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WORK OF PILE FOUNDATIONS IN SWELLING-SHRINKING AND SUBSIDENCE SOILS

Structurally unstable soils are widespread. A characteristic feature of swelling soils during soaking is a sharp increase in their volume and decrease in their bearing capacity, which leads to significant deformations of the structure. Loess subsidence soils in the natural state at low humidity have high enough physical and mechanical properties for construction, but during their wetting the structural strength decreases, which is accompanied by vertical deformations. Uneven deformations that lead to partial or complete loss of stability and serviceability of structures are especially dangerous. It should also be noted that in the early stages of the study it was accepted to include only loess soils, but as the practice of construction of recent decades shows, many clay soils of non-loess origin, loose, as well as dusty and loose sands, being soaked soils with subsidence properties. Today, various software packages (Plaxis, SCAD, ANSYS, etc.) are widely used to solve construction problems in complex geotechnical conditions. The reason for choosing these software packages is the presence of complex soil models in which the behavior of the soil mass can be modeled with varying degrees of accuracy.

The existing methods of accounting for the swelling and subsidence properties of clay soils are analyzed; modeling of the operation of the system "base − pile foundation − structure" with a base, folded with swelling soils using a software package based on finite element method has been performed; Article dedicated to the analysis of factors affecting system "base – pile foundation – structure" with a base, folded with swelling soils; analysis of the interaction of piles with subsidence soils, taking into account the additional loading forces of soil friction on the piles, caused mainly by additional loading of the surface, or the presence at the base of soils with specific properties that significantly affect the adoption of constructive solutions for pile foundations. Tests of full-scale bored piles for the action of pulling and pressing loads in difficult soil conditions to determine the potential loading forces of friction on their side surface.

Key words: *swelling soils, subsidence soils, load, finite element method, system "base – pile foundation – construction", additional loading friction forces.*

Formulation of the problem. A characteristic feature of swelling soils when soaked is a sharp increase in their volume and a decrease in their bearing capacity, which leads to significant structural deformations. Therefore, during the designing, it is necessary to take into account the effect of swelling on the entire system "base – foundation – structure" for more reliable operation of the structure.

Unfortunately, existing standards do not allow creating a model like this and are advised to calculate deformations from external loads and soil swelling deformations separately [1].

A review of the latest sources of research and publications. Today, there are many methods for calculating the bearing capacity of foundations [1], while in the regulatory documents [2] it is proposed to calculate the pile based on the bearing capacity of foundation soils in subsidence soils, and the recommendations also consider the possibility of determining and taking into account additional loading (negative) friction forces [3], however, as our investigations shows, the proposed regulatory engineering techniques and field methods have a number of assumptions, which is associated with fundamental differences in the interaction of the soil massif with the lateral surface of the piles under the action of static loads [4, p. 170–178].

Main material and results.

1. Modeling the operation of the system "base – pile foundation – structure" with a base composed of swelling soils

To take into account the influence of the swelling-shrinkage properties of soils on the stress deformation condition of the system "base – pile foundation – structure", the base consisting of swelling soils is presented in the form of a linearly deformable environment. In this case, the swelling of the base is taken into account as an additional effect, close in nature to the temperature, and the swelling soil is considered as a material with orthotropic properties.

Using software systems (for example, SCAD), operating on the basis of FEM, the finite element design scheme of the system “base – pile foundation – aboveground part of the structure” in a flat version is modeled and a force calculation is performed for the action of specified loads, including load combinations. In this case, the stress states of the foundation are determined, and nine zones are established, for which the corresponding deformation characteristics are determined and entered into the initial information of the stiffness characteristics of finite elements [5, p. 54–60].

Next, the entire system is calculated for swelling from a change in the specified humidity as a temperature problem for a temperature effect equal to **mΔw**. The resulting stress state of the base is summed up with the stress state from swelling and the position of zones with different levels of $\boldsymbol{\sigma_j}$ is specified in comparison with the swelling pressure – $\mathbf{p_{sw}}$. After that, the deformation characteristics are clarified for the new zones and a new calculation is made. After calculating the new values of the total stresses, the zones are refined, etc. The calculation ends when no change in zones with different $\boldsymbol{\sigma_j}$ occurs.

It is proposed to consider as an example of the calculation of structures on swelling soils of a three-story brick building on a pile foundation in the city of Kupyansk, Kharkiv region. The base is covered with medium swelling clays at a depth of 2.5m, the thickness of the layer is 1.5m. Bored piles 6m long and **Ø**630mm in diameter are adopted. The base, walls and foundation are modeled by rectangular FE, size 0.4×0.4m. The overlap is modeled with bar elements. During operation, the soil may get wet, and as a result, its swelling (Fig. 1). We assume that the soaked soil works as if exposed to temperature: **mΔw** = 0.066, with a swelling coefficient **m**=1.237 [6, p. 255-258].

