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Analysis of interaction of precast concrete joint piles with problematic soil conditions Prorva

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ABSTRACT: The Cargo Offloading Facility is an essential strategic project for the expansion of oil fields. The Cargo Offloading Facility is located along the quay and represents a special reinforced concrete surface supporting large cranes needed to unload both bulky and general cargo. According to the design drawings, the Cargo Offloading Facility construction site was planned by installing precast concrete joint piles. Investigation of the interaction of precast concrete joint piles used for the first time on construction site in Kazakhstan with complex soil conditions. In this paper the joint piles with the cross section of 400x400 mm and with pin-joined connection were considered and their interaction with the soil of Western Kazakhstan will be analyzed. Evaluation of bearing capacity of PCJP by interpretation methods of field test data, computational methods using the APILE analysis computer program and the Kazakhstan stand-ard, as well as a dynamic PDA (pile driving analyzer) method while piles driving.

1 INTRODUCTION

Kazakhstan is the world's ninth biggest country by size and the largest landlocked country, and it is the essential transportation hub between Russia, Central Asia, China and Europe. Cargo offloading facility (hereinafter – COF) has been built in the north-eastern part of the Caspian Sea in Western Kazakhstan for the development of transport infrastructure. This facility was started as a part of the Future Growth Project, which will enable the expansion of the large Tengiz oil field, where more than 23 thousand piles were installed. In 2017, a new cargo transportation route has been constructed from the Northeast Caspian Sea to Tengiz for creating access channel to the new facility on the port of Prorva, which designed for offloading the heavy vessels and barges delivered by marine transport. The construction of a cargo offloading facility is considered unique and is an important strategic project to expand oil fields in West Kazakhstan (see Figure 1).

The expediency of using pile foundations is explained by the need to ensure a high bearing capacity of structures. Their effectiveness essentially depends on the accuracy of determining the bearing capacity of the pile and the design load on it. Standards for the design of pile foundations are intended to determine their bearing capacity by an analytical method using reference generalized tables or according to field test data of a loaded pile by static or dynamic load. Before applying these methods, engineering and geological surveys are required to determine the indicators of the properties of each engineering-geological element in contact with the pile. The survey also allows the designer to assign the parameters of the piles and calculate their bearing capacity, which is traditionally considered to consist of the soil resistance under the tip and along the lateral surface of the pile (Zhussupbekov et. Al 2015).

According to the design drawings, COF construction site was planned to be installed by PCJP. This was the first experience of installing such type of piles in Kazakhstan. Applying PCJPs for the first time demanded a comprehensive approach. Therefore, it was decided to

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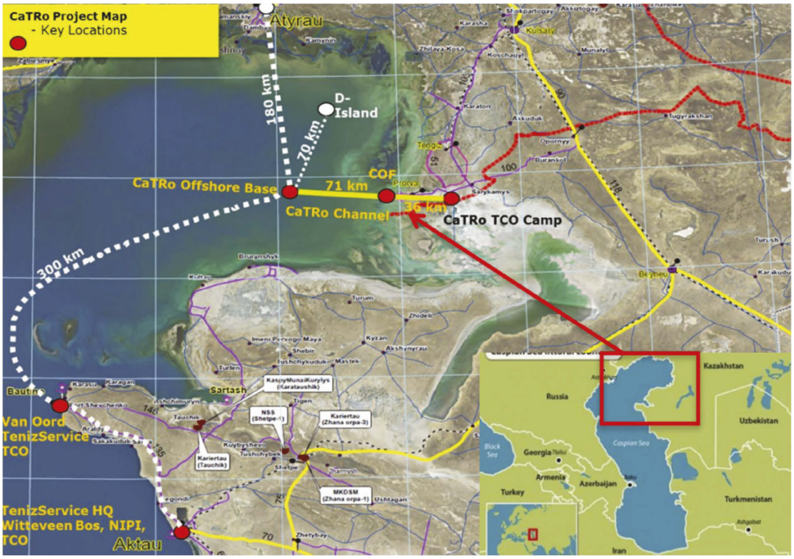
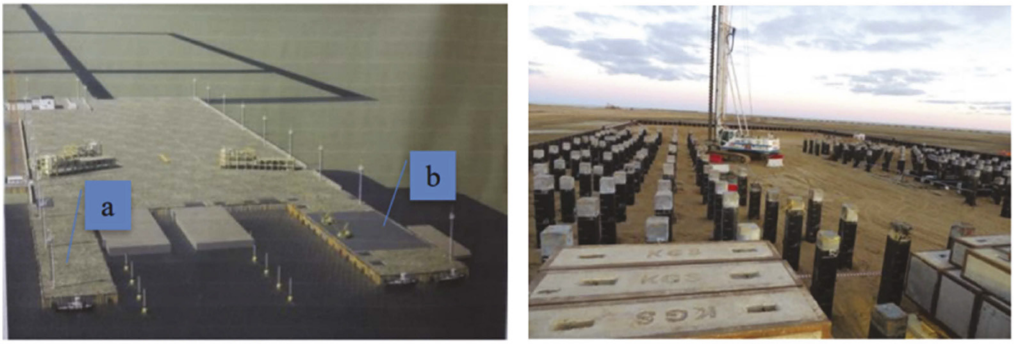


