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INNOVATIVE METHODS OF THE ROCK MASSIF FRACTURES SURVEY AND TREATMENT OF ITS RESULTS

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ІННОВАЦІЙНІ СПОСОБИ ЗЙОМКИ ПОРУШЕНОСТІ МАСИВУ ТА ОБРОБКИ ЇХ РЕЗУЛЬТАТІВ

Structural features of a rock massif are one of the most important factors determining the geomechanical processes. The method of their study was limited mainly to the direct measurements in outcrops at the surface, on the slopes of quarries and mines by a mining compass. Nowadays, mine surveying employs modern electronic devices such as 3D scanner and others. A laser scanner can be used to capture possible fracture if the device is arranged within 300 meters from the massif. One of the major advantages of the laser scanning is the possibility of obtaining information on the status of dip fractures and the size of structure blocks without direct contact of the worker with the massif. In addition, the laser scanner can be used in iron-ore opencast mines, unlike the mining compass.

Purpose. Development of the surveying method based on 3D laser scanning in opencast mines, which will reduce the measurement time and allow creation of three-dimensional models of ore bodies taking into consideration their structure.

Methodology. The research employed the surface laser scanning of rock fractures in opencast mines, collecting data in real time and computer analysis of the results.

Findings. Methods of terrestrial laser scanning for obtaining data on geometrical parameters of opencast mines, crack occurrence and faults have been developed.

Originality. The new method of surveying the structural features of a rock massif based on 3D laser scanning allows for instant three-dimensional visualization of the survey results with a high information content, precision and productivity.

Practical value. The new method is intended to create a 3D model of a dip fracture, fault and ore body reflecting its structure.

Keywords: *geomechanical processes, rock massif structures, rock fractures, occurrence of cracks, laser scanner, 3D modelling*

Introduction. At present, specialists of the mining industry have become increasingly convinced that solving issues such as pressure and displacement of rocks, stability of pit walls is impossible without considering the structural features of massif – one of the most important factors that determine the geomechanical processes.

In many careers with sufficiently large area of outcrop of rocks, the direct method with a mountain compass was used to study the structural features and the size of the usual building blocks was measured with a tape measure [1].

The rapid development of technologies in the mining industry leads to growth of mining operations, which in turn leads to the need to create more perfect technologies of maintenance of mining operations, as well as increase in secure surveying. Technological progress has affected the tasks of surveying services in the quarries significantly over the last decade.

Terrestrial laser scanning has simplified the work of a surveyor multiplying the speed and accuracy of surveying and simplifying the processing of the results. In this paper, we propose a new way of surveying disturbance array tested in the Akzhal and Akbakai quarries [2, 3].

Mining of polymetallic deposits of the Akzhal deposit is done by the *Central* opencast which reaches a maximum depth of 240–245 m. Ore-bearing and enclosing rocks are represented by rocky-fractured rocks. To survey the structural features of the near edge zone massif, the pits have a 3D scanner implemented which is the most considerable technological innovation at the beginning of the 21st century in surveying, geodesy and a number of related industries. The laser scanning technology have solved the problem of discreteness shooting due to the extremely high density of surveyed points the number of which can be tens of millions.

This density allows obtaining a ‘natural’ three-dimensional model of the object, even at the stage of surveying [4]. In this regard, the use of 3D scanning is relevant, providing instantaneous three-dimensional visualization, high accuracy and detail, high productivity, favourable conditions of field work, available results under various lighting conditions, and safety of surveying objects difficult to access.

Analysis of research and publications. Studies of stability of boards and ledges at open working include the study

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of the geological structure and the structure of the rock mass as well as engineering-geological conditions of deposits.

Based on our previous studies of the structural features of rocks of 7 deposits (Chulaktau, Aksay, Zhanatas, Akbakai: Akzhal, Rodnikovoie, Vasilkovskoie) of Kazakhstan, the obtained results were successfully implemented for the purpose of solving the issues of the sustainability of ledges and sides of the pits [5, 6].

