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Analysis and improvement of blasting practices for aggregate production: the case of the Ekona quarry (south-west Cameroon)

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ABSTRACT

The knowledge of fragmentation with explosives has allowed a critical look at the theoretical principles and rules of Langefors. The blasting operations at the Ekona quarry are usually accompanied by the production of oversized blocks, which require secondary operations that increase the cost of production. Therefore, a methodology related to the design of a blast plan allowing good fragmentation of the massif is needed. Petrographic observations made it possible to identify and generally describe the massif, which is a prismatic basalt. Structurally, the families of major fracture directions are grouped into two main types, namely, family A: N0-N30, and family B: N30-N60. The analysis of the results obtained for a given step made it possible to detect the influence of several parameters (e.g., the mesh size and inclination of the holes) on the fragmentation results. For a good distribution of the explosive charges and for a regular drilling mesh of 3×2.5 m^2 over a depth of 10 m, we obtain better results than those of the quarry with a gain in specific consumption of explosives of 35%. As a result, the adopted Langefors optimization method has shown that the cost of explosives can reach approximately 30% for 10 m holes and 41% for 12 m holes.

Keywords: Optimize; Ekona; Blasting; Fcturing; Prismation; Basalt.

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INTRODUCTION

The diversity of geological formations has provided a great variety of rocks, which contributes to the constitution of the built heritage of housing and thus allows construction activity to be a continuous engine of development in these countries. The various aggregates used in construction industries come from quarries, sometimes as loose, massive or eruptive rock. Blasting with explosives, the most common technique currently used in quarries, is the first step in the exploitation phase in the production cycle of finished products (aggregates, sand, etc.). Therefore, mastering this step would limit the specific cost to the rest of the chain. The operation of rock quarries involves blasting, crushing and screening. The blasted rock then undergoes a series of reductions and grading classifications, which results in a finished product smaller than 125 mm in size. Each process is vitally important for producing and selling the products of the quarry profitably. Knowing that everything starts with blasting, it must therefore be treated with more precision upstream to avoid repercussions downstream. Optimizing the blasting costs within the quarry is the main key to optimizing the rest of the chain. The contribution of this study is to provide a method for calculating the blast plan other than the method used in the EKONA quarry since it does not ensure a good result (presence of oversized blocks). The results and the different elements of the calculated theoretical blasting pattern are then compared with those used in the quarry. These results will allow progress in the good practice of blasting for better mastery of this essential operation.

GEOLOGICAL CONTEXT OF THE STUDY AREA

The study area is located approximately 15 km northeast of the city of Buéa, more precisely, in the locality of Ekona Mbengue, district of Muyuka, Department of Fako, South-West region (Fig. 1). Access to the massif occurs via the Buéa–Kumba axis relayed to the Ekona crossroads by a secondary road with degraded bitumen of approximately 2.5 km. The site is located on the eastern side of Mount Cameroon, which reaches 4100 m. The geographic coordinates of the massif are between latitudes 4°13'36.25" and 4°14'39.15" N and between longitudes 9°18'4.82" and 9°19'4.66" E.

Mount Cameroon (MC) is the largest and most active of the continental volcanoes of the Cameroon Volcanic Line (CVL). The CVL is a major tectonic feature in West-Central Africa that runs SW-NE following a major left-lateral fault system that extends for more than 2000 km, from Pagalu Island into West-Central Africa. The origin, geology, structure and petrology of the CVL have been discussed by several authors (Deruelle et al., 1987; Fitton et al., 1985; Aka et al., 2004). The origin of CVL is still a matter of debate. The most widely accepted structural explanation for the origin of the CVL is that it is a product of Cretaceous reactivation of Pan-African strike-slip faults trending N70E (Suh et al., 2001; Moreau et al., 1987; Deruelle et al., 2007). The MC is a steep volcanic shield covered by successions of lava flows (Wantim et al., 2011; Mathieu et al., 2011) and subsidiary scoria deposits (Fig. 2). It has a flat summit plateau, a rift zone defined by a linear cluster of eruptive vents, a deep valley (elephant valley) on the N flank, and topographic steps at the base (Mathieu et al., 2011), together with numerous faults and fissures mostly trending N40E (Deruelle et al., 1987). It is composed entirely of moderately alkaline basic lavas (alkaline basalts, hawaiites, picrites and mugearites) (Deruelle et al., 1987; Moreau et al., 1987; Halliday et al., 1988). Field observations indicate that lava flows are massive, porphyritic or vesicular. Moderately explosive Strombolian activity is common at high elevation vents (wantim et al., 2011; Ruxton, 1922; Suh et al., 2003), but lava flows are the most common products released from MC eruptions. Historically, most lava flow activity has been confined to the summit, SW and NE flanks of the MC (Fig. 2). This effectively protected the SE and NW flanks from lava inundation.

The quarry site is located in an area of intense volcanic activity at the origin of a mountainous relief whose summit rises to 4100 m (Mount Cameroon). The quarry covers an area of

