The Effect of Drilling and Charging Design on Cost of Blasting in Some Selected Rocks in Nigeria

Saliu M. A., Ajaka E.O., Ohere S. A.

Abstract— **This research investigates the effects of drilling and charging specifications on blasting cost in three selected rocks; granite, limestone and marble in Nigeria. In order to achieve this, the three rock types were characterized to determine some rock properties; uniaxial compressive strength, point load strength, Schmidt hardness and unit weight. Drilling and charging design parameters; burden, spacing, blasthole diameter, blasthole depth, stemming height, and specific charge were obtained by blast design variations using Langerford model. The cost of blasting was estimated from all input parameters; cost of explosives and explosives accessories, drill tools and accessories, and costs of other related items and activities. Sensitivity analysis was performed by selecting combination of controllable and uncontrollable (design and rock) factors over a range of value to determine the variation of cost with drilling and charging specifications for each of the selected rock types. The results obtained show that hole diameter increase with corresponding increase in blasting cost and no significant change in the drilling cost for all the three rock types. Also, increase in bench height brings about a corresponding increase in both drilling and blasting cost. Increase in burden or spacing decreases the number of holes to be drilled and consequently the amount of explosives needed for the blast. The optimum cost for granite, marble and limestone are; ₦15,000,000, ₦10,000,000 and ₦8,000,000 respectively. It can then be observed that the optimum drilling and blasting cost is dependent on the strength properties of a rock to be blasted and that the higher the strength of the rock, the higher the optimum cost required to achieve desired fragmentation. The research shows that optimum cost analysis is an important parameter required to find a common ground between optimum costs and desired fragmentation.**

Index Terms— **Blasting, Charging design, Drilling, Optimum Cost.**

I. Introduction

Rock blasting is a major activity in all mining operations – surface and underground. It is also one of the major cost components of such operations. Generally, the cost of drilling is the sum of two major components, capital and operational cost, while the blasting cost consists of mostly the cost of explosives, blasting accessories and labour. An important parameter, often linked to the distribution of explosive energy in the blast is the bore hole diameter and it controls the distribution of energy in the blast and thus affects fragmentation.

Large diameters holes are often associated with expanded drilling patterns; however large holes intersect fewer in-situ blocks of rock, resulting in more oversize, especially in the case of jointed rock [16]. Changes in the bench height when a new loading machine is introduced for any other reason, affect changes on all dependent parameters and on the blast muck pile size mix [16]. Modifications in a bore hole diameter or a bench height or a product size tend to change all other relevant blast design parameters. Changes in the bench height or bore hole diameter, when the product size is required to be kept constant due to market demand or crusher/grinder requirements, result in changes in all other parameters and ultimately changes in the capital and operational cost of drilling, and the cost of blasting. Comparative calculations in every case allow the designer to determine the optimum cost parameters. In this present work, the effects of changes of blasting parameters, when the fragmentation output is specified, were studied.

Preliminary blast design parameters are based on rock mass-explosive blast geometry combinations [6], which are later adjusted on the basis of field feedback using the design. The primary requisites for any blasting round are that it ensures optimum results for existing operating conditions, possesses adequate flexibility, and is relatively simple to employ [6]. It is important that the relative arrangement of blastholes within a round be properly balanced to take advantage of the energy released by the explosives and the specific properties of the materials being blasted [6]. There are also environmental and operational factors peculiar to each mine that will limit the choice of blasting patterns. The design of any blasting plan depends on the two types of variables; uncontrollable factors such as geology, rock characteristics, regulations or specifications as well as the distance to the nearest structures, and controllable variables or factors. The blast design must provide adequate fragmentation, to ensure that loading, haulage, and subsequent disposal or processing is accomplished at the lowest cost [6].

In modelling for the drilling and blasting specification, one means of determining the efficiency of adapted specification is by calculating the degree of fragmentation. A blasted rock muck pile and the fragment sizes within it are very important for the mining industry since they affect the downstream processes from hauling to grinding. The size distribution of the blasted muck pile can be predicted by a variety of semi empirical models which are based on blast design parameters, such as burden, spacing, bore hole diameter, bench height and explosives consumption [2]. It has been the experience of many researchers that these models are quite successful in predicting the mean fragment size; however, they lack accuracy in predicting the 80% passing size used in comminution calculations. Despite their limitations, these models are commonly used, since they provide reasonable trends to evaluate changes in blast design parameters [5]. The optimization of the final rock fragment/product size on a cost

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basis must result in the minimum total cost that the drilling and blasting design parameters can generate.

