Dewatering in urban environment
Epuisement en zone urbaine

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ABSTRACT: State-of-the art methods of underground water level lowering in urban environment have been shown. New technologies of water drawdown by means of ray-type drainage, deep wells, drainage systems and water impervious curtains have been described. Practical examples of effective site dewatering have been given.

RESUME: Le present expose donne les methodes contemporaines de la baisse du niveau des eaux souterraines en zones urbaines. Les nouvelles technologies de l'epuisement grace aux drainages-rayons, aux puits pompes, aux systemes de drainage, aux rideaux d'etancheite sont examines. Quelques exemples pratiques montrent l'efficacite de l'epuisement de la zone urbaine.

1 INTRODUCTION

Underground water level lowering and urban site dewatering are of critical importance nowadays being instrumental in solving a number of vital tasks: to eliminate humidification of basements and underground premises; to recover marsh-ridden sites; to stop deformations of foundations in subsiding and weak soils; to strengthen unstable natural slopes and artificial inclines of open pits; to preclude water intake into foundation areas during the development of deep excavations within built-in sites.

During the recent time Protekt has used many new water drawdown systems.

On built-in territories where it is impossible to use continuous trench-type or seam-type drainage systems, the so-called ray-type drainages are used. To lower the ground water level during the development of open pits or assembly of caissons, deep drawdown wells are arranged.

Where hydrogeological conditions of the sites to be dehumidified allow, it is often more reasonable to preclude the ground water inflow to the site, thus eliminating any further humidification of the territory. The use of filtration-proof curtains is one of effective methods of soil humidification prevention.

When there is a difference in the elevations within the site to be protected against underground water, and there is a necessity to arrange retaining walls, drainage backfills behind such retaining walls can provide reliable protection against water inflow.

In each case the selection of an adequate water drawdown method should be supported by a detailed and careful technico-economic analysis and comparison of the alternatives.

2 RAY-TYPE DRAINAGES

This method of water drawdown (Ginzburg, Shvets, 1984) envisages the arrangement of adequately deep vertical wells within the site to be dewatered, and from the wells horizontal ray-type holes are drilled in which filter tubes are installed which transform the rays into drains driven at the required depth.

The main value of the method is in the fact that the ray-type drains can be arranged within a built-in site, under existing buildings and facilities, leaving intact the embedded premises and communications. Since the length of the horizontal rays may reach 100 m, the water-intake capacity of the horizontal holes is very high. All this makes the usage of ray-type drainage very attractive for the protection of industrial and urban territories against ground waters.

The horizontal water collection holes were previously used only to dewater open pits and ore bodies (Anatoliyevsky, Razumov, 1970).

To be able to use the ray-type drainage to draw down the underground water level within a built-in site, necessitated to modify the previously employed technology of its arrangement, to develop a relevant design procedure and computation software applicable to new conditions. The problem is that a relatively well-employed calculation scheme was available for the case of symmetrically arranged horizontal holes in a cluster which can be driven only for dewatering of open deposits. The problem actually has no solution when the horizontal holes of a cluster are arranged arbitrarily. But when lowering the ground water level under the buildings and structures located within built-in sites, by means of ray-type drainages, the layout of the holes in a cluster can be quite arbitrary; as a rule, the lengths of the holes may vary within a wide range too. To estimate the effectiveness of ray-type drainages it is necessary to have a calculation method which allows, at least roughly, to determine the degree of ground water drawdown within the site to be protected. To this end an approximate calculation procedure is employed which is based on a consecutive use of the available formulas for the yield of a cluster with symmetric holes, and of the equation for the ground water level lowering when a hole drains water at a constant flow rate under constant infiltration conditions. Such calculations are performed on a computer according to a programme applicable for the described conditions. The calculations are carried out in the following sequence: first the yield of one ray is determined, then the total yield of each well, i.e. of the cluster of horizontal holes located therein (Fig.1), then of the whole system of interacting drains. The yield of each well is determined taking into account their interaction, as well as the inflow for each drainage, per 1 m of a horizontal drain. After that the ground water level drawdown is calculated in arbitrary points of the seam during the operation of a specified number of ray-type drainages.

