Dynamic problems of scientific support construction

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Abstract. This article presents the results of scientific support of the project and construction, as well as geotechnical monitoring of the multi-storey residential complex Bogorodsky with four towers of 35 floors and a developed underground part of two floors in difficult geotechnical conditions. In the immediate vicinity of the building under construction there is a line of high-speed city tram. In addition, since the building has a status of increased complexity, it is necessary to take into account the seismic load. As part of the geotechnical tasks of scientific support, in addition to assessing the displacement of the designed building and assessing the impact on the surrounding buildings, the forecast of additional displacements of the base from the effects of ground rail transport and seismic was considered. The geotechnical forecast was carried out by the finite element method in specialized software. The calculations are based on flat sections taking into account the elastic-plastic properties of soils. In conclusion, the results of observations of the displacements of the building under construction and the surrounding buildings are presented. Displacement graphs of geodetic marks installed on the structures of the building and surrounding buildings are presented. A comparative analysis of the results of the geotechnical forecast and the actual situation at the construction site.

1. Introduction

In the design and construction of complexes of high-rise buildings of increased responsibility in difficult engineering and geological conditions, the need arises for scientific support and geotechnical monitoring, which is provided by SP 305.1325800.2017 «Buildings and structures. Rules for conducting geotechnical monitoring during construction».

Scientific support of the project and construction consisted in a quantitative assessment of the stress-strain state of the system «heterogeneous foundation - the underground part of the complex and the surrounding buildings» (hereinafter «the system») [1], taking into account the phased construction of the zero cycle, and the uneven distribution of load on the slab foundations for tall buildings and under stylobate part of the complex.

Scientific support also included work on the analysis of the results of geodetic observations of marks installed on the slab foundations of the complex and on the structures of the surrounding buildings and the preparation of intermediate conclusions on the stress-strain state of the «system» on a quarterly basis [2].

In addition, the scientific support program provided for the calculation of the stress-strain state of the «system» from the effects of transport, seismic forces with an intensity of 6 points, as well as the influence of dangerous geological processes [3]. In this case, the effect of suffusion of fine-grained sands from the pressure water horizon through the overlapping layer of low-permeable loam.
Figure 1. Design scheme (three-dimensional geomechanical model) in PLAXIS software for determining the stress-strain state of an array enclosing the underground part of the complex and the surrounding buildings.

Figure 2. Isolines of vertical displacement of slab foundations after construction (in meters), constructed according to the results of mathematical modelling (a) and according to the results of geotechnical monitoring (in millimetres) (b).

The engineering and geological conditions of the construction site, according to surveys, belong to the III (complex) category of complexity, which is due to the presence of relatively weak clay soils with a thickness of 2 to 4 meters at the bottom of the pit, which serve as a stopper for the underlying aquifer pressure head (pressure up to 4 meters) of fine-grained sand. When excavating soil from the foundation pit, needle filters were installed that reduced the groundwater level to an absolute mark of 130.00 m. However, this was not enough due to the large area of the foundation pit. The soils were waterlogged, and the work of heavy equipment in the pit became impossible. When laying and compacting a sand-gravel layer 50-60 cm thick and concrete preparation under a slab foundation, according to our recommendation, a temporary local water reduction with needle filters within each block was carried out. This allowed the use of heavy equipment in the pit and accelerated the preparatory work at the bottom of the pit and the work of the zero cycle as a whole.

The structural diagram of the buildings that make up the Bogorodsky residential complex is an internal frame of monolithic reinforced concrete pylons with a cross section of 1200×900 mm and
walls with a thickness of 250 and 300 mm with a core of rigidity and interfloor ceilings with a thickness of 200 and 250 mm. The complex stands on a stylobate 4.2 meters high from the planning level of the earth, which is the -1st level of the underground parking lot. Multi-storey parts include 31 residential floors.

Foundations in the high-rise and stylobate parts of the building of the complex are designed in the form of monolithic reinforced concrete slabs, the total area of which exceeds 22,5 thousand m². The thickness of the foundation plates varies from 0.6 m (under the stylobate parts of the complex) to 2.0 m (under the high-rise parts). The footprints of the soles of the slabs are 132.00 m. The slabs of the high-rise and stylobate parts of the complex are separated by expansion joints.

The foundations of buildings at the indicated level of their laying will be based on moraine loams (IGE-7) with a deformation modulus of 19.4 and 32 MPa, respectively, and also partially on fine sands of medium density with a deformation modulus of 30 MPa.

The pit for the complex, depending on the relief, deepens from the surface of the earth to a depth of 7.75 m to an absolute bottom mark of 132.00 m.

The foundation pit enclosure is designed in the form of metal pipes with a blockage between them and is buried below the bottom of the cat-catch by 4 and 6 m to an absolute mark of 128 and 126 m into medium and silty sands, of medium density and dense, water-saturated. The stability of the fence for the period of excavation is provided by a two-tier spacer system in the soil of the base.

