Modification of structural properties of filled soil by the “Geocomposite” method in the base of foundation slab

Vladimir Znamensky¹, Evgeniy Morozov¹, Dmitriy Chunyuk¹ and Alexandr Vlasov²

¹Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, Russia
²Institute of Applied Mechanics Of Russian Academy of Sciences, Moscow, Russia

Abstract. The article is devoted to one of the most effective and promising methods for improving the structural properties of soils - the method of "Geocomposite". The method is based on the compaction and reinforcement of the soil through the injection of mortar under high pressure, as a result of which there is a fundamental change in the soil body and the formation of a rigid structure naturally inscribed in the soil layer. The method is widely used both to improve the mechanical properties of soils for new construction, and for raising and eliminating the tilt of the operated buildings (compensation injection). The article presents brief information about the technology of shoring soil using the “Geocomposite” method and the main differences in the formation of fixed volumes in cohesiveless and cohesive soils.

The development of methods for man-made modification of the properties of soils in order to increase their bearing capacity and reduce deformability is connected to the need of construction buildings at sites composed of filled or loose soils. The first methods of improving the physical and mechanical properties of soils at the base of the foundations were rested on their compaction and appeared in the XVIII century. Upward the 20th century, soils were stabilized by changing their composition in various ways. Widespread methods are based on the impregnation of the soil and the formation of stronger structural bonds between rock elements (cementation, silicification, bituminization, etc). The effectiveness of these methods depended on the permeability and moisture of soils and had a number of other restrictions for technical reasons and environmental index. At the end of the last century, methods and technologies of soil stabilization appeared in the world building practice, based not only on their impregnation, but also on the modification of the structure of a soil body. One of the most effective and promising of these methods is the “Geocomposite” injection method for the simultaneous compaction and reinforcement of soils, developed by B.N. Melnikov, A.I., Nesterov and V.I. and Osipov in 1985 in relation to loess soils. Later it was improved by V.I. Osipov, S.D. Filimonov and E.V. Kayle and applied to consolidate sandy and clay massifs on a number of objects [1].

This article provides generalized information about the Geocomposite method and its application in sandy and clayey soils, methods for controlling the results of the completed stabilization, methods for evaluating the effective characteristics of the stabilized soil body, as well as an example of its successful use for stabilized man-made filled soils at the base of the slab foundation of an apartment building.
When stabilizing the soil according to the “Geocomposite” method, the injection of the binder mortar into the stabilized soil body is carried out through perforated injectors. Technologically, the injection is carried out on the object as follows: cored holes are drilled to the design depth through the foundation, then injectors are immersed in them - steel pipes with holes in the form of nozzles through which the binder mortar is injected. Injectors at the wellhead are fixed with a packer and tamponed with concrete. The mortar is pumped through the pipeline and high pressure hose (Figure 1).

In cohesionless sandy and loam soils, especially mellow soil, near the injector is formed some area occupied by cement, the structure resembles a pile with varying diameter. In areas where soils have a uniform composition, the cement pile zone is replaced by a small area of soils impregnated with cement mortar. Then follows a zone of soils compacted by an expanding pile. With distance from the pile, the density of these soils gradually decreases to their density in the natural state. If in cohesionless soils in the compacted thickness there are various cavities, bands of soft rocks, cracks or simply zones of increased pinhole rating, then the mortar penetrates into these areas, filling the voids, displacing and compacting the weak depth, forming long tongues (schlierens) that reinforce the soil body in the radius to 2 meters. That's why, a pile of a certain diameter (up to 0.7 m) with reinforcing root elements is formed in cohesionless soils (Figure 2 a).

In cohesive clay soils, the formation of reinforcing elements takes place in a somewhat different pattern. First of all, a cement pile is formed around the injector, which has a much smaller diameter (up to 15 cm) than in cohesionless soils. Then the cement mortar penetrates into the soil body in weak, fractured and loose zones. The jets cut the soil in the close proximity of the steel pipe, and as this space is filled with the mortar, the pressure increases and the soil breaks in the most weakened places. The so-called “hydraulic fracturing” occurs, as a result of which the binder mortar penetrates deep into the soil body, spreading over the soft soils, pushing them apart and compacting. That way, a “geocomposite” is formed, consisting of a steel injector and root-like tongues, reinforcing the soil within a radius of up to 2 meters (Figure 2b).

The fragment of clay soil stabilized by the “Geocomposite” method is shown in figure 3.

The soil body reinforced by the Geocomposite technology is a fundamentally new man-made formation - a geotechnogenic composite consisting of several elements and possessing a high degree of rigidity and strength.
Figure 2. Distribution of composite elements in soil bodies of different composition:
   a) sandy, sandy-loam; b) clayey

Figure 3. Fragment of the soil mass, stabilized by method "Geocomposite"

During the development of the project of soil stabilization according to the “Geocomposite” method, a space-planning scheme is created, where the location of the injectors in the plan and their number, the depth of stabilization of soil body, the volume and composition of the injectable mortar, the working pressure, etc. are determined.

