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Investigations of the bearing capacity of CFA bored piles in cold climate

Askar Zhussupbekov, Abdulla Omarov, Bibigul Abdrakhmanova
Department of Civil Engineering, L.N. Gumilyov Eurasian National University, Astana, Kazakhstan, astana-geostroi@mail.ru

Ainur Montayeva
Department of Civil Engineering, Korkyt Ata Kyzylorda State University, Kyzylorda, Kazakhstan

Abilkhair Issakulov
Department of Civil Engineering, K. Zhubanov Aktobe Regional University, Aktobe, Kazakhstan

ABSTRACT: This paper presents the results of static loading tests on deep CFA bored piles conducted at a construction site in Aksay, Kazakhstan, located in a region with permafrost conditions. The aim was to determine the bearing capacity and settlement characteristics of piles under vertical compression, tension, and lateral loads in frozen soils. The study includes Static Compression Pile Loading Tests (SCPLT), Static Tension Pile Loading Tests (STPLT), and Static Lateral Pile Loading Tests (SLPLT), performed on bored piles with a diameter of 600 mm and lengths ranging from 15.51 m to 21.85 m. The SCPLT results revealed that the piles could withstand vertical loads up to 1975 kN, with load-settlement curves showing the piles' ability to resist vertical compression and maintain acceptable settlement levels. The STPLT results demonstrated the tensile capacity of the piles, with minimal settlement observed within the permissible limits for the design load. The SLPLT assessed the lateral resistance of the piles, showing maximum lateral loads of 200 kN and corresponding displacements ranging from 6.19 mm to 7.27 mm. The tests followed standardized procedures (ASTM D1143 for compression, ASTM D3966 for tension, and ASTM D3689 for lateral tests), ensuring consistent and reliable results. These tests provided valuable data about the pile behavior and soil-pile interaction in frozen ground conditions. The findings emphasize the importance of field testing in evaluating pile performance under real-world conditions in permafrost zones and offer insights for optimizing pile design, improving foundation stability, and ensuring the safety of future construction projects in such challenging environments. The results contribute to the body of knowledge for similar construction sites in frozen soil regions.

KEYWORDS: Pile, SCPLT, STPLT, SLPLT, CFA, frozen soil.

1 INTRODUCTION

Under the unique geological and climatic conditions characteristic of the Aksay, West of Kazakhstan region and Kazakhstan as a whole, pile foundations have proven to be the most efficient, economically viable, and structurally reliable solution for ensuring the long-term stability of buildings and infrastructure. Their widespread adoption is attributed to their ability to perform effectively in challenging soil environments, where other types of foundations may be less reliable or more costly. On modern construction sites, a broad spectrum of piling techniques is implemented, each selected based on the specific engineering requirements, soil characteristics, and project objectives (Issakulov and et. al. 2023).

These methods encompass driven piles installed with high-performance hydraulic hammers produced by manufacturers such as Junttan, Banut-650, and Rapat, which deliver precise and consistent impact energy for deep penetration into dense soil layers; piles driven with robust diesel hammers like the MSDSh1 and MSDT1 models, valued for their mobility and adaptability to various site conditions; and piles embedded by static indentation using advanced "Tizer" equipment, which minimizes vibration and noise impacts on surrounding structures. In addition, drilled piles with casing pipes are created using the traditional pile construction technology facilitated by SO-2 drilling rigs, offering reliability in cohesive and granular soils; bored piles with protective casings are installed with cutting-edge drilling rigs from "Bauer" and "Casagrande," ensuring high precision and quality in complex geological profiles; while continuous flight auger (CFA) bored piles are formed without the need for temporary casing, allowing rapid installation with minimal spoil removal. Further methods include drilled piles produced with short augers utilizing SM-70, SBU-100, Klemm, and Soilmec equipment for medium-depth applications; drilled bored piles in pre-rolled boreholes employing DDS (FDP) technology with "Bauer" rigs, which combine drilling and displacement techniques to enhance load-bearing capacity; and jet grouting piles formed by high-pressure injection of cementitious slurry into the soil, creating a reinforced column of improved ground. (Mussakhanova and et. al. 2023).

