IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Improving the physical and mechanical properties of fortified soil for road construction in the forest zone

To cite this article: S Chudinov 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **817** 012007

IOP Conf. Series: Materials Science and Engineering **817** (2020) 012007 doi:10.1088/1757-899X/817/1/012007

Improving the physical and mechanical properties of fortified soil for road construction in the forest zone

S Chudinov

Department of Transport and Road Construction, *Ural State Forestry University*, 37 Siberian Road, Yekaterinburg 620100, Russian Federation

Corresponding e-mail: serg-chudinov@yandex.ru

Abstract. In order to purposefully control the processes that determine the formation of the structure and properties of cement soils, studies were carried out on the strengthening of soils with Portland cement with a water-soluble additive hydropropylene emulsion (WHE). The purpose of the laboratory studies was to study the change in the ultimate strength in compression, water saturation and frost resistance of cement soils, depending on the particle size distribution of the original soil, the amount of mineral binder - Portland cement and the WHE additive. Based on the results of the research, soil strengthening with Portland cement with WHE additive allows to form a complex crystallization-coagulation structure of materials with the required values of compressive strength, water saturation and frost resistance, depending on the dosages of binding components for given climatic and transport-operating conditions. The effectiveness of the WHE additive increases with increasing dispersion of soils, so the technology of strengthening of clay soils in conditions of wet and acidic soils of the forest zone for the construction of forest roads is promising.

1. Introduction

Soil reinforcement technology for the construction of pavement layers of construction has proven itself in road construction, especially in regions with an insufficient amount of stone materials. Reinforced soils can be used in any climatic and transport-operational conditions in the construction of public roads and industrial, including forest roads.

As a binder to strengthen the soil can be used mineral and organic substances. One of the most common mineral binders for strengthening the soil is Portland cement. However, the effectiveness of the structure formation of Portland cement in cement soils depends largely on the degree of activity of sorption and ion exchange processes on the surface of fine soil particles, especially clay particles. When soil is strengthened with portland cement in the forest zone, the acidification of clay soils, which are characterized by incomplete saturation of the exchange complex with hydrogen and calcium ions, also results in crystal formation and, as a result, absorb calcium hydroxide from hydrating cement [1].

Thus, to strengthen the soil with Portland cement, especially in the forest zone, an improvement in the process of crystal formation of the mineral binder is required. One of the effective technologies for improving the quality of fortified soils in the forest zone is the use of polymer additives in the composition of cement-ground mixtures. Conducted theoretical studies have allowed to determine that WHE allows to improve the conditions of hardening of Portland cement while strengthening clay soils and improve the physical and mechanical properties of cement grounds.

To confirm this hypothesis were conducted laboratory studies. The purpose of the laboratory studies was to study the change in the ultimate strength in compression, water saturation and frost resistance of cement soils, depending on the particle size distribution of the original soil, the amount of mineral binder - Portland cement and the WHE additive.

1.1. Research tasks

- Sampling of natural soils of various types: sand, sandy loam, heavy loam, clay. Characterization of initial soil samples.
- Production of soil samples reinforced with Portland cement and WHE.
- Determination of the compressive strength of water-saturated soil samples reinforced with Portland cement and WHE.
- Determination of water saturation of soil samples reinforced with Portland cement and WHE additive.
- Determination of the frost resistance of soil samples reinforced with Portland cement and WHE additive.
- Analysis of the results of the ultimate strength in compression, water saturation and frost resistance of cement soils, depending on the particle size distribution of the original soil, the amount of mineral binder - Portland cement and the WHE additive.

2. Methods and Materials

For laboratory studies were selected natural soils from forest roads in the Sverdlovsk region of the Russian Federation. Soil tests were carried out on the basis of relevant regulatory documents. Types of tests are shown in table 1.

Table 1. Types of tests and relevant regulatory documents.

Name of soil characteristics	Regulatory Document
Dry soil density	GOST 5180 [2]
Plasticity limits	GOST 5180 [2]
Granulometric composition	GOST 12536 [3]
Optimum humidity and maximum density with standard compaction	GOST 22733 [4]
Acidity of the water extract	GOST 26423 [5]
Organic Content	GOST 23740 [6]

2.1. Characteristic of portland cement

For laboratory research, Portland cement M400 brand produced by Brozex Dry Mixes Plant LLC was used in accordance with GOST 10178 [7].

