Proceedings of the 20th International Conference on Soil Mechanics and Geotechnical Engineering– Rahman and Jaksa (Eds)

Distinctions of modern technologies for pile foundation

Distinctions des technologies modernes pour les fondations sur pieux

Assel Tulebekova, Askar Zhussupbekov, Aizhan Zhankina, Zhanbolat Shakhmov & Bibigul Abdrakhmanova
Department of Civil Engineering, L.N. Gumilyov Eurasian National University, Kazakhstan, krasavka5@mail.ru

ABSTRACT: As global experience shows, construction development directly reflects on a country's economic position in the world; it is one of the relevant fields for future advancement and development as a whole. In reforming the technical regulations of the construction industry, it is important to coordinate construction specifications and technical norms in the Republic of Kazakhstan with the requirements of international standards. Dynamic and static pile test has been routinely used for quality assurance for the past 25 years in many countries. Because of their simplicity and economy, dynamic and static pile tests are conducted on thousands of construction sites every year. The paper presents geotechnical specificity of international requirements and traditional standards in pile testing. ASTM standards are widely recognized and referred to as minimum requirements for correct testing procedures. The control equipment, technological features, advantages, and disadvantages of the aforementioned standards are important for understanding and eliminating existing differences for harmonization with international standards.

RÉSUMÉ : Comme le montre l'expérience mondiale, le développement de la construction se répercute directement sur la position économique d'un pays dans le monde ; c'est l'un des domaines pertinents pour le progrès et le développement futurs dans leur ensemble. Lors de la réforme des règlements techniques de l'industrie de la construction, il est important de coordonner les spécifications et les normes techniques de construction en République du Kazakhstan avec les exigences des normes internationales. Le test dynamique et statique des pieux est utilisé couramment pour l'assurance qualité depuis 25 ans dans de nombreux pays. En raison de leur simplicité et de leur économie, les tests dynamiques et statiques sur pieux sont effectués sur des milliers de sites de construction chaque année. Ce document présente la spécificité géotechnique des exigences internationales et des normes traditionnelles en matière d'essais sur pieux. Les normes ASTM sont largement reconnues et considérées comme des exigences minimales pour des procédures d'essai correctes. L'équipement de contrôle, les caractéristiques technologiques, les avantages et les inconvénients des normes susmentionnées sont importants pour la compréhension et l'élimination des différences existantes en vue de l'harmonisation avec les normes internationales.

KEYWORDS: pile, test, soil, standard, technology.

1 INTRODUCTION

Pile foundations are commonly used in engineering practice to transfer the loads from heavy structures such as high-rise buildings to competent soil strata. In this way, such complications as unfavorable geological conditions, compressible soil layers, and high levels of groundwater are avoided [Fleming W.G. et all 1992, Poulos H.G. & Davis E.H.1980]. About 150 types of piles are known. The use of such piles reduces the amount of labor required for the construction of foundations and often decreases the amount of time required to complete a construction project. Different types of piles are used in construction work. The specific type of pile depends on the type of loading, foundation soil, and location of the groundwater table.

Nowadays, the following types of pile foundations are u sed in Kazakhstan:

- Drilled piles using the hydro-hammer of Junttan, Banut -650, Rapat Company.
- Drilled piles using diesel-fuel hammer types MSDSH1, MSDT1.
- Piles arranged using the device of Taizer Company.
- Bored piles with pipe casing using traditional pile foun dation technology with bored CO2 equipment.
- Bored piles protected by pipe casing construction using the modern device of «Bauer», «Casagrande» Company.
- Bored piles using flight auger technology of «CFA» [Ashkey 2008].
- Bored piles using short auger construction technology of SM-70, SBU-100, «Klemm», «Soilmec».
- Bored piles by DDS technologies (FDP) using the dev ice of "Bauer" Company.
- Piles installed using the "jet grouting" process.

A classification summary of pile types with modern technologies used on construction sites of Kazakhstan is shown in Figure 1.