On the basis of studying the structure of rock massif using modern instruments, the results allowed the employees of the Department of Surveying and Geodesy KazNITU to perform the classification of geotechnical rock complexes in terms of stability of pit walls of Kazakhstan, based on the nature and extent of the fracture, as well as resistance to plastic deformation (creep) [7].

To study the structural features of rocks of near edge zone massifs and their 3D modelling, the principles of the laser scanner and the possibility of its use in the practice of open pit mining are discussed.

Problem Statement. The aim of the research is to develop and introduce a new way of surveying high structural features of rock massif using a 3D laser scanner to create 3D models of ore bodies and the main geological features of the Akzhal field.

The technique involves the use of a method of operation of terrestrial laser scanning of fracturing of rocks in quarries, collecting data in real time and electronic result processing. Laser scanning is a technology that allows creating a digital three-dimensional model of the object by presenting it as a collection of points with spatial coordinates. The technology is based on the use of new surveying instruments such as laser scanners, which measure the coordinates of points on the surface of the object at a high speed of several tens of thousands of points per second.

After that a point cloud is created with superimposed photos on the computer using Maptek I-Site Studio software. Then the volumetric electronic version of the near edge zone massif is processed on the computer in order to obtain the parameters of occurrence of cracks and faults: strike and dip angles, dimensions of the structural units formed by cracks.

The data acquisition module is responsible for collecting data in real-time measurement and control of the measurement cycle, the allowable values by monitoring messages.

The analysis module is responsible for the analysis of the measured data, reporting, editing and post-processing. Data and results are shown in numerical and graphical forms of the three-dimensional model of the object, plane drawing, a set of cross-sections, the surfaces, etc.

At the present time, issues such as pressure and displacement of rocks under the influence of underground mining, the stability of pit walls, cannot be considered without the structural features of the array, which is becoming increasingly clear for mining specialists.

Structural features of the array make one of the most important factors determining the geomechanical processes [1, 2]. In the study of fracture, two different survey methods are recommended. They are:

1) the method of point mass measurements of dips of planes of weakness;

2) the method of areal structural survey.

The choice of a certain method from these methods was determined by the complexity of the structure of the rock mass of the studied deposit part. Thus, the structure of rock deposits of Chulaktau and the northern pit wall of Aksay, which has a more sustained character, was studied by the method of point mass measurements elements of crack occurrence.

The point method of mass measurements of fracture can yield positive results for rocks having a simple structure, characterized by consistency of exceptional item occurrence of planes of weakness, both regarding the area and the depth of a career, with the number of systems which do not exceed 3–4.

With the complex structure of the array with unsustainable elements of occurrence, the point method for studying the structure cannot be used to determine the nature of the overall structure of the deposit, since in this case it is not possible to establish a connection to the same system according to several measuring points.

The method of the areal structural survey is used on deposits with unsustainable and complex structure of rocks with tectonic dislocation of rocks. The main purpose of surveying is to establish the regularity of distribution and consistency of the basic systems or groups of planes of weakness, the boundaries of weathered rocks, disjunctive dislocations, etc.

The technique of the areal structural survey is based on interval surveying of structural elements outcropping of scarps on each horizon of a career. The length of the interval can be various depending on the nature of the variability of the structure. Surveying is conducted by using a tape measure and the compass. The main fracture systems on the basis of spot measurement of occurrence elements, the sizes and shapes of structural blocks, the degree of roughness of weakening surface, length of the cracks as well as material for filling out weakening surfaces are established for each interval.

Regarding open-pit workings on a sufficiently large area of outcrop of rocks, the method of direct measurements that received widespread practice and extensive coverage in the works are surface mines appears to be the most effective [3, 4].

Methods of measuring fractures of rocks are reduced mainly to the direct measurements in outcrops at the surface, on the slopes in open pits, along the walls of pits and mine workings, to observations on the core samples of geological wells. On the open cast mining works with a sufficiently large area of rock outcrop, the most effective method is the method of direct measurements (mass or profile lines) with the help of a mountain compass [4].

