International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:11, No:10, 2017

Prediction of in situ Permeability for Limestone Rock Using Rock Quality Designation Index

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Abstract**—**Geotechnical study for evaluating soil or rock permeability is a highly important parameter. Permeability values for rock formations are more difficult for determination than soil formation as it is an effect of the rock quality and its fracture values. In this research, the prediction of in situ permeability of limestone rock formations was predicted. The limestone rock permeability was evaluated using Lugeon tests (in-situ packer permeability). Different sites which spread all over the Riyadh region of Saudi Arabia were chosen to conduct our study of predicting the in-situ permeability of limestone rock. Correlations were deducted between the values of in-situ permeability of the limestone rock with the value of the rock quality designation (RQD) calculated during the execution of the boreholes of the study areas. The study was performed for different ranges of RQD values measured during drilling of the sites boreholes. The developed correlations are recommended for the onsite determination of the in-situ permeability of limestone rock only. For the other sedimentary formations of rock, more studies are needed for predicting the actual correlations related to each type.

Keywords**—**Packer, permeability, rock, quality.

I. Introduction

THE in-situ permeability of different discontinues of rock formations is an important value to be calculated in many geotechnical studies. Tunneling, dams, dewatering, and executing of pump stations, and so on are some of the geotechnical works which need to predict the rock formation permeability. In this study, a special focus was given to predict the permeability of limestone rock formation. Many previous researches have predicted the rock permeability, [1]-[3]. In this study, four sites of Riyadh region in Saudi Arabia have been chosen. Geologically Riyadh region consists of two distinct limestone rock formations. The upper layer is consisted of the Arab limestone formation, while the lower one is consisted of the Jubiala limestone formation. The Arab formation is shown in oil exploration boreholes to consist of four distinct limestone units, each separated by an anhydrite bed, and its thickness is between 100 and 150 meters. A high degree of variation in the size of the breccia fragments and the extent of the re-cementation is a characteristic of this rock. In addition, zones of highly or completely weathered material normally occur in the upper part of the rock mass. The Jubaila formation is approximately 130 meters in thickness in the Riyadh area. It is an extremely resistant light brown to yellow limestone containing aphanitic (fine grained), dolomitic, and calcarenitic zones.

The limestone is also distinguished from the overlying Arab limestone by the lower incidence of fissures and relative absence of secondary silt, clay, and solution products. The in-situ permeability for discontinues rock formations is depending on the reliability and cost effectiveness. Using the Lugeon's water pressure tests (in situ packer permeability) is more reliable for in-situ permeability of mass rock [3], [4]. According to that, Lugeon's water pressure tests can be conducted during the progress of boreholes drilling at the studied region. In-situ permeability tests are performed at different depths measured from the existing ground surface at each site. Nappi et al. [5] studied the hydraulic characteristics of sandstone by outcropping measurements and lugeon tests. The convergent results from the two methods were indicative for complementary nature of the two approaches. Hamm et al. [6] and Qureshi et al. [7] studied the relation of hydraulic conductivity for granite with fracture frequency, squared fracture aperture, and the square aperture of major fracture orientation obtained from acoustic televiewer and core log data. They also concluded that the fracture aperture had stronger relationship with hydraulic conductivity than fracture frequency. However, those studies were mostly applicable to shallow surfaces of rock mass. Also, previous researches [8], [9] showed that discontinuities in rock mass have significant effect on the rock mass permeability. A simplest and standardized method using the RQD can be used in quantitatively describing the in-situ permeability of mass rock.

In the present study, Luegon's water pressure tests are performed at different depths for the four chosen sites in Riyadh region. Then, correlations between the in-situ permeability values and the accompanied RQD index of limestone rock mass at each test are predicted.

