

GEOTECHNICAL STUDY FOR NEW EGYPTIAN CAPITAL ROCKS

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ABSTRACT: A laboratory study was conducted to develop a database and models for predicting of unconfined compressive strength of rocks in the new administrative capital of Egypt. In this respect, the present study presents correlation equations between the unconfined compressive strength and some mechanical and physical properties of rocks. More than 249 of specimens are prepared and tested; the tests were conducted on four rock types, including basalt, limestone, sandstone, and siltstone. Based on results obtained from the following mechanical and physical tests that were performed on rock samples, unconfined compressive strength, Schmidt hammer, and Brazilian splitting test, they were conducted to determine the mechanical properties of rock specimens, water absorption, and porosity. They were conducted to determine the physical properties of rock specimens. The results of this study indicated that the correlation between unconfined compression strength and the Schmidt hammer test increases as the rock strength. The relationship is found in a polynomial equation. It has been found that the strong linear correlation between unconfined compression strength and Brazilian splitting test for the tested rocks. From this study, it has been found that there is an inverse relationship between the unconfined compression strength and water absorption. This relation is a power equation. It has been found from the present study that the unconfined compression strength increases as the porosity in the rock decreases. The relation is found to be a polynomial equation. The correlation coefficient (R^2) varies between 0.5 and 0.95 in all relations.

Keywords: Engineering Properties of Rock, Empirical Relations, Unconfined Compressive Strength, Schmidt Hammer, Water Absorption, Porosity

1. INTRODUCTION

A closer look at the construction projects and development boom that occurred in the new administrative capital of Egypt. In every construction project, geotechnical investigations are carried out; geotechnical investigations vary in complexity and prices. Some of them require days of working, procedures to be followed, and to be spent. Therefore, geotechnical engineers thought about devising easier and cheaper ways to estimate the results of some geotechnical parameters [1].

One of the essential rock parameters is the unconfined compressive strength test of rocks; it is used widely in rock classifications such as rock mass rating (RMR) and geotechnical design of various development projects. Unconfined compressive strength has been standardized by American society for testing and materials [2,3].

Testing of this mechanical property is a simple procedure in theory, but in practice, it is among the most expensive and time-consuming tests. This calls for transportation of the rock to the laboratory, sample preparation and testing based on international standards in order to carry out these standard tests. and received rocks' condition usually does not meet this requirement, or some rocks fail in the preparation stage [4].

preparation of regular- shaped samples from a weak rock is also tricky, so that it is hard to find a core piece to perform the unconfined compressive strength test on since codes require a particular length to diameter ratio of (2:1) and received rocks condition usually does not meet this requirement [5] Under these circumstances, the application of low-cost and straightforward methods to carry out the above tasks with acceptable reliability and accuracy will be necessary [6].

The main object of the present study is to correlate between the unconfined compressive strength and some mechanical and physical properties of rocks. To accomplish this study, the tests were conducted on four rock types including basalt, limestone, sandstone, and siltstone. The rocks samples were collected from different sites along with the new administrative capital of Egypt.

The new administrative capital of Egypt is located between the Cairo/Suez. The administrative capital area is approximately 700 square kilometers. The new administrative capital includes the Iconic tower is one of several Dubai-style megaprojects being built a 385-meter-tall tower, it is hoped that when completed, it will stand as the tallest building in Africa [7].

2. PREVIOUS STUDIES

There are many published works that focused on obtaining a correlation between unconfined compressive strength and by mechanical and physical properties of rocks. The Mechanical properties include rocks, unconfined compressive strength (σ_u), Schmidt hammer test (H_r), and Brazilian splitting test (σ_t). The physical properties include rocks, water absorption (W_a), and porosity (n).

Researchers have used different approaches for deriving these equations. There is no agreement between the equations derived from different researchers.

