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INFLUENCE OF GEOLOGY AND GEOLOGICAL STRUCTURES ON BLASTING: IMPLICATIONS FOR QUARRYING, MINING AND TUNNELING: A REVIEW

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ABSTRACT

Obtaining the desired fragmentation using minimum energy is usually the ultimate aim of every blasting operation done for quarrying, mining, tunneling or any other engineering construction purposes. Blasters mostly rely on explosive power and experience to achieve their objectives while little attention is paid to the rockmass conditions which include the presence and distribution of discontinuities like joints, fissure, foliation, schistosity, fault and bedding planes. This negligence may lead to detrimental effect like blast induced ground vibrations (BIGV), flyrocks and damage to adjacent structures. This paper presents a critical review on the influence of rockmass conditions on blasting and a stepwise approach that blasters can utilize, relying both on the type, distribution and orientation of discontinuities and explosive power to achieve better blasting output. A checklist is developed as a guide to follow in blasting operation.

KEYWORDS: blasting, fragmentation, structures, discontinuities

INTRODUCTION

There is an urgent need to improve the quality and quantity of infrastructures in the developing countries of the world such as Nigeria, other African countries and the third-world nations other than African countries. This need is occasioned by the rising population which requires basic amenities for sustainable developments (Nyong *et al*, 2024). Housing deficiency, deplorable status of roads, unregulated mining industry and its marginal contribution to the nation's gross domestic product (GDP) are some of the challenges that can be addressed if proper attention is given to geology and geological structures when blasting for quarry operations, mining or tunneling.

In recent times, there has been a disturbing rising cost of energy. This has automatically led to higher cost of infrastructures like pavements, housing, bridges and other engineering structures. The likelihood of lower quality of these infrastructures may be the outcome if relevant regulatory agencies do not diligently carry out their supervision duties.

Similarly, neglecting the role of geology and geological structures in mining may lead to higher energy requirements, safety concerns and higher cost of mineral resources. This will further affect the overall cost of livelihood.

Tunneling, quarrying and mining depend on blasting which is the use of explosive energy to disintegrate the rock unit into fragments. Aggregates which are important raw materials in the construction industry are obtained from quarries through drilling, blasting and crushing processes (Ugbe, 2020). Blasting is also carried out for construction purposes in the case of tunneling and mineral exploitation, in the case of mining.

The desired size of fragmentation depends on the end use of the rocks and the type and size of equipment used for subsequent handling of the rock fragments. Blasting is not an exact science hence, experience, study and proper application of the fundamentals of blasting is essential for controlled blasting (Gama, 1996).

The essence of rock blasting operation is productivity which involves maximizing the explosive energy use.

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However, the major concerns are environmental effect and safety considerations (Elevi and Arpaz, 2010). Productivity entails obtaining desired fragment size and volume of rocks using minimal energy. Environmental and safety effect include undesired ground vibration, air shock, fly rocks and excessive dust and noises as well as explosive handling and blasting procedure (Nur *et al* 2016).

The difficulty to near impossibility in predicting fragmentation during blasting due to current limited technology has made it necessary for blasters and planning engineers to apply experience and equally follow a guided pattern in blasting which have been developed by researchers using geological and structural considerations.

Nur *et al* (2016) observed that the existing discontinuities in the blast site depend on their direction and other properties like spacing and aperture, geological conditions like rock strength and bedding thickness. All these affect the size of fragments produced during blasting. According to these researchers, fragment size produced by blasting depends on two parameters: uncontrollable parameters (geology of the site) and controllable parameters (design of the blast).

This work seeks to investigate the influence of geology and geological structure on blasting product sizes and volumes. The outcome is a working guide to blasters on how to apply effective blasting technique using minimal energy to achieve greater productivity while minimizing the environmental and safety factors.

Geology and geological structures and blasting

Rock properties and rock mass properties (which include geological structures) just like blasting designs and pattern have significant effect on rock fragmentation during mining, quarrying or tunneling. The size and distribution of fragmented rocks is a function of rock mechanical properties like joint system, crack density and the distribution of other discontinuities (Takashi *et al*, 2015).

