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Application of Improved Blasting Techniques in Open Pit Mining for Maximum Productivity: A Case of Oakyam Quarry Limited, Ogun State, Nigeria

Adedara Frank[1], Peter Kolapo[2], Nafiu Ogunsola[3], Prosper Munemo[4], Abayomi Akinola[5]

[1]Oakyam Quarry Limited, Gogoro, Nigeria

[2]Department of Mining Engineering, College of Engineering, University of Kentucky, Lexington, United States of America

[3]Department of Mineral Resources and Energy Engineering, College of Engineering, Jeonbuk National University, Jeonju-si, South Korea

[4]Department of Mining and Mineral Processing Engineering, Faculty of Engineering, Manicaland State University of Applied Sciences, Mutare, Zimbabwe

[5]Department of Mining Engineering, Faculty of Engineering, University of Jos, Jos, Nigeria

Email address:

frankadedara@yahoo.com (A. Frank), kolapopeter@gmail.com (P. Kolapo), peter.kolapo@uky.edu (P. Kolapo), Olanrewajuogunsola33@gmail.com (N. Ogunsola), nafiu@jbnu.ac.kr (N. Ogunsola), munemoprosper@gmail.com (P. Munemo), prosper.munemo@staff.msuas.ac.zw (P. Munemo), abayoakinola@gmail.com (A. Akinola), akinolaa@unijos.edu.ng (A. Akinola)

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Abstract: Blasting is an important unit operation in mining and civil engineering projects that is aimed at effective rock fragmentation. However, it is always associated with some harmful and unwanted effects on the surrounding environment and humans, including ground vibration, air blast, flying rock, etc. Open-pit mining is the most widely used means of mineral exploitation in Nigeria, where it has been employed with considerable success, including at Oakyam Quarry. The conventional blasting technique has been applied in the quarry since its inception, with mixed results. Significant challenges associated with blasting, such as ground vibration, air blast, and fly rock occurrences, have been incurred at the quarry owing to the adoption of this conventional method. It is thus important to develop an alternative method to the conventional method to prevent further occurrences of the adverse blasting effects. This paper aims at developing an alternative blasting technique to improve the productivity and safety of lives and properties in proximity to quarry operations. The newly developed method, termed an alternative blasting technique, entails the replacement of delay-relays with electric detonators for blast sequencing, replacing laterite with 16mm granite chips for stemming, and adopting deck charging. The alternative method was tested and compared with the conventional methods adopted over the years by Oakyam Quarry. The technique recorded a higher degree of fragmentation with minimal air blast, ground vibration, and flying rocks. Likewise, a good muck-pile with a 14–16% reduction in explosive consumption was achieved, thereby increasing the profitability of the quarry operations. The newly developed blasting technique is proposed and recommended for adoption by engineers and blasters in various fields and aspects of blasting.

Keywords: Blasting, Fragmentation, Ground Vibration, Fly Rock, Explosive

1. Introduction

Fragmentation is one of the most critical concepts of explosive engineering. Blasting is the first step of size reduction in mining. Moreover, this involves the fragmentation of rock masses into smaller fragments using a chemical compound or mixture of solids and liquids known as explosives. It requires a small portion of explosives energy to break the rocks into fragments [1]. The efficiency of fragmentation by blasting and other unit operations such as crushing, loading, and grinding are directly proportional to the size distribution of the muckpile [2]. Therefore, the resulting size of the blasted rock is an important parameter to be considered during blast design. Therefore, the blast design should be managed so that the blasted rock can be sent directly to the processing plant for separation without going through the size reduction stage, which will increase the total production cost of mining from mine to mill [3].

Knowledge of the fragmentation mechanisms in rocks is critical for developing successful methods for rock excavations. Explosive technology has advanced considerably in the last twenty years, where explosives have evolved to be more powerful but producing fewer fumes. In rock blasting, it is understood that both the stress wave produced and the gas pressurization make significant contributions to rock fragmentation [4]. Recent studies have established that stress waves generated by the detonation of an explosive charge are responsible for the development of a damage zone in the rock mass and the subsequent fragment size distribution, while the explosion gases are essential in separating the crack pattern that is formed after the passage of the generated stress wave, and in throwing the fragments [5-7].

Many researchers listed some factors that influence fragmentation in rocks. However, most study works focused on the influence of the rock properties on the fragmentation of rocks [8]. Contrarily, Faramazi categorized the factors that influence fragmentation in rocks into two groups viz controllable and uncontrollable parameters [9]. The first group comprises controllable parameters, including blast design and explosive-related parameters. The second group is of uncontrollable parameters, including physical and geomechanical properties of intact rock and the rock mass. Monjezi stated that uncontrollable factors are effective parameters that are not in the hand of mining engineer that influences getting a specific size distribution [10]. Therefore, it is necessary to conduct proper site investigation and laboratory testing of rock specimens to select suitable explosives for the rock mass. The strength properties of rocks are the major factors to be considered in predicting the performance and behavior of rock specimens for various geotechnical tasks. In most cases, the strength of rocks is controlled by several parameters, including the variation in grain size, the nature of rocks, shape, and mineral composition [11].

The effects of poor blasting in open pit mining operations cannot be overemphasized. Not only does blasting induce vibrations, but the rock behind the slope face can also be fragmented and loosened as a result [12]. Also, the conventional method of blasting rocks is often accompanied by fly rocks, ground vibration, generation of aerial shockwave, and misfire accidents which are relatively hidden and challenging to detect, identify, and eliminate quickly [13]. The ground vibration which occurs due to poor blasting causes redistribution of stresses in the mining environment. Notably, the effects of poor blasting techniques in fragmentation majorly result in discontinuities such as fractured zones, faults, joints, and fissures in rock slopes [14]. In addition, the vibration and air blast produced could cause buildings within the area to have cracks.

Similarly, the issue of flying rocks is experienced by the residents when the rock flies and travels beyond the anticipated limit. Flying rocks and failure to secure the blasting area dominate blasting-related accidents in mining. During blasting operation, vibrations and high stresses are released from the excavation process, which poses a severe threat to the safety of the mine and environment [15]. Likewise, blasting operation in the area is sometimes accompanied by the incomplete detonation of the explosives, which has caused the release of some toxic gases into the atmosphere and pollutes the environment. It is further stated that misfires occur when the safety fuse is embedded in the solid tamping material. Controlling these problems is vital to reviewing the blasting methods [16].

