N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224-5278 **https://doi.org/10.32014/2018.2518-170X.33**
Volume 5, Number 431 (2018), 37 – 46

UDC 622.691.33

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EXPRESS-ASSESSMENT OF GEOMECHANIC CONDITION OF THE ROCK MASSIVE AND DEVELOPMENT METHODS OF ITS STRENGTHENING AND REINFORCING FOR SAFE ECOLOGICAL DEVELOPING OF THE FIELDS OF MINERAL RESORCES IN HARD MOUNTAIN-GEOLOGICAL AND MINING ENGINEERING CONDITIONS

Abstract. An important stage in the development of open mining of mineral deposits is characterized by the following features: increasing the depth of quarries, the service life of slopes of ledges and quarries, the growth of stripping volumes, the intensification and concentration of mining operations, the complexity of engineering, geological and hydrogeological conditions of field development, the low content of useful components in ore. Over 70% of quarries have a depth of more than 200 m, many quarries are working horizons 400-500 m from the earth's surface, and design depths reach 700 and more meters. The article presents the results of investigations of massive mountain and accompanying geomechanical processes during open-cast mining. The aim of project is: to work out methods for safe and ecologic field development of mineral resources: express assessment of mountain range impairment; strengthening; strengthening of quarry slopes; dust suppression on quarries roads. At the same time, a set of research methods was used, including analysis of existing scientific developments, analysis and data proces-sing using mathematical statistics, and application of modeling methods using the classical theory of elasticity. The scientific novelty of the results of the research on the proposed project is a new approach to the development of methodological complexes to increase the stability of the quarries and new ways to increase the stability of the slope of the ledges by strengthening and hardening them.

Keywords: developing fields, disturbance of the mountain massive, technogenic disorders, dust suppression, quarry, rocks massive, stability, strengthening, relaxed land parts, cracked rocks, complex mining engineering and mountain – geological conditions, geomechanical massive condition.

Introduction. For the modern stage of progress of the open field development of the minerals characterized by the following features: increasing the depth of quarries, the service life of slopes of ledges and sides of quarries, the growth of stripping volumes, the intensification and concentration of mining operations, the complexity of engineering, geological and hydrogeological conditions for the development of deposits, and the low content of useful components in the ore. Over than 70% of the quarries have the depth more than 200 meters, many quarries work out horizons of 400-500 m from the earth's surface, and design depths reach 700 and more meters. In order to increase the efficiency and completeness of field development, to improve the technical and economic performance of the enterprise, to ensure the safety of mining operations in a quarry, reliable provision of stability of pit slopes is required. In this case, the main task is to determine the optimal parameters of the slopes, ensuring their long-term stability with minimal stripping volumes.

However, despite the successes achieved and the considerable efforts made at the same time, the problem of ensuring the sustainability of career slopes has not yet been fully studied and requires further development and improvement of many of its questions. In particular, it was found that in all without exception the quarries have a different type and volume of slope deformations, in spite of the fact that some of them have not yet reached the design parameters and have actual slopes less than the design values. In this case, both the actual and projected angles of inclination are significantly smaller than the limit values determined by the stability factor.

About 30% of coal, about 75% of iron ores, up to 80% of non-ferrous metal ores, over 90% of non-metallic minerals (asbestos, graphite, kaolin, mica, talc), almost 100% of nonmetallic building materials, are produced abroad using open mining.

In foreign countries with a developed mining industry, open pit mining is conducted in the quarry "Flintkote Mine" (Canada), "Clevelanol Cliffs" (USA, "Westfrob Mine" (Canada), depth 244 m, "Pala-bora" (South Africa), "Aitik "(Sweden). In table 1, the indicators of the quarries of the developed countries of Sweden and the USA are considered [1-3].

The extraction of iron ore by the open method in the CIS is concentrated in the fields of Ukraine (Krivoy Rog basin), the Center (Kursk Magnetic Anomaly), Kazakhstan (Sokolovsko-Sarbaiskoye, Kacharskoye, Lisakovskoye, Ayatskoye, deposits) and the Urals [2]. The extraction of non-ferrous metal ores by the open method is mainly carried out in Siberia and Kazakhstan.

