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Correlation of Strength Properties of Limestone Deposit in Ogun State, Nigeria with Penetration Rate Using Linear Regression Analysis for Engineering Applications

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-ABSTRACT-

The research analyzed the correlation of strength properties of limestone deposit in ogun state, Nigeria with penetration rate using linear regression analysis for engineering applications. The research was conducted using the field data and rock samples collected from the two locations, [Sagamu (1) and Ewekoro (2)]. Field data were used for the determination of penetration rate while rock samples were used for the laboratory analysis. The average density and rebound hardness of samples from locations 1 and 2 as determined in the laboratory in order to estimate uniaxial compressive strength are 2.68g/cm^3, 32.3 and 2.71g/cm^3, 35.1 respectively. The result of Uniaxial Compressive Strength (UCS) as estimated from the correlation chart between average density and Schmidt hardness shows that location 1 has average strength of 61.8 MPa while location 2 has 72.4 MPa. The point load strength index for location 1 has an average value of 1.6 MPa and location2 has an average value of 1.8 MPa while the tensile strength as estimated from point load strength index for location 1 is 2.5 MPa and location 2 is 2.7 MPa. The penetration rate as determined from field data shows that location 1 has an average penetration rate of 0.7 m/min and location 2 has an average penetration rate of 1 m/min. The correlation between the strength properties and penetration rate for location 1 shows that there is a very strong relationship between penetration rate and uniaxial compressive strength, point load strength and tensile strength while location 2 shows that there is a strong relationship between penetration rate and uniaxial compressive strength and a moderate relationship between penetration rate, point load strength and tensile strength.

KEYWORDS *- Correlation, limestone, strength properties, penetration rate, regression analysis.*

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I. INTRODUCTION

Correlation is a statistical technique used to test the relationship between two variables (Aderoba, 1995). The variables is said to be correlated if an increase or decrease in one variable is accompanied by an increase or decrease in other variable. Rocks exhibit a vast range of properties which reflect vast varieties of structures fabric and compound, some basic properties measurements which are essential for describing rocks are physical and mechanical properties. However, the strength of a rock has an appreciable influence on drilling force required, therefore, to cause rock to break during drilling is a matter of applying sufficient force with a tool to exceed the strength of the rock (Hartman and Mutmansky, 2002). The behaviour of rock material under compression is important as the uniaxial compressive strength of intact rock is a basic parameter for rock classification and rock mass strength criteria. Therefore, the strength characteristics of rocks are usually considered to be necessary for the design of rock structures, stability of rock excavations as well as influence rock fragmentation in quarry and working of mine rocks (Ojo and Olaleye, 2002). Penetration rate is the progression of the drilling bit into the rock in a certain period of time which is generally expressed as “m/min” (Thuro, 1997). Predicting the penetration rate is very important in rocks drilling. The penetration rate is a necessary value for the cost estimation and the planning of mining project. Penetration rate has been known as the most effective parameter in determining the boundary between different rock types (Shahram, 2007). Penetration of a quarriable rocks is influenced by rock properties as well as machine parameters. Also, one key parameters have proved to be more valuable: the (net) drilling rate in meters per minute (drilling performance derived from the time of drilling one single borehole) (Thuro, 1997).

II. MATERIAL AND METHODS.

Location of the Study Areas

The study areas are Sagamu and Ewekoro designated as locations 1 and 2 in the study. The two locations are situated in Ogun State, Nigeria with coordinates of $6^{c}45^{'}$N and $3^{c}35^{'}$E for location 1 and $6^{c}35^{'}$N and $3^{c}12^{I}$E for location 2, (Figure 1). Ogun State is underlay by sedimentary and basement complex rocks. The sedimentary rock consists of Abeokuta formation lying directly above the basement complex. This is in turn overlaid by Ewekoro, Oshosun and Ilaro formation, which are all overlaid by the coastal plain of sand. The Sagamu and Ewekoro deposits are within the Ewekoro depression. The sedimentary rock in the south western Nigeria are part of those deposited within the Dahomey embayment which extends from the Volta Ghana through the Republic of Benin to Okitipupa ridge. The Sagamu formation is a massive bioclassic paleocene carbonate rock exposed in Sagamu and Ewekoro areas in the continental margins of the Gulf of Guinea that extends from southern Benin republic to south western Nigeria.

