RESEARCH ARTICLE OPEN ACCESS

Hard Rock Quarry Seismicity and Face Bursting Flyrock Range Prediction in the Granite and Migmatites Rocks of North Central Nigeria

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ABSTRACT
Flyrock is responsible for most of the injuries and property damage in hard rock quarry. Hard rock quarry activities are increasing rapidly in Nigeria especially in the granite and migmatite rocks in the north central area. Flyrock is the rock propelled beyond the blast area and blast area is determined by the nature of rock and blasting conditions. The blast area must be well secured to avoid accidents resulting from rock fragments. This work is a quantitative definition of the blast area in the quarries of the north central Nigeria using the most common blasting conditions in the quarries. The radius of the blast area is calculated as 74m. It is recommended that the nearest buildings and other infrastructures to the quarries should be twice this distance; that is 148m.
***Keywords* -** Blast area, Face bursting, Flyrock, Hard rock quarry

I. INTRODUCTION

Hard rock quarry involves blasting to break the rock into fragments that could be crushed to produce aggregates. Blasting accomplishes the task of rock breaking through controlled release of explosive energy. This produces rock fragments within the blast area. As part of quarrying practice safety measures are often put in place to ensure that nobody is injured by these rock fragments. Sometimes the rock fragments travel beyond the blast area as flyrocks. Flyrock constitutes a critical issue in hard rock quarry operations. Flyrock involves the uncontrolled propelling of rock fragment produced by blasting. Institute of Makers of Explosives (IME) has defined flyrock to distinguish it from blast area accident. It is defined as the rock propelled beyond the blast area by the force of an explosion [1]. These rocks can travel distances of more than 600 m at speeds of up to 650 km/h [2]. Hard rock quarry activities are increasing rapidly in Nigeria especially in the granite and migmatite rocks in the north central area. This work is aimed at developing maximum rock fragment throw for the granite and migmatites rocks of north central Nigeria under most prevalent blasting conditions for the purpose of defining the blast area and predicting the flyrock range.

II. FLYROCK INCIDENTS

Flyrock incidents occur wherever there is hard rock mining. Although [3], reported that flyrock accounts for approximately half of all blasting-related accidents in surface mines, the accidents are poorly documented globally. US Mine Safety and Health Administration (MSHA) compiles mining incidents in the country and available flyrock incident records are mostly from the United States of America (Table 1).

More hard rock quarries are continually being established in Nigeria to meet the growing demand for construction aggregates especially around the Federal Capital Territory where most major construction works are going on. In 2012 alone, more than seventy hard rock quarry lease certificates were granted to new applicants. Although the number of hard rock quarries in Nigeria has grown significantly there are almost no records of flyrock incidents. This most likely suggests lack of documentation rather than lack of flyrock incidents.

[4] investigated an accident at an andesite quarry and revealed that the accident was caused by discontinuity in the geology and rock

Table 1. Major Flyrock Accidents (1989-2010)

