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Estimation of Strength and Deformation Characteristics of Khondalite Rock Mass using Rock Quality Designation

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Abstract

Rock Quality Designation (RQD) is a measure used in Geotechnical engineering to assess the strength and integrity of rock core samples obtained during drilling operations, typically in the context of mining, construction, or civil engineering projects. RQD provides valuable information about the extent of weathering, fracturing, and discontinuities in a rock mass. The RQD is calculated by measuring the total length of sound or intact rock core within a specific drill run and dividing it by the total length of the run. Since the estimation of strength and deformation properties of rock masses requires sophisticated equipment, it is proposed to find these parameters through RQD values using the available analytical solutions. The drill log details of an irrigation project of Andhra Pradesh state in India were collected from the water resources department to analyze the RQD values of rock samples at different locations. The variations in RQD values of Khondalite rock with respect to depth and lateral distance are compared among 15 borehole locations of average spacing 40 m each. The values of bearing capacity, unconfined compressive strength and deformation modulus of rock masses corresponding to different borehole locations and different depths were estimated through RQD values using the analytical equations. The results were compared with respect to lateral distance and depth. Based on the analyses conducted, it was concluded that the estimation of strength and deformation characteristics of rock masses can easily be predicted from the RQD values.

Keywords: *Rock Quality Designation, Analytical Solutions, Bearing Capacity, Unconfined Compressive Strength, Deformation Modulus*

Introduction

Determining rock quality is indeed crucial in a wide range of engineering and construction works, encompassing projects such as tunnel construction, dam building, underground developments in rock formations, and any construction activities involving rocks as a foundational or structural component. Rock slope instabilities present a substantial risk to various human activities, often leading to financial losses, damage to property, increased maintenance expenditures, and, tragically, injuries or loss of life. Pantelidis, 2009 examined a range of rock mass classification systems to evaluate their effectiveness in identifying potentially hazardous rock cut slopes. His research underscored that the factors most commonly employed in these systems revolve around the general condition of the rock mass, the characteristics and geometry of structural discontinuities, and the occurrence of groundwater seepage

Rock Quality Designation (RQD) plays a pivotal role in the classification of rock masses and serves as a crucial input in commonly employed assessment methods like the Rock Mass Rating (RMR) and Q values (Lemy et al. 2001; Jian and Ju, 2006; Khademi et al., 2010; Singh and Tamrakar, 2013; Yasrebi et al., 2013; Zhao and Zhi, 2015; Mohammadi et al., 2017; Chen and Yin 2019; Jun et al., 2021; Alemdag et al., 2022). Rock Quality Designation (RQD) is an indicator used to assess the quality of rock core samples extracted from boreholes. It quantifies the extent of rock jointing or fracturing within a rock mass, expressed as a percentage. An RQD value of 75% or higher indicates the presence of high-quality, unweathered hard rock, while values below 50% suggest the presence of lower-quality, weathered rock conditions (Deere, 1988).

Several factors influence the determination of Rock Quality Designation (RQD) which include bedding and foliation, groundwater conditions, drilling and sampling techniques, laboratory testing, joint conditions such as spacing, roughness, orientation, aperture, filling and alteration, weathering and rock alteration, fracture frequency, rock strength, joint persistence etc. These factors are considered when calculating RQD, and the value is used to evaluate the suitability of rock for various engineering and construction applications, including tunneling, foundation design, and slope stability assessments. The RQD value is subject to change based on the orientation of the drill core and the selected length for RQD estimation. When drilling to a particular depth, it may be observed that the end section of the drill core doesn't consistently exhibit natural fractures. Furthermore, any additional fractures introduced during the drilling and transportation process should be considered when calculating RQD (Choi and Park, 2004). Vavro et al., 2015 have compared the experimental values of RQD with those obtained from alternative methods for different types of rocks. RQD values were alternatively estimated using high-resolution images. They found that the RQD values obtained by alternate methods are higher (about 10%–30%) than those measured from drill core analysis.

A Convolutional Neural Network (CNN) is employed by Alzubaidi et al., 2022 for the identification and categorization of both undamaged and damaged core samples, while also discerning and excluding empty areas and non-rock entities within core trays. The model is responsible for computing the length of the detected undamaged core segments and approximating the Rock Quality Designation (RQD). The CNN model was prepared by employing an extensive dataset comprising thousands of sandstone core images obtained from diverse drill hole locations in South Australia. The proposed approach is rigorously tested with a dataset comprising 540 rows of sandstone core samples and 90 rows of limestone core samples, each with a length of approximately one meter. This evaluation resulted in an average error rate of 2.58% for sandstone cores and 3.17% for limestone cores.

