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STRENGTH CHARACTERISTICS OF TWO NIGERIAN ROCKS

O. OJO and B. M. OLALEYE

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ABSTRACT

Supare granite deposit and Itakpe iron ore deposit of Nigeria were studied in order to evaluate their strength characteristics. Two types of tests were conducted: (i) the uniaxial compressive strength test and (ii) the point load strength and index test.

The results from the investigation show among others that (i) supare granite has a higher strength indices (ii) the effect of moisture on tensile and compressive strengths of Itakpe iron ore is greater than that of Supare granite (iii) drilling and blasting operations are the most appropriate excavation techniques for the two locations and (iv) economical blasting operation can be achieved at the two locations when the rock massif has a higher level of water saturation.

KeyWords: Strength, compression, point load, saturation.

INTRODUCTION

The strength characteristics of rocks are usually considered to be necessary for design of rock structures, stability of rock excavations and it also influence rock fragmentation in quarrying and working of mine rocks. However, the strength characteristics of rock do not only vary from rock to rock but also vary within the same rock mass because of the heterogenous nature of rocks and various local geological conditions. It also varies with seasons because of moisture effect on the mineral grains, Ojo and Brook (1990).

For many years, the uniaxial compressive test was the main quantitative method for characterizing the strength of rock materials, Hawkes and Mellor (1970). Strength test values are still the basis of many rock classifications. Coates and Parson (1966) and Miller (1965) have done the most extensive work on the classification of intact rock on the basis of laboratory determined values of the uniaxial compressive strength. They concluded that the compressive strength is determined on specimens with length-to-diameter ratio of at least 2.0 and that the rock is divided into one of five categories of strength which follow a geometric progression.

The work of Brady and Brown (1972) on the mechanical properties of rock were based on uniaxial and triaxial compressive strengths and point load strength test. They found out that Point load strength index (I_s) could be correlated with uniaxial compressive strength (C_o) of the rock. Franklin (1970) explained that uniaxial compressive strength and Point load strength are often closely correlated, the former usually being 20-25 times the later. However, since the ratio can vary in the range of 15-50 in exceptional cases, Pells (1975), the prediction of uniaxial compressive strength from point load strength is therefore unreliable. Point load strength is best used directly for rock classification rather than as a means of predicting uniaxial compressive strength. According to the International Society for rock Mechanics Commission on testing materials, ISRM (1981), the suggested method for determining uniaxial compressive strength, C_0 of rock is as given in equation (1).

$$C_o = \frac{P}{A} = \frac{4P}{\pi D^2} \text{ , MPa} \quad \text{......... (1)}$$

where C_o = uniaxial compressive strength, MPa.

P = applied peak load, kN.

A = cross-sectional area of the specimen, m^2.

The point load strength test in its role as an index test, is one member of the indirect tensile test family. It can also be used for the estimation of the direct tensile strength of rock materials. The standard point load strength, $I_s(50)$ is approximately 0.8 times the uniaxial tensile strength, Bieniawski (1975).

Broch and Franklin (1972) introduced an empirical relationship between uniaxial compressive strength, C_o and the point load strength reference index $I_s(50)$ as

O. OJO, Department of Minning Engineering, Federal University of Technology, Akure Nigeria
B. M. OLALEYE, Department of Mining Engineering, Federal University of Technology, Akure, Nigeria

$C_o = 24\, I_s(50)$ .... (2)

However, Bieniawski (1975) introduced a factor k to give

$C_o = kI_s$ .... (3)

where C_o = uniaxial compressive strength, MPa.

K = index-to-strength conversion factor and

I_s = point load strength index, MPa.

This was accompanied with a size correction graph for index-to-strength conversion against core diameter or platen separation. Although, this formula has been confirmed by Brook (1980), there are objections to the indiscriminate use of the factor 24 (Pells (1975); Read et al (1980) ; Hassani et al (1980) ; Greminger (1982) and Forster (1983) because of the various values of K obtained by some investigators across the globe (K = 22.7, Bieniawski (1975); K = 24, Brook (1980); K = 16, Read et al (1980) and K = 14.5, Forster (1983)).