II. GEOLOGY OF THE STUDY AREA

Three quarry sites were used for the purpose of this research work. The sites are Julius Berger in Abuja, Obajana Cement Company in Kogi State and Ewekoro Quarry Ogun State as shown in Figure 1. Julius Berger Quarry, the first study area is located in Abuja within the North-Central Nigeria Precambrian Basement Complex. The geology of the area has been studied and discussed by previous works of researchers like [14], [12] etc. They described the rocks as comprising mostly granite, gneisses, mica schists, hornblende and feldspathic schists and migmatites. Obajana Cement Quarry the second study area is located in Kogi State, Nigeria. Generally, Kogi State has two geological formations; Basement complex and Sedimentary basin. Approximately, half of the state is covered by crystalline basement complex while the other half is covered by cretaceous to recent sediments. Ewekoro the third study area is located in Abeokuta, Ogun State, Nigeria. The study area lies within the basement complex area of Ogun State in the Southwest of Nigeria and lies within latitudes 6° 00' and 8° 45' North and longitudes 5° 30' and 6° East. In the area the proliferation of many small river channels characterizes the drainage system. The vegetation is dense and made up of broad-leaved trees that are mostly evergreen. The study area is underlain by rocks of the Precambrian basement complex of Nigeria [10], [15], while the lithological units include majorly, undifferentiated gneiss, granites gneiss, biotite gneiss, quartzite and charnokite.

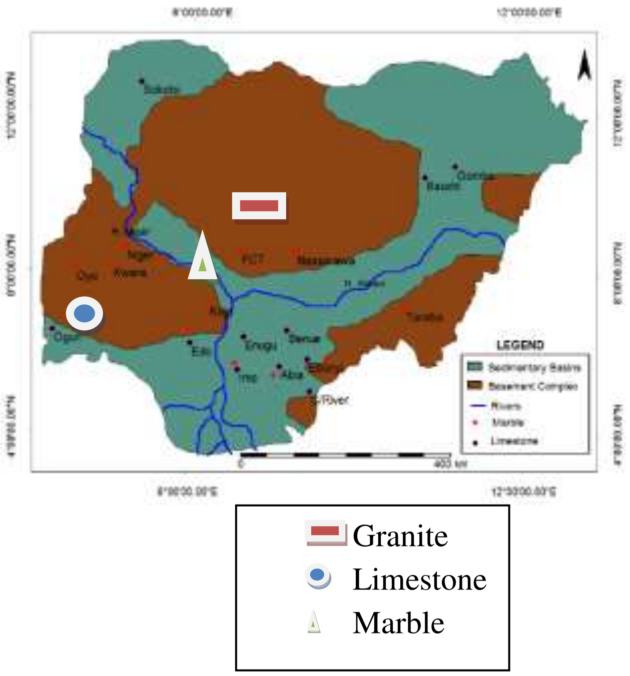

Figure 1: Geological Map of Nigeria Showing the Study Areas (Adapted from [13])

III. MATERIALS AND METHODS

Determination of Rock Properties

Laboratory tests were performed to determine the properties of Julius Berger granite, Ewekoro limestone and Obajana marble considering the suggested methods and related standards [7], [8], [1].

Determination of Density and Dry Unit Weight

Ten specimens each of irregular form ranging from 25-100g were prepared from a representative sample of rock representing different weathering grades of both limestone and marble. The determination of the density (ρ) was carried out according to the procedures suggested by [7] using Equations 1 to 4.

$$V_{bulk}=\frac{(M_{sat}-M_{sub})}{\rho_w} \quad (1)$$

$$\rho_{bulk}=\frac{M_{bulk}}{V_{bulk}} \quad (2)$$

Dry density:

$$\rho_d=\frac{M_{dry}}{V}\text{(kg/m}^3\text{ or g/c m}^3\text{ or g/mm}^3\text{)} \quad (3)$$

$$\text{Dry Unit weight} = \rho_d \times 9.8\ (\text{kN/m}^3) \quad (4)$$

where; V_{bulk} is the bulk volume; M_{sat} is the saturated mass; M_{sub} is the submerged mass, M_{bulk} is the bulk mass; M_{dry} is the dry mass and ρ_w is the density of water.

Determination of Point Load Index

The point load strength (Is) values were determined for irregular samples in accordance with the procedures suggested by [8] using Equations 5 to 10.It must be corrected to standard equivalent diameter (D_e) of 50mm using the procedure as recommended by [4]. Point load index, using 50mm diameter, is obtained using Equation 5 [4].

$$Is_{(50)} = {P}/{D^2_e} \quad \text{(MPa)} \quad (5)$$

where; P is the failure load (kN), De² is the equivalent core diameter (mm)

Determination of Schmidt Rebound Hardness

The determination of the hardness of the samples involves the use of Schmidt hammer on lump of the rock samples. The rebound value of the Schmidt hammer was used as an index value for the intact strength of the rock material. The measured test values for the samples were ordered in descending order. The lower 50% of the values were discarded and the average upper 50% values obtained as the Schmidt Rebound hardness. Five samples each were tested for each of the weathering grade. The procedures followed the standard suggested by [8], [1].The average values obtained from the Type – N machine was converted to Type – L readings by using the relationship established by [3] as shown in Equation 6.

$$R_N= 1.0646\ R_L+ 6.3673 \quad (6)$$

Where; R_N is Rebound Hardness Value from Type N Hammer, and R_L= Rebound Hardness Value from Type L Hammer.

