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METHOD OF CALCULATING THE FOUNDATIONS IN COMPACTED PIT USING BOUNDARY ELEMENT METHOD

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The main mission of civil engineer is to ensure he reliability of the structure with maximum efficiency of time, materials and energy. In construction, everything must be provided in the design workshop - both strength and economic feasibility. Balancing on the "edge of the abyss" requires a precise mathematical apparatus. The modern mathematical apparatus of soil mechanics is based on the solutions of the theory of elasticity and the theory of limit equilibrium. In this case, the calculation of the bases is carried out from the conditions of purely elastic connection and the ultimate loads are determined without connection with deformations. Most of the elastic-plastic deformation - from the end of the elastic stage to the loss of stability is not covered by the calculation models. At the same time, the reserves of the elastic-plastic zone allow to increase the load on the foundation, provided that the subsidence of the elastic stage does not yet reach the maximum allowable value for this structure. The boundary element method (BEM) allows to solve problems of this kind.

The main disadvantage of foundations on a natural basis is the complexity of its manufacture and high material consumption. These shortcomings can be eliminated by building foundations in cavities of a predetermined shape, which are formed in the soil. These include foundations in compacted ditches, which are arranged in wells with expansion at the bottom. The soil retains its full-fledged composition, so that the work includes a side surface that receives part of the vertical load and provides significant resistance to horizontal forces.

The paper presents a method of integration of a mathematical model of behavior under load of foundations in a compacted pit with a numerical BEM. A theoretical study presents the effect of the addition of sand-gravel mixture on the bottom of the compacted pit on the bearing capacity of pyramidal piles.

Key words: spring-plastic forecast, prejudice and development of runts.

Introduction

Nowadays most of the frame buildings are constructed of a columnar foundation. The pyramidal pile uses a vertical load transmitted to the base to load the soil resistance prism, which is adjacent to the side surface of the pile and thus raises the resistance of the pile. The study was conducted [1] on the experimental site, composed of loamy loams and sands (type I soil conditions for subsidence). The natural state of soils mainly determines their construction properties. Mechanical properties of soils, both deformable and strong, are important for forecasting the behavior of foundations. The subsidence was 7.5 - 10.5 m with physical and mechanical characteristics:

$$\gamma_{ск} = 1.38 - 1.56 t/m^3,\ \ \mathrm{W_T} = 0.18 - 0.25,\quad \upsilon = 0.35,\quad \mathrm{W_L} = 0.06 - 0.17,$$
$$\mathrm{W_P} = 0.14 - 0.17,\quad c = 25kPa,\quad \phi = 23^0,\quad \mathrm{E} = 10\text{-}17\mathrm{MPa}.$$

Pits of 3 m deep under the foundations had dimensions: 850 mm in diameter at the top and 700 mm in diameter at the bottom [1], thus, the pit formed a pyramidal pile.

Two schemes of pyramidal piles, which differ in the nature of concrete laying and preparation of the pit bottom, were analyzed according to BEM. According to the first scheme [1] after additional compaction of the bottom of the pit by dumping the rammer poured concrete was compacted with its deep vibrator (№ 1 in Fig. 1), according to the second scheme after compacting the pit the bottom was filled with three portions of 0.2 sand-gravel mixture in (№ 2 Fig. 1).

The side surface of the prismatic pile does not transmit normal pressures to the ground, but works by friction. Normal pressures are transmitted to the ground by the sole of the pile. The nature of the deformation zone within the compaction zone reflects the nature of the pile. The zone of deformation around the trunk of the prismatic pile is formed as a result of friction during the subsidence of the pile, and under the sole - under the action of normal pressures. In prismatic piles, 18% of the volume of the compaction zone is used, which is formed when the pile is deepened, is used, in pyramidal piles – 30 %. This explains the greater bearing capacity of pyramidal piles compared to prismatic ones at equal volumes.

The method of construction of foundations in compacted ditches on subsidence soils has been widely used in construction practice.

