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Original Research / Orijinal Araştırma

The size correction and correlation of point load index with compressive strength of dimension stones from north pakistan

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A B S T R A C T

The uniaxial compressive strength (UCS) is an important geotechnical property of rock considered in rock mass classification, tunnel design and other surface and underground mining projects. It is the key parameter of rock mass rating (RMR) and the RMR provides a base for the slope stability analysis. This key parameter of slope stability analysis and tunneling can be easily determined by the axial and diametral point load test (PLI/Is50). Various attempts have been made in the past to correlate point load index (PLI) with UCS, however, these studies are based on limited data for particular rocks. In this study, the PLI values of diametral, axial and irregular lumps have been correlated with UCS using dimension stones of tectonic regions along KKH. A methodology of size correction of irregular lumps has been set using regression analysis, the PLI of cores and lumps have been correlated with UCS. The significance of the correlation was developed by correlations coefficients. It was found that the $Is_{(50)}$ of an irregular lump of white marble is 1.8MPa. For pink and white granite the $Is_{(50)}$ values were recorded as 3.2MPa and 2.4MPa respectively. In the size correction factor (F) the power n for irregular lumps is corrected as 0.8 for marble lumps and the n value for pink and white granite is 0.9 and 1.4 respectively. For diametral and axial PLI the power n is used as 0.45. The correction factor F=(De/50)0.8 is suggested for marble irregular lumps while for axial and diametral specimens of marble the correction factor F=(De/50)0.45 is recommended. In the case of pink and white granite, the correction factors are F=(De/50)0.9 and F=(De/50)1.4 respectively.

Keywords: *Uniaxial compressive strength, Point load index, correlation, irregular lumps, size correction.*

Introduction

The dimension stones like marble and granite are the important industrial stones widely used in tile production. The dimension stones' potential for the World is shown in Figure 1. The potential marble deposits of Pakistan are listed in Table 1. The physio-mechanical behavior is important to know before using dimension stones as tiles. The determination of strength and other physio-mechanical properties needs extensive laboratory experimentations and human effort. The point load index (PLI) is an indirect method of strong determination. PLI tests may be performed either on prepared samples or lumps. The marble deposit of Ghulmet district Nagar, the Chilas pink granite and the Sakarkoi white-black granite of tectonically active regions of North Pakistan has been selected in this study to characterize and develop an easy and quick strength determination method using irregular lumps.

Initially, the irregular lump point load tests were proposed by Protodyakonov in 1960 (Protodyakonov, 1960). Later on D'Andrea et al. (1965) pointed that the point load test has a good empirical correlation with the compressive strength of rocks (D'Andrea, Fischer, & Fogelson, 1965). For irregular lumps, the ISRM (Franklin, 1985) suggests the method of point load index (Is) from the breaking load P and equivalent diameter De given by Equation 1.

$$Is = \frac{P}{De^2} \tag{1}$$

The details of the above relation are discussed in the methodology portion. The axial, diametral and irregular lumps of almost 30 samples of sandstone and norite have been studied by Bieniawski (Bieniawski, 1975). Almost 500 point load tests on irregular lumps were tested by Panek and Fannon (Panek and Fannon, 1992). Rusnak and Mark suggested a linear correlation for different rock types i.e UCS= 23.62Is(50)-2.69 (Rusnak and Mark, 2000). S. Kahraman and O. Gunaydin determined the effect of rock classes in the correlation of PLI and UCS using different rocks from Turkey (Sair Kahraman & Gunaydin, 2009). They revealed that UCS is rock dependent therefore a single correlation may not be suitable in assessing UCS from PLI. Fener et al. (Fener, Kahraman, Bilgil, & Gunaydin, 2005) studied that the derived equ-

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ations in the relation of PLI and UCS are not in the same trend so care must be taken in practical applications. A linear and power relation of PLI with rock strength has also found by Sabatakakis et al. (Sabatakakis, Koukis, Tsiambaos, & Papanakli, 2008) for marlstone, limestone and sand stone. M Akram (Akram & Bakar, 2016) developed a linear correlation of point load index and compressive strength of salt range rocks (nine types of rocks excluding marble) from Pakistan using cores. Recently studies on irregular rocks from the Hong Kong region were also conducted (Yin, Wong, Chau, Lai, & Zhao, 2017) and determined the power of correction factor of 0.55 for slightly decomposed medium grain granite and 0.675 for moderately decomposed medium grain granite. The dimension stones of active tectonic zones and their characterization are not studied yet.

