International Journal of Research and Review
[Indexed, Peer-Reviewed Journal]
Volume 12; Issue: 4; April 2025
Website: www.ijrrjournal.com
Research Paper
E-ISSN: 2349-9788; P-ISSN: 2454-2237

# Blasting Analysis on the Basalt of Diack (Senegal) Using the Langefors-Kihlstrom Theory

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**DOI: https://doi.org/10.52403/ijrr.20250418**

## ABSTRACT

The study was carried out at the Diack quarry to optimize blasting and reduce costs. The Langefors-Kihlstrom method was chosen for its proven results in blast design. The objective is to evaluate the current blasting parameters and compare them with those obtained using Langefors' approach to adjust and maximize blasting efficiency and operational safety.
The Langefors method uses a semi-empirical formula to calculate the maximum allowable Burden ($B_{max}$) based on various rock mass characteristics and explosive parameters. From this $B_{max}$, all other practical parameters, such as practical burden, sub-drilling length, hole depth, and explosive consumption, are derived.
The results show that the practical burden of 3.97 m calculated using the Langefors method is acceptable compared to the current 4 m burden used at the quarry, with notable differences in geometric parameters. Regarding loading parameters, the Langefors method suggests an EXPLUS 90 quantity per hole of 21.59 kg and ANFO of 54.78 kg, totaling 76.37 kg per hole. The optimized theoretical calculations led to a 9% increase in blasted tonnage while reducing explosive consumption by 22%, with a powder factor of 300 g/m³, lower than the 387 g/m³ used in the current method, leading to better production.
Finally, the Langefors method proves to be more efficient, offering superior breaking power and reduced specific explosive consumption. Thus, its use will reduce blasting costs.

***Keywords:*** Blasting, Quarry, Maximum Burden, Langefors Method, Diack

## INTRODUCTION

Blasting plays a crucial role in the overall economy of open-pit mines, directly influencing all associated subsystems, including loading, transportation, crushing, and grinding [1]. The efficiency of this operation depends on the accuracy of the blast design, which considers various geotechnical and loading parameters. Well-controlled blasting not only ensures effective rock fragmentation but also optimizes the use of explosives and reduces vibrations, as well as adverse effects on the environment and nearby infrastructure [2].
The Diack quarry, located in the Thies region, primarily extracts basalt and is the leading supplier of this material in Senegal. To improve the efficiency of its blasting operations, TALIX Mines uses a traditional blast design based on the empirical relation B = 40D, where B represents the burden and D the drilling diameter, set at 102 mm. However, the need to optimize resources while increasing productivity drives the exploration of more rigorous blasting

methods. It is in this context that we apply the Langefors-Kihlström method [3] to this quarry.

The Langefors-Kihlström method provides a theoretical approach for determining optimal parameters such as the maximum burden, hole spacing, and specific charge, while considering the characteristics of the rock mass [3]. The objective of this study is to compare the performance of blast designs optimized using this method with the existing practices at the Diack quarry, in terms of explosive consumption and productivity.

In this context, we have calculated and compared geometric and loading parameters, as well as blasted volumes and blasted tonnages, to assess the effectiveness of the Langefors blasting method for the Diack quarry. This study presents a critical analysis of the results, highlighting productivity gains achieved.

## MATERIALS & METHODS

### Study Site Presentation

The study focuses on optimizing a blast design at the Diack quarry, located approximately 37 km southeast of Thies, in the Ngoudiane commune [4]. The extraction area where the study was conducted belongs to TALIX Mines, a subsidiary of the TALIX Group, formerly known as EJL Africa Group. This site primarily extracts basalt, a massive and resistant volcanic rock characterized by low porosity and high density (around 3 g/cm³), used for the production of aggregates intended for high-quality concrete manufacturing and road construction [4].

