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Reliability-based assessment of drilled displacement (DDS) piles bearing capacity using field tests and FEM

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ABSTRACT: The article deals with geotechnical design of pile foundations, especially by static load tests and by calculation using numerical models. The results of comparison analysis of bearing capacities drilling displacement system (DDS) boring piles obtained by static load tests and by standard are presented in article, as well as results of compression test of surrounding soil after DDS pile installation. Drilled Displacement System (DDS) piles are an innovative technology for pile foundations. These DDS piles are created by rotary drilling with a simultaneous full displacement of the soil in a horizontal direction. The optimal design of DDS piles can be obtained in soils that allow for a horizontal displacement, which causes an increase in the shaft's resistance. Significant differences between experimental (Static Load Test by GOST) and design (by Kazakhstan Standards) values of bearing capacity of DDS pile show us incomplete usage of DDS technology resourced. The results of numerical analysis of DDS and traditional boring pile modeling by FEM (Plaxis 2D) are also presented in the paper. The numerical results have been presented with equivalent static load-settlement curve. By results of numerical analysis coefficient of surrounding work is defined. These investigations are important for un-derstanding of soil-pile interaction on problematical soft soils ground of Astana, Kazakhstan.

Keywords: DDS, bored piles, FEM, bearing capacity

1 INTRODUCTION

Pile foundations are one of the most popular types of foundations on construction sites in Kazakhstan, the expediency of using which is explained by the need to provide a large load-bearing capacity of high-rise buildings and structures. Due to the emergence of new technologies and equipment for the construction of pile foundations, designers have a need to improve the current regulatory documents, which, unfortunately, do not have recommendations for the design of piles arranged according to modern technologies [1]. In this article, the work of a bored pile arranged by the DDS method without excavation was investigated. This technology is one of the latest products of German manufacturers and is undoubtedly of practical interest for modern construction in Kazakhstan. The main advantages of this technology are: high productivity of pile production; high economic efficiency; low noise and no vibration when installing piles; and most importantly, high load-bearing capacity of the pile [2,3]. Large differences between experimental (static tests) and calculated (normative) values of the bearing

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capacity of bored piles arranged by the rolling method indicate that the resources of this technology are not fully used. The large values of the bearing capacity of the piles are explained by the fact that when the pile is installed, the excavation does not occur, the soil is radially displaced by the rolling of the drilling tool, thereby, as a result of compaction, there is a change in the strength and deformation characteristics of the soil around the pile. Thus, it becomes obvious that the work of displacement piles is different from the work of a traditional pile, and there are still many unresolved issues concerning this technology: the impact of displacement technology on the bearing capacity of piles; the effect of radial compaction of the surrounding array on the work of piles; the impact of displacement piles on the foundations of adjacent buildings and structures, etc.

2 FEATURES OF DDS TECHNOLOGY

The sequence of work on the installation of drilling piles manufactured using DDS technology includes the following operations (Figure 1): installation of drilling equipment at the drilling site; immersion of the drilling tool with a sealing system to the design mark; connection of the concrete pump followed by filling the well with concrete mixture and one-time extraction of the drilling tool; immersion in the well with concrete reinforcement frame to the design mark.