Determination of Uniaxial Compressive Strength (Unconfined Compressive Strength)

The Uniaxial Compressive Strength of the rock samples were estimated from the values of the equivalent Type L Schmidt hammer hardness and the density of the rock.

The UCS values were estimated by an equation developed by [17] as shown in Equation 7.

$$UCS = 12.74\exp(0.02 \times R_L \times \rho) \quad (7)$$

Where UCS is Uniaxial Compressive Strength (MPa); R_L is Rebound Hardness Value of Type L Hammer; and ρ is Density of rock (g/cm^3).

Selection of different Drilling and Charging Specification for different Rock Types

The drilling and blasting parameters burden, spacing, blasthole diameter, blasthole depth, stemming height, specific charge were collected from the three selected locations. Reference [11] formula was used to determine various drilling and charging specifications by varying different controllable factors for the selected rock types. Approximately one hundred holes (100) of 110mm diameter were drilled on a granitic outcrop, marble and limestone deposits at Julius Berger Quarry Site in Abuja, Dangote Cement Group in Obajana and Lafarge Cement Group in Ewekoro.

Calculation of Costs of Drilling and Blasting Drilling Cost

The drilling cost expressed per meter drilled (₦/m) was determined for this research by adopting mathematical model suggested by [9] as presented in Equation 8.

$$C_T = \frac{C_A + C_I + C_M + C_O + C_E + C_L}{P_r} + C_B \qquad (8)$$

where; C_A is depreciation (₦/h), C_I is the interest rate and insurance ($/h), (indirect costs), C_M is the maintenance and repair (₦/h), C_O is the labour cost (₦/h), C_E is the cost of fuel or energy, C_L is the cost oil, grease and filters (₦/h), C_B is the cost of bits, rods, sleeve and shanks (₦/h) (direct costs) and P_r is the drilling productivity in (m/h) [9].

Blasting Cost

The cost of blasting was determined using Equation 9.

$$C_{TB} = C_T + C_{ANFO} + C_H + C_L + C_A \qquad (9)$$

Where C_{TB} is the total cost of blasting (₦), C_T is the cost of transportation, C_{ANFO} is the cost ANFO (₦), C_H is the cost of high explosive (₦), C_L is the cost of labour (₦) and C_A is the cost of explosive accessories (₦).

Sensitivity Analysis

The drilling and blasting parameters used in the design of blasting was varied and the cost of drilling and blasting was determined for each parameter used. The sensitivity analysis was performed to determine the variation in cost of drilling and blasting at varied parameters on the base case of NPV (Net Present Value). The hole diameter was flexed within the range of ±50 % and a sensitivity analysis was computed using MS-Excel to determine its effect on the overall cost while keeping the other parameters constant.

IV. RESULTS AND DISCUSSION

Density and Unit Weight Results

Table 1 is a summary of the density result while Table 2 is that of the unit weight. The tables show that Abuja (Granite) outcrop has the highest density and unit weight values while Type I of the Ewekoro (Limestone) deposits has the least.

Table 1: Summary of Density Results in g/cm^3

Test No	Obajana Marble	Ewekoro Type I	Ewekoro Type II	Ewekoro Type III	Abuja Granite
1.	2.65	2.40	2.69	2.51	2.80
2.	2.66	2.41	2.68	2.49	2.81
3.	2.63	2.40	2.76	2.54	2.82
4.	2.50	2.37	2.72	2.49	2.77
5.	2.56	2.43	2.67	2.47	2.80
Average	**2.60**	**2.40**	**2.70**	**2.50**	**2.80**

Table 2: Summary of Unit Weight Results in kN/m^3

Test No	Obajana Marble	Ewekoro Type I	Ewekoro Type II	Ewekoro Type III	Abuja Granite
1.	25.98	23.54	26.38	24.61	2.80
2.	26.10	23.65	26.27	24.38	2.81
3.	25.76	23.51	27.04	24.93	2.82
4.	24.57	23.22	26.68	24.40	2.77
5.	25.16	23.88	26.16	24.21	2.80
Average	**25.51**	**23.56**	**26.51**	**24.51**	**2.80**

All the rock samples tested possess an average density of between 2.3 to 2.8 g/cm^3 while the estimated unit weight varies between 23.56 to27.91kN/m^3. Ewekoro (limestone) has three different types of deposits as evident from visual inspection and have densities of 2.40 g/cm^3, 2.70 g/cm^3 and 2.50 g/cm^3 while their unit weights are 23.56 kN/m^3, 26.51 kN/m^3 and 24.51 kN/m^3.Obajana (Marble) deposit is unique with a density of 2.6 g/cm^3 and unit weight of 25.51 kN/m^3. Abuja (Granite) outcrop has the expected highest values of 2.8 $g/cm^3$and 27.91 kN/m^3 for average density and unit weight respectively.

