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Bearing capacity of precast concrete joint pile foundations embedded layer predicted using dynamic and static load test by ASTM

Abdulla R. Omarov[1], Askar Zh. Zhussupbekov[1,2]
[1] L.N. Gumilyov Eurasian National University; Astana, Kazakhstan;
[2] Moscow State University of Civil Engineering (National Research University) (MGSU); Moscow, Russian Federation

ABSTRACT

Introduction. This is the first investigation of the behaviour of precast concrete joint piles utilized in challenging soil conditions on a construction site in Kazakhstan.
Materials and methods. The following techniques were applied: evaluation of the bearing capacity of SCLT using field test data interpretation techniques and the ASTM's dynamic DLT method for driving precast concrete joint piles.
Results. Only 7 % separated the dynamic DLT-PDA approach from the static approach. This implies that, in comparison to other current methods, the alternative dynamic DLT-PDA method is highly precise and effective. Dynamic tests were conducted by PDA (Pile Dynamic Analyzer) and static tests by the requirements of the American Society for Testing Materials (ASTM).
Conclusions. According to the test results have been made design changes in the pile foundation. Static tests (SLT) were carried out on 16-meter piles and precast concrete joint piles with a total length of 25.5 and 27.5 m cross-section 40 × 40 cm. SCLT is a highly accurate and robust system that enables you to monitor static pile tests whilst also ensuring the safety of site operatives. Featuring a cable, users are able to monitor safely and accurately from distance, eliminating the need for personnel to enter potentially dangerous testing zones. This study examined joint piles with a 400 × 400 mm cross section and a pin-joined connection, as well as their relationship with the soil of Western Kazakhstan will be analyzed.

KEYWORDS: PDA, SCLT, DLT, precast concrete joint piles

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Corresponding author: Abdulla R. Omarov, omarov_01@bk.ru.

Несущая способность заглубленных сборных железобетонных свайных фундаментов, прогнозируемая с помощью динамических и статических нагрузочных испытаний по методике Американского общества испытания материалов

Абдулла Рахметович Омаров[1], Аскар Жагпарович Жусупбеков[1,2]
[1] Евразийский национальный университет имени Л.Н. Гумилева; г. Астана, Казахстан;
[2] Национальный исследовательский Московский государственный строительный университет (НИУ МГСУ); г. Москва, Россия

АННОТАЦИЯ

Введение. Это первое исследование сборных железобетонных свай в сложных грунтовых условиях строительной площадки в Казахстане.
Материалы и методы. Применены следующие методы: оценка несущей способности методом статического сжатия с использованием методов интерпретации данных полевых испытаний и метод динамического нагружения при забивании готовых железобетонных свай.
Результаты. Результаты метода динамического нагружения отличаются от результатов метода статического сжатия всего на 7 %. Это означает, что по сравнению с другими существующими методами альтернативный метод динами-

ческого нагружения является высокоточным и эффективным. Динамические испытания проводились с использованием анализатора забивки свай, статические — в соответствии с требованиями Американского общества испытания материалов.

Выводы. По итогам испытаний были внесены конструктивные изменения в свайный фундамент. Статические испытания выполнялись на 16-метровых сваях и составных железобетонных сваях общей длиной 25,5 и 27,5 м сечением 40 × 40 см. Метод статического сжатия — это высокоточная надежная система, которая позволяет контролировать статические испытания свай, обеспечивая при этом безопасность персонала на стройплощадке. Благодаря наличию кабеля пользователи могут осуществлять безопасный и точный мониторинг на расстоянии без необходимости входить в потенциально опасные зоны испытаний. В данном исследовании рассмотрены составные сваи с сечением 400 × 400 мм и шарнирным соединением, также проанализирована их применимость на грунтах Западного Казахстана.

