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Stabilization of marly soils with portland cement

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Abstract. Stabilization of marlous soils with Portland cement will increase the service life of motor roads in areas where marl is used as a local road construction material. The result of the conducted research is the conclusion about the principal possibility of stabilization of marlous soils with Portland cement, and about the optimal percentage of the mineral part and the binding agent. When planning the experiment, a simplex-lattice plan was implemented, which makes it possible to obtain a mathematical model for changing the properties of a material in the form of polynomials of incomplete third order. Brands were determined for compressive strength according to GOST 23558-94 and variants of stabilized soils were proposed for road construction.

1. Introduction
Due to the lack of conditioning materials for the roadbed, marl is often used for building, repairing and maintaining roads in the Mezensky district of the Arkhangelsk region.

To improve the strength characteristics of marlous soils, based on the results of previously conducted laboratory research, work was carried out to improve the quality properties of marl as a material of road bases and coverings.

The possibility of stabilizing marly soils with portland cement was predetermined by the following theoretical premise.

Marl is defined as sedimentary, cemented (clay) rock by petrographic composition, biochemical (carbonate) in origin with siliceous inclusions [1].

In terms of mineralogy clay marl is represented by various minerals, the main ones being kaolinite, montmorillonite and hydromica.

One of the most important features of clay and colloidal particles of marly soils is that they carry an electric charge. This plays an important role in the formation of soil structure and largely determines both the variety of their properties and their different behavior when carrying out a set of measures for stabilizing soils at the base and interacting with binder and other substances [2].

2. Materials and Methods
The road-climatic zone (to which the Arkhangelsk region belongs) is characterized by the presence of absorbed cations (H+, Al+) in the absorbing complex, giving the soil an acidic medium (pH = 3 ... 7),

increased hydrophilicity and dispersity of the finely dispersed part compared to soils saturated with divalent cations.

The presence of the absorbing complex of the marlous soil, represented by divalent or multivalent cations (Ca2+, Mg2+, Fe3+, A13+) is a very positive factor that increases the effectiveness of strengthening such soil with Portland cement (figure 1).

The formation of structural and mechanical properties of the strengthened (stabilized) soil strongly depends on the degree of expression of the acidic or alkaline environment. At pH values of samples 7 ... 8, the soils can be strengthened (stabilized) by Portland cement. In the case of complex methods of strengthening (stabilization), the pH of the soil can be changed to the right direction for hardening the soil by introducing additives of various substances [3].

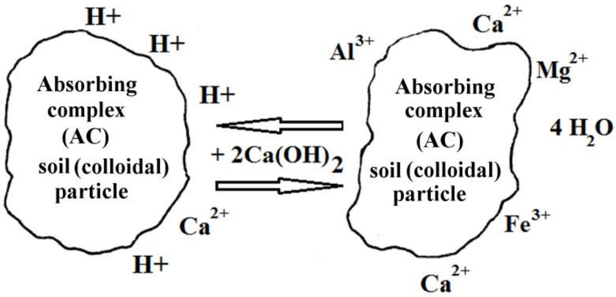

Figure 1. Scheme of physico-chemical exchange in soils while strengthening them with Portland cement

For the exploratory research, the material represented by clay marl was used [4].

The mineral part (marl) in the grain (granulometric) composition of the initial marly soil is given in Table 1. (The numerator and denominator of the fraction are the limits of the change of the different characteristics in soil samples taken after crushing under load 5 ... 6 kN).

Table 1. The mineral part (marl) granulometric composition

Characteristic	Size of sieve opening, mm						
	5.0	2.5	1.25	0.63	0.315	0.16	<0.16
Partial sieve residue, % by weight	12.0 15.0	32.5 27.0	7.0 14.0	17.0 21.0	10.0 10.0	10.0 11.0	11.5 2.0
Total sieve residue, % by weight	12.0 15.0	44.5 42.0	51.5 56.0	68.5 77.0	78.5 87.0	88.5 98.0	100.0 100.0

Based on the existing experience of hardening and stabilizing clay soils with Portland cement, the following limits of the composition of the target material (percentages by weight) were established [5, 6,21,24]:

The mineral part - marl (MP) - 76 ... 86;

Moisture of mineral material (taking into account the optimum moisture) (MM) - 10 ... 20;

Portland cement consumption (brand M400) (PC) - 4 ... 14.

