**A comparative study of the procedures for point load index test in predicting the uniaxial compressive strength of rocks**

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# Abstract

The point load index (PLI) test is one of the most frequently applied indirect methods in predicting the uniaxial compressive strength (UCS). Depending on the rock sample shape, the PLI test is performed in four procedures: axial, diametrical, block, and irregular lump tests. The present research aims to conduct a comparative study on the accuracy of these four procedures in predicting the UCS and evaluate the effect of density (ρ) and porosity (n) on the correlation between UCS and PLI. For this purpose, 15 different sandstone samples were collected from north Khorramabad, west of Iran. Some sandstone specimens were prepared for ρ, n, UCS, and PLI tests. Results indicated that PLI procedures have different accuracies in predicting the UCS, such that axial and irregular lump tests have the highest (R2 = 0.85) and the lowest (R2 = 0.70) accuracies, respectively. Moreover, the results of multivariate regression analysis revealed that ρ compared to n have a more important effect on the correlation between UCS and PLI (R2 = 0.87 and 0.92, respectively).

**Keywords:** Density, Point load index; Porosity, Sandstone; Uniaxial compressive strength

# 1. Introduction

Rock strength is among the fundamental properties to evaluate the site suitability of geotechnical projects such as dams, tunnels, mining, and slope stability. In this regard, uniaxial compressive strength (UCS) is the most important strength property of rocks used in the design of geotechnical projects. Lack of accurate measurement of this property can lead to design errors, damaging the geotechnical project (Heidari et al., 2012). According to standards such as the International Society for Rock Mechanics (ISRM 1981) and the American Society for Testing and Materials (ASTM 1986), performing the UCS test requires having rock samples with appropriate dimensions. However, in many cases, such as layered sedimentary rocks, metamorphic rocks with schistosity, and highly weathered rocks, it is impossible to obtain standard-sized rock samples for UCS testing (Jamshidi et al., 2016). Hence, indirect methods such as PLI, Brazilian tensile strength (BTS), and ultrasonic wave velocity (Vp) are used for predicting the UCS. Certainly, these methods are for the initial assessment of UCS in geotechnical projects. Therefore, obtaining reliable results for a specific site needs to carry out a series of UCS tests to calibrate the indirect methods.

The PLI test is one of the most common indirect methods for predicting the UCS. This test is very popular among rock and geotechnical engineers owing to its simplicity and quickness (Azimian and Ajalloeian 2015). Regarding the portability of the PLI test device, it can be used in both laboratory and field conditions.

So far, several studies have been conducted on correlations between UCS and PLI. Some of these correlations are presented in Table 1. In this table, the determination coefficients (R2) and the correlation form are different between UCS and PLI. This difference is a function of rock type, rock sample conditions (natural, dry, or saturated), number of tests, and the procedure of UCS and PLI tests.

In PLI test, rock samples can be in the form of either core (the axial and diametrical tests), cut blocks (the block test), or irregular lumps (the irregular lump test). One of the issues that have not been considered in previous research is the accuracy of the PLI test procedures in predicting the UCS. Accordingly, in the present study, the accuracy of procedures proposed for four PLI tests (i.e., axial, diametrical, block, and irregular lump tests) in predicting the UCS for 15 different sandstone samples is investigated. This study also aims to evaluate the effect of ρ and n on the correlation between UCS and PLI.

**Table 1**

2. Materials and Methods

To achieve the research objectives, we visited sandstone outcrops in the north of Khorramabad, Lorestan province. During the visit, 15 samples of different sandstone blocks almost shape-cubic with dimensions 20 × 20 × 30 to 30 × 30 × 40 cm3 were collected. Fig. 1 illustrates the geological map and sampling location of the study area. These sandstones are widely used in Ghasem Abad and Sarab Talkh regions, north of Khorramabad, as construction materials to construct retaining walls and bridge piers (Fig. 1). After transferring the block samples to the Laboratory of Geology Engineering and Rock Mechanics at Lorestan University, the specimens were prepared for different tests using a core drill and saw machine (Fig. 2). Then, ρ, n, UCS, and PLI tests were performed on the specimens. Finally, achieved data were analyzed with two aims: 1) investigating the accuracy of the PLI test procedures in predicting the UCS and 2) Evaluating the effect of ρ and n on the correlation between UCS and PLI.

Fig. 1.

Fig. 2.

