International Journal of GEOMATE, May 2023, Vol. 24, Issue 105, pp.11-17
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2023.105.3703
Geotechnique, Construction Materials and Environment

INVESTIGATION OF THE INTERACTION OF THE BORED MICRO PILE BY DDS (FDP) TECHNOLOGY WITH THE SOIL GROUND

Abilkhair Issakulov[1], *Abdulla Omarov[1], Askar Zhussupbekov[1], Saltanat Mussakhanova[1] and Baizak Issakulov [2]

[1]Department of Civil Engineering, L.N. Gumilyov Eurasian National University, Kazakhstan; [2]Department of Design and Civil Engineering, Baishev University, Kazakhstan

*Corresponding Author, Received:15 Nov. 2022, Revised: 07 Feb. 2023, Accepted: 12 March 2023

ABSTRACT: The article presents the results of a comparative analysis of the bearing capacity of bored piles with a drilling displacement system (DDS), obtained by tests for static load and according to GOST standards, as well as the results of tests for compression of the surrounding soil after installing the pile with DDS. These DDS piles are created by rotary drilling with a simultaneous full displacement of the soil in a horizontal direction. The optimal design of DDS piles can be obtained in soils that allow for a horizontal displacement, which causes an increase in the shaft's resistance. It is shown that drilling and ramming technologies of pile foundation construction play an important role in modern urban planning, but they are not fully universal. Actively developing, they replace traditional methods using dynamic and vibratory impacts, as they are more gentle to nearby buildings, which is most relevant for cities with dense urban development. According to the project design, the field tests of DDS bored piles with a diameter of 410 mm, and length of 6 m was performed by two static loading tests. The static loading tests were performed by GOST 5686-2012. This paper shows the results of the load-settlement and feed rate of the deep auger for pile diagrams 1 and 2 from those field tests that make it possible to determine the bearing capacity of piles on a given soil. The analysis signified that the bearing capacity of the six-meter-high bored piles meets the design requirements.

Keywords: Pile foundation, DDS, Boring piles, Static load test, GOST.

1. INTRODUCTION

Until the early 1950s, the only method for determining the settlements of single piles was the vertical static test method (Top-down), which allows the establishment of the dependence of sediment on the load S = f (P). The works of A.A. Luga, H.R. Khakimov, and A.A. Bartolomey are based on the processing of a large number of tests of piles of different lengths in different geological conditions. Based on these treatments, dependencies are obtained that make it possible to establish the precipitation of single piles without resorting to expensive static tests. The works of E.P. Sivtsova, L.B. Ogranovich, and G.S. Ter-Ovanesov are based on the application of Mindlin's formula for the vertical component of displacement from the force applied inside the half-space. V.A. Golubkov established the dependence of precipitation on load based on experimental studies and analysis of the work piles. A. Kezdi proposes to determine the draft based on the lines of influence in the function of friction along the lateral surface and the resistance of the tip. R. Hefeli and H. Becher obtained an empirical dependence for determining the precipitation of single piles.

In Kazakhstan, many huge construction projects, such as high-rise buildings, freeway bridges across rivers or seas, high-speed railways, wind power plants, and harbor constructions, are in progress in urban and coastal areas [1]. Modern construction places appropriate demands on engineers and designers, so the established traditional solutions have been replaced by new cost-effective and environmentally friendly energy-saving technology, including pile foundation technology [2]. Pile foundations are one of the most popular types of foundations at construction sites in Kazakhstan, the expediency of their use is due to the need to ensure a high load-bearing capacity of high-rise buildings and structures. In connection with the emergence of new technologies and equipment for the installation of pile foundations, designers need to improve the current regulatory documents, which, unfortunately, do not contain recommendations for the design of piles made using modern technologies [3].

