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Load-bearing capacity of a single barette (case study for the Hanoi soil condition)

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ABSTRACT: The article presents the results of analytical analysis of the bearing capacity of a single baretta in hard geological conditions in the city of Hanoi and compares it with the field test results. The methods provided in the regulatory documents SP 24.13330.2011 "Pile Foundations" [1] have been adopted when determining the bearing capacity of piles and barrettes. As well as the results of field tests with piles (static load method) were used. A new method has been proposed which accounts the mutual arrangement of piles in the ground, their length, pitch, etc. Appendix E of the specified regulatory document provides this method. The investigation shown that the test bearing capacity of a single barrette with a limiting settlement of up to 40 mm is in a good agreement with the results of analytical analysis by proposed method, which accounts unloading on soft soils in deep pits.

1 INTRODUCTION

Since the 21st century, there has been an increase in the loads transferred to the base, and the settlement of structures due to the rapid grow in the construction of high-rise buildings. These circumstance determines the wider use of pile foundations (even if there are sufficiently strong

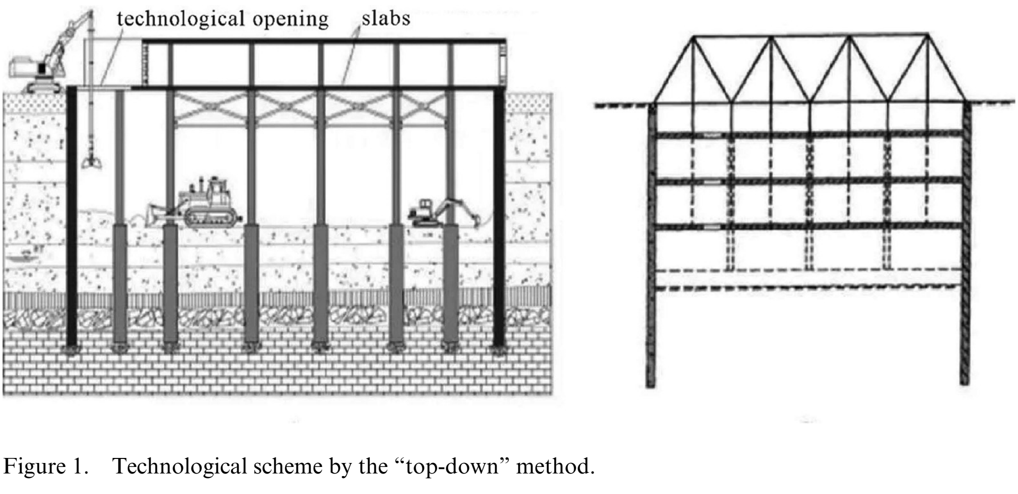

Figure 1. Technological scheme by the "top-down" method.

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soils near the surface). The technology of developing deep pits by the "top-down" method is most common approach in the construction of underground structures in such densely populated urban areas (Figure 1) [4].

Barrettes are effective foundation designs for the construction of underground structures by this method and for the work using underground space in soft soils, with a high level of groundwater and in cramped urban conditions. The technological sequence of the installation of a single barrette is the same as in the case of the installation of a "wall in the ground" (Figure 2).

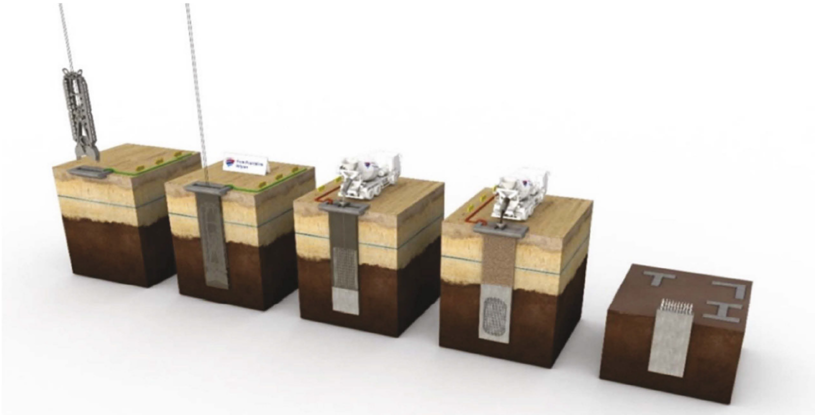

Figure 2. Technological sequence of the barrette installation.

