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Regularities of the deformed state of the geotechnical system "soil base – micropile"

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Abstract. Definition and predicting the deformed state of the geotechnical system "soil base – micropile" are the relevant scientific and technical objective when strengthening the soil base by reinforcing elements. The complexity of solving such a problem lies in the heterogeneity of the deformation characteristics for the parts of the specified system. The application of mathematical modeling based on the finite-element method allows defining the behavior of the deformed state in the geotechnical system "soil base – micropile" in the variation of the elastic modulus of its elements. In the course of the numerical analysis of twenty finite-element models characterized by a change in the elastic modulus of the micropile material and soil base, the value of maximum vertical displacements of the strip foundation for the civil structure is obtained. The generalization of these values makes it possible to construct diagrams of their changes in accordance with the variation of the elastic modulus. The obtained regularities allow predicting a deformed state for a sufficiently wide range of the elastic modulus for elements in the system "soil base – micropile".

1. Introduction

In geomechanics and geotechnics, a common problem that generates a range of scientific objectives is the interaction between two or more parts in the system under study [1, 2]. In geomechanics and mechanics of underground structures, the principle of support interaction of the underground structures with a surrounding massif is declared as the basic principle of these two sciences [2, 3]. In geotechnics this principle, for example, when analyzing the "foundation – base" system, is increasingly implemented in scientific research and engineering calculations [4].

Such increased focus on the specified problem is explained by the following factors. First, regard for the principle of interaction in geomechanics and geotechnics fully corresponds to the physical concept of the mutual impact between an artificial engineering construction and soil or rock massifs. Secondly, subject to a correct representation of interaction in geomechanical or geotechnical systems, it is possible to obtain smaller sizes of the structure, which supports or reinforces the system. This is due to the fact that the strength and the deformation property of the rock massif or the soil base are not excluded or replaced by the force or a complex of forces, but they are included together with the same characteristics of an engineering structure.

However, conformity with the principle of interaction in geomechanical and geotechnical systems significantly complicates the analysis and calculation process. This is an objective position of the research since the variety of soil conditions and heterogeneity of the rock massif is quite difficult to take into consideration, formalizing by a mathematical way in analytical constructs [5]. Therefore, the mathematical or simulation modeling of geomechanical or geotechnical systems with the help of numerical methods, in particular the finite-elements method, has become lately an instrument that allows solving the interaction tasks.

If globally, the finite-elements method as a computational environment, allows taking into account the interaction of parts in geomechanical or geotechnical systems, then tasks associated with some particular effects arise in each specific case. For example, the formation of a deformed state in the geotechnical system "soil base – micropile" interacting with the strip foundation [6], is fully dependent on the combination of deformation properties (the elastic modulus, Poison's ratio) of parts in the specified system [5, 7]. Selecting these properties (they provide the system with the smallest or predefined deformations), in particular, the elastic modulus, is possible only under conditions of obtaining their regularities. Accordingly, finding these regularities for the geotechnical system "soil base – micropile" is a purpose of the research, which is characterized by significant relevance in the field of geotechnics.

2. Methods

Strengthening soil bases or rock massifs by the injection procedure of various solutions is an effective way to reduce their deformed state [8]. The immersion of the vertical or inclined element into the soil with the help of any technology changes the overall deformation situation since the material of the reinforcement structure has an elastic modulus, which is radically different from the soil base [6]. The correlation of these moduli, all things being equal (diameter, length of micropile and the distance between them), enables to determine regularities of the deformed state, which allows predicting it in other conditions.

It is known that for the case of the panel-wall or the strip foundation, the index of its flexibility is determined by the formula of Gorbunov-Posadov [4]:

$$r = \frac{3(1-\mu_f^2)\,\pi E_s a F}{(1-\mu_s^2)\,\pi E_f h}, \tag{1}$$

where E_s, μ_s – the elastic modulus (MPa) and the Poison's ratio of soil respectively; E_f, μ_f – the elastic modulus (MPa) and Poison's ratio of foundation respectively; a, F, h – half the length (m), square (m^2) and thickness (m) of foundation respectively. Thus, according to the analysis of formula (1), the change in the elastic modulus of soil does not lead to a significant change in the foundation flexibility index. The widely known theory of the average modulus of the base, strengthened with elements of reinforcement – piles and micropiles – performed on the basis of various technologies is grounded on this statement.

However, the practice of using micropiles suggests that the change in the deformation characteristics of the micropiles material, significantly changes the deformed state, almost without affecting the foundation flexibility index. This is due to the fact that reduction of the deformation parameters to a defined average elastic modulus cannot reflect a real physical phenomenon of deformation in a heterogeneous system, although it allows evaluating its deformed state in the engineering calculation [9].

