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Resource-saving Technology of Building of Vertical Mine Working in Soil

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Abstract

It shows the distribution of the estimated cost for the construction of vertical underground constructions in soils with the use of temporary support and their comparison with the cost of transmission using the screen of the grout-injected piles, allowing to increase the stability of the rock outcrops. The proposed solutions allow the construction of vertical underground structures in the ground by the combined technological scheme. For justification of the proposed solutions technique of determination of critical normal and shear stresses based on the condition of the equilibrium state of the soil of Prandtl – Reissner and limiting soil shear strength by the condition of the strength Coulomb-Moh. It is allowed to make an equation to determine the maximum possible use of the depth of penetration of the combined scheme, depending on the soil mechanical properties. According to the results of analytical studies the mathematical model is developed of the "press-fitted body" piles, allows you to manage its load-bearing capacity. The result of research was the development of design methodology that allows, based on selected characteristics of mine working to determine the optimal parameters of the formation of the protective screen.

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Keywords: Costs; the passage; fastening; drilling - injection pile; protective screen; plan of experiment; multiple regression.

1. Introduction

The growing worldwide interest in the development of the urban sub terrestrial space is largely due to the positive qualities of underground structures, thus preserving the unique appearance of the central areas, valuable urban landscapes and whole natural complexes. Therefore, underground construction is of great importance for the

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normal functioning of the urban environment [1-3]. However, the construction of underground structures in the alluvial breeds is always accompanied by a number of problems and significantly increases the cost of construction of facilities. Currently, the vast majority of sub- terrestrial objects in the ground is carried out with the use of temporary support, despite the significant cost labor, yes, time and money. During the construction of vertical structures in alluvial rocks the greatest number of problems associated with the lack of the required coupling constant of monolithic concrete lining with a soil mass, which leads to the need for a consistent technological scheme with the erection of temporary support. Such a complex multi-stage technique requires considerable financial and labor costs, and consistent execution of construction processes leads to an increase in construction time [4-6]. Therefore, the development of resource-saving technologies of underground construction in the ground is relevant and timely.

In order to reduce the material, financial and labor costs as well as reduce the time vertical construction of sunk constructions, developed technological solutions, the essence of which lies in the device according to the contour of the projected concrete lining screen of drilling - injection pile to improve the stability of rock outcrops. In this case , when fixing the unstable zones fast hardening concrete with formwork using a shield eliminates the need for temporary support, complex and time-consuming work on the construction of a permanent concrete lining " bottom-up" with the device and dismantling of portable regiments.

2. Rationale for applications developed technologies

The drilling - injection pile is a reinforced concrete pile structure with a high load-bearing capacity, in both the longitudinal and transverse directions [7-9], which allows to keep from collapsing loose vertical borehole wall. In addition, the exposed surface "is embedded into the body" of the pile is able to withstand the weight of the concrete lining without settlement of the soil massif. This will build a permanent support from top to bottom as the excavation and to eliminate the use of temporary support. That is, to use the combined scheme sinking instead of high-cost serial tunneling [10].

To justify the proposed solutions developed a method of determining the critical normal and shear stresses based on the condition of the equilibrium state of the soil, Prandtl- Reissner - limiting soil shear strength by the condition of the strength Mohr-Coulomb [11-12].

Limit state of the vertical walls of the ground characterized by a complex stress- strain state (SSS), as naked when excavation surface clamped between slaughter and erected trunk crepe.

In the first approximation, the critical shear stress depend on the horizontal component of the rock pressure and the strength of the soil condition on the Coulomb - Mohr considering normal stresses caused by the vertical component of ground pressure.

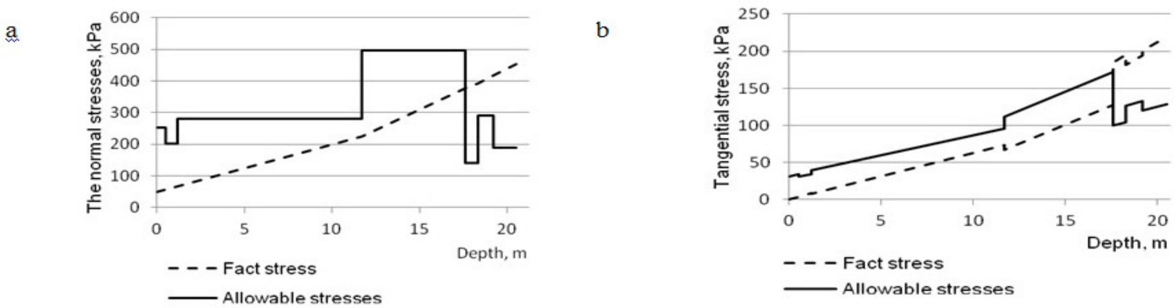

Fig.1. Permissible and acting stresses from the depth of the face: a) tangential stresses; b) the normal stresses

