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Correlation of Schmidt Hammer Rebound Numbers with Ultrasonic Pulse Velocity and Slake Durability Index of Dolomitic Limestone of Khyber, North Pakistan

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Abstract: The ultrasonic pulse velocity and slake durability index are the indirect techniques used widely for rock strength determination. Various experimental studies like slake durability apparatus, ultrasonic pulse velocity and Schmidt hammer have been conducted on dolomitic limestone. The correlation of Schmidt hammer rebound number has been developed with these properties. The uniaxial compressive strength has been determined using the correlated rebound number. Statistical analyses were conducted and the most suitable models were recommended. The linear model was suited in correlation of Schmidt hammer and durability while exponential model appeared best fit with pulse velocity. Most of the tested samples show pulse velocity in the range of 1800-3800m/s. The mean value of pulse velocity was 2751 m/s while the rebound hammer value was 45. Using the correlations from literature the compressive strength calculated by rebound hammer and pulse velocity was 146MPa and 66MPa respectively.

Keywords: Schmidt hammer, ultrasonic pulse velocity, slake durability index, dolomitic limestone.

Introduction

The compressive strength of rock is the key parameter being extensively used in surface and subsurface geotechnical projects. An indirect and nondestructive method is Schmidt hammer to predict quality of the rocks in the field as well as in laboratory. It provides a quick response to determine the physio-mechanical behavior of the rock. It was reported that for the intact rock the Schmidt hammer rebound value (N) is an index to predict uniaxial compressive strength (Haramy and DeMarco, 1985). Schmidt hammer rebound value is an indirect and nondestructive alternative of many geotechnical parameters with a suitable correlation (Singh et al, 1983). The other indirect methods of rock strength analysis are slaking durability index (SDI), and Ultrasonic pulse velocity (UPV). These are time consuming (Sharma and Singh, 2008). Whereas, Schmidt hammer is another non-destructive method for determining the hardness and strength properties Yagiz (2009). Schmidt hammer was originally developed for determination of the strength of concrete (Jones, 1970), However, today it is extensively used for determining the strength of rocks (Kolaiti and Papadopoulos, 1993). It contains spring-loaded piston with the hammer and the impact of piston has transfered the energy of the material. The energy is the measure of hardness of the material (Aydin, 2008). The another indirect method is the slake durability, which has a fundamental importance in rock mass (Franklin and Chandra, 1972). The SDI is an important engineering property used in rock engineering to extend the mean resistance (Koncagül and Santi, 1999). In most of the deterioration in rock, quality materializes after a new surface is uncovered (Latham et al., 2006). In such special situations, an index is required. A very good durability index was proposed by Franklin and Chandra (Franklin and Chandra, 1972). The UPV is another indirect technique for rock strengthening which is useful to determine the mechanical properties and elastic properties of the rock mass. It is an indirect method to find the strength of rock mass (Khandelwal and Singh, 2009). This parameter is also used to determine the degree of fissuring of rock (Kelsall et al, 1986). The SDI and UPV are very crucial for underground excavations (Sharma et al, 2011). This index helps to control both artificial and natural slope (Fereidooni & Khajevand, 2018). The SDI indicate the swelling and squeezing characteristics of rocks in tunneling (Klein, 2001). The rapid changes in the rock mass due to weathering is also determined by this index (Irfan & Dearman, 1978). The SDI depends upon slaking cycles. The SDI value decreased with increasing slaking cycles (Koncagül & Santi, 1999). Tuğrul and Zarif, (1999) stated that the mineral composition in the rock controls the slake durability. Dhakal et al. (2002) the mineralogy increased the weathering and it, decreased the slake durability. Gupta and Ahmed stated that grain size has a significant effect on durability (Gupta & Ahmed, 2007b). Fine-grain limestone is more susceptible to degradation than coarse-grained (Gupta & Ahmed, 2007a). Sharma and Singh (2010) studied the correlation of N and SDI and suggested linear model.

The study aims to develop an empirical relation of N value, with SDI and UPV of dolomitic limestone of the Khyber region of Hunza Gilgit, Pakistan (Fig. 1). A high value of the coefficient of correlation has been found for the trust worthiness of the equations. Since the N value is a quick strength determination property, so these relations are user-friendly.