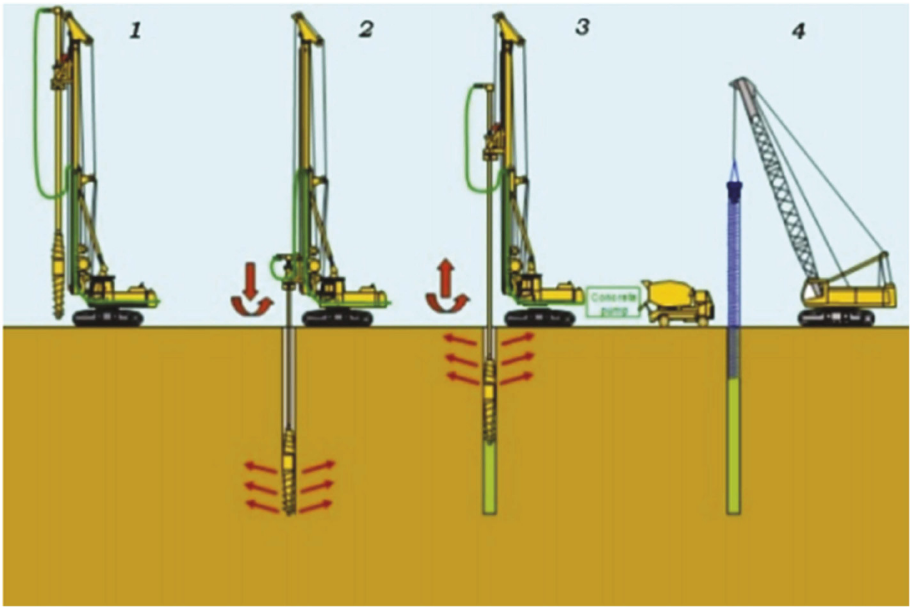

Figure 1. DDS pile devices.

A distinctive feature of the DDS technology is the drilling tool (Figure 2). When drilling the drilling tool down, simultaneously with drilling, the well is rolled out, as a result of which the radial compaction of the soil occurs without its excavation, when drilling up, the walls are compacted.

This technology allows you to arrange piles with a diameter of up to 0.6 m to a depth of up to 30 m. When calculating the productivity, the following parameters should be taken into account: the diameter of the pile, the amount of applied torque and pressing force, density (strength of the soil, compaction of the soil, power of the concrete pump [4].

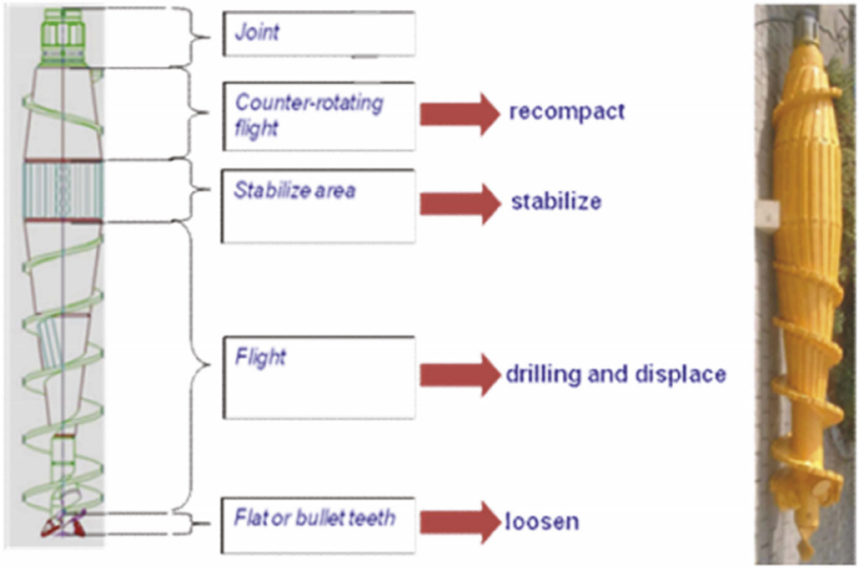

Figure 2. DDS pile drilling Auger.

3 STATIC TESTING OF DDS PILES

In order to clearly demonstrate the differences between the actual and design values of the bearing capacity, static tests of DDS piles were carried out. In total, 14 DDS piles were tested at two construction sites. At the first construction site "Khan Shatyry Shopping and Entertainment Center" 11 piles were tested, 8 of which with a diameter of 410mm, 18m long, 2 piles with a diameter of 500mm, 10m long and 1 pile with a diameter of 600m, 18m long. At the second construction site

"Production base of "KGS" LLP" three piles with a diameter of 500 mm and a length of 2.5m were tested. According to engineering and geological surveys, the geological structure of the survey site is attended by: IGE2 - alluvial medium-odd-quaternary deposits, presented in the form of alternating layers of clay, IGE3 - loamy and loamy–sandy soils, as well as IGE4 - medium-quaternary deposits, presented in the form of clay and loamy deposits [5].

