

ГЕОТЕХНОЛОГИЯ: ПОДЗЕМНАЯ, ОТКРЫТАЯ, СТРОИТЕЛЬНАЯ

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The influence of bottom-up anchors pre-tension optimization on the prediction of pit walls rockfall displacements

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Abstract

Introduction. Currently in Russia, innovations in urban subsoil facilities construction are among the key factors of economic development. To improve the efficiency of holding a pit wall in restraint urban conditions and prevent soil loosening around the pit, it is proposed to optimize the pre-tension forces of the bottom-up anchors. It has been determined that the pre-tension forces of the active anchors create extra retention forces in the sliding wedge and, in some specified sense, reinforce the walled soil.

Research methodology. When modeling the complex calculation of a pit wall, 4 main stages of the pit excavation and 3 stages of preliminary level tensions of anchor ties were preset. The numerical solution of the beam bending problem is the basic method of calculating the walling strength; the beam laying on the elastoplastic base and retained by the anchors as bonds. The bottom-up anchor structure is modeled in the operating environment of GeoWall software. The values of bottom-up anchors pre-tension are set following the ordinates of forces in the anchors, obtained from the walling stability calculation by the deterministic approach. Experimental research was carried out of the impact made by pit opening stages on the walling stress strained state.

Results. Analysis and discussion. The efficiency of bottom-up anchors optimal pre-tension, according to the research results, is obtained by constructing the diagrams reflecting the correlation dependence between the anchors loading and the walling displacement. An obvious advantage of the software is the opportunity to calculate walling and retaining structures stage by stage ignoring their construction technologies. Experimental calculation in GeoWall has shown a high bearing capacity of the bottom-up anchor support.

Summary. The nature of the obtained dependence between the anchor longitudinal forces and the pit walling horizontal displacement reflects the actual situation. Thus, for a quiet expectable value of horizontal displacement, it is required to correct the optimal value of pre-tension using the empirical-formula dependences.

Keywords: anchor support; bottom-up anchor structure; active anchors; walling displacement; retaining structures.

Introduction. On the scale of urban underground excavation, subsoil structures built by the opencast method account for a rather significant share. The successful construction of such facilities is greatly determined by retaining structures' reliability and rational engineering decisions.

To hold a pit wall in restraint urban conditions, reduce the material intensity, labor intensity, and cost of the ground anchor works, as well as to improve their bearing capacity and reliability, it is considered to optimally load the bottom-up anchor structures.

For pits walling, two types of anchors are used [1], distinguished by the load intensity: *active*, prestressed with tension as much as 30% of design load, and *passive*, i.e. having some tension that ensures anchor centering and weakness selection.

Relying upon the typical designs of pit retaining structure [2–5], it should be noted that anchors are connected with walls by a girt and are considered as elastic bonds, the reaction values of which are directly proportional to anchors deformation or displacement [6, 7]. Anchor's on-load operation is characterized by its stiffness K which bonds the value of the linear force N in anchor and anchor displacement U [8]:

$$K = \frac{N}{U}.$$

The calculation model reflecting the change in the bottom-up anchor forces under the staged pit excavation is shown in fig. 1.

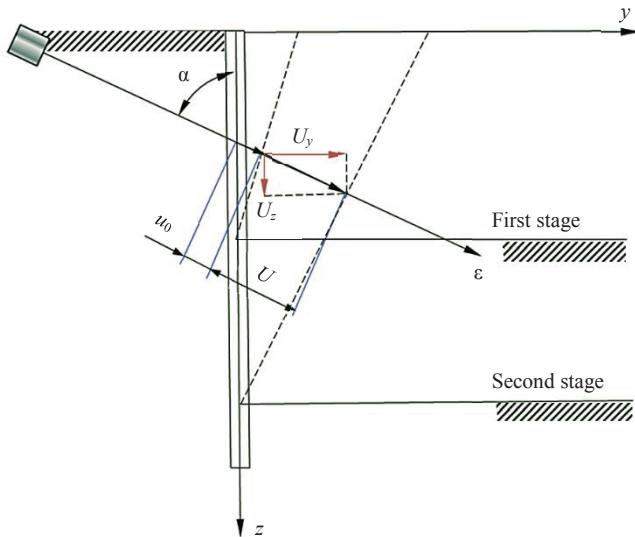


Fig. 1. Calculation model determining the longitudinal forces of the bottom-up anchors

Рис. 1. Расчетная схема по определению продольных усилий восходящих анкеров

During the staged development of a pit, the flexible retaining wall deformations increase. Besides, the hazard of its displacement increases with the growth of the pit's depth. Due to the pre-tension of anchors, soil loosening around the pit is prevented. But the action of pre-tension is limited by the finite stiffness of anchors. Moreover, the value of pre-tension, not having a strict bond with active earth pressure, results in the development of plastic deformations which are measured in dozens of millimeters.

