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# Effect of Blasting Parameters on Rock Size Induced by Fragmentation in Quarries: A Case Study

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**Abstract.** The blasting process in quarries and open-pit mines plays a very important key to achieving optimum performance from the mining company's technical and economic point of view. The magnitude of rock fragmentation is a crucial factor from an economic standpoint in any surface mining operation. The size of rock fragments directly affects drilling, blasting, loading, secondary blasting, and crushing expenses. However, the large number of parameters involved makes it difficult to control this operation. A number of studies have shown the benefits of taking into account all the parameters that affect the results of blasting. In particular, this study has highlighted the importance of designing a blast plan. The aim of our work is to study the influence of one of the controllable parameters (spacing between blastholes) on the results of blasting as a function of the parameters used in the quarry (Ain kebira cement limestone quarry, Setif - Algeria) in order to identify the most influential ones. This done by simulating blasting plans using the digital software Wip Frag and the Kuz-Ram model, in which we changed the spacing between the holes, in order to evaluate and monitor the size distribution of the blocks in the blasted piles. The results of analyses carried out using the Kuz-Ram method and image processing with Wip Frag software indicate that reducing the distance between blastholes ensured good rock fragmentation.

**Keywords:** Rock size; blast design; spacing; KuzRam; Wip Frag


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## INTRODUCTION

Blasting is widely used to break up hard rock. Today, rock blasting is the simplest and most widespread technique used in quarries and open-cast mines to exploit mineral deposits. It consists of destroying small rocks in the massif. The rock is separated from the massif using blasting, an alternative that has the advantage of fragmenting large volumes of rock for the recovery and processing of the blasted material [1].

The quality of rock fragmentation is of the utmost importance in mining and has a major impact on operating costs. It influences all the technological processes (loading, transport and crushing), and they play an indispensable role in determining the economic feasibility of mining activities.

Successful drilling planning will take into account the overall costs of mining, other than blasting, as blasting operations are critical to the overall economics of surface mining [2,3]. Blasting operations influenced directly by the geomechanical properties and the geologic characteristics of the rock.

This sub-process must produce suitable fragment size distributions to minimize production costs and energy consumption in the various downstream processes, while complying with safety and environmental standards.

The design of a blasting plan to obtain the fragment size and predict the fragmentation required will take into account two controllable and uncontrollable parameters [4-7]. The controllable parameters are firstly the geometry parameters of blast design, and secondly the explosive (type, quantity/quantity and properties). Knowing the uncontrollable of some parameters (rock geology, discontinuities orientation,…) to check that the required performance is reached, as the size of the rock removed is of the greatest significance for subsequent operations [8].

Although most previous studies have highlighted the beneficial effects of a totalitarian solution to the full mining chain, changing certain parameters of a blast pattern to determine the influence and blast geometry on fragment size distribution, total quarrying cost, and blast quality is not an option.

Research in the mining field has shown that of the three most important properties of fragmented rock heaps that influence quarry economics, namely fragmentation, flexibility and rock shape.Other studies have shown that the degree of fragmentation influences the economics of excavation [9]. Moreover, that the energy consumed by the crusher to crush rock is more sensitive to the size of the rock than to tonnage. A recent study showed that the benefits of good fragmentation could extended to the crushing circuits, since most of the energy/power used in a mine consumed by crushing and grinding.

The quarry operator may therefore wish to ensure that excessive blasting does not result in the production and excavation of rock sizes above or below a certain threshold. Research indicates that for many site mines, fines and oversize create a problem in terms of loss of marketable rock and inventory (fines) and high consumption of materials reserved for secondary cutting (such as rock breakers, loaders, trucks) in large blocks (see figure 1). Consequently, the research challenge is to provide solutions that enable quarry operators to minimize the total cost of the extraction process while guaranteeing an suitable fragmentation size for the subsequent processing [10-12].

In mining process, the definition of “oversize” is any piece produced by primary blasting, which cannot handled adequately by the operation's standard loading, conveying and crushing equipment. They further indicated that oversized rocks can described as a size that requires additional secondary crushing prior to further handling. The size and dimension of oversize varies from one operation to another. [13]. However, in most cases, the oversize are the size that cannot be loaded or transported with the normal equipment available based on the capacity of this equipment.

