https://doi.org/10.26906/znp.2018.50.1073

UDC 624.154

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LABORATORY EXPERIMENTAL RESEARCH OF LOADING FORCES DEVELOPMENT ACTING ON THE SIDE SURFACE OF THE PILES

The forces of negative friction or loading forces of friction on the piles develop due to additional deformations of near pile array and they cannot be more force of resistance on the side of pile in rest, that is formed due to own weight of the ground founding. The paper presents the results of laboratory experimental research of loading forces of friction acting on the lateral surface of the piles without taking into account the vertical load (being relatively at rest) and provided an analysis of methods for detection of negative friction forces (loading forces) acting on the lateral surface of the pile, with the appointment of their load-bearing capacity. The researches have confirmed the theoretical statement about the equality of the loading forces of friction to ground resistance forces under the action of the torque load but not the pulling load, as it is suggested in the modern standards.

***Keywords:** experiment, pile, rest, soil subsidence, side surface, loading friction force.*

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ЛАБОРАТОРНІ ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ РОЗВИТКУ ДОВАНТАЖУВАЛЬНИХ СИЛ, ЩО ДІЮТЬ ПО БІЧНІЙ ПОВЕРХНІ ПАЛЬ

Установлено, що сила негативного тертя, або довантажувальна сила на палю, розвивається за рахунок додаткових деформацій навколо пальового масиву і не може бути більшою від сили опору по бічній поверхні палі в стані спокою, що формується за рахунок власної ваги ґрунтової основи. Наведено результати лабораторних експериментальних досліджень довантажувальних сил тертя, що діють по бічній поверхні модельної палі без урахування вертикального навантаження (умовно у стані спокою), та аналіз методик визначення сил негативного (довантажувального) тертя, що діють по бічній поверхні паль, при призначенні їх несучої здатності. Виконаними дослідженнями підтверджено теоретичне положення щодо рівності довантажувальних сил тертя і сил опору ґрунту під час дії крутильного моментного навантаження, а не висмикувального навантаження, як запропоновано у сучасних нормах.

***Ключові слова:** експеримент, паля, стан спокою, просідання ґрунту, бічна поверхня, довантажувальні сили тертя.*

Introduction. Designing buildings and structures on pile foundations, the force of loading friction should be considered in cases where the conditional rate of soil deformation of the mass around the pile can exceed the rate of the pile foundation sediments which, as a rule, is in the base of structurally unstable soil as well as in other cases of the same ground layer deformations.

The issues of the loading forces of friction development in the pile foundation are discussed in work of researchers from our country and foreign countries: Brom Beng B., Felenius N., Krafford K., Endo M., Berrum L., Johansen I., Karisel J., Dalmatov B.I., Lapshin F.K., Rossikhin Yu.V., Grigoryan A.A., Zaretsky Yu.K., Morozov V.N. and others.

Except theoretical researches, there are practical ones investigating the forces of negative friction by means of the field methods, that are most reliable. It is possible to mark the use of tenzopile, and also normative and patented methods and methods of friction acting forces determination on the lateral surface of foundations and piles. However, offered field tests with the use of the considered methods or are labour intensive at application of tenzopile or the forces of negative friction determined on the basis of pile tests on the action of the pressing and pulling out loads, and the equality of the soil resistance forces along the lateral surface of the pile is assumed.

Analysis of recent sources of research and publications. The analysis of recent publications [1, 2] shows the great interest of researchers in the development of negative forces which are determined as loading forces of friction in the latter norms [3]. Existing norms [3 – 4] and «Guide» [5] regulate the detection and calculation of negative friction forces in determining the load bearing capacity of piles when they are tested with compressive and pulling out loads. This position is incorrect because the development of the loading forces of friction on the lateral surface of the piles is due to deformations s_{sl} of the soil mass where the change in the stress state of the base can be neglected [6], and in the case of application to the pile the experimental vertical load, the intense state of the soil base around the pile changes significantly. It points out to the fact that the normative method [3] of setting the calculated load on a pile in the collapsible soils does not consider the peculiarities of the friction loading forces formation in the soil and as a result it is incorrect.

