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New design of a tapered bored pile For installation in structurally unstable soils

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New designs of bored piles with a tapered shaft shape are proposed. To confirm reduction or absence of the potential impact of additional load (negative) friction forces effectiveness on piles lateral surfaces in structurally unstable soils (fill-up grounds etc.) due to a change in the edge slope angle, laboratory experimental research on models of tapered piles have been conducted; the confirming results have been provided and described in detail in the laboratory experimental research. The impact of the changed slope angle of the edge on the effect of additional load friction forces on the lateral surfaces of experimental piles was demonstrated; the correlation between the change in taper of piles and the decrease in their surface area has been proven.

Keywords: tapered pile, soil subsidence, lateral surface, additional load friction forces

Нова конструкція бурової конусоподібної палі для влаштування в структурно-нестійких ґрунтах

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Будівництво в структурно-нестійких (насипних і т.п.) ґрунтах з потужною просідаючою товщею в умовах сучасного світу стає дедалі актуальним, тому в більшості випадків найбільш економічно ефективним та проектно обґрунтованим рішенням є будівництво на пальових фундаментах. Сучасне будівництво з деяких часів усе частіше при виробництві пальових робіт звертає свою увагу на безударні технології їх виконання. Це підвищує популярність бурових паль. Як відомо, при визначенні несучої здатності бурових паль у структурно-нестійких (насипних і т.п.) ґрунтах у випадках, коли умовна деформація ґрунту навколопального масиву може перевищувати швидкість осідання пальового фундаменту, слід враховувати довантажувальні (негативні) сили тертя. Установлено, що зміна кута нахилу грані стовбура палі (конусоподібна форма стовбура) дозволяє забезпечити зниження або відсутність можливого впливу довантажувальних (негативних) сил тертя по бічній поверхні палі у структурно-нестійких (насипних і т.п.) ґрунтах, що, як наслідок, підвищує несучу здатність палі на вдавлюючі навантаження. Запропоновано нові варіанти конструкцій бурових паль з конусоподібною формою стовбура. Для підтвердження ефективності зниження або відсутності можливого впливу довантажувальних (негативних) сил тертя по бічній поверхні палі в структурно-нестійких (насипних і т.п.) ґрунтах за рахунок зміни кута нахилу грані було проведено лабораторні експериментальні дослідження на моделях конусоподібних паль, наведено підтвердуючі результати та детальний опис лабораторних експериментальних досліджень. З'ясовано залежність зміни конусоподібності палі і зменшення площі їх поверхонь, показано вплив зміни кута нахилу грані на дію довантажувальних сил тертя по бічній поверхні експериментальних паль.

Ключові слова: конусоподібна палля, просідання ґрунту, бічна поверхня, довантажувальні сили тертя



Introduction. Collapsible soils cover more than 35% of the territory of Ukraine. By little humidity, collapsible loess soils in their natural state have rather good physical and mechanical properties for construction, but in the presence of moisture, their structural stability decreases, and vertical deformations may occur. Uneven deformation is especially dangerous as it can result in partial or full loss of stability and operational capacity of buildings. It should also be noted that, in the early study phases, only loess soils were deemed collapsible, but the construction practice of recent decades has shown that many non-loess loam soils, fill-up grounds, and loose dusty sands appear to be collapsible soils when in contact with moisture.

Construction in the conditions of structurally unstable soils with thick subsiding mass has become possible primarily due to properly designed foundations, most of which are pile foundations.

When designing buildings and structures on pile foundations in the conditions of structurally unstable soils, additional load (negative) friction forces should be taken into consideration. These emerge if the nominal rate of soil deformation in the near-pile mass exceeds the settlement rate of the pile foundation, which can also occur:

- in the presence of structurally unstable soils in the foundation;
- when constructing pile foundations on very thick mounds by natural consolidation of the soil mass;
- when using pile and raft foundations or applying significant loads to the surface near a pile foundation, which occur due to buildings being constructed nearby on shallow foundations, by land planning when placing fills, when storing materials, installing equipment etc.;
- by soil compaction due to dynamic impacts and increased effective stress by lowering of groundwater level;
- by thawing of frozen soils.

Additional load (negative) friction forces of the soil caused primarily either by additional loading of the surface or due to the presence of soils with specific properties in the foundation have a significant impact on design solutions with regard to pile foundations.

Therefore, it is necessary to conduct complex experimental and theoretical research aimed at determining methods of reduction of additional load friction forces acting on the lateral surfaces of piles in structurally unstable soils, thus facilitating an increase in the bearing capacity of bored piles.

