The Nucleus **51**, No. 2 (2014) 207-213

The Nucleus

A Quarterly Scientific Journal of Pakistan Atomic Energy Commission

NCLEAM, ISSN 0029-5698

CORRELATION OF SLAKE DURABILITY INDEX WITH UNCONFINED COMPRESSIVE STRENGTH ESTIMATED THROUGH INDIRECT METHODS FOR CARBONATE ROCKS OF SALT RANGE, PAKISTAN

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(Received April 15, 2014 and accepted in revised form May 20, 2014

In evaluation of engineering behavior of rock mass and rock materials, slaking of rocks is an important consideration. For the construction industry, a durable rock is usually preferred. About 75% of the rocks outcropping on continents are sedimentary rocks. To determine rock strength and deformation, direct tests such as uniaxial compressive strength are expensive and require considerable time. Hence there is need to explore relations through other indirect methods such as Slake Durability Index, Point Load Strength and Schmidt rebound hammer test. To investigate the correlation between Slake Durability and strength, multidisciplinary approach was adopted. For this study, one of the important industrial rock groups belonging to carbonate geology of Salt Range was selected. The Slake Durability Index test was performed on 32 rock samples collected from different parts of Salt Range and the test results were compared with indirect strength such as Point Load Strength and Schmidt Hammer Hardness. Data was statistically analyzed through linear regression analysis to determine the correlation coefficient and the variability of results for each test. A strong linear correlation of 1st cycle Slake Durability Index exists with Point Load Strength and Schmidt Hammer Hardness.

Keywords: Slake durability index, Point load strength, Schmidt hammer hardness, Correlation coefficient, Linear regression analysis, Carbonate rocks

1. Introduction

About 75% of the rocks outcropping on continents are sedimentary in origin. Sedimentary rocks are divided into two broad classes, detrital (clastic) sedimentary rocks and chemical (carbonate) sedimentary rocks. Chemical sedimentary rocks are formed from material that is carried in solution to lakes and seas. If the solute precipitates out of the solution to form chemical sediments, rocks such as limestone and dolomite are formed. Limestone has numerous modern uses. As a building material it is used in the construction of the roads, foundations, bridges and tunnel lining etc. The choice of rocks or stones for buildings and monuments is mainly determined by their availability, accessibility and sometimes by beauty. Less attention is made to their durability and resistance to weathering. In this study, the main focus is the determination of 1st Cycle Slake Durability Index of some Carbonate Sedimentary Rocks from Salt Range and establishment of correlation with Indirect Strength parameters including Point Load Index and Schmidt Hammer Hardness.

In geotechnical practice, slaking of rocks is an important consideration in evaluating the engineering behavior of rock mass and rock materials. Many researchers attempt to correlate Slake Durability Index with some physical and mechanical properties of rocks including Point Load strength and Schmidt Hammer hardness. Dry unit weight, saturated unit weight and Schmidt hardness of carbonate rocks gave best relationship with first cycle durability while uniaxial compressive strength has a strong relationship with fourth cycle durability [1]. Variable durability is not dependent on a single parameter. It depends on compressive strength, grain size distribution and pore volume [2]. The slake durability of pyroclastic and sedimentary rocks is affected by mineral composition and texture. It is also affected by the kind of dissolved electrolyte and its concentration in aqueous solution [3]. Durability of mudrocks is closely related to the quantity of clay minerals and other geological parameters such as fabric and intensity of weathering. A decrease in slake durability is associated with an increase in clay content [4, 5]. Slake durability tests for shales indicate that first cycle slake durability is an excellent predictor of later cycles. Therefore testing of second cycle, as recommended by ASTM D4664 is unnecessary [6]. Khalily et al. [7] developed a relationship between durability test results, water absorption, point load index, dry density and carbonate content. Large scaled slake durability index test results for sandstone yields rock deterioration better than the small-scaled results, primarily due to the greater energy imposed to the rock fragments. Sandstone show a greater weight loss when tested with large rock fragments compared to the small