In this article, the operation of the bored pile, installed by the method of rolling without excavation, was investigated. This technology is one of the latest products of German manufacturers and is undoubted of practical interest for modern construction in Kazakhstan. The main advantages of this technology are high productivity of pile making, high cost-effectiveness, low noise level and absence of vibrations during pile driving, and most importantly, high bearing capacity of the pile. The large difference between the experimental (Static tests) and calculated (normative) values of the bearing capacity of bored piles made by the rolling method indicate the incomplete use of the resources of this technology. Large values of bearing capacity of piles are explained by the fact that during the arrangement of the pile no excavation occurs, and the soil is radially displaced by the roller of the drilling tool, thus, as a result of compaction, there is a change in strength and strain characteristics of the soil around the pile. Thus, it becomes obvious that the work of displacement piles is different from the traditional pile and there are still many unresolved issues concerning this technology: the effect of displacement technology on the bearing capacity of piles; the effect of radial compaction of the surrounding mass on the pile; the effect of displacement piles on foundations of adjacent buildings and structures, etc [4]. Currently, construction has reached an unprecedented pace and volume. Despite modern technology, new construction is becoming increasingly difficult. This is largely due to the unprecedented density of buildings in urban areas. Progress comes in the form of bored piles, which create a quality foundation in cramped conditions, erected close to existing buildings. A bored pile foundation minimizes dynamic loads on adjacent buildings and eliminates crumbling and deformation of soils [5].

2. RESEARCH SIGNIFICANCE

The instrumentation and health monitoring of DDS pile foundations is a generally well-established field. The investigated DDS technology has been long recognized worldwide, but in the difficult soil conditions of Kazakhstan, the operation of DDS piles has not yet been fully studied. The DDS piles discussed in this paper are a prime example of a unique pile foundation design structure that does not lend itself to easy health monitoring. Consequently, the account of the analysis, design, testing and field installation monitoring serves as a useful example of the constraints imposed by such pile foundation structures. All of the above indicates the relevance of the topic of this paper and requires further research on the operation of piles arranged by the method of rolling (DDS), in soil conditions.

3. TYPES OF THE DEVICE FOR BORED PILE FOUNDATIONS

3.1 Modern Technologies of Pile Foundations in Kazakhstan

Pile foundations are the most acceptable, affordable, and, most importantly, reliable type of foundation in the prevailing conditions of the Astana region and Kazakhstan in general. To date, the following types of pile foundations are widely used on construction sites (see Fig.1):

1. Driven piles using hydraulic hammers made by Junttan, Banut-650, Rapat;
2. Drive-in piles with diesel hammers type MSDSh1, MSDT1;
3. Piles were driven by indentation with the help of "Tizer" equipment;
4. Drilled piles with casing pipe using traditional technology of pile foundation making with the help of drilling equipment SO-2;
5. Bored piles, protected by casing, installed with the help of modern "Bauer", and "Casagrande" drilling rigs
6. Bored piles with a continuous through-type auger, installed by CFA technology
7. Drilled piles with short boring augers, arranged with SM-70, SBU-100, Klemm, and Soilmec;
8. Drilled bored piles in the rolled boreholes using DDS (FDP) technology, with the help of "Bauer" equipment;
9. Jet Grouting piles, "Jet Grouting" type.

Full classification of piles used at construction sites in Kazakhstan, taking into account the modern technology of their device is shown in Fig.1.