Figure 1. Location of cargo offloading facility.

first conduct their tests in a pilot site. In this study, the pilot site and COF site are marked as A and B (see Figure 2).



1 2

1 – scheme of COF in the future: a – pilot site; b – COF; 2 – construction site of COF

Figure 2. Cargo offloading facility.

In this paper, the work of precast concrete joint piles with soil of West Kazakhstan was investigated. This type of pile is one of the first products of Kazakhstani production that uses connecting material, and undoubtedly is of practical interest for modern construction of Kazakhstan. However, the application of dynamic tests by Pile Driving Analyzer (hereinafter – PDA) during the driving of precast concrete joint piles is of scientific interest .

2 ENGINEERING-GEOLOGICAL STRUCTURE OF THE CONSTRUCTION AREA

The project area is located along the east coast of the North East Caspian Sea, both onshore and offshore, near the Prorva oilfield, Kazakhstan. The project area is situated on the Northern Caspian Shelf. At present the North Caspian Sea has a limited water depth (maximum 5 to 8 m). The water level in the Caspian Sea depends on a balance between the inflow of river water and evaporation (Zhussupbekov & Omarov 2016).

This has resulted in large variations in sea level in the past. In the sedimentary succession within the planned construction site and with regard to lithology, depositional setting, structure, compositional petrology, state and physical and mechanical properties of sediments and with regard to the State Standard (GOST) 25100-95 the following geotechnical elements (GE) were specified. The physical and mechanical characteristics of soils at construction site A and B shown in the Tables 1 and 2 (Zhussupbekov & Omarov 2016).

Table 1. Physical and mechanical characteristics of soils at construction site A.

Layer thick ness, m	Geological formation	Soil type	General Consistency	γ_{sat}, kN/m^3	φ, deg	Su, kPa	E
0.5	new Caspian	Silt, slightly organic, calcareous	soft to firm	19.3	29.4	-	2.750
4	new Caspian	Sand, silty, calcareous	Medium dense to dense	20.2	31.5	-	30.000
4	Late Khvalynian	Clay, silty, calcareous	stiff	19.1	24.7	80	2.000
19	early Khvalynian	Clay, silty, calcareous	very stiff	20.2	24.7	150	2.000

