The geocomposite method for reinforcing building foundations

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Abstract: A new method of improving the engineering properties of soil foundations (GEOCOMPOSITE) was developed in the Institute of Environmental Geoscience of the Russian Academy of Sciences. This new technique is based on the principles of composite material creation.

Geocomposite itself represents a natural and man-made composite material showing high rigidity and chaotic structure. Geocomposite is created by cracking grouting of the foundation soil by injecting cement solution at a pressure exceeding the soil strength. As a result, a "soil-cement solution" boundary is formed, at which the stress is concentrated. The stress concentration causes, on one hand, the hydraulic cracking in the weakest zones and, on the other hand, consolidates the soil structure and extrudes the liquid phase.

Thus, similar to any other composite material, the Geocomposite contains a matrix of weak basement soil, into which the foreign bodies are injected, that is, the metal injector and the cement solution, which is injected under pressure and consolidates to become a cement rock or so-called "rigid inclusions" according to the composite mechanics term.

The injector and the solidified cement in voids and fractures form some chaotic cellular framework ("rigid inclusions"), which acquires "effective" mechanical properties due to the materials introduced into the matrix.

The Geocomposite method application to the mass of weak and human-made soil permits us to improve their deformational parameters by a factor of 1.5-2.5 to meet safety conditions.

Résumé: Les scientifiques de l'Institut d'Ecologie Géologique de L'Académie de Sciences de Russie ont élaboré une nouvelle méthode pour améliorer les caractéristiques techniques desterrains d'appui («Géocomposite»). La technologie de la nouvelle méthode est basée sur les principes de la fabrication des matériaux composites. Géocomposite est un tout nouveau système naturel et technogène possédant une très haute rigidité et la structure chaotique. La formation de géocomposite se fait par voie d'injection au terrain d'appui de la construction du coulis de ciment sous pression de la fracturation hydraulique. Lors du durcissement, le coulis injecté se transforme en inclusions solides. Les fragments du massif du terrain se trouvant entre ces inclusions se font consolider par la pression du coulis injecté. Grâce à ce processus de consolidation les caractéristiques mécaniques s'améliorent de beaucoup. La méthode «Géocomposite» s'applique pour améliorer les caractéristiques de tout terrain sans consistance et mou aussi d'origine naturelle que d'origine technogène. Egalement cette méthode est applicable pour tout type de fondations. Cette méthode permet d'augmenter les caractéristiques de déformation du terrain (1.5-2.5 fois) . Cela répond aux impératifs de sécurité pour la construction.

Keywords: Bearing capacity, grouting, injection, mechanical properties, reinforced materials, soil mechanics.

INTRODUCTION

A new technique of weak soil improvement was developed as a result of scientific collaboration between the Promstroiniiproekt Ural Institute (Yekaterinburg) and the department of soil and rock engineering and engineering geology in the Moscow State University under the guidance of Professor Victor I. Osipov (Mel'nikov, Nesterov & Osipov 1985; Osipov 1989). Later it was improved and modified at the Institute of Environmental Geoscience of the Russian Academy of Sciences (Osipov 1994; Osipov, 2000; Osipov 2001).

The method is based on the principles of composite materials. Any composite is mainly specified by the presence of rigid impurities in a less strong matrix. The method suggested by the authors considers soil to be a weak matrix, the rigid impurities being artificially produced by grouting. This produces a new human-made system "Geocomposite" with the better properties as compared to the enclosing weak soil. An increase in the load-bearing capacity of soils results from two processes: compaction and reinforcing of soil by the artificial rigid impurities.

The "Geocomposite" technique permits improving the strength and deformability of any compressible dispersed soils of both natural (i.e., sand, sandy loam, loam, and clay) and man-made (fill, construction garbage, etc.) origin. Under certain conditions, the method may be used in peaty soils. Ground water doesn't prevent the method application.

The "Geocomposite" method may be applied for all types of foundations, i.e., slab, strip, columnar, and pile foundations. The method appears to be applicable for solving a wide range of problems, i.e., the base improvement of buildings and constructions in emergency; base preparation for new construction; increasing the load-bearing capacity of base soils upon reconstruction and increasing the height of buildings; the improvement of soil mass properties along open (pits, trenches) and above closed mine workings; the compaction of road embankments; the stabilization of landslide slopes, etc.

