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LIKELY EFFECTS OF GEOLOGICAL FEATURES ON CARBONATE ROCK STRENGTH

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ABSTRACT

Rock strength is commonly recognized as a rock ability to resist stress or deformation without breaking down. Its measurement in either in-situ or laboratory environment is costly and requires time-consuming efforts for rock sampling, preparation and laboratory tests. There are different suggested testing methods available such as Unconfined Compressive Strength (UCS), Point Load Index (PLI), Indirect Tensile Strength (ITS), Schmidt Hammer Rebound (SHR), etc. and used to interpret of rock strength properties. The study will only focus on carbonate rocks (Upper Eocene Dammam Formation) which were collected from different selected sites in the Hafeet Mountain area, Al Ain city, United Arab Emirates. Following the sample preparations based on the ASTM standards, about fourth UCS, fourth-one ITS, thirty-seven PLI and hundreds to thousands of SHR tests were carried out on rock blocks and core samples according to ASTM Standards. The study indicates that the relationships between UCS and PLI, ITS, SHR of limestone can be estimated using the simple linear mathematical equations. However, the results exhibit a weak to weaker linear correlation with highly scattered data. This may be due to sample heterogeneity and nature of the sample. Therefore, it still needs better confirmation with more samples from different locations in order to use confidently in engineering applications.

Contribution/Originality: This study documents the likely effects of geological features on Upper Eocene carbonate rock strength. It is remarkably noted that the presence of either the cavities or fossils, that have heterogonous distribution, certainly affect geomechanical properties of carbonate rock. This impact was clearly on the laboratory results.

1. INTRODUCTION

Rock strength measurement and characteristics of discontinuities (mainly fractures) are important tasks in geo-engineering applications. Overall, rock strength is defined as the ability rocks to resist stress or deformation without breaking down. In engineering approaches, rock strength may be defined as the inherent strength of an isotropic rock under wet or dry conditions. Nevertheless, rock masses are anisotropic and therefore, the strength of rocks is influenced both by the presence of impurities, weak zones and/or discontinuities [1].

Quick changes on meter scale in carbonate rocks structures (layering, fractures, faults, folds), texture (grain size, fossil content, cementation, dissolution) and even mineralogy (dolomitization, percent of clay minerals, silicification) have always created problems in generalizing an overall bulk physical property such as rock strength, porosity and permeability. Thus, mass homogeneity may only exist at small scale, a few decimeter cubes, and rock failure problems are faced by the oil companies, construction engineering companies and environmental agencies when the size of the rock mass gets larger. The results of such rapid change in the physical properties cause unexpected rock failure or formation of karst (surface and subsurface caves and sinkholes) that are sometimes difficult to forecast. Rock mass changes in homogeneity become even worse when it is combined with water. All these factors suggest that it is essential to measure the rock strength through in-situ and laboratory studies [2-6].

On the other hand, measurement of rock strength in either in-situ or laboratory environment is relatively expensive, time consuming and requires considerable efforts for rock sampling, preparation and laboratory tests. In addition, quite number of specimens must be tested to produce a representative value for a large rock exposure. In literature, there are different suggested testing methods are available. These are Unconfined Compressive Strength (UCS), Indirect Tensile Strength (ITS), Point Load Index (PLI) and Schmidt Hammer Rebound (SHR) tests. Results of these tests can be used to interpret of rock strength properties.

The study area lies close to Jabel Hafeet (Hafit Mountain), which is about 29 km long, 3-5 km width with maximum elevation about 1240 m above sea level and lies on southeast of Al-Ain city [7-9]. In this study, carbonate rocks are designated as a targeted area since they represent large exposure of rock masses in the United Arab Emirates (UAE), easily accessible and suffers from some geo-engineering problems such as slope instability and common occurrence of landslides, rock falls, karsts and caving, etc. (Fig. 1). The objective of the study is to estimate and report the strength properties of the carbonate rocks of Upper Eocene Dammam Formation through laboratory studies and discuss their expected influences on the structures in/on rock, usage of rocks as a construction material, slope stability, karsts, caving, etc.

2. GEOLOGICAL SETTINGS AND ROCK DESCRIPTIONS

The geology of the study area is relatively well-known and documented in terms of lithology, structural features and major stress-strain fields. The Hafit Mountain is a double plunging, highly asymmetric anticline that is developed over two large thrust faults underlying on its eastern and western limbs. It is classified into three main rock units that are composed of different types of carbonate rocks (limestones) (Fig. 1). The oldest rock unit is the Rus Formation (Early Eocene 55-49 Myr) followed by Dammam Formation (Middle to Late Eocene 49-34 Myr) and then overlain by the third rock unit, which is the Asmari Formation (Early Oligocene 34-29 Myr) [5, 8, 10].

