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Models Development for Prediction of Blast Efficiency and Total Charge in a Typical Quarry

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Abstract: *The prediction of blast efficiency is usually achieved by using models; this in turn, gives better and more efficient rock fragmentation. However, the accuracy of the prediction often times relies on the model development validation. In this study, models were developed and compared upon validation for predicting the blast efficiency and total charge required for efficient fragmentation using artificial neural network (ANN). Rock samples were gathered from the study are, and the uniaxial compressive strength (UCS) test was carried out on all the samples based on international standard. The average UCS obtained from the rock samples at the Eminent quarry (EQ) is 153.61 MPa. The dimension of in-situ rock mass considered in the study area is 60 m x 40 m, and the in-situ block sizes obtained vary from 2.02 m^2 to 3.20 m^2. The average percentage value of F_{50} obtained from the Split-Desktop image analyses is approximately 72.44 cm. The various results obtained from the UCS, in-situ block size distribution, image analysis of the blasted rocks and the total charge were used to develop the models for the prediction of blast efficiency. The key issue of concern about these models is that they are mostly site specific and the fact that if they perform well in a location does not guarantee the other. Hence, the validation and suitability of these models on the mine site. The blast efficiency prediction using ANN is compared with measured efficiency and the value of coefficient of determination, R^2 obtained is 0.9733. The value of the coefficient of determination, R^2 obtained from ANN by comparing the prediction of the total charge and the measured total charge is 0.9773. The findings showed that, the proposed ANN based mathematical models are suitable and thus, give better prediction to blasting efficiency and the possible total charge.*

Keywords: *Granite Quarry, Blas Efficiency, UCS, ANN, Total Charge*

1. INTRODUCTION

Mining is the second most endeavours of human kind after agriculture. It is one of the primary industries of civilization over the ages, and it has undergone phenomenal changes from rudimentary manual cutting tools to remotely operated motorized machine. A typical mining operation involves five stages; prospecting, exploration, development, exploitation and reclamation. The opening of a mineral deposit is a component of the developmental stage while exploitation has to do with the actual recovery of minerals in quantity.

Globally, the increased industry interest in mining operations, which has its primary focus on the effects of rock fragmentation on economic operations was made prominent by MacKenzie, [1, 2]. The degree of rock fragmentation either increases or decreases the costs implication of mining unit operations such as; drilling, blasting, loading, hauling and primary crushing [1]. According to him, the broad base of the saddle, appears that overall costs remain relatively constant across a wide range of fragmentation.

In MacKenzie's presentation, it is a widely adopted idea that rock fragmentation particularly through drilling and blasting are the primary means of supporting mining operations in the mining industry. However, this is a misleading perspective. Greater and more efficient rock fragmentation can be achieved if the blast is well predicted using models [3-8].

It was also corroborated by [9], who demonstrated some level of efficiencies in mining operations as to the influence of rock blasting on different fragmentation degrees. Revenue generation is a key element of the optimization effort [9]. Although he acknowledges that overall costs in mining operations have decreased, he points out that an operation's profitability can only be increased by either raising revenues or cutting costs, or by doing both. He also argued from the outset that there are multiple scenarios that vary the best option over an extensive range of the potentially combined blasting and cost of processing.

The effect of blasting on fragmentation has been reviewed by numerous authors; which can be seen from the rock fragmentation nature caused by blasting. The process by which fragmentation affects mining operations' efficiency were the subject of the researchers' opinions [10-13]. The findings of [14] work demonstrate the significance of models in forecasting blast fragmentation for the purpose of preserving both the intended level of blast fragmentation and the typical operating level.

However, this research focus is on the conspicuous aspect of blast fragmentation (i.e., the uniaxial compressive strength of the selected rock type, its degree of fragment size distribution of muckpile using Split-Desktop image analysis and explosive) and the hidden effect by considering the in-situ block size distributions using AutoCAD software for the model development in predicting the blast efficiency in the study area.

1.1 Description of the Study Area

The study area is situated at Oluyole Local Government Area of Ibadan in Oyo State, Nigeria. The quarry is operational and yields granite aggregates. Nigeria's Geological Map was used to create the Geographic layout of Eminent Quarry in Ibadan, Oyo State. The EQ is 159m above sea level and geographically located between latitude 7° 20' 0" N and longitude 3° 50' 0" E to 4° 00' 0" E.