In the plan, as a rule, injectors are evenly distributed over the base foundation of the structure, the base of which must be reinforced. The distance between the injectors on average is about 2 m. In the case
of a foundation slab, an edge holder is necessarily arranged along its perimeter. Its purpose is to prevent the binder mortar from going beyond the borders of the stabilized soil body.

The number of injectors at the site is based on its size, the depth of stabilization depends on the thickness of the reinforced soil body and its depth. Working pressure is largely determined by soil conditions. When reinforcing existing and restored buildings, where existing foundations can be weakened by various defects, the working pressure should not exceed the design load transmitted to the foundation from the structure.

When stabilizing the soil in the base of the foundation slab of buildings under construction, the working pressure of the stabilizing mortar is usually 15.0-20.0 atm.

The volume of the injected mortar is one of the main indicators determined at the design stage, since the end result of reinforcement of soil body is a change in its pinhole rating and density, on which the deformability of the soil body depends.

Dependence of the deformation modulus of a stabilized soil body on the volume of injected cement mortar, obtained experimentally in sandy soils Mogilevtsevoy D.I. [4], shown in Figure 4.

![Figure 4. Dependence of the modulus of deformation of the stabilized soil body on the volume fraction of the injected cement mortar](image)

The main stabilizing mortar for soil reinforcement by the “Geocomposite” method is water and Portland cement M-500 with a different water-cement ratio (W / C). In the case when it is necessary to increase the setting speed of the mortar (high water content of the soil), a small amount of liquid glass is added to it.

Direct control and experimental verification of the fulfillment of the project requirements on the quality of soil stabilization with respect to continuity and uniformity of stabilization, the shape and size of the stabilized soil body, strength, deformation and other physical and mechanical properties of the stabilized soil body is provided by the following measures:
- uncovering the area of stabilization with control pits and boreholes with their examination, sampling and laboratory determination of the characteristics of stabilized soil bodies;
- tests of the stabilized soil body with static or dynamic probing;
- investigations of the area of stabilization of the soil body by geophysical methods.
When considering the issue of the deformation modulus of a stabilized soil body consisting of several engineering geological elements (EGE), it is necessary to distinguish two concepts: the effective deformation modulus of the reinforced EGE and the effective deformation modulus of the reinforced soil body as a whole.

Evaluation of the effective modulus of deformation of the enhanced EGE can be performed by the results of probing or by the direct method, using the downhole stamp method. Evaluation of the effective strain modulus of a stabilized soil body as a whole is carried out by a calculation method or is carried out according to the results of controlling the precipitation of a building on a stabilized soil body.

The calculation method uses the principle of superposition, based on a combination of direct and inverse rules of a mixture. In accordance with this principle, the effective deformation moduli of individual EGE are first determined using Voigt averaging (a direct mixture rule).

\[
\frac{S_c}{S} E_c + \frac{(S-S_c)}{S} E_s = \frac{E_{ef}}{\left(\frac{\nu_1 E_{1ef}}{\nu_2 E_{2ef}} + \frac{\nu_{nat}}{E_{nat}} = \frac{1}{E_{ef}}\right)}
\]

where \(E_{ef}\) = effective modulus of deformation of the stabilized EGE; \(E_c\) = modulus of deformation of the cement stone; \(E_s\) = modulus of soil deformation after its stabilizing; \(S_c\) = total area of injectors in the plan; \(S\) - total area of the site.

Then, the effective strain modulus of the entire soil body is determined, including several EGE (Figure 5). The module is expressed as averaging over Reuss (inverse mixture rule) [2,3,4]. The proportionality coefficients are the proportions of the power of the reinforced, non-reinforced and soils in the natural state that fall into the zone of stabilization.

Where \(\nu_1\) and \(E_{1ef}\) are the fraction in power and the effective modulus of deformation of sections of the section where no reinforcement of soils was made, but injectors are present; \(\nu_2\) and \(E_{2ef}\) are the fraction in power and the effective modulus of deformation of the sections of the section where the soils were strengthened; \(E_{est}\) and \(E_{est}\) - share in power and modulus of deformation of soils of natural composition.

Along with the cement mortar, the presence of steel injectors in the soil also affects the effective modulus of deformation of the stabilized soil body. This influence can be estimated using the same superposition principle. According to Mogilev D.I. the difference in the effective moduli of deformation with and without steel injectors is from 1 to 13 MPa, and it is more where the injectors are longer.

Figure 5. Conventional structure of the cell "Geocomposite" in sandy soil
Below are the results of the stabilization of man-made deposits using the “Geocomposite” method at the base of the slab foundation of a 4-sectional apartment building 75.0 m high in the Moscow Region.

The thickness of the man-made deposits dumped in the course of the liquidation of the quarry building that existed at the construction site was within 19-21 m. The foundation of the building is a reinforced concrete monolithic foundation slab on a stabilized base. The pressure on the base under the sole of the slab foundation is 38 t / m².