Therefore, in order to solve the problem, a finite-element model of the geotechnical system "soil base – micropile" is developed using real geometric parameters of the strip foundation [5], the elastic moduli of the soil base and the soil-cement material of the micropile, and the possibility of comparing the obtained values of the deformed state with analytical indicators. In the finite-element model, the presented foundation that is analytically considered in [5], has a width of 1.6 m and a thickness of 0.4 m (figure 1).

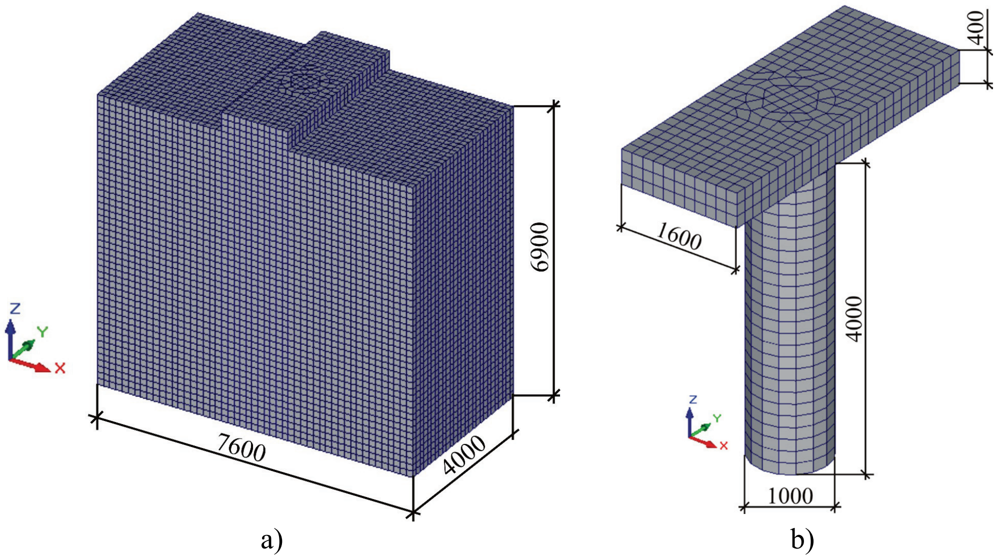

Figure 1. The finite-element model of the geotechnical system "soil base – micropile" with the strip foundation: a) a general view; b) a fragment of the model – foundation with the micropile.

The model of the finite-element method implemented in the SCAD complex [10] (license number F755B84 (KMBKB RA 4810)), has 68849 nodes, 64233 finite elements (approximately 193000 degrees of freedom, a task of high dimension). If possible of varying the system properties, the models have the following deformation characteristics: the foundation of reinforced concrete has a specific density of γ_f = 2.45 t/m^3, elastic modulus E_f = 3.25·10^4 MPa and Poison's ratio μ_f = 0.2; the soil base has a specific density of γ_s = 2.0 t/m^3, Poison's ratio μ_s = 0.3 and variation of elastic modulus: 1) E_s = 5 MPa; 2) E_s = 10 MPa; 3) E_s = 15 MPa; 4) E_s = 20 MPa. The base is fixed with the micropile with a length of 4.0 m and the diameter of 1.0 m, created on the basis of drilling and mixing technology, with a specific density of γ_{mp} = 2.05 t/m^3, Poison's ratio μ_{mp} = 0.3 and variation of elastic modulus: 1) E_{mp} = 30 MPa; 2) E_{mp} = 60 MPa; 3) E_{mp} = 90 MPa; 4) E_{mp} = 120 MPa. Value 316.83 kN/m was taken as a load of the model.

Vertical displacement of unreinforced foundation s = 1.6 cm is analytically calculated by the formula [6, 10]:

$$s = \beta \sum_{i=1}^{n} \frac{\left(\sigma_{zp,i} - \sigma_{z\gamma,i}\right) h_i}{E_i}, \tag{2}$$

where β is dimensionless coefficient equal to 0.8; $\sigma_{zp,i}$ is a mean value of vertical normal stress (MPa) from the external load in the i-th soil layer on the vertical line passing through the center of the foundation bed; h_i is a thickness of the i-th soil layer (m), it is taken no more than 0.4 in width of the foundation; n is a number of layers, into which the compressible base strata is divided; $\sigma_{z\gamma,i}$ is the mean value of the vertical stress from the own weight of soil (MPa), excavated from the foundation pit, in the i-th soil layer on the vertical line, passing through the center of the bottom, at depth z (m) from the foundation bed; E is a deformation modulus of the i-th soil layer by the primary load branch (MPa).