In particular, Pells (1975) showed that a conversion factor of 24 can lead to 20% error in the prediction of the uniaxial compressive strength, C_o for certain types of rocks. Greminger (1982) and Forster (1983), also showed that the conversion factor of 24 can not be adequately applied to anisotropic rocks, since K actually depends on the degree of anisotropy of the rocks. Consequently, the recent work of Chau and Wong (1996) examined the applicability of Brock and Franklin's formula to Hong Kong rocks and studied analytically the conversion factor K relating C_o to $I_s(50)$. They concluded that their theoretical prediction for K (= 14.9) agrees better with the experimental observation for Hong Kong rock (K = 12.5) than the Brock and Franklin's conversion factor (K = 24). Thus Brock and Franklin's conversion factor of 24 should not be treated as a universal constant. To obtain the I_s value for a standard core diameter of 50mm, $I_s(50)$ value. Brook (1985) proposed equation (4)

$$I_s(50) = F \frac{P}{D^2} \quad \text{or} \quad F \times I_s \; .... \; (4)$$

where F = the size correction factor.

Based on the log-log graphs obtained by Brook (1982) and the shape and size correction factors obtained by Greminger (1982), an average expression of F was given by Brook (1985) as

$$F = \left(\frac{D_e}{50}\right)^{0.45} \; .... \; (5)$$

where D_e = equivalent core diameter, m

For tests near the standard 50mm size, very little error is introduced by using the approximate expression.

$$F = \frac{\sqrt{D_e}}{\sqrt{50}} \; .... \; (6)$$

MATERIAL AND METHODS

The samples used in this study were collected from different locations at Supare granite quarry and Itakpe iron ore mine in Nigeria.

Cylindrical core samples of diameters 32.6mm and 42.4mm having a height to diameter ratio that averages 2.19 and 2.64 for tensile and compressive strength tests were used. Forty samples from different locations in each of the mines were prepared to the standard suggested by ISRM for the strength tests. Test characterization testing and analysis were carried out on each of the rock samples prepared under air dried and fully water saturated conditions attainable after 4 days, Ojo and Brook (1990) at 9% and 25% relative water saturation for Supare granite and Itakpe iron ore respectively. Compression machine and Point Load Tester were used for the determination of the uniaxial compressive strength and tensile strength respectively. Ten samples air-dried and ten samples fully water saturated were tested from the two mines. In the point load test, the basic diametral test was performed on the core samples. The core sample was placed between the conical platen points in a way that allowed at least 0.5D as a free end after the longest axis had been measured. The loading diameter was read from the scale pointer and recorded. Load was then applied through the platens until failure occurred. Failure load and the final platen separation were recorded. Ten samples, air-dried and ten samples, fully water saturated were tested from the two mines. Since the samples tested did not have a diameter of 50mm, the point load indices were then corrected to standard strength indices as proposed by Brock and Franklin (1972).

