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Prediction of Uniaxial Compressive Strength of Granite Rock Samples of Lugoba Quarry Using Rebound Hammer Test

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ABSTRACT

Rebound hammer test is widely used as an indirect measure of uniaxial compressive strength for engineering materials such as concrete, soil, and rock in both civil and mining engineering works. In quarries, uniaxial compressive strength is a crucial parameter in the analysis of geotechnical problems involving rock stability and rock blasting design. This study aims at establishing the empirical models of uniaxial compressive strength fits on rebound hammer number that can be used to predict uniaxial compressive strength of granitic rock at Lugoba Quarry. Data for direct uniaxial compressive strength were obtained from uniaxial compressive strength test carried out on 20 core samples at the Dar es Salaam Institute of Technology Geotechnical Laboratory using ISMR Standard Procedures. The rebound hammer test was carried out using testing hammer type N. The tests were done horizontally on two scanline's geotechnical domains of the rock mass on the footwall side of the quarry. The obtained results of UCS ranging from 105 to 132.5 MPa and RHN from 44.90 to 49.5 were found to be comparable with values of other granitic rocks in other parts of the world. Regression Analysis using SPSS software was carried out to develop 5 regression models of UCS vs.RHN. The values of R^2 obtained in this study were found to be between 0.93 and 0.95, which are comparable with other studies. This implies that RHN accounted between 93 and 95% of the total variation of the UCS and the relationships were very strong. Two models; Logarithmic and exponential were found to be appropriate and recommended for application at Lugoba Quarry.

Keywords: *Uniaxial compressive strength, Rebound hammer number, Granitic rock, Regression model.*

INTRODUCTION

Lugoba quarries located 120 km from Dar es Salaam (Figure 1) are the main sources of granite aggregates used in ordinary and strategic civil and road construction works in the city of Dar es Salaam (Twiga Cement Company, 2014). With a

population of more than 6 million people, the annual growth rate of 5% and construction growth rate of 12% (United Nations, 2019; Kikwasi and Escalante, 2020), Dar es Salaam city is expected to consume more aggregates from Lugoba quarries due to its (Lugoba) proximity to the city and the quality of the granite.

Uniaxial compressive strength is one of the key geotechnical parameters affecting the quality of both intact rock and rock mass characteristics for various intended uses such as rock fragmentation, excavation, construction and rock stability. Furthermore, design of rock fragmentation machinery, evaluation of excavatability,

rippability and blastability of rock mass, selection of primary rock fragmentation methods and achieving rock stability for excavations requires Uniaxial Compressive Strength (UCS) as a primary input parameter (Bewick *et al.*, 2015; Hack, 1998; Laubscher, 1990).