Pugliese (1972) noted that geology and geological structures play significant roles in rock blasting as they give uncomplicated first-approximation method for the design of blast technique and pattern dimension especially in quarry operation where maximum productivity is required. Spathis (2013) observed that in most blasting operations, geology has been given limited recognition and consideration which have led to low productivity and high environmental and safety concerns. Dick *et al* (1983) suggest collaboration between the geologist, the driller and local site blaster to achieve a better controlled blasting geared towards productivity and safety.

Geology and blasting

Rock blasting is a major activity in all mining (both surface and underground), quarrying and tunneling operations. It is one of the major cost components of such operations. Generally, the cost of drilling is the sum of two major components, capital and operational costs while the blasting cost consists of cost of explosives, blasting accessories and labour (Saliu *et al*, 2017). These overall costs can be affected by site geology. The energy requirement differs from one rock to another and between rock mass conditions. The fresh basement rocks require greater energy for fragmentation compared to fractured basement rocks or sedimentary rocks like limestone, marl and sandstone. This is because in fresh basement rocks, more energy is required to break grains that are tightly interlocked unlike sedimentary rocks with bedding planes and fractured rocks having preferred planes of weaknesses.

Bender (1999) noted that the description of rock mass condition from the geological perspective is important to the blaster. According to his work, a good blaster should have adequate knowledge of the regional and local geology of the site.

The five geological properties that influence rock blasting are considered below:

Mineral composition:

The specific characteristics of rock material include anisotropy, mineral composition, equivalent quartz content, micro fabric, porosity and cementation. These are the geological parameters which influences drillability and blastability of rocks.

Anisotropy is a condition of discontinuities related to the direction of testing or drilling. Rock properties and drilling are highly dependent on the orientation or weakness planes related to direction of drilling, according to Thuro and Spaun (1996). When direction of drilling is at right angles to the orientation of foliation (FIG. 1a), rock material is compressed at right angles but sheared parallel to it. Although crack will develop radial to compression, but the cracks parallel to the bottom of borehole will be used for chipping, hence, the highest drilling velocities are obtained due to favorable orientation. Minimum destruction work causes large sized chips and a maximum drilling performance. However, if drilling axis is oriented parallel to foliation (FIG 1b), compression is parallel but shear stress is at right angles. Here, fewer cracks are developed and drilling is controlled by tensile strength parallel to foliation producing small-sized fragments which lead to minimum drilling performance (Thuro, 1997).

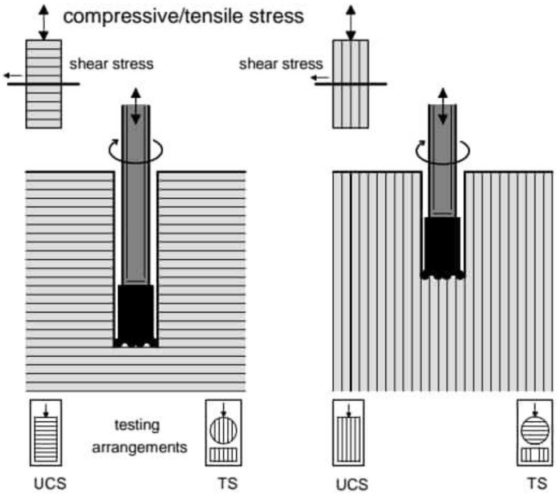

FIG. 1: Drilling perpendicular (a) and parallel (b) to foliation plane (adapted from Thuro and Spaun, 1996)

Equivalent quartz content and mineral composition equally influences rock blasting. When quartz content is high, energy requirement for blasting will equally increase.