The formation of oversize boulders in quarry sites and mine will actually occur based on different factors, which can divided into the following four categories: (1) geologically associated circumstances; (2) blasting design pattern parameters; (3) type and characteristics of explosive; and (4) human-related factors (see figure 1).


**FIGURE 1.** The main factors influencing the formation of oversized boulders

Researchers are continually developing fragmentation models to predict fragmentation and obtain the most accurate data. Numerous methods used to assess the fragmentation of the pile of fragmented rocks after the explosion, divided into two categories: direct and indirect. Screening classified in the direct category. Empirical models, image analysis, visual analysis, etc. can considered as indirect methods [14].

Each of these methods has its own advantages and disadvantages. Although screening is the most accurate method, it is expensive, time-consuming and labor-intensive [15] . It is very difficult to use in practice.

The most common empirical model used to assess blast fragmentation is the Kuz-Ram model established by Kuznetsov [[16,17]. Each method has its intrinsic advantages and disadvantages. However, digital image analysis is a product of technological progress and has become the most commonly used indirect approach to assessing blast fragmentation.

Image analysis methods include some programs Gold Size Power Sieve Blastfrag Wip Frag, TUCIPS, Split Desktop, Frag Scan, [18,19]

The aim of this research is to improve the results of blasting in the limestone quarry of the Setif plant -NE of Algeria. The methodology used is changing the distance between two blast holes and comparing the outcomes achieved by the two different methods employed: numerical and empirical, for the various blasting operations, in order to reduce the percentage of out-of-gauge rocks and propose an efficient blasting plan and guarantee an optimal size of the fragmented rocks.

## MINING SITE DETAILS

This study conducted at the Setif cement plant quarry, located in Ain El-Kebira (20 km northeast of Setif province, Algeria). Figure 2 illustrates the location of case study.

According to the topographical and geological data, the limestone quarry at the Setif cement company deposit has a mountainous relief and fractured terrains. Exploitation begins with the preparation of the summit with a single exploitable edge. In order to have a sufficient platform for the location of the machines and as one goes down from top to bottom, the method of exploitation adopted is that by transport to the external slag heap.

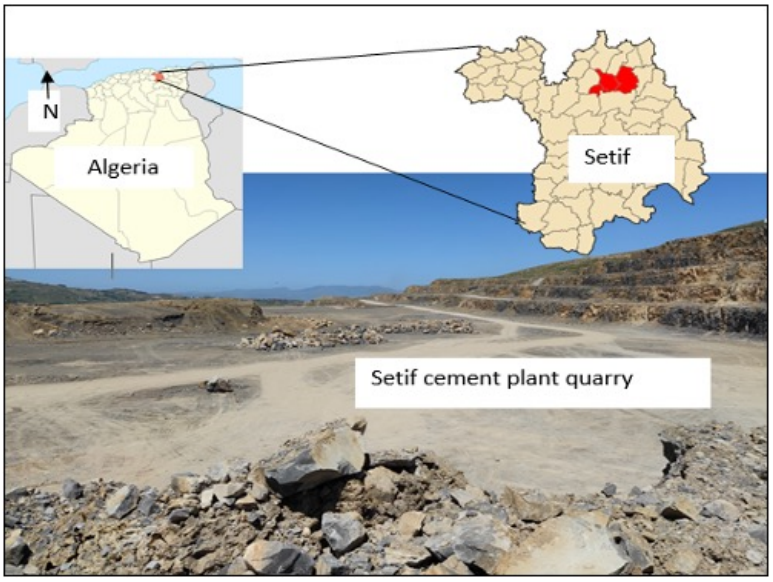


**FIGURE 2.** Location of the quarry case study.

The quarry operated by five benches, each about 15 m in height and plunging at an angle of 82°.The cement plant's primary crusher is fed with medium-sized fragmented rocks under 120 cm, while rocks over 120 cm is referred to as oversize blocks and requires secondary fragmentation using a rock breaker. Secondary fragmentation entails additional financial expense; consequently, the model specified for each blasting operation should tailored to obtain the best results in terms of fragmentation, the highest efficiency while reducing drilling, and blasting costs[4,7] .

