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Optimization of Blast Design for Quarries -A Case Study of ZIBO Quarry, Ondo State, Nigeria

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ABSTRACT: *This study, examines optimization of blast design in ZIBO quarries. To achieve this, rock samples were collected from the study area for the determination of the rock density. Schmidt hammer was used for the in situ determination of rock hardness. Uniaxial compressive strength of the rock was estimated from the values obtained from Schmidt hammer rebound hardness test and the bulk density determined from laboratory test. Blasting parameters (bench height, hole diameter, spacing, burden, hole length, bottom charge, column charge, specific charge) were also collected from the study area for optimization. The average Schmidt hammer test is 53.9 and the average density of the rock is 2.65 g/cm^3, the estimated mean uniaxial compressive strength value of the quarry is 154 MPa.The quarry uses equal dimension for its burden and spacing. The burden and spacing values are either 1.5 m or 2 m for a given blast design.The quarry's blasting patternsgivespowder factor that ranges between 0.625 – 0750kg/m^2.However, when the blasting data was optimized using Langefor and Khilstrom model, the optimized data proposed values that range between 2.27 – 3.57 m and 2.79 – 4.39 m as burden and spacing respectively. The optimized pattern resulted in a constant powder factor of 0.417 kg/m^3 for different blasting patternmodeled.Thus, the quarry should adopt the optimized pattern for it to attain optimum blasting result. Software was developed using Hypertex Preprocessor (PHP) programming language to facilitate the design of the blasting operation in ZIBO quarry.*

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I. INTRODUCTION

Despite the rapid growth in the technology of rock breaking and excavation, blasting is still the most efficient and cost-effective way of breaking rock masses and produce fragmentation. Surface mining operations and quarries projects still largely depend on blasting as the method of excavation (Hartmanet al., 2002).In open pit mining where blasting is employed for excavation, the overall cost- effectiveness of the production operations is compatible with optimization of drilling and blasting.The orientation of drill holes, pattern spacing and orientation of free faces will determine the efficiency of open pit blast.Another very important factor in blast design is fragmentation. As Wright (1986)pointed out, poor fragmentation will result in higher costs for secondary blasting, haulage, tire wear, crushing, conveying, maintenance and ground support.Several studies (Akande and Lawal, 2013; Bowa, 2015; Singh et al., 2016; and others) have shown that optimization of this operation is very important as the fragmentation obtained thereby affects the cost of the entire interrelated mining activities, such as drilling, blasting, loading, hauling, crushing and to some extent grinding. Several researchers (Kuznetsov,1973;Strelecet al., 2011; and others) have developed methods for predicting the fragmentation from the blast design. Kuznetsov (1973) was the first to propose an empirical equation to estimate the mean fragment size from the blasting parameters. Based on crack growth theory, Lownds (1983) offered a fragmentation model which gave results that were in close agreement to the simple relationship between blasting parameters and mean fragment size proposed by Kuznetsov. Extensions of this modelling technique led to a simple way to infer the appropriate Rosin-Rammler curve (1933) for the fragment size distributions.From this development, Cunningham (1983) proposed the Kuz-Ram model. Empirical studies have shown that it gives good estimates of the fragmentation size distribution, and is currently used in a number of blast design applications.A well-selected blasting pattern would produce fragmentation that can be accommodated by available loading and hauling equipment and crushing plant with little or no need for secondary blasting.To have better design parameters for economical excavation of mineral production and fragmentation, the comminution and fragmentation operations need to be studied and optimized independently, as well as together, to create optimized use of energy and cost effective operation (Hartman et al., 2002).