As stated in the preceding literature reviews, there is a need to improve the blasting techniques in mining operations to prevent damaging the rock mass, stabilize pit walls, prevent fly rocks and ground vibration, and reduce the cost of processing. However, the rock blasting and fragmentation principle in the rock mass is not well understood yet. Likewise, study on prediction and controlling of the fragment size distribution of blasted rock materials has not been concisely dealt with as a result of factors such as variation in rock properties and amount of energy (kinetic, heat, heave, and fragmentation energies) of the explosive to split the rock into several parts during blast [17, 18]. Thus, this paper will briefly introduce an effective method to improve the blasting process in a mining operation to reduce the likelihood of misfires, adverse blasting effects and ensure optimum fragmentation size. The approach makes use of high explosives such as silica gel at the base of drilled holes, and the Ammonium Nitrate with Fuel Oil (ANFO) is applied on the column while the stemming is done with 1/2-inch granite chips. The detonating cords are used for the priming operation of the hole. In contrast, the electric detonator is used instead of delay relays in blasting the rock to produce a good firing sequence and reduce the rate of fly rocks in blasting operations. This technique controls fragmentation and rock breakage with the blast pattern and delays timing to give optimum fragmentation.

2. Description of the Study Area

As shown in Figure 1 below, the study area is Oakyam Quarry (Ltd), located in a hilly environment known as Gogoro rock site in Ajebo-Obafemi Road, Ogun State, southwestern Nigeria. The quarry has an outcrop with a surface area of about 0.42km^2 with geographical coordinates 7’8’’300N and 3’39’’450E. Generally, Ogun state lies on the geographical coordinate of Latitude 6.2 °N to 7.8 °N and Longitude 3.0 °E to 5.0 °E that comprises mainly of basement complex and sedimentary rock formation [19]. Oakyam Quarry comprises basement formation rock such as migmatite, granite gneiss porphyritic granite, and biotite.

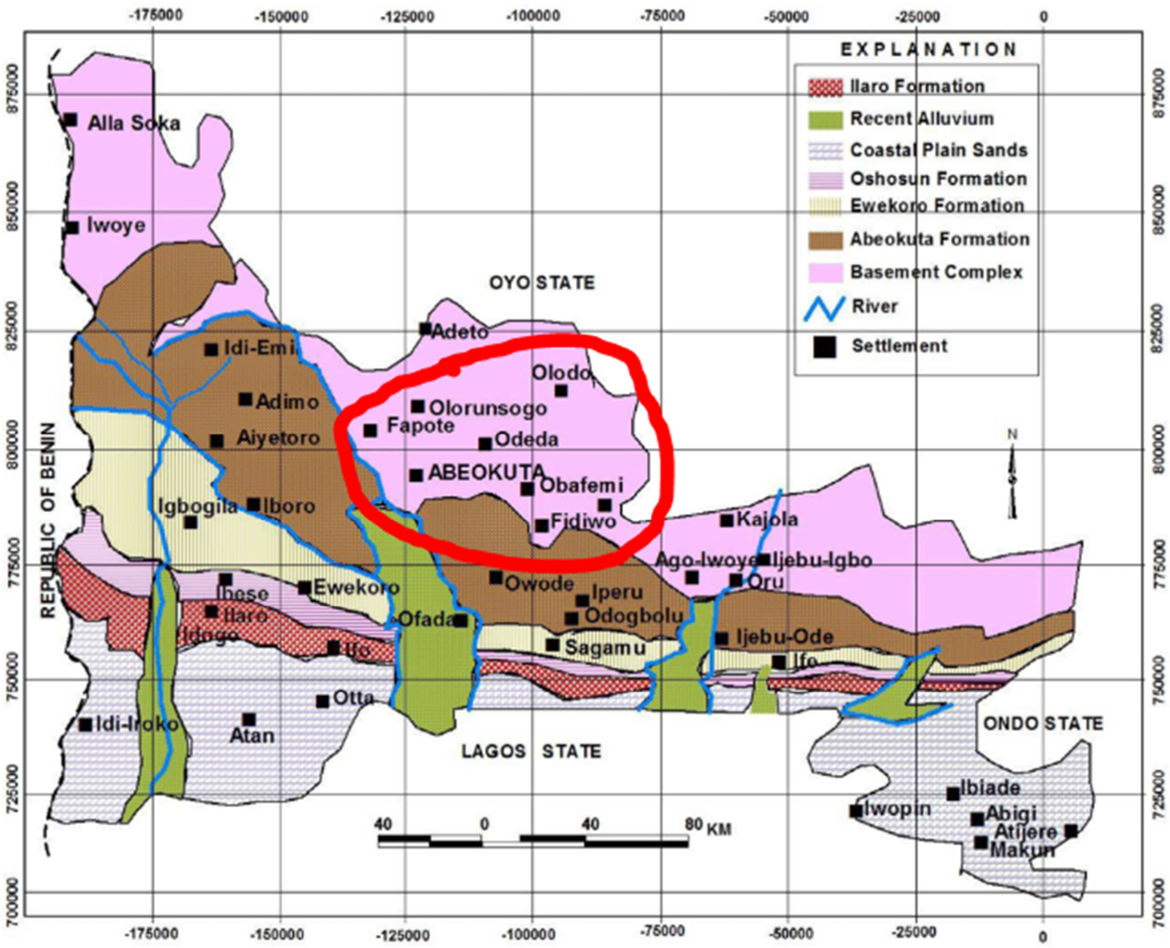

Figure 1. *Map showing Oakyam Quarry limited [19].*

The quarry lies in the tropical rain belt, contrasting the dry and wet seasons. The area is characterized by very high rainfall, low pressure, high evaporation, and relatively high humidity [20]. The dry season falls in-between November and March, while the wet season is between March and November, with a yearly rainfall of about 1500mm [21]. Notably, in the southwestern part of Nigeria, the climate can be classified as having two rainfall peaks. According to Oyedotun and Obatoyinbo, the first peak occurs between April and July, while the second peak comes between late August and late October. These two peaks can be referred to as heavy rainfall with an average annual rainfall of about 1500 – 2000mm with a relative humidity of about 75-95% [22]. The topography of the quarry area is naturally undulating, with the highest elevation of about 192m and the lowest elevation is about 160m [20]. The quarry formation is predominately granite outcrop and is the largest within the area with a minable level up to 40m with no overburden; there is no need for the stripping operation.