A number of Russian and foreign scientists [6–9] studied the applicability of piles and barrettes in practice, considering the peculiarities of the interaction of piles and barrettes with each other and with the soil. The use of barrettes in these conditions leads to the search for new ways to improve the efficiency of pile foundations. In particular, a possible important condition is the refinement of calculation methods. A new method has been proposed that accounts the mutual arrangement of piles in the soil base, their length, pitch, etc. (Appendix D to SP 24.13330.2011) [1]. The article discusses the existing methods for assessment the bearing capacity of barrettes and compares the results obtained with full-scale field static tests.

2 MATERIALS AND METHODS

In world practice, field tests for assessing the bearing capacity of barrettes allows verification and confirmation the accuracy of the analysis and the quality of the entire construction process [10]. In the problem under consideration, vertical static load testing of a single barrette was carried out using hydraulic jacks up to a maximum load of 30 MN that simulates the 'Top-Down' method. The test procedure met to GOST 20276-2012 [2]. During the field static tests, vertical displacement of the pile under test load had been determined by sensors located on the pile head according to the requirements of 8.2.2 [3].

Since the bearing capacity of a pile depends on the physical and mechanical properties of soil base, the most common analytical method for its determining is the calculation according to tables of standard soil resistances [11]. Let us calculate the bearing capacity of the barrettes, immersed with excavation and filling with concrete. In accordance with 2.7.6. [1], it can be determined from the formula.

$$F_{d,1} = \gamma_c\left(\gamma_{cR} \cdot R \cdot A + u\sum \gamma_{cf} \cdot f_i \cdot h_i\right), \tag{1}$$

where $\gamma_{cR}, \gamma_{cf}-$ are the partial factors for condition of soil base resistance under the pile tip and side surface respectively; γ_c- is the partial factor for pile behavior in the soil base, which is adopted as 1; A – is the pile area for supporting on the soil base, m^2, which adopted as cross-sectional area brutto or cross-section of the camouflage widening by its largest diameter, or by the area of the shell pile and the net hollow pile; u – is the external perimeter of the pile cross-section, m; R – is the design strength of the soil under the pile tip, kPa; f_i – is the design strength of the soil layer through the pile surface, kPa; h_i – the depth of the *i-th* soil layer, contacting with the pile surface, m.

We adopted table values of f, R and liquidity index I_L in formula (1) to evaluate the bearing capacity of a structural member (pile, barrett) through the side surface. In this problem, the design strength R of the soil under the lower end of the piles is determined in the case of coarse and sandy soils by the formula.

$$R = 0,75\alpha_4(\alpha_1\gamma_1^{'}d + \alpha_2\alpha_3\gamma_1 h), \tag{2}$$

where α_1,α_2,α_3,α_4- are dimensionless coefficients determined from the table depending on design value of the internal friction angle for the soil; $\gamma_1^{'}-$ is the design value of the specific soil weight, kN/m^3 under the pile lower end (taking into account the weighing effect of water for water-saturarted soils); γ_1- is the average through the layers design value of specific weight of the soils, kN/m^3, above the pile tip (taking into account the weighing effect of water for water-saturarted soils); d – is the diameter of the pile, m; h – is the depth from the natural relief or from the level of planning in case of cutting to the pile tip, m.

It is necessary to take into account the unloading process, when constructing deep pits. In the soil next to the pit, horizontal stresses decrease during excavation, vertical stresses do not change. At the same time, in the soil at the bottom of the pit, the horizontal stress does not change, the vertical stress decreases when the soil is excavated. At depths of more than 5 m, the effect of "unloading - reloading" becomes most pronounced for a certain thickness of the base as a result of excavation. The phenomenon of "unloading - reloading" is especially manifested in the foundations, composed of weak soils with a small modulus of deformation. Taking into account the significant thickness of soft soils with such a modulus of deformation, deformations under load will play a significant role within the barrett shaft. Applicability limits have also been introduced - the settlements of a small group ($n \leq 25$) and a large pile field are determined considering mutual influence. Therefore, the method for determining the settlement of a single pile depending on the average value of the soil shear modulus G within the pile and under its lower end is also described by the following formula according to 7.4.2–7.4.3 [1]:

$$s = \beta\frac{N}{G_1 l}, \tag{3}$$

where N – is the vertical load on the pile, MN; β – is the dimension factor; G – is the shear modulus, MPa; l – is the pile length, m.