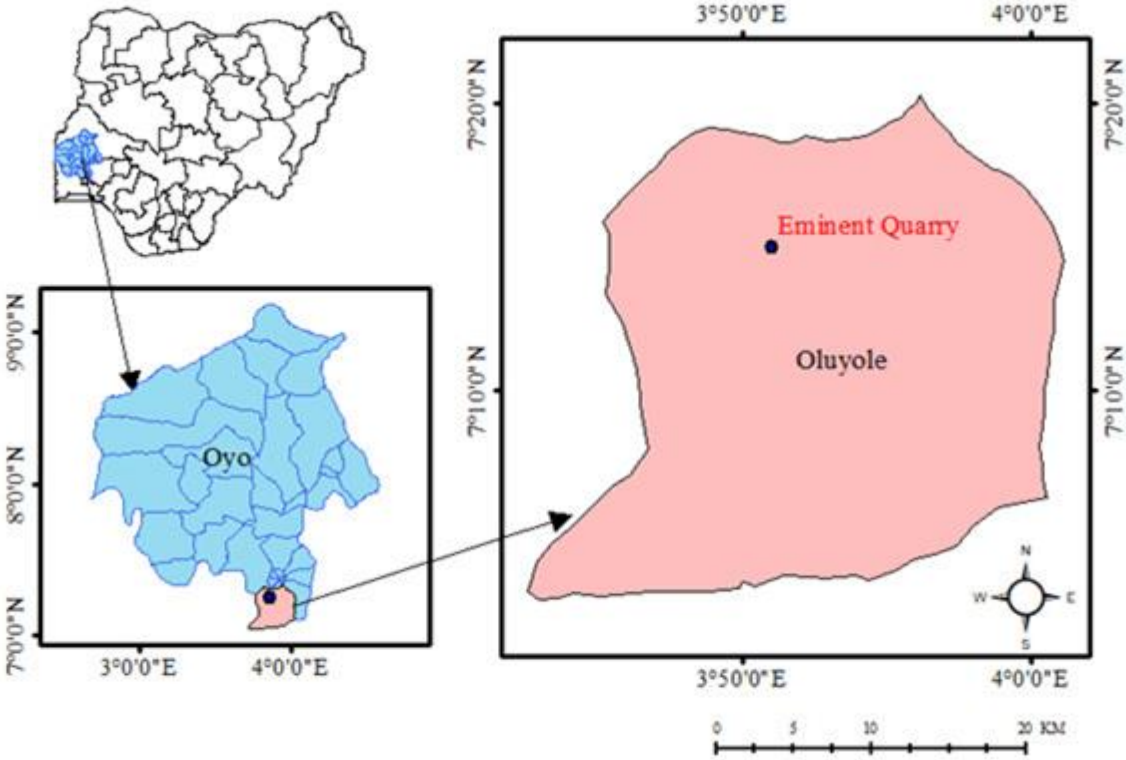


Figure 1: Study Area Map

2. MATERIALS AND METHOD

A universal testing machine was used to determine the uniaxial compressive strength (UCS) of the rock samples. A cylindrical sample of about 50mm diameter and a length-to-diameter ratio of 2:5:1 is usually used as determinant until the sample fails. This was done in accordance with the international standard [15].

The in-situ block sizes of the rock mass were determined with the aid of an automatic computer aided design (AutoCAD) tool. Its outcrop location on the earth surface, the distances between the joints, the duration of the fracture, and the joint sets' orientation are among the geotechnical data that were used to create the model. The surface area (m) of every extruded block is estimated from the generated model to produce the in-situ block size distribution of blocks within the necessary outcrop.

A Split-Desktop digital image analysis was used as a determinant for the fragment sizes of the blasted rocks. Split-Desktop analysis usually takes five phases for every picture captured. Phase 1 involves image scaling; phase 2 requires the segmentation of rock fragments; result precision is ensured at phase 3 and it involves editing to desired rock fragments; phase 4 on the image is marked as the rock fragments analysis; while the fifth stage is the size distribution result, which is often displayed in the form of diagrams [16].

Table 1 displays the blast design parameter, which calls for burden thickness and a blast-hole spacing of 2 m each for the blast operations at EQ. Its powder factor is 0.25 kg/ton, delay time is 25 milliseconds, and bench height is 10 m. the largest fragment size that the primary crusher is capable of processing is 1m.

Table 1: Blast design parameters of Eminent quarry

S/N	Parameter	Value at EQ
1	Burden (m)	2
2	Spacing (m)	2
3	Bench height (m)	10
4	Hole diameter (mm)	76
5	Stemming (m)	1
6	Sub-drill (m)	0.4
7	Powder factor (kg/tons)	0.25
8	Quantity of Explosive per meter	ANFO= 3.75kg
9	Explosive type	Ammonium nitrate and Bulk emulsion
10	Delay time/interval	25ms

3. RESULTS AND DISCUSSION

The average uniaxial compressive strength (UCS) obtained from five samples of the quarry is 151.64 MPa (see Table 2).