Alemdag et al., 2022 investigated an alternative approach for estimating the Rock Quality Designation (RQD) value by analyzing traditionally determined RQD values from core samples extracted during exploration drillings. Within this framework, they acquired the P-wave velocity (Vp) using seismic refraction tomography (SRT) based on geophysical measurements in a metamorphic rock mass. Furthermore, they assessed the discontinuity frequency parameter through line survey studies conducted on the same rock mass. They employed simple regression analyses and empirical equations with strong predictive capabilities, utilizing Vp and the discontinuity frequency parameters, to estimate RQD values without the need for drilling in the rock mass. The highest coefficient of determination (R) values for RQD was estimated with R-squared values of 0.89 and 0.82, respectively, when considering the joint frequency and wave velocity.

RQD serves as a valuable tool for assessing rock quality, encompassing factors like the extent and depth of weathering, the presence of weak or fractured rock zones. This data is instrumental in establishing foundation depths, rock-bearing capacities, potential settlement, and foundation stability against sliding. Additionally, RQD aids in identifying conducive conditions for tunneling while pinpointing areas with suboptimal rock quality that may be inadequate for supporting engineering structures. Hence, in the present study, it is proposed to examine the utilization of RQD values in estimating the strength and deformation characteristics of rock masses. The bore hole data of an irrigation project was collected corresponding to 15 locations and the rock parameters are estimated using the analytical solutions. Khondalite/Charnockite bed rock is encountered below the soil layers at all the borehole locations. The Core recovery is varying from 21% to 100% and RQD is varying from Nil to 98%. The variations in ultimate besring capacity (q_u), Deformation modulus (E_m) and Unconfined compressive strength (UCS) were compared with respect to depth and lateral distance.

Methodology

Estimation of Bearing capacity

Gül & Ceylanoğlu, 2016 and Alavi & Sadrossadat, 2016 gave various methods to estimate the bearing capacity of rocks. For the present study, the bearing capacity equation given by Peck et al., 1974 is used which is given below.

$$q_u = 1 + \frac{RQD/16}{(1-RQD/130)} \qquad (1)$$

Where q_u is the ultimate bearing capacity in MPa.

Estimation of Deformation modulus

Gardner, 1987 introduced an equation for estimating the deformation modulus of the rock mass (E_m) based on the deformation modulus of intact rock (E_r), and it incorporates a reduction factor denoted as α_E. This factor takes into account the frequency of rock discontinuities as indicated by the RQD. The equation for Em is expressed as $E_m = \alpha_E * E_r$, with the value of α_E calculated using the following formula.

$$\alpha_E = (0.0231*RQD)-1.32 \qquad (2)$$

Notably, this method was incorporated into the Standard Specification for Highway Bridges by the American Association of State Highway and Transportation Officials (AASHTO) in 1996 (Zhang, 2016). Since this method is having limitations for RQD<60% and RQD=100%, Zhang and Einsten, 2004 proposed the following equation which is used for the present study.

Modulus ratio, $E_m / E_r = \alpha_E = 10^{0.0186RQD-1.91}$ (3)

Estimation of Unconfined Compressive Strength (UCS)

The unconfined compressive strength of rock masses (σ_{cm}) was estimated using the following equation given by Zhang et al., 2010.

$$\frac{\sigma_{cm}}{\sigma_c} = \alpha_\sigma = 10^{0.013RQD-1.34} \qquad (4)$$

Where σ_c is the unconfined compressive strength of the intact rock and α_σ is the unconfined compression ratio.

Results and Discussions

The locations of 15 boreholes (B1-B15) at the study area are shown in Figure 1. The borehole details corresponding to rock masses are shown in Figures 2-4 along with the RQD values at different depths. The RQD values of different boreholes are plotted with respect to depth (Figure 5) and observed that there is no consistency in the RQD values with depth for the various borehole locations. The variations in RQD values of different boreholes with the lateral distance are compared corresponding to depths 40m, 45m, 50m and 55m (Figure 6). The RQD values are relatively consistent among different boreholes corresponding to 55m depth.

