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Simulation of a Geomechanical Monitoring Algorithm for Open-Pit Mining

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Abstract: This study contains the results of simulation of a geomechanical monitoring algorithm aimed at identification of unstable sections of open-pit sides and refuse piles of overburden rocks as well as at remedying uncontrollable water influx into barrow pit. The geotechnological conditions of exploitation are characterized by major tectonic disturbances and areas of rocks with low structural behavior which substantially release the cutoff mass. Currently, the following factors shall be taken into consideration during the exploitation of deep levels: pit wall stability time and multiple dynamic loads from huge blasts which generally minimize the wall stability. Thus, the final purpose of geomechanical monitoring is to obtain scientifically proven information which would make it possible to forecast the development of deformation processes, select the technological elements of exploitation and the parameters of pit walls to ensure the maximum efficiency and safety of mining. The long-term pit walls deformation in time forecast developed in the monitoring system is based on the results of the assessment of tectonic disturbances geodynamics at the regional level, structural features of the geology aspects of the open-pit field and geomechanical features of slips to determine the pit wall stability. Pit wall deformation forecast map is a statistically probable model of pit wall deformation in time. The probability factor contour defines the boundaries of the areas which have different deformation probability factors. The various methods to obtain information for geomechanical monitoring have been assessed.

Key words: Forecasting, geomechanical monitoring, stability level, barrow pit, monitoring methods, pit wall stability, stress-strain state

INTRODUCTION

The modern view on the strategy of field development under extreme conditions suggests a scientifically and practically acute problem of monitoring of the Stress-Strain State (SSS) of rock mass. The information on the geomechanical state of rock mass is required at all stages of mining production: from exploration to use of pit after end of recovery. Besides, due to the high level of responsibility in decision making such information shall be complete and timely (Eyo and Abasiekwere, 2009; Arriagada *et al*., 2009; Arvas *et al*., 2013; Argimbaev and Yakubovskiy, 2014; Bozkurt *et al*., 2010). Hence, the obvious necessity to create reliable, methodologically robust methods and advanced technical means of control, diagnostics and forecast of rock mass movements and state both locally and within the area of influence.

Under current conditions the efficiency of deep pit exploitation process flowsheets determines the strict requirements for mine safety and is provided by the geomechanical monitoring which includes a set of geophysical, surveying and hydrometrical observations aimed at identification of unstable pit walls and refuse piles and at remedying uncontrollable water influx into barrow pit (Burke, 2003; Bozkurt *et al*., 2010).

Based on the results of observations, a set of measures to mitigate the impact of pit walls spontaneous deformations on mining operation, mining equipment and personnel safety (Kholodnyakov and Argimbayev, 2014a, b). The mining operation is being controlled within the project framework which provides the final contouring of pit walls given the conformity of development elements to the parameters of used mining equipment.

MATERIALS AND METHODS

Geomechanical monitoring methods: The prompt assessment of pit walls state within the areas hazardous in terms of stability and identified through geographical demarcation is carried out with the use of complex geophysical research through seismometry and electrometry (Kholodjakov and Argimbaev, 2014a, b; Balaji *et al*., 2013; Yakubovskiy *et al*., 2014a, b; Pikalov *et al*., 2016; Argimbaev and Kholodjakov, 2013; Argimbaev *et al*., 2015).

The spectrum level of horizontal oscillations of rock mass at the fundamental frequency of pit walls own oscillations is adopted as a basic criterion which characterizes the seismic load on pit elements during the seismic survey.

The inhomogeneity areas with the radius of 100 m are considered the most dangerous for mining. In this regard, the demarcation of pit through seismometry shall be carried out with the frequency corresponding to the lowering of mining by the maximum fixed radius value, i.e., upon the lowering of mining by each 100 m or once in 5 year. The main reasons of deformation in identified areas are the geological conditions of bedding of rocks which lead to redistribution of inner stress in the rock mass with time (Argimbaev and Kholodjakov, 2015; Sarma, 1979; Argimbayev *et al*., 2016). The tectonic impacts on a regional scale are considered an initiating factor of deformation development together with major blasts impact. The Vertical Sounding observations (VS) on the pit walls are carried out on fixed stations.

The stationarity allows mitigating the external influence while the long-term monitoring with the frequency of 3 times per quarter creates the conditions to apply the mathematical statistics apparatus which significantly increases the accuracy of the study area dynamic model simulation. The use of VS method when observing the stress-strain state of the rock mass in time has shown that the maximum sensitivity is observed when the station is located within one hundred meters of the future deformation border where the rock mass resistance change reaches 30-40% just before the deformation (up to 3 month prior).

The existing clear correlation of values between the apparent resistance, structure and stress-strain state of rock mass allows using electrometric methods to determine the dynamics of the stress-strain state of the cutoff mass prior to manifestations of visible disturbance (Argimbaev and Kholodjakov, 2016). Taking into consideration the low sensitivity of the method, it is recommended to apply VS additionally to surveying observations (Kaerbek and Maya, 2016; Argimbaev, 2016).

