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SELECTION AND JUSTIFICATION OF DRILLING AND BLASTING PARAMETERS USING GENETIC ALGORITHMS

Purpose. Using experimental and theoretical studies to justify the rational location of charges of various types and their technological parameters in the fan, taking into account the physical and mechanical properties and structural features of the rocks in the mountain massif.

Methodology. In the experiments, an improved method of geostructural analysis of rocks was used to obtain detailed data on their properties, the block structure of the massif, and the type and direction of development of crack systems. Identification of crack systems, their density, intensity, and direction of development of crack systems is carried out on petrographic sections using microscopic analysis, these are used to calculate the average indicator of the cracking coefficient, while the funneling method – the anisotropy coefficient. The justification of the rational location and the number of charges in each fan was performed using the methods of genetic algorithms and the developed software product.

Findings. The coefficient of cracking and anisotropy of physical and mechanical properties of uranium ores was calculated, which was 78 cr/sm^2 and 1.4, respectively. According to the developed mathematical models and the software product, the optimization problem was solved using genetic algorithms, which determined the main priorities: the location of the charge in the fan according to the structure of the massif and the rational diameter of the well, which helps to limit the number of oversized blocks of reflected ore.

Originality. The regularities are established of the change in the anisotropy coefficient from the cracking coefficient, the nature of the distribution and the number of microcracks (cr/sm^2) in the quartz grains, which is present in uranium ore according to a linear law, and the output (in %) of oversized blocks during the destruction of uranium ore from the cracking coefficient – according to the polynomial law. For the first time, the optimal location and the number of charges in each fan, the diameter of the wells, taking into account the type of rock, its strength and fissure, and the geometric parameters of the ore deposit, were determined based on the constructed mathematical models and the developed software product.

Practical value. The indicated results of the experimental and theoretical studies will form the basis for the development and substantiation of rational parameters of resource-saving and seismically safe methods for breaking strong rocks of complex structure during the extraction of uranium and iron ores by the energy of the explosion in mines.

Keywords: *boreholes, solid medium, explosive, cracking, anisotropy, genetic algorithm*

Introduction. The effectiveness of the destruction of a solid medium of complex structure, which includes the uranium deposits of Ukraine, can be based on non-traditional technologies: thermal load, the impact of streams of high-energy particles, and others. But the blast has been and remains an effective way of preparing mining mass during underground mining of both iron and uranium ores. Conducting drilling and blasting operations (DBO) during the extraction of uranium ores should ensure sufficient volumes of mining mass for its processing, economic efficiency and environmental safety of conducting mining operations. It is possible to solve all these tasks only with a careful justification of the choice of rational parameters of blasting operations, which must take into account many factors. The set of necessary measures includes the following aspects of solving the problem: organization DBO, rational arrangement of charges of explosive substances in the massif of rocks, taking into account the anisotropy of physical and mechanical properties, its structural features and fissuring, substantiation and selection of the type of explosive that will be used in the charge of the explosive, etc. Their resolution will ensure a decrease in the output of crushed fractions and oversize, an increase in the extraction of minerals, thereby increasing the efficiency of DBO and reducing the negative impact on the environment. The latter acquires special importance when working out subsurface reserves of deposits in protected areas (residential and industrial infrastructure objects). That is, an important social and practical task that requires a response and effective decision-making is the development and implementation of modern seismically safe driving technologies for drilling and blasting operations.

As the latest studies [1] show, one of the effective means of managing rock crushing is the determination of the rational diameter blasthole and its location in a mountain massif of complex structure. Currently, there is no unified point of view regarding the methods for determining the diameter blasthole and geometric parameters of the location blasthole on the block (grill of borehole), and the development of models and methods that will make it possible to make a reasonable choice and control of these parameters is an urgent scientific and practical task.

Literature review. The issue of ensuring seismic safety is particularly acute at long-standing mining enterprises, where, due to the expansion of the boundaries of mining blocks of ore deposits, the ongoing mining operations are close to industrial and residential buildings and structures. At the same time, significant volumes of mining mass were removed from the subsoil from the massif located around the mining workings of the exploitation block, as the academician Shemiakin E.I. noted in his works (2005), is subjected to extremely high compressive stresses, which, depending on the depth, can reach 660 MPa. They contribute to the occurrence of mining shocks and man-made seismic disturbances (earthquakes) [2]. This is especially characteristic of deposits of iron and uranium ores, which are developed in Ukraine and are concentrated in deposits of a complex structure. In such arrays, horizontal stresses exceed the vertical component by 5 times. They have developed tectonics with intense fracturing, the coefficient of structural weakening of which is determined by the number of cracks in the rock massif per 1 m of its length and varies from 0.1 to 0.4. At the same time, physical and mechanical properties differ significantly when evaluating them in different areas of the deposit. They also include deposits that have occurrences under water masses with deposits of an

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underwater landslide structure, zones of fine tile stratification under industrial and civil structures. It should be noted that the efficiency of mining at such deposits largely depends on their structure, physico-mechanical properties of rocks and parameters of drilling and blasting operations, which take into account the blast concussion on protected objects [3]. This was confirmed in work [4], which analyzed the research of blast concussion and their destructive impact on urban and social development during the forging of upper horizons at depths of more than 330 m (using the example of the Central deposit of uranium ores, Kropyvnytskyi). And given that these massifs of ore bodies and rocks are anisotropic in their structure, difficulties arose during the development of these horizons due to different properties of the rocks, their structure and fissures and became decisive in the spread of seismic blast waves in different directions from the place of the blasting, both along the strike and across the strike of the ore deposit [5].

