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Strength parameters and their inter-relationship for limestone of Cherat and Kohat areas of Khyber Pakhtunkhwa

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Abstract

Determination of various strength parameters like Uniaxial Compressive Strength, Uniaxial Tensile Strength and Point Load Strength Index are addressed in the following research. International Society of Rock Mechanics (ISRM) standard procedure for the determination of above-mentioned parameters was adopted. Samples of limestone from Kohat and Cherat areas of Khyber Pakhtunkhwa province of Pakistan were tested for uniaxial compressive strength, tensile strength and point load index. Sixty samples were analyzed for determination of these parameters and results were plotted against each other to establish relationships between uniaxial compressive strength with tensile strength and point load index. A comprehensive review of various relationships established for same rock condition from literature has been presented. Findings of the research constitute major part of the paper and results indicate that weak correlation exists between uniaxial compressive strength with tensile strength and point load index for limestone from Kohat and Cherat. The analyses of data for various strength parameters and relationships derived so far constitute major part of this research paper.

Keywords: Uniaxial compressive strength; Uniaxial tensile strength; Point load index; Cherat; Kohat

1. Introduction

Limestone is one of the most common sedimentary rocks spread in the nature very widely. Limestone consists upon calcium carbonate with small proportion of silica, iron, aluminum, magnesium carbonate and clay. It is one of the most widely used industrial rocks and building material. As industrial rock it is mainly used in cement industry, for manufacturing of ordinary Portland cement, and in lime production industry. It also has its use in blast furnaces, bleaching, tanning and other industries (Bilqees and Shah, 2007). As a building material it is used in the construction of the road, foundations, bridges and tunnel lining etc.

Whatever be the final use of limestone, it is always required to determine the quality of limestone based on the strength parameters.

Cherat and Kohat limestones are mainly used in cement industries as well as in construction. The main objective of this study and analysis was to determine quality of Kohat and Cherat limestones based on strength parameters. The second purpose was to assess and evaluate the engineering quality of limestone especially of Kohat Limestone for construction structures within and on the rock taking feed back from the constructed and commissioned highway tunnel called Kohat Tunnel – I, so that the findings of the study could be used as a guideline for construction of Kohat Tunnel – II, being proposed in the vicinity of existing tunnel.

Uniaxial Compressive Strength (σ_c) of intact rock is the most common strength parameter for determination of behavior of rocks but the direct method as per ISRM standard is costly and the procedure for preparation of sample for the test is tedious (Stewart, 2007; Bieniawski, 1974; Hoek and Brown, 1997; Douglas, 2002). In many of these cases for example coal mining and using limestone as building material an approximate value is required. Therefore a relatively easier, economical and simple method such as point load index can be used for the purpose.

Due to simplicity of apparatus used and the procedure of point load index (Is_{50}) it is widely used economical and quickest method for approximate determination of uniaxia compressive strength using appropriate conversion factor (Diamantis et al., 2009).

In order to determine the engineering quality of limestone from two locations i.e. from Kohat and Cherat, the following strength parameters and their interrelationship were addressed in the research conducted.

1. Uni-axial Compressive Strength
2. Uni-axial Tensile Strength
3. Point Load Index

The above tests were carried out on the samples collected from both the localities and standard procedure for all the tests types was followed (Brown, 1981; ISRM, 1985). Results obtained from various samples were tabulated, analyzed and plotted to ascertain interrelationship between these parameters.

2. Geology

2.1. Geology of Cherat Limestone

Cherat limestone has fine, uniform lithology. It is yellowish brown, brownish gray and light to dark gray in color. It is very hard and compact and is thin bedded to massive rock. It is coarsely crystalline. The limestone is pure and highly fossiliferrous. Most of the fossils are recrystallized and broken into pieces. Cherat Limestone weathers into rounded nodules and looks brecciated. The nodularity is surficial. In fresh surface the limestone is very smooth. The cementing material is largely calcite and numerous calcite veins cut the rock. The base of the Cherat Limestone exposes a well marked ferruginous unconformity. In the outcrops Cherat Limestone exposes 2 to 4 ft thick, gritty bed, which is white and usually stained rusty brown (Kelvin et al., 1999).

2.2. Geology of Kohat Limestone

The Kohat limestone is from Jurassic to Pliocene in age. These ranges of limestone are exposed in the North and North-West part of Kohat. The limestone in the southern part, range in age from Eocene to Pliocene. The southern zone is 25 miles wide from North to South. The Eocene succession consists of limestone, clay and gypsum. These rocks forms low lying hills and ridges separated by valleys. The limestone of Eocene age is the most important from industrial point of view. The Kohat Limestone is creamy, yellowish, brown and pink in color. It is finely crystalline and form thin to medium bedded rocks.

