Interaction between Displacement Pile and Soil Ground

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ABSTRACT

The results of settlement and bearing capacities of Drilling Displacement System (DDS) boring piles obtained by static loading tests are compared with the design standard in this paper. The results of compression tests of surrounding soil after DDS pile installation are also studied. Significant differences between experimental (by static loading test) and design (by standards) values of bearing capacity of DDS pile showed incomplete usage of DDS technology. Laboratory testing of soil after DDS pile installation allowed an understanding of the relationship between elastic modulus, cohesion, angle of internal friction and DDS pile diameter. The results of numerical analysis of DDS and traditional boring pile using Plaxis code are also presented in this paper. Using the results of numerical analysis, the coefficient of adjacent surrounding soil was defined.

Keywords: pile, static load test, laboratory test, bearing capacity

1 INTRODUCTION

Engineers are faced with new geoengineering problems that demand new design requirements. Therefore, traditional technologies have recently been replaced by more economical, and ecologically and energy-efficient technologies, including that of pile foundation. Pile foundation is the most widely used type of foundations in Kazakhstan. Expediency of pile foundation is explained by high value of bearing capacity required by high-rise buildings. At the same time, existing design Standards are not in correspondence with newly emerged technologies, because of absence of recommendations for new pile design.

This paper presents research of a new boring pile technology named as DDS or FDP (full displacement pile) technology.

This technology was established by Germany company BAUER and undoubtedly presents practical values for modern Kazakhstan construction. The general advantages of this technology (comparing with traditional boring pile technology) are: fast installation of pile, economical efficiency, low noise during installation, absence of vibration, and high value of bearing capacity. In spite of that, DDS technology is not recommended for using near the existing buildings and construction sites due to possible influences of DDS technology on nearby foundations.

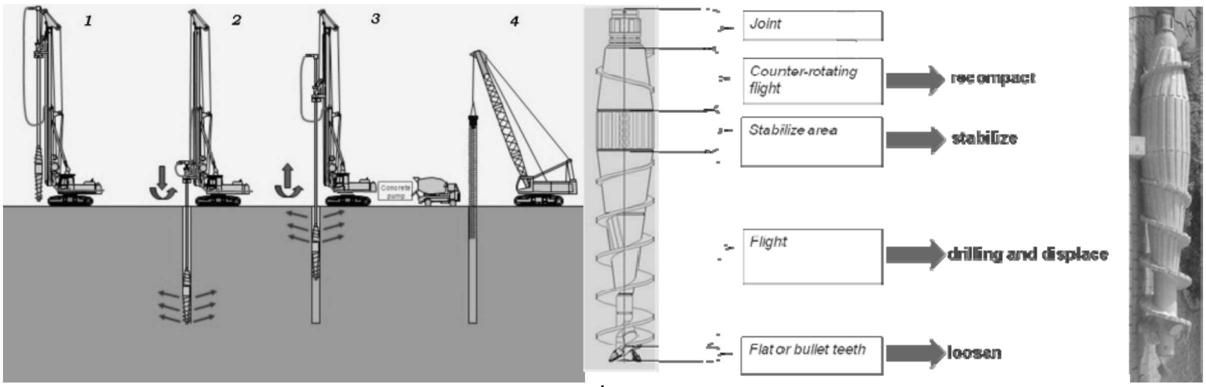
The big difference between experimental bearing capacity obtained by static loading test (SLT) and design value obtained by Kazakhstan Standard indicated incomplete usage of DDS technology.

2 TEXT LAYOUT OF THE PAPER

Installation of DDS pile consists of four steps, as described below (see Figure 1a): (1) place the boring machine to the boring place; (2) bore the pile hole to the design level; (3) fill the concrete under a pressure of 300 kPa; (4) install the steel anchor into the pile body.

The principal feature of this technology is a special boring element, presented in Figure 1b. The pile hole is formed via two stages: during the moving down of boring element, the bullet teeth loosen the soil and the stabilizer displaces surrounding soil. During the moving up of boring element, the secondary compaction of hole takes place. The features are elaborated in Sultanov et al. (2010).

