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RESEARCH ARTICLE

DETERMINATION OF THE BEARING CAPACITY OF BORED PILES ACCORDING TO EUROCODE 7 UNDER THE CONDITIONS OF THE REPUBLIC OF KAZAKHSTAN

Zhamek N.A.² , Abdrakhmanov D.I.¹ , Khomyakov V.A.^{1,2} , Jumadilova S.J.*¹ , T. Awwad³ 

¹International Educational Corporation, 050043, Almaty, Kazakhstan

²Kazakh Research and Design Institute of Construction and Architecture.050062, Almaty, Kazakhstan

³Emperor Alexander I St. Petersburg State Transport University, 190031 Saint Petersburg, Russia

Abstract. *The aim of the study is to compare the design bearing capacity of bored piles according to SP RK 5.01-103-2013 and Eurocode 7, taking into account the engineering-geological conditions of the Republic of Kazakhstan and the results of full-scale static load tests. The research methodology included an analysis of regulatory requirements, processing of test results for three bored piles with a diameter of 1000 mm and a length of 18 m, and parallel determination of the design bearing capacity using national and European approaches. Static compression load tests were carried out up to 700 tf with registration of pile settlements and subsequent interpretation of the experimental load-settlement curves. According to the test results, the ultimate loads were 658.0, 685.0, and 700.0 tf; the mean value was 681.0 tf, and the minimum value was 658.0 tf. The calculation according to SP RK 5.01-103-2013, considering the reliability factor $\gamma_k = 1.20$, resulted in a design bearing capacity of 548.33 tf. Processing the same data according to Eurocode 7, using the correlation factors $\xi_1 = 1.20$ and $\xi_2 = 1.05$, as well as the partial resistance factor $\gamma_t = 1.15$, gave a design resistance of 493.33 tf. The difference between the calculated values was 54.85 tf, or 10.0%. It was established that the Eurocode 7 approach provides a more conservative assessment of pile bearing capacity, as it additionally considers the statistical reliability of the experimental database. The practical significance of the study lies in the possibility of using Eurocode 7 as an additional tool for verifying design solutions in pile foundation design in Kazakhstan.*

Keywords: bored piles, bearing capacity, Eurocode 7, SP RK, static tests, pile foundations, geotechnical design.

*Corresponding author
Jumadilova S.J., e-mail: saule_dzhumadilo@mail.ru

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ҒЫЛЫМИ МАҚАЛА

ҚАЗАҚСТАН РЕСПУБЛИКАСЫ ЖАҒДАЙЫНДА EUROCODE 7 ТАЛАПТАРЫНА СӘЙКЕС БҰРҒЫЛАНЫП ЖАСАЛҒАН ҚАДАЛАРДЫҢ КӨТЕРГІШТІК ҚАБІЛЕТІН АНЫҚТАУ

Жәмек Н.А.² , Абдрахманов Д.И.¹ , Хомяков В.А.^{1,2} , Джумадилова С.Ж.*¹ , Т.
Аввад³ 

¹ Халықаралық білім беру корпорациясы, 050028, Алматы, Қазақстан

² Қазақ құрылыс және сәулет ғылыми-зерттеу және жобалау институты, 050062, Алматы, Қазақстан

³ Император Александр I атындағы Санкт-Петербург мемлекеттік қатынас жолдары
университеті, 190031, Санкт-Петербург қ., Ресей

Аңдатпа. Зерттеудің мақсаты - Қазақстан Республикасының инженерлік-геологиялық жағдайларын және натурлық статикалық сынақ нәтижелерін ескере отырып, бұрғылап құйылатын қадалардың есептік көтергіш қабілетін ҚР ЕЖ 5.01-103-2013 және Eurocode 7 талаптары бойынша салыстырмалы бағалау. Зерттеу әдістемесі нормативтік талаптарды талдауды, диаметрі 1000 мм және ұзындығы 18 м болатын үш бұрғылап құйылатын қаданың сынақ нәтижелерін өңдеуді, сондай-ақ ұлттық және еуропалық тәсілдер бойынша есептік көтергіш қабілетті параллель анықтауды қамтыды. Статикалық сынақтар қадалардың шөгуін тіркей отырып, 700 тс дейінгі басу жүктемесімен жүргізілді және кейіннен «жүктеме-шөгу» эксперименттік қисықтары интерпретацияланды. Сынақ нәтижелері бойынша шекті жүктемелер 658,0; 685,0 және 700,0 тс құрады, орташа мәні - 681,0 тс, ең төменгі мәні - 658,0 тс. ҚР ЕЖ 5.01-103-2013 бойынша $\gamma_k = 1,20$ сенімділік коэффициентін ескере отырып жүргізілген есептеу нәтижесінде есептік көтергіш қабілет 548,33 тс болды. Сол деректерді Eurocode 7 бойынша $\xi_1 = 1,20$ және $\xi_2 = 1,05$ корреляциялық коэффициенттерін, сондай-ақ $\gamma_t = 1,15$ жеке коэффициентін ескере отырып өңдеу есептік кедергінің 493,33 тс екенін көрсетті. Есептік мәндер арасындағы айырмашылық 54,85 тс немесе 10,0 % құрады. Eurocode 7 тәсілі қаданың көтергіш қабілетін неғұрлым консервативті бағалайтыны анықталды, себебі ол эксперименттік деректер базасының статистикалық сенімділігін қосымша ескереді. Зерттеудің практикалық маңыздылығы Қазақстанда қадалы іргетастарды жобалау кезінде Eurocode 7 әдістемесін жобалық шешімдерді қосымша тексеру құралы ретінде қолдану мүмкіндігімен сипатталады.

