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GEOTECHNICAL CONSIDERATIONS OF PILING TESTING IN PROBLEMATICAL SOILS OF WEST KAZAKHSTAN

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ABSTRACT: Estimation of bearing capacity and settlement plays an essential role in designing pile foundations of buildings. This paper presents the results of pile static and dynamic loading tests taken place in the construction sites of Caspian Sea Port Prorva and Tengiz. The static loading tests (SLT) and static compression loading tests (SCLT) were carried out according to the Kazakhstan GOST and ASTM standards correspondingly. The dynamic loading tests (DLT) were performed by GOST, as well as by pile dynamic analyzer (PDA) in accordance with ASTM standards. According to the results of DLT of driven joint piles (with a cross-section of 40×40 cm, lengths of 25 m and 27 m) performed by PDA, the bearing capacity of the piles was 2143 kN. In the construction site of Prorva, the bearing capacities of driven joint piles according to the results of SCLT were 2067 kN and 2042 kN. In the construction site of Tengiz, the bearing capacities of driven piles tested by SLT were 1000 kN and 1605kN. These investigations are important for the understanding of soil-structure interaction, especially of driven piles with a cross-section of 40x40 cm and lengths of 12 and 16m in construction site Tengiz.

Keywords: Pile, Static compression load test, Dynamic load test, Pile dynamic analyzer

1. INTRODUCTION

Tengiz is located on the 2,500 square km project license area which includes the super-giant Tengiz field, and a smaller but sizable Korolev field and several exploratory prospects.

The Tengiz and Korolev fields have the potential for an estimated 750 million to 1.1 billion metric tonnes of recoverable oil. Estimated original oil in place in the drilled and undrilled portions of Tengiz field is about 3 billion metric tonnes. At a world class size of 190 million metric tonnes, Korolev is one-sixth of the size of Tengiz.

Tengiz field is one of the world's deepest developed super giant oil fields, with the top of the reservoir at about 4,000 m. Tengiz reservoir is 19 km wide and 21 km long. The oil column measures an incredible one mile thick. The reservoir area is so large that one would have to run nearly two marathons to cover the entire distance around it.

The area of the Tengiz Oil Field where the FGP/WPMP focuses on is located in the western part of Kazakhstan, 150 km southeast of Atyrau and 100 km SSW of Kulsary. The investigated site is situated on the west of the highway from Kulsary to Beyneu. To the west, it is bounded to the northeastern shoreline of the Caspian Sea.

The Tengiz oil field accommodates a significant amount of recoverable hydrocarbon.

The aim of tests was to determine pile bearing capacities and analyze results of SCLT. Static tests were conducted by the requirements of the State Standards of the Republic of Kazakhstan (GOST).

The paper presents the analysis of the results of field tests of soils by piles on the construction site of Tengiz Oil Field in the west of Kazakhstan. Field static tests of soils were carried out by concrete piles with total lengths of 12 m and 16 meters and with a cross section of 40 × 40 cm. In this paper, the load-settlement curve of the test pile was predicted using the results of the soil investigations and the soil tests, in order to investigate the correlation of the soil parameters and the load-displacement curve. The results of CPT were used to estimate the distribution of the maximum shaft resistance down the pile shaft (see Figure 1).

Second Project construction site Sea Port Caspian “Prorva”, Atyrau Region, and the West of Kazakhstan. In Western Kazakhstan, a mega-project is “Cargo Transportation Route for Facilities of the north-eastern part of the Caspian Sea North Caspian Marine channel with berthing facilities Cargo Offloading Facility” (CaTRO, COF) the “Prorva” oilfield, Atyrau region. Testing of soils by piles was submitted data by engineers of the LLP “KGS-Astana” during November 2016 to May of 2017. This working plan (WP) has been developed for the production of driving operations of precast concrete piles consists of two segments, segment 1 and segment 2 are interconnected that supply the segment 1 length 16 m, segment 2 lengths 9.5 and 11.5 m, the total lengths 25.5 and 27.5 m, the reinforcement diameter of 8 mm with a cross section 400x400 mm [1]-[6].