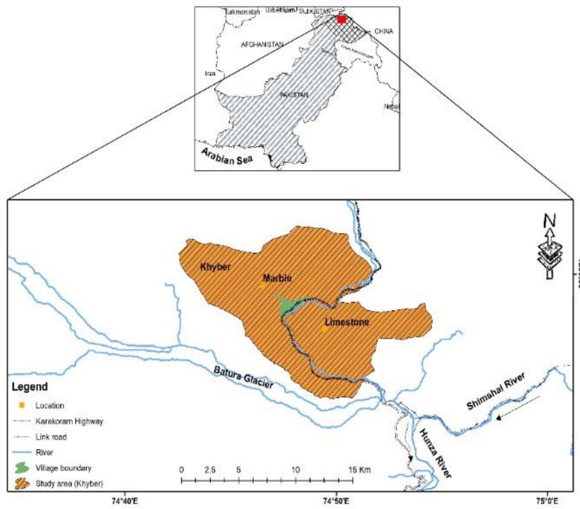

Fig. 1: Map of the study area

Material and Methods

Geological and Schmidt hammer rebound number values were collected from the field using ASTM-D5873 (Vellone and Merguerian, 2010). Average of 10 tests (N value) were conducted on each rock surfaces using Schmidt hammer apparatus. According to ASTM-D2845 (Basu and Aydin, 2005) a pulse velocity tester apparatus was used to determine the UPV, it is composed of impedance matched electronic component and a shielded lead. The wave velocity has been determined from the drill core samples, while the polished surface of the sample is fixed with smooth and airtight probes to minimize the loss of waves from the transmitter. Distance between the probes is measured and wave velocity is calculated using equation 1.

$$UPV = \frac{L}{T} \qquad (1)$$

Where T is the time travel of the pulse wave through the length of specimen L.

Franklin and Chandra (Franklin and Chandra, 1972) proposed slake durability index test method and it is followed in this study. As per ASTM standards, each sample weighing from 50g-60g was considered giving a total weight of 500g. Initially specimens have been dried in oven over a period of 10 minutes and the weight was recorded as W_1. The samples were further tested in slake durability apparatus for almost 10 minutes and the revolution time was constant for each SDI test. After the revolution time the samples were dried and the reading recorded its weight as W_2. First cycle slake durability was calculated as:

$$DI1 = \frac{W2}{W1}100 \qquad (2)$$

The same procedures were repeated and the second cycle of SDI was calculated as,

$$SDI2 = \frac{W3}{W1}100 \qquad (3)$$

The detail schematic diagram of the methodology is shown in Fig. 2.

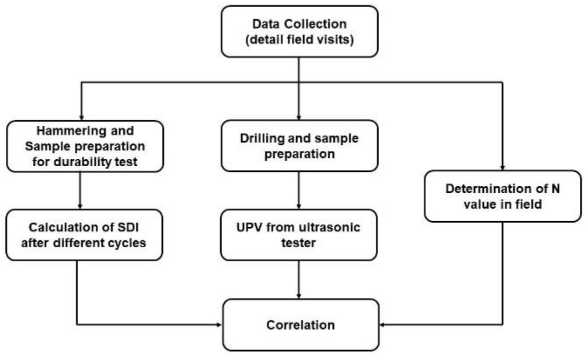

Fig. 2: Schematic diagram of experimental setup

Results and Discussion

The Schmidt hammer reading were noted in field as well as in laboratory. From the same samples, SDI and UPV were also recorded. The durability and pulse velocity are then correlated with Schmidt hammer rebound value and finally the UCS was computed from each test. The UCS determined by UPV is slightly less than the UCS directly found from Schmidt hammer reading. The correlations and statistical analyses are presented in the section below.

Correlation of pulse velocity and Schmidt hammer rebound number

The results of correlations pulse velocity tester and Schmidt hammer rebound number (Fig. 3). The average value of UPV for dolomitic limestone were 2.75km/s. The Schmidt hammer rebound average value was 45. Different correlation models were tested using SPSS software. The exponential model was the best suited in correlation of N and UPV, shown in equation 4. The R^2 with 0 value shows no correlation while R^2 greater than 0.5 indicate a good correlation. In the exponential model it was 0.939, hence the correlation is strong.

$$UPV = 1507e^{0.0127N} \qquad (4)$$

Table 1 Descriptive statistics of N and UPV

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
UPV	21	1856.13	3800.00	2751.30	121.577	557.136	310401.345
N	21	20.00	67.00	45.80	3.411	15.635	244.462

