Journal of Himalayan Earth Sciences Volume 48, No. 1, 2015 pp.9-13

Prediction of durability and strength from Schmidt rebound hammer number for limestone rocks from Salt Range, Pakistan

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Abstract

Limestone is widely used in civil engineering works and raw material for cement factories and many other industries. The determination of its durability and strength is always essential prior to its use. The testing procedure and sample preparation for slake durability index test and unconfined compressive strength test is time consuming and needs expertise. While Schmidt rebound hammer number is quick and non-destructive evaluation method of surface hardness. The focus of this research work is to develop an empirical relationship for determination of Slake durability index and unconfined compressive strength from Schmidt hammer number.

Keywords: Limestone; Durability; Strength; Schmidt rebound hammer number; Empirical relationship; Salt Range; Pakistan.

1. Introduction

Determination of durability and strength in laboratory through direct tests such as Slake durability index test and Uniaxial compressive strength test is expensive and also time consuming. On the other hand, a quick and non-destructive measure of surface hardness is provided by the Schmidt hammer which is very helpful in estimating the mechanical properties of rock material (Kahraman, 2001). Limestone is widely used in civil engineering works as road sub base, aggregate base course, Ordinary Portland cement concrete, riprap and railway ballast. It is also used as raw material for a number of other industries (Gondal et al., 2009).

Values calculated for Paleocene-Eocene limestone resources for specific gravity, water absorption, soundness, Los Angeles abrasion test, compaction test, optimum moisture content, and California bearing ratio and bitumen adhesion were much below the prescribed standards. These aggregates exhibited excellent Petrographic properties and were innocuous in plain cement concrete. Moreover, they were found to be hydrophobic in nature and therefore, their bond with bitumen would be durable (Ahsan et al., 2012). There exists a strong exponential relationship between Schmidt rebound number and unconfined compressive strength of limestone rocks from Malaysia with high degree of accuracy. This correlation has advantage on previously used Miller's correlation of being a function of only rebound number. The use of new developed correlation for UCS prediction in case of highly weathered rock is not recommended due to improper UCS prediction (Nazir et al., 2013).

For the assessment of other properties, like impact strength index (ISI), slake durability index (SDI) and P-wave velocity, Schmidt hammer rebound number is considered as one of the most important parameter. It shows linear relation with ISI and SDI, whereas exponential relation with P-wave velocity with high values of correlation coefficients for different rock types including Sandstone, Siltstone and Conglomerates (Sharma et al., 2011).

Most of the empirical equations introduced for the determination of the uniaxial compressive strength of rocks based on the Schmidt hammer rebound number have relatively low coefficient of correlations due to the fact that one formula is used for all types of rocks. The equation will yield a much higher coefficient of correlation if one specific relationship between N and UCS is introduced for one rock type and under particular geological circumstances (Torabi et al., 2010). Comparison of test results conducted by N type Schmidt hammer and L type Schmidt hammer shows that slightly higher rebound numbers are produced by N type hammer than those with L type Schmidt hammer. Schmidt rebound number yields high correlation coefficients with uniaxial compressive strength, bending strength, point load strength index, shore hardness and P-wave velocity for Limestone, Travertine and Marble rocks collected from various locations in Turkey (Guney et al., 2005). In this research work an attempt is made to develop a relationship between Schmidt hammer number with durability and strength of limestone rocks of Salt Range Pakistan.

2. Materials and methods

Overall 24 samples of Limestone belonging to Sakesar Limestone and Nammal Formation were collected from outcrops along motorway and Nammal Gorge respectively. Tests were performed to estimate Schmidt rebound hammer number, Slake durability index, Point load strength and unconfined compressive strength in the laboratory.
For Schmidt rebound hammer number (RL), methodology was complied with standard guidelines of ASTM-D5873. Test was performed on intact block samples by using L type hammer. For each sample, an average of 10 readings was taken. All tests were performed with the hammer held vertically downwards and at right angles to the horizontal rock faces.