1. **Resilience:** This refers to the elasticity of rocks. It is the ability of a rock to resist a shock wave and recover its original shape without fracturing. Experienced blasters understand the sound of resilient rocks upon tapping. A more resilient rock will require more energy for fragmentation compared to rocks that are weathered.
2. **Strength:** The mechanical properties of rocks play important role in drilling operation such as prediction of fracture. The unconfined compressive strength (UCS), Brazilian tensile strength (BTS), point load strength and Schmidt hammer rebound are the significant rock strength properties that influences penetration rate in drilling operations hence, affect blasting (Kolapo, 2021). The UCS is the most dominant strength parameter for predicting penetration rate in rotary drills (Kahrman, 1999). The compressive strength of rock is about 7 to 10 times greater than the tensile strength (Goodman, 1980). The blastability of rocks depends on its strength, though orientation of structures has greater influence on fragmentation. Table 1 summarizes the compressive and tensile strength of different rock types.
3. **Density:** During blasting, explosives detonate within the rock and useful work is shared between fracturing the rock and displacing it. The denser the rock, the more energy is required to displace it. Hence, when an attempt is made to blast dense rocks, more energy is needed in comparison with less dense rocks.

Table 1: Different rock types and their compressive and tensile in Kg/cm^2

Rock Types	Compressive Strength (Kg/cm^2)	Tensile Strength (Kg/cm^2)
Granite	2000-3600	100-300
Dolerite	2900-4000	190-300
Marble	1500-1900	150-300
Limestone	1300-2000	170-300
Sandstone	3000	300

Worsey, (2001)

Velocity of energy transmission: The velocity of energy transmission is another factor that should be considered during blasting especially when desired fragment size is needed. Fine grained rocks have higher velocity and respond better with higher velocity explosives compared to lower velocity rocks like talc, shale and some sandstone which can be blasted more successfully with lower velocity explosives (Bender, 1999).

Seismic velocity is another rock characteristic that influences its blastability. The acoustic velocity of various rocks varies from 1500 – 6000 m/s (Gregory, 1984). A hard rock with high acoustic velocity will shoot more easily especially when explosive with a high velocity of detonation (VOD) is used. This explains why granite, a seemingly hard rock can easily and conveniently be blasted. Table 2 summarizes the different rock types, their density and seismic velocity.

Table 2: Different rock types, their density and seismic velocity.

Rock Types	Density (Kg/dm^3)	Seismic Velocity (m/s)
Granite	2.7 - 2.8	4500-6000
Gneiss	2.5 -2.6	4000-6000
Limestone	2.4 -2.7	3000 -4500
Dolomite	2.5 -2.6	4500 -5000
Sandstone	1.8 -2.0	1500-2000
Mudstone	2.5 – 2.7	4000 - 5000
Marble	2.8 - 3.0	6000 –7000
Dolerite	2.8 – 3.1	4000 - 5000

ISRM, (1978)

Geological structure and blasting

If a rockmass is homogenous and isotropic, the rock properties can be correlated with excavation performance, according to the International Society or Rock Mechanics (ISRM 1978). However, the rockmass is often heterogeneous, anisotropic and frequently inflicted with structural imperfections like cracks, fissures, joints, faults, seams, bedding and foliation planes shear zones and other areas of weaknesses which can be referred to as discontinuities. These imperfections are very significant during blasting hence, the planning process should include the survey of rock structures and other rock characteristics so that the drilling and loading pattern can be optimized. Two expressions used to describe rock structures are the strike and dip. A strike is measured as horizontal direction while the dip is measured as a delineation from the horizontal direction perpendicular to the strike. It is preferable to align blast face so that one shoots with the dip. This will lead to a smooth bottom as most of the explosive energy will be used for blasting leading to a higher productivity.

When standard blast designs are used with no consideration to the variation in the geological features, the result will be blast damage and poor fragmentation (Hagan, 1983). Therefore, a critical attention should be paid to the nature, attribute and attitude of the geological structures during the blasting operations. Joint properties such as orientation, spacing, alteration, apertures and filling and other characteristics should be given adequate attention (Abdellah and Korichi, 2009).

