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PREDICTION OF ROCK FRAGMENTATION IN THE BOUKHADRA'S MINE CONDITIONS

Purpose. The objective of the study consists in obtaining better quality rock fragmentation by using inclined holes to ensure good energy distribution and better stability of the upper wall.The Kuz-Ram model and the Langefors method are best suited to achieve the goal.

Methodology. The study compares the blasting plan adopted by the Boukhadra mine located in the Wilaya of Tebessa, with that calculated by the Langefors method while using inclined holes. We chose the Kuz-Ram model as a simulation model and validation for the following reasons.

Findings. The application of the proposed method of Langefors gave a satisfactory result in terms of process efficiency, the Kuz-Ram model predicts a significant reduction in the rate of oversized blocks using an inclined hole drilling technique, from 13.1 to 5.3 %. This approach appears to improve the degree of fragmentation, reduce the percentage of oversized blocks and decrease energy loss during blasting.

Originality. Rock fragmentation, which corresponds to the size distribution of fragments of the blasted rock, is one of the most important indices for estimating the effectiveness of blasting works where the size of the fragments of the blasted pile plays an important role in efficient transportation, crushing and grinding.The size of the fragments depends on the characteristics of the rock mass, the type of explosive used, and the drilling and blasting pattern.

Practical value. The use of inclined holes is an important technique to optimize rock fragmentation in open pit mines. The inclination can be adjusted to improve the direction and distribution of blast energy, which contributes to more efficient and uniform fragmentation of extracted rocks.

Keywords: *rock, rock jointing, blasting, inclined holes, Tebessa, Algeria*

Introduction. Blasting, like most human techniques, has remained for many years an art in which the experience of the practitioner plays a preponderant role.

Current mining techniques must have at their disposal expressions rigorously defined by objective considerations, as they must be of practical use taking into account all the factors which influence mining work.

In hard rocks, blasting is usually the most effective way to create primary fragmentation. The properties of the more or less damaged rock fragments and their size and spatial distribution determine the efficiency of downstream operations such as excavation, loading, transportation, crushing (in mines and quarries), and grinding (in mines) [1].

Rock fragmentation depends on two groups of variables: the properties of the rock mass which cannot be controlled, and the blast parameters which can be controlled and optimized. The rock mass constitutes the essential primary constraint from the moment a site is selected where the characteristics of the rock have a significant influence on the following:

1. Drilling performance, the transmission of explosive energy to the rock mass, and its fragmentation can cause stability problems at blast holes and working face.

2. The size of the fragments depends on the characteristics of the rock mass, the type of explosive, and the drilling and blasting pattern [2].

3. The presence of discontinuities, such as joints and fractures, has a great influence on the quality of fragmentation through their spacing and orientation [1] and can sometimes cause additional damage at the level of discontinuities [3].

4. Rock fragmentation depends not only on the energy supplied to the system, but also on the energy distribution or effective energy used for rock fragmentation [4].

The main objective of mine blasting design is the use of explosive energy to knock down rock masses into dimensions and shapes that can facilitate subsequent operations such as excavation, loading, transportation, crushing, and grinding [5].

The primary objectives of a blasting engineer in a mine are to generate a suitable muck pile with an appropriate size distribution of the blasted rock. This is crucial for the subsequent efficient loading, transportation, and milling operations. According to [6], the size of the fragments of the blasted pile plays an important role in efficient transportation, crushing and grinding. The size of the fragments depends on the characteristics of the rock mass, the type of explosive used, and the drilling and blasting pattern [7].

Blasting aims to obtain rock fragments of the desired and optimal average size in order to minimize ore losses during loading and transporting. Smaller or finer fragments result in ore loss during loading and transportation, while larger or coarser fragments require further processing, increasing production costs [8].

The objective of the study consists in obtaining better quality rock fragmentation by using inclined holes to ensure good energy distribution and better stability of the upper wall. The Kuz-Ram model and the Langefors method are best suited to achieve our goal.

The Kuz-Ram model is chosen to perform the simulation and validation:

a – it considers the presence of discontinuities which affect the front through their orientations;

b – the model takes into account various factors that influence explosive energy management, including the characteristics of the explosives and the geometric parameters of the blast plane, such as bench height and hole diameter [9].