Since the filled soil in its natural state could not be used as the base plate of the building being erected, the project adopted the option of stabilizing it with the “Geocomposite” method for the entire depth and replacing the sand pad to a depth of 3.0 m in the zone of increased content inclusions.

The stabilization of the sand fill and the entire thickness of the filled soil was carried out with a breakdown of the stabilized soil body into 3 zones (Figure 6):
- zone 1 - sandy soils with a layer thickness of 3 m;
- Zone 2 - filled soils with a variable capacity of about 13 m within the compressible depth;
- zone 3 - filled soils with partial seizure of underlying loam (EGE-5) with a capacity of about 2 m below the compressible depth.

![Figure 6. Zones of stabilizing soil body at the base of the foundation slab](image-url)
The injection of the mortar according to the project was supposed to be carried out under pressure for the stabilized zone 1 to 10 atm., the stabilized zone 2 to 20 atm., the stabilized zone 3 to 5 atm. at the minimum feed rate of the mortar.

The predicted values of the moduli of deformation of the stabilized soil for the zone of 1–30.0 MPa, for the zone of 2–25.0 MPa, for the zone of 3–10.0 MPa. The development of the technology for stabilizing the filled soils and the assessment of the compliance of the deformation characteristics of the stabilized soil body with the predicted ones was carried out on a test site.

The experimental plot was delineated by 16 wells of the barrier row, forming a closed space in the plan, inside of which there were 11 working wells for securing the filled soil body. According to the results of static probing, the value of the modulus of deformation of filled soils of the test site on average was: at a depth of 3.0-12.0 m - 10.7-16.4 MPa, at a depth of 12.0-26.5 m - 10.9-12.0 MPa.

To assess the results of the stabilization of the filled soils at the test site, 2 engineering geological wells were drilled, static probing was carried out in 4 points along the entire thickness of the filled soil and in 3 points to a depth of 15 m, as well as drilling of engineering geological workings and 6 plate tests. Plate tests were carried out using spiral dies with an area of 600 cm² according to the scheme, “load up to 0.30 MPa — unloading up to 0 MPa — load up to 0.5 MPa — unloading up to 0 MPa‖. Tests conducted at depths of 4.50 m; 6.50 m; 10.0 m.

The analysis of data of static probing after stabilizing the soil and their comparison with the data prior to stabilizing allowed us to draw the following conclusions:
- to a depth of 12 m, the soil body became more compacted; no weakened zones (less than 1 MPa) were recorded at the test points;
- in the interval of depths of 12–20 m, the soil body is not compacted as significantly as up to a depth of 12 m, weak zones with a thickness of about 30–40 cm are recorded in places;
- weakened unconsolidated zones are registered below the depth of 20 m;
- the average values of the resistance after stabilization of the fill increased from 5.3 MPa to 9.2 MPa, i.e. 1.7 times.

The average values of the modulus of deformation E according to the results of the test plates:
- for the first load branch (25 + 25 + 33): 3 = 28 MPa;
- for the second load branch (77 + 27 + 20): 3 = 33 MPa.

This information shows us that the amount of weak layers has significantly decreased after stabilizing, but the values of resistance have increased on average 1.7 times, which is shown in the following tables.

Table 1. Values of resistance are increased on average in 1,7 times
Table 2. Number of weak layers is diminished significantly

|                        | Before fastening | After fastening |
|------------------------|-----------------|-----------------|
| Area fastening - up to 12m | 28              | 9               |
|                       | 74              | 21              |

So, the experimental works carried out on the test site during the construction of a high-rise apartment building on the filled man-made soils stabilized by the Geocomposite method made it possible to draw the following main conclusions:

- the “Geocomposite” method allows to stabilize non-uniform filled soils with the achievement of the predicted design values of their deformation modulus within 20.0-25.0 MPa. After stabilizing the soils with the indicated method, a significant decrease in the amount of weak layers is observed in them, and the value of the resistance increases on average by 1.7 times;

- the inverse mixture rule satisfactorily reflects the dependency between the volume fraction of the reinforcing element and the resulting effective modulus of deformation, which allows us to recommend its use for predicting the deformation characteristics of a stabilized soil body;

- as a whole, the “Geocomposite” method can be considered quite effective for securing non-uniform man-made soils at the base of erected buildings and structures.

References

[1] Osipov V.I., Filimonov S.D., Kail E.V. Compaction and reinforcement of weak soils using the “Geocomposite” method. // Base, foundations and soil mechanics, 2002, No. 5, p.15-21.
[2] Vlasov A.N., Merzlyakov V.P., Ukhov S.B. Effective characteristics of the deformation properties of layered rocks. Construction properties of soils, 1990, p. 19-21.
[3] Vlasov A.N., Merzlyakov V.P. Averaging of deformation and strength properties in rock mechanics. - M.: Publishing house DIA, 2009. 208 p.
[4] Mogilevtseva D.I. “Determination of the effective modulus of the total deformation of sandy soils, stabilized by the“ Geocomposite ”method” // Geoecology. Engineering geology, hydrogeology, geocryology 2012, №6, p.571-572.