Determination of the percentage of lime in the strengthening of clay soils using pH

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Abstract. The construction of roads is associated with a large resource consumption, including scarce high-strength stone materials. Transportation of these materials over long distances is economically unprofitable, especially for low-cost technical categories. Today, the strengthening of local soils with binders is an important way to be an effective and cost-effective method of construction, reconstruction and overhaul of highways. The most promising mineral binder for strengthening clay soils is lime. The paper presents the results of laboratory tests to determine the percentage of lime, depending on the value of pH.

1. Introduction

In recent years, the road-building industry in the Russian Federation has seen a steady increase in the growth rate of traffic throughout the entire road network, while the general condition of the roads is generally low. It has been established that the necessary and urgent repair of roads requires about three quarters of the country's roads, and over 60% of the roads are not adapted to the movement of modern heavy vehicles. Due to defects in pavement and, as a result, low speed of road transportation, the amount of lost profits is estimated at tens of billions annually. It is often revealed that the destruction of pavements is associated with the processes occurring in the soil foundation of the road, built from local soils. Moisture in the pores and voids, freezing, increases significantly in volume. As a result, the
surface of the coating is subjected to frost heaving and defects are formed, which we can observe annually.

The constructions of road surface dressing with the indicated values of pavement layer thickness for the roads of 3, 4 and 5 technical categories can be economically ineffective. The rock materials that are a part of mix compounds must have high brands of breakability, abrasiveness and cold resistance. Meanwhile, rock materials of high endurance very seldom occur in a greater part of the Russian Federation territory which is leading to a considerable growth of transportation costs.

The use of local soils stabilized with binding materials is an effective way of cutting construction, reconstruction and major repairs costs with regard to motor ways [1].

In the practice of road building, different methods of soil stabilization have been developed on the basis of organic and inorganic binding additives and put into action since 30th–40th years of the XX century (Table 1) [2]. At present, the amount of soil and local materials stabilization methods accounts for over 200 [3, 4], over 30000 km of motor ways having been built and in the service. Viewed in the world scale, the area of pavement layers engaged in stabilized grounds of roads and airfields exceeds 3 bln. m² [5].

Table 1. Classification of soil stabilization methods.

| Method name                        | Materials in use                                      |
|------------------------------------|------------------------------------------------------|
| Stabilization with granulometric admixtures | macadam, gravel, sand, slags, clays, clay loam soils |
| Stabilization with organic binding materials | bitumens solid and liquid, tars, bitumen and tar emulsions and emulsion slurries, synthetic resins, wood sands |
| Stabilization with mineral binding materials | cement, lime, sodium silicate (soluble glass)         |
| Stabilization with synthetic polymers  | macromolecular resins, sulfolignin, lignin-protein substances |
| Stabilization with phosphates         | double and common superphosphate, orthophosphoric acid |
| Integrated methods                   | organic and mineral binding substances containing granulometric improvers, etc |

The projects of motor ways with the use of soils stabilized with such inorganic binding agents as cement, lime, etc. are most common [6, 7, 8].

A large number of different studies are devoted to studying the processes that occur when lime is strengthened in different countries: Germany, USA, Japan, England, China, including the countries of the former USSR [9, 10, 11]. There is a positive experience of strengthening the soil with lime, for
example, in England, there is also a negative one - in Japan. Negative experience is associated with the specific climatic conditions of the use of fortified soil. As a rule, judgments about the suitability or unsuitability of a particular method of soil stabilization are based on the practice of building experimental plots.

A significant part of these studies is limited to the study of the processes occurring in the fortified soil in the period of formation of its structure, and is aimed at developing technological measures to obtain high strength properties [12]. The use of various binders of the initial components and methods for evaluating the results obtained creates difficulties, and in some cases makes it impossible to compare the results obtained by different researchers.

At the beginning of the 20th century, soil liming experiments were conducted at the Leningrad Road Research Bureau. During which it was found that the addition of slaked lime in an amount of 5% by weight of the soil decreased the stickiness and plasticity of clay soils, and the resistance to defrost increased. After receiving these data, experimental work was carried out in the Moscow region to strengthen clay and black-earth soils with lime. In the postwar period, soil liming was further developed in the work of DorNII, Saratov Road Institute and other research institutes. Practical recommendations were developed for introducing the method of liming of soils in road construction. From 1950 to 1955, a number of pilot road sections were built, fortified with lime. According to S. A. Morozov [13], the method of liming provided higher compressive strength of samples in a water-saturated state than during cementation, but the calcified soils showed low frost resistance, and therefore it was concluded that they can be used only in layers foundations of road pavement.