2. Methods

Quantitative assessment of the stress-strain state of the «system» is carried out by the finite element method (FEM), is implemented using the PLAXIS 3D software package, taking into account the phased construction of the zero cycle, including building water reduction, the construction of the enclosing structures of the pit, excavation of the pit, the device of slabs foundations and their gradual loading, as well as taking into account the elastic-plastic properties of the soil base.

![Figure 3. Isopole of vertical displacements of the surrounding soil mass within the basin and the nearest building from the edge of the foundation pit due to water reduction.](image_url)
Figure 4. Isopole of general displacements due to vibration from transport.

Figure 5. Isopole of additional total displacements due to seismic loading.
Figure 1 shows the design scheme of the «system», and Figure 2 shows the contours of vertical displacements after construction (forecast) and actual observation data. From Figure 2 it can be seen that there is an uneven settlement of plates under the high-rise parts of the buildings and under the stylobate part.

Figure 3 shows the contours of the vertical displacement of the massif during construction dewatering, including under the foundations of the building closest to the edge of the foundation pit. The maximum displacement is 9 mm.

Figures 4 and 5 show the results of the calculation of the «system» under the influence of vibration load from transport (tram, motor vehicles at a distance of 20 m from the edge of the pit) and from seismic effects, respectively. The device of a protective shield made of metal pipes, recommended by us, along the pit reduces the effect on the stress-strain state of the array. Seismic effects on the «system» judging by the displacements and accelerations are not significant. Analysis of the stress-strain state of the «system» showed that accelerations in the pressure-bearing aquifer from fine-grained sands cannot cause liquefaction [4-5].

![Figure 6](image.png)

**Figure 6.** Dependence graph of displacement (mm) of geodetic signs installed on the structures of section «G» on time (day).

3. Results

Geodetic monitoring of the complex under construction and the buildings of the surrounding buildings is carried out by specialists of the structural subdivision of OJSC «Research Center «Construction» - NIIOSP named after M.N. Gersevanov [6-8].

Instrumental geodetic observations include monitoring the precipitation of the structures of the residential complex under construction.

Precipitation monitoring, accuracy and cyclicity of geodetic measurements are carried out in accordance with current regulatory documents for this type of work. Observations are carried out in cycles with a frequency of twice a month in the process of construction and installation works [9-12].

To conduct geodetic monitoring with the aim of subsequently determining the vertical displacements (sediments) of the complex under construction, three groups of geodetic signs were installed at the facility:

- reference frames, the heights of which are considered to be stable within a strictly justified tolerance - they serve as an initial basis, relative to which the displacements of deformation marks (grades) are determined, the frames are located outside the zone of possible soil deformation;
deformation marks (observed points), the vertical displacement of which is determined in each measurement cycle - to fully describe the deformation process taking into account the building structure, deformation marks were fixed on the main structures of the complex under construction (walls and columns);

- auxiliary (suitable) signs are necessary for constructing the optimal scheme of engineering and geodetic measurements, they are used in the measurement scheme due to the inability to place reference signs near the observed objects, i.e. they are binding.

Based on the results for the entire period of observation of the precipitation of the complex under construction and the surrounding buildings located in the zone of influence of the construction of the complex, graphs of the dependence of the precipitation of grades installed on the complex’s structures on the number of cycles and on time were constructed [13].

Graphical processing of precipitation observations is presented in Figure 6.

4. Conclusions

Based on the results of observations, the following conclusions can be drawn:

1. The average displacement of all four sections (A, B, B, and D) does not exceed 85 mm, which is significantly less than 225 mm — permissible to SP 22.13330.2016 «Foundations of buildings and structures» and 170 mm — predicted by mathematical modelling.

2. The maximum incline of foundations is 0.0016, which is within acceptable values, i.e. less than 0.003, according to SP 22.13330.2016 «Foundations of buildings and structures».

The results of observations of precipitation of the surrounding buildings for the entire observation period (33 cycles) showed insignificant displacements and have now practically stabilized. Considering that for buildings of the 2nd category, the maximum additional displacements is 30 mm (according to SP 305.1325800.2017 «Buildings and structures. Rules for conducting geotechnical monitoring during construction»), and the maximum predicted displacement according to the results of computer simulation is 8 mm, we can draw conclusions about the stable position of the observed buildings that do not require reinforcement their designs.

Scientific and technical support for the project and the construction of the Bogorodsky high-rise residential complex in Moscow lasted 3 years [14-16]. Currently, the construction of the complex is completed. Actual precipitation of the foundation slabs turned out to be almost two times less than predicted, which is due to inaccuracies in determining the parameters of the soil of the base [17-21].

The performed works on scientific support and geotechnical monitoring contributed in many respects to the successful completion of the construction of the complex and its commissioning.

Acknowledgments

This work was financially supported by the Ministry of Education and Science (state task #7.3225.2017/4.6). All tests were carried out using research equipment of The Head Regional Shared Research Facilities of the Moscow State University of Civil Engineering.

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