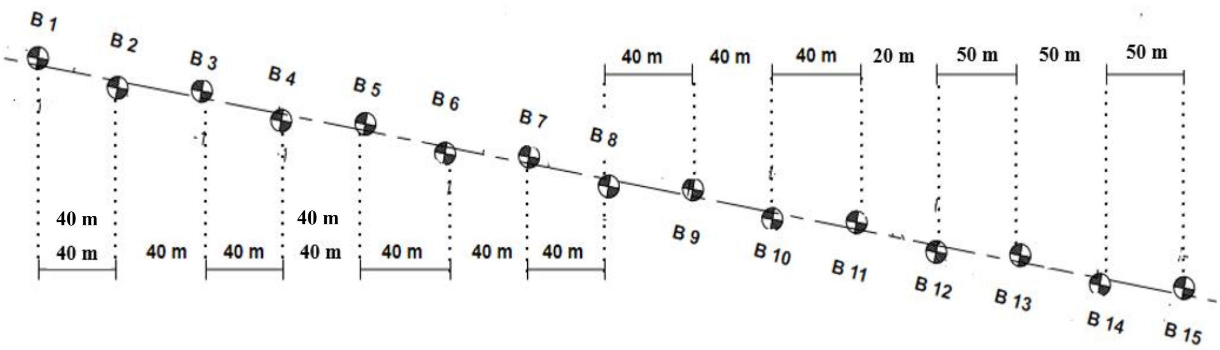

Figure 1. Locations of Boreholes at the study area

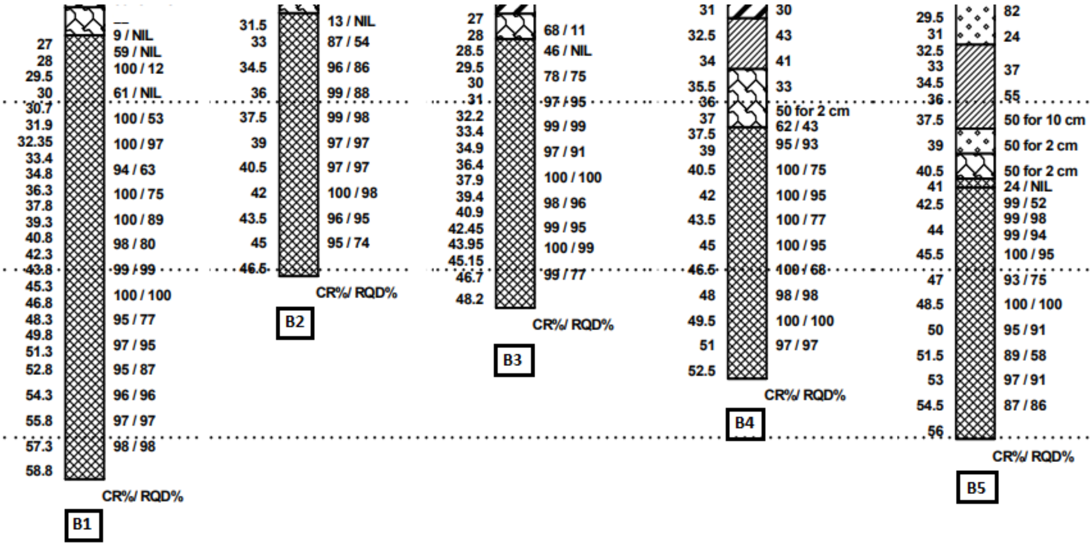

Figure 2. RQDs with depth for Boreholes 1 to 5

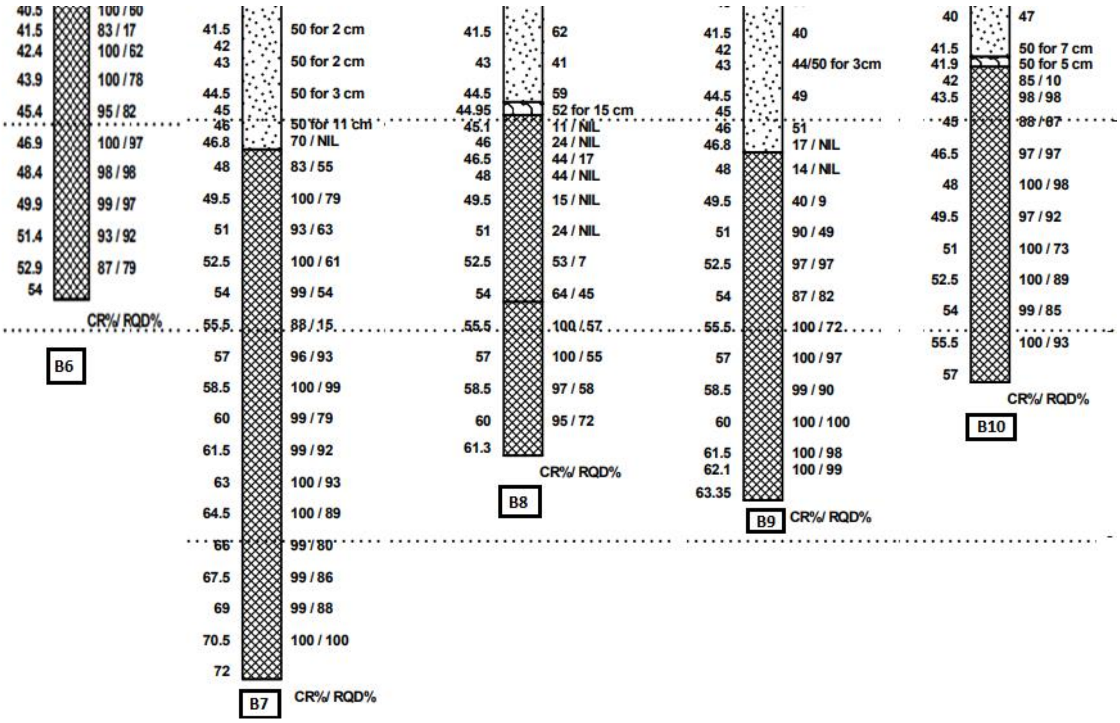

Figure 3. RQDs with depth for Boreholes 6 to 10

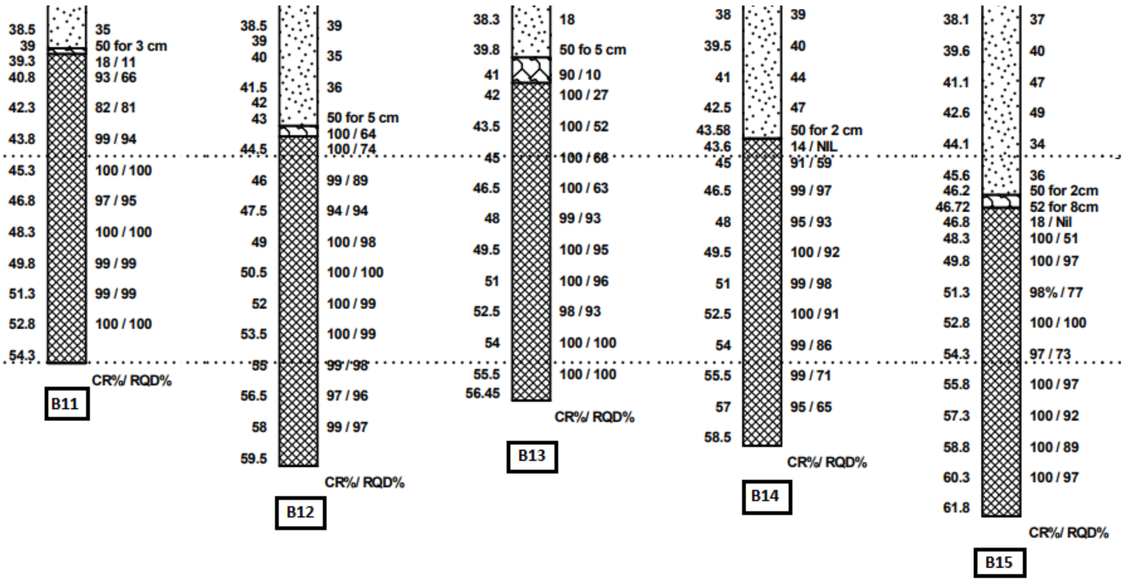

Figure 4. RQDs with depth for Boreholes 11 to 15

