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FOUNDATION ENGINEERING STRUCTURE

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Abstract

When soil conditions require deep foundations for building construction, the current practice for designing foundation structures relies on two approaches, the use of individual piles or the use of piles as a group. In the case of individual piles, they are dimensioned until the stability potential of pile and the required stability of foundation are equalized. In the case of group of piles, the sum of individual stability potential of each pile needs to be equal to the required stability of the building foundation. Nowadays, the second approach, also known as piling, prevails and becomes a starting point of any stability analysis, without considering single pile stability, which is an independent system. This implies that there is no summing of individual potential stabilities for a group of piles. In this paper, we provide evidence that the group of piles can be more than a sum of each pile, if they are positioned in a specific manner according to a statically rational sense. In such system, mutual interactions of individual piles yield new beneficial properties and altogether act as a one stability unit, i.e. a foundation structure. Using computational and practical testing of our hypothesis, we demonstrated that foundation construction composed of a specific group of piles displays improved stability than the sum of single piles. When such foundation structure are used for dimensioning of foundations, computational stability ambiguities are avoided. Moreover, we do not secure our calculations with high factors of safety as we have to do with current approaches. Our innovative foundation structure provides solution for any case of foundation with the significant reduction in pile size, contributing to preservation of the environment and reducing the cost of work.

Keywords: foundation stability structure, piling, group of piles, skin resistance, base resistance, desplacement of structure, resistance difference in equilibrium

1 Introduction

In foundation stability constructions, when piles stop being individual deep foundations of certain object and start working together, then we have a new subject of foundation. This structure is based on an optimal space disposition of piling, and piles are converted in foundation structure, not a foundation as a group of piles. Hence, we no longer consider it as a sum of corrected stabilities of individual piles. Instead, it becomes stability of foundation structure, which is accordingly designed. All known elements of individual pile stability, skin resistance, base resistance, and pile displacement longitudinally and transversally, completely convert to other form of stability in the structure. In this construction, the primary elements of stability become space disposition of piling, displacement and base resistance of construction. Since all of these elements required for the proof of stability are known, it is only needed to arrange them appropriately to achieve the goal, i.e. to prove the stability of the foundation engineering structure.

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2 Technical design for construction and proving elements of stability

In the transformation of stability elements of individual piles into stability elements of the construction, the pile resistance at skin on the most length h_1 of the pile does not exist, because there is no relative deformation between the pile and the ground on that part of the pile, σ_1=Ø. The remaining length h_S of the pile becomes anchoring part, which takes over entire load on the piles, via skin resistance which becomes primary resistance of the pile σ_S relative to the structure. This part of resistance completely encompasses also the resistance at the base of individual pile, which acts in the structure due to small relative deformation between the pile and ground at the base, and becomes the secondary resistance.
Resistance of the structure base, q_{R}, becomes the primary resistance of system as it is shown in figure 1. Construction displacement is determined from equality of the work of the pile within the block and the formed potential energy of the structure base relative to the ground. In this case, it means that structure displacement is summed as displacement of the pile within the structure and displacement of the pile base.