3. Methodology

Over the years, the safety fuse/plain caps, electric blasting and NONEL techniques are commonly used in blasting of rock mass. These techniques have been used in quarry and mining operation to fragment rock mass into desired sizes. In most cases, safety fuse/ plain caps and electric blasting cause some adverse effects on the lives and properties within the mine area and NONEL blasting is associated with detonator failures, high cost and its unavailability. The effects generated by these methods also include incomplete detonation, fly rocks, and air blast which pollutes the environment. Likewise, size reduction of fragmented rocks is done by crusher with a jaw gape of about 1100mm x 90mm, Hence, the presence of oversize fragmented rocks results in downtime and increases energy consumption, thereby causing increments in the overhead cost of producing aggregate in the quarry. Furthermore, the safety of the communities close to the mines is not put into proper consideration as a result of adverse effects of fly rocks, noise and ground vibration which are seriously causing constant damages that pose threat to the lives and property of people around the mine. On several occasions, these effects of poor blasting techniques have incurred numerous sanctions from the regulating authorities due to vibration and air blast produced that caused buildings within the area to have cracks and release of some toxic gases to the atmosphere which in turn pollutes the environment.

3.1. Existing Methods

At Oakyam Quarry, the adopted blasting methods are safety fuse/cap, electrical, and sometimes NONEL. The safety fuse method entails using a detonating cord for priming purposes and the application of delay-relay for the timing delay sequence and igniting through a safety fuse connected to a plain cap. This study explains two (2) blasting operations through safety fuse and electrical methods. For the safety fuse/plain cap methods, ninety-seven (97) holes were drilled and initiated for this experimental/trial blasting. For this experimental blasting, 1500m of detonating cord, 1100kg water slurries/silica gel, 31 pieces of relay delay, 2000kg of ANFO, 1.5m of safety fuse, one piece of a plain cap, and lighter were used. The most common firing pattern used is the V–pattern or chevron pattern, shown in Figure 2.

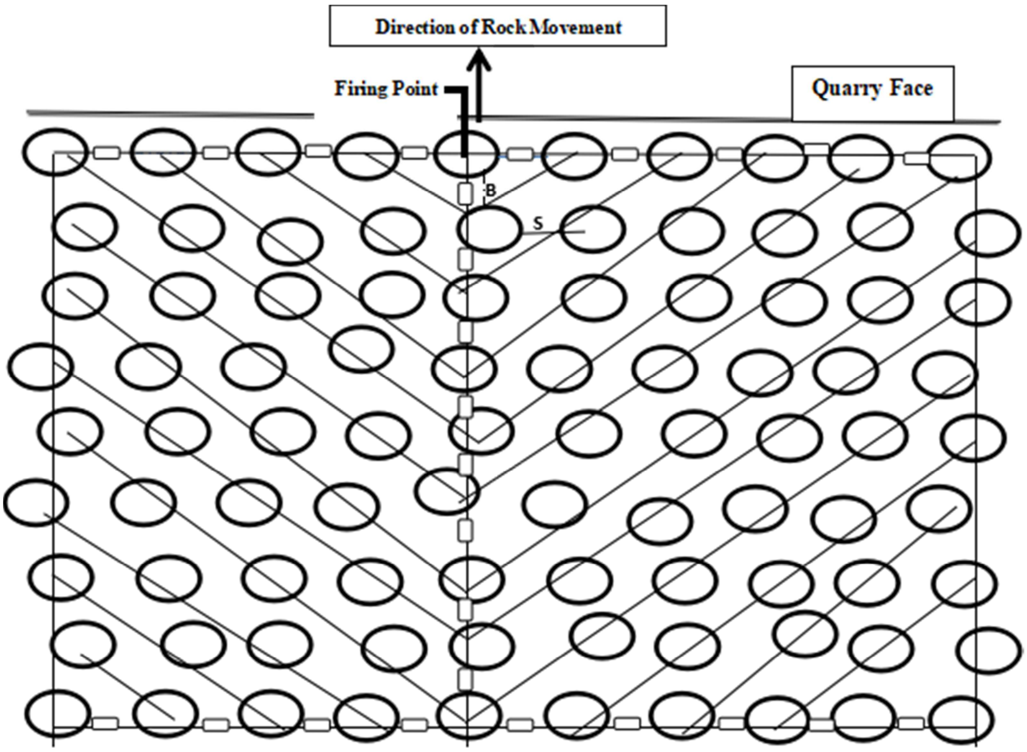

Figure 2. *Image showing a V-firing pattern with delay-relay in a safety fuse /cap initiation method.*