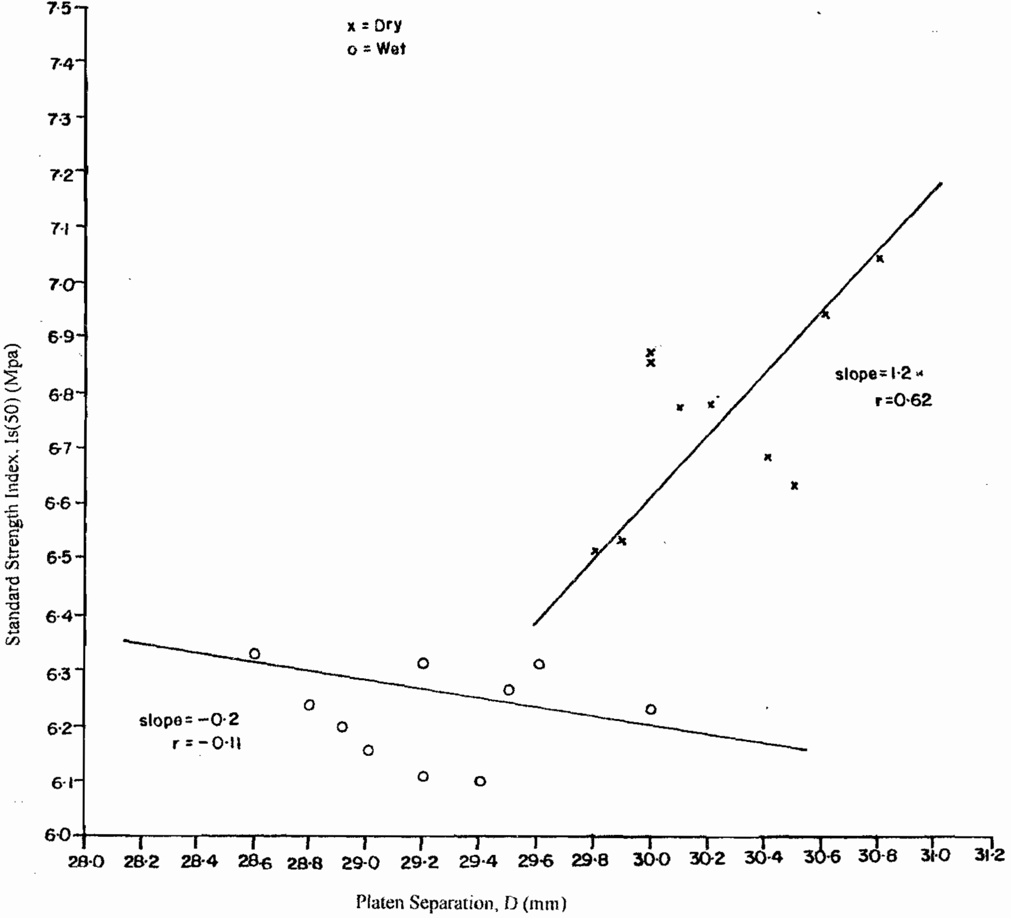

Fig. 1: Point Load Strength Index of Supare Granite After Size Correction

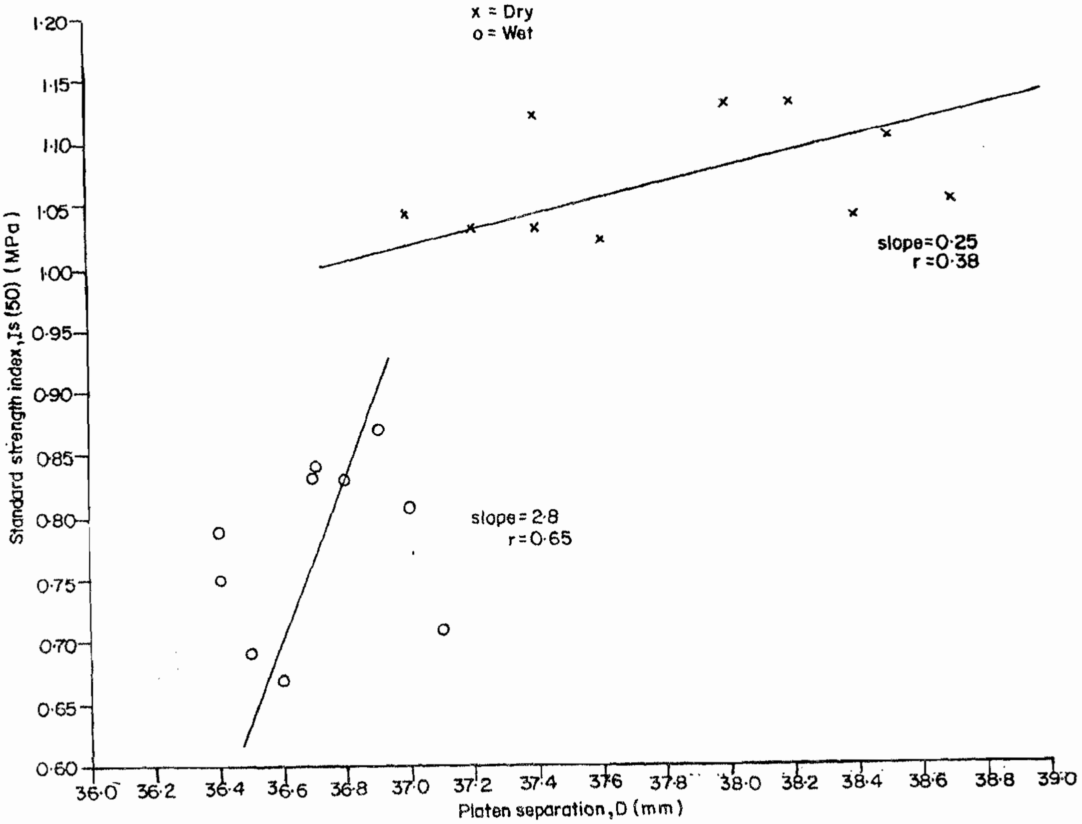

Fig. 2: Point load strength index of