There are several advantages associated with utilizing the orientation/attitude of the geological structures during blasting. These include good utilization of explosive energy, good forward heave of the blast, easy loading and fewer problems associated with breakage at the toe. The major disadvantage of blasting in the dip direction is that there will be greater back breakage and uneven fragmentation. Therefore, blast operations should be planned to achieve a more favorable possible outcome.

Blast design and energy requirement

As from the 18th century, blasters had known that the quantity of explosives needed to blast a certain volume of rock could be adjusted to obtain the desired output. Persson *et al* (1993) showed that explosive energy is proportional to the volume excavated and the surface area of the volume.

Several parameters are known to influence the efficiency of the blast. These parameters can be classified as controlled and uncontrolled parameters. Explosive parameters which include the type of explosive, detonation pressure, available energy, gas volume and density as well as the charge loading parameters, which include charge dimension, are the controlled parameters that influence the blast efficiency (Gama, 1995, 1996).

A well designed blast will efficiently utilize the explosive energy generated by the detonation of explosive in the blast hole in order to result in optimum fragmentation and displacement of the rock mass. However well a blast is designed, it has been observed that only a small portion of the explosive energy used is geared towards the fragmentation. The remaining energy generates undesirable environmental effects like ground vibrations, air blast, noises and back-breaks. Of these environmental effects stated, Erismann and Abele, (2001) noted that ground vibration, also known as blast induced ground vibration (BIGV) is the most detrimental, as it can cause serious damage to adjacent structures like pavements, buildings, dams or bridges. Engineers are therefore advised to design blast in a way that will allow greater energy to be directed towards rock fragmentation while the environmental effect is properly monitored.

Alberta (2003) posited that two approaches can be used to assess blasting energy. The first is the use of rock constant (C), which is the empirical measure of the amount of explosive (in Kg) needed for loosening 1m^3 of rock. He found out that the rock constant varies between 0.2Kg/m^3 in brittle crystalline rocks like granites to 1Kg/m^3 in stratified rocks oriented perpendicular to the blast direction.

The other approach is the use of rock mass fragmentability (K). This is defined as the threshold of specific energy of explosive that may break the rock mass just enough to separate blocks along their weakest links, while inducing no further fragmentation. Gama (1996) mathematically defined explosive energy required for block size reduction by blasting in jointed rock mass as;

$$W_B = K (S_b/S_a)^{1/2}$$

Where W_B = explosive energy consumed in KWh/ton of rocks

S_a and S_b are rock sizes after and before blasting respectively.

If $W_B < K$, there is no fragmentation. If $W_B = K$, it means $S_a = S_b$ hence, explosive energy's work is used only to separate blocks along their discontinuities. Different rock types different values of K (Gama, 1996) and the average of three rock types are presented below;

Basalt – 0.128KWh/ton of rock
Granite – 0.112KWh/ton
Limestone – 0.092KWh/ton

For fragmentation to occur in the respective rocks, W_B must be greater than K (W_B>K).

Explosive energy and its effect on blasting

The explosive energy is a solid or liquid substance or mixture of substances which on application of a suitable stimulus to a small proportion of the mass is converted, in a very short interval of time, into a more stable substance, largely or entirely gaseous, with the development of heat and high pressure (Gregory, 1984).

Five explosive properties are commonly used in the evaluation of the influence of explosive energy on blasting, considering the environment, project type and geology. These properties include explosive density, energy, velocity of detonation (VOD), detonation pressure and water resistance.

The density of explosive is its weight per given volume. It is generally proportional to the weight of explosive. The choice of higher density explosive can increase the energy within the drillhole without increasing the drillhole diameter. In situations where low energy blast is required, lower density explosive will readily provide the needed reduced explosive energy.

Explosive energy is a better way of determining how much work a particular explosive will do. It is given either in calories per gram or calories per cubic centimeter. This information is usually provided by the explosive manufacturer.