It should also be noted that deposits of a complex structure have a number of general features of genesis, confined to faults with a complex morphology of ore deposits in comparison with rocks of a homogeneous structure. Such features of the structure of the massif of rocks require the preparation of recommendations regarding the forecast and prevention of the manifestation of various forms of rock pressure during their development.

The development of computer technologies made it possible to develop models and methods of calculation and to substantiate the possible parameters of violations in underground and above-ground structures under the influence of seismic waves caused by underground blasting, the action of vibration and earthquakes. Studies have shown that when assessing the development of geomechanical and seismic processes during dynamic loading of a rock massif of a block structure [6], its structure should be considered as a system of nested blocks of different scale levels connected by layers consisting of weaker fractured rocks [7]. These features of the array must be taken into account in mathematical models. The dynamic behavior of the block environment can be described as the movement of rigid blocks due to the flexibility of the layers between them. The calculation model in this case can be a lattice array connected by springs and dampers. Within the framework of the two-dimensional model, a finite-difference solution to the problem of the dynamic impact on the surface of the blasthole of an elongated blasthole located in a block environment was obtained.

Taking into account the structure of the array, physical and mechanical characteristics, and its cracking allowed the authors of [8] to develop a mathematical model for substantiating the location of the charges in the block. But the developed model was not widely used in practice for adjusting seismically safe rational parameters of drilling and blasting operations when conducting mass blast at mines in areas with developed infrastructure.

A large number of theoretical [9] and experimental studies [10] conducted by scientists of scientific centers of Ukraine, near and far abroad [11] have been devoted to research on blast concussion effect on mining productions and objects of civil and industrial purpose with open [12] and underground geotechnologies [13]. The most common parameter, which is fixed experimentally and determined theoretically, is the speed of oscillations (shifts) in the massif in the area of the protected object [10]. However, it is known that the duration of exposure to various dynamic or other loads [14] on mining products and objects of civil and industrial purpose significantly affects the limit characteristics of strength [15], as well as the degree of deformation and destruction of rocks [16]. This is also characteristic of seismic blast waves [17].

In the work by the authors [18], considerable attention is paid to the study on the influence of the drill diameter on DBO and the analysis of existing methods for calculating the diameter of boreholes during DBO in quarries. According to these methods, this parameter was calculated based on all the known formulas for specific mining, geological and technological development conditions, and conclusions were obtained regarding the need for further research in this area, considering the dependence of the rational diameter of the drilling on specific conditions and properties of the rock. In work [1], it is stated that the issue of choosing the effective diameter of the charging chamber of an explosive substance for the destruction of rocky earth's formations in quarries has not been fully investigated, and therefore the existing calculation methods for the same conditions of drilling and blasting operations provide different values of diameters. The authors proposed a method for determining the most effective diameter of the charging chamber, which is based on the technical and economic evaluation of drilling and blasting indicators.

In work [19] it is stated that to substantiate the rational parameters of DBO, it is advisable to use mathematical and computer modeling tools, which will allow evaluating the results of blast action and optimizing the parameters of blasting operations.

Thus, the author of the paper [20] proposed a methodology for calculating seismically safe and optimal geometric parameters of the location of charging chamber in the block (grid of blastholes) and deceleration intervals when using the lower and upper detonators inside the charging chamber of explosives. These charges cross an array of rocks separated by a karst cavity, which allows for high-quality destruction of the karst arrays and reduction of oversized output.

During blasting operations, seismic blast waves excite the open surfaces of working and non-working ledges, sides of pits, mine workings, mining blocks in mines, industrial and residential buildings and structures located both on the surface and in the depth of the massif. A comparison of calculated and instrumental data given in the seismograms indicates that the actual duration of the pulse exceeds the calculated one by an average of 1.8 times. This indicates that after the front of seismic waves created during the blast action of the explosion in successively detonated groups charges of explosives with the largest amplitude, a front of waves with a smaller amplitude appears.

It follows from the above that the actual duration of the seismic impulse affects the process of deformation and the degree of destruction of objects. Therefore, to ensure the stability of objects, it is necessary to monitor and forecast the received seismic impulse indicators by adjusting parameters of the DBO for specific conditions of industrial zones of mining enterprises and for each project mass blast (MB).

Therefore, the development of new effective methods of DBO management, aimed at reducing its negative impact on surface objects and capital mining works that are under protection, increasing the intensity of mining, reducing oversize output and ore depletion, remain relevant at the present time. Such an approach will make it possible to reasonably consider the choice of rational parameters and spatial location of borehole (diameter, length, distance between borehole in the fan and between fans) in the operational block of the ore deposit and to adjust the parameters of drilling and blasting operations.

The work is carried out in accordance with the comprehensive program of the National Academy of Sciences of Ukraine for the development of atomic energy "Development of scientific foundations and improvement of methods and means of increasing the efficiency and safety of mining operations during the extraction of uranium ores" (State registration No. 0117U004231) and the agreement on scientific and technical cooperation between IGTM NAS of Ukraine and Dnipro University of Technology.