The load on the pile was applied in steps of 400kN and 200kN to the limit of 2800kN with a CM- 158 hydraulic jack. The hydraulic jack force is regulated by the fluid supply from the pumping station and is fixed by a technical pressure gauge. The movement of the pile is measured by deflection meters with an accuracy class 0.01 mm, which are fixed on a reference system fixed to the ground. The reference system is independent of the movement of the system of beams and piles. Unloading was carried out in steps of 800kN and 400kN. For the criterion of the maximum permissible precipitation, the instructions regulated in the SNIP of the Republic of Kazakhstan were adopted 5.01-03-2002 - Pile foundations [6]. For the particular value of the maximum resistance of the pile Fu to the pressing load, the load should be taken, under the influence of which the tested pile will receive a draft equal to S and determined by Formula 1:

$$S_{\mathrm{max.Sett.}} = \zeta S_{u,mt} \tag{1}$$

$S_{u,mt}$ - the limit value of the average precipitation of the foundation of the projected building or structure, for industrial and civil single-storey and multi-storey buildings with a full frame is assumed to be 8 cm (for reinforced concrete structures) according to the instructions SNiP RK 5.01-01-2002 [7];

ζ- conversion coefficient from the limiting value of the average foundation settlement of the building or structure $S_{u,mt}$ to the pile settlement obtained during static tests with conditional stabilization (attenuation) of settlement is taken equal to 0.2 according to guidelines.

4 COMPARISON OF EXPERIMENTAL AND CALCULATED VALUES OF BEARING CAPACITIES OF DDS PILES

The experimental and calculated (according to the standards) values of the bearing capacities of DDS piles are presented in Table 1. It can be seen from the table that there is a significant difference between the experimental and calculated values of bearing capacities.

Table 1. Comparison of partial values of load-bearing capacities.

№	Geometric dimensions of the pile	Number of piles	Bearing capacity, kN		k = F_u/F_d coefficients
			Experimene al F_u	Calculated F_d	
	L = 17 m d = 410 mm	№1	2280	1545	1,48
		№2	2150	1545	1,39
		№3	2325	1545	1,50
		№4	2475	1545	1,60
		№5	2200	1545	1,42
		№6	2080	1545	1,35
		№7	2190	1545	1,42
	L = 17 m d = 600 mm		2700	2110	1,28
	L = 2 m d = 500 mm	№1	470	272	1,73
		№2	490	272	1,80
		№3	460	272	1,69

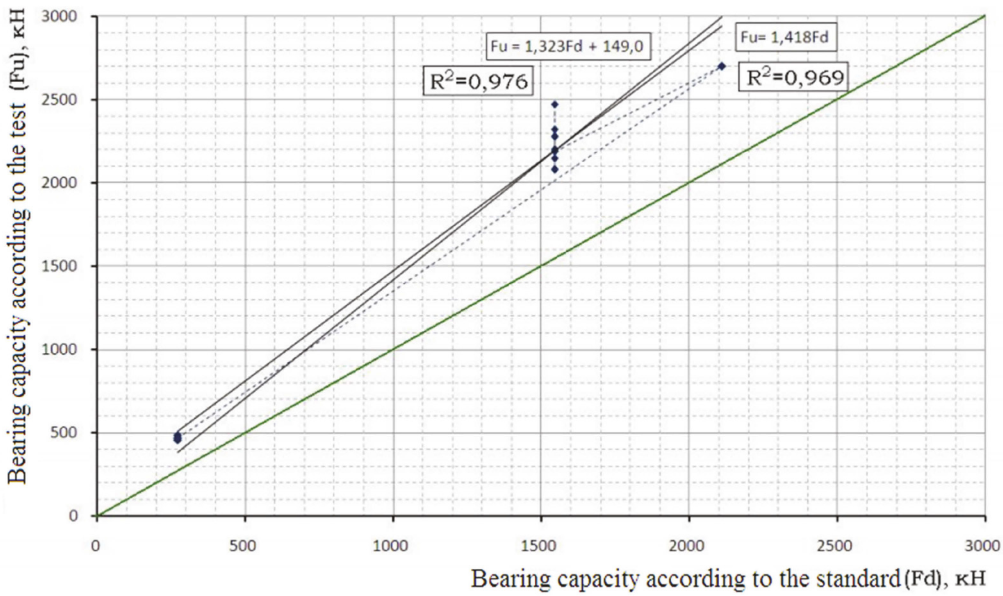

Figure 3. Comparative diagram of experimental F_u and calculated F_d bearing capacities of DDS piles [8].

