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Geotechnical issues of megaprojects on problematical soil in Kazakhstan

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ABSTRACT: The best geoengineering solution in case of inhomogeneous soil of Astana (new capital of Kazakhstan) is the use of new pile technology like CFA (continuous flight auger), DDS (drilling displacement system) and H-beam piles, that lead to increased bearing capacity and decrease the settlement of foundation. The present paper includes static and dynamic, integrity piling test results and also data of numerical analysis of interaction of piles with soil ground. The case study on several Megaprojects in problematical soil ground of Astana and also in West Kazakhstan (Caspean Sea area) will also be presented.

1 INTRODUCTION

After the collapse of the Soviet Union, Astana has become the new capital of Kazakhstan. In the past decade, many modern architectural and engineering megaprojects have emerged (such as Khan-Shatyr, Peace Palace – Pyramid, house estate of “Severnoe Siyanie”, Abu-Dhabi Plaza Hotel, New Aktau city near the Caspian Sea and so on), (Figure 1).

The forecast population of New Aktau city more than 1.5 billion people – the main goal of the project is creation of the most beautiful city, place of the rest and tourism for Kazakh people and for foreigners. Many foreign companies were attracted to realization of the project from USA, Australia, UAE and Europe.

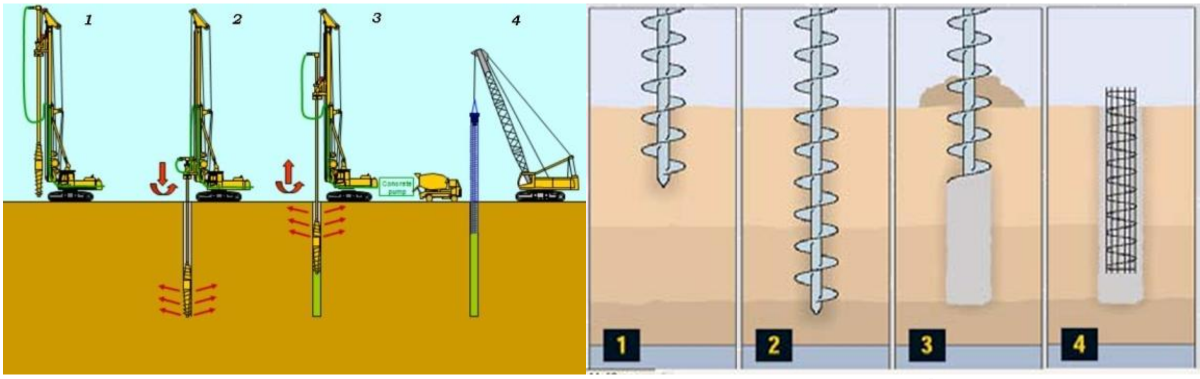
Another megaproject is construction of the unique housing estate Abu-Dabi Plaza designed by famous architecture Norman Foster. This will be a most high building in Central Asia and 14th in the world. Abu-Dabi Plaza - a complex from several tower, united around the main of the building by height 382 meters - 88 floors.

These modern megaprojects put forward new requirements to engineers utilizing more economical and technologically effective design and construction methodologies. The territory of the city of Astana is located on the Kazakh Steppe and the most apparent problem is the soil condition presented by nonhomogeneous sandwich soil layers, characterized by various types of soft and dense soil, and hard soil bands, including freezing ground. At present, pile foundations are widely used, but it is very hard to use precast piles because they may break in the soil during driving or their heads may be damaged too, while the bearing capacity is not high. The best geoengineering solution in this case is the use of new pile technology like CFA (continuous flight auger), DDS (drilling displacement system) and H-beam piles, that lead to increased bearing capacity.

