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Article

Numerical modeling of the interaction of bored micro piles with the substrate

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Abstract. The paper describes the results of a numerical simulation of micro-pile tests using the PLAXIS 2D software package. The purpose of the simulation in this article is to determine the bearing capacity of the micro pile in static tests. Axisymmetric models of a 500 mm wide and 31 m long micro pile were used in the calculation. The staged loading of the pile in the program was simulated by increasing the load on the pile by 145 kN. The main monitored calculation parameters were the magnitude of the applied load and the pile settlement. As a result, load-settlement diagrams were plotted from the pile tests. The bearing capacity of the piles was determined based on a numerical simulation of the pile and the ground in the PLAXIS 2D software package and compared with field data. This geotechnical investigation is important for understanding the soil-structure interaction on difficult and problematical soil ground conditions related to the construction sites.
Keywords: BDSLT, FEM, pile, load, PLAXIS 2D, soil.

1. Introduction

At present, numerical calculation methods, including finite element methods (FEM), finite difference methods (FD) and boundary element method (BEM) are applied for quantitative estimation of the deflectivity of heterogeneous soil masses interacting with underground structures of buildings and constructions. These methods are based on the joint solution of a system of differential equations of equilibrium, continuity and physical equations. The latter define the dependencies of the ground deformation on the stress state. Currently, there are different methods for describing the physical equations depending on the need to take into account linear, non-linear and rheological properties of soils [1].

The reliability and accuracy of the quantitative assessment of the stresses in the soil masses interacting with the underground part of the building largely depend on the choice of the geomechanical model of the massif and the design models of the soils comprising the massif in question [2].

It should be noted that the idea of limiting the computational domain in applied soil mechanics arose in the middle of the last century due to inconsistency of settlement results of foundations of structures considered by the elastic half-space model. Known are the models of N.A. Tsytovich, K.E. Egorov and others, limiting the thickness of compressible layer. There is known also the modern model limiting a computational domain both in depth and in width on the basis of which the analytical solution of a deflected mode of operation of such domain under the action of local loading in plane and spatial statement is received. Such limitation of calculation domain is caused by structural properties of strength and deformability of soils under volumetric changes and shape changes.

In order to describe the mechanical behaviour of media soils, it is possible to use several soil models in FEM [2–4]:

– linear model;
– non-linear elastic;
– Mora-Coulomb plastic model;
– The non-linear elastic-plastic Cam-glue model and the Cam-glue modification models;
– A non-linear elastic-plastic model of a Hardening soil.

The two-dimensional simulation of a bored micro pile is performed in the axisymmetric formulation of the problem, in which the pile is placed around the axis of symmetry, since in the axisymmetric formulation the lateral pressure must be the same [5–7].

The physical nature of FEM allows us to consider the "soils - pile foundation» system together. The stiffness of the foundation is defined by the description of its geometric dimensions, strength and deformation characteristics. Parameters of modelling of soil and pile foundation materials are given in Table 1.

Table 1 – Material properties of soil layers and piles

Parameters	Designation	Clay sand (brown) (EGE-1)	Silted sand (EGE-2)	Clay sand (red) (EGE-3)	Deep sand (EGE-5)	Clay sand (EGE-4)	Pile model
Material model	-	Coulomb-Mora	Coulomb-Mora	Coulomb-Mora	Coulomb-Mora	Coulomb-Mora	Linear-elastic
Ground behaviour	-	Drained	Drained	Drained	Drained	Drained	Non-porous
Weight in an unsaturated state	γ_{unsat}	16,7	18,8	19,8	17,6	17,0	24,0
Weight in water-saturated state	γ_{sat}	16,7	18,8	19,8	20,0	19,0	-
Young's module	E	9150	13000	13500	19000	20000	30000000
Poisson's ratio	v	0,3	0,3	0,3	0,3	0,33	0,3
Clutch	c	13	12	14	17	8	-
Angle of friction	φ	26	23	23	23	29	-

The geometric dimensions of the 500 mm wide and 31 m long pile model were used in the calculation.