On the other hand, the Langefors method (1963) focuses on optimizing the blast hole geometry to achieve the desired fragmentation. According to the principles of Langefors, the inclination of the holes directly influences fragmentation efficiency. For low front heights (less than 10 meters), an inclination between 0 and 5 degrees is recommended, while for higher heights (10 to 35 meters), an inclination between 5 and 30 degrees is recommended.

Usually, in the case of rotary percussive drilling, the blastholes are inclined, which, in bench blasting, gives numerous benefits amongst which, a better fragmentation, displacement and swelling of the muck-pile, as the burden value is kept more uniform along the length of the blasthole and the angle of the projection direction of the shot increases [10].

Materials and methods. Our study also aims to compare the blasting plan adopted by the Boukhadra mine located in the Wilaya of Tebessa, with that calculated by the Langefors method while using inclined holes. We chose the Kuz-Ram model as a simulation model and validation for the following reasons:

1. It considers the presence of discontinuities that affect the front by their orientations. The presence of discontinuities, such as joints and fractures, has a great influence on the quality of fragmentation through their spacing and orientation [2].

2. It takes into account a wide range of factors (controllable and uncontrollable) such as geometric (load, spacing, hole depth and load length, load per hole), explosive (type, quantity, and properties), and rock (strength of rock, porosity, specific gravity, discontinuity information, and groundwater conditions) to predict fragmentation [11, 12].

Overall, the Kuz-Ram model, with its variations and improvements, remains a viable and useful tool for predicting rock fragmentation, offering valuable perspectives for optimizing mining operations in mining processes [13, 14].

Researchers have, therefore, mainly resorted to empirical techniques to predict the outcome of fragmentation the Kuz-Ram method being the most widely used. Empirical models are preferred and widely used in daily blasting operations because they are easily configurable [15].

The Langefors method is a widely used approach to bench blast design calculations parallel to the free face. It uses a semi-empirical formula that allows the theoretical value of the maximum bench (B_{th}) to be estimated. This method is specifically applicable in scenarios where bench blasting is carried out parallel to the free face, all parameters of which are determined according to this maximum bench [16].

***Geologic and tectonic context*.** Djebel Boukhadra is located in eastern Algeria, 45 km north of the city of Tebessa and 13 km from the Algerian-Tunisian border. The Boukhadra iron deposit belonging to the Saharan domain of the Atlas is characterized by a simple anticlinal structure in an NE-SW direction with an NE periclinal termination, this particular anticlinal structure is mainly made up of Mesozoic and Tertiary sediments [17]. The core of the structure is represented by sediments from the Aptian.

From the litho-stratigraphic point of view, the Boukhadra region is made up of sediments from the Tertiary Mesozoic and partly from the Quaternary, as illustrated in Fig. 1.

The oldest formations in the region of the deposit are of Triassic age, they are developed in the south-eastern, southern, and south-western parts of the deposit.

The Triassic formations with a diapiric character surround the deposit, composed of variegated marl, gypsum, and brownish-yellow dolomites associated with visible Triassic breccias.

Water does not influence the Boukhadra mine works because the hydrostatic level is below the operating zone.

The Boukhadra region is marked by two tectonic phases: Folding tectonics and brittle tectonics. These two tectonic

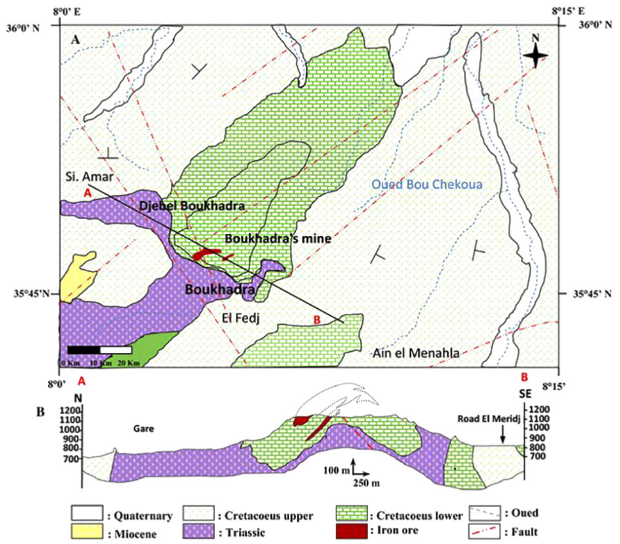

Fig. 1. Simplified geological map of Djebel Boukhadra and NW-SE geological section of the study area [18]

phases caused several faults and fissures, thus creating enormous difficulties for the conduct of extractive work at the underground mine neighboring the open-cast mine.