Point Load Strength Results

The result of point load strength on the three selected rock types is as shown in Table 3.

Table 3: Result of point load strength in the three rock types

Samples	P (kN)	D_e	D^2_e	$I_{S(50)}$ (kN/mm^2)	$I_{S(50)}$ (MPa)
Obajana	7.3	50	2500	2.92×10^{-3}	2.92
Ewekoro I	4.8	50	2500	1.92×10^{-3}	1.92
Ewekoro II	5.0	50	2500	2.0×10^{-3}	2.0
Ewekoro III	6.08	50	2500	2.43×10^{-3}	2.43
Abuja Granite	12.5	50	2500	5.0×10^{-3}	5.0

It is shown in Table 3 that Abuja (Granite) outcrop has the highest value which is in agreement with its high unit weight and hardness. Obajana marble has the second highest point load strength value with Ewekoro Type I having the least value.

Schmidt Hammer Hardness Results

Table 4 shows the arrangement of the test result in descending values. The lower 50% of the values were discarded and the average obtained of the upper 50% values for each of the rock samples as suggested by ISRM (1981). The average of the upper half is taken to represent the average rebound values of the hardness test. Table 5 is the result of the average of the upper 50% values. Type N Schmidt Hammer test is mostly use for concretes while ISRM (1981) recommends the use of Type L for rocks. Therefore, the averages values of Type N obtained were converted to Type L reading using Equation 6. The results are shown in Table 6.

Table 4: Descending Values of Schmidt Rebound Hardness

	S/N	Obajana	Ewekoro I	Ewekoro II	Ewekoro III	Abuja
Upper 50% Values	1	46	39	50	42	62
	2	45	37	49	42	62
	3	43	37	48	41	60
	4	42	37	48	41	61
	5	41	36	47	40	63
	6	41	36	46	39	61
	7	40	36	46	39	60
	8	39	35	45	38	62
	9	39	35	45	37	61
Lower 50% Values	10	39	34	44	35	62
	11	39	34	40	33	62
	12	38	31	39	31	63
	13	36	30	38	31	62
	14	34	29	35	30	63
	15	31	25	33	30	61
	16	31	25	31	28	60
	17	28	23	29	27	59
	18	26	19	29	25	58
	19	25	18	26	24	60
	20	20	17	25	19	61

Table 5: Upper 50% Values of Schmidt Rebound Hardness and their Averages

S/N	Obajana	Ewekoro I	Ewekoro II	Ewekoro III	Abuja
1	46	39	35	42	62
2	45	37	40	42	62
3	43	37	39	41	60
4	42	37	32	41	61
5	41	36	35	40	63
6	41	36	36	39	61
7	40	36	36	39	60
8	39	35	35	38	62
9	39	35	30	37	61
10	39	34	34	35	62
Average	**41.5**	**36.2**	**35.7**	**39.4**	**61.4**

Table 6: Conversion of Type N Schmidt Hammer Values to Type L Values

Samples	N Values	L Values
Obajana	41.5	35.1327
Ewekoro I	36.2	29.8327
Ewekoro II	35.7	28.4327
Ewekoro III	39.4	33.0327
Abuja	61.4	51.69

The result shows that Abuja (Granite) has the highest value of the rebound hardness and closely followed by Obajana (Marble) while the Ewekoro types have the least. A close observation of the unit weight and the rebound hardness values in Tables 2 and 4 respectively show that there is a strong correlation between the two quantities as rocks with higher unit weight also have higher density.

Uniaxial Compressive Strength Results

The Uniaxial Compressive Strength (UCS) of the rock samples was evaluated from the Schmidt Hammer hardness values using Equation 7. Table 7 shows the Uniaxial Compressive Strength results of the three rock types under consideration and their classification.

Table 7: Uniaxial Compressive Strength Results and their Rock Class

Samples	UCS (MPa)	L-Value	Rock Class
Obajana	69.04	35.13	High to Very High Strength
Ewekoro I	44.16	29.83	High Strength
Ewekoro II	46.00	28.43	High Strength
Ewekoro III	55.89	33.03	High Strength
Granite	120.00	51.69	Very high Strength

All the rock types tested are of "Very High Strength" to "High Strength" class. Abuja (Granite) outcrop has the highest value which is in agreement with its high unit weight and hardness.

