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USING THE WIPFRAG IMAGE ANALYSIS SYSTEM TO EVALUATE THE QUALITY OF EXPLOSIVE ROCK FRAGMENTATION

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ВИКОРИСТАННЯ СИСТЕМИ АНАЛІЗУ ЗОБРАЖЕНЬ WIPFRAG ДЛЯ ОЦІНКИ ЯКОСТІ ВИБУХОВОГО ПОДРІБНЕННЯ ПОРІД

Objective. To improve the technology for analyzing the fragmentation of blasted rock mass directly on the bench after drilling and blasting operations using the WipFrag™ 4 software.

Methodology. The research methodology employs the WipFrag fragmentation analysis system to assess the efficiency of rock fragmentation by explosives. The paper highlights the advantages of optical gradation methods. Gradation measurements enable the automation of fraction evaluation, eliminating the subjectivity inherent in manual measurements. This approach does not require interrupting production processes, and results are available in a very short time, enabling timely adjustments to production methods. Optical methods allow for the analysis of large volumes of rock with expanded sampling and an increased number of specimens. Photo analysis systems serve as a practical and effective tool for measuring the efficiency of explosives in rock destruction.

Results of the study. The findings can be applied to optimize blasting parameters to reduce costs. In the mining industry, the results can be utilized for monitoring and optimizing fragmentation, minimizing oversize material that may cause excessive overloading of transport systems and crushing equipment.

Scientific novelty. A research methodology is proposed using an automated granulometry system based on digital image analysis. This approach provides rapid and accurate results, which are essential for managing fragmented rock. Digital image analysis of rock for determining grain size distribution expands the applicability of empirical calibration modes.

Practical significance. The new photo analysis technology offers numerous opportunities for diagnosing oversize formation issues, increasing the efficiency of drilling and blasting operations, reducing costs, and optimizing the process of explosive rock fragmentation.

Keywords: *drilling and blasting operations, oversize material, fragmentation, explosive fragmentation, digital image, photo analysis, WipFrag software.*

Introduction. The quality of blasting is characterized by the uniformity and size of rock mass fragmentation, the width and height of the blasted rock pile, and the preparation of the bench floor. These factors play a critical role in determining the efficiency of subsequent excavation and transportation processes. The use of modern loading and transport equipment, as well as crushing and screening plants, impose strict requirements on the quality of explosive rock fragmentation, as it directly affects their productivity.

Despite the significant attention given to drilling and blasting operations, the primary obstacle to improving labor productivity, reducing production costs, and increasing the output volume remains the uneven fragmentation of rock mass, which is often accompanied by the generation of large (oversized) pieces of valuable minerals.

Fast and accurate measurement of fragmented rock is essential for blasting operations, mining activities, and material transportation. The quality of fragmentation can be used to assess the efficiency of explosives, the blasting design, and delay timing.

Relevance of the research. Managing the quality and parameters of explosive rock fragmentation in quarries remains a pressing practical challenge. Despite extensive research in this field, the issue of regulating the degree of rock fragmentation by adjusting the parameters of drilling and blasting operations has not been fully resolved.

The requirements for the quality of rock fragmentation by blasting are based on the geometric parameters of equipment and the energy characteristics of processes in quarry technological flows. The geometric characteristics of the equipment used determine the allowable size of rock fragments. When designing blasting operations, the calculated output of oversized material should not exceed 5%. Energy costs for performing the work depend not only on the proportion of oversized fragments but also on the average size of rock fragments in the blasted mass. The average fragment size significantly affects the efficiency of equipment used in the technological flows of mining and processing operations.

The quality of fragmentation must align with the type of transport and crushers used; the average fragment size should not exceed the maximum permissible dimensions.

Presentation of the main research material with comprehensive justification of the obtained scientific results. The efficiency of drilling and blasting operations has been the focus of extensive studies, which examine the influence of various factors on rock fragmentation, such as the type of explosives, charge designs, initiation patterns and methods, the use of borehole delays, borehole charge parameters, and their arrangement within the blast block [1, 2].

