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Optimization of Blast Design Parameters for Improved Loading-Haulage Performance at CGC Quarry, Itakpe, Kogi State, Nigeria

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Abstract

The first phase of production cycle in quarrying operation is rock breaking by drilling and blasting. At CGC quarry, Itakpe in Kogi State, this study was carried out to understanding the existing method of fragmentation and the impacts on the loading and hauling performance. The conventional method of blasting which is trial and error has not been able to give a consistent result of 90% passing which is about 1000mm in diameter, this challenge was well analyzed and this research deployed O-Pitblast software solution to solve this challenge. Mechanical properties of the granite rock like density, uniaxial compressive strength, porosity, point-load and tensile strength were carried out. The properties serves to guide the choice of the blast parameters for the design of the blasting operations. The fragmentation that results from the series of blasts were analyzed to determine their uniformity which was at its best after the application of O-Pitblast solution. These uniform fragmentation that ranges from 650-950mm passing were obtained which invariably enhanced efficient blasted rock movement, trucking capacity and reduced unnecessary idling.

Key words: *Blasting, optimization, fragmentation, loading, haulage, O-pitblast.*

1. INTRODUCTION

1.1 Background to the Study

Mining operations play a pivotal role in resource extraction, serving as a cornerstone of various industries. One critical aspect that directly impacts the efficiency and productivity of mining fleets is the process of blasting and subsequent fragmentation. Effective blasting and fragmentation are essential for maximizing the efficiency of mining operations. Proper fragmentation can significantly impact downstream processes such as crushing, conveying, and grinding, leading to improved overall productivity. Suboptimal blasting practices can result in oversized rocks, increased wear and tear on equipment, and reduced throughput. Therefore, there is a clear need to explore improved techniques that can optimize blasting parameters and fragmentation methods. Several factors affects the cost of fragmentation of any piece of in-situ rock. These factors include but not limited to blast geometric parameters and pattern; explosive type; density and costs, labour; oversize (relative boulders); toes and geological nature of the formation (Goswani, 2015).

A large number of factors affect successful blasting operation and can be separated into; controllable and uncontrollable. Controllable parameters are those that can be controlled and managed by the engineers and blasters (blast design parameters and explosive characteristics). Uncontrollable parameters are those associated with the formation of the rock mass such as rock and joint properties. The complexity of fragmentation phenomenon and the uncertainty in terms of the impacts of various parameters in terms of the impacts of various parameters makes it difficult to predict (Mehmmet *et al* 2013).

Rock breaking by drilling and blasting is the first phase of the production cycle in most of the mining operations. Optimization of this operation is very important as the fragmentation obtained thereby affects the cost of the entire gamut of interrelated mining activities, such as drilling, blasting, loading, hauling, crushing and to some extent grinding. Optimization of rock breaking by drilling and blasting is sometimes understood to mean minimum cost in the implementation of these two individual operations. However, a minimum cost for breaking rock may not be in the best interest of the overall mining system. A little more money spent in the rock-breaking operation can be recovered later from the system and the aim of the coordinator of the mining work should be to achieve a minimum combined cost of drilling, blasting, loading, hauling, crushing and grinding. Only a “balance sheet” of total cost of the full gamut of mining operations vis-à-vis production achieved can establish whether the very first phase- rock breaking- was “optimum” financially; leaving aside factors of human safety.

O-Pitblast is a specialized software used in the mining industry, particularly for blast design and optimization in open-pit, quarries and underground mines. The software uses advanced algorithm and data analysis to model and predict the outcomes of different blast design, allowing engineers to tailor their strategies based on specific site conditions, maximize the efficiency and safety of blasting operations (Sayadi *et al*, 2020)

Fleet performance has two major aspects to it: there is fleet optimization and then fleet management. Fleet optimization looks at establishing a perfect fleet size and perfect individual component sizes where there is a perfect match between loading and hauling machines. This has to be done during mine start up and from time to time as open pit deepens such that haul road lengthens. Fleet management then looks at the appropriate method for sustaining a fleet at optimal performance. This includes fleet monitoring; machine guidance; production tracking; safety monitoring and maintenance management.

2. Brief Description of the Studied Site

Chinese Government Company (CGC) Quarry is located in the area which consists of hills which has the following coordinate. The quarry (CGC) is link with a major highway from Okene to Lokoja which is tarred. The road that lead to the quarry is not tarred, opposite the railway Station Itakpe National Iron Ore Mining Company Kogi State (NIOMCO Nigeria Limited). The study area from the main road (Railway Station, Itakpe) junction to the quarry site is 1.6/ km and lies within Latitude (07^{0} $37^{.}$ $969^{'}$ N) and Longitude (006^{0} $18^{.}$ 023’ W) and Elevation of 240 m, in Abobo, Okehi Local Government Area of Kogi State, Nigeria.

2.1 Field Data Collection

A systematic plan to collect rock sample was developed to collect data for the optimization of the blast design parameters. Data collected include; Number of blasting holes, Hole diameter, Burden, Spacing, Bench height in multiple blasting operations, parameters were collected based on the models input, all of which are variables that vary in each blasting pattern. Other parameters of blasting pattern, such as the types of explosives and delay time between rows were ignored because they are constant in all the investigated blasting patterns.

2.2 O-Pitblast Software

O-Pitblast is an application software designed for the planning, control and optimization of rock blasting operation. Developed by O-Pitblast, is an application that pretends to fulfill all the needs of blast engineers in order to optimize, control and reduce cases and increase safety in their blasts.