The results of the deformed state obtained during the numerical analysis were compared with an analytical calculation which was accepted as the test.

3. Results and discussion

A comparison of vertical displacement s = 1.6 cm obtained from an analytical calculation with the result of a numerical analysis of the design case for the unreinforced foundation with the elastic modulus of the soil base E_s = 20 MPa has been performed before analyzing the values of the deformed state for a wide range of the elastic modulus of the micropile material and the soil base. The vertical displacement is s = 1.69 cm, which indicates an error of 5.32 % and proves that conducted numerical calculations have a high degree of accuracy of the results.

The scope of this scientific work does not allow providing all isolines and isofields of the deformed state that were obtained during the calculation of twenty finite-element models characterized by a change of the elastic modulus of the micropile material and the soil base. Therefore, the characteristic isolines and isofields of vertical displacements s (mm) in some finite-element models are given below, and only this component is provided since the horizontal one is not characteristic. This is explained by the fact that in cases under consideration, vertical deformations of the geotechnical system "soil base – micropile" are more influential and characteristic in the case of the vertical load on the symmetric structure of the foundation.

In order to understand the nature of deformation in the geotechnical system "soil base – micropile" it is sufficient to consider a quality distribution pattern of the vertical component for displacements (figure 2). Maximum displacements from all design cases are available for the case of the unreinforced weak (E_s = 5 MPa) soil base (s = 6.78 cm, figure 2, a).

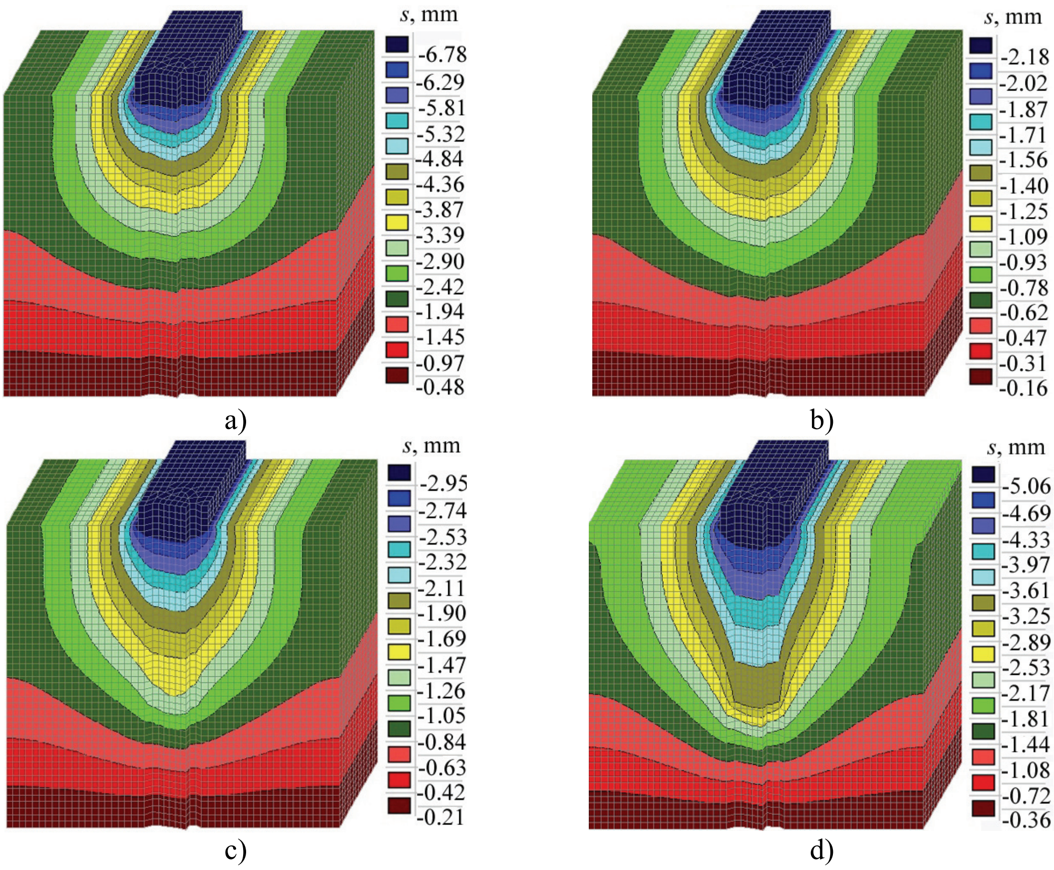

Figure 2. Characteristic isolines and isofields of vertical displacements s (mm) in finite-element models: a) unsupported by micropiles, E_s = 5 MPa; b) E_{mp} = 30 MPa, E_s = 15 MPa; c) E_{mp} = 60 MPa, E_s = 10 MPa; d) E_{mp} = 90 MPa, E_s = 5 MPa.