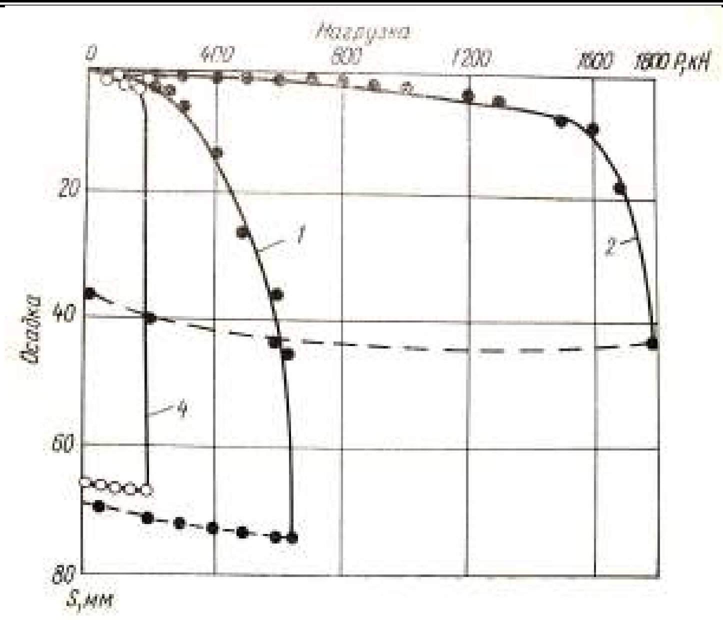

Fig. 1 The graphs of the experimental studies of the state of pyramidal piles [1]

Determining correlations

The combination of the passage of the pit with the compaction of the subsidence soil at its base and concreting of the foundation in the spacing provides an increase in the bearing capacity of the foundation structure, in addition, 1.5-2.5 times reduced cost and complexity compared to driven pile foundations. The expansion at the bottom allows you to double the load-bearing capacity.

The subsidence of the pile foundation depends on the compressibility of the soil, which is located below the level of the ends of the pile. Deformations of the soil depend on its stress state.

Numerical methods of TDS (tensely deformed state) research are now widely used in the field of construction science and beyond. Most engineering problems described by complex differential equations can be solved only by approximate methods. The mathematical model of a technical object at the micro level is a system of differential equations in partial derivatives, the exact solution of which can be obtained only in a few partial cases, so a discrete model is built using Poisson's idea that the behavior of a complex system can be represented by its individual components. In this paper, the integral equation (1) is taken as a mathematical model of the behavior of a pyramidal pile in a rammed pit under load, to which BEM [2] reduces the calculation system from 15 differential equations in partial derivatives:

$$\left.\begin{array}{r} \sigma_{ij,j} + b_j = 0 \\ \varepsilon_{ij} = \frac{1}{2}(u_{i,j} + u_{j,i}) \\ \sigma_{ij} = C_{ijkl}\,\varepsilon_{kl} \end{array}\right\} \Rightarrow C_{ij}(\xi)u_j(\xi) + \int_{\Gamma} p_{ij}^{*}(\xi,x)u_j(x)d\Gamma(x) = \int_{\Gamma} u_{ij}^{*}(\xi,x)p_j(x)d\Gamma(x), \quad (1)$$

where $\sigma_{ij,j} + b_j = 0$ – static equilibrium equations;

$\varepsilon_{ij} = \frac{1}{2}(u_{i,j} + u_{j,i})$ – geometrical equations;

$\sigma_{ij} = C_{ijkl}\varepsilon_{kl}$ – physical environment equations.

As singular solutions, which are denoted by * in equation (1), R. Mindlin's solutions for the half-plane [3] are taken, which correspond to the physical essence of the problem, because the loads, from the ground part of the structure of the foundations are transferred to the ground at certain depth.

The basic principle of BEM - the behavior of a continuous complex environment can be approximated by the total behavior of the constituent elements of this environment (discrete model).

For soils, as for porous compacted media, the effects of dilatancy are inherent. Features of mechanical behavior of such media - hydrostatic pressure affects the shape change, and tangential stresses affect the seal.

The research methodology is based on mathematical modeling [3] using the mechanics of a continuous medium, the unassociated law of plastic flow [4], the dilatational relations of porous media [4,5], the step-iterative process of O.A. Ilyushin [6].

Deformation of dispersed soil media is carried out by the dislocation of solid particles in the pore space, which inevitably leads to a simultaneous change in volume and shape.

In solving the nonlinear problem, the step-by-step method of elastic solutions was used. Ilyushin [6], deformations of the base consisted of elastic and plastic components:

$$\varepsilon = \varepsilon^{e} + \varepsilon^{p}, \qquad \varepsilon^{p} = \varepsilon^{\mathrm{p}}_{шар} + \varepsilon^{\mathrm{p}}_{дев}. \tag{2}$$

To approximate the calculated data with full-scale indicators, the dilatancy theory of the soil environment was used. Nikolaevsky [5], I.P. Boyka [4]:

$$d\varepsilon^{\mathrm{p}}_{ij(шар)} = \Lambda(\chi) \cdot d\gamma^{p} \tag{3}$$

where $d\varepsilon^{\mathrm{p}}_{ij(шар)}$, $d\gamma^{p}$ – scalar equivalents of the increase of inelastic bulk deformations and the increase of shear intensity,

$\Lambda(\chi)$ – the rate of dilatancy (he ratio of the rate of soil compaction to the rate of its deformation

$\Lambda = dV / d\gamma$) – an additional parameter of the unassociated law of plastic flow,

χ – the parameter of strengthening the soil environment, as which the model adopted the soil density.