Blasting at the quarry executed with two explosive materials, using the rotary percussion method of drilling with a 110 mm hole diameter. The blasting design parameters used shown in Table 1.

The blasting holes laid out in two rows, with a burden of 4,7 m and a spacing (Esp) of 4,7 m, giving 36 holes and the 25 MS delayed detonation capsule used as a detonating cord feed.

The stone's limestone grade is of medium hardness, and the calcareous top of the deposit is highly fissured, which makes it difficult to create oversized rocks after quarrying.

**TABLE 1.** Blasting design parameters currently used at limestone quarry of the Setif plant.

| Blasting plan parameters | Unit of measure | blasting values currently used in the quarry |
|---|---|---|
| Hole Diameter | mm | 110 |
| Bench Height | m | 15 |
| Burden | m | 4,7 |
| Spacing | m | 4,7 |
| Stemming length | m | 3,8 |
| Subdrill (m) | m | 1,5 |
| Explosive per Hole | (Kg/hole) | 111 |
| Powder Factor | ($kg/m^3$) | 0,55 |
| Initiation System | / | Detonating Cord |
| Drilling Pattern | / | Square |

## MATERIALS AND METHODS

Assessing and predicting the effectiveness of blasting, which is the most fundamental process in mining, is very important to the economics of the business. One of the main methods used to assess efficiency is the estimation and determination of particle size distribution. In this study, the empirical Kuz-Ram model and image processing analyses using Wip Frag software used to assess and contrast results obtained.

### Model Kuz Ram

In our work, the grain size range of blasted rocks analyzed. Such plots usually checked by sieving using predictive empirical models of the size particle distribution post-blasting, exemplified by the so-called Kuz-Ram method [21, 22].

The so-called Kuz-Ram is a composite of the equations of Rammler and Kuznetsov, and the prediction of the empirical experiential blasting technique. To the present time, the Kuz-Ram model is still the most widespread model used by mining engineers to forecast rock fragmentation resulting from blasting. [23].

The model of Kuz-Ram employ three essential parametric principles to estimate the average fragment size (X50) and the index of uniformity (n) resulting from an explosion to plot the distribution graph for size R(X).

Average fragment size ($X_{50}$), (m): $$X_{50} = A \times [PF]^{-0,8} \times Me^{0,167} \times \left(\frac{115}{RWS_{Anfo}}\right)^{0,633} \quad (1)$$

Distribution graph for size R(X): $$R(X) = 1 - e^{-\left(\frac{X}{X_c}\right)^n} \quad (2)$$

Uniformity index (n): $$n = \left(2{,}2 - 14\frac{B}{D}\right) \times \left(\frac{1+\left(\frac{S}{B}\right)^{0,5}}{2}\right) \times \left(1 - \frac{E_p}{B}\right)\left(\frac{L}{BH}\right) \quad (3)$$

### Digital Image Processing Software Wipfrag

The "Wip Frag" software application uses a technique for analyzing images of rock after blasting to make predictions about the size range of particles in the extracted rock mass. It originally created by Wipware, Inc, Canada [24]. it handles imagery from a variety of sources, such as photographic cameras, film recorders, photographs or digital media databases [25]. Following is a systematic process for analyzing images with Wip Frag as presented in figure 3.

-Captured rock pile images after blasting
-Import images into Wip Frag
-Define the scale
-Choose detection settings
- Hand -editing (if necessary)
-Obtain export (dimension of size distribution)