These conditions of the soil bearing capacity and changing the depth of the voltage from the action of a vertical and horizontal component of ground pressure allows to plot the array of limit states (Fig.1). However, the calculation of the multilayer array with significant fluctuations in soil characteristics associated with significant expenditure of time and large deviations between the calculated and predicted values limit the depth of the use of a combined scheme of sinking.

Therefore, using the technique of optimal design of experiments [13-15] performed calculations, the results of the regression analysis that make up the model (1), which allows to determine the maximum possible use of the depth of penetration of the combined scheme (H) , depending on the soil mechanical properties.

$$H = 19.97 + 0.16 \cdot C + 0.883 \cdot \phi - 1.83 \cdot \gamma + 0.02 \cdot Q_{CL} - 0.04 Q_F \quad (1)$$

where C, φ, γ – respectively grip , angle of internal friction and volumetric weight of the soil, Q_{CL} – the weight of the concrete lining and Q_F – formwork weight.

The resulting equation is characterized by a high degree of accuracy to describe the array of calculated data and can be used at the stage of pre- development in justifying the construction options.

3. Analytical research extension best well under pressure

The analysis of existing methods of designing steam - meter installation of ground anchors [16-18] shows that the targeted control of formation pressed into the body can only process pressure injection of cement mortar. Therefore, to solve this problem, we consider the possibility of a mathematical description of the process of expansion of the cavity of advanced borehole loaded by internal pressure. As the press-fitted body is formed as an array of drill ground, that is uniformly lengthened, we can submit it at a certain short point of time Δt short, in the form of an annular disk. In this case, in order to describe the stress and strain, resulting in the formation of an press-fitted array of body, as we will design scheme infinite plate with a circular hole of radius r to a contour which is uniformly applied gauge pressure pumping cement slurry R. That is considered flat axisymmetric problem in cylindrical coordinates R and ψ, the axis of which coincides with the axis of the press-fitted body. Accepted for consideration of elastic-plastic model with the assumption of incompressibility of soil and "press-fitted body ", as in the elastic and in plastic zones.

Besides interval of time of expansion of a cavity from r to R_0, does not exceed several minutes, which allows us to neglect the relaxation processes and to simplify the mathematical formulation of this problem. In this case, the radial and tangential stresses and σ_R σ_φ, deformation and displacement are determined by the polar radius R (Fig. 2), subject to the conditions of equilibrium [20-21]

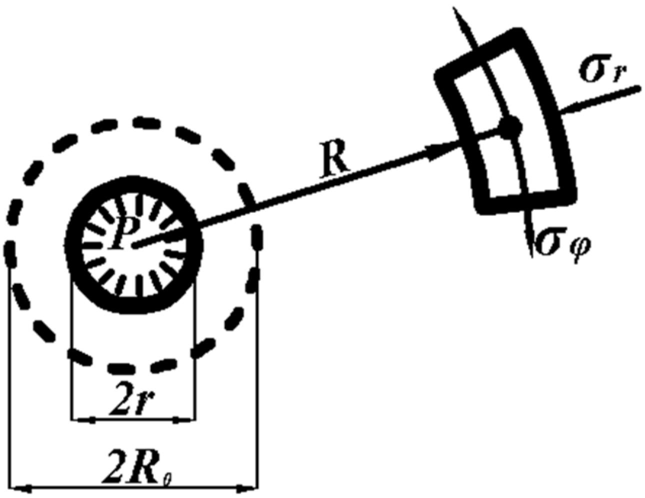

Fig.2. The scheme to the calculation of stresses

$$\frac{\partial \sigma_R}{\partial R} + \frac{\sigma_R - \sigma_\phi}{R} = 0 \tag{2}$$

and plasticity

$$\sigma_R - \sigma_\phi = \frac{2K}{\sqrt{1+n^2}} \tag{3}$$

where: K – coefficient of traction; $n=tg\varphi$, φ – angle of internal friction.