A benchmark of efficient anchor tension is a total absence of plastic deformation increase in the calculation period.

Research methodology. An example of integrated calculation of a pit walling in the layers of plastic loam, gruss, and gabbro-diorite of low or medium strength using GeoWall software is considered as an object of geotechnological analysis. Pit parameters are 30 × 20 m. For pit wall stability, a walling is provided made of a row of steel discrete I-type legs retained by the bottom-up anchor structures. After the pit is uncovered, the adjoining surface of the soil is loaded by an active load of 30 kN/m². Seismic activity in the region is less than 7 scores.

In GeoWall the wall pressure is calculated in accordance with the rules and regulations [8]. Soil stability around the wall digging-in is assessed by the limit state of soil in the area of anchorage. Passive wall pressure from the direction of backfilling is taken into account. Wall elastic bending is modeled by the finite element method with Lagrange variational

formulation, taking into account Bernoulli's hypothesis of flat cross-sections. GeoWall program package makes it possible to account for the inhomogeneity

Table 1. Physical and mechanical characteristics of soils
Таблица 1. Физико-механические характеристики грунтов

EGE	Soil type	h , m	ρ_I , g/cm ³	ρ_{sat} , g/cm ³	c_I , kPa	φ_I , degrees	k_s , kN/m ³	λ_0	E , MPa	v
1	Semi-hard loam	2.7	1.79	2.19	37.0	24.0	995	0.54	19.0	0.35
2	Crushed stone	1.5	1.92	2.27	27.2	27.9	1665	0.43	32.0	0.30
3	Gabbro-diorite of low strength	7.0	2.24	2.33	37.0	28.0	4000	0.33	40.0	0.25
4	Granodiorite-porphyry of medium strength	10.0	2.54	2.70	24.0	36.0	5000	0.25	50.0	0.20

h – the thickness of the engineering geological element (EGE); ρ_I – soil density in natural state for the first group of limit states; ρ_{sat} – soil density under the total water saturation for the first group of limit states; c_I – specific cohesion for the first group of limit states; φ_I – angle of shear resistance for the first group of limit states, degrees; k_s – coefficient of subgrade resistance; λ_0 – coefficient of passive earth pressure at a standstill; E – modulus of deformation; v – Poisson's ratio.

of base soil, soil layers inclination, and the presence of groundwater and impermeable barrier [8–10]. An obvious advantage of the software is the opportunity to calculate walling and retaining structures stage by stage ignoring their construction technologies.

Table 2. Anchor bond parameters
Таблица 2. Параметры анкерных связей

Stage	Bond type	Setting depth, m	Rigidity of bond, kN/mm	Spacing, m	Setting angle, degrees	Tension force, kN
2	Anchor	3.0	12.6	3.0	-15.0	150
3	Anchor	6.0	10.5	3.0	-27.0	240
4	Anchor	9.0	8.7	3.0	-35.0	270

Physical-mechanical characteristics of soil are presented in table 1.

Anchors bearing capacity calculation was carried out by the method of VSN 506-88 (Minmontazhspetsstroi). Anchor bond parameters and design parameters of the bottom-up anchors are presented in tables 2 and 3.

Table 3. Design parameters of the bottom-up anchors
Таблица 3. Расчетные параметры восходящих анкеров

Parameters	Level 1	Level 2	Level 3
Anchor type	Strand	Strand	Strand
Unbonded length, m	10.0	12.0	14.5
Bond length, m	1.0	1.0	1.0
Anchor overall length, m	11.0	13.0	15.5
Bond diameter, mm	1000	1000	1000
Anchor cross-sectional area, mm ²	600.0	600.0	600.0
Tie ultimate strength, MPa	1550	1550	1550

The calculation model of the fender reinforced by three layers of bottom-up anchors [11, 12] is presented in fig. 2.

