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EFFECT OF YOUNG'S MODULUS AND MINERALOGY ON ROCK STRENGTH

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ABSTRACT: The mineralogical composition is one of the main properties controlling the rock strength. Mineralogical properties between unconfined compressive strength and Young's modulus and X-ray fluorescence spectrometer were assessed for four rock types, including basalt, limestone, sandstone, and siltstone, collected from different places in the new administrative capital of Egypt. During this respect, the present study presents correlation equations between the unconfined compressive strength and Young's modulus and X-ray fluorescence spectrometer of rocks. More than Seventy of specimens are prepared and tested of rocks. The mineralogical composition was determined by X-ray diffraction. The abundance of quartz and calcium oxide can affect rock strength. A high percentage of quartz and calcium oxide gave high strength to the rocks. This study indicates that there is a straight-line correlation between unconfined compressive strength and quartz for basalt, limestone, and siltstone rocks. This study indicates that there is a straight-line correlation between unconfined compressive strength and calcium oxide for sandstone rocks only. The proposed equations are valid only for selected rocks in the new administrative Capital of Egypt or close to it.

Keywords: Unconfined Compressive Strength, Young's modulus, Mineralogical properties of rocks

1. INTRODUCTION

The mineralogical properties of the intact rock are essential in civil engineering studies if interaction will occur between the rock and construction materials, underground structures, dams, or foundations on rock and rock slopes. The geotechnical behavior of rock depends on various factors, such as grain size, mineral composition, rock origin, degree of weathering, modulus of elasticity, and loading direction [1].

Unconfined compressive strength is a critical test to be done on the rock to give a full understanding of the rocks' capabilities to accommodate proposed project loads. Sometimes, Rock Quality Designation (RQD) of a certain core specimen is of a level so low that it is hard to find a core piece to perform the unconfined compressive Strength test on since codes require a special length to diameter ratio of (2:1) and received rocks' condition usually doesn't meet this requirement. On the other hand, other tests can be done on these rocks' core specimens like Young's modulus(E) and X-ray Fluorescence spectrometer(XRF). Therefore, it is assumed that there is a need for a more straightforward way to determine the unconfined compressive strength of rocks [2].

The study of the properties of rocks and their respective mineralogy characteristics are important in determining the rocks strength and its capability from failure [3]. The properties of rock are influenced by the mineral composition, texture. Rocks have variety in their mineralogy and engineering properties. Mineralogical properties could affect the mechanical properties of the rock [4].

X-ray fluorescence (XRF) technology has come to an extended distance over the past six decades. X-rays are a short wavelength (high energy, high frequency) electromagnetic wave. Spectrally speaking, they are located between the gamma rays. X-Rays are the mechanism utilized in scanning and analyzing major and trace elements in metals, ores, soil, and other materials. The first, high energy X-ray photons emitted by the source can excite secondary, lower energy, "fluorescent" X-ray photons from the sample's atomic structure. The study respective mineralogy characteristics of rocks and are essential in determining the rock's strength and its capability from failure [3].

The main objective of this research is to develop empirical relations between unconfined compressive Strength and mineralogical properties and Engineering properties of Rocks. The specific objectives of the study are to relate the unconfined compressive Strength to Young's modulus(E) and X-ray fluorescence spectrometer(XRF). All of this in order to simplify the approach of estimating the unconfined compressive Strength for weak rocks.

2. PREVIOUS STUDIES

There are many published works that focused on obtaining a correlation between unconfined compressive strength and by mineralogical properties of rocks. The properties of rocks include unconfined compressive Strength to Young's modulus (E) and X-ray fluorescence spectrometer (XRF).

Researchers have used different approaches for deriving these equations. 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.

2.1 Young's Modulus (E)

The ASTM merged the determination of the unconfined compressive strength and Young's modulus of rocks into one code starting from 2005. The code ASTM D-7012 [5] is the standardized procedure now to perform Young's modulus test. In this study, the average modulus method was used to calculate Young's modulus. The Young's modulus was determined using Eq. (1). which is the average slope of the apparently straight line of the stress-strain diagram.

$$E = \frac{\delta}{\mathrm{L}} \tag{1}$$

where (δ) is the instantaneous deformation and (L) is the sample length.

Tziallas, etal. [6] did good research in correlating the unconfined compressive strength to Young's modulus through different models. They concluded that Young's modulus can be determined as a function of unconfined compressive strength with high R^2 value equals 0.95. The following equation is their concluded correlation; where Young's modulus and unconfined compressive strength.