According to Jimenoet al. (1995), the design of any blasting plan depends on the two types of variables; uncontrollable variables or factors such as geology, rock characteristics, regulations or specifications as well as the distance to the nearest structures, and controllable variables or factors. The process of design then proceeds from here by manipulating design variables so as to satisfy non-negotiable constraints and optimizing those which are negotiable. The designed process is the identification, classification and selection of constraints (Dino, 2001).For example, a blast design must support certain uncontrollable parameters rock characteristic such as the Uniaxial Compressive Strength (UCS), the Point Load Index (PLI), while the choice of drill-hole diameter, burden and spacing etc. will be considered as the controllable parameters.Thus, blast design is a semi-empirical systematic method that involves balancing numeric and qualitative assessments of rock properties, explosives, and desired products (Hartman et al., 2002). Drilling and blasting cost in any project can be as high as 25% of the total production cost (Borquez, 1981). In spite of this, the design and implementation of a well-planned blast that provide adequate fragmentation has been a major source of concern in mining industries especially quarries over the years.A number of quarries often result in secondary blasting during which they break down boulders resulting from primary blasting to smaller sizes before they are transported to the crushing plant. It is very important that blast design can be quickly and accurately analyzed before actual blast. The process of designing blasting is however a complex phenomenon in which several parameters requiring difficult evaluation dictates the outcome.Since proper adoption of drilling and blasting contribute significantly towards profitability, thus optimizations of these parameters are essential.This study therefore optimized blast design parameters obtained from Francisca Miunat Limited quarry (ZIBO quarry) using available mathematical model and developed software.

II. MATERIALS AND METHODS

The study area, the materials, and methods adopted for this research are explained in this section.

2.1Location of the Study Area

The study area, ZIBO Quarries is situated in Ondo State, Southwestern part of Nigeria. The quarry is into the production of crushed aggregate for neighboring construction companies and builders.The granite deposit in FM Quarry Aaye lies within latitude 7^{o}20' 261'N' and 7^{0} 20' 468"N and longitude 005^{0} 10' 173"E and 005^{o}10' 357"E. Figure 1shows the location of the study area.

This part of southwestern Nigeria (where FM Quarry Aaye Leases is located) is underlain by the Precambrian Basement Complex Rocks. The lithological units vary from the migmalitic – gnesis – quartzite complex; slightly migmatised to non-migmatizedparaschists (i.e metasedimentary) and metaigneous rocks including phyllite, schist, quartzite, polymic conglomerates calc-gneiss, marble, iron-formations, flaggy gneiss, and amphibolites and talc-tremolite-actinolite-chlorite schist; members of older granite suites like porphyritic and non-porphyritic granites and granodiorities, adamelites, tonalite, quartz diorite charnokite and minor syenite; to minor felsic and mafic intrusive composed of concordant and discordant dykes, veins and irregular bodies of pegmatite, aplite, quartz, gabbro, pyroxenite, lamprophyres and serpentinite.

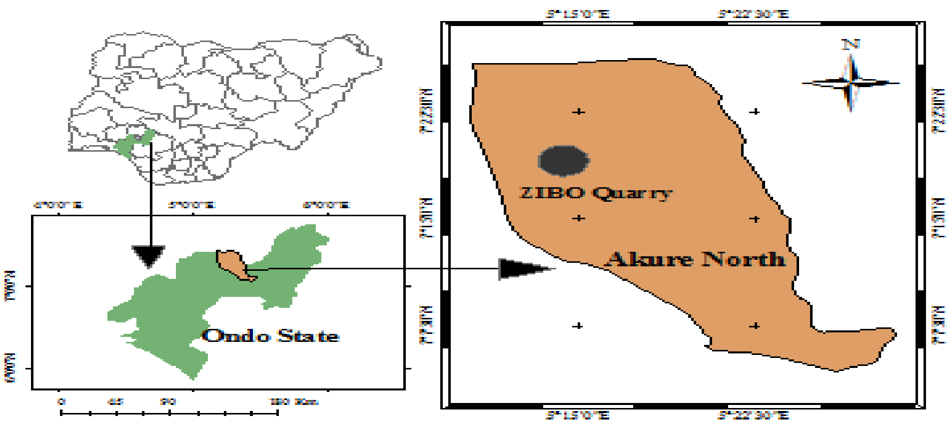

Figure 1. Map showing the study area

2.2 Collection of Samples and Preparation

Schmidt hammer tests were carried out on the quarry in siturock to determine its hardness. Grab samples were also taken from the study area and tested in the laboratory to determine the bulk density of the quarry's rock.

