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Prediction of Noise Generated by Blast at the Hiré Gold Mine, Cote d'Ivoire

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Abstract: In an effort to diversify its economic resources, Côte d'Ivoire has decided to exploit its mineral reserves. Industrial gold mining in Côte d'Ivoire began in 1991 with the opening of the Ity gold mine in the department of Zouan-Hounien, in the west of the country. From this date, there are ten gold mines in operation. In the department of Divo, the Hiré gold mine opened in 2013. The mine's operations consist of open-pit mining with the regular use of explosives. Based on the results of the research work coupled with those of the exploitation, the mining company requested and obtained from the State of Côte d'Ivoire the possibility of carrying out blasting two hundred and fifty meters from the first dwellings, posing the problem of controlling the nuisance linked to blasting given the proximity of the communities. The situation appears to be unprecedented in Côte d'Ivoire mining sector. Blasting is a source of nuisance, including vibrations, dust, projections and noise. Our study focused on the prediction of noise related to blasting. Our study methods consisted of determining the acoustic constant of the Hiré site from the blasting operations carried out, and predicting the value of the noise generated by the blasting operations from the said constant and from simple and easily available means.

Keywords: Mine, Blast, Housing, Noise, Prediction

1. Introduction

Mining has contributed and continues to contribute to the development of many countries in the world and continues to be a significant contributor to national and regional economies. It is one of many countries' main drivers of economic development [2]. However, it is one of the activities that have negative environmental impacts and is often contested by specific environmental civil society organizations and local communities that are directly affected by its nuisances [5]. In Côte d'Ivoire, agriculture has been the mainstay of the Ivorian economy and the primary source of employment since independence. However, to overcome this sector's fragility and diversify economic resources, Côte d'Ivoire has turned to exploit its mineral reserves [19]. Industrial gold mining began in Côte d'Ivoire in 1991 with the opening of the Ity gold mine in the west of the country [1]. Gold mining production has continued to grow from two tones in 1991 to thirty-eight tones in 2020 [6]. The mining sector's contribution to national and regional economic development has continued to grow. In the town of Hiré, in the west-central part of Côte d'Ivoire with a mining tradition [11], the exploitation of a gold mine was authorized in 2013. The operation is an open-pit operation with regular use of explosives. In 2017, the mining company requested and obtained permission from the Ivory Coast State to carry out explosive blasting within a limit of two hundred and fifty meters of the first infrastructure [4]. The situation appears to be unprecedented in the Côte d'Ivoire mining sector and raises the issue of the possibility of agglomeration mining in the Ivorian context. From the literature on blasting, it appears that blasting is a source of nuisances such as vibrations, dust, projections and noise [13]. Our study focused on the analysis of this last nuisance. Noise is one of the nuisances that cause the most discomfort and inconvenience to local communities [14]. From the state of the art on the question of nuisance caused by explosions, we conclude that from any explosion, a part of the energy, 5 to 10%, is transformed into airwaves, which are the source of noise [3]. Our study methods consisted in measuring the noise value from two sensors equipped with geophones for the blasts in the first quarter of 2020. From the value of the site constant determined, we set up a model, using simple and readily available tools, which allow us to predict the value of the noise that will be generated for a shot to be fired. Good control of the noise parameter should help to guarantee a good cohabitation between the mine and the neighbouring communities.