$\Lambda(\chi) = f(\rho / \rho_{кр})$ – soil density function,

$\rho_{кр}$ – critical soil density.

The results of the research

Applied elastic-plastic problems are essentially nonlinear. Their solution requires the use of sufficiently effective methods of linearization of nonlinear problems and solution of linearized problems.

A special place in the nonlinear mechanics of a rigid deformed body is occupied by the stepwise method of elastic solutions O.A. Ilyushin [6], which was used in solving the nonlinear problem under consideration.

The starting point of the approximate solution of boundary value problems is the discretization of the continuum - the transition from an infinite number of degrees of freedom to the finite.

Force influences when moving the foundation structure in the soil base cause the emergence of the boundary layer (core), which significantly affects the nature of the movement. The calculation scheme of the core core is taken as a system of triangular finite elements (FE). The core is a zone of deformation, within which for some time develops a dynamic process of soil compaction, which reflects the essence of the joint work of the foundation and the foundation before it comes to equilibrium. The sampling of the core is given in Fig.2.

During the development of the algorithm, the maturity maturity of BEM was determined, which characterized the physical and mechanical characteristics of soils at each load step, and as is known, the matrix inverse to the flexibility matrix is a stiffness matrix.

The results of numerical studies on BEM are presented in Fig. 2,3.

As can be seen from Fig.2,3 with a permissible subsidence of 20 mm or a sharp bend in the graphs, the possible loads on the foundations according to schemes 1, 2, respectively, amounted to 480 and 1550 kN. For BEM: respectively: 463 and 1630 kN.

Thus, both experimental studies and numerical studies show that raising the modulus of deformation in the soil base in the concentration of normal stresses by ramming into the bottom of the pit sand-gravel mixture raises the resistance of the foundation by 2.3 times.

Conclusions

1. The proposed dilatancy model makes it possible at the design stage to predict the state of the base in different engineering and geological conditions and allows to raise the quality of the design calculation by adjusting its VAT. The solution of this problem has both scientific and applied significance.

2. The model allows to consider the boundary state of the base for two groups (bearing capacity and deformations) within one calculation model.

