ANNOTATION

thesis for the PhD degree in the specialty 6D070700 - “Mining”

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GEOMECHANICAL SUPPORT THE STABILITY OF PIT EDGES AT HIS DEEPENING

The history of open-pit mining indicates a tendency of increasing depths of mining. At the beginning of the 20th century, mining operations were carried out within sedimentary rocks, the maximum depth of the pits did not exceed more than 100 m from the surface, but already several decades later, the maximum depth of mining of the deposits by the open method reached 200-300 m.

A further increase in the demand for mineral raw materials led to the improvement of techniques and technology, and in some cases, the maximum depth of mining by the open-pit method began to reach 400 m.

Due to such characteristics as high efficiency and productivity of the extraction of minerals from the subsoil, the open method of development remains the leading one in terms of the percentage ratio of the extracted minerals. According to the data given in the works of domestic and foreign scientists, about 80% of all the mineral resources mined fall on the open mining method.

One of the main issues in the development of mineral resources by the open method is to ensure safety in mining operations and the achievement of rational mining of deposits. Increasing the depth of the development of deposits by the open method usually leads to the separation of the pit edge and an increase in overburden volumes. Another option to engage in the development of deep horizons of the open-pit without a significant increase in the cost of mining is to revise the original project and increase the final angle of the edge. This option raises the question of ensuring the stability of the pit edge and the choice of parameters of newly designed ledges on deep horizons that are rational from the point of view of geomechanics.

The main condition necessary for the revision of the initial mining projects is information about the geomechanical state of the rock mass, in which, along with the parameters of the stress-strain state, the geological and structural features of the field, are knowledge of the physical and mechanical properties of the enclosing rocks and ores.

The methods developed and adopted at the enterprises do not fully cover all the problems arising during the development of deep pits. According to these regulatory documents, the determination and justification the parameters of the pit edge and bench should be performed using the method of calculating the safety factor using the classical limit equilibrium method. However, these methods do not take into account structural fault of the rock mass, which have a negative influence on stability.

Also, currently existing theoretical approaches to substantiation the stability angles of the pit edges, as a rule, do not consider the real stress-strain state of rock mass, believing that it is only due to its own weight of overlying rocks.

During the calculation of stability of the pit slopes according to the 1972 methodology, in all schemes only the own weight of the landslide prism is taken into account. Although, in rock massifs, where horizontal stresses in most cases exceed vertical, neglecting of unloading strains predetermines the possible development of emergencies at the depths of open pit more than 200-250 m. As a result of these processes, the splitting of the rock mass into steeply falling "layers" begins, which leads to inversions and bending.

The question of need improvement of the existing methods of ensuring stability of the operating and projected pits was considered in the works by the following scientists Trubetskoy K.N., Rylnikova M.V., Tsirel S.V., Zoteev O.V.

In dissertation work are applied modern methods of the analysis and mathematical modeling on the example of the operating mining enterprise. The developed algorithm of actions is possible for inclusion in the updated method of providing a steady condition of edges and bench of deep pits.

The basis and initial data for the development of the topic. The basis for the development of the topic is the geomechanical support of the stability of the pit edges when it is deepened for introduction into the mining of deep-lying ores. The following data were chosen as initial data for the development of the research topic: the geomechanical conditions of the largest operating iron ore deposit in Kazakhstan, developed by the open-pit mining.

Justification of need for the research work. The demand for mineral raw materials is increasing from year to year, which will imply the need to increase the production capacity of the mining industry. Deposits with simple mining and geological conditions and a high content of the useful component in the ores have already been developed or are close to completion. Therefore, the modern development of the mining industry is characterized by the increasing complexity of mining production conditions due to the increase in the depth of development and the exploitation of deposits with difficult mining and geological conditions. With an increase in the depth of the existing open-pits, the stability issues of the sides turn into problems of great economic importance for mining enterprises. In this regard, the justification of the stable parameters of the edges and bench of deep pits opens up new opportunities for mining deep-lying ores for existing enterprises.

Information on the planned scientific and technical level of development, patent research and conclusions from them determined by the completeness of the conducted patent search review on the problem of ensuring the stability of the edges and bench of open-pits, the choice of modern research methods, programs and methods for analyzing the sustainability of pits elements, the system of organizing and conducting field and laboratory studies.

Results of the scientific analysis of the current state of a scientific and technical problem and researches on forecasting of the further directions of scientific developments in the field of ensuring stability of edges and bench of deep pits are given in dissertation work. It is revealed that the existing universal

techniques do not include an integrated approach at the solution of problems of stability for deep pits.

Data about the metrological support of the thesis. The reliability of the received results is confirmed by application of a complex of physical and mechanical methods of a research, field measurements of structural features of the rock mass, use the methods of mathematical modeling of stability and the intense stress-strain state of rock mass.

For conducting laboratory and field researches in the framework of this dissertation work, instruments that passed the state metrological testing during the operation period were used.

