ANNOTATION

Dissertation for the Degree of Doctor of Philosophy (PhD) in the educational program «8D07302– Geoinformatics» by Nazym Atalykova on the topic: «Development of a methodology for studying the stability of pit walls at deposits in Kazakhstan»

In the first chapter, the relevance of developing an integrated methodology for investigating the stability of open-pit mine slopes is substantiated. This methodology is based on the integration of geodetic and geoinformation monitoring methods, the modeling of geomechanical processes, and the analysis of factors affecting the stability of near-slope rock masses. Further research is aimed at improving the accuracy of observations, forecasting hazardous deformations, and developing practical solutions to ensure rational management of slope stability during the exploitation of mineral deposits in Kazakhstan.

The second chapter demonstrates that modern GIS technologies provide a complete cycle of spatial data processing, from their acquisition and storage to the visualization, analysis, and generation of cartographic and geomechanical model outputs. The use of multilayer data structures, advanced spatial analysis tools, terrain models, geostatistics, and cartographic visualization offers fundamentally new analytical capabilities. This makes it possible to identify patterns in the development of technogenic processes, model the deformation state of pit walls, and support the adoption of optimal management decisions.

Special attention is paid to modern specialized software products used in the mining industry. Programs such as Micromine, Surpac, Vulcan, Datamine, Leapfrog Geo, ArcGIS/ArcGIS Pro, QGIS, GeoStudio, and RS2 enable 3D modeling of geological structures, optimization of mining operations, calculation of slope stability, and analysis of the stress–strain state of the rock mass. Comparative analysis shows that these systems are characterized by a high level of integration, support for large databases, and a wide range of analytical tools, which makes them universal instruments for geoinformation modeling.

In 2006, five profile survey lines were established by the mining geomechanics department on the southwestern and western pit walls of the Itauyz open pit, specifically along its two upper berms. The results of the 2006 survey showed that the maximum subsidence along the upper berm reached up to 71 mm, and up to 162 mm along the second berm, while the subsidence rate ranged from 20 to 40 mm per month [126, p. 244].

In May 2012, in the southwestern sector at elevations of 430–415 m (sections 34–34), maximum subsidence of up to 150 cm was recorded after the formation of the berms and the appearance of cracks [123, p.].

From June to November 2012, KazNIMI carried out measurements of surface displacements and performed laser scanning along three profile lines at the upper levels of the Itauyz open pit. The measurement results did not exceed the permissible measurement error [123, p.].

In 2012, specialists of KazNIMI conducted monitoring and laser scanning along three profile lines at the Akchiy–Spassky open pit. Minor subsidence ranging from 44 to 5.5 mm was observed. Overall, the recorded deformations were within the limits of measurement accuracy [123, p.].

The concluding chapter presents the main results and statements constituting the scientific novelty of the research. Within the framework of the stated objectives, a hybrid methodology for assessing the stability of pit walls was developed and validated, combining geomechanical modeling and multicriteria analysis. The proposed approach is based on the joint application of the geomechanical modeling packages Examine2D, FLAC3D, and Midas GTS NX, which enables a detailed analysis of the stress–strain state of the rock mass at different spatial scales.

During the investigation of the Akzhal, Akshy–Spass, and Itauyz open pit mines, a comprehensive monitoring methodology based on the integration of GIS technologies and multisensor satellite data was applied. Sentinel-2 optical imagery clearly revealed the planimetric expansion of the pits, the enlargement of waste dump areas, and the development of production infrastructure during the period 2016–2025. InSAR analysis based on Sentinel-1 data (2020–2025) identified relative ground displacements in the line-of-sight (LOS) direction within the Akzhal open pit area, allowing a quantitative characterization of the deformation component of morphological changes.

Basis and initial data for the development of the topic. «Basis and initial data for the development of the topic» the basis for the development of a dissertation work on the topic is the need for reliable geomechanical, Geodetic and information support of the stability of Quarry boards.

In this case, there is a need to develop a methodology based on field observations, instrumental Geodetic monitoring, satellite methods and integration of Geoinformation systems, which will allow forming a single digital model of the array and spatial analysis of deformation processes.

Justification of the need to conduct research work. The demand for mineral resources in the Republic of Kazakhstan and in the world is constantly increasing, which makes it necessary to significantly increase the production capacities of mining enterprises. At that time, most of the deposits with simple mining geological conditions and a high content of a useful component were withdrawn from production or located at the stage of completion of production. As a result, the modern mining industry is often faced with the need to develop deposits with a complex geological and structural structure and deepen open-pit mining.

The planned scientific and technical level, patent studies and their conclusions are determined by a full-fledged analysis of existing scientific and engineering solutions in the field of ensuring the sustainability of open pit sidewall and slope of an open pit. The patent search showed that most modern methodologies are focused on the use of individual geomechanical or Geodetic approaches, do not provide for a comprehensive combination of instrumental monitoring, numerical modeling and spatial analysis.

In the course of the dissertation work, an in-depth scientific and technical review was carried out on methods for calculating surface stability, geomechanical

modeling algorithms, software complexes used in stress-deformed state (SDS) analysis, as well as instrumental control systems based on modern Geodetic and satellite technologies (GNSS, automated stations, remote monitoring). Special attention was also paid to the possibilities of integrating Geoinformation systems for spatial data processing, visualization of structural elements of the array and modeling of potential instability zones.

Information on Metrological support of the dissertation. The reliability of the results obtained is confirmed using a complex of Geodetic, geomechanical and quantitative research methods, including instrumental observation of surface deformations, field measurements of the structural features of the Massif, as well as modern methods of mathematical modeling of the stability and stress-deformed state of the of the rock mass. When performing field work, high-precision Geodetic instruments and satellite receivers were used that have passed the state Metrological inspection and meet the current regulatory requirements of the Republic of Kazakhstan.