Injury/ Damage/Fatality	Location	Description of Incident	Date	Reference
1 Minor Injury	Johnson County, USA	Flyrock struck the roof of a car.	July 18, 1989	[5]
1 Minor Injury/1 Fatal Injury	Webster County, USA	Flyrock from a surface coal mine.	August 29, 1989	[6]
1 Fatal Injury	Caldwell County, USA	Flyrock	July 5, 1990	[7]
1 Fatal Injury	Livingston County, USA	Flyrock travelled about 930ft to injure a resident mowing grass in his property	July 11, 1990	[8]
1 Fatal Injury	Walker County, USA	Flyrock injured a man outside the mine property.	September 22, 1990	[9]
1 Fatal Injury	Luna County, USA	Flyrock from a surface silica mine.	October 12, 1990	[10]
1 Fatal Injury	Mingo County, USA	Flyrock traveled 750 ft and fatally injured the blaster	February 1, 1992	[11]
1 Fatal Injury	Campbell County, USA	Flyrock originating from an overburden blast in a nearby coal mine.	June 4,1993	[12]
1 Fatality	Greene County, USA	Flyrock from a surface coal mine struck a 34-year driller/loader.	April 25, 1994	[13]
1 Fatality	Madison County, USA.	Flyrock that struck the victim in the back.	May 23, 1994	[14]
1 Fatal Injury	Pike County, USA	Flyrock	Febuary 15, 1999	[15]
1 Fatal Injury	Lancaster County, PA	Flyrock entered into a cab through the windshield and fatally struck the victim	December 21, 1999	[16]
Property damage	West Lebanon, NH	Flyrock thrown about 3,000 feet into an industrial park doing damage to a building and vehicles	June 11, 2007	[17]
No injury	Ontario, Canada	Flyrock propelled into the air and onto a private property causing damage to a house and car	November 26, 2007	[18]
No injury	Dhanbad, India	The flyrocks punctured the iron sheet roof of a material test laboratory	September 22nd 2010	[19]
1 fatality/2 injuries	Guvenlik, Turkey	Fly rock killed one worker and injured 2 others	July14, 2010	[20]
No injury	Abule Eye, Odeda Local government area, Ogun State, Nigeria	Flyrock pierced through the roof of a residential building	Not given	[21]

structure. The causes of flyrock have been extensively investigated by several other workers and shown to include insufficient burden, improper blasthole layout and loading, discontinuity in the geology and rock structure, very high explosive concentration, inadequate stemming height and inppropriate stemming material, small stemming height to hole diameter ratio and inadequate delay time [22, 23, 24, 2].

III. Blast Area

The U. S. Code of Federal Regulations (CFR), Title 30 defines ‘Blast Area’ as the area near a blasting operation in which concussion (shock wave), flying materials, or gases from an explosion may cause injury to persons or damage to property. Rock fragments are not expected to travel beyond this limit. Flyrock is therefore generally perceived as the rock that has travelled beyond the blast area. The blast area must be well secured to avoid accidents resulting from rock fragments. Inadequate blast area security and ineffective blast area access control are some of the primary contributors to fatal injuries at quarry sites. [25] included blast area security among the four major causes of blasting-related injuries in surface mining operations between 1978-1993. [2] estimated 68% of the mine accidents to be caused by flyrock and lack of blast area security. The U. S. Code of Federal Regulations definition of blast area is purely qualitative and it is difficult to rely on the definition for enforcing blast area safety regulations. There is need for a quantitative definition of blast area in surface mines and this is the goal of this work.

IV. GEOLOGY OF THE AREA

North Central Nigeria is dominantly underlain by the Precambrian to Lower Paleozoic Basement Complex (Fig. 1). This complex experienced some tectonic events during the Archaean and early Proterozoic involving migmatization, granitization and intrusion of large volumes of granitoids [26, 27]. The basement rocks are generally characterized by dominant N-S and NE-SW fractures [28, 29].

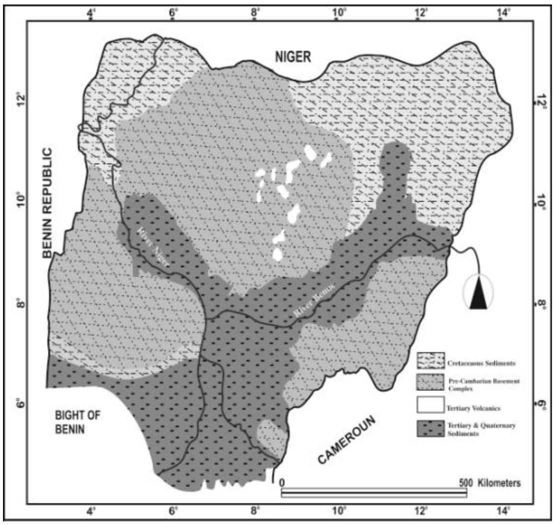

Figure 1. A General Geological Map of Nigeria

These events resulted in three major rock units namely (i) a gneiss migmatite complex, (ii) A N-S trending schist belt and (iii) the older granites. The migmatite-gneiss is an ensemble of undifferentiated rocks comprising of of gneiss, quartzite and calc-silicate rocks and marble. The gneiss consists of early gneiss, mafic – ultramafic and granitic or felsic components [26, 30].