Түйін сөздер: бұрғылап құйылатын қадалар, көтергіш қабілет, Eurocode 7, ҚР ЕЖ, статикалық сынақтар, қадалы іргетастар, геотехникалық жобалау.

*Автор-корреспондент
Джумадилова С.Ж., e-mail: saule_dzhumadilo@mail.ru

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НАУЧНАЯ СТАТЬЯ

ОПРЕДЕЛЕНИЕ НЕСУЩЕЙ СПОСОБНОСТИ БУРОНАБИВНЫХ СВАЙ ПО EUROCODE 7 В УСЛОВИЯХ РЕСПУБЛИКИ КАЗАХСТАН

Жәмек Н.А.² , Абдрахманов Д.И.¹ , Хомяков В.А.^{1,2} , Джумадилова С.Ж.*¹ , Т.
Аввад³ 

¹ Международная образовательная корпорация, 050028, Алматы, Казахстан

² Казахский научно-исследовательский и проектный институт строительства и архитектуры, 050062,
Алматы, Казахстан

³ Санкт-Петербургский государственный университет путей сообщения Императора Александра I,
190031, г. Санкт-Петербург, Россия

Аннотация. Цель исследования заключается в сравнительной оценке расчетной несущей способности буронабивных свай по СП РК 5.01-103-2013 и Eurocode 7 с учетом инженерно-геологических условий Республики Казахстан и результатов натурных статических испытаний. Методика исследования включала анализ нормативных требований, обработку результатов испытаний трех буронабивных свай диаметром 1000 мм и длиной 18 м, а также параллельное определение расчетной несущей способности по национальному и европейскому подходам. Статические испытания выполнялись вдавливающей нагрузкой до 700 тс с регистрацией осадки свай и последующей интерпретацией экспериментальных кривых «нагрузка-осадка». По результатам испытаний предельные нагрузки составили 658,0; 685,0 и 700,0 тс, среднее значение - 681,0 тс, минимальное - 658,0 тс. Расчет по СП РК 5.01-103-2013 с учетом коэффициента надежности $\gamma_k = 1,20$ дал расчетную несущую способность 548,33 тс. Обработка тех же данных по Eurocode 7 с учетом корреляционных коэффициентов $\xi_1 = 1,20$ и $\xi_2 = 1,05$, а также частного коэффициента $\gamma_t = 1,15$ показала расчетное сопротивление 493,33 тс. Разница между расчетными значениями составила 54,85 тс, или 10,0 %. Установлено, что подход Eurocode 7 дает более консервативную оценку несущей способности свай, поскольку дополнительно учитывает статистическую надежность экспериментальной базы. Практическая значимость исследования состоит в возможности применения Eurocode 7 как дополнительного инструмента проверки проектных решений при проектировании свайных фундаментов в Казахстане.

Ключевые слова: буронабивные сваи, несущая способность, Eurocode 7, СП РК, статические испытания, свайные фундаменты, геотехническое проектирование.

***Автор-корреспондент**

Джумадилова С.Ж., e-mail: saule_dzhumadilo@mail.ru

1 INTRODUCTION

Pile foundations are one of the most widely used types of foundations in the construction of buildings and structures under complex engineering-geological conditions. Their application is especially relevant in cases where the upper layers of the soil foundation do not provide the required bearing capacity, stability, and permissible deformations. In the Republic of Kazakhstan, the use of pile foundations is of significant practical importance due to the presence of heterogeneous, water-saturated, fill, and seismically hazardous soils. Under such conditions, the reliability of the designed foundation largely depends on the correct assessment of pile bearing capacity, the quality of engineering-geological investigations, and the reliability of the interpretation of full-scale test results.

In the practice of pile foundation design in Kazakhstan, the main regulatory document is SP RK 5.01-103-2013 “Pile Foundations” [1]. At the same time, in recent years, the importance of applying international approaches, including Eurocode 7, has been increasing. Eurocode 7 is based on the concept of limit states, characteristic values of parameters, partial safety factors, and statistical processing of test results. Unlike the traditional approach, Eurocode 7 makes it possible to consider not only the minimum value of the ultimate load, but also the reliability level of the experimental database through correlation factors that depend on the number of tested piles.

The relevance of the study is determined by the need to compare the national and European approaches to determining the design bearing capacity of bored piles under the conditions of the Republic of Kazakhstan. Despite the existing regulatory framework and practical experience in pile foundation design, the issue of quantitatively comparing the results obtained according to SP RK 5.01-103-2013 [1-5] and Eurocode 7 based on the same full-scale static load tests remains insufficiently studied. It is especially important to analyze how differences in design coefficients and methods of processing experimental data affect the final value of the design bearing capacity of a pile.

The aim of this study is to perform a comparative assessment of the design bearing capacity of bored piles according to SP RK 5.01-103-2013 and Eurocode 7 based on the results of full-scale static load tests carried out under the engineering-geological conditions of the Republic of Kazakhstan.

The scientific novelty of the study lies in the parallel processing of one experimental series of static load tests of bored piles using two regulatory approaches: the national method according to SP RK 5.01-103-2013 and the European method according to Eurocode 7. The study quantitatively demonstrates the influence of different principles of test result processing on the design bearing capacity of a pile. According to SP RK, the calculation is based on the minimum value of the ultimate load and the reliability factor, whereas Eurocode 7 takes into account the mean and minimum test values, the correlation factors ξ_1 and ξ_2 , as well as the partial resistance factor. This approach makes it possible to assess the degree of conservatism of the European methodology as applied to the soil conditions of Kazakhstan.

