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Base deformation's features during deep foundation pit excavation

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The problems of estimating the stress-strain state of the foundations during the deep foundation pits installation are considered. The results of finite element calculations in the plane formulation of the stability of the pit walls and the retaining structures' operation under dense urban development are presented. It is proved that the proposed method specifies the calculation of determining the impact of the new building on existing buildings and structures, which enables assigning the design of retaining structures from drilled piles on the conditions of normal further operation of existing facilities. It is established that the parameters of the structures retaining the walls of deep foundation pits in the presence of existing buildings, should be assigned based on the actual condition of these buildings and the allowable additional deformations.

Keywords: soil massif, dip foundation pit, stress-strained state, finite element method, retaining structure, drilled pile.

Особливості деформування основ при влаштуванні глибоких котлованів

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Розглянуто проблеми оцінювання напружено-деформованого стану основ при проходженні глибоких котлованів. В основу алгоритму визначення додаткових деформацій існуючих будівель і споруд, розташованих навколо котловану, покладено принцип підсумовування деформацій від впливу усіх суттєвих факторів (зниження напружень у масиві навколо існуючих фундаментів при розробленні котлованів, бічний активний тиск ґрунту на існуючі фундаменти, втрата стійкості ґрунту навколо фундаменту, нерівномірне випирання ґрунту на дні котловану; витискання ґрунту з-під підошви фундаменту в бік котлована), що їх викликають. Після порівняння граничних і розрахункових додаткових деформацій цих будівель і споруд призначають заходи зі зниження негативного впливу нового будівництва. Наведено результати розрахунків методом скінченних елементів у плоскій постановці з використанням пружно-пластичної моделі грунту та узагальненого критерію міцності Мізеса-Шлейхера-Боткіна стійкості стін котлованів і роботи утримуючих споруд за умов щільної міської забудови. Доведено, що запропонована методика конкретизує розрахунок визначення впливу новобудови на існуючі будівлі та споруди, що дозволяє призначати конструкцію утримуючих споруд із буронабивних паль з умов подальшої нормальної експлуатації існуючих об'єктів. При моделюванні розглянуті варіанти влаштування паль у один та два ряди, а також використання ґрунтових анкерів. Встановлено, що параметри споруд, утримуючих стінки глибоких котлованів (тип, кількість, жорсткість, місцерозташування) при наявності поряд існуючих будівель, повинні призначатися, виходячи із фактичного стану цих будівель і допустимих додаткових для них абсолютних і відносних деформацій. Також встановлено, що слід враховувати послідовність робіт і характер навантажень, відповідні характеристики матеріалів конструкцій. Показано, що утримуюча споруда, при розрахунку за таким принципом, може мати більшу матеріалоємність, ніж та, яка розрахована лише за міцністю, але вона повністю виключить можливість руйнування існуючих навколо котловану будівель.

Ключові слова: грунтовий масив, глибокий котлован, напружено-деформований стан, метод скінченних елементів, утримуюча споруда, буронабивна паля.

Introduction

At the present stage of the construction industry development in Ukraine, the reconstruction of large cities is being carried out intensively, which, in particular, includes new construction of houses of various purposes (including high-rise ones) with a developed underground part, underground structures of public and technical purpose (parks, shops, underground passages, warehouses), transport and communication tunnels, etc.

Groundworks are mostly performed in an open way.

Review of the research sources and publications

Reconstruction, in this case, is understood as the placement of these objects among the existing buildings and structures in terms of compact urban development. The contours of the underground space, within which the foundation part of new buildings and structures is located, are directly close to the existing foundations [1 – 5].

Experience shows that as a result of such an approximation, the violation created before the new construction, stress-strain state (SSS) of the foundation is possible. This leads to cracks in the load-bearing structures of existing buildings, skew of the openings in the walls, displacement of floors, and so on. [1 – 5].

The main factors that arise as a result of new construction and cause the listed damages are changes in the SSS of the basis of existing buildings due to [1 – 8]:

– at the stage of construction of new foundations - foundation pit excavation;

– at the stage of further construction and operation - the emergence of additional stresses from the weight of the new building.