The processing of the obtained data, including the analysis of GNSS-observations, the creation of digital models of terrain, geo-applied fixation of results and modeling of deformation processes, was carried out in the "Laboratory of Applied Geodesy and digital cartography", which has a certified software and structural complex. All computational operations were carried out using special software, which provides the required level of accuracy and meets the international quality requirements for data processing.

In the work, the units of measurement were used in accordance with the Metrological requirements of the international system of units (ISU) and current standards. The use of certified equipment and an accredited laboratory base ensures high reliability of the results obtained.

Relevance of the topic.

Currently, the development of the mining industry in Kazakhstan is associated with the introduction of modern technologies and high-performance equipment, which makes it possible to increase the pace of open-pit mining and expand their range. Due to the increase in production volumes, the need for the development of deposits with a complex geologo-tectonic structure and the task of forming quarry boards with an increased angle of inclination are simultaneously increasing.

Due to the increase in production volumes, the need for the development of deposits with a complex geologo-tectonic structure and the task of forming quarry boards with an increased angle of inclination are simultaneously increasing. Problems of their sustainability in the event of a transition to lower, deeper horizons are the main factor in the safe operation of the quarry, improving the economic efficiency of mining operations and reducing the risks of emergency situations.

In these conditions, there is a need to develop a scientifically based methodology for studying the stability of Quarry boards based on an integrated approach that combines the analysis of structural and tectonic features of Kazakhstan's deposits, geomechanical calculations, instrumental Geodetic observations and digital modeling.

The use of digital technologies also includes the use of special software complexes (RS2, FLAC3D, Rocscience), which make it possible to quantitatively simulate the stress-deformed state, optimize the parameters of individual stages and assess the stability of Quarry boards in conditions of various development scenarios.

Digitalization of production processes at the fields contributes to the formation of an integrated system for monitoring and managing Geodynamic risks, increases the accuracy of engineering and geological data, and provides scientifically sound support for the development of sustainable parameters of Quarry boards.

Novelty of the topic. Development of a comprehensive methodology for studying the stability of Quarry boards in Kazakhstan deposits based on the integration of Geodetic, geomechanical and digital technologies. Analysis of literary sources and modern research in the field of stability of the sides and slopes of deep quarries shows that most modern quarries are characterized by a significant complication of mining conditions caused by an increase in the depth of development and the involvement in the operation of deposits with a complex geological and structural structure.

In such conditions, the importance of a systematic approach to assessing the stability of slopes increases, based on the combination of instrumental monitoring, analysis of structural and tectonic features, determination of physical and mechanical properties of the Massif and quantitative modeling of the stress-deformed state.

For the first time, a method is recommended that provides for the use of the complex:

- high-precision Geodetic measurements (GNSS, automated stations, ground scanning);
- Geoinformation technologies for spatial analysis of deformations and the formation of a digital model of an array;
- modern software complexes of geomechanically modeling.
- integration of Field, Laboratory and digital data into a single system for assessing the stability of Quarry slopes.

The proposed approach creates a new scientific and methodological basis for assessing and predicting the stability of deep quarries, taking into account the special geological, tectonic and man-made conditions of Kazakhstan's deposits.

The objectives of the study are to improve Geodetic methods for monitoring the state of the onboard arrays of quarries using Geoinformation technologies to increase the efficiency of monitoring the stability of slopes and ensure the rational and safe development of mineral deposits.

The object of the study was the Akzhal field during the transition from open-pit mining to underground mining, as well as the akchiy - spas and Itauz fields, which are being developed by open-pit mining.

Research objectives and their place in the implementation of research work:

1. Development of a methodology for instrumental control of deformations of Quarry slopes using modern Geodetic instruments.

2. Development of basic principles for creating an automated system of instrumental control and geodetic monitoring in the quarry.

3.Improving the methodology for calculating the stability of Quarry slopes, taking into account the actual data of Geodetic observations.

4.implementation of Geoinformation analysis methods (GIS) for spatial assessment of deformation processes, modeling and visualization of potential instability zones.

The tasks set are correct and logically consistent, ensure the internal integrity of the research work and are aimed at achieving the goal of the study.

Methodological basis of the study

The main research and analysis methods used in the implementation of the dissertation work include:

- Modeling of geomechanical processes at the akzhal, Akchiy - spas and Itauyz fields during the transition from open-pit mining to underground mining;
- Development of proposals on the required volume, composition and methodology of observations at the Akchiy-Spassky and Itauz fields;
- Assembly of the control station project;
- Analysis of Sentinel-1 data and download images related to the designated area;
- Processing space images using the methods of radar interferometry (InSAR), with the help of which to obtain maps of the displacement of the Earth's surface, identify active deformation zones and build time series of changes.

Conclusions recommended for defense

The following conclusions are proposed for the defense of the dissertation work:

- The stability of Quarry boards and edges depends on the structural features and strength properties of the rock, which vary in depth.
- Zones of possible deformation during the deepening of the quarry are determined by the model of spatial variability of the physical and mechanical properties of rocks (in area and depth).
- Geomechanical justification of the stability of Quarry boards is ensured by combining a complex of Geodetic observations, natural and laboratory research, GIS analysis and modeling data into a single digital database.

The practical significance of the dissertation is manifested in the development of a methodology that provides an increase in the reliability of assessing the stability of Quarry boards. The proposed complex includes Geodetic observations, laboratory research, GIS-analysis and modeling, which makes it possible to take into account the real variability of the physical and mechanical properties of the array, structural features and deep production factors.

Structure and scope of the dissertation: the dissertation work consists of an introduction, 4 chapters, a conclusion, A list of 151 named literature and appendices. The work is set out on 131 machinopist pages, it contains 55 figures and 22 tables.