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Analysis of blasted rocks fragmentation using digital image processing (case study: limestone quarry of Abyek Cement Company)

Alireza Tavakol Elahi and Mehdi Hosseini*

*Correspondence: meh_hosseini18@yahoo.com
Department of Mining Engineering, Imam Khomeini International University, Ghazvin, Iran

Abstract

One of the inseparable parts of mining activities is blasting which one of its important outcomes is fragmentation. Fragmentation is the first result of blasting that is directly related to the mining costs. There are various methods for determining the degree of fragmentation which are divided into two groups, direct and indirect methods. Among direct methods, sieve analysis and, among indirect methods, observational, empirical and digital image processing methods may be referred. In this study, which dealt with the amount of fragmentation in Pir Ali limestone mine, the digital image processing method and Split Desktop software that is the most efficient software in this respect were used. Three blocks with different blast patterns were analyzed to study the fragmentation phenomenon and, ultimately, the F_{20}, F_{50} and F_{80} and top size values for each block were obtained separately. Outputs of the Split Desktop software were obtained in tabular form as well as cumulative grain-size curves. The F_{80} values for the 2.5 × 2.5 m, 2 × 2.5 m, and 2.5 × 3 m patterns were approximately 65.8, 56, and 70 cm, respectively. Finally, outputs of Split Desktop were compared to the results of the Kuz-Ram experimental model. The F_{80} values obtained for the 2.5 × 2.5 m, 2 × 2.5 m, and 2.5 × 3 m patterns were 54.9, 43.5, and 62.03 cm, respectively, which were in close agreement with the outputs from the software. It can be concluded that the closer F_{80} of the blasted rocks to the crusher entrance (60 cm), reduced the production costs, which is an outcome practically realized for the 2.5 × 2.5 m pattern.

Keywords: Blasting, Fragmentation, Abyek cement, Digital image processing, Split Desktop software

Introduction

Blasting is the most efficient way of drilling for extraction of hard rocks. In open-pit mines, the bench blasting method is used for in situ lifting of rocks and their crushing to the desired size. At the time of determining design factors, the most effective way of achieving the desired fragmentation is selected [1]. Fragmentation degree plays an important role in control and reduction of loading, transportation, and crushing expenses [2]. Blasting is the first step to reduce rock size, which is followed by the crushing and grinding phases. The efficiency of these operations depends on size distribution of blasted rocks. Therefore, measurement and analysis of fragmentation of blasted rock masses are highly essential [2].

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Many methods are available for assessment of blast fragmentation. These methods are generally divided into the direct and indirect categories. The direct group includes the sieving analysis method, while the indirect group includes observational, experimental and image analysis methods [3, 4].

The following mechanism is applied using the image analysis method to determine grain-size distribution: selecting the sampling site, imaging, and image analysis. The sampling phase involves selection of sites to obtain samples that represent the blasted rock mass. In the imaging phase, high quality images, which can be analyzed in the analysis phase, are prepared. In the last phase, the size distribution of fragments marked on the image is measured after drawing the perimeter of fragments on the image [3].

One of the advantages of the image analysis method is that there is no limitation on the mass size and volume. Samples (images) are prepared quickly and do not disrupt the production process. Moreover, the results could be analyzed quickly, based on which the parameters of the blast pattern can be optimized. Considering the ease of sampling, a large number of images can be prepared so as to reduce analysis error. The price of equipment required for this method is also more affordable. As a disadvantage of this method, the domain of initial information is dependent on the mass surface. Hence, the sample should be obtained from a reference surface. On the other hand, high quality images should be prepared for the purpose of precise detection of fragments and reduce errors. Although pointer-aided manual edge detection is precise, it is highly time consuming. Another problem is extraction of accurate three-dimensional information from two-dimensional images which calls for formulation of hypotheses for the third dimension of fragments [5].

Some of the programs for this purpose are Gold Size, Wip Frag, Wip Frag Online, Split Online, and finally Split Desktop, which is the most recent software for this purpose. Digital image processing programs are basically operated the same way, therefore, it is only some unique features which makes the distinctions between these programs.

The biggest advantage of an online system is its ability to display real-time measurement results, which can consequently be used to quickly transmit information to control systems, allowing them to process the data online. In this research, the Split Desktop image analysis software was used to study fragmentation. Split Desktop is the latest digital image processing software, featuring advantages such as a more user-friendly interface compared to its previous versions. Moreover, results of this software are more accurate and involve less error. Due to these features, various projects in this field, including this research, are carried out using Split Desktop worldwide.

