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RESEARCH OF BEARING CAPACITY OF PILE PRESSED FOUNDATIONS DEPENDING ON SOIL TYPE AND PILE DIAMETER

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Abstract. Pile foundations are widely used to transfer structural loads to hard soil layers with high bearing capacity. During the design work, it is often necessary to combine the structural solutions of the foundations with the properties of the subsiding soils at the construction site. This article deals with pile foundations and their bearing capacity dependences on embedment depth, soil properties and pile diameter.

Keywords: piles, soils, foundations, bearing capacity

INTRODUCTION

This paper presents a study of the dependences of the load-bearing capacity of squeezed piles on soil properties and embedment depth. Compared to other types of piles, squeezed piles compact the soil around them during embedment [1, 2, 3].

Pole foundations are calculated using the limit state method. This method evaluates the bearing capacity and deformation limit states. The bearing capacity of foundations is determined by two conditions - the strength of the foundation soil and the strength of the pile material. It is designed according to the lower carrying capacity of one of them [4].

The article presents the dependences of the bearing capacity of piles of different diameters embedded in one-layer soil on the depth of pile insertion. The embedment depth for pole foundations is recommended to be at least three diameters of the pile base or at least the side of a rectangle covering a smaller group of piles (at the depth of the pile base), but in all cases at least 5 m below the pile base. In this study, the penetration depth of the piles was chosen to be 9 meters.

METHODOLOGY FOR CALCULATING THE BEARING CAPACITY OF THE PILE BASE

During the study, the limit bearing capacity of the pile foundation was calculated using the empirical method based on the data of static soil probing. During static probing, the limit bearing capacity $R_{c;m}$ is determined, to which the partial coefficients γ_R (γ_b, γ_s, γ_t) are applied, and the design bearing capacity R_d is found using equation (1) [4]. According to LST EN 1997 – 1:2003 [5], these coefficients depend on the number of tests performed.

$$R_d = [R_{c;m}] / \gamma_t; \tag{1}$$

Here γ_t is a partial coefficient, which depends on the pile installation method.

When carrying out calculations of the load-bearing capacity of the pile base, first the load-bearing capacity of the pile $R_{c;cal}$ is calculated. Then the characteristic value of the load-bearing capacity $R_{c;k}$ is determined and the design value of the load-bearing capacity $R_{c;d}$ is calculated.

The load-bearing capacity R_c of one pile is calculated as the sum of the load-bearing capacity R_b of the foundation under the base of the pile and the load-bearing capacity R_s of the sides of the pile:

$$R_c = R_b + R_s \tag{2}$$

The bearing capacity of the base under the pile is calculated using equation

$$R_b = \alpha_b \cdot q_c \cdot A_b \tag{3}$$

Here q_c is the cone strength of the soil, MPa; α_b – empirical correlation coefficient between q_c and base strength; A_b is the area of pile sole in m^2. Cylindrical piles were investigated in this work.

The bearing capacity of the pile sides is calculated using equation

$$R_s = \sum (A_{si} \cdot q_{ci} \cdot \alpha_{si}) \tag{4}$$

Here A_{si} is the surface area of the pile sides of the i^{th} soil layer, m^2; q_{ci} is conical strength of the i^{th} soil layer, MPa; α_{si} is empirical coefficient of correlation between q_c and soil friction strength, depending on soil type.

The bearing capacity of the pile is calculated using equation

$$R_{c,cal} = R_b / \gamma_{Rb} + R_s / \gamma_{Rs}; \tag{5}$$

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Here γ_{Rb} and γ_{Rs} are modeling coefficients that depends on the method of pile installation. In this work, clamped bored piles were investigated, so γ_{Rb} = 1.1 and γ_{Rs} = 1.35 [4].

The characteristic value of the bearing capacity of the pile base is calculated using equation [6]

$$R_{c;k} = min\{(R_{c;m})mean / \varsigma_1; (R_{c;m})min / \varsigma_2\}; \quad (6)$$

Here $(R_{c;m})mean$ is the average value of the bearing capacity of the pile base, N; $(R_{c;m})min$ is the minimum value of the bearing capacity, N; ς_1 and ς_2 are correlation coefficients, the values of which depend on the number of poles tested under static loads.

