Sustainable Structures and Materials, *Vol. 6, No. 1, (2023) 144-148*
DOI: https://doi.org/10.26392/SSM.2023.06.01.0144

Rock Quality Analysis using Empirical Techniques (RMR & Q-SYSTEM) along the Headrace of a Hydropower Project in Kalam, Swat, Pakistan

Malik Muhammad Saad[1,2], Muhammad Zahid Iqbal Minhas[3], Rimsha Rauf[4], Muhammad Shahab[*2,5], Danish Raza Shaukat[1], Kaleem Ullah[1], Muhammad Hassnain[2]

[1]Institute of Geology, University of the Punjab, Pakistan
[2]NCE in Geology, University of Peshawar, Pakistan
[3]University of Sargodha, Pakistan
[4]Schlumberger Pakistan
[5]GIS and Space Application in Geosciences Lab, NCE in Geology, University of Peshawar, Pakistan
*Corresponding author Email: shahabgeo07@gmail.com

(Received March 19, 2023, Revised April 19, 2023, Accepted June 4, 2023)

ABSTRACT. *The principal goals of this research were to examine the rock mass classification (RMC) and characterization as well as the support assessment for the proposed headrace tunnel route of an approximately 11 km long hydropower project (HPP) in Kalam valley, Khyber Pakhtunkhwa (KP), Pakistan. It was important to look at the key discontinuity factors for the classification of rock masses. To accomplish the aim, field discontinuity surveys were carried out to obtain rock mass parameters, and collected samples along the proposed tunnel route. Furthermore, characterization and classification of rock mass have been done using empirical techniques (ET) such as Beiniawski's Rock Mass Rating (RMR) and Barton's Tunnelling Quality Index (Q). The rock types were identified as Kalam Quartz Diorite, Gabbro and Granodiorite from literature. The prominent discontinuity sets were evaluated by exporting discontinuity data to DIPS. Quality Index was determined by calculating, its parameters, Quality Index values range between 3.74-17.00, 3.74 (poor at DS-04), 7.08-7.33 (fair at DS-01, DS-11 and DS-18) and 10.07-17.00 (good at DS-02, DS-09, DS-13, DS-14, DS-17 and DS-19), whereas, rock mass classification values ranges from 47-60 (fair at DS-01, DS-02, DS-04, DS-09, DS-11, DS-13, DS-14, DS-18, DS-19) to 64 (good at DS-17). The rock support according to the RMR scheme suggests fully grouted systematic bolting 3 to 4 m in length and 1.5 to 2.5 m spaced and 50-100 mm shotcrete in the crown and 50 mm in sides, while Q-system suggests spot bolting to Systematic bolting with 40-100 mm unreinforced shotcrete.*

Keywords: Rock Mass Rating, Rock Mass Classification, Q- System

1. INTRODUCTION

The government of Pakistan is working to create hydroelectric projects, particularly in northern Pakistan, to address the country's severe electricity shortfall. Small hydropower along the Swat River in Kalam Valley, KP, Pakistan, is suggested in this regard. The empirical design tools used in rock engineering, particularly in subterranean excavations, support design, and construction, include methods for classifying rock masses. They have traditionally been crucial in determining the amount of support needed for excavations [3]. Their primary use in subterranean excavation design can be directly linked to 4 factors: 1) Rock provides special design and construction issues that are not typical in other engineering materials since it is a complex material with widely varied qualities. 2) Engineering excavations in rock, particularly underground excavations, sometimes cross more than one type of rock, each with a unique set of characteristics. 3) Even with the sophisticated equipment and techniques currently available, it is almost impossible to determine the precise engineering qualities of rock masses involved in an excavation operation. 4) The stress field in a rock is controlled by the weight of the rocks above it as well as a number of other variables, including the rock's geological structure, tectonic forces, and geological history [1,2].

Even when there is a lack of geotechnical data available, empirical design methods based on rock mass classification systems can quickly determine the support requirements for subterranean excavations, particularly tunnels. The empirical approaches do not demand as high-level expertise as the analytical ones. Several categorization systems have been developed over time to satisfy the industry's need for quick evaluations of rock mass quality and support needs for excavations. Two techniques that were introduced by [1,2], respectively, have stood out: Rock Mass Rating (RMR) and Tunnelling Quality Index (Q). These are simple techniques and can be used from the early stages of planning [3].