2. GEOLOGICAL DATA AND PILE INSTALLATION

The Tengiz field is located in the North Caspian Basin, which is a pericratonic depression that formed during Late-Proterozoic until Early Palaeozoic time. The North Caspian Basin extends from the southeastern margin of the Russian Platform to the northern coast of the Caspian Sea. It is bounded to the north and west by the platform of the Volga-Ural Province, to the east by the Ural fold belt and the Mugodzhary zone, and to the east and south by the South Emba and Karpinsky Hercynian fold belts (see Figure 2).

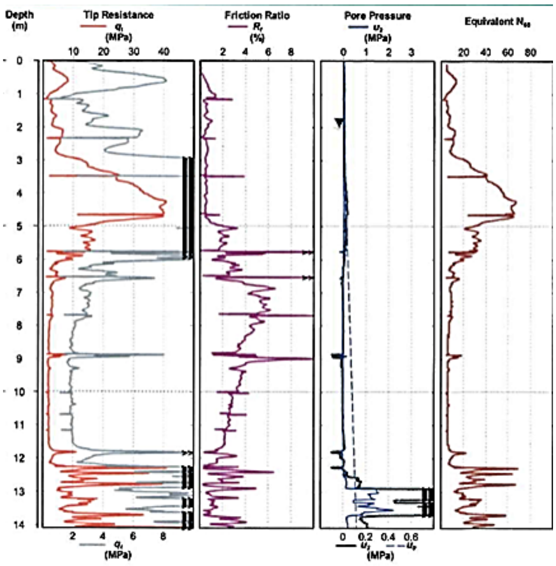

Fig.1 CPT on the construction site on Tengiz

The reservoir of the Tengiz field is formed by an isolated carbonate platform of Devonian to middle Carboniferous carbonates which have mainly developed from shallow-water carbonate facies and from reef build-ups. The platform more than 4 km of depth shows steep abrupt edges which shoal out to gentler slopes into the basin. The carbonate sequence contains significant amounts of hydrocarbon both onshore and offshore originating from Carboniferous shale and Devonian shale's carbonates. The structure of the Tengiz field is characterized by abrupt changes in porosity and permeability, thickness changes within the reservoir (overall thickness estimated to about 1.5 km) and a patchy distribution of the reservoirs.

The main purposes of the Cone Penetration Test survey program are (see Figure 1):

- to define physical-mechanical properties of the soil;
- to assess engineering-geotechnical conditions of the investigated area.

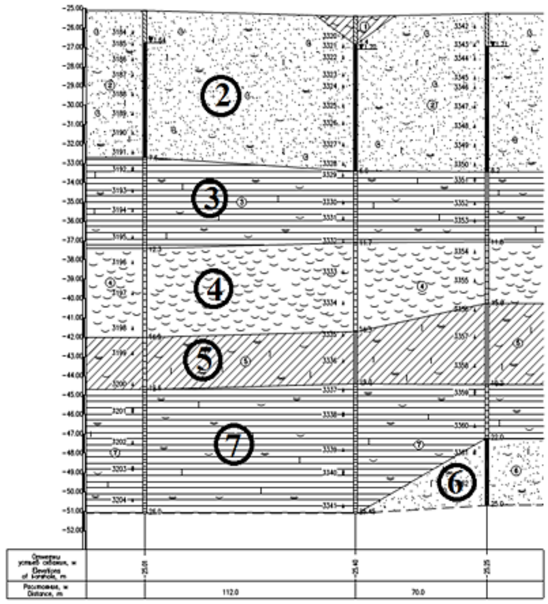

Fig.2 Geotechnical cross-sections on the construction site on Tengiz

Note 2 – calcareous fine sand; 3 – calcareous, light silty clay; 4 – gypsiferous (gypsified) soil; 5 – calcareous, arenaceous light loam; 6 – calcareous silty sand; 7 – calcareous silty clay.