КЛЮЧЕВЫЕ СЛОВА: анализатор динамики свай, метод статического сжатия, метод динамического нагружения, сборные железобетонные сваи

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ДЛЯ ЦИТИРОВАНИЯ: *Омаров А.Р., Жусупбеков А.Ж.* Несущая способность заглубленных сборных железобетонных свайных фундаментов, прогнозируемая с помощью динамических и статических нагрузочных испытаний по методике Американского общества испытания материалов // Строительство: наука и образование. 2025. Т. 15. Вып. 1. Ст. 12. URL: http://nso-journal.ru. DOI: 10.22227/2305-5502.2025.1.12

Автор, ответственный за переписку: Абдулла Рахметович Омаров, omarov_01@bk.ru.

INTRODUCTION

In Kazakhstan, pile foundations are currently the most crucial component of large-scale construction progress, particularly in Astana, the country's relatively new capital, where high-rise construction is moving quickly forward. The viability of pile foundations is explained by the need to provide great bearing capacity for high-rise buildings and structures. Because they enable data to be gathered on the relationship between the stress-strain state and the pile's bearing capacity, field methods of soil testing with piles are pertinent in this context. When design modifications are made in response to the data, these data are especially crucial in the initial phases of construction. One of the primary approaches to optimizing the choice of pile length and diameter in the pertinent engineering and geological conditions is a preliminary joint experimental and theoretical study, including analytical and numerical methods, of the interaction of long piles with surrounding and underlying soils. It should be kept in mind that the interaction of the pile with the surrounding and underlying soil is one of the trickiest problems in applied soil mechanics and structure. Significant contribution to pile foundation construction was made by: M.Y. Abelev, P.A. Abbasov, A.A. Bartolomei, N.M. Gersevanov, B.I. Dalmatov, R.A. Mangushev, E.A. Sotnikov, Z.G. Ter-Martirosyan, S.B. Ukhov, A.B. Fadeev, N.A. Tsytovich, C. Terzaghi, A.J. Zhussupbekov, T.M. Baitasov, B.A. Bazarov, R.K. Bazilov, S.B. Yenkebaev, R.E. Lukpanov, E. Ashkey, R. Frank and many others [1–10]. The bearing capacity of precast concrete joint pile foundations embedded in a layer is a crucial topic in geotechnical engineering, particularly when assessing their performance under dynamic and static loads. The analysis and prediction of this bearing capacity are typically approached using both dynamic and static load tests. Here's a general outline of how these tests and methods might be used to evaluate such foundations (Fig. 1).

1. *Static Load Test (SLT).* This is a common method used to determine the ultimate bearing capacity of piles. It involves applying a gradually increasing load to the pile until it reaches a predefined settlement or failure point. The test provides direct measurements of pile settlement and load capacity. Procedure: A static load is applied to the pile, and the resulting settlements are recorded. This helps in determining the pile's load-settlement behaviour. Data Analysis: The results are used to assess the ultimate bearing capacity, settlement under design loads, and the load distribution along the pile shaft and tip [11–20].

2. *Dynamic Load Test (DLT).* This method evaluates the behaviour of piles under dynamic loads, such as those

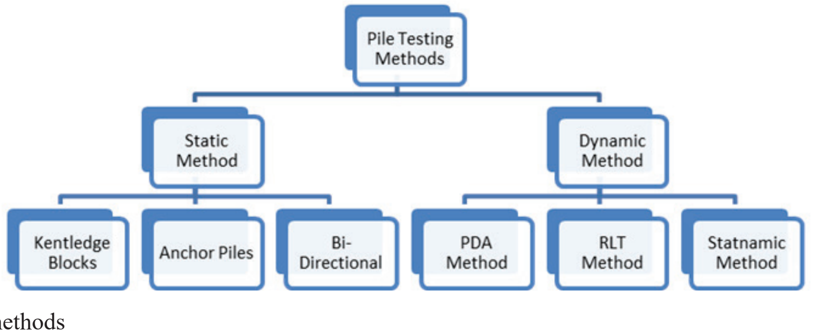

Fig. 1. Pile testing methods

Рис. 1. Методы испытания свай

caused by construction activities or seismic events. Dynamic load tests can provide information about the pile's ability to withstand short-term, high-intensity loads. Procedure: A dynamic load is applied to the pile, typically using a drop hammer or a similar device. The response of the pile to this dynamic load is measured. Data Analysis: Dynamic load tests use principles such as the case method or wave equation analysis to estimate pile capacity and analyze dynamic behaviour [20–25].

