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A Comparison Between Schmidt Rebound Hammer Test and Point Load Index Test (I_{S50}) for the Effectiveness in Estimating the Unconfined Compressive Strength of Intact Rock- A Case Study with respect to Limestone of Early Eocene Nammal Formation, Central Salt Range, Pakistan

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Abstract: In a bid to find some possible relation of Unconfined Compressive Strength (UCS) with relatively simple laboratory tests like Point Load Test (PLT) and Schmidt Rebound Hammer Test (SRHT), some 50 core samples of Middle Eocene Nammal formation from Central Salt Range in Pakistan were collected and subjected to these test methods as per respective test standards of International Society of Rock Mechanics (ISRM). The values of SRHT and PLT were separately compared to the respective values of UCS so as to find the linear relations. On the basis of the R^2 value of Regression Analysis, it has been found that a strong correlation with a high degree of accuracy exists between PLT and UCS while the degree of accuracy between SRHT and UCS was found to be low.

Keywords: Correlation, uniaxial compressive strength (UCS), Schmidt rebound hammer number (N-value), point load strength index (Is).

Introduction

Unconfined compressive strength (UCS) is an important mechanical property of rock material (Brady and Brown, 2005), (Karakus et al., 2005) & (Rajabzadeh et al., 2011) which is widely used in many rock engineering design parameters and is an integral part of modern day rock mass classification systems (e.g. RMR, Q-system). As many intricacies are involved in sample preparation, conforming accepted international standards formulated by the International Society of Rock Mechanics (ISRM) and American Society of Testing Materials (ASTM) for determining UCS is important. Thus, there arises the need for developing correlations among UCS and some other relatively simple and cost-effective index tests. These correlations are frequently used by the planners, designers, and researchers particularly at pre-feasibility and feasibility stage of the rock engineering projects. Among the most widely used index tests for estimating UCS are Schmidt Rebound Hammer Test (SRHT) and Point Load Index (PLT). Since a subtle variation exists among such correlations developed all over the world, therefore, these correlations depend upon the rock units and should specifically be evaluated. In this study, a comparison has been made between SRHT and PLT for their effectiveness to reliably predict the UCS for Nammal Formation's limestone (Early Eocene) in the Central Salt Range of Pakistan.

Many researchers (Dincer et al., 2004), (Kahraman et al., 2005), (Dincer et al., 2008), (Kilic and Teymen, 2008), (Yilmaz and Sendir, 2002) have made attempts to develop correlations of unconfined compressive strength with Point load strength index (I_{s50}) and Schmidt Rebound Hammer's N value. As many as two-hundred core samples taken from outcrops of nine rock formations in the Salt Range, Pakistan was analyzed by Akram and Bakar (2007) to find out the correlation (UCS=22.792 I_{s50}+13.295, for limestone and UCS=11.076 I_{s50} for Sandstones between UCS and Is50). In a recent study Akram et al., (2014) developed encouraging correlations between axial and diametrical values of Point load index, Schmidt rebound number and corresponding UCS values for Sakesar limestone in salt range, Pakistan.

Franklin and Broch, (1971) developed the following equation linking index strength found out by PLT and UCS for the hard rocks (Equation. 1)

$$UCS = (K)\, I_{s50} = 24\, I_{s50} \quad \textbf{(1)}$$

Similarly, many attempts have been made to estimate UCS of rocks using SRHT number (N), like (Deere and Miller, 1966) found the following relationship (Equation. 2):

$$UCS = 10^{(0.000014\gamma N+31.6)} \quad \textbf{(2)}$$

Where N denotes rebound number of SRHT, while ϒ shows rock density. Table 1 shows some of the correlations between UCS and SRHT. Some references for correlating the estimation of UCS of rock material by Schmidt rebound number are given in Table 1

As the rocks are heterogeneous in nature and their strength do vary from area to area, there occurs a great need to extend above-mentioned studies for other rock units in the area to establish a national database for rock strength.

Table 1. Some Correlation equations established by different researchers showing the relation between UCS and SRHT.

