Geotechnical considerations of piling construction and testing in problematical soils of Kazakhstan

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ABSTRACT

Traditionally, pile load tests in Kazakhstan are carried out using static (SLT by GOST 5686) and dynamic (DLT by GOST 5686) load test methods. In cost and time for the static pile load test are relatively high compared to the dynamic pile load testing. Experienced driving piles with lengths of 7.5 m and 8.5 m, cross section 30x30 and bored piles with length of 31.5 m, diameter 1000 mm. The results of testing by the piles with the methods of vertical static compression loading test (by ASTM – SCLT), static loading test (by GOST – SLT) and bi-direction static loading test (by ASTM - BDSLT) methods are presented in this paper. This geotechnical investigation are important for understanding of soil-structures interaction on difficult soil ground conditions of construction sites of EXPO in the Capital of Kazakhstan.

Keywords: pile loading test, SLT, DLT, BDSLT, SCLT

1 INTRODUCTION

In this paper are provided results of static tests of soil, and comparing of bearing capacities by results of static and dynamic tests. Static tests of piles on the vertical indenting load, being the simulation which is the brought most closer to the reality step loading of a pile in the course of construction exponentiation, show real system behavior "pile- soil" in specific geological conditions. Test results are of great scientific interest based on which are made analytical researches and detections of empirical regularities. The purpose of comparing is determination of accuracy of an empirical method of determination of bearing capacity of piles dynamic loads. In relatively recent times, pile testing has been revolutionized largely because of high-powered computers (Zhussupbekov et al. 2017; Zhussupbekov et al. 2016). Fifteen to twenty years ago, testing options were restricted to static loading tests, with some costly and slow forms of integrity testing available. This paper presents details on the pile-testing regime used in Kazakhstan today (see Figure 1).

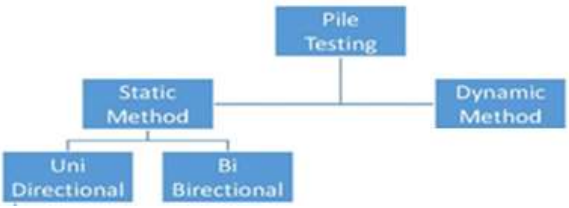

Fig. 1. Pile testing methods (Kazakhstan).

The complex of Expo in Nur-Sultan will comprise 4,000 apartments, a new hotel, a Congress Hall, and an indoor city stretching from the Nazarbayev University to the center of the New Capital of Kazakhstan. There will be located shopping malls, entertainment and service facilities as well. The total area of the exhibition stands at 174 hectares. The symbol of the exhibition EXPO will be the Kazakhstan platform itself made in the sphere form several floors high with 24000 m^2 in total. The symbol of the exhibition is located in the center of the exhibition village. It is surrounded by international, thematic and enterprise platforms.

Field-testing of soils by static sounding was executed for more detailed partition of soils and determination of bearing capacity of piles on soils. Soil test at each point of penetration came to an ends when the limit forces on the probe in accordance with GOST 19912-2001. A complex of laboratory and field researches of ground base was set at the construction site. Shown in Table 1 of the main characteristics of the subsoil near the experimental construction site Expo in Nur-Sultan (Zhussupbekov et al. 2016).

Table 1. The geological engineering elements.

Soils	Design data soil soaking in natural state				
	E, MPa	ρ	C	φ	Ro, kPa
Loams	12,5	1,91	38	19	-
Sands	17,0	1,92	2,0	35	-
Coarse sands	21,0	1,92	1,0	38	-
Gravel soils	23,0	-	-	-	300
Loams	14,0	2,04	27	27	-

Soils	36,4	-	-	-	400
Rock debris soils	-	-	-	-	450

2 STATIC LOAD TESTS OF BORED PILES

Static testing with Bi-directional Static load method (O-Cell testing) was carried out for the test of deep foundations at the site of the construction of this object. Four bored piles were subjected to static tests (O-cell testing- 2 piles and SCLT- 1 pile and SLT by GOST-1 pile) (see Figure 2) (Zhussupbekov et al. 2016; Zhussupbekov et al. 2018).