During mass blasting operations, it is critical to meet the following requirements:

- achieve high-quality fragmentation of the rock mass;
- preserve the level of the bench floor;
- form a compact heap of fragmented rock mass;
- mitigate seismic effects, air shock waves, and the scattering of rock fragments.

Scientific research aimed at improving the process of rock mass fragmentation progresses in several directions. One of the most effective methods for managing blast energy in open-pit mining is controlling the parameters of the explosive impulse by modifying the explosive charge design [3].

Prolonging the impact of the explosion on the rock mass can be achieved by using charges with air gaps. Enhancing the composition of charge stemming affects the duration of explosive loading, and, consequently, the stress field parameters and the nature of material destruction. The shape and size of the charge’s cross-section significantly influence the stress wave parameters.

Multi-row short-delay blasting creates stress waves in the rock mass that propagate in all directions. During the interval between the explosions of two adjacent charge groups, a system of cracks forms in the rock mass due to the action of stress waves. An essential factor that improves rock fragmentation is the collision of rock masses during explosive destruction. This effect can be enhanced by employing various blasting schemes. Adjusting the spacing between boreholes can improve the technical and economic performance of drilling and blasting operations.

During the detonation of an elongated charge in a borehole, complex gas-dynamic processes occur. The methodologies for calculating drilling and blasting parameters currently in use, which serve as the basis for many software products, were developed in the last century. These methodologies lack rigorous theoretical justification and do not fully account for the real properties of the rock being fragmented. As a result, the parameters calculated using these methods are considered approximate and must be adjusted based on the results of experimental industrial blasts.

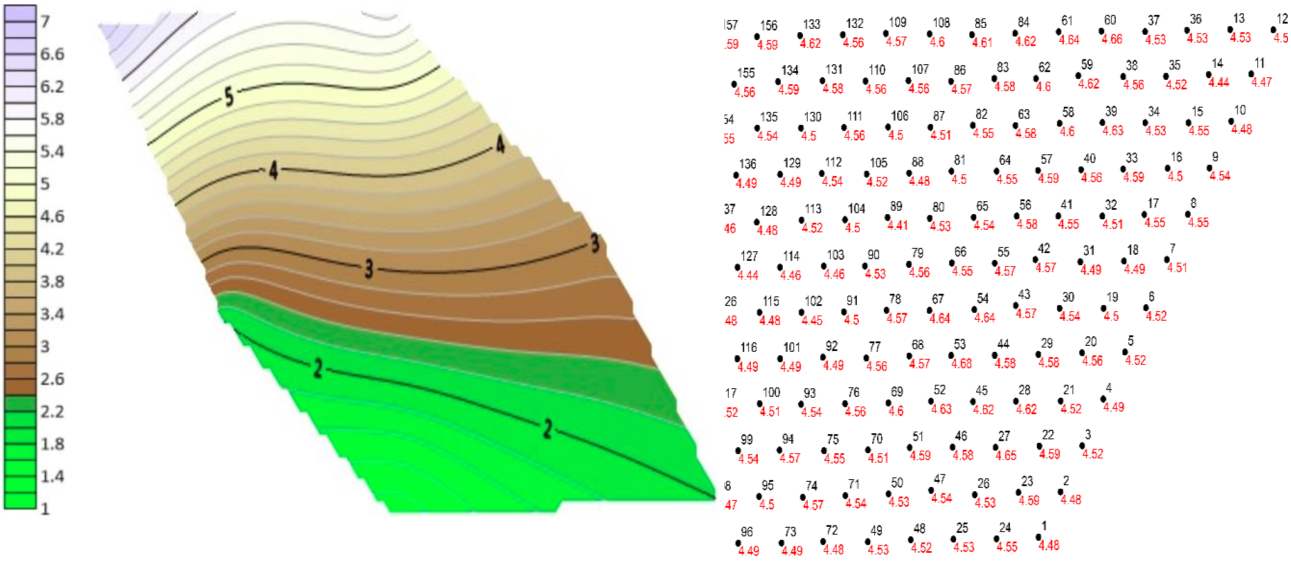
Drilling and blasting operations significantly influence technological processes, from the initial separation of rock from the mass to subsequent stages leading to the production of marketable products. In the mining of gold-bearing quartzites with complex morphologies, where heterogeneous layering of the deposit is observed, there is a risk of generating large volumes of oversized fragments. This leads to additional costs for re-blasting substandard rock masses.