This platform allows the user to import terrain features, like topography and rock characteristics and design the best blast for each operation. This is possible due to the artificial intelligence (AI) module that identifies potential safety risks and KPI's capable to generate savings. Besides all the operation modules, it has a management section that permits the recording of blast data, generation of blast plans and reports, KPI control graphics, track and trace technology, user control and multiple project management (Pyra and Godek, 2020).

2.3 Methods

For this research, the study of the existing practice was done followed by pre-blast, in-blast, and post-blast survey. Then the data were analyzed and a model was interpreted. All the parameters were then compared and worked on for the best suiting result. They observed that to achieve a certain degree of refinement in blast design, scientific and systematic approach is needed. With instruments like VOD probes, laser profiling system, etc the monitoring becomes easier, efficient and cost effective.

2.3.1 Determination of Uniaxial Compression Strength

The Uniaxial compressive strength (UCS) was carried in accordance with method suggested by International Society of Rock Mechanic Commission (ISRM, 1989). Uniaxial compressive strength of intact rock is a basic parameter for rock mass classification criteria. Uniaxial compressive strength (UCS) is the maximum vertical normal stress a rock sample can withstand before failure occurs (Bhadawdekar *et al* 2021). Uniaxial compressive strength of a typical rock sample subjected to load can be calculated using Equation (1).

$$UCS = \frac{F}{A} = \frac{4P}{\pi D^2} \qquad (1)$$

Where; UCS is the compressive strength, F is the applied load, and A is the area of the rock sample.

2.3.2 Determination of Point Load Strength Index

Point load strength index were determined on the rock samples collected from working pit face in Q1 and Q2. The samples were prepared with accordance to ISRM 1985. The uncorrected point load strength, *Is*, can be obtained using Equation (2).

$$I_s = \frac{P}{(D_e)^2} \qquad (2)$$

$=$

Where;

I_S is uncorrected point load strength

P is the force at failure,

D_e^2 is the square of the "equivalent core diameter", equal to D^2 for diametral tests.

$$I_{s(50)} = FI_s \qquad (3)$$

$$F = (D_e/50)^{0.45} \qquad (4)$$

Where

F is the size correction factor determined by Equation (4)
D_e is the equivalent core diameter in mm.

2.3.3 Determination of Rock Density

The Rock density will be tested in accordance with International Society of Rock Mechanics Commission (ISRM, 1981). The bulk density was determined using Equation (5).

Bulk Density (ρ)

$$\rho\ (g|m^3) = \frac{m}{v} \tag{5}$$

Where; M is the mass of the sample (kg); and V is the volume displaced (m^3). Engineering.

Table 1: Geometric Parameters for CGC Blast

Parameters	**Quarry Design Explosive Rock and Parameter**
Blasting hole diameter (mm)	105mm
Depth of hole (m)	22(7 rods)
Spacing (m)	2 mm or 2.5 mm
Burden (m)	3mm or 2.5mm
Number of hole in blast	140-160
Stemming Length	2.5
Drilling pattern	Staggered
Powder Factor	0.25
Blasted tons (kg)	1000
Blasted Volume	1400m^3
Types of Rock	Granite

3. Development of a Blast Optimization Model

Selection of proper explosive in any blasting round is an important aspect of optimum blast design. Basic parameters include VOD of explosive (m/s), Density (g/cc), Characteristic impedance, Energy output (cal/gm), and Explosive type (ANFO, Slurry, Emulsion etc.). However, all these parameters cannot be taken for optimizing the blasting method successfully. Some of the parameters are taken for minimizing the blasting cost. These cost reduction and optimum blast design parameter will give an economical result. The parameters are

i. Drill hole diameter,
ii. Powder factor (desired),
iii. Cost of explosive,
iv. Numbers of holes required to blast.

3.1 Design and optimization of blasting operations using O-Pitblast software

O-Pitblast software is a comprehensive tool for designing blasting operations and predicting the outcome, using the actual topographic models of the working. Based on actual data, including slope profile and parameters, the free front view available at the design stage is similar to the actual conditions (Pyra and Godek, 2020).

