Geotechnical Issues of Megaprojects on Problematical Soil Ground of Kazakhstan

Questions géotechniques de mégaprojets sur sol problématique du Kazakhstan

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ABSTRACT: 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 and so on). 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 inhomogeneous 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), FDP (full displacement piles), DDS (drilling displacement system) and H-beam piles, that lead to increased bearing capacity. The present lecture includes static and dynamic, integrity piling test results and also data of numerical analysis of interaction of piles with soil ground.

RÉSUMÉ : Après l'effondrement de l'Union soviétique, est devenue Astana, la nouvelle capitale du Kazakhstan. Dans la dernière décennie, de nombreux mégaprojets modernes d'architecture et d'ingénierie ont vu le jour (comme Khan-Shatyr, Palais de la Paix - Pyramide, immobilier maison d'"Severnoe Siyanie", Abu-Dhabi Plaza Hôtel et ainsi de suite). Ces mégaprojets modernes proposer de nouvelles exigences pour les ingénieurs qui utilisent conception plus économique et techniquement efficace et méthodes de construction. Le territoire de la ville d'Astana est situé sur la steppe kazakhe et le problème le plus évident est la condition du sol présenté par inhomogènes couches de sol sandwich, caractérisées par différents types de sol souple et dense, et des bandes de sols durs, y compris congélation du sol. À l'heure actuelle, les fondations sur pieux sont largement utilisés, mais il est très difficile d'utiliser des piles préfabriquées, car ils peuvent se briser dans le sol pendant la conduite ou la tête peut être trop endommagés, tandis que la capacité portante n'est pas élevé. La meilleure solution dans ce cas, la géo-ingénierie est l'utilisation de la technologie nouvelle pile comme CFA (tarière continue), FDP (piles déplacement complets), DDS (système de déplacement de forage) et H-beam pieux, qui conduisent à augmenter la capacité portante. La conférence présente comprend statiques et dynamiques, les résultats de tests d'intégrité des pieux ainsi que les données de l'analyse numérique de l'interaction avec des tas de terre du sol.

KEYWORDS: pile technology, field and laboratory test, FEM modeling.

1 INTRODUCTION. FIRST LEVEL HEADING

During the last 20 years of independence, in the scopes of geoengineering, Astana had been grown significantly, many outstanding megaprojects have been raised for the relatively short time: Khan-Shatyr, Peace Palace – Pyramid, house estate of “Severnoe Siyanie”, Abu-Dhabi Plaza Hotel, New Aktau city near the Caspian Sea and so on, and many other (Zhussupbekov A.Zh. 2012).

These modern megaprojects put forward new requirements to engineers and lead to proceed to 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. The short information about new and traditional pile technology are using in Kazakhstan is presented in Figure 1.

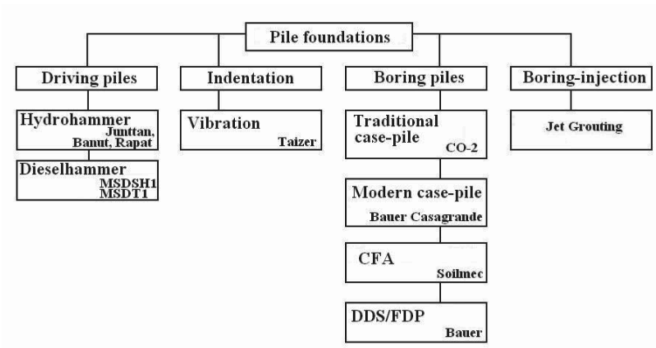


Figure 1. Pile foundations on construction sites of Kazakhstan

It has been mentioned previously that existing Kazakhstan standard of pile design is out of date and does not meet the modern geoengineering requirements. The preliminary design is performed based on the engineering and geological investigation of construction site. Accuracy of pile design generally depends on the accuracy of data presented in geological report. Final pile design project is corrected after approval by field tests. Nowadays conception of pile foundation Figure 2.

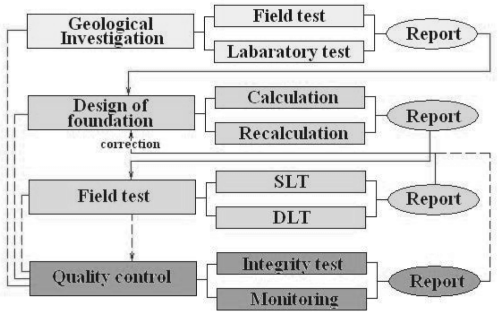


Figure 2. Pile foundation design concept

2 FEATURES OF NEW PILE TECHNOLOGIES

The DDS technology was established by Germany Company BAUER and undoubtedly presents practical values on Kazakhstan construction sites. 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 (Sultanov G.A. 2010).