2. Materials and Methods

2.1. Material

The study material consists of explosive substances, distance measuring equipment, data processing software, and noise measuring equipment, camera equipment, data from previous blasts and data from future blasts. The explosives used to carry out the blasting are detonating explosives, subdivided into primary and secondary explosives [3]. The primary explosives used in our study are non-electric detonators and surface fittings. The choice of the non-electric detonator is justified by the fact that the non-electric detonator allows for greater safety in use compared to electric detonators, and also greater flexibility in reducing the number of blast holes detonated at a time. The secondary explosives used in our study are booster and emulsion made by the French manufacturer Explosive and Chemical Product (EPC) with a density of approximately 1.15 [9]. The nature of the explosive substances used is guided by the aim to produce as little noise as possible and to minimize the risk of detonation during the loading of the volley. Detonating cords and ammonium nitrate were therefore not used. The choice of explosive emulsion lies in the fact that the explosive emulsion arrives on the non-explosive site [18], thus allowing the quantity of explosive product present on the flight to be reduced. The geometric parameters of the blast, borehole diameter, hole spacing, bank and tamping height are determined according to the Langefors formulae [12]. The depth of the boreholes is on average eleven meters and depends on the height of the benches in the mine. The equipment used to measure the distances was a Global Positioning System (GPS). The GPS receiver, having in its base the position of the satellites at each moment, is able to give several informations, including the distance between two points [10]. The GPS used in our study is the Garmin Gpsmap 66st. The computer equipment was used for data processing, the realization of regression curves, the implementation of the noise prediction model and the drawing of the various interpretation graphs. The software used for this purpose was Microsoft Excel, as the statistical functions of Excel have evolved favorably in recent years [15]. The choice of this tool lies in the fact that it is readily available and easy to use. The equipment used during the study to collect the noise data was the GTM 2480 sensor from the Australian manufacturer Texcel. The measuring equipment used is equipped with a large aperture diaphragm microphone connected to a recorder with an input for a three-way vibration sensor [8]. The sensor has the advantage that the measured vibration can be read directly from the screen. The figure below gives a view of the study equipment. Two sensors were used for the study.

Figure 1. *Noise measurement equipment.*

The figures below show a schematic of a typical blast hole and connection plan used for the study.

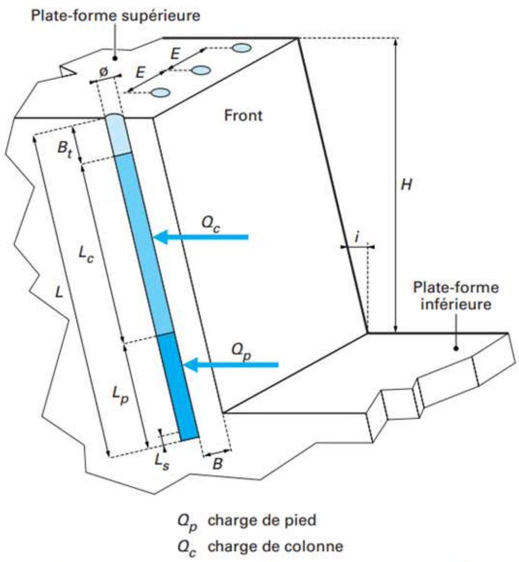

Diagram of a mine hole (Blanchier A. et Al)

With:

E = Spacing
a = drilling diameter
Bt = jam height
Lc = column height
Lp = foot height
Qc = column load
Qp = Foot load
H = Vertical height

Figure 2. *Diagram of a mine hole.*

The typical connection plan used in the study is shown in the figure below.