Table 2. Descriptive statistics of N and SDI

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
N	21	20.00	67.00	45	3.411	15.63	244.4
SDI	21	96.56	99.46	97.98	0.2018	0.921	0.856

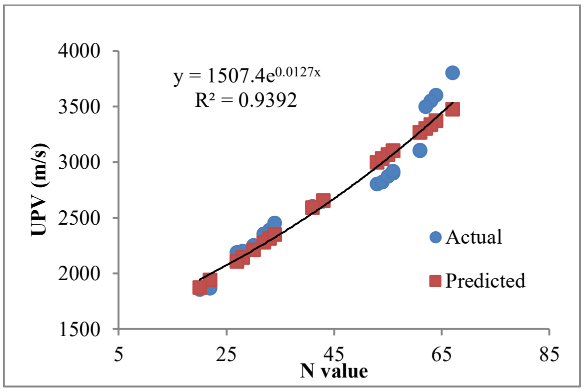

Fig. 3: Relation of N value with UPV

The pulse velocity of limestone reported by E. Vasaneli was 2000-3800 m/s (Vasanelli, et al., 2015). In this study, most of the data show value below 3800 m/s. The pulse velocity value of the studied dolomitic limestone ranges from 1800m/s-3800m/s. The low value is because of greater percentage of limestone and the cracks which are mostly visible during coring. Whereas samples showing high value of UPV indicates more percentage of dolomite over limestone. The very low value of UPV may be due to weathering, and the presence of micro cracks in the rock mass.

The slake durability index is also a non-destructive method of determining uniaxial compressive strength through indirect testing. This parameter is also correlated with Schmidt hammer rebound value. The best suited model in this case is linear with 0.958 R^2 value. The average SDI was 97.8%. The SDI value decreased with increasing cycles. Figure 4 represents the correlation between Schmidt hammer rebound values (N) and slake durability index (SDI). The descriptive statistics of the SDI and N are given in Table 2.

$$SDI = 0.0579N + 95.329 \quad (5)$$

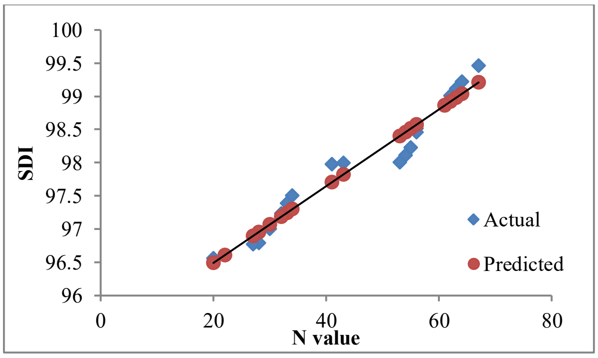

Fig. 4: Relation of N value with SDI

The UCS value were determined from different correlations of rebound and pulse velocity shown in Table 3. The UCS value determined from each correlation is not constant. Hence, based on rock type and geological conditions specific correlations are recommended. A single correlation may not be suitable for all rock types.

Table 3 Correlation of UCS with UPV and N

Correlations	UCS (MPa)	R
$UCS = 16.73UPV + 21.25$	66	0.9
$UCS = 10.57\ UPV - 19$	9.5	0.8
$UCS = 0.045UPV + 24.3$	24.4	0.81
$UCS = 20.39UPV - 25$	30	0.67
$UCS = 0.49N - 6$	22.05	0.9
$UCS = 2N$	90	0.94

Statistical Analyses

The model summary and the estimates of parameters of durability and pulse velocity with N are shown (Table 4,5). Two models linear and exponential are suitable for slaking durability and Schmidt hammer rebound number with the same correlation coefficient of 0.958. While only exponential model is suggested in the correlation of UPV with N value.

Table 4. Model Summary and Parameter Estimates of durability and N

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Linear	0.958	433.401	1	19	.000	95.329	.058
Exponential	0.958	438.773	1	19	.000	95.359	.001

Table 5. Model Summary and Parameter Estimates of pulse velocity and N

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Linear	.915	204.684	1	19	.000	1189.822	34.086
Exponential	.939	293.394	1	19	.000	1507.432	.013