3. Results

3.1. Density (ρ) and Porosity (n) Tests

Some physical properties of the samples, including ρ and n, were determined using the saturation method following ISRM (1981). Eqs. (1) and (2) were respectively used to calculate ρ and n:

(1)

(2)

where Ms is the solid mass of the specimen, Msat is the surface-dry saturated mass, V is the bulk volume, and ρw is the density of water.

Five specimens from each sandstone sample were used, and their mean values were obtained. Based on the test results (Table 2), the samples are classified as rocks with moderate and high density (2.20-2.55 and 2.55-2.75 g/cm3, respectively) and low and medium porosity (1-5 and 5-15%, respectively) according to the classification suggested by Matula et al. (1979).

3.2. Uniaxial Compressive Strength (UCS) Test

We prepared cylindrical specimens with a diameter of 54 mm and a length to diameter ratio of 2 from sandstone blocks using a core drill machine. The ends of the specimens were smoothed and parallelized by the saw machine. Afterward, the UCS tests on the specimens were carried out according to the International Society for Rock Mechanics standard (ISRM 1981) (Fig. 3). The stress rate on the core specimens was controlled at 1 MPa/s. The maximum load at failure was applied to calculate the UCS of the specimens. Five specimens from each type of sandstone were tested, and their average was considered the UCS of the sample. The results are presented in Table 2 and graphically illustrated in Fig. 4. Studied sandstone samples were classified according to the method suggested by ISRM (2007). As shown in Fig. 4, most samples fall into the rock classes with medium strength (50-100 MPa), and the other samples are classified as having a low strength (25-50 MPa).

**Fig. 3**.

**Fig. 4**.

3.3. Point Load Index (PLI) Test

The PLI test is intended as an index test for the strength classification of rock material. It may also be used to predict other strength parameters related to it, such as UCS (Heidari et al., 2012).

To carry out the PLI test in this study, we used specimens in the shape of either core (the axial and diametral tests), cut blocks (the block test), or irregular lumps (the irregular lump test) (Fig. 5). Based on the shape of the specimen, PLI tests were performed in four procedures according to ISRM (1981): axial (PLIA), diametrical (PLD), cut block (PLIB), and irregular lump (PLIIL) tests. For each procedure, five specimens from each sandstone were used. Eventually, Eq. (3) was used to calculate the PLI:

(3)

where P is peak load and De is equivalent core diameter, which was determined as , where A = WD and W = the smallest and largest specimen width perpendicular to the loading direction (Fig. 5). For axial point load testing, D is equal to the distance between the platens at failure, and F is the size correction factor, i.e., (De/50)0.45.

The mean values of PLI tests in different procedures are presented in Table 2. The studied samples were classified based on their PLI value, according to Broch and Franklin (2007). Fig. 6 shows that most samples in terms of PLI test procedures fall into the same rock classes with very high strengths, except sandstones 3, 7, and 13 (which are classified as having high strengths).

**Table 2.**

**Fig. 5**.

**Fig. 6.**

**4. Discussion**

4.1. The correlation between UCS and PLI

Regression analyses are among the most widely accepted methods of investigating empirical relationships between rock properties (Zalooli et al., 2016; Jamshidi et al., 2021). This research tried to develop the best correlation between UCS and PLI(50) of samples to attain the most reliable empirical relation. To this end, linear (y = ax + b), power (y = axb), exponential (y = aex), and logarithmic (y = a + ln x) curve fitting approximations were executed and the best approximation correlation was determined.

The plot of the UCS as a function PLI(50) for different test procedures is drawn in Fig. 7. The equations of correlations between UCS and PLI test procedures are as follows:

**UCS** = 4.9403**PLI(50)A** + 33.034 R2 = 0.85 For axial test (4)

**UCS** = 4.8123**PLI(50)D** + 33.554 R2 = 0.80 For diametrical test (5)

**UCS** = 5.2913**PLI(50)B** + 30.780 R2 = 0.77 For cut block test (6)

**UCS** = 5.5244**PLI(50)IL** + 30.627 R2 = 0.70 For irregular lump test (7)

As shown in Fig. 7, R2 between UCS and PLI test procedures ranges from 0.70 to 0.85. The statistical significance of R2 values can be evaluated by t-test. The test compares the computed t-value with a tabulated t-value using the null hypothesis. If the computed t-value is greater than the tabulated t-value, the null hypothesis is rejected, suggesting that r is significant. A corresponding critical t-value of ±2.145 is obtained for Eqs. (4-7). It can be seen from Table 3 that all the computed t-values are greater than the tabulated t-values, suggesting the statistical significance of these equations for UCS from PLI(50).