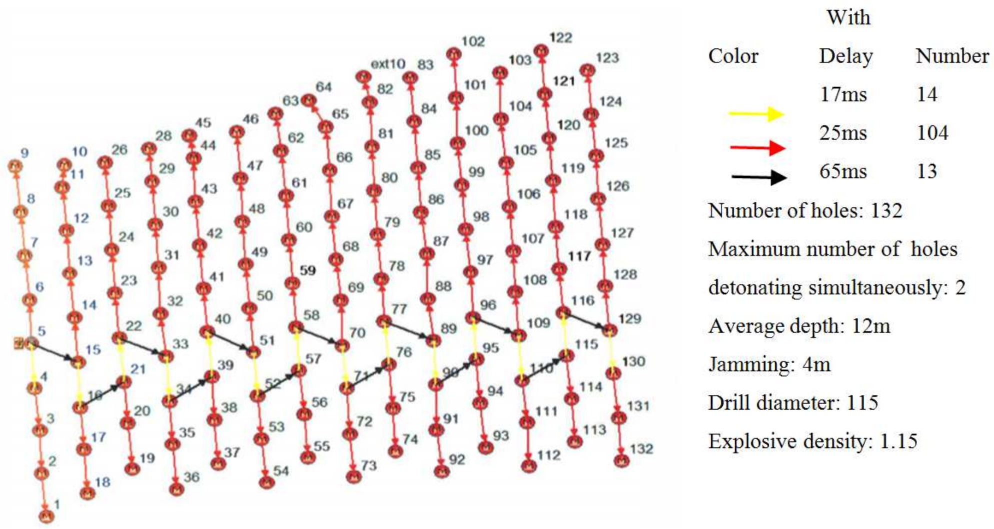

Figure 3. *Typical connection plan.*

2.2. Methods

Our study methods can be summarized in three phases. Firstly, we carry out blasting operations under practically similar conditions (maximum unit load, time of blasting, direction of blasting) and determine the specific instantaneous load for each of the blasts and measure the value of the noise generated by the blast using two sensors. In a second step, we determine from the collected data the value of the acoustic constant of the site. In a third step, we predict the value of the noise generated by a shot to be fired from the pre-established model and compare this value with the value that we measure. We carried out forty-two blasts from 01 January to 30 June 2020 and measured the distance and the noise value for each blast. Two measurement points were established for each blast, namely the electrical transformer station located not far from the blast pit and the nearest house.

From the state of the art on the question of noise linked to blasting, we retain that the noise is mainly linked to the overpressure generated by the blast and the overpressure is a function of two major parameters, namely the maximum instantaneous load and the distance of the blast [14]. The overpressure generated by a shot propagates through the air at the speed of sound (340m/s). The peak pressure decreases with distance by expansion of the wavefront surface. The typical relationship to describe this variation is of the form:

$$P = K_a(D/Q^{1/3})^{-1,2}$$

With:
P: pressure in Pa (Pascal);
D: distance between the shot and the measurement point in m;
Q: unit charge of explosive in Kg;
Ka: overpressure constant of the site.

Also, the overpressure is related to the measured noise by the formula

$$PdB = 20 \text{ LOG } (P/Po)$$

Where
PdB = pressure expressed in decibels or noise level;
P = overpressure expressed in Pascal;
Po = reference sound pressure Po = 2×10^{-5} *Pascal [14].*

2.2.1. Determination of the Distance D

The determination of the distance D is done with the GARMIN GPSMAP 66st. Two measurement points were set up for each shot, the electrical transformer station and the house closest to the blast area. The coordinates of the top of the flight are taken and the coordinates of the noise measurement point, thus giving the linear distance between the two points.

2.2.2. Determination of the Maximum Unit Load Q

The maximum unit charge was determined by summing the mass of all charges detonating within a time interval of 8ms between all charges in the shot and 17ms between adjacent charges [3]. The maximum unit charge Q is determined from the shot data, the connection mode used. It is given by the formula

$$Q\ (Kg) = \pi D^2.hc.d/\ 4000$$

Where
Q = maximum instantaneous load,
D = drilling diameter,
d = density of the explosive,
hc = height of the explosive charge.

2.2.3. Noise Measurement

The value of the noise generated by the shot is directly read on the screen of each sensor as shown in the figure below.

Figure 4. *Noise reading on the sensor.*

2.2.4. Determination of the Overpressure P Associated with the Noise

From the given noise value, we determine the associated overpressure from the formula

$$PdB = 20\ LOG\ (P/Po).$$

We deduce that:

$$P = 10^{(PdB/20)}.\ Po$$

The parameterized Excel model for determining P is as follows.

Table 1. *Determination of Pressure.*

Noise value (PdB)	PdB/20	$10^{(PdB/20)}$	Minimum pressure Po	$P = 10^{(PdB/20)}$ x Po
V1	V2	V3	V4	V5

Where:
V1 = recorded noise value
V2 = Noise value / 20
V3 = Ten exponent noise value
V4 = Minimum reference pressure
V5 = Sound pressure value P in pascal.

2.2.5. Determination of Ka from the Obtained Overpressure Values P

From the value of P obtained, the value of the constant Ka is derived, based on the formula $P = Ka\ (D/Q^{1/3})^{-1.2}$

We obtain

$$Ka = P / (D/Q^{1/3})^{-1.2}$$

The value of Ka is obtained according to the Excel model established below:

Table 2. *Determination of constant K_a.*

D	Q	$Q^{1/3}$	$D/Q^{1/3}$	$(D/Q^{1/3})^{-1.2}$	P	$P/(D/Q^{1/3})^{-1.2}$	Ka

Where:
P = Overpressure generated by the shot
D = distance of the shot
Q = maximum instantaneous load.

