IOSR Journal of Engineering (IOSRJEN)
e-ISSN: 2250-3021, **p**-ISSN: 2278-8719
Vol. 3, Issue 7 (July. 2013), ||V1 || PP 25-30

Characterization of Some Selected Limestone Deposits in ogun State, Nigeria for Prediction of Penetration Rate of Drilling

Okewale I.A[1], Olaleye B.M[2]
[1]Department of Mining Engineering, School of Engineering and Engineering Technology, The Federal University of Technology, Akure, Nigeria.
[2]Department of Mining Engineering, School of Engineering and Engineering Technology, The Federal University of Technology, Akure, Nigeria.

Abstract: - The research correlated physical and mechanical properties with penetration rate of drilling in some typical limestone quarries in Ogun State, Nigeria. The work was carried out using the field data and rock samples collected from the two locations [Sagamu (A) and Ewekoro (B)]. Field data were used for the determination of penetration rate while rock samples were used for the laboratory analysis. The result of modal analysis from the thin section shows that sample A has the mineralogical composition of 79.5% calcite, 13.5% quartz and 7.0% opaque while sample B has 77.5% calcite, 17.0% quartz and 5.5% opaque. The average density, porosity and rebound hardness of samples from locations A and B as determined in the laboratory are 2.68g/cm^3, 3.08%, 32.3 and 2.71g/cm^3, 3.06%, 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 A has average strength of 61.8 MPa while B has 72.4 MPa. The point load strength index for location A has an average value of 1.6 MPa and B has an average value of 1.8 MPa while the tensile strength as estimated from point load strength index for A is 2.5 MPa and B is 2.7 MPa. The penetration rate as determined from field data shows that location A has an average penetration rate of 0.7 m/min and location B has an average penetration rate of 1 m/min. Statistical model was developed using Statistical Package for Social Sciences (SPSS) software and the result shows that there is a strong correlation between penetration rate and porosity, rebound hardness value and density. The result also shows that the porosity, rebound hardness value and UCS have negative influence on penetration rate while density has positive influence on penetration rate.

Keywords: - *Characterization, limestone, physical properties, strength properties, correlation, penetration rate.*

I. INTRODUCTION

Rock properties are essential for the prediction of penetration rate when drilling and boring tools are employed in a quarry, (Adebayo and Agbalajobi, 2009). 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. Drilling and blasting play a vital roles in open cast mining, these operations do not affect the cost of production directly but the overall operational cost (Busuyi, 2009). The penetration rate and the economics of the blast holes opened during the development and production activities in underground and open pit mines and dams, tunnels and road construction play a crucial role. Therefore, prediction of the penetration rate is a necessary value for the cost estimation and the planning of the project. Penetration rate mainly depends on operational variables and rock characteristics. Operational variables are known as controllable parameters: rotational speed, thrust, blow frequency and flushing. However, rock properties and geological conditions are uncontrollable parameters, (Mc Gregor, 1967; Beste *et al.*, 2007). Penetration rate is the progression of the drilling into the rock in a certain period of time which is generally expressed as “m/min”. According to the factors that affect penetration rate, penetration rate can be classified as changeable and unchangeable factors. Fast and economic penetration depends on the mineralogical structure of the rock, drilling machine, geo-mechanical characteristics and choice of drilling tools appropriate to the rock, (Onan and Muftuoglu, 1993). Performances of a drilling operation are dependent on technical characteristics of the drilling, drillability of rock and work organization. First of all, rocks characteristics are to be chosen accordingly. It is very important that pressure, torque, rotation speed and impact frequency called operational parameters should be applied according to formation characteristics. In addition to them, if work organization is designed carefully, maximum performance of the drilling machine can be achieved, (Kahraman and Mulazimoglu, 1999).

