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Drilling and Blasting Pattern Selection for Fragmentation Optimization in Raycon Quarry Ore, Ondo State

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Abstract: The main objective of this research is to design the most economic blast design the will give good fragmentation in aggregate and economical. The structural geological investigation of the deposit is carried out with combination of both window mapping and scanline mapping. The dip and dip direction of the two main joint sets as observed in this area are, 84/318 and 84/025, respectively. Investigation into the best method of breaking in-situ rock from this site show that the rock can only be broken by fragmented (i.e. drilling and blasting) because the deposit is having very large in-situ block size which can not economical break by other breaking methods (e.g. Ripper, Bull Dozer etc). The classification of the deposit shows that the rock falls in-group of very good rock using RMR and Q- system. The drilling and blasting pattern being used in Ore quarry is adapted using Langerford formula and some limit of application were suggested for various design above which poor fragmentation should be expected.

Key words: Burden, spacing, stemming, specific charge, fragmentation, optimization

INTRODUCTION

For years in Nigeria, blasting was done on a hit-or-miss basis. The blaster would on the basis of experience chose the drilling and blasting pattern that would likely give the desired result without considering the structural geological condition of the rock. According to Pettifer and Fookes (1994) drilling and blasting should be used to achieve in-site rock breakage (fragmentation) if the spacing index of the deposit is greater than 2 and point load index greater than 3.0MP$_a$. If this values are less than specified, the other alternative as specified in revised excavatability graph (Pettifer and Fookes, 1994), should be used.

The point load index is determined by Bieniawski (1975) as

$$I_s = P/D^2 \quad (1)$$

Where,

I_s = Point load index.
P = Applied load KN.
D = Distance between the loading point.

The standard value is obtained by Brook (1985) as

$$I_s = F.P/D^2 \quad (2)$$

Where,

F = The size correction factor

In mining and quarrying, with the spacing index of the deposit greater than 2 and point load index greater than 3.0MP$_a$, as peculiar in Nigeria granite deposits, the in-site rock breakage is achieved by drilling and blasting with the main objective of fragmentation optimization. Fragmentation optimization involves breaking of rocks to ensure quality control, safe, consistent and efficient blasting. Big boulder or the opposite, excess fines can result from poorly selected drilling and blasting pattern. A well-selected pattern would produce fragmentation that can be accommodated by the available loading and hauling equipment and crushing plant with little or no need for secondary blasting. It is well accepted that performance of basic mining operations such as excavation and crushing rely on a fragmentation which has been pre-conditioned by the blast. By pre-condition, it means well fragmented, sufficiently loose with adequate muck pole profile (Scott *et al*., 1999).

When the explosive in a blasted hole is fired, it is transformed into a gas and pressure of which may sometimes exceed 100000 atmosphere (Langerfors and Kihlstrom, 1978). The tremendous energy liberated shattered the rock around the blast hole and exposes the rock beyond enormous tensile stress. This takes place under the influence of shock waves, which radiate from the explosion at between 3000 and 5000 m s^{-1} (Langerfors and Kihlstrom, 1978). A zone intense deformation occurs about blast hole, its thickness

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frequently approximately to the diameter of the hole and radial cracking extends appreciably further (Hustrulid, 1999).

There is a body of evidence that blasting affects mineral liberation (Hustrulid, 1999). The orientation of drill holes, pattern spacing and orientation of free faces will determine the efficiency of open pit blast. Ash (1980) and Hagan (1986) pointed out that blasting can affect subsequent drilling. When the blasting causes considerable over break for example, the mean inclination of the newly created face is often so small that the toe burden for front row vertical blasting in the results are sub-optimal.. Langerford formula as used in the study is as below.