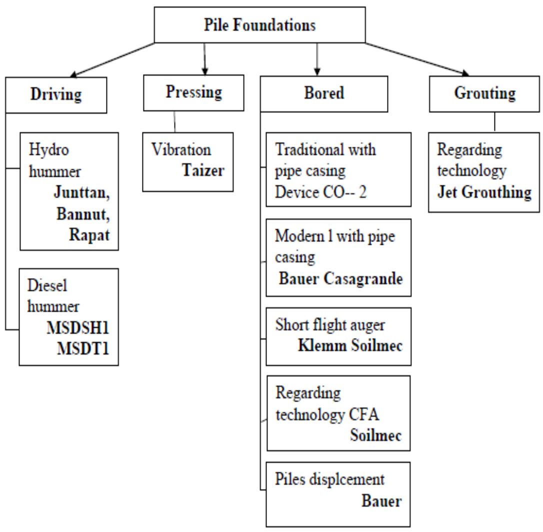

Figure1. Pile foundations used on construction sites of Kazakhstan.

2 WORLDWIDE DYNAMIC AND STATIC FOUNDATION TESTING CODES AND STANDARDS

J. Beim [Beim J. et all 1998] developed broad codes and standards relating to high and low strain dynamic testing. In many countries, the national government monitors the regulatory development of codes, standards, and specifications, as well as compliance.

For example, the U.S. government established the National Bureau of Standards in 1901, though U.S. manufacturers and the engineering community of the early 20th century resisted the creation of such a bureau, which was modeled after its European counterparts [Chaboto C.L. 2007].

The American Society for Testing and Materials (now ASTM International) was founded in the city of Philadelphia in 1898. During this period, the American Society of Civil Engineers and other professional organizations also developed standard specifications for various industries [ASTM D-4945]. In the United States, codes, standards, and specifications that normalize, adopt, or recommend non-destructive testing have been in existence since 1998. Over the last ten years, many existing standards have witnessed updates and revisions, and new publications have emerged, some of which relate to cross-sound logging.

Worldwide, ASTM standards are widely recognized and referred to as minimum requirements for correct testing procedures. For example, ASTM [ASTM D 4945] consists of standardized procedures for dynamic tests with large deformations. The American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA) has been working together to develop design codes and guidelines for the installation of foundations on transportation projects. The American Society of Civil Engineers manual on pile foundation design and installation [ASCE 1996] considers dynamic testing as a routine practice and presents an approach for the multiplication of partial safety factors.

Table 1 summarizes the safety factors for pile bearing capacity used in different countries.

Table 1. Standards of compression pile load test in various countries [Matsumoto T. et all 2008]

Country	S.F. w/o LT	S.F. with SLT	S.F. with DLT	Number of load tests required in a site and notes
1	2	3	4	5
Canada	3.0	1.8	2.0	1 SLT for 200 piles
Europe		2.29		if one SLT is performed
EC7 2001		1.64		If SLTs greater than 5 are performed
			2.23	if two DLT are performed
			1.95	if DLTs greater than 20 are performed
Europe		2.18		If the number of tests is equ al or less than 2
EC7 2003		1.91		If the number of tests is ≥ 2 0
Germany		1.93		If 2 tests are performed
DIN 105 4-2003		1.67		If tests greater than 4 are performed
Japan	3.0	2.7	2.7	not specified
Kazakhst an	1.5	1.4	1.2	SLTs on 0.1 % of constructed piles

3 METHOD OF HIGH-STRAIN STATIC PILE TESTS

3.1 *Static Pile Tests according to ASTM (USA)*

The ASTM [ASTM D 1143] standard requires that a sufficient number of anchor piles or suitable anchoring device be installed to provide adequate reactive capacity and a clear distance from the test pile or pile group at least five times the maximum diameter of the largest anchor or test pile, but not less than 2m.

Test beams of sufficient size, strength, and with sufficient clearance between the bottom flange of the test beam and the top of the test pile or pile group must be provided to provide for the necessary bearing plates, hydraulic jack, and load cell if it is used. When applying loads to an individual batter pile, the test beam should be oriented perpendicular to the direction of the batter.

