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Optimal Blast Design Considering the Effects of Geometric Blasting Parameters on Rock Fragmentation: A Case Study

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Abstract. In quarries and mines, the drilling and the blasting activities is an essentially fundamental way of excavating rock. The blasting process is an integral and important part of mining operations and is intrinsically destructive for a variety of different reasons, notably efficiency, cost effectiveness and the capacity to shatter away even the most solid rock. The primary and main purpose of designing a blast pattern in an open pit or quarry is to use quantities of explosives to fragment the rock material down to smaller pieces and shapes that can make it easier to carry out various subsequent operations such as excavation, charging, transporting, crushing, grinding etc. The conception of a blasting model depends on two sorts of variables: firstly uncontrollable factors, such as the geological structure and the properties of the rock mass. Secondly controllable factors, such as the geometric model (height of the bench, length of the charge, diameter, spacing, burden, stemming length, etc.), the properties of the explosives used (type, resistance, energy, etc.) and the temporal parameters (time delay and initiation sequences). The different fragmentation blasting analysis procedures have inherent difficulties, which result in varying levels of accuracy. Consequently, each technique is adapted to a particular purpose. This research assessed and then compared the particle size distribution of limestone rocks from the New Cement Quarry (NCQ) at Setif -NE Algeria, using the Wip Frag computer imagery processing program and one of the empirical models called Kuz-Ram. Three blasts from the quarry, using different mesh designs in terms of load and spacing (rectangular, square and triangular) analyzed using the two methods. The design parameters of the blast obtained and evaluated as input to the Kuz-Ram model. Pictures of the pile taken and downloaded to the Wip Frag software for analysis. The obtained results in the case of a change in the geometrical parameters of the explosion show that a significant reduction in the size of the oversized products observed by the numerical method. Furthermore, in this study, the ratio between the spacing and the charge in the case of the triangular pattern has a major influence on the size of the fragments and makes it possible to make optimum use of the distribution principle and the amount of energy of the explosive.

Keywords: Rock fragmentation, blast pattern, kuz-ram, wip frag, particle size

INTRODUCTION

In the case of rock-hard mines, explosive blasting is the predominant and highly efficient method of excavation. Blasting used in mines and quarries to break down in situ rock into smaller pieces that can manipulated with ease by the charging, transport and crushing machinery available [1]. The primary objective of the blasting process is to extract the maximum quantity of rock material from the terrestrial environment at the minimum possible economic cost. [2].

To ensure maximum total profit from quarries and mines, the quality and quantity required for explosive fragmentation are essential conditions to respect.

The success of these procedures hinges on the particle dimensions of the blasted rock. It is therefore necessary to quantify and analyzing the fragmentation of detonated rock masses. The main design parameters for production blasting on a bench are: the height of the bench, length of drill hole, the diameter of drill hole, the spacing, the burden, the bottom charge, the column charge, the specific length of the hole and the specific charge, stemming length....

The fragmentation of the rock depends essentially on the conception of the blasting and the characteristics of the rock mass. The homogeneity of the rock leads to a greater or lesser distribution of the size of the clusters of blasted mud, which influences the stability of the benches [3]. The prediction of the distribution of fragment size plays an influential part in the overall economy of mining and quarrying. Properly designed blasting as the first crushing step can greatly reduce the cost of other operations in the mining technology process, such as excavation, charging, transport, crushing and grinding [4]

The material treatment and crushing processes in mines and quarries account for a large percentage of overall costs of production. The success and cost of these twin operations largely depends on the size distribution of the particle piles of crushed and broken rock.

Several researchers have noted that the size and quality of the fragments obtained by blasting influenced by the texture of the rock, the explosives used and their distribution in the rock mass. Consequently, assessing the fragmentation of explosives is necessary for both safety and economic reasons [5].