On opencast deposits of *Zhanatas* production association, deposits of *Karatau* and *Central*, the survey of fractures was carried out with a mountain compass of 2003. The dimensions of structural blocks (the distance between fractures) were measured with a conventional tape measure, while incidence angles and azimuths of fractures and their trending were measured with a mountain compass.

The main material and results. Currently, in the manufacturing practices of surveying and geodesic works there are modern electronic devices such as a 3d scanner, a tacheometer and others. During surveys these devices allow obtaining an object in electronic form. Laser scanning is a technology that allows you to create a digital three-dimensional model of the object, presenting it with a set of points with spatial coordinates. This technology is based on the use of new surveying instruments such as laser scanners that measure the coordinates of points on the surface of the object with high velocity of several tens of thousands of points per second [5].

The ground laser scanning method is widely used to obtain data on the geometric parameters of the quarries, the elements of occurrence of cracks and rupture destructions, rock dumps, tailing pits and other objects placed on the surface. The accuracy of the survey parameters is determined by the distance between the device and the subject surveyed.

Using the results of the survey with a laser scanner to get elements of occurrence of cracks and the size of the structural blocks is possible when the distance between the device and near edge zone massif is up to 800 meters. Thus, there is unique possibility get information on the status of massif without a performer's direct contact [6]. The proposed method of studying elements of the occurrence of rock cracks using a laser scanner is as follows:

- on the career a point is selected for surveying cracks at near edge zone massif where a tripod and the laser scanner are set to conduct a survey of massif (Fig. 1). It is worth mentioning that the point should allow surveying exposed part of the near edge zone massif structure to the greatest possible extent. The surveying distance in this case should not exceed 800 meters;

a *b*

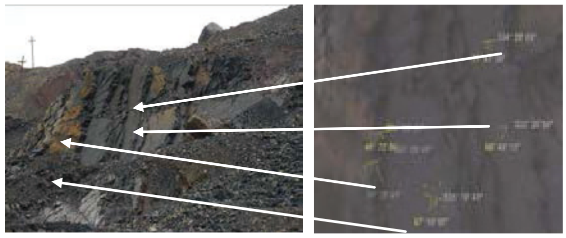
Fig. 1. Survey of near edge zone massif of a career with laser scanner Leica HDS4400

- the scanner is switched on and the survey of slope surface of structural features of near edge zone massif is conducted through the established scanning step;
- then a point cloud is created with superimposed photos on the computer using Maptek I-Site Studio software;
- an obtained volumetric soft copy of the massif is processed on the computer (Fig. 2) in order to obtain the parameters of occurrence of cracks and rupture distractions, namely, the angles of incidence and bedding, the size of the structural blocks formed by cracks (Fig. 3).

The dimensions of the rock blocks between fractures are calculated by the difference between the coordinates of points taken at rates between fractures, while elements of crack occurrence, angles of inclination and bedding are determined as a result of building the surface of cracks.

The values of directional angles and inclination angles of weakness can be calculated through the coordinates of the points taken at the fracture surface (Fig. 3).

Obtaining a digital model of near edge zone massif of the career is possible due to the use of Maptek I-Site Studio software (Fig. 4), where the values of the elements of crack occurrence are calculated: the trend azimuth, incidence angles and size of rock blocks. In this case, the digital model contains complete information about near edge zone massif rocks. By using the software processing the data on rock fracturing, it is possible to determine fracture systems, the block sizes with the purpose of applying the min passports of strength regarding the massif. The results of processing fractures of rocks by observation stations and comparing their measurements done with a mountain compass to those obtained with the laser scanner gave 3–4 %,discrepancy which is allowable.



a *b*

Fig. 2.Investigation of rock fracturing of a career: a – cracks in the slope of the ledge; b –elements of crack occurrence

