PAPER • OPEN ACCESS

Soil stabilization with modern TM MAPEI materials in reconstruction of buildings and structures

To cite this article: S V Panchenko *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **708** 012066

IOP Conf. Series: Materials Science and Engineering **708** (2019) 012066 doi:10.1088/1757-899X/708/1/012066

Soil stabilization with modern TM MAPEI materials in reconstruction of buildings and structures

S V Panchenko[1], G L Vatulia[2], O V Lobiak[2,5], M V Pavliuchenkov[2], O S Herasymenko[3] and S M Bohdan[4]

[1] Department of Automation and Computer Train Operation Remote Control, Ukrainian State University of Railway Transport, Feuerbach sq., 7, Kharkiv, Ukraine
[2] Department of Structural Mechanics and Hydraulics, Ukrainian State University of Railway Transport, Feuerbach sq., 7, Kharkiv, Ukraine
[3] Department of Building Materials and Structures, Ukrainian State University of Railway Transport, Feuerbach sq., 7, Kharkiv, Ukraine
[4] LLC "Mapei", 13 E. Sverstiuka St., Kyiv, Ukraine

[5] Email: lobiak@ukr.net

Abstract. The article deals with the findings of experimental and theoretic research into the efficiency of applying prepared substances TM MAPEI for chemical soil stabilization for foundations of buildings in reconstruction. The objects of the study were soils of rapid, average and slow permeability. Determination of physical and mechanical characteristics of soils before and after stabilization was conducted in laboratory environment. The results were obtained on the basic of the project into stabilization of foundations under complex reconstruction of a four-storied building. The chemical stabilization technology for foundations purported uniform mixing of soil with a special mixing screw, supplying needed components, and further consolidation. A design diagram for the building was made in software package Lira-SAPR 2018. Calculations of carrying capacity of the foundation were made for six design patters which differed in characteristics of the stabilized soil according to the materials applied. The first design pattern considered the application of non-stabilized soil. Results of the calculations are presented as isofields, soil reaction coefficients C_1 and C_2, loads (pressure) on the foundation P_z, and vertical deformations. On the basis of the research the authors state that application of TM MAPEI for chemical stabilization of collapsible soils under reconstruction allows increasing the foundation rigidity by three times and more, the carrying capacity by 10 times and more, depending on the formulations accepted.

1. Introduction

Soil stabilization is an urgent problem in reconstruction of buildings in cities. A need for such work is conditioned by commercial attractiveness of purchasing structures located in the city center for heightening the building or internal re-planning. Each case implies greater loads on the foundation. Besides, in cities and rapidly growing towns there is a liability to soil watering with anthropogenic and ground water, which leads to foundation weakening.

Advantages of soil chemical stabilization are relative production simplicity, possibility to stabilize soil at any depth without foundation opening, short production terms, and continuous use of the building during reconstruction [1-4]. Occasionally, chemical stabilization is the only technical possibility to improve stability and rigidity characteristics of the foundation.

IOP Conf. Series: Materials Science and Engineering **708** (2019) 012066 doi:10.1088/1757-899X/708/1/012066

2. Determination of physical and mechanical characteristics of soils

Physical and mechanical characteristics of soils before and after stabilization were defined in laboratory environment [5] with application of sets of soil samples under study and formulations. Sand of average fineness and density was taken as soil of rapid and average permeability. And loamy plastic sand was taken as soil of slow permeability in the research. The stabilized soil samples were manufactured with modern materials TM MAPE of a wide range of application, including one for soil stabilization. The composition formulation, and also the name and description of additives are given in Table 1.

Table 1. Composition formulations under study.