**Fig. 7.**

The criteria for the best-fitting line are the determination coefficient (R2) and standard error of estimate (SEE) statistics. These two criteria can measure the degree of fit to a curve. R2 measures the proportion of variation in the dependent variable. Besides, SSE is an essential measure for indicating how close the measured data points fall to the estimated values on the regression curve. It is of note that a relation with the highest R2 has the smallest SEE. In general, a better relation has a higher R2 and a smaller SEE value. The results of the regression analyses are given in Table 3. As can be seen from this table, the highest (R2 = 0.85) and lowest (R2 = 0.70) values of R2 between UCS and PLI(50) was obtained based on axial (PLI(50)A) and irregular lump (PLI(50)IL) test procedures, respectively. On the other hand, the lowest (SEE = 3.43) and highest (SEE = 4.83) of the standard error of estimate, between UCS and PLI(50), was obtained based on the axial (PLI(50)A) and irregular lump (PLI(50)IL) test procedures, respectively. The values of R2 and SEE suggest that UCS can be predicted with more accuracy from PLI(50)A than other PLI test procedures. The higher accuracy of PLI(50)A for predicting the UCS can be attributed to the same loading conditions in UCS and PLI(50)A tests (which are axial), while in other PLI test procedures, i.e. Pli(50)D, PLI(50)B and PLI(50)IL, loading conditions are different. For example, in PLI(50)D test, the specimens are subjected to diametrical loading (see Fig. 5).

**Table 3**.

A comparative study with the previous researchers was carried out to verify the limitations of the earlier equations proposed by various authors with correlated UCS with PLI(50). For this purpose, the PLI(50)A observed in this study, which has the most accuracy among PLI test different procedures, was put in the equations proposed by various researchers to predict UCS. Afterward, the observed PLI(50)A was plotted versus predicted UCS. It can be seen from Fig. 8 that the UCS data predicted by Mishra and Basu (2012) (See Table 1) equation are in good agreement with those observed in this study for the UCS range of 49 to 72 MPa and PLI(50)A range of 3.5 to 6.4 MP. Meanwhile, it predicts UCS with lower and higher values than observed UCS<49 MPa and UCS>72 MPa, respectively.

As can be seen from Fig. 8, there are some differences between the observed UCS data and those predicted by the equations of Das (1985), Hawkins and Olver (1986), Ulusay et al. (1994), Rusnak and Mark (1999), Zorlu et al. (2004), and Singh et al. (2012) (Table 1) such that they give higher values compared to the observed ones.

The difference in the observed UCS in this study and predicted UCS by other researchers could be due to difference in the range of physical and mechanical properties of the samples used, the tested rock types, the sample conditions (air-dried and saturated states), number and dimensions of samples, and stress rate in UCS test.

**Fig. 8**.

4.2. The effect of ρ and n on the correlation between UCS and PLI

The multivariate regression analyses were applied to evaluate the effect of ρ and n on the correlation equation between UCS and PLI(50)A. In this analysis, UCS was considered as the dependent variable, and ρ, n, and PLI(50)A were regarded as independent variables as shown below:

UCS = β0 + β1ρ + β2PLI(50)A (8)

UCS = β0 + β1n + β2PLI(50)A (9)

where UCS is the predicted value of the uniaxial compressive strength, ρ and n are the density and porosity, respectively, PLI(50)A is the point load index in axial loading condition (axial test), β0 is a constant, and β1 and β2 are the regression coefficients.

The test results presented in Table 2 were analyzed using the SPSSv.25 statistical software. The results of these analyses are given in Table 4.

Multivariate regression equations were carried out with a 95% confidence level, and the best-fit curves were obtained between variables using the least-squares method. The analysis results given in Table 4 are expressed as Eqs. (10) and (11):

**UCS** = 81.769 – 17.693**ρ** + 4.248**PLI(50)A** R2 = 0.87 (10)

**UCS** = 62.577 – 2.018**n** + 1.6778**PLI(50)A** R2 = 0.92 (11)

R2 and SEE were used as the numerical measures of the goodness of fit for the regression equations. The R2 of Eqs. (10) and (11) are higher than 0.87, which is at an acceptable level. The SEE values for Eqs. 10 and 11 are 3.34 and 2.62, respectively (Table 4). These measures show the reliability of these Eqs. (10) and (11) for predicting UCS from ρ, n, and PLI(50)A.