Table 2: Uniaxial compressive strength of rock samples of EQ

Sample No.	Failure Load (KN)	Cross Sectional Area (mm^2)	Mass before Test (g)	Compressive Strength (MPa)	
EQ 1	480	22.8	421	209.02	
EQ 2	330	22.8	290	145.08	
EQ 3	270	22.8	237	118.03	
EQ 4	325	22.8	285	142.21	
EQ 5	350	22.8	307	153.69	
			Average	**153.61**	**High Strength**

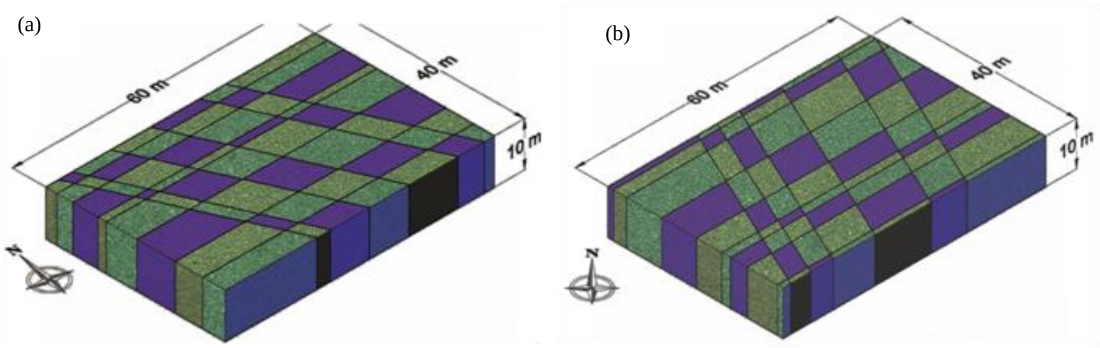
Mean = 153.606; and Standard Deviation = 77.974

3.1 The Uniaxial Compressive Strength

The Eminent quarry has UCS of rock samples that vary from 118.03 MPa to 209.02 MPa. The variation in the UCS of the rock samples is basically as a result of their mineralogical compositions within the rock mass. There is a tendency of higher UCS values with those that have high percentage of quartz [17]. The strength classification of the rock type in the study area averages 153.61 MPa which is an indication of the degree of coherence and level of competence of the rock. The UCS classification of the rock is of high strength [17, 18].

3.2 In-situ Block Size Distribution

Plotting the cumulative graph curves of several blasts with comparable dimensions and modelling the in-situ rock mass conditions resulted in the average in-situ block size distribution. The AutoCAD block size distribution for the five blasts of the quarry is shown in Figure 2. The AutoCAD model dimension of the in-situ rock mass for each blast at the quarry is 60 m × 40 m with a bench height of 10 m.