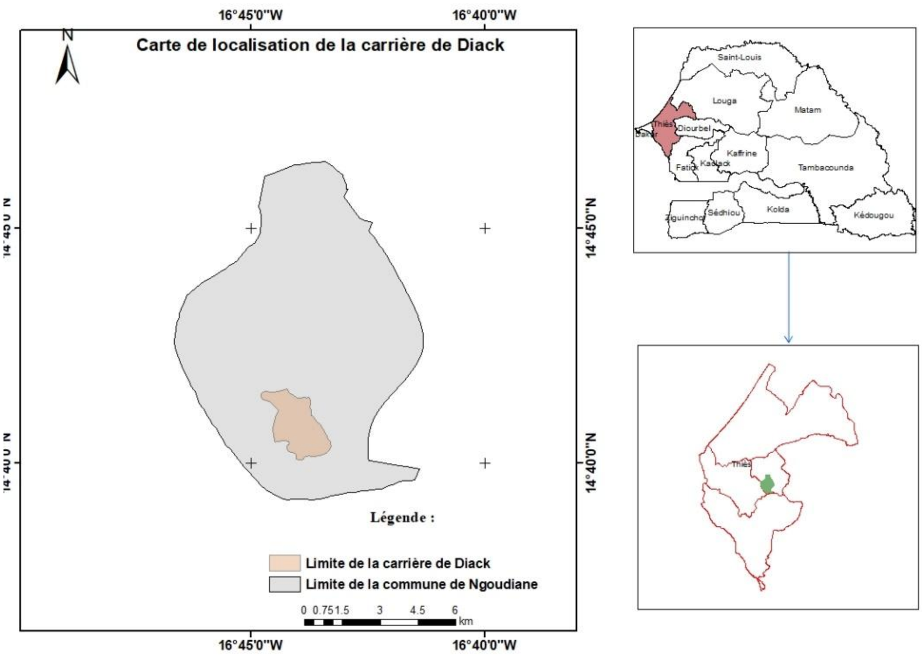



**Figure 1: Location of the Diack Quarry**

The Diack basalt is a massive volcanic rock composed mainly of plagioclases and pyroxenes with occasional olivine and magnetite [5]. This basalt originates from alkaline, basic, and highly sodic lavas [6]. Three main facies types are generally distinguished at Diack with a certain continuity between them: a very fine-grained basanite facies forming most of the Grand Piton, a medium-grained dolerite facies, and coarse-grained gabbro-dolerite facies [7].

These different facies exhibit geometric characteristics related to the overall grain geometry, such as granularity, grain size and shape, angularity, and roughness, and mechanical properties assessed based on hardness and grain strength [8].

## Application Method of the Langefors-Kihlström Theory

Langefors' calculations are based on systematic blasting experiments, derived from theoretical deductions, and carefully verified through blasting different types of rocks worldwide [9]. These calculations have been successfully applied to develop new methods in rock blasting techniques [3].

This method uses a semi-empirical formula relying on experimental parameters, allowing the theoretical maximum burden value to be calculated [10, 11, 12]. This value, denoted as $B_{max}$ (Equation 1), is determined based on the drill hole diameter ($d_b$), which is equivalent to the bit diameter at the bottom, the loading density ($P$), the weight strength of the bottom charge ($s_b$), the stress factor ($f$), the rock factor ($\bar{c}$), and the burden-to-spacing ratio ($E/B$).

$$B_{max} = \frac{d_b}{33}\sqrt{\frac{P \times s_b}{\bar{c} \times f \times (E/B)}} \qquad (1)$$

*Loading Density (P) of Explosives*

The loading density $P$ of the explosive (Equation 2) is defined as the amount of charge (explosive) in kilograms per cubic decimetre (kg/dm³) of the nominal borehole volume. This nominal volume can be 5 to 15% lower than the actual volume, making P about 6% higher than the actual explosive density in the hole [3]. According to [11], for a cartridged explosive:

$$P = (d_e / D)^2 \times \rho_e \qquad (2)$$

Where:

$d_e$ : Explosive diameter (mm)

$D$ : Borehole diameter (mm)

$\rho_e$ : Density (mass per volume) of the explosive (g/cm³ or kg/dm³)

**Table 1: Loading Density Values Based on Loading Method [3]**

| Loading Method | Loading Density (P) (kg/dm³) |
|---|---|
| Tamping pole | 1.0 – 1.4 |
| Pneumatic cartridge loader | 1.3 – 1.6 |

*Burden and Spacing (E, B)*

The practical spacing (Equation 3) corresponds to the distance between adjacent blast holes in a row [9]. Traditionally, spacing is similar to or slightly greater than the burden (E ≤ 1.3 B) for bench blasting [3, 13].

$$E = 1.25\,B \qquad (3)$$

According to Olofsson (1990), the modification of the E/B ratio influences fragmentation:

- E/B > 1.25 : finer fragmentation
- E/B < 1.25 : coarser fragmentation

*Relative Weight Strength (s) of Explosives*

The relative weight strength (Equation 4), according to Langefors-Kihlström, represents the energy available per unit mass of explosive compared to an equal mass of Swedish dynamite (standard explosive). Since ANFO is now widely used, it has replaced Swedish dynamite as the reference explosive [14, 15, and 16].

$$s = \frac{1}{0.82}\left[\left(\frac{5}{6} \times \frac{Q}{Q_r}\right) + \left(\frac{1}{6} \times \frac{V}{V_r}\right)\right] \quad (4)$$

Where:

$\frac{Q}{Q_r}$ : Ratio of the detonation energy of the used explosive to the standard explosive.