In this study a simple methodology was developed to find the index value of irregular lumps and a correlation of this index value with compressive strength has also been developed using some statistical tools. The linear, exponential and power models were applied for each test and suggested the most appropriate tool. This is the first attempt to formulate a correlation of irregular lumps PLI with UCS of dimension stones along KKH. The proposed method is economical and time-saving at the same time. The method provides a convenient way to determine the UCS indirectly using irregular lumps.

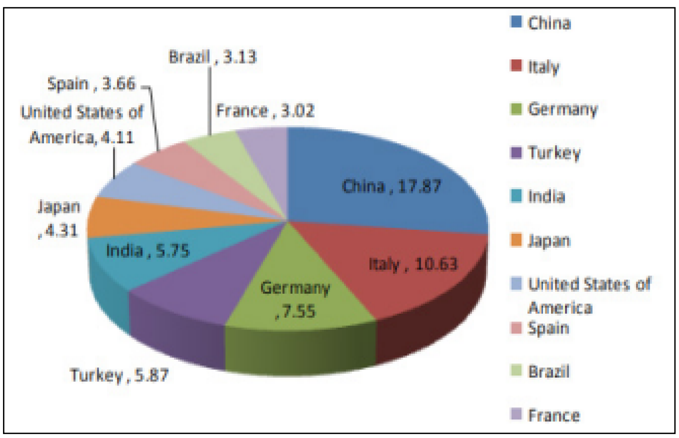

Figure 1. *Dimension stone production of World (Raza et al, 2020)*

1. The Potential of Dimension stones along KKH

The KKH passes through mountainous regions (having dimension stones) of China and Pakistan. The Gojal marble deposit and Ghulmet marble deposits (Figure 2) lie along KKH. The Sakarkoi black granite and white-black granite are at a distance of 10-15km from KKH. Similarly, dolomite and limestone deposits are also located at Khyber Hunza on the side of KKH. Near Chilas a unique type of Pink granite Quarry has recently developed. A black and greenish type deposit has also been discovered at Heramosh district Gilgit. Some of the dimension stones along KKH are shown in Figure 2.

Table 2. *The dimension stones potential along KKH*

Dimension stone	Location	Color	Specific gravity	Porosity %
Marble	Ghulmet	White	2.6	0.966
Marble	Nasirabad	White	2.5	0.9
Marble	Jamal Abad Gojal	Off white	2.4	0.9
Marble	Mahpon Ghojal	Off white	2.5	0.67
Marble	Shahtot Heramosh	Off white	2.6	0.89
Granite	Heramosh shuta	Pull green	2.7	0.77
Granite	Heramosh shuta	Black	2.7	0.56
Granite	Chilas	Pink	2.7	0.34
Granite	Hanzal	Coarse black grain	2.54	0.66
Granite	Basin Gilgit	White granite	2.7	0.54
Granite	Sakarkoi	Black	2.8	0.4
Lime stone	Khyber	Off white	2.4	0.96
Dolomite	Khyber	Off white	2.78	0.47
Granite	Minawaer	Black	2.8	0.5

Table 1. *The dimension stones of Pakistan (Raza et al, 2020)*

Marble color	Occurrence	Descriptions
White	Muhammad Agency, Chitral, Buner, Swat, Parachinar, Gilgit, Hunza, Swabi, Malakand	Pure white: white with pink, brown and green shades, white to grey with yellowish patches, white to light grey with yellowish brown patches, creamy white
Black	Buner, Bajour. Mardan, Bela	Deep black with patches of white, black with white and golden steaks
Green	Swat, Swabi, Buner, Azad Kashmir and Lasbela, Jhuli,Zard Khan, Zeh	Dark green, green with streak and patches of white grey and black, greenish white, dark green with layers of light green, green with streaks of white and yellow
Pink	Nowshehra, Chitral, Lasbela	Pink with streaks and patches white, grey, red and brown pink with fossils
Grey	Buner, Bajour, Mardan, Swat, Muhammad Agency, Lasbela	Grey with white bands, grey with pink, brown and green patches
Brown	Bunner, Swat, Kohat, Waziristan, Khuzdar	Dark brown with white lines, brown with yellow patches, light brown with fossils
Yellow	Bunner, Swat, Kohat, Waziristan, Khuzdar	Yellow with golden patches, yellowish golden with fossils