$$V_{max} = 45 \times d \qquad (3)$$

$$U = 0.3 \times V_{max} \qquad (4)$$

$$H = (K+U)\ 1.05 \qquad (5)$$

$$F = .05 + .003 \times H \qquad (6)$$

$$V_1 = V_{max} - F \qquad (7)$$

$$E_1 = 1.25 \times V1 \qquad (8)$$

$$Q_{bk} = d^2/1000 \qquad (9)$$

$$H_b = 1.3 \times V_{max} \qquad (10)$$

$$Q_b = hb \times Q_{bk} \qquad (11)$$

$$Q_{pk} = (0.4 \text{ to } 0.5)\ Q_{bk} \qquad (12)$$

$$H_o = V_1 \qquad (11)$$

$$H_p = H-(hb+ho) \qquad (13)$$

$$Q_p = hp \times Q_{pk} \qquad (14)$$

$$Q_{tot} = Q_b + Q_p \qquad (15)$$

$$q = \frac{\text{Holes/row} \times Q_{total}}{V1 \times k \times B} \qquad (16)$$

$$b = \frac{\text{holes/row} \times H}{V1 \times K \times B} \qquad (17)$$

The classification of rock is obtained as in Bianewiski (1989) for RMR AND Q- system which state that

$$RMR = UCS + RQD + S + J + G \qquad (18)$$

Where,

UCS = Uniaxial compressive strength rating
RQD = Rock quality designation rating
S = Spacing condition rating
J = Joint condition rating
G = Ground water condition rating

$$Q = RQD/J_n * J_r/J_a \qquad (19)$$

Jn = Number of joint sets.
Jr = Joint roughness.
Ja = Joint alteration.

The block size for revised excavability graph is obtained from modified GSI table after (Ulusay and Sonmez, 2003).

$$Jv = 1/S_1 + 1/S_2 + 1/S_n \qquad (20)$$

Where, S_1, S_2 ….S_n is the average spacing (m) of the joint sets.

MATERIALS AND METHODS

The location of the quarry is Ore in Ondo state. The structural geological investigation of the outcrop is conducted. As a result of the nature of the quarry face, this is done with the aid of both window and scanline mapping. A meter tape of length 80 m is extended on the first Scanline in E-W direction while the second Scanline is having a tape 60 m long extended in N-S direction. All the fracture along the scanline as well as within the window were mapped.

The point load index of ore granite deposit is conducted by taking an irregular lump from the quarry face and chiseled to produce nearly rectangular shape. The sample is placed between the conical platen points in a way to allow at least 0.5 D as a free end after the longest axis has been measured. Load is then applied through the platens until failure occurs. The failure load is recorded by the dial gauge and final platen separation is recorded. The Point load index is determined using Eq. 2.

The quality of the rock is determined using RMR and Q system using Bianewiski (1989). Using Eq. 18 and 19. The RMR and Q-value of Ore granite deposit is then determined.

The drilling and blasting data were collected from company. Langerford formula is then applied to optimized the drilling and blasting pattern adopted in the quarry. Langerford formula serves as a guide to the prediction of the best drilling and blasting pattern that will ensure efficient fragmentation.

RESULTS AND DISCUSSION

Structural investigation: Structural geological investigation of Ore granite deposit shows that 2 main joints sets are observable in the area. Figure 1 shows the polar concentration of the area. The 2 main joint sets with dip and dip direction, 84/318 and 84/024, respectively are the dominant sets in this quarry shown in Fig. 2.

The joint set 1 is having average spacing of 3.16 m while the joint set 2 is having average spacing of 2.79 m as in Table 1 and 2. The rock mass classification using RMR and Q-system indicated that the deposit fall is a category of very good rock as in Table 3.

The deposit is having a structural rating of 90 which denote an outcrop with a very large block, Fig. 3 and the point load index for Ore granite is determined by Odutayo (2005) as 18.8 Mpa. From Fig. 4, using the above 2 conditions (i.e block size and point load index), it is indicated that the deposit falls in extremely strong rock which will require drilling and blasting to achieve in-situ breakage.