Increasing needs of Kazakhstan for fuel and mineral raw materials are provided through an open method of development, and include the extraction of coal, gold, uranium, iron, copper, nickel, lead-zinc, bauxite and other ores.

Deposits of minerals, developed by the open method, are characterized by a great variety of mining-geological, mining, geomechanical and technological conditions.

About 35% of copper ore is mined at the quarries of the Severo-Zhezkazgan mine, the Nikolaevsky and Shemonaikha mines of the East Kazakhstan copper plant and Konyrat of the Balkhash mining and smelting complex. Since 2003, the new powerful quarry "Nurkazgan" has been working on the extraction of copper near the city of Temirtau. The design depth of the quarry is 600 m [3].

Due to the depletion of ore reserves located at accessible depths, the main development direction of the mining industry is the further development and improvement of the open method of mining operations, involving the exploitation of deposits with complex mining and geological conditions and large (up to 700 m) development depth [4-6].

With the transition to deeper horizons will be accompanied by a complication of mining and geological conditions, an increase in the intensity of the massifs and a change in the deformation-strength characteristics of rocks. Therefore, the problem of geomechanical support for the stability of workings and the worked out space with new resource-saving technologies of open development comes to the first plan.

Methodology. Analysis of development experience, actual data on the stability of the sides of some of the ore mines in Central Kazakhstan shows that the efficiency of the open method of mining of mineral deposits can be significantly increased through the use of engineering management methods, which in turn is ensured by obtaining reliable information on the geomechanical state of the array.

Therefore, the problem of ensuring the sustainability of career slopes is the most important in mining. This is especially true for rocky and semi-local fractured massifs, since in the case of high strength of individual monolithic blocks, the presence of weakening surfaces in the form of cracks in the form of long-distance cracks, the surfaces of tectonic disturbance mixers, contacts of layered rocks sharply worsens the stability of slopes.

Of the many factors influencing the stability of slopes with enclosing rock and semi-rock rocks, three main factors that require compulsory registration in the study of geomechanical processes can be distinguished:

l) structural and tectonic features of the mountain massif;

2) physical and mechanical properties of rocks;

3) investigation of the influence of the time factor and the effect of mass explosions on the stability of slopes.

Of the above, the first two factors are natural, inherent in a particular array, they can only be taken into account in calculating the stability of slopes. The third factor is technogenic, and should be managed when solving the problem of ensuring the sustainability of career slopes. All other factors have a subordinate value and can be accounted for in calculations through the safety factor.

Ensuring the stability of slopes and ledges of quarries is a complex task, the solution of which should include not only the definition of parameters of sustainable slopes, but also their management for achieving better economic results and natural resources.

Table 1 shows the systematization of the management of the stability of quarry boards during the study of geomechanical processes.

Table 1 – Systematization of the management of the stability of the sides of the quarry

The study of the actual state of slopes, the types of their deformations and factors affecting the stability of slopes composed of fractured rocks	
Natural factors	Structural-tectonic features of the mountain massif
	Physicomechanical properties of a fractured massif
Technological factors	Time factor
	Impact of drilling and blasting workings

The structural structure of the massif is one of the main factors determining the strength and stability in the field development. The structure is understood as the nature and degree of fracture of the massif, which includes the linear dimensions of the cracks: their length and thickness, morphological features, the presence of aggregates, the spatial orientation of the cracks, their intensity, and a number of others characterizing the disturbance of the natural environment. Investigation of fracturing is associated with carrying out numerous field measurements and their subsequent statistical processing. In arrays with a high degree of disturbance and external chaos of fracturing, it is known that mining is carried out under the condition of isolation of outcrops, which to a certain extent narrows the object of study, limited space. All this entails an increase in the duration of research, since the more complex the array, the more statistical material is required to identify the real picture [7-10].

Therefore, the study of fractured masif's rocks is one of the first steps in assessing the stability of open mine workings.

As many researchers note, the influence of fracturing on the stability of the sides of quarries manifests itself in two main directions [11-13]:

1. Reducing the strength properties of the array. The evaluation of their influence in this case reduces to the determination of strength characteristics, both over the weakening surface and the most fractured massif.