To produce an objective forecast of the fragmentation composition, it is necessary to accumulate a substantial amount of statistical data from blast results. Reducing the output of oversized fragments is one of the most critical tasks addressed by optimizing drilling and blasting operations parameters. The highest proportion of oversized material typically forms along the separation line of the design block and near the first row of boreholes.

In works [4, 5], modern technical solutions and software products were presented, aimed at minimizing oversized material output and improving the arrangement of boreholes by considering the structural heterogeneity of the blast mass to achieve optimal blasting results. A comprehensive approach was outlined for enhancing the borehole drilling grid, taking into account the fracture intensity index obtained through digital solutions and specialized systems, which effectively reduced substandard fractions, as demonstrated in the example of the Tulallar deposit.

Knowing the fracturing and blockiness of the rocks comprising the bench, it is possible to adjust the placement of boreholes and arrange them in such a way that the designed drilling grid accounts for the identified characteristics of fracturing and blockiness. This factor is critical for achieving uniform rock mass fragmentation. The design parameters are aligned with the changes in the structure and type of rocks identified during surveying and mapping using GIS technologies.

Figure 1a shows the results of fracture analysis in a specific section of the deposit, where variations in fracture intensity are observed. The primary indicator for quantifying fracture intensity is the specific fracture density, determined from measurements conducted on different sections of the quarry. Zoning was carried out based on averaged specific fracture density values, and the rocks were categorized according to their fracture intensity. Accordingly, the classical diagonal borehole drilling grid, depicted in Figure 1b, was modified to account for natural fracturing.



a) b)

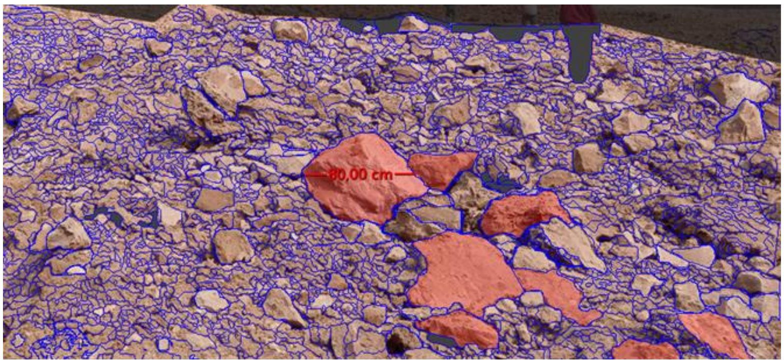
Fig. 1. a – Specific fracture density, m^{-1}; b – Borehole drilling scheme, where the total number of boreholes is 258, the borehole diameter is 102 mm, the average borehole length is 5.5 m, the distance between boreholes is 2.5 m (horizontal) × 3.0 m (between rows), and the diagonal spacing is 2.92 m

As a result, drilling and blasting operations processes were improved by optimizing the borehole drilling scheme, which accounted for the natural fracturing of the rock mass. This optimization resulted in the transition from a uniform blasting grid to a zonal scheme. The zonal mass blasting approach proved to be technologically advantageous, as adjusting the drilling grid based on rock fracturing reduced the drilling volume by 6%. Subsequently, an assessment of the fragmentation of the blasted rock mass was conducted in the field conditions. The granulometric composition analysis of the blasted rock mass was performed by processing photographs taken directly on the bench after the drilling and blasting operations using a mobile device.

During the experimental blasts, four key parameters were identified and considered: natural fracturing, the spacing between boreholes, the delay interval between rows, and the configuration of the charge in the borehole. The combination of these parameters was selected based on prior research [6, 7]. As a result, areas with varying fragmentation of the blasted rock mass were obtained, as illustrated in Figures 2 and 3.