Of course, at the stage of the foundation construction, other influences on the basis of existing structures are possible, such as dynamic - from the operation of mechanisms, and even more with the dynamic immersion of piles and soil compaction; consequences of water lowering, etc. [1 – 5].

From the above analysis it follows that when building in dense conditions to ensure the preservation and subsequent normal operation of building structures existing in the building area of buildings and structures, additional requirements should be made to the choice of design solutions, technologies, and construction of new buildings [6 – 8].

This requires the development of special enclosing walls and retaining structures, in all cases, to reduce the settlement of existing buildings [1 – 5, 9 – 11].

This is also accompanied by an assessment of the SSS of the foundations of new buildings to determine the additional deformations existing along with the new buildings and structures during construction and operation [2 – 4, 12].

Definition of unsolved aspects of the problem

When excavating pits and trenches near existing buildings, vertical and horizontal stresses in the soil mass around the existing foundations are reduced. This causes a decrease in the strength of the base due to the disappearance of the lateral load.

At the same time, there are some other negative phenomena, namely: lateral active soil pressure on the existing foundation (in buildings without basements); loss of soil stability around the foundation; uneven protrusion of soil at the bottom of the pit; squeezing the soil from under the base of the foundation towards the pit, etc. [6 – 8].

When deepening pits near buildings on pile foundations below their grilles, the soil may spill out of the inter-pile space and expose piles, which may eventually lead to uneven subsidence and destruction of grilles, floors, damage to inlets and outlets of communications [2, 5].

Problem statement

Therefore, the goal of this paper was to improve the method of determining the impact of new buildings on existing buildings and structures, which would enable selection of the retaining structures design, based on the conditions of the further normal operation of existing buildings.

Basic material and results

Thus, the main task in the design of buildings and structures in dense urban development is the principle of "do no harm".

It is implemented in the following sequence:

– within the construction site, buildings and structures that may be affected by new construction are identified;

– technical inspection of certain existing buildings and structures is carried out in order to establish their technical condition, which determines their maximum additional deformations;

– for specific conditions, the negative factors of new construction which will affect the condition of existing buildings and structures are determined;

– from each factor the additional deformation of the building is defined, preference is given to methods of calculation which allow considering together the influence of more factors;

– total additional deformations of existing buildings and structures are defined as the sum of deformations from the influence of all identified factors;

– on the basis of boundary comparisons and calculated additional deformations, measures on reduction of the new construction negative influence are defined.

Further, it was considered the features of the SSS change of the existing buildings and constructions' basis only during the foundation pits' excavation for new construction.

As a result of the pits' excavation due to partial unloading of the base, there are deformations (Fig. 1), which can be divided into two groups:

– the first group of deformations is the protrusion of the pit bottom, with the maximum values they have in the center and the minimum at the periphery of the pit ($s_{h\,max}$ and $s_{h\,min.}$);

– the second group of deformations is associated with the operation of the pit slopes, they occur with the loss of their stability (u_1 and u_2).