Laboratory of branch RSE «National Center on complex processing of mineral raw materials of the Republic of Kazakhstan» D.A. Kunayev Mining Institute accredited in the accreditation system of the Republic of Kazakhstan in accordance with GOST ISO / IEC 17025-2009 "General requirements for the competence of testing and calibration laboratories." The certificate of calibration number is BA-03-02-00889 (valid until 09/18/2019).

In the tabular and graphical data, the units of measurement are used that meet the metrological rules and standards of the International System of Units.

Relevance of the topic. At present, large mineral deposits developed by the open mining are moving to the development of deep horizons. With increasing depths, ensuring the stability of the edges and bench of open-pit is one of the main task of the mining industry.

Forecasting of deformation processes in a near boards zone of pits is possible on the basis of an integrated approach to the analysis and synthesis of the data including studying of the structural and tectonic building and strength properties of the rock mass, tool observations of deformation of various sites of the near boards mass, assessment of the stress-strain state and also carrying out geomechanical calculations of stability.

The introduction of digital technologies in various areas of activity allows to solve many problematic issues in the development of mineral deposits. Sokolov-Sarybai Mining Production Association (SSGPO) has already embarked on the development path of the Digital Kazakhstan program by launching one of the Smart Pit components based on the Modular dispatching system, which allows increasing the productivity of transport equipment by 10%.

Intellectual (“smart”) pit is a set of systems for automated control and dispatching of the mining process, aimed at continuous improvement of manageability, cost reduction and improvement of working conditions and safety.

One of the elements of such control systems should be the creation of a digital geomechanical model. Such a model is implemented with the help of modern software that links the geological, strength, structural and geomechanical components of a open-pit into a single database.

The database structure is a group of interrelated models containing a digitized spatial-coordinate description of graphic elements (points, lines, nodes, closed contours).

The novelty of the topic consists in geomechanical support the stability of pit edges at his deepening. The analysis of literary sources in the field of sustainability of the edges and bench of deep pits allows us to conclude that the modern open-pits are characterized by the increasing complexity of mining operations due to the increased depth of development and the exploitation of deposits with complex mining and geological conditions. Under these conditions, the issues of geomechanical sustainability of deep open-pit are of great importance. In this regard, for the first time, an integrated approach to the geomechanical support of the stability of the pit edges during its deepening will be proposed.

The following new scientific results were obtained:

- regularities of changes in the structural formation of the massif block (in the form of the dependency of the structural attenuation coefficient to the value of the rocks adhesion) and mechanical properties with increasing depth of mining operations for the Sarbay open pit, based on the field and laboratory studies;

- areas of possible deformations of the Sarbay open-pit slopes were determined by increasing depth of its mining based on mathematical modeling taking into account the blocky structure of the rock massif and changes in the mechanical properties both by the area of distribution and the depth of bedding of rocks;

- the development of a digital database consisting of a geological, structural, hydrogeological model and the results of mathematical modeling of stability and stress-strain state, which is a three-dimensional geomechanical model, on the basis of which the parameters of the open pit slopes and benches, which ensure the safety of mining operations with increasing depth of mining up to 700 meters.

Communication of this work with other research projects.

Dissertation work is performed in department "Geomechanics" the Institute of Mining named after D. A. Kunaev and JSC “SSGPO” within the framework of the research project "Conducting research to develop recommendations on the parameters of the edges and bench of the Sarbay and South Sarbay open-pits JSC" SSGPO", ensuring their stability and the development of Regulations on the stability of the edges and bench of the Sarbay, South Sarbay and United Sarbay and South Sarbay open-pits" from 2016 to 2018 and implementation of the scientific and technical program No. BR05236712 "Technological modernization of mining operations on the basis of the transition to a digital economy" in the framework of program-targeted funding for 2018-2020.

Research of objective - geomechanical support the stability of pit edges at his deepening on the basis of the geomechanical model of the field including basic mining-and-geological data, results of mathematical modeling and zoning.

The object of the research is the Sarbay iron ore deposit developed by the open mining.

The subject of research is geomechanical processes that affect on the stability of the edges and bench of the pit with increasing depth of mining.

Research problems, theirplace in performance of research work in general:

– conducting laboratory and natural researches of the rock mass, processing and interpretation of the obtained data;

– mathematical modeling of stress-strain state of the rock mass and determination of safety factors of edges;

– creation of the uniform database in the form of geomechanical model which includes results of the previous and conducted in dissertation work researches of the rocks mass;

– development of recommendations for ensuring the geomechanical stability of the pit edges, depending on the geological, hydrogeological and structural features of the field.

The tasks assigned are consistent and logical, they define the internal unity of the research work and are aimed at achieving the stated research goal.