II. MATERIALS AND METHODS

2.1 Location of the Study Areas

The study areas are Sagamu and Ewekoro designated as locations A and B in the study. The two locations are situated in Ogun State, Nigeria with coordinates of 6°45'N and 3°35'E for location A and 6°35'N and 3°12^{I}E for location B, (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

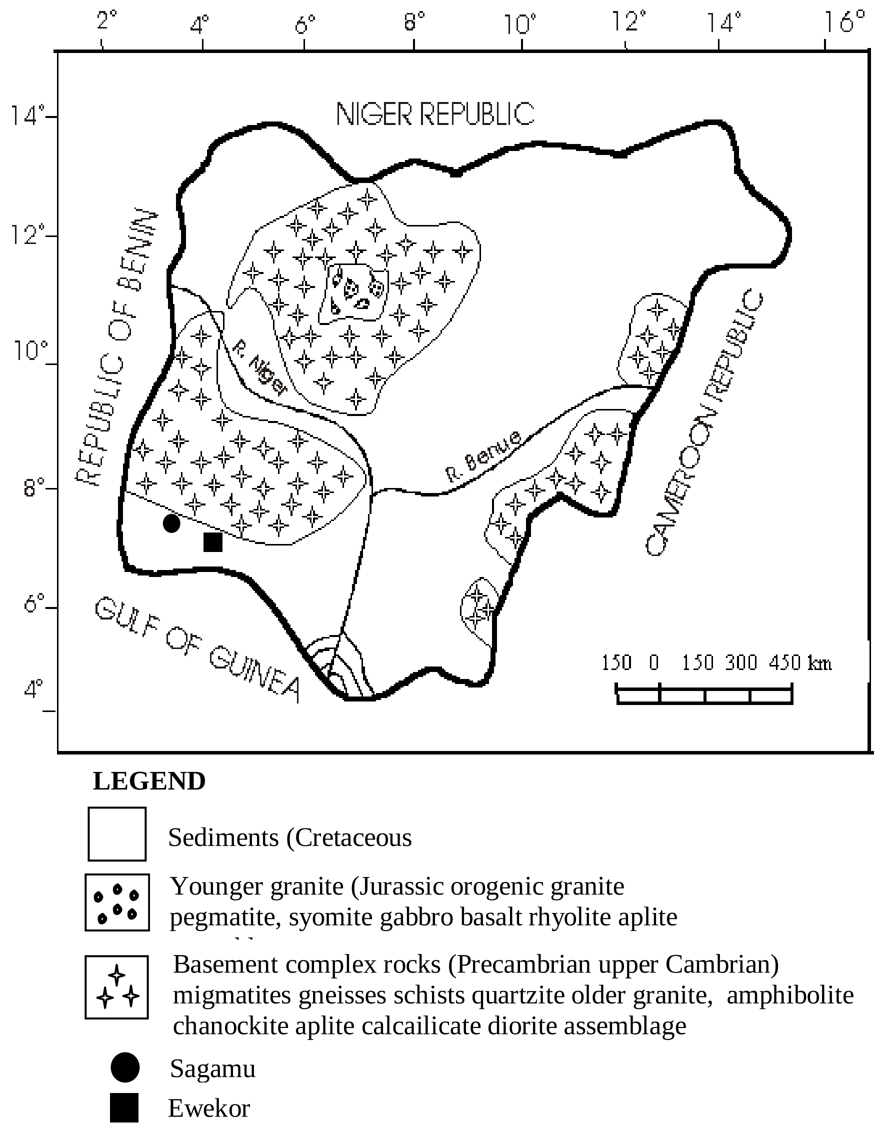


FIGURE 1: Simplified geological map of Nigeria showing the study locations

2.2 Mineralogical Analysis

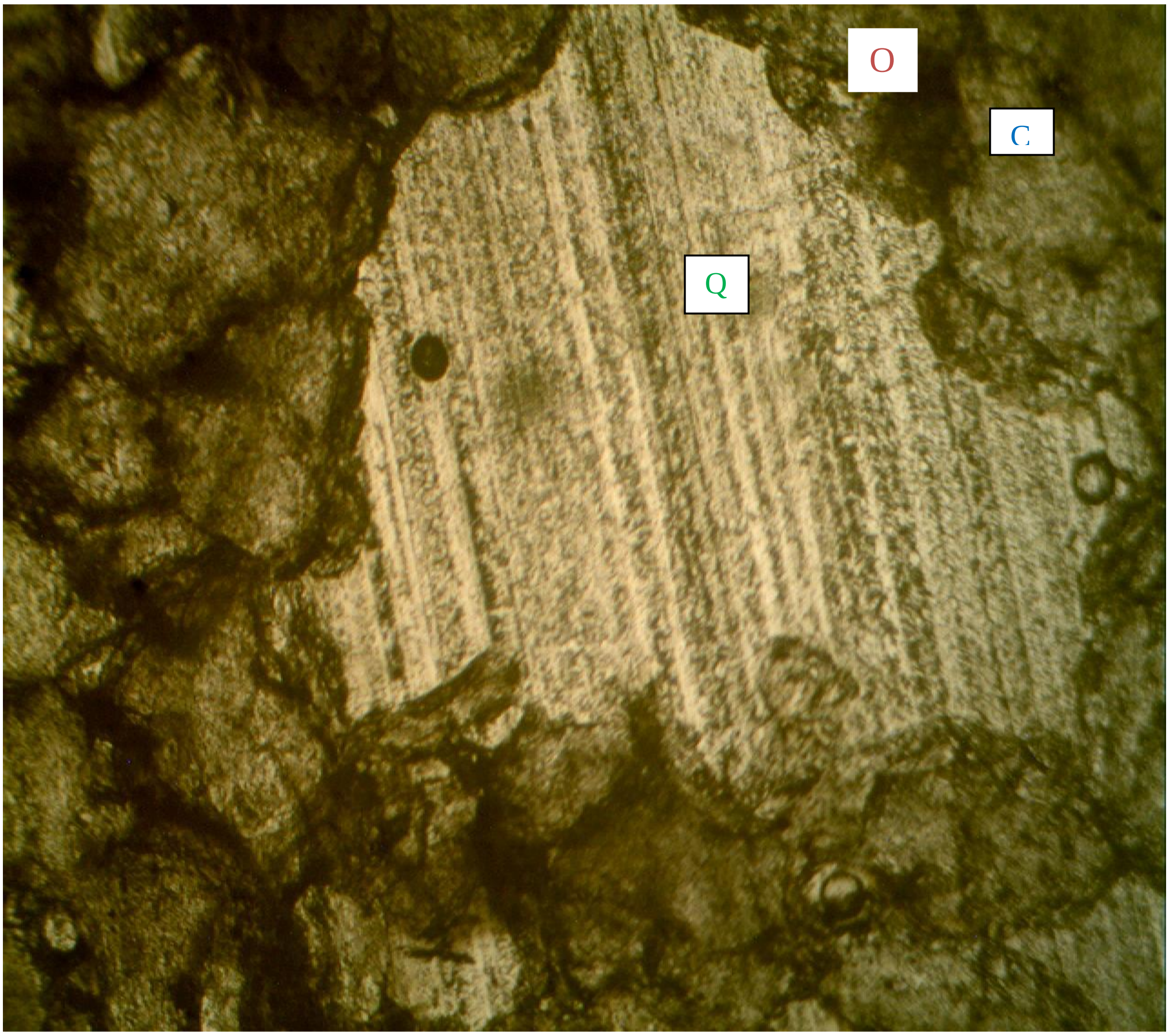
The laboratory work involved preparation of thin section of the samples, study of the thin section under the microscope and taken the photomicrograph of the samples. The procedures for thin section preparation are: impregnating, cutting, trimming, grinding, lapping, mounting, further grinding, lapping, further trimming, covering, washing, drying and labelling. The slides were then carefully studied under microscope to identify the mineralogical composition of the samples. The modal analysis technique was used to estimate the percentage of each mineral present in the samples. The modal analysis (Tables 1 and 2) of the samples involve taking three different count of each mineral from different part of the slide and adding all the count to calculate the percentage of each mineral present in the rock sample. Also, photomicrographs of the slides were taken to show features of geological interest as shown in Figures 2 and 3.

