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Geomechanical monitoring of rock mass during underground mining of Mir Pipe

AS Chaadaev and IV Zyryanov

Yakutniproalmaz Institute, Republic of Sakha (Yakutia), Russia

E-mail: ZyryanovIV@alrosa.ru

Abstract. The implementation of geomechanical monitoring in Mir Mine is discussed. The proposed integrated system of geomechanical monitoring makes it possible to improve the reliability of control over initiation and development of displacements in rock mass.

Safe mining needs implementation of special measures in hazardous production zones [1]. Mir Mine extracts ore reserves under the open pit mine bottom, under an aquifer, with the protection represented by a safety crown pillar.

Safety of mining is based on prediction and ground control in enclosing rock mass, ore body and backfill, using a hydro-geomechanical monitoring project, covering detection of water-permeable cracks and determination of strains and displacements at rock mass and ore pipe interface, in the safety ore ore crown and in the zone of artificial crown formation in case of the downward mining.

An integral part of the geomechanical monitoring is getting initial information on mechanical properties and stress state of rock mass under the open pit mine bottom, on their change in the course of mining based on the observations over undermined rock mass subsidence and damage control in hazardous contact zones. The obtained information is used to adjust parameters of numerical stress state modeling which is later on corrected using the in situ monitoring data towards enhanced reliability of prediction of state of the safety crown pillar.

Moreover, the hydro-geomechanical monitoring project includes analyses of the structure, damage and stress state of ore body, enclosing rock mass and backfill; studies into effect of brines and ambient medium on the physical properties of rocks; recommendations of safety of underground mine in case of water level in the pit exceeds the project level and water inflows in underground mine intensify; computer modeling of the monitoring object and investigation of hazardous geomechanical and hydrogeological processes in the crown pillar; development of quantitative geomechanical, geophysical and hydrogeological criteria to predict geodynamic processes in the crown pillar, ore body, enclosing rock mass and backfill.

Since 1957 till 2001 Mir kimberlite pipe had been developed by the open pit method down to a depth of 525 m, with the exposure of Metegero-Ichersky aquifer, under water inflow rate of 1200 m^3/h. The further extraction below the actual elevation -190 m involves the underground method under protection of 'dry' conservation system, which means filling the open pit mine with coarse rock material, creation of rock-and film shielding and deep-level water discharge at the actual elevation of -141 m. Conservation of the underground ore body is implemented by means of filling the open pit with three layers of rocks with a total thickness of 50 m. the bottom layer to 30 m thick is composed of coarse dolerite and is characterized as the hurricane-resistant layer. This layer is overlaid with a loamy cushion covered by an impermeable film 2 mm thick. The film is covered from the top by clayey soil.

Mining phase I in Mir Mine in block 1 (–210–310 actual elevation) was started in 2009. Extraction is carried out under the dead-storage open pit Mir in accordance with the project developed by the Yakutniproalmaz Institute (2008) in the top-down sequence. The current method is cut and fill.

For the protection of the mine under the open pit bottom (-190 m actual elevation), a crown pillar 20 m is left; the size of the pillar is approved by the the Federal Service for Ecological, Technological and Nuclear Supervision of Russia (Decree No. 13-13/3819 as of Dec 29, 2008). The reserves in the safety crown are categorized as temporally suspended. Moreover, the mine is topped with 3 safety layers each 5 m thick, i.e. overall thickness of the crown is 35 m.

The mine safety is determined by the criterion of mine water discharge which is ratio of the maximum output of mine discharge to the maximum expected water inflow.

Water protection system used the ‘dry’ conservation scheme. To this effect, on the pit bottom, a dolerite break stone layer is placed and then overlaid with an anti-seepage screen (-159 m actual elevation). Brines and atmospheric precipitations are discharged from the open pit via a tunnel (bottom elevation -159 m). The water inflow rate in the pit is 1200 m^3/h. To catch water inflow through the anti-seepage screen and through the pit walls, 3 catch galleries are driven at the actual elevation of -201 m, and fans of drainage holes are drill from the tunnels. At the same elevation of -210 m, auxiliary pumping stations (APS) is installed to discharge water from the mine into the open pit, while district pump stations at the actual elevations of -310 and -690 m pump inflow water to the main water discharge installation at the actual elevation of -210 m.

APS 1 is equipped with 5 pumps to pump out water from drainage and slightly inclined catch holes to the main water drainage system. APS 2 is equipped with 7 pumps (2 pumps TsNS-300/180, 2 pumps TsNS-300/120, 2 pumps 1-D-630/90 and 1 pump DE-500/63 to pump out water to the main water drainage system and the discharge gallery.

All levels of block 1 are serviced by the brine discharge system (catch facilities, sumps, by-pass holes) to redirect water to the level at the actual elevation of -327 m equipped with 4 pumps NTsSK-180/212. The pumping station pumps out water to the main water discharge system (MWDS 1 and MWDS 2 at the actual elevation of -201 m and, then, to the surface.

In 2015 the main water discharge system at -210 m was redesigned for the general water inflow rate of 1240 m^3/h.

