The study of materials for soil stabilization and their practical application

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Abstract. The article describes the buildings bases consolidation on the example of a 12-storey residential building with two levels of underground parking adjacent to the existing buildings. The cement with different additives mechanical properties laboratory studies results and the components consumption per unit of working solution are given. The foamed soil cement compositions preparation technology is described.

Introduction
In recent years, the multi-storey buildings (mostly with underground premises) construction volume has significantly increased. In addition, the old dilapidated housing stock is being demolished, and the buildings that meet modern requirements are erected in its place. As a rule, such buildings are built in a dense urban area, which causes certain difficulties. At the same time, some traditional foundations use is unacceptable. There is a need to improve the physical mechanical characteristics of soils, the subsidence properties elimination in various ways. The most effective of these is the use of injection methods for transforming structurally unstable soils and creating fixed arrays [1, 2].

Targets and goals
In connection with the complex engineering and geological conditions (the presence of subsiding soils of the I-th type), as well as adjoining the existing structures, a constructive solution was provided to strengthen the residential house slab foundation soils by cementation method with erection along the cut-off fencing plate contour and separating rows from the bored piles. Cut-off and separation rows are used to fence the pit and eliminate the influence of the building under construction on adjacent structures.

Strengthening the soil base plate basement of a 12-storey residential building is designed with elements of increased rigidity of soil cementstone. Reinforcement is performed by directional fractures, arranged when soil cement solutions injected according to the author’s certificate No. 1444473 [3] and to the invention patent No. 2122068 “Method of preparing the base” [4].

A 12-storey residential building with two levels of a basement under a parking lot, frame-monolithic normal level of responsibility with dimensions of 17.2 x59.4 meters in plan. The foundation slab of monolithic reinforced concrete. Adjacent to the building there is a 2-level underground parking lot consisting of two parts of a frame-monolithic structure on slab foundations.

According to the survey materials, the construction site belongs to the ground conditions of type I by subsidence. At the structure base to a depth of 4.8-12.2 m. Light, subsidence, silt loams of solid consistency IGE-1 are deposited. The drawdown due to the ground’s own weight does not exceed 3.4-
4.6 cm. The water saturated non-subsidence heavy loams EGE-2, EGE-3 and light semi-solid consistency of the EGE-4 loam occur below. The groundwater level is fixed at a depth of 11.0-13.9 m from the ground. Groundwater is aggressive to mortars and concrete on conventional cement. Characteristics of the soil are shown in Table 1.

Table 1. Physical mechanical soils characteristics

| Name of characteristics | EGE-1 | EGE – 2 | EGE –3 | EGE-4 |
|--------------------------|-------|---------|--------|-------|
| Density with natural humidity, g / cm³ | 1.79 | 1.91 | 1.94 | 1.93 |
| Deformation modulus at $S_r<0.80/S_r>0.80$, MPa | 11.5/4.3 | -14.1 | -38.9 | -33.2 |
| Specific cohesion, kPa | 10 | 17.5 | 22.1 | 17.2 |
| Angle of internal friction, degree | 14 | 20 | 19 | 21 |
| $I_1$, at $S_r<0.80/S_r>0.80$ | 0/0.67 | -0.08/0.34 | 0.03/0.14 | -0.22/0.23 |

Materials and methods

To determine the soil cement material characteristics used to strengthen the soil at the base of the base plate of a 12-storey residential building, in the laboratory of the INTROFEK Research and Production Enterprise, environmentally-friendly cement-base compositions with different cement contents were investigated.

The main components of the mixture were cement grade M 400, loam, process water and a foaming blowing agent (FMA) - technical sulphanol NP-1. The surfactants low introduction FMA concentrations allow to improve the soil cement suspensions technological properties due to the achievement of high mobility and the compositions thixotropy, reducing sedimentation and delamination.

The use of loamy soil as the reinforcing solution main component significantly reduces the corrosion of soil cement stone in aggressive media. In a series of experiments, the content of FMA in the solid phase (soil-cement) on the basis of previously conducted research in the laboratory was chosen constant and equal to 0.05%. The cement content (M 400) in the solid phase was 20-50%, the ratio of water and solid phase was 0.5.

The foamed soil cement compositions preparation technology consisted of the following:
- the soil was soaked in water for 30 minutes, stirring was performed until a homogeneous suspension was obtained, surfactant was added and the soil suspension was foamed;
- cement was added to the remaining volume of water, mixed, and the resulting solution was added to the foamed ground slurry until a homogeneous, easily mobile composition was obtained.

Samples were prepared from the obtained soil cement suspensions by the method of pouring, which after a day of hardening in an air-humid environment were placed in water.