#	Composition name	Description of the additive	Composition formulation
1	Expanjet Ground	Single-component cementing mixture based on special hydraulic cementing components with high content of fine additive of expansion property of over 70% relative to the injected amount	Expanjet – 1 kg Sand – 0.01 m^3 Water – 0.00055 m^3
2	Expanfluid Ground	Powder additive of expansion property, added to cement for preparation of non-shrinking and plastic mixtures for injecting	Expanfluid – 43 gr. Sand – 0.01 m^3 PC I-500 – 1.43 kg Water – 0.00051 m^3
3	Dynamon Easy Ground	Modified superplasticizing agent based on acrylic for prepared concrete, mixtures or soils	Dynamon Easy 11 – 10 gr. Sand – 0.01 m^3 PC I-500 – 1 kg Water – 0.0008 m^3
4	Microcem Ground	Microthin hydraulic cementing (with a particle size of up to 25 mkm) with pozzolanic activity for consolidation and hydro-isolation of soil under injecting cement mixtures	Microcem 8000 – 0.75 kg Loamy sand – 0.01 m^3 Water – 0.00075 m^3 Dynamon Easy 11 – 7.5 gr.
5	Viscofluid Jet Ground	Cementing modifier of injecting formulations as flimsy natural cellulosic polymer.	Viscofluid Jet 5000 – 10gr. Loamy sand – 0.01 m^3 PC I-500 – 1 kg Water – 0.0008 m^3

Resistance of soil cut (τ), angle of internal friction (φ) and specific cohesion (C) were determined on the basis of the findings of the study on the samples with the method direct shear in cutting devices of fixed cutting plane. The method is based on a shift of one part of a sample relative to the other part by applying tangential load at simultaneous impact on the sample of the load, normal to the cut plate (Figure 1).

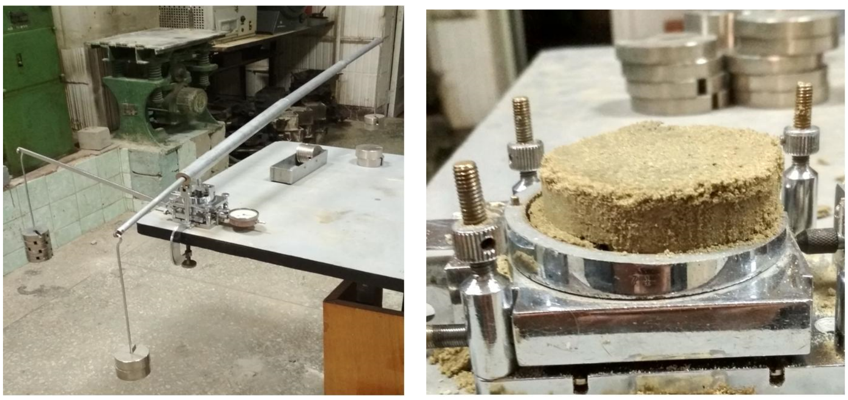

Figure 1. Tests on soil samples with the method of direct shear.

IOP Conf. Series: Materials Science and Engineering **708** (2019) 012066 doi:10.1088/1757-899X/708/1/012066

Resistance of the soil cut was defined as the boundary average tangential stress at which the soil sample was cut off along a fixed plane at a set normal stress. For defining the specific cohesion and angle of internal friction more than three tests were conducted at various values of the normal stress. And a sample ring with the soil was fixed in the cutting box. Then, a solid stamp was established, loading mechanism was regulated, a gap of 0.5-1 mm between the movable and unmovable parts of the cutting box was fixed, a device for measuring deformation of the cut was fixed, and the initial indicators were recorded. As soon as the normal load was transferred, the mechanism for tangential loading was activated and the sample was cut. The tests were considered finished when during a regular stage of tangential load a part of a sample was immediately cut (torn) off one part of the sample relative to another or the total deformation of the cut exceeded 5 mm.

For defining the compressibility factor (m_0) and the deformation modulus E tests on the samples with the method of compression pressure were conducted. These characteristics were defined by results of the research on the samples of soil in compression devices – odometers (Figure 2), which exclude a possibility for a soil sample to be expanded at vertical loading.