2.1 Schmidt Hammer (H_r)

Faisal I. Shalabi, Edward J. Cording, and Omar H. Al-Hattamleh [8] carried out research about the estimation of rock engineering properties using Schmidt hammer. The main idea was to estimate some important rock properties such as unconfined compressive strength, using easier and cheaper methods such as Schmidt hammer. They used dolomitic limestone, shale, from different locations in California and New York. They concluded that a linear model could be used to estimate the unconfined compressive strength of sedimentary rocks from other properties such as the Schmidt hammer test number. They used this relation as given in Eq. (1). The value of R^2 was as medium as 0.76.

$$\sigma_u = 3.201H_r - 46.59 \quad (1)$$

Another interesting paper was about the correlation of unconfined compressive strength with Schmidt hammer for limestone from Malaysia by Ramli Nazir, Ehsan Momeni, Danial J. Armaghani, and Mohd M. Amin [4]. They used the exponential model to express this relation. They used this relation as given in Eq. (2). The value of R^2 was as high as 0.91.

$$\sigma_u = 12.83e^{0.0487H_r} \quad (2)$$

An interesting study was conducted by S. R. Torabi, M. Ataei, M. Javanshir [5]. Immediate roof rock of coal seams in the North-Eastern coal fields of Iran was selected. They used the relation is found to be a polynomial equation. They used this relation as given in Eq. (3). The value of R^2 was as high as 0.86.

$$\sigma_u = 0.0465H_r^2 - 0.1756H_r + 27.682 \quad (3)$$

2.2 Brazilian Splitting Test (σ_t)

Ramli Nazir, Ehsan Momeni, Danial J. Armaghani, and Mohd M. Amin [9] conducted research regarding correlating unconfined compressive strength to the Brazilian splitting strength of limestone samples. Firstly, they collected different relations from recent studies. The following table 1 summarizes these relations. The correlation coefficient (R^2) varies between 0.5 and 0.79 in all relations.

Table 1 Recent correlations between (σ_u) and (σ_t)

Authors	Equation
Kahraman etal[10]	$\sigma_u = 10.61 \sigma_t$
Farah [6]	$\sigma_u = 5.11 \sigma_t - 133.86$
Altindag etal [11]	$\sigma_u = 12.38 \sigma_t^{1.0725}$

They also stated that one of the most agreed upon correlations is the one done by Sheorey, where σ_u equals ten times the Brazilian splitting strength. They concluded that there is a relation between σ_u and σ_t . They used this relation as given in Eq. (4).

$$\sigma_u = 9.25\sigma_t^{0.947} \quad (4)$$

2.3 Water Absorption (W_a)

An interesting study was conducted by Adnan A. Barahim, Ibrahim A. Al-Akhaly, and Is'haq R. Shamsan [12] studied the correlation between unconfined compressive strength and water absorption. They used this relation as given in Eq. (5). The value of R^2 was as high as 0.8.

$$\sigma_u = -3.774W_a + 83.74 \quad (5)$$

A study confirms that was carried out by Abdul Karim M. Zein and Mutasim A. Sandal [13] studied the correlation between unconfined compressive strength and water absorption. They used this relation as given in Eq. (6). The value of R^2 was as Medium as 0.726.

$$\sigma_u = 22.76 - 1.266W_a \quad (6)$$

2.4 Porosity (n)

An interesting study was conducted by Davood Fereidooni [14] studied the correlation between unconfined compressive strength and porosity. They used this relation as given in Eq. (7). The value of R^2 was as high as 0.89.

$$\sigma_u = 149.33n^{-0.53} \quad (7)$$

A study confirms that was carried out by Anikoh G. A. and Olaleye B. M.[15] studied the correlation between unconfined compressive strength and water absorption. They used this relation as given in Eq. (8). The value of R² was as high as 0.83.

$$\sigma_u = -4979n + 51.507 \quad (8)$$

3. EXPERIMENTAL PROGRAM

To achieve the proposed objectives of the study, tests were performed in the Housing and building national research Center of Egypt. Referring to geotechnical engineering, there are two methods that are used to get the sample at the site area, which is disturbed rock samples method and undisturbed rock samples method. In this study, the will be used is undisturbed rock samples to maintain the natural properties of rock. All Samples were acquired from the various sites located in the city of the new administrative Capital of Egypt. These samples were prepared and tested in accordance with the ASTM for all tests except for the Porosity test with the ISRM. The weight of the samples as using electronic balance shown in figure1 is determined on all prepared core samples for the tests. The diameter (D) and height (H) of core samples were measured using an electronic vernier caliper with an accuracy of 0.01 mm, as shown in figure2. There are four experiments that will be done in this study. To determine the mechanical and physical properties of rock. The mechanical properties such as unconfined compressive strength, Schmidt hammer test, and Brazilian splitting test are determined for all kinds of studied rock. Physical properties are determined on all prepared core samples for the unconfined compressive strength, such as water absorption and porosity. Tests should be used with caution, and that to avoid overestimation of unconfined compressive strength for any design purpose.