2.2.1Determination of Rock Hardness

The hardness test involved the use of Schmidt Impact Hammer type L for the hardness determination of in situ rock. The standard method for the Schmidt Hammer test as described by (ISRM, 1995; and ASTM, 1994) was followed.

The measured test values were ordered in descending order. The lower 50% of the values and the upper 50% values were discarded; the remaining values were averaged to obtain the Schmidt Rebound Hardness (ISRM, 1995).

2.2.2 Determination of Rock Bulk Density

The objective of the test is to measure the dry density of rock samples of irregular form from ZIBO granite quarries. The determination of the rock bulk density (ρ) was carried out using the standard procedures suggested by (ISRM, 1995).

The bulk density was calculated using Equation (1).

$$\text{BulkDensity}(\rho) = \frac{M}{\Delta V}(g/cm^2) \quad (1)$$

where,

M is the bulk sample mass

$$\Delta V = \text{bulkvolumeofthesample}\ (V_f - V_i) \quad (2)$$

where$V_f$is the final cylinder reading, V_i is the initial cylinder reading.

2.2.3Uniaxial Compressive Strength

The determination of uniaxial compressive strength was obtained from the chart (Figure 2) suggested by Deere and Miller (1966) using the Schmidt hammer rebound value and rock density. The chart shows the correlation for Schmidt hammer, relating rock density, compressive strength and rebound number.

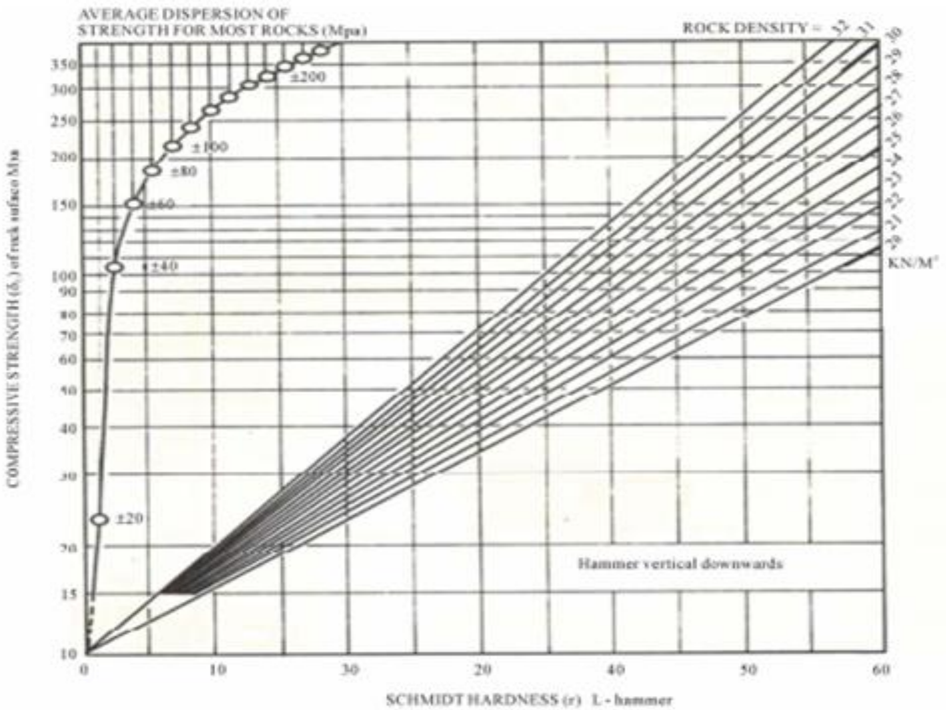

Figure 2. Correlation Chart for Schmidt Hammer, Relating Rock Density, Compressive Strength and Rebound Number (After Deere and Miller,1966).

2.3Collection of Blasting Data

The following information and blast design parameters were collected from the study area: Blasthole diameter (mm), bench height (m), burden (m), spacing (m), weight of bottom charge (kg), weight of column charge (g), quantity of explosives used per hole (kg).

The information provides means through which the performance of the developed model can be compared with that of the case study method.