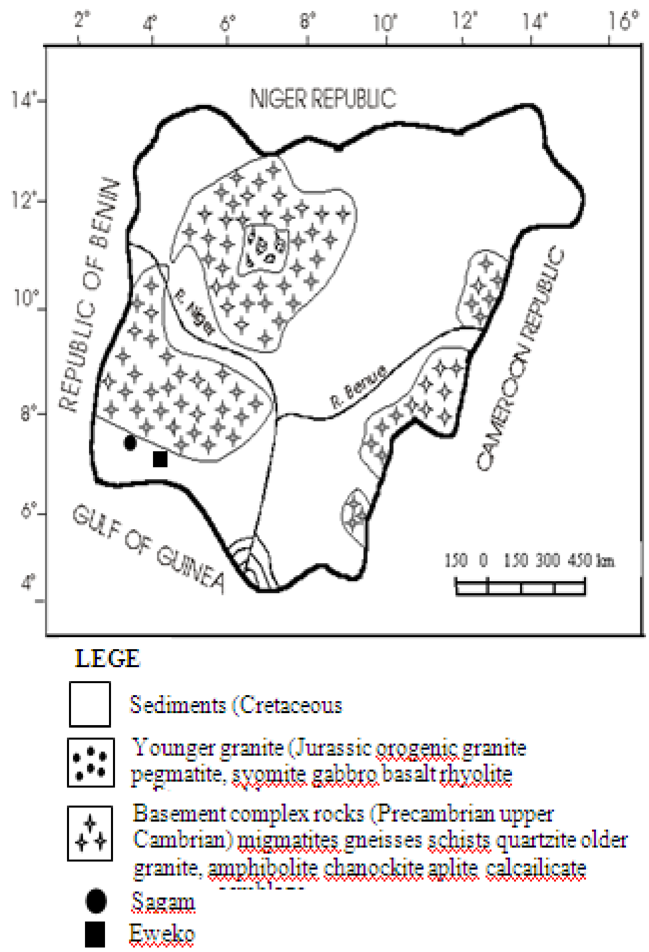

FIGURE 1: Simplified geological map of Nigeria showing the study locations

Determination of Density

Five in-situ rock samples from each from the locations were collected, weighed and recorded. The determination of the density (ρ) was carried out according to the procedures suggested by ISRM (1989) using equation 1 and the results obtained are presented in Tables 1 and 2.

$$\rho = {}^{M}/_{\Delta V}\,(g/cm^3) \qquad (1)$$

where M is the mass (g) and V is the volume (cm^3)

Determination of 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. The procedures followed the standard suggested by ISRM (1989) and the results presented in Tables 1 and 2.

Determination of Uniaxial Compressive Strength

The Schmidt hammer was first used on the samples to determine the rebound number. The values obtained were arranged then correlated using Deere and Miller (1966) chart to determine the uniaxial compressive strength of the rock. The results obtained are presented in Tables 1 and 2.