2.2. Characteristics supplements WHE

The stabilizing additive WHE is a water-soluble hydropropylene emulsion with an agglomerative effect on clay soil particles. Physico-chemical characteristics of the WHE supplements are presented in table 2.

IOP Conf. Series: Materials Science and Engineering **817** (2020) 012007 doi:10.1088/1757-899X/817/1/012007

Table 2. Physical and chemical indicators of the WHE supplement.

Name of the indicator	Method of Definition	Magnitude	Unit
pH	DIN 38 404-C5	11.0	-
Temperature (for pH)	DIN 38 404-C4	25.0	ºC
Chloride	DIN EN ISO 10304	1.0	mg / l
DOC	DIN EN 1484	1.9	mg / l
Zinc	DIN EN ISO 11885	0.03	mg / l

2.3. Determination of the minimum required number of observations in laboratory studies

When studying the issues of soil reinforcement, it is considered that sufficient reliability of the experiment is ensured with a measurement accuracy of 5% and a confidence level of 0.95. The required number of samples, when determining any indicator of the strength or deformation properties of the soil, was established by the formula (1):

$$n = \frac{u^2 \sigma N}{(N-1)\Delta^2 + u^2 \sigma^2} \tag{1}$$

where, n – the required number of observations; σ – the sample variance; N – the number of preliminary tests performed; Δ – the permissible deviation from the average value; u – the deviation value depending on the specified confidence level (p = 0.95; u = 1.96).

On the basis of preliminary data obtained experimentally, the minimum number of observations was determined when studying such properties of cement soil as the compressive strength of water-saturated samples. The calculation of the average value of the experiment from n measurements was performed by the formula (2):

$$\bar{y}_n = \frac{1}{n}\sum_{i=1}^{n} y_i \tag{2}$$

where, $\bar{y}_n$ – the average value of the experience; n – the number of samples in the experiment; y_i – the single result of observation in experience.

The estimate of the variance of the sample of n values was determined by the formula (3):

$$\sigma = \frac{1}{n-1}\sum_{i=1}^{n} \left(y_i - \bar{y}_n\right)^2 \tag{3}$$

The results of statistical processing of indicators of preliminary tests are presented in table 3

Table 3. Statistical processing of preliminary test results.

Observation results, MPa			Number of measurements, *N*	Average value, MPa	Estimation of variance, σ	Number of observations required	The deviation value, U	Tolerance, Δ, MPa
2.8	2.64	2.65	24	2.715	0.0114	2.57	1.96	0.135
2.69	2.75	2.54						
2.74	2.9	2.5						
2.83	2.66	2.75						
2.72	2.82	2.73						
2.06	1.94	1.78						
1.80	1.88	1.85						
1.95	2.12	2.02						

Thus, as a result of statistical processing of data from preliminary tests of the compressive strength of water-saturated samples of cement grounds with a base area of 20 cm^2, it can be concluded that the compressive strength should be defined as the arithmetic average of the results of testing three samples.

2.4. The composition of the mixtures of soils reinforced with Portland cement with the addition of WHE

In order to study the changes in compressive strength, water saturation and frost resistance of cement ground depending on the particle size distribution of the soil, the amount of mineral binder - Portland cement and WHE additives, various compositions of cement – ground mixtures were prepared and tested.

For laboratory studies, various types of soil were used: coarse sand, sandy sandy loam, heavy silt loam, light silt clay. The amount of Portland cement introduced into the soil, was: 0%, 3%, 5%, 7%, 9% by weight of dry soil. The amount of WHE additive introduced into the soil was 0%, 0.03%, 0.06%, 0.2% by weight of dry soil.

The list of the compositions of soil mixtures: coarse sand, sandy sandy loam, heavy silty loam, light silt clay strengthened with Portland cement with WHE additive for laboratory research are presented in table 4.

Table 4. The list of soil mixes: coarse sand, sandy sandy loam, heavy silt loam, light silt clay, fortified with Portland cement with WHE additive.