Based on the data obtained from photographic analysis, the distribution of the granulometric composition of the blasted rock mass was constructed. The following parameters were recorded: the average size of rock fragments in the blasted mass, the percentage of oversized fractions, and the uniformity index of the fragmentation distribution. The size limit for oversized material was determined based on the specifications of the crushing equipment. In this case, fractions larger than 60 mm were classified as oversized.

The data collected regarding the granulometric composition before and after implementing the proposed solutions to adjust borehole spacing according to specific fracture density are presented in the graphs in Fig. 2 and Fig.3.



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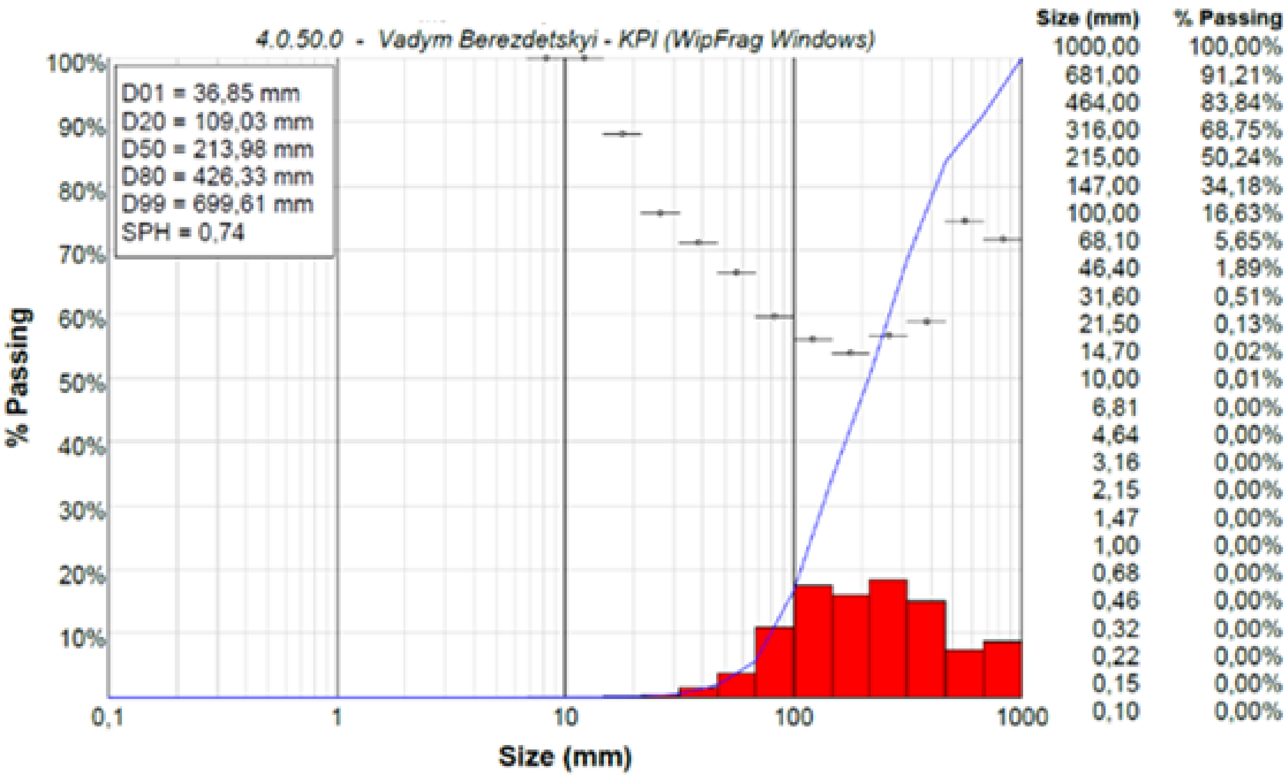
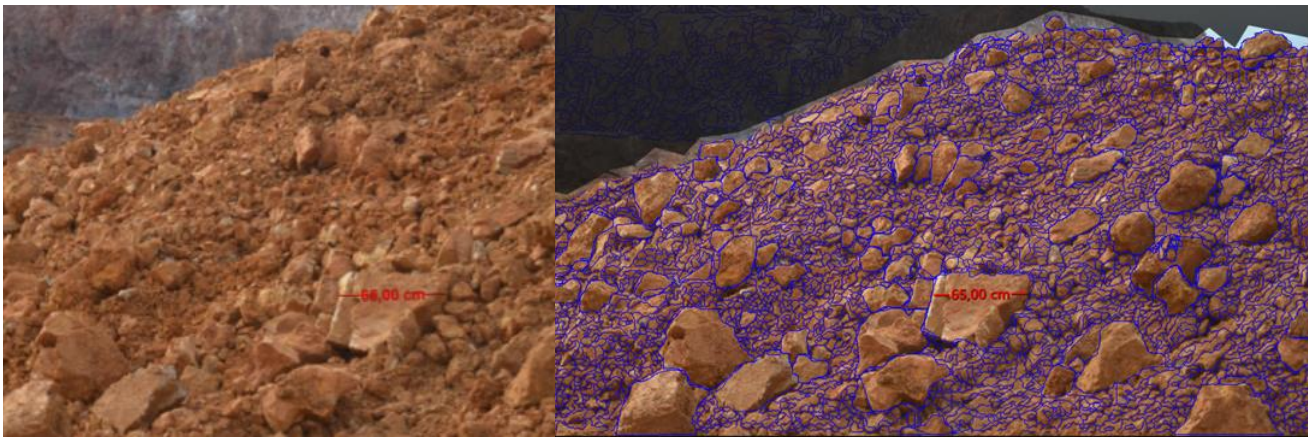


