The method for determining bored piles load-bearing capacity, taking into account the direction of vertical loading in water-saturated soils

Le procédé de détermination de la capacité portante des pieux forés, en tenant compte de la direction du chargement vertical dans les sols saturés en eau

Sergii Tabachnikov
Department of Soil Mechanics, Foundations and Engineering Geology, O.M.Beketov National University of Urban Economy in Kharkiv, Ukraine, s.v.tabachnikov@ukr.net

ABSTRACT: Based on the laboratory and theoretical studies of the resistance forces of sand soil on the lateral surface of the model pile, a new method for determining the load-bearing capacity of bored piles in water-saturated soils is proposed depending on the effects of upward or downward loading. The validity of the method is confirmed by in situ pile tests.

1 INTRODUCTION

Current regulatory documents (DBN V.2.1-10-2009, Rev. 1, "Structures Bases and Foundations. Basic provisions for design" and SP 50-102-2003, "Design and Arrangement of Pile Foundations") do not consider the direction of vertical loading (upward or downward) when determining pile skin friction capacity. At the same time, if we consider the pile service factor in soil γ_c, then the ratio of the load-bearing capacity for downward loading to upward loading $F_{d,f}/F_{du,f}$= 1.25.

2 LABORATORY AND THEORETICAL STUDIES

Using a patented method (Ukrainian Patent No. 96859, S.Tabachnikov and O.Samorodov 2015), the nature of the distribution of skin friction forces in sandy soil was identified for a multisection model pile with length L at rest T_0, without consideration of vertical load (Fig. 1, a).

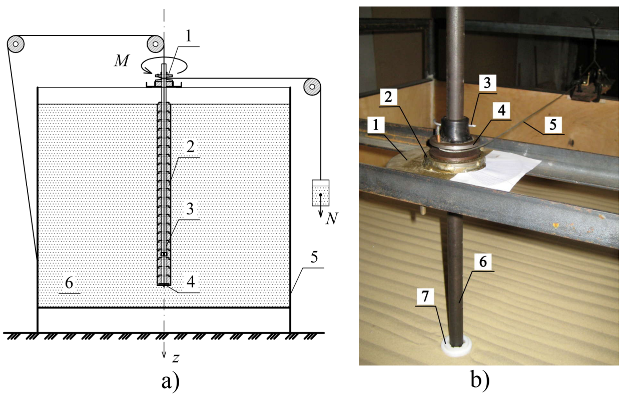


Figure 1. a) Diagram of the installation at rest for a fill height H of 1.0 m: 1) rotating mechanism with motion sensor; 2) model pile; 3) pivoted rod; 4) cover plate; 5) tank; 6) sand; b) Design of the pivoted mechanism: 1) metal disk; 2) cell with thrust bearing inside; 3) pin; 4) pulley with a developed tubular part; 5) metal cable Ø2.0 mm; 6) pivoted rod; 7) model pile.

The structure of the model pile is divided by elements with height Δh and is freely suspended vertically in an empty tank, after which loose material is poured into the tank to height $L=n\Delta h$. Using a special rigid design (Fig. 1, b), a rotational moment load M is applied about the z axis to a pile element with height Δh at any depth z.

The pile skin friction force in loose material $T_{0,i}$ without consideration of vertical load, is taken at corresponding depth z in relation to moment force M that corresponds to the start of rotation, per the relation $T_{0i}=(M_i-m)/d$, where d is the outside diameter of the model pile, m is the moment force due to friction between corresponding pile elements.

2.1. *Results of the tests*

A series of experiments was carried out for different ratios of model pile length to diameter (L/d), which enabled the identification, after statistical processing, of the qualitative nature of the depth distribution of pile skin friction forces at rest (Fig. 2, a) and to approximate it with the relation:

$$T_{0,i}=-0.0014\left(\frac{z}{d}\right)^2+0.0694\frac{z}{d}+0.0047 \qquad (1)$$

where the confidence level of the approximation $R^2 = 0.98$.