3. *Combined Analysis.* Using both dynamic and static load tests can provide a more comprehensive understanding of the pile's performance. The dynamic tests might be used to estimate the pile's behaviour under rapid loading conditions, while static tests provide insight into its performance under sustained loads. Prediction of Bearing Capacity: Static load tests generally provide more reliable estimates of the ultimate bearing capacity. Dynamic tests are useful for understanding the pile's response to dynamic loads and validating the results obtained from static tests. In research literature, studies often combine these testing methods to improve accuracy and reliability in predicting the bearing capacity of precast concrete joint pile foundations.

Precast joint piles are multi-section reinforced concrete structures consisting of several connecting elements. Such piles make it possible to create supports of maximum length (up to 36 m), which is impossible to do with solid piles due to the limited capacity of the pile driving equipment. Any reinforced concrete piles used to support the foundation must be deepened to the level of high-density soils. If the bottom of the pile is in soil with insufficient bearing capacity, the house foundation will not have the necessary stability, causing it to shrink under the weight of the building. The need to use composite piles arises when the top layer of unstable soil on the construction site is thicker than the maximum length of solid reinforced concrete piles. Precast Concrete Joint Piles: These piles are designed with specific joints that can affect their load-bearing behaviour. Both static and dynamic tests help in understanding how these joints influence overall performance. Embedded Layer: The bearing capacity can be influenced by the soil or rock layer into which the pile is embedded. The interaction between the pile and the layer is crucial for accurate bearing capacity predictions. "Dynamic Testing and Static Analysis of Pile Foundations": This paper would discuss methodologies and findings related to combining dynamic and static testing approaches [25–29].

MATERIALS AND METHODS

SCLT testing of precast concrete piles

Due to the widespread use of pile foundations in soft soil conditions, as well as with the increase in the number of stories in construction, it becomes necessary to install composite piles longer than 12 m. There are many ways to connect piles, and it is difficult to determine which method is the most effective. Fig. 2 shows a structural diagram of the work performed using the technology for constructing composite pile foundations. It is obvious that the processes of engineering and geological surveys of the construction site and the design of pile foundations are practically independent of the manufacture of composite piles and their delivery to construction sites. This indicates that a flexible technological process has been obtained, where independent stages of work are carried out aimed at obtaining a single final product. Manufacturing plants, regardless of the design solutions for pile foundations of a specific facility, and taking into account the plan for the release of reinforced concrete products, can manufacture composite piles and have a certain stock of products. A contractor to obtain the required volume of composite piles, indicating their specific dimensions and curing the product until it gains the strength specified in the project. With the new technology of erecting pile foundations, in addition to the above-described advantages, their design is significantly simplified. Factory technology for the manufacture of prefabricated piles can be carried out using automated technological lines, and special vehicles equipped with equipment for loading and unloading operations can be used to deliver them to construction sites. The use of prefabricated piles for the construction of pile foundations will improve labor safety and ensure compliance with technical requirements for delivery, storage and execution of works [5–8].

Static and dynamic tests were carried out on precast reinforced concrete composite piles with a total length of 27.5 m. They consist of two sections with a cross-section of 40 × 40 cm: a lower section 16.0 m long and upper sections 9.5 to 11.5 m long (Fig. 2). When constructing a pile foundation, each driven pile can be subject to control, which provides very valuable information that, in our opinion, must be used from calculation, design and ending with the production of pile work. In addition, to obtain an effective type of pile foundation, as noted repeatedly, it is necessary to strive for maximum use of the bearing capacity of the piles on the soil, bringing it closer to the bearing capacity of the piles on the material. Static compression tests were performed on precast concrete composite piles No. TP-03, No. TP-02, No. TP-01.5, and No. K-3, which are moved under the control of the cargo unloading facility (COF) area with a depth of 23 and 26.75 m, and pre-drilled with an auger with a diameter of 330 m, depth of 11.40 m. The platform is made of steel, which consists of a metal beam and two platforms located at equal distances from the center of the main beams (Fig. 3).