Four of the many applications of this software are pointed out in the followings.

The first application involved measurement of size distribution of the fragmented blasted rock mass in Dewan limestone quarry of Karachi (Pakistan) to assess efficiency of blasting operation. Results of image analysis indicated that the mean size of particles was 149.76 mm and the P_{20}, P_{80}, and size of the largest particle were 11.66, 426.310, 1057.44 mm, respectively. The primary crusher installed in the mine accepted 1000 mm feeds and produced a product of less than 30 mm size. Almost 25% of the fragments had a size of less than 30 mm and did not need crushing as they easily passed through the primary crusher's sieve. Moreover, results indicated that only 1% of crushed fragments had a size of over 1000 mm and needed secondary fragmentation [2].

The second case involved measurement of fragmentation using Split Desktop in Goltas limestone quarry. To capture images from the crushed rock mass, a digital camera was used, and scaling was carried out with two balls with diameters of 254 mm. The uniformity index was $n = 0.79$ and the mean size of fragments ($S_{50} = 37.5$ cm) showed the high percentage of boulders in the rock mass. Therefore, the burden thickness and spacing of blast holes were reduced to $B = 3$ m and $S = 3.5$ m, respectively. This change in pattern led to a mean fragment size of 24 cm [6].

In the third case, the mean fragmentation size of the blast-produced mineral was estimated using the modified Kuz-Ram model in Zone 5 of Rashkan limestone quarry. Following the blasting, using the image analysis method in Split Desktop, which is the latest and most efficient software of this kind, the grain size curve and average size of crushed fragments were obtained. In the course of analysis of grain size in this software, the frequency of grain sizes was calculated, and the mean rock size was determined based on the results. Afterwards, results of analysis of all images were combined in the software. The mean weighted size of rocks resulted from image analysis on zone 5 of Rashkan quarry was 11.42 cm. The output of the modified Kuz-Ram model was 9.52 cm, which was smaller than the result of the image analysis method [7].

In the fourth case, the effect of explosive variations on degree of fragmentation in Lalahan limestone quarry in Turkey was examined. The first blasting took place with ANFO and the second blasting was carried out using BARANFO 50. The mean P_{20}, P_{50}, P_{80} and top size values in the second blasting were 2.52, 1.93, 2.05, and 1.94 times less than the first blasting, respectively. The mean sizes of fragments in the first and second explosions were 23.08 and 11.96 cm, respectively. Hence, smaller fragments were obtained with BARANFO50 because the shock wave of this explosive was 55% bigger than ANFO. Research results revealed that variations in blast design parameters significantly influence fragmentation [8].

Implementation of projects of this kind is among the most essential measures needed to be taken in every mine. The objective of this project was to study the degree of fragmentation of limestone in Pir Ali Quarry of Abyek cement, which supplies the feed of this plant directly.

Materials and methods

An introduction to Split Desktop

Split Desktop is designed for analysis of digital images obtained from digital camera and for determining blast-induced fragmentation gradation distribution. The more basic version of this software was developed with the 10-year effort of a research team from the mining engineering and earth sciences Department of Arizona University in the United States. Currently, the latest release of this software available in the market is version 3.1, with improvements compared to the older versions. This software provides for manual and automatic segmentation of fragments as well as editing of segments manually and automatically.

The difference between this software and other image analysis programs lies in features that facilitate its use and reduce some errors considerably. Some of the advantages of this software are as follows [7].

1. Possibility of applying three scale bodies on the image;
2. Possibility of changing resolution of images in the software;
3. Possibility of working with common and various extensions for digital images such as tiff, jpg, and bmp;
4. Possibility of determining the zones of fine materials and areas that do not require analysis;
5. Possibility of fusing the resulting size distribution diagrams of each image as a project in the software and presenting the final size distribution curve of the project;
6. Possibility of magnifying the image and automatic segmentation of fragments;
7. Possibility of exporting final results to Excel and conducting further analyses on the results using a shortcut key in the software.

Split Desktop involves five main phases of analysis for each image. The image is scaled in the first stage. The second stage is dedicated to segmentation of rock fragments in each image. In the third stage, the permission for editing the desired rock fragments is issued to ensure precision of results. The fourth stage involves analysis of rock fragments marked in the image. Finally, in the fifth phase the size distribution results are displayed in the form of diagrams [9].