Figure 1. Engineering megaprojects

2 FETURES OF DDS AND CFA PILE TECHNOLOGIES

Installation of DDS pile consist of four steps, the steps of the DDS technology are: placing the boring machine to the boring place; boring the pile hole to the design level; filling the concrete under the pressure of 300 kPa; installation of steel anchor into the pile body (Sultanov et al. 2010). Installation of CFA pile consist of following steps: placing the boring machine to the boring place; boring the pile hole to the design level; removing the screw with simultaneous concrete filling under the high pressure and replace the boring machine, installation of steel anchor into the pile body with preparation of pile head (Klosinski & Rychlewski 2003), (Figure 2).



a b

Figure 2. a) DDS and b) CFA pile installation.

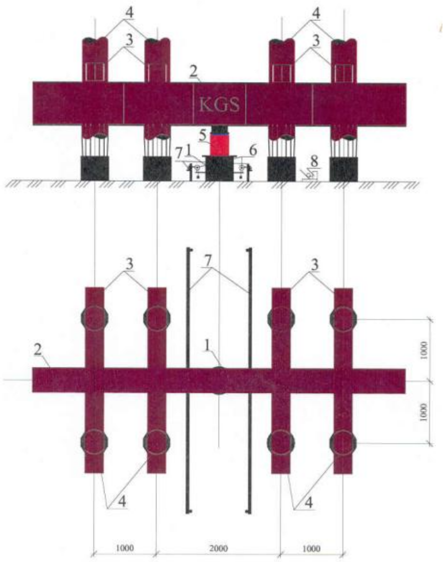
In modern CFA technology the systematic employment of devices auto-recording the drilling data represent a real breakthrough considering that in the past the CFA method was not accurate, and relied on the operator’s ability: now such devices guarantee the control and recording of the data during the whole construction process. The recorded working data are usually drilling/withdrawal speed, rotation speed, depth, concrete pressure and delivery rate per increment of auger lift during casting.

3 STATIC LOAD TEST OF DDS and CFA PILES

The construction site is “Trade and Entertainment Centre Khan Shatyry” (See Figure 1). 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(Q_{II-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(Q_{II-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 & Bukenbayeva 2008).
The loading test was done by Kazakhstan, US and European Standards (SNIP PK, ASTM, Eurocode) 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 by manual oil pump station MNSR-400. The load was controlled by 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.

Totally it was performed 14 static tests of DDS and 5 CFA piles of different diameters and length. There are 7 tested DDS piles of 410 mm diameter and 18 m length, 2 piles of 500 mm diameters and 2.5 m length1nd one pile of 600 mm diameter and 12 m length. Field static load tests were carried out for CFA and traditional piles with diameter of 600 mm and 630 mm and length of 10, 20, 22 24 and 28 m.

The loading was done in stages of 400kN and 200kN until 2800kN. Reloading was conducted in stages 800kN and 400kN, see Figure 3.



1 –DDS tested pile; 2 – basic beam; 3 – auxiliary beam; 4– pipes welded to anchor bar; 5 – jack SMJ-158A; 6 - caving in-measurer 6-PAO; 7 - benchmark system; 8 – pump NSR-40 and, with monometer MTP-160.

Figure 3. Static load test performance

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.

4 COMPARISON CFA AND CASING BORING (TRADITIONAL) PILES

The FEM elasto-plastic analysis was provided by computer program (Tadatsugu Tanaka). It was used the mechanical properties of soil ground for the numerical calculation of bearing capacity and settlement. For analyzing bearing capacity of working as friction CFA and Casing piles were modeled and compared with results of static load test. FEM mesh for calculation of single bored pile is illustrated in Figure 4.

Taking advantage of the axi-symmetric nature of the problem, only a half domain of the model ground and pile were analysed. The soil ground and pile were descretized into four noded quadrilateral elements. Number of nodal points are 675, number of finite elements are 606, number of materials are 4 (1is sand with gravel, 2 is hard clay, 3 is clay, 4 is bored pile).