2.3.1Determination of Total Explosive Charge

The total explosive charge is the quantity of the explosive needed to fragment the rock. The total explosives charge was estimated using Equation (2):

$$Q_t = Q_c + Q_c \quad (2)$$

whereQ_c is total explosive charge (kg), Q_c is weight of column charge (kg) and $Q_b$is weight of bottom charge (kg)

2.3.2Determination of Volume of Rock Blasted and Powder factor

The total volume of rock blasted for a given hole was obtained using Equation (3).

$$V_o = B \times S \times H \quad (3)$$

where$V_o$is the rock volume (m^3), B is the burden (m), S is the spacing (m) and H is the bench height (m)
The Specific Charge or the powder factor which gives the quantity of explosive required to fragment m^3 of rock for a given number of holes is calculated using Equation (4).

$$q = \frac{Q_c}{V_o} \quad (4)$$

2.4 Optimization of the Quarry Blasting Parameters

2.4.1Optimization Methodology

The parameters were obtained using the Swedish technique developed by Langefors and Kilhstrom (1978). Here, the geometric design of the blasting pattern and the calculation of the charges are based on the uniaxial compressive strength of the rock. Table 1 shows the tentative values of the geometric parameters asfunction of the compressive rock strength. The stemming length and that of sub-drilling were also calculated according to the blasthole diameter and the compressive rock strength.Recommended lengths of bottom charges are given in Table 2. Equations (5) and (6) were used in the calculation of the column charge length and charge concentration per meter respectively.

Table 1. Variation of Parameters with UCS of Rock and Diameter of Hole (After Jimenoet al.,1995).

Design parameter	Uniaxial Compressive Strength (Mpa)			
	Low <70	Medium 70 – 120	High 120 – 180	Very high >180
Burden – B	39D	37D	35D	33D
Spacing – S	51D	47D	43D	38D
Stemming – T	35D	34D	32D	30D
Subdrilling – J	10D	11D	12D	12D

Table 2. Variation of Bottom Charge Length with UCS and Diameter (After Jimenoet. al, 1995)

Design Parameter	Uniaxial Compressive Strenght (Mpa)			
	Low <70	Medium 70 – 120	High 120 – 180	Very high >180
Bottom charge Length	30D	35D	40D	46D

Charge Distribution,

$$\text{Columnchargelenght(m)} l_c = L_t - (l_b + T) \quad (5)$$

$$\text{Chargeconcentrationpermeter} (kg/m) q = \frac{\pi D^2 \rho}{4} \quad (6)$$

whereL_t is length of drill hole, l_b is length of bottom charge, T is stemming,$\rho$is explosive density (ANFO – 800kg/m^3, Slurry for bottom charge – 1200kg/m^3), D is drill hole diameter and q is mass of explosive per linear meter(kg/m).

2.5Fragmentation Size Prediction

The Kuz-Ram modelsuggested by Cunningham (1983) was employed to determine the mean fragmentation size that a blast design would likely produce. Equation (7) was used for the determination of the mean fragmentation size.

$$X_m = F_r q^{-0.8} Q_E^{0.167} (115/S_{ANFO})^{0.633} \quad (7)$$

where, X_m is the average fragment size (cm), F_r = Rock factor, q = Powder factor (kg/m^3), Q_E = Explosive charge in the blasthole (kg), S_{ANFO} = Relative weight strength of the explosive .

2.6Software Development

The plan is to develop a software that would give the desired powder factor and keep it within the recommended limits has characterized by the Uniaxial Compressive Strength (UCS) of the case study's rock and also predict the fragmentation size for a number of blastholes. In this research, bench blasting design parameters were optimized using suggested empirical equations by Jimenoet al. (1995). The empirical equations were derived based on the Uniaxial Compressive Strength of a given deposit.

The software data for the granite quarry were generated from the data collected, in-situ test and laboratory test conducted on ZIBO quarry located at Ijare Road, Akure. In the software development, the Uniaxial Compressive Strength, Density and the Rock factor were treated as constraints while the Powder factor, burden and spacing were taken as the objective functions.

The software incorporated the empirical relationships between the parameters as given in Tables 2 and 3.