Assessing and interpreting explosive fragmentation involves specific investment, new ideas and major challenges [6]. It takes a long time to build, operate and incorporate such a procedure into the production process

In the mining industry, rock fragments obtained by blasting generally processed to extract the minerals of value or to obtain the appropriate fragment size for the end use [7]. The properties of these fragments are very important, as they influence the overall efficiency and cost of subsequent processes, including loading, transport and final treatment. It is therefore imperative to pay particular attention to the design of blasting and explosion models [8]. To this end, available fragmentation prediction and evaluation models can be used to both predict the fragmentation distribution resulting from the use of a particular set of blasting parameters and, consequently, select those that give the optimum and required fragmentation [9].

In the field of mining engineering, there are numerous techniques and methods for assessing the fragmentation of rocks by blasting. These techniques and methods can classified into indirect and direct approaches [10, 11 and 12]. The direct approach comprises the sieve analysis method, while the indirect approach comprises the techniques of observation, empirical analysis and imagery analyses, as shown in the figure.

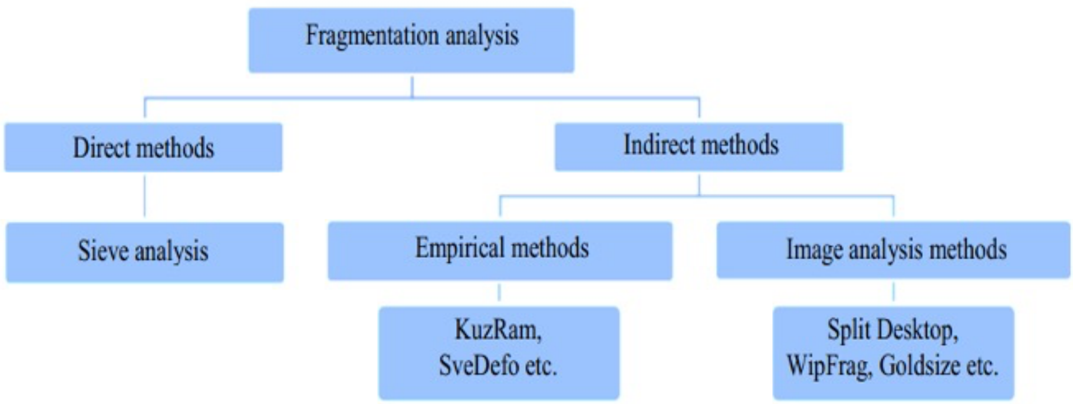

FIGURE 1. Flow chart for assessing blast fragmentation methods [13]

Sieving is the most precise technique for evaluating fragmentation analysis, but it is too time-consuming and costly, which limits its use. In several empirical models used in rock fragmentation analysis, such as the SveDeFo formula, the Larsson equation, the KuzRam model, etc., blasting factors taken into consideration to determine the particle size distribution of the blasted rock and are introduced before the blasting [14].

The empirical model currently most commonly used to assess the fragmentation of explosions is the Kuz-Ram model developed by Kuznetsov [15]. All methods have their intrinsic advantages and disadvantages. However, with the development of mining technology, the analysis of numerical imagery is the one of the fruits of this progress and development, and has become the most the most widely utilized indirect method for evaluating the fragmentation of blasting in quarries and mines.

Image analysis methods include certain programs such as GoldSize PowerSieve BLASTFRAG WipFrag, TUCIPS, Split Desktop, FragScan, etc. [16]. These programs take into account a variety of factors (both controllable and uncontrollable) in the design of blasting models ‘Figure 2’, such as geometric parameters (hole depth, charge, spacing, and charge length), explosives properties (type, quantity/quantity and characteristics) and rock properties (porosity of rocks, rock resistance, the specific gravity, information and data of the quality of the joints, fractures and underground waters) to predict fragmentation [17].