Amount of portland cement % by weight of dry soil	*The amount of additive WHE,% by weight of dry soil*			
	0	**0.03**	**0.06**	**0.20**
0	+	+	+	+
3	+	+	+	+
5	+	+	+	+
7	+	+	+	+
9	+	+	+	+

3. Results and Discussion

3.1. The results of laboratory studies to determine the ultimate strength in compression of water-saturated samples of fortified soil

The results of determining the compressive strength (Z, MPa) of water-saturated cement-ground samples depending on the particle size distribution of the soil and the dosages of Portland cement (X,%) and the WHE additive (Y,%) are presented in Figure 1-4.

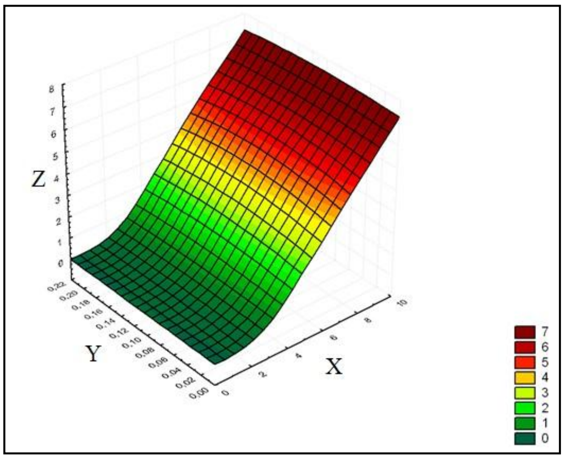

Figure 1. The surface values of the ultimate compressive strength for coarse sand, depending on the content of binders.

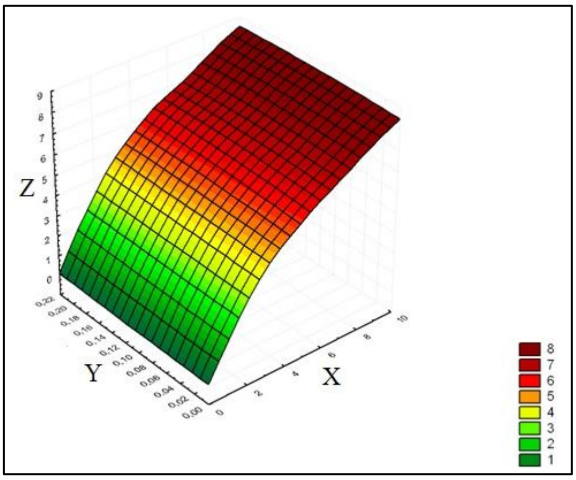

Figure 2. The surface values of compressive strength for sandy sandy loam depending on the content of binding materials.

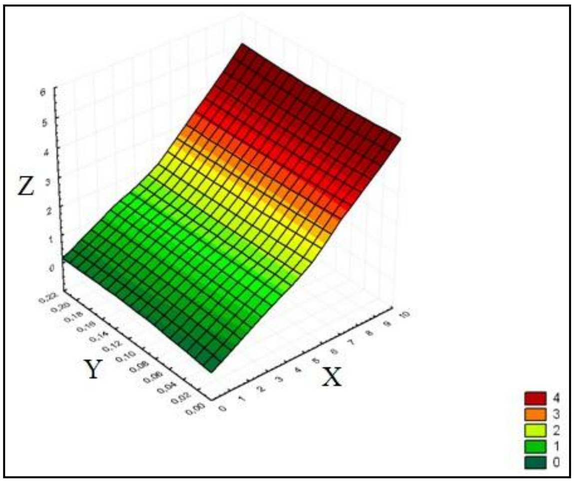

Figure 3. The surface values of the ultimate compressive strength for heavy loam depending on the content of binders.