A 15-node finite element mesh was automatically generated by Plaxis. In order to obtain a qualitative picture in the areas near the pile the finite element mesh was chopped up. After the element mesh was generated, the initial stress state from the self-weight of the soil was modelled. All displacements obtained during the initial stress-strain modelling phase were zeroed out before the probe plunge began. The calculation was carried out using a variable mesh with the Update Mesh option, implying the use of the so-called Updated Lagrange, where the finite element mesh is continuously updated during the calculation process [8].

The version of Plaxis used allows only a linear colour scale. Because of this, due to the large difference between the minimum and maximum shear strains, it turned out to be impossible to display them simultaneously in the same figure [9-10].

The calculations were carried out according to the finite element diagram shown in Figure 1.

Due to the symmetry of the pile foundation cross-section relative to the vertical axis, only half of the soil mass and pile foundation area were considered in the computational scheme and were automatically divided into triangular finite elements. The number of considered element types (layers) is 5 (the sequence of soil layers is shown in Figure 1).

The 31 m long piles were tested by means of a variety of simulations (Figure 1):

a) Model 1 – jack is installed inside at a depth of 1/2 pile – 15 m (method of Bi-Directional Static load test);

b) Model 2 – jack is installed inside the pile at a depth of 29 m (method of Bi-Directional Static load test);

c) Model 3 – jack is mounted on the pile head (method of Top down).