Itakpe Iron ore after size correction

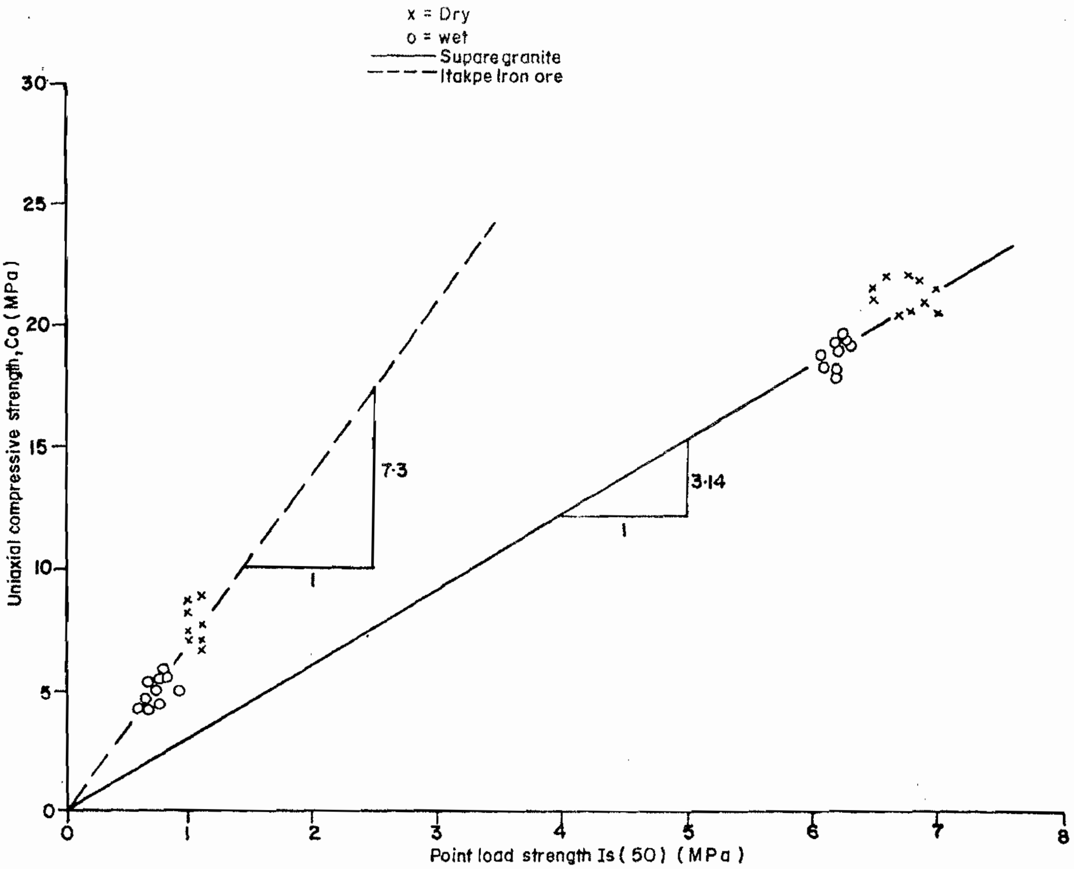

Fig. 3: The uniaxial compressive strength (Co) Vs the point load strength Is (50) for Supare granite and Itakpe Iron ore

