Correlation between Uniaxial Compressive Strength and Point Load Index for Salt-Range Rocks

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Abstract

Nine rock types including Sandstone, Limestone, Siltstone, Dolomite and Marl collected from six different rock formations of the Salt Range area of Pakistan were tested to evaluate the correlations between the uniaxial compressive strength and the corresponding values of the point load index. Two hundred rock cores were drilled and used for the uniaxial compressive strength and point load index tests. Results indicate the existence of two rock groups showing distinct behaviour in the context of this correlation. The first group of rocks, Group A, consists of hard Jutana Sandstone, Baghanwala Sandstone, Siltstone, Sakessar Massive Limestone, Khewra Sandstone and Dolomite. The second group of rocks, Group B, consists of relatively soft Dandot Sandstone, Sakessar Nodular Limestone and Marl. The correlation equations for predicting compressive strength using point load index for each group are presented along with their confidence limits to show the variability of results produced from each equation.

Key Words: Uniaxial Compressive Strength; Point load Index; Confidence limits.

1. Introduction

Rock engineers widely use the uniaxial compressive strength (UCS) of rocks in designing surface and underground structures. The procedure for measuring this rock strength has been standardized by both the International Society for Rock Mechanics [1] and American Society for Testing and Materials [2]. The method is time consuming and expensive. Indirect tests such as Point Load Index ($I_{s(50)}$) are used to predict the UCS. These tests are easier to carry out because they necessitate less or no sample preparation and the testing equipment is less sophisticated. Also, they can be used easily in the field.

Index to strength conversion factors have been proposed by a number of researchers and have been found to be rock dependent [3]. There is no reported research in this regard for local rocks in Pakistan. The rationale of the study presented herein is to evaluate the indirect methods of estimating the uniaxial compressive strength of specific rock types of Salt Range. For this purpose nine rock types including Sandstone, Limestone, Siltstone, Dolomite and Marl collected from six different rock formations of the Salt Range were tested to evaluate the correlations between the UCS test results and the corresponding test results of $I_{s(50)}$. The data was analyzed statistically to determine the degree of correlation and the variability of results.

2. Previous Investigations

The point load test has been reported as an indirect measure of the compressive or tensile strength of the rock. D'Andrea et al.[4] performed uniaxial compression and the point load tests on a variety of rocks. They found the following linear regression model to correlate the UCS and $I_{s(50)}$.

$$q_u = 16.3 + 15.3\ I_{s(50)}$$

where

q_u = Uniaxial Compressive Strength of rock.
$I_{s(50)}$ =Point Load Index for 50 mm diameter core.

Broch and Franklin [5] reported that for 50 mm diameter cores the uniaxial compressive strength is approximately equal to 24 times the point load index. They also developed a size correction chart so that core of various diameters could be used for strength determination.

$$UCS = 24\ I_{s(50)}$$

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Bieniawski [6] suggested the following approximate relation between UCS, I_s and the core diameter (D).

$$UCS = (14 + 0.175\ D)\ I_{s(50)}$$

Pells [7] showed that the index-to-strength conversion factor of 24 can lead to 20 % error in the prediction of compressive strength for rocks such as Dolerite, Norite and Pyroxenite.

According to ISRM commission on Standardization of Laboratory and Field Test report [8], the compressive strength is 20-25 times I_s. However, it is also reported that in tests on many different rock types the range varied between 15 and 50, especially for anisotropic rocks. So errors up to 100 % should be expected if an arbitrary ratio value is chosen to predict compressive strength from point load tests.

Hassani et al. [9] performed the point load test on large specimens and revised the size correlation chart commonly used to reference point load values from cores with differing diameters to the standard size of 50 mm. With this new correction, they found the ratio of UCS to $I_{s(50)}$ to be approximately 29.

Brook [10] emphasized the possible sources of error when using the point load test, and proposed an analytical method of “Size Correction” to a chosen standard size. The formula containing the “Size Correction Factor”, f, is:

$$I_{s(50)} = f.\ F/\ D^2_e$$

Where

$$f=(D_e/50)^{0.45}$$

and

- F = Applied Load.
- D_e = Equivalent Core Diameter.
- f = Size Correction Factor.