3. Results

When planning the study experiment, a simplex-latticed plan for planning and processing the data of the laboratory experiment was realized, which makes it possible to obtain a mathematical model for changing material properties in the form of polynomials of incomplete third order and to interpret these changes in the form of a composition-property triagram.

The conditions of the study experiment are listed in Table 2, and the planning matrix for the laboratory experiment is in Table 3.

Table 2. The conditions of the study experiment

Level	Natural factor value		
	MP (X_1)	MM (X_2)	PC (X_3)
Upper	86	20	14
Lower	76	10	4
Variation interval	10	10	10

Table 3. The planning matrix for the laboratory experiment

No. Experien ce	Factor					
	Coded value			Natural factor value,% by weight		
	X1	X2	X3	X1 (MP,%)	X2 (MM,%)	X3 (PC,%)
1	1	0	0	86	10	4
2	0	1	0	76	20	4
3	0	0	1	76	10	14
4	0.5	0.5	0	81	15	4
5	0.5	0	0.5	81	10	9
6	0	0.5	0.5	76	15	9
7	0.333	0.333	0.333	79.3	13.3	7.3
8	0.2	0.6	0.2	78	16	6

The output values of the optimization parameters are represented by the basic physico-mechanical properties of the strengthened soil and are given in Table 4 [8].

Table 4. The output values of the optimization parameters.

No. Series	Composition of the mixture			Optimization parameter			
	MP, %	MM, %	PC, %	p	W, %	R_c	R_b
1	86	10	4	2.093	23.90	0.667	0.305
2	76	20	4	1.957	26.86	1.558	0.408
3	76	10	14	2.046	21.03	5.466	0.671
4	81	15	4	1.958	26.50	1.966	0.365
5	81	10	9	2.077	18.01	4.942	0.900
6	76	15	9	2.037	23.49	4.192	0.514
7	79.3	13.3	7.3	1.992	23.43	1.825	0.407
8	78	16	6	1.952	28.45	1.917	0.340

Where: p - average sample density, g/cm3; W% - water content of samples, % by volume; Rc - ultimate strength of the samples under compression, MPa; Rb - ultimate tensile strength of samples in bending, MPa.

4. Discussion

Mathematical models, represented as polynomials of incomplete third order, have the following form in the coded variables [9, 10]:

$$P = 2.103X1 + 1.960X2 + 2.046X3 - 0.295X1X2 + 0.011X1X3 + \\ + 0.137X2X3 - 0.745X1X2X3; \quad (1)$$

$$W\% = 23.903X1 + 26.86X2 + 21.027X3 + 4.460X1X2 - \\ - 17.820X1X3 - 1.813X2X3 + 32.110X1X2X3; \quad (2)$$

$$Rc = 0.667X1 + 1.558X2 + 5.467X3 + 3.417X1X2 + \\ + 7.500X_1X_3 + 2.717X_2X_3 - 60.850X_1X_2X_3; \quad (3)$$

$$R_b = 0.305X_1 + 0.408X_2 + 0.667X_3 + 0.036X_1X_2 + \\ + 1.649X_1X_3 - 0.101X_2X_3 - 6.204X_1X_2X_3 \quad (4)$$

Graphical interpretation of mathematical models in the form of composition-property triagrams [11] is presented in Figure 2-3.

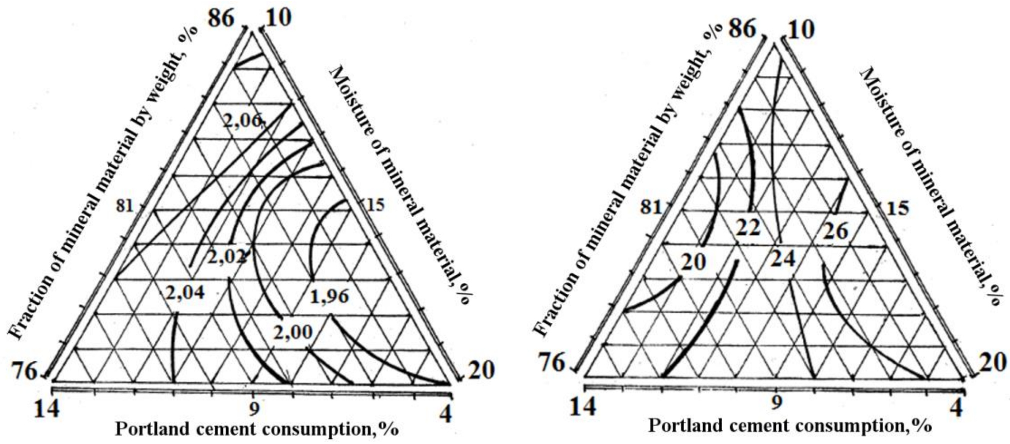

Figure 2. The isolines of the change in the average sample density (on the left) and the water saturation of the samples (on the right), depending on the composition of the mixture