The schist belt is a group of rocks comprised of the newer metasediments. This group, according to [31] consists of pelitic, quartzite and amphibolite, talcose rocks, meta-conglomerate, marbles and talc-silicate rocks.

The older granites range in size from plutons to batholits. The rocks are granites, granodiorites, monozonotes, syenites, and pegmatite. Granitic-granodioritic, compositions are most common [31]. The pegmatites which occur as near vertical dykes strike mainly in the NNW-SSE direction intruded into the older granite. They range in dimensions from a few metres to about a kilometer in length while the width varies from a few centimeters to ten meters and more [32].

V. METHODOLOGY

There is a strong correlation between the shot conditions and the maximum rock fragment throw and this can be used to define the blast area in which no personnel should be present during blasting unless the person is in blast protection. Blast area in this study is defined as the area of the circle whose radius is equal to the maximum rock fragment throw (L_{max}) for a given blast condition (Fig. 2). Rock fragments can originate from the vertical highwall face (face bursting) or the bench top (cratering and rifting). Face bursting is by far the commonest form of flyrock and is the case considered in this work. Flyrock distance from face burst is usually more than flyrock distance from cratering or rifting and is therefore most suitable for defining a pragmatic blast area of a mine. [33] explained the mechanism of face bursting. Wherever there is a zone of weakness in a rock quarry wall pressure explosive gases try to vent out through such zone resulting in concentration of gas with very high expansion energy in the high wall. This in turn often results in flyrock. Back break, concavity, unusual jointing and overhang can also cause face bursting [19]. The burden B, charge weight m, hole depth H, charge length L and stemming S are some of the shothole conditions that contribute to the size of the blast area. Other parameters that contribute to the quantitative definition of blast area include the material to be blasted, shothole diameter, angle of the holes, delay systems and powder factor.

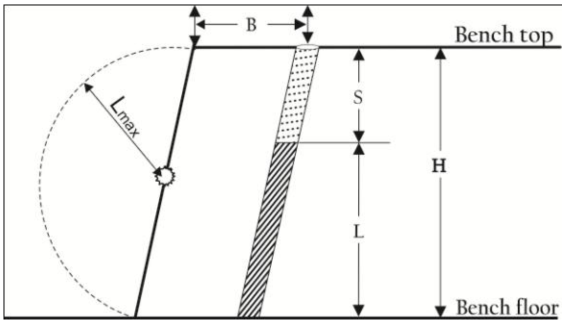

Figure 2. Blast Area from Face Bursting

The modified Gurney formula considers the burden, amount of explosive used, shothole angle and the geology of the material to be blasted as the most important factor in face bursting.

The maximum throw from face bursting is given by modified Gurney formulae as:

$$L_{max} = \frac{k^2}{g}\left(\frac{\sqrt{m}}{B}\right)^{2.6} \sin 2\theta \qquad (1)$$

L_{max} = maximum throw in metres, m = charge weight/m (kg/m), B = burden in metres, g =

gravitational constant (9.81m/s^2), θ is the initial angle of propelling, k is a constant which depends on the type of rock. From (1) the maximum throw is obtained at a fly angle of 45^o when (1) becomes simply:

$$L_{\max} = \frac{k^2}{g}\left(\frac{\sqrt{m}}{B}\right)^{2.6} \quad (2)$$

Burden distance is the most critical dimension in blast design and the factor that affects face bursting most. The safe burden depends on the type of explosive, the density of the rock and the blasthole diameter. [34] safe burden equation was modified to convert it to the metric unit and used to determine the safe burden for the granite and migmatite rocks of the area.

$$B = \left(\frac{2SG_e}{SG_r} + 1.5\right)0.0131D_h \quad (3)$$

$B = burden$

$SG_e = specific\ gravity\ of\ the\ explosive$

$SG_r = specific\ gravity\ of\ the\ rock$

$D_h = diameter\ of\ the\ shothole\ in\ cm$

Rock density is an indicator of strength, which in turn governs the amount of energy required to fragment the rock. The specific gravity of migmatite and granite rocks have been estimated at 2.8 [34]. The average shothole conditions from five quarries in the area were used to determine the safe burden. The average specific gravity of dynamite, charge weight and shothole diameter in quarries in the study area is 1.3, 25kg/m and 165mm. The value of k for granite and migmatite rocks has been given by [35] as 27.

