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Investigation of laboratory and field tests of piles installed by displacement technology

Abstract. *When compared to conventional pile systems, the Drilled Displacement System (DDS) and Continuous Flight Auger (CFA) piles offer advantages in terms of improved load-carrying capacity, quicker installation, and less spoil generation. In this article, experiments on miniature piles built utilizing the Drilled Displacement System (DDS) and Continuous Flight Auger (CFA) technologies in a soil-filled test tank are described. For the study, model piles with dimensions of 20 mm in diameter and 300 mm in length were used, scaled at 1/20. The model piles are subjected to static loading, and throughout each phase of the loading process, the relevant displacements are measured. For both DDS and CFA piles, the analysis's findings on load-settlement curves and estimates of ultimate bearing capacity were compared. The results of model tests showed that the load-bearing capacity of DDS technology is 3.2 times higher than CFA technology. Using the model test results, a recommendation was made to apply DDS technology to field test work. Additionally, full-scale field tests with static loads were performed on DDS-drilled piles with dimensions of 400 mm in diameter and 6 m in length. The field test's load-settlement response exhibits good agreement with the model testing. Overall, the study's findings offer insightful information about the behavior and performance of DDS piles that may be used to improve the design and installation of these piles in various soil types.*
Keywords: *scaled model tests, model piles, bearing capacity, static load test*

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1. Introduction

Pile foundations are the most demanded type of foundations at construction sites on the territory of Kazakhstan. 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.

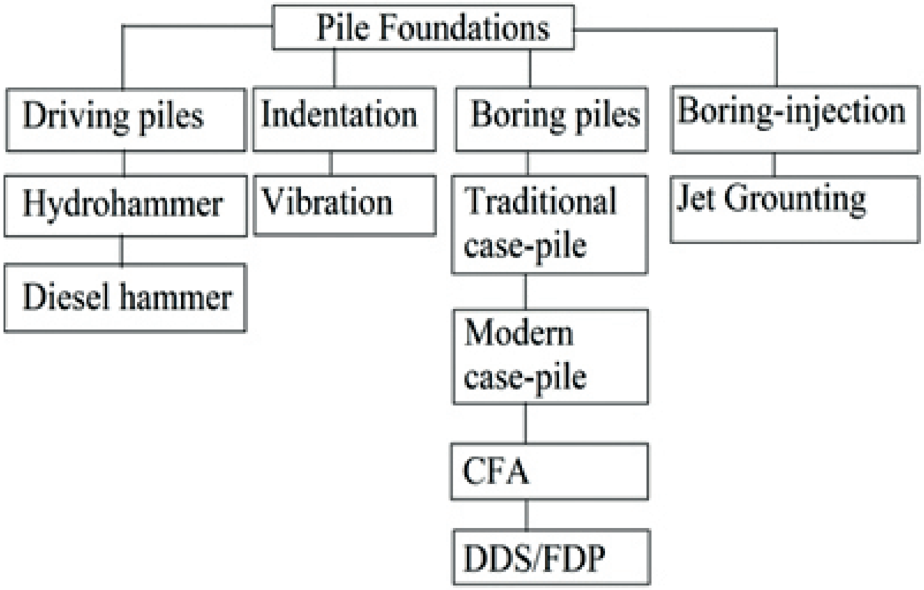

Figure 1. Pile foundations used on construction sites in Kazakhstan

The study of pile foundations, as well as DDS (FDP) and CFA technology, has been studied by many domestic and foreign scientists at different times. A significant contribution to the issue under consideration was made by Decourt et al. [1], Van Impe [2], Bazarbayev [3], Rad et. al [4], Zhusupbekov et al. [5].

On Kazakhstani soil, pile foundations are the type of foundation that is most frequently used at construction sites. The reason why pile foundations are so popular is because they protect the pile's load-bearing capacity, which is drilled and filled as a result of the increased load from high-rise buildings and structures. Due to the lack of current regulatory documents and recommendations for the installation of pile foundations using contemporary technologies, new technologies and devices that have emerged in connection with the installation of drilled-filled pile foundations force designers to improve regulatory documents [6].