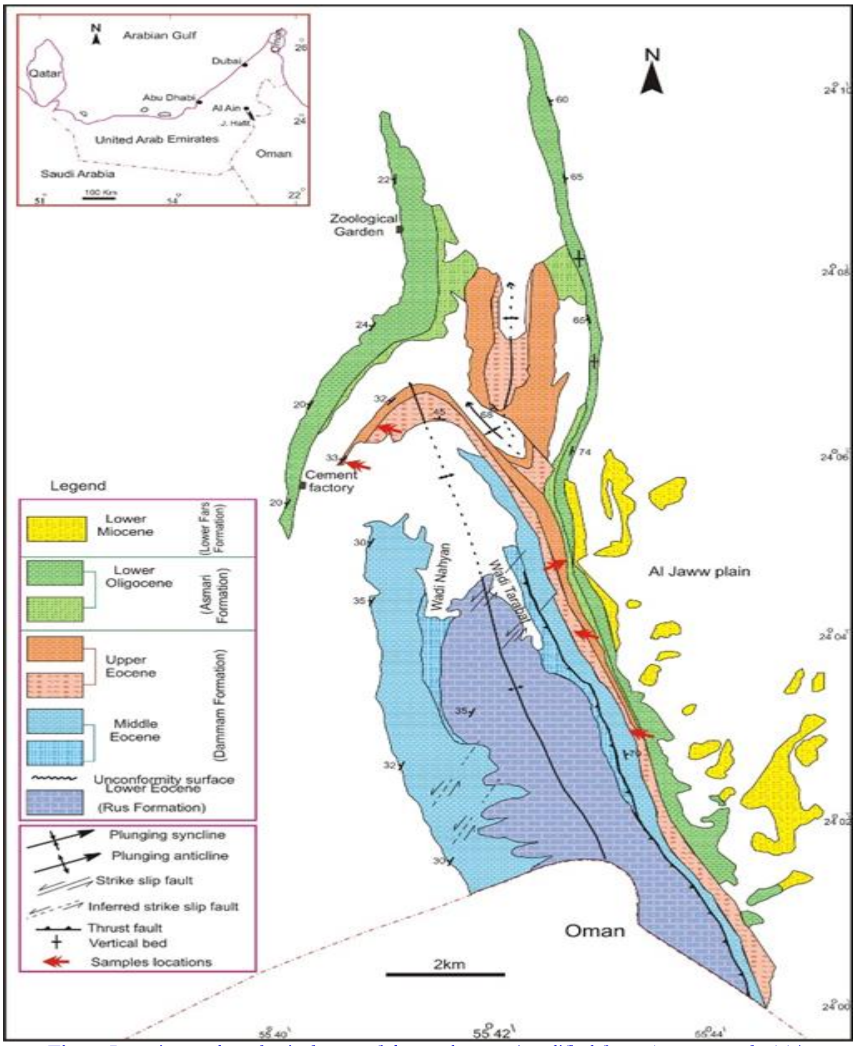

Fig-1. Location and geological map of the study area (modified from Arman, et al. [5]).

The Dammam Formation is widely exposed around the western periphery of the northern Oman Mountains and is divided into three members in eastern UAE; Mezyad Member, Ain Al Faydah Member (Eastern limb) and Wadi Al Nahyan Member. It is about 600 m thick and consists of tan to light colored limestone with interbeds of shale in lower part and marl in upper part. This formation consists of buff to grey weathered medium-grained fossiliferous, nummulites rich limestone interbedded with yellow marl of Middle – Upper Eocene age at its type of locality in Ain Al Faydah Member [4, 8, 10, 11].

3. SAMPLE PREPARATION AND EXPERIMENTAL STUDY

Five locations of limestone outcrops were selected to collect the representative rock block samples from Upper Dammam Formation, Jabel Hafeet Mountain (Fig. 1). To eliminate any anisotropic effects on the measurements, the rock block samples having no bedding planes were selected and collected. The rock block samples were brought to the laboratory.

Before preparing core samples, laboratory SHR measurements (about 2250) were performed on rock block samples. Precautions were taken to avoid obvious (macro) fractures, discontinuities or proximity to edges during performance of SHR measurements. The position of the rock hammer was vertically downward and at least 2 – 3 cm away from the block edge to avoid boundary effects. The SHR_{cor} (corrected value of SHR) value of each test was determined and reported according to ASTM Standard [12]. Then, for the UCS, PLI, ITS and SHR tests, NX size core samples (about 150) were prepared from rock blocks. Before testing, all core samples were weighted and their dimensions, diameter and length, were measured.