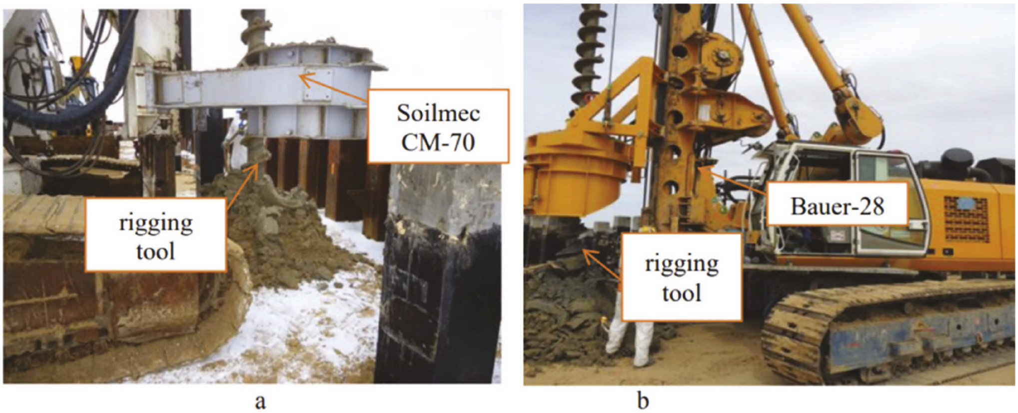
Table 2. Physical and mechanical characteristics of soils at construction site B.

Layer thick ness, m	Geological formation	Soil type	General Consistency	γ_{sat}, kN/m^3	φ, deg	Su, kPa	E
4	new Caspian	Sand, silty, calcareous	Medium dense to dense	20.2	31.5	-	2.750
4	Late Khvalynian	Clay, silty, calcareous	stiff	19.1	24.7	80	30.000
4	inter Khvalynian	Sand, silty, calcareous	very dense	20	31.8	-	40.000
5	early Khvalynian	Clay, silty, calcareous	very stiff	20.6	23.8	150	4.000
10	early Khvalynian	Clay, silty, calcareous	very stiff	20.2	24.7	150	2000

Soils building up a geological environment at a depth down to 10 m from ground surface are salinized; salinity level is high; at sulfate nature of salinity they contain increased amount of carbonates, gypsum and insignificant amount of organic matters (humus). Loamy silt relates to slightly saturated clayey soil group; it possesses thixotropic properties Light silty clay possesses slight degree of swelling. The ground waters relate to the weak brine group in upgraded version. Water-and-soil environment possesses a medium degree of aggressivity in reference to W8 graded concrete. Soils possess high aggressivity to low-allowed and carbon steel.

3 INSTALLATION OF PRECAST CONCRETE JOINT PILES

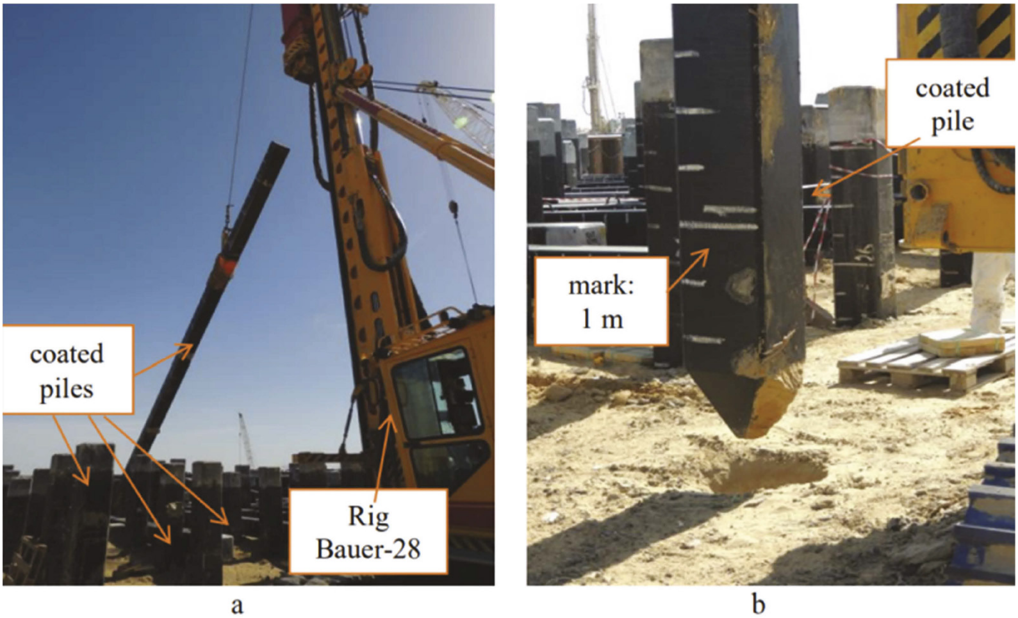
The leader boreholes were made before installation of piles. The leader well is a well created for the subsequent immersion of a precast concrete pile. Leader wells are guide holes in the ground, greatly facilitating the process of sinking of the piles. The leader drilling allows piles to sink in vertical direction to a certain depth to reduce the noises occurred during the pile driving [111]. The boreholes were made with preaugering and pre-drilling methods. The pre-augering was executed by clockwise rotating auger insertion up to designated depth and by removing rotating auger in counterclockwise direction. With this method, a few amount of soil was removed from borehole by a fully hydraulic, self-erecting drilling rig Soilmec CM-70 (see Figure 3a). In the pre-drilling method removing was performed without rotation by Rotary Drilling Rig Bauer-28 (see Figure 3b) (Zhussupbekov & Omarov 2017).