Figure 2. *Dimension stones along KKH*

2. The regional Geology

The Northmost province of Pakistan is Gilgit-Baltistan (GB) having India in the east, China in the north and Afghanistan in the west (figure3). The GB has a unique geology. It has spectacular tectonic entities of the Asiatic plate (AP), Indian plate (IP) and the Kohistan-Ladakh arc (KLA). The Northern Suture Zone (NSZ) or Main Karakoram Thrust (MKT) separates the KLA from AP in the north while the Maim Mantle Thrust (MMT) separates the KLA from IP in the south. These different tectonic events have generated various types of igneous and metamorphic rocks in the form of gigantic mountain chains in the region. Considering the metallogenic provinces related to such types of tectonic environments the world over, it can be suggested that the GB province may have the potential for the occurrence of economic mineral deposits.

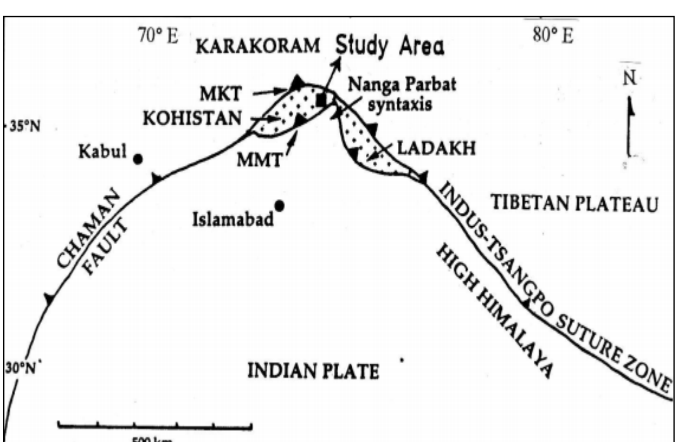

Figure 3. *The tectonic zones and the study area*

3. Method for test analyses

The rock boulders were collected from Ghulmet marble Quarry, Chilas pink granite and Sakarkoi white-black granite Quarry along KKH to develop a relation of cores and irregular lumps with UCS. For irregular lumps PLI the ISRM suggested method (Franklin, 1985) has been used. More than 50 irregular lumps of each sample were tested. The data points of close correlation were considered and the irrelevant points were discarded.

$$De = \sqrt{4WD/\pi} \tag{2}$$

Where W is (W1 + W2)/2 is defined in figure 4.

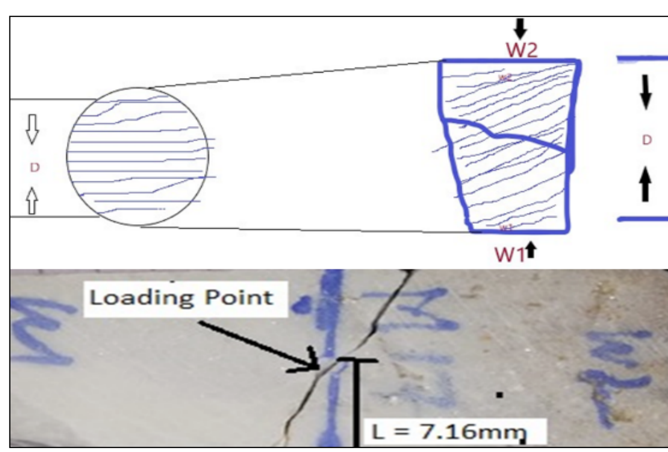

Figure 4. *The equivalent diameter De and specimen dimension*

The De has been obtained using Equation 2 and correlated with 50 mm diameter using the Equation 3. The purpose is to obtain the point load index for 50 mm diameter called Is50.

$$F = \left(\frac{De}{50}\right)^n \tag{3}$$

The correction factor F is used when the cores of diameter not equal to 50mm. In this study the power of the correction factor (n) has been determined for irregular lumps and cores for axial and diametral PLI of Ghulmet marble. The Is_{50} value is determined using Equation 4. Below is the suggested methodology of determination of correction factor power (n) for marble deposit.