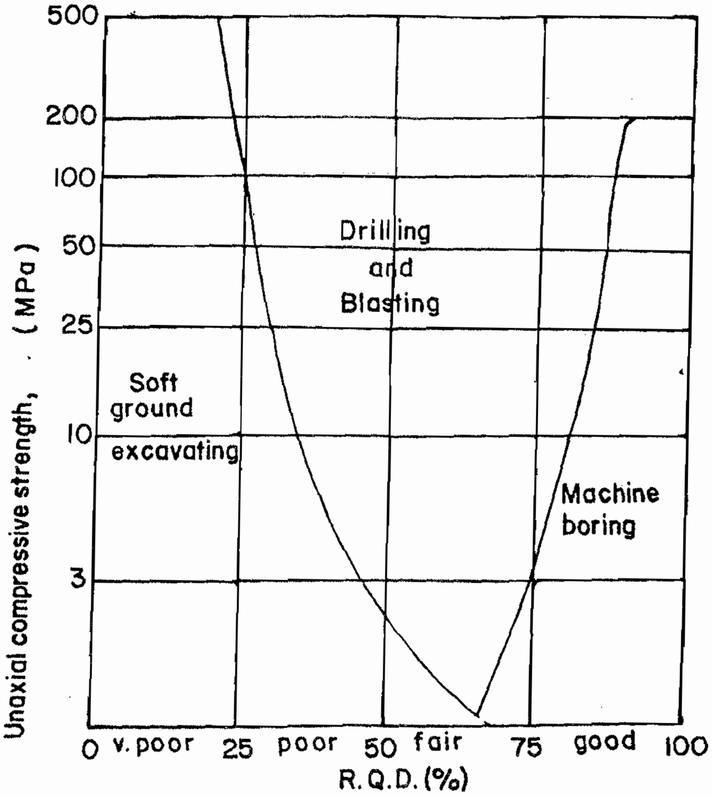

Fig. 4: Diagram of workability of rock.
(Muir-Wood, 1972)

Table 1: Uniaxial compression test and Tensile test results of air dried samples of Supare granite.

Specimen number	Uniaxial Compression Test			Tensile Test		
	Failure load (kN)	Cross sectional area (mm^2)	C_o (MPa)	Failure load (kN)	$I_s(50)$ (MPa)	% red. in sample dia.
1	18.2	830	21.93	8.5	6.64	6.44
2	17.8	835	21.32	9.01	7.04	5.52
3	17.9	835	21.44	8.42	6.54	8
4	18	830	21.69	8.8	6.87	7.98
5	16.8	835	20.12	8.62	6.69	6.46
6	17.6	835	21.08	8.35	6.52	8.59
7	18.3	835	21.92	8.74	6.79	7.08
8	17.8	835	21.32	8.9	6.95	6.13
9	17.1	835	20.48	8.68	6.78	7.67
10	17.4	835	20.48	8.84	6.86	7.69

Table 2 : Uniaxial compression test and Tensile test results of fully water saturated (9%) samples of Supare granite.

Specimen number	Uniaxial Compression Test			Tensile Test		
	Failure load (kN)	Cross sectional area (mm^2)	C_o (MPa)	Failure load (kN)	$I_s(50)$ (MPa)	% red. in sample dia.
1	15.4	835	18.44	7.8	6.11	10
2	15.2	835	18.2	8	6.24	11.4
3	15.8	835	18.92	8.1	6.31	8.92
4	16.6	835	19.16	8	6.23	7.98
5	15.6	830	18.68	7.9	6.16	11
6	16.1	835	19.4	8.1	6.33	12.3
7	15.9	835	19.04	8	6.31	10.4
8	15	835	18.32	7.9	6.1	9.54
9	14.9	830	17.95	8	6.2	11.1
10	15.7	835	18.8	8	6.27	9.51

