ANNOTATION

to the dissertation submitted in fulfillment of the requirements for the degree of Doctor of Philosophy (PhD) in the specialty 6D070700 – "Mining"

ABDIKARIMOVA GULNUR BAKHYTBEKKYZY

DEVELOPMENT OF SCIENTIFIC AND METHODOLOGICAL FOUNDATIONS FOR CREATING A UNIFIED SYSTEM OF GEOMONITORING OF THE STRESS-STRAIN STATE OF THE ROCK MASS AT THE KACHAR OPEN-PIT MINE

Assessment of the Current State of the Scientific and Technical Applied Problem: The deepening of open-pit mining operations is accompanied by increased stress levels in the rock mass, which in turn increases the risk of pit slope collapses, potentially leading to serious operational disruptions. To reduce such risks, monitoring systems are being implemented to track slope conditions using advanced tools that record their changes over time.

The stress state of the rock mass is a primary factor in the geomechanical conditions during the development of deep open pits. Currently, there is a pressing need to account for the actual stress-strain state (SSS) during the exploitation of increasingly deep levels of solid mineral deposits. In high-stress, massive, and brittle rock masses, displacements may be difficult to detect until collapse occurs. Managing unstable slopes affected by stress-strain conditions is one of the most critical safety challenges at the Kachar open-pit mine.

The Kachar deposit is characterized by complex engineering-geological and hydrogeological conditions. Extended periods of open-pit mining and the associated large-scale rock movement have disrupted the natural stress-strain state of the Earth's crust in the area.

At the Kachar open-pit mine, an unforeseen deformation process caused by changes in the stress-strain state due to geodynamic activity led to significant destruction and a temporary suspension of operations in 2015, incurring economic losses. During the construction of concrete retaining walls, the southwestern pit wall experienced severe deformation at levels from –30 to –120 meters. The failure was attributed to increased tangential compressive stresses acting along this part of the pit wall, resulting in shear-type collapse.

Methods for assessing the stress-strain state of rock masses used in domestic and international practice can be divided into two significantly different groups: the first includes methods based on measuring deformation parameters of rock, and the second encompasses geophysical methods using natural or artificially induced field variations.

The disadvantages of using geophysical geomechanical monitoring methods in open-pit mining include the difficulty of correlating geophysical field parameters with stress and deformation indicators, which complicates their application to practical mining problems.

Deformation methods provide information about the formation of energy-saturated zones associated with impending failures. Rockbursts caused by high-stress conditions are, from a physical standpoint, sudden (brittle) failures of certain rock volumes or displacements of structurally heterogeneous blocks with the release of accumulated energy.

Virtually all rocks composing the slope areas of the Kachar pit are brittle. Most rock failures (rockfalls, landslides) on steep slopes composed of hard rocks indicate typical brittle behavior. Sudden collapses may also involve large rock volumes. Brittle failures under tensile or shear stress on steep slopes are particularly difficult to predict due to their abrupt and potentially rapid nature.

Therefore, to achieve the stated research objective, deformation monitoring systems that reliably correlate with the rock mass stress state will be applied.

Today, modern computing capabilities and advancements in 3D software interfaces support the transition to using 3D modeling for assessing and forecasting the stress-strain state of rock masses. Stability modeling, deformation forecasting of pit walls and benches, and slope deformation monitoring have traditionally been separate tasks conducted at different project stages. Many geotechnical studies have demonstrated that today there is scientific understanding of various types of pit collapses. Knowledge of potentially hazardous zones allows for the identification of failure-prone areas during the design and development stages, enabling the implementation of preventive measures. With appropriate geotechnical assessments and a regulated observation system, failures can be scientifically predicted.

The research includes a geotechnical analysis of the instability of the contour rock mass at the Kachar pit caused by various types of failures, including those driven by stress-strain conditions. Mining operations in deep pits disrupt the initial stress state of the rock mass. Resulting tensile and compressive deformations in the slope area create additional stresses that further disturb the original stress equilibrium. In high-stress, brittle rocks, displacements may be challenging to detect before failure.

The study proposes a scientific and technical methodology for geotechnical monitoring of the slope surface at the Kachar pit. The proposed surface geomonitoring framework includes a methodology for predicting deformations, and the mechanisms of slope displacement and failure under stress field influence.

To forecast rock deformation, displacement, and failure under stress field conditions, numerical methods were employed to simulate changes in the stress-strain state. Numerical modeling was implemented using RS2 RocScience software. Forecasting stress and deformation in the Kachar pit's slope area enables a reliable geomechanical assessment of slope stability at various mining stages. The developed numerical model can be calibrated with in-situ stress data.