II. Methodology of Study

TABLE I
SITE LOCATIONS AND NUMBER OF PERMEABILITY TESTS

Site No.	site location in Riyadh	No. of Permeability tests	Coordinates	
1	north east	23	E	0683681
			N	2743592
2	north	18	E	0664485
			N	2744548
3	west	17	E	0659067
			N	2736606
4	south east	22	E	0664543
			N	2729418

The in-situ permeability of limestone rock mass formations is very important in geotechnical engineering. In the present study, four sites in Riyadh region of Saudi Arabia were chosen to develop and predict the in-situ permeability of limestone.

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ISSN: 2517-942X
Vol:11, No:10, 2017

The in-situ permeability is performed using the Lugeon's water pressure tests at different depths. Table I represents the locations of the four sites of study in Riyadh region with their number of permeability tests.

RQD index data at each depth of investigation are recorded during boreholes drilling. In the following paragraphs, more details about the in-situ permeability test are given.

A. RQD Index Data

The RQD index data of limestone formations are determined for each depth of permeability test. The determination of RQD index was recorded during the field investigation tests and before executing of each in-situ permeability test. In each borehole, the drilling was advanced by rock coring using a double tube core barrel equipped with a diamond bit. The coring was carried out in successive "core runs" of 1.5 meters. The percentage of core recovery and RQD for each "core run" of 1.5 meters was noted and recorded on the boreholes logs.

The RQD index is a convenient parameter to assess the quality of rock quantitatively, which is introduced by researchers [10]-[12]. This concept of quantitative description of rock is defined as "the percentage ratio of the sum of rock core parts greater than or equal to 0.1 m in the core run and divided by core run length" which is 1.5 m in our tests. This RQD index values are recorded during the drilling of boreholes along with their recovered cores.

B. Lugeon's Water Pressure Tests

The hydraulic conductivity in rock mass depends on the aperture, spacing, and infilling of its discontinuities. Thus, the accurate estimate of the hydraulic conductivity of rock mass formation can be better obtained using in-situ tests [3], [9]. In-situ permeability tests are performed at different depths of the four sites in Riyadh region mentioned above during the drilling of boreholes. The Lugeon's water pressure tests with their respective RQD index values at the same section depth are recorded. The lugeon's water pressure test is a constant head type test which is conducted in an isolated section of borehole. Water at constant pressure is injected in the rock mass through a slotted pipe bound by pneumatic packers, and discharge is measured. The maximum pressure of water should not exceed the rock confinement stress expected at the center of respective test section. The schematic diagram of the methodology of the Lugeon's water pressure test is represented by Fig. 1. Fig. 2 illustrated the increments stages of applying the water pressures up to its maximum value and then the stages of relief the water pressure till end of test. The in-situ permeability test for limestone rock was performed at depths ranged between 4 m and 52 m below the existing ground surface for all sites. There are more than 100 tests of in-situ permeability of limestone rock which are performed at the chosen sites. In the present study, only about 80 in-situ permeability tests are used to predict empirical correlations between the limestone permeability values and the rock designation quality RQD index.

III. Results and Analysis

The limestone permeability was calculated using (1) after performing Lugeon's water pressure tests at depths ranged between 4 meters and 52 meters below the existing ground surface. The collected test data illustrated that the limestone rock permeability ranged between the values of 10^{-6} and 10^{-9} m/sec. The corresponding RQD index at each permeability test section is defined. Fig. 3 shows RQD index versus depth of the tested sections of limestone permeability.