A comparative diagram of experimental F_uu and calculated $F_d$bearing capacities of DDS piles is shown in Figure 3. As can be seen from the comparative diagram, all points are located above the diagonal, which indicates that all values of experimental bearing capacities are greater than the values of bearing capacities defined by standards.

5 LABORATORY TESTS OF SOIL COMPACTED AROUND THE PILE

The purpose of the laboratory study of the soil mass near the pile is to determine the effect of radial compaction on the physical and mechanical properties of the soil. To study the physical and mechanical properties, soil samples were taken before and after the installation of DDS piles at the construction site of the Khan-Shatyry Shopping and Entertainment Complex in Astana, where DDS piles of various diameters were used (previously mentioned). Soil samples for laboratory studies were selected after static tests of DDS piles at a distance of up to 0.1, 0.2, 0.4, 0.6, 08 and 1 m from the edge of the pile, in order to determine the soil compaction zone along the lateral surface of the pile. More than 30 test wells were drilled with a depth of up to 10 m with an interval of 0.5 m in depth. The distances between the wells were 0.2--1.2 m depending on the distance from the pile. Laboratory tests were carried out in accordance with GOST 12248-96 [9].

The test results were subjected to statistical processing, the purpose of which was to determine the zone of radial compaction, as well as to identify elements of randomness (random values), the cause of which may be the difficulty of extracting soil in an undisturbed state or the error of measuring instruments.

According to the test results, the radial sealing zone for IGE2 was 0.6-0.8 m, for IGE3 and IGE4 0.4-0.6 m. The obtained values of the modulus of deformation, the angle of internal friction and adhesion are displayed graphically in Figures 4-6. With the help of nomograms, it is possible to adjust the deformation modulus, the angle of internal friction and adhesion depending on the diameter of the DDS pile at the design stage [10-12].

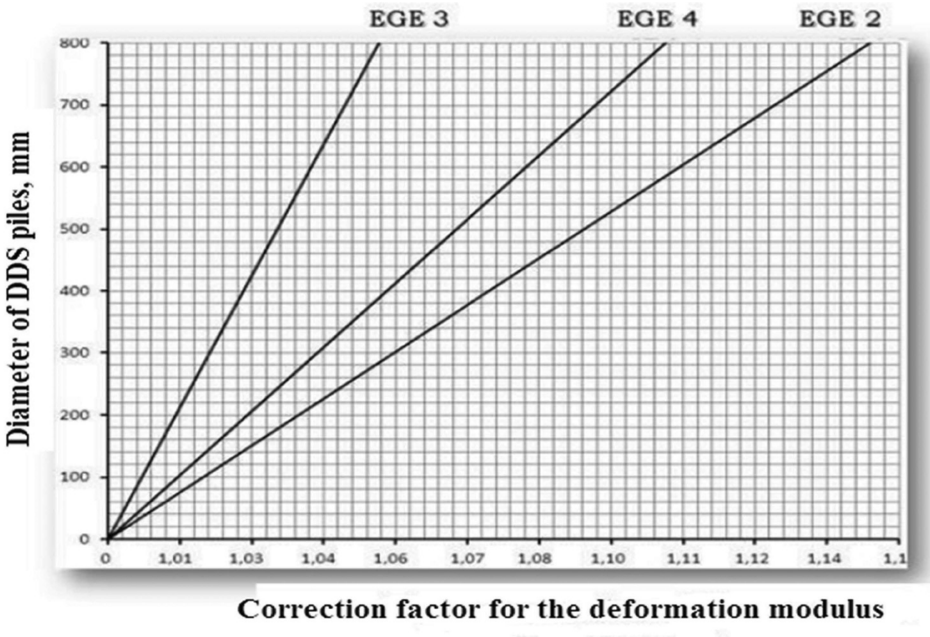

Figure 4. Nomogram for correction of the deformation modulus.