2. Deformation of the massif as anisotropic or quasi-isotropic medium, the nature of deformation of a fractured massif is the basis of the choice of the design scheme. Consequently, in calculations of the stability of the sides, the choice of the design scheme is predetermined by the spatial orientation of the anisotropy, their extent and location relative to the sides of the quarry, and the calculated characteristics of the rock solidity depend on the size and shape of the structural blocks and the nature of the anisotropy surface.

Statistical research of the fragmentation of the massif assumes the analysis of full-scale data of spatial orientation, crack capacity, intensity, presence of a filler, its characteristics and a number of other morphological features. Research and analysis of all these parameters is mainly based on the data of geological services, which in the process of penetrating the mine workings lead the certification of the structural pattern in the area of the development of the massif.

The physical and mechanical properties of the rocks in correlation with the structural-tectonic features of the mountain mass determine its tense state in the ledges and sides of quarries under the influence of internal and external forces. A thorough and comprehensive study of the strength of the mountain massif must precede the solution of problems to prevent deformation of slopes in quarries.

The main physical and mechanical properties of rock and semi-rock massifs, for solving the stability of slopes in quarries, are the density γ, resistance of rocks to compression$\sigma_{сж}$ and gap $\sigma_р$, clutch C and the angle of internal friction p. These properties are different in the piece (sample) and in the array for the type of rocks. For example, the cohesion of rocks obtained from laboratory tests in a sample can be tens of times greater than for the same rock in the array. The angles of internal friction of rocks in the sample and in the array have an insignificant difference. In addition, the resistance of rocks to tearing in a monolith can reach a considerable value, and in a fractured massif it is practically zero. The thing is that the real mountain massif is usually broken by a network of cracks, different in size, intensity of manifestation, etc. Therefore, the reliability of the data obtained is largely influenced by the scale factor, as the characteristics of the rocks obtained from the tests of the elementary structural block may differ from those in the mountain mass, which is a set of elementary structural blocks. In this connection, for example, the bond of adhesion in a piece and an array is established through the coefficient of structural attenuation.

Since often anmassif of rock fractured rocks collapses on open surfaces on surfaces of attenuation of various origins, it is necessary to know the shear characteristics of these surfaces. Practice has established that the adhesion of cracks or contacts of rock layers can be several times smaller than the cohesion in the massif [14-16].

The density of rocks, their resistance to compression and tearing, adhesion and the angle of internal friction in the piece are usually obtained in laboratory conditions by testing samples prepared from wellbores or by sawing them from stone stone cutting machines. For rock and semi-local rocks, the selected core or ore is usually not required to be refined.

The average density of samples of the correct geometric shape is determined by the formula

$$\gamma = \frac{P}{V}, \tag{1}$$

where P – sample weight, g; V – sample volume, calculated by linear measurements, cm^3.

The average density of irregularly shaped samples can be obtained by hydrostatic weighing

$$\gamma = \frac{P}{P - P_1}, \tag{2}$$

where P_1 – sample weight in water, g.

Determination of the strength of rocks for uniaxial compression is performed in accordance with the international standard [8]. The required number of test pieces is determined depending on the coefficient of variation.

V, %=30, at the number of samples 9; cV, %=25, at the number of samples 6;

V, %=20, at the number of samples 4; cV, %=15, at the number of samples 3.

In the test, usually cylindrical or cubic forms are used with a ratio of height to diameter or base equal to one. The end support faces are ground, making them parallel with a deviation of no more than 0,5 mm. The sample is placed in the center between the plates of the press during testing. The loading speed is taken from 5 to 10kgf/cm^2 sec. before destruction..

The temporary resistance of rocks to uniaxial compression is calculated from the formula

$$\sigma_{сж} = \frac{P_{\max}}{S}, \tag{3}$$

where $P_{тax}$ – destructive load for the sample, kg/n; S – area of the sample, cm^2.

In practice, many methods are known for testing the tensile strength of a rock. The most reliable and available at present is the method for determining the tensile strength by splitting cylindrical specimens in diameter, called "Brazilian".

The tensile strength of rocks in this method is determined by the formula

$$\sigma_P = \frac{2P}{\pi \cdot d \cdot l} \tag{4}$$

where P – destructive load for the sample; d – sample diameter, cm; l – sample height, cm.