VI. RESULTS AND DISCUSSION

The safe burden is 5m while the blast area is the area defined by a circle of radius 74m given the other shothole conditions in Table 2. This is the exclusion area that must be cleared prior to blasting to prevent injury to the quarry workers and the public. Given other appropriate shothole conditions, the rock fragments are not expected to travel beyond the calculated limit of blast area in the study area. All workers and visitors must be moved a safe distance away from the blast area during shot firing. The blaster man or any other person required to remain within the blast area must do so under a blast shelter. All entrances to the blast area must be securely guarded to prevent inadvertent entry of persons into the blast area.

Table 2. Shothole Statistics and the Maximum Rock Fragment Throw

SG_e	SG_r	D_h (mm)	B (m)	k	g (m/s^2)	m (kg/m)	Ø	L_{max} (m)
1.3	2.8	165	5	27	9.81	25	45	74

Fig. 3 shows the relationship between maximum throw and burden when the charge weight is kept constant at 25kg/m in the study are.

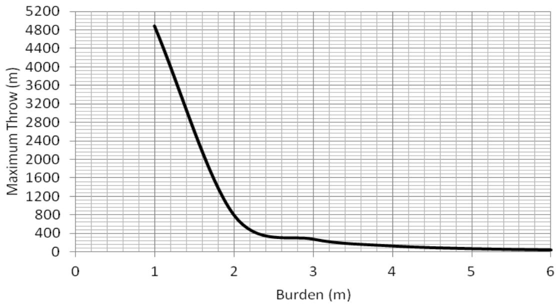

Figure 3. Relationship between Burden and Blast Area

Any burden less than 2.8m could generate flyrock of extreme high throw reaching up to more than 4000m. The safe burden must always be somewhere between 5-2.8m. Quarry vertical faces are often irregular such that burden is not uniform throughout the face height. Cave-ins on the vertical face may result in much smaller burden than the measured and this will most probably result in flyrock. Also any deviations from the initial drill angle will result in increase or decrease in the planned burden and flyrock. There is need for the blaster man to visually examine or run a laser profile of the highwall face for anything that could diminish the planned burden.

The fragmented rock throw is more sensitive to reduction to burden than to increase in charge weight (Fig. 4).

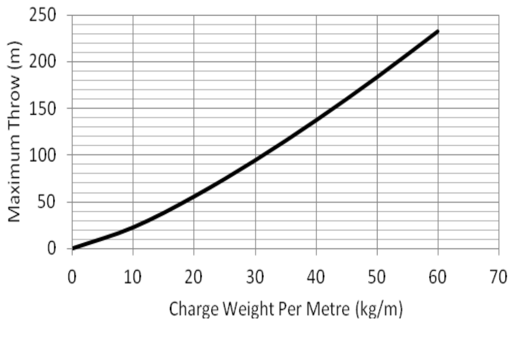

Figure 4. Relationship between Charge Weight and Blast Area

After the 2.8m lower limit burden has been reached, a 100% reduction in burden could result to a 600% increase in flyrock throw. The maximum increase in fragmented rock throw that can result from 100% increase in charge weight is 280%.

VII. CONCLUSION

The radius of the blast area in the migmatite and granite rocks of the north central Nigeria is about 74m. The burden should not be less than 3m to avoid flyrock incidents just as the charge weight should not exceed 20 kg/m. It is recommended that the radius of the blast area should be twice the distance to the nearest building to the quarry. Flyrock documentation is important in Nigeria to allow for more detailed study of the shothole conditions necessary to avoid flyrock accidents.

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