Water-bearing System in Clayey Spoil Banks

By Jan MORAVEC[1]

[1]Institute of Geotechnics, Czechoslovak Academy of Sciences
V Holešovičkach 41,CS-18209 Praha, Czechoslovakia

ABSTRACT

The paper analyzes the general aspects concerning the formation of water-bearing system in clayey spoil banks in the North Bohemian Brown Coal Basin, Czechoslovakia.

The hydrogeological evaluation of spoil banks must be carried out according to the uniform methodology to provide the opportunity of reciprocal comparison of the obtained results.

When performing the methodological evaluation of water-bearing system in spoil banks, the real geological and hydrogeological conditions must be respected.

Similarly, the draining of spoil banks in every stage of their construction is inevitable in order to reduce the influence of water-bearing system in spoil banks.

The monitoring of the altitude of water level in hydrogeological observation boreholes is very important for the parallel evaluation of changes in the water-bearing systems as well as for the preventive danger signaling concerning the slope failure of spoil banks. This slope failure occurs whenever the water level rises to a critical point.

INTRODUCTION

The points at issue of hydrogeology of clayey spoil banks are connected with maximum utilization of spoil bank space and the stability of spoil banks slopes in the open cast mines in the North Bohemian Brown Coal Basin, Czechoslovakia.

Not long ago, the spoil banks hydrogeology has been studied only in case the breakdown situations have to be solved. To improve the general status, the methodology has been developed to evaluate the water-bearing system in spoil banks, which is pointed at the realization of concrete solutions in the individual localities [(1)].

The evaluation of water-bearing system in spoil bank is one of the prerequisites for realization of the effective technological and hydrogeological measures to be undertaken to increase the effectivity and safety of the spoil banks operation.

The solution of the capacity, stability and incorporation of the spoil banks into the landscape ecosystem are tipical from the point of view of open cast mining in the North Bohemian Brown Coal Basin.

WATER-BEARING SYSTEM IN THE SPOIL BANKS

Clayey spoil banks are man-made bodies characterized by the formation of a special water-bearing system and a hydrogeological regime. The spoil bank water-bearing system is a system of water-bearing aquifers with a variable rate of hydraulic continuity and with specific boundary conditions.

The spoil banks are hydraulically and hydrogeologically anisotropic and heterogeneous bodies. The clayey spoil banks have slight to very slight permeability with the coefficient of hydraulic conductivity $k=1x10^{-6}$ to $1x10^{-8}$ m/s.

The spoil bank is a three-phase system. The system consists of a solid phase, water and air. Each of the phases can be dominant under the specific conditions. This means that spoil bank soils of the same modal composition may behave in quite a different manner. If the entire volume of voids (interstices) is filled up with water, then spoil bank soil is saturated and forms a two-phase system. The shear strength of soil is unfavorably influenced by the two-phasse system (the value of the angle of internal friction and cohesion decrease).

The problem consists in determination of the physico-mechanical and hydraulic properties of spoil bank soils, which have dirrerent water contents in different parts of the spoil bank. The prediction of water-bearing system evolution related to the consolidation of spoil bank is necessary.

The extent of water-bearing system is affected by the structure of spoil bank and the ratio between the water inflow and outflow from the spoil bank body.

The interaction between the water-bearing system in the spoil bank and the surrounding environment is performed by means of hydrologic regime of the spoil bank. The spoil bank hydrologic regime is a complex of regularities, affecting volume of retained water in the spoil bank, its circulation and chemical composition.

The hydrologic regime of the spoil bank influences the hydrologic regime of surrounding environment and is reversely influenced by this regime. It means that the hydrologic regime change of the spoil bank induces the hydrologic regime change of the surrounding environment and vice versa. This change is time dependent. The change is not usually manifested immediately but in a certain delay.

The formation of the water-bearing system in the spoil bank is conditioned by the natural and man-made factors, some of which have the stochastic nature. If at least one factor of precisely defined relation is stochastic, then the whole relation appears to be a stochastic one. The stochastic factors are variable quantities in a certain range of values, each of which has the possibility of achieving a certain probability [(2)].

The water-bearing system in the spoil bank with its own hydrologic regime is thus stochastic system, which is defined by the finite number of relationships of cause and effect.

For a practical utilization, there is an important fact that the assumed effects come from the given causes. It means that on the basis of outer stimulations (causes) it is possible to estimate the probable behavior of the system (the possible effects).

THE FACTORS OF WATER-BEARING SYSTEM FORMATION IN SPOIL BANKS

The spoil banks water-bearing system formation is affected by the action of natural and man-made factors. These factors develop in mutual interactions. Their action is dynamic. This means that the water-bearing system in spoil banks also evolves in time and space.

However, the water-bearing system is also influenced by some factors of static nature. These are geographical factors and some geological factors.