DLT is a fast bearing capacity analysis field test and gives more or less reliable value of pile bearing capacity. For a definition of the bearing capacities of piles, it is required to use average refusal which is obtained during red-riving of the piles after their "rest". The rest time depends on soil condition of the site: for clayey soil 6 -10 days, for sandy and gravel soils up to 3 days. DLT and SLT 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 the type of hammer. The piles were driven to have an embedment length, Ld, of 12, 14, 15 m below the excavated ground surface, i.e, the pile tip level was 12 and 16 m below the original ground level (in construction site Tengiz).

Figure 3 shows the driving records of the test piles No.0353, 023, 7192, 097 and No.0724. The fall height of the hammer, the total number of blows, the number of blow per 0.25 m penetration and the set per blow, S, are shown in the figure. The driving records of the other test piles were similar to those shown in Figure 3 (in Tengiz Project).

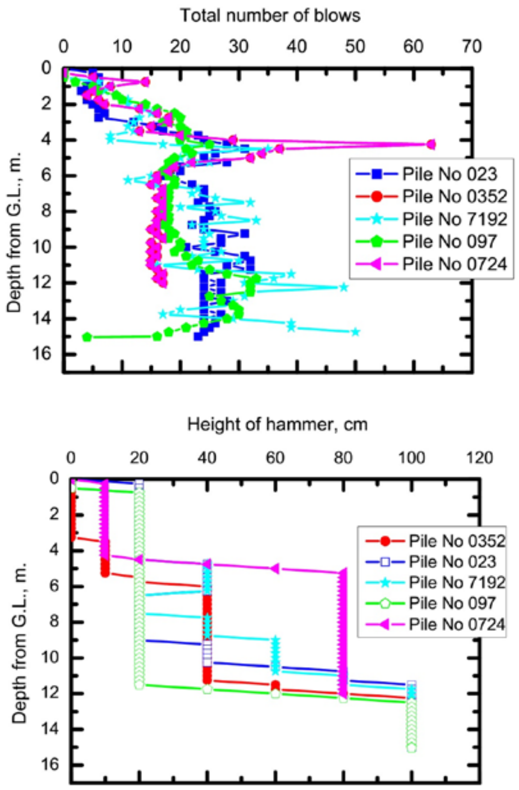

Fig. 3 Driving records of piles on site on Tengiz

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. SLT one of the more reliable field tests in analyzing pile bearing capacity [7-13]. SLT should be carried out for driving piles after the “rest” (see Figure 4). The work procedure covers the static compression load test on concrete piles cross section: 40 x 40 cm and length: 12 m and 16 meters. The base material is reinforced concrete with a reinforced tip. The Concrete grade is B35 with a minimum cement content of 400 kg/m^3 and a maximum water-cement ratio of 0.42 giving a compressive strength of 35 N/mm^2 after 28 days.

For the installation of the piles in this area a Junttan PM 25H hammer was used. The total mass of hammer is 13 tonnes with a stroke at maximum rated energy 1.2 m mass of the striking part of the hammer: 8 t. Certified impact energy of the hammer: 9600 kg·m. A Shock pad in the drive head of 20 cm Plywood was used. The Weight of the drive cap was 790 kg with an external diameter of top part 878 mm. The dimension of the drive cap: 42x42 cm (see Figure 4).

Fig. 4 Dynamic load testing in construction site on Tengiz

3. TESTING OF PILES

Pile Dynamic Tests were performed on precast concrete joint piles No. G-26 and B-38. Piles were tested with PDA (Pile Driving Analyser – Model PAX) using hammer JUNTTAN PM25LC with a hydraulic hammer HHK-9A of 9 tons of weight and a head-cap of 990 kg. On the tested pile a pair of accelerometers and at least a pair of strain transducers are attached at least two pile diameters below pile head.