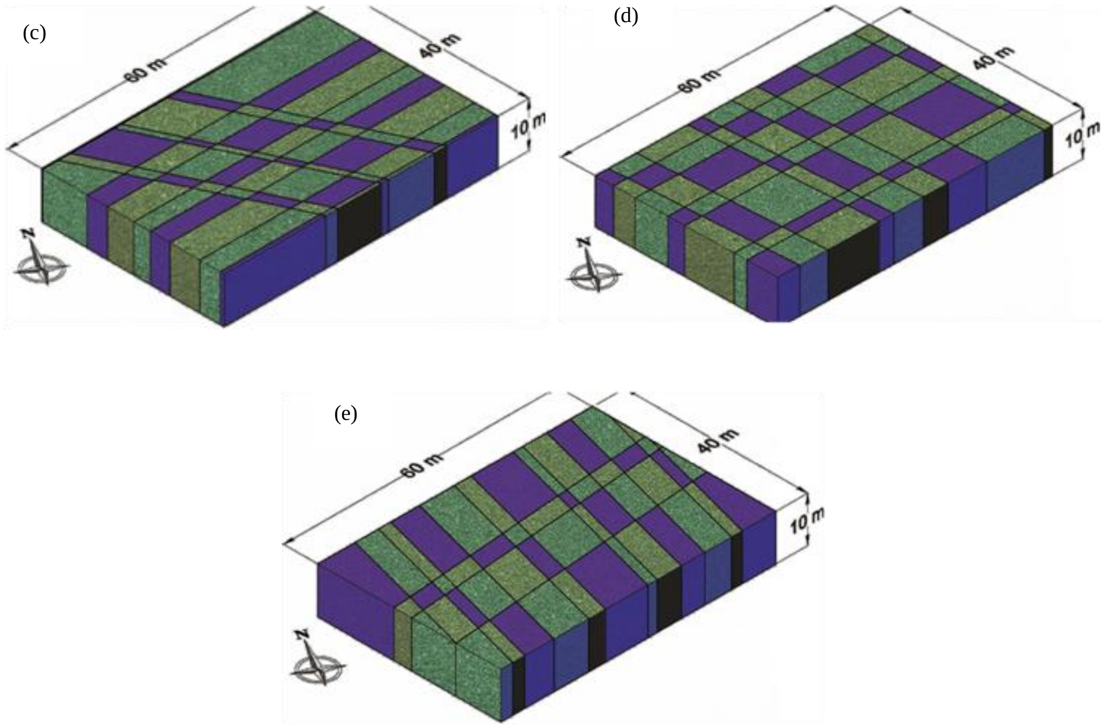
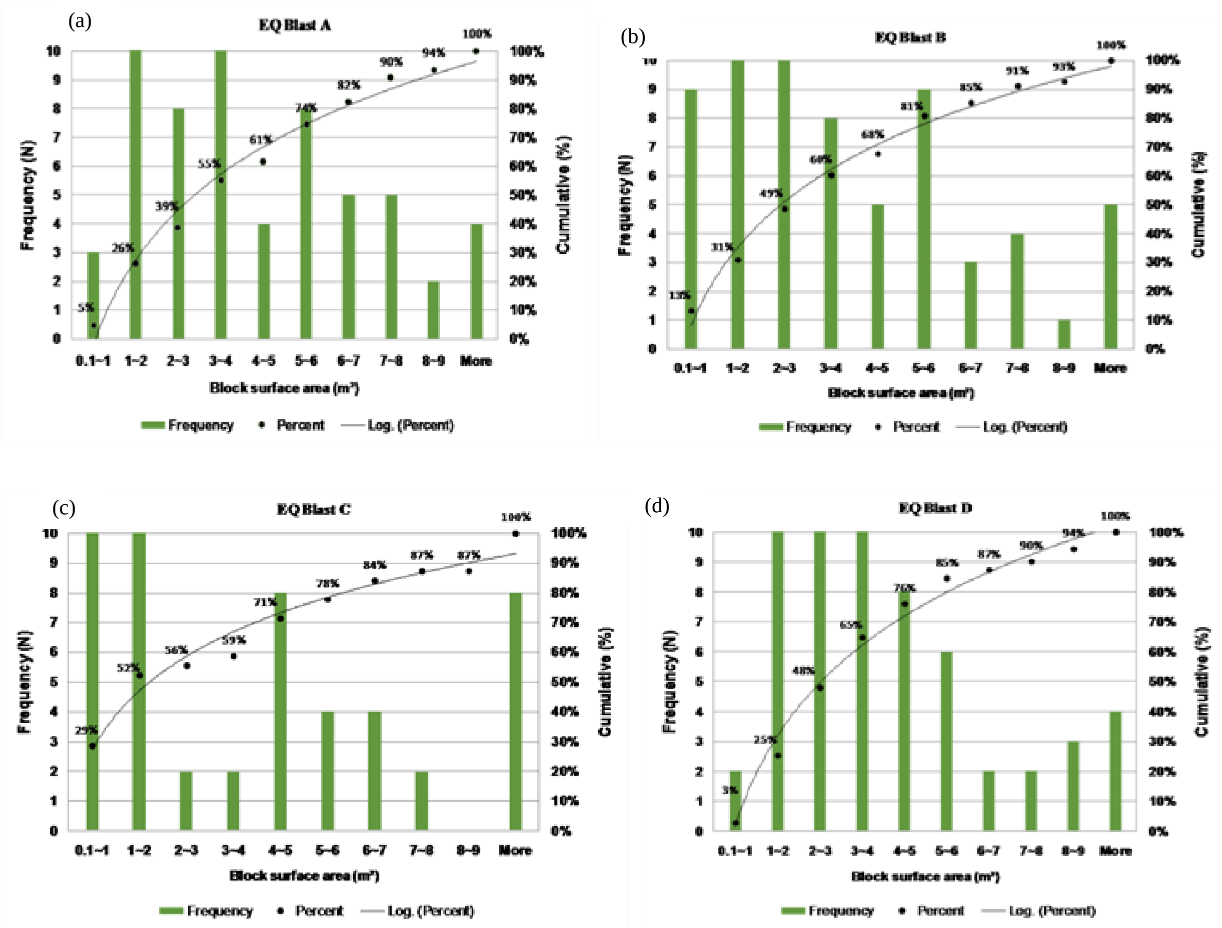


Figure 2: The AutoCAD block size distribution of blasts A - E at EQ

The cumulative graph curves of the in-situ block size distributions for the five blasts A to E, at the quarry are presented in Figure 3. At EQ, in-situ block sizes vary from 2.02 m^2 to 3.20 m^2.