Images used in this software should meet the following requirements [2]:

1. The imaging method should be practically the same for all samples.
2. Images should cover the whole range of dimensional spectrum of fragments (including large- to fine-sized fragments).
3. Images should be obtained such that they lack any shade and benefit from uniform lighting.
4. At the time of imaging, the camera lens shall be placed as normal as possible to the fragmented rock mass.

The images may be obtained from a crushed rock mass, the minerals-carrying truck, damped wastes, mine repository, moving conveyor, or any other situation that may provide clear images of rock fragments [9]. In this research, version 3 (developed by Split Engineering LLC in 2010) of this software was used.

Limestone quarry of Abyek Cement Plant

Abyek Cement Plant is one of the biggest industrial units of Iran located in Abyek District of Alborz Province. Abyek District is located at northern latitude of about 36.4° and eastern longitude of about 50.45°, at a 50 km distance from Karaj township on the roadside of Tehran–Qazvin highway in Alborz Province. The elevation of the plain at which the factory was located, was about 1300 m above sea level.

One of the factors in the success of this company is its use of low-cost and high-quality raw materials, which are available in its neighboring areas. These materials are supplied by the mine adjacent to the plant, which is called the Pir Ali Mine [10].

Drilling of explosion blast holes in Pir Ali limestone quarry of Abyek Cement Plant is carried out using five drilling machines (including two semi-hydraulic, two pneumatic, and one Russell drilling machines). The benches in this mine generally have a height of

8 m, and blast holes with a diameter of 76 mm and length of 9 m are bore to blast these benches. The sub-drilling is assumed to be 1 m.

To apply primers into blast holes, Emulite with diameters of 27 and 45 mm are used. Considering the blast pattern, the primers are distributed differently in the blast holes. Moreover, ANFO is used as the main charge, while electric detonators are used in each Blast holes to blasting. On small sites, the blasting pattern is arranged in series and on large sites it has a series–parallel arrangement. To start blasting, the first-row blast holes are blasted with detonators no. 1 and or 2, and then the blast holes in the next row are blasted with a 2-unit delay. The delay between 2 consecutive detonators is 25 ms. A delay of 0.05 s is applied to ensure the efficiency of explosion between two rows of blast holes and to improve fragmentation.

Figure 1 shows the site following the blasting.

Results

Recording results of processing and analyzing information on blasted rock fragments

To study the fragmentation of blasted rocks in Pir Ali Limestone Quarry of Abyek Cement Co., a total of three blasted blocks were analyzed.

The feed for Abyek Cement Plant's crusher includes 60 cm fine rocks and rocks larger than 60 cm. The latter rocks are known as boulders and need secondary fragmentation with jackhammer. Secondary fragmentation brings about additional costs, and thus the pattern specified for each blast operation should be designed such that more desirable fragmentation and the highest efficiency are obtained at low drilling and blasting costs.

A total of three blocks were analyzed. In the first block, the burden thickness was 2.5 m and longitudinal spacing of blast holes was 2.5 m. In the second block, the burden was 2 m and longitudinal spacing of blast holes was 2.5 m. In the third block, the burden was 2.5 m and longitudinal spacing of blast holes was 3 m. Except for the values of burden thickness and longitudinal spacing of blast holes, other parameters of drilling pattern and blasting were the same for the three blocks. In each of the images obtained

Fig. 1 The site after blasting (Pir Ali Quarry)

after blasting using a digital camera, two plastic balls with a diameter of 170 mm were selected as scale bodies.

Table 1 presents the data on the drilling pattern of the three initial blocks.

Table 2 presents the data on blasting and explosives used in the process.

Results of analyzing fragmentation of five blocks in Split Desktop are shown in Table 3. In this table, values of F_{20}, F_{50}, and F_{80} obtained from analysis of images of the first block are listed.

Block no. 1 contains high-quality limestone and has relatively desirable geological and tectonic conditions as well as joints and cracks. As seen in Table 3, the final F_{80} is 658.24 mm, which is very close to the entrance of the crusher, i.e. 60 cm. Therefore, the suitable blasting conditions in this block could be identified based on figures resulted from analyses.