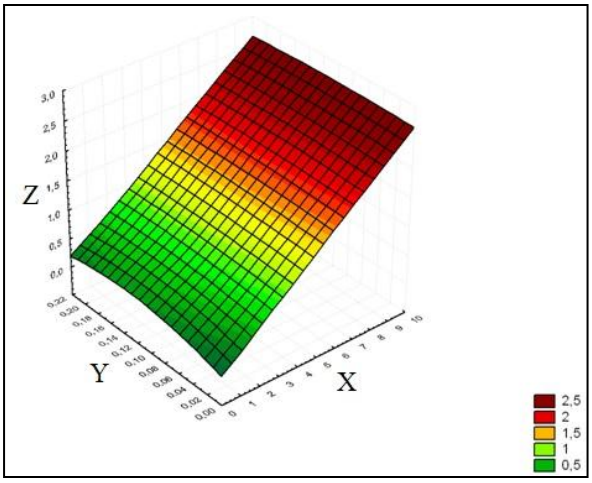

Figure 4. The surface values of the ultimate compressive strength for clay dust depending on the content of binders.

Thus, based on the results of laboratory studies of the dependence of the compressive strength of water-saturated soil samples: coarse sand, sandy sandy loam, heavy loamy silty clay, light silt clay strengthened with Portland cement with the WHE additive, the following conclusions can be made:

1. The use of the WHE additive in strengthening the soil without a mineral binder - Portland cement leads to a slight increase in the strength of the soil.

2. The effectiveness of the application of the WHE additive in strengthening the soil without a mineral binder - Portland cement increases with increasing dispersion of soils in the direction: sand - sandy loam - loam - clay.

3. The use of the WHE additive in conjunction with Portland cement allows, depending on the dosages of the binding components, to achieve the required values of the compressive strength of the cement for the given climatic and transport and operating conditions.

3.2. The results of laboratory studies to determine the water saturation of samples of fortified soils

The results of determination of water saturation (Z,%) of samples of fortified soils depending on the particle size distribution of the soil and dosages of Portland cement (X,%) and the WHE additive (Y,%) are presented in Figure 5-8.

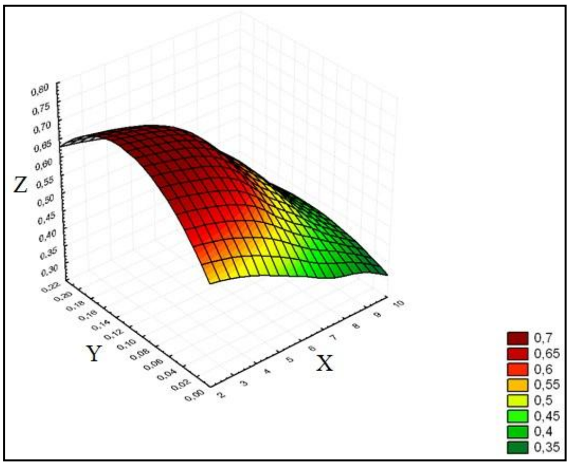

Figure 5. The surface water saturation values for coarse sand depending on the content of binders.

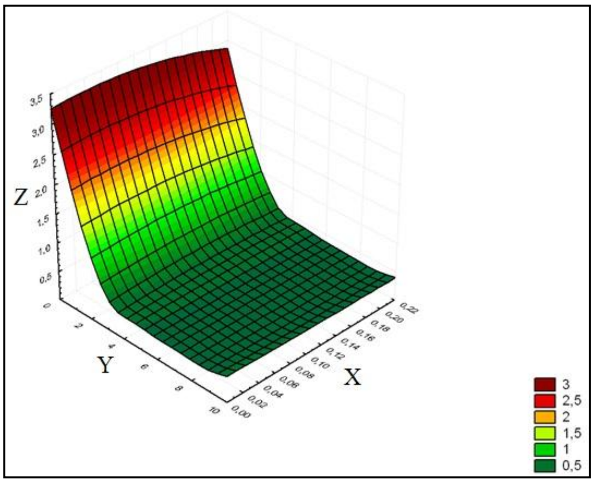

Figure 6. The surface water saturation values for sandy sandy loam depending on the content of binding materials.