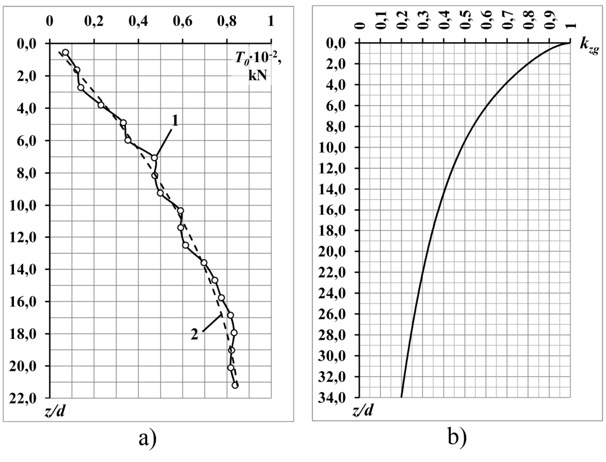


Figure 2. a) Distribution of friction forces in sandy soil at rest T_0 on depth z: 1) experiment; 2) dependence; b) Dependence of stress attenuation coefficient.

The influence of downward and upward loading on pile skin friction capacity in sandy soil was also determined within the experiment scope. It was determined that the ratio of load-bearing capacity due to skin friction forces for downward loading $F_{d,f}$ and upward loading $F_{du,f}$ lies in the interval $2.2 < F_{d,f}/F_{du,f} < 2.9$, depending on the pile length-to-diameter ratio L/d (Fig. 3), which differs significantly from the regulatory value $F_{d,f}/F_{du,f}$= 1.25.

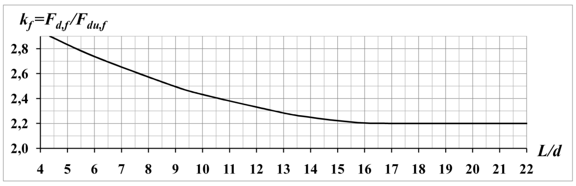
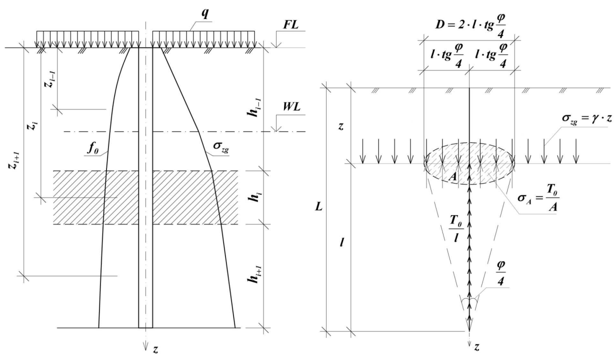


Figure 3. Dependence of k_f on L/d in response to downward loading.

Experiment results show that the direction of vertical loading is one of the principal factors impacting the stressed state of the soil near a pile, and is the fundamental significance when determining pile skin friction capacity.

3 EXPLANATION OF NEW METHOD FOR DETERMINING THE LOAD-BEARING CAPACITY OF BORED PILES IN WATER-SATURATED SOIL

The proposed method, which is based on a differentiated approach to determining pile skin friction capacity, permits the examination of shear along the pile shaft using a "ground to ground" scheme (bored, driven, etc.) and to determine: the overall friction forces along the pile shaft at rest T_0, depending on the stressed state of the soil near a pile and the physical-mechanical properties (γ, ν, φ и c) of soil layers; additional compression force T_{du} in response to vertical loading; the pile skin friction capacity in response to upward $F_{du,f}$ and downward $F_{d,f}$ loads.



a) b)

Figure 4. a) Analytical model for determining overall friction force T_0. b) Analytical model for determining additional compression force T_{du} due to uniformly distributed upward load T_0/l.

The overall friction force T_0 is determined in accordance with proposed analytical model (Fig. 4, a):

