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Strengthening of Clay Soils of Buildings Bases under Reconstruction by Means of Alkalization

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ABSTRACT

The experience of use of natrium hydroxide solutions for strengthening of clay soils of buildings bases under reconstruction in city Ufa is described. The method applied allows to increase the design soil resistance from 0.16 to 0.4 MPa and decrease the labour expenditures at site by 40 %.

Due to a great necessity in reconstruction of industrial and civil structures, more and more actual becomes the strengthening of water saturated clay soil. In conditions of great moistening of soil, the existing methods of a base preparation as well as methods of technical reclamation are ineffective or economically unsuitable in many cases. So, the method of a foundation strengthening by means of its broadening (Babushkin, 1984) or injection piles penetration (Polishchyuk, 2006) is very complicated and labour consuming. The well known silicatization method (Rzhanitsyn, 1984) can not solve the problem of strengthening of the subsident soils especially in water saturated conditions. The electrochemical method of clay soil strengthening is complicated and doesn't always efficient. In this connection, based on experimental and theoretical investigations of interaction between clay soil and caustic alkali solutions, the Institute "BashNIIstroy" together with the Moscow University has worked out the method of clay soil strengthening with alkalization (Volkov, 2005).

The method is based on use of water solutions of alkali metals hydroxides (caustic alkalis) that react with clay minerals and as a result, neogenesis cementing soil particles are being formed. Synthesis of binders occurs directly in soil at the expense of its own resources extracted from the mineral components of soil in conditions of intensely alkali medium.

Dissolving of clay minerals in intensely alkali medium can be presented schematically on the example of kaolinite. So, injection of OH^- of alkali ion into the coordination medium of Al and Si atoms of alumosilicates leads to failure of Si-O-Al relations, then to that of Si-O-Si with the outflow of silicium and aluminium oxides into solution:

$$Al_2Si_2O_5(OH)_4 + NaOH \rightarrow NaAl(OH)_4 \cdot nH_2O + 2Na_2O \cdot SiO_2 \cdot mH_2O \qquad (1)$$

or

$$Al_2Si_2O_5(OH)_4 + 10OH^- \rightarrow 2Al(OH)_4^- + 2SiO_4^{4-} + 3H_2O \qquad (2)$$

with the following formation of a new solid phase of natrium hydroalumosilicates of hydrosodalite type:

$$2SiO_4^{4-} + 2Al(OH)_4^- + 2Na^+ \rightarrow \left[Na_2O \cdot Al_2O_3 \cdot 2SiO_2\right] \cdot nH_2O \qquad (3)$$

The more intensive is mineral dissolution (subtraction of calcium and aluminium ions into the solution), the faster the solution is saturated in respect to silicate and aluminium ions. When the definite concentration of Si^{4+} and Al^{3+} is reached, the less soluble compound – natrium hydroalumosilicate – is extracted from the solution in the first place.

The formation of natrium hydroalumosilicate in intensely alkali medium is possible owing to that its structure consists of alternating silicium alumooxigenous tetrahedral groups giving bonds Si^{IV}-O-Al^{IV}, stable in alkali medium (Zhdanov, 1980).

The extreme instability of highly dispersed minerals to the influence of the concentrated alkali solutions is favourable for development of dimensional condensate-crystallized structure in clay soil. As a result of this process, a new crystalline or amorphous phase is extracted from the oversaturated metastable solution. The coagulative structure of the alkalized samples changes into the condensate crystalline one (according to P.A. Rebinder). Soil becomes water-resistant and strong.

The influence of alkali solutions on the change of clay soil structure and properties was investigated on the great number of samples of alluvial and talus sandy loam, loam and clay sampled on sites of Bashkortostan Republic.

The influence of 2.5 – 10 N alkali solutions on clay rock improved its engineering properties. So, the value of its specific adhesion increased from 0.013 - 0.023 to 0.055-0.18; the inner friction angle increased from 6-18^0 to 30-48^0; modulus of deformation increased from 5-10 to 20-120 MPa. Experiments with the samples of clay soil showed the stability of the above changes after alkalization when long storage in water (Volkov, 1988).

The regularity of improvement of clay rock physical-mechanical properties under the influence of alkali solutions has been used when strengthening of clay soil of structures bases under reconstruction.