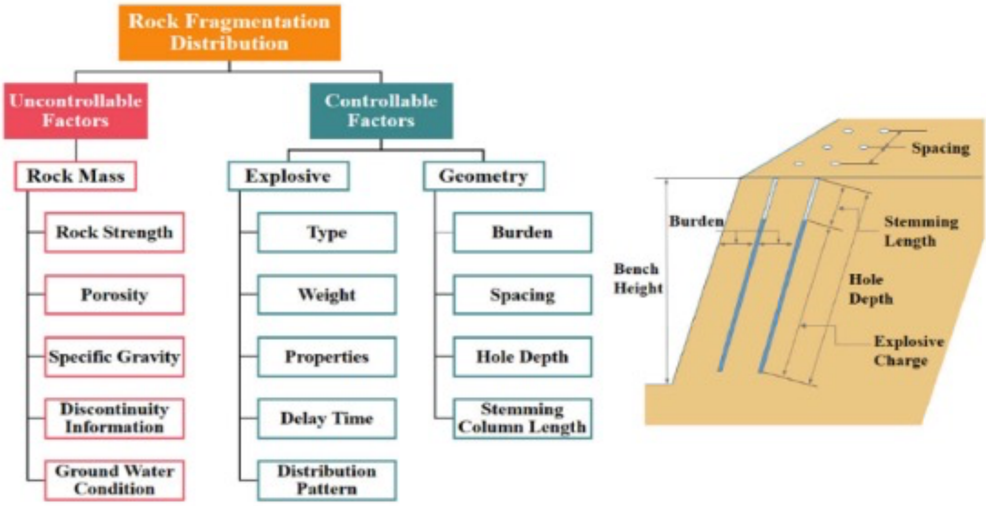

FIGURE 2. Blast design parameters that affect the fragmentation distribution of rocks [18]

The aim of this research is to evaluate in order to improve the blasting results at New Cement Quarry (NCQ) of Setif -NE of Algeria, and to compare the results obtained by the two empirical and numerical methods used for different blasts and discuss the commonalities and differences between them in order to propose an effective blasting plan.

MATERIALS AND METHODS

The New Cement Quarry (NCQ) created in 2017 in the province of Setif, 300 km from Algiers, in the north-east of the country. It situated at a northern degree of latitude of about 36°20‘and an easterly longitude of about 5°27’ and at a height of 1040 m above sea level, 20 km north of Setif ‘Figure 3’.

FIGURE 3. New Cement Quarry (NCQ) of limestone at Setif-NE of Algeria

At the start of operations, annual production amounted to 2500000 tons, supplying crushed aggregates to the cement industry. The geological reserves of the deposit that currently provides the quarry exceed 200 million tons of limestone, giving the quarry a lifespan of 80 years, depending on production capacity. The quarry exploited by 5 benches, each about 15 m high and 82° of dip angle.

Blasting operations in the quarry carried out using two types of explosives out using the roto percussion drilling method with a diameter of mine hole 110 mm. the design parameters of the existing blasting operation used in the quarry, as shown in (Table 1).

TABLE 1. Designed drill and blast parameters at New Cement Quarry (NCQ)

Designed Parameters	Symbol	value
Bench height (m)	BH	15
Burden(m)	B	4
Stemming height (m)	U	2,5
Spacing between holes (m)	S	4
Diameter of mine hole(mm)	HD	110
length of load (mm)	CL	14,3
Charge density of explosive (kg/m^3)	SDE	0,51
Hole length (m)	HL	16,5
Subdrilling hole (m)	SH	1,5
Total explosive quantity(kg)	TEQ	100

Each hole was loaded with a foot blast (MARMANIT III: 37.5 Kg/hole) and a column blast (ANFOMIL: 62.5 Kg/hole), with a total quantity of explosive per hole of 100 Kg. The blast hole pattern was arranged in two rows, burden 4m and spacing of 4m, with the total number of holes equaling 36.

In New Cement Quarry (NCQ), the limestone rock is moderately hard, the compressive strength of the rock is 85 MPa and the working platform of the limestone quarry is cracked and fractured, which poses problems of loss of explosive energy in the holes during fragmentation of the rock. Which affects the quality of granulometry and after mining creates oversize (dimensions of X_{50} and X_{80} outside the standards of mining equipment), which affects the operations of loading, transport, crushing, and need for secondary breaking 'Figure 4'.

FIGURE 4. Secondary breaking process at New Cement Quarry (NCQ)

In order to put in place the best engineering parameters for cost-effective extraction of minerals and efficient rock breaking, drill and blast operations need to be tuned to improve rock breaking, with real benefits for materials production by reducing the time and energy required for loading, transport and crushing. [19].