$\frac{V}{V_r}$ : Ratio of the volume of gaseous reaction products of the used explosive to the standard explosive.

Reference values $Q_r = 1195{,}03\ kcal/kg$ and $V_r = 850\ dm^3/kg$ at STP (Standard Conditions of Temperature and Pressure) were determined for LFB dynamite, which was a common explosive in Sweden in the 1950s [17].

*Stress Factor (f)*

The stress factor $f$ depends on the inclination $\beta$ of the blast hole and whether its bottom is free or fixed (Figure 2). Table 2 presents the values of $f$.

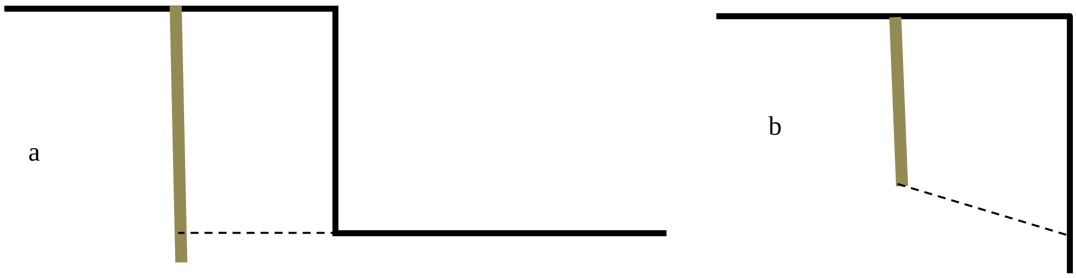



**Figure 2: Hole with Fixed and Free Bottom (a. fixed bottom, b. free bottom): β = 0**

**Table 2: Stress Factor *f* Based on Hole Inclination β [3, 13].**

| | | Fixed Bottom | | | Free Bottom |
|---|---|---|---|---|---|
| Inclination $\beta$ | Slope (vertical: horizontal) | ∞: 1 | 3 :1 | 2 :1 | |
| | Angle in degrees (°) | 0 | 18 | 27 | |
| $f$ | | 1 | 0.9 | 0.85 | 0.75 |

*Rock Factor* $\bar{c}$

For satisfactory fragmentation, an adjusted value of $c = 1{,}2\, c_0$ is generally used [18, 19, 3]. This means that the actual charge is 20% higher than the limit charge to compensate for geological variations and ensure effective blasting.

In the concept of maximum burden calculation, Langefors and Kihlström introduced a correction factor $\bar{c}$ (Equation 5), applied to the constant $c$. Note that $c$ characterizes the rock's resistance to explosive force or the powder factor required to break the rock without projecting it [20, 21, 23].

$$\bar{c} = \begin{cases} c + 0.05 & , B_{max} \in \left]1.4m - 15m\right[ \\ c + 0.070/B_{max} & , B_{max} \leq 1.4m \end{cases} \quad (5)$$

**Table 3: Values of *c* and *c₀* [3]**

| **Rock Type** | **Limit Charge $c_0$ (kg/m³)** | **Adjusted Charge *c* (kg/m³) with 20% Safety Margin** |
|---|---|---|
| Brittle crystalline granite | 0.17 | 0.204 |
| Other unfractured rocks | 0.28 – 0.35 | 0.336 – 0.42 |
| Layered (stratified) rocks | 0.83 | 1.0 |
| Other rocks with complex cleavage | 0.83 | 1.0 |

For blast design, c = 0.4 kg/m³ is directly used. Larson (1974) proposed that the constant rock value, generally 0.4 kg/m³, could vary by up to ±25percentage [18].

The blasting parameters and explosive characteristics involved in the Langefors-Kihlström model are discussed in detail in the following sections. These parameters include various geometric and energy variables influencing the efficiency of blasting and rock fragmentation [22].