III. RESULT AND DISCUSSION

Table3 shows the results of laboratory tests conducted on rock samples from ZIBO quarries for the determination of rock density. The average bulk density of the rock samples as shown in (Table 3) is 2.65 g/cm^3. Table 4 shows the results of field test conducted on in situ rocks in the study area with Schmidt hammer, density from laboratory test and estimated uniaxial compressive strength. It could be observed that the Schmidt hammer test is 53.9 while the corresponding uniaxial compressive strength is 154 MPa, indicating a medium hard rock.

Table 3. Bulk Density of the Rock Samples.

S/N	Mass of the Bulk Sample (W_1) (g)	Initial Volume (V_i) (cm^3)	Final Volume (V_f) (cm^3)	Change in Volume (cm^3)	Density (ρ) (g/cm^3)
1	103	250	289	39	2.64
2	113	250	294	44	2.56
3	98	250	283	33	2.97
4	104	250	293	43	2.42

Table 4.Results of Schmidt Hammer Tests for the Determination of Uniaxial Compressive Strength.

Average Schmidt Hammer Result	Average Density from Laboratory Tests (g/cm3)	Equivalent Uniaxial Compressive Strength (MPa)
53.9	2.65	154

3.1Conventional Blasting Parameters at ZIBO Quarry

Information regarding drilling and blasting parameter as collected from Zibo quarry for optimization is shown in Table 5. As presented (Table 5), the blasting pattern adopted at the quarry has specific charge that ranges between 0.625 – 0.750 kg/m^3.

Table 5. Blast Design Pattern Adopted at ZIBO Quarry.

Diameter (mm)	Depth of hole (m)	Burden (m)	Spacing (m)	Weight of Charge Per Hole (kg)	Specific Charge (kg/m^3)
65	18	1.5	1.5	40.0	0.740
89	27	2.0	2.0	67.5	0.625
102	27	2.0	2.0	81.0	0.750

3.2Optimization of the Blasting Parameters

Table 6 shows the results obtained when the design parameters were optimized for different hole diameter and hole depth. The optimized results show that when drilling to a depth of 18 m with 65 mm hole diameter, the burden and spacing are 2.27 m and 2.79 m respectively while the weight of charge is 47.78 kg. When 89mm hole diameter was used with a hole depth of 27 m, the burden and spacing are 3.15m and 3.83m respectively and the weight of charge per hole is 134.37 kg. Also when drilling to a depth of 27m with 102mm hole diameter, the burden is 3.57m, spacing are 4.386m and the weight of charge is 176.49 kg/m^3. The optimized values have a constant specific charge of 0.417 kg/m^3 which is in line with the recommendations of Ash (1963) for medium hard rocks. It could also the observed from the results presented in Table 6 that the mean fragmentation size predicted ranges between 12.43-12.80 cm, the relatively close fragmentation values predicted for different blast pattern considered indicate that the adopted model has the capability to keep the final output within the expected fragmentation size as the case may be.In all cases, the values of the burden, spacing and charge per hole used being in the Quarry is lower than the value obtained from optimization.

Table 6. Optimized Blast Design Pattern at Zibo Quarry According to LangeforsandKuz-Ram model Approaches.

Diameter (mm)	Depth of hole (m)	Burden (m)	Spacing (m)	Weight of Charge per Hole (kg)	Specific Charge (kg/m^3)	Mean Fragment Size (cm)
65	18	2.27	2.79	47.78	0.417	12.43
89	27	3.15	3.83	134.37	0.417	12.60
102	27	3.57	4.386	176.49	0.417	12.80

3.3Correlation between Variables

Figures 3 – 5 show the correlation between various blast design variables. In all the cases (Figure 3 – 5), as the diameter of the hole increases, the burden, spacing and weight of charge per hole increase in turn.