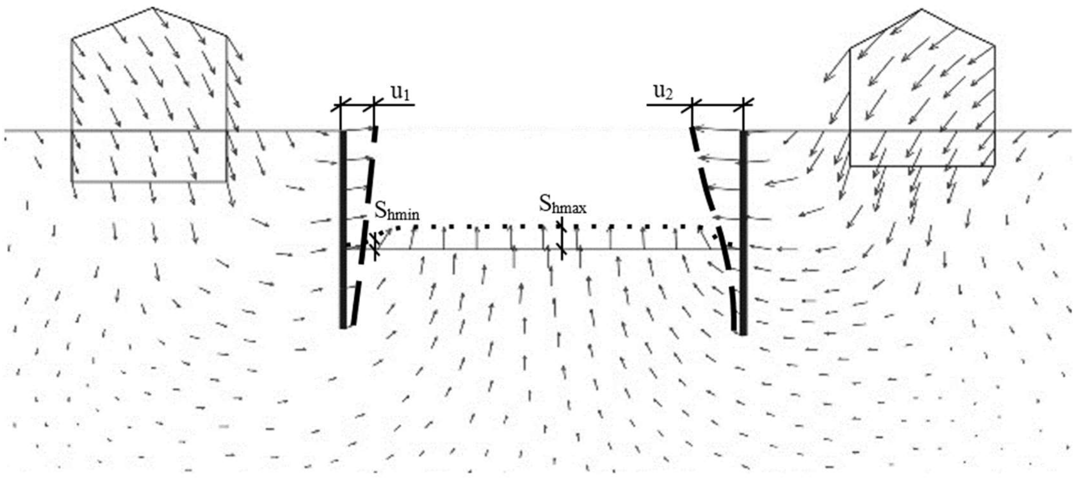


Figure 1 – Deformations development scheme during the foundation pit excavation

In the standards for foundations of buildings and structures [7, 8] in this regard, in particular, it is said that "temporary and permanent attachments of deep pits, for which the requirements for displacement are set, must be calculated by the finite element method (FEM).

At the same time, it is necessary to consider the sequence of works and the load nature, to use the specified models of soil base, and also the corresponding characteristics of structural materials, and to provide measures for influence reduction of new construction on the existing building.

Modeling of retaining structures work can be carried out both by the plane, and spatial calculation scheme.

The choice of the scheme depends on the size of the structure in length. With a significant increase in the length of the supporting structures, the results of calculations in the flat and spatial settings are close in value.

Therefore, the assessment of SSS bases should be carried out with due regard to all the features of the supporting structures and the pit in the challenging urban and geological conditions.

Calculations of the pits' excavation at the second boundary condition make it possible to design more reliable retaining structures, excluding any destruction of existing buildings.

To establish the base's SSS, we used the software package "CONCORD - 4.2" (author – S.F. Klovanych) FEM in a plane setting [13].

The theoretical basis of the "CONCORD - 4.2" is a mathematical description of the soil as a continuous isotropic medium. The proposed soil model is a development of the theory of small elastic-plastic deformations by AA Illiushin and the deformation theory of G.A Geniiev.

This phenomenological model takes into account physical and geometric nonlinearity, dilatancy, compaction in the process of deformation, different resistance to compression and tension, pore and hydrostatic pressure, shrinkage, and swelling of the soil. When posing the problem of nonlinear soil mechanics, the following hypotheses are adopted [13]:

– manifestations of nonlinearity are taken into account: they contain plastic deformation of shape change under a complex stress state, the connection between the components of stress and strain deviators is nonlinear;

– plastic deformation takes into account dilatancy, ie the nonlinear relationship between the components of volumetric stress and strain tensors;

– unimpeded deformation of the soil during stretching.

The model of the soil is based on the relationship between octahedral tangential stress and displacement. The initial characteristics of the soil:

– specific cohesion c;

– internal friction angle ϕ;

– deformation module *E*;

– displacement module *G*;

– spatial deformation module К, – change in the calculation process is a function of the SSS of the soil massif [13].

To describe the ultimate strength, a generalized Mises-Schleicher-Botkin criterion is used, which determines the value of the octahedral tangential stress depending on the octahedral normal stress $\tau_0 = \sigma_0 \text{ tg } \phi_0 + c_0$. The strength surface by this criterion describes the cone in the space of principal stresses [13].

The algorithm of the software complex automatically takes into account the compaction of the base soil under the foundations during the operational period (for an existing building).

The application of the complex enables estimating the SSS of the system, to get an image of the possible impact of new construction on existing structures and buildings, to make decisions on preventing the undesirable impact of new construction on both existing and project facilities. [13].

The main problems in modeling the installation of deep pits will be considered by the example of the construction of a high-rise residential building in Kyiv. The calculation scheme for modeling the deformations of the base is shown in Fig. 2.