RESULTS

Table 1-4 shows the uniaxial compressive strengths and point load strength indices of Supare granite and Itakpe iron ore under air-dried and fully water saturated conditions. Tables 5 and 6 are the classification of intact rocks based on uniaxial compressive strength and point load strength as suggested by ISRM (1981) and Bell (1992) respectively. Tables 7 and 8 shows the compressive strength classification and point load strength classification of Supare granite and Itakpe iron ore. Figures 1 and 2 depict the standard point load strength indices of Supare granite and Itakpe iron ore respectively. Figure 3 shows the relationship between

Table 3 : Uniaxial compression test and Tensile test results of air dried samples of Itakpe iron ore.

Specimen number	Uniaxial Compression Test			Tensile Test		
	Failure load (kN)	Cross-sectional area (mm²)	C_o (MPa)	Failure load (kN)	$I_s(50)$ (MPa)	% red. in sample dia.
1	10.2	1412	7.22	2	1.04	9.43
2	9.4	1412	6.66	2.2	1.13	9.91
3	11	1412	7.8	2.1	1.1	9.2
4	11.8	1405	8.4	2	1.02	11.3
5	10.6	1412	7.51	2	1.05	8.51
6	12.5	1405	8	2.2	1.12	11.8
7	11.8	1412	8.36	2	1.03	12.3
8	9.8	1412	6.94	2.2	1.13	10.1
9	10.6	1405	7.54	2	1.03	11.6
10	12.2	1412	8.64	2	1.04	12.7

Table 4 : Uniaxial compression test and Tensile test results of fully water saturated (25%) samples of Itakpe iron ore.

Specimen number	Uniaxial Compression Test			Tensile Test		
	Failure load (kN)	Cross-sectional area (mm²)	C_o (MPa)	Failure load (kN)	$I_s(50)$ (MPa)	% red. in sample dia.
1	6.8	1405	4.84	1.6	0.83	13.2
2	7.2	1412	5.1	1.52	0.79	14
3	7.6	1412	5.38	1.68	0.87	13.2
4	6.9	1412	4.89	1.34	0.69	13.9
5	8.2	1405	5.84	1.57	0.81	12.7
6	7.8	1412	5.52	1.62	0.84	13.2
7	6.4	1412	4.53	1.45	0.75	14.2
8	8	1405	5.7	1.38	0.71	12.5
9	6.7	1412	4.75	1.29	0.67	13.7
10	8.4	1412	5.95	1.6	0.83	13.2

Table 5 : Uniaxial compressive Strength Classification (ISRM)

Strength classification	Strength (MPa)
Low	under 6
Moderate	6 - 20
High	20 - 60
Very high	60 - 200
Extremely high	over 200

Table 6 : Point load strength classification (After Bell, 1992)

Strength classification	Point load strength index (MPa)
Very high strength	over 10
High strength	3-10
Medium strength	1-3
Low strength	0.3-1
Very low strength	0.1-0.3
Extremely low strength	under 0.1

Table 7 :Compressive strength classification of Supare granite and Itakpe iron ore

Location	Strength (MPa)		Strength classification	
	Air dried	Fully water saturated	Air dried	Fully water saturated
Supare granite	21.21	18.69	High	Moderate
Itakpe iron ore	7.80	5.25	Moderate	Low

Table 8 : Point load strength classification of Supare granite and Itakpe iron ore

Location	Strength (MPa)		Strength classification	
	Air dried	Fully water saturated.	Air dried	Fully water saturated
Supare granite	6.71	6.23	High	High
Itakpe iron ore	1.07	0.78	Medium	Low

Note: Figures haev been saved in the diskette as CorelDraw scanned Files Ojo1-4.

uniaxial compressive strength, C_o and the standard point load strength $I_s(50)$ for Supare granite and Itakpe iron ore while figure 4 is the graph of workability of rock as observed by Muir-wood (1972).