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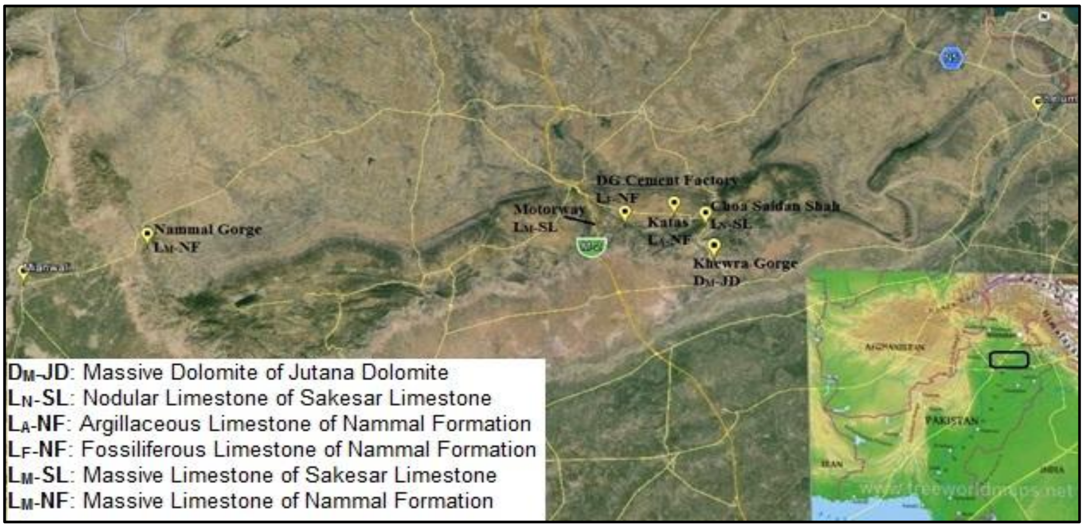

Figure 1. Location of study area, indicating sample collection points. (Google Earth 2014).

rock fragments [8-9]. An empirical based classification of lower Paleozoic carbonate bearing rocks for field based geotechnical applications was developed by Overfield and Bethany, 2011 [10]. Sharma and Singh performed regression analysis to establish statistical relationship between Schmidt Hammer Rebound numbers with Impact Strength Index (ISI), Slake Durability Index (SDI) and P-wave velocity [11]. Shape and surface roughness of the testing material also affects the results of durability indices. Well rounded samples having lowest fractal values give the best results [12]. Koncagul and Santi [13] established a relationship between the Uniaxial Compressive Strength, the Slake Durability and Shore Hardness using mineralogical and intrinsic properties of shale samples to explain the differences between the measured and the predicted results. This study has been performed in the Department of Geological Engineering, UET, Lahore as a part of M. Sc. research of principal author, registration number2011-MS-GS-02 and partial results are being published in this paper.

2. Materials and Methods

To investigate the correlation between 1st Cycle Slake Durability and strength, multidisciplinary approach was adopted. Salt Range of Pakistan has unique geologic history and great importance with respect to mineral availability and a good source of aggregate. Hence for this study, one of the important industrial rocks belonging to carbonate geology was selected. Samples of Limestone, Dolomite and Argillaceous Limestone were collected from different parts of Salt Range (Figure 1).

32 samples were collected to perform Slake Durability Test and indirect strength measurements including Point Load Strength and Schmidt Hammer Hardness. The results of these tests were used to perform regression analysis and to correlate these durability and strength parameters (Table 1).

For estimation of Slake Durability Index, standard guidelines were adopted [14]. Test sample comprised of 10 intact, roughly equidimensional and spherical rock fragments, each weighing 50±10g, produced by breaking the rock blocks with a hammer. The total sample was approximately 500±50g.

Oven dried sample was placed in the drum and mass of drum plus oven-dried sample in grams (A) was calculated before first cycle. After that, drum was mounted in the trough and coupled to the motor. Trough was filled to 20 mm (0.8 in.) below the drum axis with tap water at room temperature. Drum was rotated at 20 rpm for a period of 10 minutes. After the completion of first cycle, drum was removed from the trough and the drum plus retained sample was dried in the oven for 4±2 hours or to a constant mass. Weight of drum plus oven dried sample (W_1) was calculated to obtain the oven-dried mass for the second cycle. The whole procedure was repeated and drum plus oven dried sample was weighted again (W_2) to obtain a final mass. The first cycle slake durability index was calculated as:

$$Id^1 = \frac{W1 - B}{A - B} \text{ x } 100$$

Where Id^1 = First cycle slake durability index (%).