The Eq. (11) derived in this study was compared with those available in the literature. For instance, Palchik and Hatzor (2004) investigated the influence of n on the relation between UCS and PLI(50) for porous chalks. They showed that the ratio UCS/ PLI(50) is not constant but is n dependent. An increase in n from 18% to 40% leads to a decrease in UCS/ PLI(50) from 18 to 8. In another study, Kahraman et al. (2005) investigated the influence of n on the relation between UCS and PLI(50) for different rock types (i.e., igneous, sedimentary, and metamorphic). These authors reported a statistically significant (but not strong) correlation between UCS and PLI(50) for all rock types. However, strong correlations were obtained when the rocks are divided into two groups according to n values (n<1% and n>1%). The slope of the regression line of the rocks having porosity values lower than 1% is much greater than that of the rocks having n values higher than 1%.

**Table 4**

The analysis of variance (ANOVA) was carried out to test the global usefulness and the significance of Eqs. (10) and (11). F statistics test is widely used in regression and analysis of variance. The null hypothesis (H0) for this test is β1 = β2= 0 while the alternative hypothesis (H1) is at least one of β1 or β2 is not equal to 0. The ANOVA results for the regressions are given in Table 4. For a significance level of 5%, the tabulated F-ratio with the degrees of freedom υ1=2 and υ2=12 is 3.89. Since the F-ratios computed for the Eqs. (10) and (11) are more significant than the tabulated F-ratios, the null hypothesis is rejected. Therefore, it can be concluded that these equations are appropriate for predicting the UCS from ρ, n, and PLI(50)A.

The results of simple and multivariate regression analyses showed that the highest determination coefficient, R2=0.92, was obtained for correlation between UCS with n and PLI(50)A (Eq. 11). On the other hand, the lowest was for correlation of UCS with ρ and PLI(50)A (Eq. 10) and correlation of UCS and PLI(50) based on the different PLI test procedures (Eqs. 4-7) with determination coefficients range of 0.70 to 0.85. As a result, Eq. (11) is the most reliable relation for predicting the UCS than Eqs. (10) and (4-7).

Although the determination coefficients (R2) of Eqs. (4-7), 10, and 11 are 0.70 to 0.92 (which are acceptable values), they do not show their validity. The regression equations proposed in this study were evaluated by comparing their results with each other. The UCS values predicted by Eqs. (4-7), 10, and 11 were then plotted versus the measured values of UCS using diagonal lines (Figs. 9-14). A point lying on the line indicates an exact estimation.

In the plots for Eq. 11 (Fig. 14), the points are scattered uniformly about the diagonal line, suggesting the reliability of the equation. However, the points in the plot for Eqs. (4-7) and (10) (Figs. 9-13) deviate somewhat from the diagonal line, suggesting some inaccuracy of the equation. Simple regression (Eqs. 4-7), as the simplest form of regression analysis, has one independent variable and one dependent variable. In this regression, the relationship between the variables is approximated by a straight line (Tumac 2015). On the other hand, multivariate regression analysis (Eqs. 10 and 11) is more amenable to ceteris paribus analysis because it allows researchers to control explicitly many other factors that simultaneously affect the dependent variables. Multivariate regression equation can accommodate many explanatory variables that may be correlated. Therefore, researchers can hope to infer causality in cases where simple regression analysis would be misleading. Hence, the multivariate regression equation outperformed the simple regression equation to determine the UCS. Also, comparing coefficients of determination and diagonal line of Eqs. (4-7), (10), and (11) revealed that Eqs. (10 and 11) are most reliable for predicting the UCS than Eqs. (4-7).

**Fig. 9.**

**Fig. 10**.

**Fig. 11.**

**Fig. 12.**

**Fig. 13.**

**Fig. 14.**

**5. Conclusions**

In the present study, 15 different sandstone samples were collected, and their ρ, n, UCS, and PLI were measured. According to data analyses, the following conclusions were obtained:

1- Based on the PLI test procedures, sandstone samples fall into different rock classes with high strengths and very high strengths.

2- Among PLI test procedures, axial test (PLI(50)A) (R2= 0.85) has more accuracy than other test procedures (i.e., diametrical (PLI(50)D), cut block (PLI(50)B), and irregular lump (PLI(50)IL), R2 = 0.80, 0.77, and 0.70, respectively) for predicting the UCS. This result can be attributed to the same loading axial conditions in UCS and PLI(50)A tests, while in other PLI test procedures, loading conditions are different.

3. The results of multivariate regression analysis revealed that ρ compared n has a stronger effect on the correlation between UCS and PLI(50) (R2 = 0.87 and 0.92, respectively).