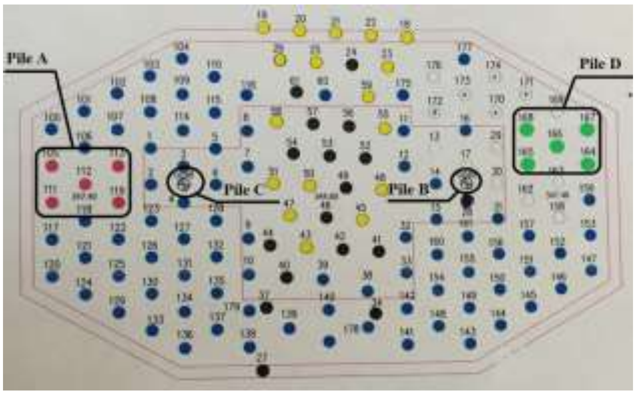

Fig. 2. Pile name and test methods in construction site: Pile A -SCLT; Pile B (O-Cell-1); Pile C (O-Cell -2); Pile D (SLT).

2.1 Static Load Test (SLT) in accordance with the requirements of Kazakhstan Standard (GOST 5686)

Static tests of soils for bored piles are carried out in accordance to GOST 5686-94. Test was carried out after the pile concrete strength had attained more than 80% of the design value (Zhussupbekov et al. 2018).

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 consistence 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 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:

-in the last 60 min observations if under the lower end of a pile sandy soil or clay soil from solid to low-plastic consistence;

-in the last 2 hours of observations if under the lower end of a pile clay soil from high-plastic to free-flowing consistence.

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 speed of loading, with each stage of exposure of at least 15 min (Zhussupbekov et al. 2016).

The bearing capacity of the tested piles with static vertical-pressing forces, at the above construction site, was 12000 kN (see Figure 3). It should be noted that even with a maximum test load of 12000 kN, only the elastic operation of the pile in the ground is manifested, as evidenced by a slight residual soil settlement after unloading, which is 1.4 mm. In Kazakhstan, a safety factor of 1.2 is adopted in pile design, if static load test are carried out on one pile in the construction site. Therefore, the design value of ultimate pile capacity, Qd, was estimated to be Qd= 12000/1.2=10000 kN.

2.2 Pile Static Compression Load Test in accordance with the requirements ASTM

Static compression loading testing was carried out in accordance to ASTM D 1143.

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. In the first cycle, the experimental pile was loaded to 100% of the design load, in the second cycle to 200% (12 000 kN). The holding time of intermediate loading stages was 30 minutes, unloading - 20 minutes. The time for maintaining peak loads was 120 and 240 minutes, respectively (Zhussupbekov et al. 2016).

The test pile was a 1000 mm diameter bore pile. the static load test is performed as per ASTM D1143. Test pile up to 12000 kN.

Reaction piles to be used No.164, 165, 167, 168 (see Figure 3). Reaction Piles Length: 31.5m and cross-section 1000mm. Tension Load per Reaction Pile 12000/4=3000kN. Friction force: 1.0m * 3.14 - 31.50m * 75kPa * 0.75 = 5563 kN/ FS=2.0, Fall=2782 kN.

Reaction pile weight:

$$31.5*1.0*2/4*3.14*25=618kN+2782kN=3400kN$$

3400kN>3000kN;

Fig. 3. Static top-down load test in construction site.

Following results are obtained from the mentioned static compresion load test preliminary test pile:

a) the maximum settlement up to 6000 kN is 2.09 mm;

b) the maximum settlement up to 12000 kN is 10.51 mm (Zhussupbekov et al. 2016).

The working test pile is loaded up to 200% of the working load and settlements of the pile under various load steps are recorded. Recorded settlements of 2.09mm (at 100% working load) and 10.51mm (at 200% working load) are observed to be within acceptable limits which calculated as below (1):

$$Uz = (\frac{PL}{AE}) + 0.01d \qquad (1)$$

Uz=0.025m=25mm>10.51mm.

The Figure 4 shows results of static compression load test by ASTM and static load test by GOST.

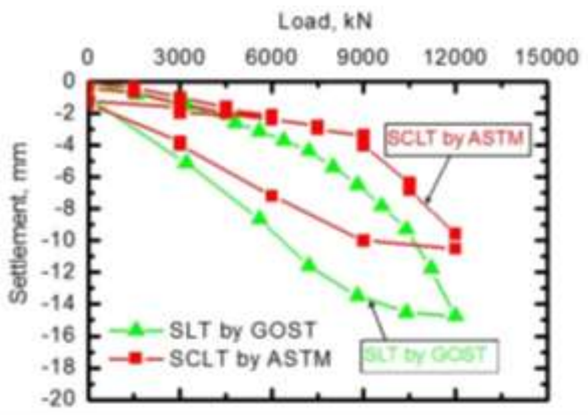

Fig. 4. Results of static loading tests (methods: SCLT and SLT).