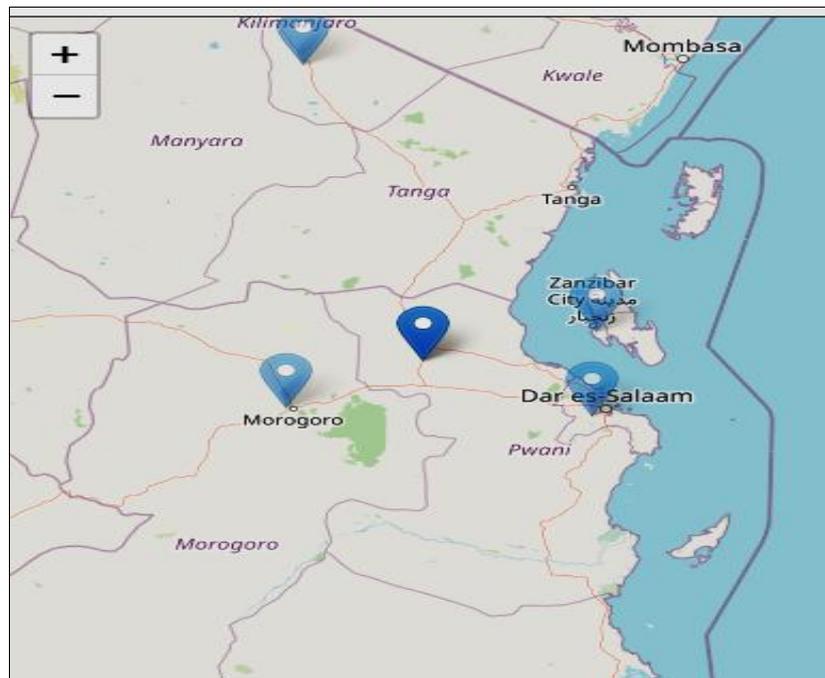


Figure 1: Location Map of Lugoba and Dar es Salaam

Both direct and indirect method can be used to obtain UCS in different situations. Direct method - uniaxial compressive test carried out in the laboratory, apart from being expensive and time consuming, is also destructive and not always practical especially in highly weathered rock samples. On the other hand, indirect method such as rebound hammer test using rebound Schmidt hammer, Brazilian test, point load and field estimation methods are less expensive, less time consuming and non-destructive. They are more useful in prediction of uniaxial compressive strength of intact rock and rock mass (Kahraman, 2001).

The rebound hammer or Schmidt hammer test is one of the mostly widely used non-destructive testing for uniaxial

compressive strength estimation in mining. Literature related to prediction of uniaxial compressive strength using rebound hammer test is increasing since publication of Schmidt and Miller (Miller, 1965). Since that application of rebound hammer test using Schmidt hammer is increasingly used as alternative method of estimating UCS (Cobanoglu and Celik, 2008). Rebound number is an indicator of surface hardness of the sample. In civil and construction, non-destructive testing is widely employed for evaluating the quality of the concrete in the finished structures (Katz *et al.*, 2000). In testing using rebound hammer, the hammer yields there bound number which gives an indication of the strength of the material being tested, for the rebound hammer test to be used; a typical regression model of UCS versus

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RHN established using data obtained from field tests is normally used. Compressive strength of a rock material may be defined as the capacity of the rock to withstand loads tending to reduce size under compression (Deere and Miller, 1966), and is regarded as an index that can be used to test rock material for identification and classification (Shalabi *et al.*, 2007).

Numerous studies have attempted to determine UCS and RHN values for granite. Available data indicate that granite is considered as one of the strong and competent rocks that break with one firm blow from hammer end of geological pick.

The UCS values ranges between 100 and 200 MPa while RHN (N-type) varies between 50 and 60 (Goudie, 2006; Selby, 1993). Other studies such as Hoek and Brown (1980) and Hoek *et al.* (1992) considered 95 MPa as minimum and 230 MPa as maximum while 160 MPa is taken as an average. Other studies indicate that UCS values for granite rock lies between 100 and 250 MPa. Other UCS values for granites obtained from other studies may be summarized in Table 1. Similarly, studies on RHN values for granite from a few studies as summarized by Goudie (2006) and adopted in this study are given in Table 2.

Table 1: Some UCS values of Granite from Selected Studies

Researcher	UCS value (MPa)
Stillborg (1986)	100-200
Sundara (2009)	115.6
Amadei (2000); Johnson and DeGraff (1988)	181.7
ISRM (1978)	136.32
Singh <i>et al.</i> (1983)	119.78 – 136.32
Quane and Russell (2003)	138.59

Table 2: Some RHN Values of Granite from Selected Studies

Researcher	Granite Sampling Location	Mean value of RHN
Ericson (2004)	Sierra Nevada, USA	48-53
Katz <i>et al.</i> (2000)	Mt Scott granite, Oklahoma	73.4
Ericson (2004)	Sweden	55-56
Brook <i>et al.</i> (2004)	Scotland (Cairngorms granite)	66.5
Day and Goudie (1977)	Shap, UK	59.4- 61.1
Goudie (2006)	Namibia (Salem granite)	59.4
Kahraman <i>et al.</i> (2004)	Turkey	55.7 – 62.5