The calculations are performed by the method of consecutive approximations for several reference points in the most critical locations of the site being drained. The required draining effect is achieved by increasing the number of the ray-type holes; the calculation operations are stopped when the required water level lowering is reached in the specified site locations.

For illustration we shall dwell on the water drawdown that was carried out by means of the ray-type drainage on the site of the Dnepropetrovsk Tyre Factory.

Since 1970 cracks from 50 to 200 mm wide started developing in the walls of the factory buildings. Observations and studies of the local conditions showed that subsidence of the foundations which reached 40-100mm was caused by humidification of loess-like subsiding soils on which the production facilities of the factory were built.

No ground water was found to the depth of 30-35m during the survey period (1956) preliminary to the factory greenfield construction. By 1978 the ground water level was at the depth of 5-7m, that means that during that factory operation period the ground water level raised by 25-30m, and that rize steadily continued. As a result of humidification of the soils of which the compressible mass consists, the deformations of the foundations could drastically increase, therefore it became necessary to take urgent measures to reduce the underground water level and, which is the main purpose, to preclude its further rise.

It was impossible to use vertical or horizontal drainage in the actual conditions of operating production shops, because the buildings are close to one another and contain a lot of equipment, and there is a dense network of underground communications. Therefore it was decided to perform water drawdown under the factory's buildings by means of ray-type drainage units.

An individual water drawdown system was designed for each building. For example, for the main building there was designed a ray-type drainage comprised of eight shaft type reinforced concrete wells with 40-90m long horizontal ray-type drains (calculated to cover all the surface area under the building). The 14 m deep wells were arranged along the outer perimeter of the building, with 4–5 rays from each well.

Under smaller size structures of the factory water drawdown was effected by a system of rays driven from one well. Such a scheme was accepted, for instance, for water level lowering under the mazout storage of the power-and-heat supply boiler house (Fig.2). The ray-type drains of this system were arranged under the embedded storage premises in order to lower the ground water level below the foundations, and to dry out the basements (Fig.3).

During the ray-type drainage operation, the ground water flowing into the ray-type drains is directed into the water collecting pit of the shaft-type well from which it is periodically pumped off into the storm sewerage system.

The ray-type drains are comprised of 135mm diameter frame-wire mesh filters made of 2 mm diameter stainless steel coiled wire with a 3.5 mm clearance between the coils. The surface of the wire coils has a filtering coat consisting of 4-5 layers of unvowen glass fiber cloth, type BB1.

The walls of the shaft-type well were made by the "wall-in-soil" method: into a trench dug by a wide-web grab (under clay mortar), there were lowered prefabricated reinforced concrete panels of the well walls grouted therebetween. Then the soil was taken out of the well by the grab, and a monolith reinforced concrete bottom of the well was arranged over the drainage fill and hydroinsulation.

The horizontal ray-type holes were drilled from the well by an ULB-130 drilling rig in 150 mm diameter casing tubes which were pulled out by the same rig after the filters have been installed therein.

The ray-type drainages produced at the Tyre factory have operated quite successfully. The ground water flowing into the drains flows down by gravity into the shaft-type well, from each it is pumped off automatically.

After the ray-type drainage has started operating at the main building, the ground water level was reduced by 0.2-0.8m within four months, hence the envisaged level reduction has been achieved. No subsequent ground water level rize has been recorded, while building walls deformations have been arrested.

Monitoring of the ray-type drainage operation on the site of the Dnepropetrovsk tyre factory has shown that their use requires moderate expenses. Initially it was envisaged that in case of colmatage of the filters in the ray-type drains they will be cleaned by water fed from the well under pressure. But operation has shown that no filter colmatage takes place. In one case the water stopped flowing into the well, and colmatage was suspected, but the observation holes showed that simply the ground water level had dropped below the expected one. As soon as the level rose, the rays again started operating.