Methodological base of research. The main research methods and analyzes used in the dissertation work include:

– testing samples for uniaxial compression and tension on a universal testing machine (VEB No. 282/89);

– determination of the elastic modulus and Poisson's ratio from the propagation velocity of longitudinal and transverse elastic waves in samples using appropriate ultrasonic equipment "Pulsar 2.2";

– measurement of the effective horizontal stresses in the near edge zone based on the use of the Kaiser effect of rocks when loading the walls of the well with the Goodman hydraulic jack;

– calculation of safety factors by the method of limiting equilibrium by the method of lateral pressure using the USTODU software;

– calculation safety factors by the method of marginal equilibrium using the Slide software;

– slope stability calculation based on the Strength Reduction Method using the finite element method in Midas GTS NX software;

– stress analysis method based on finite elements in the Midas GTS NX software;

– 3D modeling of stress-strain state by stress analysis method based on finite elements in Midas GTS NX software.

The provisions submitted for protection. The following provisions are submitted to the defense of the thesis:

- the state of stability of the pit slopes and benches of the Sarbay open pit is predetermined by the structural features and strength characteristics of the rock massif, changing with the depth of the open pit;

- zones of possible deformations arising from increasing depth of mining of the Sarbai open pit up to 700 m are determined on the basis of mathematical modeling, taking into account the features of the spatial variability of the physical and technical properties of the rock mass, both in the area of distribution and in the depth of the rocks;

- the geomechanical justification of the stability of the pit slopes and benches of the Sarbay open pit during its deepening is provided on the basis of a

comprehensive consideration of the results of field and laboratory studies and mathematical modeling of their condition, represented by a single digital database.

The practical significance of the thesis lies in the development of a unified database, represented by the geomechanical model of the field, on the basis of which it is possible to predict the occurrence of deformation processes of the edges and bench of the open-pit during its further development.

The research results are implemented at the Sarbay open-pit of SSGPO JSC, as received by the relevant Act and in the performance of the research work of the department.

Publications and approbation of work. Publications include four articles in publications recommended by the Committee on the Control of Education and the CCE RK; one article in the rating "Mining Journal" (Scopus database); eight articles in collections of international conferences, forums and congresses.

The main provisions of the thesis and the results of the research were reported, discussed and approved at 6 international scientific conferences: "Mining sciences in the industrial and innovative development of the country", Almaty, "Innovative technologies in geodesy, surveying and geotechnics", Karaganda, "Fundamental and applied issues of mining sciences", Novosibirsk, "World Mining Congress", Astana, "Miner's Week 2018", Moscow, including at the VII Ural Mining and Industrial Forum in the section "Geomekhanic in mining"; the author's report was nominated as the" Best Report ".

The structure and scope of the thesis: the dissertation work consists of an introduction, 4 chapters, conclusion, list of references from 123 items and applications. The work is presented on 119 pages of typewritten text, contains 60 figures, 28 tables.

The introduction presents a general description of the work. The relevance of the topic, the purpose and objectives of the research are formulated, the scientific provisions for the defense and practical significance of the work are stated.

The first chapter considers the current state of studying the geomechanical conditions of rock mass with increasing depth of mining of open-pit mining; a brief mining, geological and hydrogeological characteristics of the object of study; identified the main factors affecting the deformation processes.

The object of research in the thesis is the Sarbay iron ore open-pit, the design depth of which is 700 m. The geotechnical conditions for mining the Sarbay pit are complex due to the strength properties of the rocks, the structure of the mass (high thickness of loose rocks up to 140 m, weakening surfaces: layering in loose rocks, fracturing, shale in rocks), the tendency of rocks to weathering, hydrological factors - water content of rocks and loose rocks.

The modern development of the Sarbay field is characterized by a significant increase in the depth of the open-pit (up to the absolute bottom level of minus 500 m) and the transition to the development of deep-lying ores. This raises the question of ensuring the stability of the pit wall and the choice of parameters of newly designed edges on deep horizons that are rational from the point of view of geomechanics.

The main condition necessary for revising the initial mining project is information about the geomechanical state of the rock mass, in which, along with the parameters of the stress-strain state and the geological and structural features of the field, are knowledge of the physical and mechanical properties of the ores and rocks.

The analysis of the state of geomechanical problems in the development of deep quarries shows that the problem of stability of the edges and bench of the open-pit is relevant. At the same time, existing methods require changes. When justifying the stable parameters of deep pits, it is necessary to take into account the influence of the physical and mechanical properties of the rocks, hydrogeological conditions, structural features of the deposit, and the influence of the stress-strain state.

The purpose of the study: Ensuring the stability of the pit walls at its deepening based on the geomechanical model of the field, including the initial mining and geological data, data obtained during laboratory and field studies, the results of mathematical modeling and zoning.

Setting the tasks of the thesis. With regard to the conditions of the Sarbay field, the implementation of work to ensure the steady state of the edges and bench of the open-pit requires the following tasks:

- to determine the factors affecting the stability of the pit edges while increasing the depth of its mining;
- to conduct laboratory and field research of the rock mass, processing and interpretation of the data;
- to perform mathematical modeling of the stress-strain state of the rock mass within the mine excavation;
- to determine the stability factors of the pit edges stability;
- to develop recommendations for ensuring the geomechanical stability of the pit edges, depending on the geological, hydrogeological, and structural features of the field;
- to present the results of laboratory and field studies, mathematical modeling and calculations in the form of a single electronic database (geomechanical model).