2.3 Bi-Directional Static Load Test in accordance with the requirements ASTM

Bi-Directional static tests of soils for bored piles are carried out in accordance to ASTM D8169. Bi-Directional static load tests by the Osterberg method are carried out at the pre-project stage, before the design and mass penetration of the piles begins. The method makes it possible to separately determine the bearing capacity of the ground along the tip and along the lateral surface of the pile. It is usually used for testing large or large drill or ramming piles.

When testing piles using the immersed jack, the O-cell power cell is installed directly into the body of the test pile. The power cell is a system of calibrated hydraulic jacks in a protective casing. It divides the test pile into two elements: the upper one, located above the power cell, and the lower one, located under the power cell.

The monitored load in the power cell (O-cell jack) is created by the hydraulic pressure from the oil station pump located on the surface and connected to the power cell by the oil pipe. The pressure is controlled by a precision electronic pressure gauge calibrated in the general scheme of the hydraulic system. In the process of increasing the load on the walls of the jack piston, the power cell opens. The result of this disclosure is the Settlement of the upper element of the pile upward and the lower element downward. The Settlement of the upper element is measured by rod strain gages mounted on the upper plate of the jack and by displacement sensors installed in the upper part of the steel pipe. The settlement of the lower element is measured by means of rod strain gages mounted on the lower plate of the power cell (O-cell jack).

The tests are continued until one of three conditions occurs: it will be that the limit of surface friction or lateral shear is reached; the ultimate load-bearing capacity will be reached; the maximum power of the power cell (O-cell jack) will be reached. Osterberg's method allows testing piles of large dimensions without the use of anchor piles, which reduces costs at the stage of geotechnical surveys.

According to the results of engineering and geological surveys, bored piles 31.5 m long and 1000 mm in diameter were used as foundations. In order to control and evaluate the compliance of the bearing capacity of piles on the ground, the design loads were field static tests by the Osterberg method (see Figure 5).

The hydraulic jack is installed at a depth of ½ the length of the pile - 16.8 m. The power cell is connected by hydraulic hoses to the hydraulic pump located on the ground surface.

When designing the O-Cell test, special attention should be paid to the study of the geotechnical structure of the soil massif of the construction site, since the location of the jack in the body of the pile depends on the accuracy of the survey data, in particular the results of assessing soil resistance. The correct decision to place the jack affects the quality of the tests carried out, since the differentiated determination of the load-bearing capacity components (along the lateral surface and below the lower end) is reduced to the correct selection of an equal ratio of the lateral resistance of the soil along the upper element to the resistance below the lower end of the lower element of the experimental pile.

Fig. 5. Bi-Directional static load test in construction site.

2.4 Results of field trials using the Static Load Test and Bi-Directional Static Load Test methods

On results, tests the charts of dependence were got settings of pile from loading and change setting on the stages of loading in time.

For a criterion maximum possible setting were accepted pointing regulated in SNIP RK 5.01-03-2002 - Pile foundations sub clauses:

- for the particular value of maximum resistance of pile Fu the pressing loading is necessary to accept loading under act of that the tested pile will get setting, equal S and determined on a formula (2):

$$S = \zeta S_{u,mt} \ , \tag{2}$$

where $S_{u,mt}$ - maximum value of middle settings of foundation of the designed building or structure, for productive and civil one-story and multistory building with complete framework a 8cm (for reinforce-concrete constructions) is accepted by equal on pointing of SNiP RK 5.01-01-2002 – Bases and foundations;

ζ - transition coefficient from a maximum value of middle settings of foundation of building or structure Su, mt to setting of the pile got at static tests with the conditional stabilizing (damping) of settings, accepted by equal 0,2 on pointing (by MSP 5.01-101-2003).

The Figure 6 shown a comparison of the test results: the "load-sludge" curve obtained by the SCLT method and the equivalent "load-settlement" curve determined by the O-cell method. For the comparative criteria of Pile A (SCLT by ASTM), Pile B (O-Cell-1), Pile C (O-Cell-2) and Pile D (SLT by GOST) results fixed settlements of 10 and 14 mm has been taken.