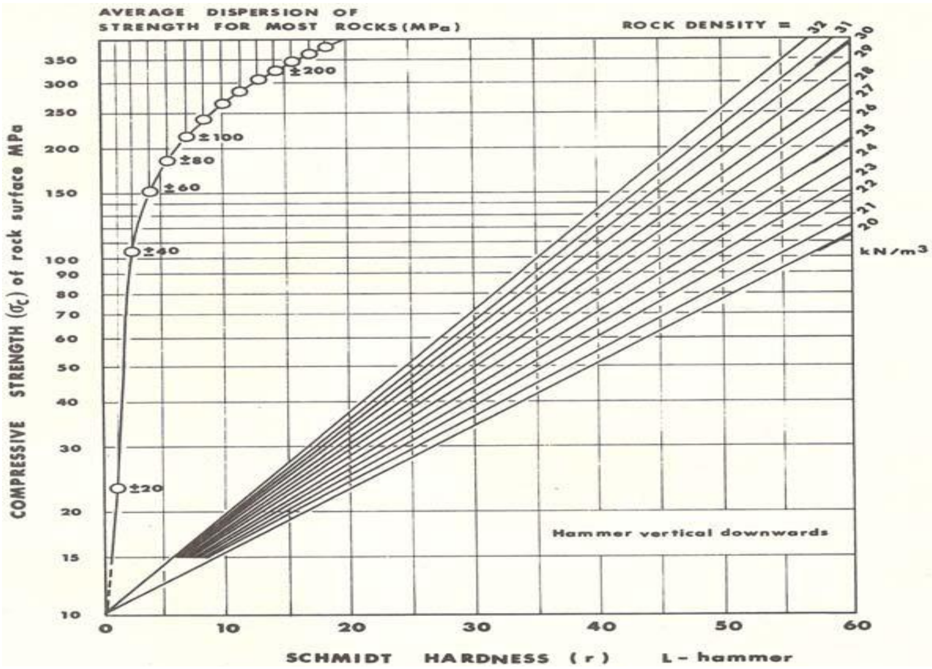

Figure 2: Correlation chart for Schmidt (L) hammer, relating rock density, compressive strength and rebound number (After Deere and Miller, 1966).

Determination of Point Load Strength

The point load strength values were determined in accordance the procedures suggested by ISRM (1985) using equations 3-6.

$$I_s = {}^{P}/_{D_e{}^2} \quad (3)$$

where I_s is the point load strength index (MPa), P is the failure load (KN) and D_e is the equivalent diameter (mm).

$$D_e{}^2 = \frac{4A}{\pi} = \frac{4DW}{\pi} \quad (4)$$

where D is the distance between load contact points (mm), W is the width of the sample (mm) and A is the minimum cross-sectional area of the loading points.

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

where F is the correction factor.

$$I_{S(50)} = FI_S \qquad (6)$$

where $I_{S(50)}$ is the corrected point load strength index.

The results obtained are presented in Tables 1 and 2.

Determination of Tensile Strength

The tensile strength of the rock samples was estimated based on the relationship suggested by Brook (1993) and ISRM (1989) which shows the general relationship between the point load strength (I_s) and the tensile strength (T_o) as expressed in equation 7 and the results presented in Tables 1 and 2.

$$T_o = 1.5I_{s50} \qquad (7)$$

Determination of Penetration Rate

The penetration rate was determined at each location of the deposits. The penetration rate was determined from the equation 8 according to Thuro, (1997).

$$\text{Penetration rate} = \frac{\text{borehole depth}}{\text{net drilling time}}\ (\text{m/min}) \qquad (8)$$

III. RESULTS AND DISCUSSION

Table 1: Experimental Results of Strength Properties of Samples from Location 1

Rock code	Density (g/cm^3)	Rebound Hardness	Point Load Strength (MPa)	Tensile Strength (MPa)	Uniaxial Compressive Strength (MPa)	Penetration Rate (m/min)
S1	2.75	33.7	2.185	3.278	63.6	0.60
S2	2.70	32.3	2.061	3.092	63.5	0.64
S3	2.68	32.3	1.604	2.406	61.9	0.69
S4	2.64	32.2	1.241	1.862	60.4	0.75
S5	2.64	32.1	1.104	1.656	59.4	0.81

Table 2: Experimental Results of Strength Properties of Samples from Location 2

Rock code	Density (g/cm^3)	Rebound Hardness	Point Load Strength (MPa)	Tensile Strength (MPa)	Uniaxial Compressive Strength (MPa)	Penetration Rate (m/min)
E1	2.75	36.4	3.363	5.045	77.2	0.75
E2	2.75	36.4	1.609	2.414	75.5	0.83
E3	2.70	34.8	1.453	2.180	74.8	0.94
E4	2.70	34.0	1.238	1.857	70.8	1.10
E5	2.64	34.0	1.194	1.791	63.7	1.15

The uniaxial compressive strength of the samples was estimated from the chart named after Deere and Miller, (1966). The uniaxial compressive strength of location 1 varies from 59.4 MPa to 63.6 MPa as shown in Table 1. The strength classification is of moderate to high strength. The uniaxial compressive of location 2 samples varies from 63.7 MPa to 77.2 MPa as shown in the Table 2. The strength classification is of high strength. The point load strength index is obtained from the laboratory results are shown in Tables 1 and 2. The point load strength index for location 1 samples varies from 1.104 MPa to 2.185 MPa and that of location 2 samples varies from 1.194 MPa to 3.363 MPa. The strength classifications fall within the range of moderate to high strength class. The tensile strength is obtained from point load strength and the results are shown in Tables 1 and 2. The values location 1 samples range from 1.656 MPa to 3.278 MPa. The tensile strength values for location 2 samples range from 1.791 MPa to 5.045 MPa.The penetration rate was taken on the field and it varies from 0.61m/min to 0.81m/min for location 1 as shown in Table 1. The value for location 2 samples ranges from

