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## PROGNOSTIC MODELLING OF STRUCTURAL BLOCK SIZE DISTRIBUTION IN THE ROCK MASS

**Purpose.** Improving the efficiency of mining operations at deposits with complex geological structures through automated design of rational drilling-and-blasting and excavation-loading parameters.

**Methodology.** In conducting scientific research, comprehensive methods were utilized, including the analysis and synthesis of scientific and technical information, theoretical studies, mathematical modeling methods, mathematical statistics methods for processing experimental data and techno-economic justification of various technology options, correlation-regression analysis, as well as empirical and object-oriented programming methods for creating software modules.

**Findings.** Analytical dependencies of natural fragments in small-block, medium-block, large-block, and very large-block rock masses have been established. The content of natural fragments in a rock mass generally follows an exponential law. A structural-hierarchical model of rock mass fracturing has been created, allowing for the determination of the calculated granulometric composition of natural fragments in rock masses of various block sizes based on their average size at different scales of natural fragment sizes. A classification of rock masses by block size, indicating the percentage content of natural fragments, has been proposed.

**Originality.** It lies in developing innovative methods and creating an automated design system that provides justification for rational parameters of ore extraction technologies of a given quality and the required volumes in solid mineral deposits with varying levels of structural and geological complexity.

**Practical value** is determined by the high applicability of the obtained results for implementation and use in designing rational drilling-and-blasting and excavation-loading parameters in development and extraction workings of open-pit and underground mines.

**Keywords:** *drilling and blasting operations, granulometric rocks composition, rocks fracturing*

**Introduction.** The problem of efficient mining operations at deposits with complex geological structures remains relevant for the mining industry. A key factor determining both the product quality and the overall environmental and economic performance of hard rock mining is the proper development of a drilling and blasting project, as well as the determination of key extraction and loading parameters. In practice, competent mining planning and a sound assessment of a deposit's investment attractiveness begin with a clear understanding of the natural state of the rock that makes up the deposit. Insufficient consideration of rock mass blockiness and fracturing leads to increased losses, ore dilution, and reduced efficiency of downstream technological processes. The challenge lies in the variability of the natural structure of rocks and the absence of universal tools for its quantitative assessment. Therefore, there is a need to develop innovative methods for automated determination of rock granulometric composition, enabling adaptive planning of extraction technologies. The presented study aims to address this issue by developing a scientifically grounded methodology and corresponding software support.

**Literature review.** To address methodological issues related to assessing rock blastability, the influence of individual indicators of fracturing and the physical-mechanical properties of rocks, as well as the nature of the relationship between rock strength and blockiness, were considered.

**Rock mass fracturing.** It is evident that the primary factor affecting rock blastability is the background macro-fracturing, which determines the division of rock into elementary structural blocks – natural discontinuity fragments – constituting block-forming fracturing. The length of such fractures ranges from decimetres to several tens of metres, occasionally up to 100 m; their aperture (opening between fracture walls) varies from  $10^{-6}$  to  $10^{-1}$  m; and the spacing between fractures ranges from a few centimetres to 1.5–2 m, rarely exceeding these values. Microfractures with lengths between 0.01 mm and 10 cm, along with defects in the crystal lattice of minerals, affect the resistance of discrete rock blocks to explosive fragmentation.

The effect of fracturing as the main factor governing explosive rock mass fragmentation has been investigated at different times by A. N. Khanukaev, L. I. Baron, V. K. Rubtsov, D. M. Bronnikov, N. F. Zamesov, H. P. Demydiuk, B. M. Kutuzov, F. I. Kudriavyyi, Ye. I. Yefremov, M. A. Kuk, O. V. Shapurin, and other authors [1].

Their research results indicate that, in general, this influence manifests in a dual manner. Consequently, fracturing largely determines, especially within the zone of poorly controlled fragmentation, the block size and shape of blasted rock fragments. Observations in pit benches and in saw cuts made by stone-cutting machines at the toe of blast boreholes have shown that the propagation of blast-induced fractures is often limited by the nearest natural fracture [2, 3].

Fracturing is characterised by several parameters: fracture intensity (degree of fracturing), orientation of fracture systems and density of fractures within each system, fracture aperture, nature of infill, and bonding strength between individual blocks.