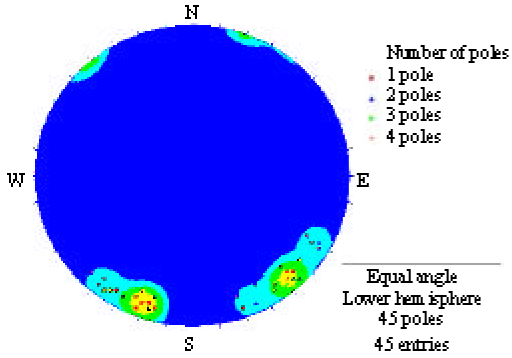

Fig. 1: Polar and concentration plot of Ore granite outcrop

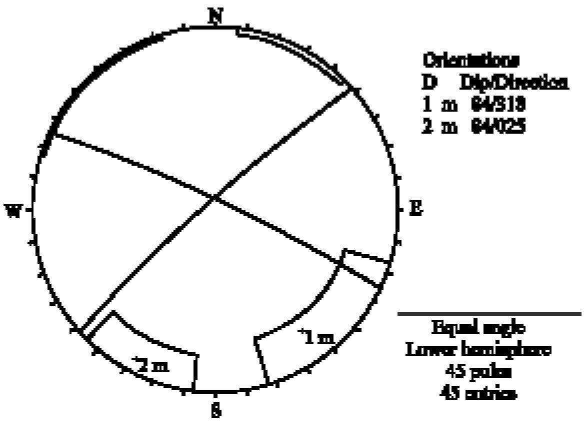

Fig. 2: Major pole plot of Ore granite outcrop

Table 1: Volumetric joint count parameters of Ore granite deposit

Joint sets	Average spacing (s) in meters	Number of joints/ scanline (N)	Length of scanline (L) in meter
Set1	3.16	26	80
Set2	2.79	19	50

Table 2: Surface roughness condition variables for Ore granite deposit

Variable	Condition	Rating
Surface roughness (Rr)	Slightly rough	3
Surface weathering (Rw)	None	6
Infilling (Rf)	None	6

Drilling and blasting pattern selection: The drilling and blasting pattern adopted in Raycon Quarry, Ore, Ondo state is shown in Table 3. The drilling and blasting parameters obtained are:

- Diameter of blast hole. (mm)
- Depth of blast hole. (m)
- Burden (m)
- Spacing (m)
- Weight of charge/hole (kg)
- Specific charge (kg/m^3)

Table 4 present values of burden, spacing, weight of charge per hole and specific charge used with differences drill hole diameter (ranging from 38-200 mm) for bench height 8, 13, 15 and 20 m being used in Raycon quarry.

Table 5 shows the optimized drilling and blasting pattern for Raycon Quarry. On comparing Table 4 and 5, the following deduction are made:

- In both tables, as the diameter of hole increases, the burden, spacing and weight of charge /hole increases in turn.
- In both tables, as the bench height increases for the same diameter of hole, it will require different values of burden, spacing and weight of charge per hole.
- In most cases, the values of the burden, spacing and charge per hole used in the Quarry is lower than the value obtained from optimization since the pattern adopted in Raycon Quarry is not correspondent to the optimized value, it will always result in poor fragmentation which is characterized by big boulder. This will make secondary blasting imperative.
- The specific charge of the explosive used in Raycon Quarry is 0.35 kg m^{-3}, which is constant for all the patterns available in the Quarry, while the optimized value has varying values of specific charge, ranging from 0.29-0.38 kg m^{-3}. A particular drilling and blasting pattern must have a peculiar value of specific charge for effective fragmentation. In Table 4, the pattern having specific charge higher than that in Table 5 will result in excessive fragmentation, characterized by excess fines.

Table 3: Classification of Ore granite deposit using Q-system and RMR system

		RMR_{89}		RMR_{76}	
Q-variable	Rating	Variable	Rating	Variable	Rating
		UCS	12	UCS	12
RQD	100	RQD	20	RQD	20
J_n	4.0	Spacing	20	Joint spacing	20
J_r	3.0	Joint condition	21	Joint condition	16
J_a	0.75	Ground water	15	Ground water	10
$Q = RQD/J_n * J_r/J_a$ $= 100/4 * 3/0.75$					
Total	67		88		78