Using the data of PLI of different sizes a relationship of log (Is50/Is) and log (De/50) has been generated as described by Equation 5.

$$Is50 = FIs \tag{4}$$

$$Is50 = \left(\frac{De}{50}\right)^n Is$$

$$\frac{Is50}{Is} = \left(\frac{De}{50}\right)^n$$

$$log\left(\frac{Is50}{Is}\right) = n \log\left(\frac{De}{50}\right) \tag{5}$$

The laboratory testing and evaluation

The diameteral, axial and irregular lumps point load test were conducted by Point load index apparatus in Rock Mechanics Lab, Department of Mining Engineering Karakoram International University, Gilgit. The UCS tests were also performed followed by ASTM standard (ASTM, 2006). The standard method suggested in the literature is used for PLI (Bieniawski, 1975). The Schematic of the test method is shown in Figure 5. The PLI tests were evaluated in Figure 6. The average PLI of the irregular lumps of marble is 1.8 MPa. Few of the samples show a PLI value of 2.4 MPa in the case of irregular lumps. The PLI values lie in between 1.6-2.4 MPa. In cases of the diametral test, most of the samples represent a maximum PLI of 2.3 MPa. The cluster of the data lies in between 1.5-3.1 MPa. In the case of axial PLI, the cluster of the data lies in between 2.6-3.4 MPa. The peak UCS of the marble deposit is 59 MPa. The cluster of the data lies in the range of 34-59 MPa.

