HYDROTECHNICAL CONSTRUCTION

A NUMERICAL SIMULATION OF THE THREE-DIMENSIONAL FILTRATION IN AN ENVIRONMENTAL SAFETY ANALYSIS OF BUILT-UP AREAS

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Built-up areas are in many cases prone to flooding because of the disorder of their dynamic equilibrium water regime or penetration of hydraulic structures below the natural level of underground waters. The main measure to be taken to prevent flooding is an adequate system of water management of which the most important element is drainage. The choice of a rational drainage system is primarily based on the available prognosis of its effect on the underground water regime in the province of interest. Such a prognosis is made based on filtration analysis data, at present most frequently prepared using computer-assisted numerical simulation methods.

A drainage feasibility analysis method was developed in a filtration studies laboratory at the B. E. Vedeneev All-Russia Research Institute of Hydraulic Engineering (VNIIG), based on the DRENA program package which allows one to handle spatial filtration problems under complex hydrogeological conditions [1]. In particular, this method was used for a feasibility analysis of the protection of basement rooms from flooding at the GUP Vodokanal SPb (St. Petersburg Water Supply Management) and the Thermoline Engineering Joint-Stock Co. and underground rooms in the Ladozhskii Railway Terminal (St. Petersburg). In this study, the latter will be used as an illustrative example throughout the text.

Our goal in this study was to develop a rational drainage system for protection of the basement of a railway terminal and to analyze the performance efficiency of drainage facilities. In conducting civil engineering work at the railway terminal, it has become necessary to analyze the critical hydrogeological conditions which entailed flooding of the underground structures, which, in turn, created a hydrostatic pressure acting on the footing of the foundation plate and the depth-embedded wall of the terminal’s underground outline. The cause for the flooding of the foundation pit was neglect of adequate engineering solutions concerning the drainage facilities; by design, the only protection of underground premises from underground waters was waterproofing. The railway terminal was located on a flat ground where the groundwater level was rather low; to make things worse, a buried flood plain fed by a surface stream (a brook) with a thick peat bog (up to 4 m) was found to occur in the vicinity of the building site and served thus as an additional source of flooding. In these settings, drainage of the basement has become a necessity rather than a mere expediency.

To remedy the situation during the building and for further service, several drainage variants were considered: (i) an annular drainage pattern along the perimeter of the building site outline; (ii) vertical drainage with individual drain wells located close to shallow water pits over the entire area of the foundation plate; (iii) a combined drainage pattern, that is, a combination of the former two where the surface pits are deepened and lengthened into surface drains. To choose from among the three variants, numerical experiments with a model simulation of the flooding regime at the building site were carried out.

The hydrogeological pattern at the railway terminal site was conceived as a two-layer spatial structure: the water-bearing rocks with their filtration characteristics were conventionally divided into: (i) upper water-permeable top layer 5 mm thick including the bank earth and peat, and a weakly water-permeable bottom layer 3.5 m thick including sandy loam. The filtration factor for the top layer was $k = 1 \text{ m/d}$ and the storage coefficient was $\theta = 0.07$; for the bottom layer, it was $k = 0.2 \text{ m/d}$ and $\theta = 0.02$, respectively. The confining bed was the roof of varved clay. The confining bed surface, the layer interface, and the day surface were, by convention, horizontal planes at marks $-3$, $0.5$, and $5.5$ m abs., respectively; the bottom mark for the foundation plate was $0.5$ m.

Eight model variants have been considered. Variant 1 was the design engineering solution: the drainage scheme in this model was a cavity-free drain line at mark $0.0$ m and eight shallow pits reaching mark $0.5$ m in depth (Fig. 1a). Calculations show that the draining effect due to the shallow pits and cavity-free drain is local in character. As is seen from the water table contour maps in Fig. 2a, the foundation...
plate will most likely be flooded virtually over the entire area (the flooded portion of the foundation plate is shown hatched) and will be under the action of a hydrostatic pressure head of 2 m or even higher.

In variants 2, 3, and 4, the basic drainage scheme was different from the former in that it had two cavity-free drain lines added (Fig. 1b). Furthermore, in variants 3 and 4, the shallow pits were deepened to 0.5 and 1 m, respectively. Simulation results show that the deepening of shallow pits caused a decrease in depression surface only in the direct vicinity of shallow pits; in the remaining building site area, the depression surfaces in variants 2 – 4 were virtually identical and, as is seen in the water table contour map for variant 4 (Fig. 2b), most of the basement (except for the portion drained by the cavity-free drain) will be flooded.

Variant 5 was an open annular drainage scheme at mark 0.0 m (Fig. 1c). Simulation results show that this scheme ensures the required water level drop, and the foundation plate experiences no uplift pressure from the underground water (Fig. 2c). In variant 6, the annular drainage was modified with four shallow pits at marks 0.0 m (Fig. 1d). Calculations show that the shape and position of the depression surface remained practically unchanged.

Variant 7 was based on a drainage scheme that was an improvement of variant 1: to the actual drain line, a further two lines were added (like in variants 2 – 4); the deepened and lengthened shallow pits were simulated as short horizontal drains 12 m long at marc –0.5 m (Fig. 1e). By calculations, this scheme fails to provide the required water level reduction, since the radius of influence of short horizontal drains is several times less than the spacing between the two neighboring drain rows (Fig. 2d). In variant 8, the drainage scheme of variant 7 was augmented with a cavity-free drain at mark –0.5 m between two rows of modified shallow pits (Fig. 1d). The benefit from this drain, even though positioned under constraint conditions, is evident: the depression surface goes down below the foundation mark virtually everywhere, except for the area subjected to the uplift pressure head up to 0.5 m (Fig. 2e).

Thus, the annular drainage (variant 7) provides the required water level reduction over the entire area where the foundation plate of the terminal was placed, whereas the drainage scheme after variant 8 — only about 90% (the remaining 10% of the foundation plate area is exposed to a small hydrostatic head which in project will be removed as the planned expansion of building and drainage facilities of the terminal is put in practice). With allowance for possibilities in the actual building phase, the last variant can be recommended for practical realization.

Another field for application of the filtration method proposed is provision of the environmental safety at slag-and-ash landfill sites, waste dumping grounds, etc. An example of the environmental safety feasibility analysis is provided by