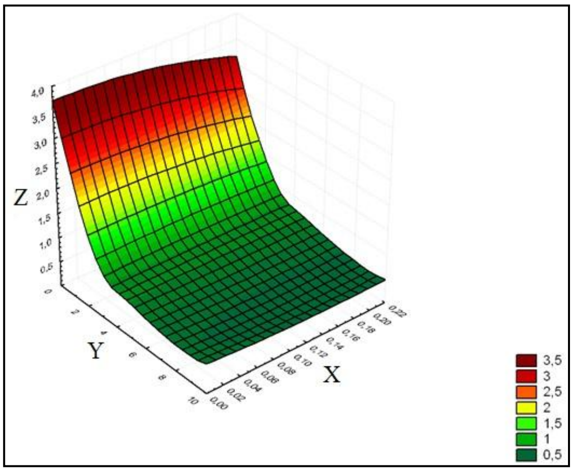

Figure 7. The surface water saturation values for heavy loam depending on the content of binders.

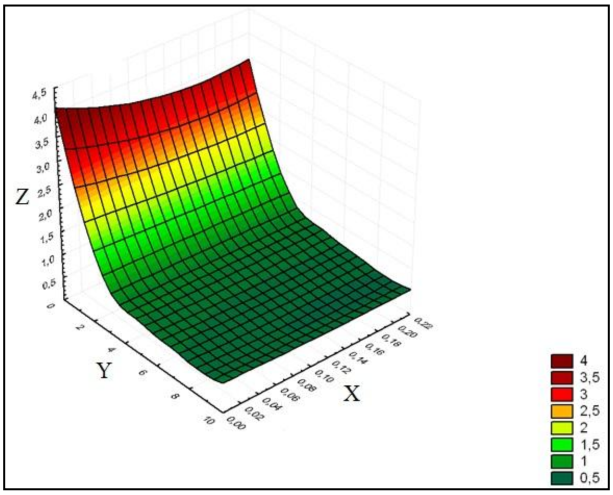

Figure 8. The surface water saturation values for clay dust depending on the content of binders.

Thus, based on the results of laboratory studies of the dependence of water saturation of soil samples: coarse sand, sandy sandy loam, heavy silty clay loam, light silt clay strengthened with Portland cement with WHE additive, we can draw the following conclusions:

1. The use of the WHE additive in strengthening the soil without a mineral binder - Portland cement leads to a slight decrease in the water saturation of the stabilized soil.
2. The effectiveness of the application of the WHE additive in strengthening the soil without a mineral binder - Portland cement increases with increasing dispersion of soils in the direction: sand - sandy loam - loam - clay.
3. The use of the WHE additive together with Portland cement allows, depending on the dosages of the binding components, to achieve the required values of water saturation for given climatic and transport and operating conditions.

3.3. The results of laboratory studies to determine the frost resistance of samples of fortified soil

The results of determining the frost resistance of samples of fortified soils depending on the particle size distribution of the soil and dosages of Portland cement and the WHE additive are presented in Table 5-8.

Table 5. The results of studies of frost resistance of coarse sand, reinforced with Portland cement with WHE additive

Brand on frost resistance, F		**Amount of additive WHE, % by weight of dry soil**			
		0	**0.03**	**0.06**	**0.20**
The amount of Portland cement, % by weight of dry soil	0	–	–	–	–
	3	F0	F0	F0	F0
	5	F5	F5	F5	F5
	7	F5	F5	F5	F5
	9	F10	F10	F10	F10

Table 6. The results of studies of frost resistance of sandy, reinforced with Portland cement with WHE additive

Brand on frost resistance, F		**Amount of additive WHE, % by weight of dry soil**			
		0	**0.03**	**0.06**	**0.20**
The amount of Portland cement, % by weight of dry soil	0	–	–	–	F0
	3	F0	F0	F0	F0
	5	F0	F0	F0	F0
	7	F5	F5	F5	F5
	9	F10	F10	F10	F10

Table 7. The results of studies of frost resistance of heavy loam hardened with Portland cement with WHE additive

Brand on frost resistance, F		**Amount of additive WHE, % by weight of dry soil**			
		0	**0.03**	**0.06**	**0.20**
The amount of Portland cement, % by weight of dry soil	0	–	–	F0	F0
	3	F0	F0	F0	F0
	5	F0	F0	F0	F0
	7	F0	F0	F0	F0
	9	F5	F5	F5	F5

Table 8. The results of studies of the frost resistance of clay light silt, reinforced with Portland cement with the additive WHE