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

The principal feature of this technology is a special boring element. 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.

DDS technology allows installation of the pile up to 1200mm 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 CFA pile is a type of drilled foundation in which the pile is drilled to the final depth in one continuous process using a continuous flight auger. The use of the continuous flight auger rig avoids many of the problems of drilling and concreting piles experienced when using conventional power augers. The new CFA equipment can perform piles in most type of soils (including sand, gravel, silt, clay, chalk and weak weathered rock) with diameters up to 1200 mm and lengths down to 35-40 meters. So, with proper planning and design, performing equipment and skilled personnel, high production rates and high quality product can be achieved (Ashkey Y. 2008).

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.

The high quality of piles is ensured by not soil extraction for DDS and by high filling pressure for CFA.

Figure 3. New pile technologies

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:

$$F_d = \gamma_c(\gamma_{cR} RA + u \sum \gamma_{cf} f_i h_i) \qquad (1)$$

where γ_c = safety factor; γ_{cR} and γ_{cf} = coefficients of soil work condition under the pile tip and around the pile, respectively.

Unfortunately, existing Kazakhstan Standards do not take into account soil compaction under the high concrete pressure in case of CFA technology and soil displacement without excavation in case of DDS technology that lead to reduction of settlement and increase in bearing capacities of pile foundation. Therefore it had been suggested to use following coefficients of soil working condition as presented in Table 1.

Table 1. Suggested coefficient of soil works for DDS and CFA piles

Type of pile	γ_{cR}	γ_{cf}
Driving Pile	1,0	1,0
Boring Pile	0,7-1,0	0,7
DDS (FDP) Pile	1,3	1,0
CFA Pile	1,0	1,0

3 TESTING OF PILE FOUNDATION

Many static and dynamic load tests were performed on this construction site. The SLT one of the more reliable field tests in analyzing pile bearing capacity in Kazakhstan. DLT is a fast bearing capacity analysis field test and give more or less reliable value of pile bearing capacity.

Dynamic load test (DLT). For definition of the bearing capacities of piles, it is required to use average refusal which are obtained during redriving of the piles after their "rest". The rest time depend on soil condition of site: for clayey soil 6 -10 days, for sandy and gravel soils up to 3 days.

Bearing capacity of the piles is defined by following empirical equation:

$$F_u = \frac{\eta AM}{2}\left[\sqrt{1+\frac{4E_d}{\eta AS_a}\cdot\frac{m_1+\varepsilon^2(m_2+m_3)}{m_1+m_2+m_3}}-1\right] \qquad (2)$$

where η=factor, dependent on concrete strength of the piles; A=cross section of tested pile; M=1 – factor, dependent on pile driving hammer's impact; E_d =effective energy of blows of the hammer, kNm.

According to Kazakhstan Standard at least 6 piles must be tested by DLT on each construction site.

Static Load Test (SLT). SLT one of the more reliable field tests in analyzing pile bearing capacity. SLT should be carried out for driving piles after the "rest" and for bored piles after achievements of the concrete strength, by more than 80%.

According to requirements of Kazakhstan Standard - SNiP RK 5.01-03-2002 (SNiP RK 2002) – ultimate value of settlement of the tested pile is depending on category of construction and is equal 16 or 24 mm. The last argument shows conditional character of SLT method.

According to Kazakhstan Standard 1% of constructed piles on construction site must be tested by SLT, but at least 2 SLTs in a site must be done.

Comparison of SLT and DLT. SLT and DLT both are practiced in Kazakhstan construction. According to experience on construction sites of Astana, some difference exists between SLT and DLT results. Moreover, results of bearing capacity of pile depend on type of hammer. Thus, DLT results obtained by using hydro-hammer are more approximate to the SLT results, namely more reliable than results obtained by using diesel hammer (Ashkey Y. 2008). The safety factor as defined by comparative analysis of many DLT and SLT data is presented in Figure 4.

