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Automated determination of rock crushing zones in the collapse

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Abstract

Purpose. Development of an automated method for determining the zones of rock crushing in the collapse in order to select rational technologies for drilling and blasting operations.

Methods. Methods for determining the positions of nodal and internal points of the coordinate grid of blasted rock collapse, approximation methods, matrix theory, numerical methods in technology are used.

Findings. An automated method for determining the zones of rock crushing in the collapse is described. It is based on an analytical method for determining the granulometric composition of blasted rocks in zones of active and passive crushing. The meth-od correlates the granular composition of the blasted rock mass with blockiness of the rock mass, physical and mechanical properties of the blasted rocks, physical and chemical characteristics of the explosive used, and parameters of charge location in the rock mass.

Originality. Based on the joint application of methods for determining the nodal and internal points of the coordinate grid and calculation of rock crushing zones in the blasted block, an analytical method for determining the sizes of rock crushing zones in the collapse was developed for the first time in mining.

Practical implications. On the basis of the developed method, a computer program was created for the automated determination of the crushing zones sizes of a blasted block. With the help of this program, zones of small, medium and large crushing of the blasted block can be quickly and fairly accurately determined under various parameters and conditions of blasting rock masses. Locations of the blasted block crushing zones thus established serve as a tool for choosing rational technologies of drilling, blasting, excavating and loading operations, which determines their practical value.

Keywords: *blockiness, granular composition, D&B parameters, crushing zones, collapse*

1. Introduction

Predicting the placement of dissimilar rock ledges in the collapse of blasted rocks is extremely important in mining. It is relevant when mining complex structural rock ores, when shipping rocks of various lumpiness from different zones of collapse. Establishing the internal structure of blasted rocks will make it possible to reasonably choose rational technologies for drilling, blasting, excavating and loading operations and increase the efficiency of open development of multi-component, complex structural deposits.

The formation of the collapse of the blasted rocks obeys the laws arising from the model of the phased destruction of the rock mass by the explosion of explosive charges (EX) [1]-[3]. According to this model, the main destruction of rocks occurs in the first stage of an explosion under the influence of stress waves excited in the medium by an explosive charge explosion, and the gaseous products of the explosion themselves. In the second stage of the explosion, the whole fragmented rock mass ejected by the explosion products in the space occupies a position determined by the specific value of the initial speed of the beaten off part of the ledge. It depends on the physicomechanical properties of the rocks of the blasting block, the physicochemical characteristics of the explosive used, and the location parameters of the explosive charges in the explosive mass. In the third stage, the ejected rocks are sagged of the crushed part of the ledge in the field of gravity and a blasted rock mass is formed. The fixed elements of the blasting block in the collapse occupy the positions determined by the initial data of a specific mass explosion. Such an approach to the mechanism of rock destruction by an explosion is used in the works of scientists from near and far abroad.

According to N.Ja. Repin [4] the intensity of explosive crushing of rocks is determined primarily by the parameters of crushing zones formed around the charges, as well as the degree and uniformity of saturation of the massif with crushing zones. B.N. Kutuzov [5], V.M. Komir [6] in their works describe in detail the various stages of the impact of detonation waves, stress waves and gaseous detonation products. It also describes the processes and causes of the formation of crushing and cracking zones.

E.I. Efremov et al. [7] present calculations on the impact of an explosive explosion in the near zone, in the destruction zone, and describe the process of converting the explosion

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energy into the mechanical energy of crushing. It is noted that the determination of the zone of rock crushing under the action of an explosion of a cylindrical explosive charge is one of the most important characteristics of the destruction process, which is necessary to justify the applied blasting parameters.

A.N. Khanukaev [8] shares the character of the explosive explosion in the rock depending on its acoustic hardness. It affects the degree of impact of the energy of the shock wave, stress waves on the destruction of the rock.

In the works of K.N. Trubetskoy, V.V. Adushkin, S.D. Viktorov et al. [9]-[11], along with various types of explosive impact on rock, such as high-explosive or blasting, the influence of the mechanical characteristics of the state of the massif on the destruction of the rock is shown.

In the works of F.I. Galushko, A.V. Dugatsirenov et al. [12]-[14] emphasized the importance of determining the optimal parameters of drilling and blasting, which improves the quality of crushing and reduces costs in the extraction of solid minerals. Wei-Gang Shen [14][15] presented a numerical simulation of the impact on rock by the discrete element method (DEM). The results allow us to state that the impact loading rate directly affects the degree of rock crushing.