Figure 2. Tests on the soil samples with the method of virgin compression.

After the tests the results were processed and the average values of soil characteristics obtained were compared (Figures 3, 4, 5).

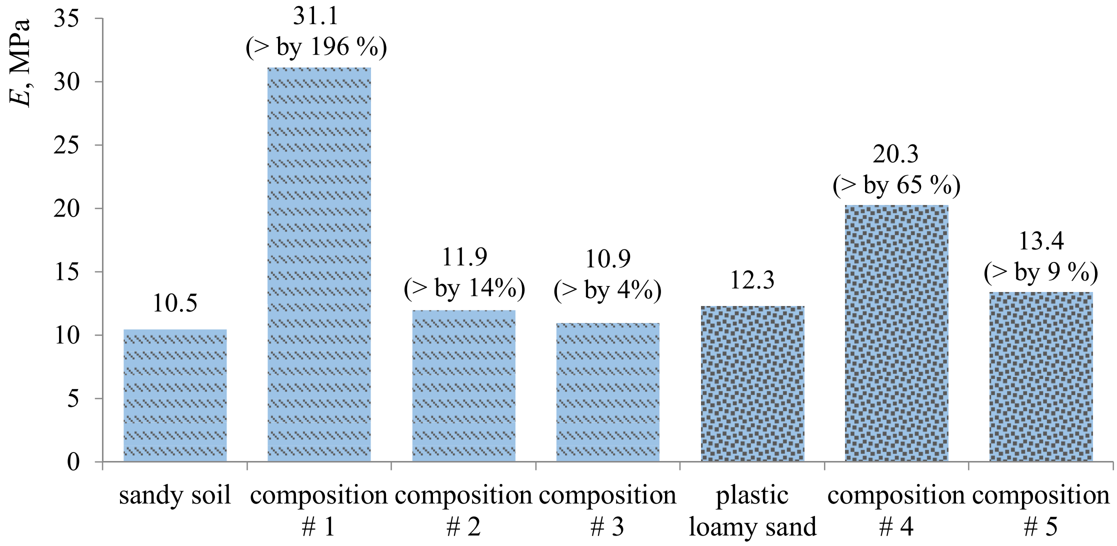

Figure 3. Results of defining the deformation modulus.

IOP Conf. Series: Materials Science and Engineering **708** (2019) 012066 doi:10.1088/1757-899X/708/1/012066

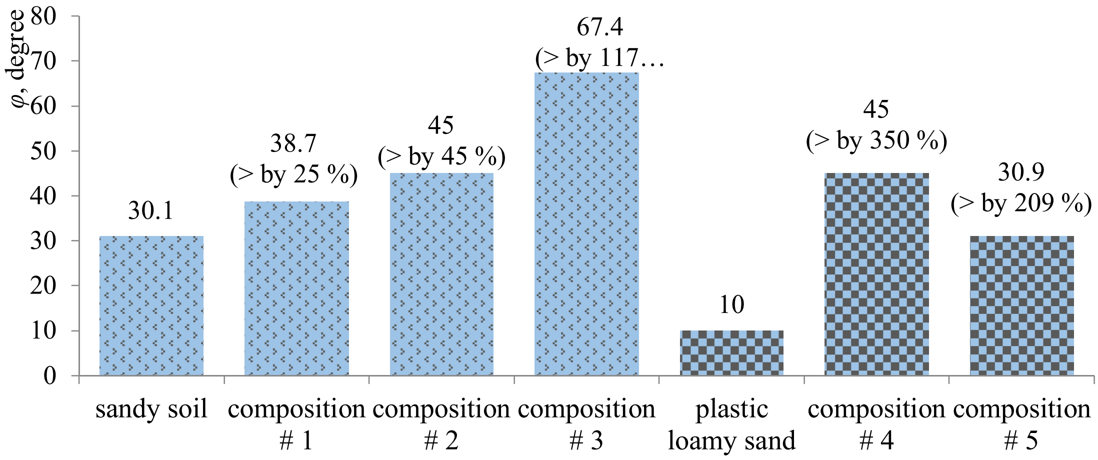

Figure 4. Values of the angle of internal friction in the test sets of soil.