Continuous Flight Auger (CFA) piles represent a specialized type of bored pile foundation in which the pile is drilled to the design depth in one uninterrupted operation using a continuous flight auger. CFA piles are classified as replacement, cast-in-place piles with minimal soil displacement, offering a combination of stability and efficiency. The construction process typically involves three main stages: the drilling phase, the extraction phase (which simultaneously removes soil and injects concrete), and the reinforcement installation phase. This method is applicable to a wide range of soil conditions, including sands, clays, loams, water-saturated soils, loose gravelly layers, and even soft rock formations. In foundation engineering, CFA technology is widely used due to several advantages over traditional bored pile methods, particularly in terms of cost-effectiveness and time savings. The process generates no impacts, vibrations, or excessive noise, making it ideal for use in urban environments; it requires relatively compact equipment, enabling work in restricted spaces; and it allows for high rates of production in large-scale projects. The technique partially displaces soil laterally during drilling, increasing the final transverse bearing capacity of the pile—a factor influenced by the ratio between the auger diameter and the central stem diameter. The auger's cutting head drills through the soil, which is conveyed upward along its flights. Upon reaching the required depth, corresponding to the auger's length, the tool is withdrawn while concrete is pumped through the hollow central stem to fill the borehole. The reinforcement cage is then inserted into the fresh concrete. Typical CFA piles range from 600 mm to 1200 mm in diameter and can reach depths of up to 50 meters. A plug positioned at the auger's base prevents soil from entering the hollow stem during drilling and is expelled by the pressure of the injected concrete during concreting. A cleaning device, mounted at the mast's base, removes soil from the auger blades during extraction and maintains alignment in the initial drilling meters. The auger extension passes through a rotary head, enabling uninterrupted concrete delivery from a suitable pump via flexible hoses or pipes. Extensions can be added to increase drilling depth when necessary, providing adaptability to various site conditions.

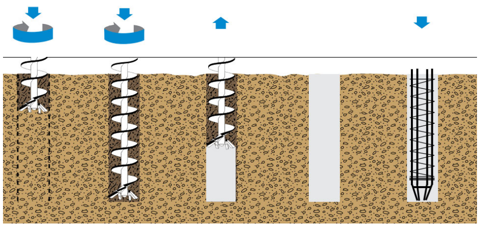

Figure 1. Pile installation process using CFA technology.

Over the past two decades, the field of pile testing has undergone a profound transformation, largely driven by the advent of high-powered computing technologies, which have enabled the development and practical application of far more advanced and efficient testing methods than were previously available. In the past, roughly fifteen to twenty years ago, engineers were restricted to a narrow range of static load testing procedures, most of which were not only expensive but also time-consuming, limiting their use to select high-priority projects. Today, however, the situation has changed dramatically: a broad spectrum of techniques exists to either evaluate or directly measure the load resistance of piles, as well as to rapidly and economically assess their structural integrity without the need for dismantling or intrusive inspections. In Kazakhstan, modern practice encompasses three main categories of pile testing—static load testing, dynamic load testing, and integrity testing—each of which has further subdivisions tailored to specific site conditions and engineering requirements. Static load testing now includes vertical load tests, which determine the pile's bearing capacity under axial compression; horizontal load tests, used to evaluate lateral resistance and flexibility; and bidirectional load tests, which simultaneously measure upward and downward resistance within the same pile element. Dynamic load testing methods have also diversified significantly: traditional impact-based tests in accordance with GOST standards remain in use, but have been complemented by Rapid Load Testing (RLT), which offers accelerated data collection with minimal site disruption; Pile Driving Analyzer (PDA) technology, which provides real-time monitoring of hammer blows during pile driving to assess capacity and stress levels; and the Statnamic load test, which applies a high-magnitude, short-duration load that simulates static conditions with greatly reduced testing time. Integrity assessment techniques have likewise evolved, with methods such as the Pile Integrity Test (PIT) and Sonic Integrity Testing (SIT) enabling the detection of cracks, voids, or changes in material quality within the pile shaft, ensuring early identification of defects that could compromise performance (Zhussupbekov, et. all. 2019a).