Concrete blocks are used for platforms, and one platform can accommodate a total weight of 200–205 tons. The vertical loading is created by a DG500 G250 hydraulic jack. The pressure in the jack was created using an NER-1.6A40T1 electrohydraulic pump with a manual distributor. For the support beams, two H-shaped beams with a height of h = 20 cm and a length of 5.3 m were used, which were fastened with bolts with a BAU 114 × × 4 × 2,000 clamp. During the tests, the benchmarks and

Fig. 2. SCLT static load testing of precast concrete joint piles

Рис. 2. Испытание методом статического сжатия сборных железобетонных свай с шарнирным соединением

Fig. 3. Equipment for loading precast concrete joint piles

Рис. 3. Оборудование для нагружения сборных железобетонных свай

deflection gauges were protected from the effects of wind, temperature and other negative effects (Fig. 2, 3).

For composite pile No. K-3, the load was 1,639 kN (this is equal to 125 %), and for other piles, the maximum load was 3,278 kN (this is equal to 250 %) of the working load [6–14].

Testing of precast concrete piles using the PDA method

Despite its name, this test using an oscillographic pile driving analyzer (PDA) can be performed on any type of deep foundation. Dynamic pile testing is based on the theory of stress wave propagation on piles and includes the following:

- installation of accelerometers and stress sensors on the pile or bored column;
- recording and transmission to the PDA of acceleration and stress signals at each impact of the ram or hammer on the pile;
- computer processing, reproduction and storage of signals, as well as performing automatic calculations.

Pile dynamic tests were performed on precast concrete piles No. TR-1.02, No. TR-1.03, No. TR-1.05 and No. TR-02. The piles were tested using a PDA (Pile Driving Analyzer — Model PAX) using a JUNTTAN PM25LC hammer with a 9 ton HHK-9A hydraulic hammer and a 990 kg head attachment. The sensors are connected to the analyzer (PDA) which internally performs all the necessary signal conditioning and processing to obtain output results during the drive for each hammer blow and an immediate display on the screen of the measured force on the pile head ($v_{meas(t)}$) and the speed of the pile head movement ($v_{meas(t)}$) as a function of time [6–14].

The test results obtained by this method, when processed using the wave theory of impact, make it possible to approximately estimate the effective resistance of the soil along the lateral surface and the heel of the pile, and to model the "load – settlement" relationship.

Determining the specified values over time during the impact allows plotting graphs of the dependence of the pile settlement on the dynamic forces acting in it, which can be recalculated for the corresponding static loads.

Signals from the sensors are transmitted to the measuring computer using a cable. Signals from the sensors must be recorded in digital form on a hard disk.

Determination of the bearing capacity of a pile on the soil is carried out using specialized software developed based on the principles of the wave theory of impact [25].

When using wave calculation to determine the resistance of single piles working to press the piles into the soil, the reliability of the calculation must be confirmed by the available positive results of static tests of piles of the same cross-section in similar soil conditions.

The results we obtain are as follows:

- load-settlement graph (Pile Top);
- total bearing capacity of the pile;
- bearing capacity along the lateral surface of the pile;
- bearing capacity across four piles;
- load-settlement graph four piles (Bottom);
- presence of any significant discontinuities in the shaft.