They concluded that Young's modulus can be determined as a function of both unconfined compressive strength. The following Eq. (2). is their concluded correlation; where Young's modulus and unconfined compressive strength. They concluded that Young's modulus could be determined as a function of both unconfined compressive strength.

$$E = 3576.5e^{0.016\sigma_u} \tag{2}$$

M. Colwell and R. Frith [7] researched the estimation of rock engineering properties using Young's modulus. They concluded that a linear model could be used to estimate Young's modulus using Eq. (3). The value of R^2 was as Medium as 0.60

$$E = 4.1141\sigma_u^{\;0.9176} \tag{3}$$

2.2 X-ray Fluorescence Spectrometer (XRF)

Meriam et al. investigated and clearly stated the connection between quartz and, therefore, the lastingness. A higher percentage of quartz has a higher strength of rocks. In contrast to the presence of feldspar, the strength of rocks seems decreased [8]. Zarif and Tugrul acknowledged in their study a few modal analysis made by Mendes et al. This analysis is about the granite texture and microstructure alongside the mineralogical composition. They established that petrographic characteristics had an honest correlation with the mechanical properties. Exist have tons of studies and investigations regarding the correlations and, therefore, the mechanical properties of rocks, the effect of mineralogical, and therefore the engineering properties remain not well identified. This is often because different rocks have different mineral contents. Therefore, there are not any specific mineralogical properties that will be laid on to work out the strength of rocks for the three sorts of rocks; igneous, sediment, and rock [9].

N.Q.A.M.Yusofa, H.Zabidia conducted a study on the relationships between the petrographic and mechanical properties of granitic rock from Hulu Langat, Selangor. Rock samples were collected from the study area. to review the mineralogy characteristics of rocks. The mechanical properties determined on the core samples included the purpose load strength, the uniaxial compressive strength, and, therefore, the lastingness. By of these methods, it shows the connection between mineralogy characteristics and mechanical properties of the granite [10], so as to work out the influence of The relationships are as shown in Eq. (4). consistent with this figure, the connection between the quartz to feldspar ratio and unconfined compressive strength is linear, but the correlation is not significant because the degree of alteration affects this ratio.

$$\sigma_u = 426\,Q + 24.4 \tag{4}$$

It has been studied by Ilia Ioanna, Rozos Dimitrios, Perraki Theodora, Tsangaratos Paris studied thirty collected samples of hard soils-soft rocks like marls, originating from Euboea Island and Peloponnesus area, were investigated to gauge their geotechnical behavior. Certain parameters were determined and used for empirical correlations with their mineralogical characteristics. The mineralogical composition decided by x-ray diffraction, thermo-gravimetric and thermal analysis, succeeded by a textural analysis performed by Optical Microscope. With the assistance of the above-mentioned tests, we interpreted the observed geotechnical behavior of the examined weak rocks by means of mineralogical composition and texture. Durability and thus, the unconfined compressive strength was found to be influenced by high percentages in carbonate minerals. Additionally, it had been found that a decrease in clay content resulted in higher strength and sturdiness values. The concluded empirical correlations verified the influence of those parameters and gave a general overview of the engineering behavior of the examined weak rocks [11]. There's a robust correlation of the physical characteristics, the structure, and mineralogical composition of rocks.

3. EXPERIMENTAL PROGRAM

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. for any design purpose. The testing, such as unconfined compressive Strength(σ_u), Young's modulus (E), and X-ray fluorescence spectrometer(XRF) are determined for all kinds of studied Rocks.

3.1 Unconfined Compressive Strength(σ_u)

There are three sorts of compressive strength tests of rocks. The primary is that the unconfined compressive strength (σ_u) where only the axial load is applied to a rock sample and no lateral a lot of any type are applied, mathematically speaking. The second is that the triaxial loading where not only axial loading is applied to the rock sample, but also equal lateral loading is applied to the opposite two dimensions. The third is that the right triaxial loading, almost like triaxial loading, but the difference being that lateral loads are not equal [12]. The following Fig. 1. Illustrates different compression types. (a) Implies unconfined compressive Strength, (b) implies triaxial loading, and (c) implies true triaxial loading The most commonly used test is the unconfined compressive strength(σ_u) test as it is the easiest and less sophisticated among all three compression test types. Other tests are needed if a further understanding of rock failure in semi-natural cases is required. But in general, rock triaxial and true triaxial is seldom performed. Another advantage of rock unconfined compressive Strength (σ_u) test is the unconfined compressive strength (σ_u) value that is used to determine the point bearing capacity of piles resting on rocks.