The practical significance of the study is that the obtained results can be used in the design and verification of pile foundations under complex engineering-geological conditions of the Republic of Kazakhstan. Comparison of the design values according to SP RK [1-7] and Eurocode 7 makes it possible to reasonably account for the influence of the regulatory methodology on the assigned design load, the number of piles, and their length and diameter. The results of the study may also be applied in the adaptation of Eurocode 7 provisions to domestic geotechnical design practice and in the development of recommendations for interpreting static load tests of bored piles.

Although pile design methods have developed significantly in recent decades, the determination of the axial bearing capacity of piles still largely depends on the use of empirical correlations. As a result, for many soil types, bearing capacity can be estimated with an accuracy of only approximately $\pm 30\%$ [8], while in rock masses it may be significantly underestimated. Due to the uncertainty associated with predicting load-settlement behaviour using existing calculation methods, pile load testing is widely used in practice to verify design solutions.

The information obtained from pile load tests can be used for several purposes [9], including:

- checking the quality of construction and workmanship;
- confirming design data;
- enabling more refined or more reliable design, with the potential to reduce the cost of subsequent piling works.

Since pile testing can be expensive, especially on small projects, the need for such testing should be considered from the standpoint of risk reduction. On large construction sites where a significant number of piles are installed, testing may also be considered from the perspective of potential cost savings. Pile tests can provide refined design parameters, which makes it possible to optimize pile design, for example, by reducing pile length [10-11].

The pile testing strategy recommended by the Federation of Piling Specialists [12] in the Handbook on Pile Load Testing is presented in Table 1. Similar recommendations for testing preliminary and working piles under low- and medium-risk conditions are also provided in BS 8004:2015.

Table 1. Typical pile testing strategy depending on risk level [12]

№	Characteristics of piling works	Risk level	Pile testing strategy
1	Complex or unknown ground conditions	High	Both preliminary pile tests and working pile tests are required
	No previous pile test data available		1 preliminary test for every 250 piles
	New pile installation technology or very limited relevant experience		1 working pile test for every 100 piles
2	Uniform ground conditions	Medium	Pile testing is required
	No previous pile test data available		Preliminary tests and/or working pile tests may be used
	Limited experience with pile installation in similar ground conditions		1 preliminary test for every 500 piles; 1 working pile test for every 100 piles
3	Previous pile test data are available	Low	Pile testing is not mandatory
	Significant experience with pile installation in similar ground conditions		Where testing is specified, preliminary tests or working pile tests may be used; 1 preliminary test for every 500 piles; 1 working pile test for every 100 piles

In general, static pile testing methods are expensive and time-consuming [13-16], with both cost and duration increasing as the required load increases. However, their advantage lies in the relative simplicity of analysis and interpretation of the results. In contrast, dynamic and rapid load testing methods allow tests to be performed faster and, at high loads, become less expensive than static tests; however, they require more specialized equipment and more complex interpretation of results.

Recent studies conducted in Kazakhstan also emphasize that the stress-strain state and the dimensions of the compacted zone around piles significantly influence their bearing capacity and should be considered during design [17].

Modern studies show that determining the bearing capacity of bored piles remains an important task in geotechnical design, since calculation methods may produce different results depending on the initial soil parameters, the method used to interpret the load-settlement curve, and the adopted design model. Vural et al. proposed an approach for estimating the ultimate bearing capacity of piles based on pile load test data and noted that methods of interpreting test results can significantly affect the final bearing capacity value [18].

For large-diameter bored piles, static load tests are considered the most reliable basis for predicting ultimate bearing capacity. However, bringing such piles to complete failure in practice is

often difficult due to the large loads required and the development of significant displacements [19-22].

The use of machine learning models for estimating the bearing capacity of bored piles based on pile and soil parameters has also been considered in recent studies. The results show that modern computational and analytical methods can be used as an additional forecasting tool; however, they require verification using full-scale test data [23-25].

Using bored piles with Expander Body technology as an example, Monteiro et al. demonstrated the need to assess the accuracy of semi-empirical methods by comparing calculated values with the results of load tests. This approach is consistent with the general logic of Eurocode 7, according to which the reliability of the design resistance of piles should be related to the quality and quantity of experimental data [26-28].

When considering the second generation of Eurocode 7, Moormann and Burlon note the development of approaches to pile foundation design based on limit states, partial factors, and a more systematic assessment of the reliability of geotechnical data. This confirms the relevance of applying the provisions of Eurocode 7 when analyzing the bearing capacity of piles under the conditions of the Republic of Kazakhstan [29, 30].

3 MATERIALS AND METHODS

The research materials included regulatory documents on the design of pile foundations, the provisions of Eurocode 7, engineering-geological investigation data, and the results of static compression load tests of bored piles.

The investigated site is located in the Almaty Region, Ili District, Otegen Batyr settlement. The geological structure of the site consists of alluvial-proluvial deposits of Upper Quaternary age, ap(QIII-IV), which are overlain from the ground surface by fill soils. According to the engineering-geological investigations, within the investigated depth of up to 60.0 m, 6 layers and 12 engineering-geological elements were identified. The main soils include fill soils of various composition, silty sands, coarse sands, medium sands, gravelly sands, sandy loams, loams, silty deposits, and gravelly soils.

The hydrogeological conditions are characterized by the presence of groundwater, the level of which is subject to seasonal fluctuations: the minimum groundwater level is observed in March, while the maximum level occurs in early May. Groundwater recharge occurs due to infiltration of atmospheric precipitation, and in spring due to meltwater and floodwater. These conditions are important in assessing the performance of bored piles, since water saturation of soils may affect the deformation characteristics of the foundation soil and the mobilization of shaft resistance along the pile surface.