The UCS tests were performed on 40 rock core samples, prepared according to the ASTM Standard, with length to diameter ratio of approximately 2:1. The ends of the core were cut to provide smooth surfaces normal to the core long axis, and a constant loading rate was axially applied to the core specimens [13]. The PLI and TSI tests were performed on 34 and 41 core specimens following the procedure given by ASTM Standards [14, 15].

4. TEST RESULTS AND DATA PROCESSING

Tables 1 shows the test results and basic test statistics. The UCS of the samples (41 samples, see Table 1) ranges between 26.85 and 115.31MPa with average value of 65.28 MPa. According to the UCS classification for intact rock [16] the studied limestone rocks can be classified as strong by referring their mean values (see Table 1). These categories are matched with the lithologic properties of the corresponding samples. The minimum and maximum values of PLI are 2.58 and 5.48 MPa, with an average value of 8.82 MPa (34 samples, see Table 1). The average value of ITS is 6.73 MPa, with variation from 4.66 to 9.32 MPa (41 samples, see Table 1). The highest SHR number (N) on core samples and rock blocks was about 43 and 39, the lowest was 35 and 25 MPa, and the mean average value was about 38 and 32 MPa (74 cores and 14 rock blocks, Table 1).

The respective relations between the mean PLI for 50 mm in diameter size rock sample, ITS, SHR_c, SHR_R and the mean UCS, are shown in Fig. 2. Data points are highly scattered. The R^2 values in Fig. 2 are indicative of weak to weaker relationships.

The mean values of PLI for 50 mm in diameter size samples were plotted against the mean values of ITS for each test (Fig. 3). This figure also shows a weak correlation between the mean PLI values for the 50 mm in diameter size samples and the mean ITS values. This may be due to sample heterogeneity.

5. CONCLUSIONS AND RECOMMENDATIONS

This study mainly focuses on the Upper Eocene carbonate rocks in the Dammam Formation. It is remarkably noted that the presence of either the cavities or fossils, that have heterogonous distribution, may affect the expected geomechanical properties of the limestones. This influence was clearly seen on the laboratory results since data exhibited high scattering. Therefore, more detailed studies are certainly needed. Future study may eliminate differences and narrow the scattering of data.

Table-1. Strength Properties of the Upper Eocene Carbonate Rocks

Sample No.	UCS (MPa) (mean)	PLI (for 50 mm in diameter size sample, $I_{s(50)}$) (MPa) (mean)	ITS (MPa) (mean)	SHR (N) (mean)	
				Cores	Blocks
B1	53.49	2.77	5.51	34.95	25.00
B2	65.88	2.58	6.00	35.60	35.00
B3	26.85	3.21	7.65	36.66	31.00
B4	65.93	3.53	7.21	38.95	25.00
B5	63.97	4.57	6.96	39.40	34.50
B6	70.38	4.81	7.94	42.45	31.60
B7	42.64	2.69	4.66	34.90	24.60
B8	71.37	5.48	7.78	40.42	35.00
B9	93.06	4.46	9.22	41.00	34.00
B10	115.31	4.35	6.75	41.81	32.00
B11	41.43	3.76	5.47	36.21	29.50
B12	109.86	3.43	5.59	40.00	39.00
B13	49.95	4.03		40.93	38.00
B14	43.87			35.01	31.00
Min.	26.85	2.58	4.66	34.90	24.60
Max.	115.31	5.48	9.22	42.45	39.00
Mean	65.28	3.82	6.73	38.45	31.80
STD	25.90	0.89	1.32	2.78	4.59
Total Sample	40	34	41	74	14

UCS Uniaxial Compressive Strength, PLI Point Load Index, ITS Indirect Tensile Strength, SHR Schmidt Hammer Rebound, Min Minimum, Max Maximum, STD Standard Deviation