RESULTS OF THE RESEARCH

Results of field tests using the SCLT method

Fig. 4 shows the results of testing by the SCLT method. According to the results of composite piles No. TR-03, No. TR-02 and No. TR-01.5, the curved line in the "settlement – load" graph shows that the convergence of the graphs is observed only at the initial stage of loading, and then there is a change in the trajectory of the curve of composite piles No. TR-02 and No. TR-03, charac-teristic of the stage of resistance to creeping soil, while the curve of composite pile No. TR-01.5 (at this stage of loading) is more characteristic of the elastic resistance of the soil [9–11].

The Davisson Limit Value (Ultimate Load) Method offers the advantage of allowing the engineer, when checking a pile for a given allowable load, to determine in advance the maximum allowable displacement for that load, given the pile length and size. Pile section area, $A = 0.16$ m^2; Pile diameter approximation, D = 45.0 cm; Load, P = 3,000 kN; Pile number TR-02; Pile length L = = 26.75 m; Young's modulus (B40), E_{con} = 45,000,000 kPa; Elastic line = $(P \cdot L)/(A \cdot E)$ = 0.011 m = 11 mm; Davisson line (ASTM): $\Delta = D/120 + 0.4$ = 0.78 cm = = 7.8 mm; the ultimate pile capacity (pile number TR-02) Fu = 2,480 (Fig. 5).

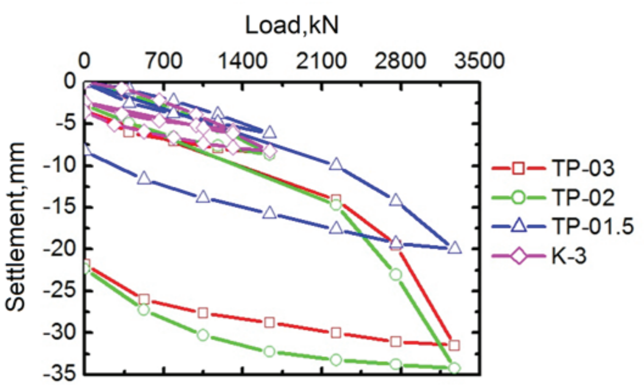

Fig. 4. Load calculation graphs from SCLT methods

Рис. 4. Графики расчета нагрузки по методу статического сжатия

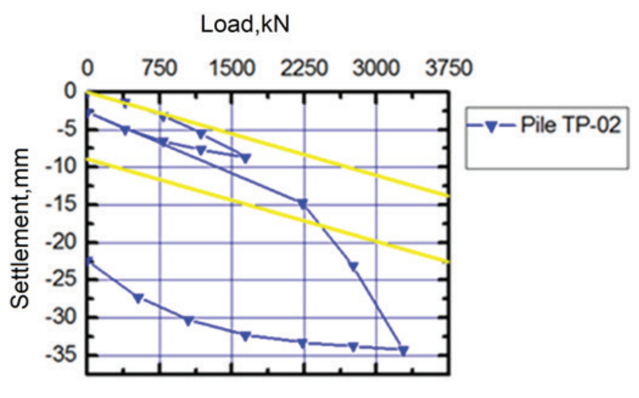

Fig. 5. Load-settlement graph for pile No. TR-02

Рис. 5. График изменения нагрузки для сваи № TR-02

The main advantage of this method is that the actual limit line can be drawn on the load flow diagram before the test begins. The limit load displacement criterion is primarily intended for the interpretation of fast testing methods, but it can also be used to interpret the results of slow methods [9–11].

The ultimate bearing capacity of the pile (pile No. TR-02) *Fu* = 2,450 kN (Fig. 4). In Kazakhstan, the safety factor for static tests of piles is 1.2. Therefore, the calculated value of the permissible pile capacity, Q_d, was estimated as Q_d = 2,480/1.2 = 2,067 kN (pile No. TR-02) and 2,450/1.2 = 2,042 kN (pile No. TR-03).

Results of field tests using PDA and DLT methods

When constructing a pile foundation, each driven pile can be subject to control, which provides very valuable information that, as we believe, must be used starting from calculation, design and ending with the production of pile works. In addition, to obtain an effective type of pile foundation, as noted repeatedly, it is necessary to strive for maximum use of the bearing capacity of piles on the soil, bringing it closer to the bearing capacity of piles on the material.