Identification of general problem parts unsolved before. In the paper [6 – 8] Samorodov A.V. proposes the theoretical idea about the equality of the loading force of friction P_n and the strength of the resistance at rest T_0 on the lateral surface of the piles (Fig. 1) revealed previously [7 – 9]. T_0 is the resistance force acting on the pile of the torque load M formed depending on the stress state of the soil mass around the pile due to its own weight when there is not the vertical load on the pile which is conditionally at rest, kN.

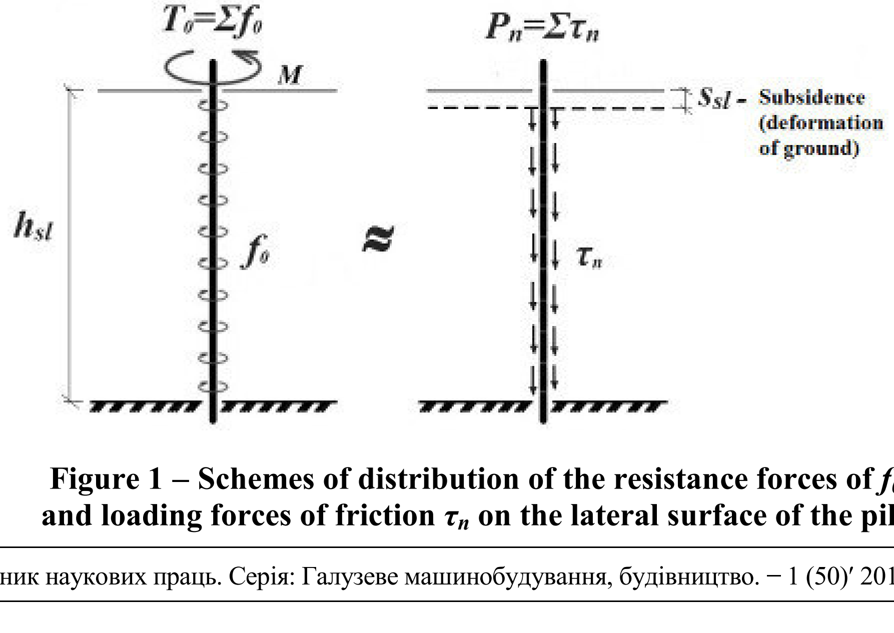

Figure 1 – Schemes of distribution of the resistance forces of f_0 and loading forces of friction τ_n on the lateral surface of the pile

To confirm the theoretical position: $P_n \approx T_0$ (Fig. 1), laboratory experimental researches with similar parameters of the previously investigated system for the determination of T_0 by means of reeling torque load M [9] were performed.

The purpose of this work is to do laboratory experimental research to confirm the theoretical position: $P_n \approx T_0$ (Fig. 1).

Basic material and results. As an experimental installations (Fig. 2) it is used a specially equipped tray in the form of a metal barrel of height H = 900mm, Ø 560mm and thickness of 10 mm, in the lower part of which was a «double» bottom with a gap (h = 100 mm), which was filled with a rubber air «pillow».