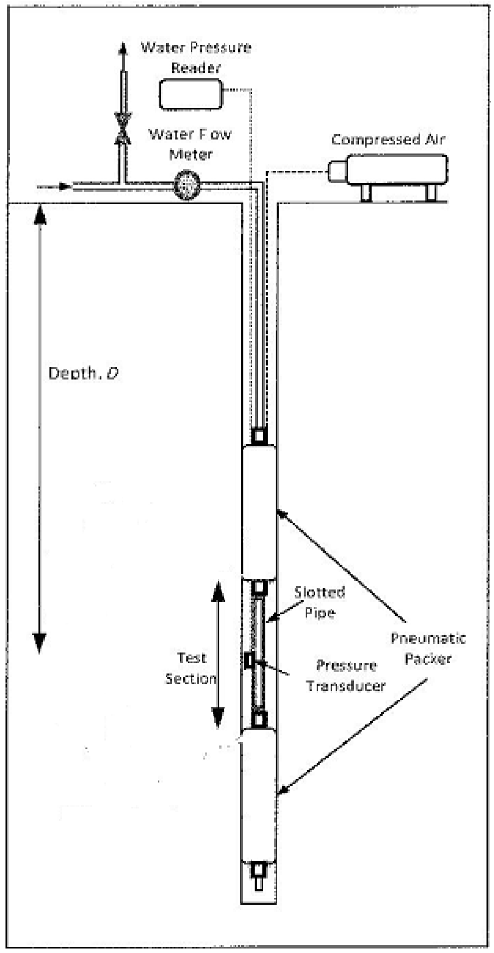

Fig. 1 Schematic diagram of Lugeon test

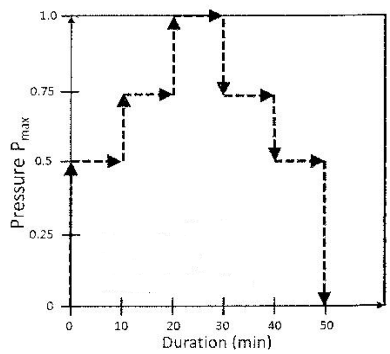

Fig. 2 Water pressure stages during Lugeon's test

$$K = (Q / 2\pi H L)\ \log (L / R) \tag{1}$$

where K is the limestone permeability in m/sec, Q is the water discharge in m^3/sec, H is the total head value at test section in meter, L is the length of tests section between packers, and R is the radius of the drilling hole section.

Figs. 4 and 5 are plotted after gathering all the data achieved from the in-situ permeability tests for limestone and the corresponding investigation values of RQD index. Figs. 4 (a) and (b) show correlations between the limestone permeability and the RQD index values for RQD <50% and RQD > 50%, respectively. It is noticed that the limestone rock permeability at shallow depths up to 10.0 meter from ground surface shows a high permeability as RQD index is low, while the rock permeability is very low as RQD index is high.