The pattern was changed in block no. 2 based on experiments of the previous block. In the new pattern, the burden thickness was 2 m and longitudinal spacing of blast holes was 2.5 m. The only difference between this pattern and patterns of previous blocks is that the burden thickness is reduced by 0.5 m. According to this pattern, the blast holes are closer than before and the number of blast holes in the block increases consequently. In block no. 3, the new blast pattern has a burden thickness of 2.5 m and longitudinal blast holes spacing of 3 m.

Table 1 Data on drilling patterns of three blocks

Row	Parameter	Value	Standard deviation
1	Blast holes diameter (mm)	76	–
2	Average stemming length of blast holes (m)	2.25	0.2
3	Bench height (m)	8	0.5
4	Specific drilling (m/ton)	0.06	–
5	Sub-drilling (m)	1	0.7

Table 2 Blasting and explosives data

Row	Parameter	Value	Standard deviation
1	ANFO per blast holes meter (kg)	4	–
2	Electric detonator (quantity)	126	–
3	Delay between rows (ms)	25	–
4	Average charging length in blast holes (m)	6.75	0.34
5	Charge in each blast holes (kg)	27	1.5
6	Emulite use per rock ton (kg)	0.005	–
7	Specific charge (kg/ton)	0.2	–

Table 3 Values of F20, F50, and F80 for the first block

Percent passing	Size (mm)
F_{20}	112.64
F_{80}	316.84
F_{80}	658.24

Table 4 shows the values of F_{20}, F_{50}, and F_{80} obtained from analysis of images of blocks no. 2 and 3.

Analysis of the F_{80} value obtained from fragmentation analysis of block no. 2 indicates that this value is equal to 568.15 mm, which is smaller than the crusher's entrance (60 cm). Although this pattern yields a suitable F_{80} value, it increases drilling costs by adding to the number of blast holes, which is not economically desirable. Moreover, an increase in the specific charge leads to excessive back break in the last row of blast holes and escalation of vibrations. Due to the proximity of Pir Ali limestone quarry to Hiv City, these results are not desirable and cause safety problems.

As a result of the new pattern for block no. 3, the F_{80} value rises to 70 cm and numerous boulders are formed to the point that many coarse aggregates remain in their place and form plenty of summits. The resulting boulders cause problems in the loading of crushed blasted rock and their secondary fragmentation.

Figure 2 depicts the cumulative grain-size curves obtained from analysis of the five images of block no. 3. The final cumulative grain-size curves of block no. 3 can be seen in Fig. 3.

Comparing results with results of Kuz-Ram experiential model

In this section, results of digital image processing are compared to results of the Kuz-Ram experiential model. Equation (1) is used for this purpose [11].

$$X_{50} = A \times [PF]^{-0.8} \times Me^{0.167} \times \left(\frac{115}{RWSanfo}\right)^{0.633} \tag{1}$$

where X_{50}: Mean size of fragments (m); PF: Specific charge (kg/m^3); Me Charge mass per blast holes (kg); RWS_{anfo}: The relative weight strength of the explosive to ANFO (%); A: Rock coefficient, which is assumed to be 10.

Equation (2) is used for size distribution curve.

$$R(X) = 1 - e^{-\left(\frac{X}{X_c}\right)^n} \tag{2}$$

Uniformity index and characteristic size were calculated via Eqs. (3) and (4).

$$n = \left(2.2 - 14\frac{B}{d}\right)\left(\frac{1 + \left(\frac{S}{B}\right)^{0.5}}{2}\right) \cdot \left(1 - \frac{E_p}{B}\right) \cdot \left(\frac{L}{H}\right) \tag{3}$$

Table 4 Values of F20, F50 and F80 for blocks no. 2 and 3

Percent passing	Block no. 2	Block no. 3
F_{20}	132.57	181.31
F_{80}	297.51	412.99
F_{80}	568.15	700.03