*Fracture intensity (degree of fracturing)* is the principal parameter influencing rock resistance to explosive fragmentation. It is included in almost all formulas used to calculate the specific consumption of explosives [4]. In engineering terms, rock fracturing is usually described by its average block size, determined from direct field measurements in both surface and underground mining conditions [5, 6].

However, this characteristic is essentially redundant, since the fractional composition and average size of structural blocks in rock masses are functionally related. This was confirmed by the studies of B. R. Rakishev [7], which demonstrated that the average block diameter calculated from the granulometric distribution of blocks obtained through in situ measurements coincides with the average spacing between fractures.

Operational experience in drilling-and-blasting works at open-pit mines extracting various mineral resources has convincingly shown that as the category of fracturing increases and rock blockiness grows, the specific consumption of explosives required to obtain blasted rock of the desired quality rises significantly. With the same specific explosive consumption, an increase in the fracturing category results in a predictable deterioration of blasting fragmentation quality [8, 9]. The higher the degree of fracturing (i.e., the smaller the block size), the larger the volume of poorly controlled fragmentation relative to that of controlled fragmentation generated by blasting.

*Orientation of fracture systems and fracture density within each system.* Rock masses are predominantly characterised by systematic fracturing, meaning fractures are spatially grouped into several systems. Under systematic fracturing, in addition to the average natural block size, the spatial orientation of fractures and the anisotropy of the rock mass caused by different fracture densities across systems significantly influence blasting results [10]. These factors also determine the shape of blocks within the rock mass and the morphology of coarse fragments in the blasted material.

Numerous laboratory studies and practical blasting experience at open-pit mines have shown that maximum fragmentation and smooth bench faces are achieved when blasting is conducted perpendicular to the principal fracture system, which dips steeply to sub-vertically – i. e., perpendicular to the longitudinal block orientation [11, 12]. The most unfavourable condition occurs when blasting is carried out at approximately 45° relative to the main fracture system; in this case, poor fragmentation is accompanied by back-break along fractures behind the blasted face. Horizontal orientation

of the dominant fracture system, perpendicular to the axis of borehole charges, is also disadvantageous in terms of achieving quality blasting outcomes [13, 14].

*The aperture of fractures* significantly affects blasting efficiency because it directly determines the loss of wave energy and explosive gas pressure. However, measuring this parameter during field observations in open pits involves considerable difficulties. The issue lies in the fact that measurements taken on exposed bench faces do not represent the natural fracture void, but rather the void formed as a result of previous mass blasting. The zone disturbed by blasting extends into the rock mass with gradual attenuation of blast-induced deformations up to 10–15 m from the bench face and 3–8 m vertically from the upper berm [15]. This implies that natural fracture aperture is effectively inaccessible for direct measurement in open pits. Observations in underground workings have shown that in unweathered rock masses, tightly closed or slightly open (0.2–0.5 mm) fractures overwhelmingly predominate. Technogenic fracture opening measured on pit benches usually does not exceed 1–2 mm and remains relatively uniform across the pit area. Only in the upper weathered zone of rock masses does fracture aperture increase, which negatively affects blasting outcomes, particularly when large blocks of competent rock are separated by gaping fractures or those filled with loose weathering products. Such conditions are characteristic, for example, of specific zones within the weathering crust of ferruginous quartzites at the Inhulets and Mykhailivsk deposits [16, 17].

*Fracture infill* affects rock blastability in an ambiguous manner: firstly, as a cement binding the blocks, and secondly, as a medium influencing the attenuation of blast wave energy [18, 19]. In unweathered rock masses, fractures forming block boundaries typically lack solid mineral infill. Air or water acts as the infill medium. Air-filled fractures sharply reduce wave stress intensity [20], and large open fractures completely absorb it, acting as free surfaces. When fractures are filled with water, waves propagate through them without significant energy loss.

In the hypergene zone, fractures may be filled with mineral weathering products in the form of mechanical or hydrochemical precipitates, predominantly clay material with iron hydroxides. Due to its low strength, this infill is incapable of functioning as cement, as it weakly bonds rock blocks together, and its elastic properties governing wave energy attenuation are relatively constant.