It forms long to narrow ridges in Southern, South-East and South-Western part of Kohat. Thin beds of shale have been identified at these places. Kohat Limestone is highly fossiliferous. The thickness of the outcrop varies in this area and average thickness is about 500 feet (Technical Report, 2003; Ahmad et al., 2001).

3. Uniaxial Compressive Strength (σ_c)

Uniaxial Compressive Strength (σ_c) is the most common and important parameter in rock mechanics and direct test method for determination of this parameter is costly and procedure for preparation of samples for ISRM standard test is not an easy job (Akram and Bakar, 2007).

Summary of the results of uniaxial compressive strength from each location has been presented in Table 1. Uniaxial compressive strength has its mean value 43.85 MPa with standard deviation of 9.72 MPa for overall data from both locations.

4. Brazilian Tensile Strength

Brazilian tensile test is most commonly adopted direct test for determination of uniaxial tensile strength (σ_t).

Summary of the results of Tensile Strength (Brazilian) from each location has been presented in Table 1, and has its mean value 5.91 MPa with standard deviation of 1.22 MPa for overall data from both the locations.

5. Point Load Index (Is_{50})

Point Load Index (Is_{50}) test determine crude results and cannot be used for design purposes. However the method has advantage over other methods of strength determination as it is relatively simple and can be easily performed on rock samples. Moreover the results provide a general idea about the rock strength to classify it on the basis of strength in the preliminary stage of engineering design in and on rocks.

Table 1. Test results for Kohat and Cherat limestones

	Kohat Limestone			Cherat Limestone		
S.#	**Uniaxial Compressive Strength (MPa)**	**Tensile Strength (MPa)**	**Index Strength (MPa)**	**Uniaxial Compressive Strength (MPa)**	**Tensile Strength (MPa)**	**Index Strength (MPa)**
1	29.39	4.26	1.96	34.08	5.54	2.00
2	26.56	4.69	2.89	29.39	5.96	2.70
3	38.34	5.54	1.50	61.76	5.96	2.23
4	48.99	6.82	1.57	54.10	7.67	1.99
5	40.47	4.69	1.94	59.29	7.89	2.40
6	44.18	5.57	1.61	57.33	6.87	2.60
7	45.15	4.90	1.96	57.90	7.23	2.55
8	37.28	5.01	1.85	37.72	7.52	2.54
9	36.52	4.56	1.87	47.09	6.75	1.99
10	35.89	4.55	1.95	51.08	6.50	2.01
11	34.75	3.99	2.01	51.18	7.11	2.22
12	37.75	4.62	2.07	51.27	7.32	2.31
13	38.01	4.79	1.99	53.40	6.85	2.38
14	38.11	4.61	1.92	51.34	7.01	1.98
15	37.95	4.98	1.87	50.22	7.50	1.95

The general procedure for determination of Point Load test as per ISRM standard is adopted and 15 samples from each location are tested and presented in Table 1. All the results included in this study fulfill acceptance criteria proposed by Hoek and Bray in 1981 as clean fracture is observed in all samples from one loading point to other (Hoek and Bray, 1981). Mean of the Point Load test results for overall data of the test is 2.09 MPa with standard deviation of 0.33 MPa.

Statistical analysis of different test results of Kohat and Cherat limestones are depicted in Figure 1 (a) (b) & (c).

6. Relationship between Uniaxial Compressive Strength and Tensile Strength

Rocks are complex material and there is no single factor to relate uniaxial compressive with tensile strength like other strength parameters such as shear strength etc. According to Griffith criterion for brittle material the relationship between uniaxial compressive strength and Tensile strength is given by equation (1) (Brady and Brown, 2004):