W_1 = Weight of drum plus sample retained after first cycle (g).

A = Mass of drum and oven dried sample before first cycle (g)

B = Mass of drum (g).

Table 1. Summary of test results performed for slake durability index, point load index and Schmidt hammer hardness.

Sample No.	Rock Unit	Formation/Age	Sample Collection Location	Test Results				
				Slake Durability Index	Point Load Strength Index		Schmidt Rebound Hammer	
				(Id^1) %	Is_{50}	UCS (MPa)	R_L	UCS (MPa)
1	Massive Limestone	Sakesar Limestone/Early Eocene	Motorway	99.6	4.4	102	41	94
2				99.7	4.6	105	40	92
3				99.6	4.5	103	38	83
4				99.6	4.4	101	39	87
5	Nodular Limestone		Choa Saidan Shah area	98.5	3.5	80	33	63
6				98.7	3.7	85	35	69
7				98.2	4.1	93	36	73
8				98.5	3.9	90	34	67
9	Massive Limestone	Nammal Formation/Early Eocene	Nammal Gorge	99.5	4.3	99	44	108
10				99.6	4.7	108	43	98
11				99.8	4.5	104	42	95
12				99.4	4.4	101	43	98
13	Fossiliferous Limestone		D G cement factory area	99.3	3.7	85	39	80
14				99.2	3.5	79	40	84
15				99.6	3.6	83	39	80
16				99.2	3.9	90	37	75
17	Argilaceous Limestone	Nammal Formation/Early Eocene	Katas area	92	2.3	53	20	25
18				91	2.5	58	22	27
19				92	2.5	58	19	24
20				92.6	2.7	62	21	26
21				92	2.6	60	27	35
22				92	2.4	57	25	32
23				93	2.2	51	23	29
24				91	2.1	48	22	27
25	Massive Dolomite	Jutana Dolomite/ Early to Middle Cambrian	Khewra Gorge	99.8	7.9	183	47	160
26				99.6	7.7	178	48	167
27				99.8	7.6	175	49	173
28				99.8	7.3	168	47	160
29				99.7	8.8	202	46	150
30				99.6	8.1	186	47	160
31				99.6	8.2	189	43	135
32				99.8	8.5	196	45	145

Table 2. Statistical analysis of test results.

Test Performed	Rock Unit	Maximum Value	Minimum Value	Mean	Standard Deviation	Coefficient of Variance (%)	95% Confidence Interval	
1st Cycle Slake Durability Index	Sakesar Limestone	99.7	98.2	99.05	0.63	0.64	98.61	99.49
	Nammal Formation	99.8	99.2	99.45	0.21	0.21	99.30	99.60
	Argillaceous Limestone	96	95	95.5	0.53	0.55	95.13	95.87
	Jutana Dolomite	99.8	99.6	99.7	0.10	0.10	99.63	99.77
Point Load Strength	Sakesar Limestone	105	80	94.8	9.28	9.79	88.37	101.23
	Nammal Formation	108	79	93.6	10.77	11.51	86.14	101.06
	Argillaceous Limestone	62	48	55.8	4.76	8.54	52.50	59.10
	Jutana Dolomite	202	168	184.6	11.13	6.03	176.89	192.31
Schmidt Hammer Hardness	Sakesar Limestone	94	63	78.5	12.00	15.29	70.19	86.81
	Nammal Formation	108	75	89.7	11.57	12.90	81.68	97.72
	Argillaceous Limestone	35	24	28.1	3.72	13.24	25.52	30.68
	Jutana Dolomite	173	135	156.2	12.28	7.86	147.70	164.70