MWDS 1 is equipped with 5 unit pumps AENTsSK(K)-180/700 and MWDS 2—with 5 unit pumps AENTsSK(K)-400/600.

In the first quarter of 2017, water discharge rate in the mine and open pit is 1200–1250 m^3/h. Some brines at the flow rate of 790–84 m^3/h are pumped out by RITs pumps fed from the pit and by APS 2 via holes 12 and 7Sh to the water discharge gallery. Pumps discharge water at the flow rate of 450–460 m^3/h to MWDS. Water flow through block 1 is 100 m^3/h regardless process water.

The drainage system operates efficiently and eliminates hydrodynamic pressure on the roof of the ore crown pillar.

Since 2011 safety of mining is ensured by the integrated hydrogeomechanical monitoring in accordance with the geotechnical monitoring project Technical Upgrading. Mir Mine. Integrated Hydro-Geomechanical Monitoring of Mining Phase I (Yakutniproalmaz Institute, Mirny, 2015) by the Geotechnical Monitoring Service of the Mirny Mining and Processing Plant jointly with the Institute of Mining, SB RAS, Research Institute of Design and Technology and NOVOTEK Center for Science and Technology.

The hydro-geomechanical monitoring project involves a set of instrumental methods to obtain initial data on deformation of enclosing rock mass, undermined ore body and backfill, including surveying lines, deep-seated plugs and directional survey. The mining-induced damage and cracking is controlled visually, using downhole endoscope and sets of perimeter and deep-seated plugs. Furthermore, the project provides for the geophysical investigation of properties and condition of the crown pillar left under the open pit mine bottom.

Decided by the management of Mirny Mining and Processing Plant and approved by ALROSA, drivage of three subparallel openings at the level of -210 m along the long axis of the horizontal position of Mir Pipe (so-called trident) with the control over hydro-geomechanical behavior of the ore crown allows reliable information on the behavior of the pillar depending on the preparatory works and actual mining in block 1. It has become possible to organize a stationary non-undermined hydrogeological and geomechanical monitoring network directly at the zone of the ore crown pillar.

The geomechanical monitoring network at the top of block 1 and in the crown pillar is aimed at:

—assessment of displacements and deformations in space and time at the bottom of the crown pillar (actual elevation –215÷ –230 m);

—plotting of the displacement trough along and across the strike of the ore body;

—determination of possible lamination zones in the ore body (actual elevation –215÷ –230 m);

—control of subsidence and horizontal movement in the backfill in the initial cut layer 4 during to-down mining in block 1;

—refinement and control of sub-backfill height in the in the initial cut layer 4 in the area of observation stations in the course of undermining of the backfill layer;

—estimation of mechanical properties of ore body and backfill in the area of observation stations;

—analysis of the measurement data in connection with the theoretical calculations upon the change in the geotechnical situation in the block and operational application of the results to the estimation of the geomechanical behavior of the ore crown pillar;

—adjustment of the geomechanical model by the obtained data for the enhanced reliability of stress state prediction in the structural elements of the mining system.

Displacements were measured by the Geotechnical Monitoring Service of Mirny Mining and Processing Plant, and the checking measurements at the deep-seated plugs and directional survey stations—by the specialists from the Institute of Mining, SB RAS.

The instrumental observation data are monthly sent to the Yakutniproalmaz Institute for the quarterly reports on the mining safety by the data of processing and analysis of the in situ monitoring of the ore body movement by the stakes of the survey lines installed in the water discharge systems at the actual elevation of –214 ÷ –219 m and in the backfill drift at the level of –260 m, deformation marks in the mine openings along the rock mass and ore contact at the level of –210 m, direct survey stations at the level of –272 m and deep-seated plugs at the levels of –265 and –272 m.

The specialists of the Yakutniproalmaz Institute and the outside contractors assess stress state in the mine using the methods of borehole slotter and parallel drilling.

The Geotechnical Monitoring Service of Mirny Mining and Processing Plant implement rock mass quality classification by the rating indexes RMR-89 (Bieniawski) and Q (Barton).

The seismic monitoring in Mir Mine uses the methods of seismoacoustics by system Prognoz-ADS. This system implements continuous monitoring of rock mass and mine structures and predicts hazardous events due to rock pressure with regard to geo-cryology [2].

The geoacoustic control allows assessment of rock mass conditions in the crown ore pillar under the influence of mining at the lower lying levels and the external load from the watered rock mass in the conditions of 'dry' conservation in the permafrost zone.

The proposed system of integrated geomechanical monitoring allows reliable control over the processes of displacements in the crown pillar and in its backfilled bottom layer.

During the analysis of displacements at the stakes of the survey lines by the method of interpolation, zoning of rock mass at the actual elevation of –210 m has been performed (Figure 1).

The convergence of the roof and floor in the catch galleries is determined using the floor stakes. The analysis of the data obtained in the observation cycle in the first quarter of 2017 (Figure 2) has allowed determining the subsidence in the north-east of the rock mass, at the actual elevation of –210 , (stakes 5–7 in the south, stakes 1–3 in the center), which is confirmed by the seismoacoustic monitoring (Figure 3).