To provide a more detailed description of the engineering-geological conditions of the site, Table 3 presents the main physical and mechanical properties of the soils used in the interpretation of the static load test results of bored piles.

The importance of comprehensive field investigations for obtaining reliable geotechnical parameters has also been confirmed by recent studies performed in Northern Kazakhstan. Recent studies in Kazakhstan demonstrate that improving the engineering properties of soils by modern strengthening technologies, including polyurethane injection methods, can significantly increase the reliability of foundations under difficult ground conditions [31,32]. Table 2 presents a summary of the physical and mechanical properties of the soils at the study site.

Table 2 - Summary of physical and mechanical properties of the site soils [Authors' material]

	Soil / EGE	ρ , g/cm ³	E, MPa natural / saturated	c, kPa natural / saturated	φ , degrees natural / saturated
1	Layer 1 - fill soil, pulp	1.97	9.32 / 5.95	80 / 62	23 / 21
2	Layer 2 - fill soil, sands of various grain sizes	1.67	10.30 / 4.97	3 / 3	20 / 19

3	Layer 3 - fill soil, sandy loam	1.92	10.97 / 8.89	37 / 33	18 / 17
4	Layer 4 - fill soil, loam	1.97	9.92 / 8.43	52 / 47	26 / 23
5	Layer 6 - silty deposits	1.91	11.13 / 8.59	40 / 37	19 / 18
6	EGE 1 - silty sand	1.87	28.00	6	34
7	EGE 2 - coarse sand	1.67	13.07 / 10.94	12 / 11	23 / 21
8	EGE 3 - medium sand	-	17.87 / 15.61	3 / 2	30 / 27
9	EGE 4 - gravelly sand	1.77	18.78 / 16.69	8 / 4	36 / 33
10	EGE 5 - hard sandy loam	2.05	12.85 / 10.39	63 / 53	17 / 15
11	EGE 5a - plastic sandy loam	2.02	10.00 / 6.00	54 / 48	20 / 15
12	EGE 6 - hard and semi-hard loam	2.04	9.57 / 8.37	76 / 61	17 / 15
13	EGE 6a - stiff-plastic and soft-plastic loam	1.95	9.75 / 8.40	48 / 44	17 / 14
14	EGE 7 - gravelly soil	2.12	21.00	-	-

Note: ρ is soil density; E is deformation modulus; c is cohesion; φ is the angle of internal friction. For several sandy soils, based on dynamic probing data, it is recommended to adopt increased values of the deformation modulus: 66.0 MPa for silty, medium, and coarse sands; 62.0 MPa for medium and coarse sands at depths of 6.0-22.0 m; and 66.0 MPa at depths of 22.0-30.0 m.

The analysis of the engineering-geological conditions shows that the performance of bored piles at the investigated site is formed within a heterogeneous soil mass, including fill soils, sandy soils, sandy loams, loams, silty deposits, and gravelly soil. Soil density, deformation modulus, angle of internal friction, and cohesion are of the greatest importance for interpreting static load tests, since these parameters determine the pattern of pile settlement development and the mobilization of resistance along the shaft and under the pile base.

According to the dynamic probing data obtained to a depth of 30.0 m, coarse and medium sands were identified at the site, occurring from a depth of approximately 6.0 m. The minimum conditional dynamic resistance was 4.79 MPa, the maximum was 28.8 MPa, and the average value was 20.5 MPa. Based on the assessment results, the sands are characterized as dense and medium-dense, and the probability of liquefaction is considered practically impossible. This factor is important when assessing the reliability of a pile foundation in a seismic region. The figure 1 shows a static pile load test setup: 1 — test pile; 2 — working anchor pile; 3 — reference system equipped with displacement measuring instruments; 4 — hydraulic jack with a pressure gauge; 5 — support and beam system; 10 — thermometric device.

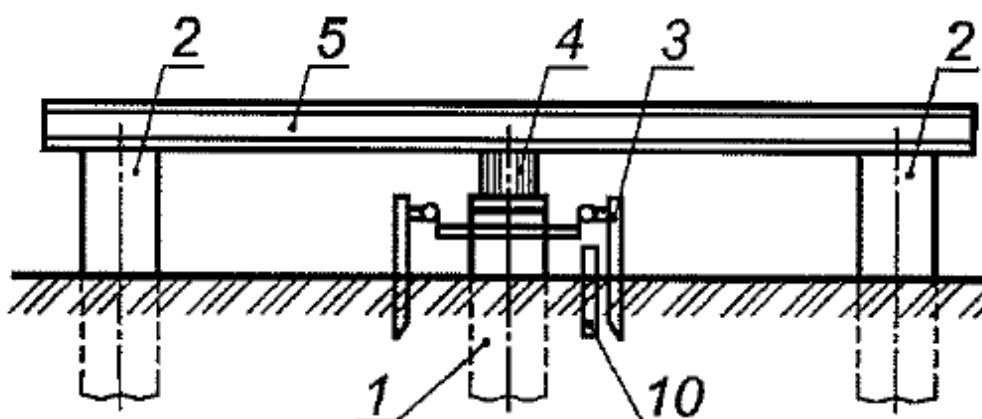


Figure 1 - Layout of the static pile test setup with a beam system and anchor piles (GOST 5686-2020) [33]