4. The multivariate regression equations are more reliable for predicting UCS than simple regression equations.

**Compliance with Ethical Standards**

**Conflict of interest:** All authors declare that they have no conflict of interest.

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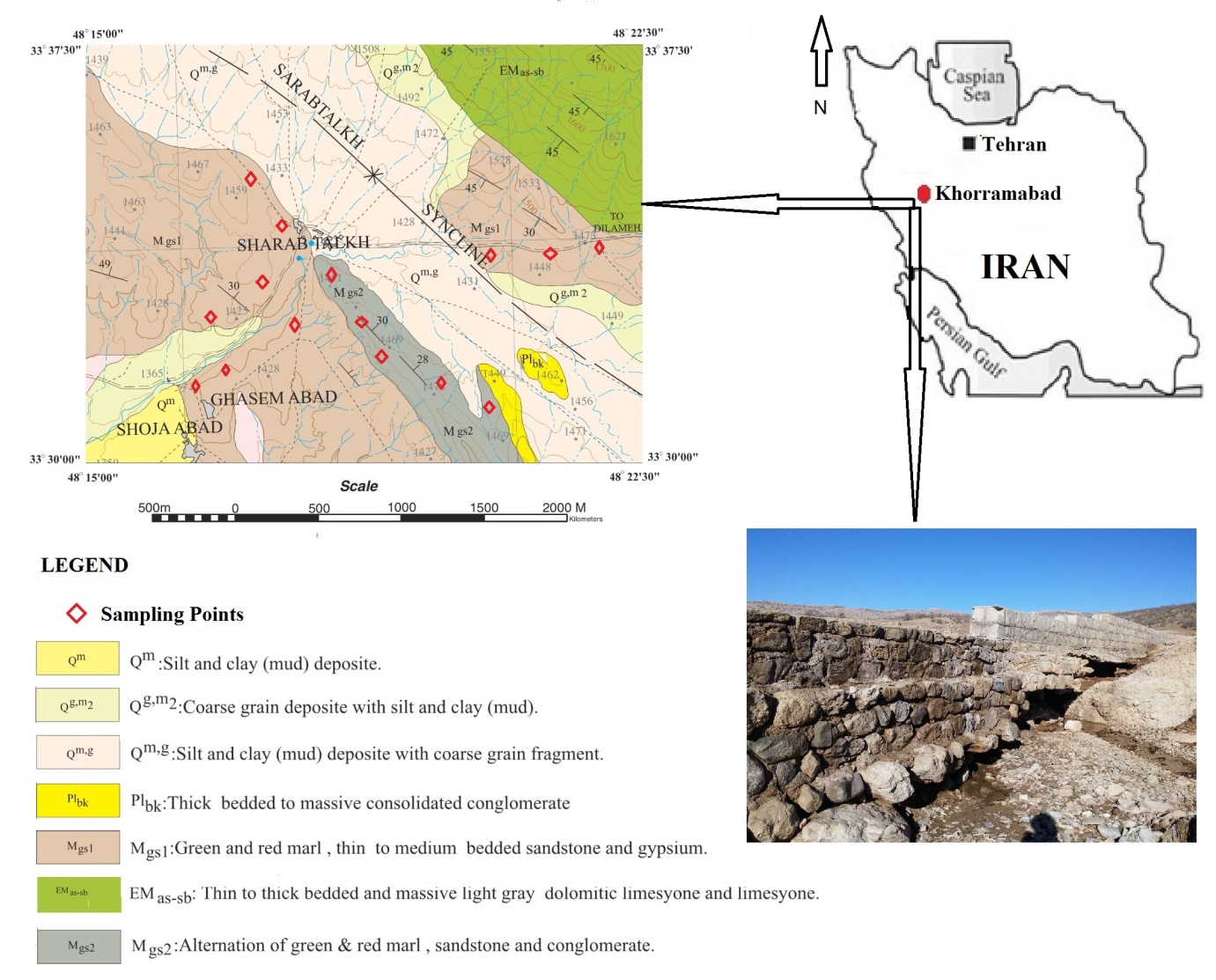


Fig. 1. Geological setting of the sampling area and sandstones under study as building material