The dependence of the UCS versus $I_{s(50)}$ correlation on rock types was demonstrated by Cargill and Shakoor [11]. They found the following correlation equation:

$$q_u = 13 + 23\ \ I_{s(50)}$$

Chau and Wong [12] proposed a simple analytical formula for the calculation of the UCS based on corrected I_s to a specimen diameter of 50 mm $I_{s(50)}$. The index-to-strength conversion factor (k) relating UCS to $I_{s(50)}$ was reported to depend on the compressive to tensile strength ratio, the Poisson’s ratio, the length and the diameter of the rock specimen. Their theoretical prediction for k=14.9 was reasonably close to the experimental observation k = 12.5 for Hong Kong rocks.

Rusnak and Mark [13] reported the following relations for different rocks:

For coal measure rocks:

$$qu= 23.62\ I_{s(50)} - 2.69$$

For other rocks:

$$qu= 8.41\ I_{s(50)} + 9.51$$

Fener et al. [3] reported the following relation between Point load index and UCS:

$$qu= 9.08\ I_s + 39.32$$

3. Research Methodology

3.1 Sample Collection

The rock samples for this study were collected from the Salt Range area shown in Figure 1. A total of nine rock types from six different rock formations were sampled and tested for this study. Sampling has been done from the Choa Saiden Shah to Khewra road side section and the Khewra Gorge section. The rock type, age and formation names of the samples are given in Table 1. An attempt was made to collect rock blocks that were large enough to obtain all of the test specimens of a given rock type from the

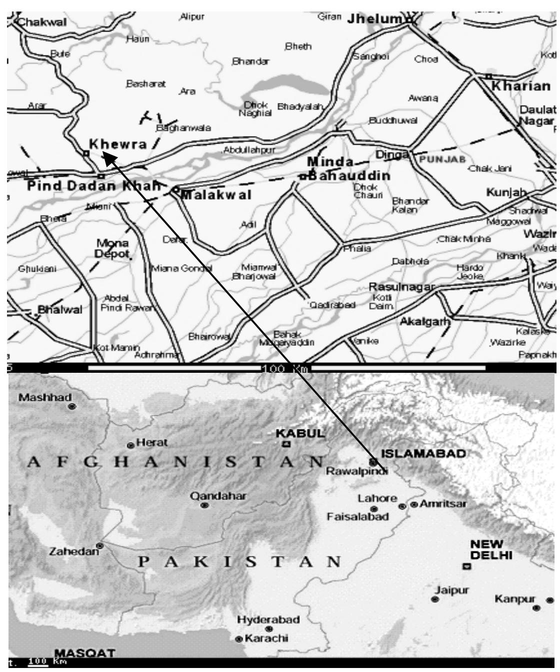

Figure 1: Location of the Study Area

Table 1: Sampled Rock Types

Rock Type	Age	Formation	Rock Description
Sandstone	Permian	Dandot	Fine grains interlocked with each other, with siliceous and micaceous cements, light grey.
Sandstone	Cambrian	Jutana	Medium fine grained deposited in clay matrix, highly micaceous, slightly pyretic, medium hardness, dark grey to brown.
Sandstone	Cambrian	Baghanwala	Very fine grained, hard and compact, slightly pyretic, multi coloured rock, cream, pink, light to dark brown.
Siltstone	Permian	Tobra	Slightly metamorphosed, very hard and compact, light grey in colour with thin films of iron oxide.
Nodular Limestone	Early Eocene	Sakessar	Hard and compact, light cream in colour, containing a number of micro and macro fossils.
Massive Limestone	Early Eocene	Sakessar	Very hard and compact, cream to slightly grey, slightly micaceous.
Sandstone	Cambrian	Khewra	Medium grained, hard and compact, dark red , slightly micaceous.
Calcareous Marl	Late-Precambrian	Salt Range	Soft, dark brown to red, embedded in caly matrix.
Dolomite	Cambrian	Jutana	Hard and compact, light pale to off-white, clay partings at places.

same block. Each block was inspected for macroscopic flaws so that it would provide test specimens free from fractures, joints or partings.

3.2 Sample Preparation

Rock blocks were cored in the laboratory using 54 mm, 42 mm and 30 mm diameter diamond coring bits. A total of 200 rock cores were drilled and the samples with cracks or flaws were excluded from further analysis. The trimming and lapping of the rock cores was done in accordance with the ISRM [1] guidelines.

