

# Characterisation and Index Properties Correlations for Marlstone and Marly Limestone of Saudi Arabia

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**Abstract** - It has been a common practice to estimate the Unconfined Compressive strength (UCS) of rock through correlations that relate it to other index parameters such as the Brazilian Tensile Strength (BTS) and the Ultrasonic Pulse Velocity  $V_p$ ; nonetheless, selecting the most appropriate equation to use has always been a challenge considering the heterogeneity of rocks and their variant behaviour. Therefore, the use of equations which are especially developed for certain rock type at a specific location is recommended. This paper suggests 3 equations to predict UCS from BTS, bulk density ( $\rho$ ) and  $V_p$  for marlstone of the Eastern Province of Saudi Arabia. 35 core samples are collected and tested in the laboratory for UCS, BTS and  $V_p$ . Statistical analysis is performed on the experimental results, and subsequently 3 statistical models that relate BTS,  $V_p$ , and rock bulk density  $\rho$  to UCS are developed. Corrected correlation coefficients of the three models are found to be 0.575, 0.663, and 0.641, respectively. Additional reliable equation that relate the bulk density to  $V_p$  is produced with a corrected correlation coefficient of 0.95.

**Keywords:** Unconfined Compressive Strength, Indirect Tensile Strength, Ultrasonic Pulse Velocity, Marlstone

## 1. Introduction

Unconfined Compressive Strength (UCS) is an indispensable parameter that has been commonly used in the analysis of geotechnical problems such as tunnelling, slope stability, and blasting. Determination of UCS through direct approach as standardised by the American Society for Testing and Materials [1], and International Society for Rock Mechanics [2] can be time-consuming, costly, and occasionally difficult to perform especially when adequate number of samples is not available, or when coring in weathered rock where proper samples cannot be extracted [3]–[6]. As a result, estimating UCS indirectly through correlations that relate index parameters like indirect tensile strength, ultrasonic pulse velocity, and rebound number (RN) of Schmidt Hammer became widely accepted due to the low cost, easiness, mobility, and short time associated with performing these tests. Quite a number of such correlations do exist in the literature; nevertheless, it is always difficult to make a decision on the most appropriate equation to use. Rocks are heterogeneous, and their behaviour varies from location to another; hence, one equation cannot be generalised. This study suggests three equations to estimate UCS from indirect tensile strength, bulk density and ultrasonic pulse velocity based on the experimental program conducted on marlstone and marly limestone samples obtained from the Eastern Province of Saudi Arabia.

## 2. Previous Studies

It is well-established that the BTS and other index parameters such as  $V_p$  are related to UCS. Selcuk and Nar, 2016 [7] stated that predicting UCS from ultrasonic pulse velocity test only may not be accurate. They reported that different factors control the ultrasonic velocity, like discontinuities, moisture content, and micro cracks, which affect the reliability of the results. Therefore, the authors conducted both ultrasonic pulse velocity and Schmidt hammer tests on 42 samples of rocks including marlstone obtained from different locations in Turkey. Their statistical analysis yielded 4 equations. Karaman et al, 2015 [8] conducted a study on 47 rock samples from Black Sea region. The samples were tested for UCS, BTS and Triaxial compressive strength and an equation was created that relate indirect tensile strength to UCS. Azimian et al, 2013 [9] performed UCS, ultrasonic pulse and point load tests on 40 Marl rock samples obtained from Shiraz, Iran. They reported 8 different relationships between UCS and P-wave velocity. The authors compared their generated equations with

previous studies, and found some differences due to the fact that marlstone was not sufficiently studied by researchers. In other words, their equations are applicable only to marlstones. They pointed out that ultrasonic velocity equations give good results for the velocities in the range 1145.67 to 3959.18 *m/s*. Further, very low or very high velocity may give poor estimation for UCS. Another study was conducted by Abdul-Jabbar, 2011 [10]. He evaluated the UCS, ultrasonic pulse velocity and point load index tests results of 57 rock samples obtained from Taq Taq dam, Iraq. The study yielded 2 equations that correlate the UCS with point load and ultrasonic pulse velocity. Table 1 summarises some of the recent studies.