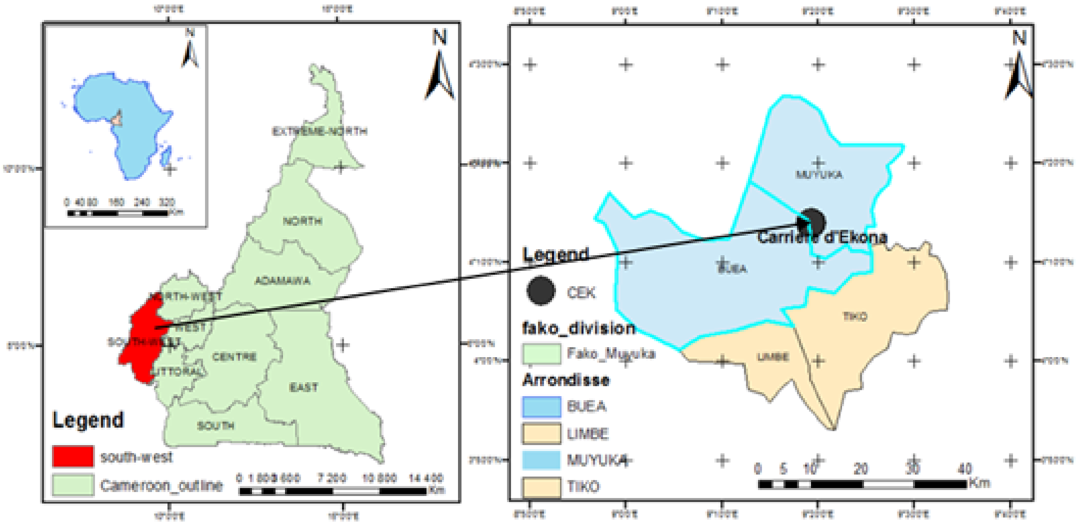

Fig. 1: Location map of the study site

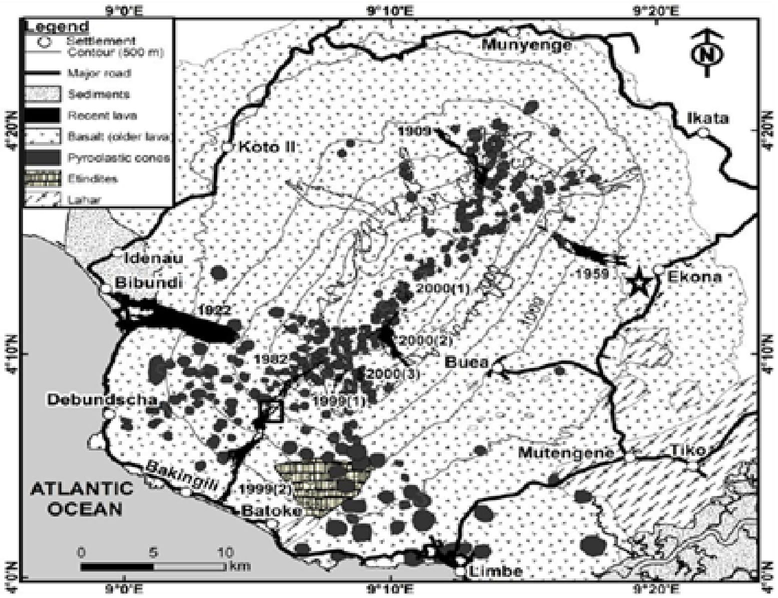

Fig. 2: Map of the geology of Mount Cameroon and the scenes compiled from past dissertations. The pyroclastic cones and historical lava flows indicated by their years, with the numbers in brackets (1, 2, 3) representing the different eruption sites, were mapped from digital elevation models (DEMs; 30 and 90 m) and other satellite imagery (multispectral Landsat TM, ETM+ and ASTER scenes). The star presents the quarry of Ekona, which is the study area.

41 hectares. Located in the vicinity of Mount Cameroon, the district of Muyuka is rich in Andosols, although water remains a vital natural resource that attracts the inhabitants of the eastern slope. The region is rich in sandy, volcanic black soil with a high humus content, although traces of clay soil can also be found in some areas. The rocks mined at the site are from solidified lava flows from the 1959 volcanic eruption (Moreau et al., 1987; Lemoigne, 2010). These are mainly basalt and pozzolana.

The topography of this area is characterized by steep and gentle slopes and plains. The settlements are located between 45 and 898 m above sea level.

METHODOLOGY

Petrographic and structural characterization

The petrographic characterization consisted of sampling the rocks in place, particularly samples of basalt, to carry out macroscopic descriptions and determine the texture, size and color of the various minerals present. The aim of structural analysis of the massif is to study the geological and geometric distributions of structural discontinuities, which are three-dimensional objects. The main characteristic of the rock mass is that it is heterogeneous, which complicates the design and construction of a blasting plan. This heterogeneity affects the structure of the massif, depending on the tectonic constraints experienced (presence of discontinuities) and its lithological nature. Thus, the characterization of a large-scale quarry involves studying the heterogeneity and fracturing of the massif.

In addition to the specific geometry of the discontinuities, structural analysis will seek to define their major orientations and their influences on the design of the firing planes. The traditional method for recording the discontinuities affecting a rock mass is the manual method, which calls for the use of a compass and a clinometer. This study is only based on the directions of fracturing encountered at the level of the various benches present in the quarry.

Quantification of fracturing via software (Georosis): Projection methods make it possible to synthesize and represent the orientations of discontinuities in 2D. The directions of the fractures taken from the bench (350) will be integrated into the Georose software, which will allow us to carry out a statistical study of the orientation data of the families of discontinuities at the same time to present the direction rosettes by different benches.

Method of calculating firing parameters

Theoretical method of calculation

Choice of drilling diameter: The drilling diameter must be adapted to the nature of the rock and the height of the massif. The relationship between the diameter of the hole and the length of the hole is defined by formula (1) (Coulombez, 2011).

$$\text{Ø}_t = K \times \alpha \times \sqrt[3]{L} \qquad (1)$$

Table 1 shows the coefficient of proportionality as a function of the hardness of the rock.

Table 1: Coefficient of proportionality α as a function of the hardness of the rock

Rock	Tender	Little hard	Hard	Very hard
α	1	1.02	1.06	1.26

where K = 37 (standard coefficient): coefficient of hardness of the rock; L: drilling length in m; and Øt: drilling diameter in mm.