After 28 days, the test and determination of the strength of cubes with a 100 mm edge was carried out in accordance with GOST 10180-2012.

Testing of prisms with the determination of prism strength and modulus of elasticity was carried out in accordance with GOST 24452-80. The measurement of the longitudinal and transverse deformations of each prism was carried out by 8 dial gauges installed on all four faces of the prism according to the scheme given in GOST 24452-80.

To clarify the characteristics of soil cement was tested 4 composition. The total number of cement samples was 24 pcs.

The composition of the studied soil cement suspensions and the characteristics of the soil cement stone are given in Table 2.
Table 2. The soil cement mechanical properties composition and main indicators

| No. | Composition | Strength on uniaxial compression, [MPa] | Elastic modulus Ex103, [MPa] |
|-----|-------------|----------------------------------------|-----------------------------|
|     | Cement, [\%] HF | FBA, [\%] HF | Soil, [\%] HF | Ratio Water: HF |                                      |
| 1   | 10          | 5           | 89.95        | 0.6          | 0.80                  | 0.50                               |
| 2   | 20          | 5           | 79.95        | 0.6          | 1.15                  | 0.70                               |
| 3   | 30          | 5           | 69.95        | 0.6          | 3.25                  | 1.16                               |
| 4   | 50          | 5           | 49.95        | 0.6          | 6.0                   | 2.53                               |

According to the calculation, the 12-storey residential building foundation plate base soils reinforcement should be performed by arranging the cement elements with 20% cement content (composition No. 2, Table 2), as well as the water amount that provides wetting of the soil massif to the optimum humidity. The recommended composition main components consumption is given in Table 3.

Due to the aggressiveness of the soil to the usual Portland cement for the preparation of the working solution used loam with a plasticity number of not more than 0.14 and sulfate-resistant cement grade not lower than M400 according to GOST 22266-2013.

Table 3. Components consumption per 100 l of working solution

| % the cement content in hard phase | Cement amount, [kg] | Soil amount, [kg] | FBA amount, [kg] | Quantitative water in liters for mixing | Options for soil suspension density γ*, [g/cm³] |
|----------------------------------|---------------------|-------------------|-----------------|-----------------------------------------|---------------------------------|
| 20                               | 23.0                | 85.0              | 0.06            | 0.06                                    | 1.31                           |

* Density of the soil suspension and the working solution due to foaming, on average, decreases relative to non-foamed solutions by 1.3 times.

According to the soil cement mixture composition selection results, the following parameters of the fixed base were taken. The reinforced base height is 8.0 m below the base plate. The arm elements are 2.5 m long, placed in plan with a step of 1.0 m and have a uniaxial compressive strength of 1.15 MPa at 20% cement content in the solution. The reinforcing elements volume is 5% of the fixed soil total volume. Cementation is envisaged with injection tubes installed in the body of the plate. The results are shown in Table 4.

Table 4. The fixed soil parameters

| House in axes, number of floors, foundation type | 12 floors plate | Slab dimensions in the plan taken to calculate, x l, [m] | Pressure at the base of the base plate Pp, [kPa] | Height of fixing zones | Calculated base reinforcement RAR, [kPa] | Reinforced base module Emat /Eadd, [MPa] | Draft reinforced base Srec/Snet, [cm] | Relative difference sediment, % |
|------------------------------------------------|----------------|----------------------------------------------------------|-----------------------------------------------|-----------------------|------------------------------------------|----------------------------------------|--------------------------------------|______________________________|
| Residential building in axes “B - K”, “1-20”   | 17.3x57.5       | 280                                                       | 8.0                                           | 454                   | 45.9/39.1                                | 7.4 /11.2                              | 0.002                                | 2                             |

* Density of the soil suspension and the working solution due to foaming, on average, decreases relative to non-foamed solutions by 1.3 times.
As it can be seen from the table, the project adopted the following characteristics of the reinforced base: Rar = 454 kPa; Eest = 45.9 MPa; Yezam = 39.1-48.4 MPa. According to the calculation results, the absolute draft of the slab foundation on a reinforced base is Sav = 7.4-11.2 cm; the relative difference between sediments is ΔS / L = 0.0022, which does not exceed the maximum permissible values regulated by Appendix D to SP 22.13330.2016 for this type of structure.

**Summary**

As noted above, one of the most effective ways to consolidate the base is the converting soils injection method. However, it can be applied in each specific case after a detailed consideration of many factors, such as soil conditions, composition and main indicators of the cement mechanical properties, laboratory tests of fixed array samples. This article presents some of such studies results and, as a major factor, actual deformations observations of a building on a fixed soil foundation, which did not exceed the maximum permissible.

**References**

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