The suggested technology is environmentally friendly; it is less costly, less laborious and less material consuming as compared to the other existing grouting methods.

THEORETICAL FUNDAMENTALS

Theoretical fundamentals of "Geocomposite" method are well developed in the theory of composite materials, which is widely applied in different technological branches. According to this theory, hard inclusions inserted into a weak matrix produce a new material with much higher mechanical properties as compared to that of the initial matrix.

The geocomposite mass is created by the injection of calculated volumes of solidifying solution into a weak soil. Upon its solidification, this solution forms rigid inclusion (Figure 1). The soil-mass fragments enclosed between these inclusions are compacted by the pressure produced by the injected solution (which acts as an inner soil jack) to acquire significantly better mechanical properties. The rigid framework of solidified solution strengthens additionally the compacted soil mass.

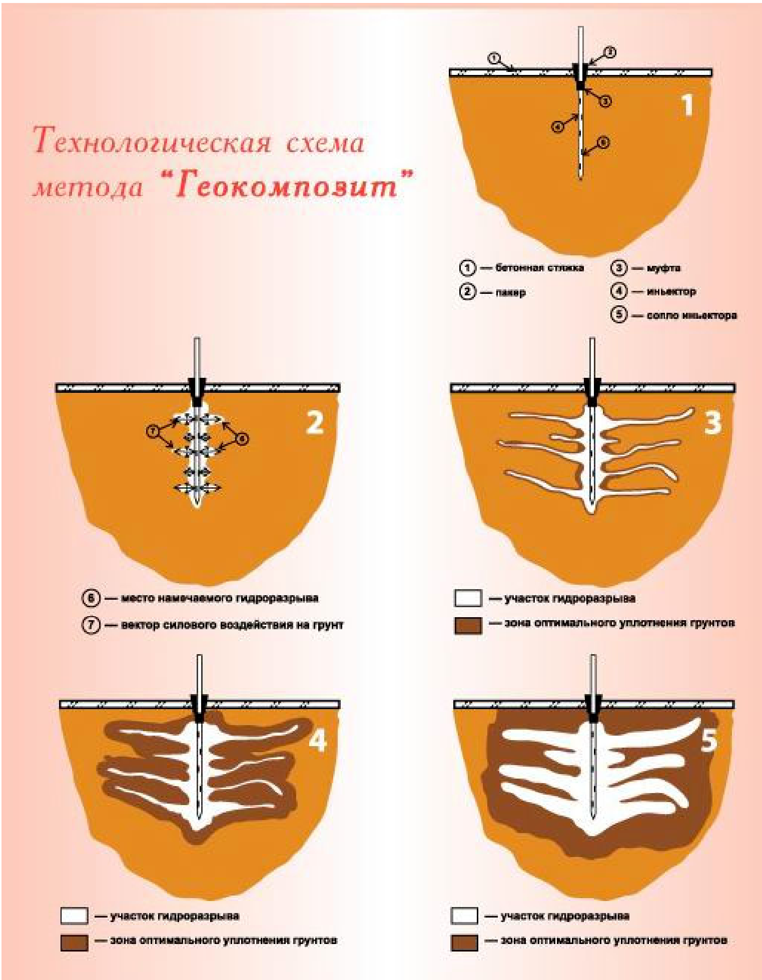

Figure 1. Technological scheme of the “Geocomposite” method. Designations: (1) concrete stay; (2) packer; (3) socket; (4) injector; (5) jet orifice; (6) points for planned hydraulic failure; and (7) vector of impact on soil. Dark brown - hydraulic failure zone; white – the zone of optimal soil compaction.

The injected solution manifests a high selectivity by improving the weakest zones of a mass, which leads to an increase in its bearing capacity and homogeneity.

The deformation modulus of geocomposite with lamellar artificial inclusions is calculated proceeding from the following equation:

$$E_e = CE_p/2 + E_m,$$

where E_e is the effective modulus of geocomposite, E_p is the elasticity modulus of rigid lamellar inclusions, E_m is the deformation modulus of weak matrix with the account of its compaction upon geocomposite formation, and C is the volume concentration of rigid inclusions in geocomposite mass.

The injection parameters, i.e., the number of injection points, the distance between them, the treatment depth, and the volume of the treated mass, are calculated depending on the problem to be solved and the physico-mechanical properties of the grouted soils.