3.3 Test Procedures

The uniaxial compressive strength test was performed in accordance with ISRM suggested methods [1]. The Shimadzu 200 tons universal testing machine was used for testing (Figure 2). All core samples for this test were drilled perpendicular to bedding, had a minimum length- to-diameter ratio of 2, and met the strict tolerance limits as specified in the suggested test procedure.

The point load test was performed in accordance with the procedure described by Broch and Franklin [5] and standardized by ISRM [14]. Digital Point Load test apparatus, model 45-D0550/D, made by Controls, England was used for Point Load testing of the rock samples (Figure 3). The core samples were diametrically loaded during the test. Samples of three different diameters 54 mm, 42 mm and 30 mm were used for this purpose. Corrections were applied to calculate the equivalent diameters for samples other than 54mm in diameter.

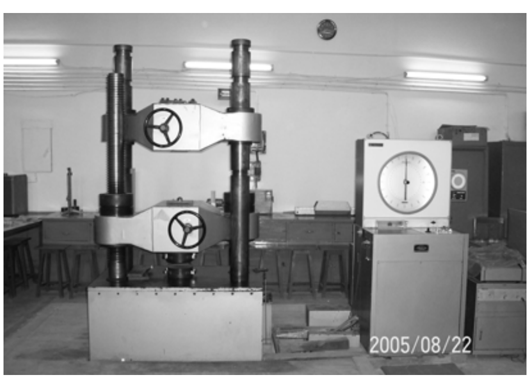

Figure 2: Shimadzu 200 tons Universal Testing Machine.

Figure 3: Digital Point Load Test Apparatus.

3.3 Statistical Analysis

The variability of results for each test and rock type was evaluated by determining the coefficient of variation. This statistical parameter is calculated by dividing the standard deviation by the mean and expressing it as a percentage.

The results of the uniaxial compression test were correlated with strength index test results using the method of least squares regression analysis. The equations of the best fit curves, the 95% confidence limits, and the correlation coefficients (R^2) were determined for each case. These equations could be used to predict the uniaxial compressive strength from the results of the point load test.

4. Test Results and Discussion

4.1 Uniaxial Compressive Strength Test Results

The mean values of uniaxial compressive strength of the tested rocks are listed in Table 2. The strength values range from a low of 9.16 MPa for Marl to a high of 101.08 MPa for Sakessar Massive Limestone. The coefficient of variation ranges from 10.3 % to 37.7%.

4.2 Point Load Test Results

The results of the point load test are given in Table 3. The point load strength index values range from 0.36 MPa for the Jutana Sandstone to 5.24 MPa for the Dandot Sandstone. The coefficient of variation ranges from 5.3 % for Dandot Sandstone to 60.7% for Jutana Dolomite. Broch and Franklin [5] report that the point load test results are less scattered as compared to the UCS test results, whereas Bieniawski [6] reports just the opposite. The scatter in the coefficient of variation observed in this study is due to the difference in the rock lithology of tested samples.

Table 2: Results of the Uniaxial Compression Test

Rock Type	UCS (MPa)	Standard Deviation (MPa)	Coefficient of Variation (%)	95% Confidence Intervals (MPa)
Dandot Sandstone	57.24	10.557	18.4	36.55 to 77.93
Jutana Sandstone	25.75	2.65	10.3	20.56 to 30.94
Baghanwala Sandstone	51.33	14.37	28.0	23.16 to 79.50
Khewra Sandstone	43.42	12.17	28.0	19.57 to 67.27
Sakessar Nodular Limestone	40.23	10.98	27.3	18.71 to 61.75
Sakessar Massive Limestone	101.08	17.38	17.2	67.02 to 135.14
Siltstone	98.07	17.59	17.9	63.59 to 132.55
Marl	9.16	2.39	26.1	4.48 to 13.84
Jutana Dolomite	33.13	12.506	37.7	8.62 to 57.64

Table 3: Results of the Point Load Test

Rock Type	$I_{s(50)}$ (MPa)	Standard Deviation (MPa)	Coefficient of Variation (%)
Dandot Sandstone	5.24	0.28	5.3
Jutana Sandstone	0.36	0.04	11.1
Baghanwala Sandstone	1.35	0.18	13.3
Khewra Sandstone	1.51	0.40	26.5
Sakessar Nodular Limestone	3.59	0.37	10.3
Sakessar Massive Limestone	3.69	0.68	18.4
Siltstone	3.46	1.00	28.9
Marl	0.80	0.10	12.5
Jutana Dolomite	1.07	0.65	60.7

4.3 Analysis of UCS and $I_{s(50)}$ Results

By plotting UCS against $I_{s(50)}$ it was found that there are two major rock groups showing distinct trend (Figure 4). The two rock groups identified are listed in Table 4. The UCS of the Group A rocks is plotted against the $I_{s(50)}$ of the Group A rocks and the plot of the same is given in Figure 5. The UCS of the Group B rocks is plotted against the $I_{s(50)}$ of the Group B rocks and the plot of the same is given in Figure 6.