Fig. 3. Identification of elements of crack occurrence

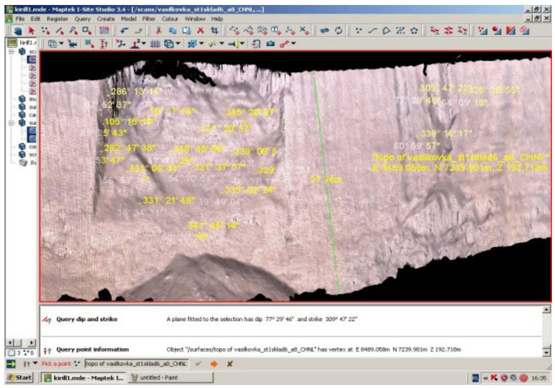


Fig. 4. Identification of elements of crack occurrence at stations with the help of Maptek I-Site Studio software

In the processes of studying rock fracture, a great amount of data on field measurements is accumulated. At the first stage of processing the results of measuring mass crack occurrence, different pie charts and stereographic grids, which have a number of drawbacks, were used. Statistical processing of a scatter chart involves counting the number of cracks, which are located at certain intervals of area, that is smoothing is produced, and then isolines of crack concentration are drawn. All stereographic grids are inconvenient, since it is very difficult to decipher fracture systems concentrated in the centre of grids. In addition, smoothing is complicated on the stereographic grids due to different-sized areas of the trapezoid. The rectangular diagram does not feature these drawbacks.

This article describes the methodology of selecting active conjugated fractures (system of fractures) according to the data of field observations with application of GIS-technologies on the basis of using database of geological-surveyor information.

Methods of rock fracture measurement basically represent the direct measurements on surface uncovering, open pit slopes, at boring pit walls and mine working walls, and observations of core samples of earth bores. At the open working explorations with a rather big area of uncovering of rocks, the most effective method is the method of direct measurements (mass measurements) with the help of miner's compass or with phototheodolite. During fracture observation a large number of measurements are accumulated. The processing and summarizing of these measurements are performed with the help of pie charts, square diagrams and fracture stereograms. On the basis of these graphs the structure sections and maps for fractures are being constructed.

Square diagrams allow defining the number of conjugated fractures by each gage station and by open pit as a whole, as well as defining the domination of certain conjugated fractures, elements of their bedding.

The term 'conjugated fractures' is usually referred to multiple fractures situated approximately parallel to some definite axis. Let us specify the amount of mentioned definition for the formalized description within a coordinate system of trend azimuth and angle of incidence. From the definition it can be seen that, first, the conjugated fractures consist of separate fractures the attitude of which is uniquely defined by two parameters – trend azimuth and angle of incidence. In the coordinate system the trend azimuth and angle of incidence are reflected by a point and further we shall call them observations.

Second, the conjugated fractures have an axis the attitude of which is also defined by two parameters – its trend azimuth (***A***) and angle of incidence (δ). Due to the fact that the axis of conjugated fractures is shown as a point we shall further call it as a centre of conjugated fractures.

Third, all fractures which are present in the conjugated fractures should be approximately parallel to its axis, that is the difference between the values of parameters of the centre and parameters of observations should not exceed a definite value within the limits of which they can be considered parallel. Now, taking into account the mentioned specification we shall formulate the problem description for selecting conjugated fractures according to the field observations data.

Problem Description. On the basis of data received during the field observations it is necessary to identify the conjugated fractures in accordance with the following criteria:

- the position deviation of separate observations from the centre of conjugated fractures should not exceed a definite given value (the condition of parallelism);

- the number of observations united into system of observations should not be less than a definite critical value ensuring the reliability of the received data (the condition of representativeness).

Mathematical Problem Statement. In order to formulate the mathematical problem statement for selecting conjugated fractures on the basis of filed observation data we shall introduce the following designations.