Framework of Methodology Study

In the particular case, when the rock is cracked; blast configuration parameters result in less cooperation between blast holes, while the rock mass between several holes cannot sufficiently broken up due to the uneven distribution of blast energy. On the other hand, in when the space between the holes and the charge is too large, the blast energy may not be sufficient [20]. In this case, the explosion energy cannot effectively overcome the strong confinement at the bottom of the hole, resulting in the formation of big blocks after the explosion Figure 5'. For this reason, we have tried to modify and propose a new plan of blasting which is adequate and suitable for the rock mass, and give a good result of blasting.

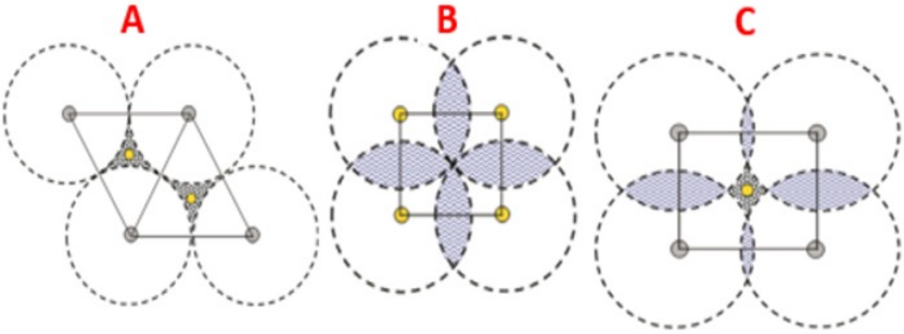

FIGURE 5. The three types of blast plan

Three different blasts from the quarry NCQ, using different burden and spacing design meshes as shown in Figure 5 (triangular A, square B and rectangular C) were analyzed by two methods. The three different types of pattern blasting carried out in different areas of the benches (triangular at bench No. 5, square at bench No. 3 and rectangular at bench No. 1).

In this study, we implemented the diagram presented in 'Figure 6' to evaluate and compare the dimension of particle size distribution by blasting limestone from the New Cement Quarry (NCQ) at Setif -NE in Algeria. The design of blasting parameters acquired and exploited as data introduced into the Kuz-Ram model before blasting. After blasting operation, photos of the pile taken and downloaded to the computer for Wip Frag analysis.