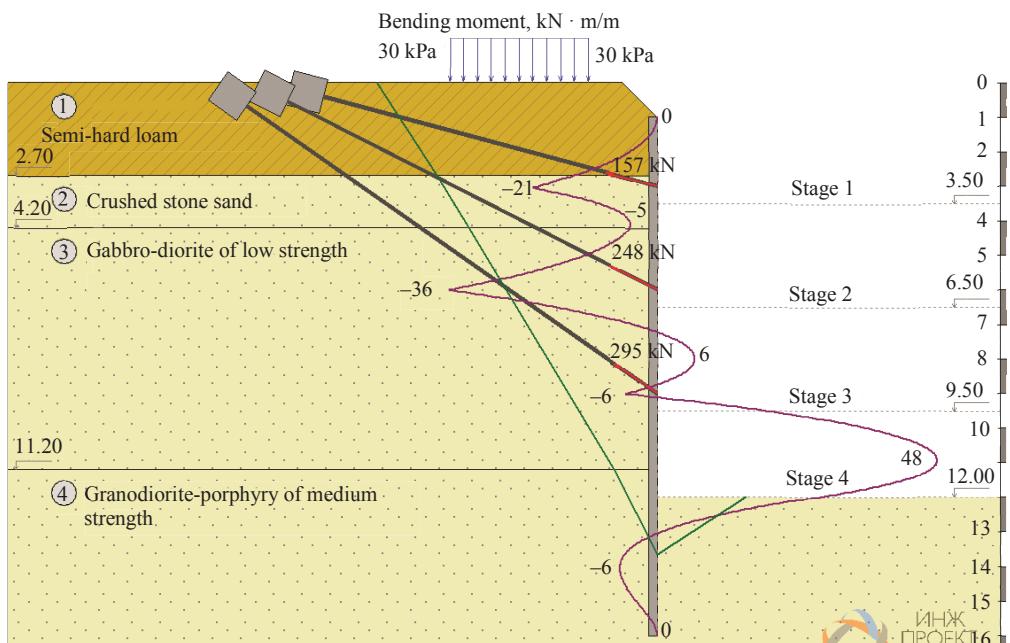


Fig. 2. Calculation model of the pit walling, including the outline of the bending moments, $\text{kN} \cdot \text{m}/\text{m}$, and possible wedge of soil movement for the 4th stage of soil excavation

Рис. 2. Расчетная схема ограждения котлована, включая очертания эпюры изгибающих моментов, $\text{kH} \cdot \text{м}/\text{м}$, и возможной призмы сдвига грунта для 4-го этапа экскавации грунта

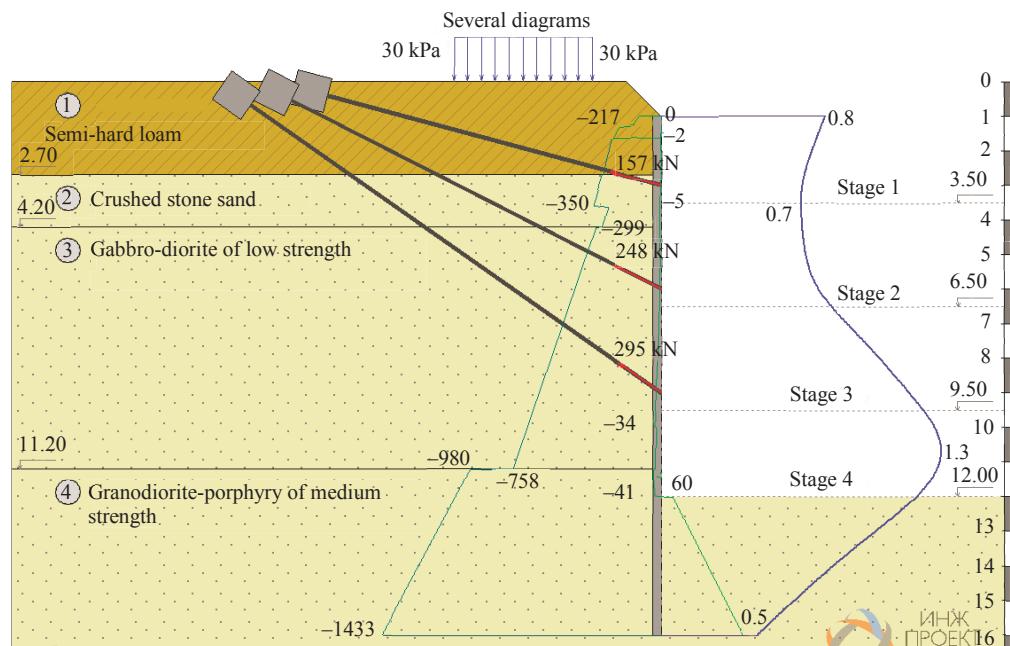


Fig. 3. Diagrams of maximum wall pressure, kPa (on the left), and horizontal displacement, cm (on the right), for the 4th stage of walling design

Рис. 3. Эпюры предельного давления на ограждение, kPa (слева), и горизонтальных перемещений, см (справа), для 4-го этапа расчета ограждающей конструкции

Results. Analysis and discussion. When modeling a pit wall integrated calculation, 7 basic stages of pit construction were preset, including 3 stages of active anchors level installation.

