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ASSESSMENT OF THE STRESS-STRAIN STATE OF RETAINING WALLS OF DEEP PIT IN CONDITIONS OF DENSE URBAN CONSTRUCTION

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ABSTRACT

The comparison of the results of geodetic monitoring of displacements of existing buildings and retaining walls construction and numerical simulation of the stress-strain state of the system 'soil - retaining walls - existing buildings' is shown. The back analysis was performed and the parameters of the soil model were verified. It is recommended to verify the soil model parameters on the basis of laboratory tests of soil parameters in a wide range of loading/unloading using axial and triaxial soil compression.

Keywords: retaining walls, dense urban construction, geodetic monitoring, numerical simulation.

INTRODUCTION

The construction of deep pits for the construction of underground parts of buildings in dense areas involves significant amounts of earthworks. Such construction affects the change in the stress-strain state of the soil, pit enclosure structures and existing buildings. For the safe performance of such works and selection of effective parameters of retaining walls of the pit, it is necessary to perform a comprehensive assessment of the stress-strain state of the system 'soil - retaining walls - existing buildings' using numerical simulation. Solutions to similar problems are presented in the works of Sinem Bozkurt (2023), Monika Mitew-Czajewska (2019), Alessandra Di Mariano (2021), Filip Dodigovic (2022), Xin Yan (2025) and others. It is important to choose the correct model of interaction between the soil and structures, as well as to determine its main design parameters based on in situ and laboratory tests. A practical case of designing and constructing a deep pit in Kyiv is shown.

CONSTRUCTION SITE CONDITIONS

The construction site is located in the historical part of Kyiv, in a dense urban construction. Brick houses are located in the immediate vicinity of the construction site. Building No. 1 is three storeys high, the distance from the building to the edge of the pit is 3 m. Building No. 2 is five storeys high, with a distance of 11 metres from the building to the edge of the pit. The foundations of these buildings are strip shallow foundations, and located well above the depth of the new building's pit, which is 7.5m. These buildings are sensitive to uneven deformations, so it is important to assess

the impact of the new construction on them. The location of the buildings in relation to the construction site is shown in Fig. 1.

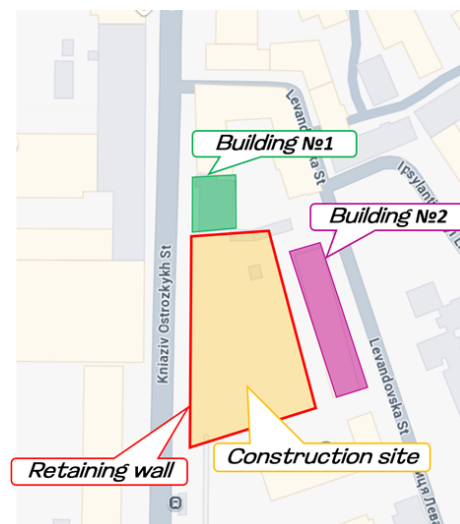


Figure 1 Layout of the construction site and surrounding buildings

The soils within the construction site are silty clay, with subsiding properties in the upper part. The groundwater level is located at a depth of 7.8-9.0 m.

The pit has a trapezoidal shape in plan. Retaining walls of 820 mm and 1020 mm diameter bored piles was constructed around the perimeter of the pit. The piles are connected by a 0.8 m high monolithic capping beam. The length of the piles is variable

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and ranges from 16.3-18.4 m. To increase the spatial rigidity and reduce the displacement of the retaining walls in the areas of existing buildings, a spacer system of 820x10 mm pipes was installed at a depth of about 3.0 m. A fragment of the retaining walls for the excavation is shown in Fig. 2.



Figure 2 Construction site and retaining walls

DEFORMATION MONITORING

It is important to ensure the safety of the surrounding buildings to monitor the condition of retaining walls and existing buildings before and during construction. Such observations were carried out at this construction site. When measuring the horizontal displacements of the retaining walls, the measurement accuracy was ensured to be ± 2 mm. The scheme of the retaining walls, the location of the observation points and the values of the displacement vectors are shown in Fig. 3.

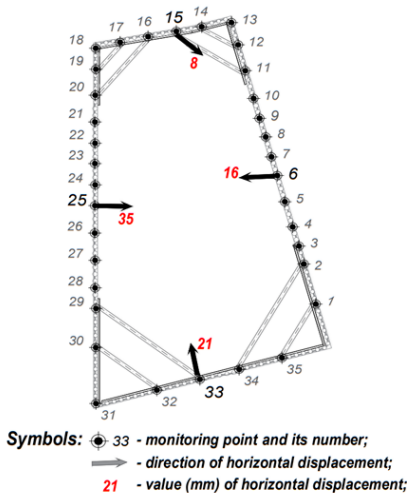


Figure 3 Results of geodetic monitoring of the retaining walls

Additional settlements of the existing buildings were measured before the start of the works, during the construction of the retaining wall and during the excavation of the pit. The accuracy of the settlements was ± 1.0 mm. The maximum values of the actual additional settlements of the existing buildings that they received during the excavation of the pit are shown in Table 1.

Table 1 Additional settlements of existing buildings

Building	Settlements, mm
Building №1	6
Building №2	3

NUMERICAL SIMULATION

During the design of the retaining walls, the numerical simulation of the stress-strain state of the system 'soil - retaining walls - existing buildings' was performed using the finite element method. The finite element model of the system 'soil - retaining walls - existing buildings' created in the Plaxis 3D software package is shown in Fig. 4.