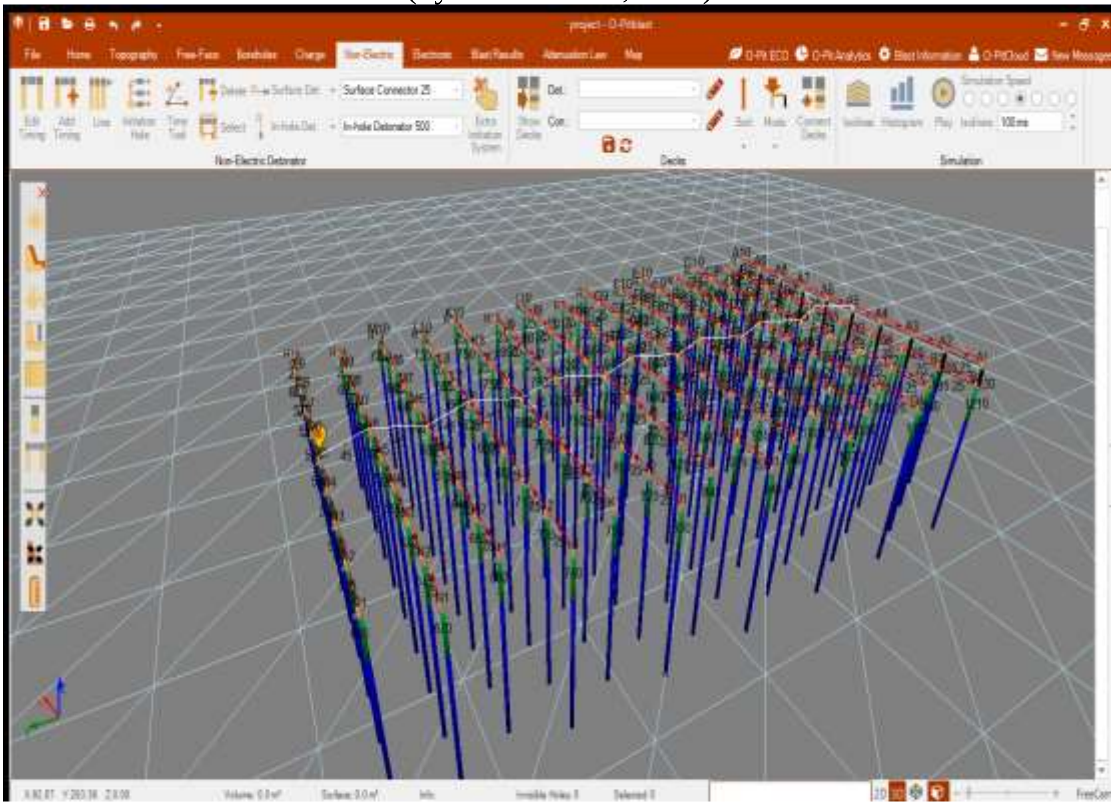
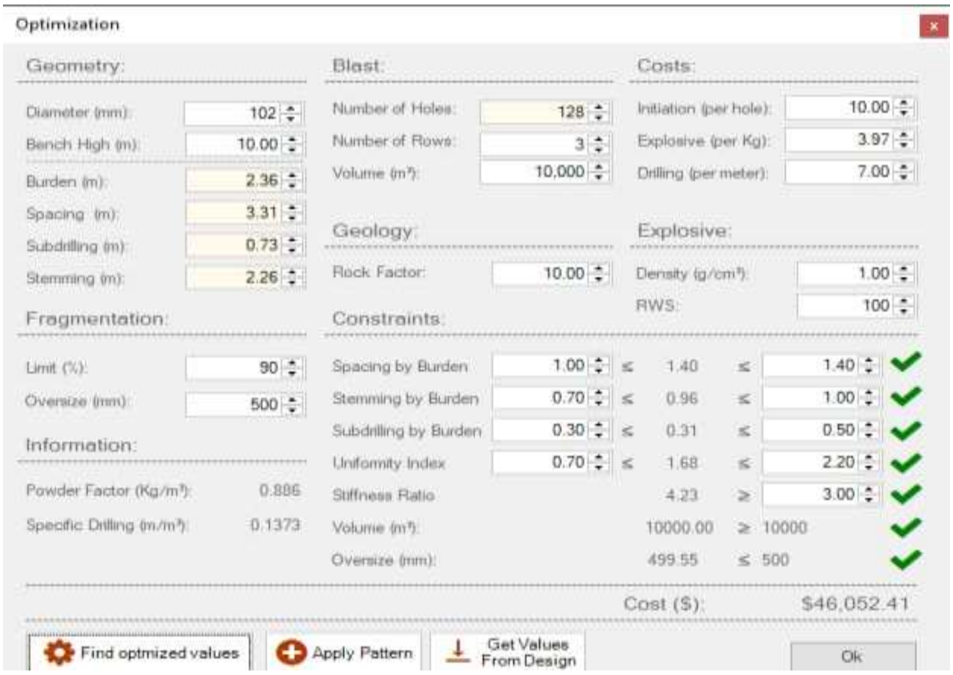


Figure 1: Example dialog box in O-Pitblast Software

O-Pitblast calculates the parameters based on input data for the rock mass, type and parameters of the explosives and other equipment used in the design (base charges, in-hole detonators, surface connectors). The software enables the total costs of the modelled blasting operations to be estimated by entering the unit price of explosives, detonators or blast hole drilling.



Geometry:
Diameter (mm): 102
Bench High (m): 10.00
Burden (m): 2.36
Spacing (m): 3.31
Subdrilling (m): 0.73
Stemming (m): 2.26

Blast:
Number of Holes: 128
Number of Rows: 3
Volume (m³): 10,000

Costs:
Initiation (per hole): 10.00
Explosive (per Kg): 3.97
Drilling (per meter): 7.00

