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HYDROGEOMECHANICAL PROBLEMS IN MINING

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ABSTRACT

The hydrogeomechanical problems of mining are considered, which deal with rocks and ground water as a single mechanical system. Among these problems are the open-pits slopes stability, rocks consolidation and surface subsidence due to ground water level lowering, water inrushes into mine workings, rock bursts prevention by using the water injection into the advance boreholes, etc. The paper contains the basic theoretical grounds, as well as in-situ and laboratory methods for the investigation of these processes.

The combined study of ground water regime and rock deformations has resulted in the theoretical substantiation of the hydrodynamic and geomechanical processes within the scope of unique scientific direction-hydrogeomechanics (Mironenko, 1974). The hydrogeomechanical models are widely used now for the analysis and forecasting the extremely important processes connected with the safe and efficient mining operations, as well as with the protection of geological medium. Among these processes are:

- deformations of the open-pit slopes and spoil dumps;
- consolidation of rocks due to the ground-water pressure drop;
- water-and-rock material inrushes into mine workings caused by deformations of the undermined rock mass;
- geodynamical processes due to the changes in ground water regime;
- artificial hydrofracturing in rocks;
- transformations of clay linings under the tailing ponds and other technical water basins.

THE STABILITY OF OPEN-PIT SLOPES IN WATER-BEARING ROCKS

This problem should be analysed with due account of: a) variations of the rock stresses attributed to the ground water; b) rock deformations due to water seepage; and c) changes of rock mechanical properties caused by the ground water.

It is proved now that the hydrostatic and hydrodynamic forces can dramatically decrease the stability of open-pit slopes. Therefore, the necessity arises for the advanced ground water level lowering, especially in the confined aquifer under the impervious basement of the slope. This water level lowering is more advantageous than the equivalent reductions of the slope general angle or the compensations for damages caused by the large landslides which had occurred repeatedly in many open-pit mines due to the high water pressure (Mironenko, 1985). Similar large-scale deformations of spoil dumps are provoked by the excessive pore-water pressure in clay rocks of their foundations.

The local seepage deformations of open pit slopes and their foundations include the suffusion, boiling of sands or their surface transport along the slope, water erosion of rocks along fissures, inrushes of water and collapsed rocks. From these factors the most significant seems to be the surface transport of sands within seepage interval of the slope which determines the required intensity of drainage of the deforming sandy-clay slope. The erosion of rock mass along joints in weak sandstones which is encountered rather seldom may lead, however, to the catastrophical consequences.

The deterioration of rock strength under the influence of ground water is primarily attributed to the so-called quicksands (although in practice one deals prevailingly with the pseudo- quick sands) and the swelling of clay. In particular, the decrease of the rock strength may be connected also with the disturbance of the cementing cohesion resulted from the swelling of rocks or their leaching because of the technogenious variations of the chemical composition of ground water. In the old spoil dumps of silty materials one may also observe the catastrophical deformations, similar to the dynamic liquefaction. Under all these processes drainage can prevent the rock deterioration rather rarely first of all, if they are caused by the ascending seepage of water through semipervious layers.

CONSOLIDATION OF ROCKS DUE TO GROUND WATER LEVEL LOWERING

This problem is of great importance for the construction and operating conditions of mine shafts and other underground mine workings, as well as for the ground subsidence and environmental conditions on the earth surface. For prediction the consolidation regime of the drained rock mass it is necessary to analyse separately two stages of the process, ie., the initial stage (seepage stage) and the secondary stage-creep of the rock skeleton. The observations carried-out at the Yuzhno-Belozersck and Yakovlevsk iron ore deposits completely confirmed that the reliable forecast for the secondary stage of rock consolidation may be realized based on the laboratory compression tests. At the same time for the forecasting of the initial stage of consolidation in the deep-lying and over-compressed fissured clays the data obtained by the large-scale in-situ tests are usually required (Mironenko, 1974) Another important outcome of these observations is the evidence of the possible prevailing of the elastic ground water storage within the semipervious beds in the total storage of the water-bearing formation.

The predictions performed from this point of view for the Yuzhno-Belozersk ore deposit had offered the values of maximum vertical displacements of about 3.1 m, sometimes with the rate up to hundreds of millimetres per year, which were appropriately confirmed by the practice. After the 27 years of drainage the surface subsidence has reached 2.9 m. Concurrently with the vertical deformations the rocks exerted also the horizontal ones, so that the shaft top was displaced up to 0.5 m during the period of observations. The normal operation of mine shafts should be ensured by the provision the waterproof telescope-type joints, their parameters of deformability being in agreement with the predicted regime of rock consolidation. Unfortunately, this measure is applied still rather seldom, and therefore the serious failures of mine shafts may occur, ie. the deformations of their rigid lining followed by the ground water inrushes (Mironenko, 1974).