The purpose. Using experimental and theoretical studies to justify the rational location of charges of various types and their technological parameters in the fan, taking into account the physical and mechanical properties and structural features of the rocks in the mountain massif.

Materials and research methods. The choice of a rational technology for drilling and blasting operations at the existing mining enterprises of Ukraine, which ensures the optimal speed of underground workings, crushing and processing of minerals, is the main condition for the intensification of mining production [3] and its seismic safety [4].

One of the ways to improve the quality of drilling and blasting operations is the effective use of blasting energy due to more complete consideration of the structural features, physical and mechanical properties of the rocks being destroyed, as well as the parameters of blastholes (length, diameter), the design of explosive charges and their location in the massif

In order to solve the above problems, several stages of the research are envisaged.

At the first stage of the research, it is planned to carry out experiments in industrial and laboratory conditions to obtain detailed data on the properties of rocks of the block structure of the massif and the type and direction of the development of crack systems according to the methods of geostructural analysis of rocks. Sections are made on the selected geological exploration cores in laboratory conditions, from which petrographic slides are made. Then, using a digital camera, photography of petrographic sections is carried out. According to the obtained pictures, using the method of microscopic analysis, crack systems are identified, their density, and the intensity and direction of development of established crack systems are investigated, crack/sm^2, from which the average indicator of the cracking coefficient is calculated. Then the anisotropy coefficient is calculated based on the obtained parameters of the explosion crater – explosion crater radius, during detonation in a single blasthole of explosives in production or in a mining block. According to the obtained data of the coefficient of anisotropy and fissuring of rocks, the main priorities are determined – these are the technological indicators of destruction during the extraction of uranium ore.

The next stage of research included conducting computer modeling to justify the rational location of charges of various types and determining their technological parameters in the fan, taking into account the clarifying data on the properties of the rocks, the block structure of the massif, and the type and direction of the development of crack systems for the specific conditions of the uranium ore deposit.

To implement this stage of the research, mathematical models were developed using the genetic algorithm method, a software product for solving the tasks and conducting computer simulations in the test mode with the analysis of the obtained results.

Research results and their discussion. ***Experimental studies on the justification of the place of laying and adjustment of the grid of location of blastholes in the block, taking into account the structural and physical and mechanical properties of rocks.*** To solve the problems related to the justification of the location of blasthole in the block, experimental studies were carried out on the adjustment of the location grid of well charges in the operational block based on taking into account the microcracks of the collapsing rocks and the anisotropy of physical and mechanical properties.

For this purpose, in areas of drilling with a machine tool NKR-100M, exploration wells are drilled with a diameter of 75–100 mm, the selection of cores is carried out with the help of a core selector, for example, EZY-MARK^{TM}. Sections are made on the selected geological exploration cores in laboratory conditions, from which petrographic slides are made. Next, using a microscope, for example, MP-2, ПОЛАМ, MIN-8 with an increase in 240′ and 600′ and a digital camera, photography of petrographic sections in A4 format is carried out and deciphered. Based on photographs, the identification of crack systems, their density, and the intensity and direction of development of crack systems in crack/sm^2 in the horizontal and two vertical planes of the petrographic section are investigated. Based on the obtained results, the average indicator of the cracking coefficient is calculated according to the expression

$$K_{cr.med} = (K_{cr1} + K_{cr2} + K_{cr3})/3,$$

where K_{cr1} is intensity of microcracking in the horizontal plane; K_{cr2} and K_{cr3} are the intensity of microcracking in the vertical plane, respectively. Then, in order to calculate the anisotropy coefficient, in the same area of the production or mining block several holes are drilled with a diameter of 43 mm and a depth of 1.0–1.5 m, charged industrial explosive cartridge and detonated. According to the obtained parameters of the explosion crater – the radius of the explosion crater, namely – the major and minor axes of the explosion crater (crater of destruction), the anisotropy coefficient is calculated from the ratio $K = a/b$, where: a and b are the major and minor axes of the explosion crater (crater of destruction), accordingly. The calculations showed that for rocks that have granites in their structure, the average coefficient of microcracking was $K_{cr.med} = 78$ racks/sm^2, which corresponds to the anisotropy coefficient, equal 1.4.

According to the studies carried out by Kratkovskyi I. L. (1984) and other researchers found that the spatial distribution of quartz and its defects in granites and other rocks that have quartz in their structure performs the role of "cement", which contributes to the change in the direction of the crystal lattice during deformation under the action of tectonic forces and thereby the intensity of the propagation of microcracks in quartz grains. These changes in quartz are spatially related to anisotropy coefficient by corresponding dependence on intensity of microcracks in quartz grains, which were processed by correlation analysis, the regression equation of which is $K_{anisotr.} = 0.0052K_{cr} + 0.9954$ (Fig. 1).

Based on the experimental research and practice results on the influence of the structure of the rock massif and the technological parameters of the DBO on the indicators of crushing of the rock mass by the energy of the explosion, which were systematized by N. H. Dubinin (1968), which were used to calculate the effect of rock mass fracturing on rock mass yield per 1 m of well (Fig. 2, *a*) and oversize (%) (Fig. 2, *b*) at different well diameters, which were processed by correlation analysis and regression equations and determination coefficient for the first option were obtained – $y = -7.979x^3 + 37.613x^2 - 39.738x + 21.063$; $R^2 = 0.9972$, for another $2.2458x^3 - 9.3372x^2 + 7.8834x + 7.9667$; $R^2 = 0.9499$.

