Research article

Correlation of sandstone rock properties obtained from field and laboratory tests

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ABSTRACT

The unconfined compressive strength of rocks plays an important role in many practices for geotechnical engineering. It is used to determine the bearing capacity of soil specially rocks. The real value of this parameter requires a special technique such as undisturbed samples. So, prediction of unconfined compressive strength of sandstone rocks with the help of rock quality designation (RQD) provides a good opportunity to obtain this parameter without using of more laboratory tests. The RQD is commonly used for rock description or classification, and ….etc. Correlation of properties obtained from field and laboratory tests is considered the most important challenge for geotechnical engineers to save time, effort and many tests. This study was undertaken in order to quantify the variation of the values of unconfined compressive strength due to variation of (RQD). Many field boreholes have been investigated for this purpose. Unconfined compressive strength tests were conducted using samples of different values of RQD. This paper proposed a new empirical equation to predict the unconfined compressive strength for sandstone rock.

Keyword: Sandstone, unconfined compression strength, RQD, tests, jointing, fracture.

1. Introduction

Most problems in soils and construction involve either the strength of the in-situ soil or the compressibility of the soil mass. For purposes of design it is necessary to represent, in equations of engineering mechanics the corresponding numerical values representing an appropriate in-situ property. Strength values determined from laboratory testing of intact soil cores are recognized as not being directly applicable to the in-situ soil mass because of the scale effect. Presence of joints in sandstone rock (sedimentary rock type) has rendered it to be discontinuous in nature. Expressed in terms of Rock Quality Designation (RQD), this discontinuous to nature makes sandstone mass to behave differently than intact samples used in laboratory tests. Some forms of reduction on the properties must be applied as intact sandstone rock is usually stronger than a discontinuous mass.

The rock quality designation (RQD) index was introduced 20 years ago at a time when rock quality information was usually available only from geology descriptions and the percentage of core recovery. The RQD is modified core recovery percentages in which unrecovered core, fragments and small pieces of rock, and altered rock are not counted so as to downgrade the quality designation of rock contain these feature (Deere, 1988). In soil masses, the existence of discontinuities makes the material properties of soil masses differ greatly from that of intact soils. Although sandstone masses are composed of intact sandstone samples and discontinuities, the deformation of sandstone masses occurs mainly in the discontinuities, especially when subjected to low stress state. Experiments have also shown that the permeability of rock masses is primarily on the discontinuities (Jiang, et al., 2009). In engineering applications, RQD is usually calculated as the percentage of the borehole core in a drill run consisting of intact lengths of greater than or equal to 100 mm, which can be mathematically expressed as

$$RQD = 100 \sum_{i=1}^{n} \frac{x_i}{x} \ \%$$

Where x_i are the lengths of the individual pieces of core in a drill run having lengths ≥ 100 mm and x is the total length of the drill run.

Many engineers have frequently determined the soundness of rock masses through only the RQD combined with their own experiences. The rock quality designation (RQD) rough measure of the degree of jointing or fractures in rock mass and affect in the permeability of rock mass. The RQD is a modified percent core-recovery which incorporates only sound pieces of core that one 100mm (4inch) or greater in length along the core aims (Singh & Goel, 1999). It is commonly used for rock description or classification, and ...etc. This parameter is routinely performed in field while boreholes are performed. However there is also potential to use the rock quality designation (RQD) as a basis for estimating rock behavior, end bearing capacity of rock socketed shafts (Zhang, 2010). Theoretically representing the rock quality designation (RQD) provides several benefits. First, the sandstone rocks may be classified using this parameter. Second, it is used to estimate or prediction the bearing capacity of sandstone rock. Third, a mathematical equation can provide a method of representing the entire curve between measured data and unconfined compressive strength of sandstone rocks. Numerous methods have been developed for determination the unconfined compressive strength. These methods include the field and laboratory tests. Also, to determine the real value of unconfined compressive strength of rocks, special techniques should be followed such as undisturbed samples and initial overburden pressures should be taken into consideration. On the other hand, only the rock quality designation (RQD) does not depend on undisturbed sample. The interpretation of the rock quality designation (RQD) is typically carried out using field samples.

