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MODELING OF MINING AND GEOLOGICAL OBJECTS AKZHAL CAREER

Abstract. The methods considered in this article are used to solve problems of complex optimization of open-pit mining, which ensures continuous improvement of reliability and cost-effectiveness of design of mining enterprises and maintenance of their operating mode throughout the entire life of the deposit. Due to the diversity of manifestations of elements (depth of occurrence of the deposit, angle of dip of the ore body, thickness of the ore body, morphology of the ore body, mechanical properties of ore and host rocks, tectonic disturbance, fracturing of rocks and ores) of the geomechanical structure, it is difficult to link them together into a single functional dependence. In the article, several elements are conditionally identified to determine between them quantitative and qualitative relationships necessary for generalization of the geomechanical assessment of the massif state.
Key words: *modeling, geomechanics, geodynamics, fracturing, programming, design.*

Ақжал карьерінің тау-геологиялық объектілерін модельдеу

Андатпа. Мақалада қарастырылған әдістер кен өндіруші кәсіпорындарды жобалаудың сенімділігі мен экономикалық тиімділігін үздіксіз арттыруды және кен орнының бүкіл қызмет ету мерзімі ішінде олардың жұмыс режимін сақтауды қамтамасыз ететін ашық әдіспен өндіруді кешенді оңтайландыру мәселелерін шешу үшін қолданылады. Элементтердің әртүрлі көріністеріне байланысты (кен орнының тереңдігі, кен денесінің құлау бұрышы, кен денесінің қалыңдығы, кен денесінің морфологиясы, кен және негізгі жыныстардың механикалық қасиеттері, тектоникалық бұзылулар, тау жыныстары мен кендердің жарылуы) геомеханикалық құрылымды ескере отырып, оларды бір-бірімен біртұтас функционалдық қатынасқа жатқызу қиын. Мақалада массив жағдайының геомеханикалық бағасын жалпылау үшін қажетті сандық және сапалық байланыстарды анықтау үшін бірнеше элементтер шартты түрде анықталған.
Түйінді сөздер: *модельдеу, геомеханика, геодинамика, жарықшақтық, бағдарламалау, жобалау.*

Моделирование горно-геологических объектов карьера Акжал

Аннотация. Рассмотренные в статье методы применяются для решения задач комплексной оптимизации открытых разработок, что обеспечивает непрерывное повышение надежности и экономичности проектирования горнодобывающих предприятий и поддержание режима их работы в течение всего срока эксплуатации месторождения. В связи с многообразием проявлений элементов (глубина залегания месторождения, угол падения рудного тела, мощность рудного тела, морфология рудного тела, механические свойства руды и вмещающих пород, тектоническая нарушенность, трещиноватость пород и руд) геомеханической структуры их трудно связать между собой в единую функциональную зависимость. В статье условно выделены несколько элементов для определения между ними количественных и качественных связей, необходимых для обобщения геомеханической оценки состояния массива.
Ключевые слова: *моделирование, геомеханика, геодинамика, трещиноватость, программирование, проектирование.*

Introduction

At present, monitoring the state of the regions environment for the purpose of assessment and forecasting is one of the most important issues concerning the implementation of measures compliance with environmental safety. However, in all regions of Kazakhstan there are enough problems to ensure not only environmental but also industrial safety.

The scale of modern mining production development requires in-depth study and constant monitoring of the ongoing geomechanical and geodynamic processes in the bowels of the Earth. Therefore, a system of geomechanical and geodynamic monitoring of the state rock massifs should be created on the territory of the enterprise for the development of deposits to ensure industrial safety of the subsoil development [1].

The development of the methodology of the systems approach has led to the emergence of a new, more advanced and targeted methodology for solving problems of large and complex dynamic systems, this is object-oriented analysis, design and programming, which were formed on the basis of computer science. Fundamental and applied problems of analysis, design technologies, programming and creation of databases, as well as the formation and functioning of information flows are widely reflected in the works of A.M. Alekseev, G. Buch, V.N. Burkov, F. Gill, I. Graham, G.A. Denisov, A.D. Ivannikov, Yu.I. Klykov and other scientists. A significant contribution to the development of scientific areas of geoinformatics in mining was made by the works of such scientists of Kazakhstan as D.Sh. Akhmedov, D.G. Bukeikhanov, S.Zh. Galiev, A.F. Tsekhovoy, S.V. Tsoi and a number of other scientists.