The data obtained above made it possible to adjust the borehole patterns in the block for the destruction of ore deposits. Thus, the adjusted grid of borehole charges without localization of blast energy was 1.15 × 1.9 m, while the distance between rows of boreholes is 1.15 m, and between boreholes is 1.9 m. Another option is when we have localization of blast energy in a block that collapses, in the places where the cut is located, then the pattern has the following dimensions: 1.2 × 1.95 m with the distance between the rows of boreholes equal 1.2 m, and between boreholes in a row – 1.95 m.

Modeling to substantiate the rational parameters for drilling and blasting operations for the removal of uranium ores. *Formulation of the problem.* According to the technology of drilling and blasting operations, charges are formed in boreholes, which are grouped in fans and drilled in a massif of rocks of different strength and fissures. The diameters of the boreholes used are from 46 to 150 mm, the line of least resistance (LLR)

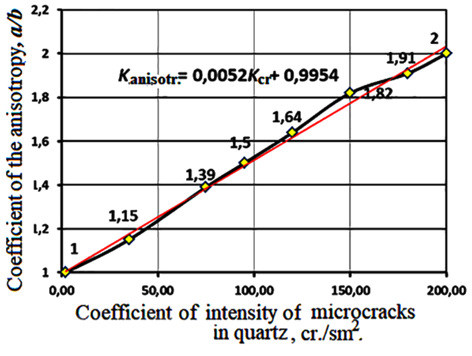
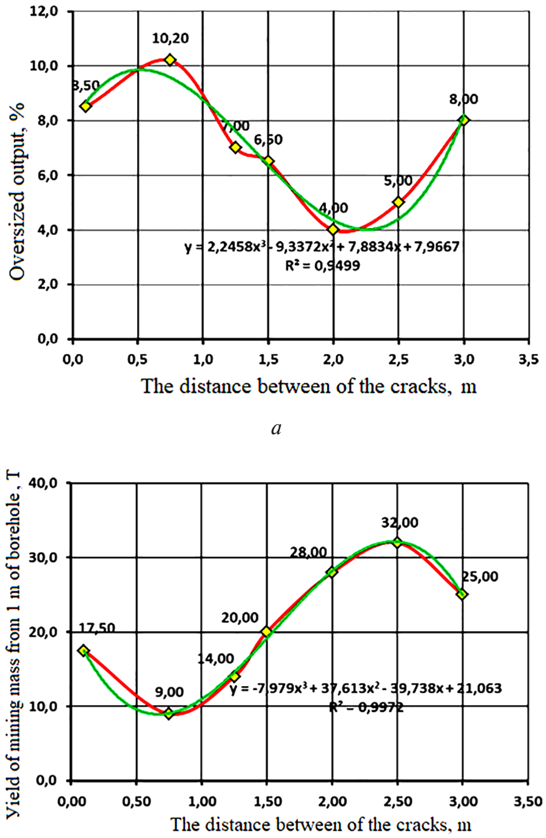


Fig. 1. Dependence of the anisotropy coefficient on the intensity of the development of microcracks (cr/sm^2) in quartz grains



a

b

Fig. 2. Typical dependences of the influence of rock mass fracturing on the output of oversized fractions (*a*) *and rock mass from the* 1^{st} *m of the borehole* (*b*) *at different borehole diameters*

is from 1.02 to 1.8 m, and the distance between the ends of the boreholes in a row is from 1.8 to 2.5 m.

The output of ore from 1 m of borehole in each fan and the percentage of output of oversized pieces when detonating charges in the boreholes were confirmed experimentally in industrial conditions and systematized by N. H. Dubinin (1968).

Thus, depending on the diameter of the charge, the strength and fissuring of the ore, its production volumes and the amount of obtained oversize change. The efficiency criteria were chosen as the total output of ore from 1 m of the borehole in each fan, taking into account the fissuring of the rock and the percentage of the output of oversized pieces when detonating charges in the borehole. In addition, the technology of drilling and blasting operations during the development of uranium ore deposits requires ensuring the seismic safety of protected objects. Therefore, there is a limit on the maximum weight of explosives for one blast according to DSTU 4704:2008 and DSTU 7116:2009 [21, 22].

It is necessary to determine the optimal geometric parameters (from the point of view of the selected criteria) of the location of blasthole (grill of borehole), the number and type of charges in each fan, taking into account the type of rock in terms of strength and fissures and restrictions on seismic safety.

To solve the problem, we will build mathematical models of accommodation.

For the purpose of simplification, three types of rocks by strength factor were considered: of medium strength, strong and very strong rocks and four types of wells for rocks of medium strength and strong rocks and two types for very strong rocks. To determine the main priorities – technological indicators of the destruction of minerals during the extraction of uranium ore, we will use the known data of practice, which are selected and grouped by N. H. Dubinin (1968) into a separate category of indicators (Table 1).

Construction of a mathematical model. Assume that it is known:

1. $\rho(x)$ fracture or other characteristic that describes the properties of the rock, such as the average distance between cracks at a point x.
2. $V(m, \rho)$ Output of ore from a 1 m borehole for a breed that has a characteristic ρ and charge mass m.
3. $g(m, \rho)$ – the percentage of oversized pieces, which is obtained when using a mass charge m for the rock with a characteristic ρ.
4. $d(\rho)$ the minimum permissible distance between charges for the rock with a characteristic ρ.
5. The boreholes in the fan are located along one line and their location is described by one coordinate.