a – pre-auger by Soilmec CM-70; b – pre-drilling by Bauer-28

Figure 3. Pre-auger and pre-drilling processes.

The Junttan PM 25HD is a medium weight piling rig designed for pile driving steel and concrete piles. The rig has excellent stability and wide leader inclination angles. The recommended hammer weight is from 5000 to 9000 kg and the maximum pile length is 24 meters. The rig has proven productivity. The telescopic leader ensures easy and fast handling of piles. Top pile driving performance is guaranteed with Junttan hydraulic hammers. Piles were coated by corrosion protection material (bituminous) and marked by cross-lines every 0.25 m. (see Figure 4).



a – coated PCJP; b – installation of marked coated piles in boreholes

Figure 4. PCJP pile with protective coating and marked every 250 mm.

The head of bottom segment and the bottom of upper segment had steel plates “Emeca 3-Minute Splice”, which had jointing and locking mechanisms. Two female (socket) and two male (stud) locking mechanisms are welded on opposite sides of each base plate (see Figure 5).

a b

a – bottom segment; b – connection of two segments

Figure 5. Two female (socket) and two male (stud) locking mechanisms.

Locking mechanisms are welded to long pieces of reinforcing bar. Two segments of PCJPs were gathered by the four locking pins (see Figure 6) (Zhussupbekov et.al 2018).

a b

a – joint of two segments by pin; b – installation of two segments by hammer

Figure 6. Installation of two segments of PCJP.

To ensure the integrity of precast concrete joint piles from destruction in the process of driving parts, a type of equipment was calculated with an effective impact energy according to the formula recommended in the SNiP and in the one-dimensional Wave Equation Analysis program. According to the results of calculations in this construction site, it was decided to use driving equipment with a hammer 9 ton for driving 27.5 m of precast concrete joint piles, for installation of 25.5 m piles – was used 7 ton equipment.

The leader drilling technology with pre-augering and pre-drilling methods for time saving, preserving of pile head was applied before the installation of precast concrete joint piles.

Protected from corrosion precast concrete joint piles were composed of upper segment with the length of 16.0 m and upper segment with the length of 11.5 m and 9.5 m on test area. During the driving piles nylon and wooden plates were used for protection pile head from structural failure. The locking and jointing mechanism of two segments of pile were connected by the four pins (Zhussupbekov et.al 2019).

Dynamic tests were carried out on two parts of joint reinforced concrete piles separately, and the results of the bearing capacity were determined automatically by the program as an average value. After driving the first part of the joint pile, a pair of accelerometers and strain transducers were attached to the second part of the pile at 8 meters, the data of the piles were entered into the program, and the PDA dynamic tests were continued. After the execution of field part of dynamic test, selected blow data (often one of the last blows) are analyzed in the computer program Case Method &iCAP® in the software PDIPLOT2, Ver 2016.1.56.3.