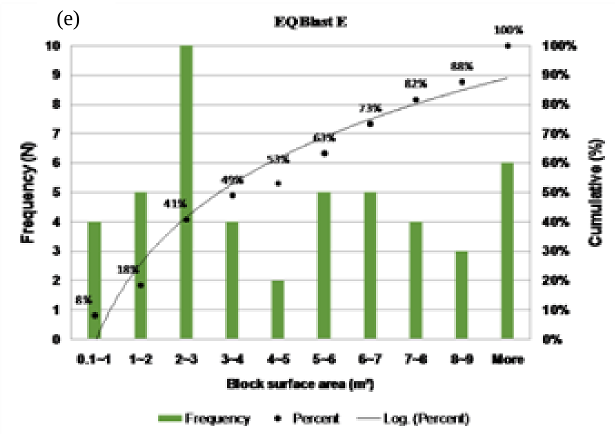
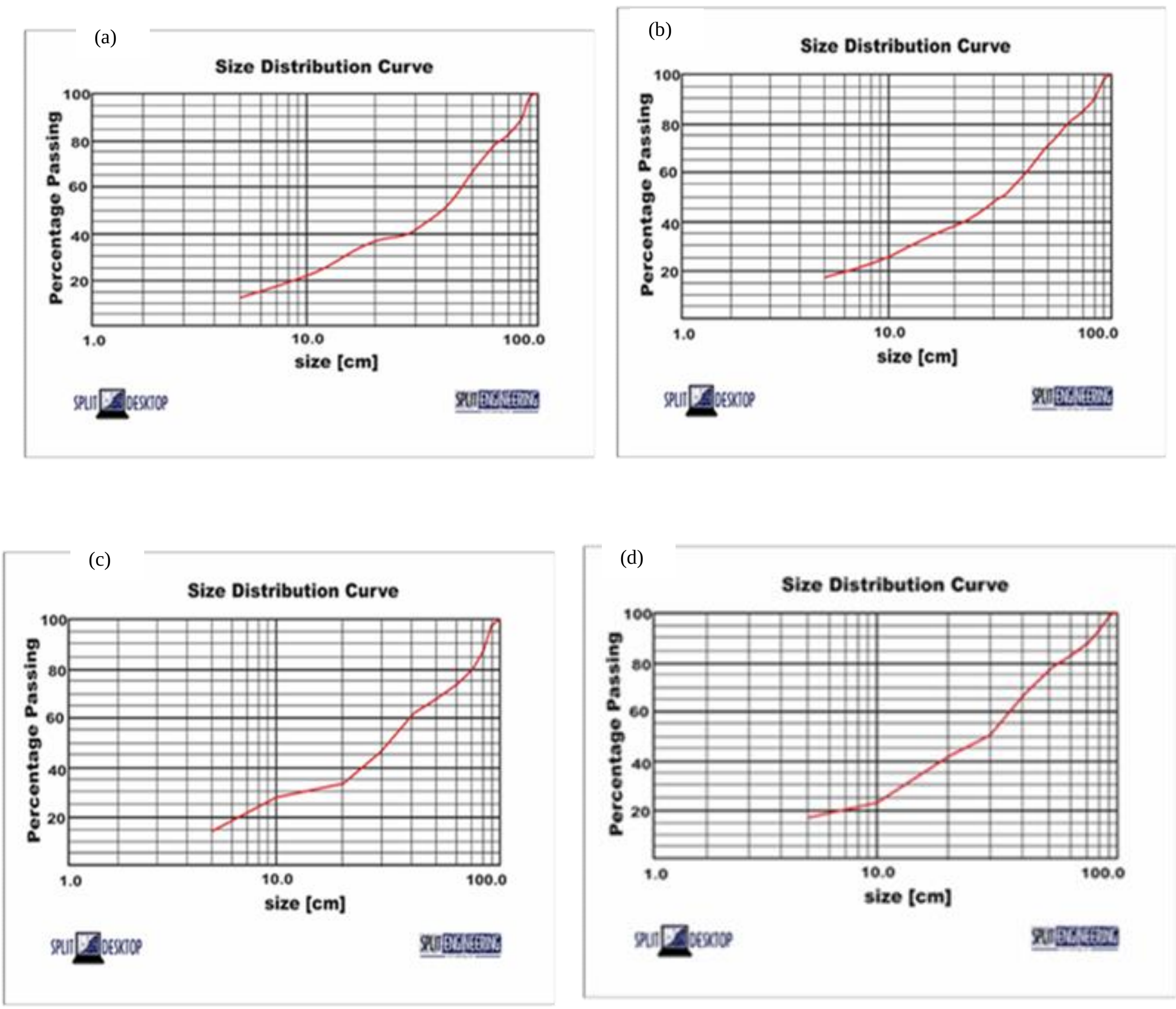