Let us introduce the following notations: τ_i – location coordinate of the $i^?$ borehole; m_i – mass explosives in borehole i, $i=\overline{1,n}$; C – the maximum allowed mass explosives for one deceleration; a_i and b_i – maximum and minimum charge mass in the borehole i, $i=\overline{1,n}$.

Then the total yield of ore from 1 m of all boreholes can be described as follows

$$F_1((\tau_1,m_1),(\tau_2,m_2),\ldots,(\tau_n,m_n))=\sum_{i=1}^{n}V(m_i,\rho(\tau_i)),$$

and the total number of oversized pieces – using the following function

$$F_2((\tau_1,m_1),(\tau_2,m_2),\ldots,(\tau_n,m_n)))=\sum_{i=1}^{n}g(m_i,\rho(\tau_i)).$$

Given the technological requirements, we will introduce the following restrictions:

- in relation to the total mass of explosives in one fan for one deceleration

$$\sum_{i=1}^{n}m_i\le C,$$

where $a\le m_i\le b$ – in relation to the mass of explosives in one borehole; $|\tau_i-\tau_k|\ge d(\rho(\tau_i))$, $i\ne k$ $i,k=\overline{1,n}$ – regarding the minimum permissible distance between boreholes, depending on the type of rock and the diameter of the borehole.

Thus, we have the following task:

Task 1

Table 1

The main technological indicators of the destruction of ore deposits by the energy of the blast

Indexes	Ores of medium strength			
The diameter of the borehole, mm	46–59	60–80	100–130	150
Output of ore from a 1 m borehole, t	5–7	15–20	20–70	25-75
Outsize output, %	5–12	6–13	12–40	5–21
Indexes	The ores are strong			
The diameter of the borehole, mm	46	60–80	100–130	150
Output of ore from a 1 m borehole, t	5–6	6–12	16–50	16–40
Outsize output, %	10–13	7–23	5–45	7–20
Indexes	The ores are very strong			
The diameter of the borehole, mm	100–130	150	–	–
Output of ore from a 1 m borehole, t	15–36	20–30	–	–
Outsize output, %	7–25	9–20	–	–

$$F_1((\tau_1,m_1),(\tau_2,m_2),\ldots,(\tau_n,m_n))=\sum_{i=1}^{n}V(m_i,\rho(\tau_i))\rightarrow\max; \qquad (1)$$

$$F_2((\tau_1,m_1),(\tau_2,m_2),\ldots,(\tau_n,m_n)))=\sum_{i=1}^{n}g(m_i,\rho(\tau_i))\rightarrow\min, \qquad (2)$$

with restrictions

$$\sum_{i=1}^{n}m_i\le C; \qquad (3)$$

$$a_i\le m_i\le b_i; \qquad (4)$$

$$\left|\tau_i-\tau_k\right|\ge d(\rho(\tau_i)),\quad i\ne k,\quad i,k=\overline{1,n}. \qquad (5)$$

The proposed model assumes that the total number of wells n is a predetermined value. As a result of solving the problem, the coordinates of the location of the boreholes and the charge (mass of explosives) in each well will be determined. The charge (mass of explosives) in each borehole depends on its diameter and is limited by values a_i, b_i, which are constant for each type of borehole.

Note that ***Task 1*** is a continuous placement task [23]. The dependencies necessary for its full description are usually not analytically defined. They are obtained experimentally at some points of the area and, as a result, the necessary characteristics are known only in the form of tabular functions, and analytical dependencies can be obtained as a generalization of these data.

One of the ways to solve this problem is to switch to a discrete model [8]. One of its variants was proposed by the authors in [24], but, on the one hand, this leads to a large-dimensional problem, and on the other hand, it limits the area of possible boreholes placement points to a predetermined set [25].

Another mathematical model can be obtained under the assumption that the geometric parameters of blastholes (length, diameter) are defined. For example, in the conditions of this study, we have 4 types of wells used for rocks of medium strength and strong and two for very strong rocks. We also believe that the mass of explosives depends on the parameters of the blasthole and is constant for this type of rocks.

To build the model, we denote: x_{ij} – the number of boreholes of type i located in the rock block of type j, v_{ij} – Output of ore from a 1 m borehole of type i, placed in the rock block of type j; g_{ij} – percentage of oversized pieces from the borehole of type i placed in the rock block of type j, $i = 1, 2, \ldots, n$, $j = 1, 2, \ldots, m$; m_i – mass of explosives in borehole of type i, $i = 1, 2, \ldots, n$; d_{ikj}– the minimum permissible distance between boreholes i, k, depending on the type of rock and borehole $i,k=\overline{1,n}$ $j = 1, 2, \ldots, m$; n – the number of types of boreholes, m – the number of types of rocks, G – the maximum permissible level of oversized pieces (%), C – the maximum allowable mass of explosives for one deceleration.

Then the mathematical model can be described as follows.