2.2.6. Noise Prediction

The prediction of the noise generated by the shot is done in two steps.

Firstly, from the value of Ka obtained, we predict for each shot to be performed.

In a second step, from the determined overpressure, we deduce the value of the associated noise. We carry out fifty three blasts and predict for each blast the value of the noise generated.

2.2.7. Prediction of the Overpressure

Using the formula $P = Ka\ (R/Q^{1/3})^{-1.2}$, we establish the following model.

Table 3. *Prediction of overpressure.*

Hole Diameter (mm)	Hole Depth (m)	Jam (m)	Load Column (m)	Explosive density (g/cc)	Charge per Hole (Kg)	Number of detonating holes at a time	Maximum instantaneous load (Kg)	Distance	Site Constant	Reference pressure	Sound pressure (overpressure)
V	V	V	V	V	V	V	F	V	K_a	Po	P

2.2.8. Prediction of Noise

The noise is predicted from the following Excel model

$$PdB = 10\ LOG\ (P/Po)^2$$

$$PdB = 20\ LOG\ (P/Po)$$

***Table 4.** Prediction of noise.*

Sound pressure (overpressure)	Minimum reference pressure	P/Po	Noise (20 LOG (P/Po))
P	Po		PdB

With:
K_a = noise confinement coefficient
Q = maximum instantaneous load (kg)
D = distance from the load (m)
Po = Reference pressure
P = Overpressure generated by the shot.

3. Result

Forty-three shots were fired during the first half of 2020 and the noise measurements are derived from sensor data positioned at the electrical transformer station and at the threshold of the nearest house. The noise values recorded as a function of distance are presented in the following figure.

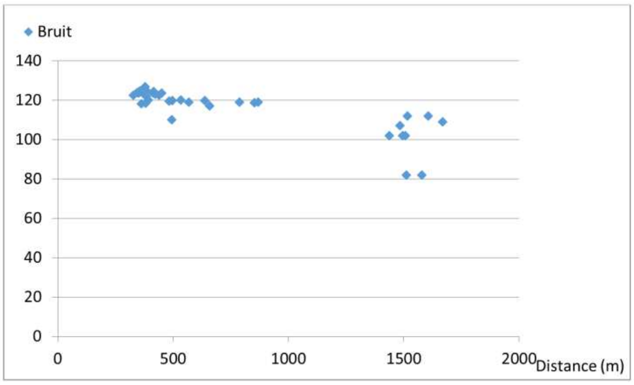

***Figure 5.** Recorded noise as a function of shooting distance.*

The figure shows that the noise value increases inversely with distance. Noise values above 120 dB, the threshold for the onset of hearing pain [16], are all recorded at a distance of less than 500m. The maximum value recorded is 127.6 dB for a distance of 460.11m.

3.1. Value of the Overpressure Associated with Each Shot

We obtain the value of the associated overpressure from the noise value recorded for each shot. The figure below shows the suppression values recorded for the different shooting distances.

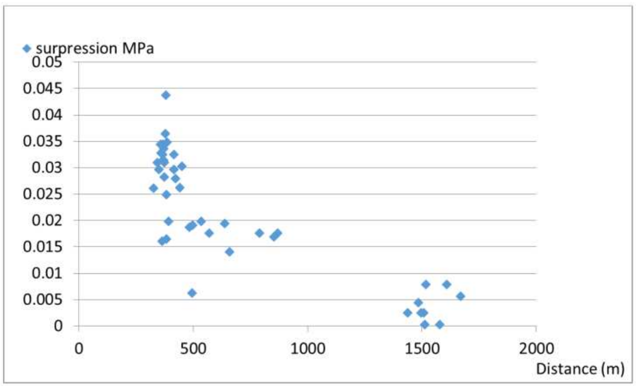

***Figure 6.** Overpressure generated as a function of firing distance.*

3.2. Determination of K_a

From Table 3 we obtain for each of the 42 shots a Ka value represented in the figure below.