Fragmentation analysis. Our study focuses on level 1030 (Fig. 2, *a*), which belongs to the Southeast body (Fig. 2, *b*) of the deposit. The latter is affected by two families of joint type discontinuities of stratification of preferential direction N32 35W. These joints are closed with a filling of clay or marl and others are open to a thickness of 0.03 m, with a distance between them varying from 0.11 to 0.39 m (Fig. 2, *c*).

The blasting of rocks in the Boukhadra iron mine is carried out using explosives following electric blasts. A schematic of a blasting plan is established for each blasting operation. The analysis of the heaps of rock, after each blasting of the explosive charges, in the current conditions of the Boukhadra mine allowed us to note the presence of outsized blocks (*a*), back effects (*b*), and poor exit from the bench base (*c*),(Fig. 3).

Langefors method. The Langefors method was used for blast design calculations. This method uses a semi-empirical formula, which makes it possible to calculate the theoretical maximum burden value (B_{th}) from five parameters and a constant [17].

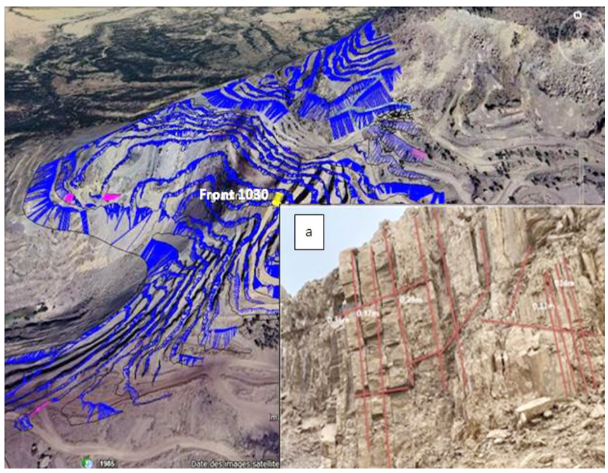

Fig. 2. Study area: level 1030:

a – Presentation of the front-level 1030S

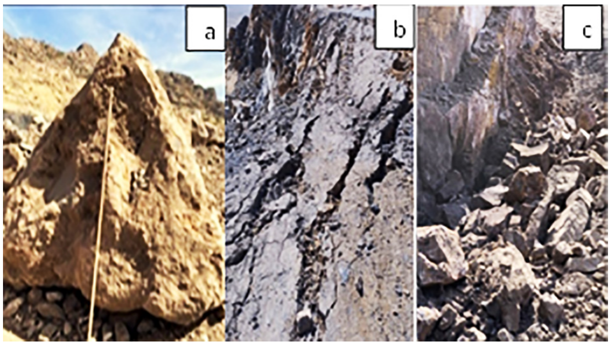

Fig. 3. View of the blasting effects:
a – outsized blocks; b – back effects; c – bench base

$$B_{th} = 1 \cdot 08 \sqrt{\frac{S \cdot Lf}{C \cdot R \cdot \frac{E}{B}}}. \quad (1)$$

The concept of weight strength (S) or energy coefficient in the context of explosives relates to the energy distribution and effectiveness of different explosive charges. This coefficient is particularly relevant when dealing with various types of explosives in a single application, such as in blasting operations.

Energy Coefficient Calculation. The energy coefficient (S) can be defined based on the contributions from different explosive loads. For instance, if there are two types of charges involved, the overall energy coefficient can be calculated using the formula

$$S = 0.6Sc + 0.7SB, \quad (2)$$

where Sc represents the energy coefficient of the shear charge; SB represents the energy coefficient of the column charge.

