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Single pile's displacement under action of negative friction forces in new design of a pile raft foundation

Déplacement d'un seul pieu sous l'action de forces de frottement négatives dans une nouvelle conception d'une fondation sur pieux

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ABSTRACT: In the construction of multi-storey and high-rise buildings, where there are significant loads on a subsoil base consisting of not rocky soils, the so-called combined pile raft foundation is being used recently to reduce the absolute and relative settlements, taking into account the inclusion of soil under its raft part. Nowadays widespread use has been made of pile raft foundations, which take into account inclusion of soil under its raft part. We proposed a new design of a pile raft foundation and an engineering method for determining the main parameters of such a foundation, where one of the parameters is the settlement of piles from action of negative friction forces P_n. We carried out full-scale tests of a multi-section pile with loading at depth, on the basis of which a comparative analysis of the settlement of single piles from action of negative friction forces, obtained with help of adapted and existing methods and experimental data. Is proposed to determine the settlement of the piles from the additional frictional forces using adapted method.

RÉSUMÉ : Dans la construction d'immeubles à plusieurs étages et de grande hauteur, où il y a des charges importantes sur une base de sous-sol constituée de sols non rocheux, la fondation dite combinée de radier sur pieux est utilisée récemment pour réduire les tassements absolus et relatifs, en tenant compte compte de l'inclusion de terre sous sa partie radier. De nos jours, on a largement utilisé les fondations sur radier sur pieux, qui tiennent compte de l'inclusion du sol sous sa partie radier. Nous avons proposé une nouvelle conception d'une fondation de radier sur pieux et une méthode d'ingénierie pour déterminer les principaux paramètres d'une telle fondation, où l'un des paramètres est le tassement des pieux sous l'action des forces de frottement négatives Pn. Nous avons réalisé des essais grandeur nature d'un pieu multi-sections avec chargement en profondeur, sur la base desquels une analyse comparative du tassement de pieux isolés sous l'action de forces de frottement négatives, obtenu à l'aide de méthodes adaptées et existantes et de données expérimentales . Il est proposé de déterminer le tassement des pieux à partir des forces de frottement supplémentaires en utilisant une méthode adaptée.

KEYWORDS: pile raft foundation, clearance, single pile, settlement, «ONLY-DOWN» method

1 INTRODUCTION

In the construction of multi-storey and high-rise buildings, where there are significant loads on a subsoil base consisting of not rocky soils, the so-called combined pile raft foundation is being used recently to reduce the absolute and relative settlements, taking into account the inclusion of soil under its raft part (Katzenbach et al. 2015).

The purpose of this paper is to perform a comparative analysis of the settlements of single piles from the action of negative friction forces obtained from various adapted methods with experimental data.

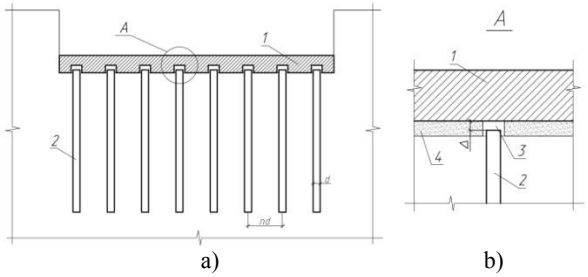
1.1 *Combined pile raft foundation*

For a real inclusion of the base under the raft in the monograph (Samorodov 2017), a new construction of the pile raft foundation was proposed (Figure 1).

Pile raft foundation consists of a raft 1 and piles 2 with diameter d, with a clearance 3 with height Δ (for example, in a concrete cap 4 below the raft), and the distance between the pile axes is nd.

At the same time, the new design lacks the drawbacks of existing constructive solutions and methods for constructing such pile raft foundations (Penkovskiy et al. 2007).

The developed engineering method for determining the main parameters of such a pile raft foundation based on the maximum allowable structure settlements involves determining the height of the clearance Δ between piles and the raft part, which is equal to the value of additional pile settlement caused by the development of negative friction forces along their lateral surface within compressible thickness under the raft.



a) b)

Figure 1. Pile raft foundation: a) common scheme; b) the scheme for detail A

2 METHOD

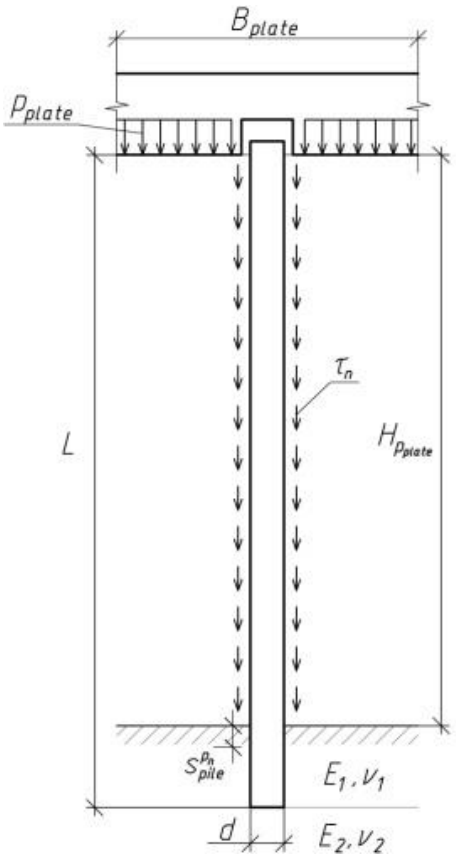
2.1 *Pile settlement determine methodology*