Slake durability index test was performed according to the guidelines of Franklin and Chandra (1972). 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. Test was carried out for two cycles and 2nd cycle Slake durability index was calculated as follows;

$$ID_2 = \frac{C-E}{A-E} \times 100$$

Where

A = Initial weight of sample + drum (gm)

C = Weight of sample retained + drum after second cycle of rotation (gm)

E = Weight of empty drum (gm)

ID_2 = 2^{nd} cycle Slake durability index (%)

For Point Load Strength, methodology was adopted from ASTM-D5731. Test was performed on irregular shaped specimens having diameter to width ratio (D/W) between 1/3 and 1. The Point Load Strength was calculated as;

$$I_S = P/D_e^2$$

Where

I_S = Uncorrected point load strength index

P = Failure load (N)

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

In irregular lump test, a size correction was applied to obtain a unique point load strength value. In this study, size correction factor was calculated as follows;

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

Size-corrected point load strength index was calculated as

$$I_{S\,(50)} = F \times Is$$

For the evaluation of unconfined compressive strength for the rock core samples, ASTM standard test method under method D 2938 was adopted. For sample preparation, requirements of ASTM-D 4543 were fulfilled. For each sample, a right circular core with length to diameter ratio (L/D) of 2.0-2.5 having diameter not less than 47mm was used.

3. Results and discussions

The results of tests for density, Schmidt rebound hammer, slake durability index, point load strength and unconfined compressive strength are given in Table 1. In order to depict the relationships between Schmidt rebound hammer number with Slake durability, Point load strength and unconfined compressive strength of the tested rocks, regression analysis was performed. The equation of the best fit line and the coefficient of correlation (R^2) were determined for each test results.

The plot of the Schmidt rebound hammer number as a function of Slake durability index is shown in Fig. 1. It is obvious from the Figure 1 that there exists a strong linear relation between Schmidt rebound hammer number and Slake durability index for studied rocks having a strong coefficient of correlation (R^2 = 0.945). The best fit trend line can be explained by following equation:

$$ID_2 = 0.489 \times R_L + 79.22 \qquad (R^2 = 0.945)$$

Similarly, a strong linear relationship has also been observed between Schmidt rebound hammer number and Point load strength of studied rocks. A strong coefficient of correlation (R^2 = 0.906) is present between these properties (Fig. 2). The best fit trend line has the following equation for the relationship between Schmidt rebound hammer number and Point load strength:

$$Is_{(50)} = 2.113 \times R_L + 13.67 \qquad (R^2 = 0.906)$$

For Schmidt rebound hammer number and Unconfined compressive strength, curve shows an exponential relationship with a coefficient of correlation of 0.777 (Fig. 3).

Table 1. Results of tests performed.

Rock Unit	***Density (g/cc)***	***Schmidt Rebound Number***	***Slake Durability Index (%)***	***Point Load Strength (MPa)***	***UCS (MPa)***
Limestone-1 (Intact, Massive)	2.753	41	99.2	102	108
Limestone-2 (Intact, Massive)	2.749	40	99.3	105	95
Limestone-3 (Intact, Massive)	2.751	38	99.4	103	103
Limestone-4 (Intact, Massive)	2.764	39	99.3	101	88
Limestone-5 (Intact, Massive)	2.758	33	96.8	93	90
Limestone-6 (Intact, Massive)	2.750	35	97.1	90	98
Limestone-1 (Intact, Fossiliferous)	2.651	44	99.3	99	93
Limestone-2 (Intact, Fossiliferous)	2.647	43	99.2	108	87
Limestone-3 (Intact, Fossiliferous)	2.657	42	99.4	104	80
Limestone-4 (Intact, Fossiliferous)	2.654	43	99.2	101	78
Limestone-5 (Intact, Fossiliferous)	2.650	39	98.9	85	68
Limestone-6 (Intact, Fossiliferous)	2.653	40	99	90	75
Limestone-1 (Intact, Marly)	2.345	20	88	53	42
Limestone-2 (Intact, Marly)	2.339	22	91	58	46
Limestone-3 (Intact, Marly)	2.348	19	90	58	45
Limestone-4 (Intact, Marly)	2.341	21	88	62	48
Limestone-5 (Intact, Marly)	2.337	23	89	60	47
Limestone-6 (Intact, Marly)	2.344	25	91	57	46

