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Hydrogeological modelling in the geotechnical forecast

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Abstract. Underground development project activities for structures located below existing level of groundwater can cause changes in hydro-geological conditions on the construction site and adjacent territories and lead to development of unfavourable engineering-geological processes. Article presents results of hydrogeological forecast at the construction site with foundation pit enclosed in diaphragm wall. To recreate existing hydrogeological conditions and to create accurate model, inverse problem was solved with a multivariate selection of the filtration parameters of the modeled system in such way that there was a satisfactory alignment of modeled groundwater levels and groundwater levels marked during well-drilling, and analytical data, acquired during analysis and compilation of existing hydrogeological data. Upon solution of inverse problem to replicate existing hydrogeological conditions on the model, a series of forecasting tasks was undertaken to assess the impact of planned construction on hydrogeological situation of the construction site and adjacent territories. Construction was modelled in a multi-variant setting for a completely impermeable diaphragm wall and a permeable diaphragm wall with coefficient of filtration of 0.005 m/day. It is advisable to provide a comprehensive hydrogeological and geotechnical forecast at the design stage as it helps to predict how changes in hydrogeological regime affect deformation behaviour of surrounding buildings.

1 Introduction

Both during reconstruction, and new development, there is often a need to create additional space. Underground space directly under the reconstructed building or adjacent to it is often used for this purpose. Often, underground structures are located below the existing level of groundwater. Planned construction activities can often lead to changes in existing hydro-geological conditions on the construction site and adjacent territory and, as a result, lead to development of adverse engineering-geological processes.

In this situation, during design stage, it is necessary to consider possible changes of hydrogeological situation and to provide a set of measures, that would ensure normal conditions for the construction and operation of designed facilities on the one hand, and, on the other hand, would allow to minimize changes in existing hydro-geological conditions caused by the construction and operation of structures in the adjacent territory [1, 2]. A

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significant influence on the choice of such measures is provided by the prediction of hydrogeological situation during implementation of the project and preparation of recommendations for the selection of design solutions aimed at minimizing changes in hydrogeological conditions and ensuring normal operating conditions of the facility. Modern regulatory documents [1,2] regulate geotechnical forecast, which consists of hydro-geological forecast and geomechanical calculation and analytical work to determine the impact of construction project on adjacent buildings.

Hydrogeological forecast provides a quantitative estimate of the possible changes in hydrogeological conditions already at the design stage. In this case, usually, the following problems are solved [3]:

1. Assessment of existing hydro-geological and engineering-geological conditions of the construction site and the adjacent territory;
2. Creation of a geofiltration model;
3. Hydrogeological conditions forecast and timeframe for construction and operation of an underground structure;
4. Assessment of options for protective measures in connection with possible changes of hydrogeological conditions.

2 Methods

To solve the first task, data for the area under consideration is collected, analyzed and compiled. Size of the analyzed area is usually within 0.3 – 1 ha range, it can be larger in some cases, depending on the dimensions of planned underground construction. Based on results of the analysis, structural maps of water-hazardous layers are constructed, as well as maps of hydrogeological aquifers.

To solve the second task, boundary conditions of the first kind are defined along the boundaries of the modeling area, that way, existing groundwater levels are indicated. It should be noted that experimental observations at Moscow sites, show that for every meter of groundwater level decrease in quaternary alluvial sediments, ground surface subsides for about 2-3 mm.

Geofiltration modeling is done using GWFS software, developed by ZAO “Geolink-Konsalting” in the framework of creating automated information system of constantly operating models (AIS PDM) of Moscow region. Software complex GWFS (Ground Water Flow Simulation) is designed to solve hydrogeological (geo-ecological) tasks associated with the analysis and prediction of groundwater filtration in multi-layered soil strata.

System allows to model (at phreatimetric and confined – phreatimetric types of filtration) partial or complete drainage of aquifers that have inclined and horizontal confined layers. Infiltration recharge of groundwater is either set constant (piecewise-homogeneous) or depending on the depth of groundwater level. In urban development conditions, where the role of technogenic recharge is significant, infiltration recharge in the model is set piecewise-heterogeneous. GWFS system allows to specify in any layer an unlimited number of wells and drains for modeling the drainage (dewatering or pumping), i.e. wells and drains can be specified in each calculation block of the model.

During schematization of natural conditions, the type of calculated layer of the model and the set of its defining hydrogeological parameters and characteristics are determined.

Filtration of groundwater in an anisotropic permeable layer can be described in the Cartesian coordinate system by the following equation:

$$m\,(x,y)\frac{dH}{dT}=\frac{d}{dx}\left[T(x,y)\frac{dH}{dx}\right]+\frac{d}{dx}\left[T(x,y)\frac{dH}{dy}\right]+A_{0\,t}(x,y)*(H-H_w)+A_{0\,b}(x,y)*(H-H_d)+Q(x,y) \quad (1)$$

Where: m – coefficient of elastic (for pressurized layer) or gravitational (for non-pressurized layer) capacity (During variable confined – phreatimetric regime. coefficient of capacity takes position depending on the position of groundwater to the roof of the stratum).