Tables 1: Modal Analysis of Samples from Location A

Mineral Present	1st Count	2nd Count	3rd Count	Total	Percentage (%)
Calcite	40	47	37	124	79.5
Quartz	5	6	9	21	13.5
Opaque	3	4	4	11	7.0
Ground Total				156	100

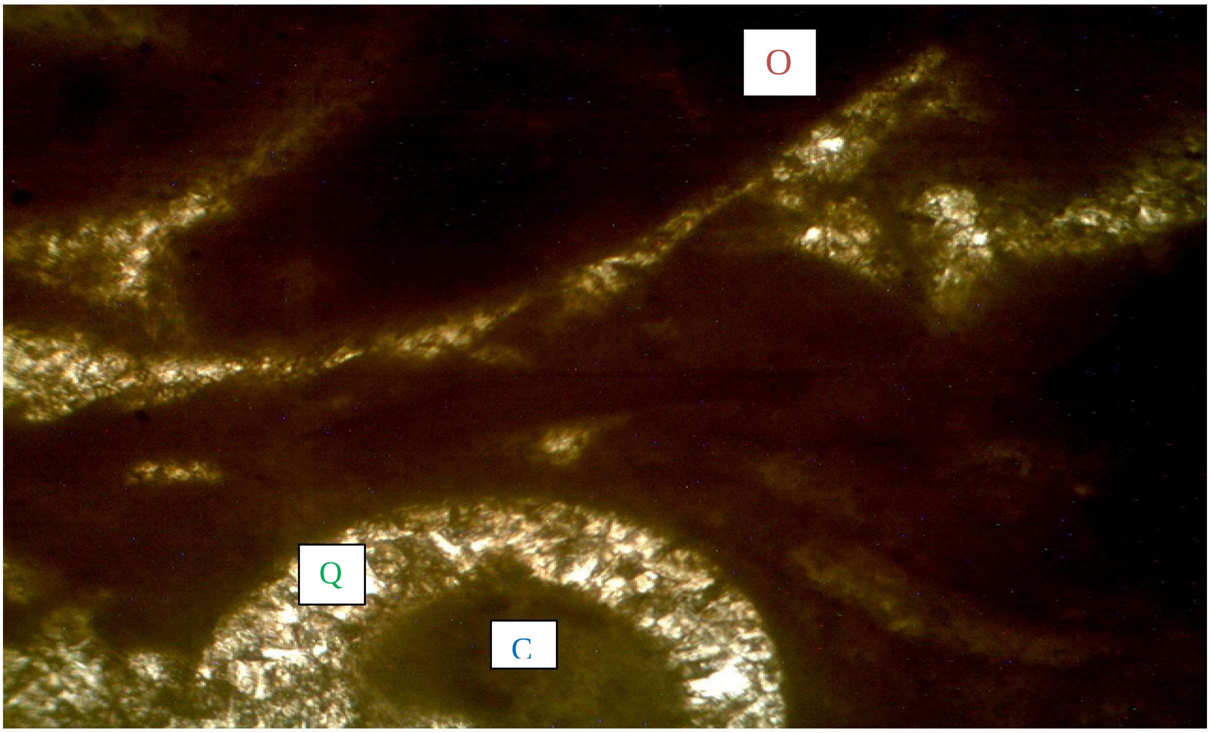
Tables 2: Modal Analysis of Samples from Location B

Mineral Present	1st Count	2nd Count	3rd Count	Total	Percentage (%)
Calcite	40	40	37	117	77.5
Quartz	6	8	12	26	17.0
Opaque	2	2	4	8	5.5
Ground Total				151	100



C – Calcite, Q - Quartz, O- Opaque

Figure 2: Location A Sample Photomicrograph



C – Calcite, Q - Quartz, O- Opaque
Figure 3: Location B Sample Photomicrograph

2.3 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 3 and 4.