**Determination of Blasting Geometric Parameters**

The depth of overdrilling (sub-drilling), as defined by Langefors (Equation 6), is necessary to prevent rock remnants (stumps) above the theoretical level [9, 23].

$$J = 0.3B_{max} \quad (6)$$

The hole depth $L$ (Equation 7) depends on the height of the bench ($H$), the sub-drilling (J), and the inclination ($\beta$) of the blast hole.

$$L = \frac{H}{\cos\beta} + J \quad (7)$$

Deviation errors allow for the correction of the maximum theoretical burden into a practical burden (Equation 8). This depends on the positioning error of the hole opening $\varepsilon_0$ *(m)* and the alignment error $\varepsilon_a$, estimated at 0.03 m per meter of hole depth [9, 24].

$$\varepsilon = \varepsilon_o + \varepsilon_a \times L \quad (8)$$

Where:

$\varepsilon_o = \frac{D}{1000}$

$\varepsilon_a = 0.03\ m/m$

Instead of applying the theoretical maximum burden ($B_{max}$), Langefors recommends using a reduced practical burden (B) (Equation 9) to compensate for errors due to hole deviations. The practical burden is calculated as follows:

$$B = B_{max} - \varepsilon \quad (9)$$

**Determination of Blasting Charge Parameters**

Langefors defines the bottom charge $Q_b$ (Equation 10) as the charge contained between

$-0.3B_{max}$ and $+0.96B_{max}$ [3].

$$Q_b = I_b \times l_b \quad (10)$$

Where:

$I_b = 0,6 \times B_{max}$ : height of the bottom charge

$l_b = P_{EXPLUS\ 90} \times (d_b/36)^2$ : charge per meter or linear concentration of the bottom charge.

Since the bottom charge $Q_b$ is sufficient to cause breakage up to a bench height of $1.96B_{max}$, the additional charge required when the bench height exceeds $1.96B_{max}$ is defined as the column charge $Q_p$ (Equation 11). According to Langefors, the charge per meter at the bottom of the hole should be 2.0–2.7 times higher than in the column section.

$$Q_p = I_p \times l_p \quad (11)$$

Where:

$I_p = L - I_b - T$ : height of the column charge

$l_p = P_{ANFO} \times \left(d_p/36\right)^2$ : charge per meter or linear concentration of the column charge

$T = B$ : stemming length suggested by Langefors

The specific charge (powder factor) $q$, varying between 0.3 and 0.6 kg/m³, is a measure of the explosive mass required to break a unit volume or unit mass of rock [25]. It is calculated based on the total charge per hole $Q_t$ and the total volume $v$ of rock blasted with this charge (Equation 12).

$$q = \frac{Q_t}{v} \quad (12)$$

Where:

$Q_t = Q_b + Q_p$

$v = H \times B \times E$

## RESULT

The working conditions established require using the same input parameters as those employed by the company on-site, both for the terrain and the explosives. The maximum bench height $B_{max}$ (Equation 1) used for the calculation of the practical bench height is:

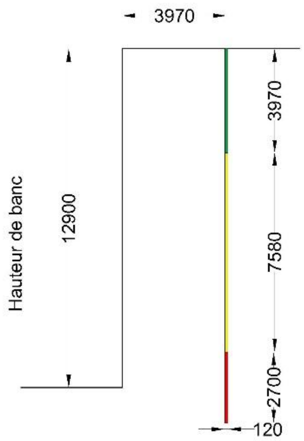
$$B_{max} = \frac{102}{33}\sqrt{\frac{1 \times 1.2}{0.45 \times 1 \times 1.25}} = 4.5\ m$$

The results are recorded in Table 4.

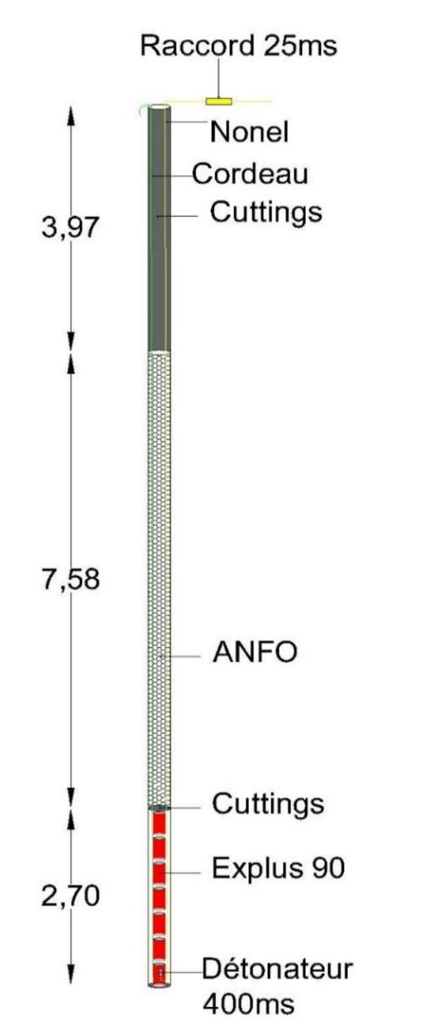
**Calculation of the Practical Bench Height *B***