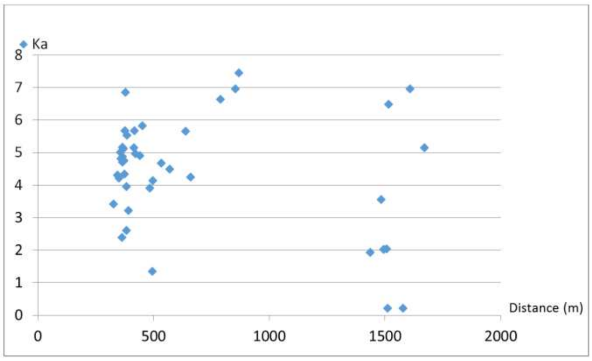

***Figure 7.** Determination of the acoustic constant Ka.*

From the arithmetic mean obtained from the different values of K_a, we derive that Ka = 4.4.

3.3. Prediction of the Overpressure

From the values of the K_a, we predict the value of the overpressure and then the noise for the shots in the second half of the year 2020. We obtain the following values given in the figure below:

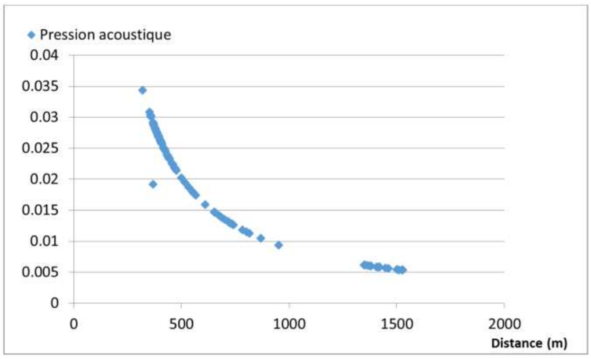

***Figure 8.** Predicted overpressure.*

The overpressure prediction curve shows that the smaller the short distance, the greater the vibration. The predicted overpressures range from 0.057 MPa for a distance of 1621.2 m to 0.0348 MPa for a length of 393.7 m.

3.4. Noise Prediction

From the obtained overpressure values, we predict the noise value as a function of distance for a given maximum unit load depending on the shot parameters and the connection mode.

The predicted noise versus distance curve for a relatively constant maximum unit load shows that the curve is power-shaped with a peak in noise elevation from a distance of 500 m. The noise value 125 dBL, the threshold set by the environmental impact assessment, is reached from 403 m.

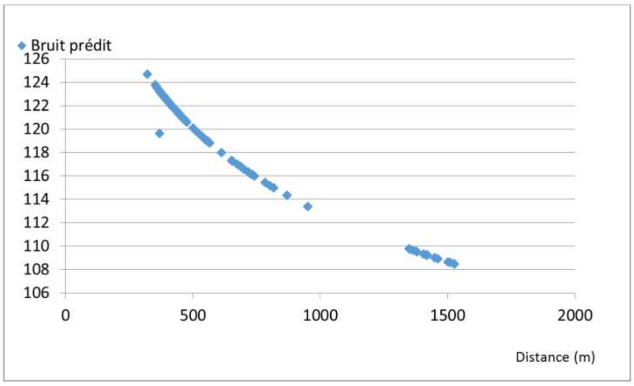

Figure 9. *Predicted noise as a function of distance.*

3.5. Comparison Between Predicted and Measured Noise

The predicted noise values are compared to the recorded values for the same shots. The following figure shows the comparison between predicted and measured noise.

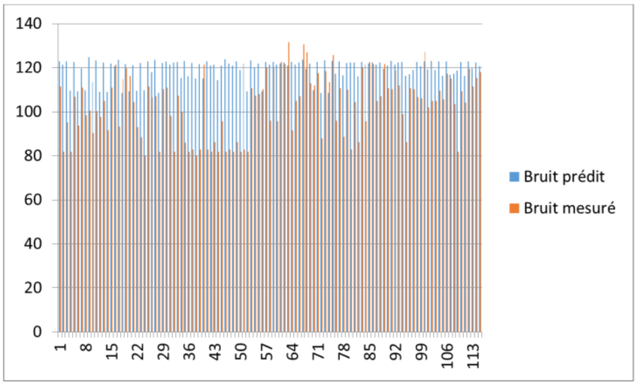

Figure 10. *Comparison between predicted and measured noise.*

The comparison between predicted and measured noise gives an average measured noise/predicted noise ratio of 86.28%, with a predominance of predicted values over measured values.