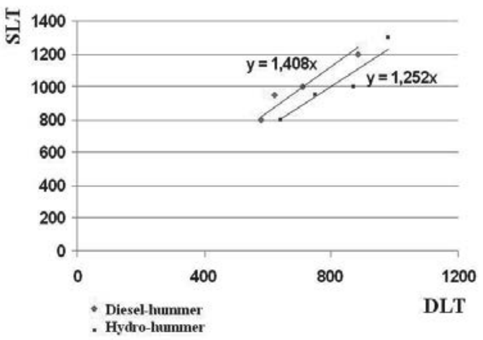


Figure 4. Comparison SLT and DLT

Alternative Load Test Method. From aforementioned it follows that SLT and DLT both have disadvantages. SLT required a lot of time, works and cost. Prescribed by Standard quantity of required SLT is not enough to adequately realize soil condition of construction site (2 SLT for 200 piles only). DLT is much faster but is not so reliable and is applicable to driving piles only.

Alternative load test method which precluded disadvantages of both SLT and DLT was used on this construction site – Pile Dynamic Analysis Method (PDA). PDA allows tests up to 10 piles per day and much cost effective than SLT. The comparison of SLT, DLT and PDA approved superiority of Pile Dynamic Analysis Method.

The O-cell bi-directional test of bored piles was firstly used on construction site of Astana. The general advantages of this method as compared with SLT and DLT are follows: no anchor piles, no external reaction system, no heavy transport is required, only half the stresses applied to the concrete, significant cost saving as loads increase.

Quality control of pile foundation. Pile integrity test is one of the non-destructive methods of pile quality control. This method allows analyzing integrity control for all existing types of piles (boring, injection, driving and so on). PIT is base on wave propagation theory in rigid body and is concerned with one of the modern quality control methods used world-wide. PIT allows detecting pile defects: approximate pile length, expansion and narrowing of pile cross section, modification of soil layers, heterogeneity of pile material, cracks in cross section of pile, extrinsic material in pile body.

Advantages of PIT are as follows: portable device is easy to carry. One operator will be able to test over 100 piles per day, depends on site condition, pile head preparation and approach to the pile; minimum influence to the construction work on the site; significant defects may be detected in the beginning of the construction. PIT has some limitations: reflection of the bottom of pile sometimes has errors depending on soil condition; little deflection (less than 5 %) of pile cross section cannot be identified.

According to Kazakhstan Standard requirements it is necessary to test 60% of boring piles and 50% of driving piles.

Geomonitoring. Geomonitoring for foundation settlement is one of the quality control methods that can be carried out during and after construction in exploitation period. Monitoring is indirect control of pile installation evaluation.

The principle of this method is monitoring the settlement of special marks which are installed to interested points of construction. Monitoring starts from the beginning of construction and allows revealing defects of foundation installation.

4 COMPARISON OF SLT RESULTS

SLT of different types of pile was performed with a view to compare bearing capacity of traditional (namely, boring casing pile and driving pile) (Zhussupbekov A.Zh. 2012).

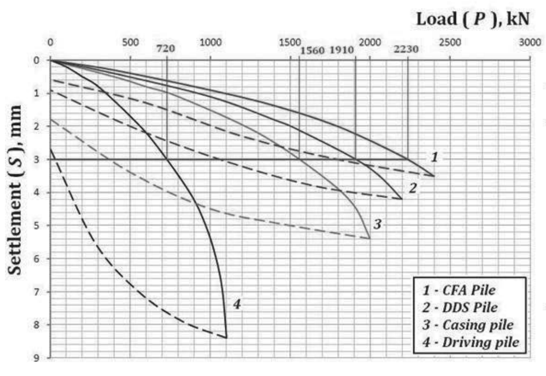
All the piles were designed to the criteria of 2200kN bearing capacity. Designed parameters of piles (length and cross section) by Kazakhstan Standards are presented in Table 2.

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 5.

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; therefore coefficient equal 1.43. DDS pile approved effluence of compacted soil; therefore coefficient equal 1.22 (DDS versus casing). Differences between driving and casing pile neglected small, the reason of differences is empirical coefficients required by Standards.



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 5. Bearing capacity comparison of different piles

5 FEM MODELING OF BORED PILES

CFA Boring pile technology. The FEM elasto-plastic analysis was provided by computer program established by Prof. 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.