Building pile foundations recently has included the utilization of Continuous Flight Auger (CFA) piles and Drilled Displacement System (DDS) piles. When noise and vibration levels need to be kept to a minimum in urban settings, DDS piles are a form of displacement pile that are frequently employed. With the aid of a hydraulic press, a steel casing is pushed into the earth while soil is also removed and a hole is made. Concrete and reinforcing steel are then used to fill the space, creating a sturdy base upon which to erect the structure. DDS piles can be constructed in a variety of soil conditions and are commonly utilized for small to medium-sized structures. On the other hand, a continuous flight auger is drilled into the earth to the needed depth in order to construct a CFA pile, a sort of auger cast pile. The auger is then pulled out and concrete is injected through its hollow stem to fill the space it leaves behind as it is pulled out. As a result, a continuous concrete column is produced, serving as a sturdy base for the subsequent construction of the structure. Large constructions with difficult soil conditions, such as soft soil and rock, frequently use CFA piles.

DDS technology reduces the time, effort, and cost associated with earthworks while simultaneously increasing the load-bearing capacity of piles. Over the past ten years, installation of drilled-filled piles using DDS technology has gained popularity in both Europe and the US. The major benefits of this method include great economic efficiency, noise and vibration reduction during pile installation, and increased pile bearing capacity [7]. Despite the benefits listed above, this technology has a drawback in that it runs the risk of affecting the foundations of existing buildings and structures. For this reason, it is not advised to use this method in situations where there is dense urban construction.

Installation of drilling equipment at the drilling site; immersion of the drilling tool with a sealing system to the design mark; connection of the concrete pump followed by filling the well with concrete mixture and simultaneous extraction of the drilling tool; immersion in the well with concrete reinforcement frame to the design mark; are the operations that make up the sequence of work for installing drilling piles made using DDS technology. The drilling instrument (Figure 2) is a unique aspect of the DDS technology. Because the well is being dug out simultaneously with the drilling, the soil is compacted radially without having to be dug up, and the walls are compacted when drilling up [8]. With the help of this technique, heaps up to 0.6 meters in diameter and 30 meters in depth can be arranged. The following factors should be taken into account when evaluating productivity: pile diameter, torque and pressing force exerted, and density (soil strength, soil compaction, and concrete pump power).