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

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

2.4 Determination of Porosity
The saturation and buoyancy technique for determination of porosity (Φ) of irregular rock samples was adopted using equation 2.

$$\text{Porosity, } \Phi = \frac{100 V_v}{V}\% \qquad (2)$$

where V_V is the volume of void (cm^3) and V is the total volume (cm^3)
The experimental procedures followed the standard suggested by ISRM (1989) and ASTM (2001). The results of the porosity of the rock samples from the two locations are presented in Tables 3 and 4 respectively.

2.5 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 3 and 4.

2.6 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 3 and 4.

2.7Determination of Point Load Strength
The point load strength values were determined in accordance the procedures suggested by ISRM (1985) using equations 3-6.

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

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

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

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.

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

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 3 and 4.

2.8 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 3 and 4.

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

2.9 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).

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

Table 3: Experimental Results of physical and Strength Properties of Samples from Location A

Rock code	Density (g/cm^3)	Porosity (%)	Rebound Hardness	Point Load Strength (MPa)	Tensile Strength (MPa)	Uniaxial Compressive Strength (MPa)	Penetration Rate (m/min)
SA01	2.75	3.2	33.7	2.185	3.278	63.6	0.60
SA02	2.70	3.1	32.3	2.061	3.092	63.5	0.64
SA03	2.68	3.8	32.3	1.604	2.406	61.9	0.69
SA04	2.64	2.7	32.2	1.241	1.862	60.4	0.75
SA05	2.64	2.6	32.1	1.104	1.656	59.4	0.81

Table 4: Experimental Results of physical and Strength Properties of Samples from Location B

Rock code	Density (g/cm^3)	Porosity (%)	Rebound Hardness	Point Load Strength (MPa)	Tensile Strength (MPa)	Uniaxial Compressive Strength (MPa)	Penetration Rate (m/min)
EW01	2.75	3.20	36.4	3.363	5.045	77.2	0.75
EW02	2.75	3.20	36.4	1.609	2.414	75.5	0.83
EW03	2.70	2.80	34.8	1.453	2.180	74.8	0.94
EW04	2.70	3.40	34.0	1.238	1.857	70.8	1.10
EW05	2.64	2.70	34.0	1.194	1.791	63.7	1.15

III. RESULTS AND DISCUSSION

The density and porosity of samples from location A varies from $2.64g/cm^3$ to $2.75g/cm^3$ and 2.60% to 3.80% as shown in Table 3 and that of location B ranges from $2.64g/cm^3$ to $2.75g/cm^3$ and 2.7% to 3.4% as shown in Table 4. The result revealed that sample from location B is less porous as compared to location A. The Schmidt hammer rebound number of samples from location A varies from 32.1 to 33.2 and location B from 34.0 to 36.4 (Tables 3 and 4).The uniaxial compressive strength of the samples was estimated from the chart named after Deere and Miller, (1966). The uniaxial compressive strength of samples from location A varies from 59.4 MPa to 63.6 MPa thereby classifying the rock as moderate to high strength while that of location B ranges from 63.7 MPa to 77.2 MPa making the rock to be classified as high strength. The point load strength index is obtained from the laboratory results (Tables 3 and 4) and varies from 1.104 MPa to 2.185 MPa for location A and 1.194 MPa to 3.363 MPa for location B. The strength classifications fall within the range of moderate to high strength class. Also, the tensile strength, obtained from point load strength ranges from 1.656 MPa to 3.278 MPa and 1.791 MPa to 5.045 MPa for locations A and B respectively.

The penetration rate of drilling was determined on the field and varies from 0.61m/min to 0.81m/min and 0.75m/min to 1.15m/min for locations A and B respectively. They are both classified as having a low penetration. Penetration rates of drilling of the rock 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.