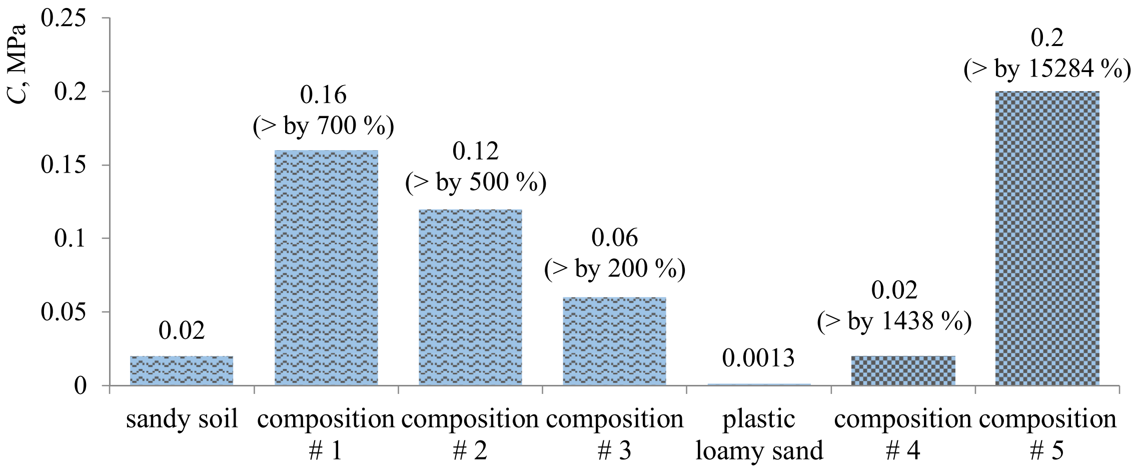

Figure 5. Values of the specific cohesion in the test sets of soil.

3. Soil stabilization of the foundation in reconstruction of a building

The results of laboratory tests before and after soil stabilization were on the basis of the project on soil stabilization under complex reconstruction of a four-storied building. The structural layout of the building before reconstruction was a wall-bearing (external and internal) brick structure. The structural layout of the building after reconstruction was a non-complete framed structure with external and internal self-bearing walls and an internal monolithic reinforced concrete frame. The total rigidity and stability of the frame was provided by united work of diaphragm plates, stairs, columns, slabs and floor beams, and also slab foundation, united in a spatial system. A need for recostruction was conditioned by emergency technical state and spatial rigidity damages due to cracks in both the bearing walls, and external and internal walls, which divided the building into parts.

Combined foundations in the form of natural slab (for the columns and stairs in the input section) and slab-type pole foundations (for two other sections), with column support of the frame in the centers of the sections (columns' central location) were added during reconstruction. The foundation under additional bases, chemically stabilized, was composed of collapsible loamy soils with an initial collapsing pressure of 0.12 MPa.

The chemical soil stabilization technology implied formation of an artificial substructure by the uniform mixing of the soils with special mixing screws [6] with a simultaneous supply of needed components, blending and further consolidation before building additional foundations (Figure 5).