Unconfined compressive strength (Qu) is a means of determining the ability of a sandstone rock to withstand loading pressures. It is an important consideration in the design of structures that will be supported by the rock, as it is used in calculating how much stress, or weight, the rock will initially support. To determine Qu, pressure is applied to a cylinder of the sandstone rock mass until it fails, the data gathered is charted, and the unconfined compressive strength is derived. The engineering properties of sandstone rocks have great importance in designing surface and subsurface structures, in slope stability analysis, and for the design of drifts, ore passes, tunnels, and rock caverns. Mining methods based on caving and blocking of the ore, such as sublevel caving and block caving, also, require knowledge of rock strength. Furthermore, Knowledge of rock strength is of great importance in order to reduce potential settling of rock foundations (Naderi, 2011).

The rock quality designation (RQD) has been extended to other areas of rock mechanics, and it has become a fundamental parameter in geotechnical engineering. The success of the RQD is due, in large part, to its simple definition as mentioned in equation (1). However, this index is affected by a number of well known limitations. For instance, its value can be different for a given location when obtained from cores with different drilling orientations. In additions, the RQD may be affected by the rock strength and core size (Li, et al., 2009). For RQD determination, the International Society for Rock Mechanics (ISRM) recommends a core size of at least NX (size 54.7mm) drilled with double-tube core barrel using a diamond bit. Artificial fractures can be identified by close fitting of cores and unstained surface. All the artificial fractures should be ignored while counting the core length for RQD. A slow rate of drilling will also give better RQD. The relationship between RQD and the engineering quality of the rock mass as given in Table 1. Also these ratios are approximately used for field/laboratory compressive strengths. When cores are not available, RQD may be estimated from number of joints (discontinuities) per unit volume Jv (Keykha and Haut, 2011). A simple relationship which may be used to convert Jv into RQD for clay-free rock masses is

$$RQD = 115 - 3.3Jv \qquad (2)$$

Where Jv represents the total number of joints per cubic meter or the volumetric joint count. Large scale rock mass characterization introduces several material parameters in relation to mechanical properties. Two of the most important ones are the deformation modulus and the unconfined rock mass strength. These material parameters are frequently related to laboratory data characteristics of intact rock samples and to the classical rock mass classification systems such as RQD. There are several empirical relations between the rock mass mechanical parameters (unconfined compressive strength, deformation modulus) and of the rock mass classification systems. These uniformly show increasing deformation modulus and compressive strength with the increasing quality of the rock mass (RQD), (Ván and Vásárhelyi, 2010).

Table 1: Description of rocks according to RQD

No	RQD (%)	Rock quality
1	25	Very poor
2	25 – 50	Poor
3	50 – 75	Fair
4	75 – 90	Good
5	90 – 100	Excellent

This study was undertaken in order to know the correlation of properties obtained from field and laboratory tests, and specially, to quantify the variation of the values of unconfined compressive strength of sandstone rock due to variation of rock quality designation (RQD). Field and experimental tests were conducted for this purpose. Also, this paper proposed a new empirical equation to identify the unconfined compressive strength of sandstone rock using rock quality designation (RQD).

2. Field and experimental work

The field work consisted of drilling and sampling of more than 200 boreholes to depths between 10 m to 15 m below ground surface. The site of this work is, Al-Jouf university, KSA. The borehole logs mainly consisted of surface layer of white, very dense and dry silty sand with gravel underlined with sandstone rock layer of white gray, moderately weathered, very highly fractured to massive. Many specimens of sandstone with different rock quality designation (RQD) have been taken out. To carry out the various laboratory tests, the specimens were carefully transported to laboratory according to standard classification and techniques. The overburden and the upper levels of the bedrock were sampled by carrying out Standard Penetration Tests (SPT) and obtaining split barrel samples. Also, a rock recovery

(REC) was determined. The bedrock core was logged and samples were selected for strength testing. Drilling performed using tri-cone bit and casing and double tube core barrel.