Discontinuities are crucial in explaining the deformational behaviour and rock mass strength under various circumstances. Joints, bedding planes, schistosity planes, faults, weakness planes, etc. are examples of discontinuity. For a scanline survey, International Society for Rock Mechanics (ISRM) standardises the following variables. 1) Discontinuity orientation 2) Discontinuity spacing 3) The continuation of discontinuities 4) Wall texture 5) Wall toughness 6) Discontinuity aperture 7) Filling up discontinuities with material 8) Seizures 9) The number of joint sets Block dimensions. Therefore, the primary focus of current study is on preliminary RMC coupled with an evaluation of the necessary support along suggested tunnel paths. Therefore, field observations involving geological mapping, discontinuity surveys, and sampling were carried out in order to attain this purpose. When there is limited information available, a geomechanically investigation of the rock mass is a crucial step in the HPP feasibility phase to ascertain how the rock will behave when disturbed or excavated. In order to categorise the rock mass, RMCs are determined by empirical categorization systems [4]. So, it is crucial to classify the rock mass using the RMR and tunnelling quality index (Q) classification systems. RMR and Q schemes have been used extensively in investigations. [5,6,7]. The cost of the project is significantly impacted by the tunnelling through various rock types. Various rocks have diverse properties based on their state, environment, and overburden pressure. Rock that has cracks and joints deteriorates with time and needs greater support. Various methods and applications of rock mechanics can be used to observe, forecast, and estimate the state of rock mass. Over the past few decades, a variety of methods, including empirical approaches, analytical techniques, observational methods, and numerical modelling, have been utilised to estimate RMC at the site. For the estimation of the rock condition, these various methodologies required varied input parameters and field data. Each method has advantages and disadvantages, so you can choose one that best suits the needs of your research. The purpose of this study was to produce a geological map along the headrace tunnel route, undertake a detailed geologic analysis of the area, and recommend a viable site for a hydropower project.

1) To prepare Geological Map along the headrace tunnel route
2) To gather RMC discontinuity surveys were conducted along the tunnel route
3) To identify and distinguish the rock mass units using the ET systems i.e., RMR and Q

2. GEOLOGY AND LOCATION OF THE STUDY AREA

The study area is a section of the northern Himalayan, a region composed primarily of igneous, intermediate to basic plutonic rocks such as diorite, gabbro, and granodiorite. The study area is located along the right bank of the River Swat, about 2–14 kilometres south of Kalam city, close to Asrit town in the Kalam Tehsil of district Swat. It is roughly 200 kilometres from Peshawar, the capital of KP, and 60 kilometres from Mingora, district headquarter.

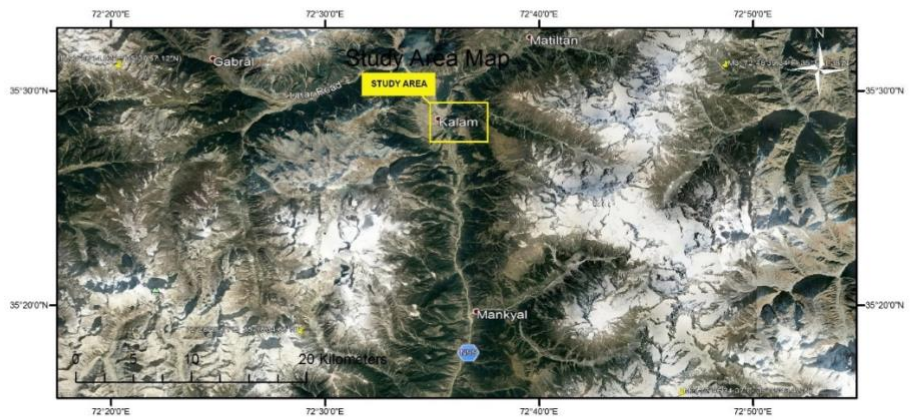
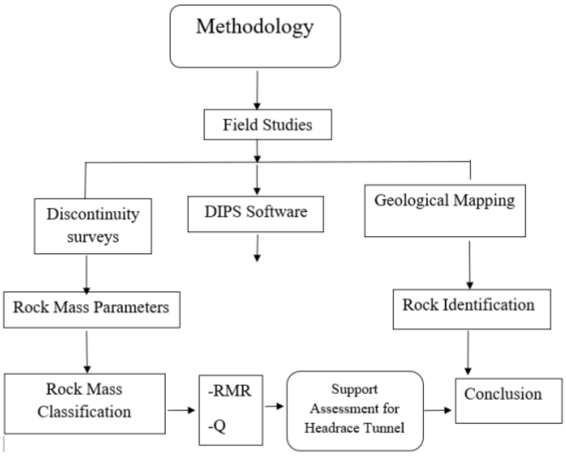