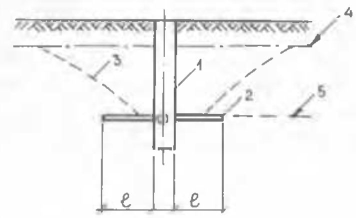

Fig.1. Ray-type drainage (schematic view)
1-well; 2-horizontal ray-type holes; 3-depression curve; 4-existing level; 5-designed level of underground water; l-ray length

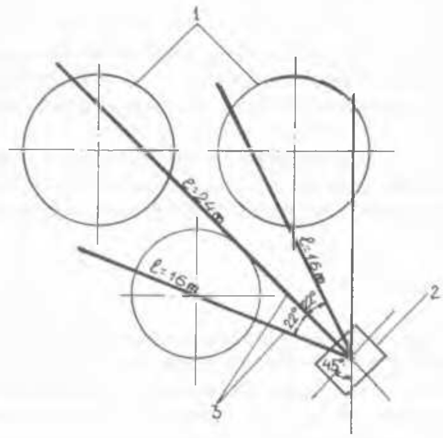

Fig.2. Ray-type drainage for the mazout storage, Dnepropetrovsk tyre factory (schematic view)
1 - storage buildings; 2 - vertical shaft-type well; 3- horizontal ray-type drains

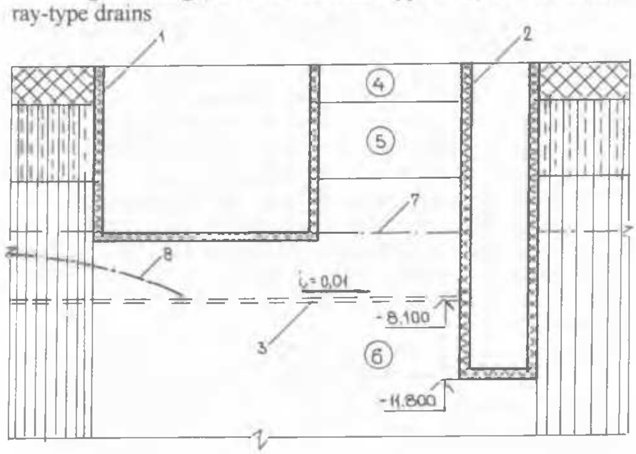

Fig.3. Ground water level lowering under the mazout storage
1 - underground storage premises; 2 - vertical shaft-type well: 3 - ray-type drain; 4 - soil filling; 5 - loess-like loam, 6 - loess; 7 - existing ground water level; 8-lowered level

In any case, the ray-type drainage operating costs are insignificant because they include only follow-up of the automatically operated pumps, their preventive maintenance, and electric power consumption.

3 IN-DEPTH WATER DRAWDOWN

The method of ground water level lowering by means of in-depth water drawdown holes is rather widely used. As it is known, this water drawdown method principally includes driving of deep holes which are provided with filtering columns with a drainage fill, in depth pumps and a water elevating column through which the pumped-out water is fed to the surface (Fig.4).

Usually the most complicated procedure is the depth calculation of the water drawdown holes, and of their quantity required to adequately lower the ground water level on the given site.

In general, the methodology of such calculations is conventional, but the results of such calculations largely depend on the validity of the characteristics of the waterlogged soils, which are determined during engineering geological survey. The main calculation characteristics of the soils for the purpose of water drawdown include the filtration coefficient and the water yield coefficient. Using these coefficients, as well as some other physico - mechanical characteristics of soil, the following parameters are calculated: flow rate of each hole, radius of its influence, the required number of holes, their depth, design, etc. Even minor faults in the determination of the design characteristics can lead to a negative result during the operation of the designed holes.

As a vivid example can serve an attempt to dewater one of the sites in Dnepropetrovsk during the construction of a sewerage pumping station in the city (Fig.4).

It was necessary to lower the underground part of the pumping station by the caisson driving method to the depth of 6.5m into loamy and sandy soils. Initially the station was lowered while soil was taken out from the inside simultaneously, without any water drawdown. But the water inflow with soil inflow into the caisson was so intensive that it forced to stop the well driving to the design level and to start urgently the water drawdown operations.