The most popular formula correlating UCS and RHN is that of Miller known as Miller’s correlation formula $UCS (MPa) = 12.83 e^{0.047RHN}$. However, Wang *et al.* (2016) admits that the most evident attribute of empirical correlation is that the fitting relationship varies in different rock types and also exhibit variation for similar type of rock. The empirical relationships between UCS and RHN for granite and non-granite are in the forms of linear, exponential, power,

quadratic and natural logarithm as shown in Table 3. The values of R squared in the table indicate very strong relationships between UCS and RHN. It is evident that the empirical correlations for the same rock type could be different for different samples coming from different locations. For example, the linear relationship models provided by Vasconcelos *et al.* (2007) and Tugrul and Zarif (1999) for granite samples were different since the samples were from different locations.

Thus, the main objective of this paper is to develop regression models of UCS vs. RHN based on data from Lugoba quarries that can be used to predict UCS at Lugoba quarries and other areas with similar rock

characteristics. Such regression models have not been established and the existing ones cannot predict UCS of granite samples from Lugoba quarries with high accuracies.

Table 3: Various Forms of Empirical Relationships of UCS and RHN for Various Rocks

No	Researcher	Empirical relations	R ²	Rock type	Form of relationship
1	Shalabi <i>et al.</i> (2007)	$UCS = 3.20RHN - 46.59$	0.76	Shale, anhydrite, dolomite	Linear equation
2	Dincer <i>et al.</i> (2004)	$UCS = 2.75 RHN - 36.83$	0.95	Andesite, basalts and tuffs	Linear equation
3	Saptonoet <i>et al.</i> (2013)	$UCS = 0.308RHN^{1.327}$	0.9	Coal bearing strata	Power function
4	Nazir <i>et al.</i> (2013)	$UCS = 12.83e^{0.0487RHN}$	0.91	Limestone	Exponential equation
5	Torobi <i>et al.</i> (2010)	$UCS = 0.0465RHN^2 - 0.175$	0.86	Roof rock of coal mine	Quadratic equation
6	Vasconcelos <i>et al.</i> , (2007)	$UCS = 12.24RHN - 739.94$	0.83	Granite	Linear equation
7	Kats <i>et al.</i> (2000)	$UCS = 0.00013RHN^{3.09074}$	0.99	Granite	Power function
8	Tugrul and Zarif (1999)	$UCS = 8.36RHN - 416.00$	0.87	Granite	Linear equation
9	Aydin and Basu (2005)	$UCS = 1.45e^{(0.07RHN)}$	0.92	Granite	Exponential equation
10	Dearman and Irfan (1978)	$UCS = 1.6 \times 10^{-4} RHN^{3.47}$	0.94	Granite	Power function

MATERIALS AND METHODS

Determination of UCS for granite from Lugoba Quarry is based on the hypothesis that mathematical relations between RHN and UCS exist. Based on these mathematical relations RHN can be used to predict UCS.

Model Formulation

The models are in the form of linear, power, exponential, quadratic, and natural logarithm shown in equations (1) to (5).

Linear model
 $UCS = aRHN + b \dots \dots \dots (1)$

Power model
 $UCS = aRHN^a \dots \dots \dots (2)$

Exponential model
 $UCS = aRHN e^b \dots \dots \dots (3)$

Quadratic model
 $UCS = aRHN^2 + bRHN + c \dots \dots \dots (4)$

Natural logarithmic model
 $UCS = a \ln RHN(b) \dots \dots \dots (5)$

Where **a**, **b** and **c** are the regression coefficients to be estimated in the regression analysis and **RHN**- rebound hammer number.

Laboratory Test for Determination of UCS

Uniaxial compressive tests comprising a total number of 20 granite core samples (A-T) were carried out at the DIT Laboratory using procedures suggested by ISRM (1978) and Aydin (2008). The samples were collected from designated scanlines at Lugoba Quarry. The samples from drill cores were prepared by cutting them in such a way that the

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lengths/diameter ratios were between the recommended ratios of 2 to 3.