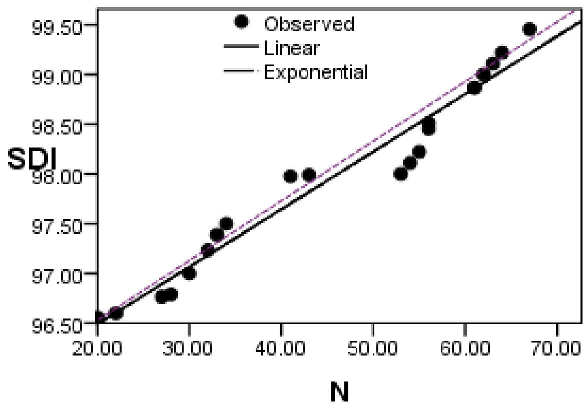

Fig. 5 Correlation models for SDI and N

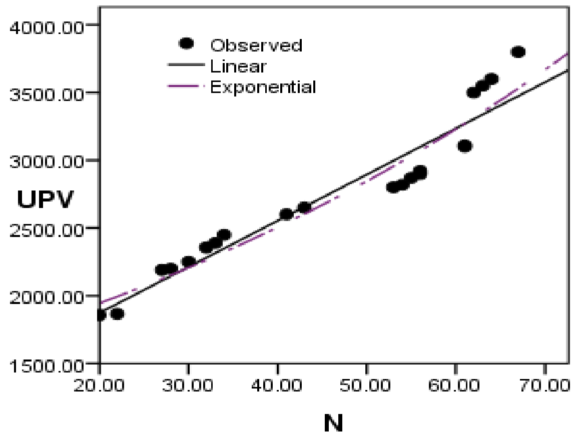

Fig. 6: Correlation models of UPV and N

To check the reliability of N value with SDI and UPV t-test was conducted using the below equation,

$$t = \frac{\sum D}{\sqrt{\frac{n\sum D^2 - (\sum D)^2}{n-1}}} \quad (6)$$

Where variable D is difference of two means, n is number of observations and n-1 is called degree of freedom.

The Value of t is considered as positive if the first mean is larger than the second value. The correlation is considered significant if the computed value of t is larger than the tabulated value. For reliable and significant results a risk level called alpha level must be achieved. The alpha value of 0.05, or 95 percent confidence interval, is commonly used. The calculated and tabulated value of t is shown in Table 6. The estimated value is bigger than the tabular value in both circumstances. As a result, the developed equations have a significant high association. These attributes can now be determined using the obtained equations based on the N value.

Table 6. Statistical analyses of t-test

Rock Test	**t-test**	
	Tabulated	calculated
Rebound number and UPV	2.08	9.95
Rebound number and SDI	2.086	16

Conclusion

The Uniaxial compressive strength is the key parameter in designing surface and subsurface projects. Laboratory testing and sample preparation are required to estimate the rock strength. To avoid time consumption and provide a number of convenient ways some indirect methods are also recommended. The conclusion of the some indirect methods are presented below.

The slake durability index and pulse velocity depends on rock type and can be correlated with Schmidt hammer rebound value. The best fit lines of durability index and pulse velocity with Schmidt hammer are,

$SDI = 0.0579N + 95.329$ $\quad R^2 = 0.958$

$UPV = 1507e^{0.0127N}$ $\quad R^2 = 0.9392$

The UPV values of the dolomitic limestone range from 1800-3800m/s, whereas the slake durability value ranges from 96-99%. Some dominant cracks were also seen in core samples, resulting in low value of pulse velocity. Core samples of high fractures record high time of pulses. The UCS value ranges from 66MPa 146MPa from UPV and N, respectively. A single correlation may not be suitable for all rock types. Based on geological conditions all rock types should be treated separately, otherwise indirect methods may not be suitable for assessing uniaxial compressive strength.

References

Aydin, A. (2008). ISRM suggested method for determination of the Schmidt hammer rebound hardness: revised version. *The ISRM Suggested Methods for Rock Characterization, Testing and Monitoring*: 2007-2014, 25-33.

Basu, A., & Aydin, A. (2005). Evaluation of ultrasonic testing in rock material characterization. *Geotechnical Testing Journal,* **29**(2), 117-125.

Dhakal, G., Yoneda, T., Kato, M., & Kaneko, K. (2002). Slake durability and mineralogical properties of some pyroclastic and sedimentary rocks. *Engineering Geology*, **65**(1), 31-45.

Fereidooni, D., & Khajevand, R. (2018). Correlations Between Slake-Durability Index and Engineering Properties of Some Travertine Samples Under Wetting–Drying Cycles. *Geotechnical and Geological Engineering,* **36**(2), 1071-1089.