The second chapter presents the results of engineering and geological surveys, which revealed:

1. According to the results of laboratory researches of rock and ore samples from the Sarbay open-pit mine, the variability of the physical and mechanical properties was noticed even within one lithotype (Figure 1), which is explained by the significant influence of such factors on them as the intensity of fracturing, schistosity, brecciation of rocks, metamorphism.

2. Based on the analysis of lithological signs and physical and mechanical properties of rocks of the field, 6 engineering-geological elements were identified: limestone, tuff, tuffite, metasomatite, diorite, ore.

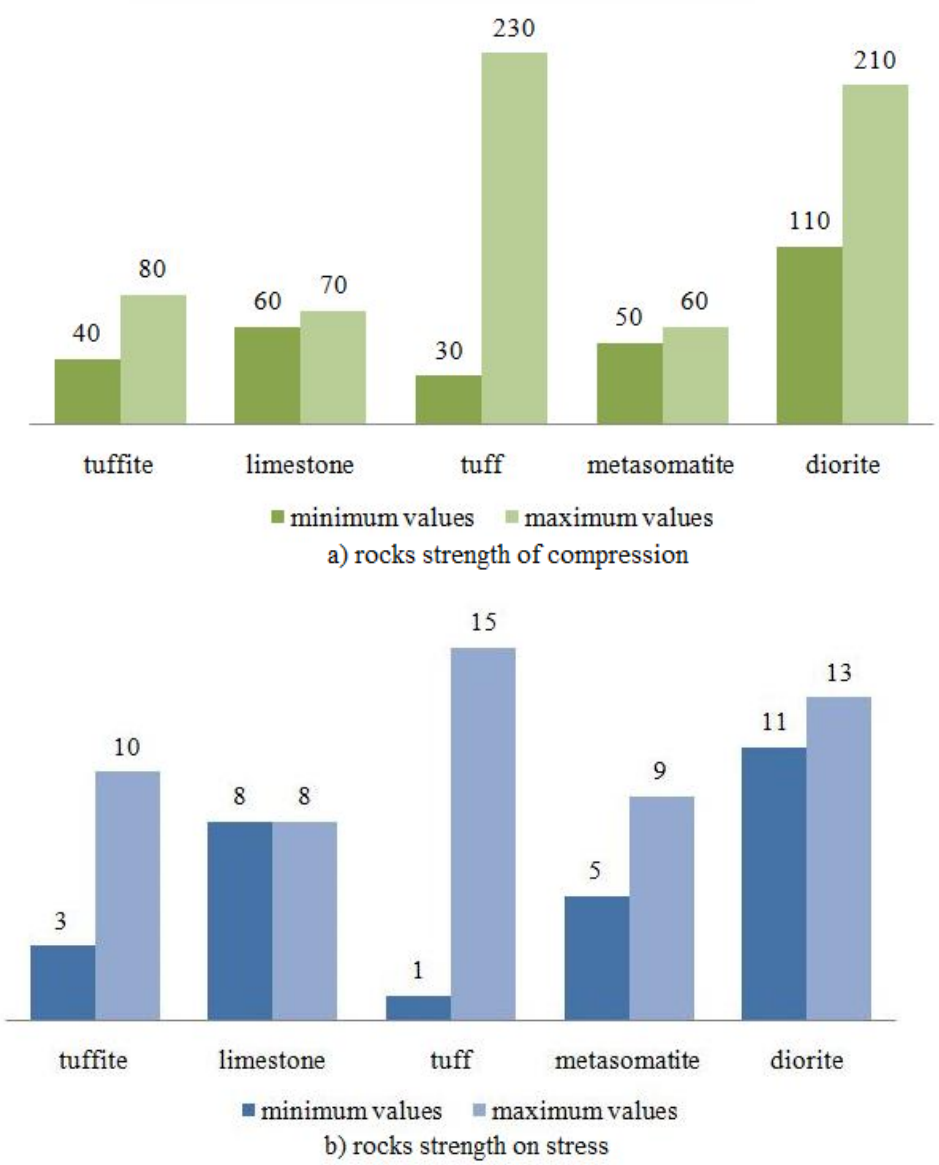

Figure 1- Minimum and maximum values of rocks strength by results of engineering-geological surveys

3. As the depth of the pit increases to an absolute level of minus 500 m, the most unfavorable engineering and geological conditions will be observed on the eastern edge. This is due to the fact that the edge is oriented along the strike of the Eastern ore body and the intensively fractured tuffite enclosing it. Rocks that lie in the eastern edge of the pit and the system of cracks developed in them fall towards the bottom of the pit at angles of 50 ° –70 °. When setting the pit edge to the final position and chipping slopes of the ledges, their tilt angles will be close to the falling angles 1 of the crack system and, if located in the thick of tuffite, can lead to collapse processes.

4. As a result of engineering and geological work, for the zoning of the near-side massif of rocks of the Sarbay open-pit, taking into account the depth to the absolute level of minus 500 m, 6 systems of tectonic cracks in the first series of measurements and 5 systems in the second series were identified. It was revealed

that only 1 and I systems associated with the natural layering of the array coincide completely in the parameters of occurrence.