Determination of strength characteristics of rocks C and p in laboratory conditions is based on obtaining normalσ_n and tangentialτ stresses when testing specimens on a shear device with a press at different angles of inclination of the shear plane to the applied load. For the test, 3-4 samples of the same rock are made, they are placed in special clips and cut at angles an equal to 30, 45 and 60° on a shear device. When cutting the specimen, the shear area (S) is measured, and the load (P) at which the shear occurred is taken from the press manometer. The normal and shear stresses at shear are calculated by the formulas:

$$\sigma_n = \frac{P}{S} \cdot \cos\alpha; \quad \tau = \frac{P}{S} \cdot \sin\alpha \tag{5}$$

According to the presented methodology, a rock solidity passport is compiled.

Results. Investigation of the data on the stability of the sides of some ore mines in Central Kazakhstan shows that the efficiency of the open method of mining mineral deposits will be greatly enhanced by the use of engineering management methods.

The study of the actual stability of the slopes, the revealed main types of deformations in the instrumental massifs, as well as the results of the structural features and physico-mechanical properties of the rocks, made it possible to obtain grapho-analytical relationships between the parameters of the slopes and the properties of the rocks[17-22].

Analysis of the dependence of the angle of slope on the angle of incidence of cracks shows that the fall of cracks in the direction of the quarry significantly affects the slope of the ledge, and this dependence is rectilinear, i.e. a steep fall in the cracks causes a steep angle, and a gentle drop - a gentle slope of the ledge (figure 1).

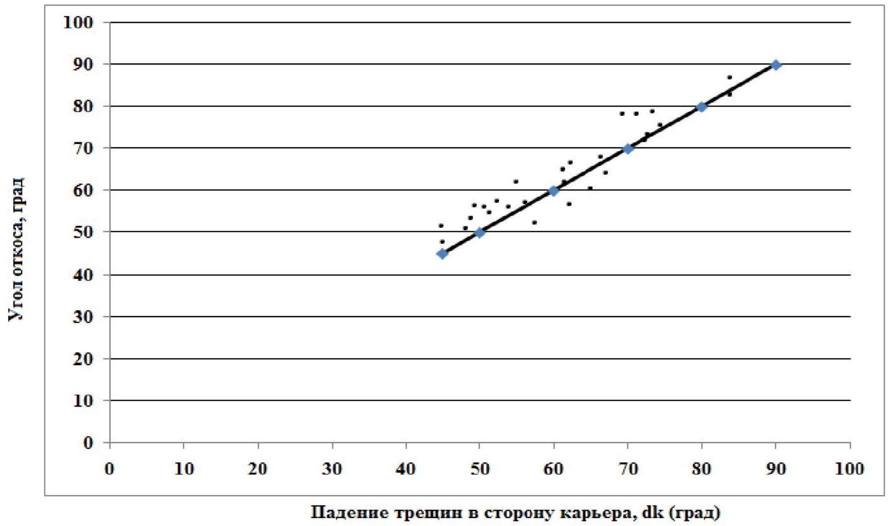

Figure 1 – Dependence of the angle of slope from the angle of falling cracks

To identify the cracks in the area of the collapse that occurred on the example of the Konyrat quarry, a rectangular fracture diagram was obtained. The vertical axis of the diagram characterizes the angles of incidence of cracks through the interval 10°, and to the horizontal azimuth of the strike of the cracks, through the interval -10°.

Each measurement is represented on the diagram by the center of a circle of small diameter. Then, contouring of individual fracture systems was performed, grouping them in the intervals of the angle of incidence and the strike azimuth equal to 30° (figure 2). As a result of this treatment, the diagram clearly identifies 6 systems of cracks.

Table 2 – Characteristics of the distribution of the systems of cracks in the quarry Konyrat

Cracks systems	Elements of occurrence		Geometric classification
	Azimuth of extend, degree	Falling angle λ, degree	
I	298	72	Transversal, according to the incidence angle, steep
II	14	74	Transversal, according to the incidence angle, steep
III	338	79	Transversal, according to the incidence angle, steep
IV	8	42	Longitudinal, according to the incidence angle, inclined
V	75	75	Transversal, according to the incidence angle, steep
VI	298	28	Transversal, according to the incidence angle, flat