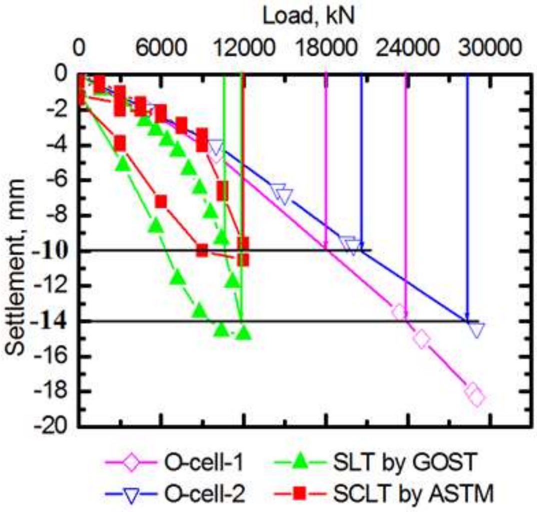

Fig. 6. Comparison of test results carried out by methods: SCLT, SLT and BDSLT (O-cell).

Table 2 presents a comparative analysis of the bearing capacity of piles, obtained by different methods in this research.

Table 2. Results of pile testing

ID	The results of fixed settlements of 10 and 14 mm has been taken	
	10 mm	14 mm
Pile A (SCLT by ASTM)	11788 kN	-
Pile B (O-Cell-1)	18220 kN	23985 kN
Pile C (O-Cell -2)	20535 kN	28385 kN
Pile D (SLT by GOST)	10630 kN	11814 kN
Fixed Turnover Ratio Definition		
Pile A (SCLT by ASTM) / Pile D (SLT by GOST)	1.1	-
Pile C (O-Cell -2) / Pile B (O-Cell-1)	1.1	1.1

3 STATIC LOAD TESTS OF DRIVING PILES (SLT BY GOST)

Static tests were conducted in accordance with the requirements of GOST 5686-94 "Soils. Methods of the field tests by piles".

3.1 Results of static tests of soils by driving piles

On results, tests the charts of dependence were got settings of pile from loading and change setting on the stages of loading in time.

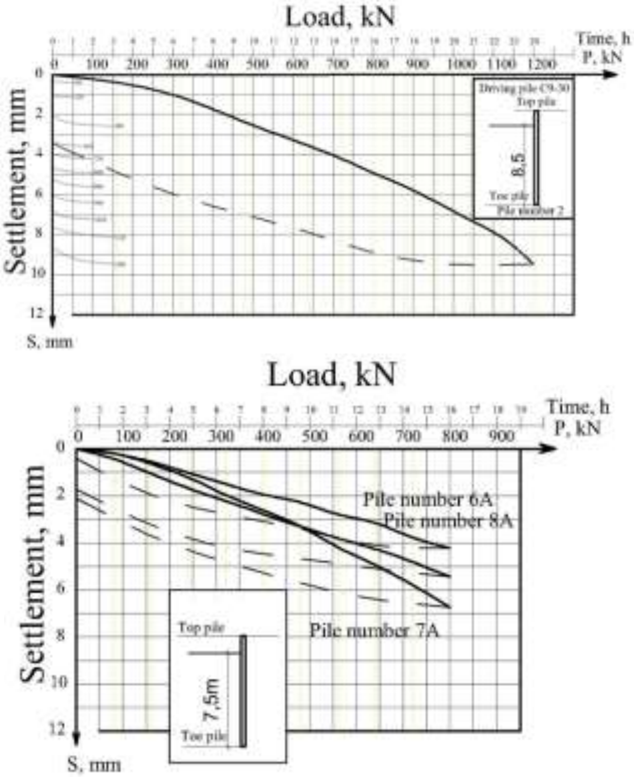

Fig. 7. Results of Static load test (SLT).

