Interaction of clay soil components with portland cement and complex additive based on octyltriethoxysilane and sodium hydroxide

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Abstract. Clay soils are widely used materials in various fields of science and industry in natural and modified form. The promising direction clay soils using in road construction is the use organosilicon compounds additives, which makes it possible to obtain hydrophobic and frost-resistant materials, as well as electrolytes, which gives high strength characteristics to clay soils strengthened by cement. To determine the interaction of soil and its components with complex additive based on octyltriethoxysilane OTES and sodium hydroxide SH, we tested the basic physical properties, strength and deformation characteristics of studied soil with complex additive, as well as the physimechanical properties of kaolinite, montmorillonite, sand and silty-clay soil particles strengthened by Portland cement with the addition of OTES and SH. The use of OTES and SH additives led to increase the strength and frost resistance of kaolinite, montmorillonite, sand and silty-clay particles strengthened by cement.

Keywords: clay, soil, Portland cement, octyltriethoxysilane, sodium hydroxide, physical and mechanical properties.

1 Introduction
Clay soils are widely used materials in various fields of science and industry in natural and modified form, mainly intermediate, in obtaining finished products. This work is aimed at studying the clay soil modification for road construction. Road construction consumes a large number of building materials, especially durable crushed stone, the transportation needs of which significantly increases the estimated cost. It is possible to refuse or significantly reduce using imported rubble by using soils and materials unsuitable for construction due to the high content of dusty clay particles, which are strengthened by cement. Improving of efficiency and quality of cement-strengthened soil, as well as many building materials, is relevant problem that cannot be successfully solved without modification by chemical additives that affect on structure and properties of binder and resulting material [1–3].

The most promising direction in solving this problem is the use of organosilicon compounds additives, allowing to obtain hydrophobic and frost-resistant materials, as well as electrolytes, which ensure the achievement of cement-strengthened soil high strength values. Previously installed, it was determined that the maximum effect was obtained when octyltriethoxysilane OTES and sodium hydroxide GN have been added to the soil strengthened by cement [4].

Complex thermal analysis, X-ray powder diffraction, Electron microscopy methods confirmed the effect of octyltriethoxysilane and sodium hydroxide on clay soils strengthened by cement [5]. Research in this area is mainly related to the production of organoclay and polymer nanocomposites [6–26]. A large number of studies in the clay soils application associated with their heat treatment [27–37].

Among various clay-organic interactions, considerable attention is paid to the intercalation process [38–40]. In building materials science, it is important to understand not only the processes that occur when soil interacts with chemicals, but also the ability to control this interaction to obtain materials with the desired properties. Therefore, to determine the results of interaction of soil and its components with complex additive, the basic physical properties, strength and deformation...
characteristics of the studied soil with complex additive, as well as the physicomechanical properties of kaolinite, montmorillonite, sandy and dusty-clay particles of soil, strengthened by Portland cement (10 %) with additive of OTES and SH were carried out.

2 Materials and methods
The soil mineralogical composition has a significant impact on its physical properties and strengthening result. The most non–resistant to water and frost effects in strengthened soils are clay minerals – kaolinite and montmorillonite. To study the influence of mineralogical composition the soil is divided into two main components – sand and silty-clay fractions. Clay minerals are present in small amounts in polymineral loams composition, and their isolation from general composition is impossible. To test the main minerals, the clay was taken in montmorillonite form, which had about 70 % of montmorillonite in its composition, and as kaolinite was taken the rock with more than 90 % of kaolinite. The mineralogical composition of the studied polymineral soil is represented by the following minerals: quartz – 70.3 %, feldspars – 26.9 %, clay minerals – 2.8 %. The amount of dusty particles was 58.4 %, sand – 41.6 % of the total soil mass.

The rolling boundary (lower plasticity limit) was defined as the moisture content of the paste prepared from the test soil, at which the paste rolled into a bundle with a diameter of 3 mm begins to disintegrate into pieces 3-10 mm long. The liquid limit (upper plasticity limit) was determined as the moisture content of the paste prepared from the test soil, at which the balancing cone is immersed under its own weight for 5 s to a depth of 10 mm. The plastic limit was defined as the difference between the liquid limit and the rolling boundary.