Fig -1 is a google imagery showing the location of the study area

3. METHODOLOGY

In order to evaluate and classify rock masses, it is essential to determine ground conditions such as rock mass, stress, water, and weathering accurately. A thorough field investigation from Kalam to Asrit was planned to gather data. To gather information on rock mass, 20 discontinuity analyses were carried out along the tunnel paths. Various geological units, slope washes, and glacial deposits were identified using engineering geological mapping, and samples were taken from each of the 20 discontinuity sites for the rock specimens' mineral analysis. RMR and Q were used to analyse and categorise the rock mass properties. The next section discusses the RMR and Q ratings for support evaluation outcomes.



Regional Geological Map of Kalam to Bahrain

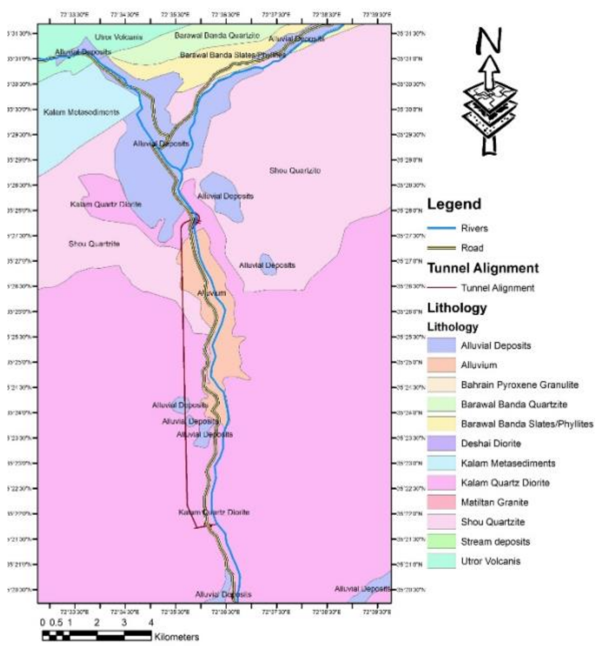


Fig -2 is showing the Geological map of the area supposed for the hydropower project in kalam valley Swat

4. ROCK MASS CLASSIFICATION (RMC)

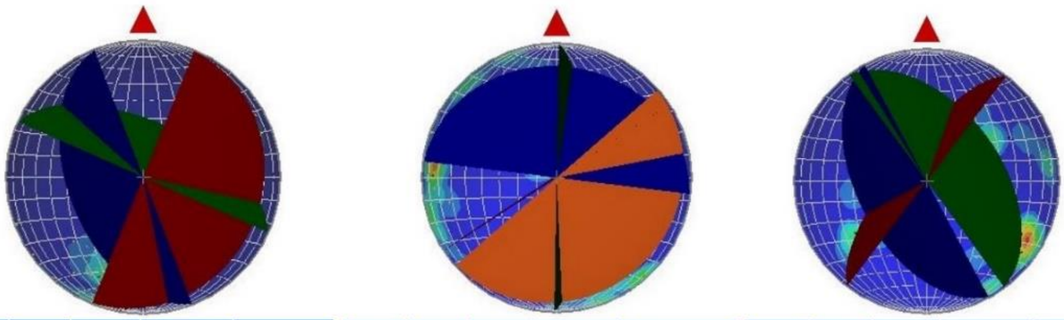
To gather the necessary parameters for the estimate of RMR and Q values, various locations for data discontinuity surveys were chosen. The DIPS (version 7.0) computer tool was used to analyse the orientation data, which revealed that 2-3 and 4 joint sets were the most common in the research area. It displays a dip in the direction of the tunnel axis, yet there are some sites where the trend is away from the tunnel axis and locations are parallel to it. The correlation between Rn and unit weight was used to compute the Uniaxial Compressive Strength (UCS). The RMR readings range from 47 (fair) to 64 (good), with a mean of 56, and were used to determine RQD. Comparing the RMR and Q values results allowed for the calculation of the empirical rating for the tunnel alignment section (8300-9000) shows decent rock, but the Q system only recognises six segments as good rock. Only one part was labelled as poor-quality rock, while three portions were recognised as a fair rock. According to the calculated ratings, the Q system for classifying rocks used a more conservative approach than the RMR system. The variation in RMR and Q values are plotted in (Fig 2)