WORK TECHNIQUE

The technological scheme of geocomposite formation is a patented invention. It assumes the controlled injection of calculated volumes of solidifying solutions into the soil mass depending on the specific engineering geological and hydrogeological conditions, as well as the desired final strength and deformability. The necessary volumes of solution and the injection schemes are calculated proceeding from the special computer programs based on the composite mechanics principles.

Construction works are accompanied by soil reinforcement according to the "geocomposite" method. The following procedures are used to prepare foundations for new building construction: trenching, blinding of a trench bottom, embedding of injectors to a required depth, assemblage of a construction slab, and erection of three or four building storeys. The main construction works are accompanied by injection of grout in order to reinforce foundation soils (Figure 2).

The soil reinforcement quality control is performed after the completion of the injection works.

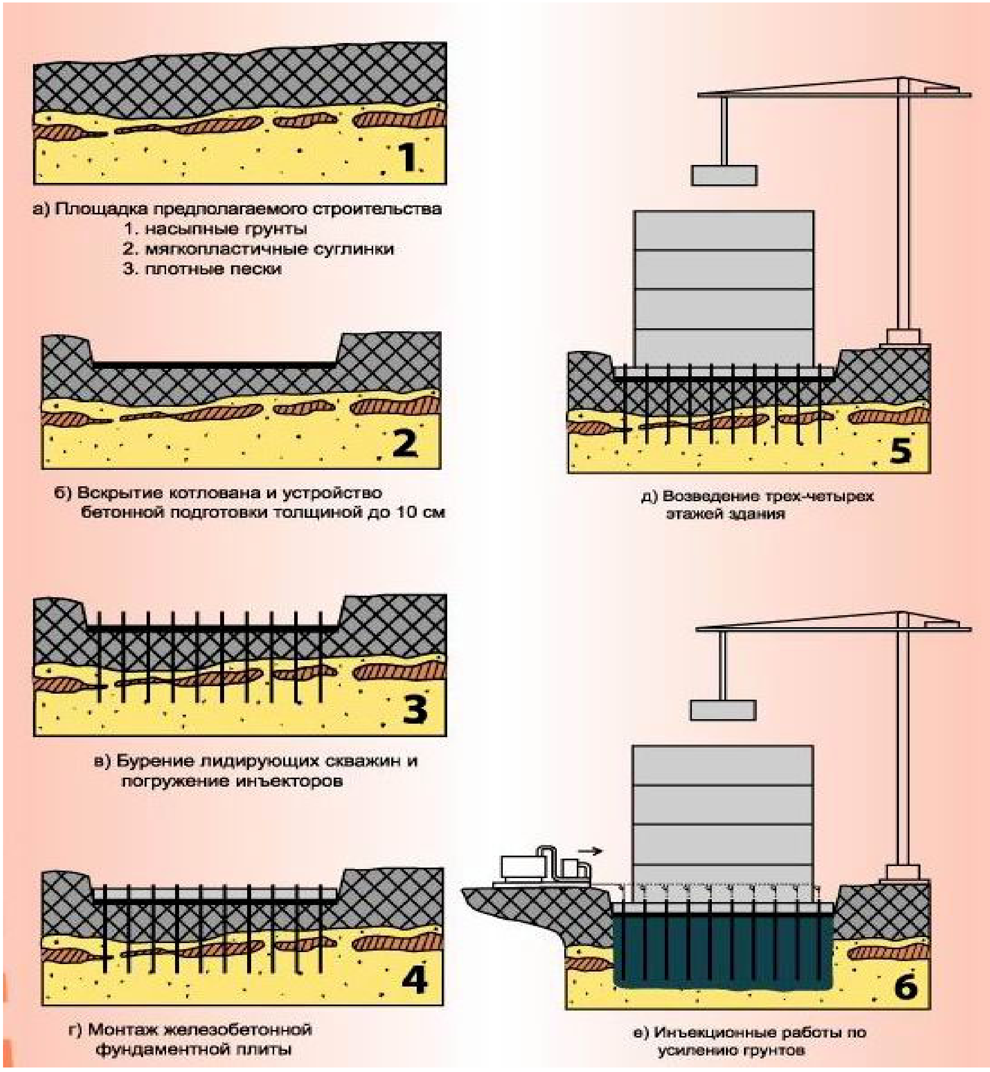

Figure 2. Technological scheme of soil reinforcement using the "Geocomposite" method at the construction site. Designations: (1) Planned building site, (a) fill; (2) soft-plastic loam, (3) dense sand; (2) Trenching and formation of a foundation mat with a thickness of up to 10 cm; (3) Drilling of leading boreholes and embedding of injectors; (4) Assemblage of a reinforced concrete foundation plate; (5) Erection of three or four building storeys; (6) Soil reinforcement with the help of injected grout.

