Soil bases modified with lime waste and polycarboxylates

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Abstract. Increasing the volume of road construction is one of the priority areas of infrastructure development in any country. When building roads, it is preferable to use local materials to reduce the cost of their transportation, therefore, it is advisable to build the roadbed on local soils. It is worth noting that clay water-saturated soils are the most common, which complicates the construction of the road due to some features of this type of soil. The object of the study is a water-saturated clay with the following characteristics: natural humidity from 25.3 % to 28.1% by weight, optimal humidity from 11.8 % to 16.7% by weight, the number of plasticity from 0.118 to 0.153. Clay soils have a number of features: waterlogged soils are difficult to compact and develop, it is quite problematic to dry them, and thixotropy is also characteristic of clay soils. In this regard, it is most advisable to use the method of complex mineral binders to optimize their physical and mechanical properties. In the course of laboratory studies, compositions of soil compositions with the addition of lime waste and superplasticizer P-17 were developed. The dependence of the strength on the consumption of mineral binders and surfactants is established: the maximum compressive strength of the soil being fixed is achieved at a lime content of 25 wt.% and at a P-17 content in the range of 0.10-0.5 wt.%.

1. Introduction

The construction of the new M12 motorway from Moscow to Kazan is one of the largest and most relevant projects contributing to the development of the transport infrastructure of Russia. The highway will connect the Volga region with the central territory of Russia. During the construction of the M12 motorway, it becomes necessary to build up territories that are composed of weak water-saturated clay soils. To create a strong and reliable road surface, it is necessary to provide a solid ground base. Clay soils are characterized by thixotropy of properties, that is, when an external mechanical influence is applied, its mechanical equilibrium is disturbed, so such a soil cannot be considered a reliable base. To stabilize weak soils, it is necessary to optimize their physical and mechanical properties by applying mineral binders based on carbonate rock waste, since this method is the most appropriate taking into account all the features of this soil.

The urgency of using modified soils in the construction of the M-12 highway is due to the lack of stone materials and a large number of territories that are composed of weak water-saturated soils. Waste of carbonate rocks is an affordable and economically profitable material.

There is a large amount of research in the field of fixing waterlogged soils with various mineral binders [1-8]. The study [1] describes in sufficient detail the effect of the interaction of a finely dispersed part of the soil with binder particles. In the works [2, 3] it is emphasized that lime is sufficient in an amount of 2-4% to increase the strength of the soil. However, it is worth noting that with the loads that the highway perceives, adding a binder in such an amount is not very effective.
In the study [4], there is also a tendency to search for the minimum amount of added lime, while the compositions of soil-concrete compositions are not presented in the work, and the experimental results are presented in a fairly generalized form.

The soil massif proposed in the studies [5, 6] has low strength characteristics due to its heterogeneity, there is also a risk of losing the acquired properties during flooding. Surfactants make it possible to achieve hydrophobicity of the soil fixed with mineral binders. Surfactants are quite an expensive material, but it is worth noting that the use of more economical materials is ineffective.

The studies [7,8] are of an overview nature and do not give a complete picture of the physical and mechanical properties of the soil being fixed, where the result of the interaction of the binder with soil particles is given only from a theoretical point of view.

To achieve optimal physical and mechanical characteristics of the strengthening soil, it is most effective to use a comprehensive method of soil stabilization. In this case, the modification of the soil is achieved by the introduction of several components: organic and inorganic binders, surfactants.

2. Materials and methods

The object of the study is clay soil, which was selected on the overpass of the M12 motorway in d. Oderikhino for Yuryevets. Figure 1 shows the results of geological surveys on the section of the overpass.

Figure 1. The results of geological surveys on the section of the overpass.

Table 1 shows the physical and mechanical properties of the studied clay soils.

| Property name                      | Semi-solid loam | Plastic sandy loam |
|------------------------------------|-----------------|--------------------|
| Natural humidity, %                | 25.3            | 28.1               |
| Humidity at the rolling boundary, %| 17              | 18.3               |
| Humidity at the yield point, %     | 31.1            | 16.7               |
| Optimal humidity, %               | 16.7            | 11.8               |
| Plasticity number                 | 0.118           | 0.153              |
| The indicator of soil fluidity     | 0               | 0.37               |
Table 2 shows the chemical composition of the clay soil under study.

**Table 2. Chemical composition of clay soil.**

| Oxides  | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | TiO$_2$ | CaO |
|---------|---------|-------------|-------------|---------|-----|
| The content of the wt., % | 52.1 – 65.5 | 28.9 – 33.6 | 0.43 | 1.01 | 0.49 |

Table 3 shows the chemical composition of lime waste used in the study.

**Table 3. Chemical composition of lime waste.**

| Oxides | Ca(OH)$_2$ | CaCO$_3$ | MgO | SiO$_2$ |
|--------|------------|----------|-----|---------|
| The content of the wt., % | 65.35 | 22.23 | 6.12 | 3.29 |

The polycarboxylate superplasticizer P-17 was also used in the work, which, due to its structure, increases the reactivity of materials due to spatial repulsion. Table 4 shows the properties of the P-17 superplasticizer used.

**Table 4. Properties of polycarboxylate P-17.**

| Property name | Polycarboxylate superplasticizer P-17 |
|---------------|--------------------------------------|
| Appearance    | Colorless liquid without mechanical impurities |
| Density, g / cm$^3$ | 1.120±0.004 |
| Dry matter concentration, % | 38-40 |
| Dynamic viscosity, MPa·s | 130-250 |

According to studies [9, 10, 11], the optimal content of polycarboxylates for clays is in the range of 0.3-0.7 wt %, for loams – 0.2-0.5, for sandy loams-0.15-0.18.