*Block-to-block bonding.* Rock masses are almost never “dismantlable” because fractures are generally discontinuous in character. When fractures taper into fine cracks or disappear entirely, the rock mass retains substantial structural integrity. The tighter the fractures are closed and the rougher their surfaces, the higher the block bonding strength. Determining a reliable value for block bonding strength in rock masses is extremely challenging. Therefore, its effect on rock blastability across different fracturing categories is accounted for using results of previous blasting, which are applied to adjust the calculated specific explosive consumption or modify the values in design formulas that reflect bonding effects during fragmentation (for example, Mironov’s crushing constant or B. R. Rakishev’s coefficient [21]).

**Purpose.** The aim of the study is to enhance the efficiency of drilling-and-blasting and excavation-loading op-

erations in development and extraction workings of open-pit and underground mines by developing and implementing innovative methods for automated determination of the granulometric composition of natural structural blocks in rock masses of varying blockiness, thereby enabling scientifically justified design of rational extraction technology parameters under complex geological conditions.

**Methods.** During field investigations of rock mass fracturing in open pits for evaluating blastability, it is essential to document fracture orientation, block size, and block shape. There is no need to record fracture aperture or infill characteristics, as these parameters exhibit weak spatial variability, and fracture opening is generally minor in magnitude and influence on blast performance. Only within the hypergene zone is it necessary to delineate unfavourable areas for blasting, characterised by coarse-block structures with gaping fractures or fractures filled with weathering products. The bonding strength between blocks within a rock mass is difficult to determine; its effect on the blastability of rocks of a given fracturing category is assessed based on the outcomes of executed blasting operations.

Determining the granulometric composition of natural blocks in a rock mass – particularly in structurally complex deposits with variable orebody geometries – plays a key role in developing methodologies for establishing rational drilling-and-blasting and excavation-loading parameters. The subsequent selection of an appropriate drilling-and-blasting scheme at open-pit mines relies on evaluating the blastability of the rocks being extracted, which includes characterising their blockiness (block size) and anisotropy of fracturing intensity. Accurate determination of the granulometric composition of natural blocks, along with its adaptation to specific mining conditions – whether in surface or underground settings – enables selection of the most suitable approaches for predicting the structural characteristics of blasted rock [22, 23] and for defining extraction technologies for structurally complex deposits [24].

Because of technological constraints, it is often difficult to reliably determine rock-fracturing characteristics in underground mining. For that reason, such studies are typically performed for conditions of open-pit mining [25, 26]. The findings, particularly those used to define the size distribution of natural blocks within the rock mass, can then be transferred and interpreted for underground applications. In this context, the planned research was conducted at open-pit mines of ferrous and non-ferrous metallurgy in Kazakhstan [21].

**Results.** The investigation of fracturing at the Akzhal, Sarybai, and other deposits was conducted almost continuously along bench slopes, excluding areas covered by debris from blasted rock or deemed hazardous for work [27]. Since the rock mass at the Akzhal deposit is stratified, complexly folded, and exhibits systematic fracture development, fracture orientation measurements were performed at each observation station strictly by fracture systems. The fracturedness of the block was then recorded using a measuring ruler as the distance between adjacent cracks within each crack set. The fracturedness of the rock mass was then represented by the average diameter of the blocks, obtained as the arithmetic mean of all measured distances along the identified crack systems.

The results of actual data obtained at the studied deposits for varying natural block sizes from 0 to 1.4 m in increments of 0.2 m are presented in Table 1 and graphically illustrated in Fig. 1, and they closely correspond to measured field values.

The analysis of the data in Table 1 indicates that natural structural blocks represent fundamental elements of the rock mass, and their size ranges – up to 0.2, 0.21–0.40, 0.41–0.60, 0.61–0.80, 0.81–1.00, 1.01–1.20 m, and greater than 1.20 m – reflect hierarchical levels of these elements. Thus, the analytical expression of the percentage content of natural blocks of various sizes within the mass and their graphical representation constitute a structural – hierarchical model of rock masses [28].