Relationship between the objects of the analyzed set (points of observation) of *Z* is determined by the square diagram for fractures (*XOY*). The axis *OX* embodies the values of trend azimuth (***A***), the axis *OY* has the values of angle of incidence (δ), and the position of observation point can be uniquely represented by the regular discrete function of the following kind

$$Z = f(x, y, t), \tag{1}$$

where *x*, *y* are current values of trend azimuth and angle of incidence of observation point ***Z***; *t* is the number of fractures registered at this observation point, that is, the coefficient of significance (density).

For notational convenience, further we shall call this parameter as the significance of observation point. *t* reflects the actual number of fracture traces with the values of trend azimuth equal to *X* and an angle of incidence *Y* which have been registered during the process of field observations.

Today, having the advanced level of development of scientific and technical progress, thanks to wide implementation of computer techniques into practical works the solution of issues of processing the results of mass measurements of fracture bedding elements has turned into a process with new qualitative approaches. The methodology for automated drawing of square diagram for fractures has been developed and its block diagram is shown in Fig. 5.

The methodology for automated drawing of "Fracturing Diagram" that we have developed is a computer technology of modelling structural features.

The main idea of the algorithm is in the following. At the first stage it is aimed at detecting the areas with the biggest concentration of observation points and these areas are further used for finding the optimal way of breaking down the initial set of point into conjugated fractures. After that, on the basis of adaptive adjustment of coordinates of the conjugated fractures centre and on the basis of the composition of the objects included into it the search for 'real' position of these classes at the coordinate space is being conducted, that is called the optimization of parameters of conjugated fractures.

The statistical treatment of fracture measurements is done by program in three stages. At the first stage the screening out of 'random' measurements, which do not fall into the accumulation of measurements and, therefore, do not relate to the conjugated fractures, is conducted.

At the second stage, by grouping the available measurements the selection of conjugated fractures and classification of concrete measurements into systems is performed. The third stage is a period of obtaining values describing the statistical characteristics of conjugated fractures.

After that, through interpolation between the grid node points we create the broken lines which are smoothed with