**Figure 4 Suggested Drilling Plan**

**Table 4 Summary of Blasting Parameters**

| **Blasting Conditions and Constraints** | | **Charge Distribution** |
|---|---|---|
| Drill hole diameter (*D*) | 102 mm |   |
| Spacing ratio (E/B) | 1.25 | |
| Bench width (w) | 35 m | |
| Bench thickness ($l_o$) | 12 m | |
| Bench height (H) | 12.9 m | |
| Rock constant (c) | 0.4 kg/m$^3$ | |
| Rock density ($\rho_r$) | 2.6 g/cm$^3$ | |
| Weight strength at hole bottom ($s_b$, EXPLUS 90) | 1.20 | |
| Weight strength in column ($s_p$, ANFO) | 1 | |
| Charge density at hole bottom ($P_b$) | 1 g/cm$^3$ | |
| Charge density in column ($P_p$) | 0.9 g/cm$^3$ | |
| Drill hole inclination (β) | 0° | |
| Loading conditions | Dry holes | |
| Résultats | | Charge Model |
| Practical burden (B) | 3.97 m | |
| Practical spacing (E) | 4.96 m | |
| Stemming length (T) | 3.97 m | |
| Deviation error (ε) | 0.53 m | |
| *Charge Distribution* | | |
| Linear charge concentration at hole bottom ($l_b$) | 8.00 kg/m | |
| Linear charge concentration in column ($l_p$) | 7.23 kg/m | |
| Charge length at hole bottom ($I_b$) | 2.70 m | |
| Charge length in column ($I_p$) | 7.58 m | |
| Charge at hole bottom ($Q_b$) | 21.59 kg | |
| Charge in column ($Q_p$) | 54.78 kg | |
| *Total Charge and Specific Parameters* | | |
| Total charge per hole ($Q_t$) | 76.37 kg | |
| Total charge per round ($Q_{round}$) | 1603.75 kg | |
| Powder factor ($q$) | 0.30 kg/m$^3$ | |
| *Geometric Constraints* | | |
| Minimum bench width ($w_{-min}$) | 34.72 m | |
| Minimum bench thickness ($l_{o-min}$) | 7.94 m | |

| *Drilling and Volume Parameters* | |
|---|---|
| Number of holes per row | 8 |
| Total number of holes | 23 |
| Total rock volume ($V_{round}$) | 5842.28 $m^3$ |
| Rock volume per hole ($v$) | 250.36 $m^3$ |
| Tonnage | 15189.93 t |
| Total length drilled per blast or Total linear length | 327.74 m |
| Specific drilling volume ($b_s$) | 0.056 $m/m^3$ |




Bench blasting is optimized considering the following conditions and constraints: a drilling diameter of 102 mm, a spacing ratio (*E/B*) of 1.25, a bench width and thickness of 35 m and 12 m, respectively, and a height of 12.9 m. The rock, with a density of 2.6 g/cm³ and a constant of 0.4 kg/m³, is charged with explosives having a strength of 1.20 for the hole bottom (EXPLUS 90) and 1.0 for the column (ANFO). The charging densities are 1 g/cm³ and 0.9 g/cm³ for the hole bottom and column, respectively.

The results show a practical burden of 3.97 m, a spacing of 4.96 m (Figure 4), and a stemming length of 3.97 m. The total charge per hole is 76.37 kg, and the entire blasting operation requires 1603.75 kg of explosives with a powder factor of 0.30 kg/m³. The operations cover 23 holes distributed over 8 rows, allowing the extraction of a rock volume of 5842.28 m³, equivalent to a tonnage of 15189.93 t. The specific drilling rate is 0.056 m/m³, indicating technical and economic efficiency.