The issues of the development of negative friction forces in pile foundations have been addressed in works of national and foreign researchers: Dalmatov B.I., Lapshin F.K., Rossikhin Yu.V., Grigorian A.A., Zaretskii Yu.K., Morozov V.N., Broma Beng B., Fellenius B.H., Crawford C.B., Endo M., Bjerrum L., Johannessen I.J., Kerisel J., Lee C.J., Bolton M.D. [14, 15] et al.

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.

Review of the latest research sources and publications. In rough engineering and geological conditions, especially in case of multi-storey and high-rise structures, reinforced concrete auger cast or injection piles (bored piles) [1] are used, including pedestal ones. These piles are installed directly into the soil, which envisages forming a pile shaft by drilling a hole with the target depth using an auger with the required diameter and applying the rotary drilling principle depending on used equipment [2].

There are well-known methods for installing auger cast piles in structurally unstable soils using steel, polyethylene, and other casings, which ensure reduction of additional load friction forces due to lower values of friction against soil in case of the casing material compared to those of a concrete pile surface [2], but such methods are characterized by higher costs and lower antifriction properties [3]. Other known methods applying a so-called «antifriction jacket» [4] make the process of installing bored piles very complicated.

It is known that reinforced concrete driven piles are used that possess a pyramid, trapezoidal, or tapered shaft shape [1, 2, 5], which is also used as a mold for special rammers when installing concrete or reinforced concrete cast-in-place piles (foundations) in a stamped out bed (pit) [1, 4, 6, 7]. Also, for driven piles with constant cross-section, antifriction coating is used along the length of the lateral surface [1]. However, such driven and cast-in-place piles have a limited length (up to ≈ 10 m) and application field, and the effect of reduction of additional load forces along the lateral surface of these piles due to additional squeezing of the soil mass around the piles during their installation is doubtful.

In his thesis [8], Vertynskii O.S. has proposed a design solution of a tapered cast-in-place pile for structurally unstable soils. This pile represents a structure consisting of a metal pipe and outer tapered casing. The structure is intended to be submerged into a hole until the final position is achieved, then concrete is pumped under pressure into the space between the metal pipe and the casing. During this procedure, the casing thrust occurs, and a tapered pile emerges. A drawback of this method is high labor intensity of works aimed at achieving the desired effect.

The research conducted by scientists O. Yeshchenko and D. Cherniavskiy [9, 10] should be mentioned who address issues of the bearing capacity of tapered injection piles in various types of soils; however, the au-

thors do not consider the impact of additional load friction forces on the lateral surface of piles.

Definition of unsolved aspects of the problem.

At present, no rational and reliable method for installing tapered bored piles in structurally unstable soils has been proposed, which would reduce the impact of additional load friction forces of soil on their lateral surfaces; research in this direction doesn't exist either.

Research objective. This article offers designs of bored piles created using the patented method [13] in order to ensure reduction or absence of the impact of additional load friction forces of soil on the lateral surface of bored piles in structurally unstable soils (fill-up grounds etc.).

Main material and results. Fig. 1 shows fundamental designs of bored piles installed using the proposed method; the tapered shape of the shaft of the pile 1 is shown, which is created by drilling out a hole using a tapered auger with required geometric parameters (d_e and d_n) and depth H and broadening 2 at the end of the pile shaft 1.

The laboratory experiments were based on the method for determining specifically maximum additional load friction forces of soil on models of piles, which was proposed and implemented by Prof. Samorodov O.V. and Naydenova V.E. and published in works [11, 12], (Fig. 3).

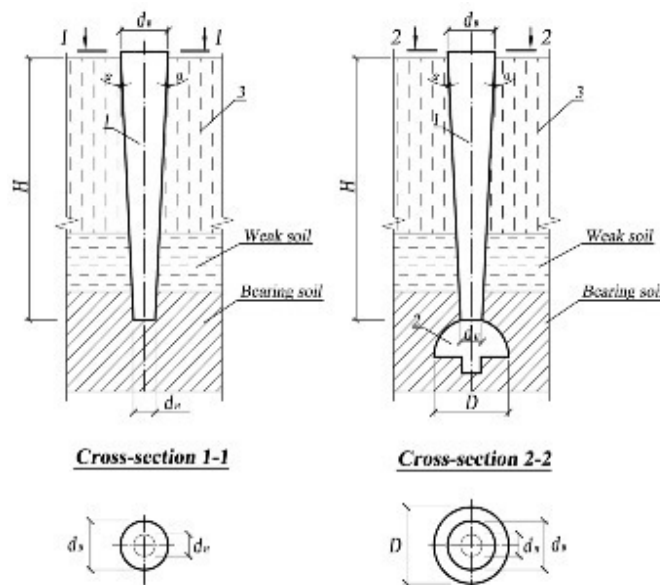


Figure 1 – Fundamental designs of bored piles installed using the proposed method