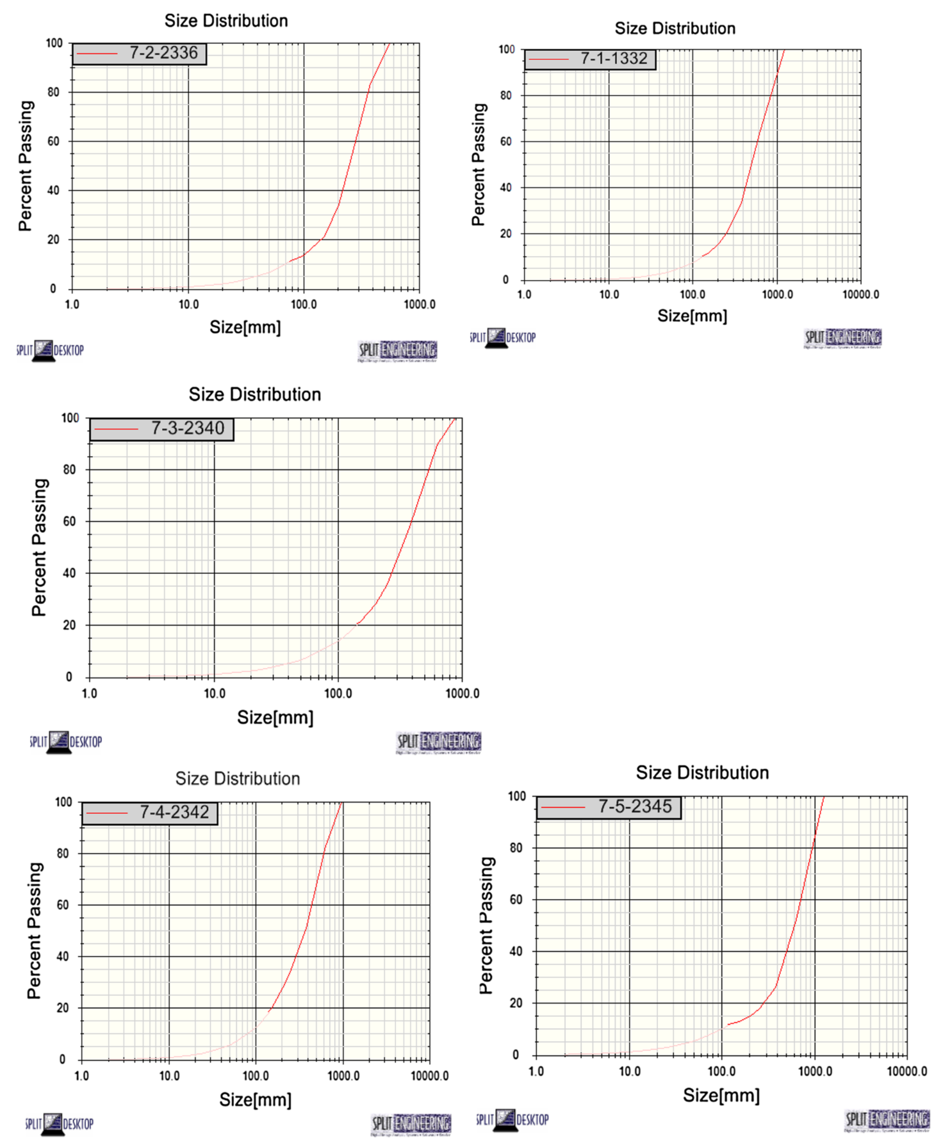

Fig. 2 Cumulative grain-size *curves* of block no. 3

$$X_c = \frac{X_{50}}{(0.693)^{\frac{1}{n}}} \tag{4}$$

where L: is the charge length (m), H: is the bench height (m), S: is longitudinal spacing of blast holes (m), B: is burden (m), d: is blast holes diameter (mm), and E_p: is blast holes deviation [11].

Table 5 presents results of the Kuz-Ram experiential model.

The semi-logarithmic diagram obtained from the Kuz-Ram experiential model and the diagram resulted from digital image analyses in Split Desktop are shown in Figs. 4, 5 and 6 for the three patterns.