CAPWAP (Case Pile Wave Analysis Program), which is based on wave equation. Pile model and soil model is initiated with measured value of pile velocity (Vmeasured(t)). The result of CAPWAP analysis is calculated response (Fcalculated(t)), which in the case of perfectly accurate pile and soil model data should be completely identical with the measured force curve.

Static loading tests of PCJPs were carried out according to the requirements of ASTM D1143 – Standard Test Methods for Deep Foundations Under Static Axial Compressive Load. Testing platform (see Figure 7) presented itself system from steel, which consists of metallic beam and 2 load platforms located on equidistant distances from the center main beams. For platforms used concrete blocks, which pack on one platform by total weight 200-205 (250) tons.

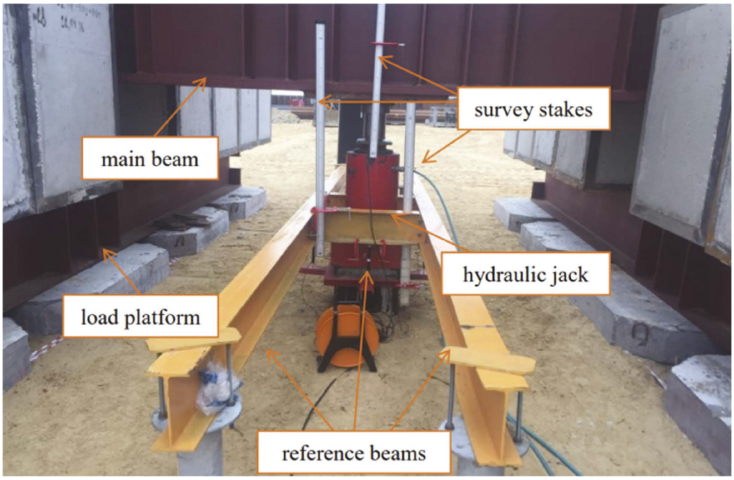


Figure 7. Testing platform for static compression load test.

As reference frame, two H-beams with h = 20cm and length 5.3 m were used which bolted with clamp to screw piles BAU 114*4*2000 drilled in soil with depth 1.5 m. (which were placed on either side of the pile on steel support brackets bolted on piles). The two beams acted as reference for the displacements sensors (see Figure 8a). The reference frames, was regularly checked with an optical level instrument to detect any movements and cross reference the movement of the pile (see Figure 8b).

The load and deflection readings are collected by a data logger, which simultaneously downloads data to a PC. Data is simultaneously displayed and stored for printing. With the concern of limit load, three SLTs were conducted with maximum load of 3278 kN at construction site A. For working load concern, four tests were conducted with maximum load of 1638 kN at construction site B (Zhussupbekov et.al 2019).

Tables 3 and 4 list the pile load test information at these construction sites respectively.

Three SLTs were conducted with maximum load of 3278 kN at construction site A. Figure 9a shows the load-settlement curves obtained from these tests. Four tests were conducted with maximum load of 1638 kN at construction site B. Figure 9b shows the results respectively.

a b

a - reference frame; b – checking the pile settlement with an optical level instrument

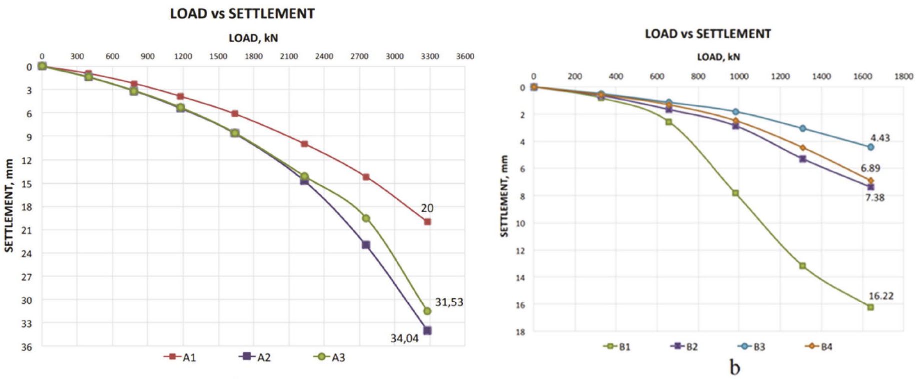
Figure 8. During the static compression load test.