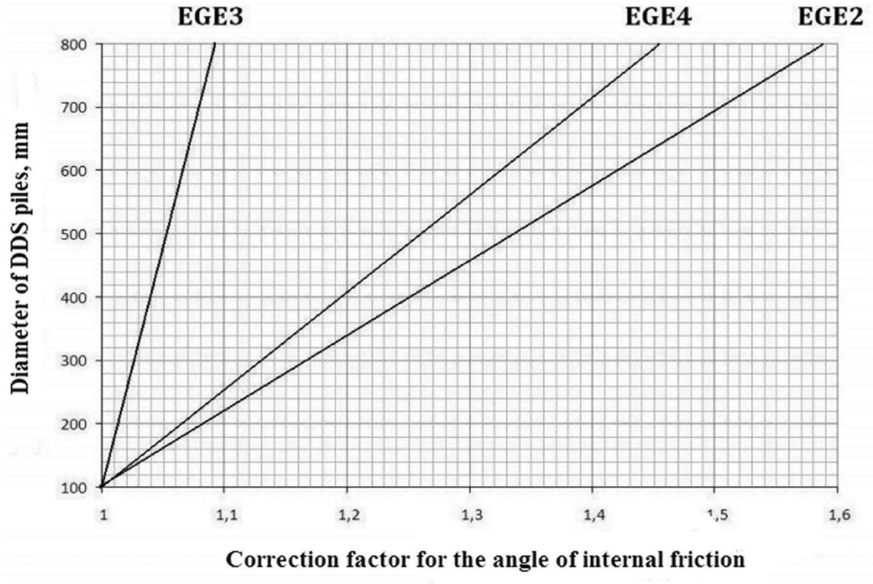

Figure 5. Nomogram for adjusting the angle of internal friction.

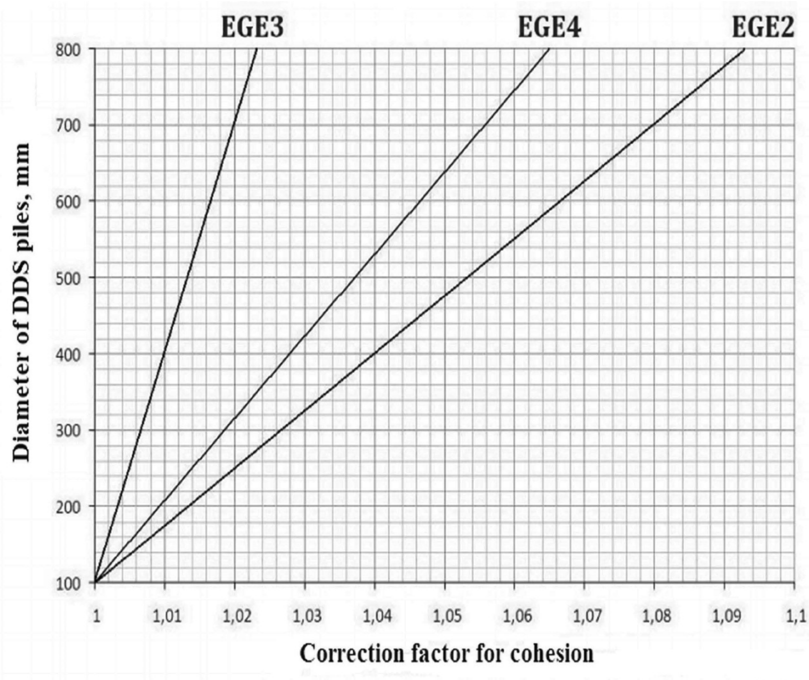

Figure 6. Nomogram for clutch adjustment.

6 NUMERICAL SIMULATION OF DDS PILES

The aim of the study is to determine the effect of soil compaction as a result of its displacement on the bearing capacity of the DDS pile.

Modeling of a bored pile is carried out in an axisymmetric formulation of a two-dimensional model of hardening soil. The dimensions of the geometric model are assumed from the condition that the stress distribution will be negligibly small within a given zone.

Figure 7 shows a geometric model of a bored pile, including the separation of soil within a separately considered engineering-geological element, the pile element and a uniformly distributed load on the pile. The separation of the soil within one IGE implies that the compaction of the soil under the lower end of the pile does not occur, therefore, the cluster located under the lower end of the pile is assigned the parameters obtained from the results of field and laboratory studies of soils before their compaction.

