Reconstruction of Shallow Foundations Using Peracetic Silicate Solutions

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Abstract. The modern world is facing the acute issues of environmental pollution. Recently, they have begun to come out on top in the global relations and in the cooperation of various global business entities. The states allocate significant funds both for measures to prevent environmental pollution and to combat their consequences. The operating experience of many enterprises has shown that the issues of reconstruction of the foundations of existing buildings and structures are currently acute and urgent. One of the most effective types of soil consolidation is stabilizing with various binders, such as silication, bituminous grouting, tarring, cementation. As economic exploitation of soils intensively increases, various pollutants, both organic and nonorganic, affect them by deteriorating their composition, structure and properties. Different types of soils react differently to pollutants, some of them are more “sensitive” to them while others are less “sensitive”. Pollution and environmental deterioration of soils due to the uncontrolled accumulation of various industrial wastes in the soils are the main problems. In this regard, under current conditions, along with the elimination of sources of pollution, it is necessary to develop new methods and technologies to prevent pollution. Physiochemical methods can solve these problems.

1. Introduction

As a rule, foundation consolidation is performed with vertical or inclined reinforcing elements. This is due to the technical characteristics of the construction equipment used, as well as the design requirements, while the consolidation of the soil layer is carried out at a sufficiently large depth. However, in cases of reconstruction of buildings and structures, additional superstructure, confined areas or prevention of the development of active deformations, it is reasonable to stabilize the soil at a shallow depth directly under the foundation in the zone of base active deformations [1–2].

Figure 1. Schematic of the possible location of the injectors when stabilizing the foundations:
1 - reconstructed foundation; 2 - injector; 3 - stabilized soil body; 5 - pit.
When carrying out work on the stabilization of soil bodies, it is necessary to consider the environmental state of the plots to be stabilized, to strive to minimize the introduction of chemicals required for the work.

The proposed stabilization method should ensure the stabilization of deformations as the bases of the system “base - foundation - structure”.

After carrying out the work, the mechanical and deformation indicators of the stabilized soil body should increase.

The integrity of the stabilization the contaminated soil body should be ensured throughout its entire scope.

The condition for the choice of a certain stabilization technology is the condition for the fulfilment of all the listed requirements at a time. It is the most optimal method for finding and choosing the most effective method for chemical stabilization of soil bodies contaminated with industrial wastewater [3].

2. Basic material and results

Three methods of soil stabilization are most commonly used: boring and mixing method, jet silication, jet and mixing silication. The most widespread domestic method is boring and mixing, due to the simplicity of the mechanisms for its implementation.

The method consists in mechanical excavation and mixing of soil with a binder, which is fed in the form of a ready-made solution. Usually the binder is mixed with the soil to be stabilized directly in the well without excavation. The advantage of this method is the economy of the binding solution and the constant cross-section of the stabilized element in accordance with the diameter of the operating auger.

Regarding the jet silication method, it is possible to use one- and two-component binding solutions. It depends on the initial soil conditions and the required final stabilization conditions.

The studies on soil stabilization in two ways: by boring and mixing method and jet silication, were carried out in this paper.

The environmentally friendly compositions of silicate and peracetic gels were used in the studies, as can be seen in Table 1.

Table 1. Environmentally friendly compositions of silicate and peracetic gels.

| Density of sodium silicate solutions, g/cm³ | Time intervals for the beginning of gelation, min | Boundaries of the volumetric ratios of the original components “sodium silicate/peracetic acid” | pH interval |
|------------------------------------------|-----------------------------------------------|------------------------------------------------|-------------|
| 1.10                                     | 1 - 60                                        | 4.5 - 8.0                                      |             |
| 1.15                                     | 1 - 60                                        | 6.5 - 10.5                                     |             |
| 1.20                                     | 1 - 60                                        | 7.5 - 13.5                                     | 6.0-8.0     |
| 1.25                                     | 1 - 60                                        | 12.5 - 16.0                                    |             |

For the jet technology, the characteristic of the penetrating ability of the stabilization solution is the density of sodium silicate solutions. By reducing the density of the solutions used, it is possible to expand the range of soils to be stabilized in terms of permeability and particle size distribution.