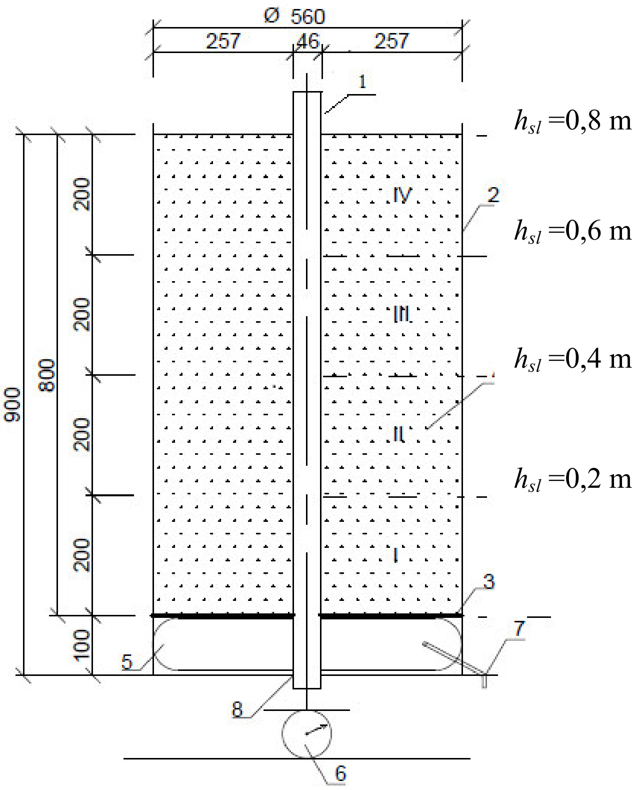

Figure 2 – Plan of installation during the experiment to determine the loading forces of soil friction P_n on the lateral surface of the model pile at different height of filling h_{sl}:
1 – model fluoroplastic pile Ø46 mm; 2 – tray; 3 – partition wall (flake board); 4 – sand (fine, dry, homogeneous sand: $\gamma \approx$ 15 kN/m^3, $\varphi \approx$ 30°); 5 – rubber air «pillow»; 6 – measuring instrument (electronic scales, model: AXIS A20); 7 – hole for hose used for inflating-blowing out «pillow»; 8 – throughput system (rubber pressure seal)

A model of fluoroplastic pile with similar parameters of the previously investigated system was used to determinate T_0 by means of the torque load M [9]: Ø 46 mm and a height of 1000 mm, which has been made basing on the theory of similarity [10] on a scale of M ≈ 1:10, that is the relator of two numerical values of the model pile, such as the length of the pile L and its diameter D, was similar to the ralator of the same numerical values for a real pile (Fig. 3, *a*). Fine, dry, homogeneous sand was used as filling (γ = 15 kN/m^3, φ = 30°). The average grain of sand size is from 0,20 to 0,25 mm. The tray has been filled with the sand evenly, not in large portions, like rain to the required filling height h_{sl} = 0,2; 0,4; 0,6 and 0,8 m. After complete filling before the beginning of the first series of experiments, the installation was kept in the design position for a minimum of 30 minutes.

The distance between the pile and the walls of the tray is approximately 257 mm.

Preparation for the experiment and its implementation included several stages (Fig. 3):

– the modeling pile was installed in the design vertical position by means of free hanging, where the lower end of the pile was passed through the entire buffer on the weights (Fig. 3, *b*) through the special hole in the bottoms where the pile leans on the scales surface (Fig. 3, *c*);

– the sandy ground was filled to the height of h_{sl};

– simulation of the touching down process of the entire thickness h_{sl} by a value s_{sl} = 100 mm was blowing out air from the «pillow». The beginning of the soil mass movement at each loading stage was fixed visually;

– additional weight of the P_n pile was recorded due to loading forces of the soil τ_n on the lateral surface of the pile. Electronic transmission scales (*AXIS A20* model) were used to transfer the force (Fig. 3, *c*).

Thus, a series of experiments were made to determine the loading forces of the soil friction on the lateral surface of the model pile at the height of the fillings: h_{sl} = 0,8 m (h_{sl}/D =17,39); h_{sl} = 0,6 m (h_{sl}/D =13,04); h_{sl} = 0,4 m (h_{sl}/D = 8,70); h_{sl} = 0,2 m (h_{sl}/D = 4,35). For each height of the filling h_{sl}, seven experiments were made, they allowed to do qualitatively statistical processing of the private values of the experimental data according to [11]. The results of the experiments are summarized in Table 1, which also gives comparison of the results of determining the resistance forces at the pile side surface at the rest T_0 obtained earlier by PhD Tabachnikov S.V. [9].