QUALITY CONTROL

The quality of soil-mass improvement by geocomposite may be controlled by either direct or indirect methods. Direct methods involve routine methods of studying soil deformability and strength both in field and laboratory. The plate load tests appear to be the most reliable. This test method was applied for the quality control of loess grouting. The works were performed at 16 test sites in the southern regions of Russia. The plate load test with the plate area of 10 000 cm^2 at the full wetting of loess was used. Both untreated and treated loess masses were simultaneously tested.

The results obtained from the plate load tests prove that the collapsible loess loses completely this property after grouting. In addition, the plate load tests attests to a 2-3 fold increase in the compressibility modulus of the improved soils and to a 2.5-3.5 fold increase in the limit resistance as compared to the untreated loess.

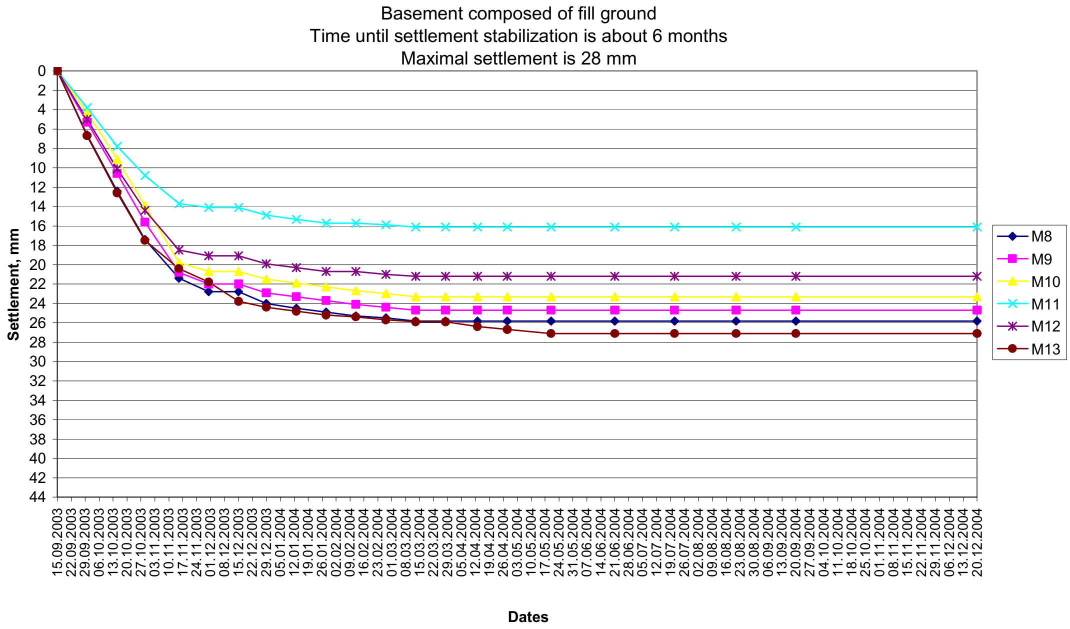

Figure 3. Building foundation settlement, Elevatornaya str., Moscow

The indirect methods of soil grouting quality control include the settling monitoring according to geodetic marks, static test of piles, dynamic and static sounding, the cone penetration test, electric vertical sounding, microgravity, etc.

For example, Figure 3 illustrates the monitoring results of settling of an 18-storey dwelling house in the Elevatornaya Street erected on fill ground. The 15-month-long monitoring of the building settling proved to the stabilization of the foundation settling in 6 months after the end of grouting works; the maximal settling during this period having been equal to 28 mm.

In Moscow, at the construction site of the 14-storey dwelling house in the Mariinsky park district, the transformation of bearing capacity of friction piles after their treatment by the geocomposite method was estimated by the static load test. Grouting soils by the geocomposite method resulted in an increase in the bearing capacity of piles from 36 to 72-78 tons.