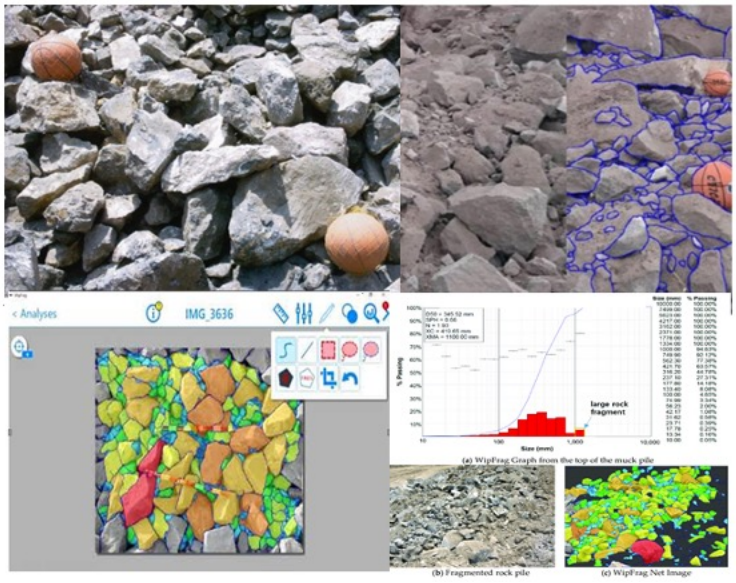


**FIGURE 3.** Systematic process for analyzing images with Wip Frag

As part of this study, five blasting plans monitored in limestone quarry at the Setif cement company. Images were taken from the controlled blasts to represent the make pile. The images subjected to processing steps in the Wip Frag software and graph of particle size distribution for each blast obtained. Given that the blasting parameters entered in Kuz-Ram do not change during mining operations, except for the distance between holes, the following results obtained

The values of pass and refusal with respect to particle size of the fragment distributions obtained using Wip Frag and the Kuz-Ram model shown in the particle distribution graphs.

In each of the images captured after each shot, using a height-quality digital camera, a plastic balloon with a diameter of 240 mm is chosen as the measuring object scale as shown in figure 4.

**FIGURE 4.** Image captured after blasting with object scale at limestone quarry of the Setif plan

## RESULTS AND DISCUSSION

A granulometry analysis carried out to determine the percentage of fragments. The aim of this section is twofold: firstly, to determine the percentage of passing average fragment size and the percentage of oversize blocks in two cases of Spacing Esp (Esp= 4m and Esp=3,5m) , and secondly, to determine the effect of the spacing between blastholes on the quality of rock fragmentation, the results presented in table 2 .

**TABLE 2**. Fragmentation analysis results Obtained by Kuz-Ram model

| Size of particles (mm) | % of Passing in spacing ESp=4m(m) | % of Passing in Spacing ESp=3,5m (m) |
|---|---|---|
| 2,5 | 0,16 | 0,3 |
| 10 | 0,37 | 0,4 |
| 20 | 0,78 | 0,9 |
| 30 | 1,53 | 1,4 |
| 40 | 2,00 | 2,33 |
| 50 | 3,45 | 3,53 |
| 60 | 5,87 | 6,11 |
| 70 | 7,21 | 7,98 |
| 80 | 11,09 | 13,65 |
| 90 | 18,75 | 21,45 |
| 100 | 23,24 | 25,76 |
| 200 | 30,93 | 32,78 |
| 300 | 41,91 | 43,99 |
| 400 | 66,62 | 71,76 |
| 500 | 68,14 | 73,65 |
| 1000 | 70,36 | 76,01 |
| 1200 | 72,90 | 77,54 |

The result of particle size distribution (Kuz-Ram) is show in figure 5 and presented the variation in pass rates (%) as a function of fragment size