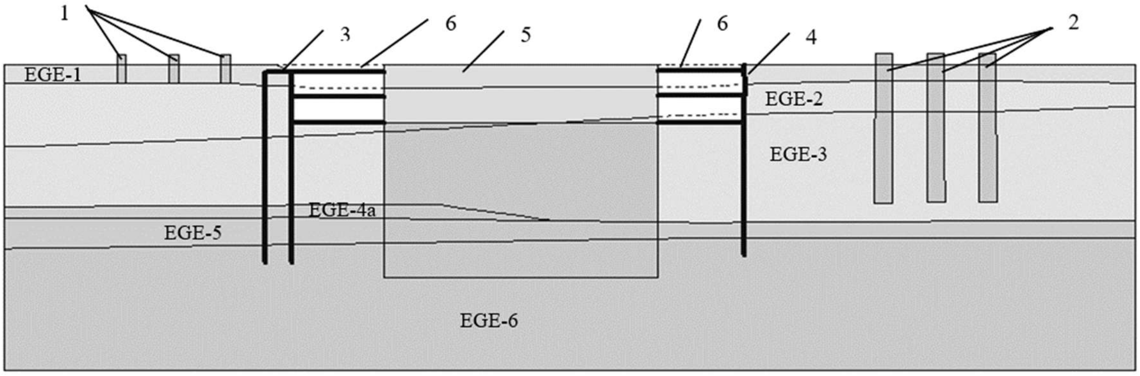


Figure 2 – Calculation scheme: 1, 2 – foundations of existing buildings; 3 – retaining wall of two rows of drilled piles; 4 – retaining wall of one row of drilled piles; 5 – new building; 6 – parking

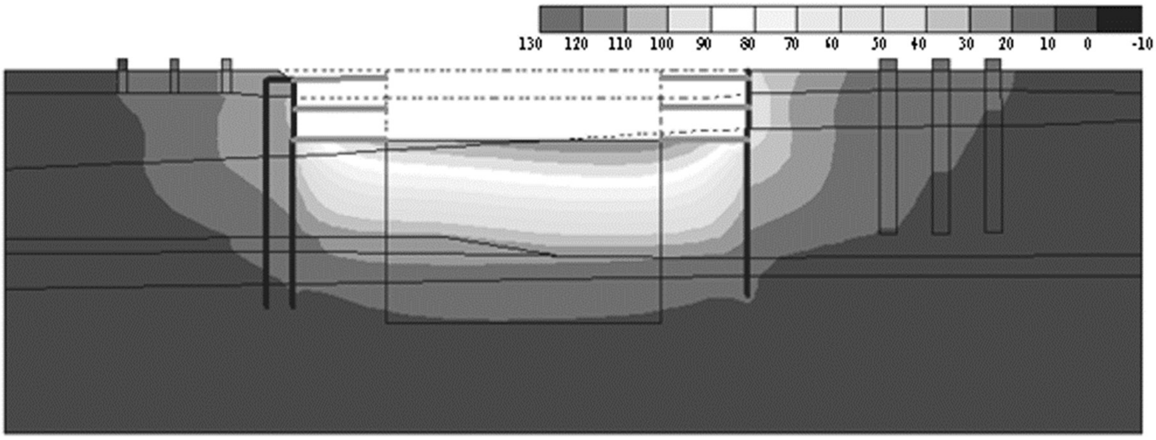


Figure 3 – Base displacement of the foundation pit setting up

The base of the foundations is represented by six engineering-geological elements and includes sandstones and clays with a total thickness of up to 10 – 15 m, which are underlain by low-moisture fine dense sands.

An aquifer was found in the sandstone, which is caused by precipitation and leaks from aquifers. It is considered that piles rest on shallow dense sand.

The high-rise building is located in a dense urban development on a landslide-prone slope. The foundations of the building are piles with a grille performed as monolithic reinforced concrete 2 m thick slab. The length of the piles from the bottom of the grille is 22 - 25 m, diameter 800 mm.

By the technological solution, the piles are drilled. Existing buildings adjoin the new one on both sides at a distance of 4 m and 15 m.

A 10 m deep pit is used to erect the building's foundations and its underground part. To prevent the destruction of the walls of the pit and undesirable deformations of the existing building, the installation of retaining structures in the form of a retaining wall of drilled piles with a diameter of 1000 mm and a length of 23 - 25 m with the stiffness per 1 running meter of EA = $3{,}0\cdot10^6$ kN and EI = $4{,}7\cdot10^4$ kNm^2.