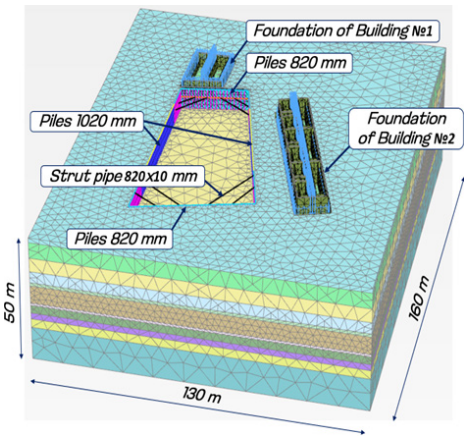


Figure 4 Finite element model in the Plaxis 3d

In this paper, the model of elastic-plastic deformation of soils, the Hardening Soil Model, with parameters varying depending on the level of stress in the soil, is used to model the interaction of soils and is an advanced model for describing the behaviour of soils in a wide range of loads with the Mohr-Coulomb strength criterion. The main feature of the chosen model is that it takes into account the dependence of the stiffness of the soil on the level of acting stresses (Schanz, Vermeer, Bonnier 1999).

Initially, the calculation was performed with the input parameters of the soil model specified in the geological survey report on the site, and then the model parameters were verified based on monitoring data to approximate the results of numerical simulation and actual geodetic monitoring data on the displacement of structures.

The main parameters of the soil model for which verification was carried out are: the modulus of deformation determined in the odometer $E_{od,ref}$, the modulus of deformation at 50% strength $E_{50,ref}$, the modulus of deformation at unloading/reloading $E_{ur,ref}$, the friction angle φ , and cohesion c .

The simulation takes into account the main stages of construction:

Phase 1 - gravity loading of the soil;

Phase 2 - consideration of loads from the foundations of existing buildings;

Phase 3 - simulation the appearance of a retaining walls;

Phase 4 - excavation of the pit to a depth of 4.0 metres;

Phase 5 - installation of piles for the new building and installation of expansion pipes;

Phase 6 - excavation of the pit to the design level of -7.5 m.

The results of the simulation, namely the displacement of the retaining walls and additional settlements of the existing buildings, obtained with the input parameters of the soils are shown in Fig. 5.

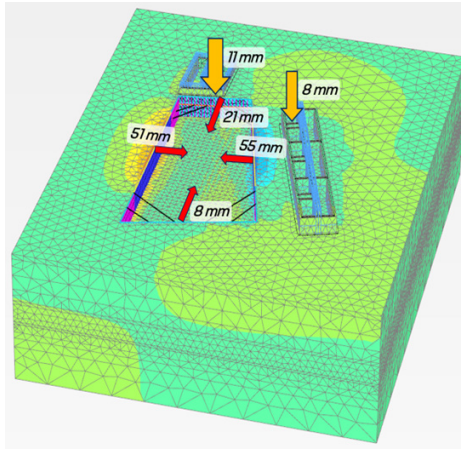


Figure 5 Simulation results with input parameters of the soil conditions

Based on the results of the initial simulation using the initial parameters, conservative values of the existing building settlements and retaining walls displacements were determined, which were significantly higher than the data obtained from monitoring. Therefore, it was decided to conduct a back analysis to verify the parameters of the soil model in order to bring the simulation results closer to the actual geodetic observations.

COMPARISON OF RESULTS

Comparison of the results of numerical simulation using the input and verified model parameters with the data on monitoring of horizontal displacements of the retaining walls is shown in Table 2.

Table 2 Horizontal displacements of the retaining walls at the control points

Variants of the results received	Horizontal displacements No. of points, mm			
	No 15	No 6	No 33	No 25
Monitoring	8	16	21	35
Numerical simulation with input soil model parameters	21	55	8	51
Numerical simulation with verified soil model parameters	16	34	4	31

Comparison of the results of numerical simulation using the input and verified model parameters with the data on monitoring of settlements of existing buildings is shown in Table 3.

Table 3 Additional settlements of existing buildings

Variants of the results received	Additional settlements of buildings, mm	
	Building No 1	Building No 2
Monitoring	6	3
Numerical simulation with input soil model parameters	11	8
Numerical simulation with verified soil model parameters	7	3

Analysing the above data, it can be stated that in numerical simulation using the input parameters of the model, the additional settlements of the foundations of existing buildings predicted by numerical simulation exceed the actual monitoring data by about 2 times, which indicates a conservative assessment due to the use of inaccurately determined input parameters of the soil model. In numerical simulation using the input parameters of the model, the horizontal displacements of the retaining walls exceed the monitoring data by 2-3.5 times. When using the verified model parameters, the results of the subsidence prediction are almost identical to the monitoring data, and the calculated displacements of the retaining walls have significantly decreased, but in some points exceed the monitoring data by 2 times.

CONCLUSIONS

It is shown that the direct use of soil parameters given in the geological survey report for numerical simulation of the stress-strain state of the system 'soil - retaining walls - existing buildings' without their verification can lead to significant (2-3.5 times) inaccuracy in determining the calculated values of displacements of structures and soils. The main reasons for this are: inaccurate determination of soil parameters during geological surveys and inconsistency of their testing modes with actual changes in their stress state, heterogeneity of soil conditions, the impact of retaining walls technology on the condition of the soil, etc.

Verification of the soil model parameters used for numerical simulation allows to obtain a good convergence of numerical simulation data and actual monitoring data. Verification is recommended to be performed on the basis of laboratory tests of soil parameters in a wide range of loading conditions, including: loading, unloading and reloading of soil samples, under axial and triaxial compression. An alternative method for verifying the design parameters of the soil model is to construct pilot pits to determine the actual values of retaining walls displacements and, based on the inverse analysis, to refine the design parameters of the soil model to match the results of numerical simulation and the data of actual measurements of structural displacements. Implementation of these recommendations will make it possible to bring the displacements predicted by numerical simulation closer to real values during construction works involving deep pits.

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