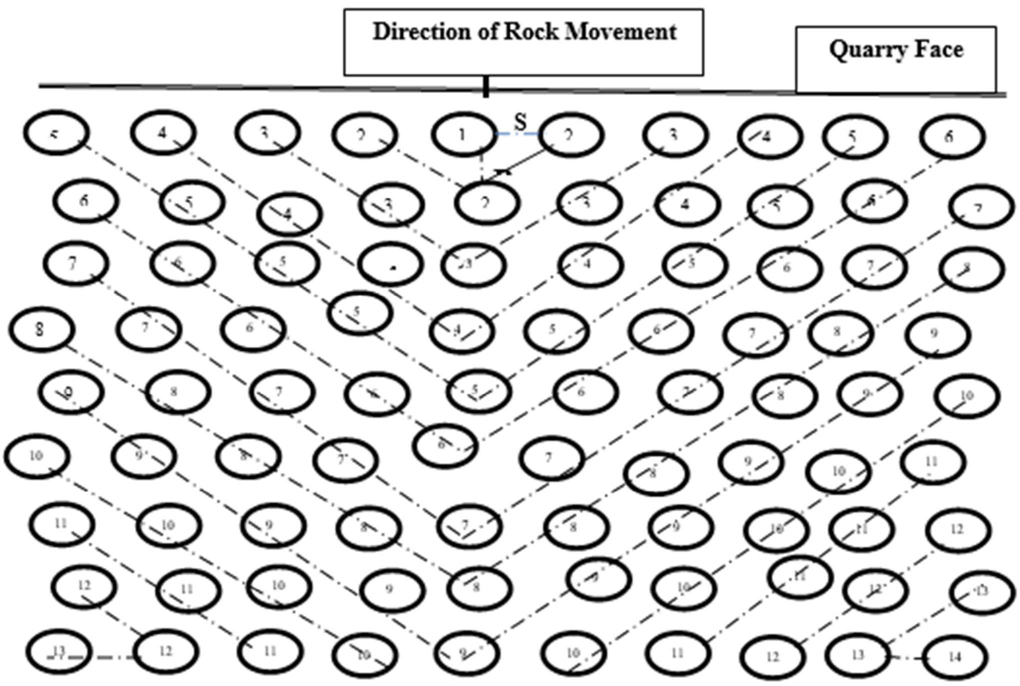

Figure 3. *Image showing a V - pattern in an electric blasting method.*

On the other hand, the electrical method involves three (3) connection methods: parallel, series, and parallel-series. The parallel-series connection is commonly used at Oakyam Quarry. The electric detonators are packed in periods of 1 to 10, making the detonation periodical as each blasting cap has a different delay time in milliseconds (ms). Notably, it is suggested that electrical connections for drilled holes lesser than 40 in number should be connected in series due to its simplicity. However, a parallel-series connection is recommended when the holes exceed 40 to 50. The process involves dividing the circuit into individual series containing equal caps to ensure even current distribution. The series connections are then connected to a bus wire parallel and attached to a permanent blasting wire. Ninety (90) holes are drilled and initiated through electrical methods. More importantly, a careful approach should always be adopted during the stemming operation to avoid damaging blasting cap wires.

For this trial blasting, 1100kg of water slurries/silica gel, 90 pieces of electric detonators, 2200kg of ANFO, and 500m of connecting wire and exploder were used. The V- pattern is used when carrying out electrical blasting, as presented in Figure 3. The parameters B and S represent the burden and spacing between the holes, respectively.

Furthermore, the charging operation of drilled holes is another critical factor to consider during the blasting operations' design. The conventional approach for blasting operation is categorized into three sections: stemming, column charge, and the base charge, as presented in Figure 4.

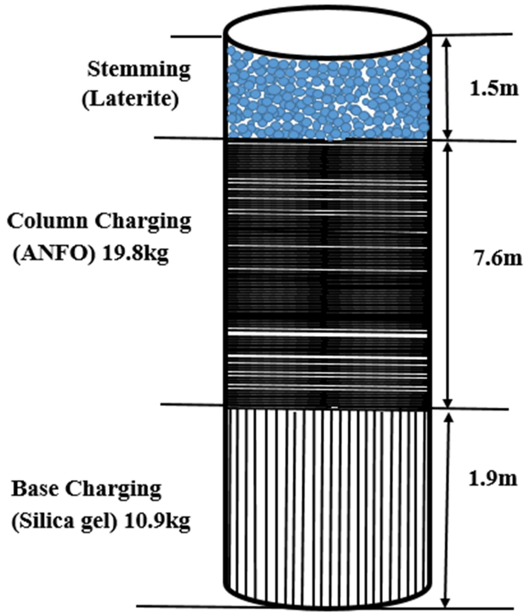

Figure 4. *Conventional hole charging method.*

The outcome of this approach has resulted in the production of large fragmented rocks (boulders) after detonation, as shown in Figure 5. This type of charging is also accompanied by ground vibrations and cracks on the pit wall, detrimental to quarry slope stability. Likewise, buildings around the mines show varying degrees of deterioration, and sometimes windows are broken.

Figure 5. *Image showing misfire and back break produced during electrical blasting at Oakyam Quarry.*

This poor blasting operation has affected the profitability of the quarry operation as the fragments require secondary breakage before taking it to the crusher for final size reduction. Therefore, the process of secondary size reduction has a detrimental effect on the economy and productivity of the quarry operation.

3.2. Improved Method

In order to address the issue of large fragments and other related problems associated with blasting, the authors researched ways to reduce boulders to allow easy passage of fragments through the crusher gape at Oakyam quarry. The new method replaces delay-relay with electric detonators, and priming is now done using detonating cords. Moreover, deck charging was introduced for good confinement and good energy distribution. A series connection was used to connect the blast holes, making it easier for the circuit to be checked for any discontinuity, eliminating the technicalities encountered when using a parallel-series circuit. An oxygen-balanced mixture containing 94.5 percent ammonium nitrate (AN) prills and 5.5 percent fuel oil (diesel) was used as a column charge. A detailed description of how the drilling and charging parameters were derived is shown in the section below [23].

Table 1. *Drilling parameters for a hard rock.*

	Parameter	Calculation
1	Maximum burden (B.Max)	= 20D/1000 = 20 X 76/1000 ≈ 1.52m
2	Sub-drilling (u)	= 0.3B.Max = 0.3 x 1.52 ≈ 45cm
3	Bench height (H)	= R (k + u) = 1.05 (10 + 0.45) ≈ 11m where k = 10m, u is the sub-drilling length, and drilling constant factor (R) = 1.05
4	Errors in drilling (f)	= (collaring error + derivation) = 0.003H + 0.05 = (0.003 x 11) + 0.05 ≈ 0.08m
5	Practical burden (B_1)	= B.Max – f = 1.52 – 0.08 ≈ 1.45m
6	Practical spacing (S).	= $1.25B_1$ = 1.3 x 1.45 ≈ 1.90m

3.2.1. Blasting Hole Design

A staggered drilling pattern, shown in Figure 6, was followed, and the parameters were derived based on the empirical formulae suggested by Dyno Nobel [23], and these are shown in Table 1. For a migmatite rock of 2.72 specific gravity, hole diameter and a drilling inclination angle of 76mm and 20° were used.