Aims of the Dissertation

The aim is to develop scientific and methodological foundations for establishing a unified geomonitoring system of the natural stress state of the rock mass at the Kachar open-pit mine to forecast and prevent critical slope deformations under tectonic stress conditions using modern monitoring systems.

The dissertation addresses the following objectives:

- Assess the current state of the pit slope rock mass using geomechanical modeling;
- Identify stress-strain distribution patterns and develop a methodology for forecasting unstable zones in the slope area using numerical SSS modeling;
- Develop a comprehensive geotechnical monitoring program for the Kachar pit (equipment selection, location planning, methodology);
- Determine movement threshold values for the pit wall's expected behavior, evaluate events, and define response plans to stress-induced displacements.

Object of Study: The slope rock mass at the Kachar open-pit mine.

Subject of Study: Displacements caused by stress-strain state effects.

Research Methods:

- Review of existing SSS assessment methods and geomechanical monitoring tools;
- Analysis of prior research results on the object;

- Development of a scientific and technical methodology for slope surface monitoring under SSS influence;
- Numerical evaluation of the stress level of the rock mass and pit excavation using 2D methods;
- Review of available monitoring tools and their effectiveness;
- Design of a geomonitoring structure considering SSS conditions;
- Determination of movement threshold values for the expected pit wall behavior;
- Event assessment and response planning.

Main Provisions for Defense:

- Reorientation of principal stresses occurs in blocks of the rock mass in the tectonic fault zone at elevations –300 to –330 m of the Western pit wall. Zones of tensile and compressive stresses alternate;
- Potentially hazardous dynamic failure zones are formed in the lower part of the Western pit below –380 m down to the pit bottom (a pattern of maximum shear stress τxy distribution was identified);
- Criteria for dangerous conditions based on modeling allow the substantiated identification of deformation zones caused by tectonic stresses.

Main Research Results:

- A geomechanical hazard map of the Kachar pit, including SSS-induced zones, was developed;
- A comprehensive geotechnical monitoring program was developed, enabling forecasting and early warning of critical slope deformations due to tectonic stress fields using modern monitoring systems;
- For each geotechnical monitoring domain, the composition, equipment types, volumes, and observation frequencies were defined;
- Movement threshold values for expected pit wall behavior were determined, and operational response plans were outlined;
- The monitoring program supports landslide detection and preventive measures to ensure safe working conditions for personnel and equipment;
- The developed scientific and methodological foundations for a unified geomonitoring system of the stress-strain state at the Kachar pit can be applied at similar mines in Kazakhstan.

Scientific Novelty:

- A regularity in the alternation of tensile and compressive stress zones in blocks of the Northwestern pit wall's tectonic fault zone was identified;
- For Kachar pit conditions, scientific and methodological foundations were developed for a unified geomonitoring system for forecasting and early warning of critical slope deformations under tectonic stress conditions using modern monitoring tools;
- A geomechanical hazard (risk) map of the Kachar pit was created.

Practical Significance:

- Based on the research, a geomechanical hazard map of the Kachar pit was created;
- A comprehensive geotechnical monitoring program was developed;
- For each monitoring domain at the Kachar pit, the monitoring methods, equipment, volumes, and observation frequencies were defined;
- Movement thresholds for expected pit wall behavior were identified, and response plans were developed;

- The monitoring program ensures safe working conditions for personnel and equipment;

- The developed scientific and methodological foundations for a unified geomonitoring system of the stress-strain state of the rock mass can be applied at other mines in Kazakhstan.

Publications include six articles in indexed journals, such as: "Mining of Mineral Deposits" (percentile 53, Q2); "News of NAS RK. Series of Geology and Technical Sciences" (percentile 43, Q3); Four papers in journals recommended by the Committee for Control in Education and the Ministry of Science and Higher Education of the Republic of Kazakhstan and the RSCI, such as "News of Higher Educational Institutions. Mining Journal", "Mining Journal of Kazakhstan", and "Surveying and Subsoil Use"; Two papers in proceedings of international conferences, including:“International Multidisciplinary Scientific GeoConference SGEM” (percentile 17, Q3, Albena, Bulgaria, 2020); Proceedings of the International Scientific and Practical Conference dedicated to the 115th anniversary of A.Zh. Mashanov and the 100th anniversary of Zh.S. Erzhanov (Almaty, 2022); 1 Certificate of Authorship No. 12049 of September 17, 2020 (Application No. 17650 of September 16, 2020).

Structure and Volume of the Dissertation: The dissertation consists of an introduction, three chapters, a conclusion, and a list of references. The document comprises 107 pages of typewritten text, includes 12 tables, 47 figures, and a bibliography of 72 titles.