5. By analyzing the results of jointing treatment, it has been revealed that the following joint systems can be potential weakening surfaces for the Sarbay open-pit:

- for the North and Northeast edges of the open-pit - the system of joint II-1;
- for the East and Southeast edges - system V;
- for the South edge - III system of joints;
- for Southwest and Western edges – the I system of joints, also on I', to II-2 and the III systems formation the prisms of possible collapse is probable.

6. By results of natural measurements of jointing parameters the logarithmic dependence of coefficient of structural easing on coupling size in a sample (Figure 2) is received.

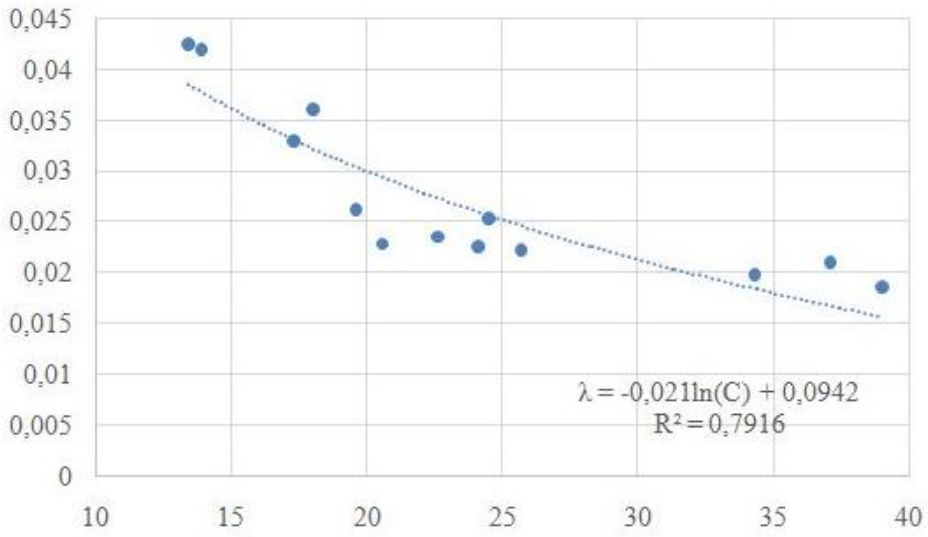

Figure 2 - Dependence of structural loosening coefficient (λ) on coupling value in exemplar (C)

7. By results of natural and laboratory researches the consistent pattern of the structural building, physical and mechanical properties with increase in depth of mining operations for the Sarbay open-pit (Figure 3) is determined.

The results obtained in Chapter 2 are necessary for the further implementation of the mathematical modeling of the stability of the pit edges and the modeling of the distribution of the main acting stresses in the near edge zone of rock mass.

The **third chapter** presents the results of numerical simulation for calculating the stability of the pit edges by two methods - the method of limiting equilibrium (USTODU and Slide) and the finite element method (Midas GTS NX).

The stability of the pit edges was calculated using transverse, longitudinal and diagonal engineering-geological sections (Figure 4), which are typical for the near-surface zone of the Sarbay open pit in the final position, taking into account

the depth to minus 500 m, performing numerical mathematical modeling and identifying potentially dangerous areas.

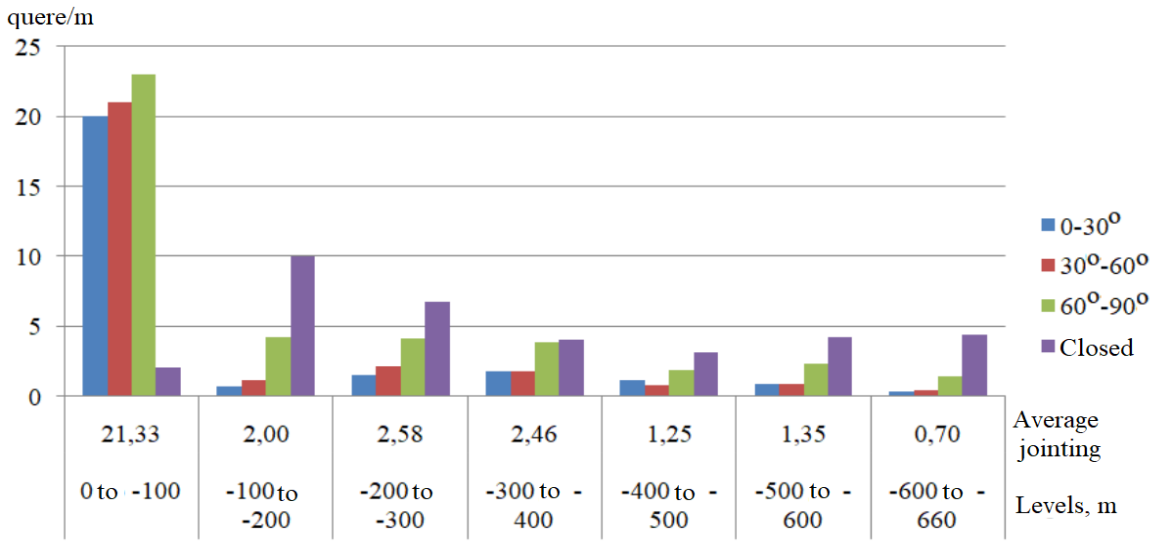

Figure 3 – Results of determination of rock mass jointing by geotechnical drilling