The drained angle of internal friction and specific adhesion was determined by the method of single-plane shear according to the tests results of soil samples in single-plane shear devices with a fixed shear plane by shifting one part of the sample relative to the other part of it with a horizontal load under preliminary loading of the sample with a load normal to the shear plane.

The deformation modulus was determined by compression method based on the results of testing soil samples in compression instruments (odometers), which exclude the possibility of lateral sample expansion when it is loaded by vertical load.

Compression strength was determined on water-saturated during 2 days samples after 28 days of normal hardening with diameter and height of 2 cm.

Frost resistance was studied on samples with diameter and height of 2 cm after 28 days storage of normal hardening. Freezing time was at least 2.5 hours at minus (18±2) °C of temperature, thawing 2±0.5 hours in water at (18±2) °C of temperature. The frost resistance coefficient was determined as the ratio of the sample strength after testing for repeated freezing and thawing to the sample strength before testing. The frost resistance coefficient was found after 5, 10, 15 cycles of freezing and thawing (F5, F10, F15).

3 Results
The change of physical properties, strength and deformation characteristics the test soil with the introduction of 0.03 % octyltriethoxysilane and 0.1 % sodium hydroxide [4] are presented in table 1.

The complex additive introduction into the soil led to decrease of ductility limit by 17 %. In this case, the drained angle of internal friction increased by 12 %, and the specific adhesion by 18 %. The additive in the soil also affected on deformation modulus, increases it by 15 %.

Table 1. Change of physical properties, strength and deformation characteristics of the soil with the introduction of octyltriethoxysilane OTES and sodium hydroxide SH

| Characteristics | Material | Ductility limit | Drained angle of internal friction, degrees | Specific adhesion, MPa | Deformation modulus, MPa |
|-----------------|----------|----------------|--------------------------------------------|------------------------|--------------------------|
|                 |          |                |                                            |                        |                          |


The results of compressive strength tests of kaolinite, montmorillonite, sandy and silty-clay soil particles, strengthened by Portland cement in 10 % of particles (minerals) mass and modified by addition of OTES and SH, are presented in Fig. 1–4.

|            | Compressive Strength | Modulus of Elasticity | Poisson’s Ratio | Ultimate Compressive Strength |
|------------|----------------------|-----------------------|----------------|------------------------------|
| Natural soil | 10.2                 | 17                    | 0.049          | 1.88                         |
| Modified soil | 8.5                  | 19                    | 0.058          | 2.16                         |

**Fig. 1.** Effect of OTES and SH additives on the compressive strength of kaolinite strengthened by 10 % cement.

**Fig. 2.** Effect of OTES and SH additives on the compressive strength of montmorillonite strengthened by 10 % cement.
Fig. 3. Effect of OTES and SH additives on compressive strength of sand particles by 10 % cement. 

Fig. 4. Effect of OTES and SH additives on the compressive strength of silty-clay particles by 10 % cement.

From fig. 1 and 2 obviously that the greatest increase the compressive strength of samples of kaolinite and montmorillonite strengthened by cement is provided at maximum dosages of OTES and SH. It should be noted that samples of montmorillonite, strengthened by 10 % cement, have zero strength. The strength growth rate of strengthened kaolinite and montmorillonite decreased with an increase the indicated dosages. In the studied dosage range, the use of complex additives led to increase the strength of strengthened kaolinite more than twice, while strengthened montmorillonite in this case acquired the strength close to the strength of strengthened kaolinite 3.0 MPa.

It was found that the optimal content of OTES additive for sand particles strengthened by cement was 0.015 %, SH – 0.05 %, for silty-clay particles – 0.06 % and – 0.1 %, respectively (Figs. 3, 4). At the same time, for sand particles, a strength of 2.5 MPa was provided, for dusty-clay is 7.0 MPa. Thus, the strength of strengthened sand and dusty clay particles increased by 1.3 and 1.5 times.
Previously, it was found that the strength of the original polymineral soil, strengthened by 10% of cement modified by the complex additive increased by 31% compared with the strength of the soil cement with control composition [4].