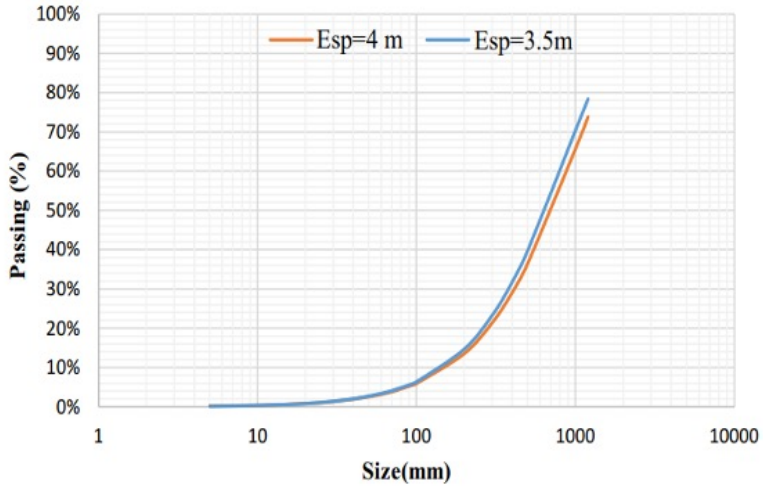


**FIGURE 5.** Granulometry curve obtained by the (Kuz-Ram) model in two cases Esp4m=and Esp=3,5m

The results obtained by table 2 and figure 6 show that:- In the case for a hole spacing of 4 m and 3.5m, the average size of the equivalent fragments the of passing fragments is equal to 72,90 % (Rate Over size 27,10 % ) and 77.54 % (Rate Over size 22,46 %) respectively in the size particle of primary crusher.

In the light of all these results, it can concluded that the spacing between the holes had a significant impact on the fragmentation results of particle size distribution.

## Analysis of Fragmentation Using Digital Image Processing Software (Wip Frag)

The numerical method is widely used in the field of engineering for the size distribution analysis of rock fragmentation due to its simplicity, speed and ease of execution. However, it has certain disadvantages that can influence the results of the analysis, especially automatic delineation. The aim of this analysis is to confirm or refute the achieved outcomes

by the model empirical (Kuz-Ram). The digital method (image processing) using Wip Frag software carried out a size distribution analysis of several photos (taken after each blast). The results of this method under the new cases of spacing (Esp= 3,5m and Esp=3m) in conditions of the limestone quarry case study presented figure 6.

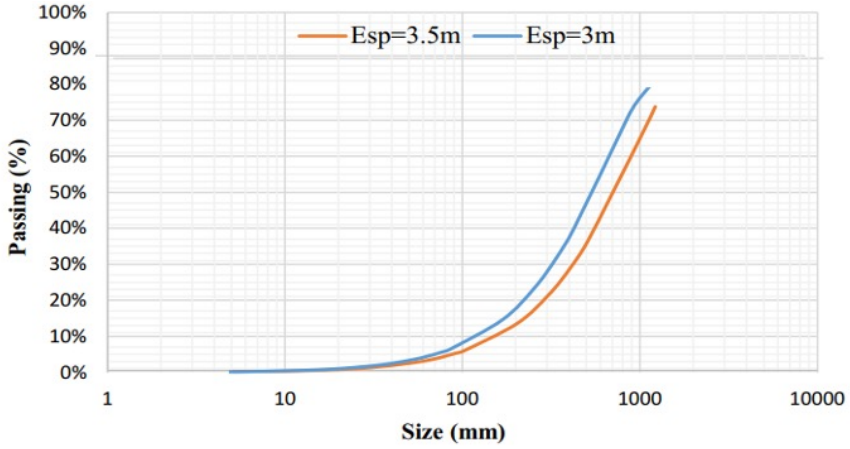


**FIGURE 6.** Granulometry curve obtained by the Wip Frag in two cases Esp3,5m=and Esp=3m

The results obtained in this new cases show that:

- For a spacing of 3.5m and 3m between holes, the average size of the equivalent fragments the of passing fragments is equal to 79,13 % (by Kuz Ram in this case Esp=3,5 m we obtained 77.54 % ) and 83.54 % respectively in the size particle of primary crusher.

- The percentage of Oversize blocks for a spacing of 3,5 m and 3 m is 15.1% and 13.46% respectively.

In the light of all these results, it can concluded that the Wip Frag image processing method confirmed that the spacing between the holes had a significant impact on the fragmentation results, with the height precision.

The geological characteristics of sites vary during mining operations and these characteristics form part of the uncontrollable blasting parameters. With Kuz Ram, the rock factor and blasting parameters used to o find out the grain size particle distribution. Although the rock factor taken into account when creating the empirical formula, it does not provide the closest result to reality.

For better results, we changed the distance of spacing other times (Esp=3m ,and Esp=2,5m) for confirmation and more accuracy of previous results, The results obtained in this case presented in figure 7.