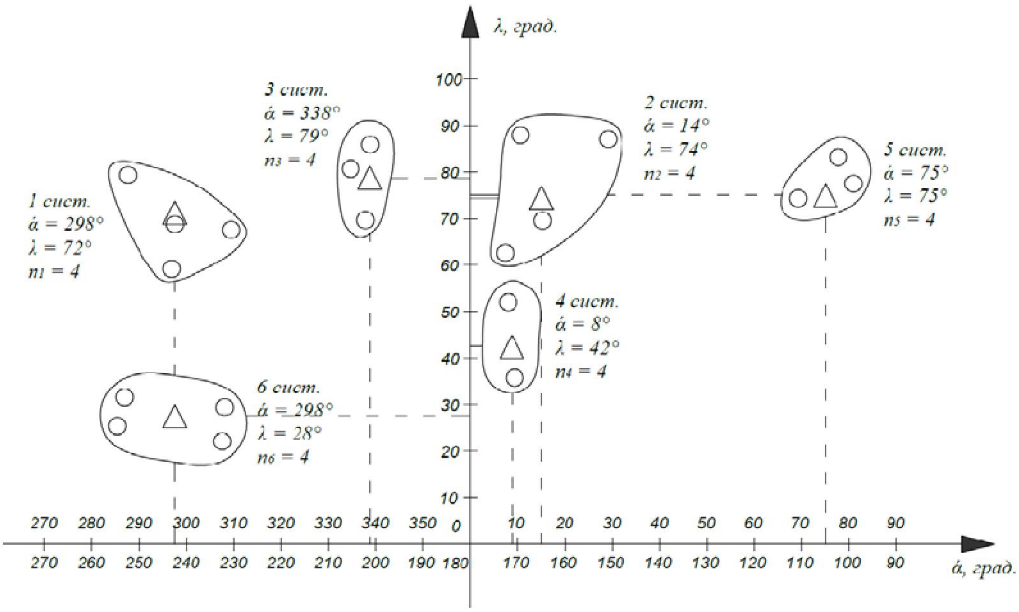

Figure 2 – Rectangular diagram of fracturing

Researches have shown that isolation of the site of homogeneous fracturing is not carried out accurately, since large disjunctive disturbances are accepted outside the site [23, 24].

On the basis of the above technique, curves of the angles of incidence of fracture systems are plotted for sections or for the entire quarry. It should be noted that on the quarry in the instrumental massif most often occur diagonal and longitudinal cracks, and according to the falling two times more often than the inconsistently falling.

Observations of the surface of the slopes of the ledges showed that with the passage of time the magnitude of the inclination angles of the ledges decreases intensively, and in the first 3-4 years a very intensive flattening of the inclination angles occurs, and later this process affects more slowly. On the basis of the foregoing, it can be concluded that the flattening of the general angle of inclination of the ledge is mainly due to the destruction of its upper part. Leaving safety berms on one side are crumbled (in the upper edge of the ledge), and on the other side they are covered (near the bottom edge of the ledge), thereby connecting the slope into a continuous line. This makes it difficult to conduct mining operations in the quarry, which ultimately leads to an increase in the stripping volume.

Conclusions on the basis of the research results. Studies have shown that the northern side of the Konyrat quarry, composed mainly of strong rocks, has permissible angles of inclination with two twin terraces (51–54° at a height of 30–40 m); however, the absence of berms of the required sizes on the upper horizons requires a revision of their parameters.

The unsatisfactory state of the quarry sides is also due to the propensity of the rocks to fracture.

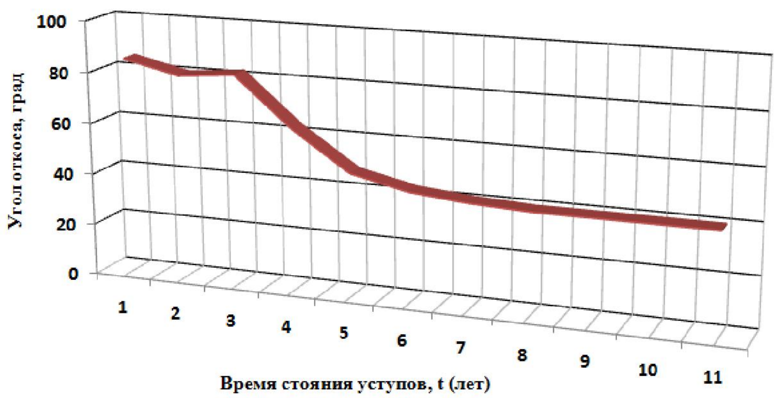

Figure 3 – Dependence of the angle of inclination of the ledge on the time of standing of the ledges

It is established that the main types of deformation of the ledges composed of rocky and semi-local fissured rocks are scree and collapse. On the ledges, scree and collapse are formed due to the impact of drilling and blasting operations on the stability of the rock massif.