For test loads of high magnitude requiring several anchors, a steel framework may be required to transfer the applied loads from the test beam to the anchors.

All reference beams and wires shall be independently supported with supports firmly embedded in the ground at a clear distance of not less than 2.5 m from the test pile group and as far as practical from the anchor piles or cribbing .

Reference beams shall be sufficiently stiff to support the instrumentation and should be cross-connected to provide additional rigidity such that excessive variations in readings do not occur [ASTM D 1143].

Dial gauges should have at least 50mm travel; longer gage stems or sufficient gage blocks should be provided to allow for greater travel if anticipated. Scales used to measure pile movements should read to 1/64th of an inch or 0.25mm. Target rods should read to 0.3mm [ASTM D 1143].

All dial gages, scales, and reference points should be marked with a reference number or letter to assist in recording data accurately.

Two parallel reference beams, one on each side of the test pile or pile cap, shall be oriented in a direction that permits placing their supports as far as practicable from anchor piles or cribbing. Dial gages, approximately equidistant from the center of and on opposite sides of the test, should be present [ASTM D 1143].

Alternatively, the two dial gages shall be mounted to bear on opposite sides of the test pile cap below the test plate, with stems parallel to the longitudinal axis of the piles and bearing on lugs firmly attached to the reference beams [ASTM D 1143].

Gages may, however, be mounted to bear on the top of the pile cap or the test plate, provided that two additional gages shall be mounted on opposite sides of the test plate to measure relative movements between the test plate to measure relative movements between the test plate and the pile cap. The lateral movements of the top of the pile group shall be measured to an accuracy of 2.5 mm using either of the following methods: two dial gages mounted on the reference beam 90º apart with their stems perpendicular to the longitudinal axis of the test pile cap [ASTM D 1143].

The test piles shall be instrumented as specified to determine the distribution of load transfer from the pile to the soil.

The influence of the sheathing on the elastic properties of the pile section shall be considered. If electric resistant strain gages are used, the gage type and installation shall be as specified and shall include temperature compensating gages.

Pile butt axial movements shall be measured with dial gages. The movements shall be measured with dial gages. The movements of the top of each strain rod relative to the top of the test pile shall be measured with a dial gages reading of 0,025mm.

Dial gages shall be referenced to points on the test pile below the test plate except that they may be referenced to the top of the test plate if the plate is welded to the pile or if relative movements between the top of the test pile and the test plate [6].

Unless failure occurs first, load the pile to 200% of the anticipated pile design load for tests on individual piles or to 150% of the pile group design load for pile groups, applying the load in increments of 25% of group design load. Each load increment shall be maintained until the rate of settlement is not greater than 0.25 mm. Provided that the pile group has not failed, the total test load shall be removed any time after 12 hours unless the settlement over one hour exceeds 0.25 mm; otherwise, the total load is allowed to remain on the pile group for 24 hours [ASTM D 1143]. After the required holding time, the test load is removed in decrements. If pile failure occurs, the pile jacking continues until the settlement equals 15% of the pile diameter or the diagonal dimension. If pile failure occurs, jacking of the pile continues until the settlement equals 15% of the pile diameter or the diagonal dimension.

During loading, provided that the test pile group has not failed, additional readings are taken and recorded at intervals not exceeding 10 min during the first ½ hour or 20 min transfer for each load increment.

ASTM regulated the following safety requirements [ASTM D 1143]:

- All operations in connection with pile load testing shall be carried out in such a manner to minimize hazards to people;
- All work areas, platforms shall be kept clear of scrap, small tools, etc.;
- All timbers, blocking and cribbing materials shall be of quality material and be in good serviceable condition with flat surfaces;
- Hydraulic jacks shall be equipped with spherical bearing plates;
- Loads shall not be hoisted, swung, or suspended over anyone;
- All reaction loads shall be stable and balanced, during testing, movements of the reaction load or system should be monitored to defect impending unstable conditions;
- All test beams, reaction frames, and boxes shall be adequately supported at all times.