The integrated analysis enables detecting a probable deformation zone (Figure 3) and shearing in the rock mass (shear angle > $5*10^{-3}$ deg).

As mining is advanced to deeper levels, ALROSA system of control is persistently updated and refined. The location of the new observation points is chosen based on the previous measurement auditing.

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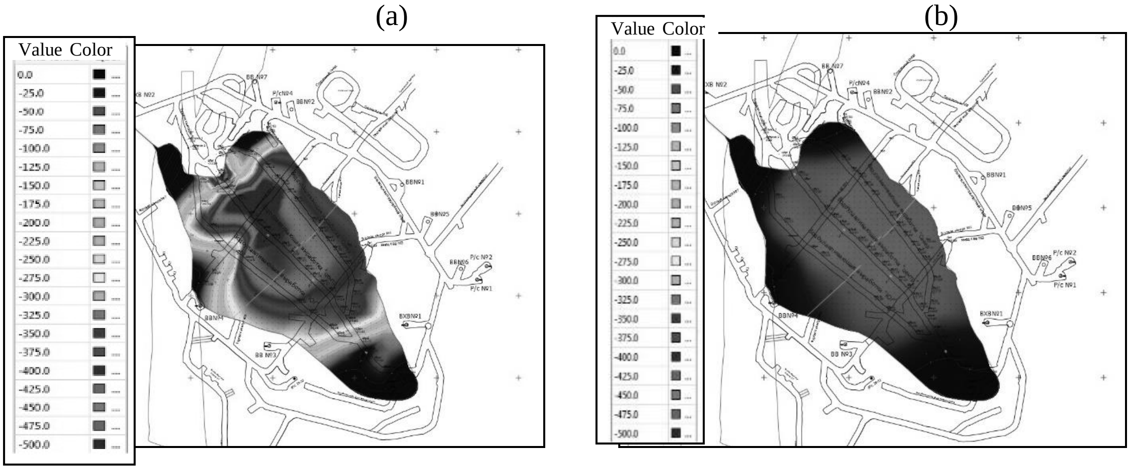

Figure 1. Subsidence of the profile line stakes in the roof of the catch galleries at the actual elevation of –210 m: (a) May 2014–March 2017, (b) first quarter of 2017.

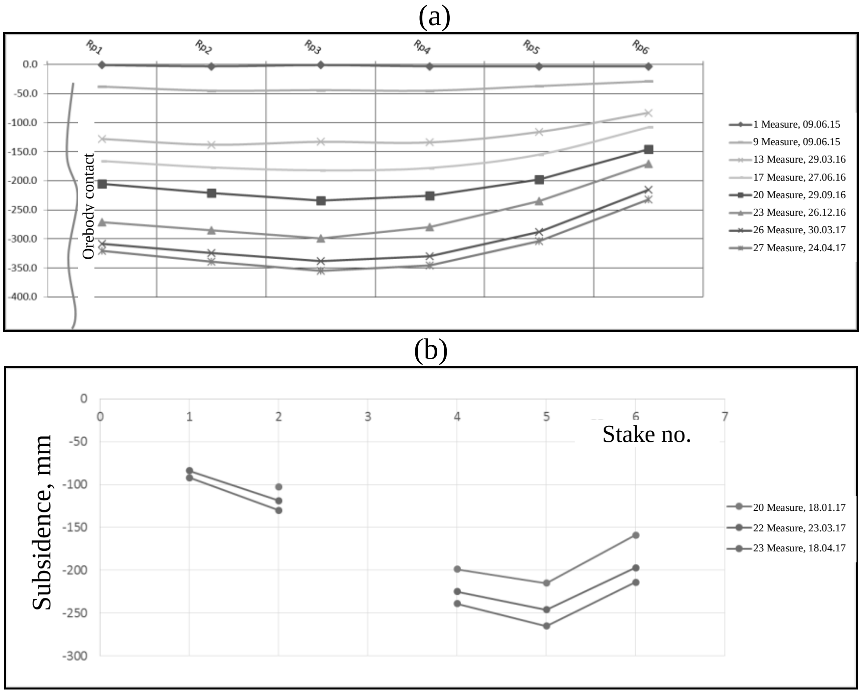

Figure 2. Subsidence of the profile line stakes in the catch galleries (a) Center and (b) South.

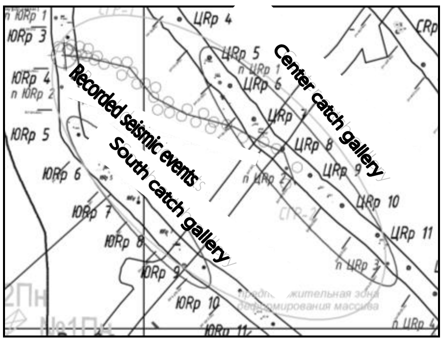

Figure 3. Probable deformation zone at the actual elevation of –210 m.

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In 2014 ALROSA management has decided on the initiation of the geomechanical service in the mines. The key tasks of the service are the control of the conformity of mining processes with the approved projects, detection of violations and deviations, and determination of the influence of the latter on the alteration of the rock mass stress state in the mining zones with a view to the risk assessment of hazardous events.

References

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