2.1 Rock description and its properties

The borehole logs mainly consisted of surface layer of white, very dense and dry silty sand with gravel underlined with sandstone rock layer of white gray, moderately weathered, very highly fractured to massive. One of borehole logs is shown in Figure 1.

The specimens were taken at different depths below ground surface. The properties of the sandstone rock specimens such as dry density (γ_d), recovery (REC), rock quality designation (RQD), and unconfined compressive strength (Qu) were determined. These properties for random thirty chosen specimens were tabulated in Table 2.

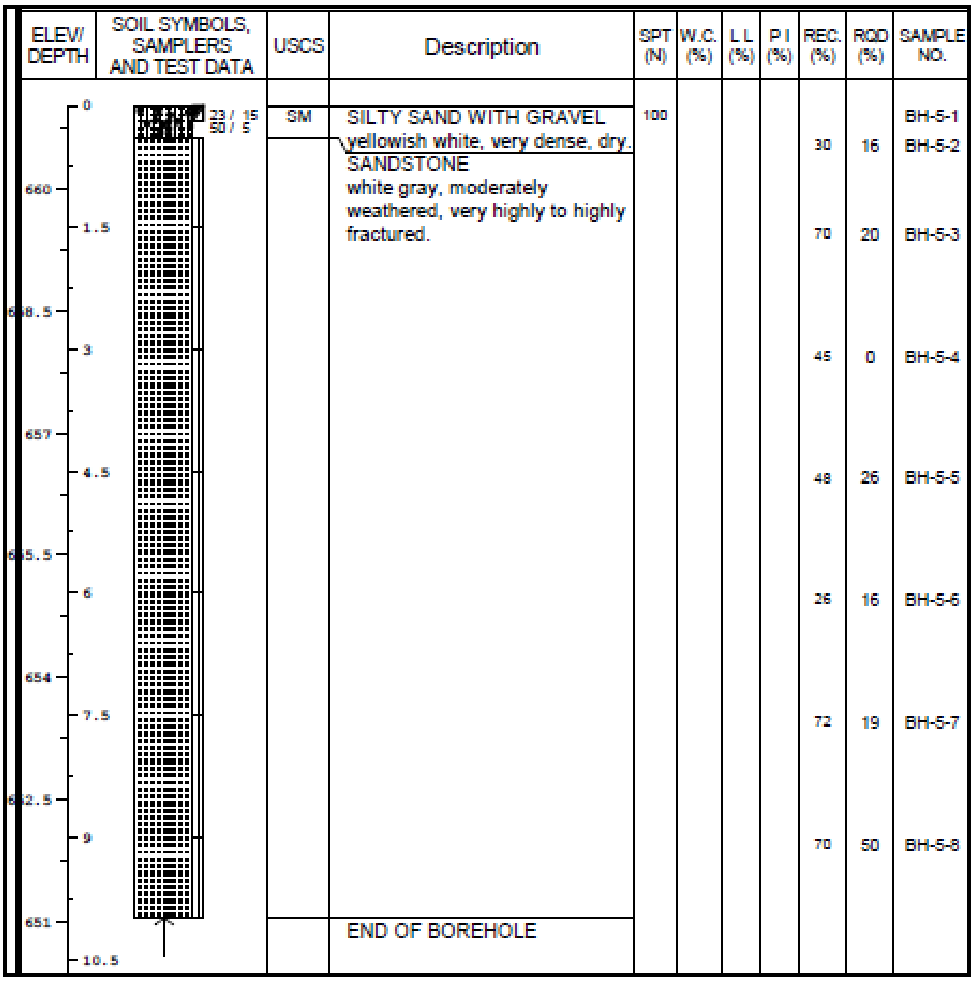

Figure 1: One of test boring log

2.2 Scope of study

There are many different boreholes were obtained to determine the correlation of properties obtained from field and laboratory tests, specially, the unconfined compressive strength (Qu) of sandstone rock and the data are tabulated as shown in Table 2. There are different parameters were taken into consideration such as depth of rock below ground surface (D), dry density (γ_d), recovery (REC), rock quality designation (RQD), and unconfined compressive strength (Qu). In this study, the relations between these previous parameters and their effects on unconfined compressive strength (Qu) have been presented.