For Point Load Strength, methodology was adopted from ASTM-D5713 [15]. Test was performed on irregular shaped specimens having external dimensions not less than 30 mm and not greater than 85 mm. Samples having *D/W* ratio between 1/3 and 1 were inserted in the testing machine. By steadily increasing the load, such that failure occurs within 10 to 60 seconds, failure load (P) was recorded. The Point Load Strength was calculated as

$Is = P/De^2$

Where

Is = Uncorrected point load strength index

P = Failure load (N)

De = Equivalent core diameter

$De^2=4A/\pi$ for lump tests, mm^2

Is varies as a function of *De* in irregular lump tests, so that a size correction is applied to obtain a unique point load strength value for the rock samples. There are different methods for finding the size correction factor. In this research work, size correction factor is calculated as follows.

$F = (De/50)^{0.45}$

The value of $Is_{(50)}$ corresponding to De^2 = 2500 mm^2 (*De* = 50 mm) is obtained by the use of size-corrected point load strength index calculated as

$Is_{(50)} = F \times Is$

For estimation of Schmidt Hammer Hardness, methodology was adopted from ASTM-D5873 [16]. For each rock type, representative block samples fulfilling the requirement of edge length of at least 15 cm was collected. Test was performed by using L type hammer having impact energy of 0.735 Nm. Instrument was oriented perpendicular to the test surface of the specimen. Hammer spring was compressed by gradually depressing the plunger until it is triggered and impact occurs. Before restoring the piston to its original extension, the height of the plunger rebound recorded to the nearest whole number, as measured on an arbitrary scale of 10 to 100 divisions located on the side of the hammer. For one test specimen, ten readings were taken at representative locations separated by at least the diameter of the piston. UCS was estimated from the graph having different curves corresponding to different values of unit weight.

3. Results and Discussion

The test results are summarized in Table 2. In order to correlate the Slake Durability Index with indirect strength parameters of Carbonate rocks, regression analysis technique is adopted. To analyze the relationship between dependent and independent variables, linear curve fitting method was used. The curve with highest value of coefficient of determination (R^2) was considered as most appropriate.

Before applying the regression analysis, test data was plotted in two dimensions as XY-scatter plot. It allowed the visualization of the test data before

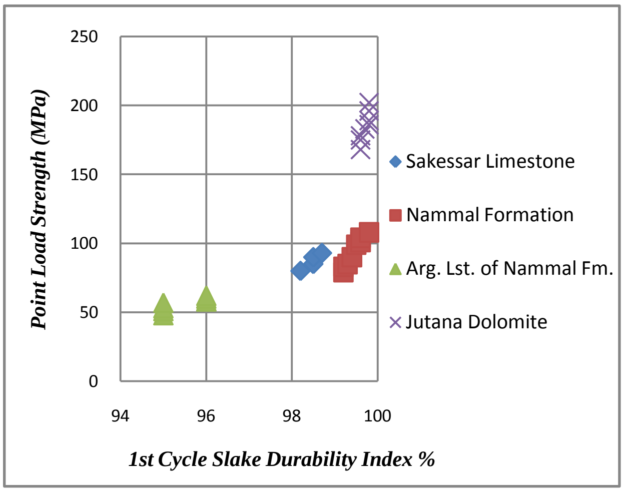

Figure 2. 1st cycle slake durability index vs point load strength of all rocks.

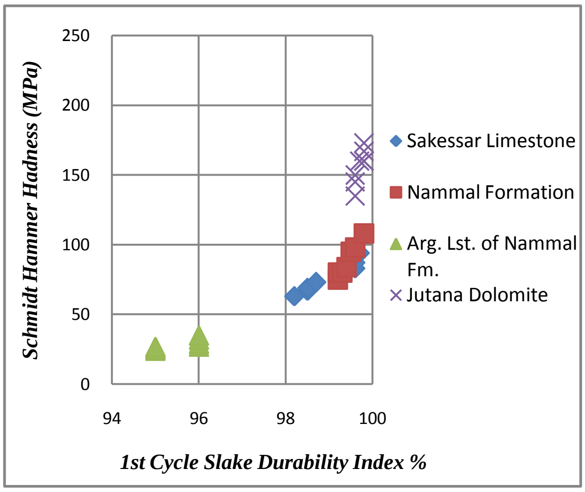

Figure 3. 1st cycle slake durability index vs Schmidt hammer hardness of all rocks.