In the course of the work, the density of synthesized samples at different ages was determined, strength tests were also carried out using ultrasound, frost resistance was studied by an accelerated method using a sodium chloride solution. The samples were also tested for water resistance. The physical and mechanical properties of the initial materials and the resulting soil-concrete compositions were studied by standard methods.

**3. Results and discussions**

In the course of laboratory studies, samples of clay soil fixed with lime waste were synthesized. The compositions of the obtained soil-concrete compositions are presented in Table 5.

**Table 5. Compositions of soil-concrete compositions with lime waste.**

| Soil composition | Components, wt. % |
|-----------------|-------------------|
|                 | Clay soil | Lime waste | Bischofite |
| GZI-1           | 73        | 20         | 7          |
| GZI-2           | 68        | 25         | 7          |
| GZI-3           | 63        | 30         | 7          |
| GZI-4           | 58        | 35         | 7          |

Table 6 shows the physical and mechanical properties of the obtained soil-concrete compositions with the addition of a binder based on lime waste.
Table 6. Physical and mechanical properties of soil-concrete compositions with lime.

| Soil composition | Compressive strength, MPa | Frost resistance, number of cycles | Water resistance, % | Density, g/cm³ |
|------------------|---------------------------|-----------------------------------|-------------------|---------------|
|                  | 28 days | 60 days | 60 days | 60 days | 28 days | 60 days |
| GZI-1            | 1.7     | 3.4     | 10      | 0.28    | 1.45    | 1.31    |
| GZI-2            | 1.8     | 4.2     | 15      | 0.31    | 1.54    | 1.24    |
| GZI-3            | 1.5     | 3.7     | 15      | 0.34    | 1.55    | 1.26    |
| GZI-4            | 1.4     | 3.5     | 15      | 0.43    | 1.59    | 1.24    |

Figure 2 shows graphs of the dependence of density and strength on the percentage of lime waste in clay soil.

![Graph of density vs. lime waste content](a)

![Graph of strength vs. lime waste content](b)

Figure 2. Graph of the dependence of: a) density on the content of lime waste in the strengthening soil b) strength on the content of lime waste in the strengthening soil.

As can be seen from the graph shown in Figure 2a, with an increase in the concentration of lime in the modified clay soil, the density of the resulting material decreases. At the same time, the graph shown in Figure 2b proves that a decrease in density does not affect the strength indicators.

According to the data presented in Table 6 and Figure 2, it can be concluded that the greatest effect of optimizing the physical and mechanical properties of clay soil is achieved by adding lime waste in an amount of 25%. To obtain the most durable soil composition with optimal physical and mechanical properties, it was decided to introduce a surface-active additive, which is a polycarboxylate superplasticizer P-17, into the composition of GZI-2.

The compositions of the developed clay soils with the addition of surfactants are presented in Table 7.

Table 7. Compositions of soil-concrete compositions with the addition of surfactants.

| Soil composition | Components, wt. % |
|------------------|-------------------|
|                  | Clay soil | Lime waste | Surfactant (polycarboxylate P-17) |
| GZIP-1           | 74.9      | 25         | 0.1 |
| GZIP-2           | 74.75     | 25         | 0.25 |
| GZIP-3           | 74.5      | 25         | 0.5 |
In the course of laboratory studies, the physical and mechanical properties of the obtained composites were studied in order to determine the optimal amount of surfactants in the fixed soil. Table 8 shows the physical and mechanical properties of soil-concrete compositions with the addition of P-17 in various quantities.

**Table 8. Physical and mechanical properties of soil-concrete compositions with the addition of surfactants.**

| Soil composition | Compressive strength, MPa | Frost resistance, number of cycles | Water resistance, % |
|------------------|---------------------------|-----------------------------------|--------------------|
|                  | 28 days       | 60 days   | 60 days   | 60 days   |
| GZIP-1           | 3.91          | 8.72      | 30        | 0.58      |
| GZIP-2           | 3.61          | 8.09      | 30        | 0.54      |
| GZIP-3           | 3.43          | 7.87      | 30        | 0.51      |
| GZIP-4           | 3.34          | 7.66      | 25        | 0.52      |
| GZIP-5           | 3.16          | 7.45      | 25        | 0.49      |
| GZIP-6           | 3.07          | 7.36      | 25        | 0.47      |
| GZIP-7           | 3.14          | 7.39      | 25        | 0.50      |

Figure 3 shows a graph of the dependence of the strength of the synthesized soil fixed with lime waste on the amount of added polycarboxylate P-17.

**Figure 3.** Graph of the dependence of the strength of soil-concrete compositions depending on the content of P-1.
adding surfactants is reduced. The results of the conducted laboratory studies are in good agreement with the works [12, 13, 14] on the issue of the optimal amount of added polycarboxylate.

4. Summary
The results obtained in the course of laboratory studies allow us to conclude that it is advisable to use clay soils modified with waste products and polycarboxylate superplasticizer P-17 in road construction.

When small particles of soil and slaked lime interact, clay is modified at the first stage, the soil becomes more compressible and the ability to swell appears. At the next stage, there is a significant increase in the strength of the soil due to the formation of hydrosilicates and hydroaluminates, which have cementing properties.

On the basis of lime, it is possible to obtain a binder, which, according to its properties and technical characteristics, can be compared with some cement binders. When slaked lime and superplasticizer P-17 are introduced into a water-saturated clay soil, its strength characteristics are improved and water resistance increases. In the course of the work, compositions of soil-concrete compositions were developed with the addition of a binder based on waste of carbonate rocks and polycarboxylate superplasticizer P-17. During the experiments, it was found that the best characteristics are the soil with the addition of lime in the amount of 25% and surfactant P-17 in the range of 0.25-0.75%.

5. References
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