Effect of Hole Diameter on Drilling and Blasting Cost

The practical burden used in each case was derived from Jimeno's formula multiplied by an "uncertainty factor" of 0.5, 0.65 and 0.75 for granite (2.5m), marble (3.2m) and limestone (3.7m) respectively. All other parameters were calculated based on the adjusted burden. The reason for this "uncertainty factor" is to account for the variation between what is obtainable from Jimeno's formula and what was practicable on the three sites under consideration. This variation could be as a result of local geological conditions (fracture intensity and degree of weathering) and geomechanical properties of the materials under consideration.

For Julius Berger granite, the hole diameter was flexed within the range of ±50 % and a sensitivity analysis was computed using MS-Excel to determine its effect on the overall cost while keeping the other parameters constant. Figure 2 shows that increasing hole diameter, when all other parameters are kept constant, corresponds to an increase in blasting cost and no significant change in drilling cost.

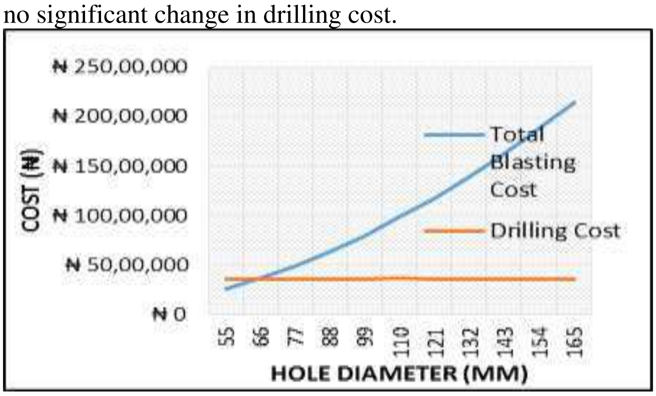

Figure 2: Relationship between Hole Diameter and Costs for Granite.

For limestone, approximately one hundred 110mm holes were also drilled on a limestone deposit and the diameter was flexed between the range ±50%. The practical burden used was 3.7m. Figure 2 shows the effect of changing hole diameter on the overall drilling and blasting cost. Figure 2 shows that increasing hole diameter, when all other parameters are kept constant, corresponds to an increase in blasting cost and no significant change in drilling cost. This result is consistent with the case of granite.

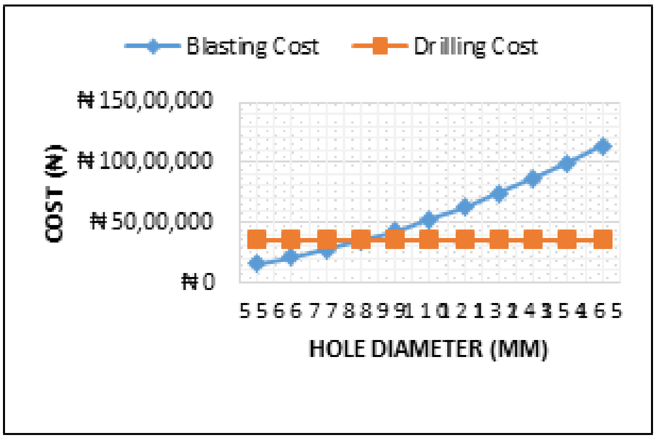

Figure 3: Relationship between Hole Diameter and Costs for Limestone.

The practical burden used for the case of marble was 3.2m and approximately one
hundred holes of 110mm diameter were drilled with a diameter flex range of ±50 %. Figure 3 shows that increasing hole diameter, when all other specifications are kept constant, corresponds to an increase in blasting cost and no significant change in drilling cost. This result is consistent with the cases of granite and limestone.

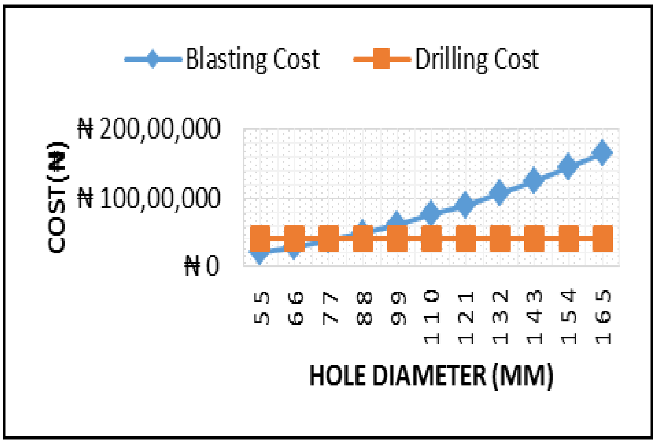

Figure 4: Relationship between Hole Diameter and Costs for Marble

Effect of Bench Height on Drilling and Blasting Cost

As the bench height increases, there is a corresponding increase in the depth of hole to be drilled and also the amount of explosives required to fill these holes. Therefore, in light of the above statement, it can be inferred that increase in bench height causes an increase in both drilling and blasting cost as shown in Figures 5 to 7 for the three rock types. The fragmentation of the blast became more satisfactory as the bench height increased which confirms the optimum bench height to burden ratio.