Source	Relation
(Singh, et al., 1983)	UCS=2N
(Sheorey, et al., 1984)	UCS= 0.4N-3.6
(Haramy & DeMarco, 1985)	UCS= 0.994N -0.383
(O'Rourke, 1989)	UCS = 702N – 11040
(Aggistalis, et al., 1996)	UCS = 1.31N -2.52
(Dincer, et al., 2004)	UCS = 2.75N-36.83
(Gupta, 2009)	UCS = 29.8N-706
(Torabi, et al., 2010)	$UCS=0.0465N^2-0.1756N+27.682$
(Ferner, et al., 2005)	$UCS = 4.24e^{0.059N}$

Material and methods

Sampling

The study area is situated in Salt-Range which is part of the Himalayan fold and thrust belt (Gee, 1989). About 85 km wide and 200 km long, the Salt-Range is a discrete structural zone having the Main Boundary Thrust (Sarwar, 1979), (Coward et al., 1986) in North. The Salt Range Thrust, Kalabagh Fault, and the Surghar Thrust form its Southern margin. Jhelum Fault marks the Eastern extent of the Salt-Range while in the West it is bounded by Kurram Thrust (Kazmi and Rana, 1982). The approximate location of study area near the town of Kallar Kahar in central Salt-Range is shown in Figure 1.

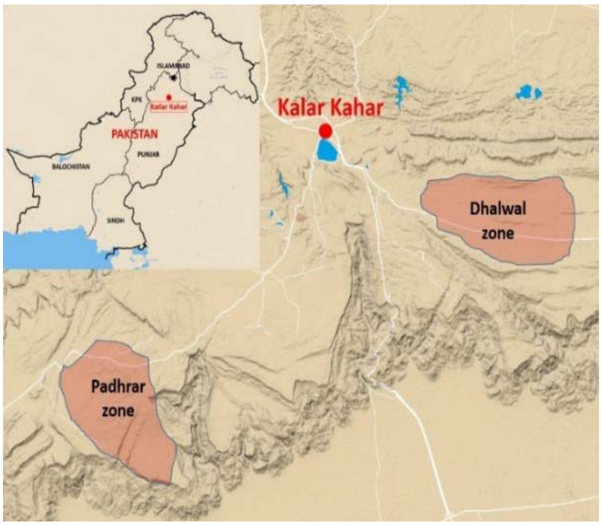

Fig. 1 Location map of study area.

The straight rotary method was used to get the core samples of Nammal Formation at Padhrar and Dhalwal Village in central Salt Range, Pakistan. As many as 50 core samples of NQ size (D≈47.5mm) were collected, wrapped with plastic and transported to the laboratory (Figure 2). Each of these 50 samples was cut into three pieces suitable for conducting UCS, PLT, and SRHT. Every care was exercised to collect the samples without any structural or machine-made defects.

Specimen Preparation

For the test, the specimens were prepared in compliance with the relevant standard/procedures laid down by the International Society of Rock mechanics (*ISRM).* For UCS, following the ISRM (Brown, 1981) requirements of sample preparation, specimens were cut from the cores, with their length to diameter ratio (L/D) remaining between 2.5 and 3. The standard requires the ends to be in parallelism, and for achieving this, they were cut and then ground by sand-paper mounted grinder. For PLT (Diametral), according to Standard requirements, the length to Diameter (L/D) was kept below 1. As Schmidt Rebound Hammer test may induce micro-cracks inside the rock fabric so the separate specimens were cut out from cores for determining N-Values of SRHT. Figure 3 shows the cutting process and prepared samples for UCS, PLT and SRHT.

Fig. 2 Sampling from the drilling site.

Testing Procedures

Unconfined Compressive Strength (UCS)

As many as Fifty (50) rock core specimens, fulfilling the length to diameter ratio requirement of ISRM (Bieniawski and Bernede, 1979), were subjected to UCS test prior to which attributes like length, diameter and Unit-Weight of all samples were measured. Universal compression machine is used to apply vertical load on well-prepared cylindrical rock samples (Figure 4). Having placed it within the platens, each core sample was given the load at the standard rate. The load, at which this failure occurred, was divided by the area of the specimen to find the unconfined compressive strength for each of the specimens.