DDS technology allows installation of the pile up to 0,6m of diameter and 30m of length. During DDS pile design, it is required to take into account following parameters: diameter of pile, torque moment, indentation forces, density (strength, compaction of soil and power of concrete pump).



a b

Figure 1. DDS pile technology features

3 STATIC LOADING TEST OF DDS PILES

A total of 14 static tests of DDS piles of different diameters and length have been conducted on two construction sites. The first construction site is "Trade and Entertainment Centre Khan Shatyry". Totally, 11 piles were tested on this site; 8 tested piles of 410 mm diameter and 18 m long, 2 piles of 500 mm diameters and 10 m long, and one pile of 600 mm diameter and 18 m long. Construction sites №2 is "Industrial Base" where 3 DDS piles of diameter 500 mm and length 2.5 m were tested.
Studying engineering-geological features of soils on the construction sites, based on in-situ soil description and results of laboratory tests, revealed that there were three engineering-geological elements (EGE): EGE-2 - alluvial mediumquaternary modern deposits a(QII-IV), consisting of clay and filled-up soil with thickness from 1,2 to 3,5 m. The density of the soil is equal to 1,87 g/cm^3. EGE-3 is an alluvial mediumquaternary modern deposits a(QII-IV), consisted of clay and sandy-clay soils. EGE-4 is the eluvial deposits of e(C_1), which is composed of clay and loam soil (Alibekova et al., 2008).
The loading test was done in stages of 400kN and 200kN until it reached 2800kN by three hydraulic jacks of type CMJ- 158A, which were connected in parallel. The pressure in the jacks was created with the help of manual oil pump station MNSR-400. The load was controlled with monometer MTP-160, and the moving piles was fixed by caving in-measurers of the type 6-PAO, which were positioned in the both sides on unmovable bearings of benchmark system. Reloading was conducted in stages of 800kN and 400kN.
According to requirements of the Kazakhstan Standard - SNIP RK 5.01-03-2002 – ultimate value of settlement of the tested pile is determined by following equation:

$$S = \zeta S_{u,mt} \tag{1}$$

where ζ - coefficient for conversion factor of the limit value of mean settlement of foundation of the building or structure $S_{u,mt}$ into pile settlement obtained during static tests at conventional settlement stabilization. According to the requirements, $\zeta=0.2$ shall be taken as the coefficient value. Su,mt - is maximum permissible value of foundation settlement of the designed building or structure as stated either in the project statement or Kazakhstan Standards requirements.

4 DESIGN OF BORING PILE BY KAZAKHSTAN STANDARD

To analyze the bearing capacities obtained by SLT, the calculation of design bearing capacity by Kazakhstan Standards was performed by SNIP PK 5.01.01-2002. The classically bearing capacity is subdivided into two constituents: shaft and tip resistance. In Kazakhstan's Standard, the classical equation was modified and presented by following equation:

$$F_d = \gamma_c(\gamma_{cR}RA + u\sum \gamma_{cf} f_i h_i) \tag{2}$$

where y_c – safety factor; y_{cR} and y_{cf} – coefficients of soil work condition under the pile tip and around the pile, respectively.

DDS pile works identically, but in case of DDS pile where surrounding soil is subjected to compaction, this leads to an increase in DDS pile bearing capacity. In this case, we are interested by the coefficients of soil work condition around the pile. These coefficients are recommends by Kazakhstan Standard for different types of pile. For example, driving pile has a coefficient equal to 1, for boring pile it is 0,7, and the biggest value of 1,3 for pile of DIT (discharge impact technology). DIT technology means reprocessing of fine concrete body by high-voltage charges. This technology is usually used in saturated soil. And in the end of installation, pile's diameter is doubly increased depending on the hydro-geological condition of the site. This coefficient depends on the compaction condition of adjacent soil. In the case of traditional bored pile, there is no compaction, therefore the coefficient is equal to 0,7, and in the case of DIT pile, due to the double expansion of pile this coefficient is equal to 1,3. From aforementioned condition, it is necessary to modify the coefficient of DDS pile. Moreover, in the case of DDS pile, only surrounding soil undergoes compaction, but not under the pile. Thus, we are interested in the coefficient of soil work condition around the pile.

5 COMPARISON OF EXPERIMENTAL AND DESIGN BEARING CAPACITY

Experimental and designed values of bearing capacities are presented in Table 1. There is a big difference between experimental results and design values of predicted bearing capacities (Sultanov et al., 2010).

Table 1: Experimental and designed values of bearing capacities

№	Description of piles		Bearing capacity, кN		Coefficient k= F_u/F_d
			Experimental F_u	Designed F_d	
1	Pile DDS L=17m d=410 mm	№1	2280	1545	1,48
2		№2	2150	1545	1,39
3		№3	2325	1545	1,50
4		№4	2475	1545	1,60
5		№5	2200	1545	1,42
6		№6	2080	1545	1,35
7		№7	2190	1545	1,42
8	Pile DDS L=17m d=600mm		2700	2110	1,28
9	Pile DDS L=2m d=500mm	№1	470	272	1,73
10		№2	490	272	1,80
11		№3	460	272	1,69

The comparison diagram of SLT and design value of bearing capacity is presented in Figure 2. All the linear function points are higher than the diagonal that means all experimental values of bearing capacity are higher than those designed for.
Significant differences between experimental and designed bearing capacities of DDS, in case of DDS pile having surrounding soil subjected to compaction.