Fig. 6, 7 show the results obtained by the PDA method when driving precast concrete joint piles [9–11].

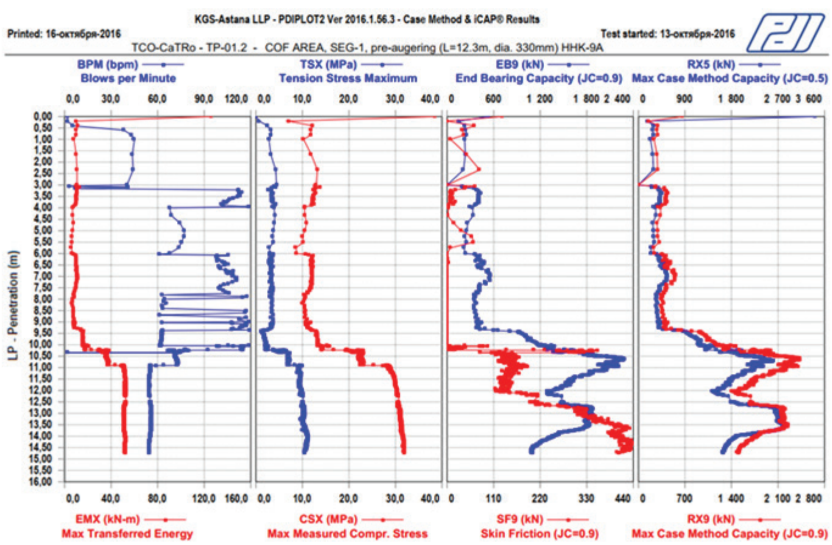

Fig. 6. Graphic results of driving precast concrete joint piles using the PDA method, TR-01.2, depth from the beginning of driving to 14.8 m

Рис. 6. Графические результаты забивания сборных железобетонных свай, полученные с помощью анализатора забивки свай, ТР-01.2, глубина от начала забивки до 14,8 м

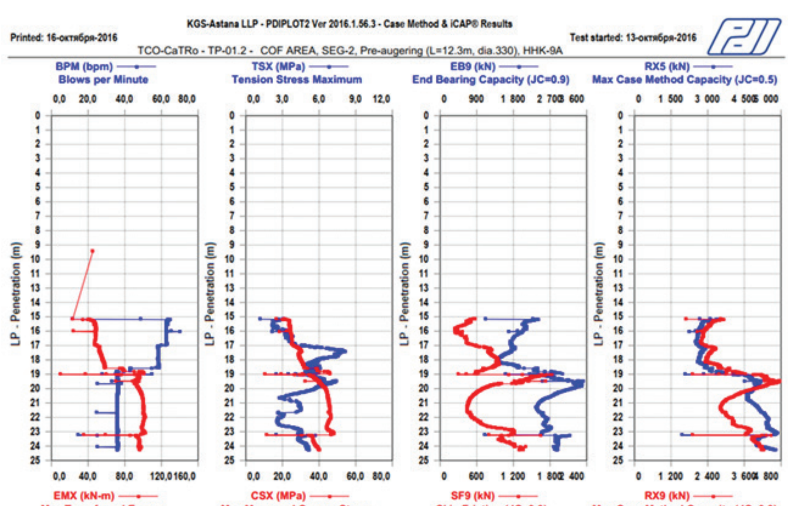

Fig. 7. Graphic results of driving precast concrete joint piles using the PDA method, TR-01.2, Depth from 14.8 to 24.3 m

Рис. 7. Графические результаты забивки сборных железобетонных свай, полученные с помощью анализатора забивки свай, TR-01.2, глубина от 14,8 до 24,3 м