It was assumed that $\varsigma_1 = 1$ and $\varsigma_2 = 1$ (numerical values selected according to [4]) in this work.

The design bearing capacity of the pile is calculated using equation

$$R_{c;d} = R_{c;k} / \gamma_t; \quad (7)$$

Here $\gamma_t = 1$ is a factor depending on the pile installation method [4].

In order for the pole foundation to safely withstand the calculated compressive loads (in all cases of safety limit state loads and their combinations), the following inequality must be satisfied [7]:

$$F_{c;d} \leq R_{c;d}; \quad (8)$$

Here $F_{c;d}$ is the calculated value of the representative axial compressive force of the load of the pile or their group, including the weight force of the pile itself or their group (N); $R_{c;d}$ is calculated value of R_c (N); R_c is bearing capacity (N) of the compressive pile foundation.

DEPENDENCES OF PILE BEARING CAPACITY ON HOMOGENEOUS SOIL

The following conditions were adopted during the study:

- The cross section of the pile is round;
- The soil into which the pile is pressed is homogeneous;
- The entire pole is fully (100%) pressed into the ground;
- The weight of the pile is not evaluated;
- The influence of groundwater on the compressive strength of the soil is not evaluated.

Seven different diameter piles (from 0.3 m to 0.4 m) were analyzed during the research.

The test is performed by driving a round pile into different types of soil with different compressive strengths. Formulas (1) - (8) were used for calculations. The piles are driven deep until a maximum depth of 9 m is reached and their ultimate bearing capacity is calculated every 1 m. Homogeneous soils are studied in order to highlight the specific properties of the soil.

Calculations were made after choosing four different soil types: sand, sandy loam, loam and clay. The compressive strength of each soil was also varied. The characteristics of the soil are presented in Table 1.

Table 1

Mechanical characteristics of soils

		Compressive strength q_c, MPa
Sand	Sand (1)	4,1
	Sand (2)	11,3
	Sand (3)	25,0
Sandy loam	Sandy loam (1)	1,9
	Sandy loam (2)	8,59
	Sandy loam (3)	13,29
Loam	Loam (1)	1,5
	Loam (2)	4,9
	Loam (3)	12,7
Clay	Clay (1)	1,1
	Clay (2)	3,6
	Clay (3)	6,27

The dependences of pile bearing capacity on soils of different strength are presented in Figure 1. The graphs show the results of pile bearing capacity calculations for piles of three different diameters: 0.3 m, 0.35 m and 0.4 m.