As a result of testing the samples (see Figure 2) of the stabilized soil, it was found that with an increase in the density of sodium silicate and the concentration of peracetic acid, the calculated resistance of the soil, R, increases.
Figure 2. Soil compression testing. 
(a) soil samples before testing; (b) sample during testing; (c) sample after testing.

The mechanical characteristics of soils after stabilization, which were determined as a result of laboratory tests, are given in Table 2.

Table 2. Mechanical characteristics of soils after stabilization

| Mechanical characteristics of soils after stabilization | \( \varphi \), deg | \( E \), MPa | \( C \), kPa | \( R \), kPa |
|--------------------------------------------------------|-------------------|------------|-------------|-------------|
|                                                        | 23.9-39.8         | 37.9-42.0  | 38.2-39.2   | 220-560     |

After processing the results obtained, the diagrams of the dependence of the strength of the stabilized soil on the density of the applied sodium silicate solutions were plotted (see Figure 3).
Regarding the radius of soil stabilization during jet silication, it depends on two components: soil density and stabilization solution density.

The physical and chemical process of soil stabilization by silicatisation is based on the sufficient penetrating ability of a silicate solution, which has a low viscosity with the fast release of a silicic acid gel film, which cements the soil.

The research and comparative parallel analysis of the formulation of single-solution, two-component silication with solutions with a density of 1.05 g/cm$^3$, 1.10 g/cm$^3$, 1.15 g/cm$^3$, 1.20 g/cm$^3$ when stabilizing four groups of soil samples are carried out.

Based on the data obtained, the dependence of the stabilization radius on the density of sodium silicate solutions was plotted (see figure 4).

**Figure 3.** Dependence of the strength of the stabilized soil on the density of sodium silicate solution.

**Figure 4.** Dependence of the stabilization radius on the density of sodium silicate solutions.

\begin{equation}
    y = -0.0264x + 0.8835
\end{equation}
The plot shows that with a decrease in the density of sodium silicate solutions, the stabilization radius increases.

Also, the stabilized soil samples were tested for durability and resistance to aggressive media. Tap water with ion concentration of pH = 8.1-8.3 and 3% peracetic acid solution were used as an aggressive medium.

After 30 days and 90 days, the test samples were extracted and tested for compressive strength. The results of the tests performed are shown in table 3.

Table 3. Compressive strength of stabilized soil after being exposed to aggressive media.

| Studied soils | Aggressive medium       | Ultimate compressive strength $R_{\text{compr}}$, kPa, when exposed to aggressive medium, days. |
|---------------|-------------------------|---------------------------------------------------------------------------------------------|
| Soil I        | Water pH = 8.3           | 288                                                                                         |
|               | Peracetic acid 3%        | 301                                                                                         |
|               | Water pH = 8.3           | 199                                                                                         |
| Soil II       | Peracetic acid 3%        | 286                                                                                         |
|               | Water pH = 8.3           | 196                                                                                         |
| Soil III      | Peracetic acid 3%        | 216                                                                                         |
|               | Water pH = 8.3           | 196                                                                                         |
| Soil IV       | Peracetic acid 3%        | 342                                                                                         |

The laboratory tests carried out indicate that the stabilized soil samples are resistant to aggressive media for a longer period.

This is primarily due to the resistance to acid aggression of the peracetic acid gel, which is the main binding material in the studied formulation.

The strength of the base soils increases, their mechanical characteristics improve after the stabilization by two methods, jet silication and boring and mixing. In some cases, the mechanical characteristics of the stabilized soil exceed their value in the natural state by several times. In clays, the soil strength $R_{\text{compr}}$ increases by 1.81 to 3.01 times. The specific adhesion $C$ of sandy loam increases by 9.6 times, and the deformation modulus $E$ increases by 2.48 times. The angle of internal friction $\phi$ increases on average by 1.56 times.

3. Conclusions

Considering the above factors and based on the studies carried out, the authors recommend the use of a peracetic and silicate formulation for consolidation and reconstruction of the foundations of existing buildings and structures.
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