L.X. Xie, H.M. An, J.K. Furtney, Z. Mao et al. [16]-[19] apply modern numerical methods for modeling the explosive destruction of rocks. Various hybrid finite element methods are used, which in one way or another are consistent with theoretical and empirical data.

However, in the above works, little attention is paid to the distribution of pieces of rocks of various sizes in the collapse of the blasted rock mass. It is known that it has a strong influence on the productivity of mining and loading equipment. In connection with the stated urgent task of mining science and production is the establishment of the granulometric composition of the blasted rock mass and its placement in the collapse of blasted rocks.

The purpose of the article is the analytical determination of the sizes of various zones of crushing rocks in the collapse of blasted rock mass and the development of a computer program for its implementation.

2. Initial data and results of mass explosions of borehole charges

The initial data of a mass explosion: the dimensions of the blasted rock mass block: length (L), width (B), height (h); structural characteristics of the mass (fracturing, particle size distribution of natural particles in the massif [$p(x_1)$, $p(x_2)$,…$p(x_n)$], average diameter of natural particles, d_e), elastic (density ρ, speed of sound c, Poisson's ratio v) and strength properties of the rocks (ultimate compressive strength σ_{com}, ultimate tensile strength σ_t); characteristics of the type of explosive used (density ρ_{ex}, detonation velocity D, initial pressure of explosion products (EP) P_i).

The parameters of the spatial distribution of explosive charges in the blasting unit: well diameter d_0, resistance line along the sole of the bench W, spacing a, burden a_b, charge length l_1, explosive column length h_3, stemming l_2, subdrill length l_s, the length of the air gap $h_{a.g}$ (Fig. 1a), charge mass Q in the blast hole, specific consumption of explosives q_{ex}, scheme, deceleration time between explosive charge groups of different explosives τ.

The final results of the explosion: the limiting radius of the cavity r_l, the radius of the zone of fine crushing r_2, the radius of the zone of radial cracks r_1, the granulometric composition of the blasted rock mass [$p'(x_1)$, $p'(x_2)$, $p'(x_n)$], the geometrical dimensions of the rock collapse: the width of the collapse B_c, the width of the discarded part of the collapse B_d, the height of the collapse at the point of intersection with the slope line h_s, the height of the collapse at the separation line h_1, the maximum height of the collapse h_c, the coefficient of loosening of rocks k_l in the collapse, placement of fixed elements of the block G (y_k, z_k) in the collapse, the sizes of the zones of active and passive crushing in the massif and in the blasted rock mass.

(a) (b)

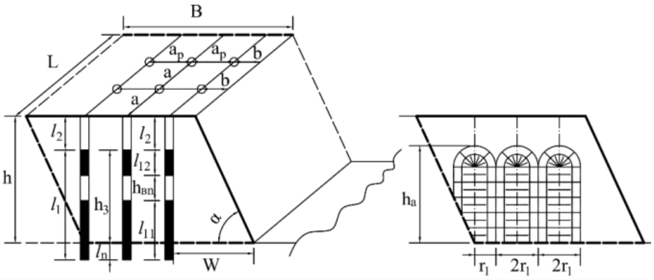

***Figure 1.** The location parameters of explosive charges in the massif (a) and the sizes of the zone of intense crushing of rocks (b); W – resistance line along the sole of the bench; L – bench length; B – bench width; h – bench height; α – the angle of slope of the bench; a – spacing; a_p – burden; l_1, l_{11}, l_{12} – charge length; l_2 – stemming; l_n – subdrill; h_3 – explosive column length; $h_{в.п}$ – the length of the air gap; r_1 – the radius of the zone of radial cracks; h_a – intensive crushing zone height*

3. Analytical determination of rock volumes and their particle size distribution in the zone of intensive and passive crushing

In [14], we found that the quality of blasted rock mass in quarries is most fully characterized by the granulometric composition of blasted rocks – a combination of pieces of various sizes. Based on the fact that the maximum linear size of pieces of rock in the collapse rarely exceeds 1.4 m, they are divided into 7 classes in increments of 0.2 m. The first class includes pieces up to 0.2 m in size, the second class includes pieces 0.21-0.40 m in size, the third class includes pieces 0.41-0.60 m in size and so on until the seventh class, to which carry pieces larger than 1.21 m [4]-[8]. Pieces of rocks of the first three classes are formed in zones of fine crushing and radial cracks. The combined zone can be called the zone of intensive crushing of rocks (Fig. 1b). Subsequent classes of rocks are formed in the remainder of the detonated block of the ledge minus the volume of the zone of intense crushing from it. This zone can be called a zone of passive crushing. In it there is an explosive disintegration of the rock massif into natural units with insignificant fragmentation.