Linear Charge (Lf). For explosives delivered in bulk, the linear charge (Lf) can be calculated by multiplying the volume of one meter of the hole by the density (d) of the explosive product, kg/m

$$Lf_{bulk} = \pi\phi^2 d. \quad (3)$$

For cartridged explosives, the linear charge (Lf) is calculated by determining the number of cartridges or fraction of a cartridge that occupies one meter length of the drilled hole. One applies to it a different packing coefficient (Kt) according to the nature of the explosive and one multiplies the result by the unit weight of the cartridges, kg/m

$$L_{Cartridge} = \pi\phi^2 dKt. \quad (4)$$

1. For explosives delivered in bulk (d: density of the Milanit explosive, 1.05).
2. For products supplied in cartridges: cartridge diameter ($\phi = 80$ mm; cartridge weight, 2.5 kg; length, 500 mm).
3. Kt – packing coefficient 1.04 to 1.06 Medium consistency explosive (Dynamite).

The energy coefficient (S), weighting the linear charge is necessary to provide an average linear charge when using various types of explosives in the bottom charge.

$$\textit{Linear charge average} = (Lf_{Cartridge} \cdot 0.6) + (Lf_{Bulk} \cdot 0.7)/1.3. \quad (5)$$

Inclination Coefficient (C_{in}). During the blasting process, the compression shockwave reflects in tension off the free surface. This causes secondary fracturing, which is responsible for rock fragmentation. Its effectiveness is proportional to the size of the free surface available. The clearance surface changes depending on the slope of the blast front. It increases with the slope.

The inclination coefficient (C), For $\alpha = 15°$, $C = 0.92$.

Resistance to pulling (R). In the case of a homogeneous terrain, the coefficient of resistance to pulling (R) is primarily determined by the shear strength of the rock material.

The formula for calculating the resistance to pulling (R).

(R) Tensile strength, for rock of medium hardness and rock mass is highly fractured, $R = 0.45$.

The Pattern or Stiffness Ratio (E/B). The E/B ratio is a critical design parameter that influences the overall effectiveness and efficiency of the blasting operation, as it impacts the granulometry and handling properties of the blasted rock material. Spacing is a function of burden. For most situations, the spacing to burden ratio is between 1 and 2. In general, a ratio of 1 : 4 is used as an ideal geometric balance for breakage of massive [19], in the condition case of Boukhadra mining $E/B = 1.25$

Langefors's Constant. The value Bth thus obtained is a theoretical value which must be corrected according to several parameters which depend on the site conditions. We take into account [17].

Burden corrected

$$(B_{thc}) = B_{th} - \sum\varepsilon, \quad (6)$$

where applied ($\sum\varepsilon$) of Implementation error = 0.01 m; drill angle, adjustment mode = 0.1 % ≈ 0.001; drill position = 0.75 · 0.165 = 0.123 m; drilling deviation = 0.005 · 15 = 0.75; $\sum\varepsilon = 0.01 + 0.001 + 0.123 + 0.75 = 0.884$; $B_{thc} = 4.23$ m.

The holes over drilled are over a length of 0.3Bth, with an angle of inclination of 15° B_{th} being the bench in the felling direction, i.e. the thickness of the slice felled between the first line of holes and the front, or between two lines of holes. The bottom charge extends over a length of 1.3B_{th}. The tamping height is equal to the burden (B_{th}). The column load occupies the remaining space in the hole. The calculation results are shown in Table 1.

Fragmentation analysis using the Kuz-Ram model. In the Kuz-Ram model, one of the key data needed is the allowable size of the blocks after blasting. This allowable size is determined by the dimensions of the crusher opening (Co) and the hopper (b)

$$Co \leq 0.8b, \text{ m; for } b = 1 \text{ m}, Co = 0.8 \text{ m oversized.}$$

Therefore, in the context of the Boukhadra mine, the allowable size of large blocks after blasting is 0.8 meters, this means that blocks larger than 0.8 meters will be considered oversized and will need to be further fragmented before being processed by the crusher. The rest of the basic data needed for the Kuz-Ram model are shown in Table 2

Results and discussion. In this study, the size distribution of rock fragments from the Boukhadra mine was predicted by the Kuz-Ram model for an evaluation, as comparative, of the obtained results by the parameters of the real blasting plan of