Brand on frost resistance, F		Amount of additive WHE, % by weight of dry soil			
		0	0.03	0.06	0.20
The amount of Portland cement, % by weight of dry soil	0	–	F0	F0	F0
	3	F0	F0	F0	F0
	5	F0	F0	F0	F0
	7	F0	F0	F0	F0
	9	F5	F5	F5	F5

Thus, based on the results of laboratory studies of the dependence of frost resistance of soil samples: coarse sand, sandy sandy loam, heavy silty clay loam, light silt clay, fortified with Portland cement with WHE additive, we can draw the following conclusions:

1. Frost resistance of cement soils increases with decreasing dispersion of the original soil in the direction: clay - loam - sandy loam - sand.
2. The effectiveness of the application of the WHE additive in strengthening the soil without a mineral binder - Portland cement increases with increasing dispersion of soils in the direction: sand - sandy loam - loam - clay.
3. The use of the WHE additive together with Portland cement allows, depending on the dosages of the binding components, to achieve the required values of frost resistance for given climatic and transport and operating conditions.

4. Conclusions

1. As shown by the results of studies of water saturation, ultimate compressive strength of water-saturated samples and frost resistance of soils, different granulometric composition: coarse sand, sandy sandy loam, heavy clay loam and clay light dusty, reinforced with portland cement with the WHE additive, depending on the number of binding components , cement grounds have high strength characteristics. The use of the WHE additive in soil consolidation with Portland cement allows the formation of a complex structure of cement ground - crystallization-coagulation, characterized not only by high strength, but also by plasticity and crack resistance [8].

2. The use of the WHE additive without a mineral binder - Portland cement allows the formation of a coagulation structure of fortified soils with elastic-viscous-plastic properties, low strength and water saturation [9]. The effectiveness of the application of the WHE additive in strengthening the soil without a mineral binder - Portland cement increases with increasing dispersion of soils in the direction: sand - sandy loam - loam - clay.

3. Strengthening of soils with Portland cement with the WHE additive allows forming a complex crystallization-coagulation structure of materials, possessing the required values of compressive strength, water saturation and frost resistance, depending on dosages of binding components for given climatic and transport and operating conditions [10].

4. Due to the fact that the effectiveness of the WHE additive increases with increasing dispersion of soils, the technology of strengthening clay soils in conditions of wet and acidic soils of the forest zone for the construction of forest roads is promising.

References

[1] Nevolin D G 2015 *Innovative technologies for the design and construction of roads* [in Russian - Innovatsionnyie tehnologii proektirovaniya i stroitelstva avtomobilnyih dorog] (Ekaterinburg: Ural State University of Railway Transport) p 291
[2] GOST 5180 *Soils. Laboratory methods for determination of physical characteristics* 2015 p 19
[3] GOST 12536 *Soils. Methods of laboratory granulometric (grain-size) and microaggregate*

distribution 2014 p 18
[4] GOST 22733 *Soils. Laboratory method for determining of maximum density* 2016 p 12
[5] GOST 26423 *Soils. Methods for determination of specific electric conductivity, pH and solid residue of water extract* 2015 p 7
[6] GOST 23740 *Soils. Methods of laboratory determination of organic composition* 2016 p 10
[7] GOST 10178 *Portland cement and portland blastfurnace slag cement. Specifications* 2015 p 7
[8] Bezruk V M 1982 *Fortified soil (Properties and application in road and airfield construction)* [in Russian - Ukreplennyie gruntyi] (Moscow: Transport) p 231
[9] Chudinov S A and Buldakov S I 2010 Theoretical studies of the processes of structure formation of *clay soils, reinforced with Portland cement with the addition of polyelectrolyte* [in Russian - Teoreticheskie issledovaniya protsessov strukturoobrazovaniya glinistyih gruntov, ukreplennyih portlandtsementom s dobavkoy polielektrolita] (Arkhangelsk: News of higher educational institutions. Forest Journal. № 5) pp 82–88
[10] Chudinov S A 2019 *Improving the quality of cement-soil coatings of forestry road* [in Russian - Povyishenie kachestva tsementogruntovyih pokryitiy lesovoznyih dorog] (Omsk: Education. Transport. Innovation. Building. Collection of materials of the II National Scientific and Practical Conference) pp 459–462