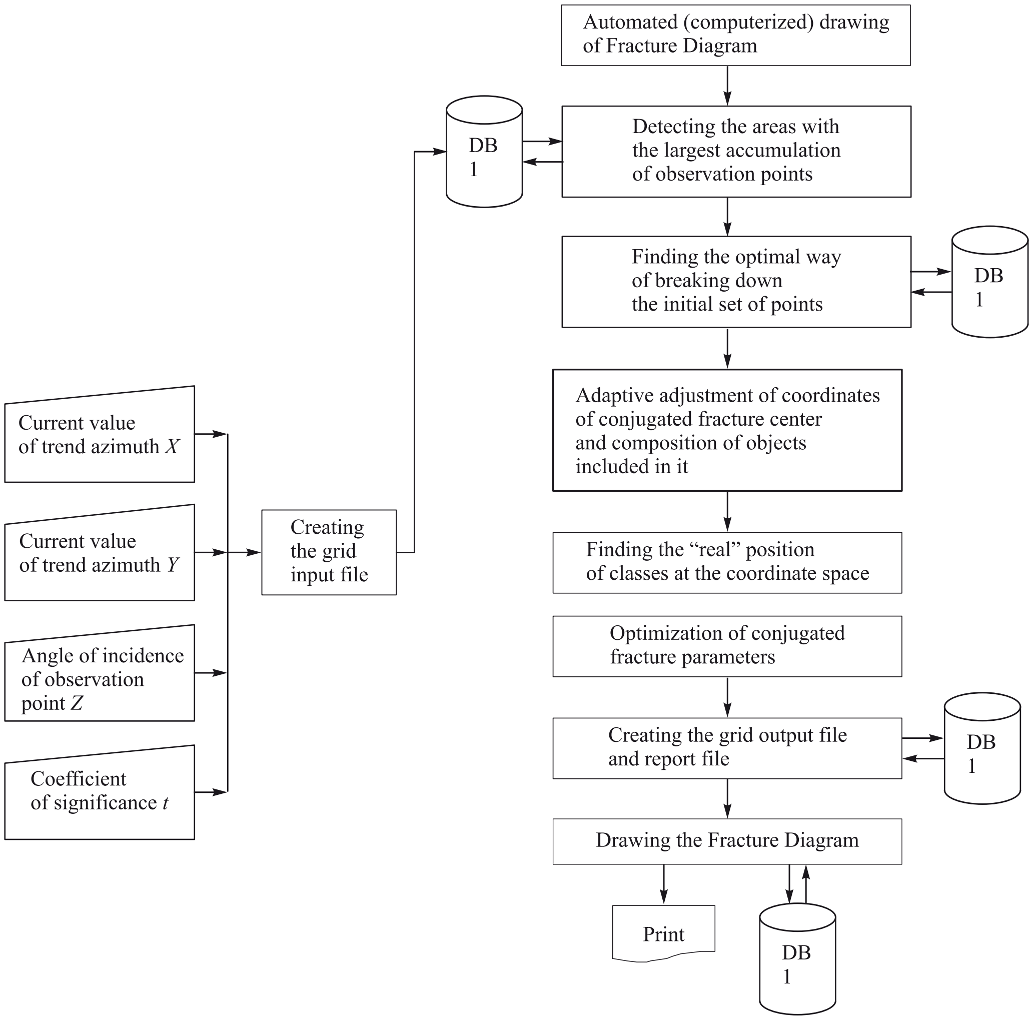


Fig. 5. Block Diagram for algorithm of automated methodologyfor Fracture Diagram drawing

the help of splines (curves which pass through all given density points). The complex is implemented with the help of the Golden Software Surfer 8.0 program. The Golden Software Surfer 8.0 program is intended for operations with geological, topographic maps and we used it for modelling structural features of rock massif.

Fig. 6 has a square diagram of fractures where the results are imaged in two ways: in isolines (Fig. 6, *a*) and in three-dimensional image (Fig. 6, *b*, *c*).

Thus, after automated (computerized) drawing of Fracturing Diagrams, it is defined that for *Akzhal* deposit the existence of 4 main conjugated fractures is characteristic, with the following average values of bedding elements (azimuth, angle of incidence): I (30, 55°), II (125, 81°), III (220, 75°) and IV (310, 89°).

The ‘diagram of fracture’ is used to enter the primary information measurements of cracking, their statistical processing, construction and printer output diagrams of fracture of the object of study for their subsequent interpretation and use to calculate the parameters of sustainable pit walls.

The modern level of development of science and technology involves the use modern research methods in the mining area which are based on applying computer technologies. There are a number of foreign software products that implement the three-dimensional modelling of deposits:

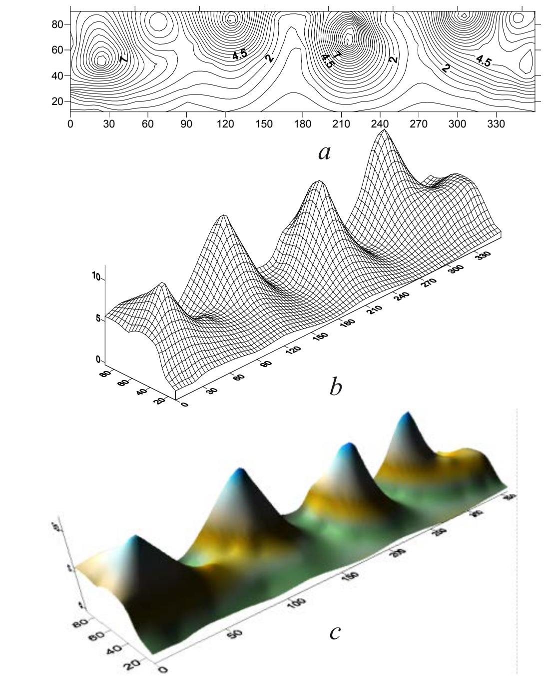


Fig. 6. Result Shape: *a – in isolines; b, c – in three-dimensional image*

DataMine (the United Kingdom), Techbfse (the USA), Surpac (Australia) and others [7–11]. Perfection of research methods lies in increasing number of necessary parameters, complicating the test models and their approximation to the actual mining and geological situation of the investigated field. A crucial step in this direction is transition to the three-dimensional modelling of deposits. Working with such models does not only allow solving technical mining tasks quickly, but also opens up broad prospects for researchers to use modern analytical and numerical methods.