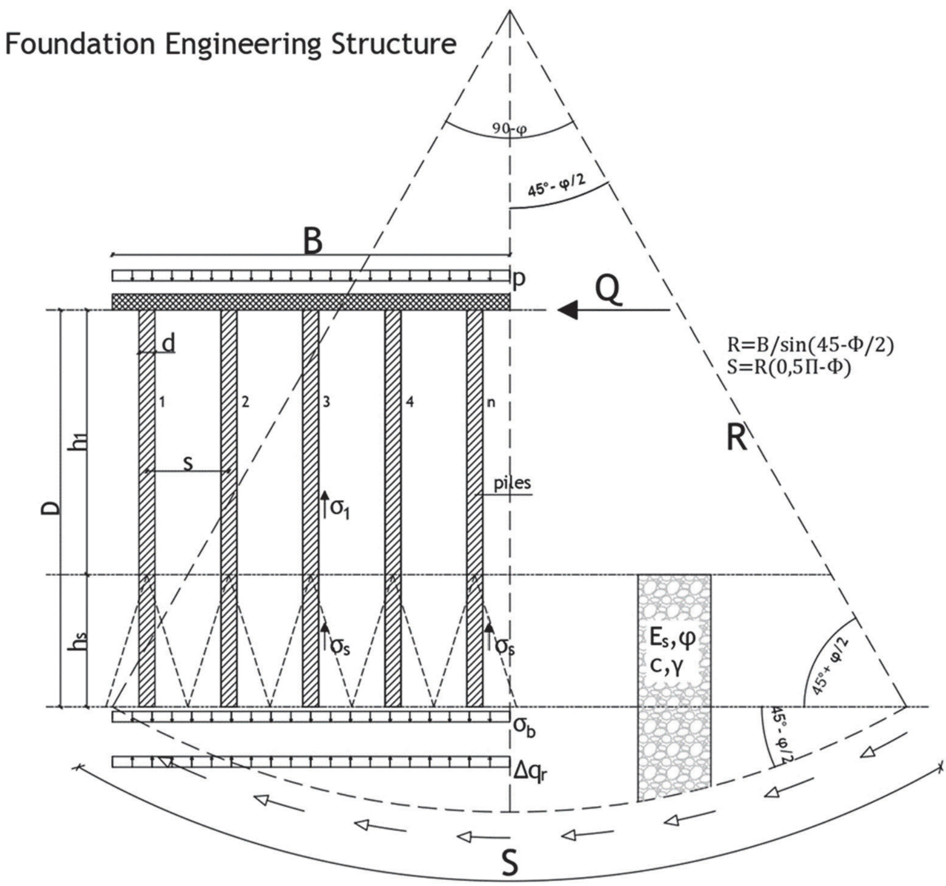

Figure 1 Foundation structure - stability model

2.1 Deformation state of structure

Total desplacement [7]

$$\sum\Delta = \Delta_{hs} + \Delta_{base} \tag{1}$$

$$\Delta_{hs} = \frac{3P \ln\left(\frac{s}{d}\right)}{2\pi h_s E_s} \tag{2}$$

Work of transmision of load in structure is equal to created potencial energy at structure base

$$W_{hs} = U_{base} \tag{3}$$

$$W_{hs} = \frac{3P^2 \ln\left(\frac{s}{d}\right)}{4\pi h_s E_s} \tag{4}$$

$$U_{base} = \frac{k_s \Delta_b^2}{2} \tag{5}$$

Modulus of subgrade reaction

$$k_s = \frac{E_s}{s\left(1-\mu^2\right)} \text{ [3]} \tag{6}$$

$$\Delta_{base} = P\sqrt{\frac{3\ln\left(\frac{s}{d}\right)}{2\pi E_s h_s k_s}} \tag{7}$$

$$\sum\Delta = P\left[\frac{3\ln\left(\frac{s}{d}\right)}{2\pi h_s E_s} + \sqrt{\frac{3\ln\left(\frac{s}{d}\right)}{2\pi E_s h_s k_s}}\right] \tag{8}$$

2.2 Stress state equations

Stress states at structure base:

a) Main stress at base

$$\sigma_b = p + \gamma D \qquad [\sigma_b < q_R] \tag{9}$$

b) Shear stress at pile skin

$$\sigma_s = \frac{P}{d\pi h_s} < \gamma D \tan\varphi_d \qquad [3h_s < D] \tag{10}$$

c) Calculated lenghts of pile skin friction

$$h_s = \frac{P}{d\pi\gamma D \tan\varphi_d} \qquad [s = 2h_s \tan\varphi_d] \tag{11}$$

d) Bearing capacity of structure

$$q_R = cN_c + qN_q + 0.5\gamma BN\gamma \text{ [5]} \tag{12}$$

e) Resistance difference in equilibrium

$$\Delta q_R = \frac{(\sigma_s \tan\varphi + c)RS - \frac{p\tan\varphi RS}{2} - \frac{pB^2}{2} - QD}{0.5B^2} \tag{13}$$

2.3 Stability evidence of the structure

$$\sum \Delta < \Delta_{admisible} \tag{14}$$

$$q_b < q_R \tag{15}$$

$$s = 2h_s \tan\varphi_d \; h_s < D/3 \tag{16}$$

$$\frac{A_p \sigma_c}{\gamma_c} > P \tag{17}$$

If , $\Delta q_R > 0$, we have safety faktor, for resistance q_R and horizontal resistance Q.

3 Conclusion

It is obvious that the foundation construction, as a physical sum of individual piles, cannot be taken merely as a mathematical sum from the stability point of view. Instead, primary corrections of stability of individual piles are necessary prior to calculating their sum. This is the current approach, and the resulting procedure contains an array of safety factors, which are necessary for the primary correction. With this work, we demonstrated a novel model that allows us to avoid extensive factorization.
The procedure is conducted by proving allowed deformation of the system. A clear and simple law of mechanics can be applied here, a balance of work and potential energy of the system. This allows us to omit the corrections of the primary procedure, because the balance of the construction is achieved in a closed mechanical system.

References

[1] Berezantzev, V.G., Khristoforov, V., Golubkov, V.: Load Bearing Capacity and Deformations of Piled Foundations, Proc. 5th Int. Conf. S.M. &F.E., 2 (1961), pp. 11-15

[2] Bowles, J.E.: Foundations Analysis and Design, Fifth Edition, 1996.

[3] Broms, B.B.: Lateral Resistance of Piles in Cohensionless Soils, J.S.M.F.D., ASCE, 90 (1964), pp. 123-156

[4] Poulos, H.G., Davis, E.H.: Pile Foundation Analysis and Design, 1980.

[5] Terzaghi, K., Peck, R.B.: Soil Mechanic in Engineering Practice, 1967.

[6] Timoshenko, P.S.: Strength of Materials, Third Edition, 1958.

[7] Whitaker, T.: The Design of Piled Foundations, Second edition, 1976.