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Analysis of using nicoflok polymer-mineral additive for replacing stone materials as road bases

I Gavrilina and A Bondar

Department of Construction Production and Theory of Structures, Architecture and Construction Institute, South Ural State University, 76, Lenin Avenue, Chelyabinsk 454080, Russia

E-mail: gavrilinaia@susu.ru

Abstract. The article considers the use of soils, treated with cement with Nicoflok polymeric-mineral composite, for replacing stone materials as the bases by the example of two variants of rigid and non-rigid structures. We carried out the laboratory studies of the polymer-cement-soil mixture, presented physical and mechanical properties of the soil samples, taken from the quarry and determined their grain distribution and physical and mechanical parameters of the cement used. In the course of the study, we determined the properties of the initial materials, their compliance with the GOST requirements, the indicators of the improved soil after 7 and 28 days of storage, according to the requirements of standard procedures. We tested the structure of a non-rigid base for strength, frost resistance and permissible elastic deflection strength, analyzed the structure based on the condition of shear stability in soil and analyzed the structure for bending tension. We determined the fatigue ratio for the rigid road structure and presented the results of calculating the dependence of the layer thickness on the fatigue ratio.

1. Introduction

In the process of building highways, there is often a need to adjust the approved design solutions. Any changes in the design solutions for road base elements lead to the structure adjustment [1]. Such an adjustment should ensure an increase in the efficiency and quality of the newly adopted structure as compared to the previously developed one. Any change to the road structure is made taking into account the production conditions, in this case, when it becomes possible to treat the soil [2] with Portland cement containing Nicoflok polymer-mineral composite. In the course of adjusting the road structure, it is necessary to make recalculations taking into account the requirements of its strength, frost resistance and reliability according to the requirements of the regulatory documentation [3]. This is particularly relevant in the regions where there is no crushed stone, which is widely used for base construction. When transporting road-building materials, it becomes necessary to determine the rational length of haul. Since the cost of local materials is the same for a given construction area, the cost of materials in the workplace depends only on the cost of transportation [4]. This issue is considered for solving the problems of resource saving and energy saving (exploitation of crushed stone in quarries, transportation to stone crushing plants and to the route).

2. Road base design

2.1. Non-rigid road base

We will preliminarily design a non-rigid road base with an asphalt-concrete coat [5] with the following initial data:

The road is located in road-climatic zone III; highway category III; given service life of the road base is 15 years; traffic intensity – 1,800 cars/day with the annual intensity increment of 1.03; design load parameters P = 0.6 MPa, D = 39 cm; strength ratio k_{st} = 1,17; coefficient of reliability k_r = 0,95; type of surface - permanent.

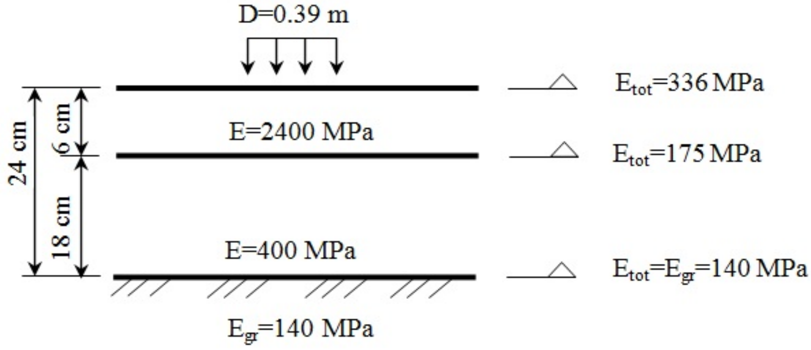

Figure 1. Design scheme of the non-rigid road structure in determining the permissible elastic deflection strength.

We tested the structure for strength, frost resistance and permissible elastic deflection strength, analyzed the structure based on the condition of shear stability in soil and analyzed the structure for bending tension [6]. The results are shown in Table 1, Table 2 and Table 5.

2.2. Rigid road base

The rigid road structure with a cement-concrete coat has the following initial data:

The road is located in road-climatic zone III; highway category III; concrete grade R_u = 45; design concrete elasticity modulus E_c = 32 MPA; wheel imprint radius D = 37 cm, P = 50 kN; coat thickness 22 cm; ground base stabilized with cement 18 cm thick; additional layer of the sand-gravel mix base 30 cm thick; road bed made of crushed stone soil [7].

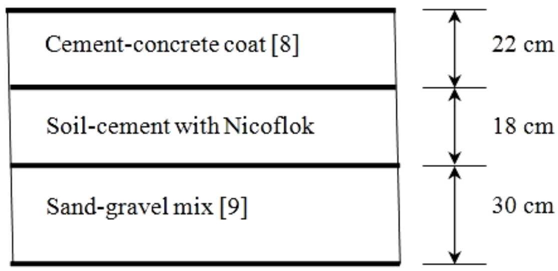

Figure 2. Scheme of the rigid road structure using Nicoflok additive.

When designing the rigid road base, we determined the traffic intensity over the period of the road base service life (25 years) and the fatigue ratio as applied to the given structure. Since for this road structure the calculated permissible frost heave value is 3 cm, the frost protection layer is not required for this calculation [10].

We calculated the dependence of the layer thickness on the fatigue ratio for the chosen road base type.