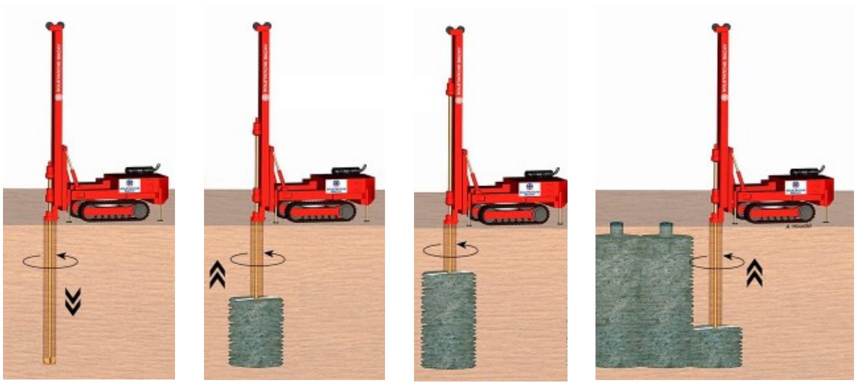

Figure 6. Diagram of chemical soil stabilization.

The major objective of blending is a uniform dissemination of soil cementing components for rapid and effective triggering chemical hydration reaction. The deep mixing technology for soils was firstly proposed in Japan at the beginning of 1950s [7]. Due to its universal nature and possibility to be applied for different soils, most popular is the moist mixing technique [8], which allows erecting on the site conditional soil-cement columns (poles) of the diameter 400-1200 mm and the maximum length 26 m. For obtaining the best results in soil-cement column stabilization, mixing process was repeated several times.

The structural calculation was made with the finite element method (FEM) in software package Lira-CAD SYSTEM 2018 [9], earlier used successfully in calculation of steel reinforced concrete structures [10] and reinforced concrete span bridge structures [11]. The design model was made with shell elements for walls, beams and covers, and universal cane finite elements for the frame (trimmer beams, columns). Universal finite elements of the cover with consideration of elastic foundation parameters, calculated on a 3D soil model, were applied for foundations. The 3D soil model was built on the basis of the results obtained in the engineering-geologic survey of the construction site. According to the model, along the whole foundations area, the authors defined the coefficients of soil reaction C_1, C_2 which depended on the proper loads on the foundations and loads from the adjacent buildings, and also calculated the compressed layer depth and sediment. Parameters of the elastic foundation were determined by the modified Pasternak's model.

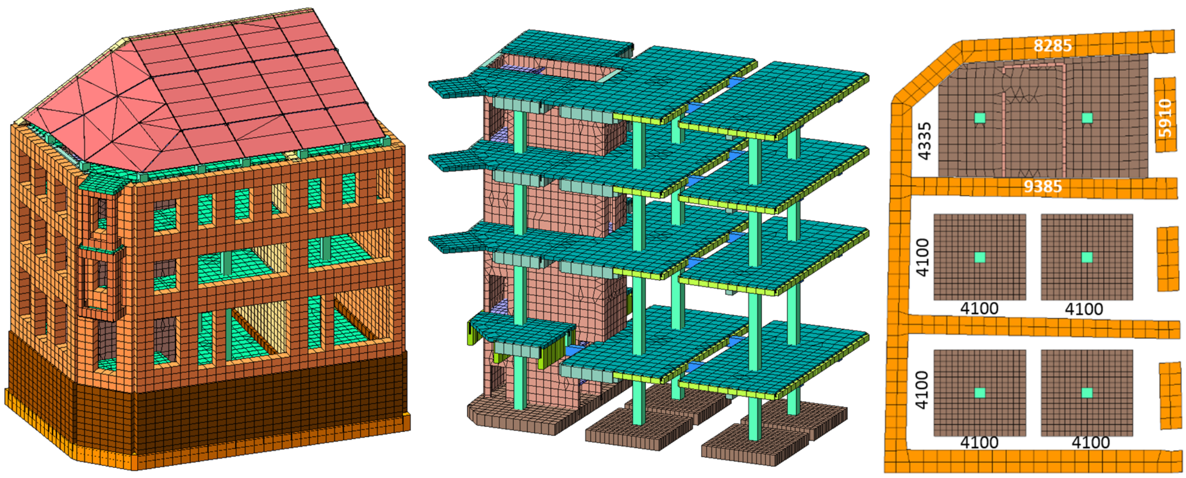

Figure 7. Design model of the building.