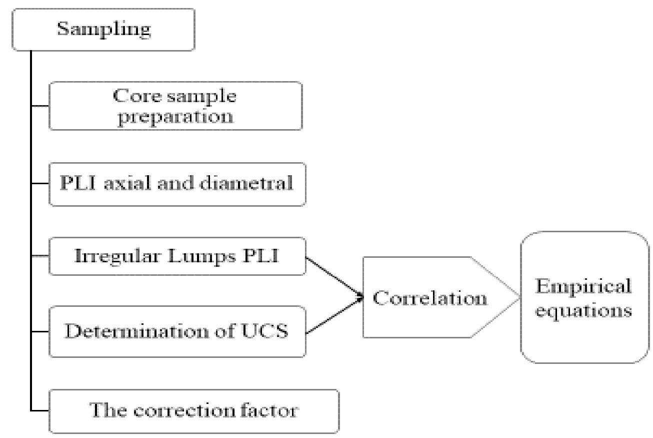

Figure 5. *The Schematic of laboratory test*

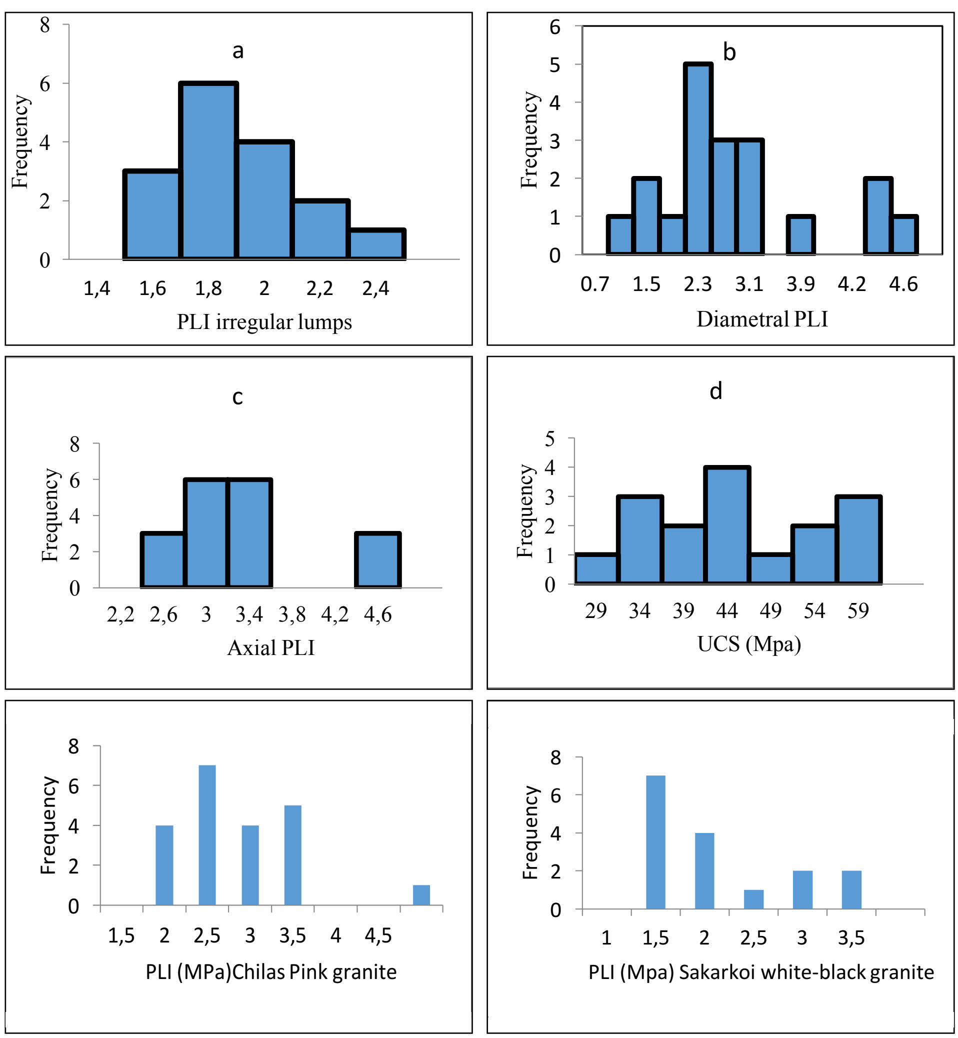

Figure 6. *Histogram showing (a) PLI of irregular lumps (b) dimetral (c) axial and the (d) compression strength of Ghulmet marble*

4. Results and Discussions

The PLI and UCS of irregular lumps were linearly correlated (Figure 7). The high correlation coefficient (>0.7) in the empirical relation of PLI and UCS shows the empirical correlations are realistic. These equations are indirect UCS predicting empirical relations for irregular lumps. As UCS determination method is time-consuming, expensive and needs sample preparation. Therefore the suggested equations are helpful for UCS using irregular lumps PLI of Ghulmet marble, Chilas pink granite and Sakarkoi white-black granite of tectonic regions. The point load strength index PLI or $Is_{(50)}$ of irregular lumps of marble, white and pink granitic specimens were determined by interpolation from a straight line fitting of P and De^2 to obtain the strength of P from De^2 = 2500. The $P_{(50)}$ value i.e load corresponds to the 50mm diameter has been determined from the P versus De^2 line (Figure 8). Then, the point load strength index $Is_{(50)}$) can be determined by $P/50^2$. The size correction factor F is a power function in which the power index n value is obtained from a straight line fitting to data (Figure 9) of log (Is_{50}/Is) and log(De/50). The value of P_{50} was observed as 4.0565 kN in the case of white marble. The Is_{50} value corresponding to P_{50} is 1.62 MPa for the case of irregular lumps of Ghulmet marble. A correlation of De^2 with load (P) has also been developed with a correlation coefficient of 0.74.