Point Load Test

The 50 specimens were tested diametrally in point load machine (Figure 5) as per the method suggested by ISRM (Franklin, 1985). After positioning the samples within the conical platens of the PLT machine, the load at a standard rate was applied with the help of a manual hydraulic pump; till the specimen failed. The distance between the platen was recorded as D, while the failure load as P. Diameter correction for Is_{50} was

Results and Discussions

The laboratory test results of 50 samples of all three

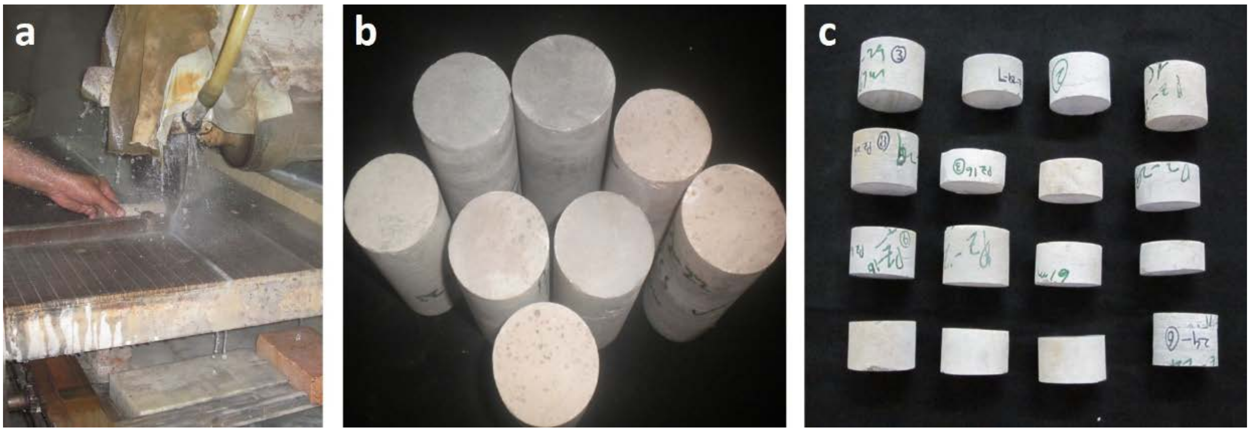

Fig. 3 (a) Cutting of core samples (b) prepared samples for UCS (c) prepared samples for PLT and SRHT.

applied and index strength was found by dividing the failure load to the square of the adjusted diameter.

Schmidt Rebound Hammer Test

The dedicated rock specimens were gone through SRHT as per ISRM (Aydin, 2009). L-type hammer with an impact energy of 0.74 Nm was used. The impact was given diametrally at three different, apparently representative, points of each of the specimen. The hammer was held perpendicular to the surface of the specimen. The mean of the three readings was taken as NR-value for the respective specimen.

Fig. 4 Universal compression machine.

tests (UCS, PLT, and SRHT) were taken for the analysis. Using these test results the correlation of UCS was made with PLT and SRHT separately by deploying a statistical technique known as Regression Analysis.

Statistical Analysis

Descriptive stat function is used to evaluate the variability of all the test results separately (given in Table 2). The values of coefficient of variation for all the three tests are slightly higher than the acceptable limit which may be due to inadequate testing conditions. The value of the coefficient of variation for UCST is 32.56 which suggests that the UCST results are more scattered than the PLT, the same trend was found by (Broch and Franklin, 1972).

Fig. 5 Point load tester.

Regression Analysis

In order to arrive at the objective of the study i.e. to compare the effectiveness of two index tests (SRHT and PLT) in precision of predicting UCS, correlations of each of the two tests results with UCS of rock material were developed using Regression Analysis which is a statistical instrument meant to estimate the value of a Dependent-Variable associated with the values of an independent variable. Prior to the analysis, the data - results of the experiments were plotted as an XY-scatter plot for visualization. Several Curve-fitting relationships like linear, polynomial, exponential, logarithmic etc. are available to evaluate the relationship of Dependent-Variable with the Independent one. Regression Analysis of a certain data produces a coefficient of determination (R^2) - the estimation of deviation (variability) on one variable which can be accounted for by the variability on another variable - (Sheksin, 2000). The curve with the highest value of R^2 is considered most appropriate and therefore such curves have been used for the study.

Fig. 6 Typical L-type hammer used for Schmidt Rebound Hammer test.

Table 2. Descriptive statistics for UCS, SRHT, and PLT.