WATER-AND-ROCK MATERIAL INRUSHES INTO THE UNDERGROUND WORKINGS

These processes are caused by undermining the rock mass, which results in: a) the changes of stress-strain state of rock mass and its permeability due to the development of technogeneous fissures; b) the formation of technogeneous accumulations of water connected with fissures developing along the bedding; c) the liquefaction of rocks in the zone of excessive pressure, etc. The investigations of this type of deformations are based first of all on the in-situ estimates of stresses in the excessive pressure zone and propagation height of the technogeneous water-conducting fissures (Mironenko, 1983 and Strelsky and Petukhov, 1984)

Changes of the effective stresses in the rock mass are accompanied by the corresponding variations of the water pressure in pores (neutral pressure). So, the pore pressure observations through boreholes enable to obtain rather simply the information on the compression zone propagation, peaks of the stresses concentrations, temporary and constant water-conducting fissures etc. This information is especially required for prediction the safe conditions of mining in the stratified deposits, in particular when the mining system with complete roof caving is used.

Besides the previously studied water inrushes from the surface basins or large aquifers (via the water-conducting fissures due to undermining), one can often observe the inrushes of water out of the newly generated intrastratal water accumulations in beds with relatively poor permeability (Mironenko, 1985). The most pronounced technogeneous accumulators of water appear to be the cavities forming between the rapidly sinking immediate roof and the temporary overhanging main roof. Subsequently, sinking of the main roof with the water filled cavity leads to the danger of rising the hydrostatic pressure in it up to the value, when the hydrofracturing and inrush of water or rock material into mine working may occur.

The development of inrushes of water or liquefied rocks into the underground workings takes place in the zones of excessive pressure, where the technogeneous loads on the rock mass may exceed 3 or 4 times the natural loads. In this case, as a result of the rock mass failure and the tendency towards the essential decrease of the pore volume in it, the pore-water (neutral) pressure begins to rise reaching the values of the total pressure. So, the rock can pass to the state which might be conditionally characterized as liquefaction. For instance, at the Artyom coal mine (the Far East region of the USSR) such inrushes were caused by the liquefaction of the fine-grained sandstones with high porosity. There the necessity arose to carry-out the observations of the initial stages of the liquefaction process by using the remote pressure gauges. Some rather important results were thus obtained. For example, the advance of the longwall face of the active working has contributed to the rapid rise of pore-water pressure in the stratified roof of the mined coal seam, which was observed at the distance of some hundreds meters from the productive working boundaries. When the advancing of the working face ceased, the pore-water pressure has partially dissipated. In the vicinity of the peaks of excessive pressure the pore-water pressure rise of about 1.2 MPa has been noted in one of the beds, or more than twice in comparison with the natural pressure. There was revealed the dependence of the rate of pore-water pressure increase on the rate of the working face advance. The observations registered also the hydrofracturing of the semipervious stratum (composed of the siltstone and fine-grained sandstone layers with the total thickness up to 20 m) between the beds with the pore-water pressure difference of about 1.5 MPa. Simultaneously the top of the water-conducting fissured zone above the productive working has been defined which accounts for about 50 m - 55 m, while the coal extracted thickness was changing from 2.5 m to 3.1 m. This information and other data were obtained by using only 6 gauges installed in one borehole within the coal seam roof.

The carried-out observations showed that the induced by mining operations processes, eg. the changes in the seepage regime (pore-water pressure), development of the water-conducting fissured zone, hydrofracturing and rocks liquefaction due to the excessive pressure may be controlled in-situ and effectively prevented if it is necessary.

DYNAMIC PROCESSES CAUSED BY THE CHANGES OF GROUND WATER REGIME

These processes may manifest in the form of rock bursts resulted from the effective pressure rise in the working face area, for example, due to the advancing drainage of the near-face zone. On the other side, by means of water injection into the advanced boreholes drilled from the working face one may artificially increase the neutral pressure and respectively, decrease the effective pressure in the near-face zone. As a result, the controlled micro-deformations are induced, and the mechanical energy of the coal seam relaxes due to the plastic deformations. This effect is used as the reliable means for rock burst prevention in coal mines, eg. at the Tkibuly coal deposit in Georgia. For the open-pit mining the most hazardous dynamic phenomenon seems to be the liquefaction of silty soils in tailing ponds dams caused by seismic loads. But in the USSR the experience of studying this hazardous process is still limited, although the number of high dams consisting of such material is growing.