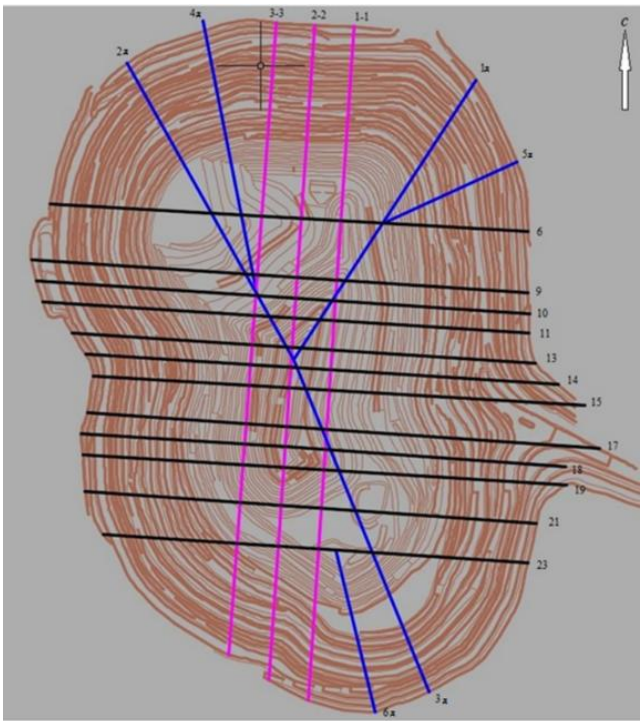

Figure 4 - Location of the calculated profiles

The calculation of the stability of the sides of the Sarbay open pit taking into account the increase in working depth to the absolute level of minus 500 m using three different methods showed that the open pit sides are generally stable, with the sustainability factors varying from 1.0 to 2.66.

The least stable areas are in the upper horizons of the open-pit. For the rock part, the safety factors for all computational methods showed results greater than 1, which indicates a steady state of the mass. However, there are areas with a SF value close to the maximum allowable. The least stable areas according to the results of the mathematical calculation of stability:

1. The upper horizons of the northern edge of the pit at elevations from the surface to + 150 m.
2. The West edge of the open-pit within 15–19 profile lines in the rock part of the mass to the bottom.
3. East edge of a pit in borders of 13 - 17 profile lines on marks-50 -100 to the bottom.

At developing of reserves on all edges of the pit, it is necessary to take into account the presence of a watered thickness of soft rocks and clays. There is a sloughing and collapse of the slopes, composed of Cretaceous sand, Neogene clay and Quaternary loam.

For these areas with increasing depth of mining is recommended:

1. Conducting instrumental monitoring.
2. In case of the manifestation of deformation processes according to the results of monitoring, additional works are carried out to strengthen the bench in these areas.

The received results of mathematical modeling of stability the bench of open-pit at increase in its depth up to 700 meters, allow to define sites of possible deformations which need to be included in the uniform database submitted by geomechanical model.

In **chapter 4** results of natural measurements of the stress-strain state, mathematical modeling of the stress-strain state of the near edge zone of rock mass and geomechanical model of the Sarbay pit are presented.

Control of tension in the the near edge zone was exercised on the basis of use Kayser's effect of of rocks when loading walls of the well by Gudman's hydrojack. Stress measurements were carried out on three experimental sites. The horizontal stresses acting along the pit edge were measured. The results of the full-scale determination of the horizontal stresses of the Sarbay open-pit are presented in table 1.

Table 1 - Horizontal stresses acting on the Sarbaiy open-pit

Absolute mark of the experimental site, m	The distance from the wellhead into the rock mass, m						
	0-1	1-2	2-3	3-4	4-5	5-6	6-7
-240	7,4	5,03	4,92	5,16	4,95	4,5	4,34
-280	7,21	6,52	6,83	4,94	6,37	6,14	5,33
-340	10,28	6,58	7,73	8,14	8,16	8,42	8,83

The calculation of the stress-strain state was carried out by the finite element method. Figure 5 shows the result of the calculation of horizontal stresses acting across the strike of the ore bodies. The values of the maximum stresses o the near edge zone reach 8.5 - 10.5 MPa. The zone of maximum horizontal stress

concentration is located in the southwestern part of the open-pit at a depth of 700 meters.