Basalt mined at Ekona derived from magmatism. Therefore, we deduce that it is a very hard rock. Thus, the rock hardness coefficient α is equal to 1.26. The drilling depth is 10 m at the Ekona quarry. Depth that we also adopt for the rest of the work.

Maximum admissible bench seat: Swedish researchers Langefors and Kihlstrom have established an empirical rule for calculating the maximum allowable bench according to the parameters inherent in the rock mass (notion of rock resistance), parameters related to the desired mesh size and the type of explosives used. The so-called Langefors rule proposes a linear relationship (formula 2) between the maximum admissible bench and the drilling diameter (Langefors, 1979).

$$B = \frac{\text{Ø}t}{34}\sqrt{\frac{S \times P}{f \times c \times \frac{E}{B}}} \qquad (2)$$

With:

B: maximum permissible bench seat (m)

S: Energy coefficient

f: Tilt coefficient

C: Pull resistance

E/B: spacing ratio on the bench

Ø_t: hole diameter (mm)

P: loading density

The energy coefficient (S)

The energy coefficient S of the Langefors formula corresponds to the energy of the foot load. This coefficient is related to the explosive, as defined by formula 3.

$$S = \frac{5}{6} \times \frac{Q}{Qo} + \frac{1}{6} \times \frac{V}{Vo} \qquad (3)$$

Q and V are the energy and volume of gases of the explosive used, and Q_0 and V_0 are those of a reference explosive (Table 2). For a calculation using the Langefors formula, nitrate-fuel should be taken as an explosive reference. We use the energy coefficient dynamite, explosive in the foot.

Table 2: Energy of the explosives used

Explosive type	Q (Mj/kg)	V (kg/m^3)
ANFO	3.91	0.973
Explus	4.8	0.75

where Q = 4,8 MJ/kg; V= 0,973 kg/m^3 (for Explus) et Q_0 = 3,91 MJ/kg and V_0=0,973 kg/m^3 (explosive energy of ANFO);

Loading density P

This is the density of the explosive, at which a corrective factor can be introduced in the case of the use of cartridges. In the case of loading with several types of explosives, we refer to the loading used for the shear of the foot because this is the part where the work of the explosive is most difficult. In the case of the quarry, loading of the foot is carried out with dynamite cartridges (EXPLUS) 70 mm in diameter. The density of loading is thus given by equation (4).

$$\boldsymbol{P = d \times \left(\frac{\emptyset c}{\emptyset t}\right)^{2}} \qquad (4)$$

where d is the density of the explosive used. It is 1.27 g/cm^3 for the Explus

Stress factor f

The stress factor introduces a correction according to the inclination given to the hole, which is a relatively independent secondary parameter. This can allow a better exit of the foot, better fragmentation of the head and a reduction in back effects.

Table 3 lists the values of this coefficient as a function of the angle intervals of the hole α.

Table 3: Values of the inclination coefficient as a function of the angle of the hole

A	0	10	20	30
F	1	0.95	0.94	0.85

Spacing ratio on the bench E/B

E is the spacing between holes, and B is the bench. This ratio influences the grain size of the products:

For obtaining aggregates, we recommend 1 <E/B <1.3.

For the production of riprap, we recommend 0.8 <E/B <1.

Too low a mesh ratio is detrimental to the average grain size.

A ratio that is too high induces poor cutting of the felling front and leads to the formation of bumps at the bottom of the step. In our case, 1 <E/B <1.3. Therefore, we choose E/B = 1.25.

Correction of the maximum allowable bench seat

During the installation of the mesh, several errors intervene; thus, corrections are necessary during the calculation of the bench. These corrections were made on the basis of the errors made during drilling. They are due either to the operator, to the equipment used or to the geology. We distinguish as errors:

Implementation errors: There are four types of implementation, each with its own error scale. Here, we retain the value 0.05 m;

Tilt errors: These errors depend on the tracking mode, and the value retained for this work is 0.001 × H;

Drilling rig positioning errors: These errors depend on the drilling rig used and the nature of the terrain at the drilling attack point. We take 0.3 × D;

Deviation errors: These errors depend on the type of machine and the natural fracturing of the massif. It is equal to 0.0005 × H.

Therefore, assuming that all the previous errors (ε) are cumulative and that there is no compensation, the practical value of the bench (B_P) is defined by equation (5).

$$\boldsymbol{BP = Bmax - 0{,}05\,H - \sum\varepsilon \quad in\ (m)} \qquad (5)$$

Determination of parameters associated with Langefors parameters: The other parameters linked to the Langefors optimization method are represented by the formulas shown in Table 4 below. According to the authors of Sandvik and Tamrock, (1999), to achieve good fragmentation, the diameter of the hole to be drilled must be between 5H and 10H (m), where H is the height of the step. This gives a diameter between 45 mm and 90 mm; however, the drill bit used at Ekona has a diameter of 115 mm. For this reason, the height of the step should be adjusted so that the diameter can fall within the recommended interval. We thus have:

$5H \le D \le 10H \Leftrightarrow 115 \le 10H$ from where $H \ge 11.5$ m

For a diameter of 115 mm, a height of 12 m is taken to comply with the recommendations of Sandvik and Tamrock.