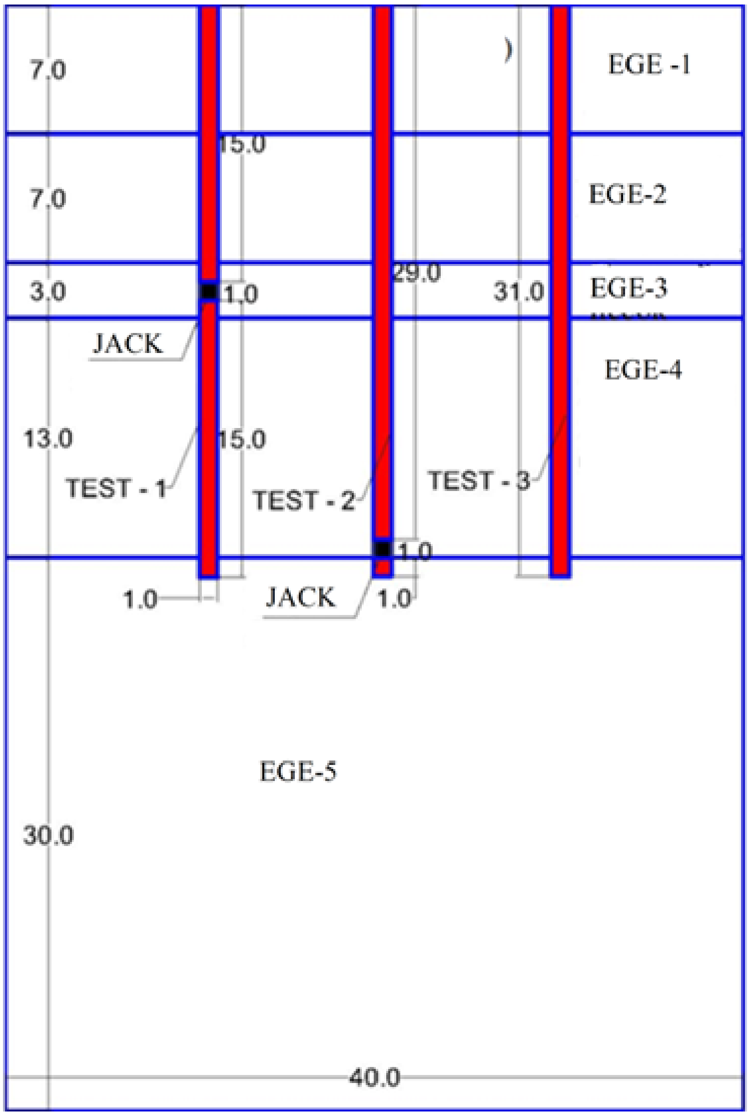


Figure 1 – Layout of the jacking arrangement of the pile or pile

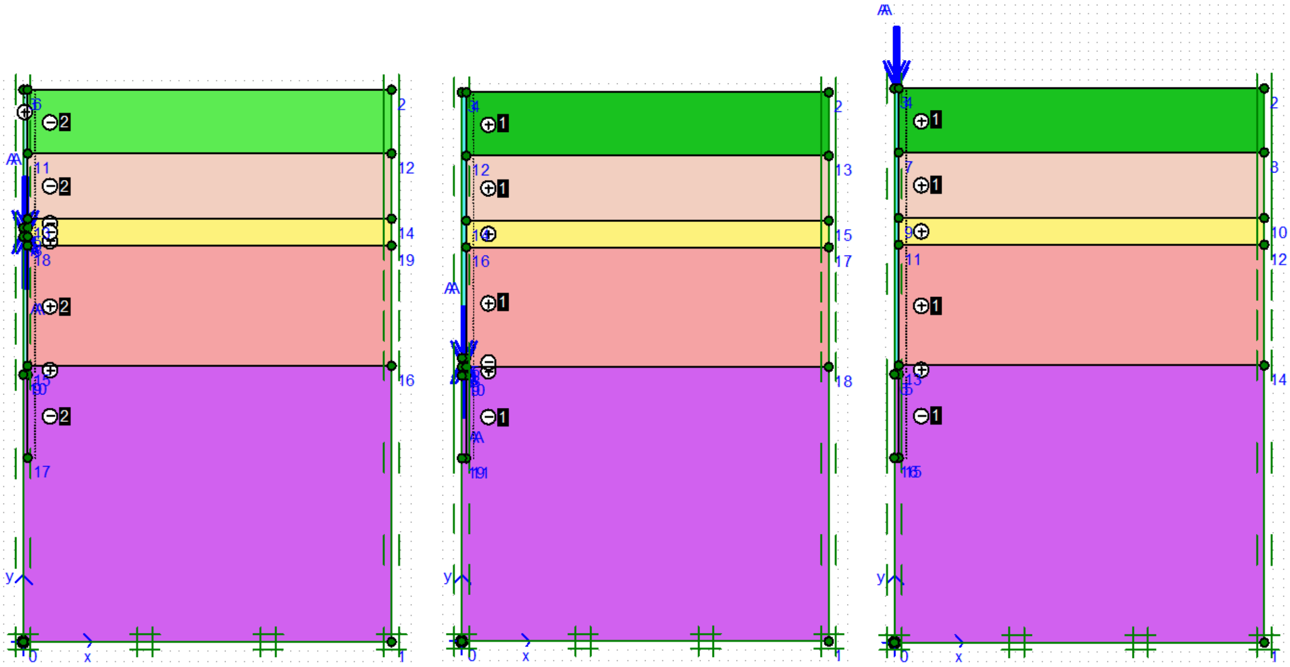
2 Numerical simulation of pile testing of BDSLT and SLT methods (for models 1, 2 and 3)

This chapter deals with the first problem: calculating settlement of a pile foundation. The general methods for creating the geometric model, constructing the finite element mesh, performing the finite element calculation and evaluating the results are discussed in detail [6-11].

The load-bearing capacity of the piles was determined using the results of numerical modelling of the pile in the PLAXIS 2D software package. The stress-strain state of the foundation was calculated using the Moore-Coulomb elastic-plastic model. The calculations were performed in axisymmetric formulation [11–13].

The staged loading of the pile was simulated by increasing the applied load on the pile by 145 kN. The main parameters monitored for the results are the magnitude of the applied load and the pile settlement. As a result of the calculation, load-settlement plots of the pile are plotted [14].