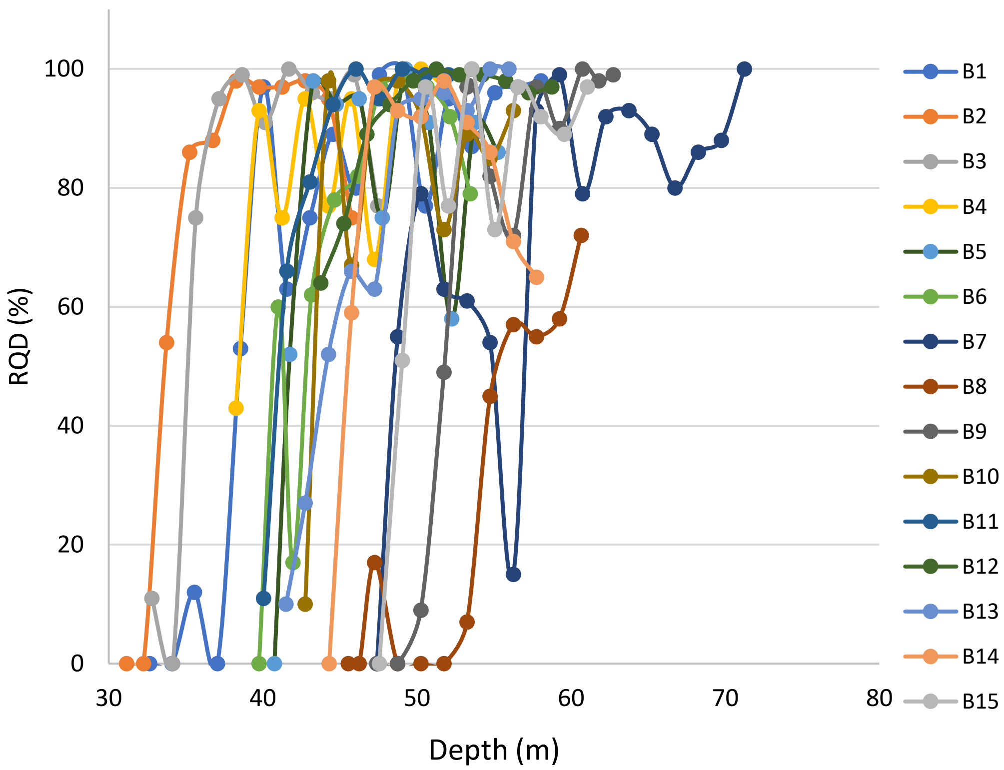

Figure 5. Depth vs RQD for the boreholes B1 to B15

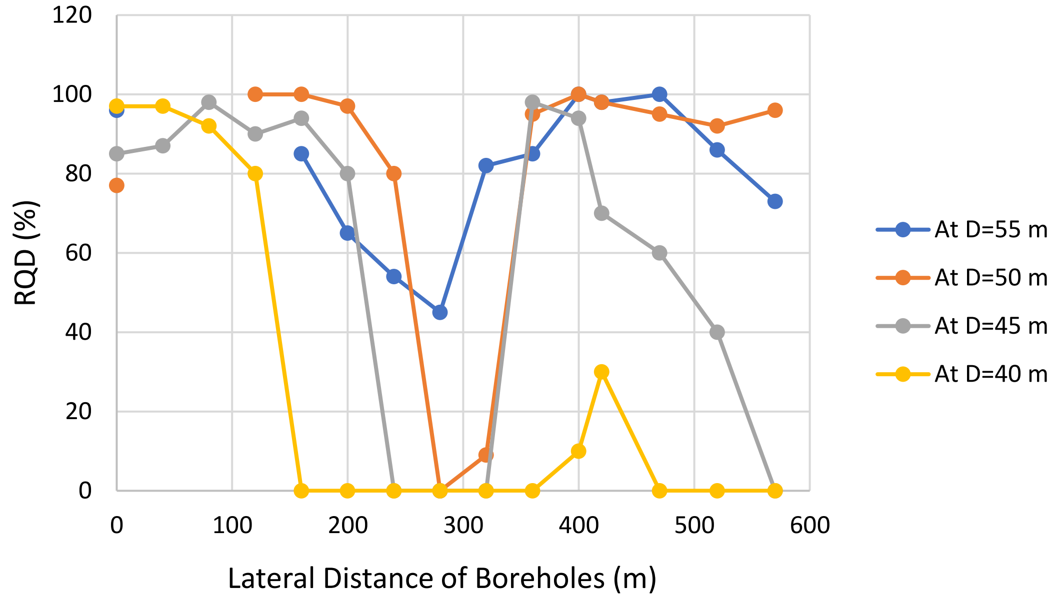

Figure 6. Variation of RQD values with lateral distance

Ultimate bearing capacity from RQD

The ultimate bearing capacity of rock masses of different boreholes are calculated using the equation (1). The variation with respect to lateral distance corresponding to depths 40m, 45m, 50m and 55m are shown in Figure 7. The estimated bearing capacities were in the range of 1 to 28 MPa corresponding to different locations of the study area. The variations in bearing capacities are comparatively higher corresponding to depths 45m and 50m. The ultimate bearing capacities are less at 40m depth for most of the boreholes.