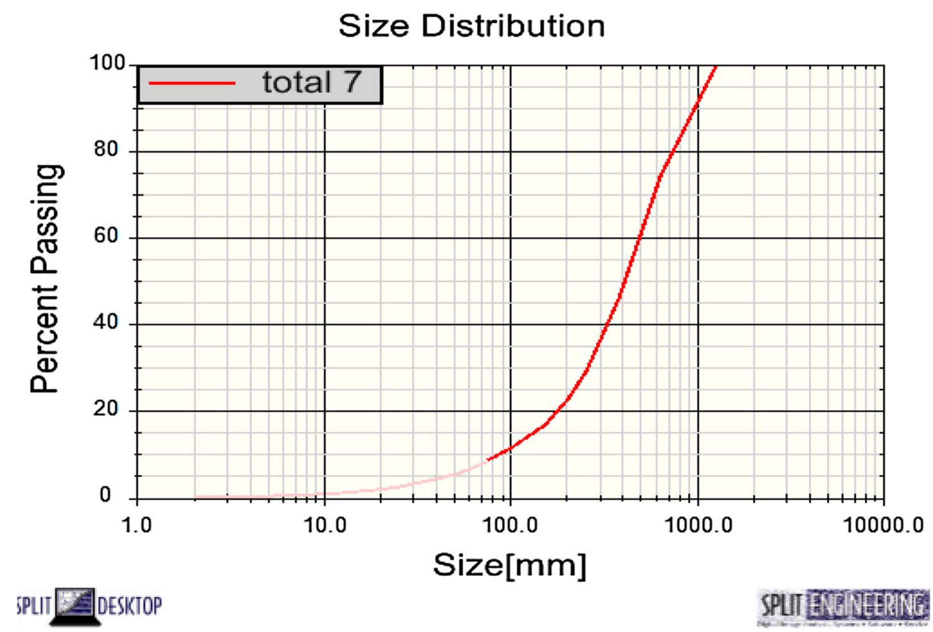

Fig. 3 Final cumulative grain-size *curves* of block no. 3

Table 5 Results of the Kuz-Ram experiential model

Percent passing	2 × 2.5 m pattern	2.5 × 2.5 m pattern	2.5 × 3m pattern
F_{20}	12.9	14.32	17.08
F_{80}	25.9	30.96	35.82
F_{80}	43.5	54.9	62.09

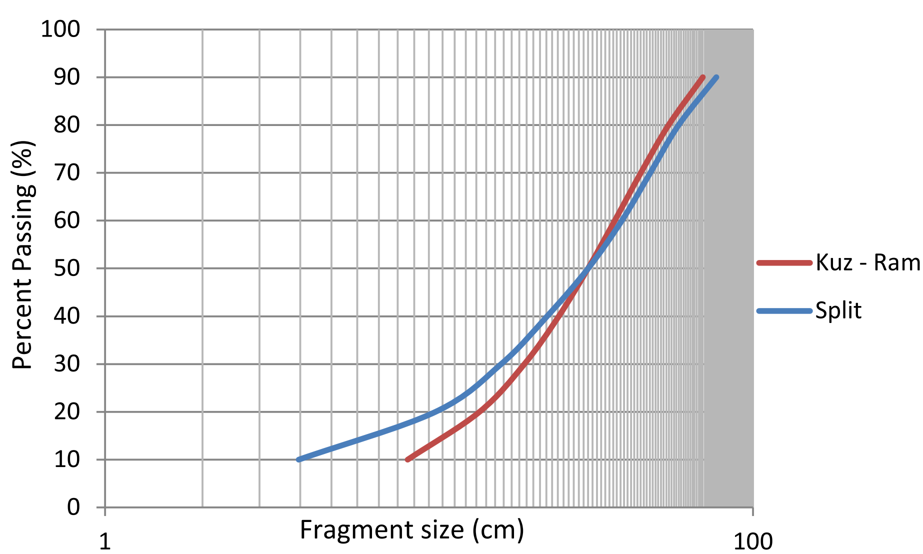

Fig. 4 Diagram obtained from the Kuz-Ram experiential model and digital image analysis in Split Desktop for pattern No. 1