According to the requirements of GOST 23558-94 “Mixes of crushed stone, gravel and sand and soils treated with inorganic binders for road and airfield construction. Specifications "to strengthen the soil should be applied building lime I and II varieties [14], air and hydraulic (hydrated, ground quicklime) lime, meeting the requirements of GOST 9179-77" Building lime. Technical conditions. Use hydraulic lime in powder form. At the same time, this document does not provide recommendations on the amount of lime to strengthen the soil.

Based on the existing experience, lime should be used to strengthen clays, loams, heavy silty sandy loams, as well as coarse-grained soils of optimal granulometric composition with the maximum allowable content of clay particles.
Clay soils strengthened with lime or lime-slag cement should have a soil moisture content at the yield strength of not more than 55% and a plasticity number of not less than 5.

Given the above, the task is set: to determine the percentage of lime to strengthen the soils of highways using a pH value, according to foreign methods.

2. Materials and methods

To determine the percentage of lime, the production of samples and the determination of their strength characteristics was selected clay soil.

Determination of particle size (grain) composition and physico-mechanical characteristics was carried out in accordance with the requirements of GOST 12536-2014 “Soils. Laboratory methods for determining the particle size (grain) and microaggregate composition " and GOST 5180-2015 "Soils. Methods of laboratory determination of physical characteristics ", respectively [15, 16].

The physico-mechanical characteristics of lime were carried out in accordance with the requirements of GOST 22688-77 “Building lime. Test methods "[17].

In the domestic regulatory and technical documentation, only approximate percentages of lime are determined, determined by the method of selection in laboratory conditions based on the required strength at the design age.

In this connection, the technique of the soil-lime mixture described in ASTM D6276 was investigated. The purpose of this method is to select the minimum amount of lime at which the pH value of the soil-lime mixture will correspond to a value of 12.40. The determination of the pH of soil samples with lime is carried out using a device for measuring pH.

The procedure for determining the optimal content of lime includes the following main steps:

- a sufficient amount of lime is added to the prepared soil sample to obtain a pH of the mixture equal to 12.40 or equal to the lime pH value. Fig. 1 presents a graph showing the dependence of the pH values on the lime content;
Figure 1. Graph of the pH value of the lime content.

- 3, 4, 5, 6 and 7% of lime from its mass is added to five containers (flasks) with the ground;
  - in a container with a mixture consisting of lime and soil add 100 ml of distilled water that does not contain CO2;
  - the mixture is shaken for at least 30 seconds, until a precipitate appears at the bottom, shaking is performed every 10 minutes;
  - after one hour, part of the suspension is transferred to a plastic cup and the pH value is measured:
  - if the pH readings correspond to a value of 12.40, then the lowest percentage of lime with a pH of 12.40 is taken as the final result;
  - if the pH value does not exceed 12.30, and 2% of lime gives the same readings, then the lowest lime content with a pH of 12.30 is taken as the final result;
  - if the highest pH is 12.30, and only 1% lime gives a pH value of 12.30, it is necessary to carry out an additional selection starting from a higher percentage of lime.

Under laboratory conditions, the percentage of lime was determined to strengthen clay soils, and samples were obtained with the percentage obtained to determine the compressive strength.

3. Results

Fig. 2 and table 2 presents the results of determining the percentage of lime and the pH value of the soil-lime mixture.
Figure 2. Determination of pH.

Table 2. The percentage of lime depending on the pH.

| No. | % lime | pH of the soil-lime mixture |
|-----|--------|----------------------------|
| 1   | 3      | 11.90                      |
| 2   | 4      | 12.63                      |
| 3   | 5      | 12.56                      |
| 4   | 6      | 12.05                      |
| 5   | 7      | 11.76                      |

For further research to determine the ultimate compressive strength, samples of fortified soil with 4, 5 and 6 percent lime content were produced. The tests were carried out on the 28th day. The results are presented in table 3.

Table 3. The results of the ultimate compressive strength depending on the percentage of lime.

| No. | % lime | The ultimate strength of specimens in compression, MPa |
|-----|--------|-------------------------------------------------------|
| 1   | 4      | 0.27                                                  |
| 2   | 5      | 0.18                                                  |
| 3   | 6      | 0.23                                                  |
4. Conclusion

1. The use of fortified soil in the construction of highways reduces the cost of construction, reconstruction and overhaul of highways.

2. Analysis of the scientific and technical domestic and foreign literature has shown positive experience in using lime as a binder as an effective method for strengthening clay soils.

3. The existing domestic literature does not contain accelerated methods for determining the percentage of lime.

4. Foreign regulatory and technical documentation, according to the obtained laboratory results, provides inaccurate results, and therefore further refinement and adaptation of this methodology is necessary.

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