Fig.1 Electronic balance



Fig.2 Digital vernier

4. RESULTS AND DISCUSSIONS

In order to estimate with a new correlation between unconfined compression strength and some mechanical and physical properties of rocks, more than 249 of specimens are prepared and tested to fulfill the standard requirements. The tests were conducted on four rock types, including basalt, limestone, sandstone, and siltstone. The Mechanical properties include rocks; Unconfined compressive strength (σ_u) this test was done in accordance with ASTM D7012-14 [16] a rock core specimen was cut to achieve an aspect ratio of (2:1). The specimen was placed in a loading machine. Axial load was applied gradually and increasingly on the specimen until peak load and failure happened. Then the unconfined compressive strength was calculated by Eq. (9).

$$\sigma_u = \frac{P}{A} \quad (9)$$

σ_u = unconfined compressive strength, MPa
 P = failure load, kN
 A = cross-sectional area, mm²

The Mechanical properties include rocks; Schmidt hammer this test was done in accordance with ASTM D-5873-13 [17] performed by subjecting a rock specimen to shock load without resulting in the failure of the specimen. The test procedure was repeated at least ten times for each specimen, and the average value was recorded as the Schmidt hammer value.

The Mechanical properties include rocks; Brazilian splitting test. This was done in accordance with ASTM D-3967-08 [18] and is meant to measure the rock's splitting tensile strength by subjecting a rock specimen to an increasingly concentrated load until the splitting of the specimen. The code states that rock engineers require the determination of complicated stress

fields where a combination of both compressive and tensile stresses are available. Furthermore, doing a pure tensile strength test is theoretically applicable but very hard to do on a practical level. This test serves as an easy alternative to find this mechanical property of rocks. In this test, the geometric constraint of length to diameter ratio is smaller and less strict. The failure load was used to calculate the tensile strength of the sample. This test was carried out on specimens with length to diameter ratios between 0.2 and 0.75. The Brazilian splitting test was determined using Eq. (10).

$$\sigma_t = \frac{2p}{\pi LD} \quad (10)$$

σ_t = splitting tensile strength, MPa
 P = maximum applied load, N
 L = thickness of the specimen, mm
 D = diameter of the specimen, mm

The physical properties include rocks; water absorption. This test was done in accordance with ASTM D6473-99 [19] using Eq. (11) .

$$\text{absorption}\% = [(B - A) / A] \times 100 \quad (11)$$

where:

A = Dry weight
 B = Wet weight

The physical properties include rocks; porosity. The objective of the test is to measure the porosity of rock. This test was done in accordance with ISRM- 2011 [20] using Eq. (12) .

$$n = \frac{V_v}{V} \times 100\% \quad (12)$$

V_v = the volume of void (cm³)
 V = the total volume (cm³)

4.1 Correlation With Mechanical Properties

4.1.1 correlation between unconfined compression strength(σ_u) and schmidt hammer test(H_r)

The results of this study indicated that the correlation between unconfined compression strength and Schmidt hammer test increases as the rock strength. The relationship is found in a polynomial equation. The correlation coefficient (R^2) varies between 0.54 and 0.95. While the relationships are presented in figures 3, 4, 5, 6, it includes all types of rocks that are included in the study. A summary is presented in Table 2 of the correlation equations between the unconfined

compressive strength and Schmidt hammer test. Schmidt hammer test value has been compared with empirical equations proposed by different researchers [4,5,8] There is no agreement between some of this study and Previous Studies. The differences noted may be related to variations in the type and characteristics of the rock studied. Although the standards stipulate the use of the higher range of correlation coefficient, it is essential to check the source of variations and not to discard any reading unless there are visible cracks or chips. For each project, it is important to develop its own database for deriving a specific relationship to be used in that site or at least to check the applicability of the above equations for that site.