Research methods

The deposit is located in Shetskyarea of the Karaganda region. The nearest mining center is the city Balkhash, located in 130 km to the southeast.

The deposit is composed mainly of limestones and sandstones in the lower Tournaisian of the Kasan layers. Massive limestones are the main ore-bearing horizon. The appearance of the limestones is quite diverse, and the varieties replace each other, both along the strike and along the dip, without any regularity. The thickness of the horizons within the deposit varies from 50-200 m.

Vein rocks accompanying intrusions are widely developed in the Akzhal ore field area. The rock complex corresponds to the second stage dikes and is represented by diorite, diabase, quartz diorite porphyrites, granosyenite porphyry [2].

The ore zone is characterized by a complex internal structure, there are sheet-like and saddle-shaped ore bodies and deposits of vein-disseminated ores, the ore bodies are not consistent in dip and strike, have constrictions and swellings, branch out and reconnect.

At present, all benches of the quarry are composed of highly fractured rocks, which pose a certain danger during mining operations. Therefore, special attention was paid to studying the structural features of the rock mass (Fig. 1).

A quarry, like any large, complex and dynamic system, is a hierarchical multi-level structure designed for the development of solid minerals by open-pit mining. The main active objects of the system located at the top level of the hierarchy are the sides of the quarry and the edge massifs of rocks.

At the top level of the conceptual model there is an object in the form of a coordinator – «Block for calculation man-

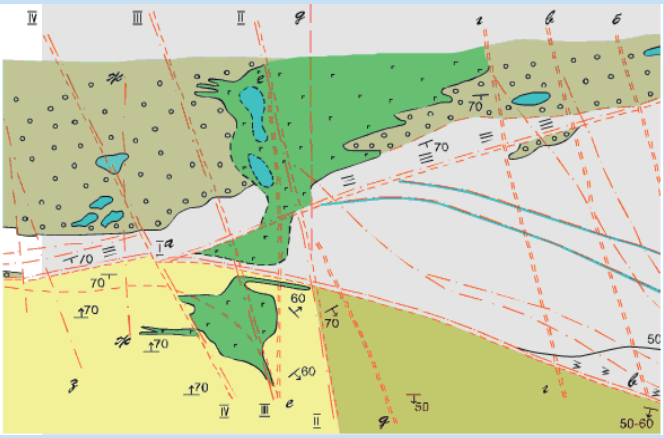

Figure 1. Tectonic map of the Akzhal deposit.
Сурет 1. Ақжал кен орнының тектоникалық картасы.
Рис. 1. Тектоническая карта месторождения Акжал.

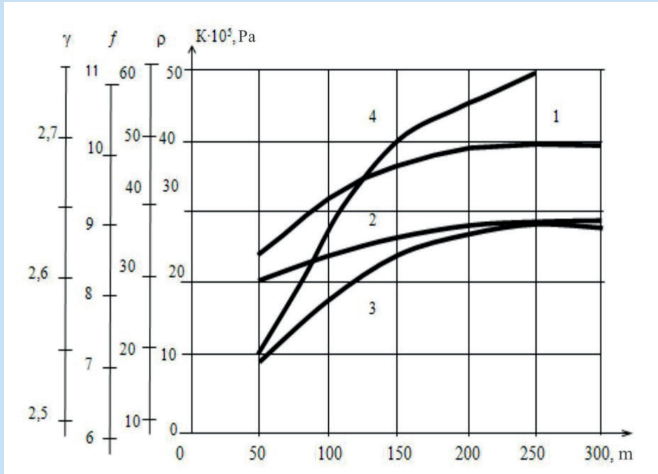

Figure 2. Dependence of strength properties of massive limestones on the depth of their occurrence in the Akzhal quarry.
Сурет 2. Массивті әктастардың беріктік қасиеттерінің Ақжал карьерінде пайда болу тереңдігіне тәуелділігі.
Рис. 2. Зависимость прочностных свойств массивных известняков с глубиной их залегания на карьере Акжал.

agement and coordination of information flows», providing a strategy for managing and coordinating calculations of quarry slope stability with decision-making priority, and at the lower level – design objects of the processes: «Automation of field survey processes and processing of their results», «Modeling of the structure of edge massif», «Automation of the engineering and environmental monitoring (EEM) system and strengthening of slopes and the surface of dumps» [3, 9].