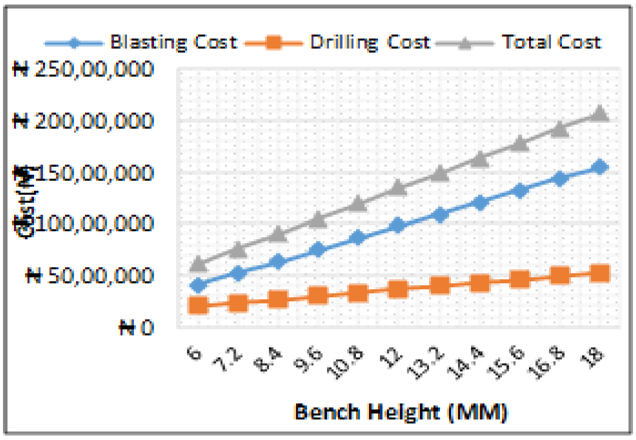

Figure 5: Relationship between Bench Height and Cost for Granite

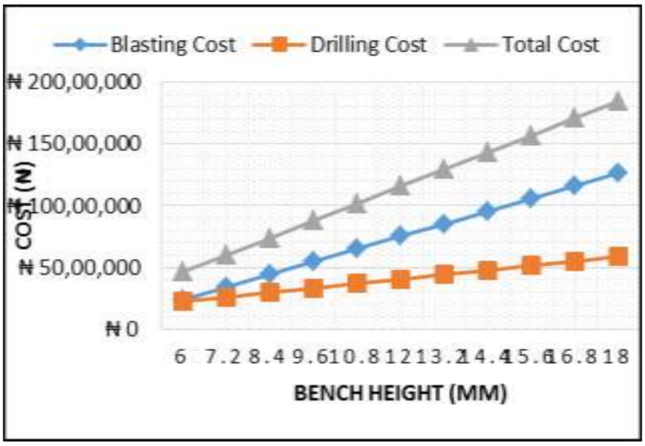

Figure 6: Relationship between Bench Height and Cost for Limestone

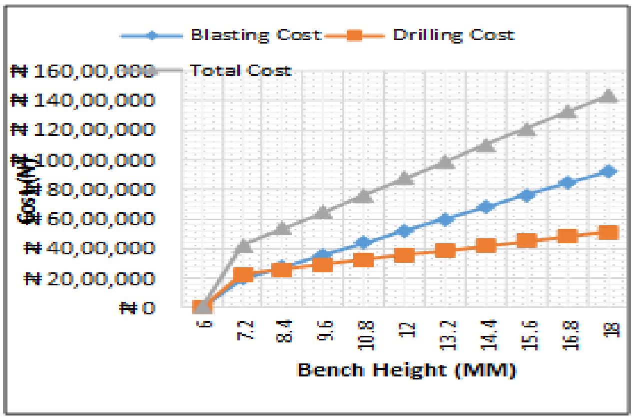

Figure 7: Relationship between Bench Height and Cost for Marble

Figures 5 to 7 show that increase in bench height cause an increase in both drilling and blasting cost.

Effect of Burden and Spacing on Cost

The burden and spacing used for each of the three rock types were flexed within the range ±50% while all other parameters remained constant. However, the number of holes required changed accordingly as the burden and spacing between the holes changed so as not to exceed the surface area earmarked for drilling and blasting. Figures 8 to 10 show the relationship between change in burden and consequent change in costs for granite, limestone and marble respectively.