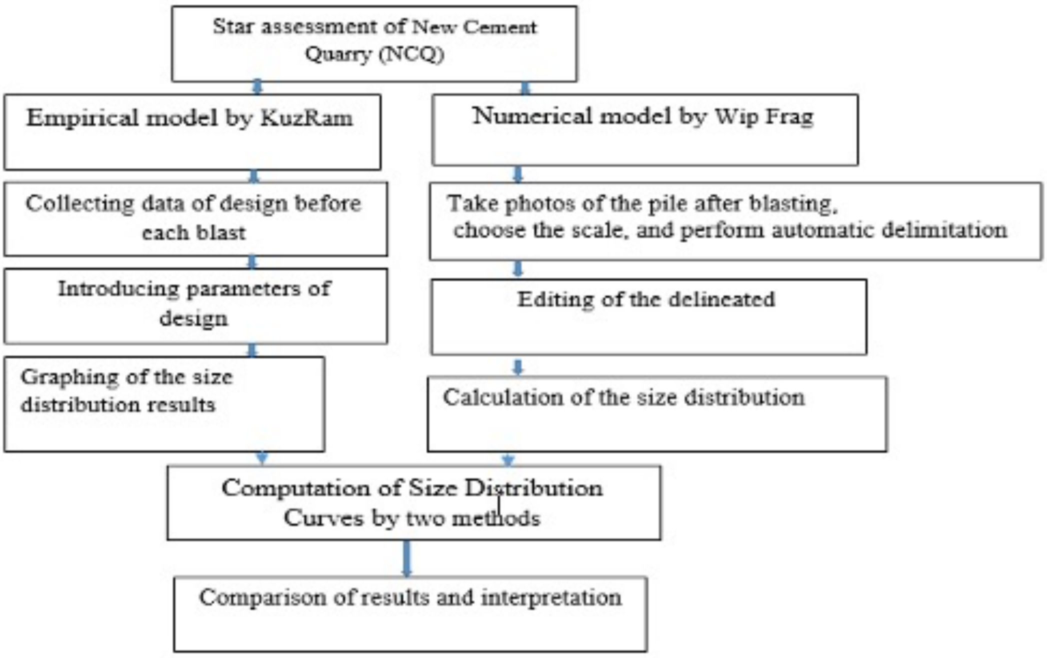

FIGURE 6. Flowchart of proposed framework in our study

Model Kuz Ram

An important part of our work involves analyzing the grain size distributions of broken rock based on the results of the graphic representation obtained. These curves generally measured by screening using empirical models for forecasting the size distribution of materials after blasting, such as the empirical Kuz-Ram model.

The Kuz-Ram model is a combined version of the classical Kuznetsov and Rosin-Rammler equations and the empirical fragmentation model. The Kuz-Ram model remains to this day the model most widely used by mining engineers to predict rock fragmentation after blasting, and many scientific studies have tried to improve the Kuz-Ram model for fragmentation prediction (Cunningham, 1983) and modified it in 1987. [21]. The Kuz Ram model uses three essential parameters, as presented in Table 2 below.

TABLE 2. Parameters and calculation equation in the model of Kuz–Ram

Designed Parameters	value
Mean size fragments (X_{50}), (m)	$X_{50} = A \times [PF]^{-0,8} \times Me^{0,167} \times \left(\frac{115}{RWS_{Anfo}}\right)^{0,633}$
Size distribution curve R(X).	$R(X) = 1 - e^{-\left(\frac{X}{X_c}\right)^n}$
Uniformity index (n)	$n = \left(2,2 - 14\frac{B}{D}\right) \times \left(\frac{1 + \left(\frac{S}{B}\right)^{0,5}}{2}\right) \times \left(1 - \frac{E_p}{B}\right)\left(\frac{L}{BH}\right)$

The Wip Frag

The Wip Frag software application in the mining industry employs technology to process rock imagery after blasting to make predictions about the particle size distribution in the pile of fragmented extracted rock. It was initially created by the Canadian company Wipware, Inc [22]. It handles pictures coming from different resources like digital cameras, film recorders, photographic files or image databases. It uses computer algorithms to detect single blocks and build a ‘network’ of contours.

Pictures of the rock mass captured in the terrain combined and compared with a scale device to reference its dimension. The captured rock mass is uploaded to the Wip Frag system. The different pictures of the fragmented rocks converted into a particulate mapping or network, converted into weights and volumes, and the resulting data displayed graphically [23]. Fast and reliable detection of fragment contours allows completely automatically controlled remote monitoring, at a time of just a very few moments or second per picture.

RESULTS

To study and assess the fragmentation of blasted rock in the New Cement Quarry (NCQ) limestone, three blasts analyzed. To optimize the efficiency of the crushing process, the primary crusher at the NCQ cement plant fed with fine to medium-sized rocks measuring less than 100 cm, while rocks larger than 100 cm called oversized blocks and require secondary breaking with a rock breaker. The secondary breaking incurs added costs and, therefore, the scheme prescribed for each blasting operation must designed to achieve the most suitable and greatest efficient fragmentation at reduced blasting and drilling expense.

Three different patterns of blasting analyzed. In the first pattern (rectangular), the width of the burden is 3.5m and the longitudinal distance spacing between the blast mine holes is 4.2m. In the second blasting pattern (square, similar the blasting design pattern used in NCQ quarry), the width of burden equal length of spacing of the blast holes mines at values 4.2 m. In the last blasting pattern (triangular), the burden rate is 4.2 m and the length spacing of the blasting mine holes measured at 4.5 m. With the exception of the distance between longitudinal holes and the burden width at the holes, the rest of the drilling and blasting data remained the same for all three blasting patterns.

In each picture captured and taken after each blast, using a high-resolution digital camera quality, a plastic balloon with a 240 mm diameter chosen as the scale to measured to particles ‘Figure 7’.