Thus, the conceptual geoinformation model reflects the structure, structure and properties of geological objects in the edge massif in a complex, the composition of the elements of which is determined taking into account the relationship between geological objects of different levels of the hierarchy and the description of geometric parameters in a single coordinate system. In this case, information flow models are used as means of interaction between objects, and models of objects in symbolic form are used as objects, between which system-forming relations are maintained through computer systems.

Results and discussion

One of the main stages of the study of quarry slope stability was the study of the physical and mechanical properties of rocks.

Using the methods of mathematical statistics and correlation analysis, it was established that there is a stable relationship between the average density, strength, adhesion, resistance and the depth of their occurrence, i.e. ***γ, f, c, σcomp = f (H).*** The relationships of the physical and mechanical properties of rocks with each other, as well as with the depth of their occurrence, are shown in Fig. 2.

If we consider a geological body of a larger scale, then the above-mentioned separate massif would be part of the first. If we study the structure of an entire mountain structure such as Central Kazakhstan, then individual deposits can serve only as an elementary part, a block of a large scale. With such judgments we can reach the whole on the scale of continents or geosynclines and platforms. The latter, in turn, are the constituent parts of the earth's crust – the geoid as a whole [4].

Modeling such a complex object as a deposit is impossible without applying the principle of a systems approach – *the principle of hierarchy*. Based on the principle of hierarchy, the following levels are distinguished: *deposit, site, exploration line, exploration well, geological object (layer, interlayer and their characteristic properties)*. This scheme (Fig. 3) is the basis for establishing a connection between geological objects located at different levels of the hierarchy.

Table 1
Equation of relationships between the properties of limestones of the Akzhal deposit and the depth of their occurrence
Кесте 1
Ақжал кен орнының әктастарының қасиеттері мен олардың пайда болу тереңдігі арасындағы байланыс теңдеуі
Таблица 1
Уравнение связи свойств известняков месторождения Акжал с глубиной их залегания

Studied value	Function equation	Reliability	Limits of action
Adhesion *k, MPa*	$k = 14.5 + 0.2H – 0.0004H_2$	0.88	300<H<50
Angle of internal friction *r*, deg.	$\rho = 25.5 + 0.2H – 0.0002H^2$	0,90	250<H<50
Fortress	$f = 6.15 + 0.018H – 0.00003H^2$	0,89	300<H<50

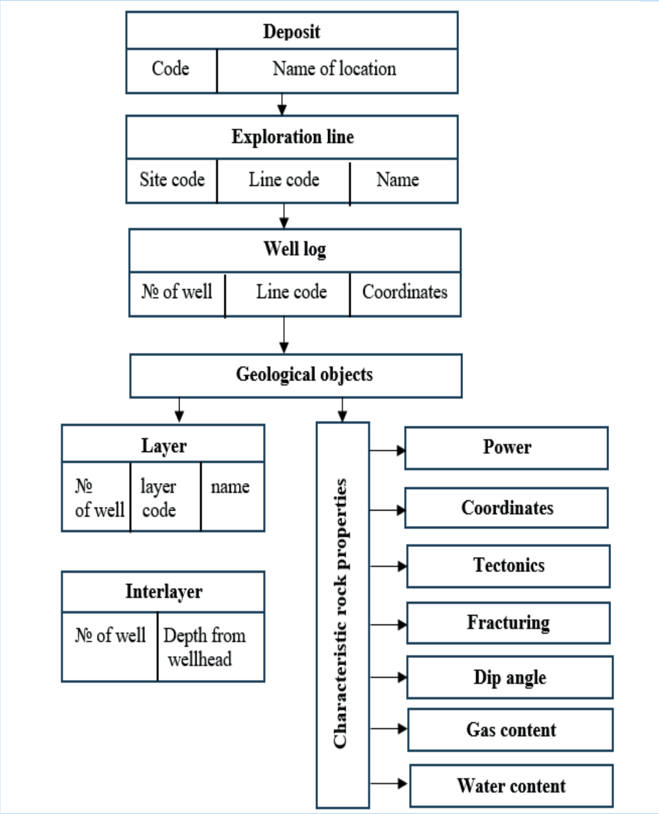

Figure 3. Relationship between geological objects.
Сурет 3. Геологиялық объектілер арасындағы байланыс.
Рис. 3. Связь между геологическими объектами.