The next stage in building the model is to derive analytical dependences that link the share (percentage) of natural blocks to their size within the rock mass, using

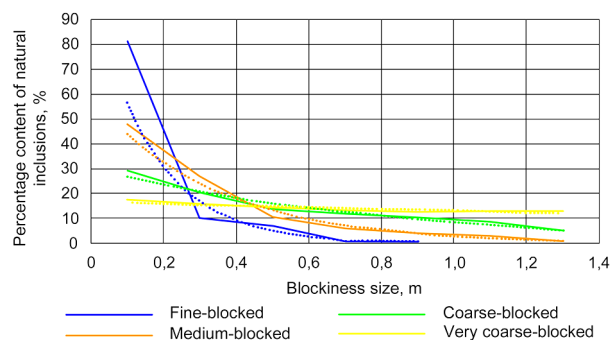


Fig. 1. Dependence of the percentage content of natural structural blocks (—) and regression lines (.....) for rock masses of different blockiness

Table 1

Granulometric composition of natural structural blocks in the rock mass

Classes of rock masses by blockiness	Rock masses by blockiness (degree of fracturing)	Content in the rock mass (%) of blocks of size (m)							Average block diameter, m
		<0.20	0.21–0.40	0.41–0.60	0.61–0.80	0.81–1.00	1.01–1.20	>1.21	
I	Finely blocky (extremely fractured)	81.2	10.3	7.0	0.8	0.7	—	—	0.15
II	Medium blocky (highly fractured)	48.0	27.0	10.5	6.0	4.2	3.3	1.0	0.31
III	Coarse blocky (moderately fractured)	29.5	20.2	14.0	11.8	10.6	8.7	5.2	0.50
IV	Very coarse blocky (weakly fractured)	17.5	16.1	14.6	13.2	12.7	12.9	13.0	0.66

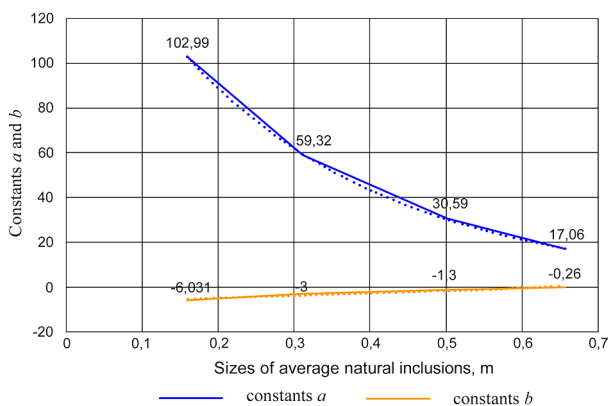


Fig. 2. Dependence of constants  $a$  and  $b$  on the average size of natural structural blocks under the basic block size scale

the data in Table 1. After that, correlation analysis can be applied to fit regression lines for each size class and to quantify the quality of the fit through approximation reliability metrics, primarily the coefficient of determination. Subsequently, using the spreadsheet tools in MS Excel, regression lines for the percentage content of natural blocks in the rock mass are derived and formalised. To accomplish this, an Excel chart must be generated to reflect the dependence of the percentage content of natural blocks on their specified size, after which a regression line of the form  $y=f(x)$  is selected for this chart.

The conducted research revealed that the content of natural blocks in rock masses of different blockiness levels generally varies according to an exponential law, namely

$$y = ae^{bx}, \quad (1)$$

where  $y$  is the percentage content of a given natural block size;  $x$  is the size of the given natural block;  $a$ ,  $b$  are constants for each blockiness class.

The dependence (1) is crucial for solving the stated problem. However, there is often a need to address the inverse task – determining the granulometric composition of natural blocks in a rock mass based on their average size, which is typically reported in the geological documentation of a project. To solve this inverse problem, it is necessary to determine the values of the constants in equation (1) as functions of the specified natural block size. For this purpose, graphs of the dependence of constants  $a$  and  $b$  on  $d_b$  (the average diameter of natural blocks) were constructed and are presented graphically in Fig. 2. Subsequently, using spreadsheet tools in MS Excel, the required values of coefficients  $a$  and  $b$  are obtained. The coefficient  $a$  is described by an

equation that varies according to an exponential law

$$a = 183.28e^{-3.6x}. \quad (2)$$

The coefficient  $b$  is described by an equation that varies according to a logarithmic law

$$b = -3.576 \ln(x) - 0.8842. \quad (3)$$

The conducted research demonstrates that, based on the average size of natural structural blocks, it is possible to determine the values of constants  $a$  and  $b$  for the considered rock mass blockiness classes. Then, using these values in equation (1), the percentage content of natural blocks in a rock mass can be calculated as a function of their size.

The results of this procedure – namely, the calculated granulometric composition of natural blocks for all blockiness classes – are presented in Table 2.