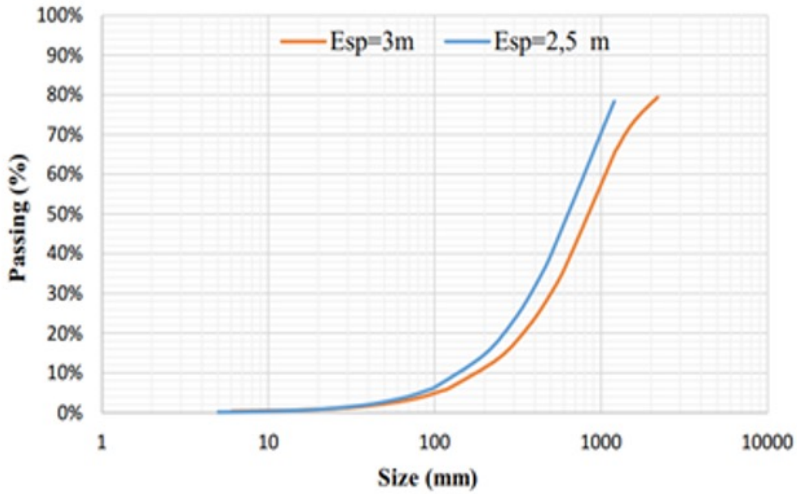


**FIGURE 7.** Granulometry curve obtained by the Wip Frag in two cases Esp3 m=and Esp=2,5m

Geological changes in the study area and application errors in blasting design have a direct impact on blasting efficiency. The difference between the Kuz-Ram model and image processing is due to this situation, and it is clear from the field studies that the results of image processing analyses are closer to reality. The comparative results of passing particle and oversize boulders by two methods are show in figure 8.

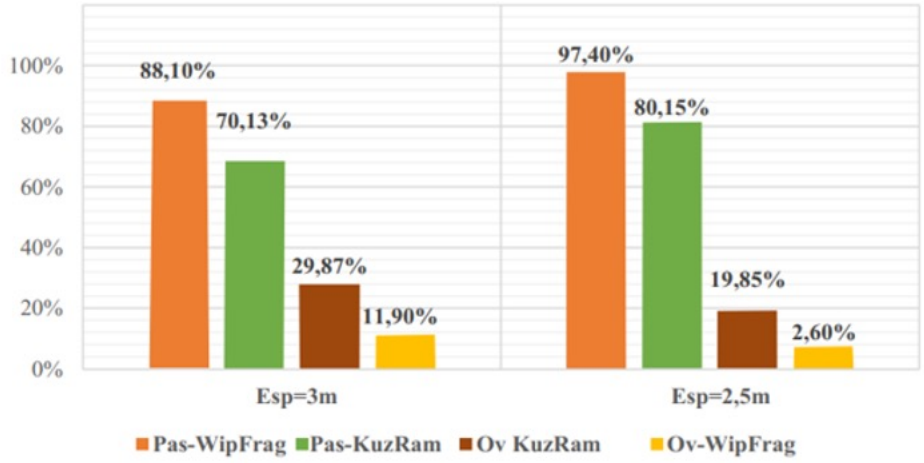


**FIGURE** 8. Results of comparative rock fragmentation analysis by Kuz-Ram and Wip Frag for Esp = 3m and Esp= 2,5m

In the light of all these results, it can concluded that the spacing between the holes had a significant impact on the fragmentation results of particle size distribution and the percentage of Oversize blocks reduced for a spacing of 3 m and 2,5 m is 11.9% and 2.6% respectively.

On the other hand, 120cm fragments and out-of-gauge blocks increased respectively by increasing the distance between holes from 4m (first case) to 2.5m (last case). Therefore, fragmentation efficiency reduced by increasing the distance between holes and vice versa.

After the analyses, the rock fragmentation results given by the two analysis methods (Kuz-Ram and Wip Frag) showed that decreasing the spacing between holes would have given a good rock fragmentation result.

