Piling Construction and Testing of Megastructures on Problematical Soil Ground of Kazakhstan

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ABSTRACT: During the last 20 years, many high-rise buildings supported by pile foundation are rising up in Astana, the new capital of Kazakhstan. Following megaprojects are already completed: Ministry of Transportation and Communication, Expo-2017, Housing estate – Izumrudny Kvartal (Emerald Square), Cultural and Entertainment Center – Khan Shatyr and so on. Many megaprojects are under construction or in planning. One of the unique projects is the housing estate "Abu-Dhabi Plaza" which started on 2011 in Astana.
The article presents loading tests of large diameter and deep boring piles on the construction site Expo-2017 in new capital city of the Republic of Kazakhstan. Results of static pile tests using the static compression loading test (by ASTM – SCLT), static loading test (by GOST – SLT) and bi-direction static loading test (by ASTM - BDSLT or O-cell) methods are presented in this paper. Hereafter the results of underground testing by the piles with the methods of vertical static testing are presented, which had been made on Expo 2017 projects, buildings of Pavilion in Astana, Kazakhstan.
Keywords: pile, SCLT, SLT, O-cell or BDSLT, load, settlement.

1. INTRODUCTION

High-rise buildings (buildings with a height of more than 75 m) pose new challenges for engineers, especially in the field of calculations and design of above-ground structures, bases and foundations. Therefore, designers of both above-ground and underground parts of the building are forced to resort to more complex methods of calculation and design. Especially this applies to geotechnicians, who are involved in the design of foundations for high-rise buildings.

By complexity, problematic design, erection, operation, impact on the environment and people, high-rises can be attributed to the structures of increased danger and complexity.

Kazakhstan has its own modern experience in designing and erecting high-rise buildings above 75 m of unique structures, including the "Emerald Quarter" (210 m), "Northern Lights 1" (180 m) in Astana, Railways Building (174/156 m), Transport Tower (the building of the Ministry of Transport and Communications) (155 m), Khan-Shatyr (150 m) (see Figure 1).

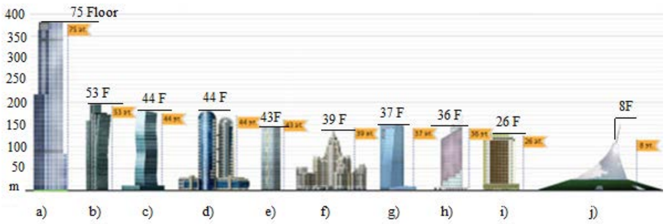

Figure 1 High-rise buildings above 75 m of unique structures in Kazakhstan

Note: a) Abu-Dhabi Plaza; b) Emerald Quarter; c) Northern Lights 1; d) Railways Building Towers; e) Grand Astana Tower; f) Triumph of Astana; g) Astana Marriott Hotel; h) Transport Tower (the building of the Ministry of Transport and Communications); i) Hotel "Kazakhstan" (Almaty city) and j) Khan-Shatyr.

After the completion, Abu Dhabi Plaza will become the tallest building in Kazakhstan and Central Asia, and the height of one of the blocks of the complex will be 320 meters.

The architectural concept is shown in Figure 2, which represents the construction site - in the centre of which a skyscraper should rise.

This grandiose skyscraper will be the fourteenth tallest building in the world. The architect of the project is famous British architect Norman Foster.

The total territory of "Abu Dhabi Plaza" will be about 500 thousand square meters, including 206 thousand square meters of ground floor for parking and retail spaces.

The Features of high-rise buildings present high requirements to the results of the EGS (engineering and geotechnical survey) and should solve the following main tasks in their implementation:

- study of the geological structure of the soil massif with large volume (up to 60 m in depth and at least 2 foundation widths beyond its contour)
- reliable assessment of the hydrogeological and hydro chemical conditions of both the compressible soil massif, and in the excavation zone and adjacent territory with the establishment of their corrosive aggressiveness, in time;
- determination of deformation and strength properties of dispersed and rocky soils at large ranges of voltage changes;
- instrumental observation and monitoring of deformations of the soil massif of the basement foundation and the adjacent territory under static effects.