When modeling a DDS pile, the soil cluster located above the end of the pile is given soil parameters determined experimentally after the DDS pile is installed, taking into account the radial compaction zone. Presumably, the bearing capacity of the DDS pile is greater than the bearing capacity of a traditional pile. We introduce the coefficient k, which shows the numerical value of the differences in bearing capacity between DDS piles and traditional piles.

$$k = \frac{F_{d\ (PLX)}^{DDS}}{F_{d(PLX)}^{tr}}\ ,\quad \mathrm{k} \geq 1 \tag{2}$$

where: $F_{d\ (PLX)}^{DDS}$ - calculated soil resistance based on the results of numerical modeling of the DDS pile, kN;

$F_{d(PLX)}^{tr}$ - calculated soil resistance based on the results of numerical modeling of a traditional pile, kN.

Коэффициент условия работы сваи DDS,

it will be determined by formula 4, taking into account the coefficient *k*.

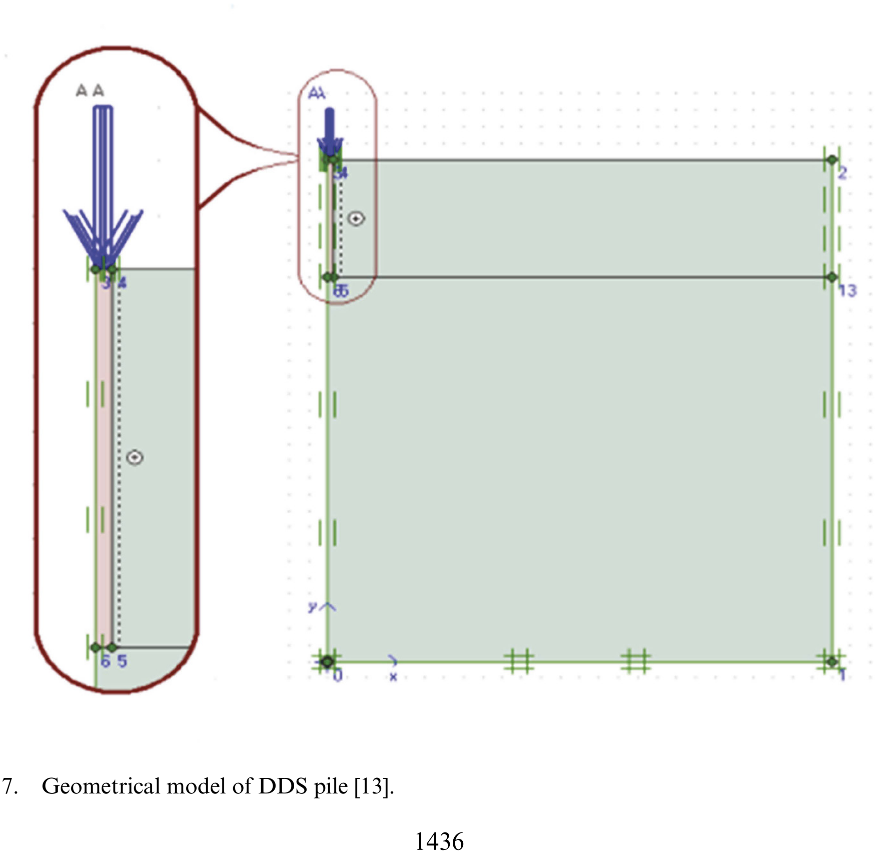

Figure 7. Geometrical model of DDS pile [13].

$$\gamma_{c_f}^{DDS} = \frac{kF_a^{tr} - \gamma_c \gamma_{cr} RA}{u\gamma_c \sum f_i h_i} \tag{3}$$

where: $\gamma_{c_f}^{DDS}$ - coefficient of soil working conditions on the side surface of the pile DDS;
F_a^{tr} - estimated bearing capacity of a traditional pile;
$\gamma_c \gamma_{cr}$ - the same as Formula 2.

To determine the dependence of the bearing capacity of DDS piles and traditional piles, we will construct comparative diagrams showing the ratios of the values of the bearing capacity of traditional piles obtained by numerical modeling to the bearing capacity of DDS piles (Figure 8).