$$\sigma_c = 8\sigma_t \qquad (1)$$

Where σ_c is uniaxial compressive strength
σ_t is Tensile strength

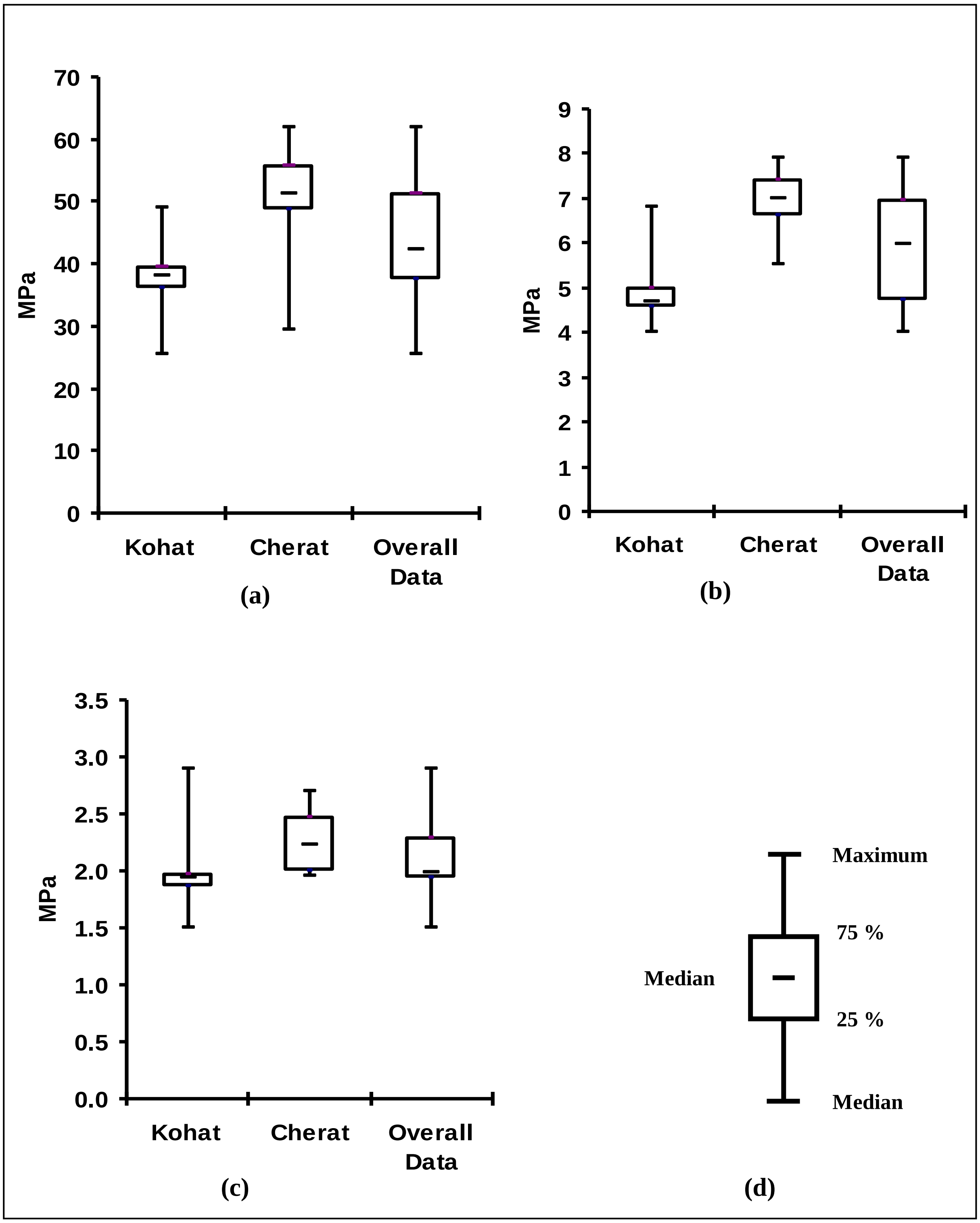

Fig. 1. Statistical analysis of data (a) Uniaxial Compressive Strength (b) Tensile Strength (c) Point Load Index (d) Legend.

Farmer (1983) gives the relationship expressed by equation (2)

$$\sigma_c = 10\sigma_t \qquad (2)$$

Study on many set of tests by Douglas (2002) has revealed that the relationship is not constant and depends on many parameters and proposes a general relationship between uniaxial compressive strength and tensile strength as given by equation (3)

$$\sigma_c = -m_i\sigma_t \qquad (3)$$

Where m_i is intact rock constant for Hoek – Brown failure criterion and ranging from 5 – 50 and even 1- 55 (Stewart, 2007).

Compressive and Tensile Strength data was plotted as depicted in Figure 2 and a linear relationship having zero y – intercept is obtained as given in equation (4) with $R^2 = 0.445$

$$\sigma_c = 7.53\sigma_t \qquad (4)$$

The value of m_i determined in previous work for Kohat limestone is in range of 6±2 also support equation (4) (Tahir, 2010).