In the existing normative documents and scientific and technical literature, there are no methods for determining the settlements of piles from the action of negative friction forces P_n.

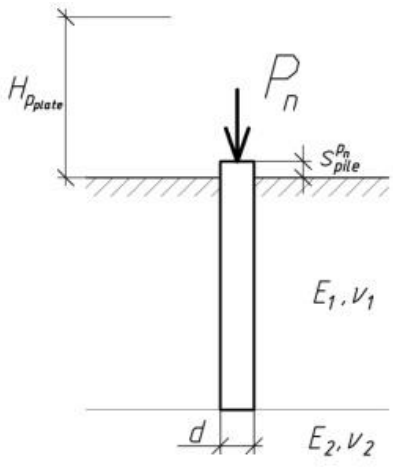
To determine the settlement of the pile $S_{pile}^{P_n}$ from the action of the negative friction force P_n, when the raft part works first, we present the calculation schemes in Figure 2, where the transition from the design scheme in Figure 2, a, but to the calculated scheme in Fig. 2, b, i.e. to the scheme of applying the load P_n to the pile at a certain depth. The lower part of the pile

is located in a two-layer base with the corresponding deformation characteristics: E_1, v_1 and E_2, v_2.

For the calculation scheme in Fig. 2, b we obtained the experimental values of the settlements for different loading levels by the force P_n when testing the soils by the full scale two-section pile by the «ONLY-DOWN» method [Samorodov et al. 2017], namely the settlements of the lower part of the pile from the applied load at the depth (Figure 3).



a)



b)

Figure 2. Calculation schemes: a) the calculation scheme for the formation of friction forces τ_n on the lateral surface of the pile; b) the design scheme for determining the settlement of the pile from the action of negative friction forces

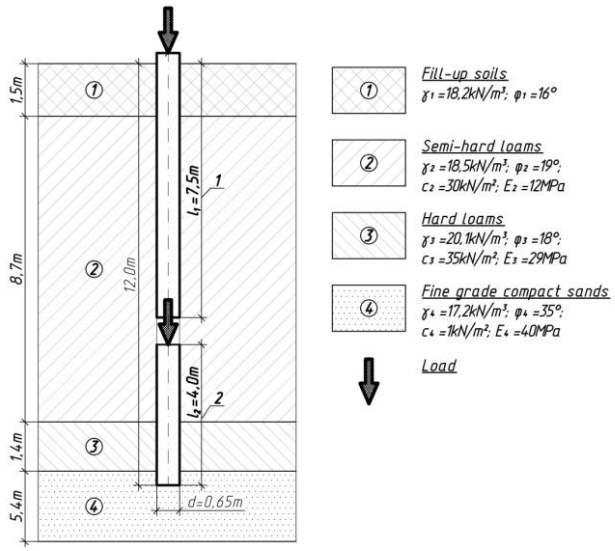


Figure 3. Scheme of testing the soil with a two-section natural pile by the «ONLY-DOWN» method: 1 - upper pile section; 2 - lower pile section

For the theoretical determination of the settlements of the lower section of the pile, the following adapted methods were considered:

- method for determining the settlement of a single pile in accordance with Ukrainian Code (DBN V.2.1-10:2018);
- method for determining the settlement of the pile according to the design scheme of the conditional foundation in accordance with Ukrainian Code (DBN V.2.1-10:2018);
- method for calculating a single pile in a two-layer elastic environment, proposed by V.G. Fedorovskii 1974;
- method for calculating the settlement of a bored pile in a bilinear formulation, proposed by B.V. Bakholdin 2010.

The main factor of application of these methods is the correct determination of the proportionality limit or the boundary of the linear area of the dependence of the settlement on the load. In the case under consideration, the P_e (1) load limiting the linear section of the pile settlement was determined in accordance with the recommendations of the DBN V.2.1-10:2018, namely:

$$P_e = 0.5P_u = 550.0\ kN \quad (1)$$

where P_u – the value of the ultimate pile resistance based on the results of full-scale tests, equal to *1100,0* kN (Figure 4).