## CONCLUSION

Fragmentation is a complex concept in the context of open-pit mining. Improving fragmentation is the miner's main challenge, because the main objective is satisfactory and acceptable fragmentation. Specialists in the mining field have shown that there is no drilling and blasting law that allows an out-of-gauge rate that is equal to zero, however, with a combination of several methods that allow this rate to reduce to acceptable values.

The objective of our work was to investigate the influence of mesh size (spacing) on the result of rock fragmentation obtained during opencast blasting at limestone quarry at the Setif cement company NE Algeria, using the empirical Kuz-Ram method. Computer applications based on digital imagery of rock fragments are one of the new technologies that are improving quarrying from a technical and economic point of view.

According to the analyses carried out using the empirical Kuz Ram model and the image processing method using the Wip Frag software, the results obtained show that reducing the distance between the blasting holes (‘Esp’ spacing) has ensured good fragmentation of the rocks.

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## REFERENCES


1 .Bhatawdekar, R.M., Mohamad, E.T., Singh, T.N., Pathak,P., & Armaghani, D.J. Rock mass classifcation for the assessment of blastability in tropically weatheredlimestones. *Proceedings of the International Conference on Innovations for Sustainable and Responsible Mining*, pp. 13–44. https://doi.org/10.1007/978-3-030-60839-2_2, 2021.

2. Tavakol Elahi A., Hosseini M. Analysis of blasted rocks fragmentation using digital image processing. Case study: limestone quarry of Abyek Cement Company. International Journal of Geo-Engineering, 8, 1–11, 2017.

3. M. Fredj, R. Boukarm, A. Saadoun, K. Menacer, and R. Nakache, "Effect of Stemming Parameters on Blast-Induced Rock Fragmentation: A Case Study," ARPHA Proceedings, vol. **7**, pp. 128–135, (2024). https://doi.org/10.3897/ap.7.e0128

4. A. Saadoun, R. Boukarm, M. Fredj, K. Menacer, D. Boudjellal, A. Hafsaoui, and I. Yilmaz, "Optimal Blast Design Considering the Effects of Geometric Blasting Parameters on Rock Fragmentation: A Case Study," ARPHA Proceedings, vol. 7, pp. 136–146, (2024). https://doi.org/10.3897/ap.7.e0136

5. A. Saadoun, R. Boukarm, M. Fredj, and Y. Isik, "Study The Influence of The Choice of Blasting Zones on The Rock Fragmentation Quality and The Stability of Benches in Open-Pit Mining by Numerical Modeling," in Proc. SGEM, pp. 439–446, (2023). https://doi.org/10.5593/sgem2023/1.1/s03.53

6. M. Fredj, R. Boukarm, R. Nakache, A. Saadoun, M. Saoudi, and I. Tighilt, "Distribution Analysis of Rock Fragments Size Based on the Digital Image Processing and the Kuz-Ram Model. Case of Jebel Medjounes Quarry," Aspects Min. Miner. Sci., vol. 2, no. 4, (2019).https://doi.org/10.31031/AMMS.2019.02.000545

7. A. Saadoun, M. Fredj, R. Boukarm, and H. Riheb, "Fragmentation analysis using digital image processing and empirical model (Kuz-Ram): a comparative study," J. Min. Inst., vol. 257, pp. 822–832, (2022). https://doi.org/10.31897/PMI.2022.84.

8. Cardu M., Calzamiglia A. Analysis of the techniques for assessing the features of blastinduced fragmentation in an open pit quarry. In IOP Conference Series: Earth and Environmental Science, 833, 1, 012121. IOP Publishing, 2021.

9. Fredj M., Hafsaoui A., Riheb H., Boukarm R., Saadoun A. Back-analysis study on slope instability in an open pit mine (Algeria). Natsional'nyi Hirnychyi Universytet. Naukovyi Visnyk, 2, 24–29. 2020.

10. Lawal A.I. A new modifcation to the Kuz-Ram model using the fragment size predicted by image analysis. International Journal of Rock Mechanics and Mining Sciences, 138, 104595, 2021.

11. P. Yan, W. Zhou, W. Lu, M. Chen, and C. Zhou, "Simulation of bench blasting considering fragmentation size distribution," Int. J. Impact Eng., vol. 90, pp. 132–145, (2016). https://doi.org/10.1016/j.ijimpeng.2015.11.015.