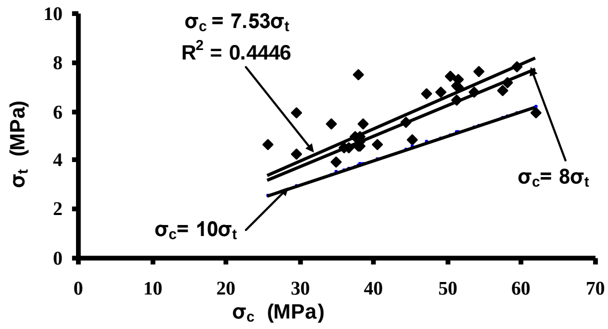

Fig. 2. Relationship between Compressive and Tensile strength for Kohat and Cherat limestones

7. Relationship between Uniaxial Compressive Strength and Point Load Index

Before suggesting a common correlation factor for determination of uniaxial compressive strength (σ_c) from Point Load Index (Is_{50}) some common correlations from literature are reviewed without considering individual rock type. In most of cases this relationship is either linear or exponential (Tziallas et al., 2009). There is no single correlation factor between point load index test and compressive strength (ISRM, 1985; Akram and Bakar, 2007; Broach and Franklin, 1972; Bieniawski, 1975; Hassani et al., 1980; Read et al., 1980; Chau and Wang, 1996; Kahraman, 2001; Tsiamboas and Sabatakakis, 2004) and a summary of the correlation between the two has been tabulated in Table 2.

A weak correlation exist between Point Load Index and uniaxial compressive strength for rocks having uniaxial compressive strength < 25 MPa and the estimates leads to ambiguity (Hoek and Brown, 1997).

Each and every equation derived is concern only to certain rock type of certain area and assumed to be correct and has its applicability for rock/rocks of that area/areas but equation (11) and (13) are of interest in this study. Equation (11) and (13) predict uniaxial compressive strength value of -2.69 MPa and 13.295 MPa respectively when the point load index value approaches to zero. Equation (13) is based on data that contain uniaxial compressive strength value less than 25 MPa (Table 2).

The data regarding point load index test and uniaxial compressive strength is in accordance with the criteria that uniaxial compressive strength > 25 MPa to establish relationship between these properties for the said rock. Uniaxial compressive strength and point load index are plotted against each other as shown in Figure 3 and a relationship is established as expressed in equation (15). The relationship is linear with $R^2 = 0.301$

$$\sigma_c = 21.691 Is_{(50)} \qquad (15)$$

Table 2. Summary of different correlation factors sourced from different references

Equ. #	Equation	Reference
5	$\sigma_c = 24Is_{(50)}$	Broach and Franklin, 1972
6	$\sigma_c = 23Is_{(50)}$	Bieniawski, 1975
7	$\sigma_c = 29Is_{(50)}$	Hassani et al.,1980
8	$\sigma_c = 16Is_{(50)}$	Read et al., 1980
9	$\sigma_c = 20Is_{(50)}$ to $25Is_{(50)}$	ISRM, 1985
10	$\sigma_c = 12.5Is_{(50)}$	Chau and Wang, 1996
11	$\sigma_c = 23.62\ Is_{(50)} - 2.69$	Kahraman, 2001
12	$\sigma_c = 7.3\ Is_{(50)}^{1.71}$	Tsiamboas and Sabatakakis, 2004
13	$\sigma_c = 22.792\ Is_{(50)} + 13.295$	Akram and Bakar, 2007
14	$\sigma_c = 11.076Is_{(50)}$	Akram and Bakar, 2007

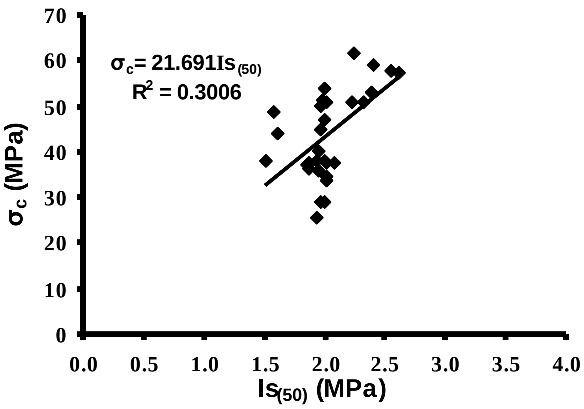

Fig. 3. Relationship between uniaxial compressive and Point load index for limestone from Kohat and Cherat

8. Conclusions

It is concluded from the analysis that a weak correlation exist between uniaxial compressive strength and tensile strength due to scattered data, however the relationship is close to the relationship proposed by Griffith. Lower R square value obtained from fitting best fit linear line with zero y–intercept to scatter plot of uniaxial compressive strength and point load index data reveals a weak correlation between the two parameters. This study suggests that extreme care must be taken for estimation of tensile strength from uniaxial compressive strength and uniaxial compressive strength from point load test for limestone from Kohat and Cherat areas.

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