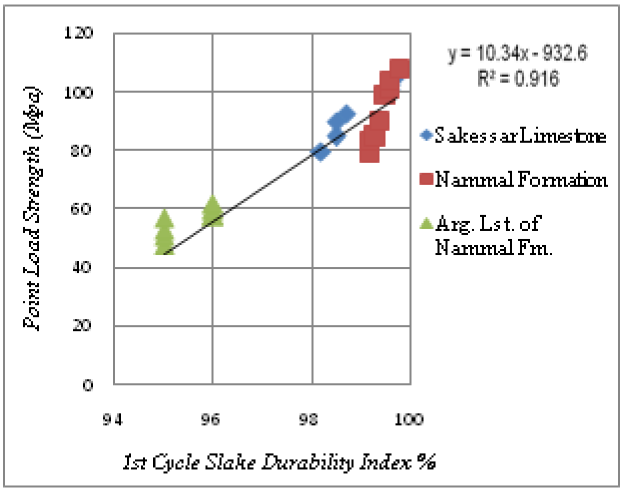

Figure 4. Scatter Plot of 1st cycle slake durability index vs point load strength with best fit equation.

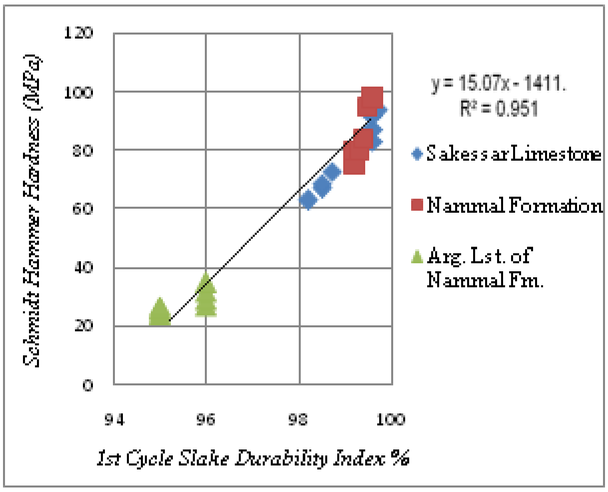

Figure 5. Scatter Plot of 1st cycle slake durability index vs Schmidt hammer hardness with best fit equation.

conducting the regression analysis. By plotting 1st cycle Slake Durability Index against Point Load Strength of all rocks, it was found that Jutana Dolomite shows a different behavior (Figure 2). Same behavior of Jutana Dolomite was observed by plotting 1st cycle Slake Durability Index against Schmidt Hammer Hardness (Figure 3). This different behavior of Jutana Dolomite is probably due to its extremely high durability and very high compressive strength. Due to this extremity, Jutana Dolomite is not included in regression analysis.

The Slake Durability Index of other tested rocks was plotted against Point Load Strength and Schmidt Hammer Hardness. Using the linear regression technique, the best fit curves were plotted on the scatter plots. Equations of lines were determined and coefficient of correlation was found with the help of Microsoft Excel (2007). The scatter plots with their best fit curves, best fit equations and coefficient of correlation are shown in Figures 4 and 5. Two main equations relating 1st cycle Slake Durability Index with Point Load Strength and Schmidt Hammer Hardness are given as below.