The information model should display not only the values of the properties of geological objects, but also the nature of their behavior in space, i.e. display the geometry of the distribution of these properties. Based on these requirements, the attributes of the model include a subset of attributes of geometric parameters and mining and geological properties [5, 8].

Description of the properties of geological bodies is inseparable from the study of their structural features. Therefore, the model should also display the nature of their behavior in space. Consequently, the model includes sets of *attributes reflecting geometric parameters and mining and geological properties.*

Subset GG in each specific case has a different composition of attributes depending on the nature of the problems being solved. For example, to calculate the stability of quarry slopes, it will have the following form:

$$GG = \{\sigma_{str}, \sigma_{comp}, K, \rho, \gamma\}. \quad (1)$$

The next type of geological object is a layer. A layer is a geological *body* isolated from the surrounding geological environment according to geological or technological criteria for independent study of its properties.

The information model of a layer is described by a relation of the following type:

$$R_S = \{I_S, K_S, G_S, GG_S\}. \quad (2)$$

For this model, the subsets of the tuple attributes consist of the following elements:

$$I_S = \{NS, HS\}; K_S = \{TS\}; \; G_S = \{X_S, Y_S, Z_S, MS\}, \quad (3)$$

where ***NS*** is the well number;

HS is the depth of the beginning of the layer relative to the wellhead, m;

TS is the type of rock (lithotype);

X_S, Y_S, Z_S are the absolute coordinates of the well, m;

MS is the visible thickness of the layer, m.

Table 2 shows a fragment of the «Layer» relation for well 404.

Such a composition of geometric characteristics allows displaying the position of geological objects in all types of graphic documents, and the presence of an attribute allows you to set its belonging to a specific top-level object.

The proposed structure of the layer information model is abstract, and on its basis specific models of geological objects of different deposits can be developed taking into account their individual characteristics. Two types of relations are used to model the structure of a graphic document.

Relations of the first type are intended to describe a geological object, and of the second type – to display their geometry and are described by a set of tuples of the «Line» and «Point»

Table 2

Fragment of the «Layer» (RS) relation

Кесте 2

«Қабат» (RS) қатынасының фрагменті

Таблица 2

Фрагмент отношения «Слой» (RS)

Well number *(NS)*	Start of layer, m *(NS)*	Layer type *(TS)*	Layer thickness, m *(MS)*	Absolute coordinates, m		
				X_S	Y_S,	Z_S
404	0	Overburden	30,00	6189,75	9309,55	517,05
404	30,00	Limestones	32,90	6274,49	9244,31	517,05
404	62,90	Porphyrites	23,30	6482,79	9331,21	518,05
404	86,20	Limestones	43,85	6397,73	9354,74	518,70
404	130,05	Diorites	35,05	6327,15	9298,15	516,00

relations. The «Line» relation is used to establish relationships between a geological object and a set of points that describe its geometry. A fragment of the graphic material is shown in Fig. 4.

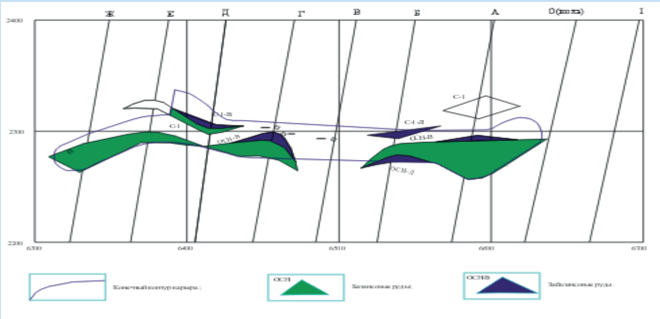

Figure 4. Fragment of the plan for the 315 m horizon of the quarry of the Akzhal deposit.
Сурет 4. Ақжал кен орны карьерінің 315 м горизонты бойынша план үзіндісі.
Рис. 4. Фрагмент плана по горизонту 315 м карьера месторождения Акжал.