DISCUSSION

Series of standard point load strength indices and uniaxial compressive strength values have been obtained from samples of Supare granite and Itakpe iron ore. From tables 7 and 8, the mean compressive strength and mean standard point load strength of Supare ganite are higher than that of Itakpe iron ore. This is caused as a result of structural differences between the two rocks. The Itakpe iron ore is more foliated than Supare granite.

In figures 1 and 2, high and low slope values indicates proportional and unproportional increase in the two plotted parameters respectively. Also positive slope values depict increase in the two plotted parameters while negative slope values indicate increase in one parameter with decrease in the other parameter. Correlation coefficient, r, (either positive or negative) shows the degree of the mutual relationship between the plotted parameters. Therefore, a closer correlation between standard point load strength index and platen separation exist in the air-dried samples of Supare granite with correlation coefficient, $r = 0.62$ as compared to $r = 1$ for a perfect fit than Itakpe iron ore with $r = 0.38$ and vice versa for fully water saturated samples.

The reduction in sample diameter of Supare granite ranges mainly between 5.52% to 8.59% and 7.98% to 12.27% for air-dried and fully water saturated samples respectively while that of Itakpe iron ore ranges between 8.5% to 12.74% and 12.50% to 14.15% (tables 1 - 4). The reason for this relatively low range for Supare granite could probably be due to its medium grained texture which did not allow extreme penetration of the conical platens during testing. This is also an indication of hardness which implies that supare granite is of higher hardness. The air-dried samples of Supare granite were between 8% and 14% stronger than those tested in the fully water saturated condition while that of Itakpe iron ore were between 37% and 49% stronger than those tested in fully water saturated condition. The low percentage strength recorded between air-dried and fully water saturated samples of Supare granite was as a result of the grain texture of the sample which allows for minimal pore space, adequate cementation of the grain boundaries and consequently minimal water retention tendency.

It should be observed that the effect of moisture on tensile and compressive strengths of Itakpe iron ore is greater than that of Supare granite. This is due to the difference in the texture of the two rock samples, that is, the coarser the grains of the rock, the more the moisture effect. Generally the effect of moisture on tensile strength is greater than on compressive strength in all samples tested.

From field records, the Supare granite has a good core recovery with RQD between 75 - 80% while Itakpe iron ore has a fair core recovery with RQD between 55-60%. Therefore, the most appropriate excavation technique for the two locations is drilling and blasting (Fig. 4). The ratio of the compressive strength to tensile strength C_o/T_o of Supare granite is lower than that of Itakpe iron ore both at air-dried and fully water saturated conditions. Since a high value of C_o/T_o is essential for easy fragmentation process of mine rocks, therefore if the same drilling and blasting parameters were employed for both mines, it is obvious that improved rock fragmentation and economical blasting would be more achieved with Itakpe iron ore.

The results of the tests also shows that the rocks from the two locations produced consistent results with small standard deviations of 0.12 for Supare granite and 0.10 far Itakpe iron ore. This means that the result is of good quality and it is reproducible. From the experimental results for C_o and $I_s(50)$ (Fig. 3), since physically a zero $I_s(50)$ implies a zero C_o, the best fit line to pass through the origin is therefore required in the analysis, thus K is found to be 3.14 and 7.3 for Supare granite and Itakpe iron ore respectively.

CONCLUSION

The experimental results of Supare granite and Itakpe iron ore during uniaxial compression and point load tests under air-dried and fully water saturated conditions have been presented. These offers an original database necessary to assist the quarry and mine operators in their quarrying and mining activities. The mechanical behaviours characterized by the index tests of the rocks have been employed in the classification of the rocks as high and moderate strengths for Supare granite at air-dried and fully water saturated conditions respectively in compression while it is moderate and low strengths for Itakpe iron ore at air-dried and fully water saturated conditions respectively in tension.

The results of this study will also be of immense use in the construction industry, mining and foundation designing because the rocks in the two locations are widely utilized rocks with prospect for more utilization as national economic development progresses.

Since tensile and compressive strengths of rocks are usually considered to be necessary for the design of rock structures and stability of rock excavations, this work will in no small way serve as a reference before and during the excavation processes. The research has also foster more understanding of engineering characteristics of some Nigerians rocks.

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