Task 2.

$$F(x_{11},x_{12},\ldots x_{nm})=\sum_{i=1}^{n}\sum_{j=1}^{m}x_{ij}v_{ij}\rightarrow\max; \qquad (6)$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m}x_{ij}g_{ij}\le G; \qquad (7)$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m}x_{ij}m_i\le C; \qquad (8)$$

$$\left|\tau_i-\tau_k\right|\ge d_{\text{з}kj},\quad i,k=\overline{1,n},\quad j=1,2,\ldots m; \qquad (9)$$

$$x_{ij}\ge 0,\quad i=1,\,2,\ldots,n,\quad j=1,\,2,\ldots,m.$$

Here, the objective function (6) describes the requirement to maximize the total production, constraint (7) is a constraint on the output of oversize, (8) is a constraint on the maximum mass of explosives for seismic safety, which can be detonated in one fan according to DSTU 4704:2008 and DSTU 7116:2009 [21, 22]. (9) – correspond to the technological conditions of the location of charges depending on the type of charge and species.

In this study, the authors proposed to use a genetic algorithm to solve ***Task 2.***

Development of a software product, computer simulation for solving Task 2 and analysis of the results. The main difference between genetic type algorithms and others is that based on initial assumptions about admissible solutions, a population is created – a certain set of possible solutions to the task. New solutions are formed through mutation, as in natural genetics, and the process can be repeated for many generations until a stopping criterion is reached or when the maximum number of generations is reached. At the same time, each solution is assigned a fitness function value, and those vectors with a higher fitness function value accordingly have a greater chance of being selected to create a new solution through crossover, similar to the survival of the fittest evolution mechanism. When the algorithm completes its work, we have some set of sufficiently good solutions, among which the best one is chosen.

The advantages of genetic algorithms are that they:

- do not require background information that may not be available for many real-world problems;
- are faster and more efficient compared to many traditional methods;
- can be applied for optimization of both continuous and discrete functions, as well as for multi-objective task;
- provide a list of “good enough” solutions, not just one optimal solution;
- receive a solution to the problem, which improves over time;
- can be applied even when the search space and the number of parameters are large.

The limitations of the genetic algorithm include:

- significant computational complexity. Since the algorithm requires multiple computations of fitness functions for certain problems, this can turn out to be a significant increase in computational complexity;
- there are no guarantees of optimality of the obtained solution or assessments of its quality.

The following assumptions were made to solve the given problem using a genetic algorithm:

1. Each fan was represented as a collection of sections of known length, with the rock type remaining constant in each section.
2. After determining the optimal charge for a given type of rock, they are located on the site in accordance with the technological conditions (constraint (9) and the optimization criterion.

According to the above assumptions, 4 types of charges can be used for medium-strength and strong rocks and two types for very strong rocks. Therefore, we will describe the solution of the problem in the form of a vector consisting of 10 elements. The first four are responsible for the rock of medium strength, 5–8 for strong rocks and 9, 10 – for very strong rocks (Fig. 3).

Each element of the vector means the number of charges of a given type that will be placed on a given section of the block. For example, the vector (0 0 2 0 0 1 1 0 0 1) means that 2 charges of the third type will be placed on a site with medium-strength rock, 1 charge of the second type and one of the third type will be placed on a site of strong rock, and on a site of very strong rock – one charge of the second type.

The fitness function is built according to the selected optimization criterion. In this study, three types of criteria were considered: the total mass of ore recovered from 1 m of the borehole (1); total percentage of oversized pieces (2); a generalized criterion that takes into account both of these indicators.

Through the fitness function, the technological limitations of the task can also be taken into account. Mutation during the implementation of the algorithm is carried out randomly, but in order not to lose the best solutions because of it, the system of “elitism” was applied, i. e. the algorithm was implemented

	Rocks of medium strength				Strong rocks				Very strong rocks	
The diameter charge, mm	46	60	100	150	46	60	100	150	100	150
No. of element	1	2	3	4	5	6	7	8	9	10

Fig. 3. Solution vector scheme

in such a way that the first ten vectors necessarily made it to the next generation.

The developed software product for calculations using the genetic algorithm provides the following capabilities:

1. Changing the parameters of the task: the length of the section and the type of rock, the properties of the charge, the value of the amount of mined ore, oversized pieces and the mass of the charge, the size of the zone of effective action of the charge.
2. Adding new model properties.
3. Setting the parameters of the genetic algorithm, namely the probability of mutation; the size of the population, the maximum number of generations, the number of the best “elitism” candidates.
4. Selection of visualization parameters: size and color of each type of charge, size and color of each type of rock, size of the visualization area.
5. Obtaining analytical data: program running time, best result, viewing every vector from the population, even those with zero fitness function.

Conducting numerical experiments. Numerical experiments were conducted using the developed software in order to study the influence of criteria and restrictions on the location of charges.

The results of the experiments are presented in Table 2, and as an example of the arrangement of charges in fan on block – Fig. 4.

Experiments 1, 2 differ in the presence of a limit on the number of oversized pieces. As can be seen, the absence of this restriction leads to a change in the type of charge and to an increase in the total amount of mined ore, but at the same time the amount of oversize also increases. In these experiments, limitations on the total mass of the charge were not taken into account.

Experiments 3, 4 differ from *1* and *2* in a different configuration of the fan, while in *experiment 3* there is a limitation on the mass of the charge, and in the fourth there is no such limitation. As can be seen from the results of the experiment, the presence of this limitation leads to a decrease in the total amount of mined ore, while the proportion of oversized pieces also decreases, but to a small extent.