A cylindrical core sample was loaded axially with no support until failure occurred. The maximum value of the axial stress was recorded as load. The uniaxial compressive strength of a sample was then calculated using equation (6).

$$UCS = \frac{\text{Load (kN)}}{\text{Area (m}^2\text{)}} \dots \dots \dots (6)$$

Laboratory Test for Determination of RHN

The 20 core samples were used for rebound hammer test using Schmidt hammer (N-type). For each sample, 15 rebound tests were undertaken at different points on the core surface to have rebound numbers. The tests were performed vertically downward in relation to the surface position and in accordance with the ASTM (2001). The average rebound numbers were calculated for each sample and results entered in Table 5. Before the tests, the rebound hammer was calibrated using concrete cubes of 150 mm side length. The cube was fixed in a heavy compression machine with a force of 40 kN. Rebound hammer was applied on two cube sides with 12 rebound numbers readings distributed on both sides. Cubes were then crushed to obtain compressive strength, the relationship between rebound number and compressive strength was established. The validation of the curve was carried out based on several concrete cube tests performed at the University of Dar es Salaam Structural Laboratory. Validation of results was consistence and appropriate for application of the rebound hammer in this study.

RESULTS AND DISCUSSION

The laboratory results for UCS and RHN are given in Table 4 and 5, respectively and a summary given in Table 6. As seen

in Table 6, the mean value of UCS for granite samples obtained from laboratory test was 119.89 MPa. This is comparable with the values (95 – 250 MPa) of other granite from other parts of the world. However, the mean value of RHN was 47.16 which was considered slightly lower than the values (50 – 60) of other granite from other parts of the world.

Model Validation

Existing models were first validated using RHN and UCS data obtained from laboratory before qualifying them for application at Lugoba. Four models namely Vasconcelos *et al.* (2007); Kats *et al.* (2000); Tugrul and Zarif (1999) and Aydin and Basu (2005) were picked from Table 3 for this purpose. RHN data were plugged in each model and errors calculated based on equation (7). Table 7 provides validation results.

$$\text{Error in UCS} = \frac{(\text{Lab UCS} - \text{Model UCS}) * 100\%}{\text{Lab UCS}} \dots \dots \dots (7)$$

It could be observed that the existing models can predict UCS for Lugoba granite samples with a minimum mean error between ±43% for Aydin and Basu (2005) and the maximum error of ±238% for Vasconseloe *et al.* (2007). These errors were considered too high for the models to be used at Lugoba quarries. However, they provide an avenue for the establishment of new models at Lugoba quarries.

Regression Analysis

In the regression analysis using SPSS software, UCS was selected as dependent variable while RHN was an independent variable. A curve estimation fit was selected since it allows fitting of one form of the five models at a time. Therefore, linear, logarithmic, quadratic, power, and exponential were fitted to generate mathematical models.

obtained by other researchers shown in Table 3.

Discussion of Regression Analysis and Models

Model summary for the 5 regression analyses of UCS versus RHN as obtained from SPSS outputs were reported in Table 8 and provides the basis for discussion. The values of R^2 for the 5 models were found to be between 0.93 and 0.95 indicating that RHN accounted between 93% and 95% of the total variation of the UCS. This implies that RHN significantly predicted UCS and the relationships were very strong with values of F very much greater than 1 and $p < 0.01$. The obtained values of R^2 are comparable with those

Regression coefficients of the five models are the unstandardized coefficients B of the RHN and constants B. Quadratic model was the only model with coefficient c which however, was not found significant and therefore was not reported in the Table. The table, further, shows: In Quadratic Model, RHN was not significantly predicting UCS, $t(19) = 1.270, p > 0.05$ and also constant $t(19) = 1.279, p > 0.05$. In Power Model, RHN was significantly predicting UCS, $t(19) = 15.908, p < 0.01$, however, constant was not, $t(19) = -1.967, p > 0.05$.