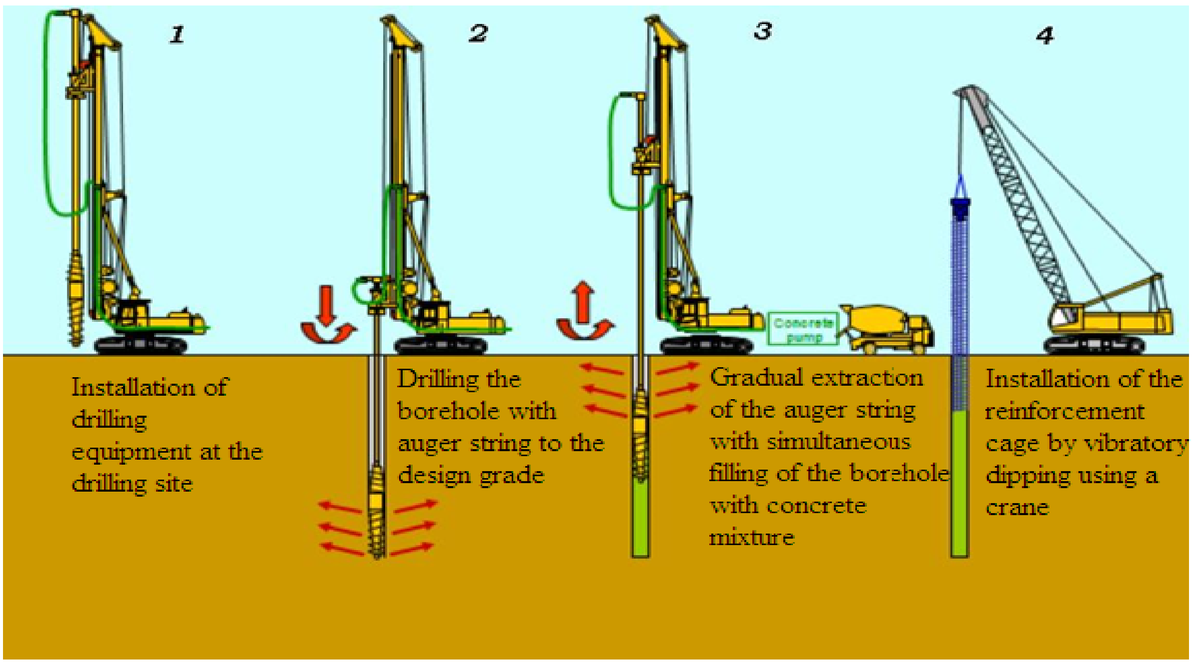

Figure 2. Diagram of pile production using DDS technology

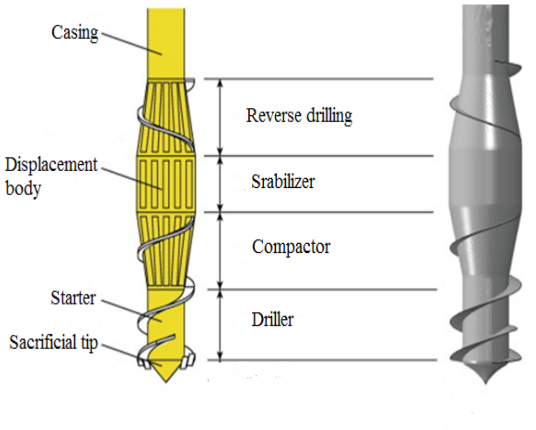

Figure 3. Description of DDS technology drilling Auger

Methods of physical modeling are used to solve a wide range of studies of the behavior of material objects both within the limits of elastic and plastic deformation and in the state of limit equilibrium and fracture. Due to the development of numerical methods for solving various problems using computational technology, mathematical modeling in many cases has become preferable to experimental modeling. However, the latter are indispensable when investigating the mechanism of the processes under study - without them, it is impossible to construct a mathematical description [9].

The purpose of the present study is to carry out scaled model tests on model test piles installed using the DDS and CFA technology and to compare the load-settlement response. Also, based on the results of model tests, to develop a recommendation for field tests.

2. Comparison of bearing capacities of model drilled micro piles using DDS and CFA technologies

In order to investigate the effect of horizontal and stepwise deformations of a soil massif on changes in its stress-strain state and on the vertical bearing capacity of foundations, model tests of bored piles in a horizontal and stepwise deformable medium on a scale of 1:20 were carried out. And also, based on the results of the tests, develop recommendations for field trials. The choice of piles of this scale was due to the need for numerous tests. In addition, the analysis of the study [10, 11] conducted on models of a close scale showed that tests of such models allow us to obtain a qualitatively correct idea of the interaction of foundations with the ground.

Model tests of piles was carried out on a test tank setup which was developed and implemented in Geotechnical Institute of the Eurasian National University (Figure. 2). The test material used is poorly graded sand of angular shape with a specific gravity of 2.62 and unit weight of 1.7 g/c^3. Based on direct shear test carried out on the test specimen, the sand was found to have an angle of internal friction of 37^o. An equivalent material (97% sand and 3% spindle oil) was used as a base to achieve minimal cohesion of 0.9 kPa and elastic modulus of 0.24 MPa. The test bed was prepared in five layers and each layer was compacted using tamping to achieve a relative density of 75%.