The effect of OTES and SH additives on the frost resistance of kaolinite, montmorillonite, sandy and silty-clay particles strengthened by 10% cement (based on the mass of minerals or particles) was also studied. The maximum frost resistance results are shown in the table 2.

Table 2. Effect of OTES and SH additives on the frost resistance of kaolinite, montmorillonite, sandy and silty clay particles of the soil, strengthened by 10% Portland cement.

| №  | Component         | OTES, % | SH, % | Frost resistance brand |
|----|------------------|---------|-------|------------------------|
| 1  | Kaolinite        | 0       | 0     | –                      |
| 2  | Kaolinite        | 0.15    | 0.2   | F10                    |
| 3  | Montmorillonite  | 0       | 0     | –                      |
| 4  | Montmorillonite  | 0.15    | 0.2   | F5                     |
| 5  | Sand particles   | 0       | 0     | F10                    |
| 6  | Sand particles   | 0.015   | 0.05  | F15                    |
| 7  | Silty-clay particles | 0    | 0     | F5                     |
| 8  | Silty-clay particles | 0.06 | 0.1   | F10                    |

Samples of strengthened kaolinite and montmorillonite without additives were destroyed during the frost test. Strengthened sand particles had frost resistance F10, dusty clay F5. The introduction of optimal dosages of OTES and SH in the composition of strengthened kaolinite resulted in material with frost resistance F10, montmorillonite – F5, sand particles – F15 and dusty clay – F10.

The frost resistance grade of the initial soil strengthened by 10% cement modified by complex additive reached F15, while the frost resistance coefficient increased by 62% compared to the soil cement with the control composition.

Consequently, the introduction of OTES additive together with electrolytes had the greatest effect on the strength of strengthened clay minerals and dusty clay particles. The frost resistance increase was also observed of strengthened sand particles.

According to the data obtained, it was found that sand particles in the composition of natural soil provided the material with frost resistance, and dusty clay ones provided strength. Modification of such particles by the addition of OTES and SH allowed us to achieve the increase of physicomechanical properties the separately sandy and silty-clay fraction, and their natural mixture.

4 Discussion

The improvement of physical properties, strength and deformation characteristics of the test soil is possibly explained by the complex additive effect on the particles and minerals that make up the soil. It is known that the reason of improving the rheological properties of dispersed soils due to small amounts surfactants addition is the change in nature of clay particles hydrated shells and surfactants adsorption on the clay minerals surface.

The study of physical and mechanical properties of the samples of kaolinite, montmorillonite and silty-clay particles strengthened by cement confirms the complex additive dispersing effect, which consists in increasing the contact area of powdery and clay fractions minerals with cement.

Sand particles strengthened by cement have a distinct optimal dosage supplements octyltriethoxysilane and sodium hydroxide. This is due to the fact that the surfactants adsorption occurs already on cement particles and the additive excess leads to hydration process deterioration.
5 Conclusions

1. The complex additive introduction in soil led to change its physical, strength and deformation characteristics. The plastic limit decreased by 17 %, while the drained angle of internal friction increased by 12 %, specific adhesion by 18 %, and the deformation modulus by 15 %.

2. The effect of complex additive on the physicomechanical properties of the sand and silty-clay component, as well as clay minerals of soil cement, was studied. In the studied dosage range, the use of complex additives led to increase the strength of strengthened kaolinite more than twice, while strengthened montmorillonite in this case acquired the strength close to the strength of strengthened kaolinite 3.0 MPa. The strength of the strengthened sand and silty-clay particles increased by 1.3 and 1.5 times. The introduction of optimal dosages of OTES and SH in the composition of strengthened kaolinite led to increase the frost resistance grade of the material from 0 to F10, montmorillonite from 0 to F5, sand particles from F10 to F15 and silty-clay from F5 to F10.

3. It was established that sand particles in the natural soil composition provided the strengthened material by frost-resistance, and silty-clay – by strength. The modification of such particles by the addition of OTES and SH allowed us to achieve an increase the physicomechanical properties of separately sandy and silty-clay fraction, and their natural mixture.

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