Table 1

Summary of calculation of blasting parameters using the langefors method

Parameters	Results
Burden theorique B_{th}	5.11
Burden corrected B_{thc}, m	4.23
Blasthole spacing, E	5.28
Sub-drilling, L_s, m	1.26
Stemming length L_B, m	4.23
Hole length, L_{tr}, m	16.88
Length of the explosive charge (L_{ch}), m	5.5
Lch_{column}, m	7.15
Charge of the column; $K_{filling} = 1$ for Mélanit	160.44
Charge of bottom hole, $K_{re} = 0.6$ Marmanit	17.22
Length of charge,m	12.65
Charge/hole,kg/hole	177.66
Number of cartridge/hole , N_C Weight of cartridge = 2.5 kg	0.7
Number of bags of explosives, Milanit, N_{bag}	0.6

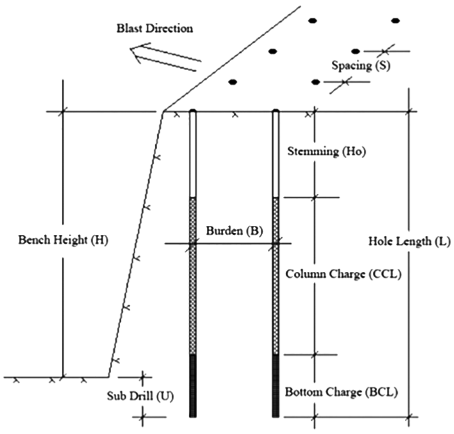

Fig. 4. Geometric parameters and terminology of Langefors

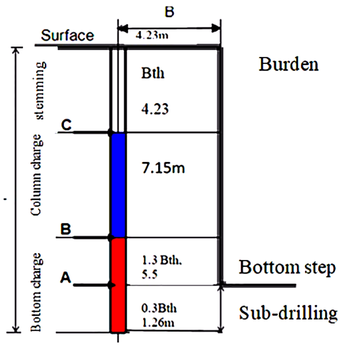

Fig. 5. Blasting plan parameters calculated using the Langefors method

the mine and that determined by application of the Langefors method, Table 5.

The processing of current data from the Boukhadra mine by the Kuz-Ram model taking into account the inclination of the hole, which varies between 5 and 10° (sub-vertical face shows production from a heap filled with a high rate of oversized blocks of 13.1 % with uniformity exponent 1.41 as shown in Tables 3, 4 and Fig. 5.

The obtained results after processing the parameters of the blast plan, calculated by the Langefors method, by the Kuz-Ram model, including an inclination of the holes varying between 10 and 20° (15°), indicate a reduction in the rate of oversized blocks from 13.1 to 5.3 % with a maximum uniformity exponent of 1.62, as the index is higher, more uniform of particle size distribution, while a lower index indicates a more heterogeneous size distribution, Tables 3, 4 and Fig. 6.

Table 2

Properties of intact rock

Rock Factor	
Rock Type	Iron ore
Rock Specific Gravity	2.7
Elastic Modulus	21
Rock Factor	78.4
Cracking	
Spacing	0.25
Dip	35°
Dip Direction	175°
Explosives	
Density, SG	1
RWS7 5 % Milanit + 25 % Marmanit, %	68
Nominal VOD m/s	3,050
Effective VOD m/s	3,000

Conclusion. Interestingly, the Kuz-Ram model predicts a significant reduction in the rate of oversized blocks using an inclined hole drilling technique, from 13.1 to 5.3 %. This approach appears to improve the degree of fragmentation, reduce the percentage of oversized blocks and decrease energy loss during blasting.

The use of inclined holes is an important technique to optimize rock fragmentation in open pit mines. The inclination can be adjusted to improve the direction and distribution of blast energy, which contributes to more efficient and uniform fragmentation of extracted rocks.

However, it is important to emphasize that the predicted results by the Kuz-Ram model still need to be validated in the field.

Field validation will allow factors specific to each mining site to be taken into account, such as rock strength, the presence of discontinuities, and the characteristics of the explosive material used. This additional information will contribute to a more accurate assessment of the effectiveness of the proposed inclined hole drilling technique.