Average Schmidt hammer reading = 46

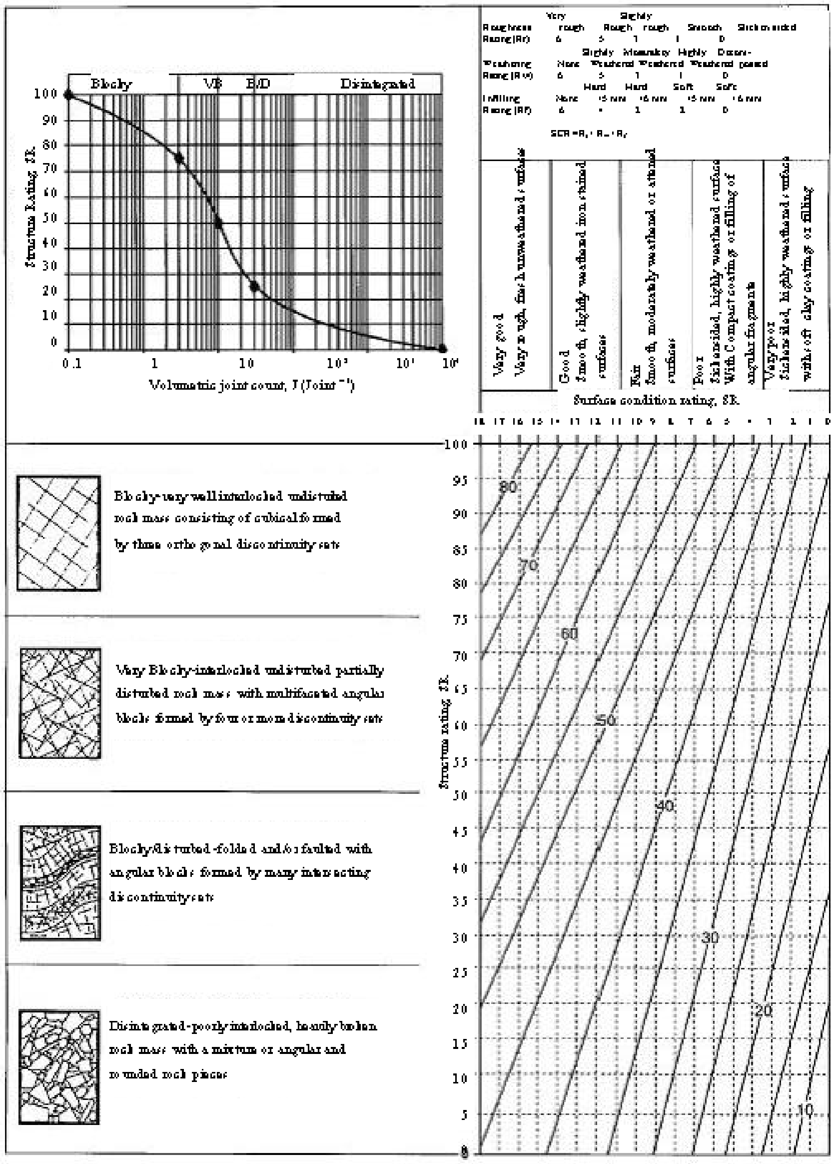

Fig. 3: Modified GSI table after (Ulusay and Sonmez, 2003)

Table 4: Drilling and blasting pattern data adopted at Raycon quarry, Ore, Ondo State

Diam. of hole (mm)	Depth of hole (m)	Burden (m)	Spacing (m)	Wt. of charge per hole (Kg)	Specific charge (Kg m^{-3})
38	8.0	1.5	1.7	7.14	0.35
63	8.0	2.6	2.8	19.37	0.35
88	8.0	2.8	3.1	25.00	0.35
100	8.0	3.0	3.0	25.00	0.35
150	8.0	4.0	4.5	50.00	0.35
175	8.0	4.5	5.0	62.50	0.35
63	13.0	2.2	2.8	25.00	0.35
88	13.0	3.1	3.5	50.00	0.35
100	13.0	3.4	4.0	61.12	0.35
150	13.0	5.0	5.5	125.00	0.35
175	13.0	5.5	6.0	150.00	0.35
200	13.0	5.5	6.0	150.00	0.35
88	15.0	3.4	3.5	65.00	0.35
100	15.0	4.0	4.4	91.68	0.35
150	15.0	5.5	6.0	175.0	0.35
175	15.0	6.0	6.5	206.25	0.35
200	15.0	6.0	6.5	208.33	0.35
200	20.0	6.5	7.0	325.00	0.35

Table 5: Optimized drilling and blasting pattern data for Raycon quarry, Ore, Ondo State using Langerford formula