2 GEOTECHNICAL CONDITIONS OF THE CONSTRUCTION AREA

The basin, covering an area of approximately 500,000 km², contains sedimentary sequences reaching thicknesses of up to 22 km in certain locations. Structurally, it is segmented into numerous zones by extensive salt domes, with the principal salt unit—the Permian Kungurian formation—dividing the stratigraphy into subsalt and suprasalt sequences. Geographically, the basin is bounded to the east by the Hercynian Ural Mountains, and to the southeast and south by other orogenic belts. To the north, it extends across the flank of the Voronezh Massif in the west and the Volga–Ural Platform in the north. Alongside the giant Karachaganak field, several other major oil and gas accumulations have been identified in the region, including Astrakhan, Tengiz, and Zhanazhol fields. The physical and mechanical properties of the foundation soils at the construction site are presented from top to bottom in Table 1. The depositional environment of the field exhibits considerable variability; core sample analyses and seismic data indicate the presence of multiple facies, including limestone, talus deposits, normal and shallow marine settings, inner reef lagoons, reef cores, deeper-water slopes, and anhydrite layers (Zhussupbekov, et. all. 2019b).

The results of laboratory testing of the physical and mechanical properties of the foundation soils at the construction site are summarized in Table 1. The parameters presented include natural density (ρ), specific cohesion (c), internal friction angle (φ), deformation modulus (E), and design resistance (R_0). For each engineering-geological element (EGE), two values are provided, representing measurements obtained from the upper and lower portions of the respective soil stratum. These properties were determined in accordance with standard geotechnical testing procedures to ensure reliability for subsequent engineering analysis and foundation design (Zhussupbekov, et. all. 2022). The geological structure of the study site comprises several engineering–geological elements. **EGE-1** consists of heavy dusty loam, yellowish-brown to brown in color, lumpy, slightly moist, with consistency ranging from solid to semisolid, and exhibiting settlement-prone behavior. **EGE-2** is composed of light clay, brownish-black to yellowish-brown and brown in color, lumpy, slightly moist, with a plastic consistency varying from solid to semisolid, and is also prone to settlement. **EGE-4** represents light dusty clay, brown to light brown in color, lumpy, slightly moist, with solid to stiff plastic consistency. **EGE-5** consists of reddish-brown to dark brown clay containing black free inclusions, solid, slightly moist, with consistency ranging from solid to stiff plastic. **EGE-6** is represented by light dusty clay, greyish-brown to dun in color, containing free inclusions of grey material, of medium density, slightly moist to moist, with consistency varying from semisolid to stiff plastic. **EGE-7** comprises light dusty clay, dun to grey and dark grey in color, of medium density, moist, and exhibiting stiff plastic consistency (Zhussupbekov et al., 2021).

The geological structure of the study site comprises several engineering–geological elements (EGE). EGE-1 consists of heavy loam, dusty, yellowish-brown to brown in color, lumpy, slightly moist, with consistency ranging from solid to semisolid, and exhibiting settlement characteristics. EGE-2 is composed of light clay, brownish-black to yellowish-brown and brown in color, lumpy, slightly moist, with a plastic consistency varying from solid to semisolid, and also prone to settlement. EGE-4 represents light clay with a dusty texture, brown to light brown in color, lumpy, slightly moist, and of solid to stiff plastic consistency. EGE-5 is reddish-brown to dark brown clay containing black free inclusions, solid, slightly moist, with a consistency from solid to stiff plastic. EGE-6 consists of light dusty clay, greyish-brown to dun in color, with free inclusions of grey material, of medium density, slightly moist to moist, with consistency ranging from semisolid to stiff plastic. EGE-7 comprises light dusty clay, dun to grey and dark grey in color, of medium density, moist, with a stiff plastic consistency (Zhussupbekov, et. all. 2021).