This test is used to measure the axial deflection of a vertical deep foundation when loaded with static axial compression. This vertical compression pile maintained load test is usually carried out to ensure the structural and geotechnical soundness of the pile and also to predict settlement of other piles. The usual procedure is to increase the load in stages until the proposed working load and a certain factor of safety is reached and then to unload and to leave the load off until the rise or rebound substantially ceases, the test in standardized by ASTM D1143 [7].

Testing with a static load (compression) was carried out in accordance with ASTM D 1143 [7]. Vertical static loading of piles using the SCLT method is one of the most widely used field test methods for soil used to analyze pile bearing capacity.

Static compression load tests were performed on precast concrete joint piles No. TP-02 and TP-03, which are driving in COF Area with depth 25.50 and 27.50, from ground level Baltic datum -25,609 m and pre-augering with auger dia. 330 m, depth 11.40 m before driving.

SCL Testing platform presented itself system from steel, which consists of the metallic beam and 2 platforms located on equidistant distances from the center main beams (see Figure 5).

Fig. 5 The testing platform for static compression load test (SCLT) in site "Prorva"

As reference frame, two H-beams with h=20cm and length 5.3m were used which were placed on either side of the pile on steel support brackets bolted on piles. The two beams acted as a reference for the displacements sensors (See Figure 6).

Fig. 6 Static load test system in construction site Tengiz

The reference frames were regularly checked with an optical level instrument to detect any movements and cross-reference the movement of the pile.

For the loading, a 185 ton (Type CLS-2006) ENERPAC hydraulic jack was mobilized. The jack used is a double acting hydraulic jack with a stroke of 150 mm and a maximum hydraulic pressure of 700bar and pressure was created by using a manual-hydraulic pump (P-462) ENERPAC.

The jack was placed onto a specially fabricated steel pile head cover of 25mm. The space between pile head and the main beam was bridged with a hydraulic jack, steel plates, and Load Cell. A 300-ton Load Cell was used.

For the measuring pile movement, the clamp was bolted to the test pile. And the space between clamp surface and reference frame were bridged four electronic displacement transducers (sensors). The sensors had a stroke of 100 mm and an accuracy of 0.01mm. Static tests were conducted in accordance with the requirements of GOST 5686-94 "Soils. Methods of the field tests by piles" [10]. Loading of the tested pile is made uniformly, without shocks, loading steps which value is set by the test program, but is accepted no more than 1/10 the greatest load, given in the program. When burying the lower ends of full-scale piles in coarse elastic rock, gravel and packed sands, and also clay soil of a solid consistency it is allowed to accept the first three steps of loading equal 1/5 greatest loadings. At each step of loading of a production pile take readings on all instruments for measurement of deformations in the following sequence: zero reading - before loading of a pile, the first counting - right after application of loading, then sequentially four counting with an interval of 30 min and further in each hour before the conditional stabilizing of deformation (relocation attenuation). For the criterion of the conditional stabilizing of deformation in case of test take the speed of settling of a pile at this step of loading which isn't exceeding 0.1 mm [14]-[18]:

- in the last 60 min observations if under the lower end of a pile sandy soil or clay soil from solid to low-plastic consistency;
- in the last 2 hours of observations if under the lower end of a pile clay soil from high-plastic to free-flowing consistency.

Load test of production pile should be brought to the value at which the total settlement of the pile is not less than 40 mm. When the penetration of the lower ends of the in-situ piles in coarse elastic rock, packed sand and clay soils which have a solid consistency, the load should be increased to the values provided by the test program, but not less than half the value of the bearing capacity of piles determined by calculation, or calculated resistance of the pile in the material. During the control testing of piles during construction the maximum load should not exceed the design resistance of the pile in the material. Unloading piles of produce after reaching the maximum load steps equal to double the value of the speed of loading, with each stage of exposure of at last 15 min. After the complete unloading (to the zero) of watching the resilient moving of pile, it is necessary to conduct during 30 minutes at sandy soils bedding under the lower end of the pile, and 60 minutes at clay soils, with the removal of counting out through each 15 min [19].