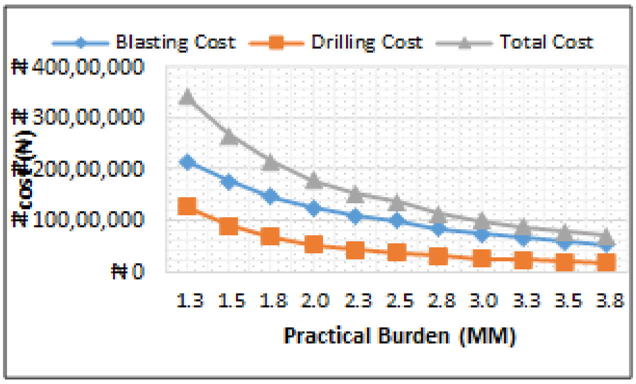

Figure 8: Relationship between practical burden and cost for granite

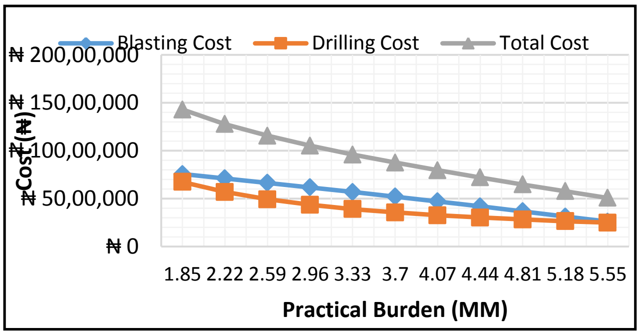

Figure 9: Relationship between practical burden and cost for limestone

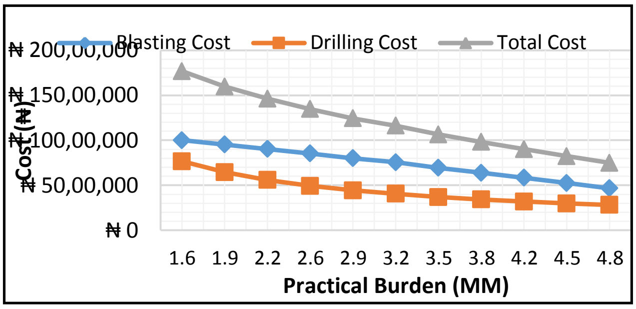

Figure 10: Relationship between practical burden and cost for marble

Figures 11 to 13 show a similar trend in the relationship between spacing and costs. It can thus be inferred that increase in burden causes a corresponding decrease in number of holes to be drilled and consequently a decrease in both drilling and blasting costs.

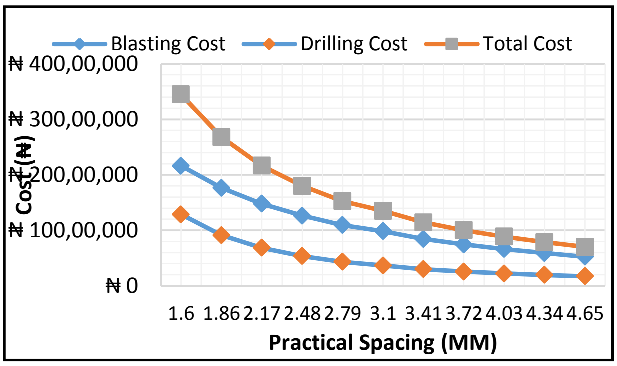

Figure 11: Relationship between practical spacing and cost for granite

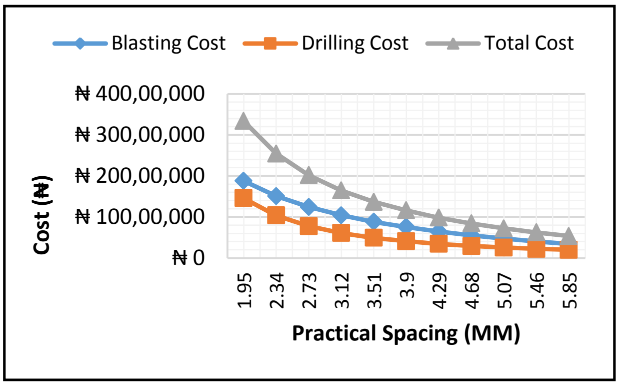

Figure 12: Relationship between practical spacing and cost for limestone

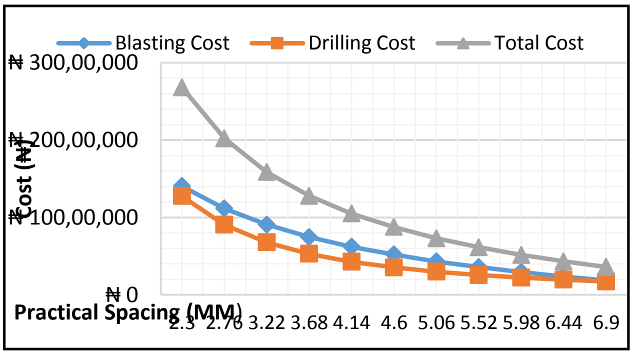

Figure 13: Relationship between practical spacing and cost for marble

It was also observed that the relationship between change in spacing and cost is similar to that between change in burden and cost. Similarly, the number of holes required changed accordingly as the spacing between the holes changed so as not to exceed the surface area earmarked for drilling and blasting. However, increasing spacing causes the degree of fragmentation to go from satisfactory to less satisfactory.

Optimum Cost

The optimum costs in the cases of the three rocks were observed to be dependent on the uniaxial compressive strength (UCS) of the rock. This is so because the strength properties of the rock determine the type of explosives, burden and spacing to be used to achieve the desired fragmentation at the optimum costs. Figures 14 to 16 show the optimum cost for each rock types.