Acknowledgments. *This work is the fruit of the contribution of several people to whom I would like to express my deep gratitude and sincere thanks. I would also like to thank the laboratory managers who contributed directly or indirectly to the completion*

Table 3

Targeted and predicted values for rock fragmentation

Targeted fragmentation parameters, m		Predicted Fragmentati, %	
		Actual	Calculated by langefors
Percent Oversize	0.8	13.1	5.3
Percent In Range	0.4	86.4	94.4
Percent Undersize	0.01	0.4	0.2

Table 4

Rockfragmentation parameters simulated by the Kuz-Ram

Fragmentation parameters	Actual	Calculated by langefors
Blastability Index	7.62	7.62
Average Size of Material	0.37	0.33
Uniformity Exponent	1.41	1.62
Characteristic Size	0.48	0.41

Table 5

Summary table of existing and calculated blast parameters for The Boukhadra mines

Parameters	Existing values	Value calculated by Langefors
Hole diameter , mm	165	165
Height benche, m	15	15
Hole inclination, °	5–10	15
Sub-drilling, m	1	1.23
Hole length, L_{tr}, m	16	16.85
Pratical Burden, m	5	4.12
Spacing, m	4	5.15
Explosive quantity per hole, Kg/hole	100–120	152.76
Stemming length, m Intermediate stemming length, m End stemming length,m	– 2 5	4.12 – –
Length of the explosive charge,m	12	12.73
Specific charge, kg/m^3	0.5	0.26
Type of detonating cord, gr/ml	–	12
Used explosives: 75 % of Milanit and 25 % of Marmanit		

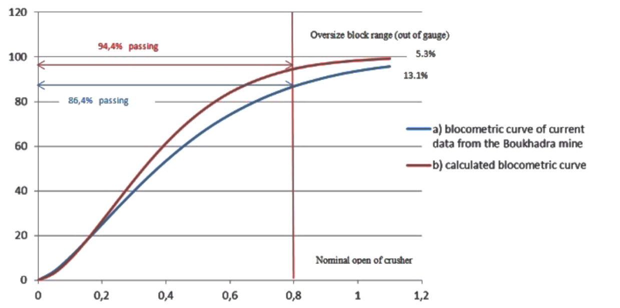

Fig. 6. Comparative curve of two case studies (a) and (b) shows the effect of the inclination of the holes

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Прогнозування дроблення гірських порід в умовах рудника кар'єра «Бухадра»

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Мета. Мета дослідження полягає в отриманні більш якісного дроблення породи за допомогою похилих свердловин для забезпечення належного розподілу енергії та більшої стійкості верхньої стінки. Модель Куз-Рама та метод Лангефорса найкраще підходять для досягнення поставленої задачі.

Методика. Було застосоване порівняння плану вибухових робіт, прийнятого на кар'єрі Бухадра, розташованому у Вілайя Тебесса, із планом, розрахованим за методом Лангефорса з використанням похилих свердловин. Ми обрали модель Куз-Рама в якості базової для імітаційного моделювання та перевірки як достовірну.

Результати. Застосування запропонованого методу Лангефорса дало задовільний результат із точки зору ефективності процесу, модель Куз-Рама прогнозує значне зниження частки негабаритних блоків при використанні методу буріння похилих свердловин, з 13,1 до 5,3 %. Такий підхід покращує ступінь дроблення, зменшує відсоток негабаритних блоків і знижує втрати енергії під час вибухових робіт.

Наукова новизна. Дроблення породи, яке відповідає гранулометричному складу уламків породи, що підривається, є одним із найважливіших показників за оцінки ефективності вибухових робіт, де розмір уламків породи, що підривається, відіграє важливу роль в ефективному транспортуванні, дробленні й розмелюванні. Розмір уламків залежить від характеристик гірської породи, типу використовуваної вибухової речовини і схеми буропідривних робіт.

Практична значимість. Використання похилих свердловин є важливим методом оптимізації дроблення гірської породи на відкритих кар'єрах. Для покращення напрямку і розподілу енергії вибуху можна регулювати кут нахилу, що сприяє більш ефективному й рівномірному дробленню породи, яка видобувається.

Ключові слова: *гірська порода, тріщинуватість, вибухові роботи, похилі* свердловини, *Тебесса, Алжир*

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