In the simulation, the options for installation piles in one and two rows, as well as the use of soil anchors with stiffness indices at equivalent length are considered to be l_e = 10 m EA = $9{,}8\cdot10^4$ kN.

The data in table 1 indicates that the parameters of retaining structures (type, number, stiffness, location) in the presence of existing buildings, should be selected based on the actual condition of these buildings and the allowable additional deformations.

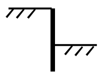
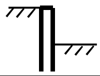
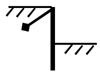
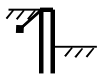
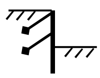
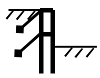
Accordingly, the retaining structure, calculated by this principle, may have a higher material consumption than that calculated only for strength, but completely eliminate the possibility of destruction of existing buildings around the pit.

So far there is no standard data on the limit values of deformations of existing buildings and structures from the impact of new construction in the conditions of dense urban development.

In our opinion, it is possible to use the data given in [6], which regulates the allowable settlement depending on the category of the existing building by its wear, i.e. on its actual condition.

According to the materials of the technical inspection, it is an existing building with four above-ground floors, frameless with load-bearing brick walls and strip foundations on a natural base.

Table 1 – Deformations of the existing building due to the construction of the pit of the new building depending on the design of the retaining structure

Variant	Bearing structure description		Foundation pit elevation, mm	Bearing structure top displacement, mm	Additional deformation	
					absolute subsidence, mm	settlement unevenness
1		drilled piles in one row	119	214	24	0,0016
2		drilled piles in two rows	117	139	20	0,0013
3		drilled piles in one row with foundation bolts’ row	97	8	12	0,0006
4		drilled piles in two rows with foundation bolts’ row	98	7	8	0,0003
5		drilled piles in one row with foundation bolts in two rows	96	5	8	0,0003
6		drilled piles in two rows with foundation bolts in two rows	96	3	5	0,00021

According to table 5 [6] the category by the condition of the load-bearing structures of the building is the second. The additional deformations limit of the existing buildings' foundation by table 4 [6] are $[S] \leq 1.0$ cm, and their relative settlement difference is $[\Delta S/L] \leq 0.0007$.

According to the results of mathematical modeling by the FEM, it is established that at the stage of operation the new building will cause additional subsidence of the foundation of the existing building $S_0 = 0.4$ cm, and the relative difference of the settlement – $\Delta S/L = 0.0005$.

When constructing a retaining structure according to items 4, 5 of the table. 1 total deformation of the foundation of existing buildings will be

$$S_0 = 0.8 + 0.4 = 1.2 \text{ cm} > [S] = 1.0 \text{ cm},$$

and

$$\Delta S/L = 0.0005 + 0.0003 = 0.0008 > [\Delta S/L] = 0.0007.$$

Thus, the conditions of the deformations' calculation for these variants of retaining structures (respectively, drilled piles in two rows with a row of anchors and drilled piles in one row with two rows of anchors) are not met.

In the construction of the retaining structure according to paragraph 6 of the table 1 total deformation of the foundation of existing buildings will be

$$S_0 = 0.5 + 0.4 = 0.9 \text{ cm} < [S] = 1.0 \text{ cm},$$

and

$$\Delta S/L = 0.0005 + 0.0002 = 0.0007 = [\Delta S/L] = 0.0007.$$

Therefore, the conditions of deformations' calculation for the sixth variant of retaining structures – drilled piles in two rows with two rows of anchors, are fulfilled.

Conclusions

Thus, the above method specifies the calculation of determining the impact of the new building on existing buildings and structures, which enables assigning the design of retaining structures from the conditions of the further normal operation of existing facilities.

Parameters of geotechnical structures (type, quantity, rigidity, location) of retaining walls of deep pits in the presence of nearby existing buildings should be selected based on the actual condition of these buildings and allowable additional and relative deformations for their foundations.

It is also necessary to take into account the sequence of works and the nature of the loads, the relevant characteristics of the materials of structures.

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