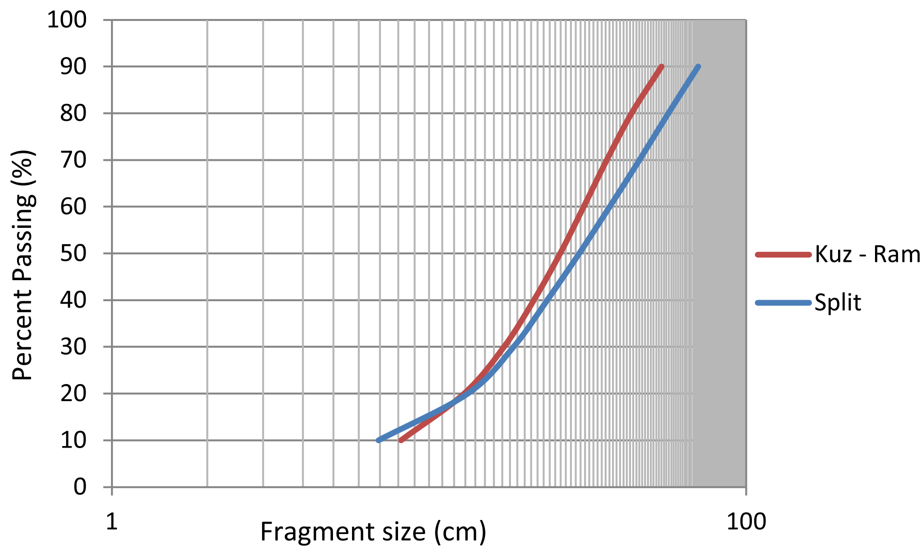

Fig. 5 Diagram obtained from the Kuz-Ram experiential model and digital image analysis in Split Desktop for pattern No. 2

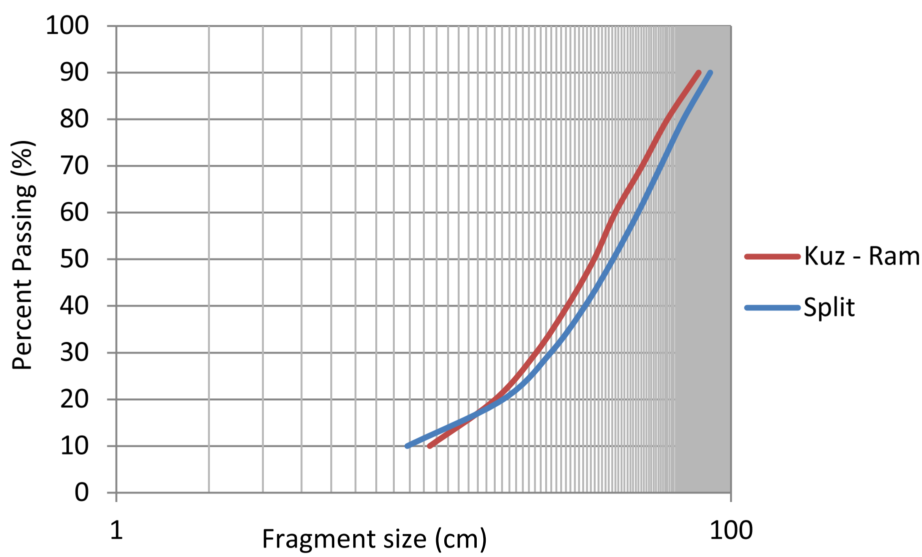

Fig. 6 Diagram obtained from the Kuz-Ram experiential model and digital image analysis in Split Desktop for pattern No. 3

A comparison of the results and diagrams obtained from the Kuz-Ram experiential model reveals that this model suits the conditions of Abyek Cement limestone quarry, because the results are similar to the results of digital image analysis in Split Desktop.

Conclusion

This research investigated blast-induced fragmentation in three blocks of Pir Ali limestone quarry of Abyek Cement Company using the digital image processing feature of Split Desktop. The following results were obtained from digital image processing.

Although the 2 × 2.5 m pattern yielded an F_{80} of 56 cm, it firstly increased the number of blast holes due to the smaller size of the blast pattern, which led to an increase in drilling costs. Secondly, it called for more specific charge, which increased blast-induced vibrations and caused troubles in residential areas around the quarry.

In the 2.5 × 3 m pattern the F_{80} value increased to 70 cm, which was not appropriate for crushing units. On the other hand, this pattern resulted in formation of numerous blast-induced boulders, which caused problems to the loading and transport of rock fragments. Moreover, many large rock fragments did not move and formed plenty of summits. All of these consequences added to the secondary fragmentation costs, which is not cost effective.

The 2.5 × 2.5 m pattern neither causes problems due to the increased specific charge amount (Which is due to more contraction of the blasting pattern), nor brings about the problems caused by the existence of numerous boulders as a result of pattern expansion. Hence, of the aforementioned three patterns, the third pattern is the best choice, which also yields an F_{80} value close to 60 cm.

In addition, the diagram of size distribution of blasted rocks reflects a similarity between results of digital image processing in Split Desktop and results of the Kuz-Ram experiential model.

Authors' contributions
The authors express their gratitude to the authorities of Pir Ali limestone quarry. Both authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

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