c)

Fig. 2. a – Photograph of the site; b – Image processing according to the selected standard; c – Analysis of the granulometric composition distribution of the blasted rock mass (9%)



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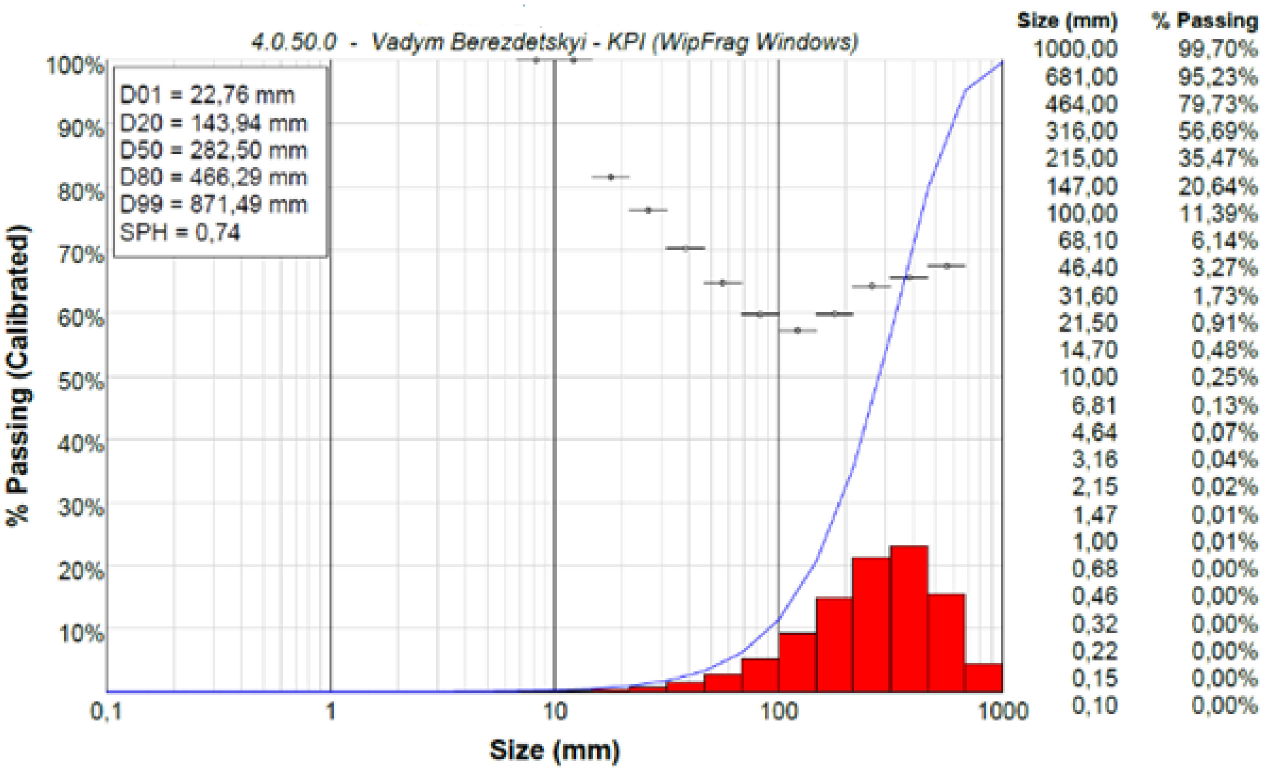