T_x and T_y – conductivities of permeable layer along the x and y axes (for an isotropic layer these values coincide)

A_{ot} and A_{ob} – coefficient of leakage for overlying and underlying low-permeability confined layers;

H, H_o and H_d – absolute (or relative) marks of groundwater levels of calculated aquifer, overlying and underlying aquifer.

x, y – linear coordinates;

t – current time;

Q – intensity of area and point sources (sinks).

With phreatimetric filtration in the permeable layer, with homogeneous layer scheme, planned conductivity is proportional to the thickness of the layer. With phreatimetric filtration in low-permeability layer vertical conductivity is inversely proportional to the thickness of the layer. For stationary filtration, the left-hand side of equation (1) is equal to zero. Simulation of equation (1) in the GWFS software system was done based on the finite difference method (i.e., the grid method).

For the first aquifer from the ground surface, the relations between groundwater and surface watercourses and water bodies can be established. This relation can be described with the following equation:

$$Q_r = Q_r \int_{i,j}^{t} = T_r(H_r - H), \quad H_r = H_r \int_{i,j}^{t} \quad, T_r = A_r \int_{i,j} * S \int_{i,j} * L_r \int_{i,j} \quad, \qquad (2)$$

Where: T_r – block conductivity of channel fill deposits;

Q – groundwater discharge into the reservoir;

A_r – coefficient of interrelation of surface and groundwater;

S and L_r – width and length of the river bed within model block;

H_r – absolute mark of the water level in the river (The GWFS system allows to consider change in water level in rivers over time).

For a more accurate model and to recreate the existing hydrogeological conditions, the inverse problem was first solved. The inverse problem was solved with a multivariate selection of the filtration parameters of the modeled system in such a way that there was a satisfactory alignment of modeled groundwater levels and groundwater levels marked during well-drilling, and analytical data, acquired during analysis and compilation of existing hydrogeological data. This condition was a criterion for the quality of the geofiltration model. When constructing initial maps characterizing the level surface of aquifers, cartographic materials of previous hydrogeological investigations and factographic information taken into consideration, which were acquired during engineering-geological and hydrogeological researches over the years. If, on a particular site, there are wells drilled at different times, data for the last year is used to build hydroisobath maps. At the same time, available material for the measurements of groundwater levels done in different timeframes are analyzed considering features of the filtration structure and time-varying technogenic load. Hydroisobath position between wells was determined by interpolation, with consideration of ground surface relief and roof of bedrock, and also with consideration of geological and hydrogeological structure of the water-bearing strata.

Upon solution of inverse problem to replicate existing hydrogeological conditions on the model, a series of forecasting tasks was undertaken to assess the impact of the planned construction on hydrogeological situation of the construction site and adjacent territories.

To trace the process of modeling, we can use an example of the construction site, which is located in the historical center of Moscow and enclosed between streets of Vozdvizhenka, Nikitsky Boulevard, Kalashny and N. Kislovsky side streets.

A hotel complex with an underground three-level parking place was planned for construction on that site. Foundation slab was used for the foundation and diaphragm wall was used as enclosing structure.

Geological structure of the area consists of alluvial filled soil, lacustrine-boggy glaciofluvial and moraine deposits, which then deeper into the ground body are replaced by carbonaceous and loamy and marly rocks of Upper Carbonic. There are no glaciofluvial and lacustrine-boggy deposits on the construction site. Below Quaternary sandy-clay rocks there are izmaylovskaya, perkhurovskaya, ratmirovskaya, suvorovskaya strata, presented mainly by limestone, and mescherinskaya, neverovskaya, voskresenskaya loamy and marly strata. Upper part of izmaylovskaya strata is presented by limestone, destroyed to rubble and calcareous flour. Below suvorovskaya strata there are limestones of the moscovskiy and podolskiy stage of Middle Carbonic. In the area under consideration (modelled area), first aquifer from the ground surface will be alluvial-glaciofluvial aquifer. At the site of construction, water-bearing aquifers are Upper Pleistocene alluvial formations, presented by sand of small and medium size with lenses of sandy loam and loam. Alluvial-glaciofluvial aquifer is phreatimetric. The level of groundwater was recorded at a depth of 8.0 - 12.0 m. Average long-term amplitude of fluctuations in the groundwater level is about 3 m. Local features of the water-bearing stratum of Quaternary sediments are associated with the appearance of temporary perched water in some areas, related to filled soil. The reason for the formation of temporary perched water is an increased technogenic recharge due to leaks from water communications. Essentially, these are disjointed lenses that do not have a hydraulic connection. Within the territory under consideration, temporary perched water is recorded at a depth of 0.5-3.0 m.

For a quantitative predictive assessment of the impact of planned activities on the existing hydrogeological situation, mathematical modeling of hydrogeological conditions was done. Based on the schematization of hydrogeological conditions, a detailed geofiltration model was developed that considers existing hydrogeological situation and construction project proposals.