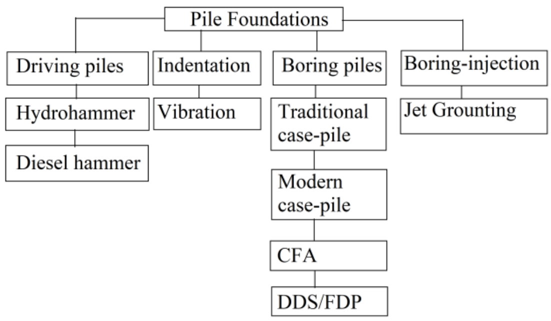

Fig.1 Pile foundations used on construction sites in Kazakhstan

3.2 Drilling Piles in the Expansion Wells, Installed Using DDS (FDP) Technology

The principle of bored piles using the DDS technology is as follows. The boreholes are rolled out, i.e. the soil is not removed, but rather compact with the help of a roller. A cylindrical cavity in the ground is formed continuously, through the deformation and compaction of the ground by the rolling mechanism. As a result, a dense soil layer is formed around the borehole. For more than five years, this technology is widely used in Europe. Recently, this method has been gaining popularity in CIS countries [6]. When constructing bored piles, a special drilling tool is used, which is rigidly attached to the drill pile. This method is effective when working in soil with dense layers of sand. If there are boulders and large stones in the soil, the rockdestroying tool is replaced by a drill bit and continues drilling. The pile-driving method generates boreholes with smooth walls of high strength and diameter. The technology of bored piles, installed by rolling with soil displacement, is relatively new and insufficiently explored. To date, the drilling rigs of the German company "Bauer" are used in Kazakhstan. DDS (Drilling Displacement System) or FDP (Full Displacement Pile) technology was developed by the same German company "Bauer" and represents the drilling of a pile without excavation with a full displacement of soil using a special drilling element - unroller. The unroller is a series of tapered rollers, successively mounted on a shaft, whose axes are offset to the sides relative to the common shaft axis. Thus, when the shaft rotates, the rollers rotate in a helical line, making the unroller feed, which allows penetration in the ground due to the torque applied to the roller shaft [7]. Using a reamer allows drilling a hole with smooth and solid walls of considerable diameter (see Fig.2).

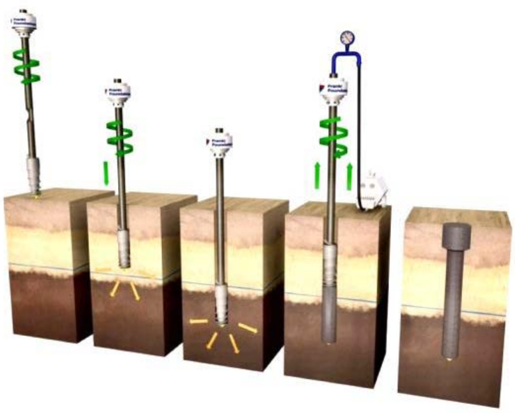

Fig.2 Pile installation process using DDS technology

The design of the bored pile allows concrete to be fed while the pile-driving machine is moving upward. DDS technology, which allows pile boring at a sufficiently high speed, without vibration and noise, has several undeniable advantages:

- high efficiency of pile boring;
- reduced cost of work due to saving money on reducing the removal of soil;
- high-quality filling of the borehole with concrete, as a result of feeding it under pressure;
- high bearing capacity of piles due to compaction of soil and supply of concrete mixture under pressure;
- high accuracy of pile boring, controlled by the onboard computer (see Fig.3).

Fig.3 High accuracy of pile boring, controlled by the onboard computer in the boring machine

The cost of work on DDS piling technology is one of the cheapest in Kazakhstan, in Table 1 you can see the price offer for each meter.

Table 1 Cost of pile work in Kazakhstan

Pile Installation technology	Cost per meter of drilling or hammering
Fundex	from 25 USD
CFA	from 35 USD
DDS	from 25 USD
CSP	from 50 USD
Double Rotary	from 50 USD
Vibration Diving	from 35 USD
Kelly rod	from 50 USD
Pile driving	from 10 USD

The use of a special boring tool makes it possible to drive piles through dense layers of sand, and if there are any obstacles in the form of rock, it is possible to continue boring by replacing the drilling tool with a drill bit. Despite the above-mentioned qualities, DDS technology has the following disadvantage:

- Increased attention to the order of work, since it is possible to affect the foundations of adjacent buildings and structures, as in the case of other compaction technologies.

4. QUALITY CONTROL AND PILE FOUNDATION TESTING METHODOLOGY

4.1 Brief Description of the Static Testing

Tests of static soil indentation loads were carried out by the requirements of GOST 5686 to determine the settlement and carrying capacity of piles DDS. To test DDS soils with piles with static vertical indentation loads, load stands were used, consisting of systems of main and auxiliary beams, as well as a load consisting of a block or slabs. The force of the hydraulic jack is regulated by the fluid supply from the pumping station and is fixed by a technical electrical pressure gauge. The movement of the pile is electrically measured by deflection meters with an accuracy class of 0.01 mm, which are fixed on a reference system fixed to the ground. The reference system is independent of the movement of the system of beams and piles [8].