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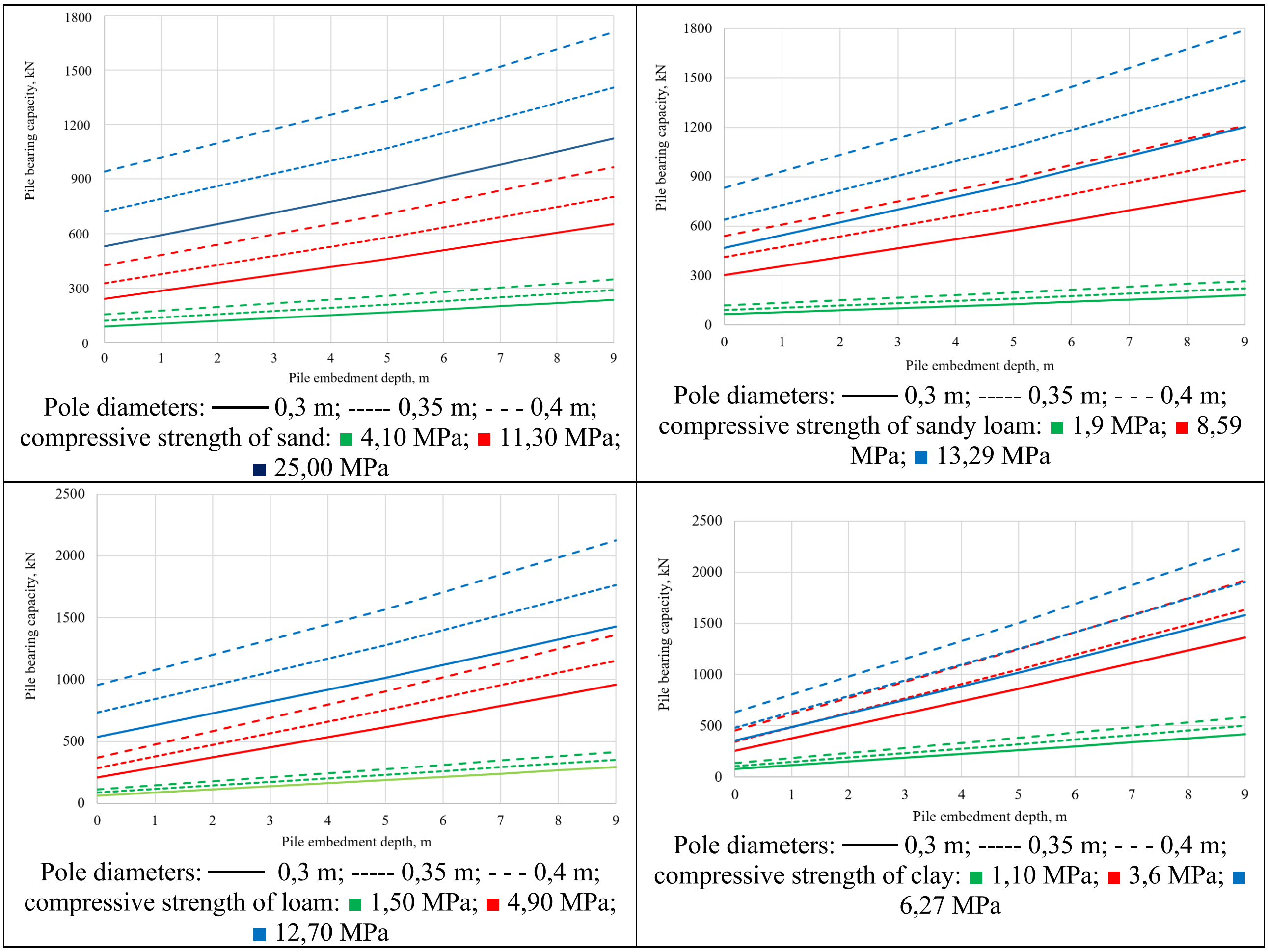

Figure 1. **Dependences of pile bearing capacity on pile embedment depth in soils of different strength**

The obtained results show that the higher the compressive strength of any of the four analyzed soils, the higher the gradient of the pile bearing capacity variation. Meanwhile, the diameter of the pile has a smaller influence on the gradient of the variation of the bearing capacity of the pile.