Thus, a set of geophysical survey methods implemented through the monitoring system is effectively applied for confirmation of geological situation and prompt identification of structural inhomogeneity of cutoff mass, determination of structural blocks borders and slip planes. The pit walls, slips and utilities stability surveying observations are fundamental in the geomechanical monitoring system and require the application of hardware for surveying observations such as tacheometers (Argimbaev and Alexandrovich, 2016; Argimbaev *et al*., 2014).

When solving geomechanical tasks, modern tacheometers such as Trimble allow carrying out observations over displacement of rock mass and development of deformations with the use of reflectorless ranging system which allows determining the geometrical parameters of deformations in previously inaccessible areas. It is now also possible to increase the ranging of sampling up to 1,500 m. Trimble tacheometer makes field operations easier to carry out and helps accelerate the processing of measurement analysis at the workplace.

Upon completion of measurement, all data is automatically entered into the PC and processed with the use of special software. Trimble tacheometers are especially effective at geomechanical monitoring of dump operations because the refuse piles are often located at a considerable distance from the main base and the mapping of piles implies measurement of considerable distances.

MATERIALS AND METHODS

Geomechanical monitoring algorithm: Through the example of Ozernoye polymetallic deposit a geomechanical monitoring algorithm was proposed. Under the complicated geomechanical conditions of Ozernoye polymetallic deposit reliable methods of diagnostics and control which would provide continuous surveillance over the state of rock mass within the deposit area are required to ensure mine safety.

Monitoring includes a complex system of periodic observations over the state of environment in order to identify negative changes and draw up recommendations on their elimination (Bukhman *et al*., 1966; June and Khalaf, 2009).

Rock mass diagnostics is based on comprehensive and systematic study of its state at all stages of mining. It includes analysis of barrow pit dimensional changes in terms of depth and frequency of undermining, various instrumental methods of rock mass physical properties measurement, including seismology and rock mass displacement. In the course of diagnostics the following is carried out: an analysis of geological and surveying documents; regular examination of barrow pit through visual observations over rock pressure manifestations; observations over earth surface displacement and rock mass seismic activity. Based on the results of diagnostics, the reason for rock mass changes are identified.

The main tasks of diagnostics are as follows: to obtain the source information on rock mass; to assess the current state of rock mass; to carry out preventive examination of rock mass and to forecast the geomechanical processes in it; to carry out the necessary observations (measurements) to prevent sudden collapse. Diagnostics helps justify the possibility of mineral recovery in mines, methods and order of depreciation of

Table 1: The assessment of earth surface stability

Depression of earth surface (mm)	Rate of depression of earth surface (mm sec^{-1})	Stability level
Up to 20	0.1	Stable
21-35	0.1-0.3	Reduced
36-50	0.3-1	Unstable
>50	>1	Intensive displacements

accumulated potentially hazardous cavities, the necessity to transfer the surface buildings, etc. Possession of information on potentially hazardous areas in terms of collapse allows identifying the areas of possible collapse as early as during the planning and design stage and taking preventive measures.

Rock mass state control follows the diagnostics stage. The tasks of control are the following: selection of rock mass areas subject to control within the pit; selection and justification of criteria for the control of rock mass or its separate elements; development of control schemes and the tools necessary for their update; notification of service personnel in case of an emergency. Control is based on the knowledge of the physical processes that take place in rock mass and shall be carried out through various types of monitoring (analytical methods, instrumental methods of control over the rock mass displacement, modern systems of automated control, immediate visual observations over mining operation).

Seismic control systems allow prompt identifying a seismic effect of each blast, carrying out the seismic zoning of the deposit in terms of industrial blast hazard level and, if necessary, adjusting blast designs. Thus, during industrial blasting, the seismic monitoring of rock mass provides reliable assessment of its seismicity and is the main measure of blast protection of utilities. Seismic monitoring allows controlling the blasting concussion and regulating the lowering of actual level of seismic oscillations to permissible values which as a result, provides efficiency and safety of blasting operations. The assessment of earth surface stability is presented in Table 1.

Based on the results of comprehensive monitoring which provides diagnostics and control of the barrow pit state, an assessment of the state of some areas of the barrow pit through instrumental and visual observations is performed. The obtained results on the state of rock mass are used to forecast the potential of the areas of deposit to sudden collapses and the best technologies and measures to prevent the negative developments are justified. In order to make the control more prompt, the technology of rock mass monitoring has been developed which allows assessing general geomechanical situation of the pit and obtaining the following main results:

- Identification of deposit areas with exposure which could be hazardous in terms of collapse, presented as forecast maps by various criteria
- Identification of areas of primary exploitation along with areas of collapse depreciation
- Automatization of classification of areas of deposit by stability level and identification of the following categories: intensive displacement areas, unstable and reduced areas
- Performance of engineering activities to prevent accidents which could be caused by a possible collapse or utilities transfer
- Diagnostics and control over the reduced areas of deposit and submission of information to the relevant agencies