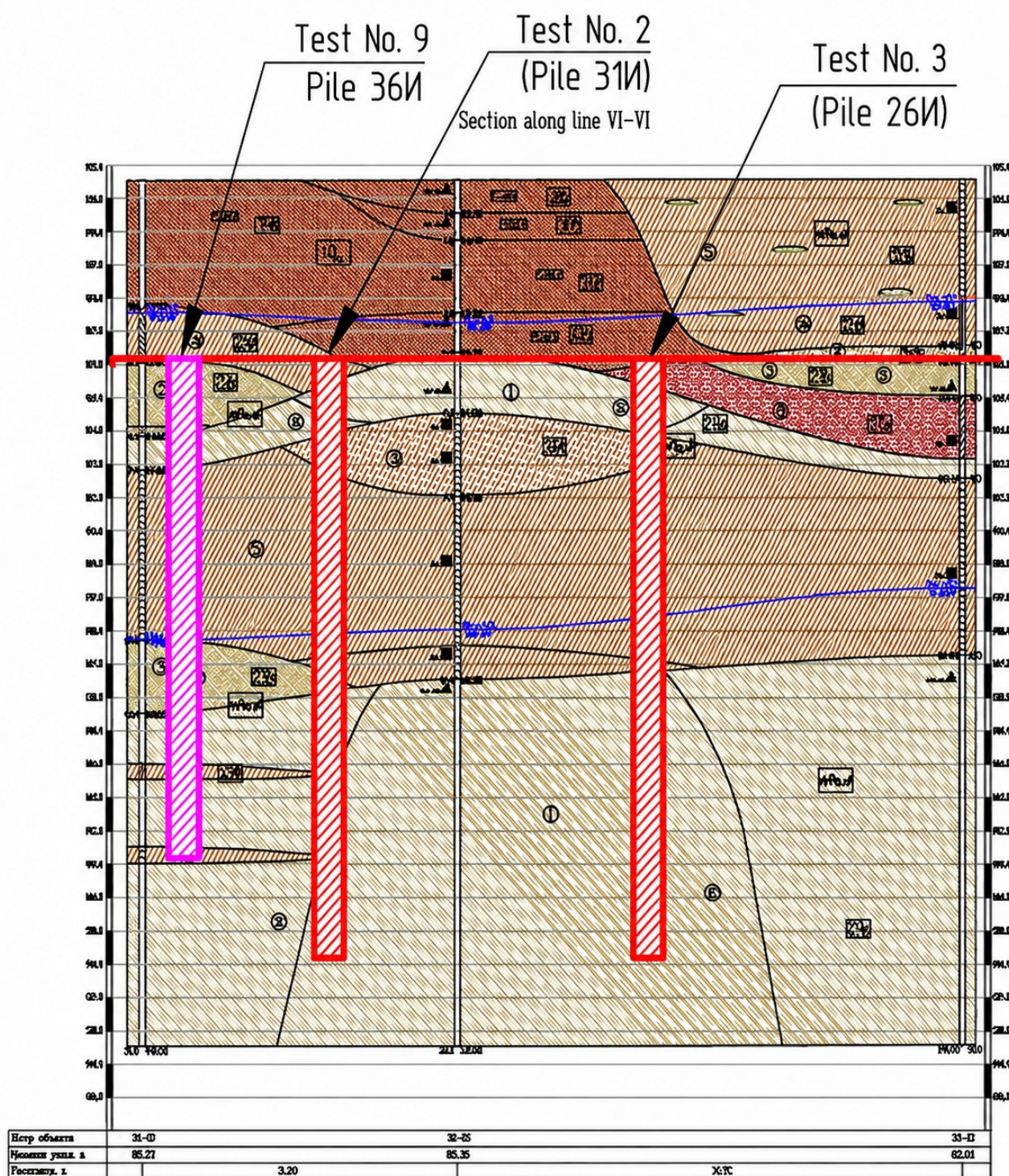


Figure 2 - Location of test piles No. 31i and No. 26i on the engineering-geological section [Authors' material]