4. RESULTS AND DISCUSSION

Figure 7 presents CAPWAP analysis results that include plots of measured pile head data obtained under the hammer blows from the end of driving and associated simulated pile head and toe static load-movement relationships.

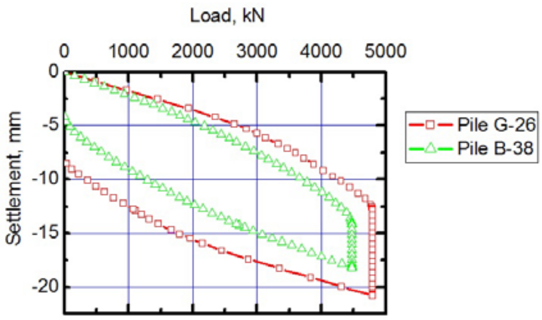

Fig. 7 Results of CAPWAP analysis in site “Prorva”

Difference between performed SCLT and PDA test could be explained partly because time gap between PDA and SCLT is 9 days and also because of driving nearby piles before SCLT test, what produce additional pore pressure and less friction at the time of SCLT. Since high bearing soil layers have large permeability it could be assumed that pore pressure effect and pile set-up are quicker.

We have to be aware that simulation of static load test with CAPWAP (or DLT) does not include any long-term effects like a creep or long-term settlements. This is why in almost all cases CAPWAP load-set curve is little higher than load-set curve from static load test, especially for higher loads and toe bearing piles.

In SCLT testing, the test load on the pile is specified for two cycles (1639 kN and 3274 kN, respectively). Loading and unloading was carried out in the following sequence: 0, 30, 60, 90, 125, 90, 60, 30, 0, 170, 210, 250, 210, 170, 125, 80, 40 and 0% of design. In the first cycle, the experimental pile was loaded to 100% of the design value (1639 kN); during the second cycle, to 200% (3274 kN). The hold time while loading was 60 min; while unloading −10 min. It took 360 min, respectively, to attain peak load [8]-[13].

Figures 8 and 9 show the results of SCLT testing.

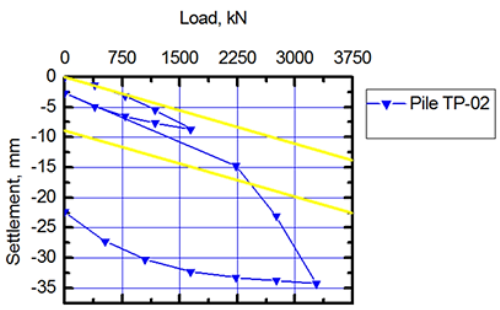

Fig. 8 Results of SCLT pile number TP-02 in construction site “Prorva”

SLT is a highly accurate and robust system that enables you to monitor static pile tests whilst also ensuring the safety of site operatives.

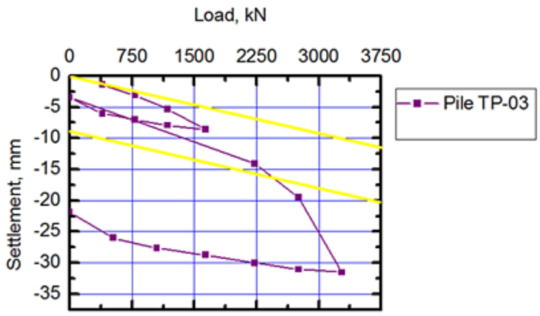

Fig. 9 Results of SCLT pile number TP-03 in construction site “Prorva”

Davisson’s Offset Limit Method (ultimate load) offers the benefit of allowing the engineer, when proofing a pile for a certain allowable load, to determine in advance the maximum allowable movement for this load with consideration to the length and size of the pile (See Table 1 and Figures 8 and 9) [20]-[22].