Figure 3: The cumulative graph of in-situ block size distribution for blasts A - E at EQ

3.3 Fragment Size Distribution Analysis

Five (5) blasted muck piles were analyzed. As shown in Figure 4, the Split-Desktop image analysis shows the particle size distribution analyses of the muck piles obtained from the five different blasts A to E. Results from the Split-Desktop show that all the muck pile fragments are less than one meter (1m) benchmark, which is the crusher gape. Moreso, the Split-Desktop analysis shows a relatively close particle size distribution for the blasts with different uniformity index of 1.727. Table 3 shows the average % passing value of F_{50} as 72.44cm from the Split Desktop image analysis for the blast operations at EQ.



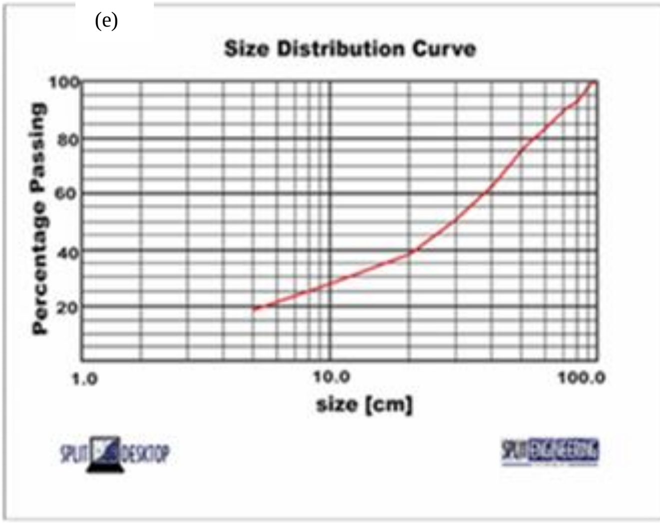


Figure 4: The cumulative grain size curves of image analysis of blasts A-E

Table 3: The average 50% passing of the fragment sizes for blasts A-E of EQ

Blast	EQ (cm)
A	68.4
B	71.8
C	68.5
D	78.2
E	75.3
Average	72.44

3.4 Model Development for Prediction of Blast Efficiency

Table 4 shows the variables used for the blast prediction model development.

Table 4: Variables for the blast prediction model development

S/N	Blast	Total Charge (Kg) [(i+ ii) × n]	Average Size of Fragment 50% passing (cm)	UCS (MPa)	In-situ Block Size (m^2)
1	EQ Blast A	15,000	68.4	209.02	3.04
2	EQ Blast B	8,995	71.8	145.08	2.41
3	EQ Blast C	11,155	68.5	118.03	2.02
4	EQ Blast D	14,160	78.2	142.21	2.88
5	EQ Blast E	10,450	75.3	153.69	3.20

Models are generated for predicting the blast efficiency using artificial neural network (ANN). The continuous quantitative variables were used to describe the analyses of the multiple data obtained and generated from the various analyses of the selected rock type as shown in Table 4. The obtained ANN model is as presented in Equation 1.

$$\%Eff = 7.8tanh(\sum_{i=1}^{3} x_i + 30.3384) + 70.7 \quad (1)$$

where,

%Eff is the blast efficiency, *TC* is the total charge,
UCS is the uniaxial compressive strength of rock, and
IB is the in-situ block size of rock.

x_i in Equation 1 is as listed in Equations 2 – 4.

$$x_1 = 30.0798\tanh(0.012237TC - 0.4495UCS + 4.73568IB - 76.5322) \quad (2)$$

$$x_2 = 30.4429\tanh(0.00438TC - 0.5088UCS + 0.82539IB + 6.140406) \quad (3)$$

$$x_3 = 30.30669\tanh(-0.01582TC + 0.96968UCS - 13.89014IB + 69.52566) \quad (4)$$

However, having known the predicted blasting efficiency of the rock, the prediction of total charge is possible using Equation 5.

$$TC = 5250tanh(\sum_{i=1}^{3} y_i + 16.1534) + 9750 \quad (5)$$

where,
TC is the total charge.

y_i in Equation (5) is as listed in Equations 6 - 8.

$$y_1 = 17.5922\tanh(0.5093UCS + 6.7555IB - 6.0888Eff + 341.9929) \quad (6)$$

$$y_2 = 16.9574\tanh(0.1906UCS - 7.6413IB - 0.4332Eff + 27.4057) \quad (7)$$

$$y_3 = 17.7936\tanh(-0.03259UCS - 0.0668IB + 0.6215Eff - 41.1094) \quad (8)$$

The prediction of the proposed model in Equation 1 is compared with the measured efficiency as presented in Figure 5. The obtained coefficient of determination, R^2 value is 0.9733.