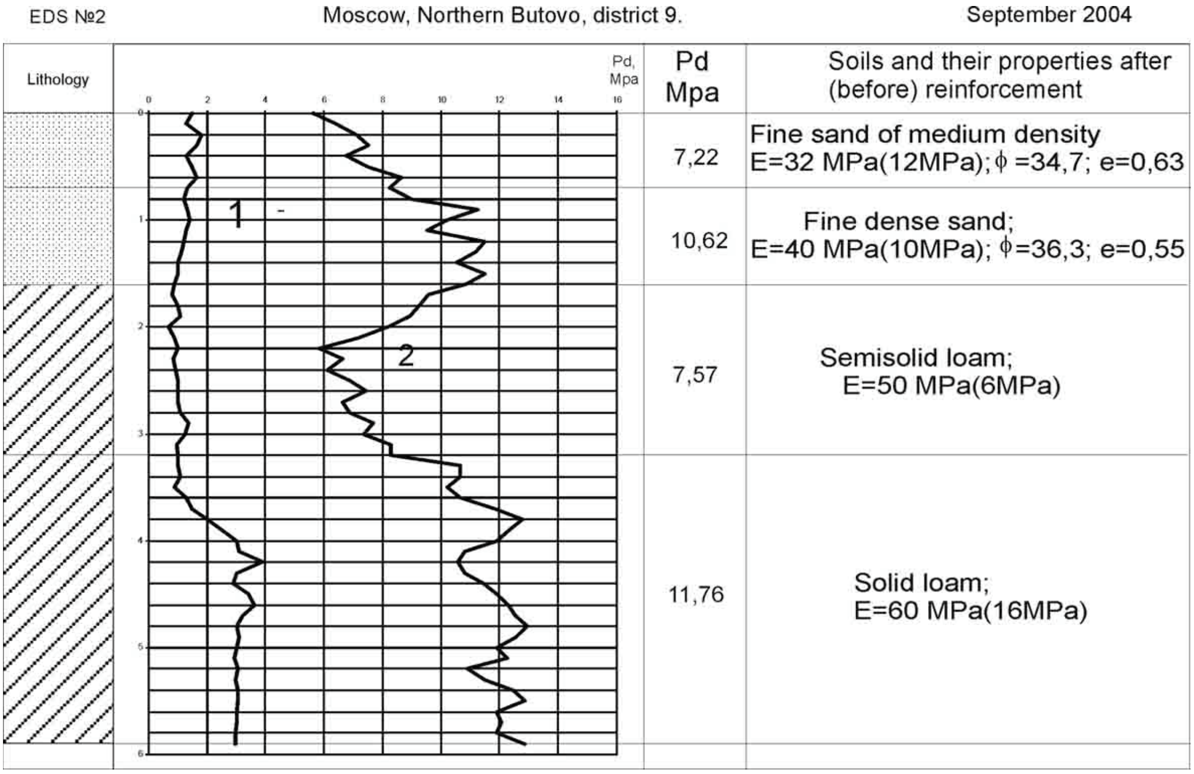

Figure 4. Results of electrodynamic sounding (EDS) before (1) and after (2) reinforcement

The dynamic sounding turned out to be rather effective for the work quality control. The repeated sounding before and after the soil treatment in the same point gives an adequate idea on the transformation of soil mass properties after the geocomposite formation (Figure 4). The data obtained for the building of the Account Chamber of the Russian Federation in Moscow and the dwelling building in the Elevatornaya street show that the dynamic resistance of soil Pd has increased approximately by a factor of 1.5-2.7. This corresponds to an increase in the deformation modulus E from 9-27 MPa (untreated soil) to 20-45 MPA (treated soil). The static sounding shows the close results (Table 1).

Table 1. Results of soil reinforcement by the «Geocomposite» method at certain sites in Moscow

Site	Soil	Average soil modulus of deformation (MPa)					
		EDS Data			Static sounding data		
		before reinforcement (br)	after reinforcement (ar)	$K_{EDS} = E_{ar}/E_{br}$	before reinforcement (br)	after reinforcement (ar)	$K_{EDS} = E_{ar}/E_{br}$
Elevatornaya st., district 1, block 1, eastern Biryulevo	Fill	9	20	2,2	14	19	1,3
	Silty sand	11	30	2,7	34	44	1,3
	Plastic sandy loam	13	23	1,8	17	31	1,8
	Soft-plastic loam	13	25	1,9	8	15	1,9
	Hard-plastic loam	15	25	1,7	15	22	1,5
RF Counting Chamber, block E	sand of medium size and moderate density to a depth of 4 m	27	45	1,7	27	50-65	1,8-2,4
	4-8 m: medium-size sand	26	38	1,5	26	35-42	1,3-1,6

CASE STUDY

Since 1985, the "Geocomposite" method has been successfully applied to loess soils in southern Russia, where the foundations of more than 30 buildings and structures have been reinforced. From 1995, the method has been used at more than 120 sites in Moscow and other Russian towns for all types of foundations to solve different problems, i.e.