Table 4: Formulas of the other parameters

Foot load according to Langefors Q_p	**$Q_p = H_p/L_{charge}$ avec L_{charge}=0.47 m en kg**
Length of the hole to be drilled L	L= H/cos(α) + S_f (m) with α = drilling angle
Column load length L_c	L_c= L- (B+ H_p) en (m)
Column load Q_c in (kg)	$Q_c = (\pi \times r^2 \times d_{ni} \times L_c \times N_t)/25000$ or $Q_c = L_c * K_{re} * L_f$ where k_{re}=0,8 and L_f= 7,99
Center distance E	E= 1.1×B (m)
The final stuffing B_f	B_f= 20× Ø in (m)
Horizontal Bench B_h	$B_h = B_p$ /cos α in (m)
Volume of influence of the hole V_{inf}	$V_{inf} = B_h \times E \times H$ (m)
Specific explosive consumption q	$q = (Q_p+Q_c)/V_{inf}$ (kg/m^3)

Studies of the blasting parameters of the Ekona quarry

Survey of the geometric data of the shot: taking the geometric data of the shot consisted of taking the distances between the drill marks along the same row (centre distance) and between two consecutive rows (bench seat). After the drilling, the same measurements were taken by the tape measure, as well as the GPS coordinates of the various points, to highlight the errors related to the drilling. The decameter also made it possible to take the depths of the holes to estimate the mining volume.

Particle size estimation method for felled piles: The granulometric estimation of the felled piles allows the size distribution of blocks to be determined to determine their percentage. The method consists of calculating the volume of the felled heap, which we subtract from the volume of material that passes to the crusher, and the result obtained gives us the volume of block out of the template. This estimation method makes it possible to easily determine the percentage (%) of large blocks in a pile of material felled by formula (6).

$$\%\boldsymbol{Bhg} = \frac{\mathbf{Ve - Vc}}{\mathbf{Ve}} \times \mathbf{100} \qquad (\mathbf{6})$$

With ***%Bhg***: percentage of block outside the template,

Ve: operating volume;

Vc: volume of material passing through the crusher.

RESULTS

Results of the petrographic study

At the Ekona quarry, the outcrop mode of the basaltic massif is in the form of prism flow. The exploited rock is a dark color (grayish) with a compact and hard appearance and is difficult to fragment, and we encounter visible basalt prisms.

The rock is generally good in nature at the base and homogeneous; it is a melanocratic to holomelanocratic rock reflecting a porphyritic microlitic texture (presence of pyroxene and olivine). The areas of discontinuities observed are horizontal joints (Fig. 3). We also have white spots of certain minerals, indicating secondary recrystallization.

Structural results

Ekona quarry structural data

At the Ekona quarry, there are two benches, which are also two fronts. These fronts are affected by several networks of fractures oriented in different directions. Practically all of these fronts face many joints. This is how our studies will be based on them. The structural measurements taken in the field via the compass and clinometer listed in Table 5 represent the different classes of structural measurements recorded at the Ekona quarry.

Table 5: Different classes of structural measurements.

Classes	Direction	Numbers	Percentage
A	N000-N030	100	28.571429
B	N030-N060	130	37.142857
C	N060-N090	10	2.8571429
D	N090-N120	47	13.428571
E	N120-N150	40	11.428571
F	N150-N180	21	6
Total		350	99.428571

Statistical analysis of fracturing

For this approach, 350 measurements of the possible fracturing directions were identified face by face via a compass. The directions of fracturing have been arranged in classes.

Waist front N° 1: two families of fractures predominate, corresponding to classes N030-N060 and N000-N030. The diagram highlights two main directional families. The first family includes fractures in directions between N030 and N060, with an average percentage of 38%. The second, from a direction between N000 and N030, is less represented, with an average percentage of 28% of all the fractures affecting step 1. The rosette of the directional distribution of these fractures confirms our results, where we notice the predominance of class B (N030-N060), indicated by the color brown; class A (N000-N030), indicated by the color light blue; and class D (N090-N120), represented by a sky blue color (Fig. 4).

Waist front N° 2: Compared with the previous front, this is the most fractured level. Additionally, it is characterized by the presence of three predominant directions where their percentage represents almost 70% of the fracturing (Fig. 5). Three main classes are visible in the stereogram: the N030-N060 direction with a percentage of 30% (brown color), the N000-N030 direction (23%) and the N060-N080 family represented by the gray color and a neighboring percentage.

Fig. 3: Minerals visible to the naked eye.

Calculation parameters

Parameters of Ekona's quarry

The variable parameters present at the level of Ekona's quarry are as follows:

Bench = 40 * drilling diameter;

1 * bench < Spacing <1.5 * bench;

On drilling = 0.15 * bench to 0.3 * bench;

Inclination between 0.5 degrees if the height of the front is <10 m;

Inclination between 5 and 30 degrees if the height of the front is >10 m;

Column load = Hole depth - Feet load height - Stuff;

Foot load = Over depth + Bench

Tables 6 and 7 present the variable parameters of the Ekona quarry:

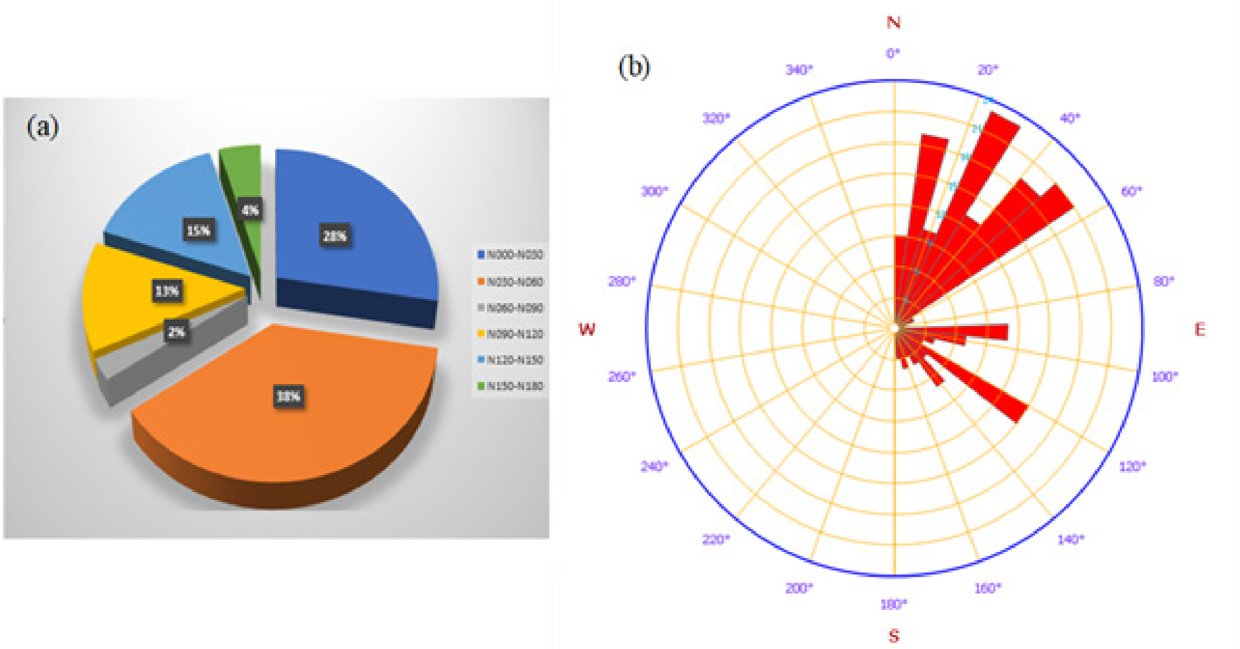

Fig. 4: a) Statistical diagram of the fracturing of step 1, b) rosette for distribution of the fracturing of step n° 1.

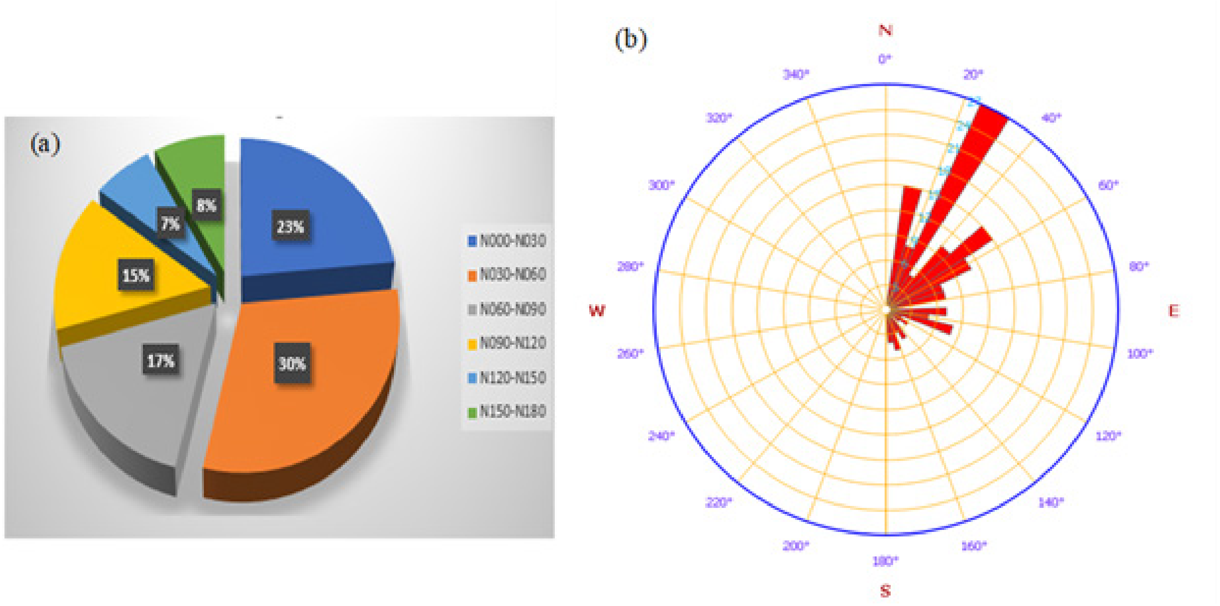

Fig. 5: a) Statistical diagram of the fracturing in step 2, b) rosette for the distribution of the fracturing of step n° 2.

Table 6: Existing drilling parameters in the Ekona quarry

Parameters	**Symbol**	**Value in the Ekona quarry**
Height of the step (m)	Hg	10 m
Drilling length (m)	Lf	10 m
Bench	B	3 m
Hole diameters (m)	D_{tr}	80 mm
Spacing (m)	E	3 m
Mesh (m)	M=B×E	9 m²
Hole tilt (degrees)	I	0°
Terminal jam	B_t	1.5 m
On drilling	S	0 m
Number of holes	Nt	Aleatory

Table 7: Charge data existing in the Ekona quarry

Parameters	**Symbol**	**Value in the Ekona quarry**
Foot load height	HCP	1.5 m
Column load height	HCC	7 m Average loading density 5.31 kg/ML
Total length loaded	L_t	
Specific consumption (kg/m³)	C_s	
Explus Numbers of cartridges/hole (2.08 kg)		4
Nitrate fuel Number of bags/ hole (25 kg)	ANFO	Aleatory
Explus (kg)		6.24
Detonating cord		Aleatory

The parameters obtained according to Langefors

The calculation results are presented in Tables 8 and 9.