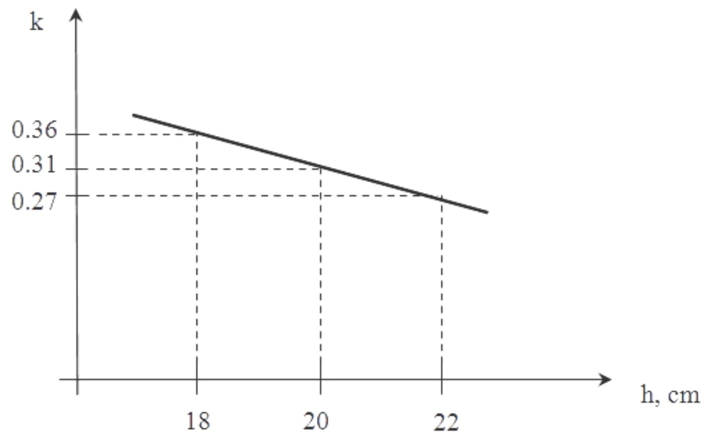

Figure 3. Dependence of the layer thickness on the fatigue ratio.

3. Laboratory studies of the polymer-cement-soil mix compositions.

Soil samples were taken from the quarry to study the usability of local soils for cement treatment [11]. Portland cement of PC 400-D-20 brand [12] was used as a cementing agent. Nicoflok polymeric additive under study is a grey fine-dispersed powder, insoluble in water. The bulk density of the composition is 0.8-0.9 g/cm^3 [13].

Table 1. Physical and mechanical properties of the soil.

Name of indicators	Units of measurement	Test result	Test methods	Requirements of GOST 25100-95
Liquid limit	%	17.9	GOST 5180-2015	Not rated
Plastic limit	%	10.5	GOST 5180-2015	Not rated
Plastic index	-	7.4	GOST 5180-2015	Over 7 to 12 inclusively
Packed density	kg/m^3	1290.0	GOST 8269.0-97	Not rated
Content of sand particles (2-0,05 mm)	% by weight	67.8	GOST 5180-2015	40 and more

Table 2. Grain distribution.

Sieve size, mm	20	10	5	2	1	0.5	0.25	0.1	0.05	<0.05
Private residue % by weight	0.93	0.26	0.91	2.83	4.44	15.10	25.22	13.54	5.26	31.51
Full residue % by weight	0.93	1.19	2.10	4.93	9.37	24.47	49.69	63.23	68.49	100
Full passage % by weight	99.07	98.81	97.90	95.07	90.63	75.53	50.31	36.77	31.51	-

Table 3. Physical and mechanical indicators of PC-400-D20 cement.

Name of indicators	Units of measurement	Test result	Test methods	Requirements of GOST 25100-95
Humidity	%	11.2	GOST 5180-2015	Not rated
Density of the stabilized soil cement	t/m^3	2.24	GOST 22733-2016	Not rated

Based on the conducted studies [14], the following conclusions can be made:

- the soil meets the requirements of the standards and can be used for stabilization with cement and polymer additives;
- the properties of the cement meet the requirements of GOST 10178 for M 400 grade and can be used for soil stabilization [15].

4. Study of the influence of Nicoflok additive

When studying the soil and cement, the following indicators were determined: properties of the initial materials (soil, cement); optimal water content; maximum density of the stabilized soil; physical and mechanical indicators of the stabilized soil samples after 7 and 28 days of storage in wet conditions according to standard procedures [16]; compressive strength and bending tension strength of the water-saturated samples, compressive strength of the samples subject to alternating freezing and thawing; elastic modulus; frost resistance coefficient [17].

Table 4. Physical and mechanical properties of the soil cement samples.

Name of indicators	Units of measurement	Composition						Requirements of GOST 23558-94
		8% - Nicoflok 8% - PC400D20 0.015% - Status-3		10% - Nicoflok 10% - PC400D20 0.015% - Status-3		10% - PC400D20 (control sample)		
		private	average	private	average	private	average	
Uniaxial compression strength at the samples' age of 1 day	MPa	2.30 2.17 2.23	2.23	2.67 2.33 2.59	2.53	1.57 1.53 1.47	1.52	Not rated
Uniaxial compression strength of the water-saturated samples at the age of 7 days	MPa	3.37 3.32 3.37	3.35	4.02 4.52 4.16	4.23	3.97 3.41 3.57	3.65	Not rated
Uniaxial compression strength of the water-saturated samples at the age of 28 days	MPa	4.57 5.50 4.23	4.43	5.01 5.26 4.93	5.01	5.11 4.85 4.98	4.98	4.0-6.0 (M40)

Table 5. Results of laboratory studies.

Composition of the mix, %	W,%	Density of the stabilized material, g/cm^3		Strength limit of the water-saturated samples, MPa		Frost resistance coefficient	Elasticity modulus, MPa	Strength and frost-resistance grade (strength class)
		ρ_{mois}	ρ_{bend}	$R_{comp,28}$	$R_{inflection,28}$		E_{el}	
Soil – 81% Cement – 10% Water – 9%	8.3	2.10	1.91	3.4	1.2	0.85	3550	M20 Class II
Soil – 81% Cement – 10% Nicoflok – 7% Water – 9%	7.0	2.09	1.95	5.2	1.85	0.85	3930	M40 Class I

5. Conclusion

Resource saving is one of the most important directions in increasing the economic development efficiency. The main source of raw materials for road building materials is natural resources. Therefore, an integrated approach to their use is required. Significant results in resource saving in road building can be achieved using local natural materials. Nicoflok additive allows us to increase the compressive strength and bending strength: seven-day samples - by 30%, 28-day samples - by 20%. When adding polymer additives, no significant changes in the frost resistance coefficient are observed in the samples. The conducted laboratory studies of soil stabilization with Nicoflok additive as bases for asphalt-concrete and cement-concrete coats suggest that the use of Nicoflok polymer additive allows us to replace stone materials as a road base with polymer-cement-soil.

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Acknowledgments
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