Table 2: Properties of sandstone rock specimens

Sample No.	D Depth below (G.S.) (m)	γ_d (gm/cm^3)	REC. (%)	RQD (%)	Qu (kgf/cm^2)
1	1.5	2.20	51	18	279
2	3.0	2.22	57	27	285
3	4.5	2.21	66	30	265
4	6.0	2.23	71	36	293
5	6.0	2.24	72	40	315
6	7.5	2.24	80	47	306
7	1.5	2.21	51	18	277
8	2.7	2.21	53	24	295
9	4.5	2.20	65	32	274
10	6.0	2.22	68	35	283
11	5.5	2.23	65	34	301
12	7.0	2.24	72	41	305
13	1.2	2.21	55	20	275
14	1.5	2.23	54	19	282
15	2.7	2.22	51	18	278
16	3.0	2.22	58	26	288
17	2.1	2.24	57	25	296
18	6.0	2.23	90	70	338
19	4.5	2.26	82	67	369
20	1.5	2.23	70	57	284
21	3.0	2.24	70	50	337
22	1.5	2.24	52	20	267
23	3.0	2.23	59	26	284
24	4.0	2.22	63	27	284
25	2.0	2.25	54	17	277
26	4.5	2.26	67	30	312
27	1.5	2.29	40	14	285
28	3.0	2.26	43	18	296
29	1.5	2.25	30	14	285
30	4.5	2.31	37	16	309

3. Analysis of results and discussions

In the following sections, the results obtained from field and experimental tests have been presented and discussed. Considering the correlation coefficient (R^2), the best fitting between the results were plotted. The purpose of use of this statistical method is to give us a statistic known as the correlation coefficient which is a summary value of a large set of data representing the degree of linear association between two measured variables. So, it is very important to understand what is the statistical correlation coefficient represents and what is means (Taylor, 1990). R is used to determine whether the relationship is positive or negative based upon the sign of R, whereas, R^2 is the predictive percent of behavior in the output that can be explained by the input. R^2 is a statistic that will give some information about the goodness of fit of a model. In regression, the R^2 coefficient of determination is a statistical measure of how well the regression line approximates the real data points. An R^2 of 1.0

indicates that the regression line perfectly fits the data. According to the value of correlation coefficient R^2, the relationship between any two parameters can be classified as follows,

i. R^2 <0.30 are considered to have no correlation and behavior is explained by chance,
ii. R^2 of 0.30 to 0.499 are considered to be a mild relationship,
iii. R^2 of 0.50 to 0.699 are considered to be a moderate relationship, and
iv. R^2 of 0.70 to 1.00 are considered to be a strong relationship.

Four scopes of study to obtain the effect and relation between different sandstone rock properties were performed as follows:

3.1 Effect of sandstone rock depth (D) below ground surface

Figures from 2 to 4 show the relationships between depth of sample below ground surface (D) and properties of sandstone rock such as recovery (REC), rock quality designation (RQD) and unconfined compressive strength (Qu), respectively. From these Figures, generally, it can be noticed that recovery (REC), rock quality designation (RQD) and unconfined compressive strength (Qu) increase as depth of sample below ground surface increases. Considering the values of correlation coefficient R^2, it can be noticed that the relationships between both recovery and rock quality designation with depth are considered to be a mild relationship as shown in Figures 2 and 3, respectively.

Whereas, in the case of relationship between unconfined compressive strength with depth is considered to have no correlation and behavior is explained by chance as clear in Figure 4. Also, it can be found that recovery is more affected by depth than others, then, rock quality designation and this is due to overburden pressure. From Figure 4, according to value of correlation coefficient $R^2 = 0.235$, it can be considered that unconfined compressive strength does not depend on depth so that the relationship can be ignored.