The volumes of the first three classes in the entire blasted rock are determined by the Formulas:

$$V'(x_1)=(1+k)\left[V''(x_1)+p(x_1)V''(x_2)+ +p(x_1)V''(x_3)\right]+p(x_1)\left[V-(1+k)V_ц\right]; \quad (1.1)$$

$$V'(x_2)=(1+k)\left[V''(x_2)+p(x_2)V''(x_3)+ +p(x_1)V''(x_2)\right]+p(x_2)\left[V-(1+k)V_ц\right]; \quad (1.2)$$

$$V'(x_3)=(1+k)\left[V''(x_3)+p(x_1)V''(x_3)+\right.$$
$$\left.+p(x_2)V''(x_3)\right]+p(x_3)\left[V-(1+k)V_ц\right], \quad (1.3)$$

where:

$V'(x_i)$ – the entire volume of the rock of class i after the explosion;

k – a coefficient taking into account the destruction of rocks due to reflected waves and EP, $k = 1$;

$V''(x_i)$ – volume of intensely crushed rock of the i-th class ($I \le 3$);

$p(x_i)$ – the content of pieces of the i-th class in the array, unit fractions;

V – the rock volume of the blasted block of the array;

$V_ц = V''(x_1)+V''(x_2)+V''(x_3)$.

As can be seen from Equations 1, the volume of rocks of the first class of fineness in the entire blasted rock consists of the volumes of those contained in the first, second and third classes in the zone of intense crushing and the volume of such classes in the rest of the blasted rock. This volume of rocks is proportional to the difference between the volumes of the blasting block and intensive crushed rocks. The proportionality coefficient is equal to the fractional content of the piece in question in the array. The volume of rocks of the second class of fineness consists of the sum of the volumes of the second and third classes in the zone of intensive crushing with the deduction of the volume of rocks of the first class and with the addition of part of the second class in the rest of the blasted rock. The volume of rocks of the third class is calculated according to a similar scheme.

Classes of rocks larger than 0.61 m in size, as mentioned above, are formed in the zone of passive crushing. By analogy with the second term of Expression 1, the volumes of these classes are directly proportional to the difference between the volumes of the blasted block and the intensely fragmented rocks in it. In this case, the proportionality coefficient is taken equal to the virtual content of natural entities in the rock mass. The volumes of rocks of the desired classes ($j \ge 4$) are determined by the Formula:

$$V'(x_j)=q(x_j)\left[V-(1+k)V_ц\right]. \quad (2)$$

$q(x_j)$ – virtual content of the j-th class in the rock mass (unit fractions) is determined by the Formulas:

$$q(x_1)=p(x_1);\ q(x_2)=p(x_2);\ q(x_3)=p(x_3);$$
$$q(x_4)=p(x_4)+\frac{1}{4}p(x_5);q(x_5)=\frac{3}{4}p(x_5)+\frac{1}{4}p(x_6); \quad (3)$$
$$q(x_6)=\frac{3}{4}p(x_6)+\frac{1}{4}p(x_7);\ q(x_7)=\frac{3}{4}p(x_7).$$

As a result, the content of pieces of rocks of the first three classes is established by the ratio ($i \le 3$):

$$p'(x_i)=\frac{V'(x_i)}{V}; \quad (4)$$

and the content of pieces of rocks of subsequent classes ($j \ge 4$) is determined by the Expression:

$$p'(x_i)=\frac{q(x_j)}{V}\left[V-(1+k)V_ц\right]. \quad (5)$$

The set of values $p'(x_1)$, $p'(x_2)$,… $p'(x_7)$ represents the granulometric composition of the blasted rocks.

Thus, according to Expressions 1-5 for given physical and mechanical, structural properties of rocks, detonation, energy characteristics of explosives, parameters and method of blasting, the granulometric composition of blasted ore and rock is easily calculated. This method of determining the lumpiness of blasted rocks fundamentally differs from the known empirical [5]-[7], [11]-[13] theoretical justification. Examples of automated calculation of parameters and results of drilling and blasting for the Sarbaiskoye deposit (Kazakhstan) are given in Table 1.