3.2 *Static Pile Tests according to GOST 5686 (Kazakhstan)*

Under GOST [GOST 5686-12], the equipment of the soil testing unit with static loading should include the following:

- A device for loading piles (typically this consists of jacks);
- A supporting structure for receiving reactive forces (typically this is a system of beams with anchor piles);
- A device for measuring pile movements during testing (typically this consists of a system of benchmarks with suitable measuring devices).

The device used for loading piles should provide axial transfer of load to the pile, the possibility of transferring loads in stages, and the constancy of pressure at each stage of loading.

The distance from the axis of the tested pile to the anchor pile must be at least 3d, but not less than 1.5 m. Devices for measuring the displacement of piles (i.e., deflectors) should provide a measurement error of not more than 0.1mm. The number of instruments installed symmetrically on equal (no more than 2m) distances from the test pile must be at least two. The displacement is defined as the arithmetic mean of the readings from all of the instruments. Deflectors typically consist of a 0.3mm diameter steel wire. Before starting the tests, the wire must be subjected to preliminary stretching for 2 days under a load of 4 kg. During the tests, the load on the wire should be between 1.0 to 1.5kg.

The limits of measurements and the reading scale of pressure gauges used to determine the load on the pile during testing are selected depending on the greatest load applied to the pile provided by the test program, with a margin of at least 20%.

Loading of the tested pile is performed evenly, in stages. The magnitude of the load 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 piles are driven into coarse-grained soils (i.e., into gravels, dense sands or clay soils of solid consistency), the first three load stages are assumed to be equal to 1/5 of the greatest load.

At each loading stage, all readings from strain gauges are taken in the following order: the “zero reading” before loading, the first reading (immediately following initiation of loading), then four consecutive readings with an interval of 30 minutes, followed by readings every hour before reaching conditional deformation stabilization (i.e., displacement attenuation).

For the criterion of conditional stabilization of deformation during testing with a pile, the rate of settlement of the pile at a given loading stage is not to exceed 0.1 mm of the last: 60 minutes of observations if sandy soils or clay soils from solid to rigid consistency are present under the lower end of the pile; 2 hours of observation if clay soils are present under the lower end of the pile with soft-plastic to flowing consistency.

The test load of the field pile shall be adjusted to a value at which the total pile settlement is not less than 40mm. When the bottom ends of the field piles are driven into coarse, dense sandy and clay soils of solid consistency, the load must be brought to the value provided by the test program, but not less than 1.5 pile load-bearing capacity determined by calculation, or the pile material strength capacity. During construction, the maximum load on the pile should not exceed the design pile resistance of the pile material. The piles are unloaded after reaching the maximum load, with each stage being held for at least 15 minutes.

Deformation measurements are taken immediately after each discharge stage and after 15 minutes of observation. After full unloading (to zero loads), the piles should be monitored for elastic movement for 30 minutes in sandy soils under the lower end of the pile, and 60 minutes in clay soils, with readings taken every 15 minutes.

During the test, the results of the test are recorded in a register in the form of graphs showing the relation between load/settlement and deformation/time during the loading stages.

4 PILE TESTING IN CONSTRUCTION SITE

4.1 *Pile testing in construction site 1*

The construction site (KPC Gas Debottlenecking Project) is located in Karachaganak Field [KGS Report 2018]. Reaction system for load test piles presented in Figure 2. Figures 3-4 show the results of the pile test. Safety factors are equal to two regarding requirements ASTM [10].