4. Discussion

4.1. The Constant Site Ka

The acoustic constant Ka determined for the Hiré site is 4.4. The Ka constant determined for the Hiré site is in line with the results of the manufacturer Dyno Nobel [7], which prescribes that Ka values have an average value of 5 for confined blasting, as is the case for the Hiré mine, where tamping is carried out in accordance with the Langefors prescription [12] and where there is no use of secondary explosive substances on the surface (detonating cord).

4.2. The Set Threshold Value

The threshold value set for the Hiré mining project with regard to noise is 125 dBL. From the literature on the issue of noise, it appears that the noise environment is considered almost inaudible below 20 dBL. Up to 40 dBL it is considered low, and then bearable up to 60 dBL. Above 65 dBL, noise is considered painful, annoying and even harmful above 90 dBL. According to the INRS, there are two types of exposure to noise [17],

1. Average daily exposure over 8 hours.
2. Instantaneous exposure to very short noises.

The noise generated by the blasting is exposure to very short noises, with a threshold value of 135 dBL [16]. The threshold set by the Hiré project is below the international regulatory thresholds for instantaneous exposure, and all the shots carried out and predicted have had values below this threshold.

4.3. Maximum Instantaneous Load

The maximum instantaneous charge is a function of the number of blast holes that explode within an interval of 8 ms for the whole flight and 17 ms for adjacent holes [14]. Using non-electric detonators allowed flexibility to detonate as few holes as possible simultaneously. The use of electric detonators would not have allowed the same flexibility. For a flight of 131 holes, firing the electric detonators (No. 0 to 20) would have resulted in six sequences of holes detonating simultaneously. The maximum unit charge would then be three times that found in the case of firing with non-electric detonators; the noise under the same firing conditions with electric detonators leads to an average increase in the predicted noise value of 3.81 dBL, taking all the shots fired at a distance of less than five hundred metres above the threshold of 125 dBL, the threshold set by the environmental and social impact study carried out for the project.

4.4. The Noise Prediction Model

The results obtained with the model show that it offers an average ratio of 86.28% of measured noise to predicted noise. The prediction model always gives higher values, except in 5 cases.

5. Recommendations

The study confirms that noise is related more to distance than the maximum instantaneous load. The mine operator should therefore work to confine the explosive charge as much as possible in order to reduce the Ka acoustic constant as much as possible. For blasting at a distance of fewer than five hundred meters, we recommend using additional means of blast containment such as blast hole plugs or covering the blasted flight with fine sand. An economic evaluation of the recommendations will be the subject of a study. In addition to the measures taken to avoid exceeding the thresholds, it is recommended that a preventive audiometric examination [17] be carried out periodically annually for communities living within a radius of 500 m of mining activities, as the audibility threshold is exceeded there. The purpose of this examination should be to diagnose any noise-induced hearing loss at an early stage and to preserve hearing function.

6. Conclusion

From previous studies on the noise issue related to blasting, it appears that noise is related to the suppression generated by the blast. Overpressure is a function of the maximum instantaneous unit load and blasting. As the blasting distance is difficult to reduce as it depends on the mineralization, the parameter that could be used to reduce noise is the maximum instantaneous charge and the reduction of the acoustic coefficient of the different blasts.

The instantaneous explosive charge is a function of the number of holes detonated at a time, the depth of the holes, the height of the tamping, the nature of the explosives used and the nature of the rock. In the case of the Hiré mine, the reduction of the instantaneous explosive charge appears imperative for successful and harmonious cohabitation. The study shows that the noise can be reduced by adjusting the height of the explosive charge and the arrangement of the detonators. The study shows that it is possible to control the noise below the indicated thresholds. The reduction of the acoustic constant Ka is achieved by maximum containment of the explosive charge. The firings are carried out with non-electric detonators and bulk emulsion, thus allowing flexibility in the maximum minimisation of the instantaneous explosive charge. However, in order to take into account errors and any weather-related peculiarities, it would be advisable for periodic hearing tests to be carried out on communities living within a 500m radius of blasting operations.

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