Diam. of hole (mm)	Depth of hole (m)	Burden (m)	Spacing (m)	Wt. of charge per hole (Kg)	Specific charge (Kg m^{-3})
38	8.0	1.4	1.8	6.28	0.35
63	8.0	2.5	2.9	18.1	0.37
88	8.0	3.7	4.0	Limit of application	Limit of application
63	13.0	2.4	3.0	28.3	0.36
88	13.0	3.5	4.0	56.6	0.36
100	13.0	4.1	5.0	74.0	0.33
150	13.0	6.4	6.7	Limit of application	Limit of application
88	15.0	3.5	4.0	64.3	0.35
100	15.0	4.0	5.0	84.5	0.33
150	15.0	6.3	6.7	198	0.38
175	15.0	7.4	10.0	Limit of application	Limit of application
100	20.0	3.9	5.0	110.0	0.32
150	20.0	6.2	6.7	254.25	0.36
175	20.0	7.3	10.0	351.78	0.29
200	20.0	8.4	10.0	468	0.34

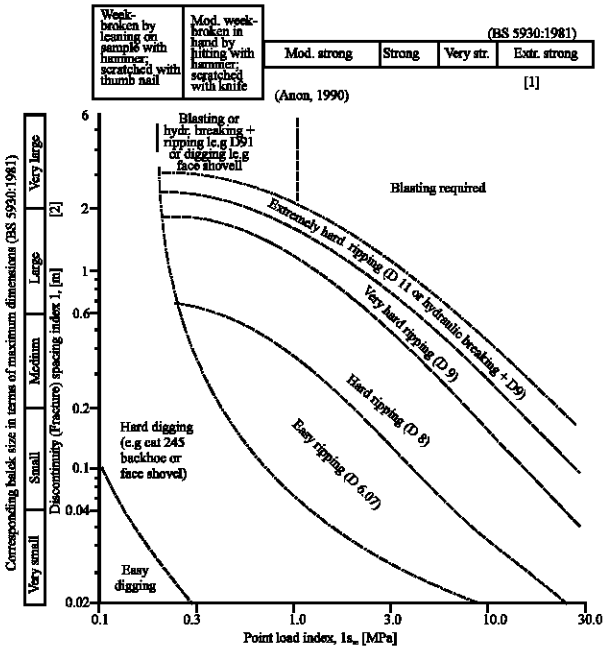

Fig. 4: Revised excavatability graph (Pettifer and Fookes, 1994)

- Table 5 shows some patterns being used in Raycon that are fundamentally not workable based on Langerford formula. While in Table 4, they are being used and the result is poor fragmentation. The pattern in Table 4 that must not be used include:
  - Pattern with 8 m bench height and hole diameter from 88 mm and above.
  - Pattern with 13 m bench height and hole diameter from 150 mm and above.
  - Pattern with 15 m bench height and hole diameter from 175 mm and above.

CONCLUSION

It is observed from the structural geological investigation of Ore granite that the deposit is a very good rock material based on RMR and Q- system of rock mass classification and that the breaking of the in-site rock can be achieved only through rock fragmentation (drilling and blasting). It is then concluded that proper selection of drilling and blasting patterns ensures fragmentation optimization, which minimizes or eliminates the need for secondary blasting. The drilling and blasting parameters that influence fragmentation include: diameter of blast hole, burden, spacing, sub-drill, weight of charge per hole and specific charge. The burden, spacing, sub-drill, weight of charge per hole and specific charge adopted in the design of a drilling and blasting pattern are all functions of the diameter of blast hole and bench height.

As the hole diameter and the bench height increases, the burden increases, since spacing is a direct function of burden, it also increases. Consequently the amount of charge per hole. All these parameters determine the value of the specific charge. It is also discovered that some drilling and blasting patterns being used in Raycon Quarry are not workable and need to be neglected. These patterns are:

- Pattern with 8 m bench height and hole diameter from 88 m and above.
- Pattern with 13 m bench height and hole diameter from 150 mm and above.
- Pattern with 15 m bench height and hole diameter from 175 mm and above.

NOMENCLATURE

V_{max} = Maximum burden in meters.
V_1 = Practical burden in meters.
F = Faulty drilling.
E_1 = Practical spacing in meters.
K = Bench height in meters.
U = Sub drill in meters.
H = Hole depth in meters.
Q_b = Bottom charge in kg.
Q_p = Column charge in kg.
Q_{tot} = Total charge in kg.
q = Specific charge in kg m^{-1}.
d = Drill hole diameter in mm.
Q_{bk} = Charge concentration bottom in kg m^{-1}.
h_b = Charge height bottom in meter.
h_o = Stemming in meters.
B = Width of round in meters.

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