Established models:

- **Linear Model:** RHN was significantly predicting UCS, $t(19) = 16.609, p < .01$ and also the constant, $t(19) = -8.639, p < .01$.
 $UCS = 5.301N - 130.00 \dots \dots \dots (8)$
- **Logarithmic Model:** RHN was significantly predicting UCS, $t(19) = 16.818, p < .01$ and also constant, $t(1) = -14.726, p < .01$
 $UCS = 250.21 \ln N - 844.15 \dots \dots \dots (9)$
- **Exponential Model:** RHN was significantly predicting UCS, $t(19) = 15.38, p < .01$ and also constant, $t(19) = -7.456, p < .01$
 $UCS = 14.70e^{0.044N} \dots \dots \dots (10)$

Table 4: UCS Test Results for Granite Rock Samples

Sample ID	Length (m)	Diameter (m)	Area (m ²)	Load (kN)	UCS (MPa)
A	0.092	0.0445	0.00156	181.33	116.24
B	0.094	0.0445	0.00156	139.00	89.10
C	0.092	0.0445	0.00156	103.90	66.60
D	0.093	0.0445	0.00156	170.00	108.97
E	0.092	0.0445	0.00156	142.09	91.08
F	0.092	0.0445	0.00156	132.32	84.82
G	0.093	0.0445	0.00156	109.65	70.29
H	0.094	0.0445	0.00156	149.41	95.78
I	0.093	0.0445	0.00156	190.08	121.85
J	0.092	0.0445	0.00156	100.07	64.15
K	0.093	0.0445	0.00156	190.78	122.29
L	0.094	0.0445	0.00156	123.09	78.90
M	0.092	0.0445	0.00156	183.32	117.51
N	0.092	0.0445	0.00156	135.89	87.11
O	0.093	0.0445	0.00156	187.62	120.27
P	0.092	0.0445	0.00156	194.07	124.40
Q	0.094	0.0445	0.00156	164.79	105.63
R	0.094	0.0445	0.00156	121.10	77.63
S	0.093	0.0445	0.00156	101.76	65.23
T	0.092	0.0445	0.00156	130.34	83.55

Table 5: RHN Test Results for Granite Samples

Sample ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average Rebound Number
A	49	34	45	50	37	40	48	46	40	54	57	46	48	46	53	46.0
B	51	58	55	32	49	49	40	34	50	56	48	44	47	53	50	46.5
C	48	41	45	44	46	44	45	47	44	38	46	45	49	44	48	44.9
D	45	40	45	49	49	50	51	53	53	50	48	49	47	47	47	45.0
E	51	49	50	45	43	51	50	48	49	40	40	43	43	42	49	46.2
F	42	50	52	44	50	43	49	50	49	38	49	47	45	44	43	46.0
G	48	42	44	42	46	50	50	40	43	44	50	56	50	49	40	46.9
H	48	40	50	47	50	47	49	42	47	50	50	50	51	50	54	45.5
I	43	48	49	49	46	47	46	50	44	45	42	49	48	40	49	46.0
J	45	47	51	52	49	48	47	50	52	52	54	47	50	50	49	49.5
K	50	46	48	47	51	49	40	39	42	42	48	47	50	49	47	47.0
L	52	50	49	40	45	44	43	45	49	44	50	50	52	54	49	47.6
M	47	47	43	42	50	44	45	50	51	48	49	47	42	44	43	46.0
N	54	50	48	50	52	50	55	56	49	47	42	40	40	41	42	47.7
O	50	52	50	49	47	42	42	48	56	44	48	48	51	51	53	48.8
P	53	54	51	51	49	44	58	48	50	52	50	46	47	42	42	46.0
Q	46	51	52	50	46	51	53	49	51	42	52	56	43	42	45	48.6
R	43	41	50	48	50	52	50	56	51	49	54	56	56	42	42	49.0
S	49	47	49	47	53	47	47	48	52	50	51	45	40	50	51	48.4
T	42	50	48	44	42	43	48	48	50	58	44	43	45	50	45	46.0

Table 6: Summary of Descriptive Statistics for UCS and RHN for 20 Observations

	Mean	Median	Mode	Std. deviation	Minimum	Maximum
UCS (MPa)	119.89	120.51	130.00	7.74	105.00	132.50
RHN	47.16	47.00	46.00	1.41	44.90	49.50

Although the generated models were linear, logarithmic and exponential in nature similar to other studies, the obtained coefficients were different. Thus, the models can only be applied at Lugoba granite quarries or in other granite quarries with similar characteristics.