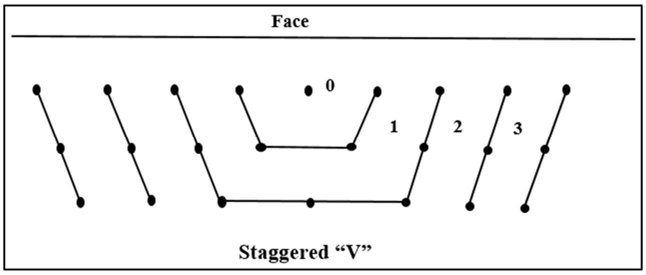

Figure 6. *Staggered V-pattern.*

3.2.2. Charging Concentration Calculation

In quantifying the charge concentration, the material data specifications for silica gel and ANFO were considered, as shown in the detailed calculations in Table 2.

Table 2. *Charging parameters for a hard rock.*

	Parameter	Calculation
1	Base Charging Concentration (Q_b)	= Q_{bk} x H_b $Q_{bk} = (76)^2/10000$ ≈ 5.78kg/m Height of base charge (h_b) = 1.3B.Max = 1.3 x 1.45 ≈ 1.89m = 5.78 x 1.89 ≈ 11kg
2	Column Charge Concentration (Q_c)	= Q_{ck} x H_c Q_{ck} = 45% of height of Q_{bk} = 45% x 5.78kg ≈2.6kg/m H_c = Bench height–Base charge height–Stemming height = 11 - 1.89 -1.5 ≈7.6m Where, stemming height = practical overburden = 1.5m = 2.6 x 7.6 ≈ 20kg
3	Total Charge per Blast Hole (Q_t)	= $Q_b + Q_c$ = 11kg + 20kg ≈ 31kg
4	Total Quantity of Explosives for 90 drilled holes	ANFO Quantity = 20kg x 90 = 1800kg Water slurry/gel = 11kg x 90 = 990kg ≈ 2790kg
5	Volume of Blasted Material	= burden x spacing x hole depth x number of holes = 1.45 x 1.90 x 11 x 90 ≈ 2727m^3
6	Blasted Tonnage	= Blasted volume x density of rock = 2727 x 2.72 ≈ 7417tonnes
7	Powder Factor (kg/t)	= 2790kg/7417t ≈ 0.38kg/t

As mentioned earlier, the improved new blasting technique involves deck charging. The approach uses inert materials, that is, the "1/2 granite chips," contrary to laterites for stemming. As shown in Figure 7, decking with inert materials enables the holes to be sealed, and it also prevents heat loss such that all the generated blast energy is effectively utilized.

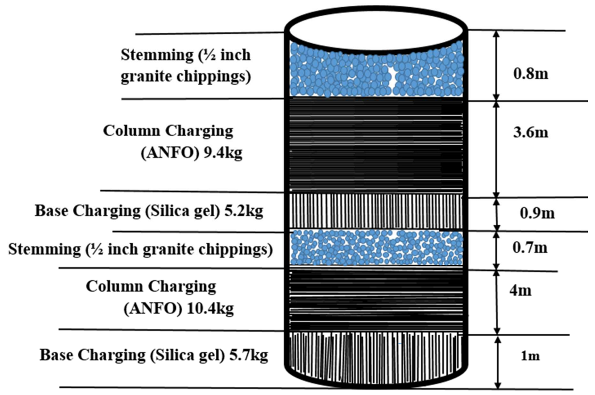

Figure 7. *Image showing improved method of charging through the use of deck charging.*

Similarly, the improved blasting method makes use of the U-firing pattern and V-firing pattern, connected in series, and it makes use of electrical detonators as delay relays for better delay sequence, as shown in Figure 8. The materials required for the U and V firing patterns varies with the number of electric detonators used for the delay timing sequence. In contrast, the quantities of other materials are kept the same. The U-firing pattern makes use of twenty-one (21) detonators, while the V-firing pattern makes use of nineteen (19) electric detonators ranging from periods 1-10 in both cases. Other materials used include 990kg of water slurries, 1800kg of ANFO, a 500m long connecting wire, and an exploder for initiating the charge.