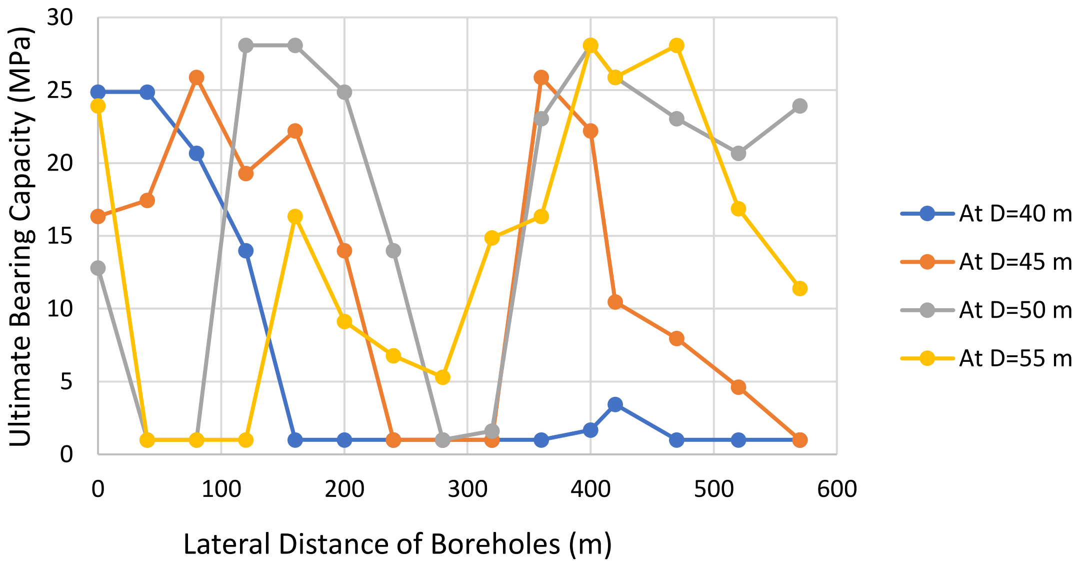

Figure 7. Variation in bearing capacity with lateral distance and depth

Deformation modulus from RQD

The equation (3) is utilized to estimate the deformation moduli of rock masses (E_m). The strength and deformation properties of different types of rocks can be found in the work by Zhang from 2016. The modulus of elasticity of Khondalite rock generally falls within a range of approximately 40000 to 80000 MPa. Assuming the modulus of elasticity of intact rock (E_r) as 60000 MPa, the E_m values are estimated through the available RQD values. The variations in the E_m values with depth and lateral distance of boreholes are presented in Figure 8. The estimated Em values were ranged from 700 to 53000 MPa. The deformation moduli at a depth of 40m are lower than those at other depths.