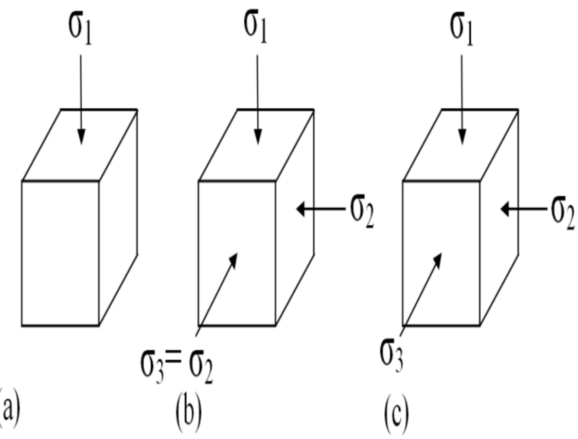

Fig.1 Different Compression States of Rock by Jaegar, etal. (2007)

This test is performed in accordance with the American Society of Testing and Materials ASTM-D7012 [5]. Length, diameter, weight, a load of failure, and any remarks that happened during the test were recorded. Moreover, the samples had a length to diameter ≥ 2. This testing machine is shown in Fig.2. Sample ready for testing. The following Eq. (5). is used to determine the unconfined compressive strength(σ_u).

$$\sigma_u = \frac{P}{A} \quad (5)$$

σ_u = unconfined compressive strength, MPa
P = failure load, kN
A = cross-sectional area, mm^2

Fig.2 Sample ready for testing for unconfined compressive strength

3.2. Young's Modulus (E)

For the engineering classification of rocks, it is essential to know the values of their elastic constants. This helps in understanding the deformation characteristics of rocks when subjected to loading. For this purpose, the compressive stress of the specimen and the corresponding longitudinal and lateral strain values are required. Hence arrangements to measure the deformation of the cylindrical specimens in both directions have to be made. The primary purpose of this study is to express the relationships between unconfined compressive strength with Young's modulus (E) of the rocks by empirical equations. Empirical equations of these relationships will make it possible to estimate tangent Young's of rocks by using the unconfined compressive strength, which is widely used as the index for a quick strength characterization due to its simplicity, and obtainable from other simple index tests. Therefore, it is hoped that this study will make a contribution to geological, civil and geotechnical engineers in making practical estimating decisions at the preliminary stage of the site investigations, in order to determine modulus (E) of rocks. Fig.3. shows the set up for measurement of vertical and lateral.

Fig. 3 shows the set up for measurement of vertical and lateral deformations

3.3 X-ray Fluorescence Spectrometer(XRF) of This Study

X-ray fluorescence was carried out using Phillips X-ray fluorescence Spectrometer Model PW16 as shown in Fig.4. The loss on ignition was measured at 1000 C. X-ray fluorescence analysis (XRF) is one of the most significant emission methods, which enables a quick analysis in a short period of time and requires minimal preparation of the sample. Due to its advantages, first of all, because it is quick, non-destructive, and less expensive, the X-ray fluorescence analysis is nowadays applied in many fields, where it is particularly necessary to point out its application in the everyday analysis.

Fig. 4 Phillips X-ray fluorescence Spectrometer Model PW16

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 Seventy 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.

4.1 Correlation between Unconfined Compression Strength(σ_u) and Young's Modulus (E)

The results of this study indicated that in general, the compressive strength increases with increasing the Young's modulus. The correlation coefficient (R^2) varies between 0.81 and 0.98. While Regression equations were established among rock parameters and correlations were expressed, The plots of unconfined compression strength versus Young's modulus in Fig. 5-8 for Basalt, limestone, sandstone, and siltstone. All correlations clearly indicate that the relation is dissimilar for different rock types; this may be attributed to mineralogical, textural, and deformational factors. A summary is presented in Table 1 of the correlation equations between the unconfined compressive strength and Young's modulus. The results of this study were compared with the results previously obtained by different researchers. It was seen that there was an agreement between this study and previous studies. 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. 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.