During CFA pile installation the question of over-expenditure of concrete was appeared. The actual volume of borehole was about 1.3-1.4 times more than theoretical volume of borehole (Zhusupbekov & Ashkey et al. 2006) After determination of preliminary average radius (r+∇r) increasing diameter of CFA piles and remodeled numerical mesh FEM analysis was repeated. It gives us increasing bearing capacity of CFA piles respectively "load-settlement" results of field static load test and stress and strain of soil around of single CFA pile through FEM computer program. The results of "load-settlement" through FEM illustrated in Figure 4.

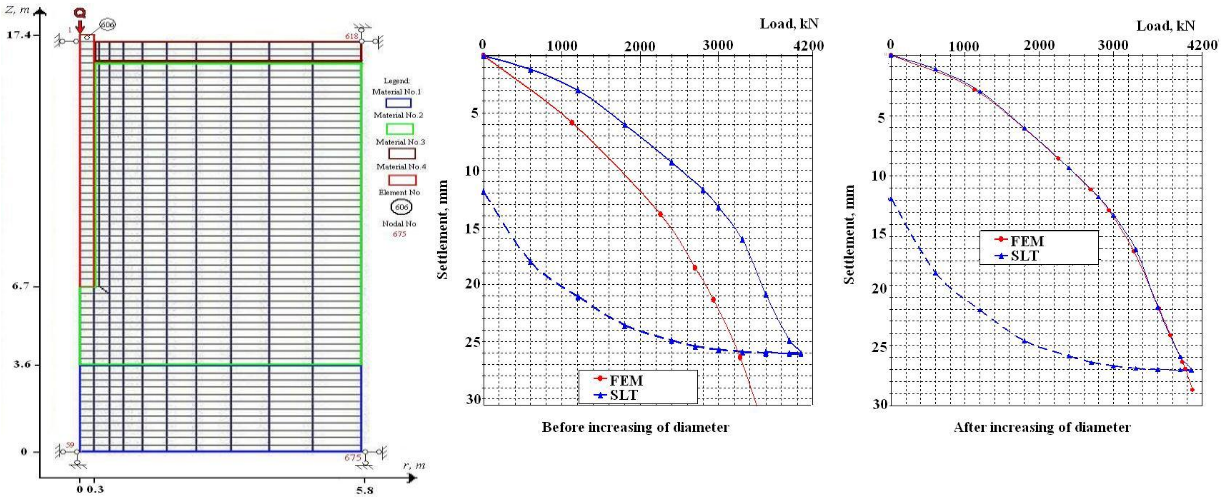


Figure 4. Results of FEM analysis

5 COMPARISON DDS (FDP) AND CASING BORING (TRADITIONAL) PILES

Comparison of DDS and Casing boring piles bearing capacities by SLT are presented in Figure 5. There is big difference between DDS and Casing boring piles bearing capacities.

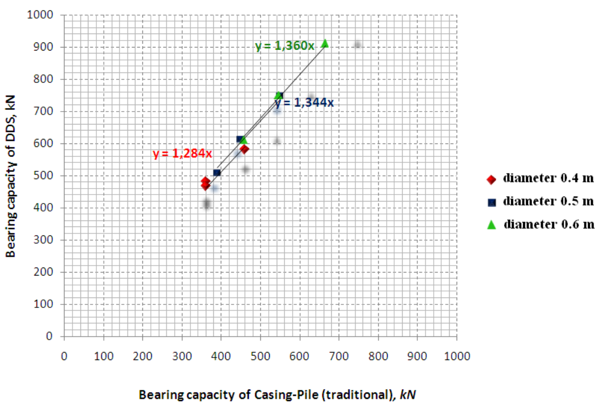


Figure 5. Comparison of DDS and Casing boring piles bearing capacities

Significant differences between bearing capacities of DDS and Casing boring piles show us incomplete usage of DDS technology resources. Classically differ two stages of pile works under the vertical load: during the first stage is developing the ultimate state of stress-stain condition of soil, during the second stage the slippage of pile through the soil has a place. DDS pile works identically, but in case of DDS pile surrounding soil subject to compaction, this lead to increase of bearing capacity. Classically bearing capacity subdivides into two constituent there are: shaft and tip resistance. In Kazakhstan`s standard - Soil basement and foundations classical equation was modified, and presented by following equation:

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

where $\boldsymbol{y_c}$ = safety factor; $\boldsymbol{y_{cR}}$ and $\boldsymbol{y_{cf}}$ = coefficients of soil work condition under the pile tip and surround of pile respectively.