Field tests of soils with static loads were carried out in the following sequence:

- the pile was “rested” for 7-10 days from the moment the DDS pile was installed (when the pile concrete reaches more than 80% of the design strength);
- the pile was loaded with a vertically indenting stepwise increasing load;
- taking readings from the deflection meters was carried out in the following sequence: the first reading - immediately after the application of the load, then four readings sequentially every 15 minutes of observation, two readings with an interval of 30 minutes, and then every 60 minutes until conditional stabilization of the deformation, i.e. until the pile settlement rate at this loading stage is no more than 0.1 mm over the last 60 minutes.
- unloading of the tested piles was carried out in steps equal to double the loading steps;
- taking readings of the elastic deformation of the soil during unloading was carried out at each stage every 15 minutes.

Based on the test results, graphs of the dependence of the pile settlement on the load and the change in settlement by load steps over time were obtained [9].

4.2 Tests of Bored Piles Installed by DDS Technology for Static Load According to by GOST

According to the provided results of laboratory and experimental works (static and dynamic sounding, tests of soils with stamps), the physical and mechanical properties of the underlying soils are evaluated, as well as the aggressiveness of groundwater and their impact on building materials. As a result of the long-term genesis of soils, the geological structure of Astana is represented by layers of six engineering geological elements (EGE). Geological and lithological sections of the construction site of the facility are shown in Fig.4. The results of the physical and mechanical properties of the soils of the foundation of the construction site are shown in Table 2. The degree of soil aggressiveness (SNiP 2.03.11-85) about W4 grade concrete varies from weak to strong, and on sulfate-resistant cement grades, non-aggressive, in a single case, non-aggressive soils are found [10].

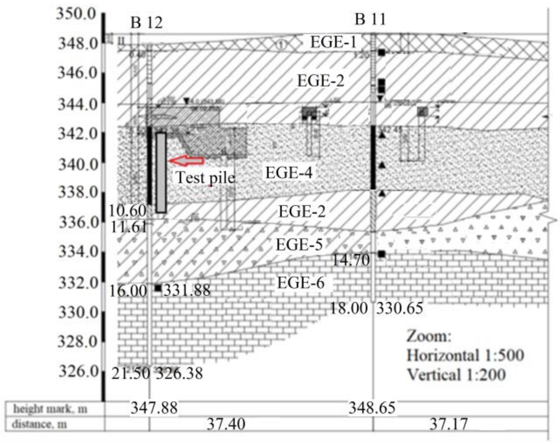

Fig.4 Engineering-geological of the soil in the construction site

Table 2 Physical and mechanical properties of soils of the construction site (borehole number 12 see Fig.4).

			Soil properties			
N of EGE	Soil description	Layer thickness, m	E, MPa	C, kPa	φ, deg.	R0, kPa
1	top soil, loam	0,4	-	-	-	180
2	loams	5,1	4,8	17,6	16	-
3	gravelly sand	5,1	35	-	39	-
4	silty clay	1,0	4,8	17,6	16-	-
5	rock debris with silty clay inclusions	4,4	-	-	-	450

4.3 Quality Control During the Construction of DDS Piles

Quality control of bored piles must be carried out at all stages of work: drilling and concreting, as well as at the end of the pile making. Quality controls are ensured by strict compliance with well drilling technology, reinforcement cage manufacturing, concreting modes, and bottom hole position measurements, as well as by sampling the concrete mixture to determine the strength characteristics. DDS bored piles require a reinforcement cage, which is lowered into the borehole using a vibratory plunger after the auger has been removed and the concrete has been pumped. The DDS piles are designed with a rebar frame installed in fresh concrete. The reinforcement cage must be manufactured according to the design documentation. The outside diameter should be smaller than the standard diameter to allow for sufficient insulation for drill augers. Plastic centralizers are attached along the entire length of the framework. The conical shape of the bottom of the cage is obtained by using the last ring with a smaller diameter than the standard ring. The borehole has to be drilled to the design elevation. In the presence of impassable obstacles above the estimated bottomhole elevation, the design organization must decide on the need for additional piles. If necessary, additional engineering and geological surveys at the construction site should be performed as part of the designer's supervision to determine the consistency of the survey data obtained during the drilling of the borehole [11]. The developers of the DDS technology have established an additional control parameter for pile making. The coefficient α is the coefficient of resistance to rotation. It is similar to the "failure" of driven piles and reflects the bearing capacity of the soil. The coefficient α is determined by the following Eq. (1):