Fig. 2. The core drill and saw machines for prepare of specimens

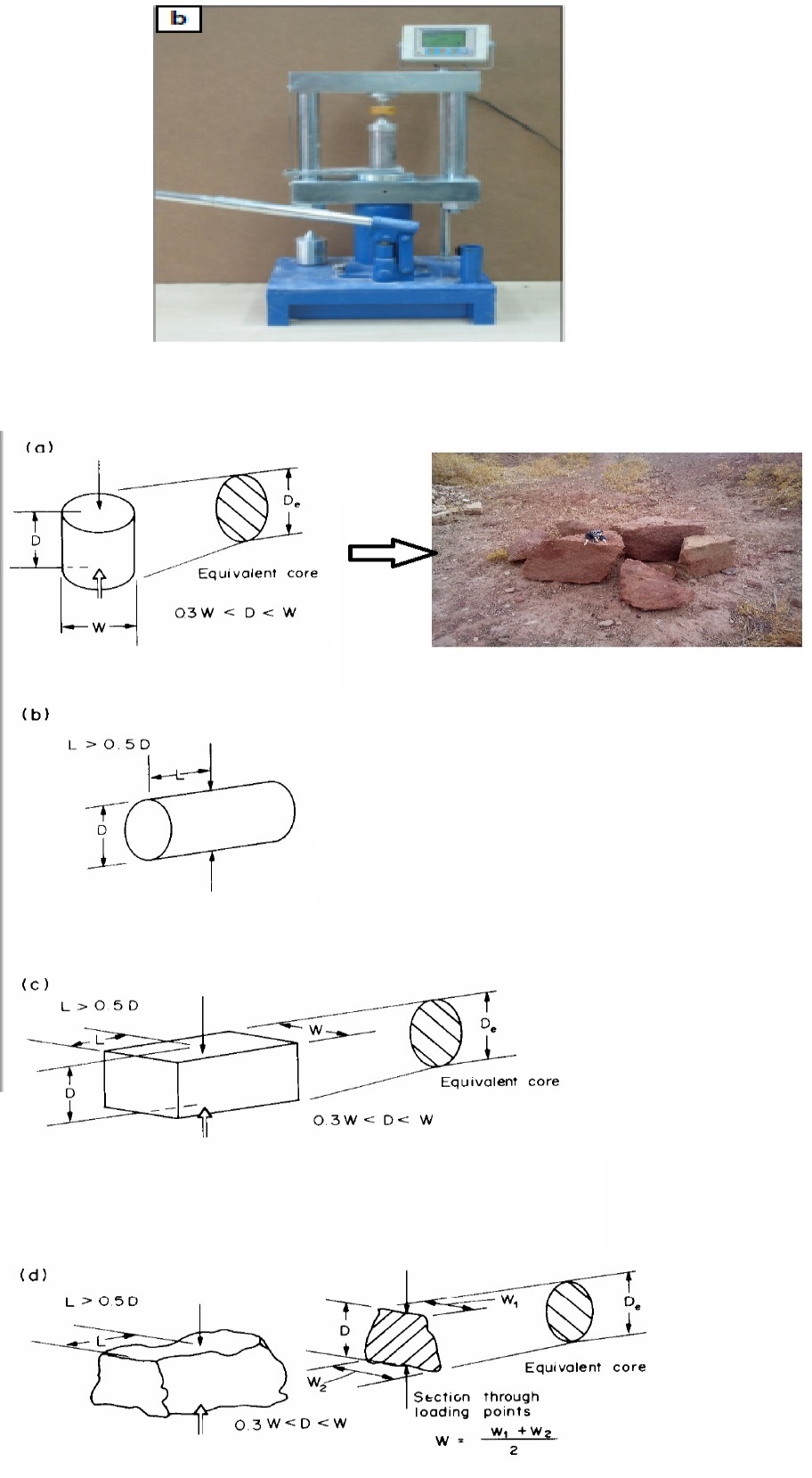
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**Fig. 3.** UCS test setup and some cylindrical specimens used for test