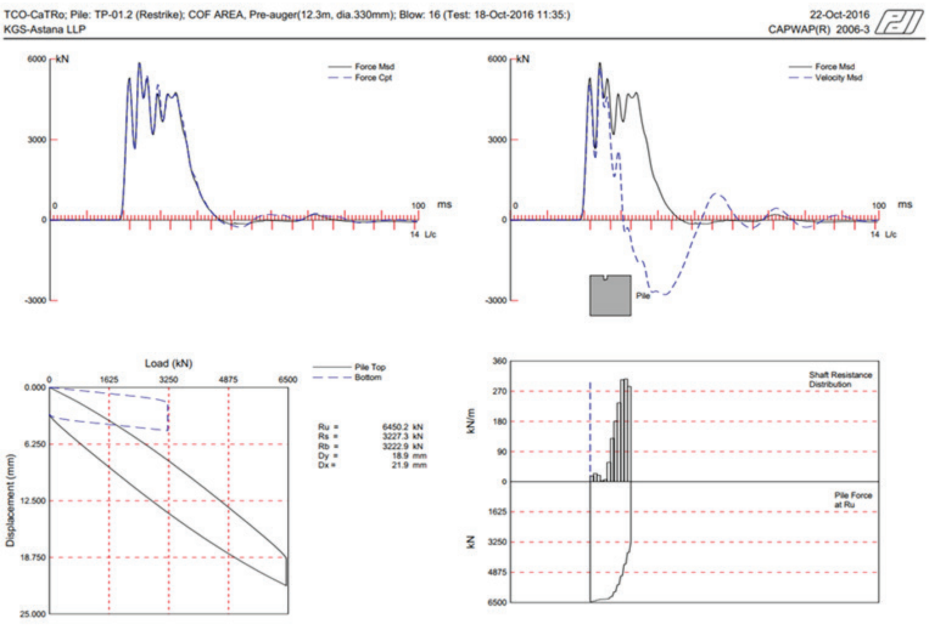

Fig. 8. Test results of composite piles by DLT method, TR-01.2, depth 24.70 m

Рис. 8. Результаты испытаний комбинированных свай методом динамического нагружения, TR-01.2, глубина 24,70 м

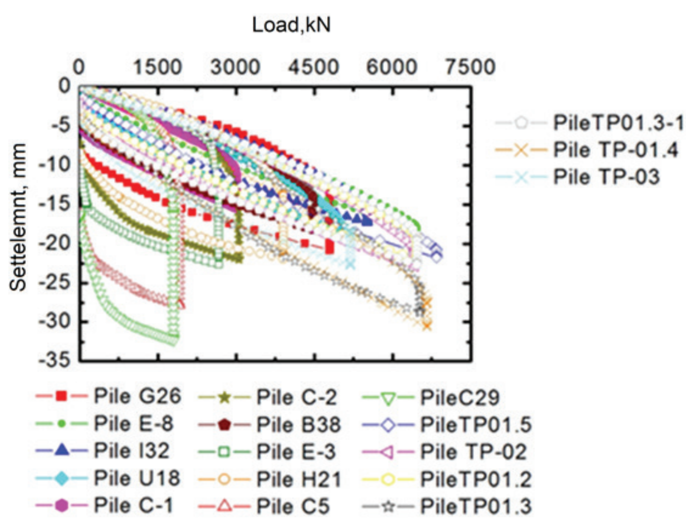

Fig. 9. Results of DLT test results for precast concrete joint piles

Рис. 9. Результаты испытаний методом динамического нагружения готовых сборных железобетонных свай

According to DLT methodology, the pile is driven into the ground until it reaches the value of the pile's pliability parameter in the ground from one impact of the pile driving equipment, corresponding to the value of the effective load carried by the pile. In cases where it is impractical to take the pile's load-bearing capacity in the soil equal to the load-bearing capacity in the material (due to the design features of the pile foundation), the effective load carried by one pile is determined by means of technical and economic calculations. It must not exceed the design resistance of the pile material to axial compression [9–11].