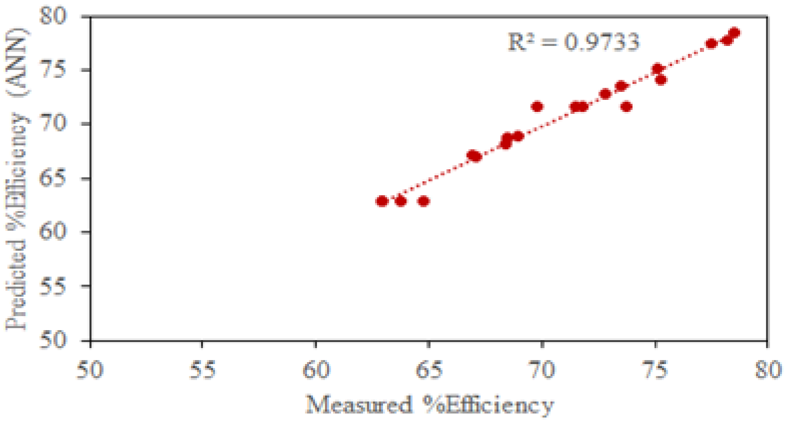


Figure 5: Comparison of the measured and predicted blasting efficiency using ANN

Also, the prediction of the proposed total charge in Equation 5 is compared with the measured values as presented in Figure 6. The obtained coefficient of determination, R^2 value using Equation 5 is 0.9783.

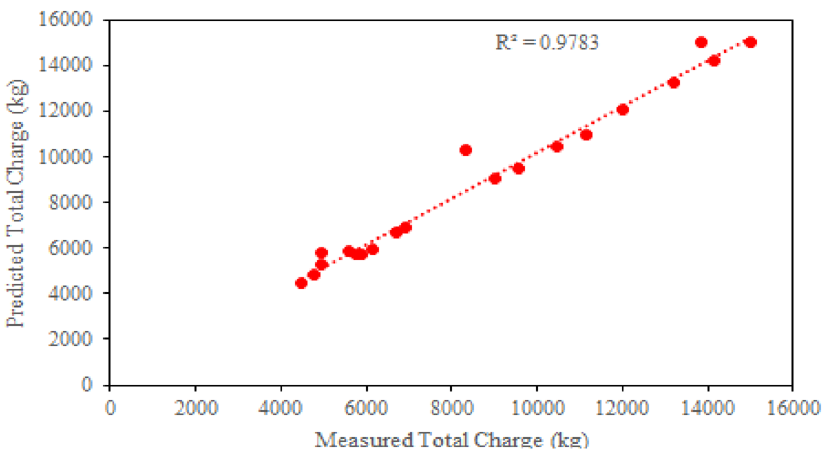


Figure 6: Comparison of the measured and predicted total charge

4. CONCLUSION

The UCS of the rock type in the study area is high as it averages 153.61 MPa which shows an indication that the rock is competent. The dimensions of the in-situ rock mass are 60m x 40m for the AutoCAD in-situ block size distribution of rock. The allowable and acceptable block size of 50% frequency of the cumulative graph of the in-situ block size distribution was recorded for each blast at the location. Consequent to natural forces from the rock mass during blasting, the particle size distribution of blast-induced fragmentation at Eminent Quarry reveals that rock masses of the same blast design tend to produce different degrees of fragmentation using the Split-Desktop image analysis of muckpiles produced during blasting operations.

Due to their proximity to the permitted value of 1m from the crusher, the average values of the F_{50} percentage passing of the muckpiles generated are deemed appropriate for the quarry operations in the study area. The results obtained from the findings were used to develop models for the prediction of blast efficiency and total charge required for efficient fragmentation. In validating the models, the model prediction for blast efficiency using ANN is compared with measured efficiency and the value of coefficient of determination (R^2) obtained is 0.9733. Subsequently, the prediction of the total charge required for efficient fragmentation is possible once the blast efficiency is determined. Hence, the value of coefficient of determination (R^2) obtained when compared with the measured values is 0.9783. Therefore, the model development using ANN based mathematical model is thus suitable for predicting blast efficiency and the total charge required for efficient fragmentation.