FIGURE 7. The site after blasting at New Cement Quarry (NCQ)

After each blast, the results of the three-block fragmentation analysis in Wip Frag were evaluated and compared by KuzRam.

The F20 values, the other reference (F50, F80) values obtained from the processing analyze of pictures from the initial building block presented in Table 3.

TABLE 3. Presents the results of the F20, F50 and F80 values in the rectangular model.

Percent passing	Size (mm)
X_{20}	412.69
X_{50}	516.86
X_{80}	658.20

In the Setif quarry, the quality of the rock varies from one zone to another at benches level. Changing or modifying the spacing and burden width in the blast design affects the energy distribution of the explosive and can have a considerable impact on the quality of rock fragmentation in the quarry.

Firstly, the burden refers to the height of the rock face that fragmented by the explosive. A thicker burden may allow a wider distribution of blast energy, resulting in more uniform rock fragmentation. On the other hand, a thinner burden may concentrate the blast energy over a smaller area, resulting in uneven rock fragmentation.

The block n1 contains good limestone quality and presents relatively favorable conditions geologically and tectonically, with fewer cracks and joints. As can be seen from Table 3, the resulting size of the focal length of the F80 is 65. 82 cm, which is near the 100 cm crusher input. The graph derived from the experimental model of Kuz-Ram and processing digital imagery analysis in Wip frag for model n1 shown in Figure 8.

Consequently, the appropriate detonation conditions in this mass can be determined on the basis of the images generated by the analyses. In blast pattern, n 2 a modification made to the spacing and burden based on the experiences of the previous blast design n 1.

In the new square, block model, the width of the burden equal 4.2 m with the spacing of the blast mine holes along the length value equal 4.2 m. The single change compared to previous block models is that the width of the burden increased by 70 cm. In this model, the blasting mine holes drilled in the NCQ quarry are closer together than previously, and the total number of blast holes in the block is correspondingly higher. In last block n3, the modified triangular blast design has a width of burden equal 4.2 m and a value spacing of the blast mine holes equal 450 cm increased by 30 cm.

Table 4 presents the results of the F20, F50 and F80 values derived from the analysis of Figures 9 and 10 for blast model no. 2 and blast model no. 3.

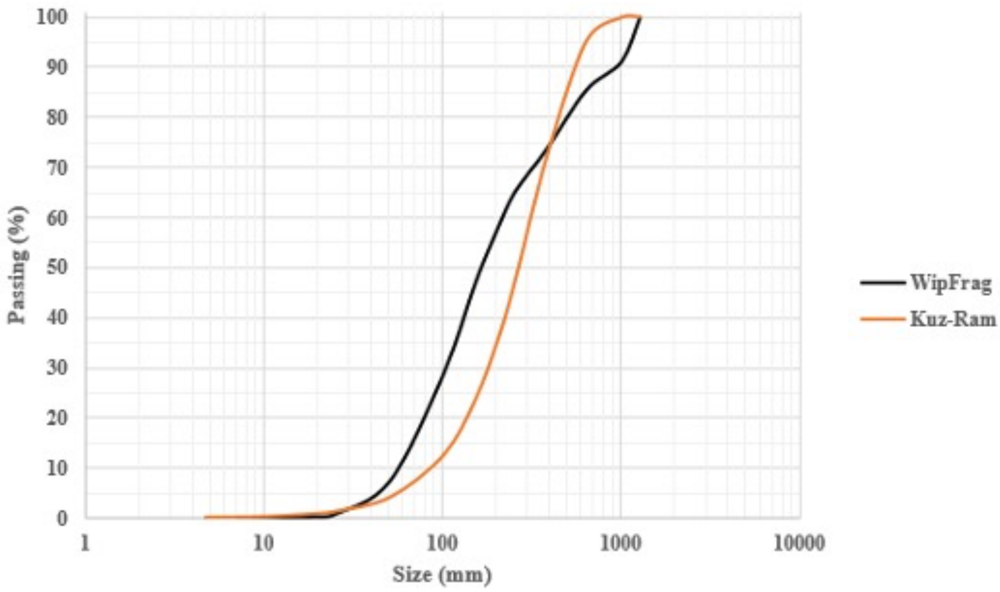

FIGURE 8. Graph acquired using the empirical Kuz-Ram model and Wip frag imagery processing analysis for the n1 blast model.