Table 3. Pile load test information at construction site A.

Pile ID	A1	A2	A3
Length, m	25.5	27.5	25.5
Cross-section, cm	40x40	40x40	40x40
Penetration length, m	24.25	26.25	22.5
Type of boreholes	Pre-augering diam.330mm, l=12 m	Pre-augering diam.330mm, l=12 m	Pre-augering diam.330mm, l=9 m
Maximum load	3278 kN	3278 kN	3278 kN
Maximum Settl., mm	20.0	34.04	31.53

Table 4. Pile load test information at construction site B.

Pile ID	B1	B2	B3	B4
Length, m	27.5	27.5	27.5	27.5
Cross-section, cm	40x40	40x40	40x40	40x40
Penetration length, m	25.63	25.4	25.86	25.78
Type of boreholes	Pre-augering diam.330mm, l=12 m	Pre-augering diam.330mm, l=12 m	Pre-augering diam.330mm, l=12 m	Pre-drilling diam.440mm, l=15.6 m
Maximum load	1639 kN	1639 kN	1639 kN	1639 kN
Maximum Settl., mm	16.22	7.38	4.43	6.89



a b

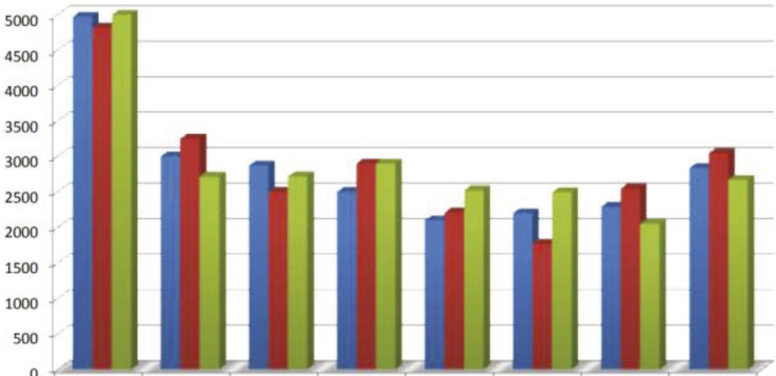
a – load-settlement curves from site A; в – load-settlement curves from site A

Figure 9. Pile loading test results at construction sites.

4 DISCUSSIONS

Estimates of bearing capacity of the PCJPs tested at construction site A (where the maximum applied load was 3278 kN) by a variety of interpretation methods showed that the Chin and Decourt methods gave the highest values. The remaining interpretation methods provided results more or less similar (2000~3000 kN) to those obtained from the APILE analyses, PDA, and manual calculations.

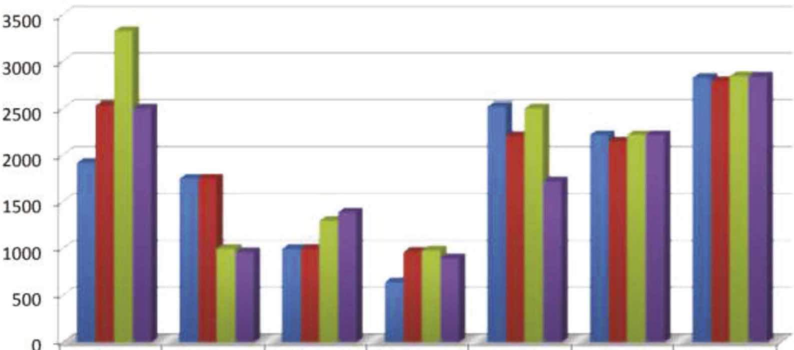
Meanwhile, the bearing capacities of PCJPs at construction site B (where the maximum working load was 1639 kN) obtained using the De Beer, Fuller and Hoy, and Butler and Hoy methods, were considerably lower than those obtained from the APILE analyses, PDA, and manual