Table 1: Summary of recent correlations between UCS and  $V_p$ , BTS, and RN.

No	Rock type	Equation	R or R <sup>2</sup>	Reference
1	Igneous rocks	$UCS = 11.8 - 29.75V_p + 7.11V_p^2 + 1.43RN$	R = 0.940	Selcuk and Nar [7]
2	Marlstone	$UCS = 19.34 * V_p^{1.21} - 17.88$	R <sup>2</sup> = 0.850	Shahri et al. [11]
3	Different rock types	$UCS = 24.301 + 4.874 BTS$	R <sup>2</sup> = 0.900	Karaman et al. [8]
4	Marlstone	$UCS = 0.026 * V_p - 20.207$	R <sup>2</sup> = 0.909	Azimian et al. [9]
		$UCS = 59.59 * \ln(V_p) - 418.67$	R <sup>2</sup> = 0.850	
		$UCS = 0.0004 * V_p^{1.4812}$	R <sup>2</sup> = 0.902	
		$UCS = 8.5078 * e^{0.0006V_p}$	R <sup>2</sup> = 0.880	
5	Marlstone	$UCS = 0.0353V_p - 48.748$	R <sup>2</sup> = 0.610	Hosseini et al. [12]
6	Conglomerate	$UCS = 0.005V_p$	R = 0.940	Minaeian and Ahangari [13]
7	Different rock types	$UCS(MPa) = 10.61BTS$	R <sup>2</sup> = 0.500	Kahraman et al. [14]
8	Different rock types	$UCS = 0.258 V_p^{3.543}$	R = 0.920	Yagiz, [15]
9	Different rock types	$UCS (MPa) = 5.364 V_p$	R <sup>2</sup> = 0.80	Abdul-Jabbar [10]
10	Different rock types	$UCS (MPa) = 12.38 BTS^{1.0725}$	R = 0.890	Altindag and Guney [16]
11	Sandstone, limestone and cement mortar	$UCS = 56.71 V_p - 192.93$	R = 0.810	Cobanglu and Celik [17]

### 3. Methodology

#### 3.1. Sample Collection

Marlstone and marly limestone rock types were selected for this study. Rock samples were collected from different locations within the Eastern Province of Saudi Arabia. A total of 43 rock cores were extracted. Extreme caution was exercised during sampling so as to obtain high-quality cores.

#### 3.2. Sample Preparation

Rock cores were cut to the recommended test size in accordance with ASTM standards [18]–[20]. It is important to point out that Brazilian test was used to obtain the indirect tensile strength. Samples were carefully trimmed to ensure level surface while testing (Figure 1). Rock cores that could not withstand those with noticeable



Fig. 1: Prepared rock samples ready for testing.

flaws and fractures were excluded. All rock samples were oven-dried in preparation for conducting tests at zero moisture content.

### 3.3. Experimental Work:

Following the oven-drying of rock samples, ultrasonic pulse velocity was measured for all samples that yet to be tested for UCS. Moreover, the dry density was also determined for UCS and BTS samples. Afterwards, samples were tested for both UCS and BTS in accordance with ASTM standards [18]–[20]. At this stage, it was difficult to maintain a constant strain rate during the tests. Therefore, both tests were performed under specific stress rates as per ASTM standards [18]–[20]. For UCS test, a stress rate of 0.8 MPa was maintained while a stress rate of 0.2 MPa was sustained for the BTS test.

### 3.4. Tests Results

Results of the laboratory tests are summarised in Table 2.

Table 2: Summary of laboratory test results.