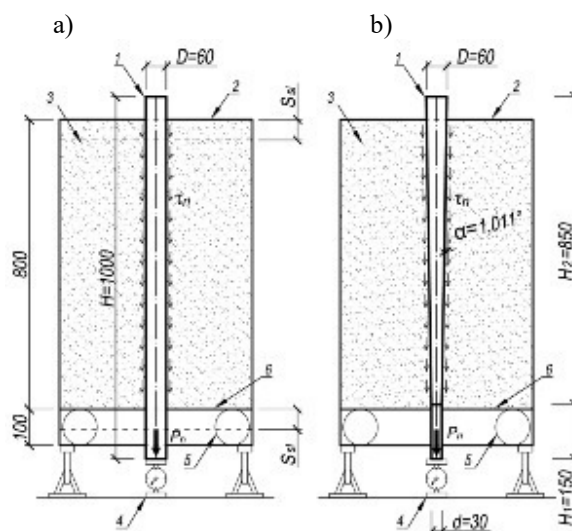


Figure 2 – Installation diagram during the experiment to determine additional load friction forces of soil P_n on the lateral surface of the pile by different angles of slope of the shaft surfaces α :

- a) standard cylindrical pile; b) proposed tapered pile;
- 1 – wooden pile model; 2 – tray; 3 – sand (fine, dry, homogenous $\gamma \approx 15 \text{ kN/m}^3$, $\varphi = 30^\circ$);
- 4 – dynamometer; 5 – rubber air «cushion»; 6 – partition (particle board)

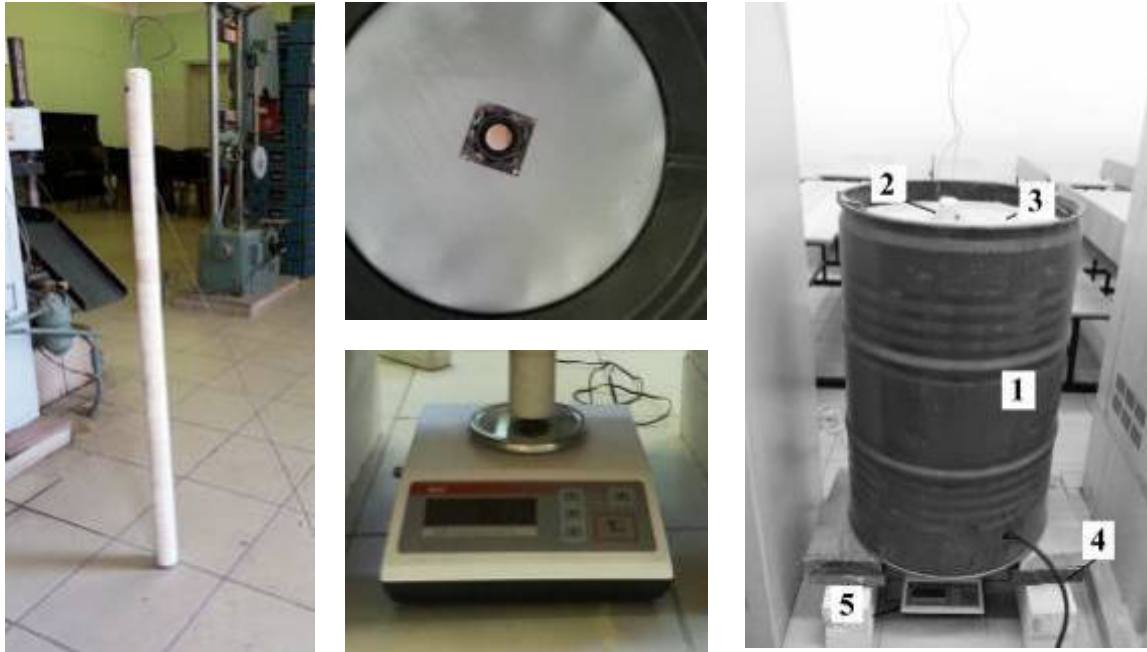


Figure 3 – Laboratory equipment

A specially equipped tray in the form of a metal barrel was used in the capacity of experimental unit (Fig. 3). Its dimensions were as follows: $H = 900$ mm, $\varnothing = 560$ mm. In the lower part of the tray, a double bottom was made with a space between ($H_1 = 100$ mm), which was filled with a rubber air «cushion».