At the first stage, single end-bearing piles were sunk to the theoretical height. The soil was excavated to the level of the drilling rig station, i.e. half a meter lower than the first girt. Until the installation of the first level of active anchors, stress strained state of the pile row upper overhanging area is recorded, maximum horizontal displacement of which is 1.7 cm. The maximum bending moment reaches $31 \text{ kN} \cdot \text{m/m}$, the shearing force is 19 kN/m . The safety factor for the steel of the I-bar is $K_s = 6.3$.

Table 4. The results of numerical modeling in GeoWall program. Comparison of the top-down and bottom-up anchor support parameters

Таблица 4. Результаты численного моделирования в программном комплексе GeoWall. Сравнение параметров нисходящей и восходящей анкерной крепи

Studied parameters	Top-down anchors parameters	Bottom-up anchors parameters
Pit depth, m	12.0	12.0
The quantity of levels	3	3
Pile sinking depth T , m	5.0	4.0
Piles spacing L , m	1.30	1.80
Calculated longitudinal force in anchors, kN	62; 98; 206	166; 263; 309
Tie load under the offset yield stress, kN	408.0; 408.0; 408.0	936.0; 936.0; 936.0
Maximum bending moment in a pile, kN · m/m	65	53
Maximum shearing force in a pile, kN	82	86
Maximum horizontal displacement, cm	2.6	1.2
<i>Characteristics of piles' cross-section</i>		
Pile profile and type	I-beam 50 B1	I-beam 40 B1
<i>Safety factors of calculation components for all levels (4th stage of excavation)</i>		
Minimum safety factor in the metal of the end-bearing pile	2.7	2.1
Safety factor in piles anchorage	5.3	3.5
Anchor's soil safety factor	1.0; 1.0; 2.0	3.8; 2.4; 2.2

The final fourth stage of walling deserves consideration. It perfectly characterizes the stress-strained state of the whole pit wall system (fig. 3)

Longitudinal anchor forces from levels 1 to 3 made up 157 kN, 248 kN, and 295 kN correspondingly, under the tension of 150 kN, 240 kN, and 270 kN. Longitudinal forces increase in anchors is due to the process of soil excavation, in the course of which the walling experiences elastic deformation. Wall displacements grow with the depth of excavation, and the behavior of anchors as elastic bonds increase in proportion to their displacements.

The values of the bottom-up anchors pre-tension were preset in accordance with the ordinates of forces in anchors, obtained from the walling stability calculation using the deterministic approach [11, 12].

However, further increase in anchor pre-tension does not contribute to the efficient reduction of horizontal deformations. Moreover, the safety factor of the pile's metal decreases, the safety factor of material and soil drops sharply, and the stability of pit

walling in general decreases significantly. Thus, experimental calculation in Geowall program showed a high bearing capacity of the bottom-up anchor support. Comparative analysis of the bottom-up and top-down anchor support is presented in table 4.

There is no doubt that the research results have proved the efficiency of the bottom-up anchors optimal tension that is presented in the diagrams reflecting the dependence between the anchors loading and the walling displacement (fig. 4). The nature of the studied interrelation for the anchors active loading is conditioned by the attainment of