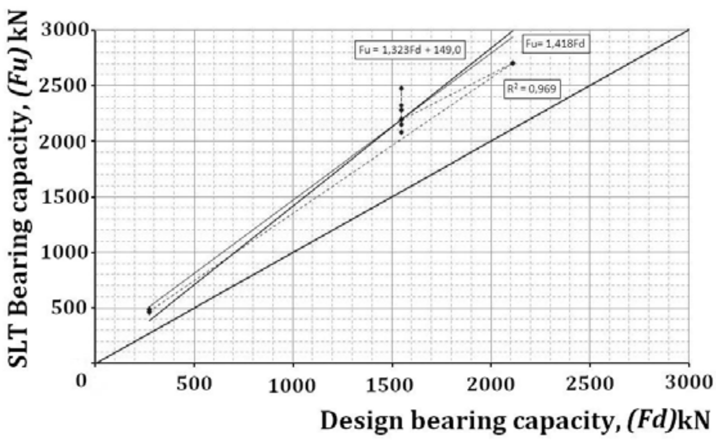


Figure 2. SLT and designed bearing capacity

6 LABORATORY TESTING OF SURROUNDING SOIL

The main goal of laboratory testing was to investigate the dependency of the properties of surrounding soils on the pile diameter: elastic modulus, angle of internal friction and cohesion. The Shelby tubes were used to take soil samples before and after DDS pile installation. The samples were taken on the aforementioned construction sites. The laboratory tests were performed according to Kazakhstan Standard – GOST 12248-96.

The obtained results were subjected to statistical analysis, the purpose of which is to reveal the random departure (random value of interested variables). The reason of this might be disturbed structure of soil during sampling or inaccurate measurement of testing equipment. Many soil specimens were taken around piles of different diameters as well as different geological elements.

After reprocessing of obtained data by statistical analysis, some results of elastic modulus were rejected from further analysis. It is necessary to take into account the elastic modulus, angle of internal friction and cohesion increase due to compaction during the DDS pile design. With that view, the nomograms were developed (see Figure 3). By these nomograms, designers may easily correct elastic modulus, angle of internal friction and cohesion of different engineering elements of Astana, to accurately design DDS piles, as presented by Sultanov et al. (2010).