Figure 2 Project of Abu Dhabi Plaza in Astana

Before you start laying the foundation, you need to decide on its technology and depth. It depends on the expected load on it and the features of the natural conditions, namely the type of soil and the depth of the groundwater. Abu-Dhabi Plaza residential skyscraper consists of 5 main towers:

-Block R- offices and living quarters;
-Block O- office building;
-Block H- hotel and furnished rooms;
-Block Y- offices of class «A»;
-Block Z-residential apartments.

2. THE ANALYSIS OF THE DEFORMATION OF THE BASE FLAC3D

The analysis of the deformation of the base is based on the production of a load of its own weight of a single design in the horizontal plane of the vertical deformation, as shown below in the Figure 3.

The horizontal grillage plan is a form of a reference deformation and is used to estimate column drafts in various places. The draft for each stage of construction is calculated using the ratio of the vertical reaction at each stage to the vertical reaction at the full design load. The block R and the basement tile of the general basement are modelled taking into account the changes in thickness. Model physical boundaries are set within the grid 9 to 21 and the grid from A to M. Figure 3 and Table 1 shows the settlement of the contour of the site using the program FLAC 3D.

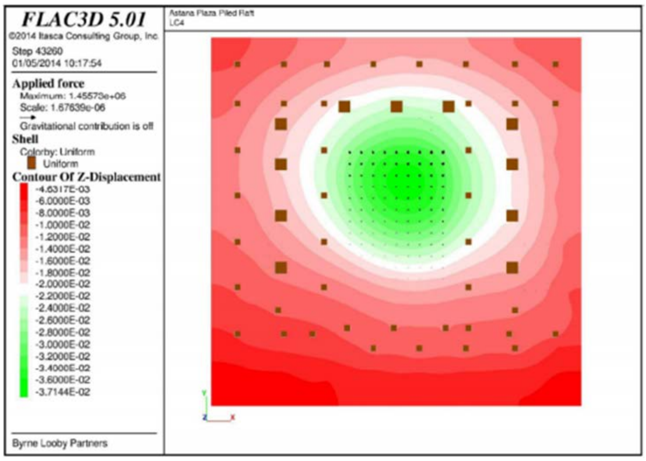

Figure 3 Deformation base (with software program FLAC 3D)

The wind forces are based on the tower dynamic parameters, such as the natural frequency and damping of the tower. The wind loads indicated in the RWDI report were based on observational data over a 50-year period. Multiplication by a safety factor 1.4 was used to estimate the ultimate wind load.

Table 1 Draft of the plate foundation under full fixed and movable loads

Location:	**Model 1 (with software program FLAC 3D)**
Core of the building (core) (Block R)	37,4 mm
Column RC1 (Block R)	14 mm
Uneven settlement (Block R)	23,4 mm

The tower's wind loads fluctuate depending on wind speed, wind direction, and local effects such as swirls. The measurement of the wind shield for comparison with the model is not suitable, and will not provide any meaningful information for the purpose of building evaluation. Nevertheless, the effect of the measured wind speed and direction is considered when comparing the results of deformation with the computational model for gravity loads. Since the design of wind loads is based on the dynamic reaction of the building, the frequency of the natural oscillation and the estimate of the damping of the tower will be measured to compare the values used to calculate the wind strength. The effect of temperature on the final model will be limited to normalize the effect on the measured data. Recorded ambient temperatures at the time of measuring the settlements of the tower are necessary to ensure the normalization of the results. The measured data must be collected in order to minimize the effect of temperature effects throughout the tower, and also to limit the effect of localized heating, the effect of solar warm amplification, and the settlement of the sun during the day. Localized temperature control at specific work sites below the working front will be taken into account. The building models will take over the temperature of the structural elements within all the façade closed floors especially not heated to the same temperature throughout the tower. If inaccessible, an external ambient temperature sensor will be used during data collection. Structural elements in unloaded floors opened to the environment will be considered at ambient temperature during the collection of these readings. Hydrostatic pressure under the slab foundation was not considered. Seismic loads are not taken into account for this project, since Astana is not classified as an earthquake zone.