The best fit trend line has the following equation for this relation:

$$UCS = 23.80\ e^{0.032\ R_L} \qquad (R^2 = 0.777)$$

To check the validity of derived equations, concept of confidence interval was used. In this research work, 99% confidence interval was calculated for the data obtained from test results. The derived empirical equations were used to predict the various properties such as Slake durability, Point load strength and UCS. It was observed that the values predicted from equations for 2nd cycle of Slake durability and Point load strength respectively, lies within 99% confidence interval. On the other hand, values of UCS predicted from equation do not lies within the confidence interval range. The statistical analysis performed on the data is shown in Table 2.

The predicted values of Slake durability, Point load strength and UCS from the corresponding equations were then plotted against the measured values, on 1:1 line. It was observed that the values of Slake durability and Point load strength lies on or near the slope line (Fig. 4 & 5) while the values of UCS lie away from the slope line (Fig. 6).

4. Conclusions and recommendations

The study indicates that the Slake durability index, Point load strength and unconfined compressive strength of limestone rocks can be estimated from their Schmidt rebound hammer values by using simple empirical relations. Slake durability index and Point load strength showed a strong relationship with Schmidt rebound hammer number whereas unconfined compressive strength showed exponential relation. The empirical expressions are as follows.

$$ID_2 = 0.489 \times RL + 79.22 \qquad (R^2 = 0.945)$$

$$Is_{(50)} = 2.113 \times RL + 13.67 \qquad (R^2 = 0.906)$$

$$UCS = 23.80\ e^{0.032\ RL} \qquad (R^2 = 0.777)$$

A strong coefficient of correlation was found between Schmidt rebound hammer number with Slake durability index and Point load strength. Schmidt rebound hammer number showed relatively poor correlation coefficient with UCS.

Prediction of UCS in correlation with Schmidt rebound hammer number needs to be improved to

Table 2. Statistical analysis on data obtained from various performed tests.

Performed Test	*No. of Samples*	*Maximum Value*	*Minimum Value*	*Mean*	*Standard Deviation*	*Coefficient of Variance (%)*	*99% Confidence Interval*	
Slake Durability Index	18	99.4	88	95.7	4.6	4.9	91.3	99.9
Point Load Strength	18	108	53	84.9	20.5	24.1	62.5	99.3
UCS	18	108	42	74	22.9	31.0	60.1	87.9