Currently, 3D models of deposits are applied in specialized commercial software systems for a variety of mining tasks for mining operations (Fig. 7).

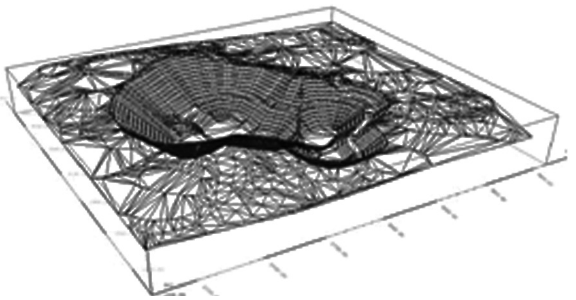


Fig. 7. 3D model of the quarry in the GEMCOM system

Three-dimensional modelling carries significant advantages for research in the field of geomechanics and geometrization of deposits:

- completeness of the analyzed data is closest to the actual mining and geological situations;
- there are possibilities to assess the relative influence of spatial elements of the model;
- development and application of geomechanical methods are possible, taking into account the volumetric distribution of loads;
- clarity and descriptiveness of the model allows revealing hidden problem areas and determining their parameters.

The initial data for modelling are the results of exploration, the primary operational and geological and graphical information. It can involve stratigraphic sections, data from wells, and the results of approbations, geological sections and horizontal plans.

Three-dimensional modelling of ore bodies for investigation the geomechanical situation was carried out in the *Akzhal* deposits (Fig.8). Taking into consideration the complexity of the issues and the advantages mentioned above, it was decided to create a digital three-dimensional model of the geological situation of deposits [4].

The first stage of modelling is to classify and primary processing of raw data, to select the necessary and sufficient volume of geological and graphic data and to bring them to a common format that allows for correct alignment.

The final stage of modelling was a three-dimensional approximation of the geometric parameters of the structural elements of the model. In this case, the analysis of their relative position and interpolation of contour forming, which creates a wireframe model of the ore bodies, was conducted (Fig. 9).

Fig. 8. Three-dimensional model of Vostochnyy quarry of Akzhal deposits

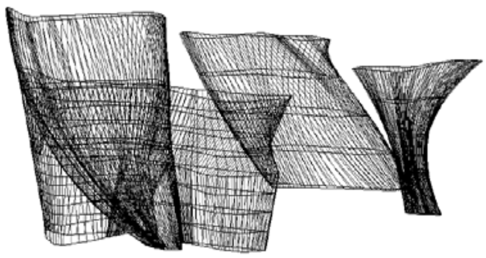


Fig. 9. Wireframe model of the ore bodies of the Central part of Akzhal deposit

Based on a wireframe model spatial triangulation is performed resulting in a three-dimensional surface of the ore bodies (Fig. 10).

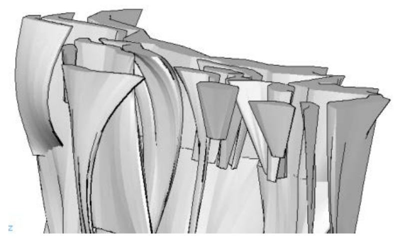


Fig. 10. 3D model of the surface of the ore bodies of the Central part of Akzhal deposit

Developing 3D models of deposits is a very relevant scientific and practical task, the successful solution of which depends on the efficiency of the mining companies on the basis of the widespread introduction and use of modern computer technology in solving mining-technical and mining-geometric problems [5].

Conclusions. As a result of the research, 3D digital models of ore bodies and the main geological elements of *Akzhal* deposits were obtained that allows integrating them into modern apparatus and program complex systems for solving urgent problems of mining.