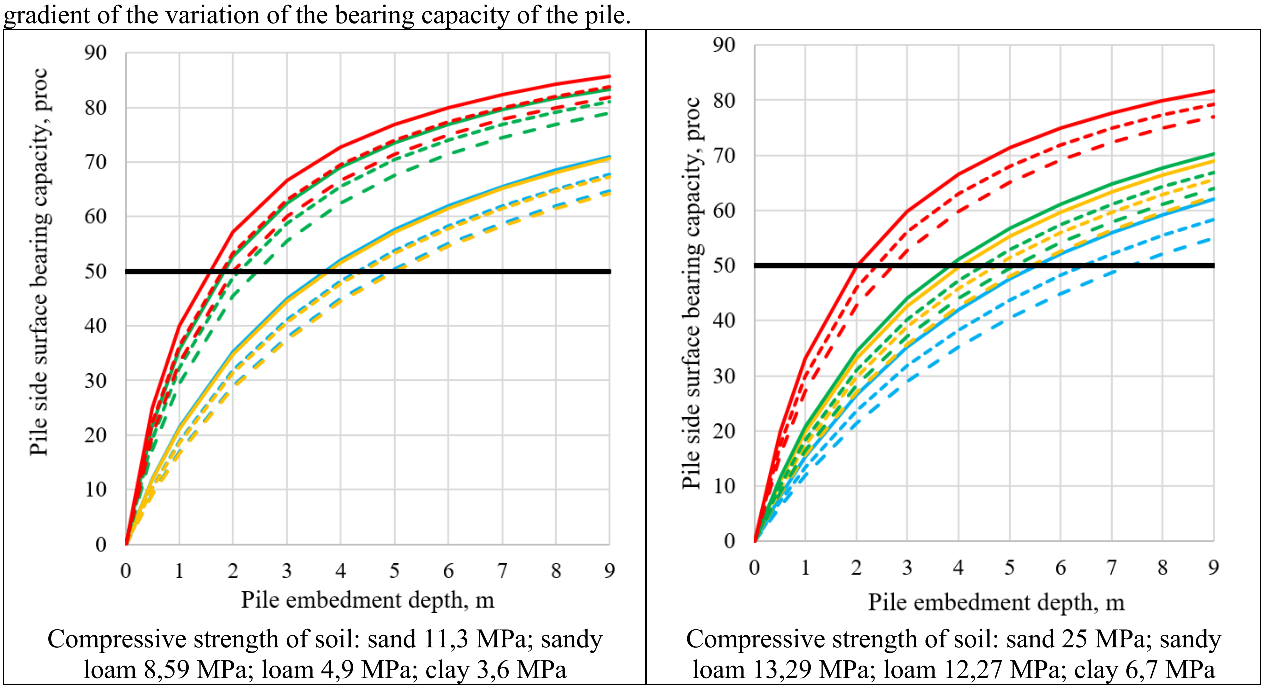

Figure 2. **Dependence of the bearing capacity ratio of the side surface of the pile to the bearing capacity of the pile base on the depth of pile insertion** (pile diameter: ——— 0,30 m; ----- 0,35 m; - - - 0,40 m; soil: ■ sand; ■ sandy loam; ■ loam; ■ clay)

The study also analyzed how the bearing capacity of the pile is distributed between the pile base and the pile side face. Figure 2 shows the results of the pile bearing capacity distribution.

From the presented graphs, it can be seen that at the initial stage of pile insertion into the soil, more than 50% of the load-bearing capacity falls on the base of the pile. The bearing capacity of the side surface of the pile, at the same embedment depth, begins to dominate (exceeds 50%) in the soil with previously lower compressive strength.

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Dependences of pile bearing capacity on homogeneous soil