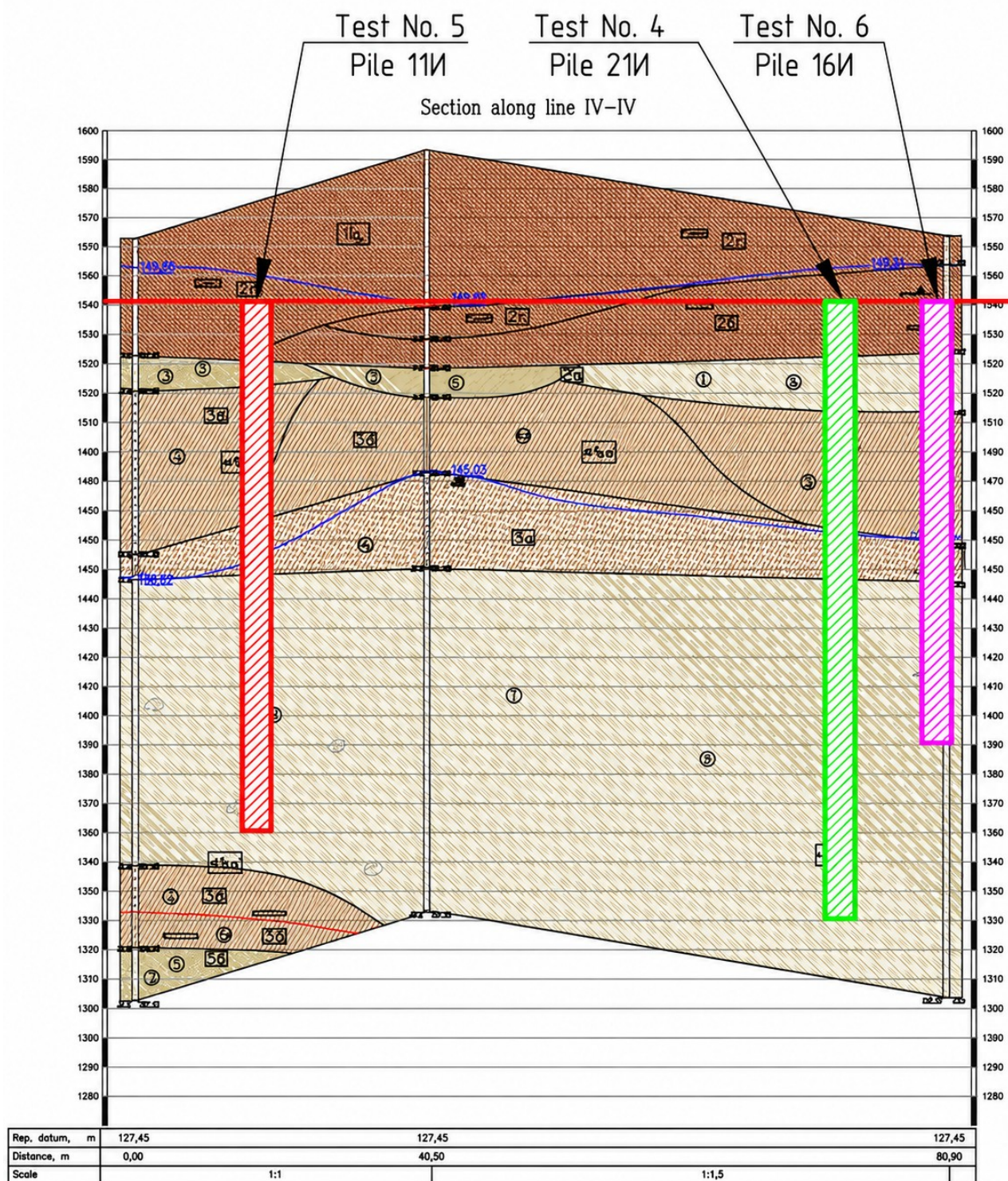


Figure 3 - Location of test pile No. 11i on the engineering-geological section [Authors' material]

During pile testing, the requirements for the field pile test programme were followed in accordance with Appendix A of GOST 5686-2020 [16].

Number of tested piles:

under natural conditions under compression load - 3 piles.

The table 3 below presents the data on the piles subjected to static load testing.

Table 3 - Initial data for the series of bored piles [Authors' material]

Test No.	Pile No.	Diameter, mm	Length, m	Maximum load, tf	Settlement at maximum load, mm
1	31I	1000	18	700	34.55
2	26I	1000	18	700	31.89
3	11I	1000	18	700	29.02

The tests were performed using a loading platform setup consisting of two longitudinal reinforced steel I-beams No. 100 and two transverse I-beams No. 120, anchored to four piles similar to the test piles. The loading platform setup complies with the recommendations of Appendix B of GOST 5686-2020 [7] and is shown in Figure 4.



Figure 4 - Loading platform for static testing of a bored pile [Authors' material]

Pile loading under compression was carried out in increments of 70 tons, depending on the magnitude of settlement and the rate of deformation stabilization. The load was applied using DG-800G300 hydraulic jacks with a load capacity of 800 tons, bearing against an anchor-reaction frame. Pressure in the jack was generated using an electric oil-pumping station supplied together with the jack.

The applied force was measured using a digital pressure gauge installed in the oil-pumping station, with a scale interval of 10.0 kg/cm².

Pile displacements were measured during testing using PSK-MG4 deflectometers installed on both sides of the pile on the fixed supports of the reference system.

Pile displacement was determined as the arithmetic mean of the readings from two instruments. The conditional settlement stabilization criterion was taken as a pile settlement rate not exceeding 0.1 mm over the last 30 minutes of observation [16].



Figure 5 - Instruments used during static load testing [Authors' material]

4 RESULTS AND DISCUSSION

During the study, three static compression load tests were carried out on bored piles with a diameter of 1000 mm and a length of 18.0 m.

The ultimate value for determining the bearing capacity of a pile was established in accordance with Clause 4.5.5 of SP RK 5.01-103-2013 [1-5]. For foundations of buildings and structures, except for bridges and hydraulic structures, the individual value of the ultimate resistance of a pile under compression load, F_u , is taken as the load at which the tested pile reaches a settlement equal to S , determined by Formula (1):

$$S = \zeta \times S_{u,mt} \quad (1)$$

where:

$S_{u,mt}$ is the ultimate value of the average settlement of the foundation of the designed building or structure;

ζ is the coefficient for converting the ultimate value of the average settlement of the building or structure foundation, $S_{u,mt}$, to the pile settlement S obtained during static tests with conditional settlement stabilization.

In this study:

$$S = 0.2 \times 150 = 30 \text{ mm.}$$

When processing the test results, the load corresponding to a settlement close to 30 mm was adopted as the ultimate compression load.

A continuous increase in settlement S without an increase in load, at $S \leq 30$ mm, for tests No. 2, No. 3, and No. 5 of piles with a diameter of 1000 mm and a length of 18.0 m occurred at the following maximum loads:

Test No. 2, pile No. 31i - 658.0 tf;

Test No. 3, pile No. 26i - 685.0 tf;

Test No. 5, pile No. 11i - 700.0 tf.

Among the three tests, the minimum obtained load was selected for further calculation:

$$F_d = 658.0 \text{ tf.}$$

The design load transferred to the pile, according to Formula (2) of Clause 4.4.1.11 of SP RK 5.01-103-2013 "Pile Foundations", is determined taking into account the reliability factor $\gamma_k = 1.20$, adopted when the bearing capacity of piles is determined based on field static load test results:

$$F_u = F_d / \gamma_k = 658.0 / 1.20 = 548.33 \text{ tf.} \quad (2)$$

Calculation according to Eurocode 7

To process the same test results according to Eurocode 7, the method for determining the characteristic resistance based on the mean and minimum values of the ultimate load was used, taking into account correlation factors depending on the number of tests. For a series of three piles, the

correlation factors $\xi_1 = 1.20$ and $\xi_2 = 1.05$ were adopted in accordance with Appendix A, Table A.9 of SP RK EN 1997-1:2004/2011.