TABLE 4. Presents the results of the F20, F50 and F80 values in the square and triangular pattern.

Percent passing	square pattern No. 2	rectangular pattern No. 3
X_{20}	417.64	319.64
X_{50}	616.84	776.84
X_{80}	798.61	858.24

The resultant of the F80 values found from the analysis of the fragmentation of block n 2 indicate that it is equivalent to 798.61 mm, which is lower than the size of the entrance to the primary breaker (100 cm). While this design achieves a reasonable F80 value, it also increases drilling costs by requiring a greater numbers of blast holes, which is undesirable from an economic point of view. In addition, the increase in the specific burden leads to over-breaking of the last row of blast holes and an increase in the level of vibration, which is undesirable and poses safety problems.

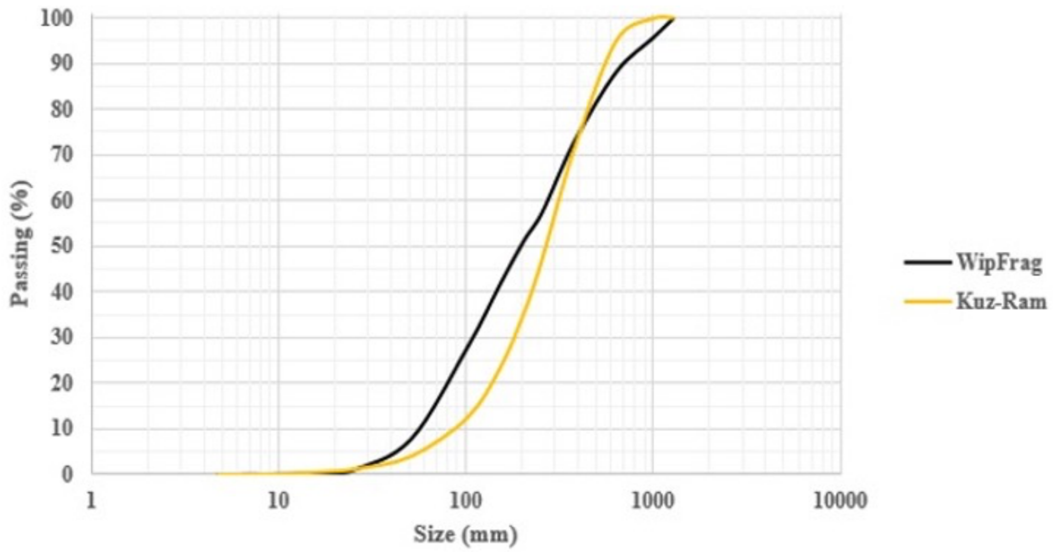

FIGURE 9. Graph acquired using the empirical Kuz-Ram model and Wip frag imagery processing analysis for the n2 blast model.

The redesign for block number 3 has increased the average F80 value to 85.8 cm, many of the blocks are well fragmented and the resulting blocks pose no difficulty for crushed rock loading and secondary breaking in order to extract the greatest quantity of rock at minimum cost and with the optimum quantity of explosives.

A comparative Study of the Results Acquired of the Image Processing Analysis by Wip Frag Software Compared with the Empirical Model by Kuz-Ram

In this study, the entry parameters of the Rosin-Rammler function of Kuz-Ram model used to evaluate and asses the dimensions and the size distribution of the rocks fragmented at the NCQ limestone quarry

Table 5 presents the results of the Kuz-Ram empirical model. The semi-logarithmic graph resulting from the Kuz-Ram model and the graph resulting from the analysis of digital images in Wip Frag are presented in Figures 8, 9 and 10 for the three models.

A close analysis of the results obtained from the particle size distribution diagrams based on the empirical Kuz Ram model indicates that this model is adapted to the conditions at the NCQ limestone quarry, as the results are comparable to those obtained from the digital images analysis by Wip Frag.