ARTIFICIAL HYDROSPLITTING OF ROCKS (HYDROFRACTURING)

The hydrosplitting role is rather significant not only in stimulating the water inrushes into mine workings but also for water-isolating cementation (grouting) around them when this process is practically not predicted and not controlled usually. So. all considerations concerning the directed using of hydrofracturing during grouting are true in the theory, for the idealised rocks. Meanwhile, use of hydrosplitting in the grouting practice without the effective methods of control more often leads to negative results, eg. the drastically prevailing penetration of cementing mixture into the hydrofracturing cracks which excludes natural fissures from the grouting process. More interesting and realistic is the application of hydrofracturing for estimation of anomalous stress state of rocks along the directions of development workings at great depths, as well as for generation of horizontal fractures in the unpermeable beds for the purpose of underground storage of the hazardous waste materials.

THE TRANSFORMATIONS OF CLAY LININGS PERMEABILITY

These transformations occur in particular in industrial wastewater ponds as a result of their linings compaction under the stored technogeneous materials and the concurrent changes of mechanical properties of clays through their convective-diffusive salinization by technogeneous brines. The compaction of clay linings under loading is investigated by the conventional, but significantly modified methods, ie. compression tests, observations for dynamics of pore-water pressure, pouring-in permeability tests in trial pits and boreholes, etc.(Mironenko, 1989). The problem of changes of the linings mechanical properties during salinization is investigated rather poorly. The experience of operation of tailing ponds in the Solikamsk-Bereznikovsk salt deposit region has shown that as a result of salinisation the clay linings are gradually losing their plasticity, then they acquire the microaggregated structure and finally increase their permeability by an order (or two) of magnitude, ie. they fail to perform their function as linings. The concurrently acting osmotic processes cause the volumetric compression of the clay soils and the development of fractures in them. In spite of rather low rates of these transformations it is essential to state rather limited possibilities of using the clay linings for long-term storage of technogeneous brines.

FIELD EXAMPLE

Summing up the foregoing statements, it could be concluded that there is a necessity of closing interconnection between the hydrogeomechanical investigations and hydrogeochemical ones, as well as the determination of mass-transport parameters. This necessity is in particular evident for the perspective activities in improving the ecological safety of mining operations. As an illustration of the fore-going one may regard the situation at the diamond pipe "Mir" (Yakutia region) where during the open-pit mining the brine-bearing horizon was discovered at the depth of 400 m, with mineralization of about 90 g/l. The pumped-out discharge of underground brines was up to 1000 m^3/h.

The impossibility to guarantee the ecologically safe storage of these brines has forced the decision on creation of the low-permeable curtain around the open-pit mine. This curtain however, cause the increase of hydrostatic pressure in the vicinity of the open-pit and threatens its slopes deformation It was possible to avoid this only by removing this curtain farther away from the centre of the quarry, and that resulted in the drastic increase of its construction costs. As the isolated stratum of the carbonaceous rocks is of relatively low permeability (the coefficient of permeability is about 10^{-5} m/sec), the grouting should be inevitably carried-out by using widely the hydrofracturing. However, the problem of crack propagation control during hydrofracturing is not solved yet, and therefore the efficiency of the designed low-permeable curtain is very questionable. The problem of the hydrofracture orientations during grouting, of the cementing mixture propagation, of the curtain safety during the gradual deformations of the quarry slopes, of the efficiency for the subsequent underground mining at great depth, of the possible substantial transformation of the current permeability under influence of brines, etc. are still to be solved.

CONCLUSION

This example shows that many problems in the field of hydrogeomechanics are quite insufficiently substantiated. On the other hand, the in-situ experimental study of the hydrogeomechanical processes accompanying the mining operations, meets very often with great difficulties because it requires the operating fullscale analogue, highly expensive arrangements of the considered experimental site, drilling of the specially purposed boreholes, mounting of the instrumentation, experimental observations etc. In this connection the most advantageous and sometimes the only achievable means for a priori analysis and forecast of the considered hydrogeomechanical processes under given geological and mining conditions seems to be their modelling by the equivalent materials and/or numerical methods based on the coupling of models of stress state, deformations, flow and sometimes mass-transport. The forecasts obtained through modelling should be taken into account, as the first approximation, in the designing of mining operations. Then they should be revised during the operation stage by means of specialized complex observations, in particular observations for the dynamics of pore-water pressure. In other words, the mining practice urgently dictates the necessity for the testing-operational approach to the analysis and forecasts of the hydrogeomechanical processes.

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