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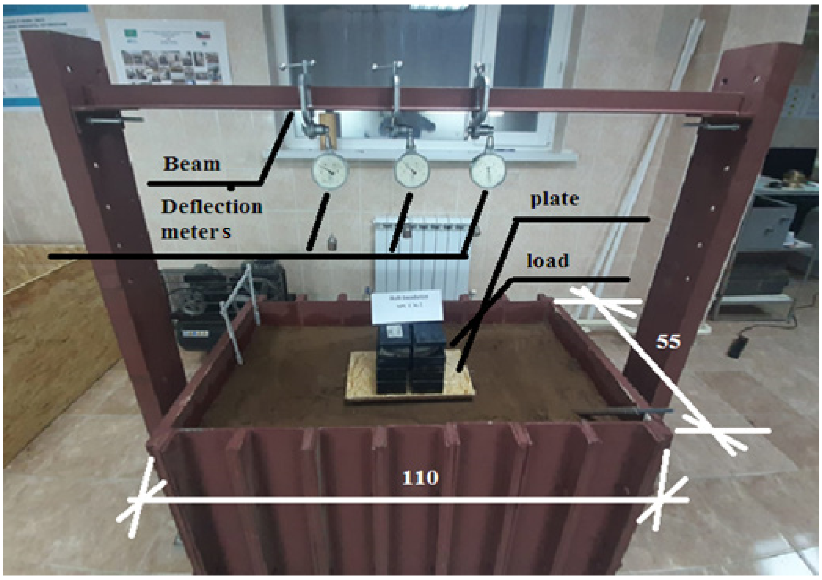
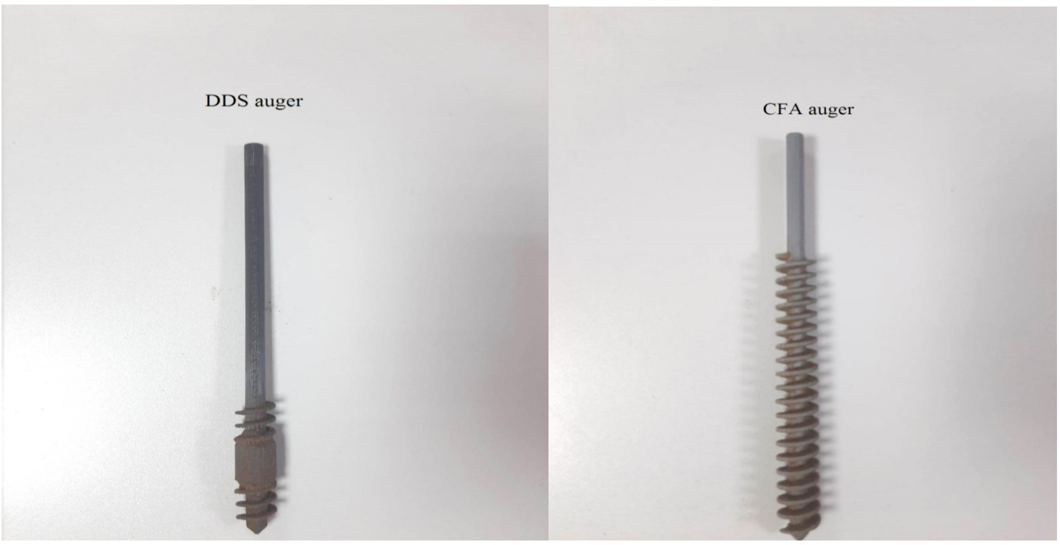


Figure 4. Volumetric stand

The augers were prepared for installation of model piles by DDS and CFA technologies with a diameter of 20 mm and a length of 300 mm considering a scale factor of 1/20. Figure 5 shows the augers used to install the model pile DDS (b) the model pile CFA (a) which performed by technologies.