The factors of the spoil banks water-bearing system formation are divided into:

Natural factors

- geographical (geographical location, altitude above sea level, geomorphology of focused area and its surrounding),
- geological (modal composition of spoil bank soil, clayey mineral structure, modal composition of underlying rocks of the spoil bank),
- hydrological (atmospheric precipitation, evapotranspiration, surface run-off),
- hydrogeological (primary water-bearing of spoil soils, water inflow into the spoil bank by infiltration of atmospheric precipitation, from its underlayer, from surrounding water-bearing collectors, from water reservoirs and streams),
- hydrochemical (interactions of water - spoil soil - atmosphere, chemical composition of water inflowing to the spoil bank),
- biogenic (kind and extent of plant coverage).

Man - made factors

- technological (the method of excavation, transport and deposition of spoil material, load of spoil soils by technological equipment, subsequent superelevation of the spoil bank, dressing of the spoil bank surface and reclamation),
- hydrotechnical (the methods of drainage of the spoil bank base, the body itself and the spoil bank surface).

THE WATER-BEARING SYSTEM FORMATION IN SPOIL BANKS

To elucidate the adverse effect of water-bearing system in the spoil banks on their stability it is necessary to characterize the movement of spoil bank water both in the zones of aeration and saturation. The reciprocal ratio between these zones is determined by the observation of the course of the spoil bank water level. The saturation zones in the spoil banks are formed by means of water inflow. The saturation of environment decreases with increasing distance from water level, which decreases the pore water pressure. The coefficient of hydraulic conductivity of spoil bank soil is also varied. It remains constant up to a certain critical height above the spoil bank free water level and equals the value of the saturated hydraulic conductivity coefficient (i.e., the hydraulic conductivity coefficient in the saturation zone). The critical height h_s above the spoil bank water level corresponds to a height of saturated part of a capillary fringe. The hydraulic conductivity coefficient in height $h > h_s$ significantly decreases.

One of the water sources supplying the spoil bank is atmospheric precipitation.

The optimum conditions for infiltration of atmospheric precipitation into the spoil bank bodies of clayey soils, which are distinctive with a slight permeability, occur during the long-lasting mild rains. That is, when the intensity of atmospheric precipitation is lower than the saturated hydraulic conductivity coefficient of the spoil bank soils. Under these conditions, the largest volume of atmospheric precipitations infiltrate into the spoil bank. Mild, long-lasting atmospheric precipitation, which immediately infiltrate into the spoil bank, may cause the water level elevation in the spoil bank body.

Atmospheric precipitation water moves through the infiltration zone of the spoil bank, through the zone of aeration to the impermeable layer inside the spoil bank, or as the case may be, to the impermeable base of dump. Above the impermeable layer or above the impermeable base, there is formed a zone of saturation (if the zone of saturation has already been formed there, the increase of volume of retained spoil bank water occurs). The intensity of water circulation in the spoil bank depends on the degree of consolidation of spoil bank soils.

The amount of atmospheric precipitation water infiltrated into the spoil bank is decreased on flowing through the spoil bank body. A part of water is captured in pores of spoil bank soils in the zone of aeration as a capillary water and a part is bound in the interlayer space of clay minerals. Therefore, the amount of gravitational spoil bank water is lower than the amount of water inflowing into the spoil bank.

The spoil bank water-bearing system formation is significantly influenced by clay minerals. Depending on the type of adsorbed ions, the clay minerals can be either dispersed or flocculated.

The clay minerals consist of colloid particles with a negative charge, which can adsorb cations (H^+, Na^+, K^+, NH_4^+, Ca^{2+}, Mg^{2+}, etc.). The surface of the clay particles with negative charge and surrounding coverage of adsorbed cations is called double layer [(3)]. If the prevailing cation in the double layer is sodium, the individual clay particles cannot be closely arranged, because the sodium ions are hydrated and form a thick double layer [(4)].

If sodium accounts for 10 to 20% of adsorbed cations then dispersion of the clay minerals occurs.

The spoil bank soils, formed by clay minerals with prevailing Na-montmorillonite, bind considerable volumes of water. Such soils show low permeability, are viscid and difficult to handle in transport and deposition on the spoil bank.

The largest volumes of water are bound by montmorillonite when moisture of clayey spoil bank soils is near to 100%, i.e., the degree of saturation is S=1. Montmorillonite with prevailing sodium content then binds large volumes of water in the interlayer space. This causes considerable difficulties in dewatering of the water-bearing spoil bank because the spoil bank water bound by montmorillonite (or by the other clay minerals) cannot be removed by gravitational dewatering methods (boreholes, drains).

If the cations in the interlayer space of clay minerals are represented mostly by calcium and magnesium, the distance between the individual double layers is shorter. The clay particles are more closely arranged. The closer arrangement is due to the fact that calcium and magnesium cations are not hydrated (4). Therefore, spoil bank soils, the clay minerals of which contain calcium and magnesium in the interlayer space, have better hydraulic properties. These soils are more permeable and have lower water content than those with dispersed clay minerals.