Graphical Presentation of the Models

The three generated mathematical models can be graphically superimposed and presented as shown in Figure 2. Validation of the Established Models

The established models were validated based on equation (7) and the results indicated that the models can predict UCS with a mean error of less than ± 10 for the logarithmic and exponential models. However, the mean error for the linear model was found to be greater than $\pm 10\%$. Based on these results, logarithmic and exponential models were recommended for use at Lugoba quarries.

Table 7: Validation Results for the Existing Models based on Laboratory Results of Lugoba Granite Samples

Lab Results		Vasconcelos et al (2007)			Kats et (2000)		Tugrul and Zarif (1999)		Aydin and Basu (2000)	
ID	RHN	UCS	UCS	Error	UCS	Error	UCS	Error	UCS	Error
A	46.00	116.00	(176.90)	252.50	17.91	84.56	(31.44)	127.10	25.03	45.59
B	46.50	125.00	(170.78)	236.62	18.52	85.19	(27.26)	121.81	25.92	44.26
C	44.90	130.00	(190.36)	246.43	16.62	87.22	(40.64)	131.26	23.17	48.39
D	45.00	121.00	(189.14)	256.31	16.73	86.17	(39.80)	132.89	23.34	48.14
E	46.20	128.00	(174.45)	236.29	18.15	85.82	(29.77)	123.26	25.38	45.06
F	46.00	123.00	(176.90)	243.82	17.91	85.44	(31.44)	125.56	25.03	45.59
G	46.90	120.02	(165.88)	238.21	19.02	84.16	(23.92)	119.93	26.66	43.16
H	45.50	123.48	(183.02)	248.22	17.32	85.98	(35.62)	128.85	24.17	46.88
I	46.00	120.00	(176.90)	247.42	17.91	85.08	(31.44)	126.20	25.03	45.59
J	49.50	132.50	(134.06)	201.18	22.47	83.04	(2.18)	101.65	31.98	35.40
K	47.00	109.99	(164.66)	249.70	19.14	82.60	(23.08)	120.98	26.84	42.89
L	47.60	130.00	(157.32)	221.01	19.91	84.69	(18.06)	113.90	27.99	41.19
M	46.00	123.45	(176.90)	243.30	17.91	85.49	(31.44)	125.47	25.03	45.59
N	47.70	111.00	(156.09)	240.62	20.04	81.95	(17.23)	115.52	28.19	40.90
O	48.80	117.90	(142.63)	220.97	21.50	81.77	(8.03)	106.81	30.45	37.61
P	46.00	110.00	(176.90)	260.82	17.91	83.72	(31.44)	128.58	25.03	45.59
Q	48.60	112.00	(145.08)	229.53	21.23	81.05	(9.70)	108.66	30.02	38.22
R	49.00	113.89	(140.18)	223.08	21.77	80.88	(6.36)	105.58	30.88	36.99
S	48.40	105.00	(147.52)	240.50	20.96	80.04	(11.38)	110.83	29.61	38.83
T	46.00	125.66	(176.90)	240.78	17.91	85.75	(31.44)	125.02	25.03	45.59