The analysis of the results presented in Tables 1 and 2 shows that the calculated natural block fractions for all blockiness classes generally agree well with field measurements. Noticeable discrepancies, when they occur, are mostly limited to the first two size fractions in the small-block rocks. However, such content more reliably reflects real conditions in practice. Overall, the calculated method for determining the granulometric composition of natural blocks within rock masses provides an effective solution to the stated problem.

When determining the granulometric composition of rock masses in underground mining, it should be noted that natural blocks in an intact rock mass remain tightly closed and are not separated by open fractures. Geological data from most Kazakhstani deposits show that the largest natural block size in undisturbed rock rarely exceeds 1.0 m. Moreover, mining and haulage equipment used in underground operations has limited dimensions and smaller cutting tools compared to open-pit equipment.

Due to these differences, it becomes necessary to reconsider the size range of natural blocks applied for open-pit mining in order to develop a new structural-hierarchical model of rock masses. In other words, the task is reduced to revising rock mass block size ranges.

Based on practical requirements of underground mineral extraction, the most suitable hierarchical levels include seven rock size classes within the rock mass at 0.15 m intervals. The first size class corresponds to blocks smaller than 0.15 m; the second covers sizes from 0.16 to 0.30 m; the third from 0.31 to 0.45 m; the fourth from 0.46 to 0.60 m; the fifth from 0.61 to 0.75 m; the sixth from 0.76 to 0.90 m; and the seventh includes blocks larger than 0.90 m. The number of size classes remains the same as under the 0.2 m scale.

Determination of the rock mass granulometric composition using the new size scale can be performed

Table 2

Calculated granulometric composition of natural structural blocks in rock masses

Classes of rock masses by blockiness	Rock masses by blockiness (average block diameter, m)	Content in the rock mass (%) of blocks of size (m)						
		<0.20	0.21–0.40	0.41–0.60	0.61–0.80	0.81–1.00	1.01–1.20	>1.21
I	Finely blocky ( $d_b = 0.18$ )	67.65	21.01	6.75	2.38	1.05	0.64	0.52
II	Medium blocky ( $d_b = 0.30$ )	47.62	25.11	13.27	7.05	3.77	2.05	1.14
III	Coarse blocky ( $d_b = 0.51$ )	27.02	20.95	16.24	12.59	9.76	7.57	5.87
IV	Very coarse blocky ( $d_b = 0.67$ )	15.88	15.32	14.77	14.25	13.74	13.25	12.78

Cumulative granulometric composition of rock masses using the base block size scale

Classes of rock masses by blockiness	Rock masses by blockiness (average block diameter, m)	Cumulative content of the rock mass (%) of blocks of size (m)						
		<0.20	<0.40	<0.60	<0.80	<1.0	<1.20	<1.40
I	Finely blocky ( $d_b = 0.18$ )	67.65	88.66	95.41	97.79	98.84	99.48	100.00
II	Medium blocky ( $d_b = 0.30$ )	47.62	72.73	86.00	93.04	96.81	98.86	100.00
III	Coarse blocky ( $d_b = 0.51$ )	27.02	47.96	64.20	76.79	86.56	94.13	100.00
IV	Very coarse blocky ( $d_b = 0.67$ )	15.88	31.20	45.98	60.22	73.97	87.22	100.00

through polynomial equations (regression curves) describing the cumulative content of natural blocks in rock masses of different blockiness categories. For this purpose, the calculated granulometric composition using the base size scale (with a 0.2 m interval) is expressed in the form of a cumulative granulometric distribution (Table 3, Fig. 3).

The existing functionality of MS Excel allows selecting the most appropriate form of equations for cumulative curves.

For the curves shown in Fig. 3, this form is a polynomial equation of the type [29]

$$y_{ij}(x_{ij}) = a_i x_j^4 + b_i x_j^3 + c_i x_j^2 + d_i x_j + e_i, \quad (4)$$

where  $a_i$ ,  $b_i$ ,  $c_i$ ,  $d_i$ ,  $e_i$  are equation constants;  $i$  is blockiness class of the rock mass;  $j$  is size class of natural blocks;  $x_j$  is average block size within each rock size class. The values of the constants and the coefficients of determination are presented in Table 4.