c)

Fig. 3. a – Photograph of the site; b – Image processing according to the selected standard; c – Analysis of the granulometric composition distribution of the blasted rock mass (5%)

Conclusions. Significant progress has been achieved over the last three decades in developing new blasting technologies. These advancements include increasingly sophisticated computer models for blast design and performance prediction. Rock fragmentation is considered the most critical aspect of production blasting due to its direct impact on drilling and blasting costs, as well as the economics of subsequent operations such as loading, transportation, and crushing. Unfortunately, rock fragmentation depends on numerous variables, including rock mass properties, site geology, fracture parameters, and blasting parameters, and therefore lacks a comprehensive theoretical solution for its prediction.

The development of technical solutions to enhance understanding of the rock fragmentation mechanism through explosives, drilling equipment improvements, and evolution in developing new explosives and blasting accessories are ongoing. The use of modern fragmentation analysis methods in field conditions enables rapid, accurate, and cost-effective measurement of fragment sizes resulting from blasting operations. Advanced granulometry analysis methods using the WipFrag software package offer a powerful tool to optimize quarry blasting operations and minimize costs.

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АНОТАЦІЯ

Мета. Удосконалення технології аналізу фрагментації підірваної гірничої маси безпосередньо на уступі після проведення буро-вибухових з використанням програмного забезпечення WipFrag ™ 4.

Методика. Методика дослідження використовує систему визначення розміру фрагментації WipFrag для оцінки ефективність процесу подрібнення гірничої породи вибухом. В роботі представлено переваги методології оптичних градацій. Градаційні вимірювання дозволяють автоматизувати процес оцінки фракційності, усуваючи суб'єктивність ручних вимірювань. Не потрібно переривати виробничі процеси, а результати доступні в дуже короткий час, що дозволяє своєчасно коригувати методи виробництва. Використання оптичних методів дозволяють аналізувати великі об'єми породи з розширеною вибіркою і збільшенням кількості зразків.

Системи фотоаналізу є практичним та корисним інструментом для вимірювання ефективності вибухових речовин у руйнуванні породи.

Отримані результати дослідження. Результати дослідження можна використовувати для оптимізації параметрів вибухових робіт з метою зниження витрат. У гірничодобувній промисловості результати можна використовувати для моніторингу та оптимізації фракційності, зменшення негабариту, який може призвести до надмірного перенавантаження транспортної системи та дробарного обладнання.

Наукова новизна. Запропоновано методику дослідження, з використанням автоматизованої системи цифрового аналізу зображень розвалу породи після проведення буро-вибухових робіт. Цифровий аналіз зображень ефективний для визначення розподілу зерен за розміром та розширює можливості застосування емпіричних режимів калібрування.

Практичне значення. Нова технологія фотоаналізу надає багато можливостей для діагностики проблем утворення негабариту, підвищення продуктивності буро-вибухових робіт, зменшення витрат та оптимізації процесу вибухового подрібнення гірської маси.

Ключові слова: *негабарит, фрагментація, вибухове подрібнення, цифрове зображення, фотоаналіз, програмне забезпечення WipFrag* .