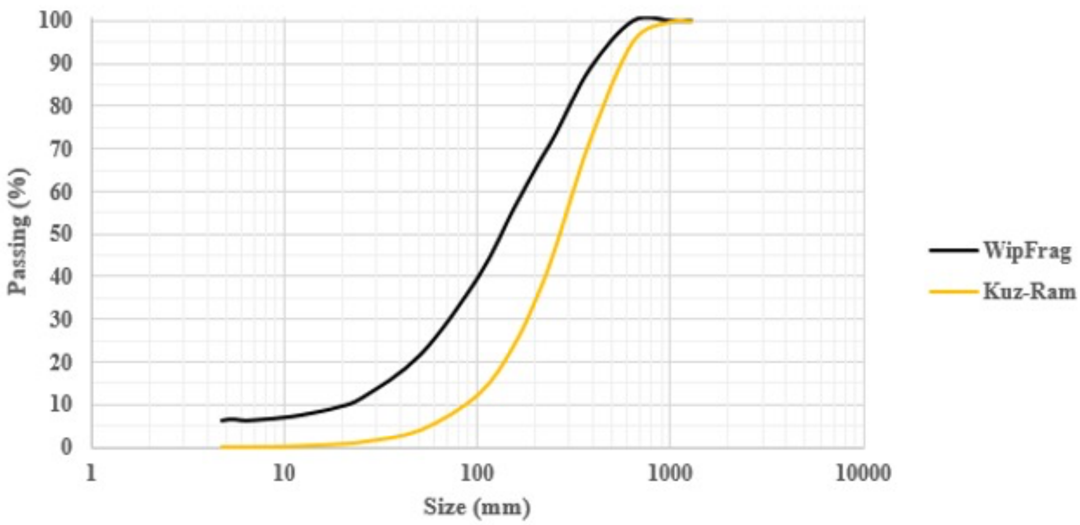

FIGURE 10. Graph acquired using the empirical Kuz-Ram model and Wip frag imagery processing analysis for the n3 blast model.

TABLE 5. Results obtained by the empirical Kuz-Ram model for the design of three explosions.

Percent passing	Rectangular pattern N 1	Square pattern N 2	Triangular pattern N 3
X_{20}	30,3	20,78	40,76
X_{50}	50,22	40,82	70,66
X_{80}	73,87	71,98	79.95

CONCLUSION

In this research paper, a novel blasting design proposed to make predictions about the size distribution of the fragments resulting from blasting operations at the NCQ limestone quarry. This proposed blasting scheme implemented based on image analysis using Wip fragments and an experimental method using the KuzRam model. The main points noted from this case study are as follows:

In the first case, for rectangular blast pattern, the dimensions of the blast design 3.5 × 4.2 m made it possible to obtain an F80 of 65 cm, but this model firstly led to and created an increase in the total number of blast holes, because of the reduced size of the blast pattern, resulted in more expensive drilling operations costs. Secondly, it necessitated a more specific weight and quantity of the explosive charge, which increased the vibrations, induced by the explosion and caused problems in the housing areas around the quarry.

In the second 4.2 × 4.2 m square blast design pattern, the values of F80 increased to 79 cm, an acceptable level for the crushing machines installed in NCQ limestone quarry. On the other hand, this design led to the creation of a large numbers of blocks formed over size boulders, which posed difficulties for charging and transporting the rock fragments. In addition, a great number of big rock fragments did not move and created numerous piles. All of these factors increased the cost of a secondary basting in quarry, which is uneconomical.

In the last 4.2 × 4.5 m triangular design, there are no difficulties due to the higher specific explosive loading (which is due to the greater blast pattern contraction), or the large number of oversized boulders in the rock mass due to the expansion of the blast pattern.

Of the three mentioned modes of blast design, the tertiary triangular blast design is therefore the preferable option, that also produces an F80 value close the primary crusher at the New Cement Quarry (NCQ)

Finally, poor distribution of explosive energy can lead to uneven fragmentation of the rock, with fragments of varying size. This can lead to problems when loading the extracted material, higher fragmentation costs and an increased risk of mining accidents.

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