To determine the granulometric composition of natural blocks in a rock mass using the new scale (with 0.15 m increments), the following procedure must be performed. Based on the cumulative curves of natural blocks of different size classes shown in Fig. 3, perpendiculars are projected from the marks 0.15, 0.30, 0.45, 0.60, 0.75, 0.90, and 1.05 m on the x-axis to their intersections with the corresponding regression lines. From these intersections, the cumulative content of these blocks in the rock mass is obtained. From the cumulative content of each fixed block size, it is straightforward to calculate its percentage content and subsequently derive the granulometric composition of natural blocks in the rock mass under the new block size scale [30]. Such data are presented in Table 5. The granulometric composition of natural blocks in the rock mass under the new block size scale is shown graphically in Fig. 4.

As confirmation of the validity of the performed transformations, a high level of consistency can be observed between the trends in rock mass granulometric composition under the base and the new block size scales, as illustrated by comparing Figs. 1 and 4.

To determine the granulometric composition of natural blocks in a rock mass based on their specified average size, it is necessary to calculate the values of constants  $a$  and  $b$  for the considered block size using formulas (2) and (3). The calculated granulometric composition under the new block size scale is presented in Table 6.

Comparison of the data in Tables 5 and 6 shows that, under the base size scale, the calculated values of percentage content for different natural block sizes across all blockiness classes closely correspond to the predicted

values (with deviations within acceptable limits). This confirms the potential for broad application of the developed methodology for determining the granulometric composition of natural blocks based on their known average size. Among other advantages, this approach enables forecasting of the granulometric composition of blasted rock under varying geological and technical mining conditions.

Based on the presented data, software was developed in the Visual Studio environment to determine

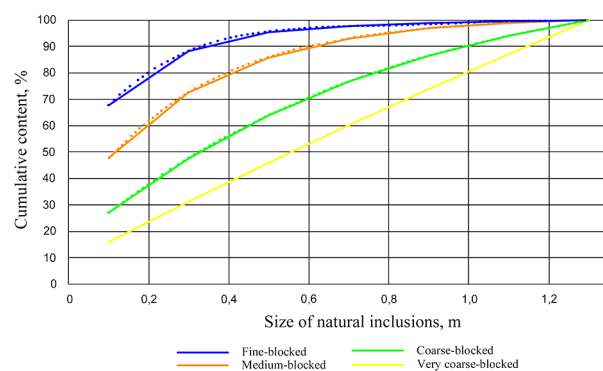


Fig. 3. Cumulative curves of natural inclusions (—) and regression lines (.....) for rock masses of different blockiness

Table 4

Constants  $a_i$ ,  $b_i$ ,  $c_i$ ,  $d_i$ ,  $e_i$  of the equation (4)

$i$	$a_i$	$b_i$	$c_i$	$d_i$	$e_i$	Determination ratio $R^2$
1	-78.27	281.97	-372.44	218.51	49.33	0.99
2	-40.68	167.49	-270.89	213.16	28.87	0.99
3	-4.88	29.16	-82.03	133.92	14.42	0.99
4	-0.02	0.43	-7.19	79.42	8.01	0.99

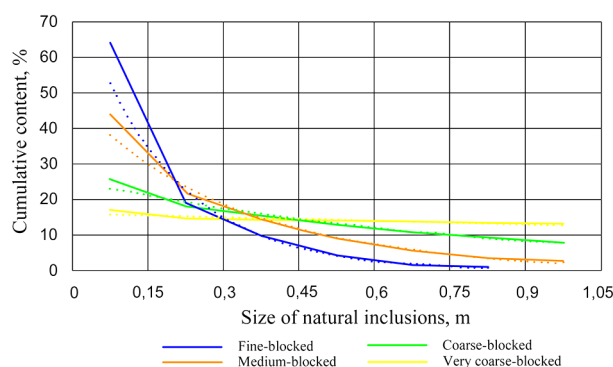


Fig. 4. Dependence of the percentage content of natural structural blocks (—) and regression lines (.....) for rock masses of different blockiness

