Assessment of the impact of the construction of semi-buried structures on the surrounding buildings and the road system

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Abstract. The purpose of the study is to perform a geomechanical forecast and assess the impact of the construction of semi-buried structures on the surrounding buildings and adjacent roads. The article presents the result of the forecast of subsidence of the earth's surface during the construction of the Foundation pit during the construction of a new facility (public service Center) and the adjacent road infrastructure, built in a dense urban development. The modeling was carried out in a three-dimensional for-emulation taking into account the nonlinear work of the soil and the phased construction of the foundation ditch. Selected parameters of bearing and enclosing structures of the foundation pit. The assessment of the impact of construction on the surrounding buildings.

1. Introduction

New construction of buildings in a dense urban environment can have a significant impact on buildings and structures in the city. To reduce the negative impact on existing buildings, various structural and technological solutions of enclosing structures are used in the development of the pit [1-3]. The most economical is considered tongue-and-groove fencing, which allows you to minimize the impact on the surrounding buildings at minimal cost [5].

Geotechnical assessment of the situation at the construction site was performed using the Plaxis 3D software package. The three-dimensional model gives an idea of the General picture of the stress-strain state of the construction site, including the 30-meter zone of work impact [11-13].

The Plaxis software package allows you to calculate the stages of construction. At the initial stage, the natural stress-strain state is formed. After each stage of construction work, a new stress-strain state is formed, corresponding to changes in the design model. Numerical analysis makes it possible to more accurately predict the development of sediments due to improved soil models, taking into account its nonlinear operation under load.

2. Methods

2.1. Description of the research object

The projected building is a sixteen-story building with an underground built-in Parking lot. The building has dimensions in terms of 1 floor – 29.8×43.99 m; Height 54.8 m. the Structural scheme of
the building is combined with a monolithic core of rigidity of the stair-lift node and columns of the frame.

The pit is located on a built-up part of the block. Existing buildings fall within the 30-meter zone of influence of construction works (Figure 1). According to the technical conclusion, the buildings belong to the II category of technical condition. In accordance with [4], the maximum de-formation of the base of the foundations of buildings and structures of the surrounding development located in the zone of influence of new construction for buildings of category II of technical condition is 30 mm, the unevenness of the sediment is 0.002.

Figure 1. Situational plan of the object.

In plan, the pit is a rectangle measuring 59×55 m. The absolute mark of the daily surface from which the sheet pile will be loaded is about +3.000. The absolute mark of the bottom of the pit, taking into account the preparation, is -1.800. The depth of the pit is about 4.8 m. The device for fixing the pit is supposed to be made of metal sheet metal Larsen brand VL-606A. The required depth of immersion of the sheet pile is determined by the presence of a strong layer, the required depth of the sheet pile wall, which ensures the sealing of the sheet pile in a solid ground, is 12 m (sandy loam №5).

Preliminary calculations of the sheet piling fence showed the need to introduce additional fastening elements in the structure of the sheet piling fence, since the horizontal displacement of the sheet piling wall according to the cantilever scheme of operation will be 18 cm.

The corners of the pit are loosened by spacers installed in two belts (pipe 377×12) at a distance of 4 m and 8 m from the corner of the pit. It also provides struts of 370×12 pipes with a step of 8-9 m.

2.2. Production technology
Sinking the sheet pile to the design mark on the pre-planned territory up to the absolute mark of +3.000. The plunging of the sheet pile is allowed to be carried out using the technology of high-frequency vibration loading.

After the formation of a closed loop, pile work is performed.
Excavation of the pit is carried out under the protection of underground berm. Berm development is carried out in sections. The initial excavation of the pit to a depth of no more than 2 m, then a binding beam and a system of angular struts are arranged at a depth of 1.5 m.

Excavation of the first section in the Central part of the pit to the design mark -1.800 m with subsequent concreting of the grill plate. Along the sheet pile wall along the contour is left a ground berm with a height of 2.8 m with a slope of 1:2. the width of the upper platform of the berm is 5 m.

Next, you hook the phased development of soil berms with the concreting of the slab grillage after each stage of adopci. Pre-installation of struts is carried out within the gripper. Installation of struts is carried out in specially prepared trenches without developing the main mass of the soil berm. Only after the struts are included in the work, further work on digging the pit is performed.

2.3. Model description

For modeling, an elastic-plastic model of hardening soil was adopted, taking into account the change in properties under small deformations (HS small), which was widely used in the prediction of deformations of the soil mass in the vicinity of underground structures. The nonlinear elastic model of the Duncan-Cheng hardening soil provides a hyperbolic relationship between the vertical relative deformations $\epsilon_1$ and the stress deviator $q$.

The behavior of the soil in drained triaxial tests is described by the following equation at $q < q_f$

$$\epsilon_1 = \frac{q_a}{2E_{50} q_a} \frac{(\sigma_1 - \sigma_3)}{(\sigma_1 - \sigma_3)}.$$  \hspace{1cm} (1)

The limit value of the voltage deviator $q_f$, and the parameter $q_a$ are determined by the formula:

$$q_f = \frac{6 \sin \varphi_p}{3 - \sin \varphi_p} \frac{(\sigma_1 - \sigma_3)}{\sigma_1 - \sigma_3};$$  \hspace{1cm} (2)

$$q_a = \frac{q_f}{R_f}.$$  \hspace{1cm} (3)

Equation (2) is derived from the Coulomb-Mohr strength criterion, and the parameter $R_f$ numerically characterizes the $q_f/q_a$ a ratio.