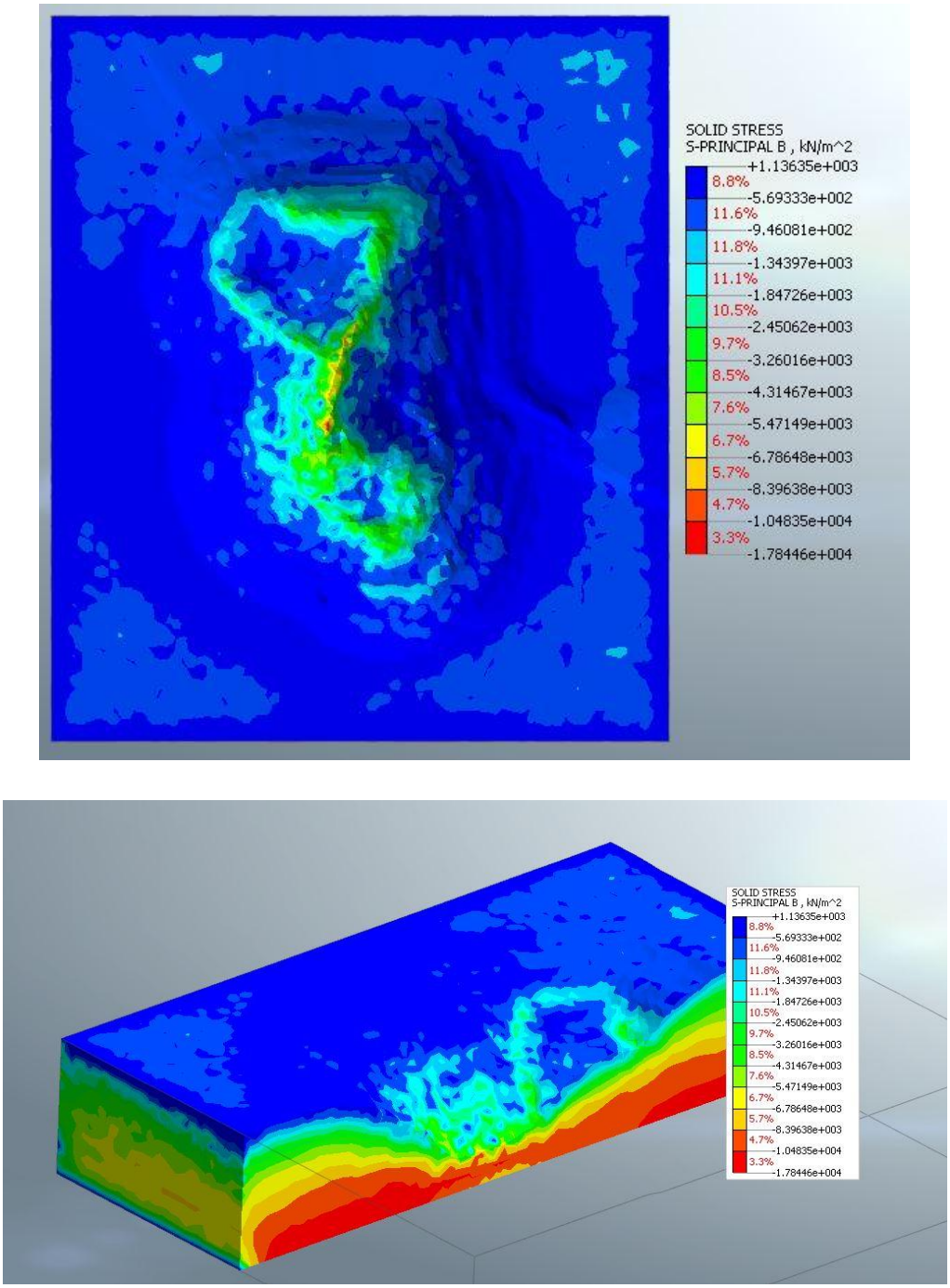

Figure 5 - Three-dimensional modeling of the Sarbay open-pit mine (horizontal stresses directed across the strike of ore bodies)

The maximum horizontal stresses acting along the strike of the ore bodies reach values of 6.8 - 8.4 MPa, the values of the maximum vertical stresses are 11.5 - 1.41 MPa.

According to the results of mathematical modeling of the stress-strain state of the Sarbay open-pit, maximum concentrations of stresses are formed at the bottom of the pit, and the values of vertical stresses are 1.3 and 1.7 times more horizontal

for stresses acting across the ore bodies.

According to the results of volumetric modeling of the Sarbay open-pit stress-strain, increasing the depth of its mining to the absolute bottom of the pit minus 500, the western side in the area of the cuts 15-18 is most unstable. In this area there is the likelihood of deformation processes.

To geomechanically ensure the stability of the pit edges, a certain amount of initial information is necessary. The sequence of creating a geomechanical model can be represented as:

- data collection;
- construction of the geological structure model. The input information is represented by the strength and lithological data of the rocks composing this particular array and its structural inhomogeneities;
- creation and filling of geomechanical model.

The created geomechanical model of the field consists of the following components:

1. Geological model.
2. Structural model.
3. Models of rock mass (rock properties).
4. Hydrogeological model.
5. Values of stress-strain state and slope stability according to the results of mathematical modeling.