(a) (b)

Figure 5. Photographs of test auger a) model DDS auger b) model CFA auger

Figure 6 shows the static load test setup for the present study. The load on the pile was applied in steps of 39 N to the ultimate 235 N with metal weights of 4 kg. The displacement of the model pile was measured by deflectometer with accuracy class of 0.01 mm, which are attached to the frame of the volumetric stand.

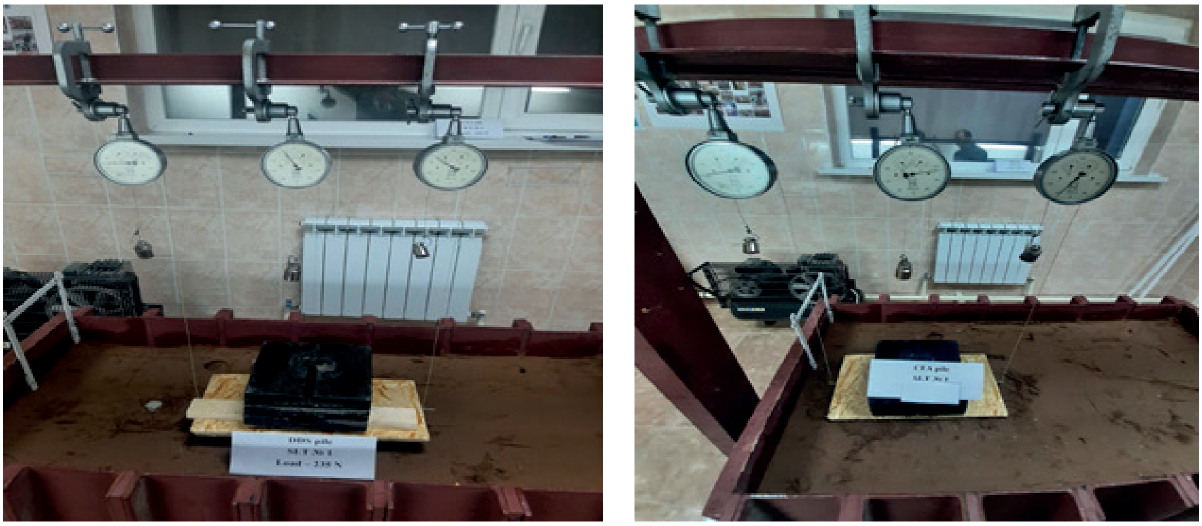


Figure 6. Static tests of the DDS and CFA model piles

2.1 Field studies on DDS piles

Based on the recommendation from model studies, field investigation was conducted on 2 test piles with a diameter of 400 mm, length 6 m at a test site in Astana, Kazakhstan using the DDS technology. The soil properties at the test site for different depths are shown in Table 2.

Table 1. Physical and mechanical properties of soils

Layer no.	Soil description	Layer thickness, m	Soil properties		
			E, MPa	C, kPa	φ, deg.
1	top soil-loam	0,4	-	-	-
2	loam	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	-	-	-

The load on the pile was applied in steps of 180 kN and 90 kN to the limit of 1080 kN by the hydraulic jack DU200P150 (Figure 7). The hydraulic jack force is regulated by fluid supply from the pumping station and fixed with a technical manometer. Pile movement is measured by means of displacement transducers with accuracy of 0.01 mm, which are fixed on a bench mark system fixed to the ground. The reference system is independent of the movement of the beam and pile system (Figure 7).