3. Ramming into the bottom of the pit sand-gravel mixture raises the possible load on the foundation by 2.3 times.

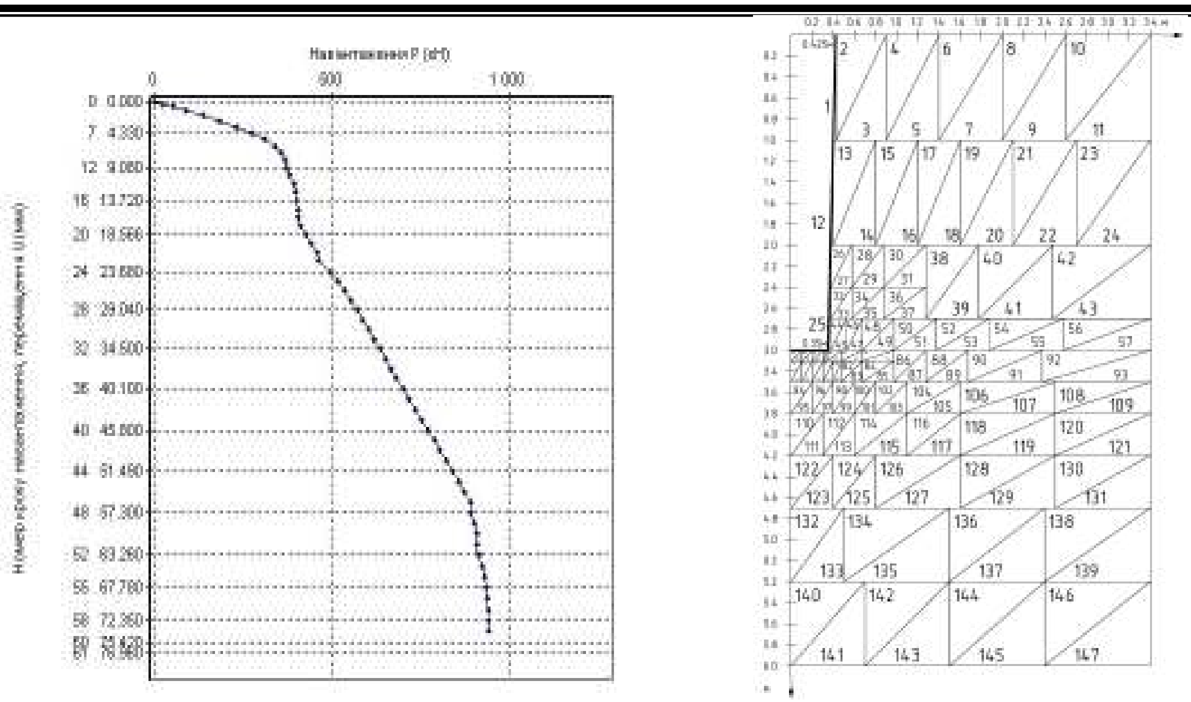

Fig.2 – Obtained by BEM graph "P-S" of the first scheme of the pyramidal pile

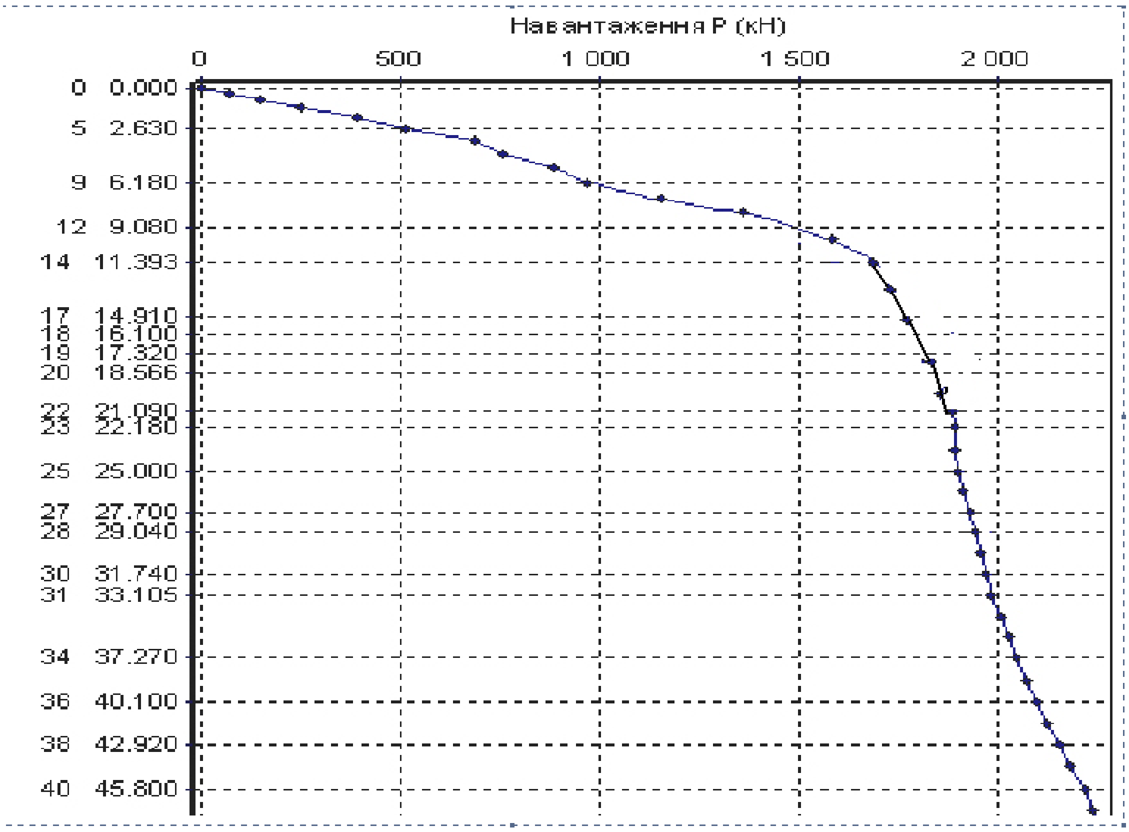

Fig.3 – Obtained by BEM graph "P-S" of the second scheme of the pyramidal pile

REFERENCES

1. V.I. Krutov, V. L. Rafalzuk, Yu.V. Vlasov. Foundations in rammed pits with a widened base. M.: Stroyizdat, BFSM №3, 1978, p. 3-6.
2. Brebbia K., Telles J., Vroubel L. Boundary element methods. M.: Mir, 1987.
3. Boyko I.P. Theoretical foundations for the design of pile foundations on an elastic-plastic foundation / I.P. Boyko, Sat. KISS “Bases and foundations
4. Boyko I.P. Theoretical foundations for the design of pile foundations on an elastic-plastic foundation / I.P. Boyko, Sat. KISI “Bases and foundations ”. – 1985 – №18, p 11-18.