The working project of strengthening of clay soil of the building base of eye disease Institute under reconstruction in city Ufa has been worked out to increase the soil load capacity to keep the increasing foundation loads.

The 3.5 x 41 m building consists of several parts attached to one another. It was built at the end of the 19th century and is now the architectural-historical monument. The walls of the building are solid clay bricks. The cracks in the building walls appeared due to earlier and present irregular base deformations. The reason of the above deformations is systematical soil moistening because of pipelines leakage and atmospheric water penetration into base soil. Crack growth reaches 20 mm. The building foundation is strip, rubble stone, 800-1200 mm wide. Its base is talus, low Quaternary sand loam and loam from stiff to soft consistency. The main design physical and mechanical characteristics are the following: three-dimensional mass – 1.88 t/m^3, specific cohesion – 0.013 MPa; angle of inner friction – 17^0; the modulus of general deformation – 7 MPa. The value of design soil base resistance is taken equal to 0.169 MPa.

The underground water in the period of exploration is tapped at the depth of 1.5 – 2.0 m from the day surface. Groundwater is unconfined, water containing soil is sandy loam, water resisting layer is clay. Aquifer is recharged due to atmospheric precipitation seepage and pipelines leakage, discharge occurs into ravine outside the site. By its chemical composition, the underground water is carbonate-sulphate, calcic, with the mineralization 1.0-2.3 g/dm^3, low aggressive (ammonia content NH_4 100mg/dm^3) to concrete.

The values of average pressure under the foundation base are within 0.204 -0.286 MPa (taking into account the building reconstruction) and exceed the value of design soil base resistance. In this connection, it was decided to strengthen the soil base with alkalization to bring its design resistance to a value of 0.3 MPa.

To evaluate the stabilizing ability of clay soil with alkali solutions and to choose the solution concentration for receiving the necessary indices of soil characteristics to reach the design soil base resistance more than 0.3 MPa, the corresponding laboratory investigations have been carried out. Water solutions of 2.5; 5.0 and 7.0 N caustic natrium were used as chemical agents. The results of the investigations are given in the table.

By results of laboratory investigations, the operating concentration of alkali solution equal to 5 N was taken. With the fact h this minimum concentration the necessary parameters of the stabilized soil characteristics are reached.
As a result of investigations, the method of stabilization of sandy loam base of a structure under reconstruction with the injection of 5 N alkali solution was worked out. The alkali solution was injected to the depth of 2.5 m below the foundation base through the injectors penetrated by perimeter of the strip foundation: the radius of strengthening from one injector and distance between injectors in a row was 0.7 and 1.2 m, respectively, solution discharge per injection point was 1.2 m^3 (fig.1). The volume of stabilized soil was 1600 m^3, discharge of crystalline alkali – 60 t. The job was done for 3 months. The quality of soil mass strengthening was checked by a hole boring in the alkalized soil mass with the samples sampling. It was found that the uniaxial compression strength of the alkalized sample sampled at the distance of 1 m from the foundation base was equal to 0.62 MPa. The visual inspection of the bored core samples confirmed the relative continuity of the stabilized soil mass.

The general efficiency of the measures undertaken was estimated by results of observation of crack growth in bearing walls in the process of reconstruction. After the year of operation, the crack growth was not observed.

The necessity to increase the clay soil bearing capacity of a foundation plate base of the elevator shaft adjoining the building under reconstruction was conditioned by the fact that bored piles arrangement (driven piles arrangement was prohibited) in soft loam below the underground water level was difficult. That’s why it was decided to stabilize soft loam with alkalization and to increase the modulus of loam deformation to a value of 15-20 MPa, instead of 8 MPa.

Table 1. Indices of loam characteristics after alkalization

Name of characteristics	Concentration of alkali solution, N		
	2.5	5.0	7.5
Specific cohesion, MPa	0.042	0.087	0.107
Inner friction angle, grad	25	30	25
Modulus of deformation,MPa	40	65	85
Uniaxial compression strength,MPa	0.35	0.55	0.75

Note.: the indices of soil characteristics are given after 28 days of hardening.