Function	*UCST*	*SRHT*	*PLT*
Mean	52.02	33.59	4.83
Standard Error	2.40	1.30	0.20
Median	49.05	33.50	4.75
Mode	38.95	22.33	4.73
Standard Deviation	16.94	9.21	1.43
Sample Variance	286.83	84.75	2.03
Coefficient of Variation (%)	32.56	27.40	29.55
Skewness	0.70	0.39	0.32
Range	69.78	39.66	6.33
Minimum	23.38	18.67	2.00
Maximum	93.16	58.33	8.33
Sum	2600.94	1679.68	241.35
Count	50.00	50.00	50.00
Confidence Level (95.0%)	4.81	2.62	0.41

UCST vs. PLT

Test results of UCS and PLT (I_{s50}) conducted on 50 core samples were compared taking UCS as the dependent variable and PL index as the independent variable. Using the Software package Microsoft Excel 2013, Regression Analysis was conducted and results are given in **Error! Reference source not found.**. Many curve fitting options like linear, logarithmic, polynomial, exponential were considered while Linear equation was found most suitable (shown in Figure 2) as a result of which the following relation was found between UCS and PLT.

$$UCS = 11.142 I_{s50} - 1.9478 \quad (3)$$

The Equation 3 presents a linear relation between UCS and I_{s50}, the R^2 value for this relation stands at 83% which indicates the presence of a pretty strong relationship between point load index strength and unconfined compressive strength for the limestone of Nammal Formation.

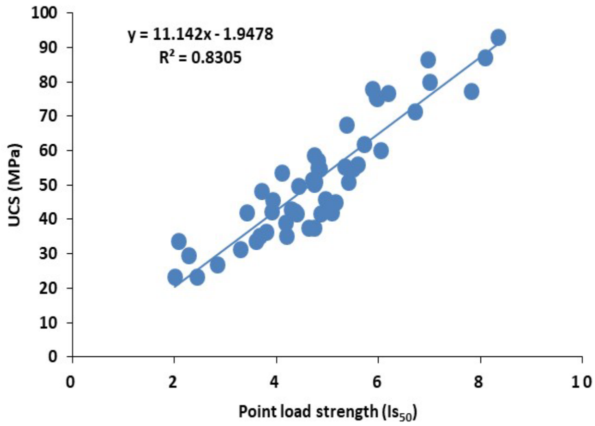

Fig. 7 Correlation between UCS and Point load strength Index (Is50)

F and T-tests are frequently used to check the fitness of the independent and dependent variable in regression equation respectively. Critical values for f and t were calculated using a 95% confidence level and 48 degrees of freedom and found to be 4.04 and 2.01 respectively given in Table 3. To pass the test both f and t values obtained with regression analysis should be greater than the respective critical values. It can be seen from Table 3 that f and t-test have been passed for the correlation equation between UCS and PLI which suggest that this correlation is significant.

Table 3. Regression Statistics of UCST with PLT and SRHT.

Regression Statistics	UCS vs PLT	UCS vs SRHT
Multiple R	0.86	0.72
R Square	0.74	0.51
Adjusted R Square	0.74	0.50
Standard Error	8.70	11.96
Observations	50.00	50.00
F-value	137.74	50.23
F Critical	4.04	4.04
t Stat	11.74	7.09
P-value	1.03E-15	5.40E-09
T critical	2.01	2.01

UCS vs. SRHT

Those 50 test results of UCS were combined with the relevant results of Schmidt rebound number to assess the correlations between the two. Equation 4 gives the linear curve fitting relationship between Schmidt rebound number and UCS's scatter as shown in (8).

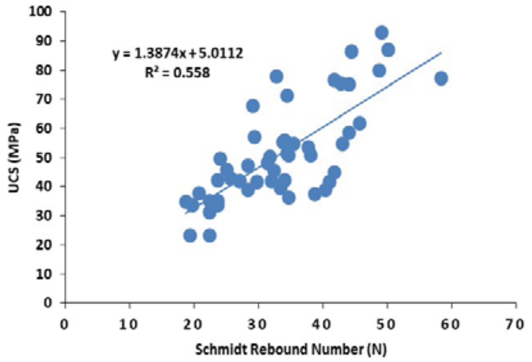

Fig. 8 Correlation between UCS and Schmidt Rebound Number (N).

$$UCS = 1.387455N + 5.0112 \quad (4)$$

The value of the coefficient of determination is 55% for this correlation which is not as good as was observed for the UCS and IS50. It, however, suggests the presence of a reasonable correlation. From Table 3 the values of f and t stat are greater than the critical values, which show that this correlation is also significant.