No.	Unconfined Compressive Strength and Ultrasonic Pulse Velocity Tests			Brazilian Test	
	$\rho$ ( $g/cm^3$ )	UCS (MPa)	$V_p$ (m/s)	$\rho$ ( $g/cm^3$ )	BTS (MPa)
1	2.416	35.503	4043.956	2.348	1.913
2	2.345	32.332	3655.556	2.268	4.094
3	2.406	34.412	4063.830	2.400	2.578
4	2.412	44.462	3882.353	2.374	2.205
5	2.320	21.129	3391.304	2.406	2.478
6	2.341	25.927	3413.870	2.390	3.136
7	2.375	14.004	4182.320	2.285	0.671
8	2.389	14.168	3776.808	2.395	2.807
9	2.396	27.719	3854.061	2.155	0.432
10	2.447	28.378	4293.103	2.223	2.729
11	2.349	28.769	3386.062	2.208	1.571
12	2.413	19.440	3923.077	2.239	1.575
13	2.384	32.744	3735.000	2.491	1.573
14	2.455	71.522	4102.981	2.432	1.680
15	2.404	41.187	3882.353	2.295	0.664

Table 2 (Cont'd): Summary of laboratory test results.

No.	Unconfined Compressive Strength and Ultrasonic Pulse Velocity Tests			Brazilian Test	
	$\rho$ ( $g/cm^3$ )	UCS (MPa)	$V_p$ (m/s)	$\rho$ ( $g/cm^3$ )	BTS (MPa)
16	2.275	19.626	3283.505	2.098	1.684
17	2.202	6.363	3072.619	2.551	3.154
18	2.426	20.017	3938.080	2.547	3.639
19	2.467	22.015	4341.297	2.411	2.293
20	1.614	5.128	1757.997	1.643	0.832
21	1.493	4.531	2038.710	1.631	1.557
22	1.718	8.299	1944.357	1.764	1.098
23	1.712	6.919	1939.778	1.464	0.752
24	1.655	2.142	1785.814	1.708	1.448

25	1.666	5.849	1510.155	1.724	1.361
26	1.645	5.478	1794.721	1.596	0.961
27	1.575	3.892	1129.812	1.472	0.703
28	1.609	3.810	1307.930	1.575	0.896
29	1.686	6.240	1731.259	1.788	0.852
30	2.040	1.668	2566.735	2.130	0.785
31	1.832	4.860	1852.459	1.743	0.446
32	1.871	5.210	1915.408	1.966	0.752
33	1.907	5.498	1894.891	1.868	0.339
34	1.859	15.280	2389.610	1.890	1.660
35	1.966	7.908	1479.561	1.907	0.302

### 3.5. Statistical Analysis and Discussion

As can be seen in Table 2 above, UCS value of the tested marlstone samples ranges between 1.67 and 71.52 MPa, BTS between 0.3 and 4.09 MPa, while  $V_p$  ranges from 1129.81 to 4341.3 m/s.

Statistical analysis is performed on the data obtained from the laboratory experiments using SPSS Statistics v.23. Four prediction models are produced to correlate the UCS and pulse velocity with different parameters as shown in Table 3. The level of significance for all models is 0.05. In other words, the level of confidence is 95%. The type of model is chosen so that best-fit prediction based on the correlation coefficient value is yielded. Magnitudes of the correlation coefficients can be interpreted as displayed in Table 4 [21].

Table 3: Prediction Models.

No	Model	Adjusted Correlation Coefficient ( $R^2$ )	Type of Model
1	$UCS = 0.299 \times e^{(1.8823 \times \rho)}$	0.641	Exponential
2	$UCS = \ln(2.5644 \times e^{(0.005 \times V_p)})$	0.663	Exponential
3	$UCS = BTS^{-0.01} + V_p^{0.511} - 38.319$	0.575	Linear
4	$V_p = 3468.353\rho^2 - 11085.754\rho + 10529.713$	0.950	Quadratic
<b>Notes</b>	Units: UCS is in MPa, $\rho$ is in $g/cm^3$ , $V_p$ is in m/s, BTS is in MPa		

Table 4: Interpretation of correlation coefficient value [21].