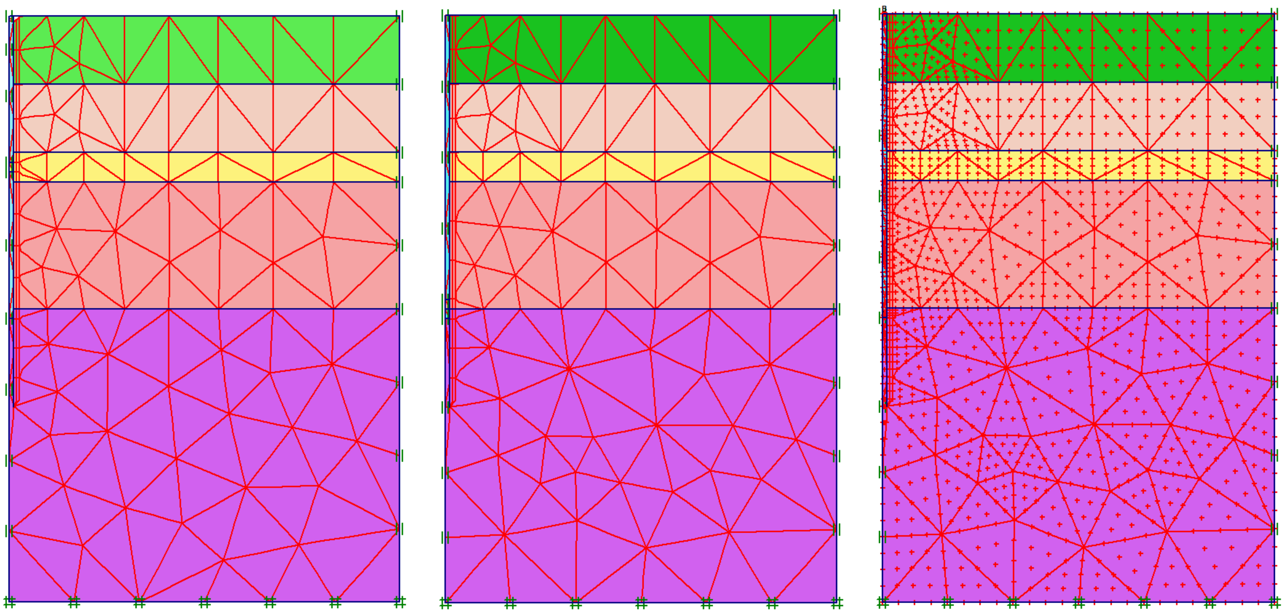
Figure 2a, 2b and 2c show geometric models of a numerical simulation of a bored micro pile, including soil separation within a separately considered geotechnical element, a pile element and a uniformly distributed micro pile load. The dimensions of the geometric model are taken from the condition that the stress distribution will be negligibly small within a given zone [15].



a) Model 1 b) Model 2 c) Model 3

Figure 2 – Geometric model of a bored piles

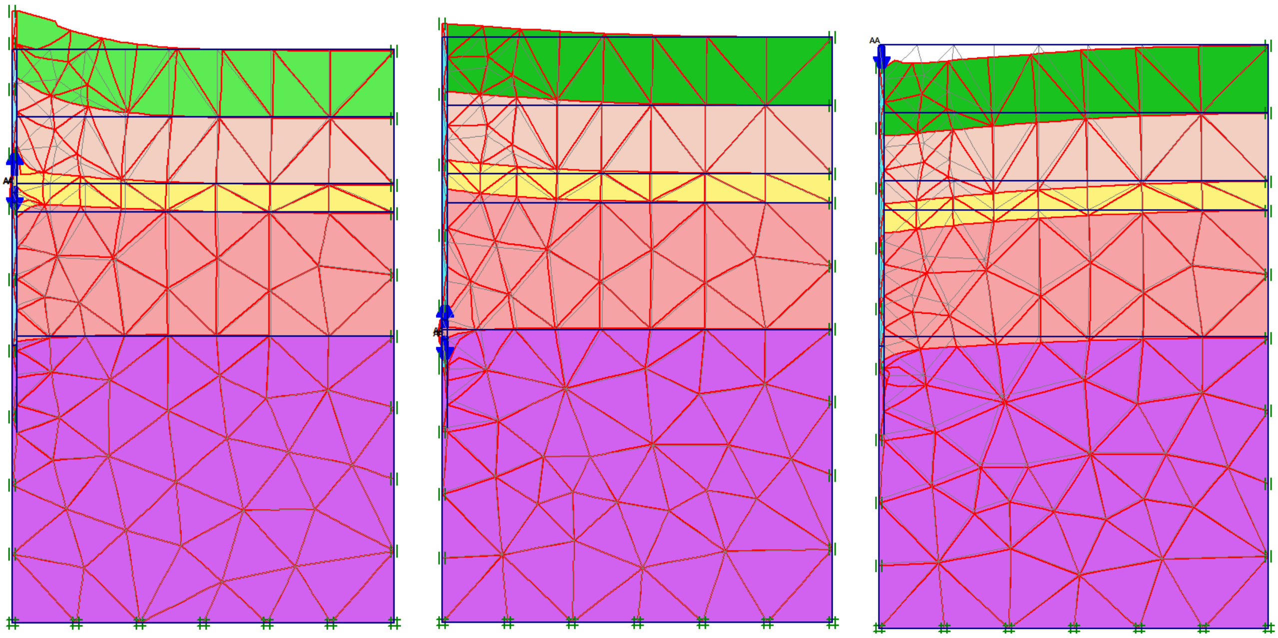
Figure 3 show the finite element meshes generated automatically by the Plaxis software and represent a triangle system. Soil foundations and piles were modeled with 15-node finite elements. The construction method is based on the stable triangulation principle which is used to find the optimum mesh dimensions.