0.75m/min to 1.15m/min as shown in Table 2.Penetration rate of samples were correlated with rock properties using method of least squares regressions. The equations of best-fit lines and correlation coefficients R^2 were generated for each regression. More importantly, rock samples with higher strength proportions recorded lower penetration values.Figure 3 establishes the relationship between penetration rate and uniaxial compressive strength for location 1. The relationship between penetration rate and compressive strength is as shown in Equation 9;

$PR = -0.044C_o + 3.450$, $R^2 = 0.973$. (9)

where PR = penetration rate (m/min) and C_o = compressive strength (MPa).

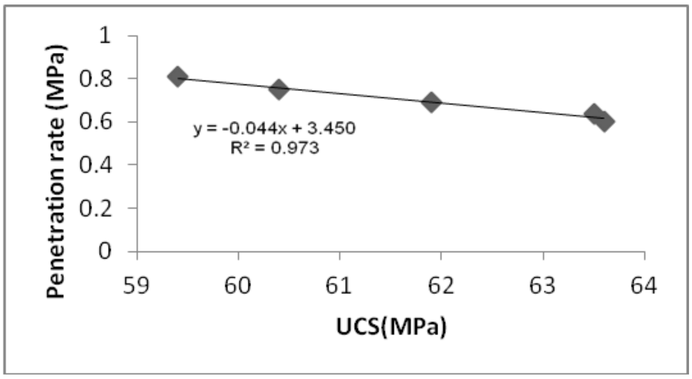

Figure 3: Penetration Rate against Uniaxial Compressive Strength (1).

Figure 4 shows the plot of penetration rate against uniaxial compressive strength of location 2.

$PR = -0.028C_o + 3.024$, $R^2 = 0.815$ (10)

where PR = penetration rate (m/min) and C_o = compressive strength (MPa).

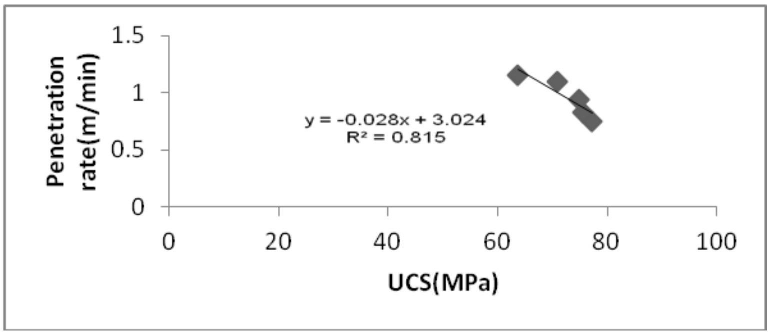

Figure 4: Penetration Rate against Uniaxial Compressive Strength (2).

Figure 5 establishes a relationship between penetration rate and point load strength index for location 1, the relationship is as shown in equation 11;

$PR = -0.1717I_s + 0.9794$, R^2=0.9612 (11)

where PR = penetration rate (m/min) and I_s= point load strength index (MPa).

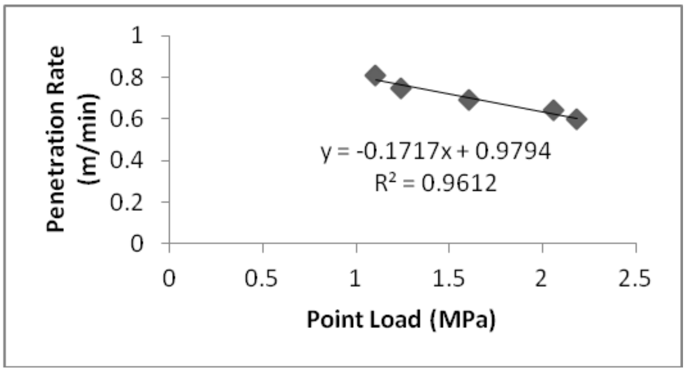

Figure 5: Penetration Rate against Point Load Strength Index (1).