$$\alpha = \frac{M}{\text{failure}}, \qquad (1)$$

where, M - torque, kN·m;

failure - is the penetration of the tool for a certain number of revolutions, m/min revolutions (see Fig.5 for piles 1 and 2).

The coefficient α is used to visualize the bearing capacity of soil layers for the operator, reflects the value of bearing capacity in the report diagram, and also allows for the optimization of the length of the piles. During the concreting process, the mobility of the concrete mix, the continuity of the concrete mix placement, and the temperature of the concrete mix (in winter conditions) must be constantly monitored (Fig.5). In the process of concreting boreholes must be carefully controlled to match the volume of concrete mix to the design volume, taking into account the overspill of concrete. The start and end time of concreting must be recorded in the work log, there are also recorded forced breaks in the process of concreting, their causes, and duration.

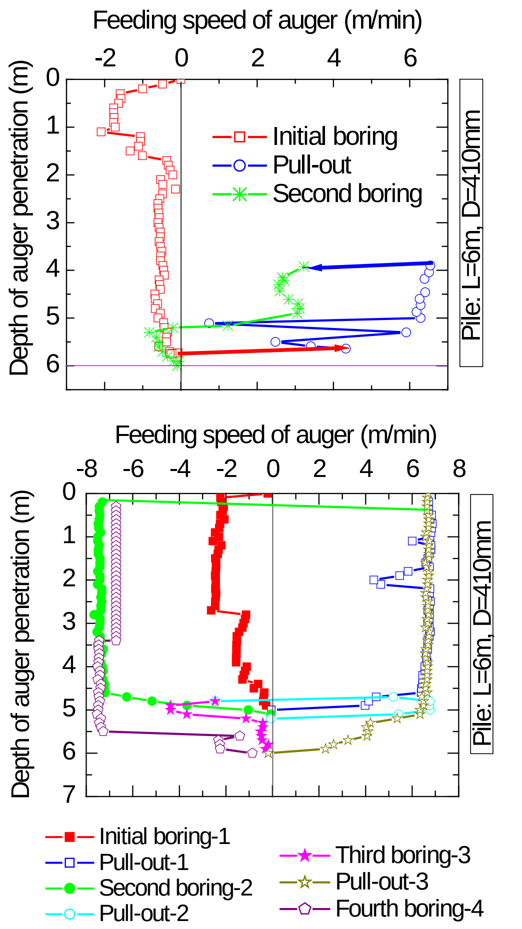

Fig.5 Depth auger feed rate results for Pile 1 and 2

Mobility of the concrete mixture must be controlled by setting the cone by sampling the concrete mixture taken when placing it in the hole. Concrete compliance with the specified class should be checked by the producer of the works according to the certificate of the concrete plant with the specified coefficient of variation and testing of the samples taken. Testing of the piles at the construction site was carried out in 2022. Two bored piles with a diameter of 410 mm and a length of 6 m were tested using displacement technology, but only one pile was suitable for the test. During the testing of pilot pile number 1, the pile head ruptured, forcing the testing to halt. There was no need to retest pilot pile number 1 because the pilot pile was loaded with 1.2 times the design load at the time the test was stopped. Soil tests with static indentation loads were conducted by the requirements of GOST 5686-2012 to determine the settlement and bearing capacity of DDS piles [12]. To test the DDS soils with piles by static vertical indentation loads we used load benches consisting of systems of main and auxiliary beams and weights. The following equipment was used to test with static loads:

- hydraulic jack of SMZh-158A brand with a load-carrying capacity of 2000 kN;

- MHCP-400 pump station with МТП-160 gauge, capacity 800 kgf/cm^2;
- four electric sag meters (to determine pile settlement).