Their distribution is classical for rigid strip-type foundations with a significant flexibility index according to the formula of Gorbunov-Posadov and represents the core (zone) of the active compression. With increasing the soil elastic modulus by three times and the presence of micropiles with a minimum elastic modulus E_{mp} = 30 MPa, (figure 2, b) there is already sharpening of the core under the foundation, which is even more characteristic for the case of increasing the elastic modulus of soil-cement and decreasing the elasticity of the soil base (figure 2, c and d).

Exactly the deformation feature in the geotechnical system "soil base – micropile", which is defined and clearly noted by the qualitative analysis of the results, indicates that the combination of elastic moduli of the micropile and the soil base maximally affects the core change of compression. But, comparing polar design cases (figure 2, a and figure 2, d), it can be concluded that for weak soils there is no clear decrease of vertical displacements when increasing the elastic modulus of the micropile. There is no doubt that decrease of displacements by 1.33 times, typical for these cases, is a positive effect that can be leveled by technological costs, since increasing the elastic modulus of the soil-cement micropile, created on the basis of drilling and mixing technology, requires additional costs of cement and additives to it. The regularity of vertical displacements from the elastic modulus of the soil base (figure 3) is approximated for each curve by trend (power law dependence).

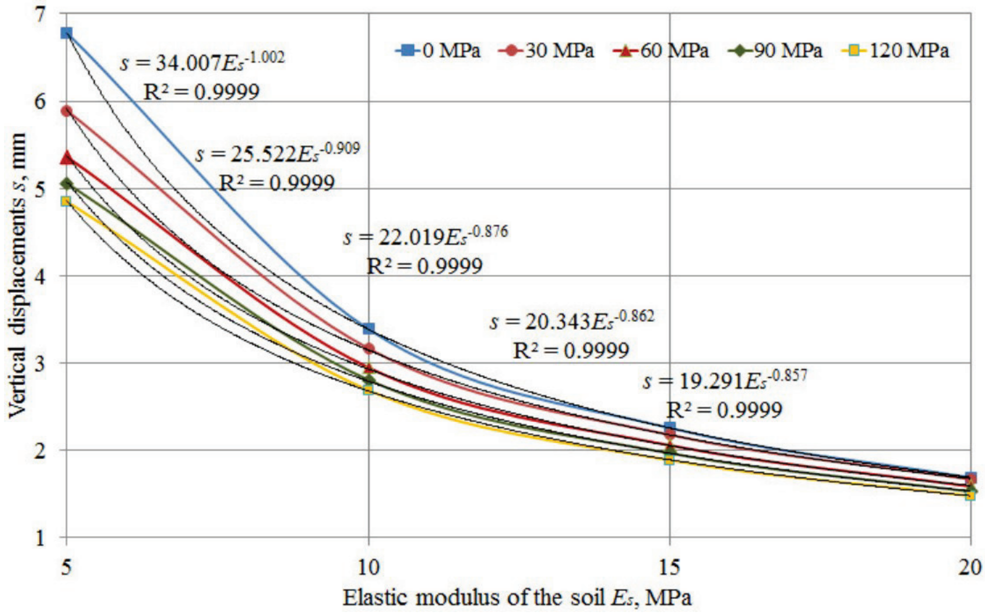

Figure 3. The regularity of vertical displacements from the elastic modulus of the soil base.