3.2 Effect of dry density (γ_d) of sandstone rock

Figures 5, 6 and 7 show the relationships between dry density (γ_d) of sandstone rock and its properties recovery (REC), rock quality designation (RQD) and unconfined compressive strength (Qu), respectively. From these Figures, it can be noticed that recovery (REC), rock quality designation (RQD) and unconfined compressive strength (Qu) increase as dry density increases. Whereas, considering the values of correlation coefficient R^2 which these values are ≤ 0.30, this means that these relationships are considered to have no correlation and behavior is explained by chance. From previous discussion, it can be concluded that, the relationships between the properties recovery (REC), rock quality designation (RQD) and unconfined compressive strength (Qu) with dry density (γ_d) have no correlation and can be neglected.

3.3 Effect of recovery (REC)

Figures 8 and 9 show the relationships between recovery (REC) and the properties of sandstone rock including rock quality designation (RQD) and unconfined compressive strength (Qu), respectively. From these figures, it can be noticed that rock quality designation (RQD) and unconfined compressive strength (Qu) increase as recovery (REC) increases. From Figure 8, a high correlation coefficient ($R^2 = 0.793$) of this figure can be an indication of a good correlation between the recovery (REC) and rock quality designation (RQD).

Whereas, in Figure 9, it can be noticed that the correlation coefficient $R^2 = 0.285$, this means that the relationship between recovery (REC) and unconfined compressive strength (Qu) is considered to have no correlation and behavior is explained by chance, so it can be ignored.

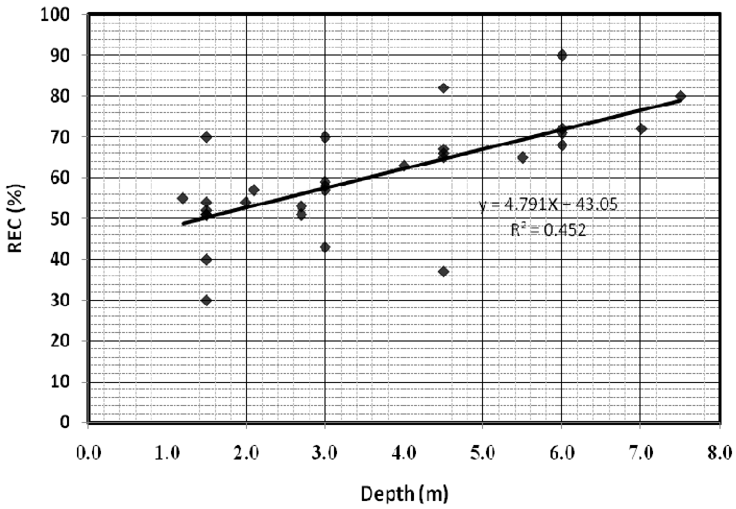

Figure 2: Depth of sample below ground surface versus recovery (REC)

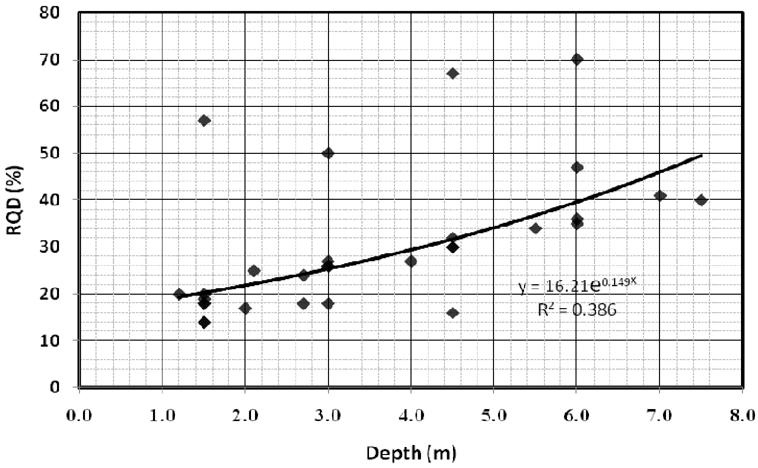

Figure 3: Depth of sample (D) versus rock quality designation (RQD)