- reinforcement of foundations of damaged buildings and structures;
- preparation of foundations for new structures;
- reinforcement of architectural monument foundations;
- soil mass reinforcement along open and above closed excavations in order to prevent neighbouring buildings and structures from damage;
- fill consolidation in order to construct houses, industrial enterprises, roads, etc.;
- soil mass reinforcement in order to increase slope stability;
- reinforcement of foundation composed of quarry stone;
- correction of building inclination;
- soil mass reinforcement in order to increase stability of excavation slopes;
- soil reinforcement in foundations of dwelling houses under construction in karst-prone zones;
- anchoring during sheet piling of construction trenches and retaining walls;
- soil stabilization at tops of galleries and tunnels under construction;
- construction of impermeable shields in order to decrease the effect of seismic vibration generated by technogenic sources (railroad, underground, etc.);
- reinforcement of embankments and dykes.

Strip foundations appear to be one of the most widespread in Moscow region. The necessity to increase the bearing capacity of soils under these foundations arises upon increasing the height of buildings, upon a decrease in the bearing capacity of soil due to the developed waterlogging, the sand mass decompaction as a result of suffusion, etc. Under these foundations (including those under old architectural monuments), the soil properties may be improved by injecting the solidifying solutions into basement soil for the entire depth of the compressible zone. This technique was applied for stabilizing the 18-storey dwelling house in Brateevo district (Moscow) and for the reconstruction of a number of buildings in the central part of Moscow.

The uneven settling of slab foundation leads to the misoperation of building systems (for example, lift wrack, etc.) and building deformation. For the most part, this is caused by highly heterogeneous basement soils and their non-uniform compressibility. The suggested method permits solving this problem successfully by the formation of geocomposite mass under the slab foundation for the entire depth of compressible soils. The design scheme of solution injection takes into account the soil mass heterogeneity, with greater volumes being injected into weaker zones and less volumes being injected into denser and stronger zones. This permits us to achieve uniform deformational properties of basement rock and to eliminate their uneven settling. This method application allowed us to stabilize the settling of a 17-storey dwelling building in Brateevo district, Moscow, which was erected on a slab foundation. The similar operations were performed under the slab foundations in the Novatorov Street.

The soil properties under piles foundation are improved in case the bearing capacity of piles cannot provide the building deformation within the permissible limits. This often happens to friction piles upon the construction topping, soil decompaction, rising soil moisture (waterlogging), or appearing negative friction. The "Geocomposite" method may be applied for increasing the bearing capacity of piles due to lateral friction and point resistance. To increase the former, the solidifying solution is injected between piles; and to increase the latter, it is injected below the piles point. This technology allows us to achieve a 1.5-2.0 increase in the bearing capacity of friction piles. In Moscow, this technique was used under the 14-storey building in the Mariinskii park district. Note also that the application of "Geocomposite" technique to piles foundations permits using shorter piles of the same load-bearing capacity.

Besides strengthening the building foundations of different types, the "Geocomposite" method may be efficiently applied to stabilizing tunnel vaults and walls in open pits and trenches in Moscow upon laying pipelines.

CONCLUSION

The theoretical grounds and practical experience in using the "Geocomposite" method attest to the wide possibilities of its application for different soil conditions and for solving a vast number of problems (ranging from the weak soil strengthening under the building foundations of various types to stabilizing rocks in tunnel vaults, mine workings, and karst voids). The method applicability does not depend on the soil mass moisture and its percolation properties (whereas, these parameters appear to be the principle factors limiting the application of routine grouting methods, i.e., silicification, cementation, for fine soils). Geocomposite technique is specified by a high penetrative capacity of injected solution, which allows us to increase the injection step as compared to routine method. This results in a high economic efficiency of our method and attests to good prospects in using the "Geocomposite" method upon various kinds of construction.

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