The behavior of the soil under loading is nonlinear and depends on the stress state at a given time. The hardening soil model uses a dependency that defines the tangent modulus of soil deformation:

$$E_{50} = E_{50}^{ref} \left( \frac{\sigma_3 + c \cot \varphi_p}{\sigma_3^{ref} + c \cot \varphi_p} \right)^m.$$  \hspace{1cm} (4)

where $E_{50}^{ref}$ is the modulus of soil deformation corresponding to the average stress $\sigma^{ref}$.

The soil deformation modulus $E_{50}^{ref}$ is determined from standard three-axis tests when the stress deviator $q$ reaches 50% of the maximum shear strength $q_f$ (Figure 2).
Figure 2. The behavior of soil when it is loading and unloading in standard drained triaxial test.

During unloading and subsequent loading, an independent elastic modulus is introduced, which can be expressed by the formula:

$$E_{ur} = E_{ur}^{ref} \left( \frac{\sigma_3 + c \cot \varphi_p}{\sigma_{ref} + c \cot \varphi_p} \right)^m,$$

(5)

where $E_{50}^{ref}$ is the modulus of soil deformation corresponding to the average stress $\sigma_{ref}$.

Thus, unloading and subsequent loading reflect the nonlinear elastic behavior of the material. The value of $\sigma_{ref}$ is assumed to be 100 kPa.

The surface of the plastic flow of the hardening soil model is written as:

$$f_{12} = \frac{q_a}{E_{50}} \frac{\sigma_1 - \sigma_2}{q_a - (\sigma_1 - \sigma_2)} - \frac{2(\sigma_1 - \sigma_2)}{E_{ur}} - \gamma^p;$$

$$f_{13} = \frac{q_a}{E_{50}} \frac{\sigma_1 - \sigma_3}{q_a - (\sigma_1 - \sigma_3)} - \frac{2(\sigma_1 - \sigma_3)}{E_{ur}} - \gamma^p,$$

(6)

where $\gamma^p$ is the volume plastic deformations.

The surface of the plastic flow that characterizes the behavior of the material during shear cannot describe the volume compaction (in other words, the volume plastic deformations) of the material obtained during isotropic compaction. It is necessary to introduce a second surface of the plastic flow, in the form of a tent, which will start from the axis of effective average stresses and end at the intersection with the plasticity surface that characterizes the shift [6-7].

$$f_c = \frac{q^2}{M^2} + (p + a)^2 - (p_c + a)^2,$$

(7)

The equation of strengthening of the tent part of the model of the hardening soil is given below:

$$\varepsilon^p_v = \frac{\lambda^*}{K^* - 1} \left( \frac{p^{ref}}{p_c^{ref}} \right)^m.$$

(8)

The General view of the surface of the plastic flow of the hardening soil model can be presented below (Figure 3).
The hardening soil model is a model with double hardening, under shear and under volumetric compression. This class of models allows you to set the shear and compression strength independently.

The main stages of calculation that simulate the sequence of work:
- determination of existing stresses in the ground mass, taking into account existing buildings;
- execution of works on the device of the sheet pile wall;
- step-by-step excavation of the pit to the design mark (Figure 4).

The simulation took into account the effect of evenly distributed technological load of 3 t/m2 from construction equipment, storage of materials and driveways at a distance of 2 m from the edge of the boiler [8-10]. The load on the Foundation of existing buildings was calculated based on the volume weight of structures 0,5 t/m³.
3. Results
The calculation results are presented by a model of deformations of the “ground – pit – surrounding construction” system, horizontal and vertical movements (Figure 6), forces in the sheet pile wall, struts and corner struts. The criteria for safe development of the pit are the maximum value of additional precipitation of the surrounding building, the load-bearing capacity of the pit attachment elements, and the overall stability of structures.

The maximum force in the corner strut is 130 t, in the struts – 70 t. The conditions of strength and deformability are met by the Larsen VL-606A sheet pile with a length of 12 m with the release of the pit corners and the device of struts. The corners of the pit are loosened by two rows of corner struts at a distance of 4 m and 8 m from the corner of the pit. The 377×12 tube is used as the corner struts. It is recommended to use a 377×12 pipe as struts. The pitch of the struts is 8-9 m. It is allowed to apply an additional time load on the edge of the pit. The value of the load at the rate of 3 t/m² at a distance not closer than 1 m from the edge of the pit.

Figure 5. General view of the calculation model: a – at the initial stage of work production; b - at the final stage of work production.

Figure 6. Isofield of vertical movements at the initial stage of pit development.
Figure 7. Isofield of vertical movements at the final stage of pit development.

The maximum movement of the tongue-and-groove fence obtained in the calculation is 6 cm (Figure 7). The maximum additional draft of existing buildings is 0.3 cm < 3 cm. The roll of buildings does not exceed 0.002 (Figure 8). the Forces in the struts and struts do not exceed the strength limit of the material.

Figure 8. Isofield of additional sediments of the surrounding development at the stages of digging the pit under the protection of ground berm and during the work of struts.
The maximum draft from the design load was 5 cm, which does not exceed the maximum permissible for the joint venture [4]. The load-bearing structures of the building meet the regulatory requirements for strength and deformability, which ensures safe construction conditions.

4. Conclusions
The numerical simulation performed in the volumetric setting, taking into account the stages of construction of the pit, showed that subsidence of the earth's surface does not cause unacceptable impacts on the surrounding buildings. The additional draft of buildings and their roll is less than the limit values. The selected parameters of load-bearing and enclosing structures ensure safe work during the zero-construction cycle.

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