The coefficients of soil reactions C_1 and C_2 were defined by the iteration method according to the pressure law on the foundation surface and the soil foundation model. Characteristics of the soils included in the calculations are given in Table 2. The calculation also considered the pressure (approximately measured) on the soil from the buildings located in direct proximity to the building under reconstruction.

Table 2. Soil characteristics.

EGE number	Name	Deformation modulus, MPa	Poisson's ratio	Specific weight, kN/m^3	Natural moisture, fractions	Flow index	Porosity factor	Specific cohesion, kPa	Angle of internal friction, °
1	Collapsible loamy soil	4.90	0.35	17.3	0.16	0.10	0.74	30.40	17
2	Loamy soil	10.8	0.35	17.9	0.21	0.14	0.76	36.30	14
3	Sand of middle density	35.6	0.30	17.6	0.09	-	0.57	0.039	32

The design diagram considered the following types of loading: constant loads (weight of carrying and non-carrying structures) and design temporary loads. The effective load on the underground floor (normative load without proper weight) was accepted 300 kg/m^2, on the 2nd and 3rd floors – 300 kg/m^2, on the 4th floor and attic floor – 200 kg/m^2.

The carrying capacity of the foundation was calculated for six design patters which differ from each other in characteristics of stabilized soil according to the materials used. The first design pattern implied application of non-stabilized soil.

Table 3. Soil characteristics for design patterns.

№	Name	*E*, MPa	*C*, kPa	*φ*, °	Design resistance, MPa
1	Collapsible loamy soil in a set condition	4.90	30.400	17.0	0.120
2	Expanjet Ground composition	14.5	243.20	21.2	2.420
3	Expanfluid Ground composition	5.60	182.40	24.6	2.270
4	Dynamon Easy Ground composition	5.10	91.200	37.0	2.610
5	Microcem Ground composition	8.10	466.80	76.5	12.07
6	Viscofluid Jet Ground composition	5.30	4676.8	52.7	98.88

The results of the calculations are presented as isopoles of the coefficients of soil reaction C_1 and C_2, loads (pressure) on the foundation P_z, and vertical deformations (Figure 7). For each case the carrying capacity of stabilized soil was evaluated according to the design resistance values of foundation soils (Table 4).

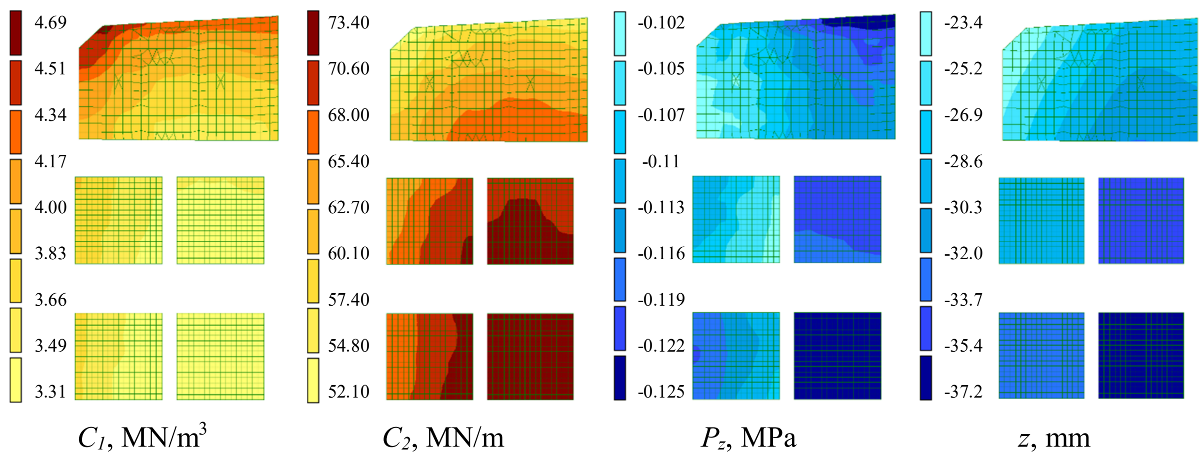

Figure 8. Stabilized soil Expanjet Ground composition.