Table -1: is showing the field data acquired during the fieldwork using different parameters which are mentioned in the table

Parameters		**DS -01**	**DS-02**	**DS-04**	**DS-09**	**DS-11**	**DS-13**	**DS-14**	**DS-17**	**DS-18**	**DS-19**
Uniaxial Compressive Strength (AVG.)	Ratings	4	4	7	7	7	7	7	7	7	7
Rock Quality Designation (Avg.)	Ratings	5	8	13	17	17	17	17	17	13	13
Spacing (Avg.)	Ratings	8	8	10	10	10	10	10	10	10	10
Discontinuity Conditions	Ratings	25	20	20	20	20	20	20	20	20	20
Water Condition	Ratings	15	15	7	7	15	15	15	15	15	15
Orientation of Discontinuity	Ratings	-5	-2	-10	-5	-12	-12	-5	-10	-10	-5
RMR values		52	53	47	56	57	57	64	59	55	60

Description		Fai r	Fair	Fair	Fair	Fair	Fair	Go od	Fair	Fair	Fair
Rock class		III	III	III	III	III	III	II	III	III	III

D Major set planes of DS-01, DS-04, DS-13



DS-01	Color	Dip (Avg.)	Dip Direction (Avg.)	Label
Mean Set Planes				
1m		20	112	Foliation
2m		50	249	Joint Set 1
3m		61	24	Joint Set 2

DS-04	Color	Dip (Avg.)	Dip Direction (Avg.)	Label
Mean Set Planes				
1m		89	327	Foliation
2m		25	7	Joint Set 1
3m		75	91	Joint Set 2
4m		16	139	Joint Set 3

DS-13	Color	Dip (Avg.)	Dip Direction (Avg.)	Label
Mean Set Planes				
1m		72	307	Foliation
2m		52	242	Joint Set 1
3m		49	54	Joint Set 2

Fig -3 is showing the 3-D major set planes of DS-01, DS-04, and DS-13, the data were obtained from fieldwork and then plotted using DIPS software to show stress directions for different spots.

4.1 Equations

The following equations were used to calculate RMR, Q Scheme

Equation 1 $\quad RMR = R1+R2+R3+R4+R5+R6$ [2]

Equation 2 $\quad Q=(RQD/Jn) \times (Jr/Ja) \times (Jw/SRF)$ [1]

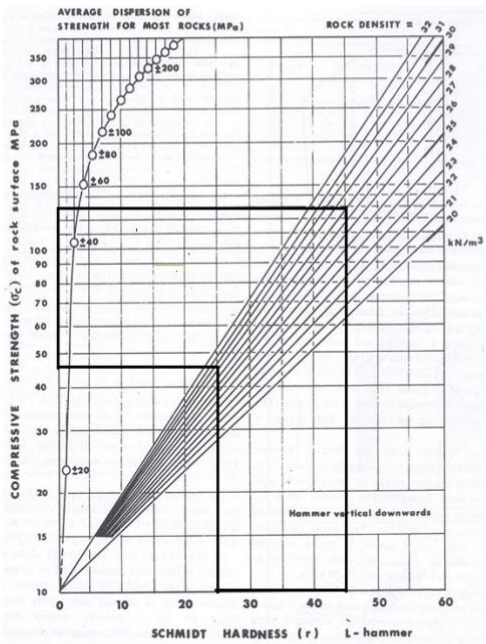


Fig -4 Uniaxial Compressive Strength was calculated by using field-based Schmidt rebound hammer and correlated with unit weight of rock mass and rebound values and Unit Weight (fig 4), Unit weight was calculated by weight to volume ratio.