Geology:
Rock Factor: 10.00

Explosive:
Density (g/cm³): 1.00
RWS: 100

Fragmentation:
Limit (%): 90
Oversize (mm): 500

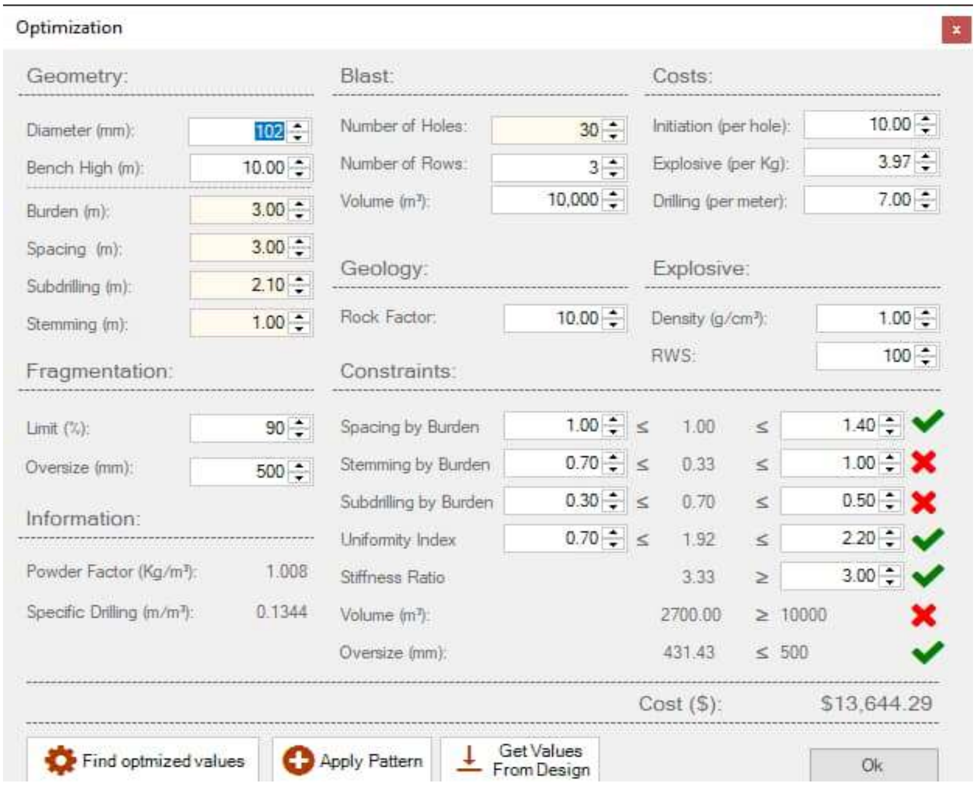
Information:
Powder Factor (Kg/m³): 0.886
Specific Drilling (m/m³): 0.1373

Constraints:

Spacing by Burden	1.00	≤	1.40	≤	1.40	✓
Stemming by Burden	0.70	≤	0.96	≤	1.00	✓
Subdrilling by Burden	0.30	≤	0.31	≤	0.50	✓
Uniformity Index	0.70	≤	1.68	≤	2.20	✓
Stiffness Ratio			4.23	≥	3.00	✓
Volume (m³):			10000.00	≥	10000	✓
Oversize (mm):			499.55	≤	500	✓

Cost ($): $46,052.41

Figure 2: Dialog box with blasting parameters before optimization



Geometry:
Diameter (mm): 102
Bench High (m): 10.00
Burden (m): 3.00
Spacing (m): 3.00
Subdrilling (m): 2.10
Stemming (m): 1.00

Blast:
Number of Holes: 30
Number of Rows: 3
Volume (m³): 10,000

Costs:
Initiation (per hole): 10.00
Explosive (per Kg): 3.97
Drilling (per meter): 7.00

Geology:
Rock Factor: 10.00

Explosive:
Density (g/cm³): 1.00
RWS: 100

Fragmentation:
Limit (%): 90
Oversize (mm): 500

Information:
Powder Factor (Kg/m³): 1.008
Specific Drilling (m/m³): 0.1344

Constraints:

Spacing by Burden	1.00	≤	1.00	≤	1.40	✓
Stemming by Burden	0.70	≤	0.33	≤	1.00	✗
Subdrilling by Burden	0.30	≤	0.70	≤	0.50	✗
Uniformity Index	0.70	≤	1.92	≤	2.20	✓
Stiffness Ratio			3.33	≥	3.00	✓
Volume (m³):			2700.00	≥	10000	✗
Oversize (mm):			431.43	≤	500	✓

Cost ($): $13,644.29

Figure 3: Dialog box with blasting parameters optimization

Table 2: Drilled holes information

No.	Depth	Burden (m)	Spacing (m)	Stemming (m)	Sub drilling	Diameter (mm)	Visible
1.	22.8	2.715	3.108	4.0	0.80	150	√
2.	22.8	2.943	3.021	4.0	0.80	150	√
3.	22.8	3.1	3.002	4.0	0.80	150	√
4.	22.8	3.138	3.016	4.0	0.80	150	√
5.	22.8	3.18	3.04	4.0	0.80	150	√
6.	22.8	3.2	3.043	4.0	0.80	150	√
7.	22.8	2.984	3.036	4.0	0.80	150	√
8.	22.8	3.014	3.001	4.0	0.80	150	√
9.	22.8	2.998	3.013	4.0	0.80	150	√
10.	22.8	2.937	3.013	4.0	0.80	150	√
11.	22.8	3.137	3.078	4.0	0.80	150	√
12.	22.8	3.145	3.015	4.0	0.80	150	√
13.	22.8	3.289	3.001	4.0	0.80	150	√
14.	22.8	3.309	3.012	4.0	0.80	150	√
15.	22.8	3.236	3.029	4.0	0.80	150	√
16.	22.8	3.16	3.031	4.0	0.80	150	√
17.	22.8	3.094	3.026	4.0	0.80	150	√
18.	22.8	3.064	3.001	4.0	0.80	150	√
19.	22.8	3.071	3.009	4.0	0.80	150	√
20.	22.8	3.101	3.009	4.0	0.80	150	√
21.	22.8	3.145	3.053	4.0	0.80	150	√
22.	22.8	3.183	3.01	4.0	0.80	150	√
23.	22.8	3.3	3.001	4.0	0.80	150	√
24.	22.8	3.314	3.008	4.0	0.80	150	√
25.	22.8	3.249	3.02	4.0	0.80	150	√
26.	22.8	3.173	3.021	4.0	0.80	150	√
27.	22.8	3.102	3.018	4.0	0.80	150	√

3.2 Loading-Haulage performance

In this research, a load-and-haul fleet optimization approach was used to identify the opportunities for operational improvement at CGC quarry. The research combines the results of a literature review, on-site time studies, and statistical data analysis to determine the best loader-truck fleet combinations for increased production. Several relevant key performance indicators (KPIs) for the evaluation and identification of productivity improvement opportunities were defined during this research. These KPIs are bucket fill factor, loading conditions, loading cycle time, utilization, and deviations from schedule (Nday and Thomas, 2019).