Table 5

Granulometric composition of rock masses under the new block size scale

Classes of rock masses by blockiness	Rock masses by blockiness (average block diameter, m)	Content in the rock mass (%) of blocks of size (m)						
		<0.15	0.16–0.30	0.31–0.45	0.46–0.60	0.61–0.75	0.76–0.90	>0.91
I	Finely blocky ( $d_b = 0.18$ )	63.89	19.06	9.72	4.18	1.50	0.99	0.77
II	Medium blocky ( $d_b = 0.27$ )	43.73	21.85	14.15	8.86	5.47	3.50	2.44
III	Coarse blocky ( $d_b = 0.41$ )	25.49	18.19	15.31	12.90	10.91	9.27	7.93
IV	Very coarse blocky ( $d_b = 0.50$ )	16.93	14.59	14.28	13.98	13.69	13.40	13.12

Table 6

Calculated granulometric composition of rock masses under the new block size scale for the considered mass classes

Classes of rock masses by blockiness	Rock masses by blockiness (average block diameter, m)	Content in the rock mass (%) of blocks of size (m)						
		<0.15	0.16–0.30	0.31–0.45	0.46–0.60	0.61–0.75	0.76–0.90	>0.91
I	Finely blocky ( $d_b = 0.18$ )	65.86	22.51	7.69	2.63	0.9	0.31	0.1
II	Medium blocky ( $d_b = 0.27$ )	49.12	25.22	12.95	6.65	3.41	1.75	0.9
III	Coarse blocky ( $d_b = 0.41$ )	25.3	20.24	16.2	12.96	10.37	8.3	6.64
IV	Very coarse blocky ( $d_b = 0.50$ )	15.51	15.09	14.67	14.26	13.87	13.49	13.11

the granulometric composition of natural blocks in rock masses using the new block size scale. Unlike previously known approaches, the developed methodology for calculating the granulometric composition of natural structural blocks in rock masses makes it possible – without conducting experimental studies – to determine the percentage content of natural blocks in various sections of the deposit under underground mining conditions. To validate the analytical determination of the granulometric composition of natural rock blocks, measurements were taken on exposed surfaces of development workings at the Zhezkazgan mines (South, East, and West). Selected fragments recorded using specialised PortaMetrics™ equipment [13] are shown in Fig. 5.

The cumulative curves of natural structural blocks for the South Zhezkazgan, West Zhezkazgan, and East Zhezkazgan mines are presented in Figs. 6–8.

Field investigations indicate that under underground mining conditions, achieving clean exposure of excavation surfaces is very difficult. As a rule, the exposed surface consists of rock fragments separated by fractures formed during blasting. Consequently, such surfaces do not accurately reflect the natural blockiness of the rock mass. Therefore, based on the conducted research, it is entirely acceptable to apply the methodology developed

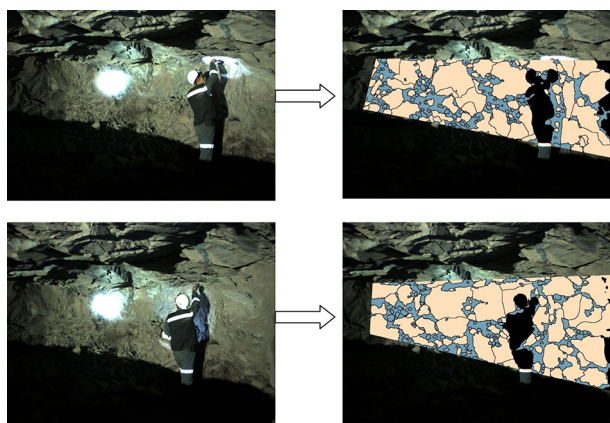


Fig. 5. Rock mass measurements at the West Zhezkazgan mine

for open-pit conditions when constructing a mathematical model of fractured rock masses under underground mining conditions.

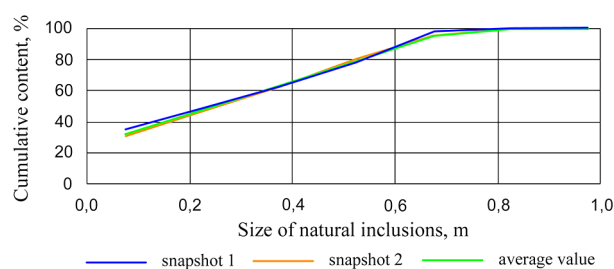


Fig. 6. Cumulative curves of natural structural blocks for the West Zhezkazgan mine

