow down the setting time. The chemical composition of Nicoflok stabilizer is represented by the following components: activated silica – 40 %, calcium salts – 15 %, sodium salts – 15 %, lignin-based polymers – 30 % [11].

To study the influence of the stabilizer on the characteristics of SPL material, similar samples

[3] GOST [State Standard] 10180-2012. Concrete. Method for determining strength using control samples. Moscow, Standartinform, 2018, 31 p. [Electronic resource]: https://docs.cntd. ru/document/1200100908. Last accessed 23.12.2023.

Table 2

Test matrix for selecting stabilizer content

Sample type*)	Test type	Number of samples, pcs.	Age of tested samples, days	Determined characteristics
Control sample: 0 % of a stabilizer	Compressive strength	9	7, 14, 28	Modulus of material deformation, MPa
	Tensile strength at splitting	3	7	Split strength, MPa
5 % of a stabilizer	Compressive strength	9	7, 14, 28	Modulus of material deformation, MPa
	Tensile strength at splitting	3	7	Split strength, MPa
	Compressive strength in water-saturated condition	6	7	Modulus of material deformation, MPa
7 % of a stabilizer	Compressive strength	9	7, 14, 28	Modulus of material deformation, MPa
	Tensile strength at splitting	3	7	Split strength, MPa
	Compressive strength under water-saturated condition	6	7	Modulus of material deformation, MPa
10 % of a stabilizer	Compressive strength	9	7, 14, 28	Modulus of material deformation, MPa
	Tensile strength at splitting	3	7	Split strength, MPa
	Compressive strength under water-saturated condition	6	7	Modulus of material deformation, MPa

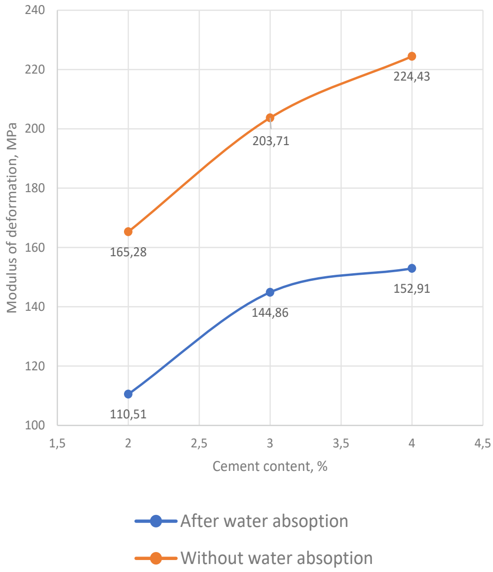
* % of a stabilizer is determined by the amount of cement.

were made with a selected cement composition, as well as with 5 %, 7 % and 10 % of Nicoflok RPP content if calculated based on the total mass of cement (0,15 %, 0,21, 0,3 % of the soil mass). According to the technical specifications for the stabilizer[4], the use of more than 10 % of the additive by mass fraction of cement is not recommended. The choice of the percentage of stabilizer was determined by the parameters of compression in dry and water-saturated conditions and tensile strength during splitting according to technique[2], based on assessment of the influence of the stabilizer on the deformation characteristics and crack resistance of SPL material. The matrix of performed tests is presented in Table 2.

TESTS RESULTS

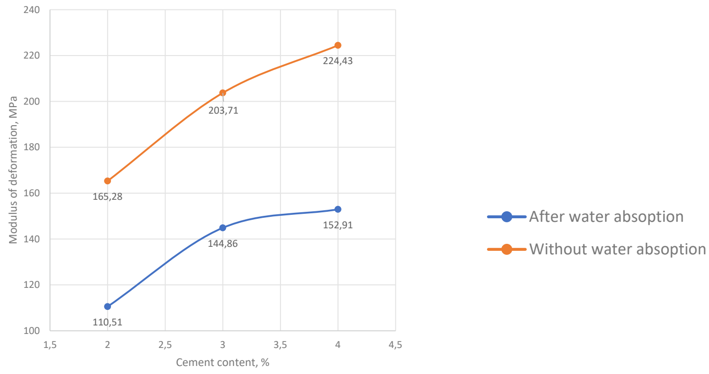
The test results for samples with Portland cement additives in dry and water-saturated states are shown in Pic. 2.