$$\frac{\partial \sigma_R}{\partial R} = -\frac{2K}{R\sqrt{1+n^2}} \tag{4}$$

After transformation, as in $R_0 = r$ $\sigma_r = -P$ obtain

$$\sigma_0 - \frac{(\sigma_0 + P)r}{R_0^2} = \frac{2K}{\sqrt{1+n^2}}(\ln r - \ln R_0) \tag{5}$$

This equation is transcendental, so his decision is approximate. Given that the delivery pressure is limited probability of break of solution to the mouth of the well advanced, when with its famous value (determined experimentally) possible solution of the equation (5) of graphic method. To do this, we equate both sides of (5) to the parameter Y. Asking step change in the radius of expanding cavity ΔR, plotted Y = f (R) and Y ǀ = f (R).

The intersection of these curves will be a desired radius of the cavity formed (Fig. 3).

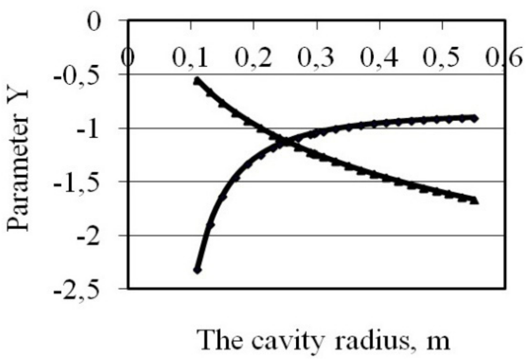

Fig.3. Charts to determine radius of the expanding cavity

The solution of equation (5) can only approximate methods, and its transformation in the case of determining the radius of the "press-fitted body" or the pressure necessary for the formation of a cavity fixing the required radius is extremely difficult, so it was decided to use optimal experimental design method to develop a simple model convenient for engineering calculations.

According to the equation the expansion cavity walls (1), on the final value of securing zone radius affected by the following factors: the radius of advanced borehole r; solution discharge pressure P of the solution; adhesion coefficient K and the angle of internal friction of compacted soil φ; the magnitude of lateral earth pressure σ. The first two factors characterize the parameters of the technology used, and the rest - the properties of the medium in which piles installed.

By analyzing the above factors, it may be noted that they are: controllable, i.e. they can be given any variation in the level determination; unambiguous; compatible with and independent of each other [22, 23]. Thus, the adopted parameter optimization factors and satisfy all the requirements imposed on them, and best reflect the qualitative and quantitative aspect of the process. Thus, the adopted parameter of optimization and the factors satisfy all the requirements imposed on them, and best reflect the qualitative and quantitative aspect of the process.

Intervals of varying controllable factors are selected on the basis of preliminary studies of areas of their definition, and varying levels taking into account the influence of factors on the parameter optimization. Moreover, the variation step was taken so that the change in the response function of the received exceeded the permissible value errors.

When implementing the plan drawn up for all combinations of factor levels graphically calculated the radius of the cavity formed by fastening cavity fixing. To do this, equating both sides of (1) to the parameter Y, and wondering step variation of the radius of the expanding cavity ΔR, plotted Y = f (R) and Y ꞌ = f (R). The intersection point of these graphs is the desired radius of the formed cavity.

Planning method Brandon experiment [24], in our opinion is more acceptable, since the matrix plan has 25 variants of calculations, and therefore a greater number of points for the description of nonlinear .

The most simple implementation and calculations in this case, has a matrix in which the number of levels equal to the number of varying factors, that is, for a given task must be five levels of variation of the independent variables dependencies.

For a preliminary assessment of the calculations graphs of partial dependence of the radius of the cavity fixing by the consolidation of R : the radius of advanced borehole r; solution discharge pressure P of the solution; adhesion coefficient K and the angle of internal friction of compacted soil φ; the magnitude of lateral earth pressure . The first and last according to a very high degree of reliability are approximated by linear functions , and the remainder polynomial , with the most notable characteristic of strength due to the radius of the dependent variable are well advanced , the injection pressure of the solution and coupling coefficient.

Initially, the multiple regression equation parameters were determined by nonlinear estimation. It revealed that the results of the calculations are described by the equation

$$R = \exp(10.41 \cdot r + 0.79 \cdot P - 1.37 \cdot k + 0.21 \cdot \phi + 0.03 \cdot \sigma - 1.84) - 0.034 \quad (6)$$

The total loss in this case is only - 0.000398, reliability at a value approximating - 0.997.

Since the equation (6) is very difficult to be transformed in the variables, it assessed the possibility of drawing up a linear model.

