The analysis and assessment of grain size distribution on the example of a chosen granite mine

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Abstract. The rock blasting is the first phase of production in the surface and underground mining operations. Because blasting works affect the efficiency of every activity that follows it, they are considered to play a significant role in the whole mining process. Furthermore, it is stated that the most significant parameter is an ore material fragmentation. Information about particle size distribution is relevant from blasting methods point of view. It enables not only to examine the results of blasting operations but also to select proper parameters of blasting operations. This paper presents the analysis and the assessment of grain size distribution of blasted rock in open pit granite mine using the indirect image analysis method. The photogrammetric techniques and the Split Desktop 4.0 computer application were used to perform the research. The photographic documentation of the entire blasted muck pile was prepared in two variants: the first one after blasting operations and the second one after removing 50% of the blasted ore material. Moreover, the whole process of preparing photographs, scaling and delineation are discussed as well as results generated by Split Desktop 4.0. The main objective of the paper is to determine the particle size distribution and the percentage share of oversized fraction both in two variants individually and in the entire blasted muck pile. As a result of the analysis, some relationships between particle size distribution and blasting operations parameters are outlined. The obtained values of size distribution analysis of the rock fragmentation may play a significant role in the blasting operations optimization in the analysed granite mine.

1. Introduction

Nowadays, the stone quarrying by blasting not only needs to lead to effective rock fragmentation but also must ensure the safety and minimize explosives’ negative impact on the environment [1]. The basis for conducting the analysis of the effectiveness of the blasting technique is a relatively precisely determined ore granulation after blasting. Achieving optimal rock fragmentation plays a significant role in loading, transporting and processing machines selection and in the entire technological system synchronization as well [2]. The wide range of factors influences the quality of grain size distribution. They can be divided into two main groups. The first one is related to blasting techniques such as blasting design and patterns, the explosives properties and delay times in blasting. The second one corresponds to particular geological and mining conditions both in surface and underground mining [2, 3].
The analysis of grain size distribution may be conducted using two separate methods: direct and indirect ones [1,4]. However, indirect methods which employ empirical relationships and are computer aided by engineering programs are increasingly used [4]. The significant role play photogrammetry techniques widely used in surface and underground mines [5–7]. It should be noted that the photogrammetry technique based on the analysis of photographs of a surface of the blasted muck pile. In order to obtain more reliable results of the analysis of blasting operations, it is needed to examine the rock material which is inside the blasted material. Literature indicates numerous examples of evaluating grain size distribution of the material on belt conveyors or in the box of haul trucks [5,8]. A particularly accurate method of assessing the grain size distribution was proposed in [9] in which the photographic documentation was carried out in two stages: after blasting rocks and after removing around 50% of the blasted muck pile. The assessment of grain size distribution enables to monitor and evaluate effects of blasting and it is a tool which supports the selection of explosives to geological and mining conditions [10–13].

According to the literature review the analysis of grain size distribution for blasted material in granite mine was carried out with the use of photogrammetry technique and the Split Desktop 4.0 computer application.

2. Research methodology
The research was conducted in ‘Wieśnica’ granite mine belonging to Berger Surowce Sp. z o. o. The Wieśnica granite deposit is the basic source in Poland of aggregates for concrete, asphalt, road and bridge constructions. Based on the geological documentation [14], it was determined that the granite which builds the "Wieśnica" deposit represents monzonite granites and it is medium-grained and coarse-grained, light grey, dense and random texture rock.

Blasting was carried out in the granite bench. The holes were drilled in a triangular pattern (figure 1) and 40 boreholes were distributed in 3 rows. The blasting operations with parameters presented in table 1 were initiated with the use of 17, 25, 42 and 67 ms delay times. The visual result of the fragmentation is shown in figure 2.

| Borehole diameter | Hole length | Borehole inclination | Burden | Spacing | Stemming length | Sub-drill |
|-------------------|-------------|----------------------|--------|---------|-----------------|----------|
| mm                | m           | °                    | m      | m       | m               | m        |
| 89                | 18          | 5                    | 3      | 3       | 2,8             | 0,5      |

Table 1. Blasting parameters.
After the blasting operations were completed the photo documentation of the entire muck pile was prepared in accordance with [15,16]. Photographs were taken in a sequential manner, dividing the muck pile into 5 sectors (figure 3). According to the recommendations described in [15], sectors should slightly overlap in order to minimize the possibility of repeatedly analysing the same part of the blasted material. The sectors have been compacted in the middle part of the muck pile because of the high variability of the rock fragmentation there. As a result, it enables to increase the level of accuracy during the delineation of rock fragments process performed by the program.

![Figure 3. The sector division of the muck pile](image)

Five photographs were taken for every sector in two variants: after blasting operations and after removing the 50% of the blasted muck pile. Besides the high quality of photographic documentation, the rock contours were identified incorrectly with the use of automatic delineation tool. To improve the delineation results, the photographs were edited i.e. the contrast, clarity and illumination of the images were increased (figure 4). The next step was to scale the photographs with principles in [16]. The scale was defined by an object of known dimensions. In this case, two basketballs, which diameter is 180 ± 0,5 mm, were used.