3 PILES ARE SUBJECTED TO STATIC LOADS IN THE FORM OF AXIAL COMPRESSIVE, TENSILE, AND LATERAL LOADS

3.1 *Static axial compression pile load test (SCPLT)*

Static compression pile load testing (SCPLT) is widely regarded as one of the most dependable field methods for determining pile bearing performance under vertical compression. At the investigated construction site, four bored piles—each 600 mm in diameter and ranging in length from 15.53 m to 21.85 m—were subjected to SCPLTs. The load–settlement relationships, obtained from measurements of pile head load (L) against settlement (S), are illustrated in Figure 5, showing that the response curves for SCPLT-1, SCPLT-2, SCPLT-3, and SCPLT-4 were generally similar, with ultimate capacities of roughly 1050 kN for SCPLT-3 and SCPLT-4, 1310 kN for SCPLT-2, and up to 1975 kN for SCPLT-1 (Figure 5). As specified in SNiP RK 5.01-03-2002, the maximum permissible settlement for a test pile—depending on the construction category—may be 16 mm or 24 mm, which reflects the conditional nature of this testing methodology. Loading was applied through a hydraulic jack operated by a NER-1,6A40T1 manual electro-hydraulic pump station, while vertical displacements were recorded using MA100BU100 gauges mounted on a fixed benchmark frame. The reference system incorporated two 20 cm-high, 5.3 m-long H-beams secured by clamps to BAU 114 × 4 × 2000 screw piles, embedded to a depth of 1.5 m. As in most cases, a reaction frame system was used to counteract the applied load. The SCPLT procedure measures the axial displacement of a deep foundation element under static vertical compression and is primarily intended to confirm structural and geotechnical reliability while enabling settlement prediction for similar piles. The load is typically increased in stages to the design working load with a designated safety margin, followed by unloading and monitoring of rebound until movement ceases. All testing in this study was performed in accordance with ASTM D1143.

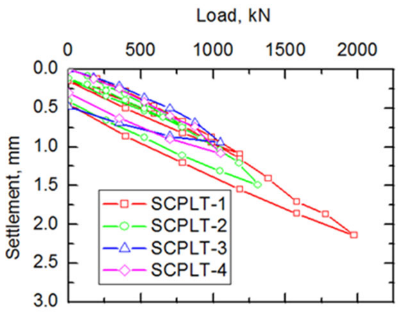

Figure 2. Top-down static pile load test results for SCPLT 1, 2, 3, and 4.

3.2 *Static tensile pile loading test (STPLT)*

Static tensile load testing is generally not applied to concrete or composite piles, prestressed reinforced concrete piles without transverse reinforcement, bored piles with enlarged bases, or screw piles. This method is permitted for use only on piles that can serve as test elements for evaluating soil response under a static top-down load. The penetration depth of the pile during such testing, when aimed at assessing negative skin friction in compressible soils, is taken as the vertical distance from the ground surface to the depth at which settlement from self-weight during saturation equals the maximum allowable settlement for the planned structure. The criterion for conditional stabilization of deformation is defined by the rate of upward movement of the pile at each stage of tensile loading; this rate must not exceed 0.1 mm in the final hour of observation for building and structure pile foundations (excluding bridges), and the same limit applies for bridge pier foundations. The maximum applied load during control tensile testing in the course of construction must not surpass the design tensile load specified in the pile foundation calculations [10]. In the present study, continuous flight auger (CFA) bored piles with a diameter of 600 mm and lengths between 15.51 m and 21.71 m were tested in static tensile loading at the Aksay construction site. The loading–unloading program for the static tensile pile load test (STPLT) was executed in the following sequence, expressed as a percentage of the design load: 0, 25, 50, 75, 100, 125, 150, 100, 50, 0, 25, 50, 100, 125, 150, 175, 200, 225, 250, 200, 150, 100, 50, and 0. In the first loading cycle, the piles were subjected to a load of 360 kN, while in the second cycle the load was increased to 600 kN. The resulting load–displacement curves from the STPLT are presented in Figure 6 (Buranbayeva, et. all, 2022).

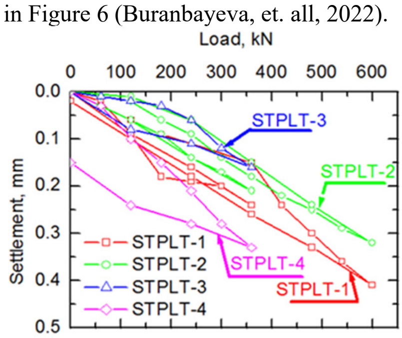

Figure 3. Static tension pile load test results for piles SCPLT-1, SCPLT-2, SCPLT-3, and SCPLT-4.