Table 1. Automated calculation of drilling and blasting parameters and granular composition of blasted rock mass in diorite-porphyritic ores blockiness B-2 and hornfelses ores blockiness B-3

Parameters	Diorite porphyrite	Hornfelses
Properties of rocks and explosives		
Rock density, kg/m^3	2830	3060
Speed of sound, m/s	5100	4410
The limit of compressive strength, MPa	190	258
Tensile Strength, MPa	16	21
Poisson's ratio	0.24	0.30
Density of explosives, kg/m^3	1100	1100
Velocity of detonation, m/s	4200	4500
Blasting parameters		
Blast hole radius, m	0.125	0.125
Bench height, m	15	15
Capacity of unit length of the hole, kg/m	55	55
The number of rows of holes, pcs	4	4
The angle of slope of the bench, degrees	65	65
Proportionality coefficient	1	1
Strength characteristics of the rock, MPa	842.94	1005.46
The initial pressure of the detonation products, MPa	2425.50	2784.38
Relative cavity radius	1.30	1.29
The maximum radius of the cavity, m	0.16	0.16
The radius of the zone of fine crushing, m	1.43	1.1
The radius of the zone of radial cracks, m	3.29	3.11
The line of resistance along the sole of the bench, m	9	8.48
Spacing, m	7.71	7.27
Blasting parameters		
Burden, m	7.71	7.27
Explosive column length, m	8.64	9.08
Stemming, m	6.36	5.92
Subdrill length, m	2.06	1.94
Charge length, m	10.7	11.02
Hole depth, m	17.06	16.94
The number of charge parts	2.14	2.20
The length of the air gap, m	1.43	1.1
Mass of charge, kg	509.44	545.69
The velocity of the holes of the cavity, m/s	147	157.50
Slowing time, s	0.02	0.02
Powder factor, kg/m^3	0.55	0.66
The output of the rock mass from one m of the hole	54.44	48.72
Grain composition		
The content of pieces of class 1 (%)	65.67	44.06
The content of pieces of class 2 (%)	21.89	25.42
The content of pieces of class 3 (%)	8.72	17.46
The content of pieces of class 4 (%)	2.19	4.74
The content of pieces of class 5 (%)	0.88	3.34
The content of pieces of class 6 (%)	0.45	2.96
The content of pieces of class 7 (%)	0.20	2.03
Diameter of the average piece, m	0.20	0.32

4. The size of the rock crushing zones in the rock mass collapse

Typically, rocks in the collapse are divided into three zones: small, medium and large crushing by size. The first zone includes fractions of pieces up to 0.20 m in size, the second zone – fractions of pieces from 0.21 to 0.80 m in size and the third zone – fractions of more than 0.81 m in size, i.e.:

$$d_1 = p(x_1);\; d_1 = p(x_2) + p(x_3) + p(x_4);$$
$$d_3 = p(x_5) + p(x_6) + p(x_7), \tag{6}$$

where:

d_1, d_2, d_3 – the percentage of rocks in the respective zones.

Subject to rational parameters of blasting operations, the volume of the zone of fine crushing is (%): in small-block rocks (B-1) – 60-70, in medium-block rocks (B-2) – 45-55 and in large-block (B-3) – 40-50. The volume of the medium crushing zone is 25-35, 30-40 and 30-40%, respectively, and the volume of the large crushing zone is 5-10, 10-15, and 10-20% [2].

To simplify the calculation of the size and shape of crushing zones during single-row blasting, we divide the zone of small crushing in the array into 3 parts (Fig. 2a): the first part is half the cylinder with the height of the borehole charge in the direction of the free surface with a radius g_{z1}; the second part is a quarter of a sphere above a borehole charge of radius g_{z1}; the third part is the area behind the well width g_{z1} and height $g_{z1} + h_3$.