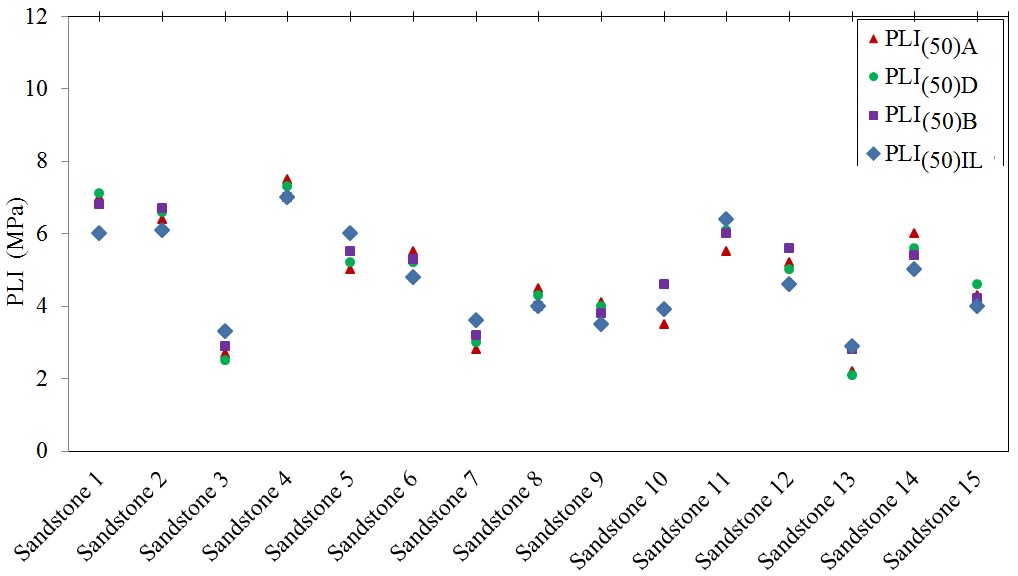
**Extremely weak strength** (UCS 0.25–1 MPa), **Very weak strength** (UCS 1–5 MPa), **Weak strength** (UCS 5–25 MPa), **Low strength** (UCS 25–50 MPa), **Medium strength** (UCS 50–100 MPa), **High strength** (UCS 100–250 MPa), **Very high strength** (UCS > 250 MPa)

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**Fig. 4.** UCS classification of samples according to ISRM (2007)



**Fig. 5.** Specimen shape requirements for PLI test a) the axial test, b) the diametrical test, c) the cut block test, and d) the irregular lump test



**Extremely high** (PLI > 10)

**Very high** (PLI = 3-10)

**High** (PLI 1-3)

**Extremely low** (PLI < 0.03); **Very low** (PLI = 0.03-0.1); **Low** (PLI = 0.1-0.3); **Medium** (PLI = 0.3-1)

**Fig. 6.** PLI(50) classification of samples according to Broch and Franklin (1972)

**a**

**b**

**c**

**d**

**Fig. 7.** UCS versus a) PLI(50)A, b) PLI(50)D), c) PLI(50)B, and d) PLI(50)IL

**Fig. 8**. The predicted UCS versus PLI(50)A: The comparison of the derived equation (Eq. 4) in this study and those obtained by other researchers

**Fig. 9.** The measured values of UCS and their predicted values from Eq. (4)

**Fig. 10.** The measured values of UCS and their predicted values from Eq. (5)

**Fig. 11.** The measured values of UCS and their predicted values from Eq. (6)

**Fig. 12.** The measured values of UCS and their predicted values from Eq. (7)

**Fig. 13.** The measured values of UCS and their predicted values from Eq. (10)

**Fig. 14.** The measured values of UCS and their predicted values from Eq. (11)

**Table 1** Correlation between UCS and PLI

|  |  |  |  |
| --- | --- | --- | --- |
| References | Rock type | Correlation equation | R2 |
| Das (1985) | Sandstones | UCS = 18 PLI(50) | - |
| Hawkins and Olver (1986) | Sandstones | UCS = 24.8 PLI(50 | - |
| Singh and Singh (1993) | Quartzite rocks | UCS = 23.37 PLI(50) | 0.96 |
| Ulusay et al. (1994) | Sandstones | UCS = 19 PLI(50)+ 12.7 | 0.81 |
| Tugrul and Zarif (1999) | Granitic rocks | UCS = 15.25 PLI(50) | 0.96 |
| Rusnak and Mark (1999) | Sandstones | UCS = 20.6 PLI(50) | - |
| Lashkaripour (2002) | Mudrocks | UCS = 21.4 PLI(50) | 0.85 |
| Zorlu et al. (2004) | Sandstones | UCS = 10.3 P PLI(50) + 28.1 | 0.76 |
| Tsiambaos and Sabatakakis (2004) | Limestones, marlstones, and sandstones | UCS = 7.3 PLI(50)1.71 | 0.82 |
| Kahraman et al. (2005) | Different rocks | UCS = 10.9 PLI(50)+ 27.4 | 0.61 |
| Fener et al. (2005) | 9 Different rocks | UCS = 9.08 PLI(50) + 39.3 | 0.72 |
| Basu and Aydin (2006) | Hong Kong granites | UCS = 21 PLI(50) | 0.93 |
| Yilmaz (2009) | 6 Different rocks | UCS = 13.3 PLI(50) + 7.43 | 0.64 |
| Yilmaz and Yuksek (2009) | Gypsum | UCS = 10.5 PLI(50) – 3.97 | 0.57 |
| Basu and Kamran (2010) | Schistose rocks | UCS = 11.1 PLI(50) + 37.7 | 0.74 |
| Singh et al. (2012) | Sandstone | UCS = 21.9 PLI(50) | 0.89 |
| Mishra and Basu (2012) | Sandstone | UCS = 13.0 PLI(50) –5.19 | 0.84 |
| Palassi and Emami (2014) | Travertine and marble | UCS = 20.1 PLI(50) – 17.1 | 0.80 |
| Azimian and Ajalloeian (2015) | Marly rocks | UCS = 56.939 ln PLI(50)– 1.6551 | 0.93 |