Table 8: Drilling parameters obtained after calculation via the Langefors method

Parameters	**Symbol**	**Calculated value**
Height of the step (m)	Hg	10 m
Drilling length (m)	Lf	10 m
Bench	B	2.5 m
Hole diameters (m)	D_{tr}	100 mm
Spacing (m)	E	3 m
Mesh (m)	M=B×E	7.5 m²
Hole tilt (degrees)	I	0°
Terminal jam	B_t	2 m
On drilling	S	0 m
Number of holes	Nt	Aleatory

Table 9 Explosive charge data obtained after calculation via the Langefors method

Parameters	Symbol	Calculated value
Foot load height	HCP	1.5 m
Column load height	HCC	6.5 m Average loading density 5.31 kg/ML
Total length loaded	L_t	10 m
Specific consumption (kg/m ³)	C_s	0.416 kg/m³
Explus Number of cartridge/ hole (2.08Kg)		4
Nitrate fuel Number of bag/ hole (25 kg)		1.4 bac
Explus (kg)		6.24
Detonating cord		Aleatory

Priming sequence: sequential firing arranged by row

Here, we use the detonating cord to ignite the charges. However, the priming sequence is sequential row by row, imposed by the priming of the master cord of each row by an electric detonator. A N° 0 detonator for the first line, N° 1 for the second, N° 2 for the third and n° 3 for the fourth. This gives rise to the following delay times:

Front row: instant;
Row 2: 25 ms delay;
Row 3: 50 ms delay;
Row 4: 75 ms delay.

These delays between lines allow staggered felling of the massif, thus facilitating loading operations.

Blasting pattern: staggered mesh

The staggered mesh consists of an arrangement of holes in groups of five so that there is one in the middle and the others are arranged at each corner of a rectangle. Thus, each hole is located on the perpendicular bisector of the segment formed by two successive points located on a neighboring line.

From the above, it emerges that the optimization of the shot according to Langefors seems the most suitable given that the deeper you go, the more continuous and healthy the massif is.

Functional analysis of firing results: Geometric mesh data

At the end of the various drilling phases carried out at the level of the Ekona quarry, we obtained the results related to the blast hole placement operations as well as the adjustment of a certain number of irregularities encountered (Fig. 6).

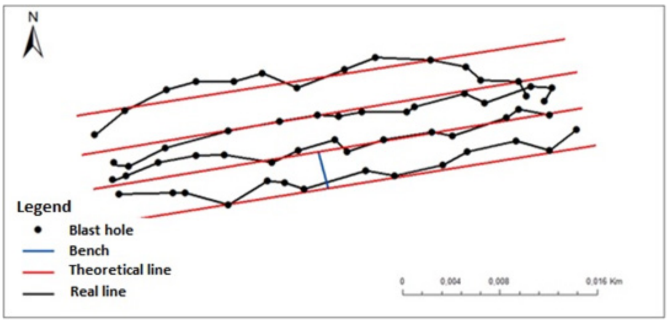

Fig. 6: Errors during drilling.

Modelling of the drilling plan shows that during drilling, the mesh of the firing platform (bench and center distance) varies randomly. Notably, these variations are due to several factors, such as errors in the marking of the drilling points, the presence of voids, which cause a change in the location indicated for the drilling, and the condition of the ground. These variations have a direct influence on fragmentation because the explosive charge contained in a blasthole has the role of overcoming the thickness of the bench. The irregularities in the distances between centers and the bench will have the consequences of either producing high fragmentation characterized by a high rate of small blocks or producing less fragmentation characterized by oversized blocks, as is the case at the quarry. We therefore deduce that one of the causes of the presence of large blocks is the non-respect of the pre-established mesh.

Comparison of the results of the different shots at the Ekona quarry

During our period of work at the Ekona quarry, we witnessed several blasts. Table 10 gives the results of several shots that were fired at the Ekona quarry. We were able to show the percentage of blocks outside the template from the data obtained at the crushing station.

Table 10: Data of some shots fired at the Ekona quarry

Shot number	Shot 1	Shot 2	Shot 3
Number of holes	58	90	64
Average forehead height (m)	9.5	7.78	6.07
Surface to be felled (m^2)	351	513	405
Explus by hole (kg)			
ANFO by hole (kg)	35.2	25.74	16.33
Specific consumption (kg/m^3)	0.568	0.664	0.643
Volume of the felled bed (m^3)	3334.5	4621.32	2458.35
Crushed Volume (m^3)	2526	3304.25	2023.23
Percentage block out of template (%)	24.24	28.5	17.7

Table 10 also shows that the percentage of blocks outside the template is greater for shots where the number of holes is high; indeed, for shots 1 and 3, where the number of holes is relatively small, there is a relatively low fragmentation rate. The poor fragmentation of shot 2 could be explained by the use of a high amount of the foot load in a cracked mass.

The foot charge (EXPLUS) has a high detonation speed, and we can deduce that the dissipation of energy is faster through the mass in place, which results in mediocre fragmentation.

From the field observations and the results obtained, it can be concluded that the lower the density of the toe load is, the more efficient the fracturing. As Hadjadj A, (1989) noted during his various works on rock fragmentation.

Comparison of firing variables according to the Langefor and Ekona quarries

In this subsection, we provide a quick summary of the comparison of the different elements of the calculated theoretical firing pattern and the Ekona quarry firing pattern.

Geometric parameters

The geometry of the shot is determined from empirical laws, which are unfortunately sometimes ignored in careers. Table 11 presents a comparison of the geometric parameters of the Ekona quarry and those calculated from these empirical laws.

Table 11: Comparison of the geometric parameters of the Ekona quarry to those of the Langefors

Parameters	According to Ekona's quarry	Calculated value
Drilling diameter	86 m	100 m
Bench	3 m	2.5 m
Mesh ratio	1	1.25
On drilling	0 m	0.75 m

The currently calculated diameter of 100 mm is adapted to the massif in relation to the diameter of 86 mm.

The order of magnitude of the bench used in the quarry is appropriate according to this approach.

The overdrilling should be 0.3B = 0.75 m instead of 0 m. This excessively low overdrilling is the cause of the resistance points observed at the base of the step. It is better to remember significant overdrilling because it is easier to fill a hole than to destroy a point of resistance.

Loading parameters

Table 12 shows the difference between the loading parameters of the quarry and those obtained in our design of the firing plan.