In theoretical soil mechanics, as in continuum mechanics, several deformation moduli are also used. What they have in common is that they are parameters of Hooke's law [5]:

$$\varepsilon = \frac{1}{E}\sigma, \tag{4}$$

where ε – is the strain; σ –is the stress, kPa; E – is the deformation modulus, kPa.

The modulus of deformation is the same coefficient of proportionality in dependence (4) and at a higher level of deformation, when residual deformation occurs during unloading.

It is necessary to determine two moduli of deformation – on the branches of primary (E) and secondary (E_e) loading (Figure 3) in order to calculate the settlement of foundations. Deformation moduli are determined by testing soil samples under uniaxial compression and axisymmetric (triaxial) compression.

In order to find the deformation modulus E_e, it is necessary to know the values of the unloading stresses, upon reaching which the soil sample should be unloaded, and then loaded again (carry out secondary loading). In accordance with the paper [1] soil unloading should be taken into account if the depth of the pit is more than 5 m.

A new method has been developed for the analysis of piles in deep pits. This method based on approach described in Appendix E [1]. The proposed modification of the analytical method for calculation the settlement of a single pile in order to take into account the unloading of the foundation during the development of a deep pit allows describing the behavior of the barrette under load with sufficient accuracy. Therefore, to calculate the settlement of barrettes in deep pits, we proposed to determine the shear modulus accounting the unloading of the soil base and the average value of the soil shear modulus. Within the unloading thickness H_{ur} for soils, the shear modulus G_{ur} of elastic deformations is defined as

$$G_{ur} = \frac{1}{2(1+\nu_{ur})} E_{ur}, \tag{5}$$

where E_{ur} – the soil deformation modulus during unloading/reloading; the lateral to longitudinal deformation ratio of the soil under unloading/reloading.

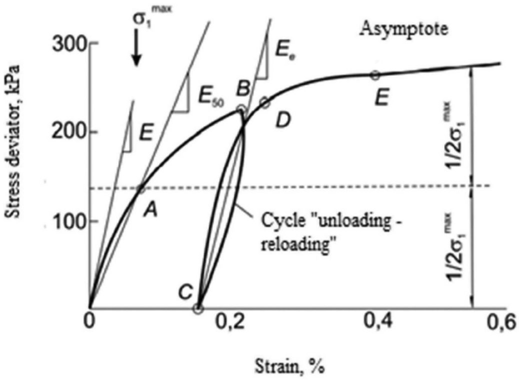

Figure 3. Stress – strain curve to determine deformation modulus in triaxial compression.

As Figure 3 shows, the modulus of soil deformation during unloading and reloading E_{ur} shall be determined from triaxial tests at a compression value equal to the modulus of soil deformation during initial loading. In fact, the soil deformation modulus E_{ur} takes values 2 … 7 times greater than the secant deformation modulus at 50% of the ultimate stress deviator under conditions of unloading and reloading. Then you can apply the following formula to calculate the approximate values

$$E_{ur} = 5E_{50}. \tag{6}$$

3 RESULTS

According to GOST 5686-2012 "Soils. Field test methods by piles" [3], testing of the barrette should be provide a vertical settlement of 40 mm, which is achieved under the action of a vertical load $F_{d,\text{исп..}}$ = 27500 kN (Figure 4).