a) Model 1 b) Model 2 c) Model 3

Figure 3 – Finite element grid: a - model 1, b - model 2 and c - model 3, respectively)

The calculation consists of six phases and will be set in Staged construction mode. Figure 4a, 4b and 4c show the deformed pile foundation meshes.



a) Model 1 b) Model 2 c) Model 3

Figure 4 – Finite element mesh deformation

Figures 5, 6, 7 show isolines of total ground motions under static bidirectional and indentation loads for models 1, 2 and 3 respectively.

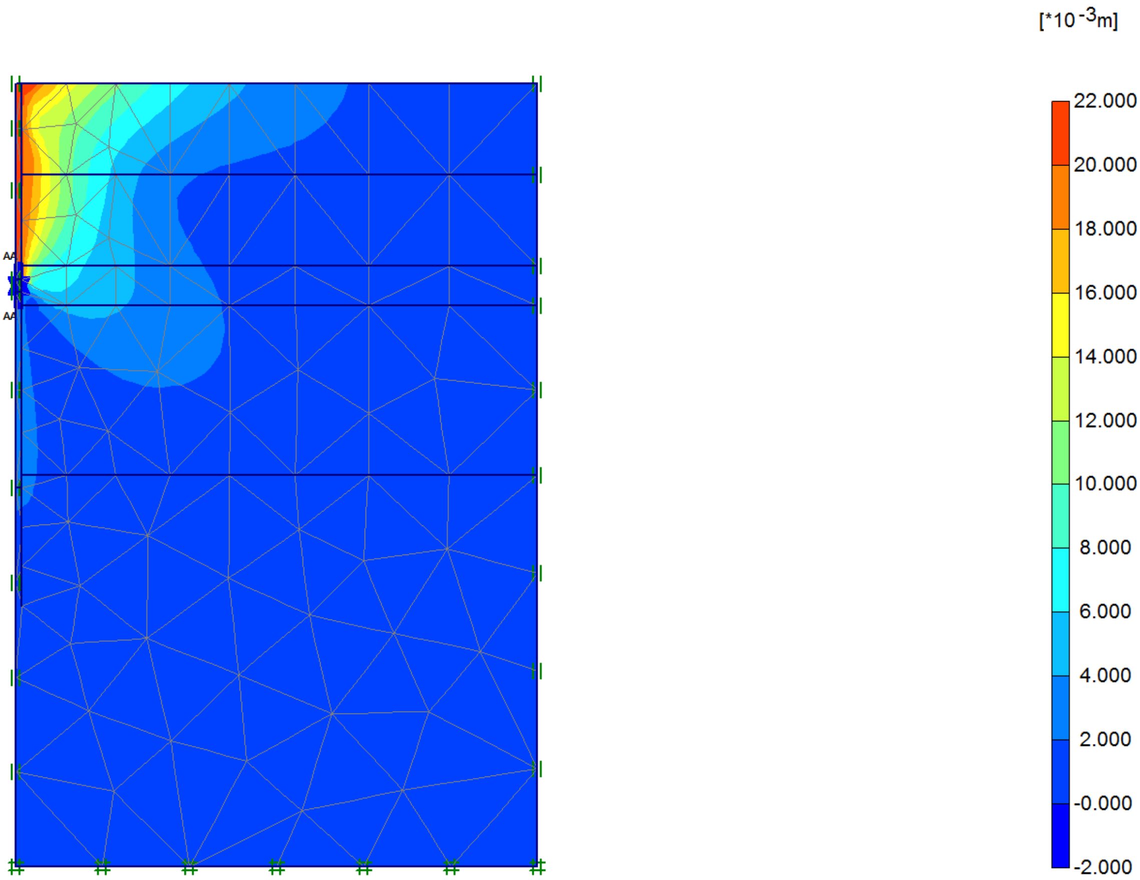


Figure 5 – Total settlement (model 1)