Table 12: Comparison of loading parameters

Parameters	According to Ekona's quarry	Calculated value
Explosive in foot	Explus 70/2100	Explus 70/2100
Column explosive	Nitrate fuel	Nitrate fuel
Number of cartridges in foot	3	3
Column load	aleatory	35.75 kg
Loading type	Floor	Continued
Intermediate jam	1	1
Final jam	1.5 m	2 m
Specific load	0.215 kg/m^3	0.416 kg/m^3

The choice and amount of explosive for foot shear are consistent. However, the column load is too low to ensure fracturing and release of the material. This is why usually, after firing, the forehead is cracked but not broken, which complicates the work of the excavator.

The final packing distance of 1.5 m for a front of 10 m is small. This is the cause of the large blocks seen on the upper part of the forehead.

A specific load of 0.215 kg/m^3 is too low compared with the capacity of the massif, which also contributes to the production of large blocks and the non-projection of materials.

Boot parameters

The priming sequence and the device play decisive roles in the fragmentation of the massif and the effects of fire on the environment. The differences between the initiation parameters of the designed firing plan and those of Ekona are shown in Table 13. Simultaneous detonation of all the lines results in a muffled shot, with no clearance surfaces. This greatly reduces the impact energy efficiency of the explosive. On the other hand, the muffled fire caused uplift of the rock mass, which was responsible for the rear effects observed on the new front.

Table 13: Comparison of Boot Parameters

Parameters	According to Ekona's quarry	Calculated value
Priming type	Lateral	Lateral
Priming device	Detonating cord	Detonating cord
Firing sequence	Muffled shot	Sequential shot arranged by row
Delay between lines	25 ms between the 1st and the other lines which jump at the same time	25 ms between the 1st and the other lines which jump at the same time

From the comparisons of the different parameters, it is clear that many shortcomings of the methods practiced at the Ekona Quarry can be corrected by following the sequential fire design methodology that we establish below.

Economic evaluation of the explosives at the Ekona quarry

Table 14 presents an economic comparison between the field survey data and the data calculated via the Langefors optimization method. Thus, for a given felled volume, we determine the explosive price differences for a step height of 8 m and for a step height of 10 m.

Table 14: Economic evaluation at different depths

	Field survey	Calculated according to Langefors	
Step height	8 m	8 m	10 m
Shooted volume Va	2045.45 m^3	2045.45 m^3	2045.45 m^3
Number of holes Nt	43	25	14
Mass of foot load ($M_{cp}= N_t \times q_{exlpus}$)	90.3 kg	78.75 kg	58.8 kg
Mass of column load ($M_{cc}= N_t \times q_{anfo}$)	1702.8 kg	954.5 kg	744.1 kg
Foot load amount in FCFA	519 857.1	453 363.75	338 511.6
Amount of column load in FCFA	1 808 373.6	1 013 679	790 234.2
Total amount of explosives in FCFA	2 328 230.7	1 467 042.75	1 128 745.8

According to the economic evaluation in Table 14, for the same height of the step and the same volume to be felled (8 m), there is a significant financial difference, i.e., savings ranging from 37-58% depending on the case. Thus, the optimization method according to Langefors is more economically advantageous.

The diagram of the drilling and blasting plan is as follows:

Drilling plan

Data:

Drilling diameter: 100 mm
Drilling: downhole, implantation with a decameter;
Height of the tier: 10 m.
Extra depth: 0.75 m.
Final jam: 2 m (gravels 6/10)
Hole inclination: 0°.
E/B = 1.25.
Rock: basalt.
Priming: punctual, downhole.

Explosives: Explus of diameter Ø = 70 and ANFO.

Figure 7 shows the drilling plan of the calculated holes.

Loading plan

Figure 8 below presents the loading plan obtained according to the theoretical method of Langefors. The theoretical seeding plan is presented in Fig. 9.

At the end of the design of the theoretical firing plan carried out by calculation through the optimization method, this firing

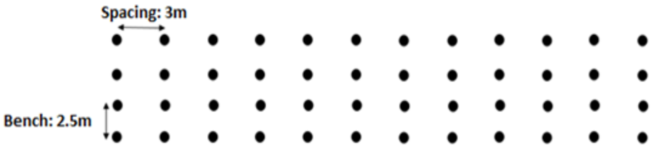

Fig. 7: Drilling plan for the calculated holes.

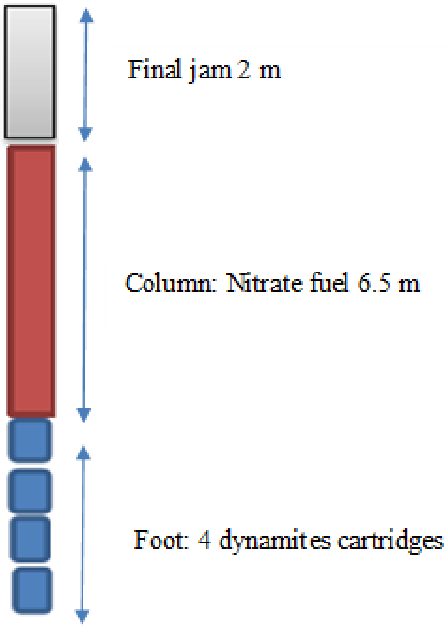

Fig. 8: Loading plan.

plan was put into practice by the host structure, which is how we obtained satisfactory results, and the structure opted for the use of the new firing plan. Figures 10a and 10b below show images of the two types of blasting.

DISCUSSION

The studies of Fourney et al., (1983) established that during the fragmentation process in a fractured medium, compression and shear waves can prolong small discontinuities or propagate discontinuities from pre-existing cracks. Winzer SR, et al., (1983) also reported this phenomenon during firing in a limestone environment. It appears that the propagation of these fractures is due mainly to stress waves, whose appearance is observed before the effects of the quasi-static pressure due to the presence of gases. Winzer SR, et al., (1983) stated that this mode of crack propagation is the most important in the case of fairly fractured massifs.