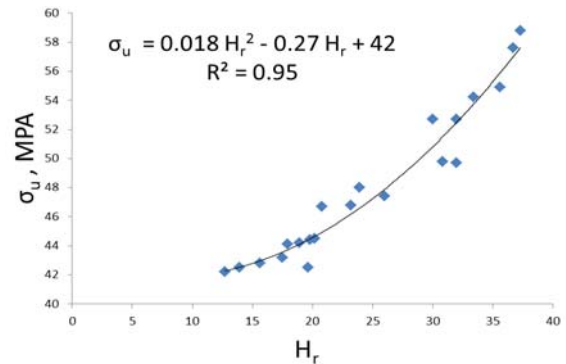


Fig.3 Relationship between σ_u and H_r for Basalt

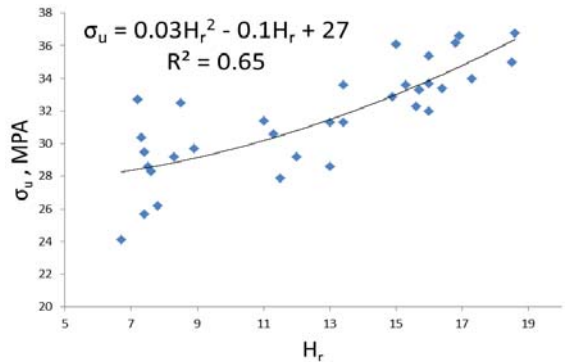


Fig.4 Relationship between σ_u and H_r for Limestone

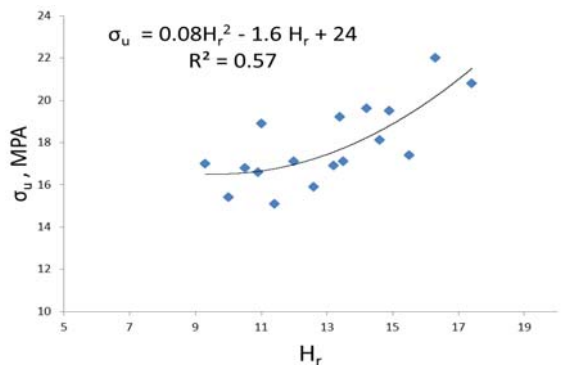


Fig.5 Relationship between σ_u and H_r for Sandstone

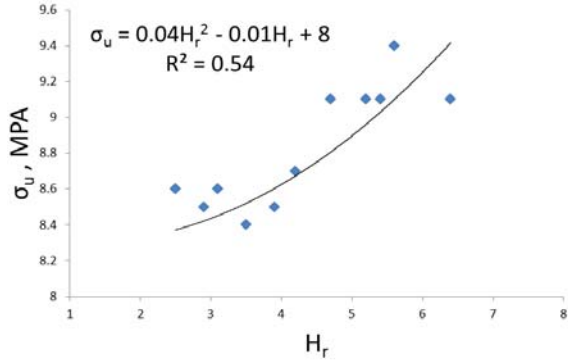


Fig.6 Relationship between σ_u and H_r for Siltstone

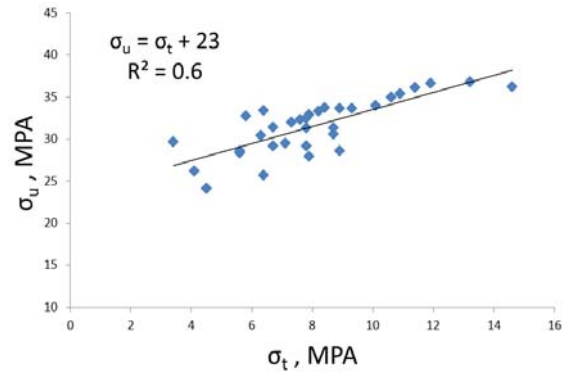


Fig.8 Relationship between σ_u and σ_t for Limestone

Table 2 Relations Summary Between σ_u and H_r

Rock	Equation	R ²
Basalt	$\sigma_u = 0.018H_r^2 - 0.27 H_r + 42$	0.95
Limestone	$\sigma_u = 0.03H_r^2 - 0.1H_r + 27$	0.65
Sandstone	$\sigma_u = 0.08H_r^2 - 1.6 H_r + 24$	0.57
Siltstone	$\sigma_u = 0.04H_r^2 - 0.01H_r + 8$	0.54