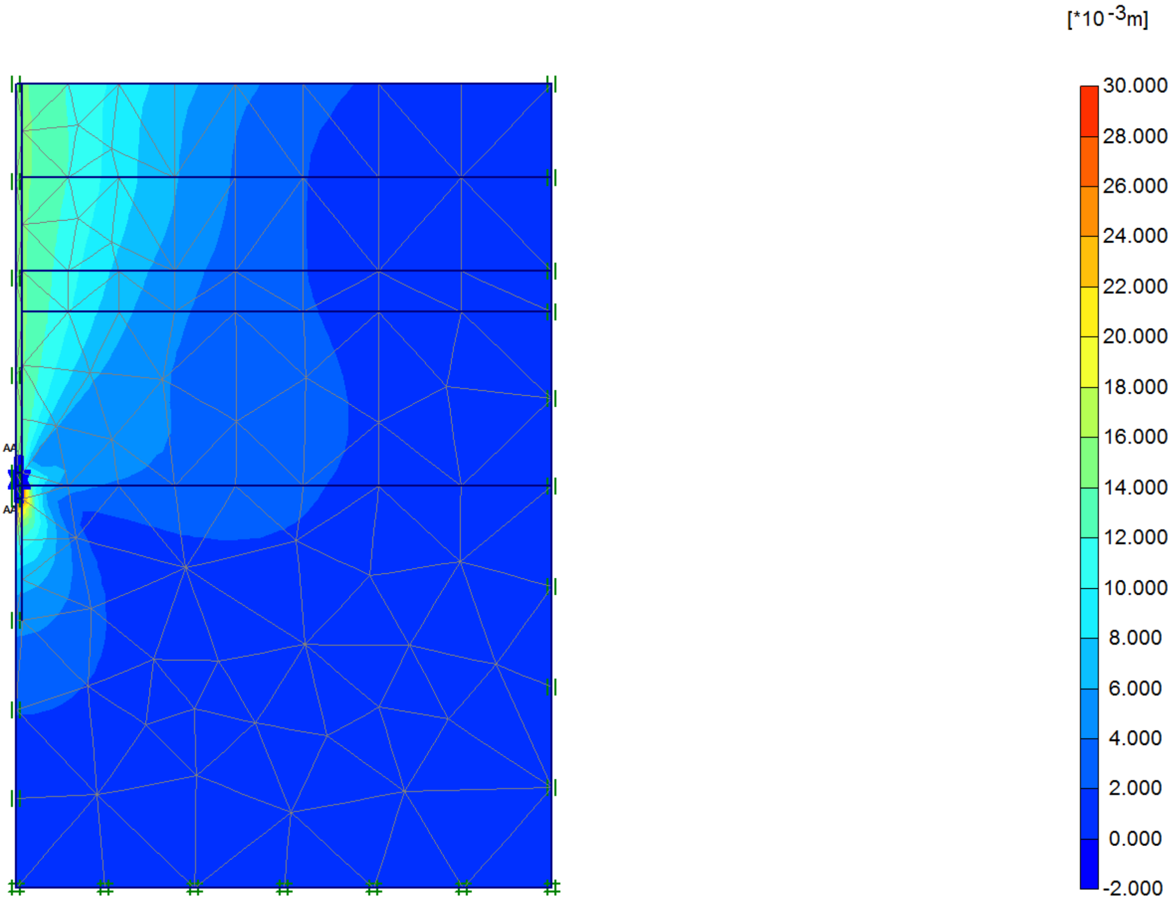


Figure 6 – Total settlement (model 2)