The force of the hydraulic jack is regulated by a liquid supply from the pumping station and is fixed with a technical manometer. Pile movement is measured using reflectometers with an accuracy class of 0.01 mm, which are fixed on a reference system fixed to the ground. The reference system is independent of the movement of the beam and pile system [13-15].

5. RESULT AND DISCUSSION

5.1 Static Test Results of DDS Piles

According to the results of the tests, we obtained diagrams of the pile settlement dependence on the load and changes in the settlement by load steps over time (Fig.6).

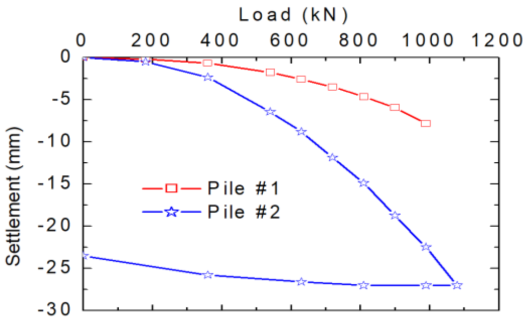

Fig.6 Results of SLT pile 1 and 2 “Load-settlement” graph

The maximum allowable settlement criterion is taken from the guidelines regulated by SNiP RK 5.01-03-2002 - Pile foundations, paragraphs. 5.3-5.5 [16]- for a particular value of the ultimate resistance of the pile Fu to the indentation load should be taken the load under the influence of which the tested pile will receive the settlement equal to S and determined by the Eq. (2):

$$S_{\max.\mathrm{Sett.}} = \zeta S_{u,mt} \tag{2}$$

where, $S_{u,\ mt}$ is the limiting 80mm value of the average settlement of the foundation of the designed building or structure.

For industrial and civil single-story and multi-story buildings with a full frame is taken according to the Construction Norms and Regulations RK 5.01-01-2002 (for reinforced concrete structures);

ζ- conversion coefficient from the limiting value of the average foundation settlement of the building or structure $S_{u,mt}$ to the pile settlement obtained during static tests with conditional stabilization (attenuation) of settlement is taken equal to 0.2 according to guidelines.

$S_{max.\ Sett.}$ = 0.2 x 80mm= 40 mm (for reinforced concrete structures).

5.2 Discussion of the Advantages of DDS Technology

High productivity was obtained - up to 25 piles up to 6 m deep per shift. No vibration or noise, which makes the technology especially attractive when working in dense urban areas. The absence of excavated soil reduces the cost of work by saving on the cost of soil removal. High accuracy of pile setting in the plan, compliance with the verticality of drilling, immersion depth of the working body, and the pressure of concrete when filling the well - all this was controlled by the onboard computer. High-quality concreting was achieved: smooth and strong walls after unrolling, pressurized concrete feeding through the hollow unroller.

6. CONCLUSION

The results of the axial compression loading tests performed in soft to firm or stiff clays demonstrated the suitability of DDS/FDP technology bored pile foundations. The results of the loading testing program confirmed that the DDS/FDP bored pile is a viable deep pile foundation option for the construction site in Kazakhstan and demonstrated their advantages.

The results of the static load tests were satisfactory, as the maximum test load on the pile was 1080 kN. The settlement was 27 mm for pile No. 2 and for pile No. 1 the maximum test load was not applied (it was limited to 990 kN) because the pile head has been destroyed, although the pile settlement was satisfactory at this stage (limited to 7.83 mm).

These investigations are important for the understanding of soil-pile interaction on the problematical soft soils ground of Astana, Kazakhstan.

7. ACKNOWLEDGMENTS AND FUNDING

This research has been funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (Grant No. AP13268718).

8. REFERENCES

[1] Omarov A., Kuderin M., Zhussupbekov A., Kaliakin N., and Iskakov S., Vibration measurements at a new monument in Nursultan

city. International Journal of GEOMATE, Vol. 21, Issue 85, 2021, pp.24–31.

[2] Zhussupbekov A., Omarov A., Shakirova N., and Razueva D., Complex analysis of bored piles on LRT construction site in Astana. Lecture Notes in Civil Engineering, Vol. 49, 2020, pp.461–471.