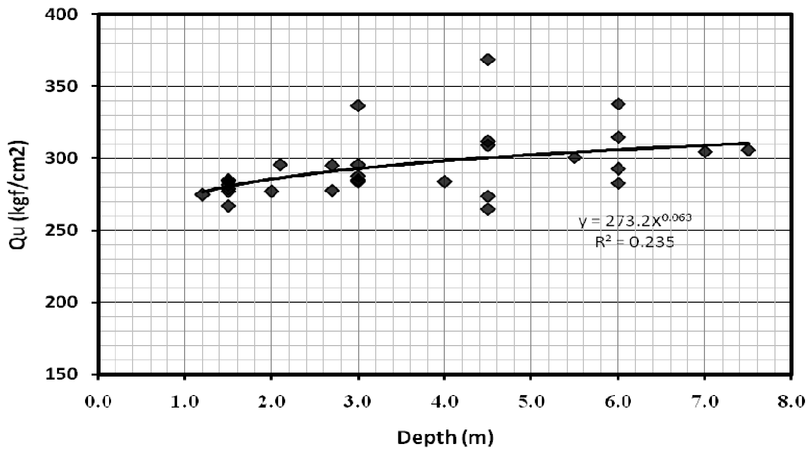

Figure 4: Depth of sample (D) versus unconfined compressive strength (Qu)

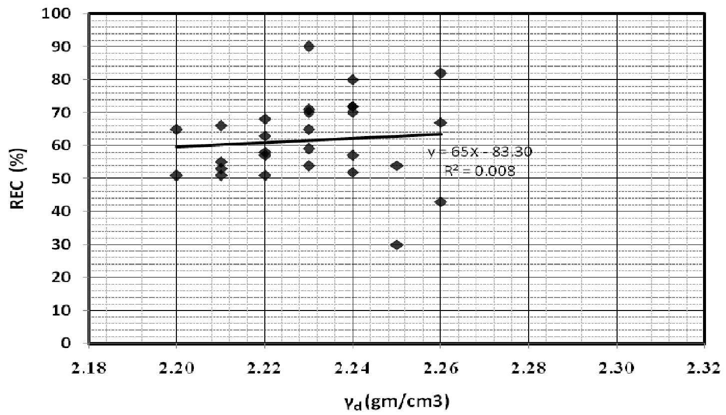

Figure 5: Dry density of sandstone (γ_d) versus recovery (REC)

3.4 Effect of rock quality designation (RQD)

Figure 10 shows the relationship between rock quality designation (RQD) of sandstone and unconfined compressive strength (Qu). From this Figure, it can be noticed that unconfined compressive strength (Qu) increases as rock quality designation (RQD) increases. It can be found that, the value of correlation coefficient (R^2 = 0.676), is considered to be a moderate relationship, and can be an indication of approximately a good correlation between (RQD) and (Qu). It can be mentioned that the two parameters rock quality designation (RQD) and unconfined compressive strength (Qu) of sandstone rock are good and positive related together. This means that sandstone rock has a small value of unconfined compressive strength tends to fracture make joints (discontinuities) and vise versa.

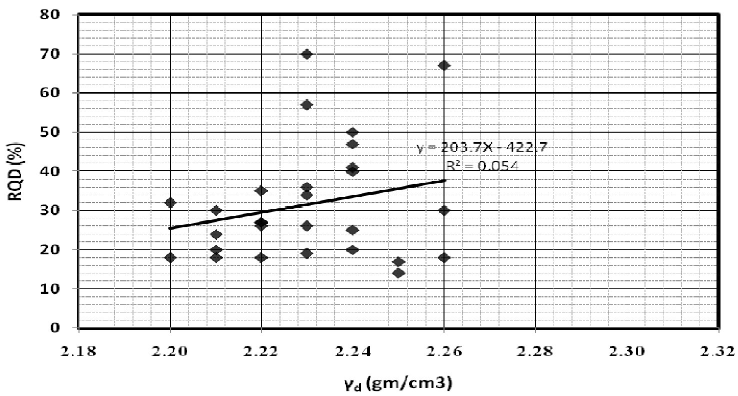

Figure 6: Dry density of sandstone (γ_d) versus rock quality designation (RQD)