In this case we interested by coefficient of soil work condition. In case of traditional bored pile no compaction is occurred therefore coefficient of shaft work of pile equal 0,7, in case of DDS piles due to of surrounding compaction of soil this coefficient must be increased. Moreover in case of DDS pile surrounding soil only undergoes to compaction, under the pile no compaction. By results of static load tests of DDS and Case piles the inverse problem was performed to definition of coefficients. Obtained coefficients of DDS piles shaft work for different EGE (engineering geological elements) were presented in Table 1.

Table1. Coefficients of DDS piles shaft work

Depth, m	Y_{cf}	$Y_{cf(average)}$
	EGE2	
5	1,23	
6	1,18	
7	1,15	
5	1,45	
6	1,37	1,38
7	1,32	
5	1,67	
6	1,56	
7	1,23	
	EGE3	
5	1,31	
6	1,25	
7	1,21	
5	1,33	
6	1,26	1,26
7	1,21	
5	1,32	
6	1,25	
7	1,21	
	EGE4	
5	1,12	
6	1,08	
7	1,05	
5	1,21	
6	1,16	1,20
7	1,12	
5	1,43	
6	1,34	
7	1,28	

After reprocessing of obtained data by statistic analysis several results of elastic modulus were rejected from following analysis. It is necessary take account elastic modulus, angle of internal friction and cohesion increase due to compaction during design DDS pile. With that view the nomograms were developed, see Figure 6. By these nomograms designers may easily correct elastic modulus, angle of internal friction and cohesion of different engineering element of Astana, to accurate design DDS piles.

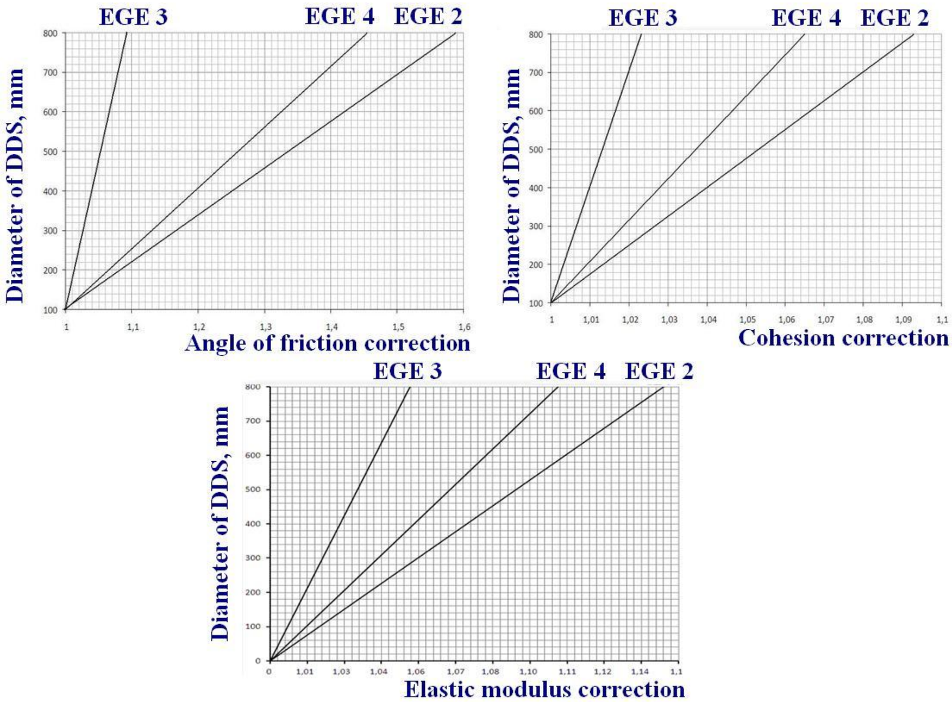


Figure 6. Correction nomograms

6 COMPARISON SLT RESULTS OF DIFFERENT TYPES OF PILE

SLT of different types of pile was performed with a view to compare bearing capacity of traditional (namely, boring casing pile and driving pile).