Table 4. Results of the calculation.

Name	Pressure on the soil	Coefficients of soil reaction		Sediment	Carrying capacity reserve of the foundation
		C_1	C_2		
	MPa	MN/m^3	MN/m	mm	
Non-stabilized soil	0.137	1.12-1.58	17.50-24.70	116	0.89
Expanjet Ground	0.125	3.31-4.69	52.10-73.40	37.2	19.6
Expanfluid Ground	0.135	1.27-1.80	20.00-28.20	101	17.1
Dynamon Easy Ground	0.136	1.16-1.64	18.20-25.70	111	19.5
Microcem Ground	0.131	1.84-2.61	28.90-40.80	68.3	93.8
Viscofluid Jet Ground	0.136	1.22-1.72	19.10-26.90	106	740

4. Conclusions

Analysis of the results of physical and mechanical characteristics of soils after stabilization with TM MAPEI materials demonstrated that they considerably improve the soil properties. Soil stabilization in reconstruction makes it possible to increase the foundation rigidity by three times and more, the carrying capacity by ten times and more relative to the compositions taken. In order to obtain rational formulations providing an adequate stabilization level at minimal financial expenditures, it is reasonable to continue the research into improved production technologies and adjusted ratios of components.

References

[1] Yhosheva L A and Hryshyna A S 2016 Review of major methods of soil stabilization for foundations. *Bulletin PNYPU. Stroytelstvo i arkhytektura* **7 (2)** pp 5-21

[2] Kryvosheiev P, Farenyuk G, Tytarenko V, Boyko I, Kornienko M, Zotsenko M, Vynnykov Yu, Siedin V, Shokarev V and Krysan V 2017 Innovative projects in difficult soil conditions using artificial foundation and base, arranged without soil excavation *Proc. of the 19th Intern. Conf. on Soil Mechanics and Geotechnical Engineering* pp 3007-3010

[3] Seed R and Duncan J 1986 Fe Analyses: Compaction – Induced Stresses and Deformations *J. of Geotechnical Eng.* **112 (1)** pp 23-43

[4] Zotsenko M, Vynnykov Y, Doubrovsky M and so on 2013 Innovative solutions in the field of geotechnical construction and coastal geotechnical engineering under difficult engineering-geological conditions of Ukraine *Proc. of the 18th Intern. Conf. on Soil Mechanics and Geotechnical Engineering* **3** pp 2645–2648

[5] DSTU B V.2.1-4-96 1997 *Soils. Methods of defining capacity and deformation characteristics in laboratory environment* (Kyiv, NDIOSP) p 102

[6] Zotsenko M L, Vynnykov Yu L and Zotsenko V M 2016 *Drilling-mixing methods for drilling soil-cement piles* (Kharkiv, "Drukarnia Madryd") p 94

[7] Jahiro T and Joshida H 1974 The characteristics of high speed water jet in the liquid and its utilization on induction grouting method *II International symposium on jet cutting technology Cambridge* pp 441–462

[8] Malynyn A H 2010 *Soil jet grouting* (Moskva, Stroiyzdat) p 226

[9] Gorodetsky A and Evzerov I 2007 *Computer models of structures* (Kyiv, Fact) p 394

[10] Lobiak A, Vatulia G and Orel Ye 2017 Simulatioon of performance of circular CFST columns under short-time and long-time load *MATEC Web of Conf.* **116** 02036

[11] Lobiak A, Plugin A, Kravtsiv L and Kovalova O 2018 Modelling of motorway bridge spans under modernization with consideration of rheological properties of the materials *MATEC Web of Conf.* **234** 04004