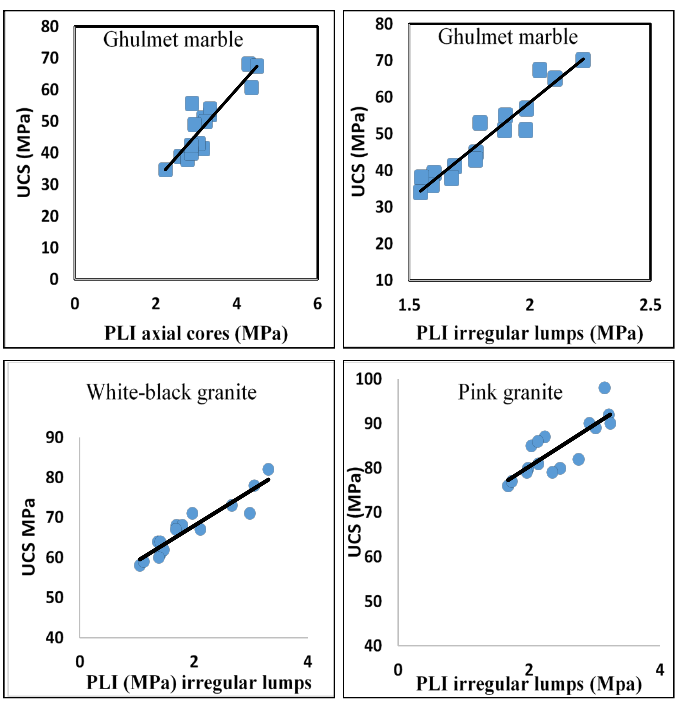

***Figure 7.** The correlation of PLI and UCS*

The PLI of axial testing samples shows a linear relation with UCS. The correlation coefficient, in this case, is 0.809. A linear correlation was also observed between PLI and the strength of marble in diametral testing. The correlation coefficient is 0.68. The correlation coefficient in the relation of PLI and UCS of white-black granite is 0.87 and the coefficient for pink granite is 0.67. The correlations coefficients and average UCS and PLI values are shown in Table 3. The correlation equations are shown in Table 5.

The P_{50} value of pink granite is observed as 8 kN and the Is50 value is 3.2 MPa. The P_{50} value of white-black granite is 6KN. And the Is50 value is 2.4 MPa.

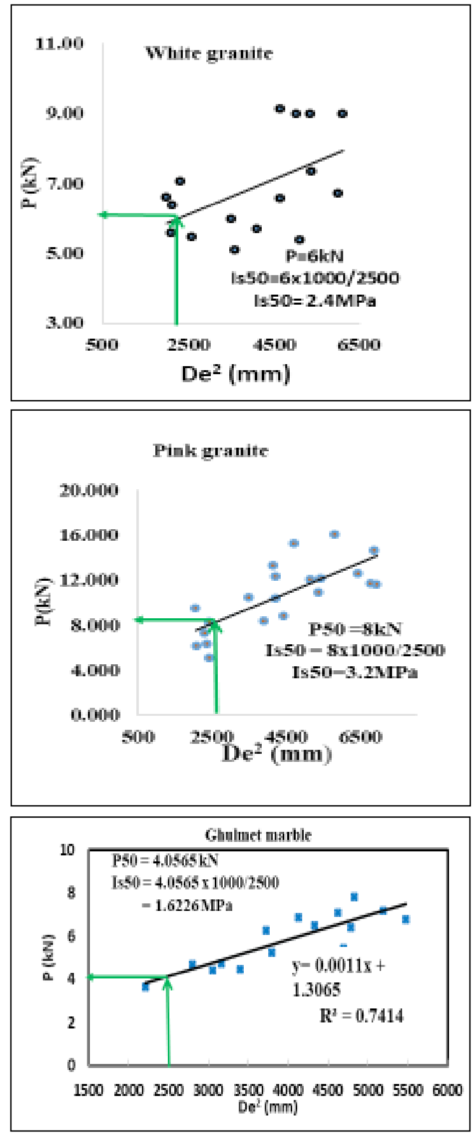

***Figure 8.** The P_{50} of marble and granite*

***Table 3.** The results of Is50 and size correction factor for three different test types*

Test type	$Is_{(50)}$ MPa	Average UCS (MPa)	n	R^2
Irregular marble lumps	1.8	48.975	0.8	0.915
Axial PLI	3.234439	49.0675	0.45	0.8097
Diametral PLI	2.249682	43.1125	0.45	0.684
White granite irregular lumps	2.4	67	1.4	0.87
Pink granite irregular lumps	3.2	84	0.9	0.67

For irregular marble lumps, the power factor n is found as 0.8. While for cores of diameter less than 50 mm the power factor was found as 0.45. The average UCS of irregular marble lumps was 48.975. The correlation coefficient of UCS and PLI of irregular lumps is 0.915. The correlation coefficients of axial and diametral PLI were 0.8097 and 0.684 respectively.