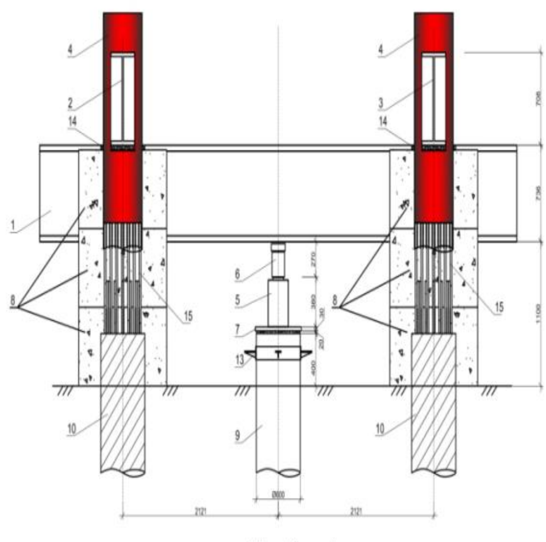

Figure 2. Reaction system for load test piles d= 600 mm. 1. Main beam H=736 mm, L=6510 mm; 2, 3. Reaction beam H=708 mm, L=5620 mm; 4. Reaction transfer tube; 5. Hydraulic jack 250t; 6. Load cell; 7. Metal plate; 8. Concrete block 600*600*1200 mm; 9. Test pile; 10. Anchor pile; 11. Reference system; 12. Screw metal piles for reference systems; 13. Clamp; 14. Wooden lining; 15. Rebar L=900 mm

3.2 Pile testing in construction site 2

The construction site is located on the south-eastern side of Astana, on the right bank of the Esil River. The city is located on the Kazakh shield and does not experience tectonic movements; as such, its territory is not considered to be seismically active.

The project provides by H-steel piles (Figure 5). I-section steel piles are usually made of high-strength low-alloyed columbium-vanadium steel. Grade 50 steel is following the requirements of ASTM A36 and A572. The mechanical properties of the I-section steel piles used at the site were manufactured by Bethlehem metal manufacturing company (USA). Table 2 lists their mechanical properties.

Load Step	Load, kN	DG3, mm	Test Pile reading, mm	Test Pile approx. displ, mm	Ref. frame reading, mm	Main beam reading, mm	Anchor pile P7 (1), mm	Anchor pile P6 (2), mm	°C
0	0	0	3947.0	0	1821	2221	0	0	4
1	198	0.15	3947.0	0.0	1821	2221	0	0	
2	395	0.31	3947.0	0.0	1821	2219	0	0	3
3	593	0.52	3947.5	0.5	1821	2218	0	0	
4	790	0.74	3947.5	0.5	1821	2217	0	0	
5	988	0.90	3948.0	1.0	1821	2216	0	0	3
6	1185	1.10	3948.0	1.0	1821	2214	0	0	
7	794	0.98	3948.0	1.0	1821	2217	0	0	2
8	394	0.60	3947.5	0.5	1821	2219	0	0	
9	0	0.21	3947.0	0.0	1821	2221	0	0	2
10	198	0.30	3947.0	0.0	1821	2220	0	0	
11	395	0.45	3947.5	0.5	1821	2219	0	0	
12	593	0.59	3947.5	0.5	1821	2218	0	0	2
13	790	0.82	3948.0	1.0	1821	2218	0	0	
14	988	0.83	3948.0	1.0	1821	2215	0	0	
15	1185	1.18	3948.0	1.0	1821	2214	0	0	2
16	1383	1.30	3948.0	1.0	1821	2214	0	0	
17	1580	1.74	3948.5	1.5	1821	2212	0	0.5	
17	1580	1.95	3949.0	2.0	1821	2212	0	0.5	3
18	1778	2.17	3949.0	2.0	1821	2211	0	0.5	
18	1778	2.29	3949.0	2.0	1821	2211	0	0.5	
19	1975	2.26	3949.0	2.0	1821	2210	0	1.0	4
19	1975	2.33	3949.5	2.5	1821	2210	0	1.0	
19	1975	2.34	3949.5	2.5	1821	2210	0	1.0	
19	1975	2.41	3949.5	2.5	1821	2210	0	1.0	3
19	1975	2.14	3949.0	2.0	1821	2210	0	1.0	
20	1578	1.87	3949.0	2.0	1821	2212	0	0.5	
21	1185	1.55	3948.5	1.5	1821	2214	0	0	3
22	790	1.22	3948.0	1.0	1821	2216	0	0	
23	395	0.88	3948.0	1.0	1821	2219	0	0	
24	0	0.51	3947.5	0.5	1821	2221	0	0	3

Figure 3. Data of static load test [11].