4. RESULTS AND DISCUSSION

4.1 Mechanical Properties of Rock Samples

Table 4.1 show the laboratory test results of the uniaxial compressive strength and point load index for the rock samples taken at CGC Quarry. The average UCS values for CGC quarry are 92.28 MPa. The results indicate that CGC has a very high strength granite rock.

Result

Tables 5 and 6 are the results of the Schmidt hardness test values, Rockwell and Mohr Hardness, density, porosity, uniaxial compressive strength (UCS), point load index and tensile strength of granite rock samples from the CGC quarry.

Table 3: Density of Granite

S/N	MASS (G)	VI (CM3)	V2 (CM3)	ʌV (CM3)	Ǫ (g/cm3)
1	27.0	300.0	310.0	10.0	2.70
2	38.0	300.0	315.0	15.0	2.53
3	26.0	300.0	310.0	10.0	2.60
4	31.0	300.0	312.0	12.0	2.58
5	29.0	300.0	311.0	11.0	2.63
		Average			**2.61**

Table 4: Porosity of Granite

S/N	MASS (g)	Ms	Md	Vv	V	ᴓ (%)
1	27.0	35	34.90	0.10	8.0	1.25
2	38.0	43	42.95	0.05	8.0	1.00
3	26.0	32	31.92	0.08	6.0	1.33
4	31.0	37	36.93	0.07	6.0	1.17
5	29.0	33	32.92	0.08	4.0	2.00
		Average				**1.35**

Table 5: Uniaxial Compressive Strength of the Granite

S/N	Is (50) (MPa)	ôc (MPa)	*Strength
1	5.85	146.63	Very high
2	8.06	197.00	Very high
3	7.52	184.69	Very high
4	5.95	148.91	Very high
5	6.76	167.37	Very high
Average		**168.92**	**Very high**

Table 6: Point Load Index of the Granite

S/N	D (mm)	H (mm)	Failure load(n)	A (mm^2)	De 2(mm^2)	Is (MPa)	F	Is (50) (MPa)	Strength classification
1	60.0	45.0	18.0	2700	3437.75	5.47	1.07	5.85	Very high
2	70.0	38.0	25.51	2660	3386.82	7.53	1.07	8.06	Very high
3	50.0	50.0	22.56	2500	3183.10	7.09	1.06	7.52	Very high
4	44.0	62.0	19.56	2790	3552.34	5.51	1.08	5.95	Very high
5	55.0	48.0	21.61	2684	3417.37	6.32	1.07	6.76	Very high
								6.83	**Very high strength**

Table 7: Tensile Strength of the Granite Sample

S/N	**Is (50) (MPa)**	**To (MPa)**	**Strength classification**
1	5.85	8.78	Very high strength
2	8.06	12.09	Very high strength
3	7.52	11.28	Very high strength
4	5.95	8.93	Very high strength
5	6.76	10.14	Very high strength
		10.24	Very high strength

Discussion

Table 3 shows the result of density of granite determined from laboratory test. The value of density for the granite ranges from 2.53 g/cm3 to 2.70 g/cm3. The result of porosity of granite determined from the laboratory is shown in Table 4, the value of the porosity for the granite ranges from 1.00 % to 2.00 %. Granite as it is evidence from the result obtained.

Table 5 shows the result of uniaxial compressive strength (UCS) of granite, the granite, the value ranges from 146.63 MPa to 197.00 MPa. The uniaxial compressive strength of granite fall with the range of a very high strength according to Broch and Franklin. Table 6 shows the results of point load test of granite, the value ranges from 5.85 MPa to 8.06 MPa for the granite. Table 7 shows the results of tensile strength of granite, the value ranges from 8.78 to 12.09 MPa for granite varies from 4.02 MPa to 7.92 MPa. The point load index values and tensile strength of both granite and fall within the range of a very high strength according to Broch and Franklin classification.