5. Nikolaevsky V.N. Modern problems of soil mechanics // Defining soil mechanics // V.N. Nikolaevsky - M .: Stroyizdat. 1975 г. – С. 210-227.
6. A.A. Ilyushin. Plasticity.M.: Gostekhizdat. 1947.

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МЕТОДИКА РОЗРАХУНКУ ФУНДАМЕНТІВ В ЩІЛЬНОМУ КОТЛОВАНІ МЕТОДОМ ГРАНИЧНИХ ЕЛЕМЕНТІВ

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Основне завдання інженера-будівельника – забезпечити надійність конструкції з максимальною ефективністю використання часу, матеріалів та енергії. У будівництві у проектній майстерні має бути передбачено все – і міцність, і економічна доцільність. Балансування на «краю прірви» потребує точного математичного апарату. Сучасний математичний апарат механіки ґрунтів заснований на рішеннях теорії пружності та теорії граничної рівноваги. В цьому випадку розрахунок основ проводиться з умов суто пружного з'єднання і граничні навантаження визначаються без зв'язку з деформаціями.

Більшість пружнопластичних деформацій - від закінчення пружної стадії до втрати стійкості розрахунковими моделями не покривається. У той же час запаси пружнопластичної зони дозволяють збільшити навантаження на фундамент за умови, що просідання пружного ступеня ще не досягне гранично допустимого значення для даної конструкції. Метод граничних елементів (МГЕ) дозволяє вирішувати такі завдання. Головний недолік фундаменту на натуральній основі - складність його виготовлення та висока матеріаломісткість. Ці недоліки можуть бути усунені шляхом будівництва фундаментів у порожнинах заданої форми, які утворюються у ґрунті. До них відносяться фундаменти в ущільнених канавах, які влаштовують у колодязях із розширенням на дні.

Ґрунт зберігає свій повноцінний склад, завдяки чому в роботі присутня бічна поверхня, яка приймає частину вертикального навантаження і чинить значний опір горизонтальним силам. У статті наведено метод інтегрування математичної моделі поведінки під навантаженням фундаменту в ущільненому котловані з чисельним МГЕ. Теоретичне дослідження є впливом додавання піщано-гравійної суміші на дно ущільненого кар'єру на несучу здатність пірамідальних паль.

Ключові слова: пружно-пластичні деформації.

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МЕТОДИКА РАСЧЕТА ФУНДАМЕНТОВ В УПЛОТНЕННОМ КАРМАНЕ МЕТОДОМ ГРАНИЧНЫХ ЭЛЕМЕНТОВ

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Основная задача инженера-строителя - обеспечить надежность конструкции с максимальной эффективностью использования времени, материалов и энергии. В строительстве в проектной мастерской должно быть предусмотрено все - и прочность, и экономическая целесообразность. Балансировка на «краю пропасти» требует точного математического аппарата. Современный математический аппарат механики грунтов основан на решениях теории упругости и теории предельного равновесия. В этом случае расчет оснований проводится из условий чисто упругого соединения и предельные нагрузки определяются без связи с деформациями.

Большая часть упругопластических деформаций - от окончания упругой стадии до потери устойчивости расчетными моделями не покрывается. В то же время запасы упругопластической зоны позволяют увеличить *нагрузку на фундамент при условии, что просадка упругой ступени еще не достигнет предельно допустимого значения для данной конструкции. Метод граничных элементов (БЭМ) позволяет решать подобные задачи. Главный недостаток фундамента на натуральной основе - сложность его изготовления и высокая материалоемкость. Эти недостатки могут быть устранены путем строительства фундаментов в полостях заданной формы, которые образуются в грунте. К ним относятся фундаменты в уплотненных канавах, которые устраивают в колодцах с расширением на дне. Почва сохраняет свой полноценный состав, благодаря чему в работе присутствует боковая поверхность, которая принимает часть вертикальной нагрузки и оказывает значительное сопротивление горизонтальным силам. В статье представлен метод интегрирования математической модели поведения под нагрузкой фундамента в уплотненном котловане с численным МГЭ. Теоретическое исследование представляет влияние добавления песчано-гравийной смеси на дно уплотненного карьера на несущую способность пирамидальных свай.*

Ключевые слова: упруго-пластические деформации.

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