The mean value of the ultimate load was 681.0 tf, and the minimum value was 658.0 tf. The characteristic resistance was determined as follows:

$$R_{c;k} = \min(R_{\text{mean}} / \xi_1; R_{\text{min}} / \xi_2)$$

$$R_{c;k} = \min(681.0 / 1.20; 658.0 / 1.05) = 567.5 \text{ tf.} \quad (3)$$

The design resistance was determined taking into account the partial factor $\gamma_t = 1.15$, according to Appendix A, Table A.7 of SP RK EN 1997-1:2004/2011:

$$R_{c;d} = R_{c;k} / \gamma_t = 567.5 / 1.15 = 493.33 \text{ tf.} \quad (4)$$

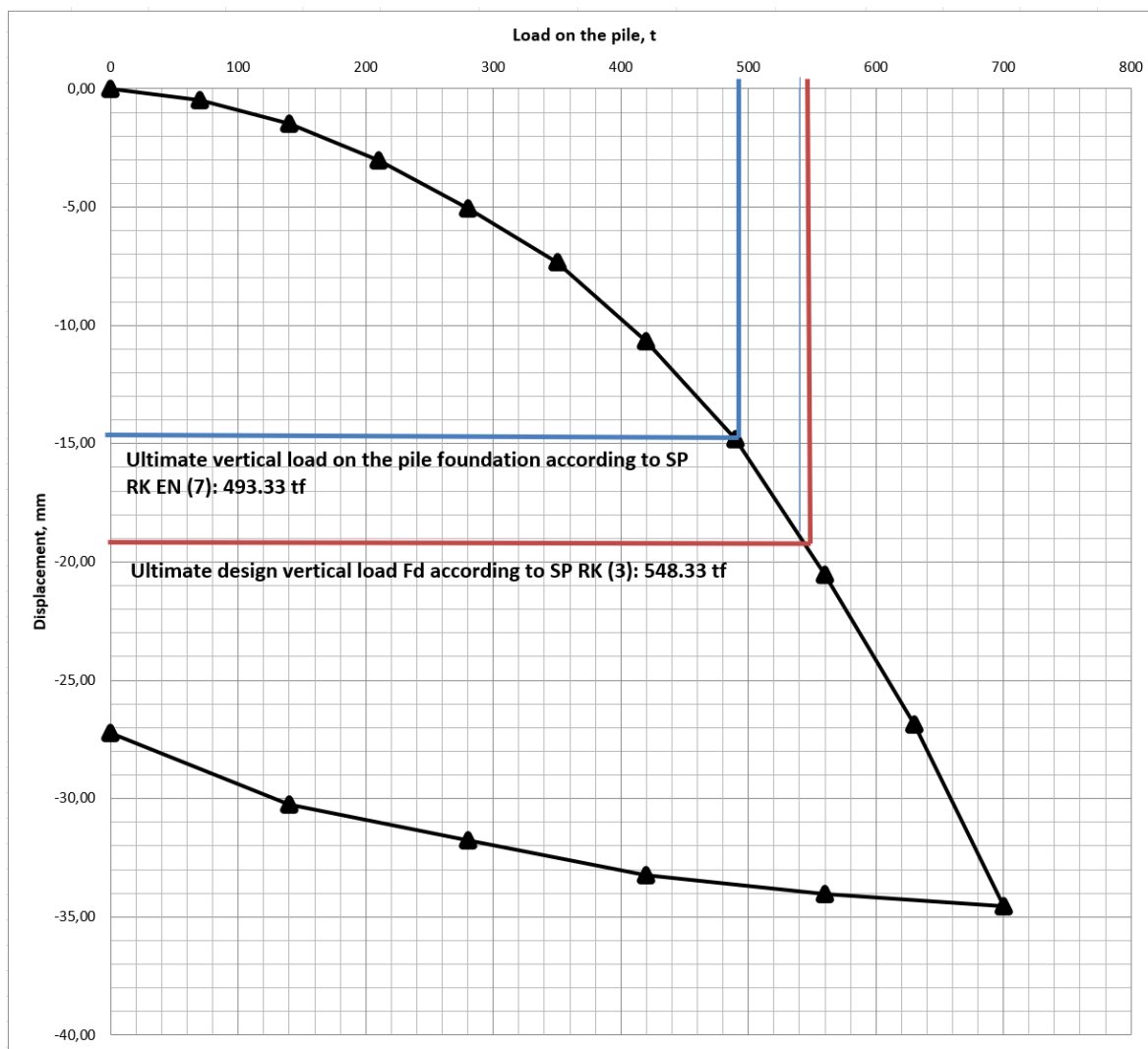


Figure 6 - Load-settlement curve of the bored pile under compression loading [Authors' material]

The ultimate loads were determined from the experimental load-settlement curves. In addition, the results were processed in parallel according to SP RK 5.01-103-2013 and Eurocode 7 for subsequent comparative analysis (Table 4).

The number of tested piles in this study was three, which corresponds to the actual experimental database of the considered site. When processing the results according to Eurocode 7, this number of tests was taken into account through the correlation factors $\xi_1 = 1.20$ and $\xi_2 = 1.05$, which depend on the number of tested piles. Thus, the limited sample size was directly considered in the calculation procedure by reducing the characteristic resistance. At the same time, the obtained results should be regarded as a site-specific assessment applicable to the considered engineering-geological conditions.