3.2 Dynamic load tests (DLT by GOST)

Dynamic Load Test is a fast bearing capacity analysis field test and give more or less reliable value of pile bearing capacity. 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. All the reinforced concrete piles having a width = 0.3 m, area cross-section = 0.09 m^2, length = 12m, weight = 2730kg, modulus of elasticity = 27500 MPa, and density ρ_p=2500 kg/m^3. In Kazakhstan, DLT is carried out by using different types of pile driving machines and hammers. Before starting the test, pile surface alone the whole length had been painted through each 1 meter by marks; last one meter is painted through each 0.1 meters. For our project pile driving was performed by using the driving machine "Junttan PM-25" with hydraulic hammer HHK-7A. The weight of the hummer is 7000 kg and the headband weight is 990 kg. During the pile driving process the number of blows of the each 1 meter of pile penetration into the soil ground and of the last one meter in each 0.1 meter were counted. The falling heights of blowing part of the hammer were recorded at the same time. Pile driving was continuing till the design refusals - 0.5 cm (cm/blow). It is common practice to use the following driving equation to estimate the driving resistance (ultimate pile capacity), Fu, in Kazakhstan (GOST 20176 2009) (3):

$$Fu = \frac{\eta AM}{2}\left[\sqrt{1+\frac{4Ed(m_1+\varepsilon^2(m_2+m_3))}{\eta AS(m_1+m_2+m_3)}}-1\right], \qquad (3)$$

where: η- coefficient dependent on the concrete strength of the piles 1500 kPa; A- cross sectional area of pile; M = coefficient (1.0 for hammer impact); Ed – potential energy of hammer – WH-hammer weight; H – fall height of hammer; h = 0.7, S-set per blow; ε-coefficient of restitution; m_1- total mass of hammer device; m_2- total mass of pile and pile cap, and m_3- mass placed between pile head and pile cap.

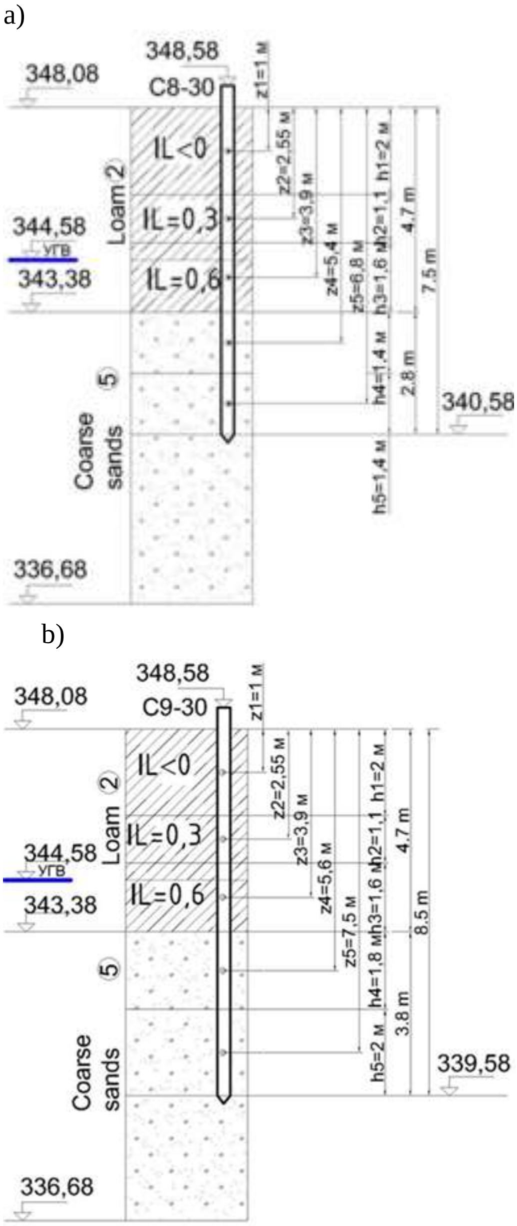

Fig.3. Charts for Calculation: a) for Precast Driven Piles C8-30, Penetration Length 7.5 m; b) for Precast Driven Piles C9-30, Penetration Length 8.5 m.

As of to calculation chart to define the design load and bearing capacity of precast driven piles C8-30 and C9-30, penetrated in soil 7.5 m and 8.5 m. Find the bearing capacity Fd on formula 7.8 [MSP 5.01-101-2003; p. 7.2.2] (4):

$$F_d = \gamma_c (\gamma_{CR} RA + u \sum \gamma_{cf} f_i h_i), \qquad (4)$$

where - γ_c factor of the conditions of the work to piles in soil, taken γ_c=1;

R - an accounting resistance of the soil under lower end of the piles, кPa, taken on table 7.1;

A - an area of the cross-section to piles, m^2;

u - an external perimeter of the cross-section to piles, m;

fi- an accounting resistance i-go layer of the soil of the basis on lateral surface of the piles, кPa (ton/m^2), taken on table 7.2;

hi - a thickness *i*-go layer of the soil, touching with lateral surface of the piles, m;

γ_{cR}, γ_{cf} - a factor of the conditions of the functioning(working) the soil under lower end accordingly and on lateral surface of the piles, taken on table 7.3. In this instance $\gamma_{cR} = \gamma_{cf} = 1$.