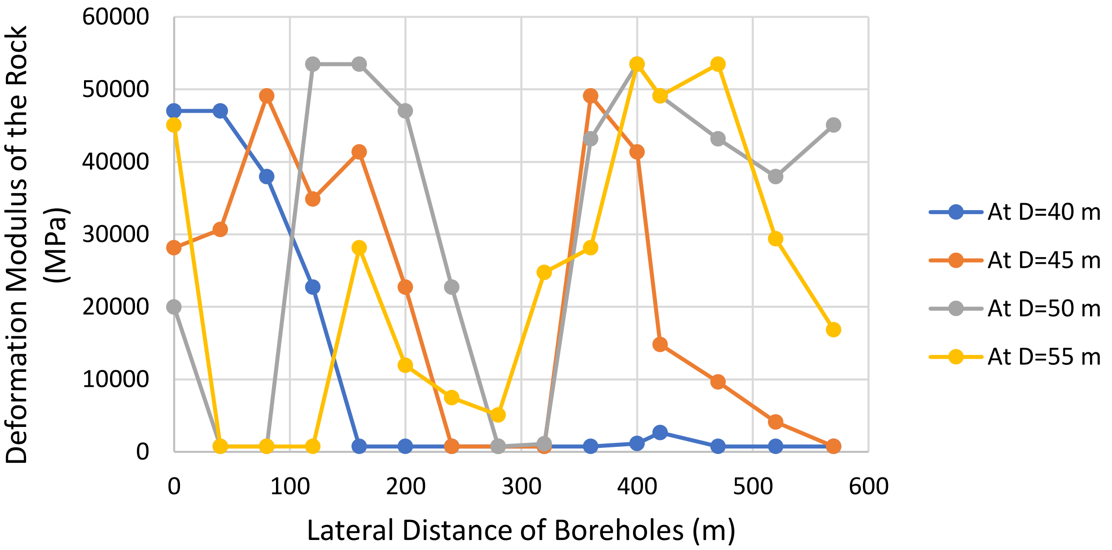

Figure 8. Deformation moduli at different locations

Unconfined Compressive Strength from RQD

The UCS of rock masses (σ_{cm}) from RQD values were estimated using the equation (4). The UCS of Khondalite rock generally varies from 50 to 200 MPa. Taking the UCS of intact rock as 100 MPa, the σ_{cm} values corresponding to various locations were estimated and are shown in Figure 9. The estimated values of σ_c were in the range of 4 to 90 MPa. The values are much lower at lateral distance of 200 to 400m.

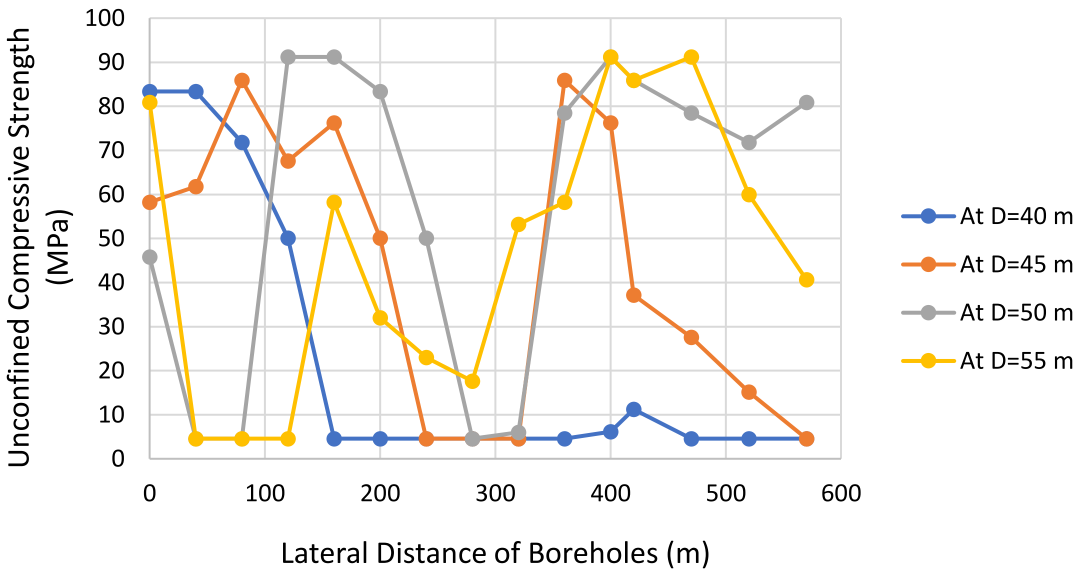

Figure 9. UCS of rock masses at study area with lateral distance

Conclusion

The Rock Quality Designation (RQD) has multiple applications to estimate the various strength and deformation properties of rock masses. The drill log details corresponding to 15 locations were collected from an irrigation project and were analyzed to evaluate the variations in RQD values with depth and lateral distance. RQD values are employed for the estimation of rock mass bearing capacity, UCS and deformation modulus. The variations in RQD values of Khondalite rock at the study location were very high with respect to depth and lateral distance indicating the presence of weathered rock at some locations. The estimated bearing capacities were in the range of 1 to 28 MPa with higher values observed at 50m depth. The range of deformation moduli among the different locations is 700-53000 MPa. Lower values of deformation moduli were observed corresponding to 40m depth. The UCS values of rock masses at the study area ranged from 4 to 90 MPa. The lower values of UCS were observed between 200 to 400m lateral distance.

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