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MODERN METHODS OF GEOTECHNIC – EFFECTIVE WAY OF PROVIDING INDUSTRIAL SAFETY IN MINES*

Results of long term researches of scientists of Kazakh National Research Technical University (KazNRTU) on the study of geomechanical processes are considered. It is shown that the problem of controlling geomechanical processes can be solved on the basis of integrated system for geomonitoring of rock massif state, providing for comprehensive accounting and analysis of all natural and man-made factors, as well as use of developed control tools by the authors.

Characteristic features of ore deposits, use of various geotechnical methods in the process of their development are analyzed. Using necessity of methods of satellite geodesy, electronic tacheometers and laser scanning for open – pit mines monitoring was revealed and substantiated. Permanent ground reference which allows to ensure speed and accuracy of centering, as well as to exclude use of tripods for installation of high-precision electronic and laser devices used for earth surface geomonitoring was developed by the authors.

Firstly, particular attention is drawn to underground monitoring of deformation and rock mass destruction. Mining works experience detects main cause of massif disturbance is fracturing which is probabilistic in nature. In addition, rock blasting operations during execution of inter-chamber pillars (ICP) are sources of additional technological rocks fracturing, that also reduces load bearing capacity and pillars and roof stability.

Secondly, during mining on chamber-and-pillar development system in mined-out chambers, repeatedly increased leading rock pressure moves between support pillars or conjunction of mine workings, which threatens with sudden roof collapse ensuing serious consequences. Therefore, to monitor roof displacement during cleaning operations, distance determination method of roof displacement has been developed and ICP, which allows operational monitoring of underground workings stability and increase safety of mining operations.

Method is based on the task of tool creating that allows to constantly register roof displacement in order to timely warn of impending roof collapse and take necessary measures.

Thirdly, considering that ultimate goal for all geomechanical studies is to ensure industrial safety, in order to prevent further progressive pillars destruction, composition for strengthening fractured rock mass has been developed. Composition is oriented for hardening fractured rocks in open – pit mines and hardening distructed inter-chamber pillars and ceilings in underground workings.

Technical result: mining waste utilization – (mill tailings), achievement of high fluidity of solution, adhesion to rocks and strength of obtained composition.

Constant monitoring of state of massif fracturing and their strengthening can significantly extend service life of pillars, increase stability of worked-out space and, thereby, ensure safety and efficiency of mining operations.

Keywords: *ore deposits, rock fracturing, deformations, geomechanical monitoring, innovative methods, geodetic instruments, massif condition assessment, cement slurry*
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Introduction

One of the urgent problems during of large-scale mining operations, especially in rock massifs is technogenic seismicity, which entails not only catastrophic technical and economic consequences (technogenic earthquakes, rock bumps, landslides, etc.), but also sometimes leading to human casualties. All this is direct consequence of geodynamic regime change of geological environment under the influence of large-scale mining, which is convincingly confirmed by results of scientific research on the example of the Zhezkazgan, Akbakay, Maikain and Akzhal deposits located in various regions of the Republic of Kazakhstan.

All these deposits are powerful subjects of anthropogenic impact on the environment, providing great opportunities for studying a wide range of man-made disasters and reducing their risk.

Problem of man-made disasters remains relevant at the present time in all countries with developed mining industry, which is once again confirmed by materials of the next 6th International Symposium on rock bumps and mine seismicity [1–3]. A lot of attention is paid to the management of various risks, as evidenced by increased number of publications on this topic [4–7].

For deposits of solid minerals, geomechanical safety of mining operations is based on engineering approaches adapted to specific mining and geological conditions of development. This approach does not take into account local structural features of underworked strata, variability of physical and mechanical properties of rocks and geomechanical characteristics of geological environment. And all this, of course, affects reliability of geomechanical assessments of real mining situations. Accountability of listed physical and geological factors in geomechanical calculations appear due to maintenance and accounting of results of geodetic observations.

Recently, data of satellite radar interferometry are being used more widely in the monitoring of technogenic processes, space sensing of the Earth. Significant contribution to method introduction of radar interferometry in monitoring displacements of earth surface on the territory of the Zhezkazgan field was made by specialists of Geotechnical Department of «Kazakhmys» corporation under leadership of V. A. Mansurov [8].

The main advantage of this method is ability to cover large areas. According to the instructions, ground observations are carried out twice a year with an interval of 6 months. During this time, collapse may develop and cannot be predicted.