We find importances R for our engineering-geological conditions calculation chart "a" for driven pile C8-30:

- for coarse sand, at the depth 7,50 m, R=7367 кPa.

Importance fi on lateral resistance of the surfaces pile:

- for loam hard with IL<0 on average depth layer Z_1=1 m, f_1=35 кPa;

- for loam halfhard with IL=0,3 on average depth layer Z_2=2,55 m, f_2=33 кPa;

- for loam with IL=0,6 on average depth layer Z_3=3,9 m, f_3=16 кPa;

- for song large and gravels on average depth layer Z_4=5,4 m, f_4=57 кPa;

- for song large and gravels on average depth layer Z_5=6,8 m, f_5=59 кPa.

The Area of the cross-section pile A=0,09 m^2.

External perimeter of the cross-section pile u=1,2 m.

Bearing capacity C8-30 and C9-30 under the coarse sand forms (4):

C8-30:

$$F_d = 1016kN;$$

C9-30:

$$F_d = 1105kN;$$

The Design load on driven piles C8-30 and C9-30 define on formula 7.2 [MSP 5.01-101-2003; p. 7.1.11]: under the coarse sand forms (5)

$$N = \frac{F_d}{\gamma_k}, \qquad (5)$$

C8-30:

$$N = \frac{F_d}{\gamma_k} = \frac{1016}{1,4} = 726kN$$

C9-30:

$$N = \frac{F_d}{\gamma_k} = \frac{1105}{1,4} = 789kN$$

Table 3 presents a comparative analysis of the bearing capacity of piles, obtained by different methods in this research.

Table 3. Results of driving pile tests (Bearing capacity).

№	Name	The value of the bearing capacity of piles, Fd (kN)	Safety factor	Bearing capacity, kN
1	DLT C9-30 (L= 8,5m)	1105	1.4	789
2	DLT C8-30 (L= 7,5m)	1016	1.4	726
3	SLT -2 (L= 8,5 m)	1200	1.2	1000
4	SLT-6A (L= 7,5m)	800		667
5	SLT-7A (L= 7,5m)			
6	SLT-8A (L=7,5m)			
7	Result of CPT (by GOST)	- at the depth of 7,0 m bearing capacity - 803kN; - at the depth of 7,2 m bearing capacity - 887kN.	1,25	(depth of 7m) -643; (depth of 7,2 m) -710.

4 CONCLUSIONS

Existing pile foundation standards practiced in Kazakhstan are out-of-date and are in urgent need for modernization. This paper presented very short descriptions of coming changes to the concept of Kazakhstan pile foundation design.

According to the results of DLT of driven piles (cross-section 30×30 cm and lengths of 7.5 and 8.5m), the bearing capacity of the piles amounted to be 726 and 789 kN. The bearing capacity of driven piles according to the results of SLT-2, SLT-6A, SLT-7A, SLT-8A amounted to be 1000 kN and 666 kN.

The overlay of the curves showed that the convergence of the graphs is observed only at the initial stage of loading, then a change in the trajectory of the SLT curve, characteristic of the creeping stage of soil resistance, is observed, whereas the O-cell curve (at this stage of loading) is more characteristic of the elastic resistance of the soil.

When testing piles using the SLT method "from top to bottom", a design load of 6000 kN corresponds to a draft of 2.09 mm, a maximum test load of 12000 kN is a draft of 10.51 mm. It should be noted that even with the maximum test load, only the elastic operation of the pile in the ground is manifested, as evidenced by a slight residual soil sediment after unloading, which is 1.4 mm.

When testing piles using the O-cell test, a maximum test load of 29000 kN corresponds to a draft of 18.35mm (for the PTP-1 pile) and - 14.40 mm (for the PTP-2 pile). During the testing of the piles, both elastic and plastic deformation of the soil was observed, due to a greater test load on the pile than in the SLT method.

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