4.1.2 correlation between unconfined compression strength(σ_u) and brazilian splitting test(σ_t)

It has been found that the strong linear correlation between unconfined compression strength and Brazilian splitting test for the tested rocks. The correlation coefficient (R^2) varies between 0.5 and 0.74. While The relationships are presented in figures 7, 8, 9, 10 It includes all types of rocks that are included in the study. A summary is presented in Table 3 of the correlation equations between the unconfined compressive strength and Brazilian splitting test. The results of the study have been compared with empirical equations proposed by different researchers [6,10,11].Conducted research regarding correlating unconfined compressive strength to the Brazilian splitting strength of limestone samples. These relations were found to be in conformance with other Previous Studies.

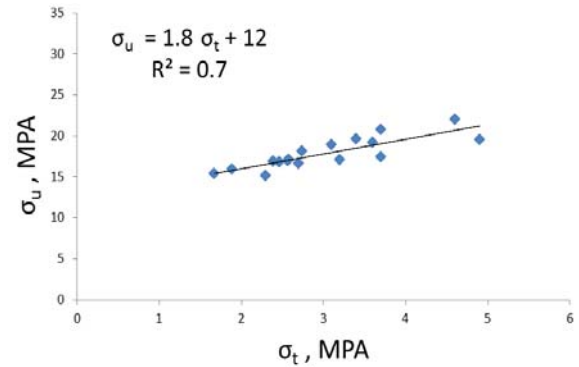


Fig.9 Relationship between σ_u and σ_t for Sandstone

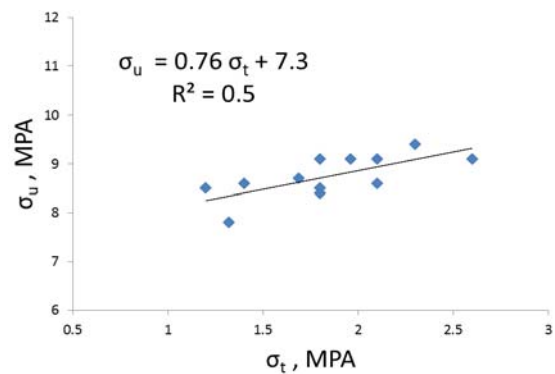


Fig.10 Relationship between σ_u and σ_t for Siltston

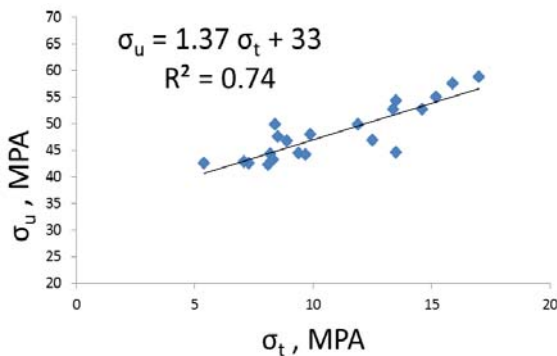


Fig.7 Relationship between σ_u and σ_t for Basalt

Table 3 Relations Summary Between σ_u and σ_t

Rock	Equation	R ²
Basalt	$\sigma_u = 1.37 \sigma_t + 33$	0.74
Limestone	$\sigma_u = \sigma_t + 23$	0.6
Sandstone	$\sigma_u = 1.8 \sigma_t + 12$	0.7
Siltstone	$\sigma_u = 0.76 \sigma_t + 7.3$	0.5

4.2 Correlation With Physical Properties

4.2.1 correlation between unconfined compression strength(σ_u) and absorption (W_a)

It has been found that there is an inverse relationship between the unconfined compression strength and water absorption. This relation is a power equation. The correlation coefficient (R^2) varies between 0.53 and 0.8. While the relationships are presented in figures 11, 12, 13, 14 It includes all types of rocks that are included in the study. A summary is presented in Table 4 of the correlation equations between the unconfined compressive strength and water absorption. The results of the study have been compared with empirical equations proposed by different researchers [12,13] Researchers have used different approaches for deriving these equations. There is no agreement between this study and Previous Studies. The differences noted may be related to variations in the type and characteristics of the rock studied or the presence of cracks. This indicates that a random application of published correlation equations may result in large errors leading to unrealistic predictions of unconfined compression strength.