Correlation Coefficient	Interpretation
0.90 – 1.0	Very high correlation
0.70 to < 0.90	High correlation
0.50 to < 0.70	Moderate correlation
0.30 to < 0.50	Low correlation
0.00 to < 0.30	Negligible correlation

As shown in Tables 3 and 4, the correlation coefficients range from 0.575 to 0.950 which yields moderate to very high correlations. The moderate correlation level of models (1, 2, and 3) can be attributed to the heterogeneity of these particular rock types which affects the UCS values markedly. Equation 4 proves that bulk density is well-related to ultrasonic pulse velocity; the higher the density, the higher the pulse velocity. Correlation coefficient  $R^2$  value for equations (1) and (2) (0.641 and 0.663, respectively) are close to those reported by Hosseini et al. [12], while other researchers like Ghazviniyan et al. and Kahraman [4], [22] reported even lower values. It should be pointed out that all of these studies were conducted on marlstone. Figure 2 illustrates the reliability of suggested correlation in comparison with previous studies.

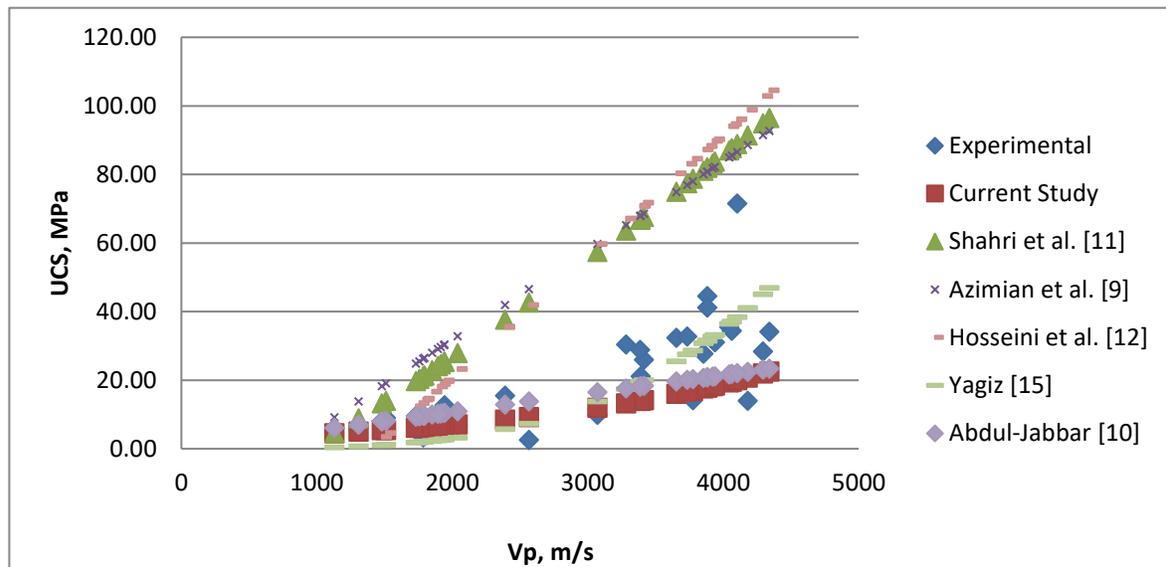


Fig. 2: Reliability of suggested correlation compared to previous similar studies.

#### 4. Conclusion

A total number of 35 marlstone and marly limestone core samples collected from a different locations within Eastern Province of Saudi Arabia were tested for unconfined compressive strength, Brazilian tensile strength, and ultrasonic pulse velocity. Statistical analysis was performed on the test results, and subsequently, three equations with an acceptable degree of accuracy were generated for estimation of UCS from bulk density, ultrasonic pulse velocity, and both Brazilian tensile strength and ultrasonic pulse velocity, respectively. Correlation coefficients  $R^2$  of the three equations were found to be 0.641, 0.663, and 0.575, respectively. An additional equation for prediction of ultrasonic pulse velocity from bulk density with high reliability and degree of accuracy ( $R^2 = 0.95$ ) was also produced. Generally, suggested UCS equations are in good agreement with other studies conducted on marlstone.

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