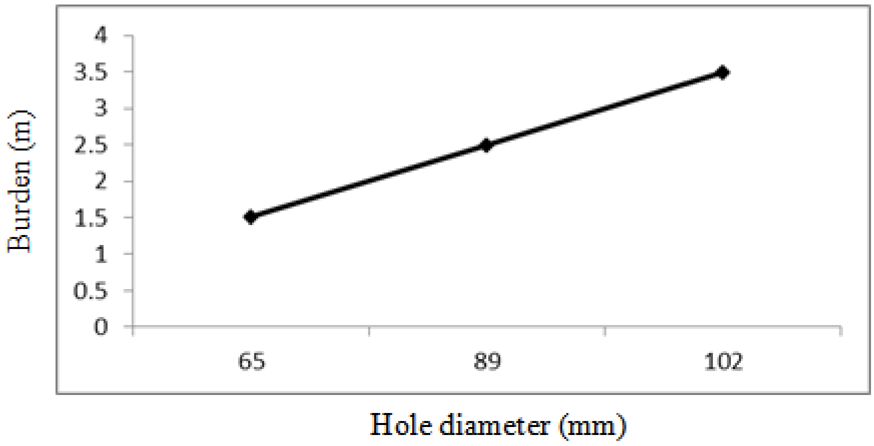

Figure 3. Effect of Hole Diameter on Burden

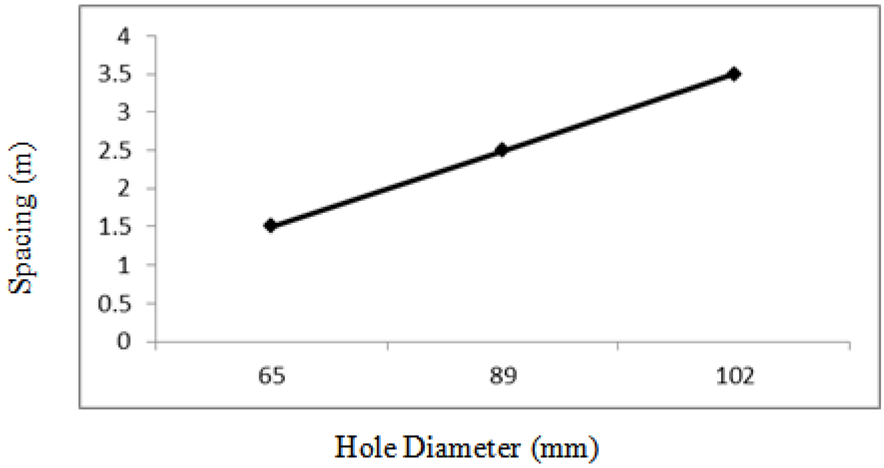

Figure 4. Effect of Hole Diameter on Spacing

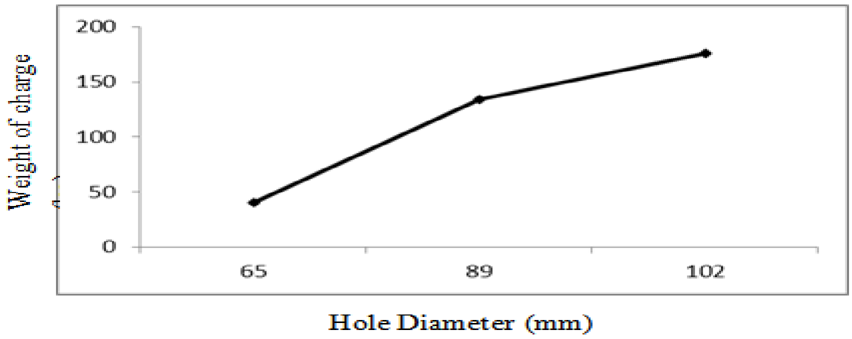

Figure 5. Effect of Hole Diameter on Weight of Charge

3.4Blast Design Optimization Software

Figures 6 and 7 show the input and the output page of the blast design optimization software respectively. The input page provides the interface that allows the user to input the necessary information for processing while the output page gives the desired parameters after computation.

The mean fragmentation size was determined theoretically based on the Kuz-Ram model prediction method. The rock factor of the quarry rock was deduced based on the Uniaxial Compressive Strength of rock already determined. The rock factor was taken as 10 for medium hard rock.