	Chin, Decourt, average	De Beer	Davidson	Fuller and Hoy	Butler and Hoy	PDA	APILE, average	Hand calculation
A1	4966	3000	2870	2500	2100	2202	2291	2836
A2	4812	3250	2500	2900	2208	1768	2544	3043
A3	4994	2714	2717	2900	2520	2497	2045	2670

a

a – for construction site A



	Chin, Decourt, average	De Beer	Fuller and Hoy	Butler and Hoy	PDA	APILE, average	Hand calculation
B1	1918	1750	1000	643	2518	2217	2828
B2	2528	1750	1000	967	2203	2148	2794
B3	3326	1000	1300	980	2502	2217	2846
B4	2498	963	1391	900	1722	2217	2840

b

b – for construction site B

Figure 10. Comparison of pile capacities at construction sites A and B.

calculations (Table 5, illustrated in Figures 10a and b). This seems to be obvious, since the APILE, PDA, and manual calculations are only appropriate for prediction of ultimate bearing capacity. For the working load tested piles at construction site B, the interpretation methods only predicted yield capacities that were about 1/2 to 1/3 of the ultimate capacities. In general, despite the different approaches used, the results were found to be rational, and consistent with Kazakhstan construction requirements.

Table 5. Comparison of pile capacities at construction sites A and B (units of kN).

Methods / Pile ID	Chin, Decourt, average	De Beer	Davisson	Fuller and Hoy	Butler and Hoy	PDA	APILE, average	SNiP RK
A1	4966	3000	2870	2500	2100	2202	2291	2836
A2	4812	3250	2500	2900	2208	1768	2544	3043
A3	4994	2714	2717	2900	2520	2497	2045	2670
B1	1918	1750	1223	1000	643	2518	2217	2828
B2	2528	1750	-	1000	967	2203	2148	2794
B3	3326	1000	-	1300	980	2502	2217	2846
B4	2498	963	-	1391	900	1722	2217	2840

5 CONCLUSIONS

The interaction of precast concrete joint piles with the square section of 400*400 mm and with the length of 27.5 m with the surrounding soil ground during the construction of a port for offloading bulky goods were considered in this thesis. When assessing the reliability of a pile foundation, one of the determining ones is the question of the bearing capacity of the pile by soil. The greatest attention is paid to the bearing capacity of piles by static and dynamic load in classical and numerical and normative methods for identification of this parameter. The determination of the bearing capacity of precast concrete joint piles by interpretation methods, in the APILE software and by the SNiP formula presents particular interest to practicing engineers and scientists.

The use of precast concrete joint piles during the construction of a cargo offloading facility in Western Kazakhstan in the Prorva field present of particular interest to designers. The identification of an effective method for calculating the bearing capacity of precast concrete joint piles with a length of 27.5 m is determined by the first experience of using these piles at a construction site in Kazakhstan.

Based on the results of this study the following recommendations are made.

1. According to the results obtained from the seven field tests of piles by dynamic and static loads at the construction site of Cargo offloading facilities and the pilot site, it is considered the dynamic tests by PDA for application of identification of bearing capacity of precast concrete joint pile. Because the results of PDA show the similarity with static loading test, analytical methods as APILE analysis and calculation by equation from Kazakhstani standard. Dynamic test by PDA is economical and time saving. Although SLT is reliable but this test is very expensive and time consuming, hence researchers have been trying to come up with other efficient approaches.
2. The bearing capacity of precast concrete joint pile from static loading test data can be determined by conventional methods as Davisson, Chin, De Beer, Fuller and Hoy, Butler and Hoy. However, they are more appropriate for interpretation of high static loading test data, where settlements are bigger.
3. Estimation of bearing capacity of precast concrete joint pile can be made by APILE analysis program and equation from Kazakhstani standard.

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