The resulting expression

$$R = 0.09 + 2.97 \cdot r + 0.18 \cdot P - 0.33 \cdot k + 0.88 \cdot \phi + 0.02 \cdot \sigma \quad (7)$$

It is characterized by low loss - 0.001526, and high magnitude squared - 0,9767.

Detailed analysis of the residues of the calculated values of the radius of the cavity and secure the injection piles predicted by equation (7) shows that the accuracy of the description of the calculation of the matrix is 3.17 %. Thus only two embodiments of the absolute deviation calculations exceed 10 % , with a maximum value of 13.6 %.

The minimum values of beta coefficients defining closeness of the relationship of the independent variables and the optimization parameter is the internal friction angle of soil φ = 0,253 , and an array of lateral pressure σ = 0,355. That is, according to the scale Cheddoka relative contribution of internal soil friction angle formed by the radius of the cavity fixing weak. However, the exclusion of this factor from the equation (7) leads to a decrease in the accuracy of the description of the matrix calculations .

Thus, analyzing the modeling error to determine the optimal parameters of the zone secure injection piles and accuracy of the description of the expansion process of the cavity formed by the equation (7) is the most appropriate.

The resulting mathematical model of "press-fitted body" drilling-injection piles, allows you to define the parameters of piles and fixing according to their load-bearing capacity.

4. Working methods of design parameters of formation of protective screen drilling-injection piles.

Development of algorithm design parameters form a protective screen is associated with the need to respect a number of conditions of stability of structures, depending on many variables.

Given the complexity of the problem, it was adopted by a number of assumptions concerning the application of the developed methodology, which allowed using the obtained relationships set the strength of concrete and cement stone over time, to develop a version of the engineering calculation of parameters forming a protective screen of CFA piles.

According to the proposed algorithm is primarily determined by the weight of 1 meter of lining construction:

$$P_L = S_L \cdot \gamma_L = \pi(R_L^2 - R_P^2) \cdot \gamma_L \tag{8}$$

where S_L - ring area of the lining , m^2; γ_L - specific weight of the material lining, кН/m^3.

Next, the load of the lining on the 1st group of piles

$$Q_{GP} = P_L \cdot k \tag{9}$$

where k - coefficient of working conditions for temporary *structures* , k=1,5.

Next determined load on 1 m single pile

$$q_P = Q_{GP} / N_P \tag{10}$$

where N_P - number of piles around construction

$$N_P = 2\pi(R_L + R_P + h_P) / l_0 \tag{11}$$

here R_L - the radius of the outer contour of the lining, m; R_P - radius " pressed into the body," the pile , m ; h_P - height of pile segment in contact with the lining, h_P = 0,05 – 0,075 m at radii pile 0.1 and 0.15 m , respectively; l_0 - the distance between the piles, which is calculated from the steady-state conditions the concrete lining segment between adjacent piles .

As a first approximation, this span roof support can be seen as a beam of rectangular cross section, jammed on supports, in this case, the condition must be respected [25]

$$M_{\max} \le \alpha R_{bt} W \tag{12}$$

where M_{max} - the maximum bending moment due to its own weight concrete , кН·m; α - coefficient taking into account the type of concrete used for heavy concrete α = 1 ; R_{bt}- early settlement of concrete tensile strength , determined period of time from its stowage recess until next stope ground by bolting , kPa ; W - Section modulus span lining, m^3 .

The maximum bending moment is determined by the formula

$$M_{\max} = q_c l_0^2 / 12 \tag{13}$$

and the moment of resistance of expression [25]

$$W = \Delta_c h_c^2 / 3.5 \tag{14}$$

When the value of stope 1m, after transformations we obtain

$$l_0 = \sqrt{24\pi\Delta_c h_c^2 R_{bt}(R_{kn} + \Delta_c)/3.5P_c} \quad (15)$$

Since the required bearing capacity drilling - injection piles in its docking area is given by [26]

$$q_P = \frac{\beta}{180}\pi \cdot R_P \cdot k_w \cdot \frac{\tau_g}{\lambda} \quad (16)$$

the desired radius of the "press-fitted body" can be defined by the formula

$$R_P = 180 q_P \lambda / \pi \cdot \beta \cdot k_w \cdot \tau_g \quad (17)$$

where k_w - coefficient of working conditions, k_w = 0,65; λ - overload factor, λ = 1,2; β - the angle of the arc of the pile surface of the ground contact (angle of wrap), β = 240 - 270o; τ_g - grip compacted soil with cement stone piles depends on the physical and mechanical properties of the soil solution and the injection pressure during the formation of the pile, τ_g= 20 - 40 kPa.