12. Souza, J.C.D., Silva, A.C.S.D., & Rocha, S.S. Analysis of blasting rocks prediction and rock fragmentation results using SplitDesktop software. *Tecnologia em Metalurgia, Materiais e Mineração*, *15*(1), 22-30. https://doi.org/10.4322/2176-1523.1234, 2018.

13. Azizi, A., & Moomivand, H. A new approach to represent impact of discontinuity spacing and rock mass description on the median fragment size of blasted rocks using image analysis of rock mass. *Rock Mechanics and Rock Engineering*, (54), 2013-2038. https://doi.org/10.1007/s00603-020-02360-4 , 2021.

14. Segarra, P., Sanchidrián, J.A., Navarro, J., & Castedo, R. The fragmentation energy-fan model in quarry blasts. *Rock Mechanics and Rock Engineering*, (51), 2175-2190. https://doi.org/10.1007/s00603-018-1470-9 , 2018.

15. Rais, K., Kara, M., Gadri, L., Hadji, R., & Khochmen, L. Original approach for the drilling process optimization in open cast mines; Case study of Kef Essenoun open pit mine Northeast of Algeria. *Mining Science*, (24), 147-159. https://doi.org/10.5277/msc172409 , 2017.

16. Bhandari, S. Changes in fragmentation processes with blasting conditions. *Rock Fragmentation by Blasting*, 301-309. https://doi.org/10.1201/9781003078104-43 , 2020.

17. Bhatawdekar, R.M., Edy, M.T., & Danial, J.A. Building information model for drilling and blasting for tropically weathered rock. *Journal of Mines, Metals and Fuels*, 67(11): 494–500 , 2019.

18. Bhatawdekar, R.M., Armaghani, D.J., & Azizi, A. Review of Empirical and Intelligent Techniques for Evaluating Rock Fragmentation Induced by Blasting. *Environmental Issues of Blasting*., pp. 21–39. https://doi.org/10.1007/978-981- 16-8237-7_2 , 2021.

19. Shehu SA, Yusuf KO, Hashim MHM (2022) Comparative study of WipFrag image analysis and Kuz-Ram empirical model in granite aggregate quarry and their application for blast fragmentation rating. Geomech Geoeng 17(1):197–205. https://doi.org/10.1080/17486025.2020.1720830
20. Idowu K.A., Olaleye B.M., Saliu M.A. Application of Split-Desktop Image Analysis and Kuz- Ram Empirical Model for Evaluation of Blast Fragmentation Efficiency in a Typical Granite Quarry // Ghana Mining Journal. 2021. Vol. 21. № 1. P. 45-52. DOI: 10.4314/gm.v21i1.5 https://doi.org/10.4314/gm.v21i1.
21 . Dhekne P.Y., Balakrishnan V., Jade R.K. Effect of Type of Explosive and Blast Hole Diameter on Boulder Count in Limestone Quarry Blasting // Geotechnical and Geological Engineering.. Vol. 38. P. 4091-4097. DOI: 10.1007/s10706-020-01280-y , 2020
22. Leng Z., Fan Y., Gao Q., Hu Y. Evaluation and optimization of blasting approaches to reducing oversize boulders and toes in open-pit mine // International Journal of Mining Science and Technology.. Vol. 30. Iss. 3. P. 373-380. DOI: 10.1016/j.ijmst.2020.03.010 , 2020
23. Babaeian M., Ataei M., Sereshki F. et al. A new framework for evaluation of rock fragmentation in open pit mines // Journal of Rock Mechanics and Geotechnical Engineering.. Vol. 11. Iss. 2. P. 325-336. DOI: 10.1016/j.jrmge.2018.11.006 , 2019
24. Maerz, N.H.; Palangio, T.W. Post-muckpile, pre-primary crusher, automated optical blast fragmentation sizing. Fragblast, 8, 119–136. 2004
25. Siddiqui, F.I. Measurement of size distribution of blasted rock using digital image processing. Eng. Sci. 2009, 20, 81–93.