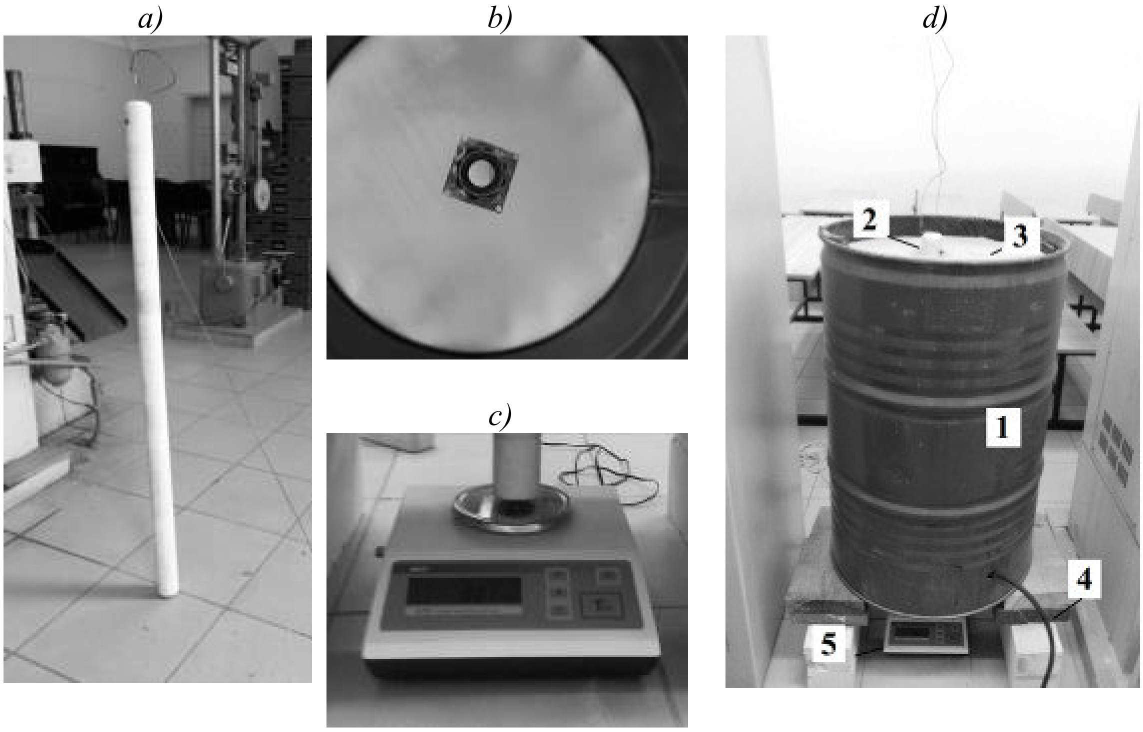

Figure 3 – Photo during the experiment:
a – model pile; *b* – a through hole at the bottom of the installation with a rubber gland seal;
c – electronic scales (model *AXIS A20*); *d* – general view of installation:
1 – tray; 2 – model pile; 3 – sand;
4 – hose, used for in flatting-blowing out «pillow»; 5 – electronic scales

Table 1 – Comparison of the friction P_n loading forces values and the resistance forces at the side surface at the rest T_0

Height of filling h_{sl} *(z)* (m)	Correlation h_{sl}/D *(z/D)*	P_n (kgf)	T_0 (kgf)	Discrepancy, %
0,2	4,35	0,648	0,466	28
0,4	8,70	1,828	1,819	0,49
0,6	13,04	4,229	4,100	3,1
0,8	17,39	7,501	7,085	5,55

For this experiment, the friction P_n loading force dependence of loose ground (sand) on the relative value of h_{sl}/D is given in the form

$$P_n = 0{,}0245 \cdot (z/D)^2 + 0{,}002 \cdot (z/D) + 0{,}0486 \quad (1)$$

and is shown graphically in Figure 4, where the plot of the dependence on the ground resistance force at rest T_0 is also shown [9].