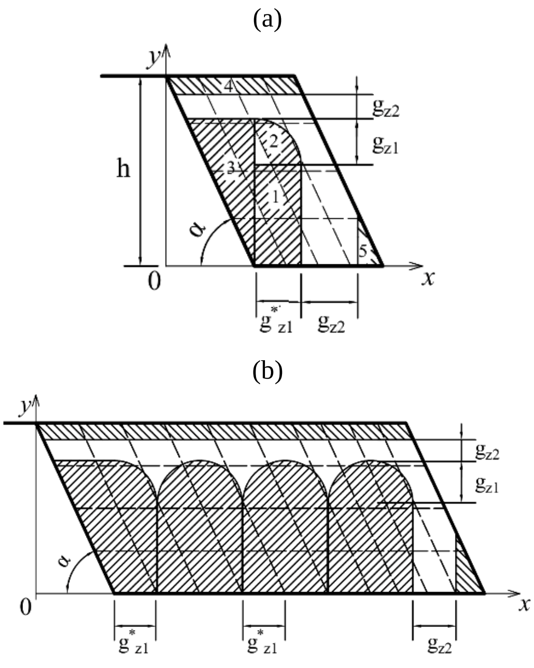

Figure 2. The size of the crushing zones and their location in the rock mass; h – bench height; α – the angle of slope of the bench; 1, 2, 3 – three part of zone of small crushing; 4, 5 – two part of zone of large crushing; g_{z1} – radius of cylindrical 1 part of zone of small crushing; g^*_{z1} – the average size of the zone of fine crushing; g_{z2} – distance between small and large crushing zones

Knowing the granulometric composition of the blasted rocks in the array, you can write:

$$V(s_1) + V(s_2) + V(s_3) = V(d_1), \tag{7}$$

where:

$V(s_1)$, $V(s_2)$, $V(s_3)$ – volumes of 1, 2 and 3 parts of the zone of fine crushing;

$V(d_1)$ – volume of the zone of fine crushing, $V(d_1) = V \cdot d_1$.

Substituting their values in (7) and performing the corresponding mathematical operations, we obtain:

$$\frac{1}{3}(\pi + 3 \cdot ctg\alpha) \cdot g_{z1}^3 + \frac{1}{2} h_3 (\pi + 4 \cdot ctg\alpha) \cdot g_{z1}^2 + h_3^2 \cdot ctg\alpha \cdot g_{z1} - V(d_1) = 0. \tag{8}$$

Denoting the constants for the variable, respectively, A_0, A_1, A_2, A_3, we have:

$$B_1 = \frac{A_1}{A_0};\; B_2 = \frac{A_2}{A_0};\; B_3 = \frac{A_3}{A_0};$$

$$p_k = -\frac{B_1^2}{3} + B_2;\; q_k = \frac{2B_1^3}{27} - \frac{B_1 B_2}{3} + B_3.$$

In accordance with the Cardano's Formula [20]:

$$g_{z1} = y_k - \frac{B_1}{3}, \tag{9}$$

where:

$$y_k = \sqrt[3]{-\frac{q_k}{2} + \sqrt{\frac{q_k^2}{4} + \frac{p_k^3}{27}}} + \sqrt[3]{-\frac{q_k}{2} - \sqrt{\frac{q_k^2}{4} + \frac{p_k^3}{27}}}.$$

The average size of the zone of fine crushing is calculated by the Formula:

$$g_{z1}^* = \frac{2\pi g_{z1}^2 + 3\pi h_3 g_{z1}}{12(h_3 + g_{z1})} \approx 0.69 \cdot g_{z1}. \tag{10}$$

To find the sizes of the zones of medium and large crushing, it is enough to find one of them. It is more convenient to find the size of the coarse crushing zone. this zone can be divided into two parts (Fig. 2a): the first part is the area in the upper part of the rock mass block, the sole of which is located at a distance g_{z2} from the boundary of the fine crushing zone; the second part is a triangular region in front of the block of rock mass at a distance g_{z2} from the well.

Knowing the particle size distribution in the blasted mass, we can write:

$$V(l_1) + V(l_2) = V(d_3), \tag{11}$$

where:

$V(l_1)$, $V(l_2)$ – volumes of 1 and 2 parts of the zone of coarse crushing;

$V(d_3)$ – volume of the zone of coarse crushing, $V(d_3) = V \cdot d_3$. Substituting their values in (11) we obtain:

$$(h - g_{z1} - g_{z2}) \cdot a_p \cdot W + \frac{1}{2} a_p tg\alpha \left(W - g_{z1}^* - g_{z2}\right)^2 = V(d_3). \tag{12}$$