3. SECOND PROJECT EXPO 2017

The site chosen to accommodate Expo-2017 Astana is located 8 km south of the old city centre of Astana and just 4 km from the new government block on the southern bank of the Ishim River. The exhibition area with a total area of 25 hectares is surrounded by a territory of 149 hectares, intended for housing residential and mixed buildings, auxiliary exhibition facilities and transport infrastructure. The total area of the Exhibition Area is 174 hectares (see Figure 4).

Pavilion of Kazakhstan (Sphere) is the only building in the world, which is a sphere of finished form with a diameter of 80 meters. Possessing unique design features, a given shape of the building, as well as the functions of the exhibition building, the pavilion at the same time serves as a prime example of the use of renewable energy sources (Zhussupbekov A.Zh., etc (2017)).

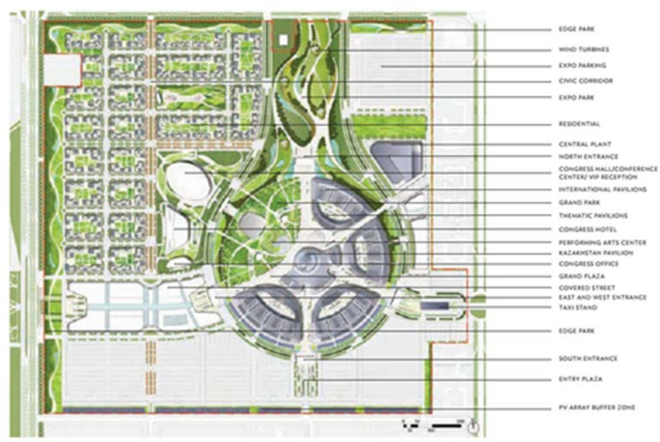
Figure 4 General layout of the Expo-2017 Exhibition

4. ENGINEERING - GEOTECHNICAL DESCRIPTIONS OF CONSTRUCTION SITES EXPO-2017

At the construction site, a complex of laboratory and field studies of the soil base was also carried out. Based on the field description of the soils confirmed by the results of cone penetration tests and laboratory tests, a division of the soils composing the site of prospecting for engineering-geological elements in the stratigraphic sequence of their occurrence was carried out (see Figure 5).
Figure 5 shows the engineering and geological sections of the EGE.

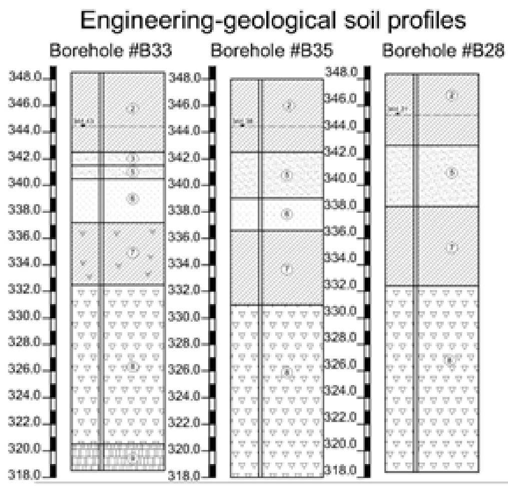

Figure 5 Engineering-geological cross- sections in construction site Expo-2017, Astana, Kazakhstan

5. STATIC PILE LOAD TESTING

Static testing with Osterberg 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).
The target of this tests was obtaining of bearing capacity of piles on problematical soils ground of Expo 2017 (Zhussupbekov and Omarov A.R. (2016))

5.1 Static tests in accordance with the requirements of GOST (CIS Standard)

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. As part of the installation for soil testing, static pressing forces should include equipment:

- device for pile loading (jack);
- supporting structure or platform for perceiving reactive forces (for example, a system of beams with anchor piles or a platform);
- device for measuring the settlement of piles during the test (reference system with measuring instruments).