Taking advantage of the axi-symmetric nature of the problem, only a half domain of the model ground and pile were analyzed. The soil ground and pile were discredited 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 (Ashkey Y. 2008). 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 6.

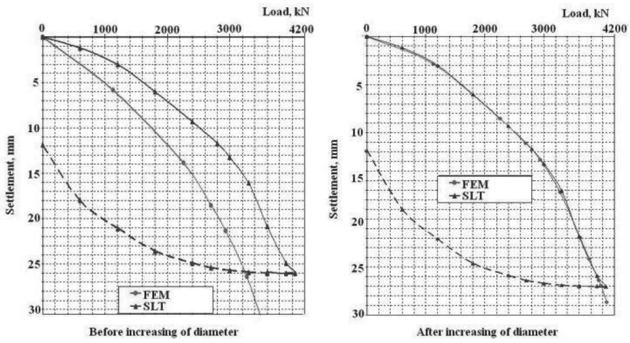


Figure 6. Results of CFA FEM analysis

DDS Boring pile technology. The FEM modeling of DDS pile was made in Plaxis 2D computer program (Figure 7).

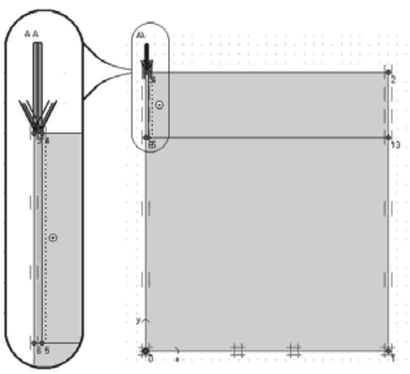


Figure 7. FEM modeling of DDS

The comparison diagram of bearing capacities of DDS and traditional bored piles by Plaxis is presented in Figure 8 (Expressed by $k=F_d/F_u$, where F_d – DDS bearing capacity, F_u – traditional bored pile bearing capacity). The points on diagram are lying above the diagonal line; it means that the values of DDS bearing capacity are exceeding traditional bored piles [2].

After some transformation it was got FEM coefficient of DDS pile works, which vary from 1.23 – 1.35 depends on type of soil (See Table 1).

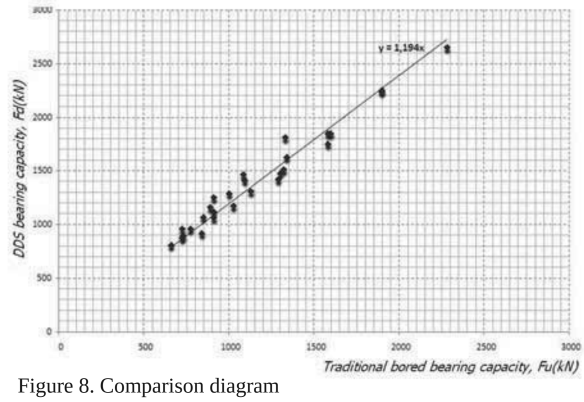


Figure 8. Comparison diagram

6 CONCLUSIONS

There were presented very short descriptions of geoengineering approach to the installation, testing and quality control of pile foundation which using on construction sites of Kazakhstan. This experience probable lead to the coming changes of the concept of Kazakhstan pile foundation design.

During designing of CFA pile of buildings and structures is need to consider volume of borehole expansion by result of additional pressure, as well as over-expenditure of the concrete which is depend on soil conditions and length of pile. Significant differences between bearing capacities of DDS and casing boring piles show incomplete usage of DDS technology resources. The coefficient of shaft work of DDS pile was defined and equal from 1.2 to 1.3 depending on soil condition.

PDA allows tests up to 10 piles per day, much cost effective than SLT, and more authentic than DLT. PDA is a type of DLT and is appropriate for any type of pile, but cannot be used to full extent on construction sites of Kazakhstan due to absence of Standard.

Pile integrity test is in the process of gaining official acceptance in Kazakhstan. PIT is a non-destructive method allowing make quality control of pile body whereupon of pile installation and even after many years of building exploitation. Geomonitoring for foundation settlement is indirect control of pile quality evaluation method and has become more relevant, especially for high-rise building construction.

Application of advanced technologies of pile foundations installation led to a significant economical efficiency. According to tests results, the piles installed by the above technologies showed high values of bearing capacity, which led to a decrease of pile length by 10 to 20% and increase economical efficiency by 20 to 30%.

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