The analysis of data in Pic. 2 shows that when the sample contains 2 % of cement, the composition in terms of deformation modulus in a water-saturated state does not meet the requirements for SPL according to[1], and an increase in cement content from 3 % to 4 % changes the deformation modulus by only 1,06 times, which is irrational, therefore, we can recommend an additive equal to 3 % cement.

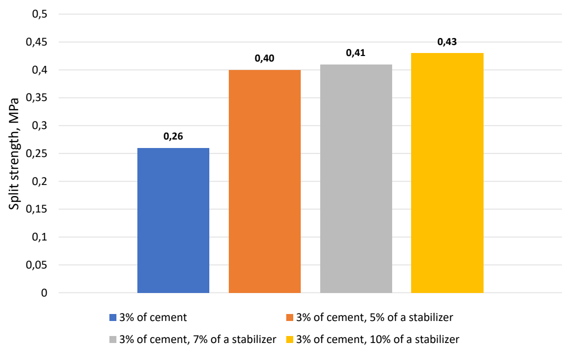


Pic. 2. Dependence of the deformation modulus on the amount of cement [developed by the authors].

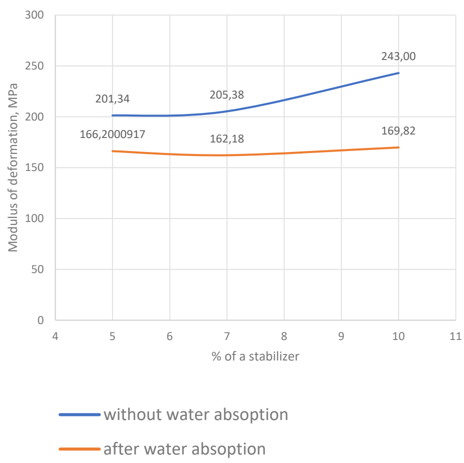
[4] STO [Standard developed by an organisation] 13881083.002–2021 Nicoflok polymer-mineral additive for mixtures with inorganic binder. Technical conditions. St. Petersburg, Nikel publ., 2021, 30 p.



Pic. 3. Dependence of the deformation modulus on the percentage of Nicoflok RPP [developed by the authors].



Pic. 4. Split strength test results depending on the percentage of Nicoflok RPP [developed by the authors].



Pic. 5. Results of compression tests of samples with Nicoflok RPR with and without water absorption [developed by the authors].

Next, tests were carried out to select the percentage of soil stabilizer at 3 % cement content. The test results are shown in Pic. 3.

As can be seen from the test results, the addition of a stabilizer increases the deformation modulus of the mixture by 12,4–23,6 %, depending on its percentage in the mixture. Also, it can be estimated that strengthening of the samples is mainly achieved within 7 days (80,6–93,5 % of the strength at the age of 28 days), therefore, the main tests can be carried out at this age, which allows optimising the time for further study.

To evaluate crack resistance and resistance to aggressive environments, splitting strength and compressive strength tests were carried out. The test results are presented in Pics. 4 and 5.

As can be seen from the graphs, the use of a stabilizer increases the splitting strength by 58–65 %. Based on this, it follows that the material treated with the stabilizer will be less destroyed by bending stresses, which will positively affect the durability of the SPL structure.

Based on the test results, it should also be noted that for this SPL material with 3 % cement content, according to the criteria of strength and deformability, 5 % of the Nicoflok additive is sufficient and its further increase is impractical.

CONCLUSIONS

During the study, a total of 84 laboratory samples were produced with different contents of Portland cement and stabilizer additives, which were subject to compression tests, including following water saturation and different strengthening times, as well as for splitting tests.

Laboratory studies of the influence of binding materials and soil stabilizers on the strength and deformation characteristics of SPL material obtained from ballast layer recycled products allow drawing a series of conclusions.

1) Based on the test results, the optimal composition of cement and stabilizer was selected for a given granulometric composition of SPL.

2) The main advantages of using soil stabilizers in comparison with samples using only cement:

• Increase in deformation modulus by 12,4–23,6 %.

• Increase in splitting strength by 58–65 %.

• Reduction in losses in modulus of deformation after water absorption by 17 %.

3) The use of binding agents in combination with polymer stabilizers makes it possible to increase the deformation modulus of the material by 3,1 times and reach values greater than 200 MPa, which makes it possible to consider the possibility of constructing SPL from recycled products obtained after cleaning the ballast layer, ensuring a reduction in the cost and duration of work during technological traffic intervals, and to remove currently existing restrictions on its use.

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