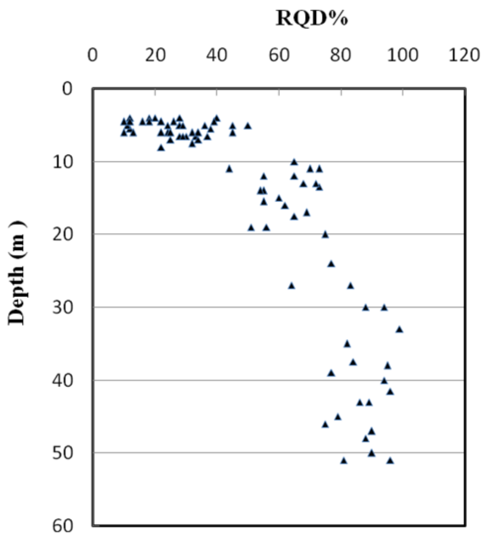

Fig. 3 RQD index values versus depth

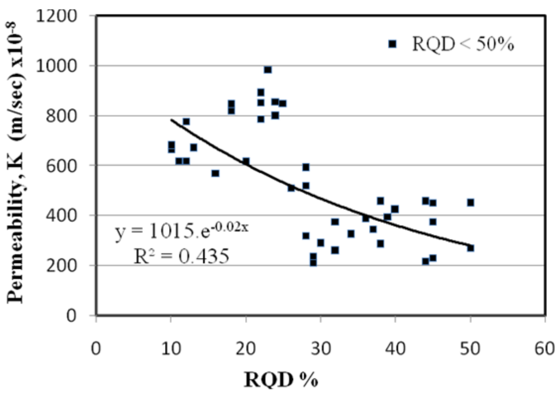

Fig. 4 (a) Correlation between limestone permeability and RQD index < 50%

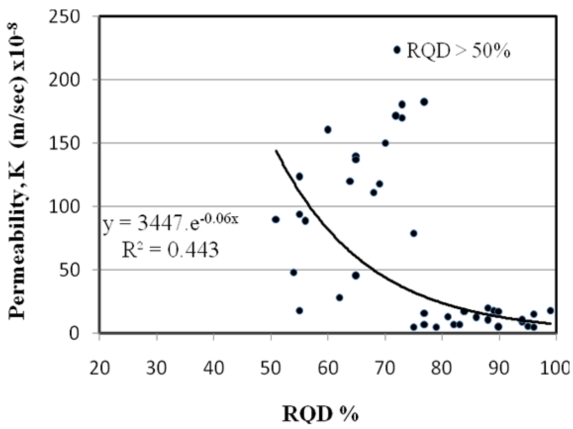

Fig. 4 (b) Correlation between limestone permeability and RQD index >50%

Fig. 4 (a) illustrated the correlation between the limestone permeability and RQD index less than 50% with a regression R^2 equal to 0.435, and (2) represented that correlation.

$$K = 1015\ e^{-0.02\,(RQD)} \tag{2}$$

for RQD < 50%. Moreover, Fig. 4 (b) illustrated the correlation between the limestone permeability and RQD index more than 50% with a regression R^2 equal to 0.443, and (3) represented that correlation.

$$K = 3447\ e^{-0.06(RQD)} \tag{3}$$

for RQD > 50%.

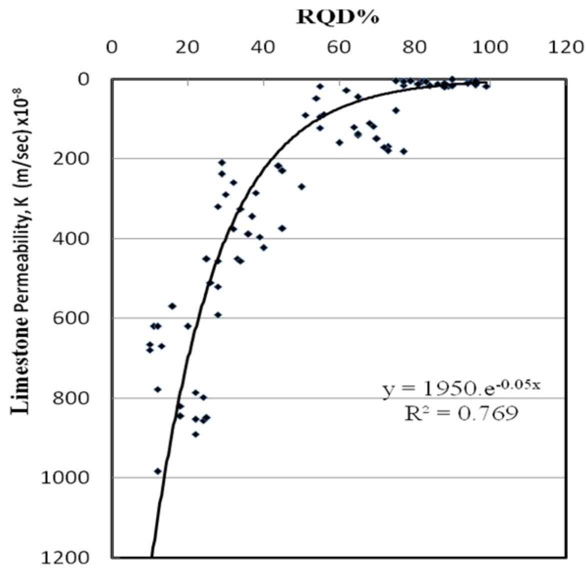

Fig. 5 Correlation between Limestone permeability and RQD index

From Fig. 5, it is noticed that a better correlation which gives a regression value of R^2 equal to 0.769 of all measured tests can be obtained. This good correlation gives a general equation for the relationship between limestone permeability and RQD index as illustrated in (3).

$$K = 1950\, e^{-0.05(RQD)} \quad (4)$$

IV. Conclusions

The conclusion of the present study can be summarized in the following statements:

1- The limestone permeability tests showed that the permeability ranged between 10^{-6} and 10^{-9} m/sec for these specific sites.

2- Results data showed that the limestone rock permeability at shallow depths up to 10.0 meter from ground surface has a high permeability and low RQD index. On the other hand, the good quality of limestone rock having a high RQD index has a very low permeability.

3- Analysis for correlations between the limestone rock permeability and RQD index values gives different correlations equations for both, RQD index less than 50% and for RQD index more than 50%.

4- Results give better correlation between the in situ limestone rock permeability and RQD index values for all data collected from the study.

The authors recommended that the present study for predicting the in-situ limestone permeability using the above empirical mentioned equations should be used by engineers as a preliminary estimation as its value depends on many factors such as the site geology and limestone fracture. According to that, a full actual in-situ permeability tests should be executed for verification of the estimated permeability of any new projects for this type of limestone rock.

Acknowledgment

The authors thank all field technicians and engineers of Riyadh Geo-technique and Foundation Company, RGF in Riyadh region for their collaboration and support for performing the present study.

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