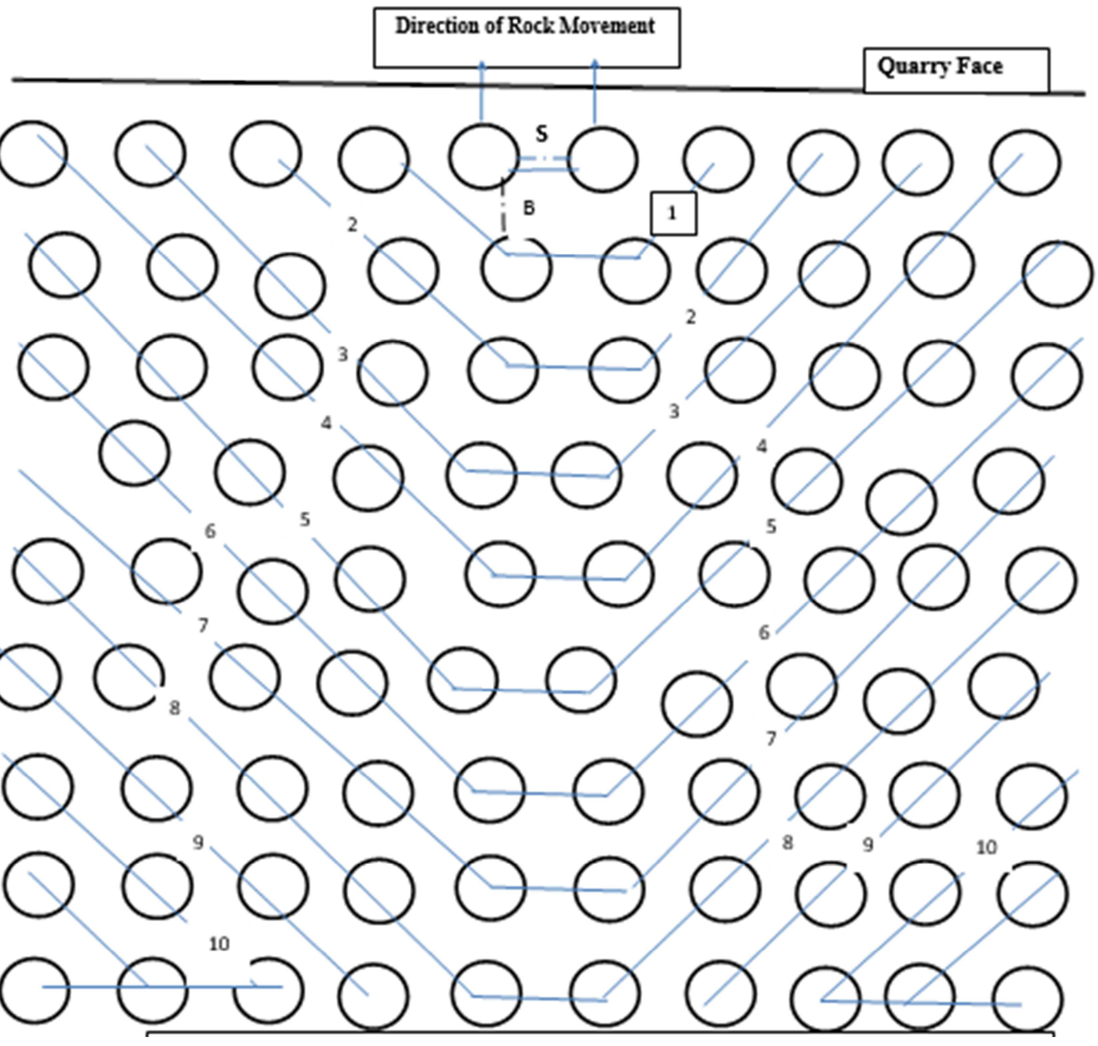

Figure 8. *Image showing the V-firing pattern connected in series for the improved blasting method.*

4. Results and Discussion

Good blasting is brought out by uniform fragment size and good environmental implications such as minimum ground vibration and fewer flyrocks. However, it has been earlier mentioned that the residents closer to the quarry site experience the adverse effects of flying rocks as rocks travel beyond the anticipated limits. Therefore, the novel improved blasting technique would prevent the adverse issues viz: boulders, ground vibration, and flyrocks. According to Dyno Nobel [23], the expected damage for the effects of pressure generated by air blasts and ground vibration are summarised in Tables 3 and 4, respectively.

Table 3. *Interpretation of various air blast pressure during blasting operation (Nobel, 2010).*

S/No	Air blast Pressure (KPa)	Expected damage
1	0.3	Window rattle
2	0.7	1% of window breaks
3	7.0	Most window breaks and plaster cracks
4	30	Risk of damage to our ear

Table 4. *Interpretation of various levels of ground vibrations (Nobel, 2010).*

S/No	Ground vibration (mm/s)	Expected damage
1	13	Lower limit for damage plaster walls
2	19	Lower limit for dry wall structures
3	70	Minor damage
4	140	>50% chance of minor damage to structures
5	90	50% change of major damage

4.1. Determination of Ground Vibration and Air Blast

The calculation for the ground vibrations experienced at the quarry was carried out using Equation 1:

$$PPV(m/s) = k\{R/Q^{1/2}\}^{b} \quad (1)$$

Where, k represents the state of confinement;
Q is the maximum instantaneous charge (kg);
R denotes the distance from charge, (m); and
b represents the constant of the exponential site.

Also, the air blast for Oakyam Quarry was calculated using Equation 2:

$$P = K(R/Q^{0.33})^{-1.2} \quad (2)$$

Where, P represents the air blast pressure (KPa);
K is the rock factor constant (heavily confined = 3.3);
Q is the maximum instantaneous charge (kg); and
R is the distance from charge (m).

The noise generated (KPa) and maximum particle vibration (mm/s) for an initiation system that uses a detonating cord coupled with electric detonators are summarised in Table 5.

Table 5. *Evaluation of air blast pressure and maximum particle vibration.*

S/No	Distance (m)	Air blast Pressure (KPa)	Maximum Particle Vibration (mm/s)
1	100	0.300	179
2	200	0.130	59.0
3	300	0.080	31.0
4	400	0.060	19.0
5	500	0.040	13.6
6	600	0.040	10.0
7	700	0.030	8.0
8	800	0.024	6.0
9	900	0.021	5.0
10	1000	0.020	4.5

The data in Table 5 was used to examine the correlation of air blast pressure with the distance, and the results are shown in Figure 9. The graph shows that the father from the blasting site, the lower the pressure generated in a granitic rock mass blasting. For example, 0.3KPa is expected to produce window-rattling on infrastructure within a 100m radius from the blasting site. However, the pressure experienced at 500m from the blasting site becomes insignificant to cause any damage. Thus, it was established that any distance above 500m is considered a safe zone from the quarry face and poses no threat to the properties and lives of people in the community.

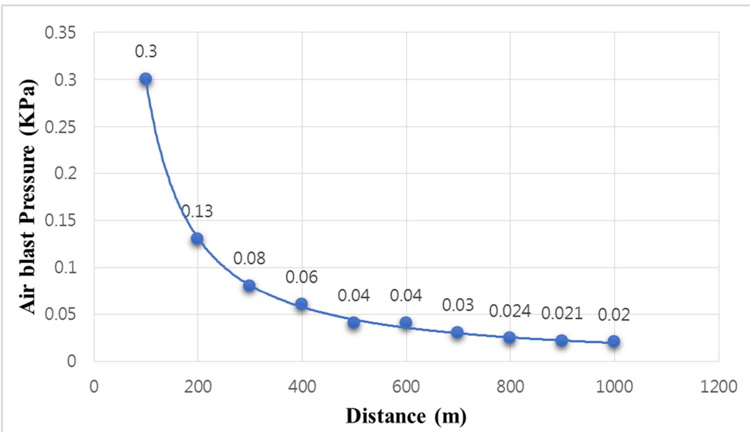

Figure 9. *Correlation of air blast pressure with distance from blasting site.*

Likewise, the effects of ground vibration at varying distances from the blasting site were also investigated. Figure 10 shows a drastic reduction in particle vibration as the distance increased from 100m to around 300m.