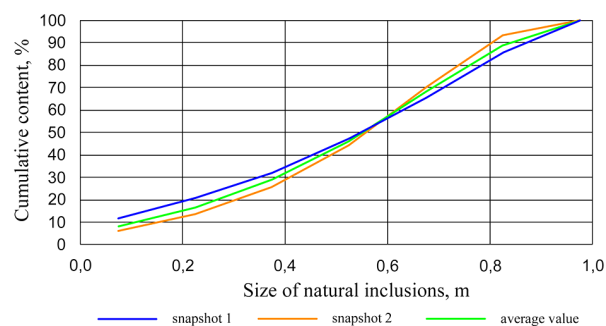


Fig. 7. Cumulative curves of natural structural blocks for the South Zhezkazgan mine

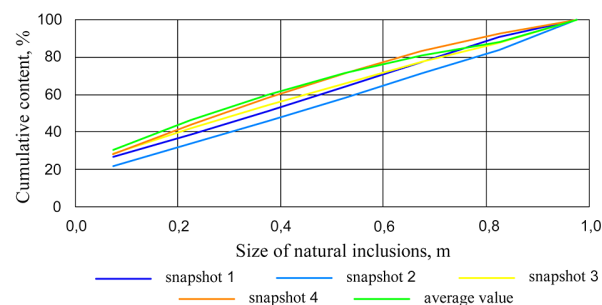


Fig. 8. Cumulative curves of natural structural blocks for the East Zhezkazgan mine

## Conclusions.

1. A structural-hierarchical model of rock mass fracturing was obtained in this study. This model enables the calculation of the granulometric composition of natural fractions in rock masses of different blockiness levels based on their average size. A classification of rock masses by blockiness with indication of the percentage content of natural structural blocks has been proposed.

2. A transition to a new scale for representing the percentage content of natural structural blocks in rock masses – more applicable for underground mining – has been proposed. Software for automated determination of the granulometric composition of natural blocks based on their average size has been developed.

3. Measurements conducted using specialised Porta-Metrics equipment on exposed development and extraction faces showed that surface appearance does not reflect the true natural blockiness of the rock mass. As a solution, it is proposed to use data obtained under open-pit conditions for constructing mathematical models of fractured rock masses in underground mining, and the feasibility of this approach has been substantiated.

4. The developed methodology for determining natural rock mass blockiness will improve the accuracy of engineering decisions when designing drilling-and-blasting operations and performing predictive analysis of the granulometric composition of blasted rock.

5. Determining rock mass fracturing enables more accurate prediction of mining costs and, consequently, assessment of the investment attractiveness of deposit development.

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## Прогнозне моделювання гранулометричного складу окремоостей у гірничому масиві

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**Мета.** Підвищення ефективності гірничих робіт на родовищах складної будови шляхом автоматизованого проектування раціональних параметрів буровибухових і виймально-навантажувальних робіт.

**Методика.** При виконанні наукових досліджень використані комплексні методи досліджень, що

включають аналіз й узагальнення науково-технічної інформації, теоретичні дослідження, методи математичного моделювання, методи математичної статистики для обробки експериментальних даних і техніко-економічного обґрунтування різних варіантів технологій, кореляційно-регресійний аналіз, а також методи емпіричного й об'єктно-орієнтованого програмування для створення програмних модулів.

**Результати.** Встановлені аналітичні залежності природних окремоостей у дрібноблочних, середньоблочних, великоблочних і дуже великоблочних масивах порід. Вміст природних окремоостей у масиві порід у загальному випадку змінюється по експоненційному закону. Створена структурно-ієрархічна модель тріщинуватості масиву порід. Вона дозволяє визначити розрахунковий гранулометричний склад природних окремоостей у масивах різної блочності за їх середнім розміром при різних шкалах крупності природних окремоостей. Запропонована класифікація масиву порід по блочності із зазначенням відсоткового вмісту природних окремоостей.

**Наукова новизна.** Полягає в розробленні інноваційних методів і створенні системи автоматизованого проектування, що забезпечує обґрунтування раціональних параметрів технологій видобутку руди заданої якості й необхідних обсягів на родовищах твердих корисних копалин із різним рівнем структурно-геологічної складності.

**Практична значимість.** Визначається високим рівнем придатності отриманих результатів до впровадження й використання під час проектування раціональних параметрів буровибухових і виймально-навантажувальних робіт у підготовчих та очисних виробках кар'єрів і шахт.

**Ключові слова:** буропідривні роботи, гранулометричний склад порід, тріщинуватість гірських порід

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