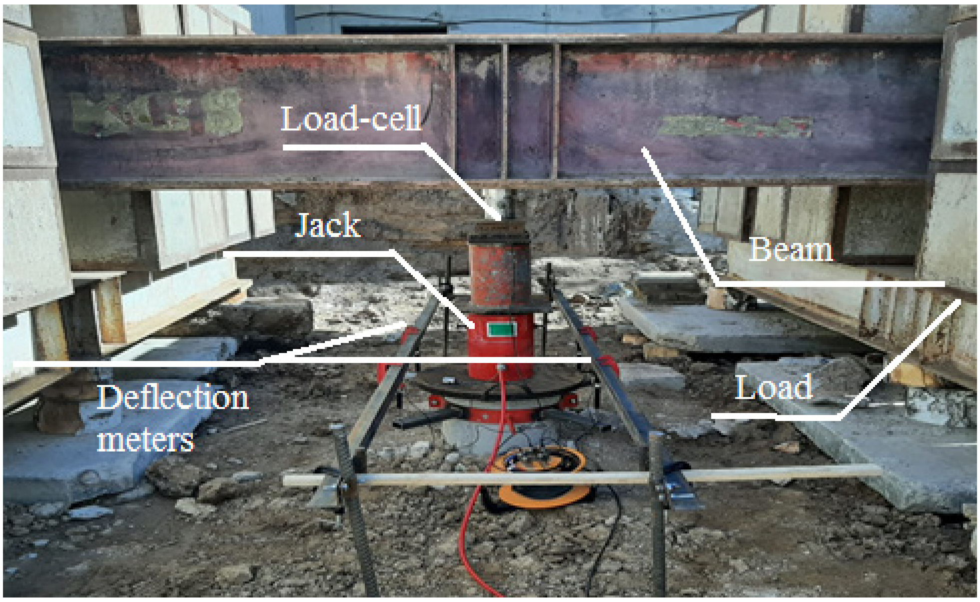


Figure 7. Field test results of load-settlement response of DDS piles

3. Results and Discussion

Static tests on the model piles DDS (Drilled displacement system) and CFA (Continuous flight auger) were carried out on the volumetric stand. After the static test, the «settlement- load» graphs of the DDS and CFA piles were obtained. The DDS model pile sag was 12.21 mm, and the CFA model pile was 19.25 mm.

The CFA technology piles at a load of 196 N were completely submerged. The test results show that the bearing capacity of the DDS model pile is higher than the CFA piles. Considering the results of our model tests, it was recommended to use DDS technology for bored piles at the «Asyltay» (Astana, Kazakhstan) construction site. At the same settlement of 12.21m, the bearing capacity of the DDS model pile was 3.2 times higher than the CFA model pile (Figure 8). Figure 8 shows graph «load – settlement» of the DDS and CFA model piles.