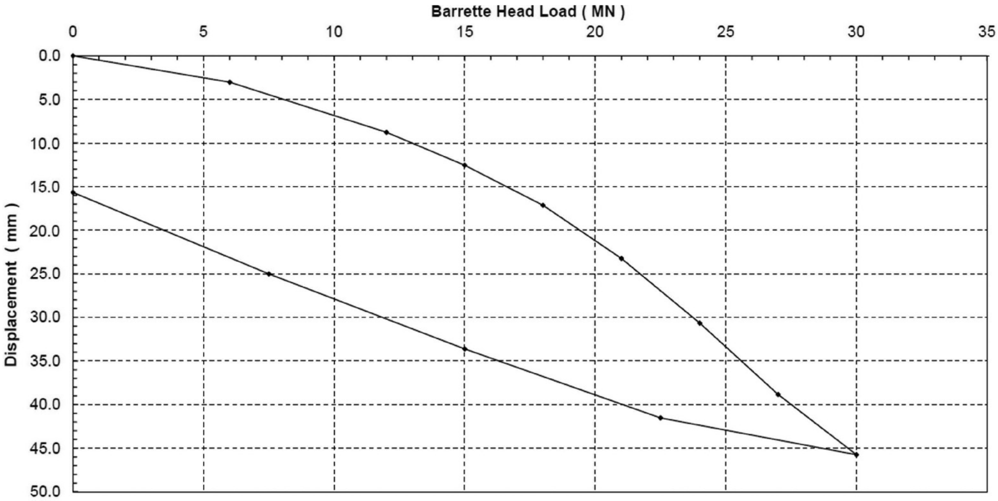

Figure 4. Settlement vs. load relation from field tests of barrettes.

To compare the bearing capacity of single barrettes according to the indicated formulas, let's consider an example for hard geological conditions at the construction site in Hanoi. Experimental single barrettes with a cross section of 800 × 2800 mm and a length of 37 m had been tested in the framework of this study. The dimensions of the baretta are typical for Hanoi. The barrettes located on a site with layers of soft soils near the surface and at a high level of groundwater at a mark from a relative mark of -0.60 m.

According to the results of engineering and geological surveys, it was established that the geological zone under the well has a depth of 61 m and consists of 9 soil layers: compacted embankment (EGE 1), fluid clay, brownish-gray, mixed with organic inclusions (EGE 2), loose sand, ash gray, medium brown, medium density, low moisture (EGE 3), fluid-plastic clay, brownish gray,

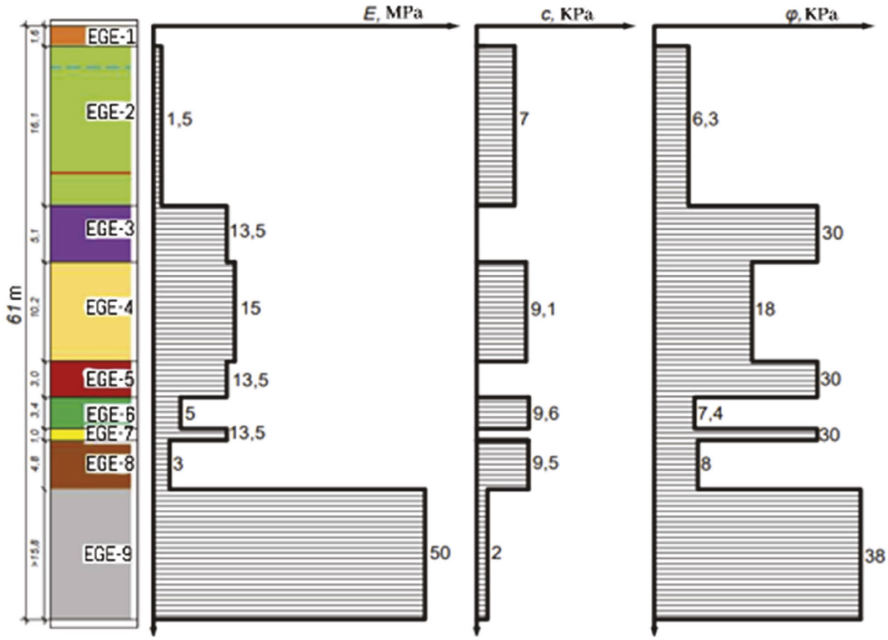

Figure 5. Geotechnical cross-section of the test site with soil characteristics under triaxial compression.

mixed with organic inclusions (EGE 4), sand fine, gray, yellowish gray, medium density, low moisture (IGE 5), soft-plastic loam, brownish-gray (IGE 6), fine, medium-sized, low-moisture sand (IGE 7), fluid-plastic loam, brown-gray, dark gray, mixed organic (IGE 8), gravel-pebble soil (IGE 9). Figure 5 shows an engineering-geological section with the characteristics of the site soils.

Thus, classic analytical calculation allows obtaining the value of the total bearing capacity of this barrette F_d = 27285 kN. According to the results of the calculation, it was found that 77% falls on the tip and only 23% on the lateral surface.