To form a broader statistical database, additional pile tests at other sites in the Republic of Kazakhstan are required.

Table 4 - Comparison of the results of static load test processing according to SP RK 5.01-103-2013 [1] and Eurocode 7

№	Parameter	SP RK 5.01-103-2013	Eurocode 7
1	Number of tested piles	3	3
2	Ultimate loads from tests, tf	658; 685; 700	658; 685; 700
3	Processing principle	Min. value	Mean and min. values with ξ
4	Mean value, tf	-	681
5	Minimum value, tf	658.0	658.0
6	Correction factors	-	$\xi_1 = 1.20$; $\xi_2 = 1.05$
7	Characteristic resistance, tf	658.00	567.50
8	Reliability factor / partial factor	$\gamma_k = 1.20$	$\gamma_t = 1.15$
9	Design bearing capacity, tf	548.33	493.33
10	Difference, tf	-	-54.85
11	Difference, %	-	-10.00

The obtained difference between the design values according to SP RK 5.01-103-2013 and Eurocode 7 is explained by the difference in the principles used to process the test results. In the SP RK approach, the minimum ultimate load from the test series is adopted as the initial value, after which it is divided by the reliability factor $\gamma_k = 1.20$. In the considered case, this resulted in a design bearing capacity of 548.33 tf.

Eurocode 7 uses a different principle: the characteristic resistance is determined as the minimum of two values - the mean test result divided by ξ_1 and the minimum test result divided by ξ_2 . The obtained characteristic resistance is then additionally divided by the partial factor $\gamma_t = 1.15$. Therefore, the design value according to Eurocode 7 was 493.33 tf, which is 54.85 tf, or 10.0%, lower than the result obtained according to SP RK [1-5].

From a practical point of view, the obtained difference means that the application of Eurocode 7 under the considered conditions leads to a more cautious assessment of the design bearing capacity of a bored pile. In design practice, this may affect the number of piles in the foundation, their length, diameter, or the need for additional testing. At the same time, the more conservative value should not be considered a disadvantage of the method, since it reflects the consideration of uncertainty in engineering-geological conditions, the limited number of tests, and the statistical variability of the results.

5 CONCLUSIONS

The conducted study showed that the comparative analysis of the bearing capacity of bored piles according to SP RK 5.01-103-2013 and Eurocode 7 is relevant for the conditions of the Republic of Kazakhstan, especially in the design of pile foundations under complex engineering-geological conditions. The experimental basis of the study included the results of static compression load tests of three bored piles with a diameter of 1000 mm and a length of 18 m.

Based on the interpretation of the experimental load-settlement curves, the ultimate loads were determined as 658.0, 685.0, and 700.0 tf. The calculation according to SP RK 5.01-103-2013, based on the minimum ultimate load and the reliability factor $\gamma_k = 1.20$, resulted in a design bearing capacity of 548.33 tf. Processing the same results according to Eurocode 7, taking into account the mean and minimum values, the correlation factors $\xi_1 = 1.20$ and $\xi_2 = 1.05$, as well as the partial factor $\gamma_t = 1.15$, resulted in a design resistance of 493.33 tf. The difference between the calculated values was 54.85 tf, or 10.0%.

It was established that, in the considered case, Eurocode 7 provides a more conservative assessment of pile bearing capacity. This is due to the fact that the European approach takes into account not only the minimum test value, but also the statistical reliability of the experimental database through correlation factors. This approach is important when the number of tests is limited and the ground conditions are heterogeneous.

The practical significance of the obtained results lies in the possibility of using the Eurocode 7 methodology as an additional tool for verifying design solutions in the design of bored piles in Kazakhstan. When applying Eurocode 7, it is recommended to consider the actual results of static load tests, the number of tested piles, the engineering-geological variability of the site, and the requirements of the National Annex to Eurocode 7.

Experimental studies also indicate that soil improvement contributes to increasing the seismic performance of foundation systems and should be considered together with reliable pile design methods [34,35].

The limitation of this study is the use of an experimental database that includes three tested piles at one site. Therefore, the obtained conclusions should be considered applicable to the investigated ground conditions. Further research should be aimed at expanding the database of full-scale static load tests of bored piles in different regions of Kazakhstan, comparing Eurocode 7 calculations with static cone penetration test results, and refining national reliability factors for pile foundations, taking into account local engineering-geological conditions.

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Information about authors:

Zhamek N.A. – PhD Student, School of Construction, International Educational Corporation, Almaty, Kazakhstan, nzhamek@kazniisa.kz

Jumadilova S.J. – PhD, Associate Professor, School of Construction, International Educational

Corporation, Almaty, Kazakhstan, saule_dzhumadilo@mail.ru

Khomyakov V.A. – Doctor of technical science, School of Construction, International Educational Corporation, Almaty, Kazakhstan, Khomyakov57@list.ru

Abdrakhmanov D.I. – Master's Student, School of Construction, International Educational Corporation, Almaty, Kazakhstan

Awwad T. – PhD, Professor, Department of Construction, Emperor Alexander I St. Petersburg State Transport University, 190031 Saint Petersburg, Russia

Author Contributions:

Zhamek N.A. – Investigation, Data Processing, Visualization, Writing – Review & Editing.

Abdrakhmanov D.I. – Conceptualization, Methodology, Investigation, Formal Analysis, Writing – Original Draft.

Khomyakov V.A. – Supervision, Methodology, Validation, Writing – Review & Editing.

Jumadilova S.J. – Conceptualization, Data Curation, Formal Analysis, Writing – Review & Editing, Correspondence.

Awwad T. – scientific supervision, methodology, validation.

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