![Figure 4. The example of quality change in photograph](image)
Subsequently, the automatic and manual editing tools were used to delineate rock particles. Firstly, the rock contours were identified. Secondly, the areas in which no solid bodies are found were excluded and marked in sky-blue colour. In this case, they were scaling objects and the part of the mined wall. Thirdly, the locations of rocks particles were too fragmented to be identified by the software which was marked in red colour. To determine the percentage share of fractions in red the Gaudin-Schumann distribution was used. The result of the delineation process is presented in figure 5.

![Figure 5](image_url)

**Figure 5.** The delineation process results for two variants a) after blasting operations; b) after removing 50% of the muck pile

3. **Results and discussions**

Generally, the result generated by the Split Desktop 4.0 software is a particle size distribution curve, which shows the percentage shares of individual fraction size. In this analysis, the grain size distribution curves were generated for every sector for two variants: after blasting operations and after removing 50% of the muck pile.

![Figure 6](image_url)

**Figure 6.** Particle size distribution for 5 sectors for the 1\textsuperscript{st} variant
As it is presented in figure 6, there are oversized rock fragments (fraction above 700 mm) in every analysed sector. Although the presented curves are very similar for fraction 0-100 mm, the relevant differences in particles size distribution for fractions above 100 mm are observed. The results for sectors from the central part of the blasted muck pile (sector 2, 3 and 4) are comparable while boundary sectors (sector 1 and 5) differ significantly. The most noticeable difference occurs for oversize fraction which accounts for 37.7% of all fractions in sector 1 and 5.11% in sector 5. Additionally, the biggest oversized rock fragment whose size was around 1484.11 mm appeared in sector 1. The value is more than twice the minimum value for the oversized fraction. Moreover, the decrease in the number of oversized rock fragments with subsequent sectors.

The blasting operations could have a direct impact on the described relationships, and the significant difference between sectors 1 and 5 could result from the blasting direction and firing pattern. Blasting initiation towards sector 1 could have a relevant impact on the amount of oversized fraction in this area. The lack of explosives in the stemming area caused large amounts of oversized rock fragments located on the surface of the analysed blasted muck pile.

Figure 7. Particle size distribution for 5 sectors for the 2nd variant

The results of the analysis of rock fragmentation for sectors 1 - 5 after removing about 50% of the blasted muck pile presented in figure 7 are characterized by a greater degree of matching of results than for the analysis immediately after blasting operations. The very little difference in fragmentation of ore material between 1 and 3 sectors and between 4 and 5 sectors is observed. Moreover, presented curves of grain size distribution are nearly identical for fraction 0-100 mm for all analysed sectors. When it comes to oversized rock fragments, they are not observed in sectors 4 and 5 but they appear in sector 2 in which they account for 4.25% of all fractions (the biggest one’s size is 933.21 mm). It is worth noting that the point 400 mm is a characteristic one because, in every sector, there is a relatively small number of fractions above 400 mm in relation to the other ones.

Figure 8 presents the comparison of the grain size distribution for chosen sectors in two variants. The angle between a curve for the second variant and the x-axis is larger than for the first variant in every analysed sector. The most significant difference, which value is estimated around 42.18% for 400 mm size fraction, between the variants is observed for sector 1. To compare, its value is around
24.76% for sector 3. In addition, a fraction above 1000 mm does not appear in sector 4 and 5, which is crucial for the crushing processes. In a result, the analysis proved that the oversized fraction accounts for less than 15% of all the fractions in every sector. The results for the rest of the sectors are presented in [17].

![Graphs](image)

**Figure 8.** Particle size distribution for the 1\textsuperscript{st} and the 2\textsuperscript{nd} variant in a) sector 1, b) sector 5

The last but not least stage of the research was to analyse average values of individual fractions in every sector for two variants and average curve of the particle size distribution for the entire material from the blasted muck pile. As it is shown in figure 9, the percentage share of oversized particles is around 11.49% for variant 1 and 2% for variant 2. Eventually, the percentage share of oversized rock fragments was estimated at 6.75% in the entire blasted muck pile.

![Graph](image)

**Figure 9.** Particle size distribution for average values from the 1\textsuperscript{st} and the 2\textsuperscript{nd} variants and the average particle size distribution for the entire blasted muck pile
4. Conclusions

Presented analyses of the rock fragmentation after blasting were carried out for ‘Wiesnica’ granite mine with the use of indirect photogrammetric technique and Split Desktop 4.0 software. The research was carried out in two variants: after blasting operations and after removing 50% of blasted muck pile.

The following conclusions are drawn from the above study:

- The presented investigation was done on the basis of the single blast. The applied photogrammetric technique allowed to a comprehensive analysis of the particle size distribution. However, the more general conclusions about the quality of used blast layout and blast parameters could be done upon the analysis of a series of blasts which would provide the necessary statistical data.
- The relevant differences in the particle size distribution were proved for two analysed variants. The fragmentation of rock is significantly lower in variant 1 than in variant 2. It results from the stemming height in which no explosives are used. Moreover, the percentage share of oversized rock fragments (fraction above 700 mm) is around 11.50% of the ore material in variant 1.
- A significantly higher percentage of the fine fraction for variant 2 was noted. The justification for the situation may be the penetration of fine material through the spaces between larger rock fragments.
- The analysis of the average curve of the particle size distribution for the entire blasted muck pile indicates that the most common fraction is a middle one and the percentage share of oversized rock fragments is acceptable (the value is 6.75%). It seems that the parameters of blasting and geological and mining conditions are taken into account during the blasting operations.

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