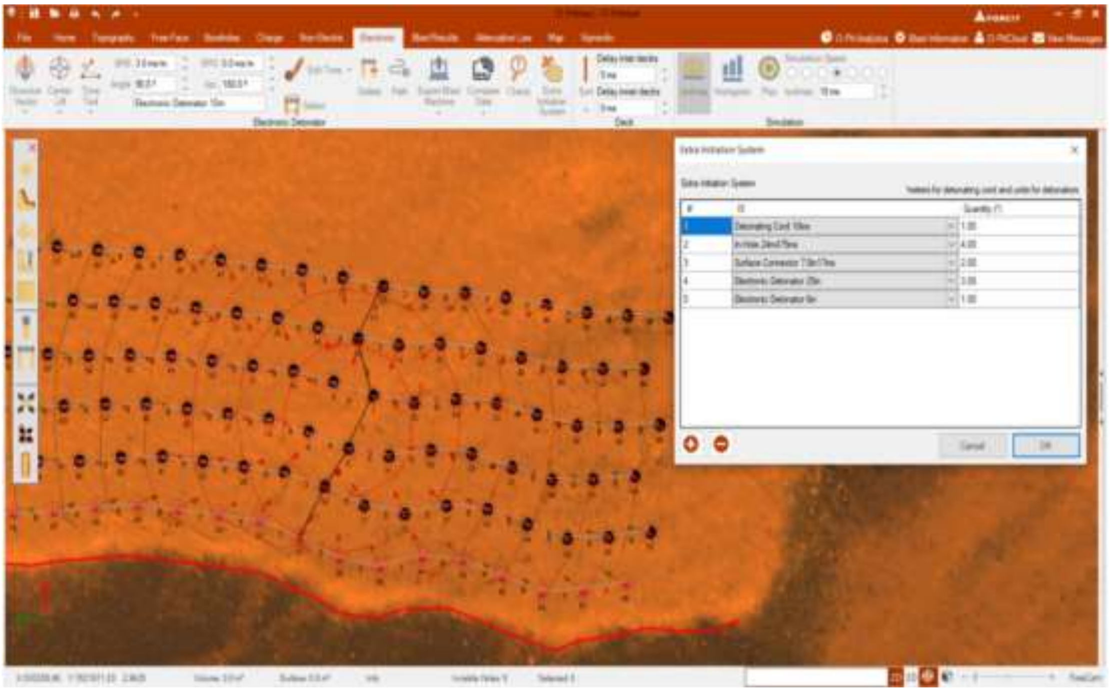


Figure 4: Showing the result of extra initiation

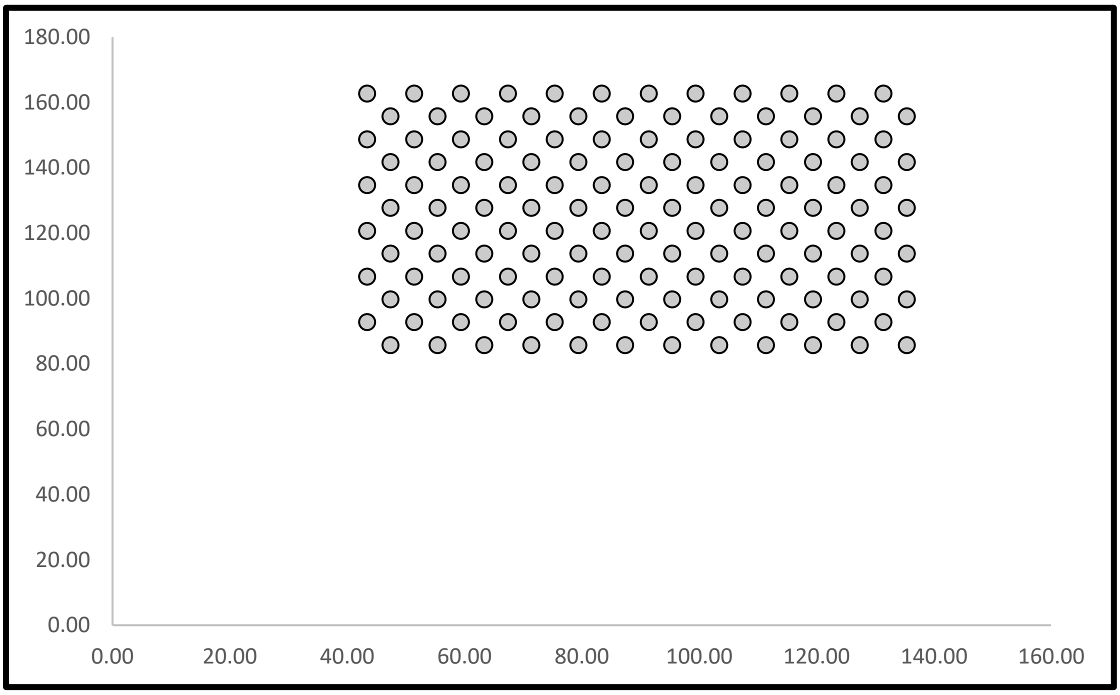


Figure 5: Burden and spacing before optimization