Thus, the comprehensive monitoring allows carrying out the exploitation under complex geomechanical conditions, by mitigating the risk of such catastrophic phenomena as collapse. Figure 1 shows the collapse forecast scheme based on the comprehensive monitoring results. When assessing the stability of deep level pit walls based on the suggested method under the complex geotechnical and hydrogeological conditions, it is necessary to observe the following provisions. Determine the lithological composition of reservoir; the structure and disturbances of rock mass, the nature and extent of fracture porosity; hydrogeological conditions of the rock mass; physical and mechanical properties of formations from sampling and rock mass itself.

Find the characteristics of rock formations properties in a sample. The accuracy of information on rock formations resistance affects the reliability of pit wall stability factor results. The research has shown that if the value of tenacity changes by 10%, the stability factor changes by 2.5%, if the value of internal friction changes by 10%, the stability factor changes by 12%. The accurate information on the nature of cutoff mass deformation depends on the obtained deformation characteristics. Draw up a geomechanical model of cutoff mass which would take into consideration the geological structure, hydrogeological characteristics of the deposit and host rock.

Analyze the obtained results with the help of numerical modeling based on the finite element method after the creation of an analytical geomechanical model of cutoff mass and addressing the set goal. The stress-strain state of cutoff mass is measured by the distribution of stress and relative deformations in the process of mining and upon placing of a wall into a final position. When

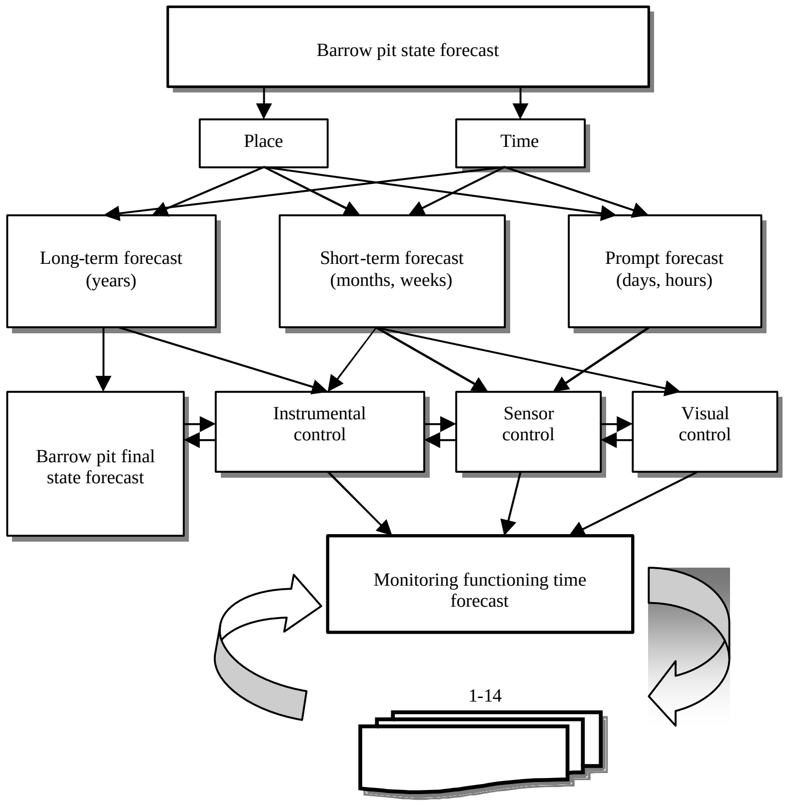

Fig. 1: The collapse forecast based on comprehensive monitoring: 1: overall width of mining; 2: frequency of undermining; 3: slabs; 4: depression of earth surface; 5: rate of depression; 6: depression by separate datum lines; 7: depression by profile lines; 8: seismic activity of oscillations; 9: seismic activity areas; 10: recurrence curve; 11: breakdown image; 12: blasting concussions; 13: geomechanical assessment; 14: mining operations

assessing the deformation process of the angle of slips, the relative horizontal deformations play a pivotal role as they help identify the extension zones and the most strained slip plane. Besides that, it is important to define the quality and quantity of deformation distribution along the pit walls: to analyze the vertical displacements along the daylight surface and the pit bottom as well as slope horizontal displacements.

Upon completion of calculations, check against the data obtained through other methods and nature observations. A conclusion can be drawn that the system of methods and instruments of accurate assessment of current stress-strain state of rock mass and the system of forecasting catastrophic manifestations of rock pressure, combines three equal functional components: obtaining of representative sampling of geophysical data on rock mass behavior; prompt processing of geophysical information based on the modern fundamental results of geomechanics and statistically probable models of data analysis; use of empirical approach, heuristic models and expert methods when assessing the geomechanical situation at the controlled facility.

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