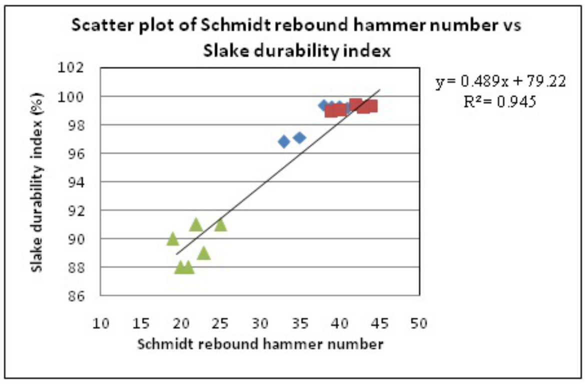

Fig. 1. Schmidt rebound hammer number vs Slake durability index

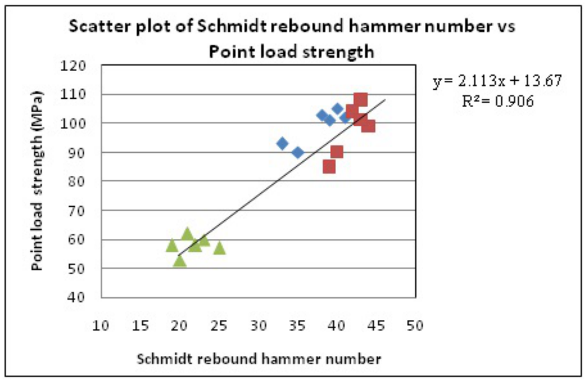

Fig. 2. Schmidt rebound hammer number vs Point load strength

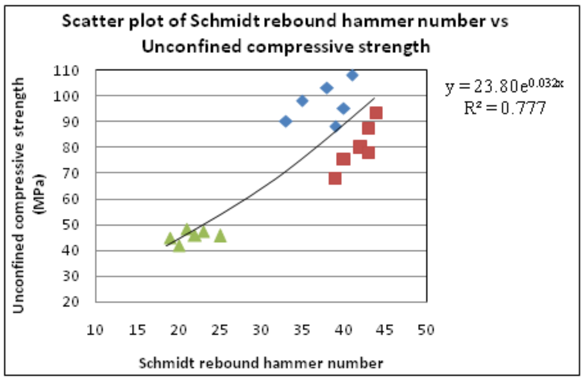

Fig. 3. Schmidt rebound hammer number vs UCS

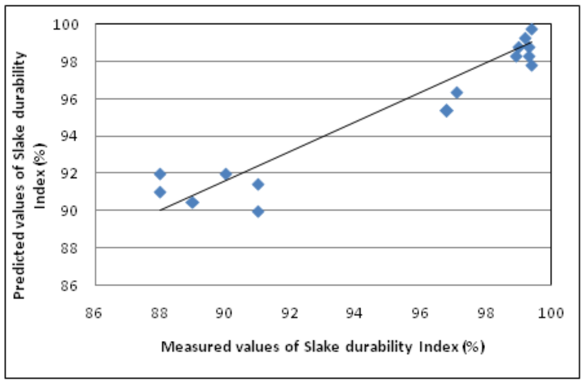

Fig. 4. Measured values vs predicted values for Slake durability index

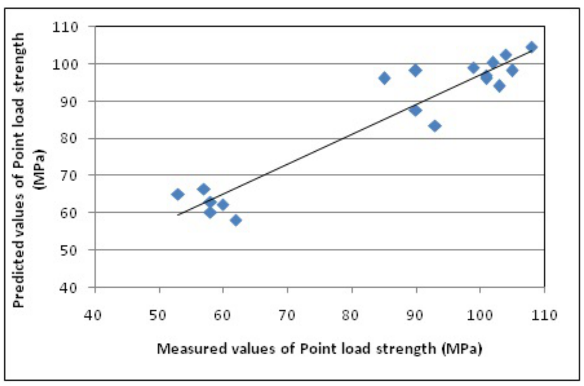

Fig. 5. Measured values vs predicted values for Point load strength

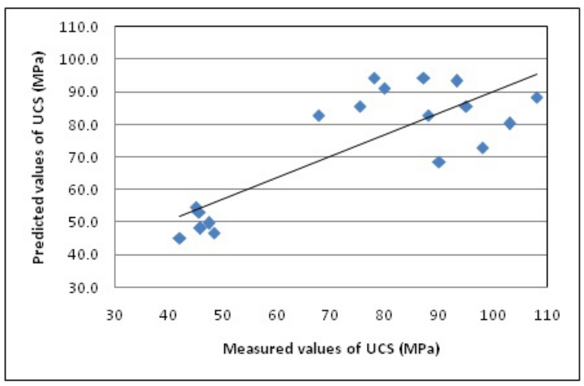

Fig. 6. Measured values vs predicted values for UCS

take into account more qualitative values that represent rock material better, such as the origin of the rocks, porosity, grain size and grain shape which affects the surface area of the interlocking bond forces at mineral grain to grain contacts.

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