3.3 *Static lateral pile loading test*

The static lateral pile load test is employed to evaluate the load–deflection behavior of vertical or batter piles, either individually or in groups, when subjected to lateral forces. This method is applicable to all types of deep foundation elements, regardless of size or construction technique, and is considered the most reliable means of determining the true lateral load capacity of the pile–soil system. When combined with appropriate instrumentation, lateral load testing—interpreted through iterative elastic analysis that accounts for the nonlinear behavior of soils—can provide essential soil parameters required for the structural design of piles to withstand applied lateral loads. In the present study, static lateral load testing was carried out on continuous flight auger (CFA) bored piles at the Aksay construction site. The tested piles had a diameter of 600 mm and lengths ranging from 15.51 m to 20.50 m (Figure 7). Similar CFA bored piles were also constructed at a Caspian Sea site for the development of additional shipping platform foundations (Zhussupbekov, et. all. 2023, and 2020).

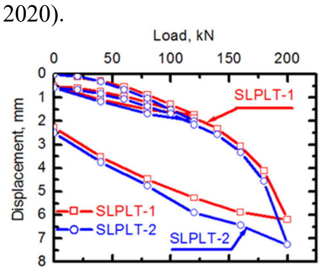

Figure 4. Static Lateral Pile Load Test Results of piles SLPLT-1, and SLPLT-2.

Table 2 presents the results of a comprehensive series of in-situ static load tests performed on piles at the project site, including static compression, static tension, and static lateral load evaluations. For each tested pile, the table lists its identification number, embedded length (L), diameter (D), and applied maximum load, and the corresponding measured displacement or settlement (S). The static compression pile loading tests (SCPLT) demonstrated maximum applied loads ranging from 1050 kN to 1975 kN, with settlements between 0.94 mm and 2.14 mm. Static tension pile loading tests (STPLT) recorded tensile loads of 360 kN to 600 kN, with displacements of 0.16–0.41 mm. Static lateral pile load tests (SLPLT) applied a lateral load of 200 kN, resulting in deflections of 6.19 mm and 7.27 mm for the respective piles.

The load–settlement responses obtained from the pile load tests demonstrate distinct deformation characteristics under static compression loading, reflecting the interaction between pile geometry, soil stratigraphy, and loading level. The SCPLT results indicate a nonlinear increase in settlement with applied load up to approximately 2000 kN. At lower load levels, settlements increase gradually, suggesting predominantly elastic soil–pile behavior. As the load exceeds about 800–1000 kN, the curves show a noticeable increase in slope, indicating the mobilization of shaft resistance and the onset of plastic deformation in the surrounding soils. Among the tested piles, SCPLT-1 and SCPLT-4 exhibit comparatively higher settlements at similar load levels, which may be attributed to local variations in soil stiffness or pile installation effects. In contrast, SCPLT-2 and SCPLT-3 demonstrate stiffer responses, indicating more favorable load transfer conditions. The absence of a sharp settlement jump suggests that ultimate bearing capacity was not fully reached within the applied load range, and the piles retained sufficient reserve capacity. The STPLT curves show significantly smaller absolute settlements, with maximum values not exceeding 0.45 mm under loads up to 600 kN, indicating a stiffer system response compared to SCPLT. The load–settlement relationship is nearly linear at low loads, followed by mild nonlinearity as the load increases, reflecting progressive mobilization of pile–soil resistance. Pile STPLT-3 demonstrates the stiffest response with the lowest settlement at comparable loads, whereas STPLT-1 and STPLT-4 show relatively larger deformations, suggesting reduced stiffness or less efficient load transfer mechanisms. Nevertheless, settlements remain within acceptable limits for serviceability criteria. Overall, the SCPLT results reflect the behavior of piles under higher compressive loading and deeper stress influence zones, while the STPLT results indicate stable and controlled deformation under moderate loading levels. The consistency of the curves and the absence of abrupt settlement increases confirm the reliability of the pile foundation system and the adequacy of the soil bearing capacity for the applied loads.