$$T_0 = u \sum f_{0,i} h_i, \tag{2}$$

where $f_{0,i}$ is the design pile skin friction of the i-th soil layer at rest, kN/m^2; u and h_i are the pile shaft cross-section perimeter and thickness of the i-th soil layer that interacts with the pile skin, respectively, m. ($h_i \leq 2.0$ m);
$f_{0,i} = (\sigma_{zg,i} + q) \cdot k_{zg,i} \cdot \lambda_{0,i} \cdot \mathrm{tg}\varphi_i + k_c \cdot c_i$, where $k_{zg,i}$ is the stress attenuation coefficient due to the dead weight of the soil ($\sigma_{zg,i}=\gamma_i z_i$) near the piles at rest ($\sigma_{zg,i}$ is determined with due regard for the weighting force of water when there is an underground water layer WL), units (Fig. 2, b); q is the continuous, uniformly distributed load at the pile crown level, considering attenuation, kN/m^2; $\lambda_{0,i} = \nu_i/(1-\nu_i)$, units; ν_i is the Poisson ratio, units; c_i is soil adhesion in the i-th layer, kN/m^2; k_c is a component that takes account of reduced adhesion to soil resulting from shear and set depending on soil consistency, units (Consistency of soil: hard – 0.22; semi-hard – 0.25; stiff-plastic – 0.29; soft-plastic – 0.65) (Gorbunov-Posadov 1985).

An analytical model (Fig. 4, b) is proposed for determining additional soil compression force T_{du} in response to upward loading, in which the distribution of vertical stress resulting from shear forces along the pile shaft while forming the reference foundation base is taken in accordance with DBN V.2.1-10-2009, Rev. 1,

$$T_{du} = \sigma_A l u \lambda_{0,avg}\, \mathrm{tg}\varphi , \tag{3}$$

where l is the design pile length; φ is the mean value of the soil internal friction angle within design pile length l;
$\sigma_A = T_0/\pi l^2 \tan^2(\varphi/4)$ is the stress due to a uniformly distributed upward load T_0/l at depth z, equal in absolute value and opposite to the direction of pressure due from the soil dead weight σ_{zg}, i.e $\sigma_A = \sigma_{zg}$ .This equation we express as:

$$l^3 - Ll^2 + C = 0, \tag{4}$$

where $C=T_0/\pi\gamma \tan^2(\varphi/4)$, m^3; γ is the mean specific gravity of the soil located above the bottom end of the pile (in water-saturated soil, with due regard for the weighting force of water), kN/m^3. It should be noted that the optimal ratio of $l/L \approx 2/3$.

As a result, the pile skin friction capacity is:

$$F_{d,f}(F_{du,f}) = \frac{F_{d,f}}{F_{du,f}}(T_0 + T_{du}) = k_f(T_0 + T_{du}), \tag{5}$$

where k_f is a factor that considers the direction of vertical load, taken equal to 1 for upward loads, and 2.2 for downward loads.

The pile capacity is written in the form:

$$\left.\begin{array}{ll} F_{du} = F_{du,f} + G & \text{for upward loading} \\ F_d = \gamma_c\left(\gamma_{cR} RA + F_{d,f}\right) & \text{for downward loading} \end{array}\right\}, \tag{6}$$

where γ_c, γ_{cR}, R, and A are taken in accordance with mentioned DBN and SP; G is the pile dead weight, kN.

3 CONCLUSION

A procedure was proposed for determining pile skin friction forces that consider the direction of vertical load, enabling a significant improvement in calculation accuracy in comparison to the procedure of (DBN V.2.1-10-2009, Rev. 1. and SP 50-102-2003); that said, the mismatch with the results of in situ pile tests for bored piles L=8-20 m in length occurring under complex geological engineering conditions is within 10%

4 REFERENCES

DBN V.2.1-10-2009, Rev. 1, Structure Basess and Foundations. Basic provisions for design [in Ukrainian], Minregionbud Ukraini, Kyiv (2011).

Gorbunov-Posadov M.I., Il'ichev V.A., Krutov V.I. and et al. 1985. *Bases, Foundations, and Underground Structures [in Russian]*. Stroiizdat, Moscow.

Patent No. 96859. *Method of determining bulk material normal pressure on barrier design*. [in Ukrainian] (O.V. Samorodov, I.Ya. Luchkovs'kii, A.V. Ubiivovk, and S.V. Tabachnikov), Byul. izobr., Ukraine, No. 23 (2011).

Tabachnikov S.V. 2015. Experimental study of resistant forces along the skin surface of a model pile. [in Russian]. *Zbirnik naukovikh prats' (galuzeve mashinobuduvaniya, budivnitstvo)*, Poltava. 1(43), 222-230.

Tabachnikov S.V. 2015. *Load-bearing capability of CFA pile anchors in dispersed soil.* Dissertation for Cand. Eng. Sci., Kharkiv.