[3] Zhussupbekov A., Chang D.W., Utepov Y. Borgekova K., and Omarov A., Estimating the Driven Pile Capacities for COF Project in West Kazakhstan. Soil Mechanics and Foundation Engineering, Vol. 52, Issue 2, pp.121–127.

[4] Zhussupbekov A., Kaliakin V., Chang, D.W., and Omarov A., Investigation of Interaction of Piles at New Cargo Sea Transportation Route and LRT Projects with Problematic Soils of Kazakhstan. Lecture Notes in Civil Engineering, Vol. 164, 2022, pp.945–957.

[5] Zhussupbekov A., Mangushev R., and Omarov A., Geotechnical Piling Construction and Testing on Problematical Soil Ground of Kazakhstan and Russia. Lecture Notes in Civil Engineering, Vol. 112, 2021, pp.89–107.

[6] Zhussupbekov A.Zh., Temirova F.S., Riskulov A.A., and Omarov A.R., Investigations of historical cities of Uzbekistan and Kazakhstan as objects of the silk way. International Journal for Computational Civil and Structural Engineering, Vol. 16, Issue1, 2020, pp.147–155.

[7] Zhussupbekov A., Iwasaki Y., Omarov A., Tanyrbergenova G., and Akhazhanov S., Complex of static loading tests of bored piles. International Journal of GEOMATE, Vol. 16, Issue 58, 2019, pp.8–13.

[8] Toleubayeva Sh., Akhmetzhanov T., Danenova G., Tanirbergenova A., and Yeleussinova A., Effect of complex additive on exothermic kinetics and hydration stages of cement systems. International Journal of GEOMATE, Vol. 19, Issue 75, 2020, pp.184–190.

[9] Mekhtiyev A., Neshina Y., Kozhas A., Aubakirova B., Aimagambetova R., Toleubayeva S., and Tleubayeva A., Monitoring reinforced concrete building structure technical conditions based on the use of quasi-distributed fiber-optic sensors. International Journal of GEOMATE, Vol. 23, Issue 97, 2022, pp.154–162.

[10] Zhussupbekov A., Alibekova N., Akhazhanov S., and Sarsembayeva A., Development of a unified geotechnical database and data processing on the example of Nur - Sultan city. Applied Sciences (Switzerland), Vol. 11, Issue 1, 2021, pp.1-20.

[11] Isakulov B.R., Dzhumabaev M.D., Abdullaev Kh.T., Konysbaeva Zh.O., and Shalabaeva S.I., Detoxication and neutralization of toxic industrial waste components for production of sulfur-containing binding construction materials. International Journal of Engineering Research and Technology, Vol. 13, Issue12, 2020, pp.4880–4884.

[12] Isakulov B.R., Akulova M.V., Kulsharov B.B., Sartova A.M., and Isakulov A.B., Formation of strength and phases of sequence of destruction of arbolite composites at various long loads. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, Vol. 4, Issue 442, 2020, pp.28–34.

[13] Sokolova Y., Akulova M., Isakulov B.R., Sokolova A., and Isakulov A.B., The study of structure formation and mechanical strength properties of sulfur-containing woodcrete composites exposed to permanently acting loads. IOP Conference Series, Materials Science and Engineering, Vol.869, Issue 3, 2020, pp.032005.

[14] Bragar E., Pronozin Y., Zhussupbekov A., Muzdybayeva T., and Sarabekova U.Z., Evaluation of the strength characteristics of silty-clayey soils during freezing-thawing cycles. Applied Sciences (Switzerland), Vol.12, Issue 2, 2022, pp.802.

[15] Unaibayev B.B., Unaibayev B.Zh., Alibekova N., and Sarsembayeva A., Installation of bored piles with a protective silicate shell of a new design in saline silty-clayey soils. Applied Sciences (Switzerland), Vol.11, Issue 15, 2021, pp.6935.

[16] SNiP RK 5.01-03-2002, Pile foundations, Kazakhstan Standard, KazGor, 2002, pp.57-61.