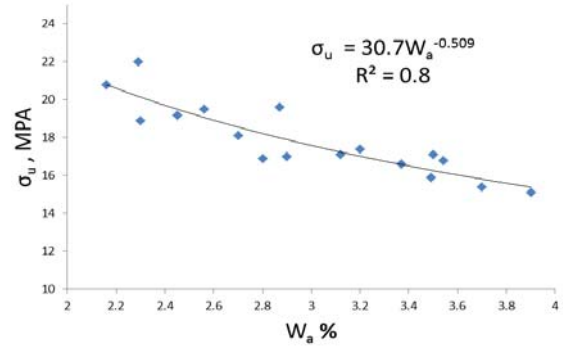


Fig.13 Relationship between σ_u and W_a for Sandstone

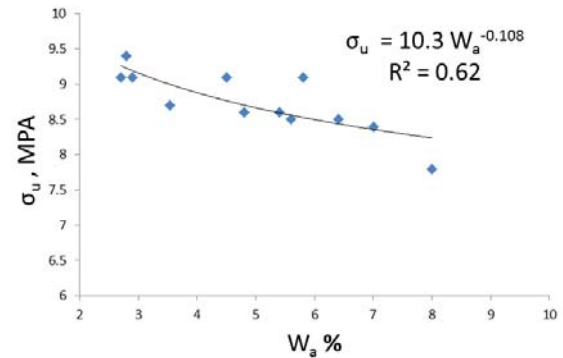


Fig.14 Relationship between σ_u and W_a for Siltstone

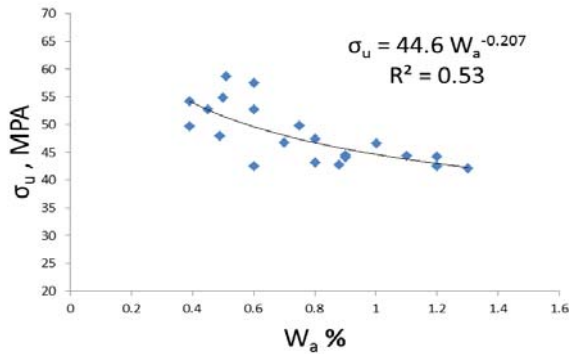


Fig.11 Relationship between σ_u and W_a for Basalt

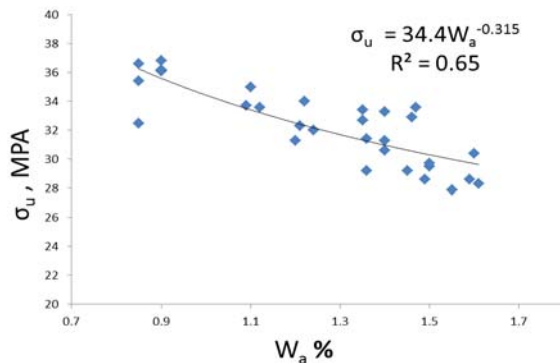


Fig.12 Relationship between σ_u and W_a for Limestone

Table 4 Relations Summary Between σ_u and W_a

Rock	Equation	R^2
Basalt	$\sigma_u = 44.631W_a^{-0.207}$	0.53
Limestone	$\sigma_u = 34.4W_a^{-0.315}$	0.65
Sandstone	$\sigma_u = 30.7W_a^{-0.509}$	0.8
Siltstone	$\sigma_u = 10.3 W_a^{-0.108}$	0.62

4.2.2 correlation between unconfined compression strength(σ_u) and porosity (n)

It has been found from the present study that the unconfined compression strength increases as the porosity in the rock decreases. The relation is found to be a polynomial equation. The correlation coefficient (R^2) varies between 0.56 and 0.77. While the relationships are presented in figures 15, 16, 17, 18 It includes all types of rocks that are included in the study. A summary is presented in Table 5 of the correlation equations between the unconfined compressive strength and porosity. The results of the study have been compared with empirical equations proposed by different researchers [14,15] researchers have used different approaches for deriving these equations. These relations were found to be in conformance with other Previous Studies.