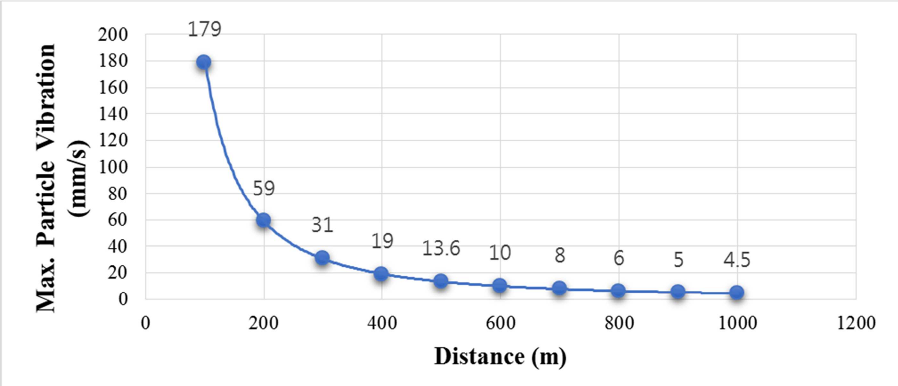

Figure 10. *Correlation of particle vibration versus distance from blasting site.*

Using the benchmarks suggested by Dyno Nobel [23], it can be seen that, at a distance of 100m with a corresponding PPV of 179m/s, there is a greater than 50% chance of significant damage to the infrastructure. However, at a distance of 500m with a corresponding PPV of 13.6mm/s, the worst case that can happen is minor damage to plastered walls.

Table 6. *Fragmentation results for the blasting trials carried out at Oakyam Quarry.*

S/N	Types of Blasting	% Rock Fragmentation Size > 1000mm	% of Fragmentation	Blasted tonnage (tons)	% Failure
1.	Electrical Blasting	5	95	4,000	5%
2.	Electrical Blasting	8	92	6,000	10%
3.	Electrical Blasting	11	89	8,000	15%
4.	NONEL Blasting	6	94	10,000	5%
5.	NONEL Blasting	5	95	5,000	5%
6.	NONEL Blasting	9	91	10,000	10%
7.	Safety Fuse/Plain cap	16	84	8,000	20%
8.	Safety Fuse/Plain cap	18	82	10,000	20%
9.	Detonating cord and Electrical Detonator	4	96	8,000	5%
10.	Detonating cord and Electrical Detonator	5	95	10,000	5%

4.2. Determination of Fragmentation and Flyrock Distance

Evaluation and prediction of rock fragmentation is a vital step in blast optimization. Therefore, indirect methods of analyzing fragmentation were carried out through observational methods and counting of boulders. Ten (10) blasting trials were carried out with various blasting techniques. The rock fragmentation and particle size distribution were recorded and presented in Table 6.

The outcome of the improved method produced blasted rock which does not require secondary blasting and can easily be transported to crushing plant for size reduction, as shown on the images in Figure 11. In comparison to other studies that utilized double primers in a charge hole, such as electronic detonators as a primer in the Salvador and Malmberget mines [25, 26], and NONEL detonators as a primer in the Malmberget mine [27, 28], our study achieves a better fragment size distribution based on field observation. This can be attributed to the precise initiation achieved by the detonating cord used as a primer in our study. The use of detonating cord as a primer ensures effective shock wave collision and eventual finer fragmentation.

The resulting fragmentation quality observed from using the new charging method helps prevent unnecessary secondary blasting costs, detrimental to the overhead mining costs.

Figure 11. *Images of fragmented rocks using an improved blasting technique.*

Some researchers have proposed empirical equations that can be used to predict flyrock distance and fragment sizes. A typical example of such empirical models was established by Lundborg & Ladegaard-Pedersen [24], based on hole diameter as shown in Equation 3.

$$L_m = 260 \times D^{2/3} \quad (3)$$

Where, Lm is the maximum rock projection distance in meters, and D is the hole diameter in inches. Considering the hole diameter of 76mm, which is approximately 3inches, the maximum rock projection at the quarry is given by:

$$L_m = 260 \text{ x } 3^{0.667} = 540\text{m}.$$

Therefore, the maximum rock projection should not exceed approximately half a kilometer. The trials have proved the idea demonstrated in a 500m radius from the charge with no flyrocks being recorded within the area.

4.3. Productivity Results

Moreover, various blasting techniques' efficiency was investigated to deduce the best blasting technique adopted at Oakyam Quarry. The percentage of detonation failures (misfires) for all four (4) different types of blasting techniques are presented in Figure 12. It also shows the volume of blasted rock corresponding to each blasting technique. The blue curve represents the volume of blasted rock, and the green bars denote the percentage of detonation failure. It can be seen that the safety fuse and detonating cord systems have the highest volumes of blasted rocks, followed by the NONEL method. It can be noticed that a higher volume of blasted rock with a lower percentage of failure was recorded with the use of detonating cord (i.e., the improved method of blasting). However, a lower volume of blasted rock was recorded using the electrical blasting technique, though with a lower percentage of detonation failure.

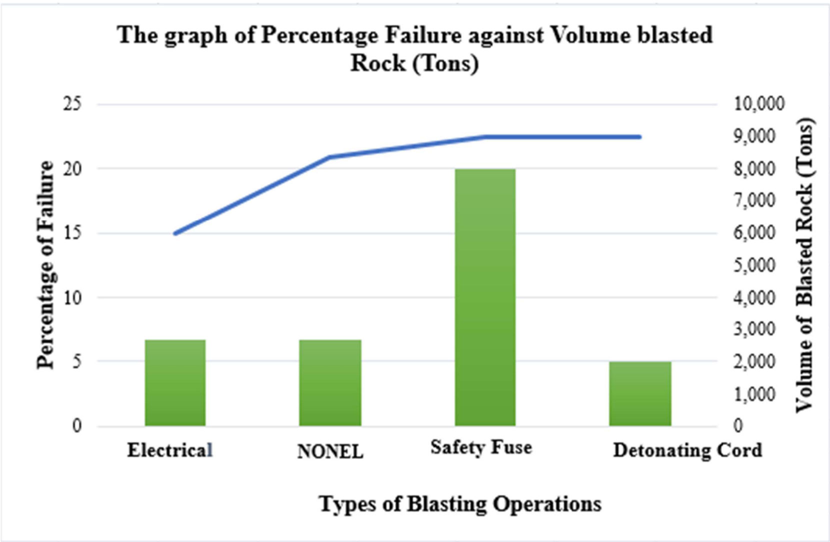

Figure 12. *Comparison of percentage detonation failure and volume of blasted rock.*