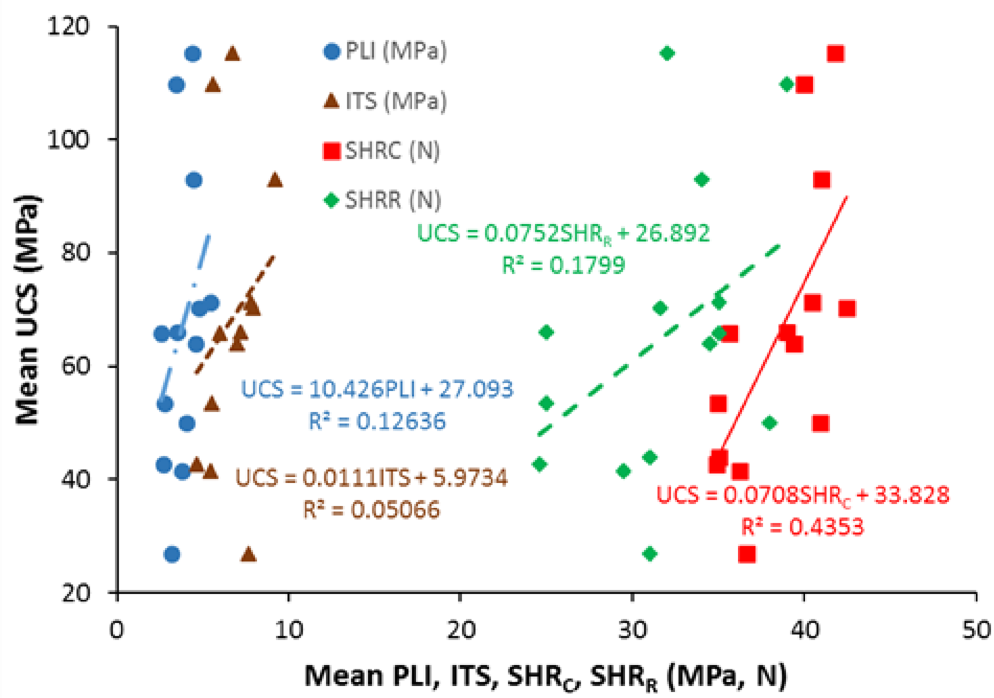

Fig-2. Mean PLI, ITS, SHR$_c$, SHR$_R$ vs mean UCS

The mean SHR$_c$ tests exhibit a weaker linear correlation with the mean UCS of the limestone. However, the correlation between the mean PLI for 50 mm in diameter size rock sample, the mean ITS and the mean SHR$_R$ is weak and data are highly scattered. In addition, it appears that there is a weaker linear correlation between the PLI for 50 mm in diameter size sample and the ITS of rock samples.

Some empirical methods such as the PLI for 50 mm in diameter size sample and the SHR$_c$ utilized in this study, were used to predict the mean UCS and the mean ITS rock samples. However, the published equations are based mainly on rock type and testing conditions. It may be necessary to include other parameters in these equations or make clearer specifications for their application.

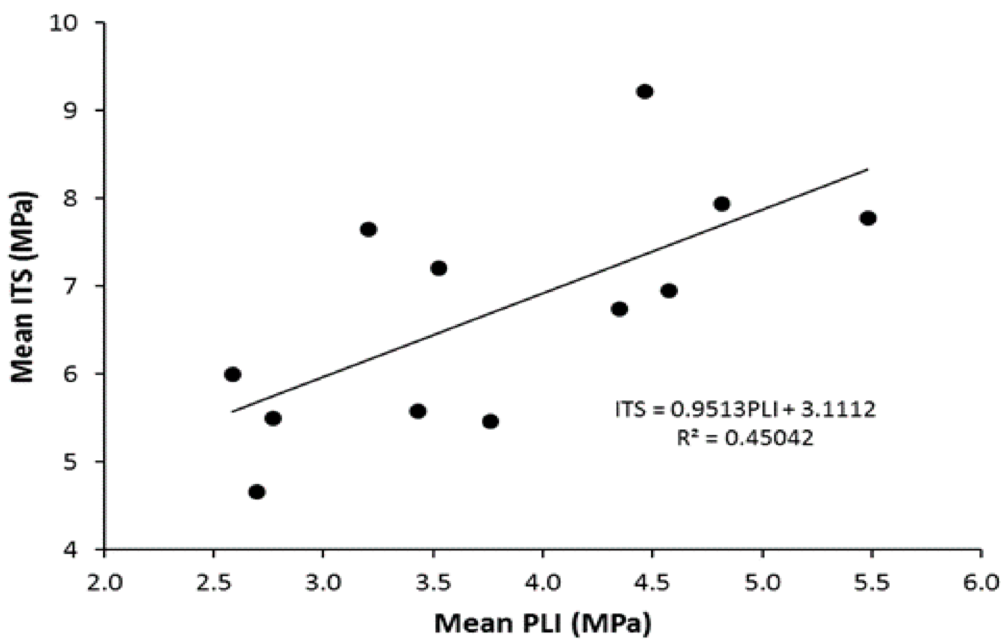

Fig-3. Mean PLI vs mean ITS

Accordingly, by knowing strength characteristics of the Upper Eocene limestone, it may possible to interoperate and discuss their likely influences on structures in/on rock, usage of rocks as a construction material, slope stability, etc. in the study area, even though obtained initial data are highly scattered.

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