3.1 Discussion Of The Statistical Model

Statistical analysis was carried out on the determined variables (density, porosity, Schmidt rebound hardness, uniaxial compressive strength, point load, tensile strength and penetration rate). Penetration rate (PR) was a dependent variable while density (ρ), porosity ($\emptyset$), Schmidt rebound hardness (RN), uniaxial compressive strength (σ_C), point load (Is), tensile strength (To) were independent variables. The regression coefficient R^2 is almost unity, which means that the input parameters make significant contribution to the models except point load and tensile strength which are automatically removed from the model. Equations 9 and 10 show the mathematical forms of the generated model for Sagamu and Ewekoro respectively.

$$PR = 3.102 + 1.075\rho - 0.017\emptyset - 0.062RN - 0.052\sigma_c \quad (9)$$

$$PR = -10.501 + 8.985\rho - 0.364\emptyset - 0.238RN - 0.047\sigma_C \quad (10)$$

IV. CONCLUSION

This study analysed the characteristics of limestone samples from two locations [Sagamu (A) and Ewekoro (B)] and the correlation of the selected physical and strength properties with penetration rate. The work revealed the various levels of the rock characteristics and their degree of competence. It also showed that if these properties are determined in similar locations, penetration rate of drilling of the rock can be predicted from the established regression equations provided that similar drilling equipment is employed. The research will be useful for mine and quarry operators in planning and management of mines particularly in the area of equipment and tools selection; and their compatibility with formation characteristics.

REFERENCES

[1]. Adebayo, B., and Agbalajobi, S. A, Correlation of Rock Properties with Rotary DrillPenetration Rate in Limestone Quarry. *Nigerian Mining Journal, 7(1), 2009, pp 1-9.*

[2]. Busuyi, A.T., Optimization of Drilling and Blasting Operations in an Open Pit Mine,*the SOMAIR experience Min. Sc. Tech. 19(6), 2009, pp. 736-739*

[3]. Mc. Gregor, K,. *The Drilling of Rock* (London: C.R. Books Limited, 1967)

[4]. Beste U., Jacobsein S., and Hogmark S., Rock Penetration into Cemented CarbideDrill Buttons during Rock Drilling Wear, *264, 2007, pp 1142-1151*

[5]. Onan, M. and Muftuoglu, Y.V., A Study of Drill Parameters and Penetration RatesRelationships in Gelik-44 borehole. *13th Mining Congress, Turkey*. 1993, pp. 221-234

[6]. Kahraman, S. and Mulazimoglu, A. (1999): The Performance Analysis of Drill Rigs used inConstruction of Pozauli- Tarsus Crossing Motor Way- Madencilik; 38(2-3): pp 31-35.

[7]. ISRM, *Rock Characterization, Testing on Monitoring. In: Brown, E.T. (edited)ISRM suggested Methods.* Pergamon Press, Oxford, UK, 1989, pp. 211.

[8]. ASTM, *Standard Test Method for Determination of Rock Hardness by ReboundHammer Method. Designation D5873,* American Society for Testing and Materials (ASTM)International, West Conshohocken, PA, USA. 2001

[9]. ISRM, Suggested Method for Determining Point Load Strength *Int. J Rock Mech.Min. Sci. Geomech. Abstr. 22(2), 1985, pp. 51-60*

[10]. Deere, D. V., and Miller, R. P., *Engineering Classification and Index Properties forIntact Rock,* University of Illinois, U.S. Department of Commerce National, TechnicalInformation Service. 1966

[11]. Brook N., *The Measurement and Estimation of Basic Rock Strength,* In Hudson, J(Ed.- in-Chief): Comprehensive Rock Engineering, Principle Practice, and Projects, vol. 3:Rock Testing and Site Characterization, Oxford Pergamon, 1993, pp 41-81.

[12]. Thuro, K. (1997): Drillability Prediction: Geological Influences in Hard Rock Drill andBlast Tunnelling. *Geologische Rundschau, 86(2), 1997, 426-38*