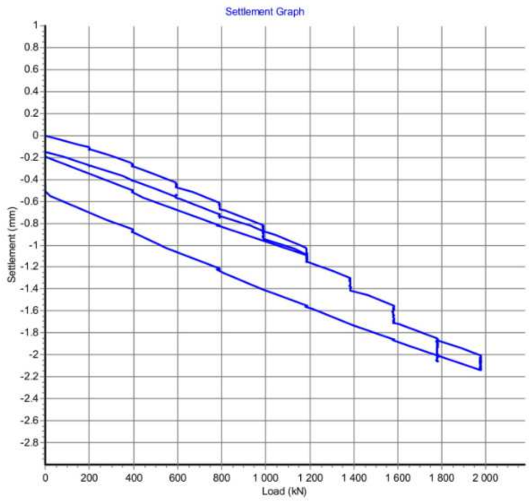

Figure 4. Graphics for the testing pile.

Figure 5. General view of steel H-piles.

Table 2. Mechanical properties of steel piles used at the site.

Name	Unit
Ultimate tensile strength	450 MPa
Elongation at rupture	21%
Elastic modulus	140000 MPa
Shear modulus	80000 MPa

The length of the steel piles is 12 m. The purpose of t the static load test is to determine the settlement and bearing capacity of piles (Figure 6).

To test the soils static vertical-pressing loads were used with anchor-support stands consisting of basic and auxiliar y beams systems, four anchor piles, and anchor strings (cl amps).

Special landfills were prepared by driving experimental and anchor piles, installing metal structures of the anchor stand, welding anchor ties to anchor piles. Static tests of s teel piles that were driven according to preliminary criteria such as pile failure of 1.25 cm to 600kN and failure of 1.67 cm to 400 kN, showed negative results.

Figure 6. Static testing of the metal pile.

After receiving negative results from static tests, the pil es were extended in length and were additionally hammer to the preliminary criteria: for the design load of 600 kN, a failure of 0.33 cm; for the design load of 400 kN, a fai lure of 0.83 cm. The piles were hammered in the same w ay as the first time, with the same hammer. Static testing of steel piles was carried out after "rest" without consecuti ve hammering of experimental piles to save time. After ex tending the length of the piles and additional driving of th e experimental piles, the soil was tested again with static l oading (see Table 4, Figure 7). Static tests were carried o ut in the same way as in previous tests.

Table 4 Results of the static test of steel piles after heightening o f pile length [Tulebekova A.S. 2015]

Number of piles	LT-1	LT-4	LT-6	LT-7
Embedded depth, m	7.00	9.25	10.25	8.00
Driving depth, m	9.75	12.75	16.00	11.25
Refusal of the pile at driving, after heighten ing pile, cm	0.31	0.27	0.30	0.78
Settlement, mm	4.80	4.96	6.27	3.38
Design load, kN	600	600	600	400
Applied load, kN	1200	1200	1200	800
Max. load, kN	1200	1200	1200	800

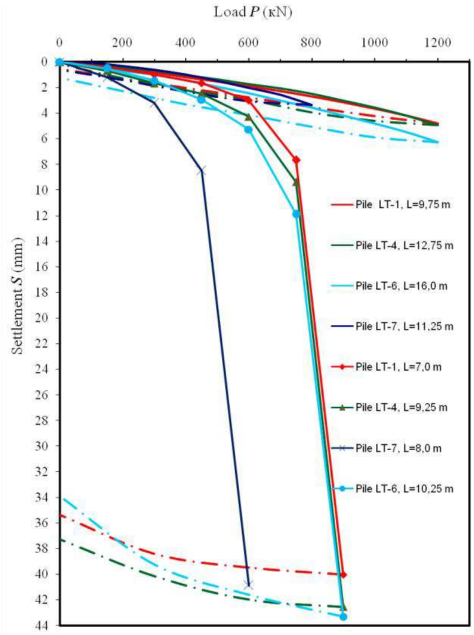

Figure 7. Correlation between settlement S and load P, the results of field static tests on piles after lengthening

5 GEOTECHNICAL SPECIFICITY OF ASTM AND KAZAKHSTAN STANDARDS

After comparing the methods of soil testing with piles a ccording to the American standard, it was noticed that mor e detailed requirements are presented, most of which are n ot mentioned in the state standard [Smolin B.S 2010]. The Kazakhstan standard considered two measurements. But AS TM regulated six measurements (Table 5).