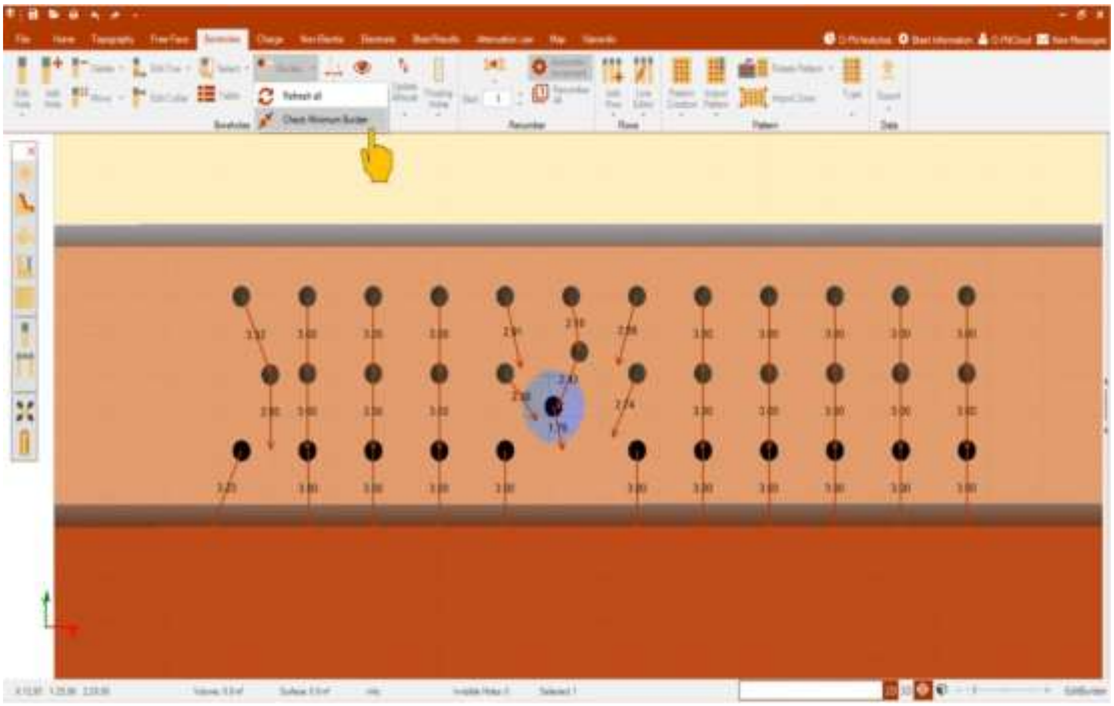


Figure 6: Checked minimum burden after optimization

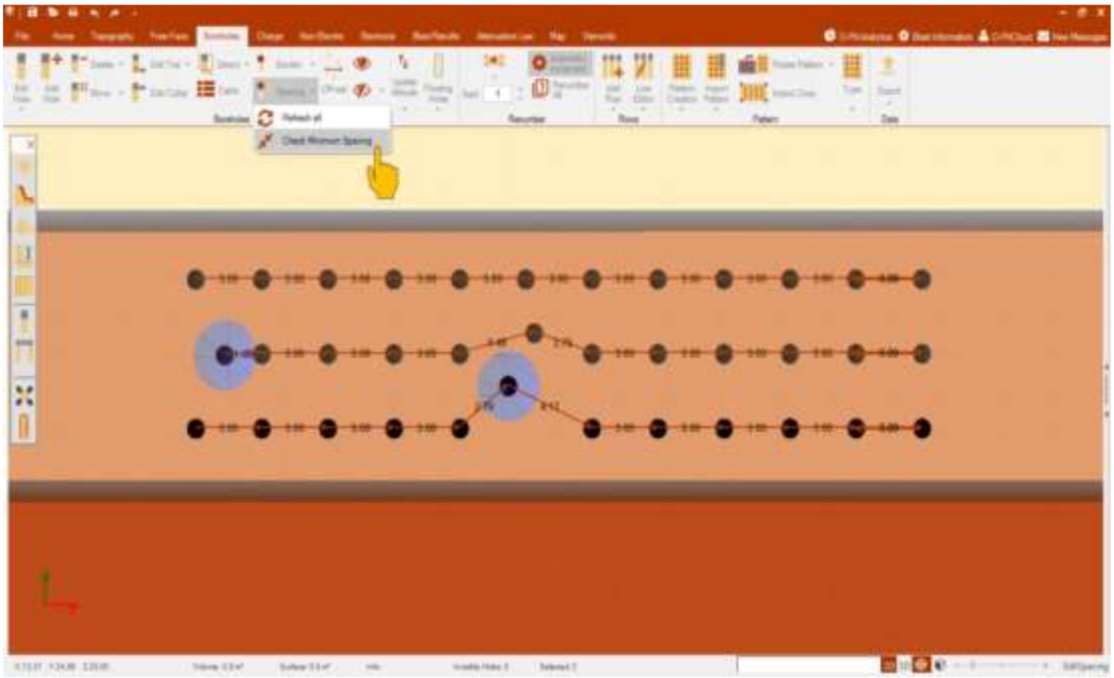
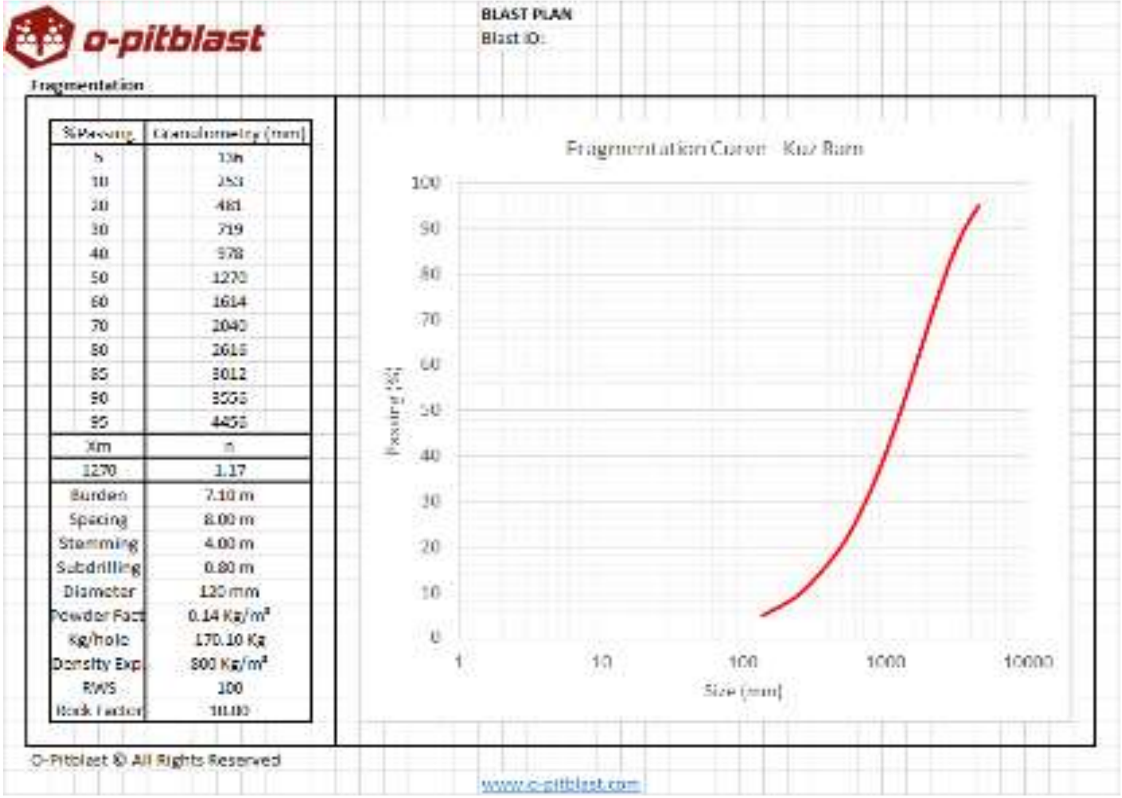