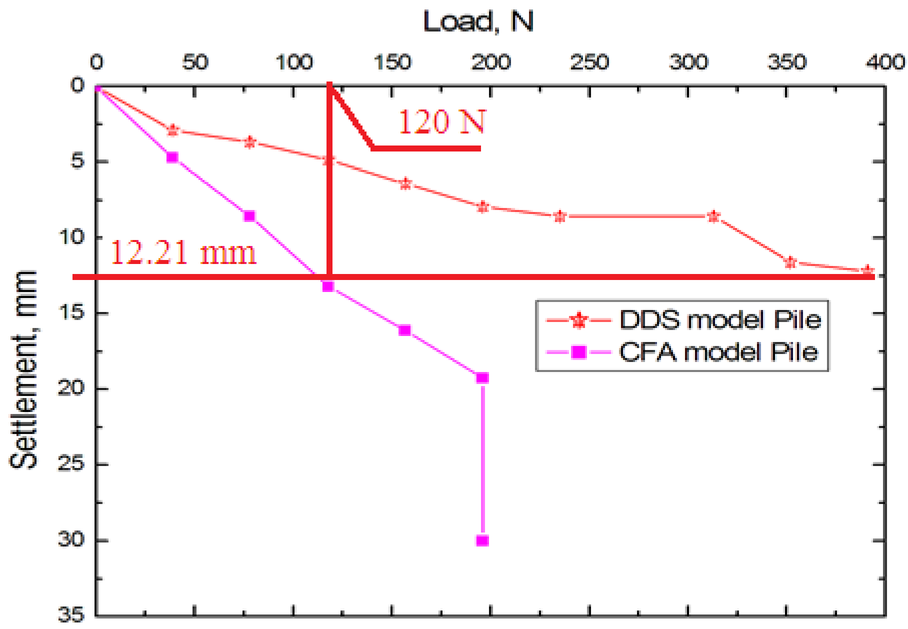


Figure 8. Load – settlement response of the DDS and CFA model piles

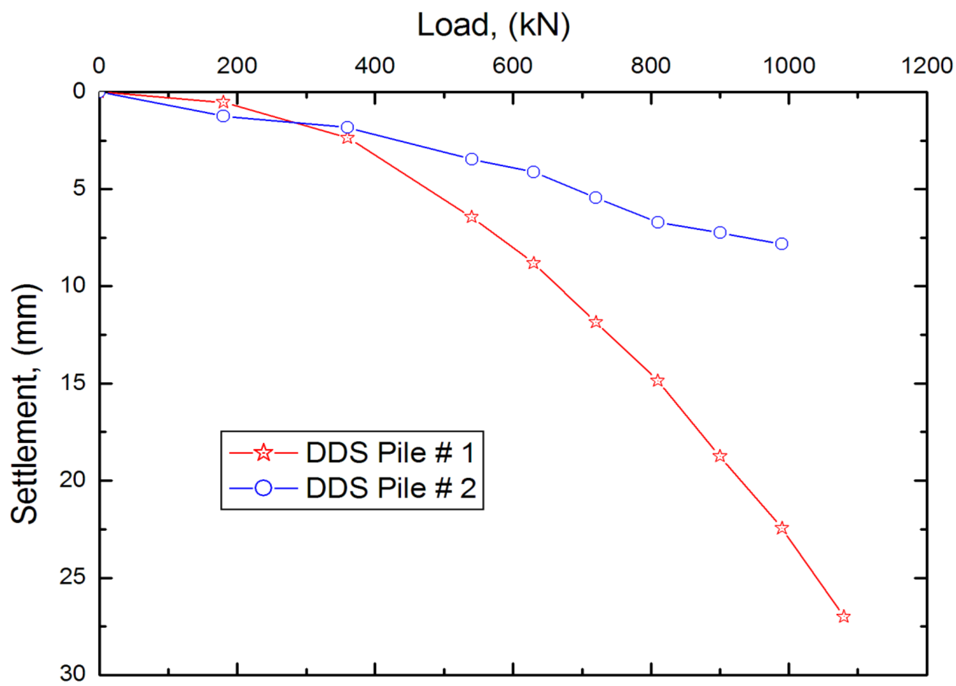


Figure 9. Field test results of load-settlement response of DDS piles

For the construction of industrial and civil multi-story buildings, the DDS pile technology is taken in accordance with the Construction Norms and Regulations RK 5.01-01-2002 for reinforced concrete structures [12]. This technology offers several advantages, making it particularly attractive for use in dense urban areas. One of the main advantages is the absence of vibration or noise during the construction process. Additionally, there is no need for soil excavation, which reduces the overall cost of the project by eliminating the need for soil removal. The onboard computer controls the entire process, ensuring 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 borehole. As a result, high-quality concreting is achieved with smooth and strong walls after unrolling, and pressurized concrete feeding through the hollow unroller.

4. Conclusion

Based on the results of testing model piles on a volumetric stand, a comparative analysis of the bearing capacities of model piles using DDS and CFA technologies was obtained. The results showed that the load-bearing capacity of model piles using DDS technology is higher than CFA piles. The results obtained served to recommend this technology for use at the Asyltas construction site. The results of the axial compression loading tests performed in soft to firm or stiff clays demonstrated the suitability of DDS technology pile foundations. The results of the loading testing program confirmed that the DDS 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 These investigations are important for the understanding of soil-pile interaction on the problematical soft soils ground of by different technologies (DDS and CFA) in Astana, Kazakhstan.