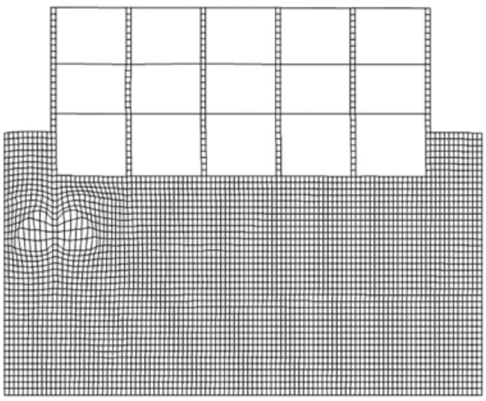
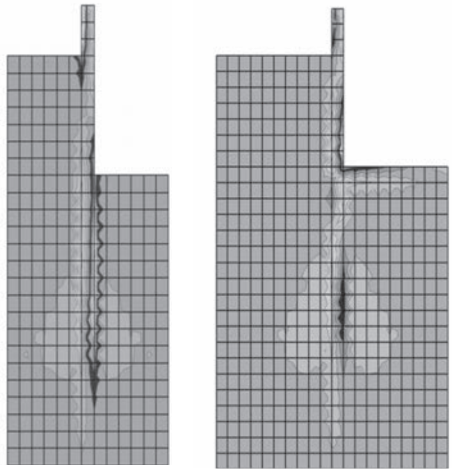


Fig. 1. Deformed scheme

The following results were obtained (Fig. 2):



a b

Fig. 2. Fragments of stress fields NZ: a - without taking into account orthotropic, b - taking into account the orthotropic properties of swelling soils

The difference between the values of the main stresses when calculating with and without taking into account swelling for foundations reaches 30%, for aboveground structures – 7%.

2. Study of the interaction of piles in subsidence soils

Modeling of the interaction of piles in subsidence soils was carried out using the PLAXIS 3D Foundation PC, based on the use of the finite element method (FEM), to simulate soil tests with full-scale experimental piles, including using various models of the soil base and contact conditions “soil base – pile”. Some features are considered when modeling the operation of piles under the action of pulling loads using standard PLAXIS tools and a soil model with Mohr-Coulomb (M-K) strength criteria, which directly affect the calculation results, where it was proposed a technique for solving such problems in modeling. The research objective is modeling and numerical analysis of SDC system “subgrade – pile” and comparison with the results of full-scale soil testing by piles. To obtain the maximum correspondence between the numerical and physical results, as the initial data, the results of soil tests with full-scale bored piles with a diameter of **Ø**600mm and a length of $\boldsymbol{L}$≈10.6m were taken with the action of pulling loads that were carried out in soils of natural moisture during the construction of a residential building in Kharkov.

A feature of soil layer at this construction site is the presence of fill soils in the upper part, which are represented by embankments and loose loams and sandy loams **IGE-1**, which have subsidence properties, the thickness of the layer is up to $\boldsymbol{h_{sl}}$≈10.6m from the projected bottom of the excavation (Fig. 3).

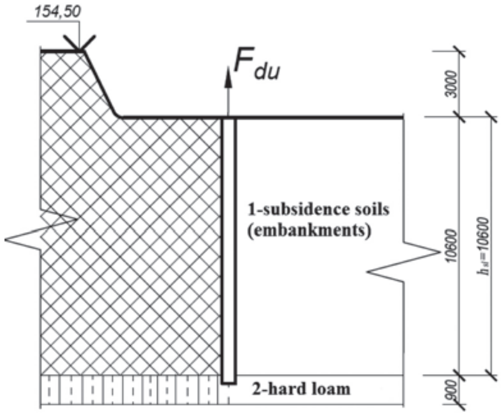


Fig. 3. Layout of an experimental full-scale pile in a soil massif

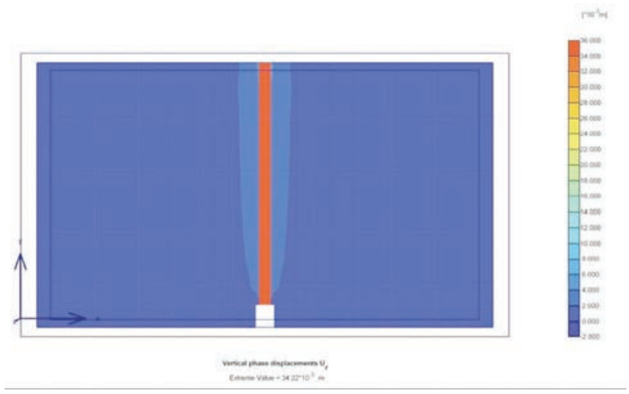


Fig. 4. Movement of piles and soil at R_{inter}=0.7

The water table was modeled below the -0.00 mark of the solid area of the foundation model. Below the subsidence layer, an incompressible layer with a thickness of ≈1.0m was modeled, for further filling the gap between the fifth pile and the soil.