According to the available geological data, seam 4 contained the most waterlogged soil. According to this data it comprised of dusty sand with the 1-3 m/day filtration coefficient.

The water drawdown holes designed and driven on the basis of this data did not give any adequate effect to reduce the ground water level.

The repeated geological surveys showed that seam 4 consisted of fine and medium-grain sands with a 9-12m/day filtration coefficient.

As a result, it became necessary to urgently add several deeper water drawdown holes.

This example shows that designing of water drawdown facilities requires very accurate and careful engineering geological survey, while the required soil characteristics should be determined by on-site trial pumping-out.

4 IMPERVIOUS CURTAINS

Impervious curtains provide an effective method to preclude water encroachment of the soils. The curtains comprise a practically water-proof vertical wall (elongated in plan) in the soil, which is built by injection via the holes into the soil of solidifying mortars or by filling up a narrow slot-type trench with some impervious material, such as clay, loam, lean concrete, soil concrete, etc.

The curtain built to protect against flooding the open pit of the Inguletsky Mining and Dressing Combine may serve as an example of an elongated filtration-proof diaphragm wall. The open pit edges lost their stability due to water infiltration from the river (this process was further enhanced due to the additional load onto the edges by the quartzite dumps). Ground waters penetrated through the open pit edges causing downflows and hydrodynamic pressure at the edges, hence reducing the strength characteristics of the soils. The designed filtration-proof diaphragm cut through all the water-pervious layers and penetrated into the water-impervious stratum (Fig.5). Calculations proved that such a diaphragm actually precluded any water approach to the open pit edge. The length of the impervious curtain was about 3500 m, the depth - about 26 m.

The trench for the 600 mm wide curtain was dug by a wide-web grab; also, a barraging machine designed by the VIOGEM Institute (Belgorod) was used. The principle of the barraging machine operation consists in loosening of the soil by special knives fixedly arranged on a beam reciprocally moving along the butt end of the trench, while rotating simultaneously. The loosened soil is weighted in the clay mortar with which the trench is filled, and is directed to a settling reservoir, where the clay mortar is regenerated for its subsequent use. The clay mortar takes away the drilled-out rock and protects the trench walls against breakdown.

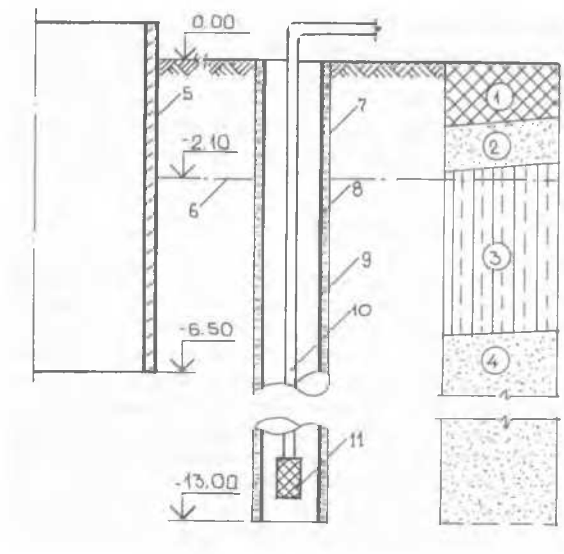

Fig.4. In-depth water drawdown (schematic view)
1-filled-up ground; 2-fine sands; 3-loams; 4-fine and medium-grain sands; 5-pumping station caisson; 6-underground water level; 7-in-depth water drawdown hole; 8-drainage cushioning fill; 9-filtering column; 10-water-lifting column; 11-submersible deep-well pump