Table 4. T-Test: Paired two sample for means.

	UCS (Predicted by SRHT)	*UCS (Predicted by PLI)*	*Actual UCS*
Mean	51.82	51.82	52.02
Variance	133.89	200.63	286.83
Observations	50.00	50.00	50.00
Pearson Correlation	0.72	0.86	
df	49.00	49.00	
t Stat	-0.12	-0.16	
P(T<=t) one-tail	0.45	0.44	
t Critical one-tail	1.68	1.68	
P(T<=t) two-tail	0.91	0.87	
t Critical two-tail	2.01	2.01	

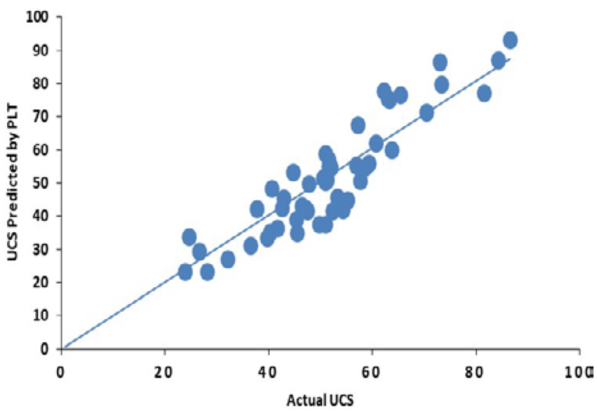

Fig. 9 Actual UCS versus predicted UCS from Equation 3.

Paired t-test for Predicted UCS and Actual UCS

In statistics, paired sample t-test is used to compare means of the two models in the case of two samples that are correlated. The paired sample t-test with a 95% confidence level was used to analyze the difference between actual UCS and predicted UCS values from SRHT and PLT (Table 4). The values of t Stat -0.12 for Equation 3 and -0.16 for equation 4 is well within t critical two-tail range i.e. ±2.01. The P-value for both the equations is greater than the 0.05 (95% confidence level), also the difference between actual and predicted means is very small. Hence, this is concluded that there is no significant difference between actual UCS and predicted UCS values.

Estimation capability of resultant equations

Actual values of UCS and predicted values of UCS by SRHT and PLT are plotted using zero intercepts shown in Figure 9 & Figure 10 to check the estimation capabilities of the resultant equations. The data points lying on the zero-intercept line indicates exact estimation while the points away from the zero-intercept line show error in estimation. In Figure 4 the data points are more or less uniformly distributed along the zero-intercept line which indicates that the two models are reasonably the same. The prediction of UCS from SRHT is less reliable and the data points are relatively more scattered in Figure 10.

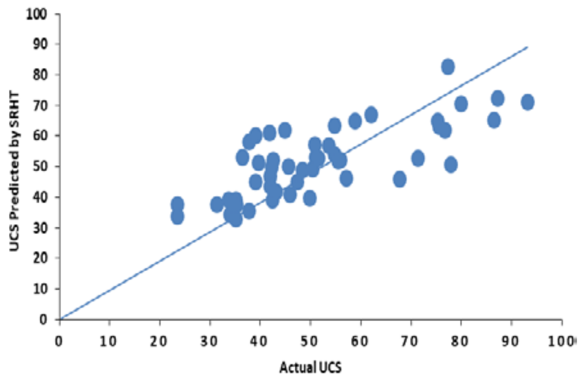

Fig. 10 Actual UCS versus predicted UCS from Equation 4.

Conclusion

Based upon this study, it is safe to conclude that a strong correlation with significant reliability (R^2=83%) occurs between Diametrical Point Load Strength (I_{S50}) and Unconfined Compressive Strength (UCS) for middle Eocene, Nammal Formation in Central Salt Range of Pakistan, thus the PLT method can be used with pretty degree of certainty to predict the UCS value for the Limestone of the aforementioned formation. The more convenient Schmidt Rebound Hammer Test, however, should be used to predict the UCS with some caution for the rock type under discussion as the study shows that the degree of reliability is not very high (R^2=55%). Both regression statistics and paired t-test suggest that these relations are significant and can be used to predict UCS for limestone of Nammal Formation. In future, the research results can play and provide an important reference for the design and construction of any project in the study area.

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