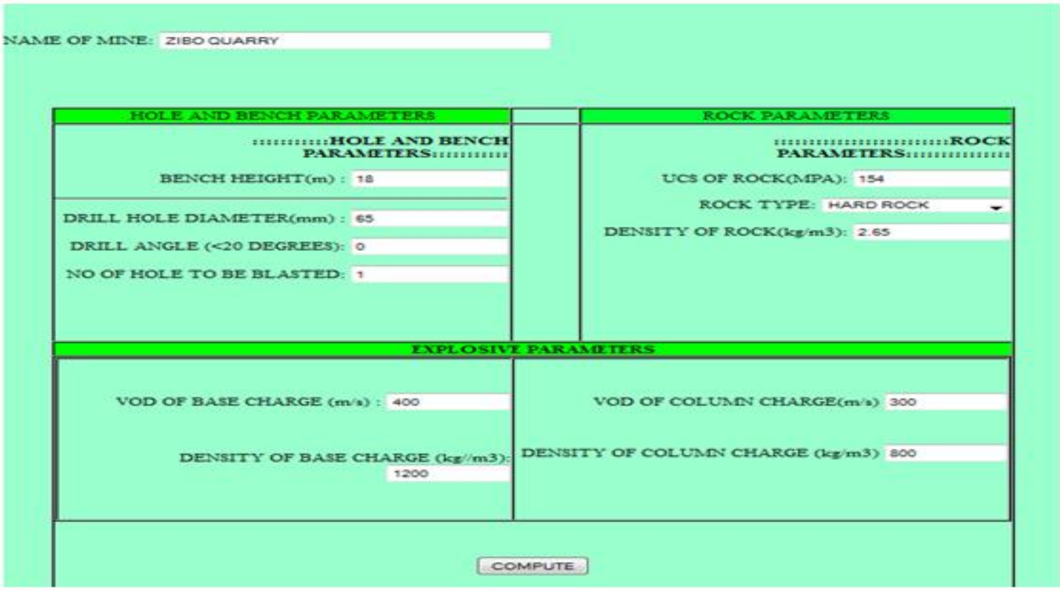

Figure 6. Input Page for Data Computation

OUTPUT PARAMETERS

PARAMETER	OUTPUT VALUE
BURDEN(m)	2.275
SPACING(m)	2.795
LENGTH OF SUB DRILLING (m)	0.78
LENGTH OF STEMMING(m)	2.08
LENGTH OF DRILL HOLE(m)	18.78
VOLUME OF ROCK BLASTED PER HOLE(m3)	114.45525
YIELD OF BROKEN ROCK (m2)	6.0945287539936
LENGTH OF BOTTOM CHARGE(m)	2.6
CONCENTRATION OF BOTTOM CHARGE(kg/m)	3.982485
BOTTOM CHARGE(kg)	10.354461
LENGTH OF COLUMN CHARGE(m)	14.1
CONCENTRATION OF COLUMN CHARGE(kg/m)	2.65499
COLUMN CHARGE(kg)	37.435359
TOTAL EXPLOSIVE CHARGE PER HOLE (kg)	47.78982
POWDER FACTOR(kg/m3)	0.4175415282392
FRAGMENTATION SIZE(cm)	1243.4024852142

Figure 7. Output Page showing Results for desired Parameters after Computation

IV. CONCLUSION

This study is focused on the optimization of blast design at Zibo Quarries. The test conducted to determine the mechanical properties of the rock shows that the deposit has uniaxial compressive strength of 154 MPa,indicating a medium hard rock.The optimization of the blasting parameters using Langefors and Khilstrommodelhas been successfully carried out.The optimized results have values that range between 2.27-3.15 m and 2.79-4.39 m for burden and spacing respectively. A constant powder factor of 0.417 kg/m^{3}was reported for different blasting parameters that were model. This shows that the model has the capability to keep the powder factor within a desired range. Hence, these optimized parameters can be very helpful in blast design at ZIBO quarries.

The software developedmade it possible to calculate changes in the design parameter, eliminates undue time spent in calculating and predicting rock fragment sizes after a blast.To further validate the model performance, it is recommended that trial blast to compare the model's result in terms of predicted fragmentation size with the reality should be carried out at the study area.

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