The works are divided into three groups.

1. Works in which the size of the zones of disturbance of the solidity of the massif, as a result of the action of mass explosions, is determined on the basis of mine surveying and seismic observations, and also empirically.

2. Work in which methods are proposed to determine the additional stresses that arise in the array of ledges during the production of blasting operations and take them into account when calculating the angles of slopes of the sides of quarries.

3. Works that contain general recommendations.

The influence of blasting on the stability of the bead in its limit position is proposed to be taken into account in two ways. The first is that to assess the stability of the side and calculate the angle of its slope as a whole, use those strength characteristics that have rocks that have experienced the impact of the explosion. The second way is to change the technology of works with the approach of the work front to the limit contour in such a way that the weakened zones of rocks arising in the explosion do not reduce the stability of the board, determined by the strength characteristics of rocks not affected by the explosion. The indicated dimensions of the zones along the surface of the ledge are confirmed by many authors [9]. Some authors argue that with mass explosions of vertical wells, the zone of burrows extends 6-13 m behind the newly formed upper curb, and the zone of shocks or residual shear deformations is 40-60 m and from the last row of boreholes. Here, the influence of the parameters of drilling and blasting on the value of the angles of inclination of the sides of quarries, folded by rock fractured rocks, is noted.

At the Konyrat quarry, the investigations of the disturbance of the massif by explosions are carried out by pouring water into the wells and determining the filtration coefficient. This method allows us to note the fundamentally new nature of the disturbance of the array not only over the surface, but also in depth.

It is known that as a result of the shock action of an explosion in the environment, stress waves arise that propagate at a high speed (280-5200 m/sec). A directional state created in a rock mass during the passage of compression and expansion waves leads (within the radius of destruction) to the emergence of a series of differently oriented cracks due to the germination of natural equilibrium microcracks of the medium into macrocracks and the appearance of new stresses under the action of energy. With the subsequent expansion of the volume of gases after the explosion, the size of the cracks increases, which ensures a complete or partial disruption of the structure of the massif.

The radius of destruction produced by the energy in the front of the compression wave is insignificant in view of the fact that the depth of germination of cracks is limited by the conditions of rock destruction in the state of all-round compression.

As a result of the research, it was revealed that in the approach of drilling and blasting operations to the design contour of the quarry, in order to exclude the deformation processes on the pit slopes that have already been put in the design position, in order to further safely conduct mining operations on the underlying horizons, it is necessary to study the mountain massif for its correction internal impairment using a variety of methods.

Discussion and conclusion. As a result of the researches, the following conclusions can be drawn: Deposits of minerals, developed by the open method, are characterized by a great variety of mining-geological, mining, geomechanical and technological conditions.

From the variety of factors affecting the stability of slopes with enclosing rock and semi-rock rocks, three main factors have been identified that require compulsory registration in the study of geomechanical processes:

l) structural and tectonic features of the mountain massif;

2) physical and mechanical properties of rocks;

3) researches of the influence of the time factor and the effect of mass explosions on the stability of slopes;

Based on the study of the fracture of the tectonics of the deposit, developed by the open method, the types of work were determined: field work, drawing up and processing of point and other diagrams based on field measurements to identify crack systems; study of physical and mechanical properties of rocks; laser scanning; geophysical research.

To strengthen career slopes of folded fractured rocks, the use of ultrasonic and thermometric methods for rapid assessment of the disturbance of the mountain massif have been proposed.