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Ығыстыру технологиясы бойынша жасалған бұрғыланып толтырылатын қадалардың лабораториялық және далалық сынақтарын зерттеу

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Аннотация. Дәстүрлі қадалармен салыстырғанда, ығыстыру технологиясы бойынша (Drilled Displacement System ары қарай DDS) бұрғыланып толтырылатын қадалармен үздіксіз шнек (Continuous Flight Auger ары қарай CFA) технологиясы бойынша жасалған бұрғыланып толтырылатын қадалар көтеру қабілетімен, жылдам орнату және бүлінудің аз қалыптасуы тұрғысынан артықшылықтарға ие. Бұл мақалада көлемді стендте Drilled Displacement system (DDS) және Continuous Flight Auger (CFA) технологиялары арқылы салынған модельді қадалардың тәжірибелері сипатталған. Зерттеу үшін диаметрі 20 мм және ұзындығы 300 мм 1/20 масштабтағы модельдік қадалар жасалынды. Модельдік қадалар статикалық жүктемеге ұшырады және тиеу процесінің әр кезеңінде сәйкес мәні алынды. DDS қадалары үшін де, CFA қадалары үшін де «шөгу-жүктеме» графигі талданып, шекті жүк көтергіштігінің бағалау нәтижелері салыстырылды. Зерттеуге сәйкес, DDS қадалары жүк көтергіштігі CFA қадаларынан асып түсті. Сонымен қатар, диаметрі 400 мм және ұзындығы 6 м болатын DDS бұрғыланып толтырылатын қадаларына статикалық жүктемелермен толық ауқымды далалық сынақтар жүргізілді. Далалық жүктемені есептеу кезіндегі сынақ нәтижелері реакциясы модельдік тестілеу нәтижелеріне жақсы сәйкес келеді. Тұтастай алғанда, зерттеу нәтижелері DDS қадаларының сипаттамалары мен өнімділігі туралы пайдалы ақпарат береді, оны әртүрлі топырақ түрлерінде осы қадалардың дизайны мен орнатылуын жақсарту үшін пайдалануға болады.

Кілт сөздер: масштабталған модельді қада, модельді сынақ, көтергіш қабілеті, статикалық жүктемелік сынақ.

Исследование лабораторных и полевых испытаний свай, установленных методом вытеснения

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Аннотация. По сравнению с традиционными свайными системами сваи, изготовленные по технологиям Drilled Displacement System (DDS) и Continuous Flight Auger (CFA), имеют преимущества в виде повышенной несущей способности, более быстрой установки и меньшего образования грунта. В данной статье описываются эксперименты с модельными сваями, построенными с использованием технологий Drilled Displacement System (DDS) и Continuous Flight Auger (CFA) в заполненном грунтом объемном стенде. Для исследования использовались модели свай диаметром 20 мм и длиной 300 мм в масштабе 1/20. Модельные сваи подвергаются статическому нагружению, и на каждом этапе процесса нагружения измеряются соответствующие перемещения. Для свай

DDS и CFA было проведено сравнение результатов анализа графика «осадка-нагрузка» и оценок предельной несущей способности. Согласно результатам исследования, сваи DDS превосходят сваи CFA по несущей способности. Кроме того, были проведены натурные испытания статическими нагрузками свай, пробуренных по технологии DDS, диаметром 400 мм и длиной 6 м. Реакция нагрузок при натурных испытаниях хорошо согласуется с модельными испытаниями. В целом, результаты исследования дают глубокую информацию о поведении и характеристиках свай DDS, которая может быть использована для улучшения проектирования и установки этих свай в различных типах грунтов.

Ключевые слова: испытания на масштабной модели, модельные сваи, несущая способность, испытание статической нагрузкой

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