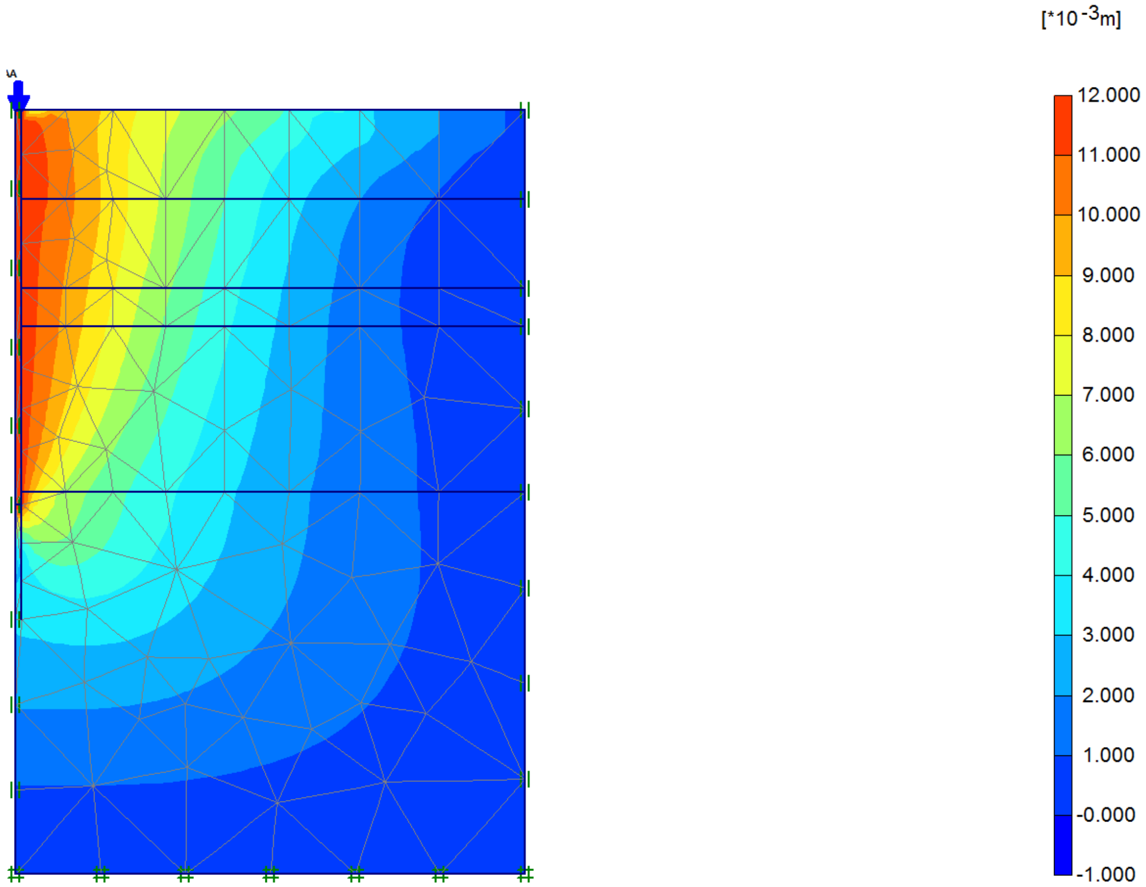


Figure 7 – Total settlement (model 3)

3. Results and Discussion

Based on the calculation results, displacements vs. bi-directional load plots are obtained (Figure 8).