*The work was attended by M. B. Nurpeisova, professor of Department of Mine Surveying of Kazakh National Research University named after K. I. Satpayev, Doctor of Engineering Sciences and Sh. K. Aitkazinova, PhD doctor.

Therefore, to solve a number of mining technical problems, calculation methods must be adjusted for specific conditions, and at the same time the influence of natural and mining technical factors, as well as values variability of strength properties of rocks in space and time, etc., should be taken into account. Despite the large number of research works [3–8], issue of forecasting and risk management of man-made disasters in view of complexity and wide variety of mining and geological features of field is still not fully resolved.

Methods and research results. State analysis of methodology for conducting mine-surveying observations and interpretation of obtained data is primarily due to lack of effective methods for values determination of subsidence of earth surface (SES), which necessitates the method improvement of mine-surveying and geodetic observations of rock deformations using modern electronic devices to increase the reliability, efficiency in parameters determination of SES for safe subsoil development and measures adoption for protection of developed facilities [9,10].

KazNRTU, including Department of Mine Surveying and Geodesy pays increased attention to industrial safety at mines. This is due to fact that major negative phenomena leading to various kinds of incidents during mining operations are associated with rock pressure management. In this case, main role is assigned to introduction into practice of modern technologies and control means and monitoring of rock mass. This is evidenced by our research on the projects «Development of innovative methods for predicting and assessment of state of rock mass to prevent technogenic emergencies» and «Comprehensive monitoring of slow deformation processes of earth surface during large-scale development of ore deposits in Central Kazakhstan» [11].

In general, geodetic observations using new generation instruments make it possible to identify massif deformations which is significantly useful for geodynamic situation assessment in field area. But they do not provide complete picture of deformation processes in time. This can only be done using comprehensive methodology for studying natural and technical system based on geomechanical monitoring, which is an original product of group of researchers from KazNRTU and is an effective tool to ensure maximum safety of mining operations based on the complexity of the approach used, which can be summarized as follows:

• based on geology analysis and region tectonics, experimental assessments of stress state and instrumental observations «energy-saturated» zones are identified in massif, which define boundaries of geodynamic monitoring zone.

• then, hazardous area monitoring is organized, which includes mainly control of deformation and level of structured of massif fracturing [12–14];

• based on results of space radar observations, number of local centers of subsidence of earth surface over areas of underground mining were established. At present, ground observations are being carried out in this area;

• hereafter, all information about process regularity of system displacement and parameters of its critical state goes to the expert system, where, based on integration of databases and knowledge, state assessment of NTS is made and corresponding decisions on the protection of subsoil and earth's surface are justified.

Another important decision to create modern geotechnical methods was directed to the area of open pit mining. It is generally accepted to ensure process of surveying in quarries is the use of traditional surveying benchmarks, which are time points, which subsequently reduces accuracy of measurements. Therefore, authors recommended constant ground reference.

Based on GPS measurements carried out, mine surveying services and observation stations of the «Akbakai», «Akzhal» and «Maikain» mines were provided with control points, coordinates of which were determined with high accuracy. Observations of absolute deformations of pit walls at the objects under study were carried out on profile lines of observation station with devices of new generation [15–17]. Repeated geodetic measurements were carried out with Leika TS110 and TS1206 electronic total stations in combination with reflectors and 3D scanners installed on permanent basis.

Long-term instrumental observations have shown the laboriousness of field work, especially transfer from one point to another set of instruments (instrument itself, tripod, rods, etc.). In this regard, for instruments installation and efficiency of measuring operations, firstly, we have developed *permanent benchmark*, which is installed at the reference point during geomechanical monitoring (**Fig. 1**). Device belongs to geodetic centers for installation of new instruments and signals. The purpose of invention is to improve centering accuracy, measurement efficiency in tripods absence at the points of standing and observation. The new device allows for quick and accurate centering, and also eliminates tripods use[18].

Significant factor in the effective solution of the problems of modern opencast is study of fracture systems and structural block sizes. To date, methods for measuring rock fracture are reduced mainly to direct measurements in outcrops on the surface, on slopes in quarries, along the walls of pits and mine workings, observations from cores of geological wells. In open pit mining, rock fracturing was studied using mining compass, i.e. the angles of incidence of cracks and azimuths of their strike were measured with mountain compass.