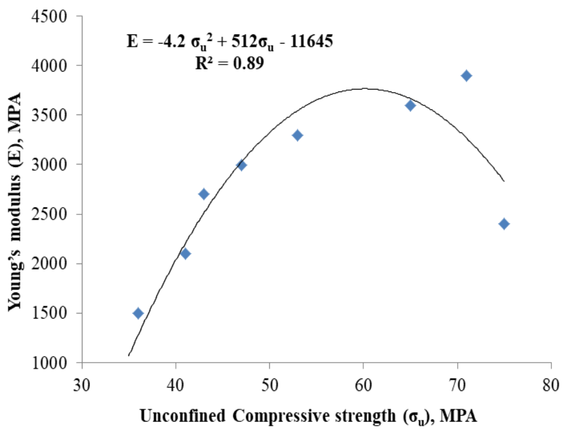

Fig.5 Relationship between σ_u and E for Basalt

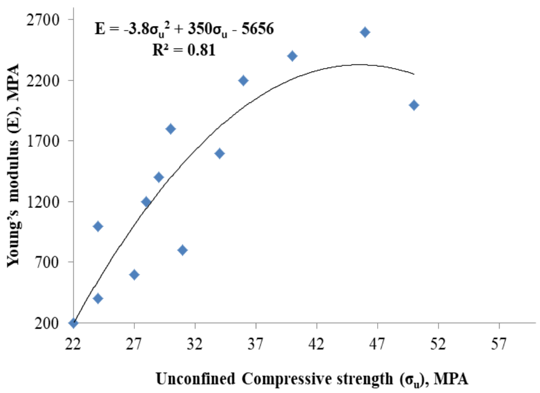

Fig.6 Relationship between σ_u and E for Limestone

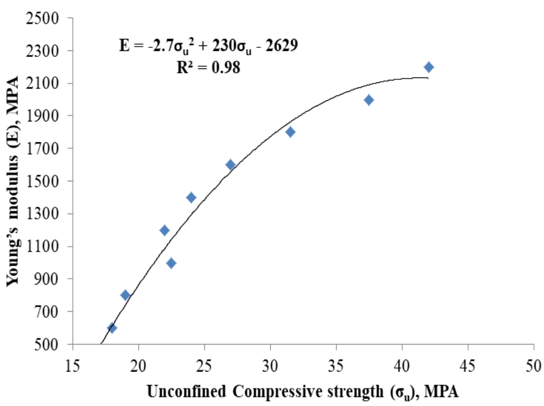

Fig.7 Relationship between σ_u and E for Sandstone

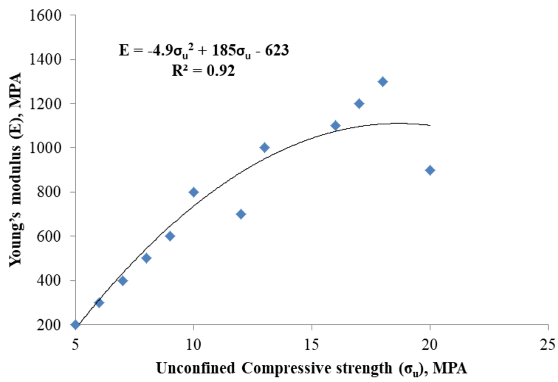

Fig.8 Relationship between σ_u and E for Siltstone

Table 1 Relations Summary Between σ_u and E

Rock	Equation	R^2
Basalt	$E = -4.2\ \sigma_u 2 + 512\sigma_u - 11645$	0.89
Limestone	$E = -3.8\sigma_u 2 + 350\sigma_u - 5656$	0.81
Sandstone	$E = -2.7\ \sigma_u\ 2 + 230\ \sigma_u - 2629$	0.98
Siltstone	$E = -4.9\sigma_u 2 + 185\sigma_u - 623$	0.92

4.2 Correlation between Unconfined Compression Strength(σ_u) and X-ray Fluorescence

It has been found from the present study that the unconfined compression strength increases as the quartz in the rock increases. An abundance of quartz can affect the rock strength, High percentage of quartz gave high strength to the rocks. There is a linear correlation between compressive strength and quartz. The correlation coefficient (R^2) varies between 0.52 and 0.90. While Regression equations were established among rock parameters and correlations were expressed, The plots of unconfined compression strength versus water quartz in Figs.9-11 for Basalt, limestone, and siltstone. While there was no relationship between the non-unconfined compression strength and the quartz of sandstone, a relationship was found between the unconfined compression strength and the calcium oxide. She was correlations expressed in Fig.12. There is a linear correlation between compressive strength and calcium oxide. All correlations clearly indicate that the relation is dissimilar for different rock types; this may be attributed to mineralogical, textural, and deformational factors. A summary is presented in Table 2 of the correlation equations. These relations were found to be in conformance with other Previous Studies, and it is important to develop its own database for deriving a specific relationship to be used in that site. 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.