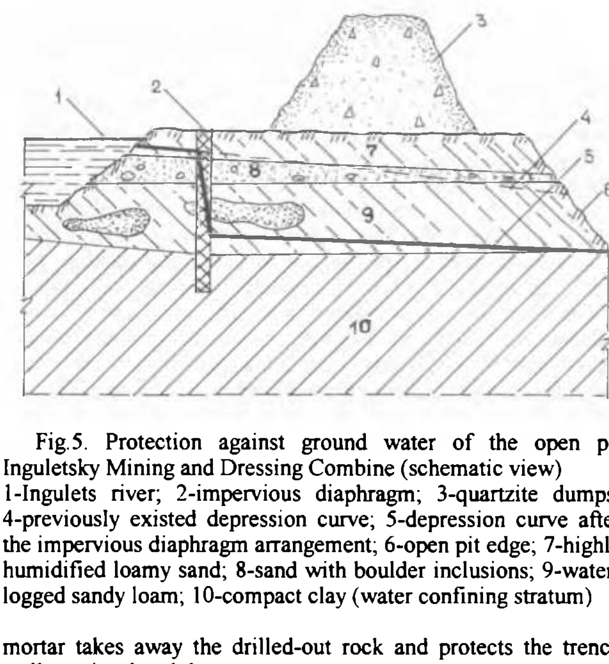

Fig.5. Protection against ground water of the open pit Inguletsky Mining and Dressing Combine (schematic view)
1-Ingulets river; 2-impervious diaphragm; 3-quartzite dumps; 4-previously existed depression curve; 5-depression curve after the impervious diaphragm arrangement; 6-open pit edge; 7-highly humidified loamy sand; 8-sand with boulder inclusions; 9-water-logged sandy loam; 10-compact clay (water confining stratum)

When a trench is to be run in waterlogged soils, the clay mortar quality is of critical importance for the stability of the trench walls. In this case the clay mortar was prepared of bentonite clays. Constant laboratory control of the conformity of the clay mortar quality with the envisaged parameters was carried out during the whole construction period. After completion of each trench portion, the clay mortar was replaced with loams and clays brought from the nearby open pits. The arranged loams and clays formed the filtration-proof material of the diaphragm.

Rather often the filtration-proof material is arranged by direct dumping into the trench. But it was found that in this case the process of the clay mortar displacement is very slow. Therefore for the curtain at the Inguletsky Mining and Dressing Combine induced feeding of the loams and clays was carried out by means of a special screw feeder. The screw, rotating in a tube, layed down the impervious material from the trench bottom upwards, thus reliably displacing the clay mortar. The soil was loaded into a bin fixedly connected to the tube. After the vertical deformations caused by curtain materials consolidation have been stabilized, the curtain body was banked up with loam to the height of 0.5 m. The diaphragm material filtration proofness was determined in the laboratory. To upgrade the filtration proofness of the curtain , a PVC film screen was additionally lowered into the trench preliminary to feeding loams therein. After the filtration-proof diaphragm has been installed the penetration of water into the open pit was practically stopped.

5 BEYOND-WALL DRAINAGE

If there is an elevation difference on the territory being protected against ground water inflow, and there is a necessity to arrange retaining walls, drainage fills beyond those retaining walls can be used as a reliable protection against water encroachment. Such a method was used in the city of Yerevan to protect against flooding the territory of the storage yard of a chemical reactants sules shop and production plant. Protection against ground water by means of an impervious curtain was also considered as an alternative version.

The site comprised of a built territory with two warehouse buildings, an office and a garage. The territory was not covered with asphalt, and was swampy in some parts, there were shallow ravines and a steep slope from which water was draining, thus constant danger of flooding the site existed. The site comprised of filled-up, loamy-sandy, sand-gravel soils and an underlying thick layer of red marly clays. The pebble-gravel-boulder and loam sand-gravel soils served as aquicludes, while clay was used as the water confining stratum. Flooding of the site reduced the load carrying capacity of the foundations, led to the development of cracks in the storage and administrative buildings, stability reduction of the natural slope which limited the territory on the southern side.