The curves for the two rock groups are the best fit lines as determined by regression analysis [15]. The correlation equations for Group A rocks and Group B rocks are given below as equations 1 and 2 respectively.

$$UCS = 22.792 I_{s(50)} + 13.295 \quad (1)$$

$$UCS = 11.076\ I_{s(50)} \quad (2)$$

4.4 Estimation Accuracy

To check the estimation accuracy of the derived equations (Equations 1, 2), the concept of "Confidence Interval" was utilized [13]. For normally distributed data, the 95% CI of the mean is expressed as:

$$CI_{95\%} = 1.96 \times \frac{SD}{\sqrt{n}}$$

Where

SD = Standard Deviation.
n = Number of tests conducted.

The mean, standard deviation and 95% confidence interval of the UCS values for all the nine rock types were calculated. The point load index $I_{s(50)}$ values were measured and converted to UCS values using the derived correlation equations established as a result of this work. By looking at the UCS range computed from the derived equations, it can be realized that all the UCS values computed from prediction Equations 1 and 2 lie within the 95% confidence interval which validates the estimation of the prediction equations (Table 5).

Table 4: Rock Groups Identified by Scatter Plot of UCS and $I_{s(50)}$

Rock Group A	Rock Group B
Jutana Sandstone.	Dandot Sandstone
Baghanwala Sandstone	Sakessar Nodular Limestone
Siltstone	Marl
Sakessar Massive Limestone	
Khewra Sandstone	
Dolomite	