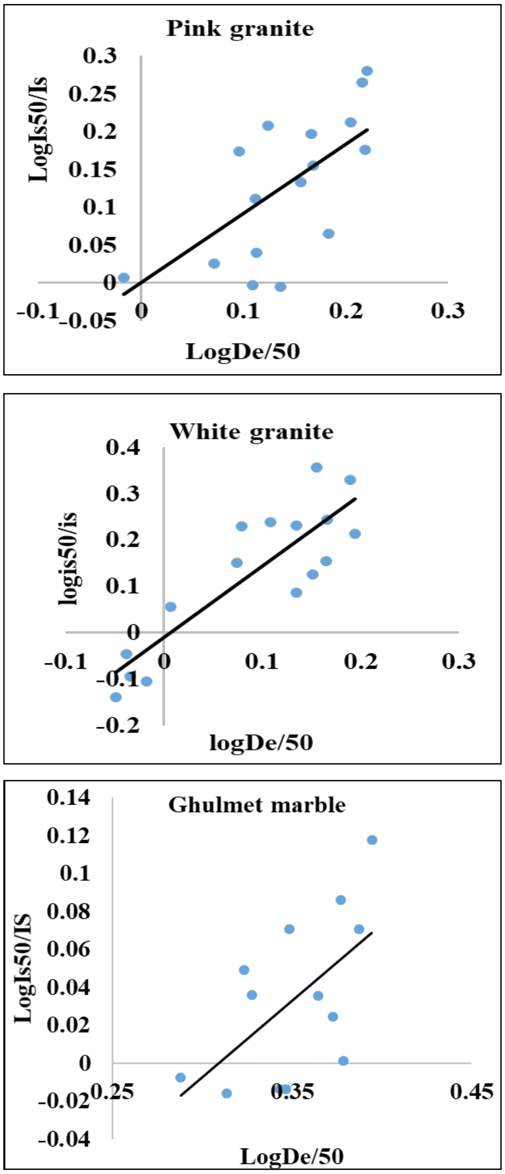

__Figure 9.__ The determination of n

Table 4 reports statistical results from t-test and p-value suggested strong correlations and the realistic of the equations. The suggested equations for the marble and granite deposits in the relation of PLI and UCS are given in table 5.

__Table 4.__ Statistical analyses results of marble for PLI and compression test.

	Coefficients	Standard Error	t Stat	P-value
Irregular lumps (marble)				
Intercept	-48.1558	7.942	-6.0632	2.92044E-05
X Variable 1	53.322	4.333	12.3036	6.78248E-09
Axial (marble)				
Intercept	2.34058	6.163	0.37977	0.30981
X Variable 1	14.446	1.87	7.71863	2.07234E-06
Diametral (marble)				
Intercept	18.1438	4.752	3.8177	0.0018
X Variable 1	11.09873	2.013	5.5114	7.66512E-05

__Table 5.__ Derived equations of PLI and UCS of marble

Equations	Test type	R-square value
UCS=11PLI+18	Diametral marble	0.7
UCS=14PLI+2.3	Axial marble	0.8
UCS =53PLI-48	Irregular lumps marble	0.9
UCS=9.46PLI+61	Irregular lumps (pink granite)	0.7
UCS=8.8PLI+50	Irregular lumps (white-black granite)	0.87

Recently Kahraman (S Kahraman. 2007)suggested an equation for marble.

UCS=18.45PLI-13.6 R^2 =0.7

This equation is similar with Ghulmet marble equation but for irregular lumps the empirical relations are little bit different. It is suggested that a particular deposit should be characterized based on the geological information.

Conclusion

In this study rock samples of marble, white-black granite and pink granite were collected from tectonic zones of North Pakistan. A methodology of irregular lumps for PLI has been set and the following conclusions were presented. The correction factor for irregular marble lumps is F= $(De/50)^{0.8}$ and for pink and white granite the correction factors are F=$(De/50)^{0.9}$ and F=$(De/50)^{1.4}$ respectively. The PLI of pink granite is in between 1.6 MPa and 3.2 MPa. The PLI of white-black granite is in between 1.05 MPa and 3.03 MPa. The UCS of pink granite is in between 76 MPa and 98 MPa. The UCS of white-black granite is in between 58 MPa and 82 MPa. The case is different for Ghulmet marble as the UCS of all the samples is less than 54 MPa. The cluster of PLI values of Ghulmet marble is in the range of 2.2 MPa to 3.4 MPa. The correlation coefficients determined in the relation of PLI and UCS of axial, diamtral and irregular lumps for marble and granite are greater than 0.7. These correlations are considered reliable. The correlations equations of irregular lumps are given below:

UCS =53PLI-48 Marble

UCS=9.46PLI+61 Pink granite

UCS=8.8PLI+50 White-black granite

Recommendations

The Region (Gilgit-Baltistan, North Pakistan) is rich of dimension stones and gemstones. The tectonic activities have created micro cracks in the studied dimension stones. It is recommended that before the usage of these dimension stones a proper physio-mechanical Characterization should be carried out

Conflict of interest

The authors have declared no conflict of interest.

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