Before starting the tests, the wire should be subjected to preliminary stretching for two days with a load at least four kilograms. During the tests, the load on the wire should not be more than one and a half kilograms. Limits of measurement and the price of division of pressure gauges used to determine the load on the pile during testing are selected depending on the greatest load on the pile provided by the test program, with a margin of at least 20 precent. Loading of the tested pile is performed evenly, without impacts, by load stages, the value of which is set by the test program, but it is taken no more than 1/10 of the maximum load on the pile specified in the program. When the lower ends of the field piles are buried into coarse-grained soils, gravel and dense sands, and clay soils of solid consistency, the first three load stages are assumed to be equal to 1/5 of the maximum load in the program. At each loading stage of the full pile, the reports for all strain gauges are taken in the following order: zero report - before loading the pile, the first report immediately after the load is applied, field this consistently four reports with an interval of thirty minutes and then every hour before the conditioned deformation stabilization (Zhussupbekov A.Zh., Omarov A.R. (2016)).

For the criterion of conditional stabilization of deformation during testing by the natural pile, the speed of the pile sediment at a given loading stage is assumed to not exceed 0.1 mm in the last 60 minutes of observation if sandy soils or clay soils lie from the hard to the turgid consistency under the bottom of the pile, the bottom end of the pile lies clay soils from the fleshy to the flowing consistency, then two hours of observation. The test load of the field pile shall be adjusted to a value at which the total pile residue is not less than forty mm. When the lower ends of the field piles are deepened into coarse - clastic, dense sandy and clay soils of solid consistency, the load should be brought to the value provided by the test program, but not less than the one-and-a-half pile load-bearing capacity determined by calculation, or the design pile resistance of the material.

The bearing capacity of the tested piles with static vertical-pressing forces, at the above construction site, was 12000 kN (Figure 7).

The calculated permissible vertical-punching load on the pile, taking into account the safety factor $\gamma k = 1.2$ according to paragraph 3.10 of SNiP RK 5.01-03-2002 "Pile foundations", it is recommended to take equal 10000 kN (Zhussupbekov A.Zh., Lukpanov R.E., Omarov A.R. (2016)).

5.2 Pile Static Compression Load Test by ASTM (SCLT method)

Static compression loading testing was carried out in accordance to ASTM D 1143-07 (2013).

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 6000 kN of the design load, in the second cycle to 12000 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 A.Zh., Lukpanov R.E., Omarov A.R. (2016)).

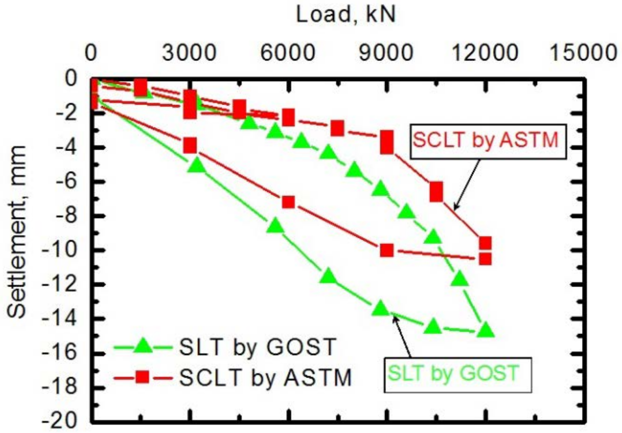

Figure 7 Results of static loading tests (SCLT and SLT)

The bearing capacity of the tested piles with static vertical-pressing forces, at the above construction site, was 12000 kN (see Figure 7). 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.

5.2 Method O-cell piles static test in accordance with ASTM

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.

The peculiarity of the O-cell test method is that the load is applied not on the head of the pile, but in the body of the pile, where the jack (power cell) is installed, working in two directions. The power cell (O-cell jack) divides the test pile into two parts: the upper (upper test element - UTE) and the lower (lower test element-LTE). The power cell (O-cell jack) is a system of calibrated hydraulic jacks combined into one module. 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 (Zhussupbekov A.Zh., Omarov A.R. (2016)).

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.

5.3 Results of field trials using the Static Load Test and Osterberg methods

Figure 8 shows 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 SLT, SCLT and O-cell results fixes settlement of 10 and 14 mm had been taken (see Table 2).