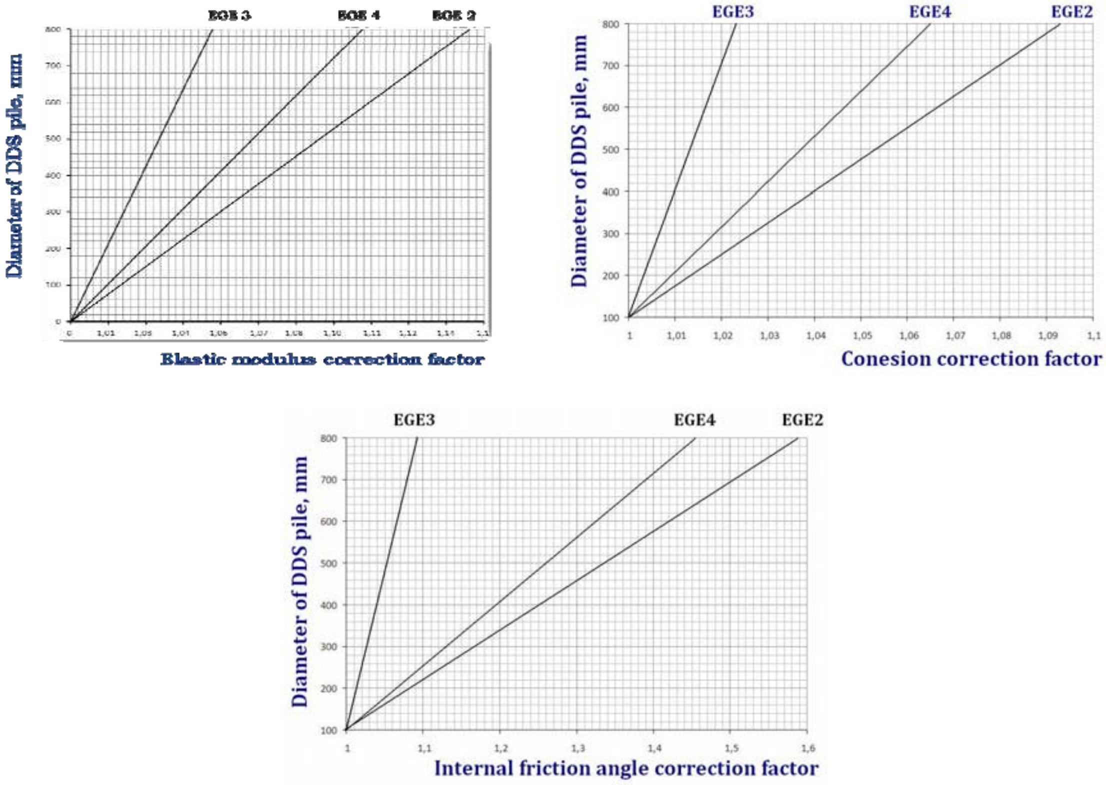


Figure 3. Correction nomograms

7 FEM ANALYSIS OF DDS PILES

The main goal of research is to determine the influence of soil compaction on the bearing capacity and settlement of pile. FEM analysis was performed to analyse the stress-strain development of traditional and DDS pile in different geological elements of Astana. The FEM model included two soil clusters. In case of traditional pile simulation this two clusters have identical soil characteristics, in case of DDS pile simulation of upper cluster was changed. This changing took allowance of compaction of soil surrounding the DDS pile. Only surrounding soil condition, but not condition under the pile, was changed; as long as nothing occur under the pile, namely no compaction.

First of all, we tried to predict bearing capacity of traditional and DDS pile. Next we compared obtained bearing capacities with the relationship presented in Equation (3). Substituted this relationship in Kazakhstan Standards equation of bearing capacity, and obtain the coefficient of surrounding soil work of DDS pile by Equation (4). The results of FEM analysis for different geological elements and different DDS pile diameters are presented on diagrams in Figure 4.

$$k = \frac{F_{d(PLX)}^{DDS}}{F_{d(PLX)}^{tr}}, k. \geq 1 \quad (3)$$

where: $F_{d(PLX)}^{DDS}$ – predictable by Plaxis bearing capacity of DDS pile; $F_{d(PLX)}^{tr}$ – predictable by Plaxis bearing capacity of traditional pile.

$$\gamma_{cf}^{DDS} = \frac{kF_d^{tr} - \gamma_c \gamma_{cr} RA}{u\gamma_c \sum f_i h_i} \quad (4)$$

where: $Y^{DDS}{}_{cf}$ – coefficient of surrounding soil work; $F^{TP}{}_d$ – designed bearing capacity of traditional pile; Y_c , Y_{cf} – coefficient of soil work; R – designed tip resistance; f_i – designed shaft resistance of pile.