Franklin, J. A., & Chandra, R. (1972). The slake-durability test. In *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts,* **9**(3),325-328.

Gupta, V., & Ahmed, I. (2007a). The effect of pH of water and mineralogical properties on the slake durability (degradability) of different rocks from the Lesser Himalaya, India. *Engineering Geology,* **95**(3-4), 79-87.

Gupta, V., & Ahmed, I. (2007b). Geotechnical characteristics of Surabhi Resort landslide in Mussoorie, Garhwal Himalaya, India. *Himalayan Geology,* **28**(2), 21-32.

Haramy, K. Y., & DeMarco, M. J. (1985). Use of the Schmidt hammer for rock and coal testing. In *The 26th US Symposium on Rock Mechanics* (USRMS). OnePetro.

Irfan, T. Y., & Dearman, W. R. (1978). Engineering classification and index properties of a weathered granite. *Bulletin of the International Association of Engineering Geology-Bulletin de l'Association Internationale de Géologie de l'Ingénieur,* **17**(1), 79-90.

Jones, R. (1970). 1 A review of the non-destructive testing of concrete *Non-destructive testing of concrete and timber* (pp. 1-7): Thomas Telford Publishing.

Kelsall, P. C., Watters, R. J., & Franzone, J. G. (1986, June). Engineering characterization of fissured, weathered dolerite and vesicular basalt. In *The 27th US Symposium on Rock Mechanics* (USRMS). OnePetro.

Khandelwal, M., & Singh, T. (2009). Correlating static properties of coal measures rocks with P-wave velocity. *International Journal of Coal Geology,* **79**(1-2), 55-60.

Klein, S. (2001). An approach to the classification of weak rock for tunnel projects. In *Proceedings of the Rapid Excavation and Tunneling Conference,* 793-806.

Kolaiti, E., & Papadopoulos, Z. (1993). Evaluation of Schmidt rebound hammer testing: a critical approach. *Bulletin of the International Association of Engineering Geology-Bulletin de l'Association Internationale de Géologie de l'Ingénieur,* **48**(1), 69-76.

Koncagül, E. C., & Santi, P. M. (1999). Predicting the unconfined compressive strength of the Breathitt shale using slake durability, Shore hardness and rock structural properties. *International Journal of Rock Mechanics and Mining Sciences,* **36**(2), 139-153.

Latham, J.P., Lienhart, D., & Dupray, S. (2006). Rock quality, durability and service life prediction of armourstone. *Engineering Geology,* **87**(1-2), 122-140.

Sharma, P., Khandelwal, M., & Singh, T. (2011). A correlation between Schmidt hammer rebound numbers with impact strength index, slake durability index and P-wave velocity. *International Journal of Earth Sciences,* **100**(1), 189-195.

Sharma, P., & Singh, T. (2008). A correlation between P-wave velocity, impact strength index, slake durability index and uniaxial compressive strength. *Bulletin of Engineering Geology and the Environment,* **67**(1), 17-22.

Sharma, P., & Singh, T. (2010). Reply to discussion by N. Arıoğlu, G. Kurt and E. Arıoğlu (DOI: 10.1007/s10064-010-0261-7) on the paper entitled "A correlation between P-wave velocity, impact strength index, slake durability index and uniaxial compressive strength" by PK Sharma and TN Singh. *Bulletin of Engineering Geology and the Environment,* **69**(3), 503-504.

Singh, R., Hassani, F. P., & Elkington, P. A. S. (1983). The application of strength and deformation index testing to the stability assessment of coal measures excavations. In *The 24th US Symposium on Rock Mechanics (USRMS).* OnePetro.

Tuğrul, A., & Zarif, I. (1999). Correlation of mineralogical and textural characteristics with engineering properties of selected granitic rocks from Turkey. *Engineering Geology,* **51**(4), 303-317.

Vasanelli, E., Colangiuli, D., Calia, A., Sileo, M., & Aiello, M. A. (2015). Ultrasonic pulse velocity for the evaluation of physical and mechanical properties of a highly porous building limestone. *Ultrasonics,* **60**, 33-40.

Vellone, D. A., & Merguerian, C. (2010). Measuring Engineering Properties of NYC Rocks using a Schmidt Rebound Hammer Preliminary Results.

Yagiz, S. (2009). Predicting uniaxial compressive strength, modulus of elasticity and index properties of rocks using the Schmidt hammer. *Bulletin of Engineering Geology and the Environment,* **68**(1), 55-63.