This approach was applied to all methods, except for the procedure for determining the settlement of the pile according to the design scheme of the conditional foundation. In this case, the conditional limit of proportionality was limited by the condition of point E.5 (Rukovodstvo 1980), when the average pressure under the base of the conditional foundation is less than or equal to the stress from the self-weight of the ground at the level of the base of the conditional foundation:
$p \leq \sigma_{zg,0}$.

3 RESULTS AND DISCUSSION

The results of calculations using the adapted methods are shown in Figure 4 in the form of theoretical dependences of the settlement of the lower section of the pile on the load, and also the experimental dependence on the test results is presented.

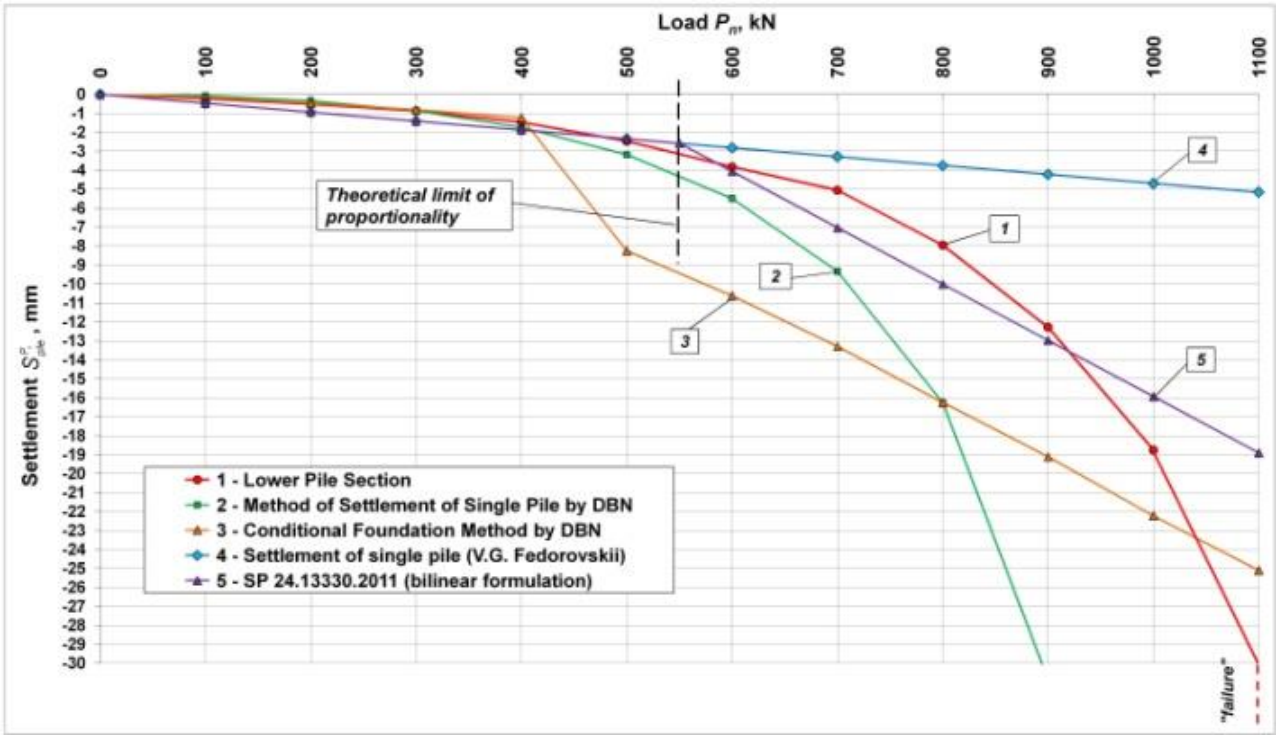


Figure 4. Graphs of the theoretical and experimental dependencies of the pile settlements $S^{P_n}_{pile}$ on the negative friction force P_n

From Figure 4 it can be seen that all the adapted methods considered allow determining the settlement of the pile up to the limit of proportionality, i.e. up to the load limiting the linear dependence of the pile settlement on the load. The method for determining the single pile settlement, proposed in DBN V.2.1-10:2018, makes it possible to reveal the nonlinear nature of pile deformation after the proportionality limit, but overstates the real values. In this case, the most accurate method was used to calculate the settlement of a single pile from the action of additional negative friction forces in a bilinear setting, proposed by B.V. Bakholdin, which shows an inaccuracy of no more than 15,0% at any level of loading.

Therefore, this approach can be used when designing a new construction of a pile raft foundation, namely, to determine the gap between the piles and the raft.

4 CONCLUSIONS

On the basis of the experimental and theoretical studies carried out, the following conclusions can be drawn:

1. A comparative analysis of the settlement of single piles from the action of the negative friction forces obtained with the help of existing adapted calculation methods and on the basis of the results of testing the soils with a two-section in situ pile.
2. At this stage of the study, it is proposed to determine the settlement of the piles from the additional frictional forces using the B.V. Bakholdin method, which is represented in the Russian codes SP.

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