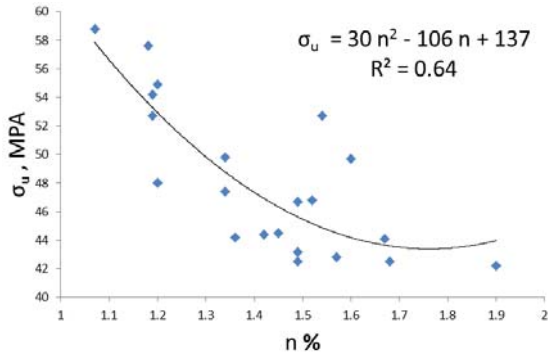


Fig.15 Relationship between σ_u and n for Basalt

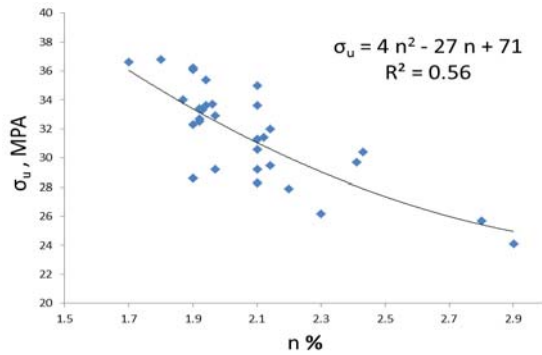


Fig.16 Relationship between σ_u and n for Limestone

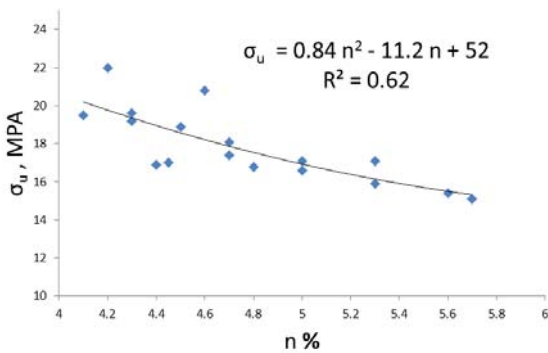


Fig.17 Relationship between σ_u and n for Sandstone

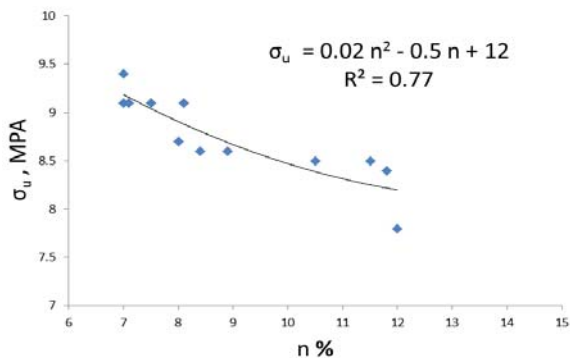


Fig.18 Relationship between σ_u and n for Siltstone

Table 5 Relations Summary Between σ_u and n

Rock	Equation	R ²
Basalt	$\sigma_u = 30 n^2 - 106 n + 137$	0.64
Limestone	$\sigma_u = 4 n^2 - 27 n + 71$	0.56
Sandstone	$\sigma_u = 0.84 n^2 - 11.2 n + 52$	0.62
Siltstone	$\sigma_u = 0.02 n^2 - 0.5 n + 12$	0.77

5. CONCLUSIONS

A laboratory study was conducted to develop a database and models for predicting of unconfined compressive strength of rocks in the new administrative capital of Egypt by some mechanical and physical properties of rocks. The study indicates that the correlation coefficient (R^2) varies between 0.5 and 0.95 in all relations. The derived equations were compared with the equations previously obtained by different researchers. It was found that there was no agreement between some of the equations suggested by different researchers. While some equations exhibit the same trend. It is not possible to obtain only one relationship applicable to all rock types even when the experimental conditions and test types are the same. Although some models are confidently conforming, this doesn't mean the end of scientific research in the field of rock engineering. For each project, it is important to develop its own database for deriving specific relationships to be used in that site or at least to check the applicability of the above equations for that site.

6. ACKNOWLEDGMENTS

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