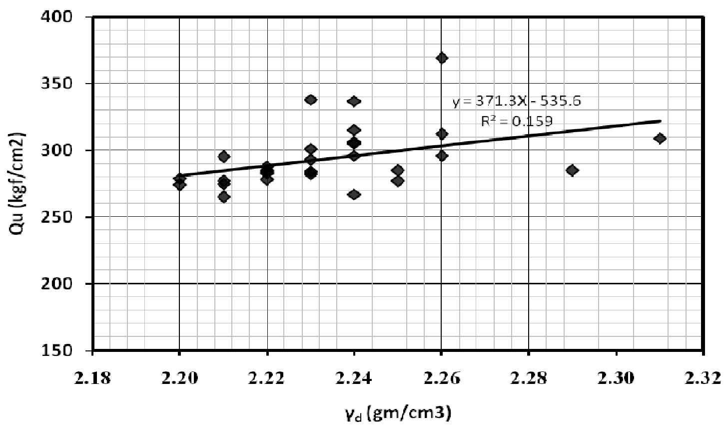

Figure 7: Dry density of sandstone (γ_d) versus unconfined compressive strength (Qu)

From the previous discussion it can be found that rock quality designation (RQD) is considered only the parameter which affects directly on the unconfined compressive strength (Qu). Whereas, the other studied parameters such as depth and dry density are considered have a small effect on the unconfined compressive strength (Qu), so that it can be neglected. Also, from the previous analysis, it can be found that the rock quality designation (RQD) is strongly affected with parameter recovery (REC).

3.5 Empirical equations to predict unconfined compressive strength (Qu)

From the above test results shown in Figure 10 and regression analysis, an empirical equation to estimate the unconfined compressive strength (Qu) for sandstone rocks having different values of rock quality designation (RQD) is predicted as follow:

$$Qu = 1.27(RQD) + 250$$

Where, RQD is in percentage (%) and Qu in (Kgf/cm^2).
The above equation has correlation coefficient (R^2 = 0.676), which is considered to be a moderate relationship and approximately a good correlation between (RQD) and (Qu). So, it can be considered accepted. Also, the estimated (Qu) , can be taken into consideration to predict the bearing capacity of sand stone rock.

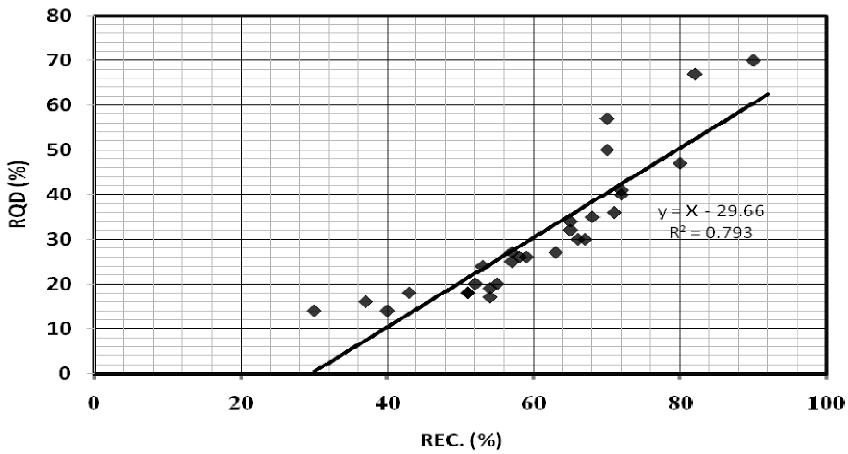

Figure 8: Recovery (REC) versus rock quality designation (RQD)