To enable the selection of the most cost- and labor-efficient alternative, two variants of water drawdown have been developed: arrangement within the natural slope of a monolythic reinforced concrete retaining wall with a wall-adjacent drainage (drainage backfill beyond the retaining wall), and a filtration-proof soil curtain with a PVC film screen crossing the flow way of the ground water. In the first variant (Fig.6), to stabilize the slopes, monolythic reinforced concrete retaining walls were erected, made of concrete on sulphate-resistant portland cement. Prefabricated walls were rejected because such structures were not produced by reinforced concrete structure plants in Yerevan. The retaining walls passed through the layers of the fill-up, loam-sand and sand-gravel soils and were embedded into the water confining stratum comprised of red argillaceous marls. In the upper part these marls are fissured, therefore it was decided to embed the retaining walls to at least 1m therein.

The near the wall drainage structure included 250 mm diameter asbesto-cement tubes with a slot-shaped knurling, on a sulphate-resistant portland cement, with a layered fill-up of medium size crushed stone (8-40mm) and coarse-grain sand (0.25-0.5mm), which operated as a unidirectional filter. A collector comprised of cast iron 250mm diameter tubes was used for water take-off into the storm sewerage system. Part of the water was collected into a monolythic reinforced concrete well for further utility use. 1m diameter observation wells were arranged to control the drainage system operation. The pit backfill from the drainage side was done using the local gravel ground, while on the other side of the retaining wall any local soils were used. In the office and garage area, near the existing foundations, the trench for the retaining wall foundation was run, while its walls were strengthened by reusable panels. On all designed inclines above the retaining walls a backfill of 0.1m thick layer of vegetation soil was envisaged with subsequent planting of perennial grasses.

The second variant envisaged an impervious soil curtain 0.6m wide, 300 m long and from 10 to 14m deep.

After comparison of technico-economic characteristics, the first dewatering variant was approved. The water drawdown system and retaining walls erected according to that variant proved to be quite effective and resulted in complete recovery of the marsh-ridden territory, elimination of the deformations of the buildings, and stabilization of the slope.

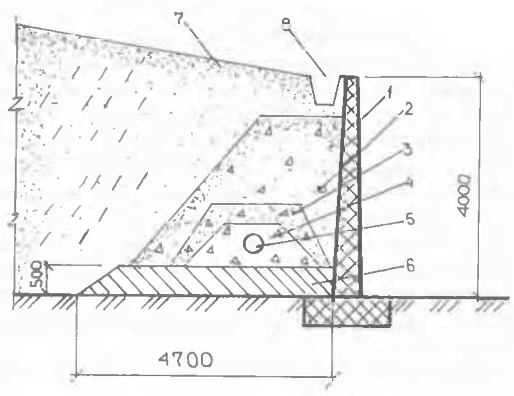

Fig.6. Beyond-wall drainage (schematic view)
1 - retaining wall; 2 - medium-grain sand; 3 - coarse-grain sand (0.25...0.5mm); 4 - medium-size crushed stone; 5 - 250mm diameter asbestocement pipe; 6-in-layer compacted pugged clay; 7-local soil fill; 8-spouting chute

It should be noted that for the normal functioning of the drainage system it is necessary to monitor its operation and the ground water dynamics. Observation of wells, drainage pipes check-ups, as well as water flow rate measurements in the take-off collectors should be carried out at least 4 times a year.

6 CONCLUSIONS

During the recent time rise of the underground water level has been often observed on urban territories. It is explained by several factors: disturbance of the balance between atmospheric precipitation and evaporation after asphalting of territories and construction of various buildings; leakage from water mains, tower-coolers, washing facilities and man-made reservoirs; inadequate water removal capacities of the existing rainfall collectors and sewage conduits; river water level rise as a result of hydrotechnical construction; filling of ravines, and construction on their slopes without provision of adequate water removal facilities; etc. The great variety of the causes of the ground water level rise, complicates protection against such events. Until the recent time the protective measures included arrangement of various vertical and horizontal structures, as well as seam drainage systems. But their arrangement on built-in urban sites with numerous underground communications is difficult.

In view of this, the search for new water drawdown systems, upgrading of the conventional systems and technologies of their construction is of critical importance.

But it should be taken into consideration that the activities to protect the urb-an environment against flooding require very thorough fulfilment of all the relevant stages of the projects - engineering geological survey, designing, and on-site water drawdown system construction.

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