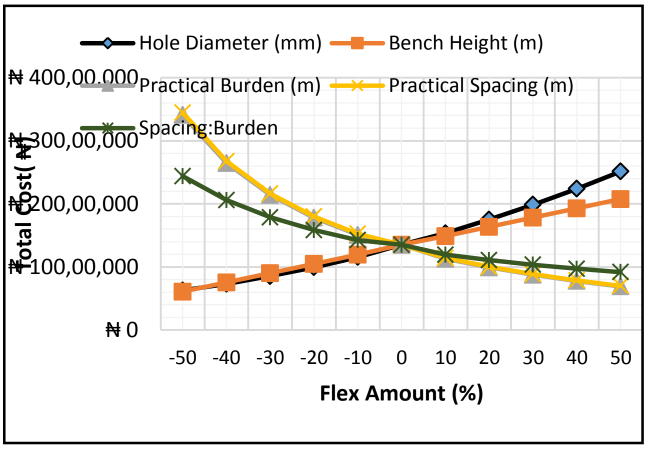

Figure 14: Optimum Cost Analysis for Granite

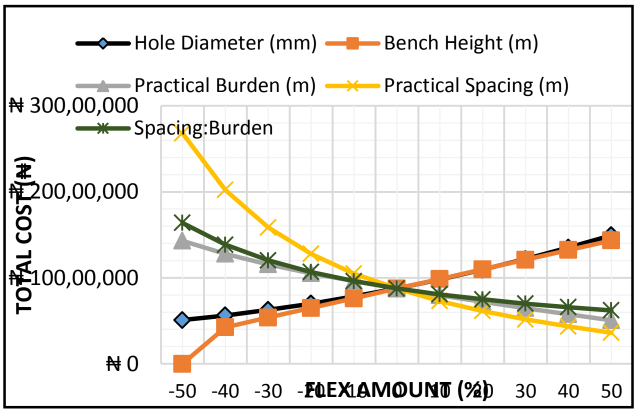

Figure 15: Optimum Cost Analysis for Limestone

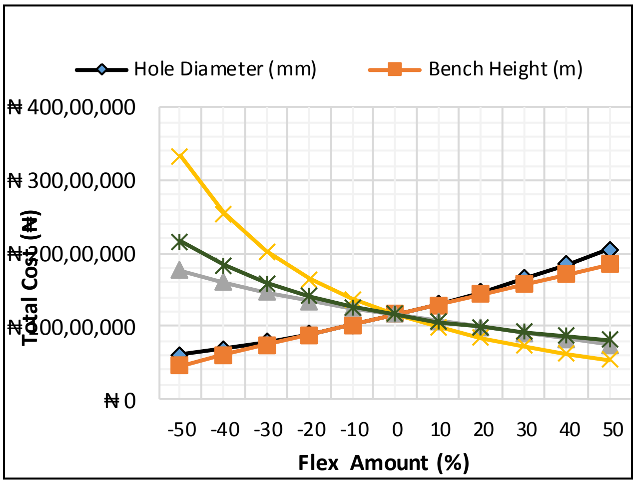

Figure 16: Optimum Cost Analysis for Marble

It can be observed from Figures 14 to 16 that the optimum cost increased from that of limestone being the lowest to that of granite being the highest. This is so because the strength properties of the rocks increase in that ascending order from limestone to granite. Figure 16 shows the bench height series falling to zero at bench height of -50% and this is so because the bench height at this point (6m) is not practically compatible with the other parameters.

V. CONCLUSION

In this study,the effects of changes of drilling and charging parameters, when the fragmentation output is specified, in three selected rocks which are granite, limestone and marbleare investigated. From the results of the analyses carried out on the selected rock samples, the following conclusions can be drawn:

(1) Julius Berger granite has the highest strength values while Ewekoro Type I has the least strength values as could be seen from the rock properties measured. The strength values have a significant effect on the drilling, blasting and the optimum cost.

(2) when hole diameter is increased, and all other parameters are kept constant, there is a corresponding increase in blasting cost and no significant change in drilling cost for all the three rock types provided the powder factor of 0.8 kg/m^3 is not exceeded;

(3) increase in bench height causes a corresponding increase in both drilling and blasting cost and that bench height limits the size of the charge diameter and the burden in a given blast design;

(4) increase in burden or spacing, decreases the number of holes to be drilled and consequently the amount of explosives needed to fill these holes which ultimately decreases the overall drilling and blasting cost and the degree of fragmentation from satisfactory to less satisfactory;

(5) The optimum drilling and blasting cost is dependent on the strength properties of a rock to be blasted such that the higher the strength of the rock, the higher the optimum cost required to achieve desired fragmentation.

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