Fig. 8, 9 show the results obtained by the DLT method after resting the composite piles.

$$\mathrm{SCLT}_{ave}\left(\mathrm{ASTM}\right) = \frac{2,067 + 2,042 + 2,333}{3} = \\ = 2,148\ \mathrm{kN} = 104\ \%;$$

$$\mathrm{PDA}_{ave}\left(\mathrm{ASTM}\right) = \frac{2,859 + 2,235 + 2,245}{3} = \\ = 2,447\ \mathrm{kN} = 119\ \%;$$

$$\text{DLT}_{ave}\left(\text{ASTM}\right)=\frac{2,400+2,485+2,236+1,952}{4}=$$
$$=2,366\text{ kN}=111\ \%;$$

$$\text{DLT}_{ave}\left(\text{ASTM}\right)-\text{SCLT}_{ave}\left(\text{ASTM}\right)=$$
$$=2,366\text{ kN}-2,148\text{ kN}=218\text{ kN}=7\ \%;$$

$$\text{PDA}_{ave}\left(\text{ASTM}\right)-\text{SCLT}_{ave}\left(\text{ASTM}\right)=$$
$$=2,447\text{ kN}-2,148\text{ kN}=299\text{ kN}=15\ \%.$$

CONCLUSION AND DISCUSSION

In this paper, according to the analysis, it is possible to observe the similarity of the obtained data from the SCLT and DLT methods (after CAPWAP interpretation). Minor deviations from SCLT equal to 7 % (218 kN) depending on the DLT method are revealed. The Davisson limit method was used as a determinant of the maximum bearing capacity.

In this section, the calculation of the pile bearing capacity is made based on the results of PDA tests of composite piles (40 × 40 cm cross-section and lengths from 23 to 26.75 m) and the bearing capacity of the piles was 2,447 kN, according to the results of SCLT data interpretation, the bearing capacity of the piles on average was 2,148 kN.

The simulation of static load tests with CAPWAP (DLT method) does not include long-term effects such as creep or long-term calculations. According to this reason, in almost all cases the CAPWAP load curve is slightly higher than the static load curve in the static load test, especially for higher loads.

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B i o n o t e s : **Abdulla R. Omarov** — PhD, Associate Professor of the Department of "Civil Engineering"; **L.N. Gumilyov Eurasian National University**; 2 Satpayeva st., Astana, 010008, Kazakhstan; omarov_01@bk.ru;

Askar Zh. Zhussupbekov — Doctor of Technical Sciences, Professor of the Department of "Civil Engineering"; **L.N. Gumilyov Eurasian National University**; 2 Satpayeva st., Astana, 010008, Kazakhstan; consultant; **Moscow State University of Civil Engineering (National Research University) (MGSU)**; 26 Yaroslavskoe shosse, Moscow, 129337, Russian Federation; astana-geostroi@mail.ru.

Contribution of the authors:
Abdulla R. Omarov — conceptualization, methodology, writing, visualization, observation, editing, writing, preparation of the initial draft.
Askar Zh. Zhussupbekov — resources, data processing.
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О б а в т о р а х : **Абдулла Рахметович Омаров** — PhD, доцент кафедры «Строительство»; **Евразийский национальный университет им. Л.Н. Гумилева**; 010008, г. Астана, ул. Сатапаева, д. 2, Казахстан; omarov_01@bk.ru;

Аскар Жагпарович Жусупбеков — доктор технических наук, профессор кафедры «Строительство»; **Евразийский национальный университет им. Л.Н. Гумилева**; 010008, г. Астана, ул. Сатапаева, д. 2, Казахстан; консультант; **Национальный исследовательский Московский государственный строительный университет (НИУ МГСУ)**; 129337, г. Москва, Ярославское шоссе, д. 26; astana-geostroi@mail.ru.

Вклад авторов:
Омаров А.Р. — концептуализация, методология, написание.
Жусупбеков А.Ж. — ресурсы, обработка данных.
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