Geomechanical models allow to combine in a single database all the parameters that affect the safety of mining. On the basis of an integrated approach and a complete classification of a mountainous massif, it is possible to predict the behavior of rocks during mining operations, which ensures the safety of mining and completeness of extraction of minerals from the depths.

Brief conclusions on the results of dissertation research.

Nowadays, there is a tendency of increase of the depth of mining operations, which in turn adversely affects the stability of the slopes and benches of mine pits. For effective and safe operation of mining enterprises, reliable, timely and as complete as possible information about the subsoil structure is necessary. The dissertation thesis presents results of geomechanical calculations of the stability of the deep pit walls using the example of an operating enterprise with the use of modern software.

The following most significant results were obtained, reflecting the scientific novelty and practical significance:

1. The analysis of the current state of studying of the geomechanical conditions of deep open pits and its mining and geological conditions of the existing iron ore deposits showed that the following factors affect the stability of the slopes and benches: the presence of loosening surfaces, water content, and strength properties of rocks.

2. The bed rocks of the Sarbay open pit have different values of mechanical properties with a significant variation of parameters such as adhesion, uniaxial compression and tensile strength, which indicates a significant spatial variability of

properties in the rock massif, both in the distribution area and in the depth rocks associated with fractured formation.

3. According to the results of the study of the structure of the rock massif, joint systems have been identified that present a glide planes and have an adverse effect on the stability of the slopes of the open-pit.

4. Taking into account the data of field measurements of the parameters of joints of the rock mass at the Sarbay mine pit, the structural weakening coefficient was determined ($\lambda = 0.02,0.04$) and the logarithmic dependence of the structural weakening coefficient on the adhesion value in the sample was obtained.

5. According to the results of multivariate numerical modeling, the pit sides are stable, but in three areas the values of the obtained stability factors are in the maximum permissible values.

6. According to the results of the measurement of the stress-strain state, the horizontal stresses acting in the near-surface rock massif are determined.

7. According to the results of the three-dimensional modeling of the stress-strain state, it was revealed that the stress concentration is under the pit bottom. Stress values under the pit bottom reach 9.5 - 10 MPa, with their value at the same depth in the surrounding massif 4 - 4.5 MPa.

8. For the first time, a digital database has been created for the Sarbay field, consisting of geological, structural, hydrogeological models and the results of mathematical modeling of stability and stress-strain state. The resulting database is a digital geomechanical model to ensure the steady state of the pit slopes and benches with an increase in the depth of the pit up to 700 m.

The results of the thesis were applied in production of the Sarbay mine group of SSGPO JSC, as evidenced by the relevant Act of introduction into the production process.

Assessment of the completeness of the solution of the tasks.

Thus, all the tasks posed in the work are solved:

- laboratory studies of the physical and mechanical properties of rocks for deep horizons;
- conduction of full-scale studies of the rock mass, processing and interpretation of the data;
- mathematical modeling of the stress-strain state of the rock mass and determination of the stability factors of the pit slopes was performed;
- a unified database has been created in the form of a geomechanical model, which includes the results of studies of rock massifs, previously conducted and during the dissertation work;
- recommendations were developed for ensuring the geomechanical stability of the pit slopes depending on the geological, hydrogeological, and structural characteristics of the field.

Recommendations and background data on the specific use of the results.

Methods and sequence of research can be applied when performing similar work for other deposits of solid minerals, developing in the open-cut mining.

The results obtained in the thesis were used for:

- carrying out research work between the Institute of Mining named after D. A. Kunaev and JSC “SSGPO” within the framework of the x / agreement “Zoning the near-side massif of rocks of the Sarbay open pit, according to geomechanical conditions, taking into account the depth of the pit to an absolute mark of 500 m”, which was used in the design of the reconstruction of the Sarbay open pit of the Sarbay branch of SSGPO.

- implementation of the scientific and technical program No. BR05236712 "Technological modernization of mining operations on the basis of the transition to a digital economy" in the framework of program-targeted funding for 2018-2020.

Evaluation of the economic efficiency of technology.

With an increase in the depth of the development of open-cut mining deposits , the pit slopes usually expand and overburden increases. However, another option is possible to introduce during the development of deep horizons of the open pit without a significant increase in the cost of mining, which is a revision of the original design and an increase in the final angle of inclination of the side. With an increase in the depth of the current Sarbay mine pit up to 700 m, they will be involved in the mining of the deep-lying ores of the Sarbay open-pit mine from minus 390 to minus 500 meters.

Evaluation of the scientific level of the work performed in comparison with the best achievements in this field.

The analysis of the bibliography, the results of laboratory, field studies and mathematical modeling presented in this work, allow us to conclude that the dissertation work corresponds to the modern scientific and technical level.

These results are reliable and of scientific value due to the use of modern methods of field research, modeling and analysis, which is confirmed by publications of the relevant scientific works of the author and discussion of the results at international conferences at various levels.

List of published papers on the thesis:

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