Table 8: Model Summary and Coefficients

	Model				
	Linear	Logarithmic	Quadratic	Power	Exponential
Model summary					
R^2	0.94	0.94	0.94	0.93	0.93
df	(1,19)	(1,19)	(2,19)	(1,19)	(1,19)
F	275.87	282.86	139.29	253.07	244.55
Sig.	0.00	0.00	0.00	0.00	0.00
Schmidt Number RHN					
Unstandardized Coefficient B	5.30	250.21	30.67	2.10	0.04
Unstandardized Coefficient Std error	0.32	14.88	24.15	.132	0.003
Standardized Coefficient beta	0.97	0.97	5.61	0.97	0.97
t- value	16.61	16.82	1.27	15.91	15.64
Sig.	0.00	0.00	0.22	.00	.00
(Constant)					
Unstandardized Coefficient B	-130.08	-844.16	-728.63	0.04	14.71
Unstandardized Coefficient Std error	15.06	57.32	569.43	0.02	1.97
Standardized Coefficient beta					
t- value	-8.64	-14.73	1.28	1.97	7.46
Sig.	0.00	0.00	0.22	0.07	0.00

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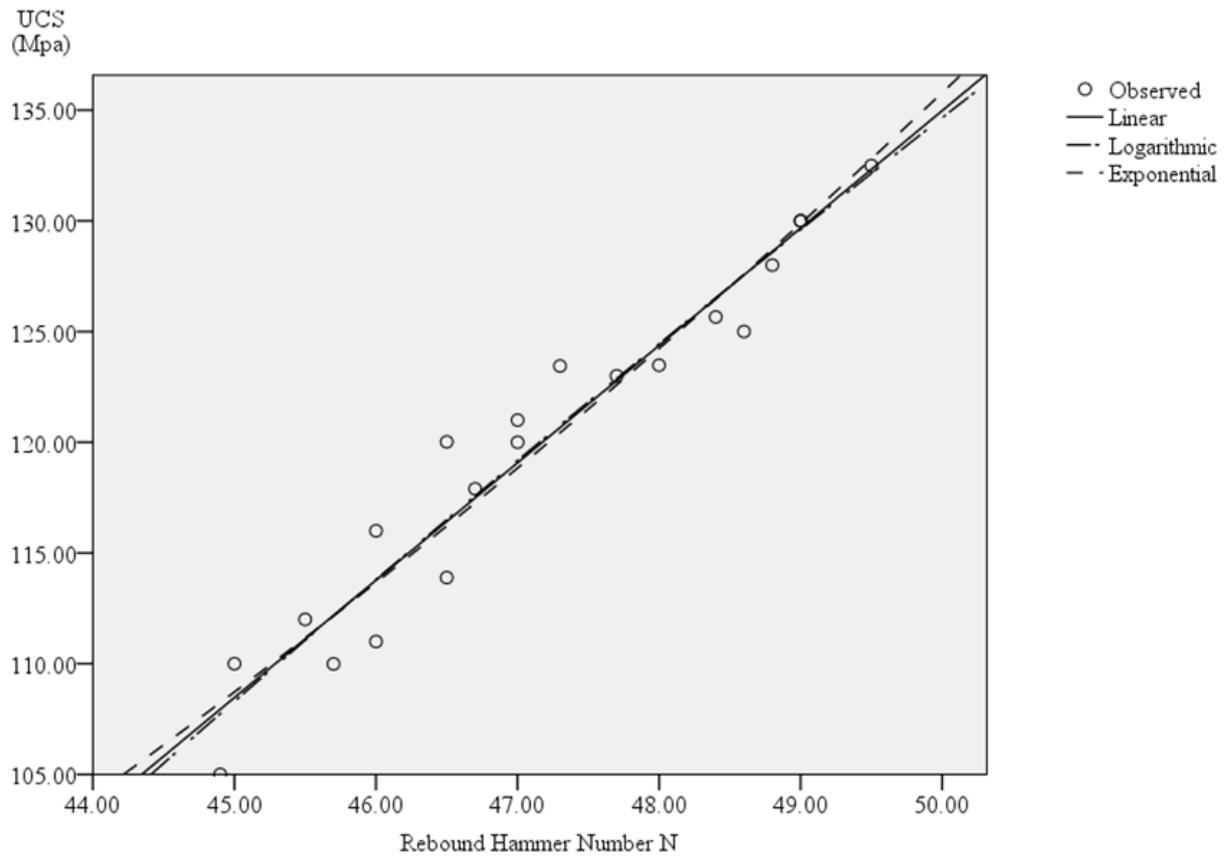