Three databases are used in the process of creating a structural-geometric model: GMI, quarry models and mass measurements of fracturing, as well as a bank of mathematical models of calculation schemes for various mining and geological conditions. Based on the constructed model, an automated method for assessing the stability of quarry slopes was developed. This method and the software package developed on its basis allow for the prompt and reliable assessment of the stability of slopes of benches composed of both fractured and layered rocks [6].

There are many calculation schemes that take into account the weakening surfaces in the rock mass. The most theoretically sound are the calculation schemes for fractured rocks, in which the parameters of stable slopes are determined taking into account the weakening planes in relation to the strength properties of the rocks of the massif. Therefore, the developed method of automated slope stability assessment is based on the calculation schemes of slope stability for a fractured massif. This set of calculations is performed on a computer for each section of the simulated section of the quarry side, summary tables are generated, which are stored in the working database (table 3), and the quarry slopes are zoned according to the stability factor.

The analysis of the data in Table 3 shows that along the southern side of the quarry, in sections of profile lines with dip angles of longitudinal steep cracks of 75-780, the stability of slopes at angles of their inclination of 65-700 is ensured. On the northern side, section of profile line I-I, as well as on the southern side (profiles M 22), the slopes will be in a temporarily stable state (η3 = 1.21-1.22), and over time, the benches may be subject to local collapses. The results of the study made it possible to clarify the parameters of stable sides and benches in the limit position and to adopt a new version of the Akzhal deposit quarry contour.

This automated calculation technique and the software package «Slope Stability Assessment» developed on its basis make it possible to promptly and reliably assess the stability of slopes of benches composed of both fractured and layered rocks.

The current level of development of science and technology suggests the use of modern research methods in the mining industry, based on the use of computer technologies. There is a number of foreign software products implementing three-dimensional modeling of deposits: Data Mine (Great Britain), Techbfse (USA), Surpac (Australia) and others.

Table 3

Assessment of the stability of the Akzhal quarry sides

Кесте 3

Ақжал карьері жақтарының тұрақтылығын бағалау

Таблица 3

Оценка устойчивости бортов карьера Акжал

Profiles	Calculation characteristics of breeds					Slope angle α, deg	Crack inclination angle δ^0	Nz, m	Stability coefficient η3
	in array			on crack					
	γ, t/m^3	*Km*, т/m^2	ρm, deg	*Kr,t on crack /m^2*	ρp, rad				
South B-IX	2,68	55,8	22,5	18,6	20,0	65	75	60	1,3567
South B-VI	2,70	62,0	22,5	19,0	20,0	70		90	1,2890
North M-22	2,70	62,0	22,5	19,0	20,0	70	75	190	1,2100
South B-X	2,68	55,8	22,5	18,6	20,0	60	75	30	2,7450
North I- I	2,68	55,8	22,5	18,6	20,0	65	75	60	1,2560
South B-IV	2,70	62,0	22,5	18,6	20,0	70	75	90	1,6030
South B-IX	2,68	55,8	22,5	18,6	20,0	75	75	190	1,2240
North M-22	2,68	55,8	22,5	18,6	20,0	75	75	190	1,2240

There is experience in using 3D models of deposits in specialized commercial software packages for solving various mining engineering problems at mining enterprises (Fig. 5.)

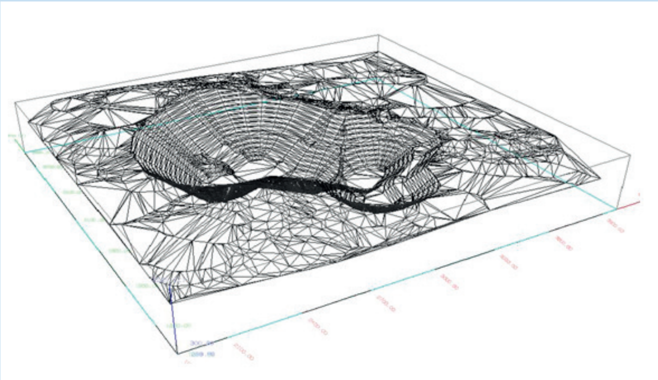

Figure 5. 3D model of the quarry in the GEMCOM system.
Сурет 5. GEMCOM жүйесіндегі карьердің 3D моделі.
Рис. 5. 3D модель карьера в сисеме GEMCOM.