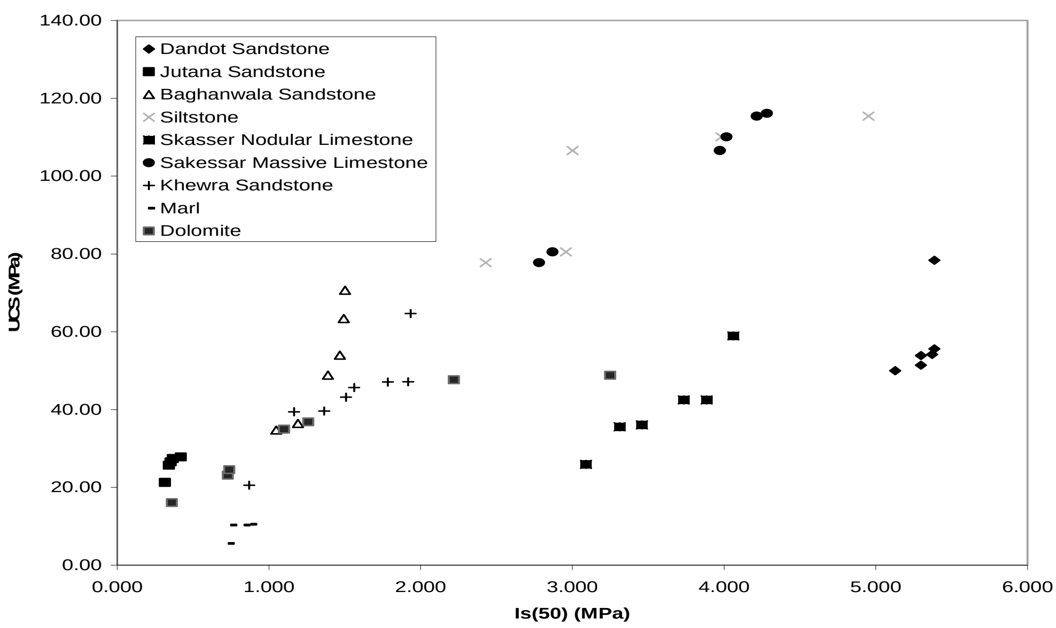

Figure 4: Scatter Plot of UCS against $I_{s(50)}$ for all the Tested Rocks

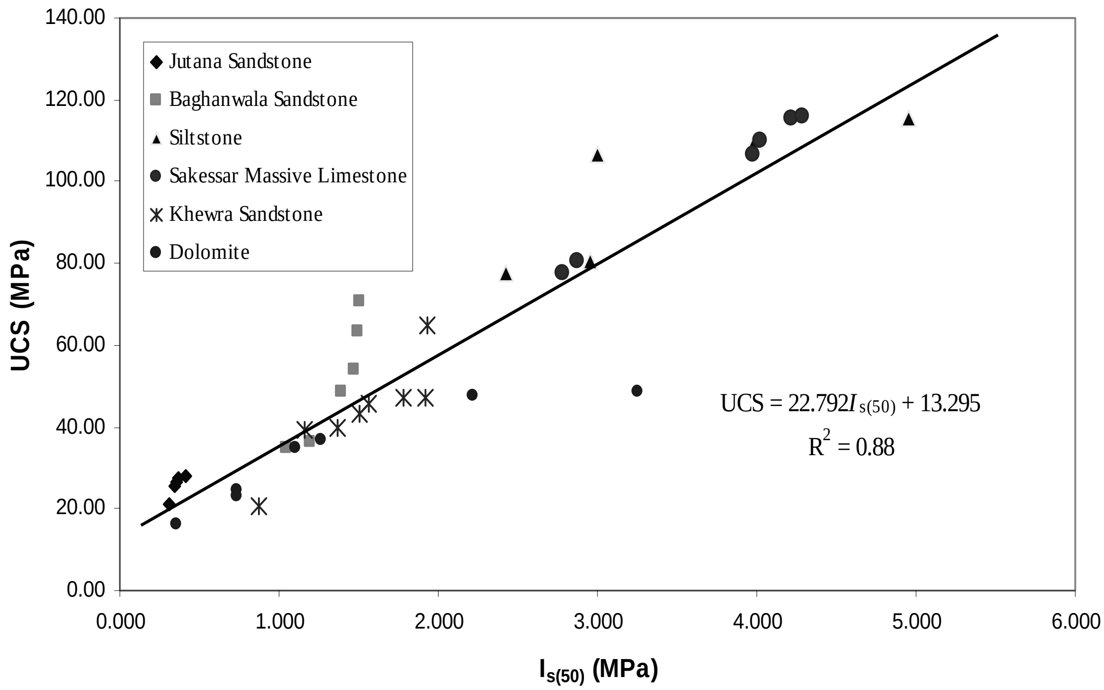

Figure 5: Relation between UCS and $I_{s(50)}$ for Group A Rocks

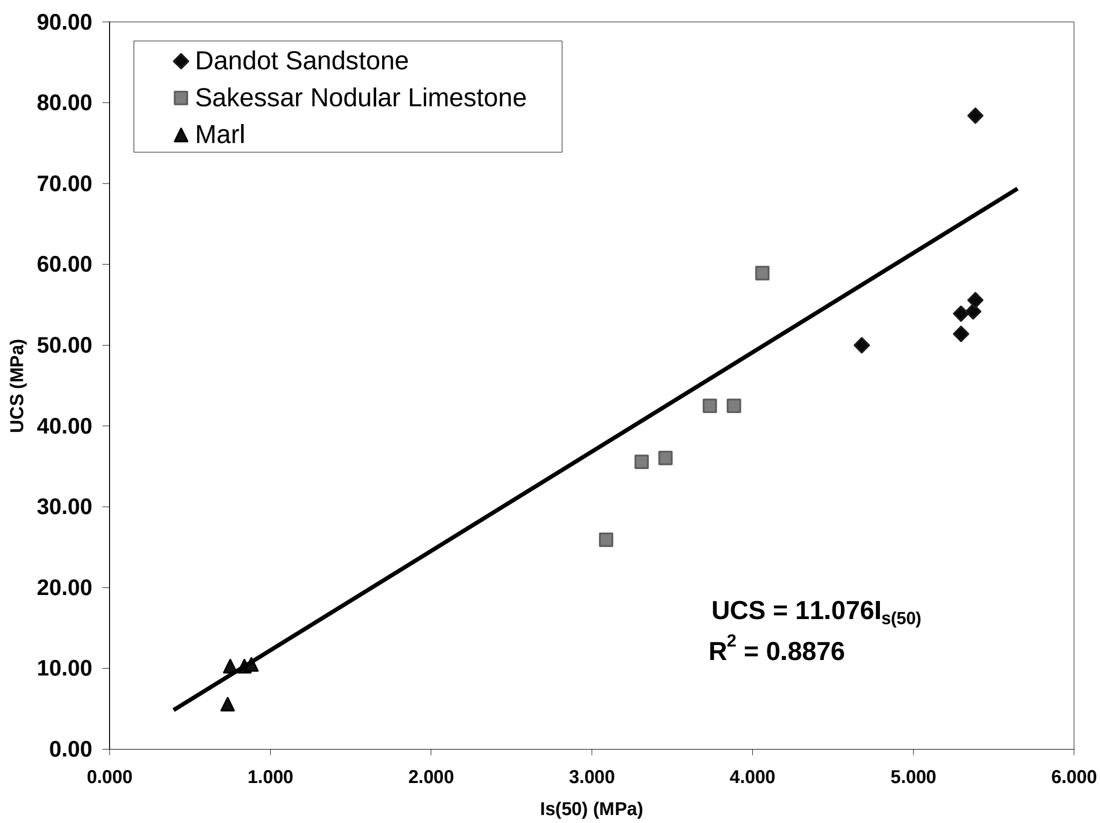

Figure 6: Relation between UCS and $I_{s(50)}$ for Group B Rocks

Table 5: Validation of Equations 1 and 2.

Sample No.	x = $I_{s(50)}$ (MPa)	y = 22.792x + 13.295 Where y = UCS (MPa) (Group A)	y = 11.076x Where y = UCS (MPa) (Group B)
Dandot Sandstone			
1	5.56	-	61.58
2	5.65	-	62.58
3	5.61	-	62.14
4	5.78	-	64.02
5	5.47	-	60.59
6	4.81	-	53.28
7	5.39	-	59.70
Jutana Sandstone			
1	0.309	20.34	-
2	0.397	22.35	-
3	0.309	20.34	-
4	0.288	19.87	-
Baghanwala Sandstone			
1	0.865	33.01	-
2	1.363	44.35	-
3	0.786	31.21	-
4	1.834	55.10	-
5	2.306	65.86	-
6	1.740	52.94	-
7	1.651	50.92	-
Siltstone			
1	2.472	69.64	-
2	1.987	58.57	-
3	2.914	79.70	-
Sakessar Nodular Limestone			
1	2.961	-	32.80
2	2.649	-	29.34
3	2.607	-	28.88
4	3.719	-	41.20
5	3.627	-	40.17
6	2.913	-	32.27
Sakessar Massive Limestone			
1	4.659	119.48	-
2	3.018	82.07	-
3	3.927	102.80	-
4	3.090	83.73	-
5	2.649	73.67	-
6	3.111	84.20	-
Khewra Sandstone			
1	1.189	40.40	-
2	1.402	45.26	-
3	1.243	41.62	-
4	1.598	49.71	-