The resulting value of radius "press-fitted body" of the pile is checked for shear of hardening concrete surface

$$q_P \le q_b \le \frac{2}{3}\pi \cdot R_P \cdot k_w \cdot \frac{R_{br}}{\lambda} \quad (18)$$

where R_{br} - concrete shear strength at an early age, kPa.

Since we have the eccentricity of load application on the weight of roof support, it is necessary to verify the strength of the compressed zone of the pile on the condition [24]

$$q_P \le \alpha R_b F_p \quad (19)$$

where R_b - the design compressive strength of concrete at early age, kPa; F_p - the area of a segment of the compressed pile area, m^2.

It also checks bearing capacity of the pile on a cut "press-fitted body" on the surface of the steel pipe weight concrete roof support rings

$$q_P \le q_r \le 2\pi \cdot R_{sp} \cdot k_w \cdot \frac{\tau_{cs}}{\lambda} \quad (20)$$

where τ_{cs} - the clutch of a cement stone with the outer surface of the pipe, τ_{cs} = 570 ÷ 960 kPa; R_{sp}.- the radius of the steel pipe pile, m.

When all the conditions calculated radius "press-fitted body" is taken to the design that allows you to define the required discharge pressure

$$P_n = (R_P + 0.33k - 2.97r - 0.02\sigma - 0.08\phi - 0.09)/0.18 \quad (21)$$

where k - the value of soil cohesion, kPa; r - the radius of the cavity in the formation of pile, m; σ - lateral earth pressure, kPa; φ - angle of internal friction of soil.

According to the above method calculated the parameters formation of shielding for workings with diameters ranging from 5 to 8.5 m, and lining thickness from 0.25 to 0.5 m with the most unfavorable soil characteristics.

According to the results of the design drawn up cost estimates for carrying and mounting facilities for a coherent and combined with a protective screen patterns. Cost analysis shows that even under the most favorable combination of factors, the effectiveness of the proposed technological solutions than 5.5%.

5. Experimental research parameters fastening piles

The process of fixing the drilling - injection pile while injecting grout, cause a complex stress strain state of the soil in the sealing area, and depends on a number of influencing factors. According to the analytical studies, the most important of them: grip and angle of internal friction of soil, the diameter of the well advanced, the solution discharge pressure, lateral pressure of the array.

Given the characteristics of the soil mass deformation experimental studies aimed at establishing the impact of structural and mechanical characteristics of the soil in the process of expanding cavity "press-fitted body" and the bearing capacity of piles.

As in the laboratory cannot be reproduced adequately array of features natural structure, the experiments are performed in real-ground arrays. To ensure the information content of experiments, we developed a special technique of modeling, which included the definition of the research process: stress causes sustained immersion piles in the array; diameter "is pressed into the body"; securing the strength of the steel pipe cement stone; limit of cement stone shear strength under different conditions of formation of "pressed into the body"; changes in the structural and mechanical properties of the soil after shaping grout.

According to the results of experimental studies tested ten groups of piles at two sites, which led to the following conclusions:

- bearing capacity in loam drilling - injection pile immersion in 2.3 - 2.8 times more than the pull-out;
- the estimated value of the maximum load to pull out piles coincides with the experimental with accuracy 12 to 20%;
- the strength of Consolidate the anchor pipe in cement stone indentation in all tests exceeded the limit voltage cut-off on contact with the ground.

Thus, the study shows satisfactory agreement between the calculated and experimental parameters fixing drilling - injection pile. These values correspond to the carrying capacity of piles and the results of tests given in [27].

6. Conclusion

The following conclusions can be drawn on the results of the research:

- On the basis of the laws of mechanics of continuous media, assumptions and boundary conditions, the regularities of the expansion cavity advanced well under the influence of excess pressure grout, which are described by a transcendental equation;
- Graphical methods for solving the problem of determining the radius of the zone termination soil piles;
- It found that the radius of the cavity is directly proportional to the discharge pressure, the radius of the well advanced, the lateral pressure and internal friction angle of the rock, and the effect of the coefficient of friction of soil is characterized by inverse power dependence.
- Science-based technique of designing the parameters fixing ground anchors and carrier capacity screen of piles for fastening vertical workings "top - down".
- Analyzes the results verified by simulation by the finite element method and experimental studies.

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