Figure 6 established a relationship between penetration rate and point load strength index for location 2 and the relationship that exist is shown in Equation 12.

$PR = -0.1498I_s + 1.2193,$ R^2=0.6292 (12)

where PR = penetration rate (m/min) and I_s= point load strength index (MPa).

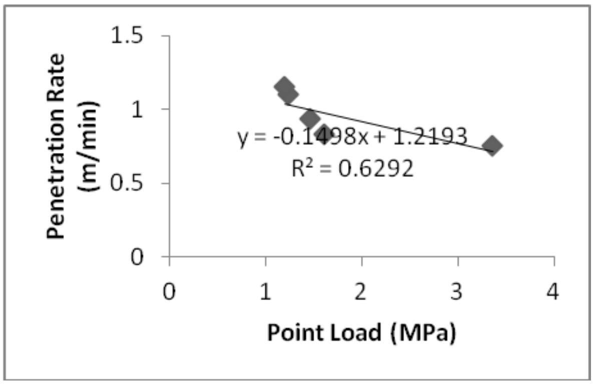

Figure 6: Penetration Rate against Point Load Strength Index (2).

Figure 7 shows a plot of penetration rate against tensile strength for location 1 and the relationship is shown in Equation 13;

$PR = -0.114T_o + 0.9794,$ R^2 = 0.9613 (13)

where PR = penetration rate (m/min) and T_o= tensile strength (MPa).

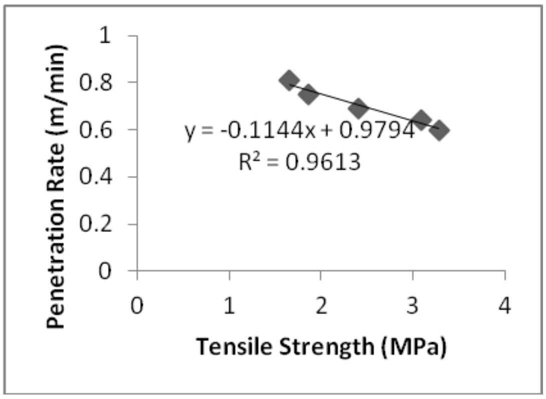

Figure 7: Penetration Rate against Tensile Strength (1).

Figure 8 shows a plot of penetration rate against tensile strength for location 2, the relationship is as shown in Equation 14;

$$PR = -0.0999T_o + 1.2194, \quad R^2=0.6294. \tag{14}$$

where PR = penetration rate (m/min) and T_o= tensile strength (MPa).

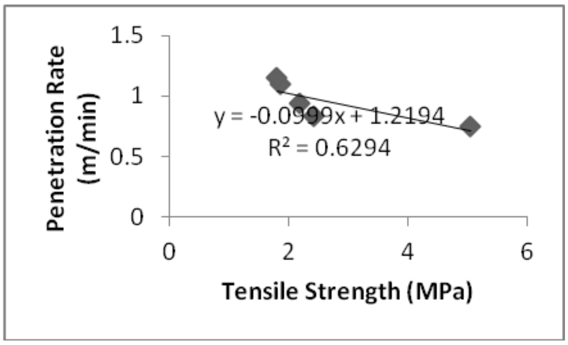

Figure 8: Penetration Rate against Tensile Strength (2).

IV. CONCLUSIONS

This study analysed the strength properties of limestone samples from two locations [Sagamu (1) and Ewekoro (2)] and correlate the selected strength properties with penetration rate using linear regression analysis. The work revealed the various levels of the rock characteristics and their degree of competence which make them suitable for engineering applications. The correlation between the strength properties and penetration rate for location 1 shows that there is a very strong relationship between penetration rate and uniaxial compressive strength, point load strength and tensile strength while location 2 shows that there is a strong relationship between penetration rate and uniaxial compressive strength and a moderate relationship between penetration rate, point load strength and tensile strength. This research will aid quarry and mine operators to know the formation characteristics and select appropriate tools for their operations and also in planning and management.

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