5	1.615	50.11	-
Marl			
1	0.746	-	8.26
2	0.865	-	9.58
3	0.943	-	10.45
4	0.618	-	6.84
5	0.784	-	8.68
Dolomite			
1	0.84	32.44	-
2	1.20	40.65	-
3	0.78	31.07	-
4	3.28	88.05	-
5	2.28	65.26	-
6	1.39	44.98	-
7	0..89	33.58	-

5. Conclusions

The uniaxial compressive strength tests and point load tests were carried out on nine rock types of Salt Range. The test results were analyzed using least square regression analysis and predictive equations for compressive strength were developed. The UCS was found to be correlated with $I_{s(50)}$ through a linear relationship having slope of 22.792 and intercept of 13.295 for Jutana Sandstone, Baghanwala Sandstone, Siltstone, Sakessar Massive Limestone, Khewra Sandstone and Dolomite (Group A rocks). The UCS versus $I_{s(50)}$ correlation for Dandot Sandstone, Sakessar Nodular Limestone and Marl (Group B rocks) was also found to be linear but with a slope of 11.076 and zero intercept. This study confirms that the UCS estimation equations are rock dependent. The equations developed as a result of this study may be checked further for validation and improved by a comprehensive testing programme suggested to be extended to other rock formations of Salt-Range.

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