In order to increase efficiency of solving this issue, 3D scanner was used in our mine surveying and geodetic practice, which made it possible to study in sufficient detail the elements of occurrence of cracks and discontinuities (**Fig.1**, *a*). The accuracy of obtaining the shooting parameters is determined by distance between device and object being shot [19].

Use of the results of shooting with laser scanner to obtain elements of fracture occurrence and sizes of structural blocks is possible when device is located from adjacent rock mass up

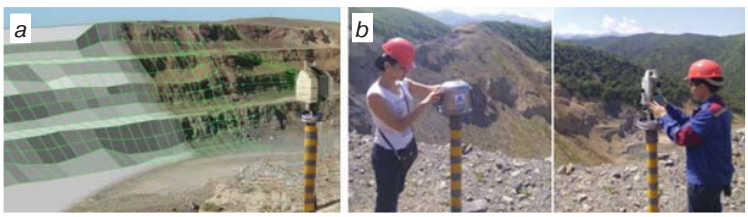

Fig. 1. (*a*) Survey of the Akzhal open-pit mine array with a Leica HDS4400 laser scanner installed at permanent station; (*b*) Permanent benchmark on concrete base with metal cap and measurement with electronic total station

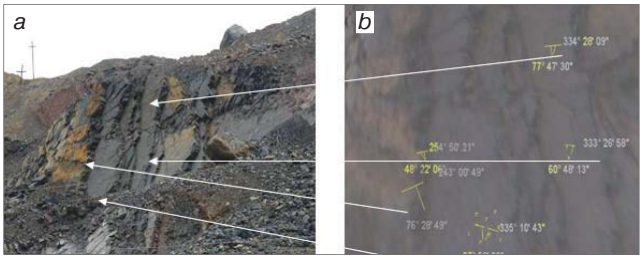

Fig. 2. Study of rock fracturing in open pit:
a – cracks in the ledge slope; b – elements of fracture occurrence on the computer screen

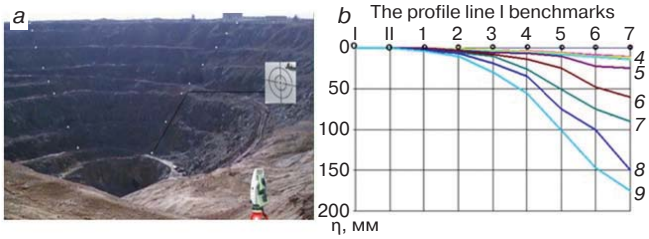

Fig. 3. *a*) benchmarks with marks on profile lines; *b*) graph of benchmark settlement on the profile line I:
observations: 4th – autumn, 2015; 5th – spring, 2016; 6th – autumn, 2016; 7th – spring, 2017; 8th – autumn, 2017; 9th – autumn, 2018

to 800 meters. This gives rise to unique opportunity to obtain information about position of adjacent rock mass without direct performer contact. During results processing of laser scanning, software package «MaptekI-SiteStudio» was used, where values of fracture occurrence elements are calculated: strike azimuth, dip angles and sizes of rock blocks (**Fig. 2**) [20].

To obtain reliable data, it is necessary, simultaneously with geodetic observations, conduct space radar interferometric surveys of fields in monitoring mode, which allows regularly obtaining displacement of earth surface with high accuracy.

According to the results of space radar observations at the Zhezkazgan copper ore zone, number of local centers of subsidence of earth surface over areas of underground mining have been established. At present, ground observations are being carried out in this area. Ground geodetic observations show that (collapse) subsidence of earth surface occurs with underground mining. Therefore, we have intensified work on underground monitoring of deformations and destruction of these sections of the rock mass.

Unfortunately, today there is not single method that can reliably predict collapse of earth surface. There are criteria for catastrophe onset, number of which (speed of displacements of earth surface, displacements acceleration) can be estimated from space radar survey data.

Geodetic observations at the fields are carried out twice a year (in spring and autumn) and additional seismological measurements are also carried out.

For each profile line, lists of vertical and horizontal benchmark displacements, as well as graphs of displacements, were compiled. In **Fig. 3, b** shows a graph of benchmarks settlements along profile line I of the Maikain deposit [21, 22].

Work experience at mining enterprises shows that adopted design parameters of chamber-and-pillar development system (dimensions of pillars, chamber spans) for specific mining and geological conditions, in general, provide long-term stability of mined-out areas.