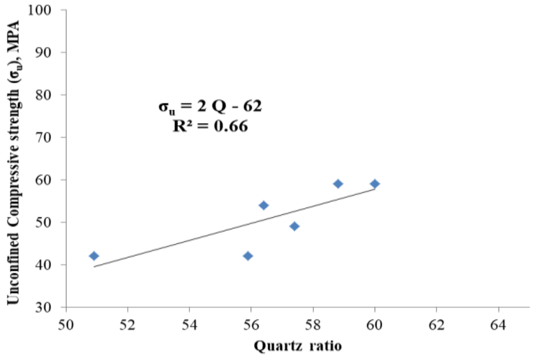

Fig.9 Relationship between σ_u and X-ray for Basalt

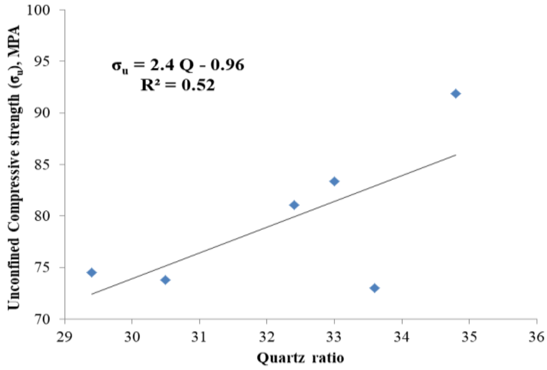

Fig.10 Relationship between and X-ray for limestone

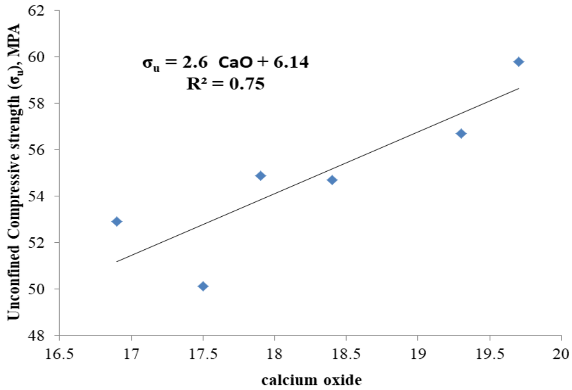

Fig.11 Relationship between σ_u and X-ray for Siltston

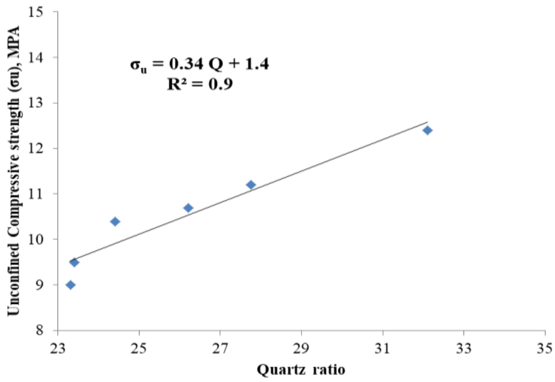

Fig.12 Relationship between σ_u and X-ray for Sandstone

Table 2 Relations Summary Between σ_u and X-ray

Rock	Equation	R^2
Basalt	$\sigma_u = 2 Q - 62$	0.66
Limestone	$\sigma_u = 2.4 Q - 0.96$	0.52
Siltston	$\sigma_u = 2.6\ CaO + 6.14$	0.75
Sandstone	$\sigma_u = 0.34 Q + 1.4$	0.90

5. CONCLUSIONS

One of the features that dominate the rock strength is mineral compositions. A laboratory study was conducted to develop a database and models for predicting of unconfined compressive strength of rocks Through Young's modulus and X-ray fluorescence spectrometer in the new administrative capital of Egypt. The abundance of quartz and calcium oxide can affect rock strength. A high percentage of quartz and calcium oxide gave high strength to the rocks. This study indicates that there is a straight-line correlation between unconfined compressive strength and quartz for basalt, limestone, and siltstone rocks. This study indicates that there is a straight-line correlation between unconfined compressive strength and calcium oxide for sandstone rocks only. 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. The proposed equations are valid only for selected rocks in the new administrative Capital of Egypt or close to it. The study indicates that the correlation coefficient (R^2) varies between 0.52 and 0.92 in all relations.

6. ACKNOWLEDGMENTS

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