Table 1 Pile characteristics and formula’s Davisson

	Pile number	TP-02
1	Pile section area	A=0.16 m^2
2	Approximated pile diameter	D=45.0 cm
3	Load	P=3000 kN
4	pile length, L	26,75 m
5	Young’s	B 40
6	Econ	45 000 000 kPa
7	Elastic line=(P*L)/(A*E)	0.011 m= 11 mm
8	Davisson (ASTM) offset Δ=D/120+0.4	0.78 cm= 7.8 mm
9	Pile Ultimate Capacity (pile number TP-02) Fu	2480 kN (see Figure 8)
Second pile (Pile number TP-03)		
10	Pile length, L	23,00 m
11	Elastic line=(P*L)/(A*E)	0.0096 m= 9.6 mm
12	Davisson (ASTM) offset: Δ=D/120+0.4	0.78 cm= 7.8 mm
13	Pile Ultimate Capacity (pile number TP-03) Fu	2450 kN (see Figure 9)

A primary advantage of this method is that the actual limit line can be drawn on the load movement diagram already before starting the test. The offset limit load criterion is primarily intended for interpretation of quick testing methods, but it can also be used when interpreting results from the slow methods.

The Davisson Offset Limit is very sensitive to errors in the measurements of load and movement and requires well-maintained equipment and accurate measurements. However, it is easy to apply and has gained wide acceptance [21].

It is seen from Figure 10 that the load-settlement curves of piles No.0353, 023, 7192, 097 and No.0724 are almost identical, having an ultimate shaft capacity of 1000 kN and 1605 kN.

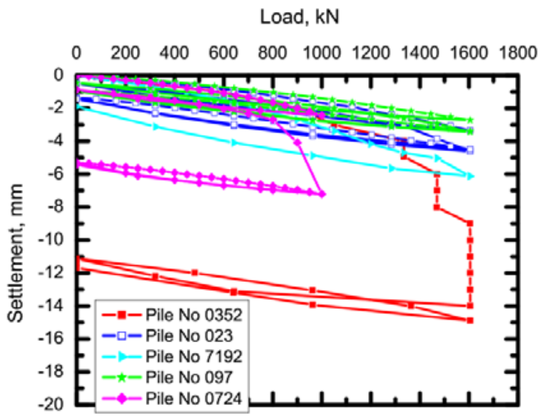

Fig. 10 Load and settlement curves of piles in construction site on Tengiz

A safety factor of SLT is 1.2 regarding of Kazakhstan Standard.

These investigations are important for the understanding of soil-structure interaction especially of driving piles with cross section 400x400 and length 12 and 16m on soil ground conditions in construction site Tengiz, Atyrau, West Kazakhstan.

5. CONCLUSION

The purpose of testing is a determination of bearing capacity and the penetration depth of immersion of composite piles in problematical ground soils of Atyrau region, Kazakhstan.

According to the results of DLT with PDA of driven piles (40×40 cm and lengths of 23 m and 26.75 m), the bearing capacity of the piles amounted to be 2143 kN. The bearing capacity of driven piles according to the results of SCLT amounted to be 2067 kN and 2042 kN (in a construction site “Prorva”, Atyrau Region, West Kazakhstan).

The disadvantage of the offset limit load lies in the difficulty of determining the modulus of elasticity E for concrete piles and concreted pipe piles. Davisson's method needs the pile to be loaded to failure to be applicable.

We have to be aware that simulation of static load test with CAPWAP (or DLT) does not include any long-term effects like a creep or long-term settlements. This is why in almost all cases CAPWAP load-set curve is little higher than load-set curve from static load test, especially for higher loads and toe bearing piles.

These investigations are important for the understanding of soil-structure interaction especially of driving piles with cross section 40x40 and lengths of 12 and 16 m in construction site Tengiz. The bearing capacities of driving piles are 1000 kN and 1605kN by SLT.

The allowable bearing capacity of the driving piles with an allowance for safety factor (FS = 1.2) equal to 833.3 kN and 1337.5 kN.

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