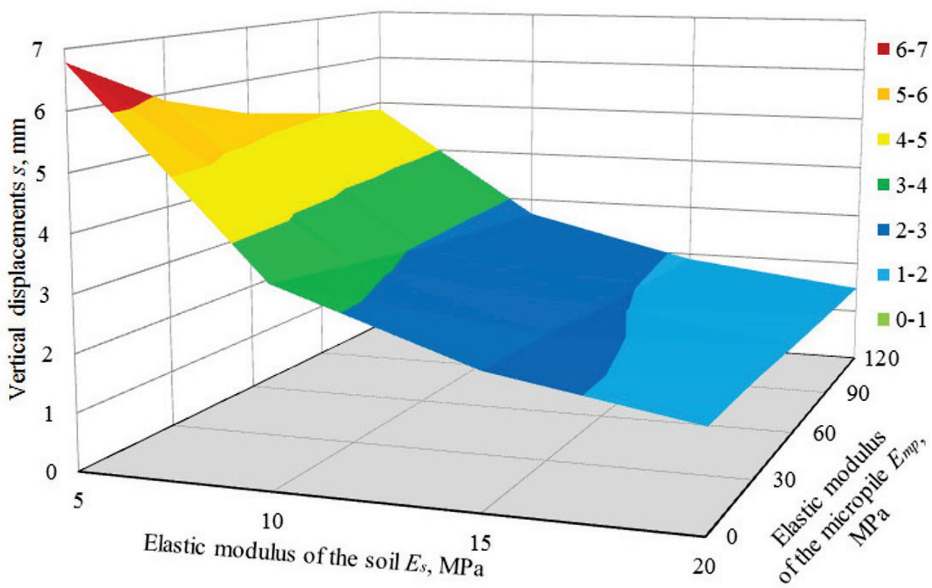

Figure 4. The regularity of vertical displacements from the elastic modulus of the soil base and the micropile.

All trend equations take the form $s = aE_s^{-b}$ and have a high degree of approximation ($R^2 = 0.9999$), which demonstrates their almost functional aspect. Already obtained regularities from figure 3, provide an opportunity to predict a deformed state for a sufficiently wide range of elastic modulus of elements in the soil base, but for the sake of clarity, a space diagram for the regularity of vertical displacements from the elastic modulus of the soil base and the micropile is constructed (figure 4).

The provided surface of vertical displacements, which is the regularity from the elastic modulus of the soil base and the micropile, characterizes the space of the deformed state of this component. Practically, it can be used to predict vertical displacements of the geotechnical system "soil base – micropile" by setting specific values of elastic modulus and receiving predictive values of the deformed state.

4. Conclusions

The obtained regularities of the deformed state in the geotechnical system "soil base – micropile" allow with a high degree of adequacy predicting a deformed state for strengthening weak soil bases with micropiles.

In addition, the results obtained during the numerical analysis prove that the impact of increasing the elastic modulus of the micropile for weak bases ($E_s = 5…10$ MPa) is not a determining factor. Further research, with regard to the obtained results, will be carried out for cases of varying geometric parameters of micropiles created on the basis of drilling and mixing technology.

References

[1] Voloshyn O and Riabtsev O 2019 Some important aspects of rock mechanics and geomechanics *Int. Conf. Essays of Mining Science and Practice* **109** 00114

[2] Bulychev N S 1994 *Mekhanika Podzemnykh Sooruzheniy* (Moskva: Nedra)

[3] Baklashov I V and Kartoziya B A 1984 *Mekhanika Podzemnykh Sooruzheniy i Konstruktsii Krepey* (Moskva: Nedra)

[4] Shvets V B, Shapoval V G, Petrenko V D, Andreyev V S, Selikhova T A and Tiutkin A L 2008 *Fundamenty Promyshlennykh, Grazhdanskikh i Transportnykh Sooruzheniy na Sloistykh Gruntovykh Osnovaniyakh* (Dnepropetrovsk: Nova ideolohiia)

[5] Dubinchyk O, Bannikov D, Kildieiev V, Kharchenko V 2020 Geotechnical analysis of optimal parameters for foundations interacting with loess area *II Int. Conf. Essays of Mining Science and Practice* **168** 00024

[6] Tiutkin O, Keršys R and Neduzha L 2020 Research of the strained state in the "subgrade – base" system at the variation of deformation parameters *Transport Means 2020. Sustainability: Research and Solutions. Proc. of 24rd International Scientific Conference* **I** 446–51

[7] Croce P, Flora A and Modoni G 2014 *Jet Grouting: Technology, Design and Control* (New-York: Taylor & Francis Group)

[8] Musiienko S, Palamarchuk T, Prokhorets L and Kurinnyi V 2020 Scientific and technical aspects of grouting of marginal rocks of mine workings *II Int. Conf. Essays of Mining Science and Practice* **168** 00057

[9] DBN V.2.1-10-2009 2009 *Osnovy ta Fundamenty Sporud. Osnovni Polozhennia Proiektuvannia* (Kyiv: Minrehionbud Ukrainy)

[10] Perelmuter A V and Slivker V I 2002 *Raschetnyye Modeli Sooruzheniy i Vozmozhnost ikh Analiza* (Kyiv: Stal)