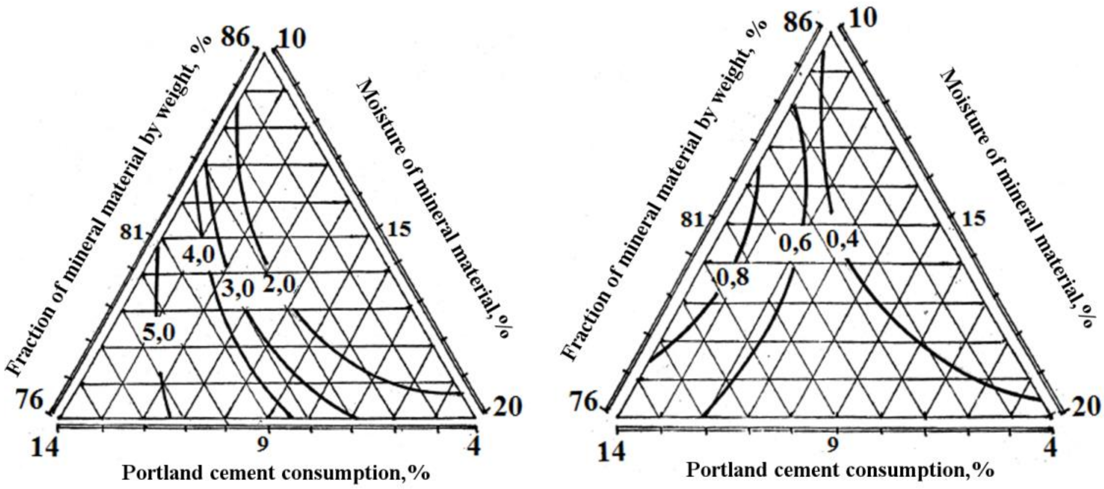

Figure 3. The isolines of the change in compressive strength of the samples (on the left) and the bending strength of the samples (on the right), depending on the composition of the mixture

Mathematical and graphical analysis of the obtained data of the laboratory experiment made it possible to determine the optimal and rational compositions of soil mixtures stabilized with Portland cement, depending on the strength brands, which are presented in Table 5 [12, 13, 18 ,20].

Table 5. The optimal and rational compositions of soil mixtures stabilized with Portland cement.

Strength brand	Recipe soil (marly) mixture stabilized with Portland cement		
	MP, %	MM, %	PC, %
Compressive strength, MPa, not less than			
M40	78* (77…79)	12* (10…14)	10* (9…11)
M20	79* (78…81)	13* (12…15)	8* (7…10)
M10	80* (78…83)	14* (13…15)	6* (4…7)
Bending strength, MPa, not less than			
M40	80* (77…82)	11* (10,5…12,5)	9* (7…11)
M20	78* (76…80)	14* (13…15)	8* (7…9)
M10	81* (78…84)	14* (12…16)	5* (4…6)

Analyzing the data of Table 5 it is possible to do a conclusion about the possibility of stabilizing marly soil mixtures with Portland cement (5 ... 10 % by weight) and obtaining a structural material of M10 ... M40 brands [14, 15].

5 Conclusions

Based on the results of the laboratory work aimed at improving and stabilizing the properties of soil marly mixtures, the following main conclusions can be drawn:

1) technological and physic-chemical compatibility of marlous soils with Portland cement allows to obtain strengthened soils of brands for compressive strength M10 ... M40 in accordance with GOST 23558-94 and then use them in the following directions:

- as a material of the brand not lower than M40 for the bases of roads with a traffic intensity of over 1000 cars per day [16, 17];
- as a material of the brand not lower than M20 for the bases of roads with a traffic intensity of less than 1000 cars per day;

2) this is possible in the case when the frost resistance brands are not lower than F25 for compressive strength brands M20 ... M40.

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