In this problem, the depth of the projected excavation is almost 15 m. After excavation of the pit, we determined the depth of the soil massif of the unloading zone within the unloading thickness for soils in the problem under consideration: H_{ur} = 10 m and the width of the pit b = 61 m. the condition for limiting the draft to 40 mm was $F_{d,2}$ = 24600 kN.

Table 1 presents the calculation and test results for bearing capacity of the barrette in the soil.

Table 1. Calculation and test results for bearing capacity of the barette in the soil.

Methods for calculating the bearing capacity of a pile	bearing capacity F_d, kN
Field test results	27500
Analytical classical method [1]	27285
Analytical method according to the criterion of settlement [1] (consider unloading)	24600
Analytical method according to the criterion of settlement [1] (do not consider unloading)	18450

Thus, it is clearly seen that the bearing capacity of the pile according to the results of field tests:

– 1.0% higher than the bearing capacity of the barette, calculated from the results of analytical solutions using tabular values of soil resistance;
– 10% higher than the bearing capacity of the barette, calculated from the results of analytical solutions for the criterion of settlement (modified) taking into account unloading;
– 33% higher than the bearing capacity of the barette, calculated from the results of analytical solutions based on the criterion of settlement without unloading.

Figure 6 shows the combined load vs. settlement graph for various considered analytical methods and full-scale tests.

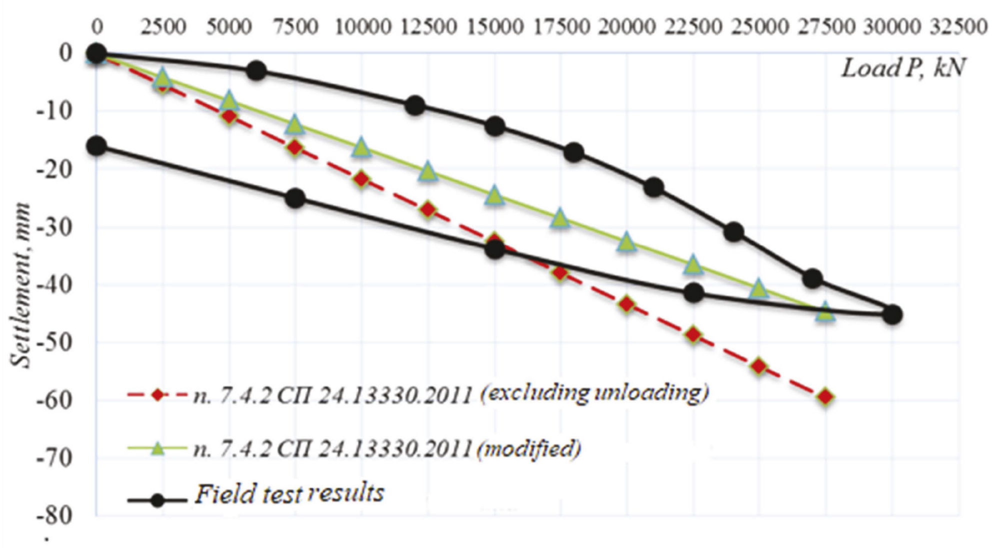

Figure 6. Combined load vs. settlement graph for analytical calculations and field tests.

As we can see from Figure 5, field tests showed a slightly higher indicator than the analytical method without taking into account unloading or modified. The soil around deep pits are always in a complex stress state and considering of the process of unloading is very important in this case. Thus, the results of conventional tests of simple models without unloading describe approximate characteristics of the stress-strain state of soils.

Methods for determining the settlement of a single pile according to the Russian standard, where the soil is considered as a linearly deformed half-space, characterized by a shear modulus and Poisson's ratio, are in good agreement with each other. The bearing capacity values differ by about 10% as Table 1 shows. However, the solutions according to these methods do not meet well with the results of field tests and cannot be applied for practical purposes in conditions of soft soils in deep pits.

4 CONCLUSION AND DISCUSSION

The analysis of the obtained results shows the convergence of the value of the calculated and test bearing capacity of the barette in the soil. In the analytical solution, the reduced shear modulus G is determined taking into account the unloading thickness of the base, for which the soil deformation modulus E_{ur} under unloading/reloading is applied.

The authors recommend further research and use of this method for preliminary calculations of settlement and bearing capacity of piles.

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