Unfortunately, most part of tested piles is not achieved ultimate settlements prescribed by Kazakhstan Standard - 24mm, and so, for bearing capacity comparison it was chosen to use 3mm settlement criteria, as long as all the piles achieved this settlement.

All the piles were designed to the criteria of 2200kN bearing capacity. Designed parameters of piles (length and cross section) by Kazakhstan Standards are presented in Table 2.

Table 2. Designed pile characteristic

Type of pile	Required quantity, e.a.	Length of pile, m	Diameter or cross section, m
CFA	1	10	0.5
DDS	1	10	0.5
Casing	1	10	0.5
Driving	2	12	0.3 x 0.3

Results of comparison are presenting in Figure 7.

All of these coefficients show incapacity of accurate design of modern pile technology by out-of date Standards, otherwise this coefficients tending to 1. The results of SLT showed entirely expected regularity. CFA piles showed highest bearing capacity as long as during CFA pile installation it was expended much more concrete (in 2 times) than during Casing pile installation. This factor was not considered during design, the coefficient therefore equal 1.43. DDS pile approved effluence of compacted soil and coefficient therefore equal 1.22 (DDS versus Casing). Differences between Driving and Casing pile neglected small, the reason of differences might be empirical coefficients required by Standards.

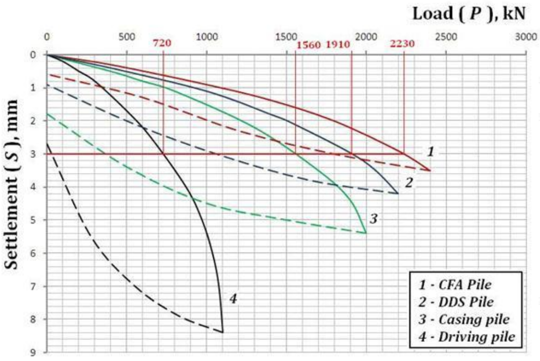


Table 3. Comparison of different piles

Description	Coefficient of reserve
F_{CFA}/F_{DDS}	1.17
F_{CFA}/F_{Casing}	1.43
$F_{CFA}/F_{Driving}$	1.55
F_{DDS}/F_{Casing}	1.22
$F_{DDS}/F_{Driving}$	1.33
$F_{Casing}/F_{Driving}$	1.08

Figure 7. Bearing capacity comparison of different piles

7 CONCLUSIONS

The results of field static load tests of CFA piles showed high value bearing capacity higher than traditional casing pile. For designing CFA technology for pile foundations of buildings and structures need consider volume changing of borehole by appearance in borehole additional pressure respectively over-expenditure of the concrete depending soil conditions and length of piles. CFA pile more productivity than traditional casing pile. It is possible to install 6 CFA piles per working day versus 3 casing piles.

Significant differences between bearing capacities of DDS and Casing boring piles show us incomplete usage of DDS technology resources. Kazakhstan standards have not any recommendations to DDS pile design, prescribed in standards recommendation applicable for traditional pile design and give not accurate results for DDS pile design. The coefficient of shaft work of DDS pile was defined and equal from 1.2 to 1.38 depending on soil condition. Application of DDS technology allows reducing total expanse per 35 to 40%.

The reason of big difference between DDS experimental and designed bearing capacity is strengthening of surround soil due to of technological compaction. Last is lead to increase of soil strength and deformation parameters such as angle of internal friction, cohesion and Young modulus. 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 during design DDS pile of 400, 500 and 600mm of diameter in similar soil condition.

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