3 Results

Created model allowed to solve the problem of reconstructing existing hydrogeological conditions, to obtain quantitative characteristics of the groundwater balance, and to carry out the forecast of the hydrogeological situation for the periods of construction and operation of the planned building, with consideration of protective measures.

Within the area under consideration (the modeled area), first aquifer from the ground surface is an alluvial-glaciofluvial horizon with overflow of groundwater through relatively confining deposits separating the alluvial-fluvioglacial aquifer and the first Carbonic aquifer located under the confining deposits.

Existing structure of the groundwater filtration flow of the first aquifer from the ground surface is shown in Fig. 1.

Approbation of geofiltration model showed that the model adequately describes hydrogeological conditions on the construction site and adjacent territory and can be used as basis for the forecast of changes in the hydrogeological situation in connection with planned activities. Analysis of project proposals and current hydrogeological situation shows that in some areas foundation slab will be located at 2.0 - 3.0 meters above groundwater level. Bottom of the diaphragm wall will be located in confining deposits of Don moraine or confining Upper Jurassic clay. Designed diaphragm wall completely covers first from the ground surface alluvial-fluvioglacial aquifer.

Fig. 1. Long-term annual average hydroisobath map of the alluvial-fluvioglacial aquifer.

In the simulation, two options were considered. First option with water proof enclosing structure, fully blocking first aquifer from the ground surface, and second option in case of possible filtration of groundwater through the diaphragm wall. It was done because diaphragm wall is not completely waterproof structure and small filtration of groundwater through it takes place. To protect underground structures from penetrating groundwater, it was recommended to provide waterproofing of the underground part of the structure and bed drainage under the foundation slab.

In the simulation according to the first option it was obtained that predicted rise in the water table at the sites adjacent to the construction site on Nikitsky Boulevard and Kalashny side street, cause will not lead to flooding of these territories. The minimum predicted depth of groundwater table at the sites adjacent to the northern side of the planned construction is about 4.0 m with consideration of long-term annual oscillations. Area part with significant predicted lowering of groundwater level is localized in the immediate vicinity of the construction site. This area is free from development. The results of geofiltration modeling are shown in Fig. 2.

With the second option, a condition was adopted in which the drainage maintained underground water level at 0.4 - 0.5 m below the foundation slab. Diaphragm wall of the planned underground construction was set in the model with coefficient of permeability of 0.005 m/day, based on experience on Moscow sites.

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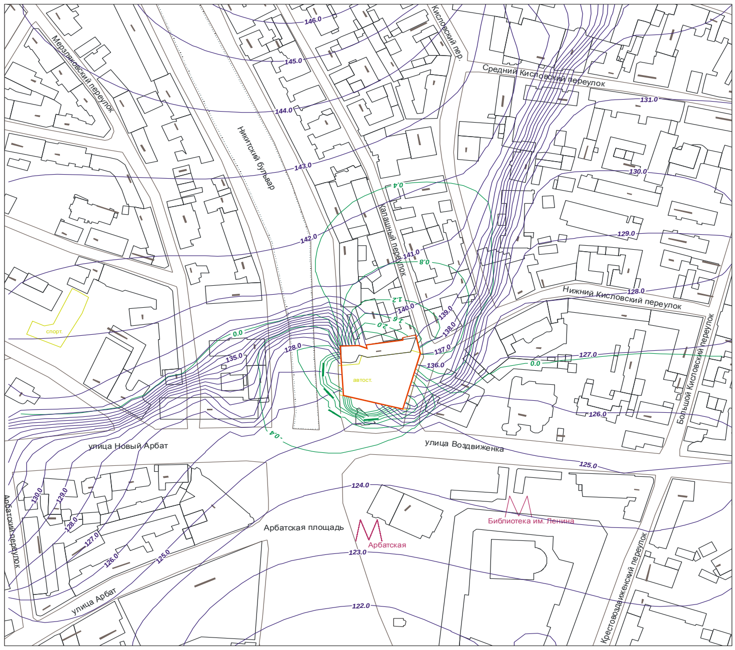

Fig. 2. Forecast map for the groundwater level changes in the alluvial-fluvioglacial aquifer if diaphragm wall is used along the perimeter of the planned construction.

4 Discussion

The simulation results showed that with coefficient of permeability of 0.005 m/day for diaphragm wall, the average predicted value of water inflows into the drainage is about 1.5 m^3/ day., while the maximum predicted water inflow into the bed drainage, taking into account the multi-year amplitude of fluctuations in the groundwater level, is about 2.5 m^3/day.

The hydrogeological forecast has shown that the implementation of project activities will not lead to the development of adverse engineering-geological processes associated with groundwater in the adjacent area.

In conclusion, it should be noted that a change in the hydrogeological regime entails a change in the physical and mechanical properties of soils. This leads to a change in the stress-1strain state of the soil body and can affect deformation behavior of surrounding buildings. Therefore, it is advisable to provide at the design stage a comprehensive hydrogeological and related to it geotechnical forecast.

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