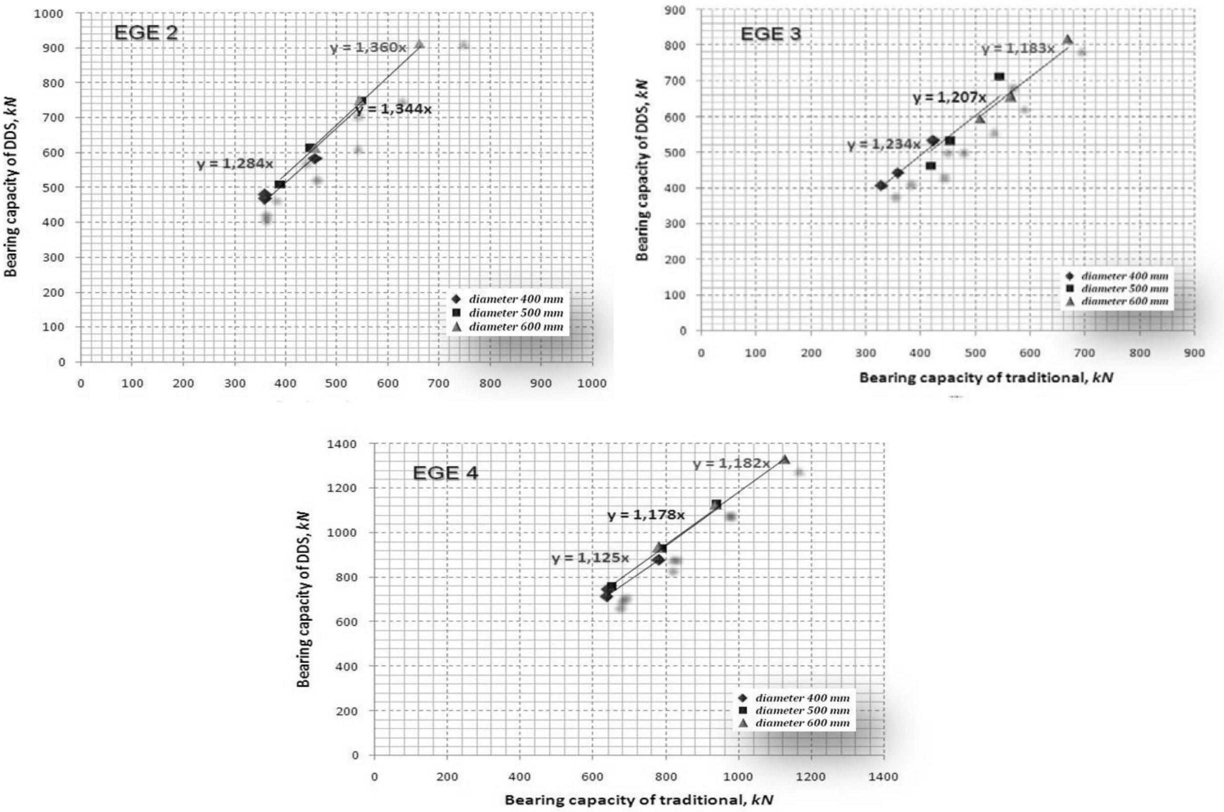


Figure 4. Results of FEM analysis

In case of DDS pile surrounding soil undergoing compaction, and no compaction under the pile, the obtained coefficients of DDS piles shaft work for different EGE (engineering geological elements) equal to: EGE2 – 1.38, EGE3 – 1.26, EGE4 – 1.2.

8 ECONOMICAL EFFICIENCY OF RESEARCH

In order to show the economical benefit by using coefficient of surrounding soil work, DDS piles were designed by the standard and proposed method. It was compared with the real piles bearing capacities of real sites as mentioned before. Table 2 shows results of designed bearing capacity of DDS pile (by standard) and recommend procedure (by proposed method). For example, for construction site 1, 1500 kPa soil resistance is required by project. The standard pile resistance is a little bit bigger and equal to 1545 kN providing that computed pile length is 15m. The recommended bearing capacity of pile is also met to required soil resistance and equal to 1556 kN, but the length of pile in this case is reduced to 12 m. Same situation with construction site 2 where designed 2 m versus recommended 1,2m.

Table 2: Designed and recommended length

Designed bearing capacity of DDS / corresponding length of DDS			
Construction site №1 (d=410mm)		Construction site №2 (d=500mm)	
Designed	Recommending	Designed	Recommending
1545kN / 15m	1556kN / 12m	272kN / 2m	274kN / 1,2m

Table 3 shows the expense for DDS pile installation. There is essential difference of pile cost between designed and recommended methods. The total expense per one DDS pile installation is reduced by 20-40%.

Table 3: Economical efficiency of developed method

Parameters		1 m^3 DDS pile installation expanse, USD	1 m^3 pile material expanse, USD	Total expanse per 1 DDS pile installation, USD	Reduction of total expanse, %
Site №1	Designed	300	100	3000	-
	Recommendin	300	100	2400	-
Site №2	Designed	300	100	630	-
	Recommendin	300	100	380	-
Economical effect	Site №1			600 USD	20 %
	Site №2			250 USD	40 %

9 CONCLUSIONS

1. The SLT of different diameters of DDS piles were performed and the obtained results were compared with designed (Standard) values of bearing capacity. The experimental bearing capacity on average was 1.5 times larger than the Standard bearing capacity. Aforementioned authenticate that Kazakhstan Standard requirements are out of date and the design by Standard rendered an incomplete usage of the DDS technology resources. The nomograms and linear functions to correct Standard bearing capacity were developed and might be used during design.
2. The reason of big difference between experimental and designed bearing capacity might be the strengthening of surrounding soil due to technological compaction during borehole formation. This led to increased soil parameters such as angle of internal friction, cohesion, Young modulus, and so on. By the results of laboratory testing, the nomograms to correct angle of internal friction, cohesion, and Young modulus were developed. It is possible to use these nomograms for DDS pile design, of diameter 400, 500 and 600 mm.
3. By the numerical modelling, the comparison between traditional and DDS pile bearing capacity was performed. The coefficient of surround soil work was defined and equal 1.28 on average. The differences between experimental and designed bearing capacity decreased from 1.51 to 1.14 using this coefficient.
4. The developed bearing capacity determination method allowed a reduction in the total cost per DDS pile installation by 20-40%.

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