4 CONCLUSIONS

The current regulatory framework for pile foundation design in Kazakhstan is significantly outdated, and the results of this study emphasize the urgent necessity for its revision in line with modern international standards. The experimental program undertaken included full-scale static compression, tension, and lateral load tests on CFA bored piles installed in the soft to stiff clays characteristic of the Aksay region in northwest Kazakhstan. These soils present notable geotechnical challenges, including low bearing strata, potential for negative skin friction, and variable moisture conditions. The compression load tests (SCPLT) revealed ultimate load capacities ranging from 1050 kN to 1975 kN, with minimal settlements between 0.94 mm and 2.14 mm, well within the allowable limits specified by SNiP RK 5.01-03-2002. The tension load tests (STPLT) confirmed tensile resistance values up to 600 kN, with displacements of only 0.16 mm to 0.41 mm, indicating excellent shaft adhesion in the clay formations. Lateral load tests (SLPLT) demonstrated pile head deflections between 6.19 mm and 7.27 mm under a 200 kN applied lateral load, providing valuable input for the structural design of piles under horizontal forces such as wind, seismic action, or wave loading in offshore and nearshore environments. These results verify the technical feasibility and reliability of CFA bored piles for use as deep foundations in oil and gas infrastructure, even in remote and geologically problematic areas. Furthermore, the measured data serves as an empirical basis to calibrate and validate predictive design models, enabling more accurate determination of pile-soil interaction parameters for future projects in similar geotechnical settings. The integration of such field-based performance data into updated design codes would significantly enhance the safety, cost efficiency, and sustainability of foundation systems in Kazakhstan.

5 REFERENCES

Buranbayeva, A., Zhussupbekov, A., Sarsembayeva, A., Omarov, A. 2022. Evaluation of the Structural Health Monitoring Results of the Applied Fiber Optics in the Pile-Raft Foundations of a High-Rise Building. *Applied Sciences Switzerland*, 12(22), 11728.

Mussakhanova, S., Zhussupbekov, A., Omarov, A., Abilmazhenov, T., Issakulov, A. 2023. Features of testing piles for high-rise buildings in difficult soil conditions in Astana. *International Journal of Geomate*, 25(110), 106–113.

Issakulov, A., Omarov, A., Zhussupbekov, A., Mussakhanova, S., Issakulov, B. 2023. Investigation of the interaction of the bored micro pile by DDS (FDP) technology with the soil ground. *International Journal of Geomate*, 24(105), 11–17.

Omarov, A.R., Zhussupbekov, A.Zh., Sarsembayeva, A.S., Issakulov, A.B., Buranbayeva, A.M. 2023. Numerical modelling micro piles and evaluation of the O-Cell test results. *News of the National Academy of Sciences of the Republic of Kazakhstan Series of Geology and Technical Sciences*, 5(461), 190–201.

Zhussupbekov, A., Chang, D.-W., Utepov, Y., Borgekova, K., Omarov, A. 2019. Estimating the Driven Pile Capacities for COF Project in West Kazakhstan. *Soil Mechanics and Foundation Engineering*, 56(2), 121–127.

Zhussupbekov, A., Iwasaki, Y., Omarov, A., Tanyrbergenova, G., Akhazhanov, S. 2019. Complex of static loading tests of bored piles. *International Journal of Geomate*, 16(58), 8–13.

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

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

Zhussupbekov, A., Morev, I., Omarov, A., Borgekova, K., Zhukenova, G. 2018. Geotechnical considerations of piling testing in problematical soils of West Kazakhstan. *International Journal of Geomate*, 15(47), 111–117.

Zhussupbekov, A.Zh., Omarov, A.R. 2020. Geotechnical considerations of piling construction and testing in problematical soils of Kazakhstan. *16th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering ARC 2019*.

Zhussupbekov, A.Z., Omarov, A.R., Mussakhanova, S.T., Issakulov, A.B. 2023. Analysis of interaction of boring CFA micro piles with problematic soil conditions Aksai, Kazakhstan. *Smart Geotechnics for Smart Societies*, Astana, 1380–1384.

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