**Table 2** The results of different tests

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Rcok type | ρ (g/cm3) | n (%) | UCS (MPa) |  | PLI(50) (MPa) | | | |
|  | PLI(50)A | PLI(50)D | PLI(50)B | PLI(50)IL |
| Sandstone 1 | 2.48 | 3.97 | 65.7 |  | 7.0 | 7.1 | 6.8 | 6.0 |
| Sandstone 2 | 2.46 | 2.64 | 71.6 |  | 6.4 | 6.6 | 6.7 | 6.1 |
| Sandstone 3 | 2.67 | 10.03 | 52.3 |  | 2.7 | 2.5 | 2.9 | 3.3 |
| Sandstone 4 | 2.48 | 3.32 | 69.3 |  | 7.5 | 7.3 | 7.0 | 7.0 |
| Sandstone 5 | 2.48 | 6.03 | 55.8 |  | 5.0 | 5.2 | 5.5 | 6.0 |
| Sandstone 6 | 2.47 | 4.19 | 62.6 |  | 5.5 | 5.2 | 5.3 | 4.8 |
| Sandstone 7 | 2.60 | 10.25 | 44.9 |  | 2.8 | 3.0 | 3.2 | 3.6 |
| Sandstone 8 | 2.58 | 7.20 | 58.7 |  | 4.5 | 4.3 | 4.0 | 4.0 |
| Sandstone 9 | 2.74 | 10.81 | 47.8 |  | 4.1 | 4.0 | 3.8 | 3.5 |
| Sandstone 10 | 2.57 | 8.26 | 49.1 |  | 3.5 | 3.9 | 4.6 | 3.9 |
| Sandstone 11 | 2.59 | 5.65 | 59.6 |  | 5.5 | 6.1 | 6.0 | 6.4 |
| Sandstone 12 | 2.67 | 7.44 | 56.3 |  | 5.2 | 5.0 | 5.6 | 4.6 |
| Sandstone 13 | 2.68 | 11.17 | 43.7 |  | 2.2 | 2.1 | 2.8 | 2.9 |
| Sandstone 14 | 2.51 | 5.17 | 61.4 |  | 6.0 | 5.6 | 5.4 | 5.0 |
| Sandstone 15 | 2.51 | 6.72 | 53.4 |  | 4.3 | 4.6 | 4.2 | 4.0 |

**Table 3** Summarized the simple regression analyses results

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Equations number | Regression equations | R2 | SEE |  | t-value | |
|  | Computed | Tabulated |
| 4 | **UCS** = 4.9403**PLI(50)A** + 33.034 | 0.85 | 3.43 |  | 28.55 | ±2.145 |
| 5 | **UCS** = 4.8123**PLI(50)D** + 33.554 | 0.80 | 3.89 |  | 28.36 | ±2.145 |
| 6 | **UCS** = 5.2913**PLI(50)B** + 30.780 | 0.77 | 4.24 |  | 27.60 | ±2.145 |
| 7 | **UCS** = 5.5244**PLI(50)IL** + 30.627 | 0.70 | 4.83 |  | 27.10 | ±2.145 |

**Table 4** Multivariate regression equations UCS with ρ, n and PLI(50)A and the results of statistical tests

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Regression equations | Determination coefficient (R2) | Standard error of estimate (SEE) | F-ratio | Tabulated F-ratio |
| **UCS** = 81.769 – 17.693**ρ** + 4.248**PLI(50)A** | 0.87 | 3.34 | 39.20 | 3.89 |
| **UCS** = 62.577 – 2.018**n** + 1.6778**PLI(50)A** | 0.92 | 2.62 | 67.52 | 3.89 |