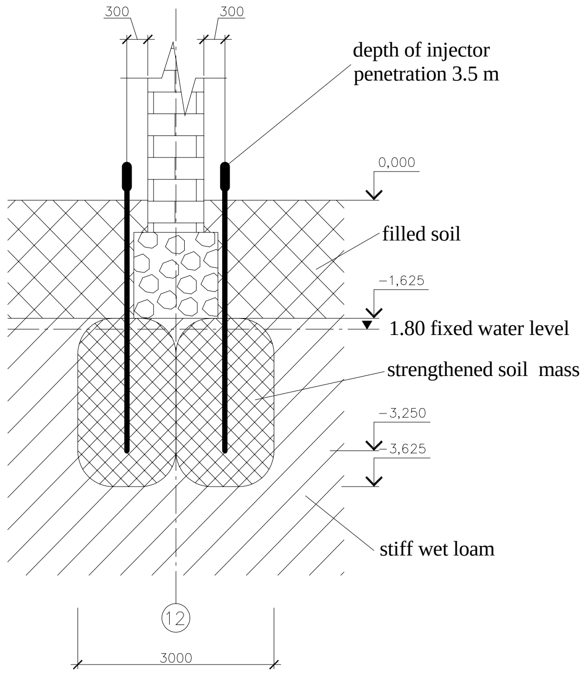

Fig.1. Fragment of base alkalization of the Institute of eye disease building.

The project of clay base alkalization was worked out with the following parameters (fig.2):

foundation plate plan	8x10 m;
thickness of the stabilized layer (with the absolute mark from 149.5 to 145.5)	4.0 m;
radius of strengthening	0.7 m;
number of injection points	48 injections;
number of levels per injection point	2 levels;
discharge of 5N alkali solution per one level	1 m^3;
discharge of crystalline alkali	20 t;
volume of stabilized soil	420 m^3

The job was done for 2 weeks.

The extent of soil mass strengthening with alkalization was checked with the unit C-832 M. The data obtained showed the specific soil resistance under the probe tip and specific soil resistance along the lateral probe surfaces to increase 4-5 times, modulus of deformation of the stabilized loam was 16-22 MPa.

Lately, employers try to use the space under the underground garages for construction of sport complexes and offices using the foundation of the garage. In city Ufa, a 3 storey skeleton sporting complex was built on the foundation of the underground garage. A project on alkalization of clay soil of the garage base was worked out in order to increase bearing capacity of soil.

The necessity of such a project is conditioned by that the construction of the sporting complex on the garage foundation will increase the average pressure under the foundation base of a series of columns by 30-70% with respect to design one.

For proper operation of both the sporting complex and the underground garage, measures have been worked out for the additional arrangement of solid foundation cushions to decrease twice the average pressure under the foundation base.

However, realization of the project will demand some extra work (digging out the soil from the foundation along the both sides to a depth of 0.9 m), arrangement of a reinforcing cage, casing concreting. All this will complicate the garage operation.

In this connection, it was decided to stabilize clay soil of the base with alkalization, i.e. to increase the design soil resistance from 0.20 to 0.50 MPa.

5 N solution of caustic natrium was injected into talus stiff loam being a foundation base.

In the process of works 288 m^3 of soil was alkalized, 10 t of crystalline caustic natrium was injected.

The quality of soil mass strengthening was checked with CPT. The investigations showed the physical-mechanical properties to be improved as a result of alkalization. So, the specific cohesion increased from 0.023 to 0.08 MPa; inner friction angle increased from 19 to 25^0, modulus of deformation increased from 8 to 25 MPa. The design soil base resistance reached 0.8 MPa after alkalization.

While alkalization of clay soil, the ecological aspect was taken into account: the specialists observed the propagation of the alkali solutions in soil; the control showed the alkali was localized in vicinity of the stabilized zone; during 5 year monitoring the alkali migration (pH=8-9) was observed at the distance of 0.3-1.0 m from the zone being strengthened. However, the alkalinity of the pore solution decreased by 3 order.

CONCLUSIONS

The experience of use of natrium hydroxide solution to improve clay soil engineering properties shows that the alkalization method for engineering of the foundation bed from the stabilized soil allows to decrease expenditures at site. The method is technologically simple and does not injure the environment as the soil serves the geochemical barrier for the alkali propagation. So, owing to the above said, the method suggested is one of the most important among the recommended means of strengthened soil base engineering (Abelev, 1990).

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