The size of the medium crushing zone is determined from the Expression:

$$\frac{1}{2}(a_p tg\alpha) \cdot g_{z2}^2 - \left[W \cdot a_p + a_p tg\alpha \left(W - g_{z1}^*\right)\right] \cdot g_{z2} - V(d_3) + W \cdot a_p \cdot (h - g_{z1} - h_3) + \frac{1}{2} a_p tg\alpha \left(W - g_{z1}^*\right)^2 = 0. \tag{13}$$

To determine the size of the zones of crushing rocks in the collapse, it is necessary to operate on the position of their characteristic points in the massif [21]. Their displacements in the collapse are determined by the system of Equations [22], [23]:

$$\{f\} = \begin{Bmatrix} u \\ v \end{Bmatrix}; \; u = a_1 + a_2 x + a_3 y + a_4 xy; \qquad (14)$$

$$v = a_5 + a_6 x + a_7 y + a_8 xy,$$

where:

u, v – the displacements of the characteristic points of the contour of the crushing zones in the horizontal and vertical directions;

x, y – coordinates of the characteristic points of the contour of the crushing zones in the block of rock mass;

a_1, a_2, …, a_8 – the constants of the system of equations.

The latter are determined from the Expression [24]:

$$\begin{Bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{Bmatrix} = \begin{bmatrix} 1 & x_\varphi & y_\varphi & x_\varphi y_\varphi \\ 1 & x_\chi & y_\chi & x_\chi y_\chi \\ 1 & x_\psi & y_\psi & x_\psi y_\psi \\ 1 & x_\omega & y_\omega & x_\omega y_\omega \end{bmatrix}^{-1} \cdot \begin{Bmatrix} u_\varphi \\ u_\chi \\ u_\psi \\ u_\omega \end{Bmatrix}; \quad ; \qquad (15)$$

$$\begin{Bmatrix} a_5 \\ a_6 \\ a_7 \\ a_8 \end{Bmatrix} = \begin{bmatrix} 1 & x_\varphi & y_\varphi & x_\varphi y_\varphi \\ 1 & x_\chi & y_\chi & x_\chi y_\chi \\ 1 & x_\psi & y_\psi & x_\psi y_\psi \\ 1 & x_\omega & y_\omega & x_\omega y_\omega \end{bmatrix}^{-1} \cdot \begin{Bmatrix} v_\varphi \\ v_\chi \\ v_\psi \\ v_\omega \end{Bmatrix},$$

where:

x_φ, y_φ, x_χ, y_χ, x_ψ, y_ψ, x_ω, y_ω – the coordinates of the nodal points of the coordinate grid element of the blasting block;

u_φ, v_φ, u_χ, v_χ, u_ψ, v_ψ, u_ω, v_ω – coordinates (displacements) of the nodal points of the coordinate grid of the blasted block in the collapse.

5. Results and discussion

Based on the totality of the found positions of the characteristic points of the crushing zones in the collapse, we establish their contours. For this, according to the proposed methodology for the analytical determination of the crushing zones of the blasted block, a computer program was created in the Microsoft Visual Studio 2019 environment [25], [26]. It allows for convenient and flexible calculation of crushing zones of rocks of the blasted block and their construction. Examples of calculations and automated construction of the profile of the collapse and crushing zones of rocks according to the Table. 1 are given in Figure 2 and 3. They confirm the efficiency of the developed analytical method for determining the crushing zones of the blasted block and the automated prediction of the placement of various ledge elements in the blasted rock mass under various conditions of blasting.

6. Conclusions

An analytical method has been developed for determining rock volumes and their granulometric composition in zones of intense and passive crushing. It correlates these results of the explosion with the blockiness of the massif, the physicomechanical properties of the blasted rocks, the physicochemical characteristics of the explosive used, the parameters of drilling and blasting and the explosion conditions.

An analytical method has been developed to determine the zones of small, medium, large crushing of rocks in the collapse of blasted rocks under various blasting conditions.