However, the Kazakhstan standard does not take into ac count the fact that when two or more jacks are used, each must be equipped with a manometer. There is only one c ommon feature on the manifold. It allows for monitoring t he work of the jacks and prevents possible irregularities in their operation, thus avoiding failure in the tests.

Table 5. Principal differences of American Standard and Kazakhstan norms.

	Kazakhstan Standards	ASTM
The parameter of experimental stand for the test		
The distance b etween the testin g pile till anchor ing pile	5d<L1>2.5m	3d<L1>1.5m
The distance b etween testing pi le till	5d<L2>2.5m	L2<2m
Devices and equipment		
for loading	jack	Jack with Spherical prop
Measurement of load on top	manometer	manometer
pile	-	Dynamometer fixed for each jack
Measurement of load on all length pile	-	Tensometer

Experience has shown that tests conducted according to the American standard make them more accurate and relia ble. The experience that has been gained using the ASTM standard during tests facilitates obtaining test results with maximum reliability.

6 CONCLUSIONS

Reliability of foundations, cheapening of work on their arrangement has always been and remains a very topical problem, the solution of which largely depends on the ability to correctly assess the engineering-geological conditions of construction sites, the properties of soils in foundations, the joint work of these soils with the deforming foundations and structures of the construction, the rationality of the selected types of foundations and foundations, and the size of the latter, the quality of the work performed. The results have shown that ASTM standard gives detailed information about the process testing and thus more reliable results. Technical details about ASTM D/D 1143M have some differences as compared to the national Kazakhstan standard GOST 5686-12 “Soils. Field test methods by piles”. The results of the research are directed to the development of recommendations for the modernization of Kazakhstan Codes and oriented to the adaptation of advanced geotechnologies. The modernization will allow completing use of advanced technologies capabilities in the existing construction condition of Kazakhstan. Also the methodic of pile test on another load have to consider in future research.

7 ACKNOWLEDGMENTS

Ministry of Education and Science of the Republic of Kazakhstan (Grant «The Best University Teacher-2020»).

8 REFERENCES

ASCE 1996. American Society of Civil Engineers. ”Standard Guidelines for the design and Installation of pile foundation” (ASCE 20-96), Reston, USA.

Ashkey E. Interactions of CFA bored piles with soil conditions in Astana: Dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of philosophy (Ph.D.). 05.23.00.-Astana, L.N. Gumilyov Eurasian National University, 2008.- p.105.

ASTM D 4945-2018 - Standard Test Method for high strain dynamic testing of piles. ASTM International, West Conshohocken, PA,USA

ASTM D1143/D1143M-07. Standard Test Method for Piles Under Static Axial Compressive Load. - American Society of Testing and Materials. – USA, West Conshohocken, Pennsylvania, 1994

Beim J., Gravare, C.J., Klingmuller, L. De-Quing and F.Rausche. 1998. Standartization and Codification of Dynamic and Static Pile Testing, a Worldwide Review, USA.

Chaboto C.L. 2007. Structural Engineering Codes and standards in the United States. *Structure magazine* 14 (8), 63.

Fleming W.G., Weltman A.J., Elson W.K. 1992. Piling Engineering. New York, USA.

GOST 5686-2012 Soils. Field test methods by piles.

Matsumoto T., Matsuzawa K., Kitiyodom P. 2008. A role of pile load test. Pile load test as element test for design of foundation system.

Poulos H.G., Davis E.H.1980. Pile Foundation Analysis and Design. USA.

Report № 2. 2018. KGS, LTD: KPC Gas Debottlenecking Project.

Smolin B.S. 2010. Peculiarities of pile tests based on Russian and American standards. Soil Mechanics and Foundation Engineering

Tulebekova A.S.2015. Control equipment for pile test according to American and Kazakhstan standards. Modern Applied Science. 9 (6), 192-198.