Figure 7: Checked minimum spacing after optimization



BLAST PLAN
Blast ID:

Fragmentation

%Passing	Granulometry (mm)
5	136
10	253
20	481
30	719
40	978
50	1270
60	1614
70	2040
80	2616
85	3012
90	3556
95	4456
Xm	n
1270	1.17
Burden	7.10 m
Spacing	8.00 m
Stemming	4.00 m
Subdrilling	0.80 m
Diameter	120 mm
Powder Fact	0.14 Kg/m³
Kg/hole	170.10 Kg
Density Exp	800 Kg/m³
RWS	100
Rock Factor	10.00

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Figure 8: Predicted run-of-mine size distribution after optimization

Material handling at CGC Quarry involves four activities; blasting, mucking, loading and hauling. These processes involved one unit back hoe excavators for loading and four unit dump trucks with 3.6 m3 bucket capacity. The cycle time data compilation for loading and hauling activities has been generated after one month field survey at the quarry. Average cycle time data are presented in table 8 and table 9.

Table 8: The average cycle time for loading

Variable	Digging (B_t)	Swing full (S_{tf})	Dumping (D_t)	Swing empty (S_{te})	Total
Cycle time – CT_m (secs)	12.60	11.20	10.80	9.60	44.2o
				Cycle time (minutes)	0.74

Excavator with 0.9 m^3 capacities required 0.74 minute to conduct one cycle for filling in dump truck bucket. Therefore, four cycles (2.96 minutes) were required by excavator to complete filling a dump truck with 3.6 m^3 bucket capacity.

Table 9: The average cycle time for hauling

Variable	Loading position (ST_1)	Loading (LT)	Transport full (TT_f)	Dump position (ST_d)	Dump (DT)	Transport empty (TT_e)	Total
Cycle time (C_{ta}) (Secs)	18.20	160.40	420.40	20.30	18.50	402.10	1039.90
						Cycle Time (minutes)	17.33

The average cycle time for a dump truck to haul the fragmented granite from pit to the crusher 17.33 minutes. Therefore, total average cycle time for four dump trucks that currently operated at CGC Quarry was 69.32 minutes. Cycle time required by both heavy equipment and number of equipment operated are two main parameters for calculating MF value. Calculation of MF value using equation (3) resulted that MF value less than one (0.74). MF value shows that dump truck works 100% effective and excavator has waiting time for each loading cycle. Improving MF value into one (MF = 1) is then required to increase mine performance.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The design of blasting operations is a complex process, dependent on several key factors, *e.g.* the mining system, geological properties of the deposit and the nature of deposition, hydrogeological conditions of the rock mass, type and properties of the explosives used or the location of protected areas in the locality. A properly designed blast series requires a detailed analysis of *in-situ* conditions. The parameters are determined for specific mining and geological conditions allowing for the widest spectrum of factors which may affect their values. Using the available empirical equations, found both in national and international literature, and

the actual geological and mining conditions in a given mine, the best fitting formula can be selected and used to calculate a specific parameter of the blasting operation.
The simulation process, for obvious reasons, has not been verified under *in-situ* conditions, since it is not possible to carry out two blasting operations under the exact same mining and geological conditions. However, the process shows that the blast hole pattern parameters (burden, blast hole and row spacing) and the blast hole parameters (explosive charge column length, stemming length, inclination angle, azimuth), may affect the results of the blasting operation. The research presents important conclusions as follows:

1. Cost efficiency: The study concludes that optimizing the cost of basting is crucial for the quarry. By using O-Pitblast software, quarry operations can achieve significant cost savings while maintaining effective blast practices.
2. Impact of blast design variability: This research highlights that variability in blast design components – such as hole azimuth, diameter and initiation methods – play a vital role in reducing explosive consumption. This variability allows for tailored solution that can enhance both efficiency and safety.
3. Choice of explosives: This study concludes that selecting the appropriate type of explosive – whether Super 80 or ANFO – can significantly influence the effectiveness of the blasting operation. This choices should be based on the specific requirements of the mining site and the desired outcomes of the blast.
4. This study found that the excavator needs 2.96 minutes to fill in a dump truck (DT) and DT requires 17.33 minutes for transporting material from the pit to the crusher. The current cycle time which required by both loading and hauling equipment generates MF value less than one. Therefore, in order to improve mine performance, the additional of two dump trucks is required for balancing work load between excavator (loading) and dump truck (hauling).

In summary, the conclusions drawn from the study underscore the significance of a comprehensive approach to blast design optimization, which include cost analysis, safety considerations and strategic use of technology like O-Pitblast software. These factors collectively contribute to more efficient and safe blasting practices in granite quarry.

5.2 Recommendations

Further research can be conducted to investigate the use of other machine learning algorithms in optimizing blast design. The study can be extended to include other rock types, and the effect of different blast parameters on fragmentation results can be explored further.

Application of System Thinking in quarry operations to optimize the quarry’s throughput.

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