The velocity of detonation (VOD) refers to the speed with which the shock wave moves through an explosive when confined in a drillhole. It gives an indication of the shatter effect that the explosive will produce. The VOD of explosive is important in the development of radial fractures in the initial stages of fragmentation.

Detonation pressure is a measure of the pressure created by the detonation wave front. It is measured in kilobars. It is related to VOD and density and refers to the ability of the expanding gas to break the rocks (Gregory, 1984).

Water resistance is an important parameter of an explosive since some blasting operations is carried out in the water environment. Resistance indicates how quickly the explosive properties will deteriorate in the presence of water. Table 3 summarizes the different types of explosives commonly used in rock blasting and their properties.

Table 3. Summary of explosive types and their properties

Explosive type	Density (g/cc)	Energy (cal/g)	VOD (m/s)	Detonation Pressure (K bars)	Water Resistance
ANFO cast	0.85- 0.89	880	3460	25	Limited
Booster	1.6	1370	7830	245	Excellent
Dynamite	1.54	1080	5300	108	Excellent
Water Gel	1.2	800	7010	76	Excellent

Gregory, (1984)

Using Table 3 as a guide, the choice of explosive type suitable for a particular project in a given geological environment, and considering the required degree of fragmentation is possible. Obviously, a higher powder factor will increase the fragmentation.

Generally, the choice of explosive type should be done in consideration of the geology of the site, prevalent rockmass condition (geological structures) and the project requirement to promote the blast efficiency.

Safe and productive blast; the precautionary measures

Blasting for mining, quarrying and tunneling is an engineering project which must be done in accordance to basic tenets of engineering practice which are safety and economy. A good blasting procedure targets obtaining desired fragmentation with minimum explosive energy and minimizing BIGV, which is detrimental to the environment. To achieve this, a good blasting should develop and follow some stepwise drilling and blasting operation procedures. These involve cutting humus, drilling of blasthole, blasting, loading, transportation, separation and secondary blasting of oversize materials.

In achieving the stated procedures, a good blaster must carefully survey the geometry of the blasthole angles and depth of drilling. He must maintain drilling and blasting records as well as drilling logs. Changes in drill logs are pointers to the presence of structures like fissures or caverns and other structures likely to greatly influence blasting.

Blastholes should be cleared with compressed air and checked for proper depth and angle of inclination. BIGV should be reduced as much as possible or even eliminated. Artificial discontinuities can be created between two points to improve the quality of the blast. An experienced blaster should develop a mental or written checklist which should include certain items before he designs his blast. This checklist should consist of the following;

- Fragmentation desired and how to obtain it
- Rock quality and structure and how it will affect the blast efficiency
- Site limitations, vibration and airblast consideration and other project specification limitations
- Environmental and safety limitations such as impact from flyrocks and rock fall
- Equipment and material imitations such as drilling equipment, explosive type and how they will affect the blast.

Every mass blasting, be it for quarrying purpose, to create route during construction or for mining should be performed in accordance with relevant laws and activities carefully monitored.

CONCLUSION

Blasting is not an exact science hence it is near impossibility to predict, with great precision, the output of each blasting operation. However, experience can contribute significantly to great success, especially if attention is paid on the conditions of each sites and the outcome of such operation.

Therefore, it can be concluded that neither geology alone, explosive energy alone nor equipment and blast design alone, relying on experience, can lead to a more productive blasting campaign, where outcomes can be predicted like a clearly defined formula. However, the correlation between the mechanical and petrographic rock properties can be used to improve fragmentation during blasting and reduce, if not eliminate detrimental environmental concerns associated with blasting such as BIGV, flyrocks or destruction of adjacent engineering structures.

Nevertheless, in preliminary site investigation, it is important to carryout basic geological mapping. Though simple, this is necessary as it will account for all the geological parameters influencing rock disintegration and fragmentation during blasting.

Finally, it is important to prepare all rock and soil descriptions in a way engineers are able to understand. This will raise a higher level consciousness and geological contribution to engineering operations. The outcome will be environmental safety and sustainability.

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