Now, let us consider the problem of optimal placement of charges for three fans, the total length of which is 80 meters. The placement scheme is shown in Fig. 5, and the numerical data in Tables 3, 4.

The execution time of the program in all three cases was 1 minute 9 seconds, to ensure the best result, the program ran up to the maximum number of generations available, i. e. 50.

The best result was obtained with the given fan sizes, taking into account the permissible number of oversized pieces of rock. The amount of ore struck in the first fan is 261 tons and the percentage of oversized pieces is 0.19904. The amount of ore struck in the second fan is 272 tons and the percentage of oversized lumps is 0.19264. The amount of ore recovered in the third fan is 249 tons and the percentage of oversized lumps is 0.19722.

So, the total amount of ore removed by three fans is 782 tons, with the percentage of oversized pieces – 0.1963. It should be noted that even with the same distance between the borehole in the first and second fans in ores of medium strength, the configuration of the location of different types of changes in order to achieve the set limit on oversized pieces of rock.

Development of the scheme of the sequence of initiation of charges explosives in the fan. Using the data from the results of

Fig. 4. Scheme of the arrangement of charges for the model without taking into account the limitation on the mass of the charge

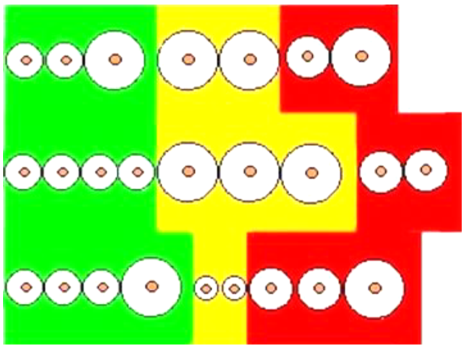


Fig. 5. Visualization of the solution of the sequential calculation of three fan configurations

Table 2

Results of numerical experiments

Experiment		1	2	3	4
The size of the rock sections in the fan (of medium strength; strong; very strong), m		(20; 20; 20)	(20; 20; 20)	(12; 4; 10)	(12; 4; 10)
Limitation	Share of oversized pieces	0.2	–	0.2	0.2
	total mass of charges, kg	–	–	800	–
Solution		(0 3 0 3 0 0 0 5 1 4)	(0 0 4 2 1 0 6 0 6 0)	(0 1 0 2 2 0 0 0 0 2)	(0 3 0 1 2 0 0 0 2 1)
Amount of ore recovered, t		641	952	242	249
The obtained share of oversized pieces		0.19976	0.35	0.1969	0.1972
Total mass of charges, kg		–	–	772	892
Algorithm execution time, s		33	13	5	5
The number of passed generations		23	9	3	3
Population size		2000	2000	2000	2000
Probability of mutation		0.9	0.9	0.9	0.9

Table 3

The result of solving three fan configurations

Rock	Ores of medium strength, mm				Strong ores, mm				Very strong ores, mm	
Charge type	46.0	60.0	100.0	150.0	46.0	60.0	100.0	150.0	100.0	150.0
The first fan	0	2	0	1	0	0	0	2	1	1
The second fan	0	4	0	0	0	0	0	3	2	0
The third fan	0	3	0	1	2	0	0	0	2	1

Table 4

Analytical data of the sequential solution three fans

Algorithm execution time	1 minute 9 seconds
The number of passed generations	50
Population size	2000
Probability of mutation	0.9
The amount of mined ore (first, second, third fan), t	261, 272, 249
Limiting the total number of oversized pieces	0.2
Percentage of oversized pieces	0.1963
The size of the rock sections in the fan (of medium strength; strong; very strong), m	(10; 8; 7); (10; 13; 6); (12; 4; 10)

numerical experiments, we obtain a detailed scheme of sequence of initiation of charges explosives in three fans, each of which has a different configuration of location of rocks of different strength in the block and type of charges, which is shown in Fig. 6.

Based on the results of the studies carried out to substantiate the scheme and location of the blasthole in the block, the design of the borehole charge, we have developed a resource-saving and seismically safe method for reflecting rocks in the ore deposit [26].

Industrial tests of the rational parameters of drilling and blasting operations of the developed method were carried out during mass blast in the operating block 1b-1-1 m of the "Inhulska" mine of the Central field of the State Enterprise "East HZK".

During the mass blast, measurements were made of seismic vibrations of the day surface at objects under protection, which did not exceed the safe level of soil vibrations according to the National Standard DSTU 4704:2008 and DSTU 7116:2009 [21, 22].

Due to the improvement in the operation of the charges explosives in the fans for the destruction of the ore deposit in the block, the proposed method ensures increasing the uniformity of the crushing of strong rocks, reducing the demineralization of ore, the seismic safety of drilling and blasting operations in territories with developed infrastructure and, as a result, reducing the specific consumption of explosive materials (EM), raising the efficiency of the blast, the productivity of crushing and sorting complexes and freight vehicles.