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Структурні особливості масиву – один з найважливіших чинників, що визначають геомеханічний процес. Метод їх вивчення зводився, в основному, до безпосередніх вимірів в оголеннях на поверхні, на укосах у кар'єрах і гірських виробках, за допомогою гірського компаса. У даний час у практиці виконання маркшейдерсько-геодезичних робіт з'явилися сучасні електронні прилади, наприклад 3D сканер та інші. Використання лазерного сканера для зйомки тріщинуватості можливе при знаходженні приладу від прибортового масиву на відстані до 300 метрів. Одним з найважливіших переваг лазерного сканування є можливість отримання інформації про положення елементів залягання тріщин і розмірів структурних блоків без безпосереднього контакту виконавця робіт з масивом. Слід зазначити, що на залізорудних кар'єрах гірничим компасом неможливо здійснити зйомку, тоді як лазерний сканер з цим справляється успішно.

Мета. Розробка способу зйомки структурних особливостей гірських порід з використанням 3D сканера, що дозволяє скоротити час на проведення вимірювальних робіт і створювати тривимірні моделі рудних тіл з урахуванням структури.

Методика. Метод наземного лазерного сканування тріщинуватості гірських порід на кар'єрах, збір даних у режимі реального часу та обробка результатів на комп'ютері.

Результати. Розроблена методика наземного лазерного сканування для отримання даних про геометричні параметри кар'єрів, елементів залягання тріщин і розривних порушень.

Наукова новизна. Полягає в розробці нового способу зйомки структурних особливостей масиву на основі лазерного сканування, що дозволяє виконувати миттєву тривимірну візуалізацію результатів зйомки з високою інформативністю, точністю та продуктивністю знімальних робіт.

Практична значимість. Полягає у створенні 3D моделей елементів залягання тріщин, розривних порушень і рудних тіл з урахуванням структури.

Ключові слова: *геомеханічні процеси, структури масиву, тріщинуватість гірських порід, елементи залягання тріщин, лазерний сканер, 3D моделювання*

Структурные особенности массива – один из важнейших факторов, определяющих геомеханический процесс. Метод их изучения сводился, в основном, к непосредственным измерениям в обнажениях на поверхности, на откосах в карьерах и горных выработках, с помощью горного компаса. В настоящее время в практике проведения маркшейдерско-геодезических работ появились современные электронные приборы, например 3D сканер и другие. Использование лазерного сканера для съемки трещиноватости возможно при нахождении прибора от прибортового массива на расстоянии до 300 метров. Одним из важнейших преимуществ лазерного сканирования является возможность получения информации о положении элементов залегания трещин и размеров структурных блоков без непосредственного контакта исполнителя работ с массивом. Следует отметить, что на железорудных карьерах горным компасом невозможно произвести съёмку, тогда как лазерный сканер с этим справляется успешно.

Цель. Разработка способа съемки структурных особенностей горных пород с использованием 3D сканера, позволяющего сократить время на проведение измерительных работ и создавать трехмерные модели рудных тел с учетом структуры.

Методика. Метод наземного лазерного сканирования трещиноватости горных пород на карьерах, сбор данных в режиме реального времени и обработка результатов на компьютере.

Результаты. Разработана методика наземного лазерного сканирования для получения данных о геометрических параметрах карьеров, элементов залегания трещин и разрывных нарушений.

Научная новизна. Заключается в разработке нового способа съемки структурных особенностей массива на основе лазерного сканирования, позволяющего выполнять мгновенную трехмерную визуализацию результатов съемки с высокой информативностью, точностью и производительностью съемочных работ.

Практическая значимость. Состоит в создании 3D моделей элементов залегания трещин, разрывных нарушений и рудных тел с учетом структуры.

Ключевые слова: *геомеханические процессы, структуры массива, трещиноватость горных пород, элементы залегания трещин, лазерный сканер, 3D моделирование*

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