In recent years, mathematical computer models have been widely used, which have made it possible to move to flexible multi-variant modeling of ore objects, taking into account the rapidly changing economic situation. The scheme of the computer system for modeling deposits provides for obtaining a geological and economic assessment of ore objects and a model of ore objects by constructing block models [7, 11].

The block model allows for a high degree of reliability in assessing geological reserves and quickly calculating the necessary indicators. A large volume of research was conducted in the open-pit mining laboratory under the supervision of Doctor of Technical Sciences, Professor D.G. Bukeikhanov.

A fundamental step in this direction is the transition to three-dimensional modeling of deposits. Working with such models allows not only to promptly solve mining engineering problems, but also opens up broad prospects for researchers to apply modern analytical and numerical methods.

Three-dimensional modeling of ore bodies for the study of the geomechanical situation was carried out at the Akzhal deposit [1, 10].

Due to the complexity of the issue being resolved and the above-mentioned advantages, it was decided to create a digital three-dimensional model of the geological situation of the deposit.

The first stage of modeling is the classification and primary processing of the initial data, which consists of selecting the necessary and sufficient volume of geological and graphic data and bringing them to a single format that allows for correct combination.

The final stage of modeling was a three-dimensional approximation of the geometric parameters of the structural elements of the model. At the same time, an analysis of their relative positions and interpolation of the contour generators were performed, according to which a framework model of ore bodies is created (Fig. 6).

Based on the wireframe model, spatial triangulation is performed, resulting in a three-dimensional surface of the ore bodies (Fig. 7).

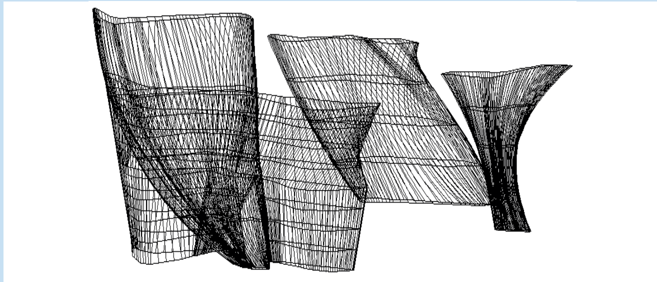

Figure 6. Wireframe model of ore bodies of the Central section of the Akzhal deposit.
Сурет 6. Ақжал кен орнының Орталық учаскесінің кен денелерінің қаңқалық моделі.
Рис. 6. Каркасная модель рудных тел Центрального участка месторождения Акжал.

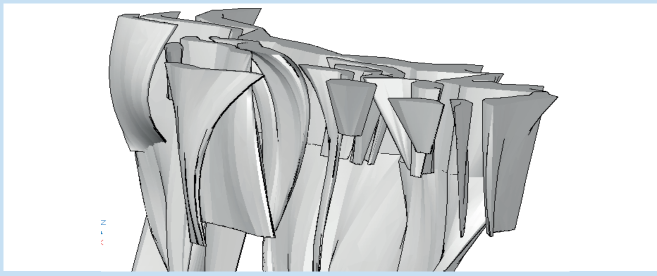

Figure 7. 3D model of the ore body surface.
Сурет 7. Кен денелер бетінің 3D моделі.
Рис. 7. 3D модель поверхности рудных тел.

The development of 3D models of deposits is a highly relevant scientific and practical task, the successful solution of which determines the efficiency of mining enterprises based on the widespread introduction and use of modern computer technologies in solving mining-geometric and mining engineering problems [1, 12].

The method of creating three-dimensional models of ore bodies at the Akzhal and Akbakay deposits can be used at other deposits.

Conclusion

The application of principles and methods of geoinformation modeling made it possible to create, with the required level of detail and in accordance with the purpose and objectives of the study, object-oriented models of the main subsystems for ensuring the stability of quarry edge massifs and their interrelations, which together represent a conceptual model for predicting the characteristics of quarry slopes.

A methodology and method for assessing the stability of quarry slopes have been developed based on the construction of a structural-geometric model of the edge massif, distinguished by a comprehensive consideration of the factors of four interconnected units with their characteristic features, which makes it possible to assess the stability of quarry slopes.

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