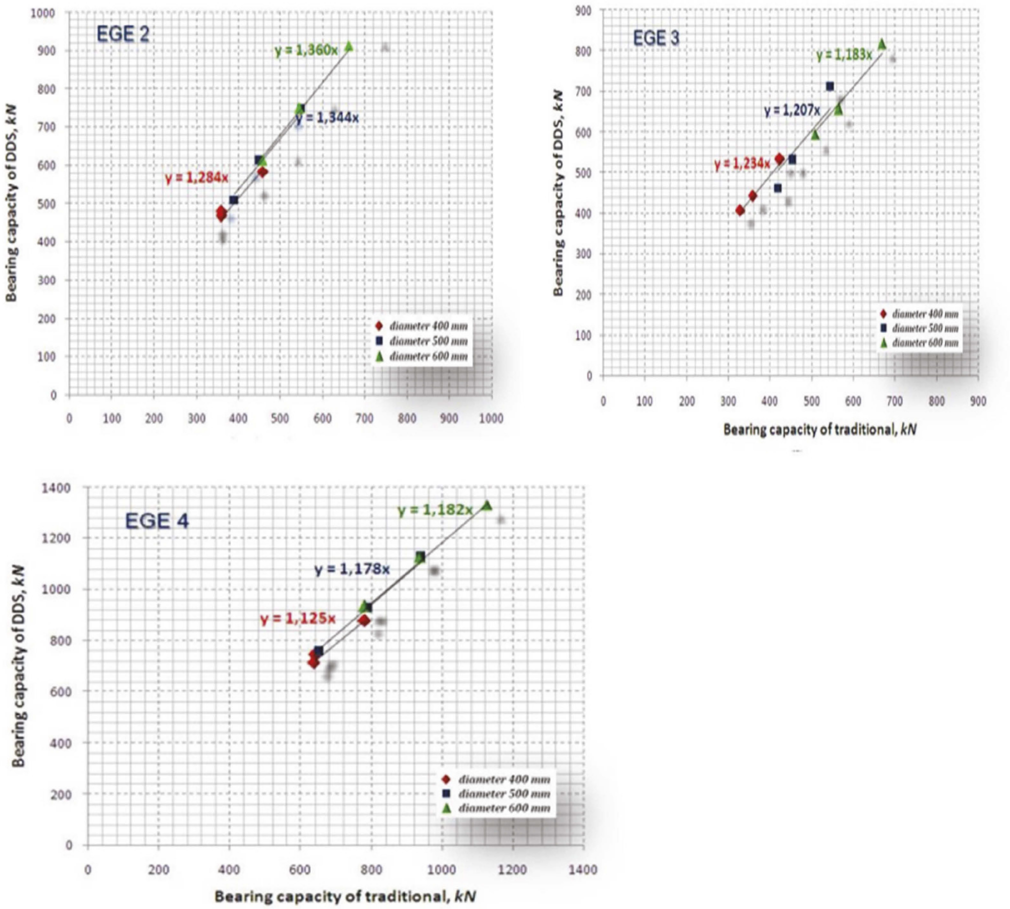

Figure 8. Simulation results.

It can be seen from the diagrams that the values of the coefficients of the soil working conditions on the side surface of the DDS pile are: for IGE2 – 1.38, IGE3 – 1.26, IGE4 – 1.2.

7 CONCLUSION

1. Static tests of DDS piles of various diameters were carried out, according to the results of which a comparative analysis of experimental bearing capacities of piles with normative

ones was carried out. The experimental values of the bearing capacity of DDS piles, on average, are 1.5 times higher than the calculated ones, which in turn indicates that the resources of DDS technology are not fully used.

2. Nomograms describing the dependence of the modulus of deformation, adhesion and the angle of internal friction on the diameter of the DDS piles were obtained. The adjustment of parameters can be used in the design of DDS piles with a diameter from 410 to 600 mm in engineering geological conditions similar to the conditions of the studied construction sites. The obtained dimensions of the radial seal were used in numerical modeling.
3. Based on the results of numerical modeling, an experimental-theoretical coefficient of the soil working conditions on the side surface of the pile DDS was obtained, equal to 1.28. At the same time, the difference between the experimental and calculated values of bearing capacities decreases from 1.51 to 1.14.

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