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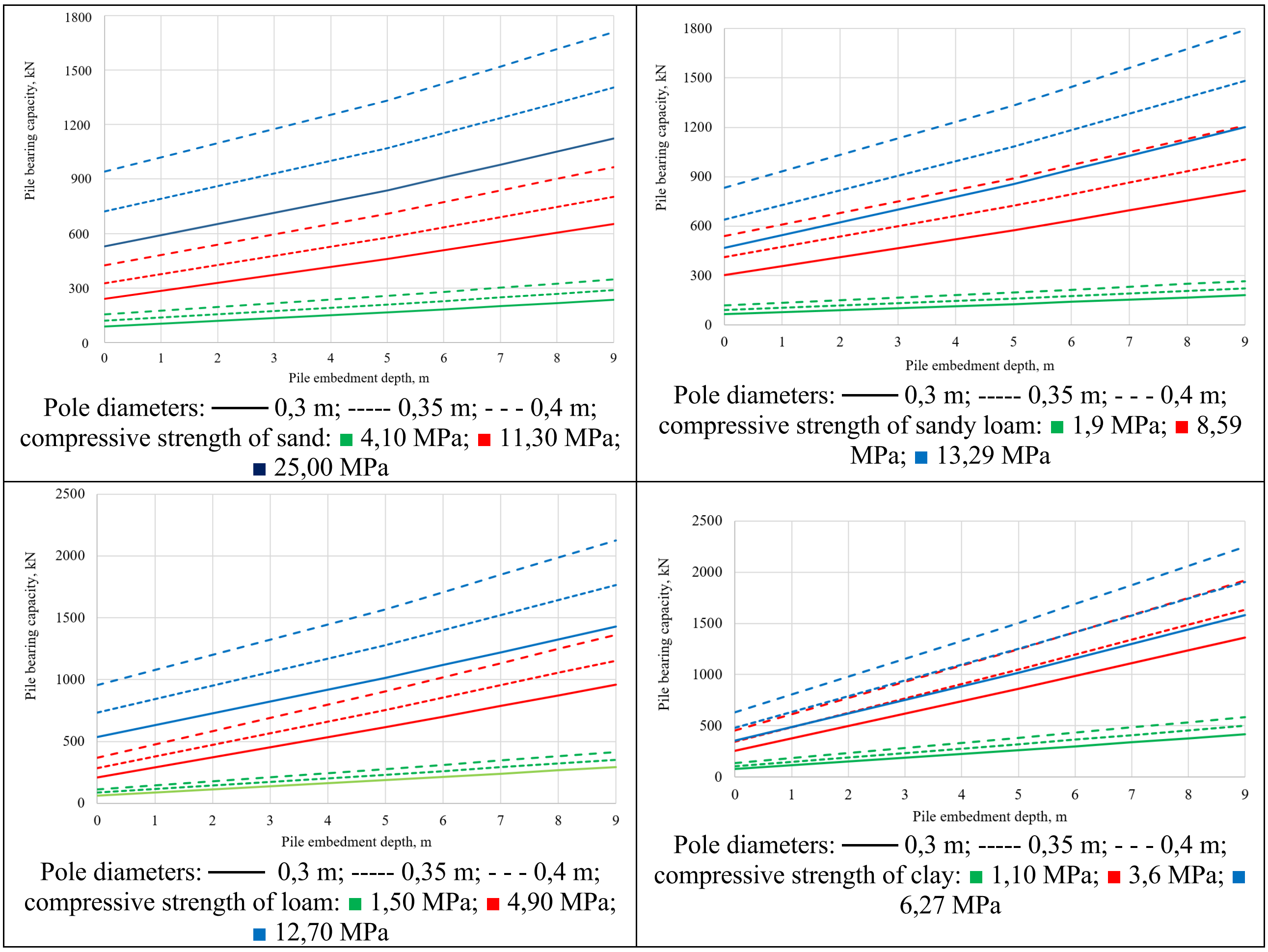
The dependences of pile bearing capacity on soils of different strength are presented in Figure 1. The graphs show the results of pile bearing capacity calculations for piles of three different diameters: 0.3 m, 0.35 m and 0.4 m.



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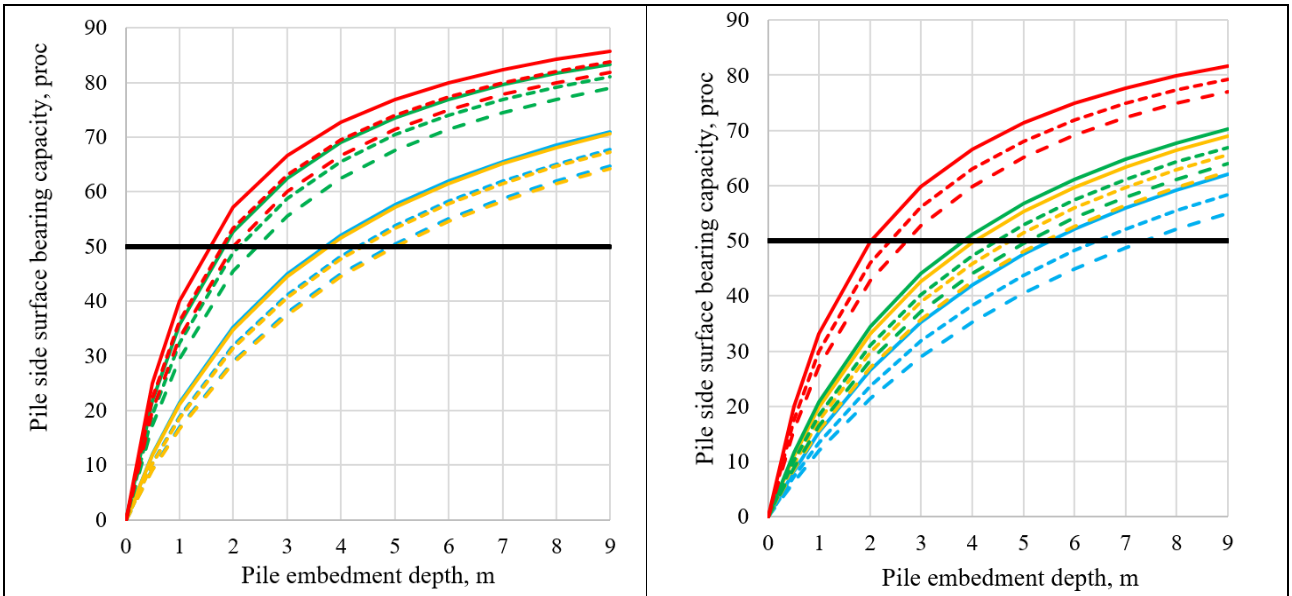