$$Is_{(50)} = 10.34\, Id^{1} - 932.6 \quad (1)$$

$$R^2 = 0.916$$

$$R_L = 15.07\, Id^{1} - 1411.0 \quad (2)$$

$$R^2 = 0.951$$

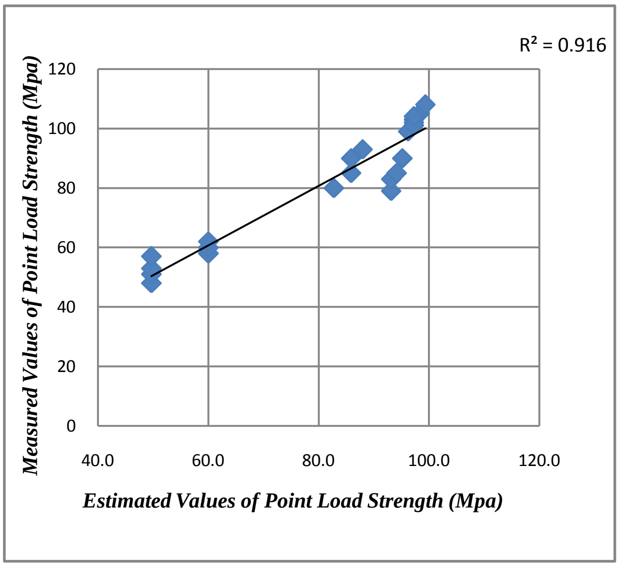

Figure 6. Plot between Estimated and Measured values of point load strength.

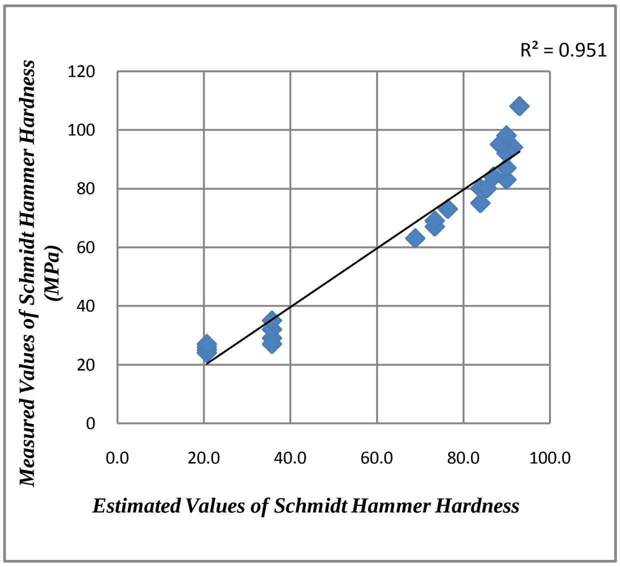

Figure 7. Plot between estimated and measured values of Schmidt hammer hardness.

To check the validity of the correlation, the measured Slake Durability Index values were used to predict the Point Load Strength and Schmidt Hammer Hardness values with the help of derived equations. The mean, standard deviation, coefficient of variance and 95% confidence interval values were calculated for Point Load Strength and Schmidt Hammer Hardness values. It was observed that all the estimated values from derived equations lie within the 95% confidence interval, which shows the validity of the derived equations.

The estimated values of Point Load Strength and Schmidt Hammer Hardness were plotted against the measured values of Point Load Strength and Schmidt Hammer Hardness as shown in Figures 6 and 7. These estimated values were very close to the measured values which show the accuracy of derived equations.

3. Conclusions and Recommendations

On the basis of this study it is concluded that

- There is a strong linear correlation in 1^{st} cycle Slake Durability Index and strength estimated by indirect methods such as Point Load Strength and Schmidt Hammer Hardness
- The correlation equation for Point Load Strength is $Is_{(50)} = 10.34\ Id^1 - 932.6$
- The correlation equation for Schmidt Hammer Hardness is $R_L = 15.07\ Id^1 - 1411.0$
- All the estimated values from derived equations lie within the 95% confidence interval which shows the validity of derived equations
- The different behavior of Jutana Dolomite is probably due to its high unconfined compressive strength and extreme durability
- It is suggested that subsequent studies for 2^{nd} and 3^{rd} cycle slake durability index may also be carried out for establishment of further correlations.

Acknowledgement

The University of Engineering and Technology, Lahore is greatly acknowledged for providing necessary facilities for field visits and laboratory testing for this study. The guidance of Dr. Muhammad Saleem Khan is very valuable for the completion of this work. The cooperation of Mr. Zahid Jameel, Mr. Mohsin Ali and engineering geology laboratory staff is very precious.

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