The contact surfaces were modeled by selecting the value of the strength reduction factor R_{inter}=*0.7÷1.0*. This coefficient relates the strength of the shell of the elements on the surface of the "soil base – pile" contact, that is friction on the surface of the pile and adhesion with the strength of the soil – the angle of friction and adhesion. As a reference model, a model with a coefficient R_{inter}=*0.7* was considered, which is consistent with the coefficient of soil working conditions along the lateral surface γ_{cf} of a large-diameter bored pile in the corresponding soils.

The formation of the SDC system of the "soil foundation – pile" system under the action of pulling loads consisted of the following stages (phases): ***1*** – load the calculated area by the own weight of the soil and the formation of the initial SDC soil massif; ***2*** – modeling of piles with a diameter of Ø600mm and a length of ***L***=10.6m; ***3*** – application of a pull-out load equal to F_{du}=400.0kN, which corresponded to the ultimate pull-out load during field tests [7, p. 184-188].

From the picture of the displacements of the calculation model (Fig. 4) it can be seen that the presence of a gap under the heel of the pile makes it possible to prevent the unrealistic inclusion of the soil massif in the work in this zone, preventing the development of displacements of the pile.

Conclusions. Swelling of the base can be considered as additional kinematic effect, close in nature to temperature.

A solution has been obtained for calculating the system "foundation – pile foundation – structure" for a plane problem, taking into account the orthotropic properties of swelling soils, which gives more accurate results.

The dependences of the pile displacement on the pull-out load obtained on the basis of a numerical solution in the Plaxis PC correlate well enough with a similar dependence during field tests of soils by piles, while the error between the values of the limiting resistance is no more than ≈6%.

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Храпатова І.В., Найдьонова В.Є. РОБОТА ПАЛЬОВИХ ФУНДАМЕНТІВ У НАБУХАЮЧО-УСАДОЧНИХ ТА ПРОСІДАЮЧИХ ҐРУНТАХ

Структурно-нестійкі ґрунти мають широке поширення. Характерною особливістю набухаючих ґрунтів при замочуванні є різке збільшення їх обсягу і зниження їх несучої здатності, що призводить до значних деформацій конструкції. Лесові просадочні ґрунти у природньому стані за невеликої вологості мають достатньо високі фізико-механічні властивості для будівництва, але під час їх зволоження знижується структурна міцність, яка супроводжується вертикальними деформаціями. Особливо небезпечні нерівномірні деформації, що призводять до часткової або повної втрати стійкості й експлуатаційної придатності споруд. Також зазначимо, що до просадочних ґрунтів на ранніх етапах вивчення було прийнято відносити тільки лесові ґрунти, але, як показує практика будівництва останніх десятиліть, багато глинистих ґрунтів нелесового походження, насипні, а також пилуваті та пухкі (рихлі) піски, будучи замоченими є ґрунтами з просадочними властивостями. Сьогодні для вирішення проблем будівництва у складних геотехнічних умовах широко застосовують різні програмні комплекси (Plaxis, SCAD, ANSYS та ін.). Причиною вибору цих програмних комплексів є наявність складних моделей ґрунту, в яких поведінка ґрунтового масиву може бути змодельована з різним ступенем точності. У цій роботі виконано аналіз існуючих методик урахування набухаючих і просадочних властивостей глинистих ґрунтів; виконано моделювання роботи системи «основа − пальовий фундамент − споруда» з основою, складеною набухаючими ґрунтами з використанням програмного комплексу, який працює на базі методу скінченних елементів; проведено аналіз факторів, що впливають на систему «основа − пальовий фундамент − споруда» з основою, складеною набухаючими ґрунтами; виконано аналіз взаємодії паль з просадочними ґрунтами, з урахуванням довантажувальних сил тертя ґрунту на палі, викликані або додатковим навантаженням поверхні, або наявністю в основі ґрунтів зі специфічними властивостями, які суттєво впливають на прийняття конструктивних рішень пальових фундаментів. Проведені випробування натурних буронабивних паль на дію висмикуючих та вдавлюючих навантажень в складних ґрунтових умовах для визначення потенційних довантажувальних сил тертя по їх бічній поверхні.

Ключові слова: *набухаючі ґрунти, просідаючі ґрунти, навантаження, метод скінченних елементів, система «основа − пальовий фундамент − споруда», довантажувальні сили тертя.*