The amount of water bound by the clay minerals is affected by the cation properties in the double layer and by water content of environment, in which clayey spoil bank soil is situated.

If sodium is present in the interlayer space of the clay minerals, the volume of spoil bank water bound by these minerals increases. It subsequently decreases the volume of gravitational spoil bank water. The volume of water bound by the clay minerals considerably affects the hydraulic properties of spoil bank soils. With increasing volume of spoil bank water bound by the clay minerals, the permeability of spoil bank soils decreases.

Under the conditions of the North Bohemian Brown Coal Basin the base of spoil bank has usually lower permeability than spoil bank soils. Water seepage from spoil bank to the underlying rock is minimum and is usually neglected. From this point of view, only the quarternary sediments with draining effect are significant. The inner spoil banks are founded directly on the decoaled bottom of an open cut mine, which is formed by basal claystone of coal measure unit with very low fissure permeability. The outer spoil banks areusually founded on the quarternary sand-and-clay sediments, or on the tertiary superposed clay or claystone, which in original order have lower hydraulic conductivity coefficient than spoil bank soils of the same material. In case the outer spoil bank is founded partly on quarternary sediments with rather high permeability (gravel and sand of transferred alluvial sediments of former creeks), the base of spoil bank may be dewatered by these sediments.

The spoil bank water-bearing system formation is influenced by small water reservoirs naturally impounded on its surface. When spoil bank soils are deposited, there is formed a number of water holes on the surface of the spoil bank without discharge. The water holes are also formed under non-uniform consolidation of spoil bank soils in various locations of spoil bank. The water retention in water holes may occur whenever the amount of atmospheric precipitation is higher than it may be infiltrated into the spoil bank (the rain intensity is higher than the coefficient of saturated hydraulic conductivity of spoil bank soils).

Duration of retention existence depends on the extent of evaporation from the open surface, and on the hydraulic properties of spoil bank surface layer, which affect the run-in into the spoil bank body.

In the basal part of the spoil bank the zone of saturation is formed by means of water inflow in those cases, when an efficient drainage system is not constructed in the base of dump.

In many cases, there is a confined water level in the underlayer and the basal part of spoil bank due to the spoil bank soil pressure on the water-bearing base of spoil bank. Depending on the spoil bank thickness, the piezometric waterlevel moves within the spoil bank, or it reaches above its surface (water spill-over).

Considering the stochastic nature of some factors of water-bearing system formation in the spoil bank, it is necessary in the individual cases to analyze and correlate the general assumptions with the data acquired by monitoring of the water-bearing system.

CONCLUSIONS

The paper summarizes the general knowledge on the water-bearing system formation in the spoil banks in the North Bohemian Brown Coal Basin. The terms spoil bank water-bearing system" and "hydrological regime of spoil bank" are defined. The factors of water-bearing system formation are also given.

The water-bearing system formation in the spoil banks are significantly influenced by:

- qualitative and quantitative composition of clay minerals in spoil bank soils,
- prevailing type of montmorillonite structure.

Further study of water-bearing spoil banks is being focused at the research of the ratio between the cations Na^+ and Ca^+ or Mg^{2+} in the structure of montmorillonite, illite and mixed clay minerals. The ratio of these cations in the clay mineral structure appears to influence the water-bearing system formation in the spoil banks. The qualitative representation and structure of the clay minerals determine if either the zone of saturation is created under the sufficient water inflow into the spoil bank, or almost all water is bound by these minerals (above all by montmorillonite and illite).

Obtained knowledge will be utilized for materialization of water-bearing system formation factors in the spoil bank in the North Bohemian Brown Coal Basin.

For a long-term evaluation of water-bearing system formation in the spoil banks in relation to their stability, it is necessary to observe the water level course in the hydrogeological observation boreholes. The movement of spoil bank soils is also observed by means of surface geodetical measurements and inclinometric boreholes. The observation is performed for preventive danger signalling of spoil bank slope failure. The slope failure occurs during the critical increase of level, and thus increase of pressure of the spoil bank water, in a certain location of spoil bank.

REFERENCES

1. Moravec J., Factors of Spoil Bank Water-Bearing System Formation; Unpubl. PhD. Thesis, IGG CSAS, Prague, 106 pp. (1987)
2. Domenico P.A., Concepts and Models in Groundwater Hydrology; McGraw-Hill Inc., New York, pp. 2-4 (1978)
3. Grim R.E., Clay Mineralogy; McGraw-Hill Inc., New York, 384 pp. (1953)
4. Van Olphen H., An Introduction to Clay Colloid Chemistry; John Wiley and Sons, New York, 301 pp. (1963)