Compressive strength of soil: sand 11,3 MPa; sandy loam 8,59 MPa; loam 4,9 MPa; clay 3,6 MPa

Compressive strength of soil: sand 25 MPa; sandy loam 13,29 MPa; loam 12,27 MPa; clay 6,7 MPa

Figure 2. **Dependence of the bearing capacity ratio of the side surface of the pile to the bearing capacity of the pile base on the depth of pile insertion (**pile diameter: ——— 0,30 m; ----- 0,35 m; - - - 0,40 m; soil: ■ sand; ■ sandy loam; ■ loam; ■ clay**)**

From the presented graphs, it can be seen that at the initial stage of pile insertion into the soil, more than 50% of the load-bearing capacity falls on the base of the pile. The bearing capacity of the side surface of the pile, at the same embedment depth, begins to dominate (exceeds 50%) in the soil with previously lower compressive strength.

CONCLUSIONS

1. The highest bearing capacity when the soil is homogeneous is found in clay soil and the lowest in sand.
2. When the diameter of the pile is 0.3 m, compared to the sandy soil, the bearing capacity is higher in sandy loam by about 10%, in loam by 50%, and in clay by 100%. When the pile diameter is 0.35 m, compared to the sandy soil, the bearing capacity is about 20% higher in sandy loam, 45% in loam, and 110% in clay. When the pile diameter is 0.4 m, compared to sandy soil, the bearing capacity is about 10% higher in sandy loam, 30% in loam, and 45% in clay.
3. When the soil is sand, the bearing capacity of a 0.35 m diameter pile increases by 3.25 times compared to a 0.3 m diameter pile, and the bearing capacity of a 0.4 m pile increases by 5.5 times. When the soil is sandy loam, the bearing capacity of a 0.35 m diameter pile increases by 3.6 times compared to a 0.3 m diameter pile, and the bearing capacity of a 0.4 m pile increases by 5.5 times. When the soil is clay, the bearing capacity of a 0.35 m diameter pile increases by 3.4 times compared to a 0.3 m diameter pile, and the bearing capacity of a 0.4 m pile increases by 4 times.

REFERENCES

1. Dong, S. et al. Numerical study on the installation effect of a jacked pile in sands on the pile vertical bearing capacities. Computers and Geotechnics. 2022, 145 [viewed at 2024-07-10]. https://doi.org/10.1016/j.compgeo.2022.104690.
2. Michail, S., Lopez-Querol, S. Numerical investigation of displacement pile installation in silica sand. Computers and Geotechnics. 2023, 161 [viewed at 2024-07-10]. https://doi.org/10.1016/j.compgeo.2023.105591.
3. Ling-Yu, X. ir kt. A simplified piecewise-hyperbolic softening model of skin friction for axially loaded piles. Computers and Geotechnics. 2019, 108 [viewed at 2024-07-07]. https://doi.org/10.1016/j.compgeo.2018.12.018.
4. Gajauskas, J., Šarakauskas, J., Motiekaitis, R. Statybos inžinieriaus žinynas. Vilnius, Technika, 2004. ISBN 9986–05–682–9.
5. Eurokodas 7. Geotechninis projektavimas. LST EN 1997 – 1:2003.
6. Ghiasi, V. ir Eskandari, S. Comparing a single pile's axial bearing capacity using numerical modeling and analytical techniques. Results in Engineering. 2023, 17 [viewed at 2024-05-11]. https://doi.org/10.1016/j.rineng.2023.100893.
7. Benjeminas, Č. Pamatų projektavimo pagal 7 eurokodą vadovas. Mokomoji knyga. Kaunas, Technologija, 2007. ISBN 9955-25-161-1.

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