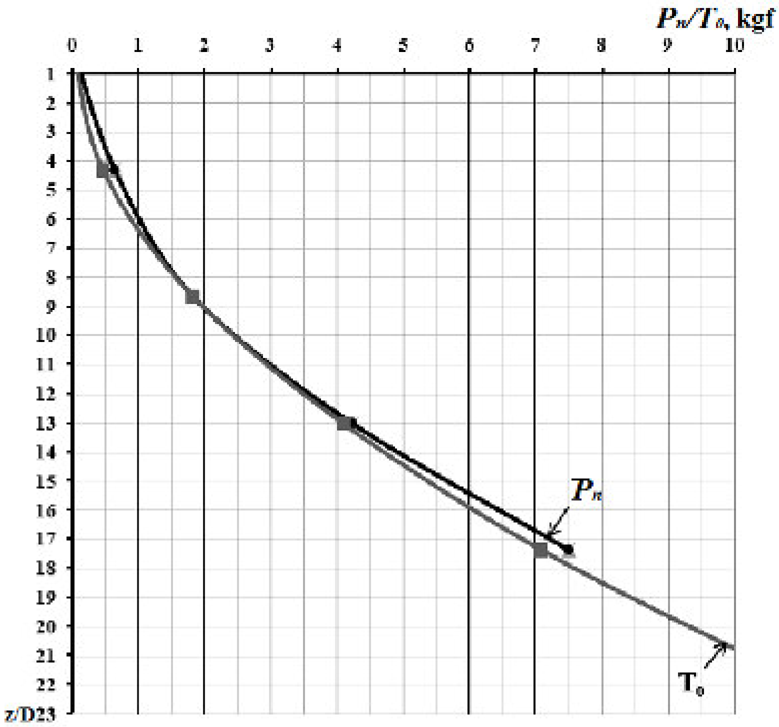

Figure 4 – Graphs of dependencies of loading forces of friction P_n and ground resistance forces at rest T_0 from h_{sl}/D (z/D)

The results of the experiment confirm the theoretical statement about the equality of forces: $P_n \approx T_0$ (Fig. 1), that is the loading forces of friction P_n must be determined with the torque load M but not the pulling load F_{du}, as has been proposed in modern standards [3]. During the additional real experiments it allows to reduce the effect of the potential loading forces of friction P_n on the lateral surface of the piles in structurally unstable soils, and, as a consequence, to increase the bearing capacity of the piles F_d under difficult conditions.

At Figure 5 the results of calculation are evidently presented: the forces of negative friction P_n [12] using different to methodologies [3 – 5], other things being equal, where higher adopted – «methodology KNUCEA» approach is offered .

According fig. 5 application of different methodologies gives considerable distinction in the values of the loading (negative) forces: the value of P_n obtained by the proposed methods of «KNUCEA» is in 2 times less than in the methods of the «Guide to the Design of Pile Foundations» [5] and «Ukrainian SBN» [3] and in 1,5 times less than the «Russian methods of SP» [4].

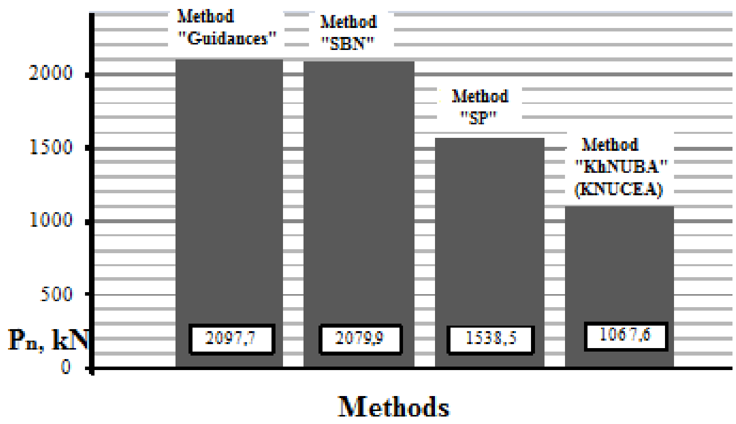

Figure 5 – The values of loading forces of friction P_n

Conclusion. On the basis of experiments and the obtained results the following conclusion can be done:

1. The conducted laboratory investigations confirmed the theoretical statement about the equality of the loading forces of friction on the lateral surface of the piles P_n and the resistance of the soil T_0 under the torque load: $P_n \approx T_0$, that is the loading forces of friction P_n must be determined by the torque load M but not the pulling load F_{du}, as it is proposed in the modern standards [3].

2. The developed methodology (method «KNUCEA») for determinations of resistance forces on the lateral surface of the piles in a state of rest T_0 [8] allows to adapt it for determination P_n, as concrete example [5] shows considerable distinction in the values of loading forces of friction P_n at application of different methodologies: the value of P_n, obtained by the method of «KNUCEA», is in 2 times less than in accordance with the methodology of the «Guidances» [5] and in 1,5 times less than the «Russian methods of SP» [4].

3. Preliminary results of the research indicate the possibility of influence reasonable reduction of the potential loading forces of friction P_n on the lateral surface of the piles in structurally unstable soils which during the additional real experimental substantiation will allow to increase the bearing capacity of the piles F_d on the compressive loads and as a consequence provide certain economic effect.

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