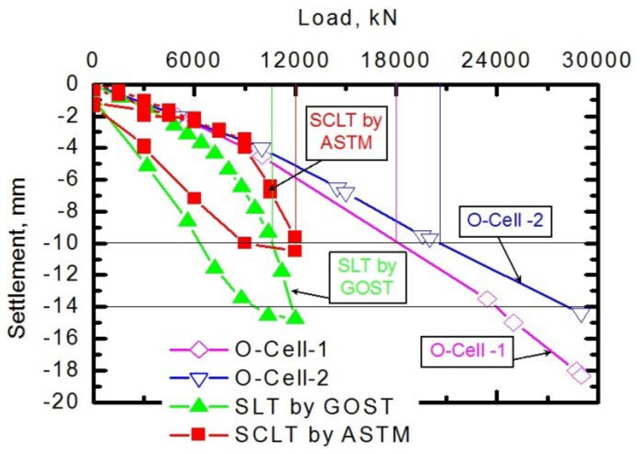

Figure 8 Comparison of test results by SCLT, SLT and O-cell methods

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

Table 2 Different tests

ID	The value of the bearing capacity of piles, Qd	Results fixes settlement	
		10 mm	14 mm
Pile (SCLT by ASTM)	12000 kN	11788 kN	-
Pile (SLT by GOST)	12000 kN	10630 kN	11814 kN
Pile (O-Cell -1)	29000 kN	18220 kN	23985 kN
Pile (O-Cell -2)	29000 kN	20535 kN	28385 kN

3. CONCLUSION

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.
According to the results of the SCLT unloading curve, elastic work of the soil is still evident. The reason for the abrupt change in the trajectory of the SCLT curve, which is not characteristic of the elastic work of the ground, is the holding time of the loading stages (lower compared to the O-cell test method), which can also explain the almost completely elastic work of the soil during O-cell tests.
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 18.35 mm (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.

4. REFERENCES

Zhussupbekov A.Zh., Omarov A.R., Zhukenova G.A. (2017). The experience in applying of static load and O-cell pile testing geotechnologies in problematical soil conditions of Astana. International Mini symposium Chubu (IMS-CHUBU)-Nagoya, Japan. Japanese Geotechnical Society Special Publication. Vol. 5 No. 2 pp 167-171.

Zhussupbekov A.Zh., Omarov A.R. (2016). Geotechnical and construction considerations of pile foundations in problematical soils. Proceedings of the 8th Asian Young Geotechnical Engineers Conference (8 AYGEC). Astana, Kazakhstan. pp 27-32.

GOST 5686-94. 1994. (1994). Methods for field testing by piles. Gersevanov Research Institute of Bases and Underground Structures (NIIOSP), Moscow.

Zhussupbekov A.Zh., Omarov A.R. (2016). Modern advances in the field geotechnical testing investigations of pile foundations. The 15th Word Conference of Associated Research Centers for the Urban Underground Space. Saint-Petersburg, Russia. Procedia Engineering, Volume 165, pp 88-95.

SNiP RK 5.01-03-2002 (2002) "Pile foundations". KAZGOR Design Academy, Almaty.

Zhussupbekov A.Zh., Lukpanov R.E., Omarov A.R. (2016). Bi-directional static load testing. Selected paper from the proceedings of the fourth Geo-China International Conference. Shandong, China. pp 35-42.

ASTM D1143M – 07 (2013) Standard Test Methods for Deep Foundations Under Static Axial Compressive Load.

Zhussupbekov A.Zh., Lukpanov R.E., Omarov A.R. (2016). Experience in Applying Pile Static Testing Methods at the Expo 2017 Construction Site. Scientific journal Soil Mechanics and Foundation Engineering: Issue 4: New-York, USA,. pp 251-256;

Zhussupbekov A.Zh., Omarov A.R. (2016). Geotechnical and Construction of pile foundations in difficult soils ground. Geotechnik-Tag in München Geotechnik Zusammen-wirken von For-schung und Praxis, München, pp 41-48.