5. COMPARISON OF RMR AND Q-SYSTEM

The empirical ratings for tunnel alignments were calculated using findings of the input parameter, and the comparisons of RMR and Q values were examined. Along the tunnel alignment, RMR indicates good rock quality at DS-17 and fair rocks at DS-01, DS-02, DS-04, DS-09, DS-11, DS-13, DS-14, DS-18, and DS-19. DS-04 displays bad quality, DS-01, DS-09, and DS-17 displays fair quality, and DS-02, DS-11, DS-13, DS-14, DS-18, and DS-19 display good quality, according to the Q-system. RMR and Q's fluctuating levels were plotted in the following

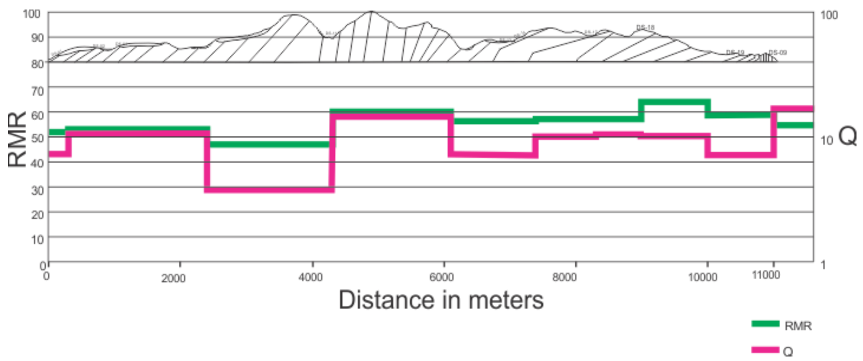


Fig -5 is presenting the summary of the project in the graph rock structure is showing the out-crop extension, the green line is representing the RMR classification results and the pink color is representing the Q classification results.

6. CONCLUSION

The paper concludes from the results of a study on rock mass quality (RMR) and Q values along the proposed alignment of a headrace tunnel that RMR suggests high strength of rock mass as compared to Q for the similar rock mass. Therefore, to ensure proper and safe support for the rock mass Q system should be followed and Factor of Safety should be calculated accordingly. The results of the study show that the RMR of the rocks along the tunnel alignment ranges from 47 to 64, with quality ranging from poor to good. The Q values vary from 3.74 to 17.00 along the proposed tunnel alignment. It further shows that segments of the tunnel alignment have good rock quality for chainage (300 to 2400, 6100-7400, 7400-8300, 8300-9000, 10000-11000, and 11000-11600) and good Q values. However, the segment (2400-4300) has poor rock quality. The segments (0-300, 4300-6100, 9000-10000) have fair rock quality. Based on the RMR scheme, the rock support suggests bolting with 3- to 4-meter-long bolts spaced at 1.5 to 2.5 meters with 50-100 mm shotcrete in the crown and 50 mm in the sides. The Q-system suggests spot bolting to systematic bolting with 40-100 mm unreinforced shotcrete.

REFERENCES

[1] Bieniawski. (1973). Engineering Classification of Jointed Rock Masses. *T. Trans South African: Institute of Civil Eng. Vol. 15*, 335-334.

[2] Barton, N. L. (1974). Engineering Classification of Rock Masses for the Design of Tunnel Support. *Rock Mechanics*, 6, 189-236.

[3] Ranasooriya, J. a. (January 2009). "An Assessment of Rock Mass Classification Methods Used for Tunnel Support Design". *International Conference on Rock Joints and Rock Masses.* Tucson: CD-ROM.

[4] Ritter, W. (1879). Die Statik der Tunnelgewölbe. In Springer, *Die Statik der Tunnelgewölbe.* German.

[5] Abu-Zeid, N. a. (1997). Geochemical Characterisation of the Out-cropping Rock Masses of the Immediate Vicinity of Wadi El-Kaffrein Dam Site. *Bulletin of the International Association of Engineering Geology*, 55, 3.

[6] El-Naqa, A. (2001). Application of RMR Q Geomechanical Classification Systems along the Proposed Mujib Tunnel Route. *Bulletin of Engineering Geology and the Environment*, 60, 257-269.

[7] Mian Sohail Akram, K. M. (2018). Assessment of Rock Mass Quality and Deformation Modulus by Empirical Methods along Kandiah River, KPK, Pakistan. *Open Journal of Geology, http://www.scirp.org/journal/ojg*, 8, 947-964.

[8] Ranasooriya, J. a. (January 2009). "An Assessment of Rock Mass Classification Methods Used for Tunnel Support Design". *International Conference on Rock Joints and Rock Masses.* Tucson: CD-ROM.