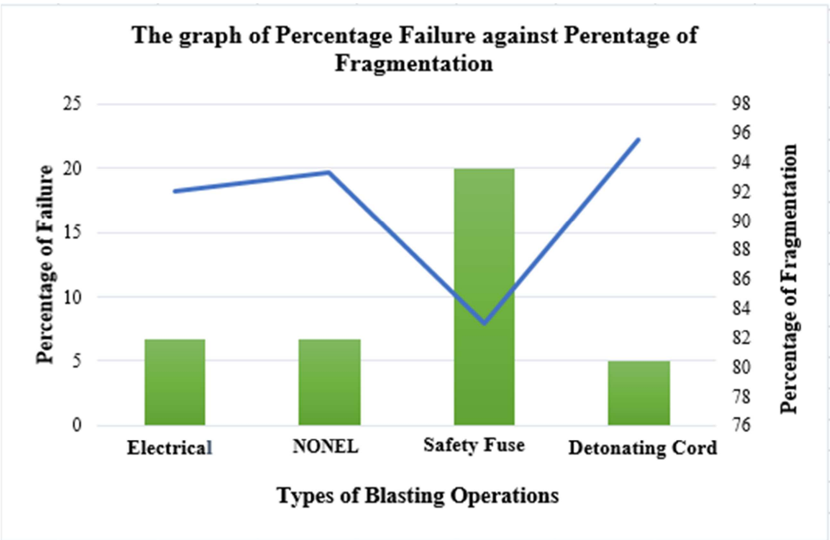

Figure 13. *Comparison of percentage detonation failure and percentage of fragmentation.*

Also, the percentage detonation failure and percentage of fragmentation were examined for the four (4) types of blasting methods. Figure 13 shows the blue curve, representing the percentage fragmentation, whereas the green bars represent the percentage detonation failure. It can be seen that the use of the detonating cord for priming (i.e., part of the strategy for the improved technique) gives the highest percentage of fragmentation accompanied by the lowest percentage of detonation failure. The success of the improved method is attributed to efficient heat conservation through the use of proper stemming, which gives proper compaction. The success of even distribution of explosives in blast holes is attributed to the adoption of deck charging. Furthermore, the V-firing pattern adopted in the improved technique gives better fragmentation, good muck pile, right bench toes, and eliminates back breaks.

The NONEL method gives good fragmentation with minor adverse effects, but the need for double-priming with NONEL detonators makes the approach expensive. Reactivity in the wet ground during the rainy season and its unavailability also discourages its use. The electrical blasting technique produces better fragmentation in dry ground and when the blast holes are reasonably few (favorable for at most 40 blastholes). However, it results in very high misfires when the connection is not arrayed correctly or dangerous when there are some stray currents. In addition, the failure of delay-relay at surface connections when using the safety fuse and initiation through the lit and run approach discourages using the safety fuse method. The improved method, which comprises detonating cords coupled with electric detonators for blast sequencing, yielded maximum productivity and reduced the cost of production at Oakyam Quarry. It is also associated with good fragmentation, low flyrocks, more minor fines from the regulatory authorities, and fewer community complaints. It has resulted in a 14-16% reduction in explosive consumption hence a reduction in explosives cost, and it minimized the overhead cost of energy incurred during crushing.

5. Conclusions and Recommendations

5.1. Conclusions

This study has established a new technique that improved blasting operations at Oakyam Quarry to achieve the expected fragment sizes of the rock mass. Prior to developing the improved method, there had been challenges in the blasting operations such as oversize in fragments, presence of flyrocks, and ground vibration. In addition, the shock from the detonation of the explosives due to the poor blasting techniques causes the redistribution of the in-situ stress in the rock mass, creating discontinuities such as fractured zones, faults, joints, and fissures in the quarry wall. Notably, this majorly affects the stability of slope walls and back breaks in the yet-to-be-drilled portions, while the presence of air blast can cause buildings and structures around the mine to experience cracks.

In the improved blasting approach, the significant change is the charging profile as inert materials are used for stemming while the conventional techniques use laterite for stemming. Likewise, the process of decking is adopted to seal the hole and make it look like the natural condition before blasting takes place. This process makes the heat exchange mechanism ultimately utilized without any escape. That is, there is complete utilization of heat from the system. In terms of the firing pattern, both U and V firing patterns connected in series with the electric detonators are utilized in the method. The outcome of this improved approach showed good fragmented rock size with noticeable reductions in the number of flyrocks and a decrease in ground vibration during blasting operations. However, the most severe expected damage that will be experienced by the new, improved method will be little window-rattling at a distance of 100m from the quarry face. Likewise, there will be a 50% chance of significant damage at a corresponding distance of 100m with a PPV of 179ms/s, and at a higher distance of 500m, the PPV value dropped to 13.6mm/s. This value implies that, as the distance increases, there is a drastic reduction in particle vibration. Also, at a distance beyond 500m, no significant damages are experienced within the quarry site and communities within.

Moreover, the detonating cord (improved method), used for the blasting operation, has the highest volume of blasted rocks with the lowest percentage of detonation failure. Hence, no doubt implementing the novel improved technique has provided a solution to the challenges of the conventional method by providing better fragmentation, reducing the number of flyrocks, and decreasing ground vibration during blasting.

5.2. Recommendations

The authors drew the following recommendations for future work to achieve good blasting operations with uniform fragment size and significantly reduced ground vibration and flyrocks.

1) Application of laterite for stemming should be discouraged. This method can be replaced with 16mm granite chips to seal up the drilled holes for proper gas confinement.
2) A staggered drilling pattern is recommended to experience a proper fragmentation and muck pile.
3) Explosive selection is another critical factor to be considered; during raining season, ANFO tubes must be carefully used in wet drilled holes, and a more significant quantity of high explosives must be encouraged.
4) The use of series connections should be encouraged during the connection of the electric detonators, and the leg wires must be shunted until when needed. Also, avoid clustering the circuits with wires after connecting the permanent wires and carefully read through the use of an ohmmeter before initiation.

Conflict of Interest

The authors declare that they have no competing interests.

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