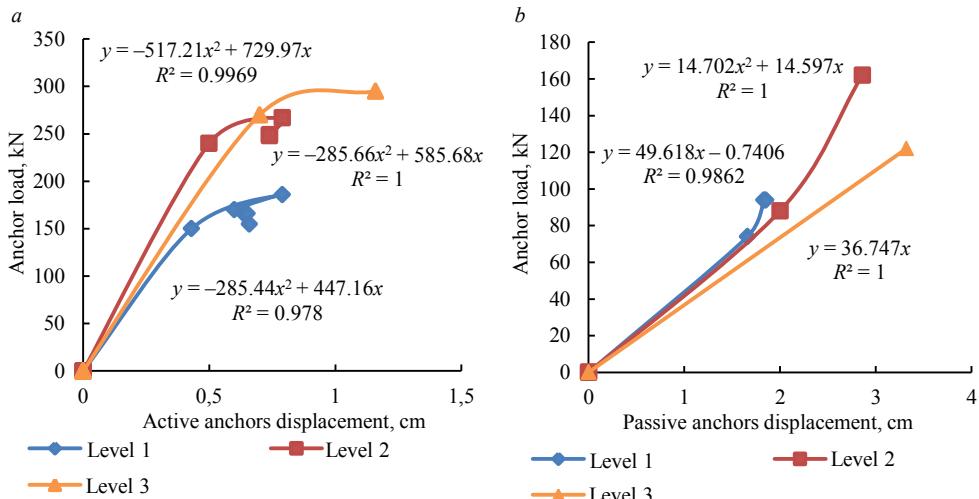


Fig. 4. Dependence diagram $N_{anc} = f(U_y)$ of anchors active – a and passive – b load and walling displacement

Рис. 4. Диаграммы зависимости $N_{anc} = f(U_y)$ активного – a и пассивного – b нагружения анкеров от смещения ограждающей системы

optimal longitudinal forces of the bottom-up anchors. The dependency graph of the anchor longitudinal forces and horizontal displacement of the walling elements $N_{anc} = f(U_y)$ represents a smooth curve with distinctive breaks in the moment of critical load. The function graph of each level has an anchor loading extremum. Thus, for a quiet expectable value of horizontal displacement, it is required to correct the optimal value of pre-tension using the empirical-formula dependences. The character of the studied dependence for anchors passive loading is conditioned by the development of significant horizontal displacements. Besides, forces in anchors can't be corrected in the conditions of passive loading of the pile row and don't ensure the safety of walling service [1, 4]. It is the switch to the pile row active loading correction that makes it possible to solve this problem.

Summary. Theoretical and experimental research analysis showed that the nature of the obtained dependence reflects the real situation. The function graph for each level of bottom-up anchors has its extremum indicating the efficient loading limit. Consequently, not exceeding the extremum, it is possible to correct the optimal value of pre-tension for a quite expectable value of horizontal displacement with sufficient reliability, using the equations of dependences obtained from the results of the trend analysis for each stage of pit excavation.

So, the improvement of the anchor structures bearing capacity and the reliable prediction of the *walling-anchor-soil* system stress-strained state ensure more efficient, safer, and more advanced industrial processes when constructing urban subsoil structures by opencast method.

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Влияние оптимизации предварительного натяжения восходящих анкеров на упреждение обвалоопасных перемещений ограждений котлованов

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Реферат

Введение. В современных условиях в России инновации в строительстве городских подземных сооружений выступают одним из ключевых факторов экономического развития. Для повышения эффективности удержания борта котлована в условиях плотной городской застройки и предотвращения разуплотнения грунта вокруг котлована предлагается оптимизировать усилия предварительного натяжения восходящих анкеров. Установлено, что усилия натяжения активных анкеров формируют дополнительные удерживающие силы в призме обрушения и в определенном смысле упрочняют ограждаемый массив грунта.

Методика исследования. При моделировании комплексного расчета ограждения котлована было задано 4 основных этапа устройства котлована и 3 этапа предварительных поясных натяжений анкерных тяг. Методической основой расчета на прочность ограждающих конструкций служит численное решение задачи изгиба балки, лежащей на упруго-пластическом основании и удерживаемой анкерными конструкциями в качестве связей. Моделирование восходящей анкерной конструкции реализуется в операционной среде программы GeoWall. Величины предварительных натяжений восходящих анкеров задаются в соответствии с ординатами усилий в анкерах, полученных из расчета устойчивости ограждающей системы детерминированным методом. Проведены экспериментальные исследования влияния этапов вскрытия котлована на напряженно-деформированное состояние ограждения.

Результаты. Анализ и обсуждение. Эффективность оптимального предварительного натяжения восходящих анкеров по результатам исследований достигается при построении диаграмм, отображающих корреляционную зависимость нагружения анкеров от смещения ограждающей системы. Безусловным достоинством программы является возможность поэтапного расчета ограждающих и удерживающих конструкций при различных технологиях их возведения. Экспериментальный расчет в программно-вычислительном комплексе *GeoWall* показал высокую несущую способность восходящей анкерной крепи.

Вывод. Характер полученной зависимости продольных усилий анкера от горизонтальных перемещений элементов ограждения котлована отражает реальную ситуацию. Таким образом, для вполне ожидаемого значения горизонтального перемещения следует корректировать оптимальное значение предварительного натяжения, используя уравнения эмпирической зависимости.

Ключевые слова: анкерная крепь; конструкция восходящего анкера; активные анкеры; перемещение ограждающей конструкции; подпорные сооружения.

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