The laboratory experiment for testing the new pile designs was conducted in a similar manner.

Two models of wooden piles were used, which were wrapped up in sandpaper for better adhesion with sand. One pile had a cylindrical shape, was 1,000 mm in length and 60 mm in diameter; the other had a tapered shape, was 1,000 mm in length and 60 to 30 mm in diameter. The correlation between the numeric values of model piles, such as their length and diameter, was similar to the correlation for actual piles.

Fine, dry, homogenous sand was used as a fill ($\gamma = 15$ kN/m³, $\varphi = 30^\circ$). An average dimension of a sand grain was 0.20 mm to 0.25 mm. After the filling up was completed, prior to the start of the first series of experiments, the unit was maintained in the design position for at least 30 minutes. The distance between the pile and the tray walls equaled approximately 250 mm.

Preparation and implementation of the experiment included several stages (see Fig. 2):

- the model pile was installed in the final vertical position by free suspension whereby the lower end of the pile was passed through the entire tray construction through special holes in bottoms, with the pile resting on a dynamometer;
- the tray was filled to the entire height with sandy soil in a «raining» manner;
- settlement of the entire soil mass by the value of $s_{sl}=100$ mm was imitated by letting the air out of the rubber chamber («cushion»);
- additional weight of the pile due to additional load friction forces of soil P_n on the lateral surface of the pile was registered using a dynamometer.

Table 1 shows the results of laboratory experimental research aimed at determining the maximum additional load friction force of loose soil P_n on the lateral surface of the pile due to a slope of the shaft surfaces.

Table 1 – Results of laboratory research

No.	H, m	H ₁ , m	H ₂ , m	D, m	d, m	α , degrees	S (h=0.85 m), m ²	P _n , (10 ⁻² kN)
a)	1.0	-	-	0.06	0.06	0	0.16	18.3
b)	1.0	0.85	0.15	0.06	0.03	1.011	0.12	7.5

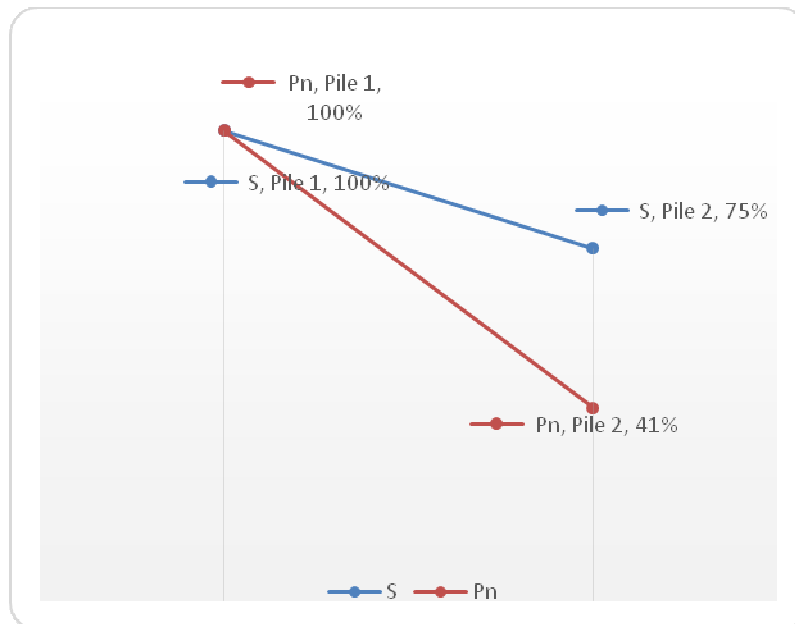


Figure 4 – Comparison of the decrease in values of the surface area of piles (S) and the maximum loading force (Pn) in percentage terms (pile No. 1 – cylindrical, pile No. 2 – tapered)

Conclusions:

The rational and reliable method for installing tapered bored piles in structurally unstable soils has been proposed.

The results of intermediate laboratory research indicate significant reduction of additional load friction forces of soil on tapered piles compared to the cylindrical shape of their lateral surface, which allows increasing the bearing capacity of piles by pressing loads when designing pile foundations in order to ensure a certain economic effect.

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