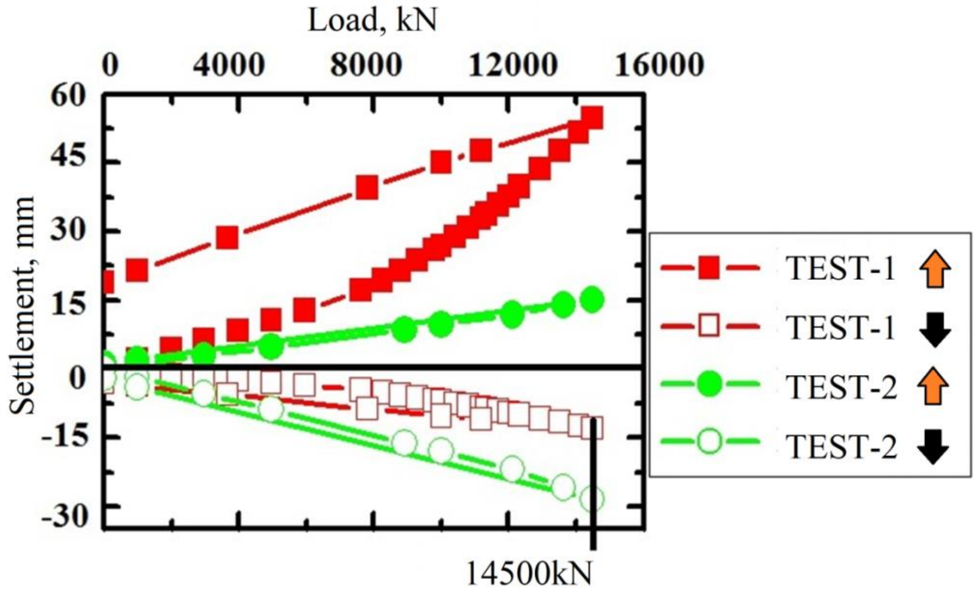


Figure 8 – Load-displacement test results (model 1 and 2, respectively)

Figure 9 shows a comparison of the numerical simulation test results: the load – settlement curve obtained by simulation 3 and the equivalent load – settlement curve of simulation 1 and 2.

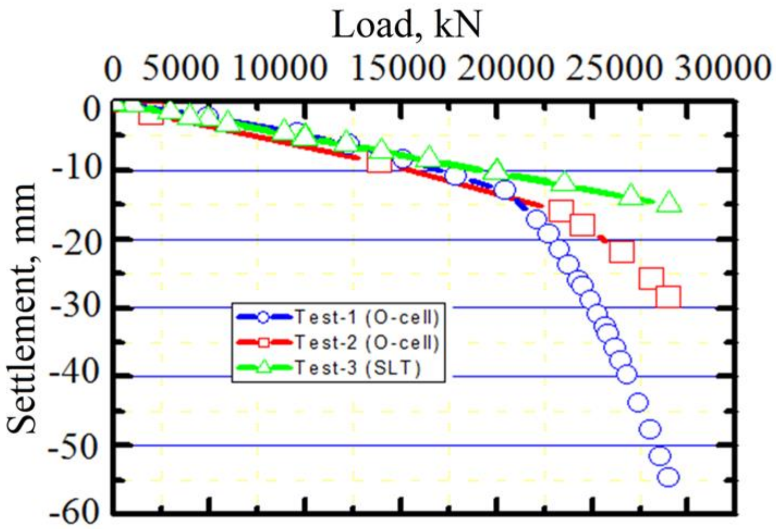


Figure 9 – Equivalent load-settlement curve and SLT test results (model 1, 2 and 3, respectively)

Overlapping of the curves showed that the convergence of the graphs is observed only in the initial stage of loading, further on the O-cell curve trajectory changes, which is characteristic of the creeping stage of ground resistance, whereas the SLT curve (in this stage of loading) is more characteristic of the elastic ground resistance.

Based on the results of the model 1 test, it was found that for a given load it was necessary to increase the jacking depth in the pile because the top test element had the lowest resistance on the side of the pile and consequently the actual ground load-bearing capacity of the pile was not determined.

Based on the results of model 2 testing, it was found that the given load and jacking depth in the pile meet the ground bearing capacity requirements of the pile. In this model it is possible to increase the jacking load until the pile reaches its full ground bearing capacity.

According to the results of the Model 3 test, the load is transferred from the jack to the pile body, and large stresses occur in the pile body. As can be seen in Figure 7, when the pile model is moved vertically, the highest stress is observed on the lateral surface and the lowest on the lower end of the pile, which is an indication of unequal load distribution.

4. Conclusions

1. The analysis of using axisymmetrical problem in elastoplastic statement by the finite element method for investigation of behaviour of the pile-to-base system has shown the expediency of using FEM implemented by the "Plaxis" software.

2. When testing the pile with hydraulic jacks and when segmenting it, special attention must be paid to studying the geotechnical structure of the soil mass at the site under investigation.

3. During the survey it is particularly important to identify possible zones of heterogeneity in the geological structure of the soils, such as areas of weathering, alternating soil layers, etc. These data have to be taken into account when testing with hydraulic jacks and dividing the pile into segments to obtain accurate design characteristics for a given soil layer.

4. When testing the soil with piles, in order to assess as accurately as possible the lateral friction and bearing capacity under the bottom end of the pile, a sound programme of load-bearing layer studies using laboratory and field tests as well as analysis of existing construction experience in these and similar soil conditions must be carried out.

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