However, it is necessary to take into account that strength characteristics and pillars dimensions for project are calculated based on the averaged data of mining and geological conditions. Meanwhile, rock mass is heterogeneous and, due to its natural structural variability, is unevenly disturbed. As practice shows, there are cases of destruction of both separate (single) and groups of ICP; delamination and falls of roof rocks occur, and sometimes, depending on influence degree of various influencing factors and intensity of irreversible geomechanical processes, and collapse of entire overlying stratum with an exit to the day surface. Forecast and geocontrol of state of rock mass will be positively resolved on the basis of the introduction of innovative methods and control means [10].

At the moment, in the practice of mining, method of monitoring the condition of roof of mine workings is widespread, by means of tacheometric and photogrammetric methods of shooting, which requires presence of people.

However, they are not effective enough due to the increased danger associated with working in the immediate vicinity of roof and low accuracy of determining rock displacements of exposed surface of chamber.

Therefore, we have developed method of permanent (remote) registration of roof rock displacements (**Fig. 4**) for monitoring displacement of roof rocks during cleanup operations in order to timely warn about impending roof collapse and take necessary measures.

Strength and stability of inter-chamber support pillars, as well as stability of adjacent rock mass are determined by degree of their fracturing. Strengthening technology of fractured massif should ensure complete filling of cracks in massif with various compositions and reliably fasten individual structural blocks into a single whole [23]. Thus, effective methods have been developed to manage the slopes stability associated with strengthening of rock mass and dusty surfaces. Solution for strengthening fractured rocks has been created, which has a low cost, sufficient fluidity to fill small cracks and adhesion to rocks, and high strength.

Solution contains cement, filler and water. Mill tailings of mining and metallurgical complexes were used as filler. At the same time, new composition was investigated and obtained for strengthening reinforcement of support points of observation station in the wells, which also makes it possible to dispose of mining waste and increase strength and frost resistance of material obtained.

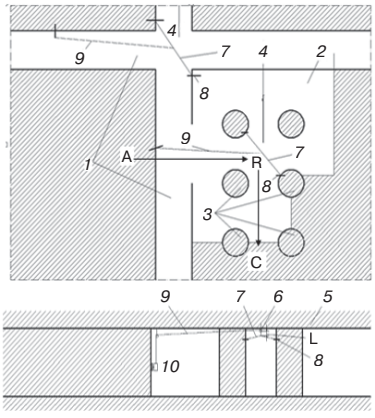

Fig. 4. *a*) plan of site for measuring the displacements of roof rocks located between the supporting pillars; *b)* vertical section along the line A-B-C:
1 – mine workings; *2* – chamber; *3* – pillars; *4* – area between pillars; *5* – roof rocks; *6* – block; *7* – flexible or rigid device; *8* – anchor support; *9* – conductor; *10* – measuring device

Technical novelty of created solutions is confirmed by patents of the Republic of Kazakhstan for invention [24].

Thus, adopted design parameters of chamber-and-pillar development system for mines of Kazakhstan (dimensions of pillars, chamber spans), in general, provide long-term stability of worked-out areas. However, studies of KazNRTU have shown, in practice it is necessary to promptly correct design solutions in connection with changing mining and geological situation.

It has been established that at the Akbakayskiy, Akzhalskiy, Mayskainskiy mines, main factor of variability is structural heterogeneity and fracturing of rock mass. In this regard, original method for solving problem has been developed, which consists, on the one hand, in the operational forecasting of areas of increased fracturing and possible rock collapse based on the method of permanent registration of roof displacements, including original measuring equipment and results processing programs, on the other hand, in the development of special technologies for increasing strength of rock mass by filling cracks with cement mortar.

Conclusions

1. Method of comprehensive assessment of rocks condition allows to consider features of geological structure of undermined strata and thus to enhance quality of geometrical maintenance of mining operations. In turn, results of geomechanical forecasts give possibility to determine the most dangerous sites, calling for regime geophysical and geodetic surveying observations to localize the anthropogenic impacte areas.

2. Method of geodetic observation on the monitoring station profile lines using new generation modern devices and tools, developed by author to improve accuracy and productivity of field measurements.

3. Method for measuring the roof subsidence has been developed, which allows operational monitoring of stability of underground workings and increases safety degree of mining operations.

4. To ensure industrial safety and prevent further progressive destruction of pillars, *composition* of solution from mining waste has been developed. Methods use for strengthening slope of ledges and dump surfaces made it possible to improve geomechanical situation in the near-edge zone and ensure environmental safety of subsoil development.

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