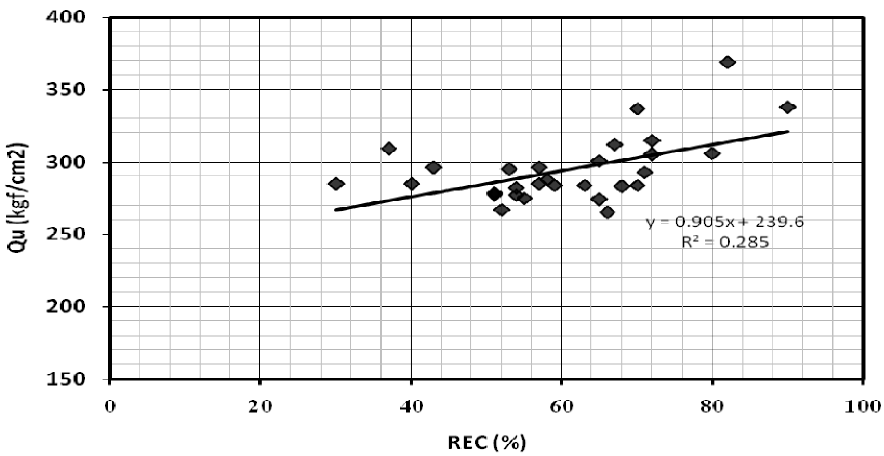

Figure 9: Recovery (REC) versus unconfined compressive strength (Qu)

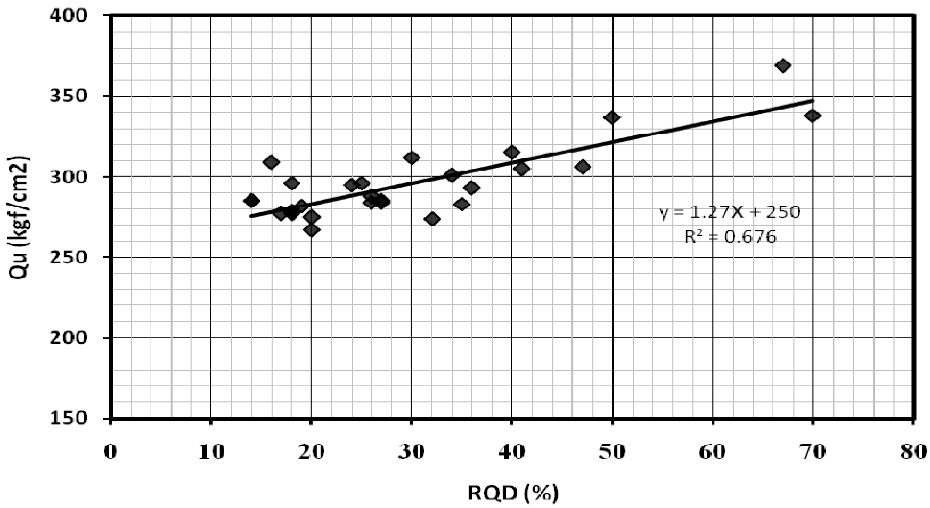

Figure 10: Rock quality designation (RQD) versus unconfined compressive strength (Qu)

4. Conclusions

The present study is concerned with the correlation of sandstone rock properties obtained from field and laboratory tests. Because the unconfined compressive strength (Qu) is considered the most important parameter to estimate the bearing capacity of rock, so, the prediction of (Qu) of sandstone rocks with the help of rock quality designation (RQD) has been presented. Based on the above discussion and analysis of obtained results, the following main conclusions are drawn:

1) The rock quality designation (RQD) is considered only the parameter which affects directly on the unconfined compressive strength (Qu).
2) The parameters such as depth (D) below ground surface and dry density (γ_d) are considered have small effect on unconfined compressive strength (Qu), so that it can be neglected.
3) Unconfined compressive strength (Qu) of sandstone rock can be estimated from rock quality designation (RQD).
4) An empirical equation to predict the unconfined compressive strength (Qu) of sandstone from rock quality designation (RQD) has been presented as mentioned in equation (3). The accuracy of this equation proved to be a moderate relationship and approximately as good as that of unconfined compressive strength test.

5. References

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