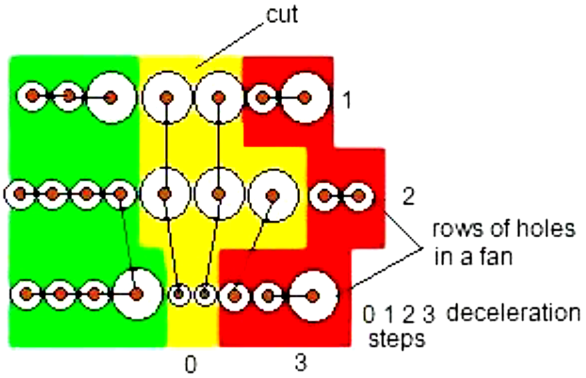


Fig. 6. Placement scheme and sequence of initiation of charges of explosives with deceleration: 0; 1; 2; 3

Conclusions. Conducting numerical experiments made it possible to implement a systematic approach to the solution of the task of multi-criteria selection and justification of the parameters of the borehole charge, its type and design, its placement in the massif of rocks, taking into account the limitations. These limitations were determined by conducting experimental studies on samples of rocks selected from the ore deposit, which determined the nature of the propagation of microcracks, calculated the coefficient of cracking and anisotropy of the physical and mechanical properties of uranium ores, which was 78 cr/sm^2 and 1.4, respectively.

Mathematical models and a software product were developed, according to which the optimization of the task was solved using genetic algorithms. The analysis of the conducted numerical experiments made it possible to determine the main priorities: the influence of the structure of the massif, fracturing, physical and mechanical properties of the rocks, their distribution in the area where the ore is crushed, the location of the charge in the fan and the rational diameter of the blasthole, limiting the number of oversized pieces in the crushed mining mass (uranium ore).

As a result of the study, it became clear how a change in the size of the area and the type of rock can affect the choice of the design of the charge in order to satisfy the set restrictions on the maximum mass of explosives in the charges or on the number of oversized pieces of crushed mining rock.

The analysis of the results of solving the task shows that with the help of a genetic algorithm it is possible to study the results of the influence of restrictions on the resulting placement scheme and the choice of the design of the charge with the corresponding parameters of blastholes. This makes it possible to obtain analytical data and increase the validity of the decision regarding the location and design of the charge for their application in specific mining and geological conditions of the ore deposit.

Based on the results of the studies carried out to substantiate the scheme and location of the blasthole in the block, the design of the borehole charge, we have developed a resource-saving and seismically safe method for reflecting rocks in the ore deposit. Industrial tests of the rational parameters of drilling and blasting operations of the developed method were carried out during mass blast in the operating block 1b-1-1 m of the "Inhulska" mine of the Central field of the State Enterprise "East HZK".

Tests have shown that due to the improvement of the operation of the charges explosives in the fans for the destruction of the ore deposit in the block, the proposed method ensures increasing the uniformity of crushing strong rocks, reducing the demineralization of ore, the seismic safety of drilling and blasting operations in territories with developed infrastructure and, as a result, reduction in the specific consumption of explosive materials (EM), raise in the efficiency of the blast, the productivity of crushing and sorting complexes and freight vehicles.

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Вибір та обґрунтування параметрів буропідривних робіт методом генетичних алгоритмів

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Мета. Експериментальними й теоретичними дослідженнями обґрунтувати раціональне місце розташування зарядів різних типів і їх технологічні параметри у віялі з урахуванням фізико-механічних властивостей і структурних особливостей порід у гірському масиві.

Методика. В експериментах використано удосконалений метод геоструктурного аналізу гірських порід по отриманню уточнюючих даних щодо їх властивостей, блокової структури масиву й типу та напрямку розвитку систем тріщин. На петрографічних шліфах методом мікроскопічного аналізу проведена ідентифікація систем тріщин, їх густину, інтенсивність і напрямок розвитку систем тріщин, за якими розраховують середній показник коефіцієнту тріщинуватості, а коефіцієнт анізотропії – методом воронкоутворення. Обґрунтування раціонального місця розташування й кількості зарядів у кожному віялі виконані методами генетичних алгоритмів і розробленого програмного продукту.

Результати. Розраховано коефіцієнт тріщинуватості та анізотропії фізико-механічних властивостей уранових руд, що склав 78 тр/см^2 і 1,4 відповідно. Відповідно до розроблених математичних моделей і програмного продукту виконані рішення оптимізаційної задачі з використанням алгоритмів генетичного типу, за якими визначені основні пріоритети: розташування заряду у віялі згідно зі структурою масиву та раціональний діаметр свердловини, що сприяє обмеженню кількості негабаритних блоків відбитої руди.

Наукова новизна. Полягає у встановленні закономірностей зміни коефіцієнту анізотропії від коефіцієнту тріщинуватості, характеру розподілу й кількості мікротріщин (тр/см^2) у зернах кварцу, що присутній в урановій руді за лінійним законом, а вихід (у %) негабаритних блоків при руйнуванні уранової руди від коефіцієнту тріщинуватості – за поліноміальним законом. Уперше за побудованими математичними моделями та розробленого програмного продукту визначені оптимальні місця розташування й кількість зарядів у кожному віялі, діаметр свердловин з урахуванням типу породи, її міцності та тріщинуватості, геометричних показників рудного покладу.

Практична значимість. Зазначені результати експериментальних і теоретичних досліджень становитимуть основу для розробки та обґрунтування раціональних параметрів ресурсозберігаючих і сейсмічно безпечних способів відбійки міцних гірських порід складної будови при видобутку уранових і залізних руд енергією вибуху на рудниках.

Ключові слова: *свердловина, тверде середовище, вибух, тріщинуватість, анізотропія, генетичний алгоритм*

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