**Comparison with the Quarry's Provided Values**

After determining the theoretical parameters, the results were compared with the current blasting practices at the Diack quarry. These results reveal significant differences between the theoretical values from TALIX and those calculated using Langefors, highlighting several optimizations introduced by the chosen calculation method. The comparison data (Table 7) indicate that the optimized method maintains blasting efficiency with a similar burden to TALIX while increasing the spacing. The total charge per blast is reduced by 22%, while the volume and tonnage of rock extracted are increased, thereby improving productivity.

**Table 7: Comparison between the Theoretical TALIX Method and the Calculated Method**

| Parameters | TALIX Theoretical Values | Calculated Theoretical Values |
|---|---|---|
| *Geometric Parameters* | | |
| Practical burden (m) | 4 | 3.97 |
| *E/B* ratio | 1 | 1.25 |
| Subdrilling (m) | 0.5 | 1.35 |
| Hole depth (m) | 13.4 | 14.25 |
| Stemming length (m) | 1.5 | 3.97 |
| Total drilled length (m) | 335 | 327.74 |
| Number of holes | 25 | 23 |
| *Charging Parameters* | | |
| Bottom charge (kg) | 10.92 | 21.59 |
| Column charge (kg) | 72 | 54.78 |
| Total charge per blast $Q_{round}$ (kg) | 2073 | 1603.75 |
| Powder factor $q$ (g/m$^3$) | 387 | 300 |
| *Production* | | |
| Rock volume per hole $v$ (m$^3$) | 214.4 | 250.36 |
| Total blasted volume (m$^3$) | 5360 | 5842.28 |
| Tonnage (tons) | 13 936 | 15189.93 |

## DISCUSSION

The comparison between the theoretical parameters calculated using the Langefors-Kihlström method and the one used by TALIX Mines shows that the optimization of blasting in the Diack quarry allows maintaining efficiency while reducing explosives consumption. In terms of geometry, the values for the bench are similar (3.97 m versus 4 m), but the higher E/B ratio (1.25 versus 1) in the optimized method increases the spacing between holes. This improves fragmentation while reducing the number of shots needed, making the blasting process more economical and efficient.

Adjusting the overdrilling (1.35 m versus 0.5 m) and hole depth (14.25 m versus 13.4 m) contributes to better penetration of the explosive charge into the rock, thus promoting more homogeneous and effective fragmentation. Moreover, a greater burden length (3.97 m versus 1.5 m) allows for better control of explosion gases, reducing harmful projections and vibrations.

Regarding explosive charges, the optimized method doubles the foot charge (21.59 kg versus 10.92 kg), improving the initial breakage of the rock. However, the column charge is reduced (54.78 kg versus 72 kg), leading to a decrease in total charge per shot from 2073 kg to 1603.75 kg, representing a reduction of about 22%. This decrease in explosives consumption helps reduce costs while maintaining satisfactory fragmentation.

In terms of production, the volume of rock per hole increases from 214.4 m³ to 250.36 m³, contributing to a higher total blasted volume (5842.28 m³ versus 5360 m³). This optimization results in an increase in aggregate production, reaching a tonnage of 15,189.93 tonnes compared to 13,936 tonnes for TALIX's method with the same initial parameters. These results indicate that applying the Langefors-Kihlström method in the Diack quarry helps increase the overall productivity of the operation.

## CONCLUSION

These results suggest that the Langefors-Kihlström method is a viable alternative to the current practices in the Diack quarry, with the potential for improved profitability. However, for full and operational implementation, it would be relevant to conduct practical field tests to validate the theoretical calculations and adjust the parameters to the actual operating conditions. These tests could also allow for measuring the environmental impact of the proposed adjustments, ensuring a global and sustainable optimization of the blasting process.

In summary, this study paves the way for improved blasting practices in basalt quarries, while emphasizing the importance of combining theoretical and practical approaches for effective resource management.

***Declaration by Authors***

**Acknowledgement:** None
**Source of Funding:** None
**Conflict of Interest:** The authors declare no conflict of interest.

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How to cite this article: Lamine BAR, Déthié SARR, Oustasse A. SALL, El Hadj Malick GUEYE. Blasting analysis on the basalt of Diack (Senegal) using the Langefors-Kihlstrom theory. *International Journal of Research and Review*. 2025; 12(4): 143-152.
DOI: *https://doi.org/10.52403/ijrr.20250418*

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