Figure 2: Superimposed Models of Linear, Logarithmic and Exponential Graphs

Table 9: Errors for the Linear, logarithmic and Exponential Models

Lab Results			Linear Model		Logarithmic Model		Exponential Model	
ID	RHN	UCS	UCS	Error	UCS	Error	UCS	Error
A	46.00	116.00	113.85	17.86	113.81	1.88	111.26	(4.09)
B	46.50	125.00	116.50	31.80	116.52	6.78	113.73	(9.01)
C	44.90	130.00	108.01	46.91	107.76	17.11	106.00	(18.46)
D	45.00	121.00	108.55	31.29	108.32	10.48	106.47	(12.01)
E	46.20	128.00	114.91	38.23	114.90	10.23	112.24	(12.31)
F	46.00	123.00	113.85	30.44	113.81	7.47	111.26	(9.55)
G	46.90	120.02	118.62	21.19	118.66	1.13	115.75	(3.56)
H	45.50	123.48	111.20	33.43	111.08	10.04	108.84	(11.86)
I	46.00	120.00	113.85	25.13	113.81	5.15	111.26	(7.28)
J	49.50	132.50	132.40	32.58	132.16	0.25	129.78	(2.05)
K	47.00	109.99	119.15	1.66	119.20	(8.37)	116.26	5.70
L	47.60	130.00	122.33	35.90	122.37	5.87	119.37	(8.17)
M	46.00	123.45	113.85	31.23	113.81	7.81	111.26	(9.88)
N	47.70	111.00	122.86	0.32	122.89	(10.72)	119.90	8.02
O	48.80	117.90	128.69	8.75	128.60	(9.07)	125.85	6.74
P	46.00	110.00	113.85	6.50	113.81	(3.47)	111.26	1.14
Q	48.60	112.00	127.63	(1.95)	127.57	(13.90)	124.74	11.38
R	49.00	113.89	129.75	(0.03)	129.62	(13.81)	126.96	11.47
S	48.40	105.00	126.57	(15.54)	126.54	(20.51)	123.65	17.76
T	46.00	125.66	113.85	35.06	113.81	9.43	111.26	(11.46)

CONCLUSIONS AND RECOMMENDATIONS

In view of the literature review, laboratory results and the generated models, we can conclude that:

- RHN has been extensively used to predict a crucial UCS parameter because of its advantages over the direct method of using UCS machine and for similar reason it can be used to predict UCS of granite at Lugoba Quarry;
- The mean value of UCS of granite samples from Lugoba quarry obtained in the UCS test carried out at DIT Laboratory based on the 20 samples were 119.89 MPa and corresponding RHN was 47.16. These values are comparable with the values (95 – 250 MPa) and (50 – 60) of other granite from other parts of the world though the mean value of RHN was considered slightly lower;
- The existing models of UCS selected in this study can predict UCS of Lugoba granite with the mean errors ranging between $\pm 43\%$ and $\pm 238\%$. The errors were considered too high for the models to be used at Lugoba.
- The five new models were established and values of R^2 for the models were found to be between 0.93 and 0.95 which are comparable with other studies. RHN accounted between 93% and 95% of the total variation of the UCS and the relationships are very strong;
- Three models - linear, logarithmic and exponential were found to be appropriate for predicting UCS at Lugoba Quarry. However, validation results indicated that only Logarithmic and exponential models can predict UCS of Lugoba granite with a mean error less than $\pm 10\%$ and therefore were recommended for further use at Lugoba granite quarry.

Rebound hammer number obtained from Rebound Schmidt hammer can be used to

predict UCS at Lugoba quarry using established regression models - logarithmic, and exponential.

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