According to NEFIS M, (2010), the poor quality of the drilling results, most often, by clearly visible deviations, to this; in the case of cutting or not directly visible, in the case of a felling, but with sometimes considerable consequences: projections, production of blocks, see in extreme cases misfiring. The type of machine used for the drilling and the direction of the dip influence the deviations. Notably, depending on the incidence of the cutting edge with respect to the bench, there is a risk of deviation in the direction of the dip or perpendicular to the banks. In general, deviations in drilling must be less than 3% (30 cm for 10 m).

According to NEFIS M, (2010), once again, inclined holes improve the quality of rock fragmentation without causing a significant increase in material expenses or organizational complications of the drilling and blasting processes. Sloping hole felling contributes to improving work safety while ensuring stable and desirable results; within the framework of planned granulometry, on the other hand, at the level of the EKONA quarry, we have a vertical slope.

Baron et al., (2014) argued that with the use of small diameters, we obtain good regularity of distribution of the explosive and an increase in the number of blocks of the massif located in the zone of action of the explosion. Likewise, a decrease in charge energy loss and an increase in the useful work of explosives have been reported.

According to Hadjadj A, (1989), a larger charge diameter results in a higher detonation speed, which promotes better energy efficiency for the fragmentation of the massif. However, this can also lead to a less efficient distribution. Owing to the fairly long packing length of the load, the solid is quite fractured. At the Ekona quarry, the drill has a cutting edge of 86 mm of gold according to Merabet et al (1997), and the diameter of the hole influences the concentration of the explosive in the massif. Thus, an increase in diameter generates an increase in the concentrated load and most often causes an increase in the number of oversized pieces.

In the case of the felling of competent eruptive materials (the hardest), the specific energy required for the shearing of the foot is, however, on the order of 2.25 MJ/m^3 and can reach 3 MJ/m^3 depending on the field (Coulombez, 2007). The values thus obtained are lower than those typically encountered in the blasting of these types of materials; therefore, the current loading is optimal. There is considerable productivity (5108.4 m^3 against 4082.4 m^3) and a remarkable energy power of 1.49 MJ/m^3.

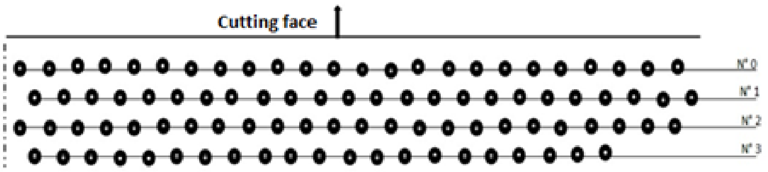

Fig. 9: Seeding plan

Fig. 10: a) Image after firing on the mesh used by the structure, b) image after firing according to the theoretical firing plan according to Langefors.

Too low a mesh ratio is detrimental to the average grain size. A ratio that is too high induces poor cutting of the felling front and leads to the formation of bumps at the bottom of the step between the holes (Langefors U and Kihlstrom B, 1979).

In general, a spacing equal to 1.25 times the bench good results. Good fragmentation can be achieved by varying the spacing between 1 and 1.5 times the bench seat without increasing the energy of the specific load (NEFIS, 2010).

The purpose of tamping is to reduce the number of projections and improve the gas effect of the explosives, which must be sufficient to avoid the "crater" work of the last charge. A weak jam will allow the explosion gases to discharge, which will create problems with projection in the air while reducing the effectiveness of the shot. While heavy, tamping will produce weak fragmentation of the rock at the top of the charge.

In general, it depends on the bench. In deep holes, its length should be equal to that of the bench seat, and it can descend 0.5 times from the bench seat in short holes. Experimental shots show that chipping (4/6) makes better use of explosive energy (NEFIS, 2010).

Slanted holes are advantageous for the first line, and by drilling holes parallel to the face, a line of constant least resistance is accomplished. To maintain a constant line of least resistance with depth for the remainder of the shot, all the holes must be tilted. According to the investigations of certain authors, the application of holes drilled at inclinations varying from 10° to 30° results in better fragmentation (Antill, Modern JM, 1964).

A larger charge diameter results in a higher and therefore more stable detonation speed. This promotes better energy yield, which helps in the fragmentation of the massif. However, this can also lead to a less efficient distribution of the load because of a rather long packing length. In addition, if the mass is sufficiently fractured, a large mesh, a consequence of a larger diameter, will not be able to achieve the desired fragmentation (NEFIS, 2010).

CONCLUSIONS

This work focused on the analysis and improvement of felling practices in an aggregate production quarry, i.e., the case of the Ekona quarry (South West Cameroon), to determine the optimal blasting parameters and compare the parameters with the theoretical results of the empirical formulas of Langefors to optimize the fragmentation of the Ekona massif. As a result, optimizing boulder fragmentation is a daunting task because every blast is different from another blast. Hence, depending on the case, the optimal felling parameters, including the mesh size, drilling, load distribution and priming sequence, need to be adapted. A comparative analysis of the firing data carried out at different operating levels revealed that the percentage of oversized blocks is high for specific high explosive consumption and poorly distributed. On the other hand, the comparison between the data recorded in the field and the data calculated by the Langefors optimization method at the same depth suggests that for a regular mesh of $(2.5 \times 3)\ m^2$, for an inclination of 10° drilling with an optimal load distribution, there is a lower specific consumption of explosives or good fragmentation. Thus, the design of a blast plan on the basis of the properties analysed could result in piles of blasted rock containing fragments of appropriate dimensions to improve the exploitation of the massif technically and economically.

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