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КҮРДЕЛІ КЕНГЕОЛОГИЯЛЫҚ ЖӘНЕ КЕНТЕХНИКАЛЫҚ ЖАҒДАЙДАҒЫ КЕНОРЫНДА ПАЙДАЛЫ ҚАЗБАЛАРДЫ ЭКОЛОГИЯЛЫҚ ТҰРҒЫДАН ҚАУІПІЗ ӨНДІРУ ҮШІН ТАУ-КЕН МАССИВІНІҢ ГЕОМЕХАНИКАЛЫҚ ЖАЙ-КҮЙІНЕ ЭКСПРЕСС-САРАПТАМА ЖАСАУ

Аннотация. Ашық тәсілмен кенорындарды игеру кезінде карьерлердің тереңдігін ұлғайына, үйінділер мен карьер беткейлерінің қызмет ету мерзімінің азаюына, кен орындарын игерудің инженерлік, геологиялық және гидрогеологиялық жағдайларының күрделілігіне, кен құрамындағы пайдалы компоненттердің аз болуына байланысты геомеханикалық зерттеулерді жүргізу қажеттігі туындайды. Қазіргі кезде кеніштердің 70% -дан астамы 200 м-ден астам тереңдікте, көптеген карьерлерді жер бетінен 400-ден 500 метр тереңдікте жұмыс істейді және жобалық тереңдігі 700 және одан да көп метрге жетуіне байланыст, осы мақалада тау жыныстарының массивтерін зерттеу және ашық кенді өндіру кезіндегі геомеханикалық үдерістердің нәтижелері келтірілген. Ашық тәсілмен қазымдалатын кенорындарын экологиялық жағынан қауіпсіздендіру үшін әдістер әзірленді: тау массивінің бұзылуын жылдам бағалау; нығайту; карьер беткейлерінбекіту; карьердегі жолдарда шаңды басу. Зерттеудің нәтижесі карьербеткейлерінің тұрақтылығынабағытталған шаралар кешенін және жаңа жолдарын көрсетеді.

Түйін сөздер: кенқорын игеру, кен массививінің бұзылуы, техногендік құламалар, шаңды басу, карьер, кен жынысының массиві, тұрақтылық, бекіту, босаңсу аймағы, жарықшақты кен жынысы, күрделі кентехникалық және кенгеологиялық жағдайлар, массивтің геомеханикалық жағдайы, ультрадыбыстық зерттеу әдістемесі.

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ЭКСПРЕСС-ОЦЕНКА ГЕОМЕХАНИЧЕСКОГО СОСТОЯНИЯ ГОРНОГО МАССИВА И РАЗРАБОТКА СПОСОБОВ ЕГО УПРОЧНЕНИЯ И УКРЕПЛЕНИЯ ДЛЯ ЭКОЛОГИЧЕСКИ БЕЗОПАСНОЙ РАЗРАБОТКИ МЕСТОРОЖДЕНИЙ ПОЛЕЗНЫХ ИСКОПАЕМЫХ В СЛОЖНЫХ ГОРНО-ГЕОЛОГИЧЕСКИХ И ГОРНОТЕХНИЧЕСКИХ УСЛОВИЯХ

Аннотация. Важным этапом развития открытых разработок месторождений полезных ископаемых характерны следующие особенности: увеличение глубины карьеров, сроков службы откосов уступов и бортов карьеров, рост объемов вскрыши, интенсификация и концентрация горных работ, сложность инженерных, геологических и гидрогеологических условий разработки месторождений, низкое содержание полезных компонентов в руде. Свыше 70% карьеров имеют глубину свыше 200 м, многие карьеры отрабатывают горизонты 400–500 м от земной поверхности, а проектные глубины достигают 700 и более метров.В статье приведены результаты исследований массива горных пород и сопутствующие геомеханические процессы при отработке открытым способом. Для экологически безопасной отработки месторождений полезных ископаемых разработаны способы: экспресс-оценки нарушенности горного массива; укрепления; упрочнения карьерных откосов; пылеподавления на автодорогах карьера.Полученные результаты исследований отражают комплекс мер по повышению устойчивости бортов карьера и новых способов повышение устойчивости откоса уступов путём их укрепления и упрочнения.

Ключевые слова: разработка месторождений, нарушенность горного массива, техногенные обрушения, пылеподавление, карьер, массив горных пород, устойчивость, укрепление ослабленные участки, трещиноватые породы, сложные горнотехнические и горно-геологические условия, геомеханическое состояние массива.

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