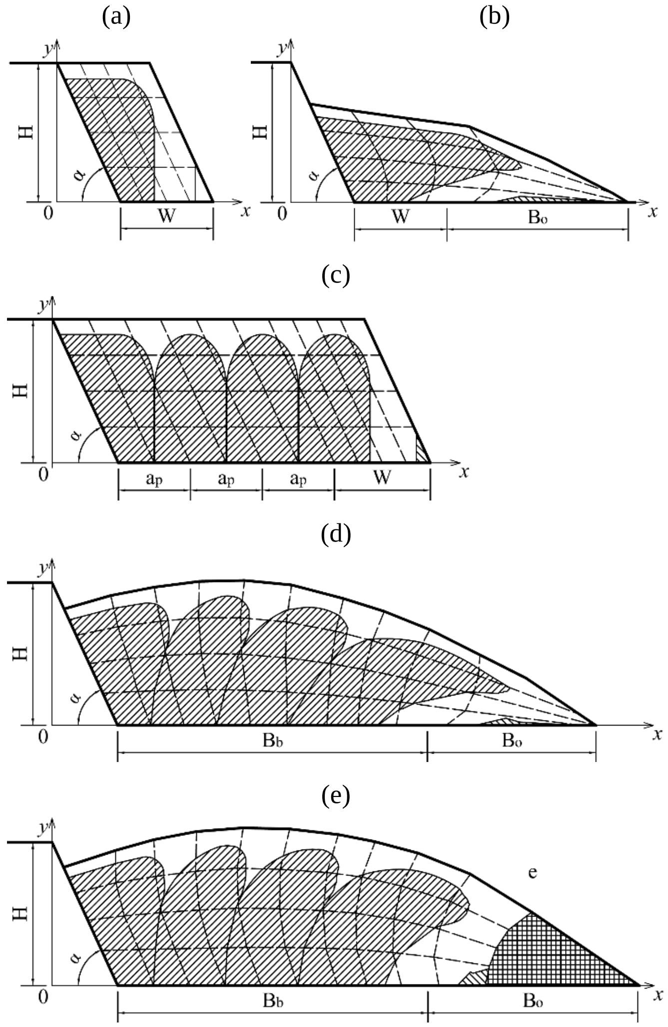

***Figure 3.** Examples of calculation of crushing zones of rocks in the massif and collapse: single-row blasting (a), (b); four-row short delay blasting on the free surface (c), (d); four-row short delay blasting with retaining wall (e); B_b – the width of the collapse; B_o – the width of the discarded part of the collapse; W – resistance line along the sole of the bench; h – bench height; α – the angle of slope of the bench; a – spacing; a_p – burden*

A computer program has been developed for the automated determination of various crushing zones in the collapse of blasted rock mass. The developed method for automated determination of the size of crushing zones in the collapse was tested in the conditions of the Sarbaisky quarry, and showed results that closely coincided with the actual data of the mine.

This method serves as a reliable tool for the operational determination of the size of crushing zones in rock breakdown, for the selection of rational drilling and blasting and excavation technologies.

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Автоматизоване визначення зон дроблення порід у розвалі

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Мета. Розробка автоматизованого методу визначення зон дроблення порід у розвалі для вибору раціональних технологій буропідривних робіт.

Методика. Використані методи визначення положень вузлових та внутрішніх точок координатної сітки розвалу підірваних гірських порід, методи апроксимації, теорія матриць, чисельні методи техніки.

Результати. Математично описаний автоматизований метод визначення зон дроблення порід у розвалі, який базується на аналітичному методі визначення гранулометричного складу підірваних порід у зонах активного та пасивного дроблення порід. Встановлено, що новий методичний підхід взаємопов'язує гранулометричний склад підірваної гірничої маси з блоковістю масиву порід, фізико-механічними властивостями порід, що вибухають, фізико-хімічними характеристиками застосовуваної вибухової речовини і параметрами розташування зарядів у масиві порід.

Наукова новизна. Вперше у гірничій справі розроблено аналітичний метод визначення розмірів зон дроблення порід у розвалі на основі спільного застосування методів визначення вузлових та внутрішніх точок координатної сітки й розрахунку зон дроблення гірської породи підірваного блоку.

Практична значимість. На основі розробленого методу створено компютерну програму автоматизованого визначення розмірів зон дроблення підірваного блоку. За допомогою цієї програми оперативно та досить точно можуть бути знайдені зони дрібного, середнього та великого дроблення підірваного блоку при різних параметрах та умовах підривання масивів порід. Встановлені таким чином положення зон дроблення підірваного блоку є інструментом для вибору раціональної технології буровибухових і виїмково-навантажувальних робіт, чим визначається їх практична цінність.

Ключові слова: *кускуватість зруйнованих порід, цифрова ієрархічна модель, гранулометричний склад, стадії вибуху, зона інтенсивного дроблення, загальний обсяг подрібнених порід*