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REFERENCES

[1] MacKenzie, A. S. (1966). The Cost of Explosives, Do You Evaluate it Properly? *International Mining Congress Journal*, 52(5), 32-41.

[2] MacKenzie, A. S. (1967). Optimum Blasting. *28th Annual Mining Symposium and the 40th Annual Meeting of the Minnesota Section, AIME*, 122-138.

[3] Monjezi, M., Hasanipanah, M. & Khandelwal, M. (2013). Evaluation and Prediction of Blast-Induced Ground Vibration at Shur River Dam, Iran, by Artificial Neural Network. *Neural Comput. Appl*., 22(1), 1637-1643.

[4] Abzalov, M. Z., Drobov, S. R., Gorbatenko, O., Vershkov, A. F., Bertoli, O., Renard, D. & Beucher, H. (2014). Resource Estimation of In-situ Leach Uranium Projects. *Applied Earth Science*, 123(2), 71-85.

[5] Shehu, S. A., Yusuf, K. O. & Hashim, M. H. M. (2020). Comparative Study of WipFrag Image Analysis and Kuz-Ram Empirical Model in Granite Aggregate Quarry and their Application for Blast Fragmentation Rating. *Geomechanics and Geoengineering, Taylor and Francis Group*, 1-10.

[6] Lawal, A. I., Kwon, S. & Kim, G. Y. (2021). Prediction of the Blast-Induced Ground Vibration in Tunnel Blasting Using ANN, Metaheuristic ANNs and Gene Expression Programming. *ActaGeophysica 10.1007/s11600-020-00532-y*.

[7] Idowu, K. A., Olaleye, B. M. & Saliu, M. A. (2021). Application of Split-Desktop Image Analysis and Kuz-Ram Empirical Model for Evaluation of Blast Fragmentation Efficiency in a Typical Granite Quarry. *Ghana Mining Journal*, 21(1), 45-52.

[8] Idowu, K. A., Olaleye, B. M. & Saliu, M. A. (2022). Prediction of Blast Efficiency of a Typical Granite Quarry. *in 7th UMAT Biennial International Mining and Mineral Conference*, *Tarkwa, Ghana* 1-8.

[9] Kanchibotla, S. S. (2001). Optimum Blasting, Is it Minimum Cost per Broken Rock or Maximum Value per Broken Rock? *International Society of Explosive Engineers, Hunter Valley, NSW*, 35-40.

[10] Valery, W. & Jankovic, A. (2002). The Future of Comminution JKMRC. *University of Queensland, Brisbane, Australia, 34th IOC on Mining and Metallurgy, Bor Lake, Yugoslavia*, 131-147.

[11] Ouchterlony, F. (2003). Influence of Blasting on the Size Distribution and Properties of Muckpile Fragments, A State-of-the-Art Review. *In. MinFo project P2000-10: Energioptimering vid nedbrytning/Energy optimization in comminution, Lulea University of Technology*, 127-132.

[12] Workman, L. & Eloranta, J. (2003). The Effects of Blasting on Crushing and Grinding Efficiency and Energy Consumption. *International Proceedings of 29th Conference on Explosives and Blasting Technique, Nashville, TN*, 23-57.

[13] Valery, Jnr. W., La Rosa, D. & Jankovic, A. (2004). Mining and Milling Process Integration and Optimisation. *Presented at the SME Conference, Denver*, 23-25.

[14] Idowu, K. A., Olaleye, B. M. & Saliu, M. A. (2021). Analysis of Blasted Rocks Fragmentation using Digital Image Processing (Case study: Limestone quarry of Obajana Cement Company). *Mining of Mineral Deposits*, 15(4); 34-42.

[15] International Society for Rock Mechanics (1999). Committee on Standardization of Laboratory and Field Tests. Suggested methods: Rock Characterization, Testing, and Monitoring. E. T. Brown, ed., *Pergamon Press, London, Great Britain*, 21.

[16] Bobo, T. (2010). What's New with the Digital Image Analysis Software Split-Desktop. *Split Engineering, LLC, Tucson*, 13-42.
[17] Hassan, N. F., Jimoh, O. A., Shehu, S. A. & Hareyan, Z. (2019). The Effect of Mineralogical Composition on Strength and Drillability of Granitic Rocks in Hulu Langat, Selangor Malaysia. *Geotechnics and Geological Engineering*, 37, 5499-5505.
[18] Deere, D. U. & Miller, R. P. (1966). Engineering Classification and Index Properties for Intact Rock. Air Force Weapon Laboratory, New Mexico, *Tech. Rept., AFNL-TR*, 65-116.