Assessment of Rock Mass Quality and Support Estimation along Headrace Tunnel of a Small Hydropower in District Mansehra, Khyber Pakhtunkhwa, Pakistan

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Abstract

The main purpose of this study is to classify the rock mass quality by using rock mass quality (Q) and Rock Mass Rating (RMR) systems along headrace tunnel of small hydropower in Mansehra District, Khyber Pakhtunkhwa. Geological field work was carried out to determine the orientation, spacing, aperture, roughness and alteration of discontinuities of rock mass. The quality of rock mass along the tunnel route is classified as good to very poor quality by Q system, while very good to very poor by RMR classification system. The relatively good rock conditions are acquired via RMR values that are attributed to ground water conditions, joint spacing, RQD and favorable orientation of discontinuities with respect to the tunnel drive. The petrographic studies revealed that study area is mainly comprised of five major geological rock units namely quartz mica schist (QMS), garnet mica schist (GMS), garnet bearing quartz mica schist (G-QMS), calcareous schist (CS), marble (M). The collected samples of quartz mica schist, marble and garnet bearing quartz mica schist are fine to medium grained, compact and are cross cut by few discontinuities having greater spacing. Therefore, these rocks have greater average RQD, Q values, RMR ratings as compared to garnet mica schist and calcareous schist.

Keywords
Tunnel, Petrography, Rock Mass Rating (RMR), Tunneling Quality Index (Q System), Support Estimation

1. Introduction

Government of Pakistan is highly committed to curtailing the energy crises of...
the country by developing various hydropower projects especially in northern
area of Pakistan. In this regard, a small hydropower project with 2.8 km long
headrace tunnel was proposed in Mansehra district, Khyber Pakhtunkhwa. In
many engineering projects including tunneling, ground excavation, foundations
and slope stability analysis, geology plays a key role. Among these projects tun-
nel constructions require a considerable geological input [1]. The overall en-
gineering design weakens by numerous fractures and cracks developed due to
tunneling in hard ground conditions leads to deteriorating the physical condi-
tion of the ground and rocks. It is necessary to study the geological behavior
(spacing and degree of jointing, strength, and attitude) of the strata for safe and
economic design of the tunnel [2]. Rock mass classification systems have been
effectively applied in many engineering projects especially tunneling projects [3]
[4]. To estimate the required support measurements the rock mass classification
systems have been proved supportive in assessing the rock mass parameters [5]
[6]. Following parameters are used to describe and classify the rock mass into
distinct classes:

1) Measurement of degree of jointing known as rock quality designation
(RQD)
2) Rock joint parameters such as joint spacing, aperture, orientation, infilling
and surface roughness
3) Uniaxial Compressive Strength (UCS) (Strength of intact rock material)
4) Ground water conditions (pressure and flow)
5) In-situ stresses
6) Geological structures such as shear zones, folds and faults

Various researchers [7]-[21] studied the rock mass characterization along
tunnel route by using empirical rock mass classification systems e.g. Rock mass
rating (RMR), Tunneling quality index (Q system) etc. to classify the rock mass
with different rock classes according to the physical characteristics of rock mass.
This study was conducted to characterize the rock mass along proposed tunnel
route by using RMR and Q system. Field studies revealed that study area com-
prised of five major rock units that have strong impact on the various properties
of discontinuities including rock mass strength.

2. Geology and Rock Mass Characterization

2.1. Geological Mapping and Discontinuity Surveys

The study area lies in the Hazara Nappe that is disjointed from Besham Nappe
to the West by dextral Thakot shear zone [22] [23]. The Hazara Nappe domi-
nantly constitutes of metapelites and metapsammites of Pre-Cambrian Tanawal
Formation (Figure 1). The Late Cambrian Mansehra porphyritic granite in-
truded into Tanawal Formation [24]. At some places dolomites of Paleozoic
Abbottabad Formation unconformably overlie the Tanawal Formation [25].
Quantitative readings of joints parameters (joint spacing, persistence (length),
roughness and joints frequency etc.) were collected at different stations using
Figure 1. Geological map of Hazara region (Modified after Calkins et al. [22]).

Scanline surveys. Geological mapping of tunnel involves the recording of following parameters: geological units, rock type, color, weathering, strength, block size and shape, water sensitivity, discontinuity type, dip direction and dip angle, roughness, spacing, aperture, fill material, persistence, ground water conditions etc.

2.2. Rock Mass Rating (RMR) and Tunneling Quality Index (Q)

Rock mass classification systems e.g. tunneling quality index (Q) [26], rock mass rating system (RMR) [2], rock mass index (RMi) [27] and geological strength index (GSI) [28] are used to classify the rock mass and to estimate the support design for underground structures. Rock mass classifications split a specific rock mass into distinct classes of similar manners, but with different qualities from
one another [5]. Palmstrom [29] Rock mass is the assemblage of rock blocks and fragments divided by discontinuities (joints, bedding planes and faults etc.). A particular value (rating) according to RMR and Q is given to rock mass according to its behavior to categorize in various rock classes according to the physical properties of discontinuities [5]. The purpose of the classifications is to Bieniawski [2]:

- Ascertain different parameters which affect the rock mass quality
- Divide rock mass into qualitatively different rock classes
- Give guidelines to estimate support for tunnels and mines

Rock structure rating (RSR) by Wickham [4] considered two elements influencing on rock mass behavior: geological parameters and construction parameters. Rock mass rating (RMR) by Bieniawski [2] also known as Geomechanics classification utilizes the basic parameters regarding the geometry and mechanical conditions of the rock mass. Q-system [26] is product of rock mass geometry, interblock shear strength and active stresses encountered during underground excavations. The RMR system was proposed by Bieniawski [2] based on 49 case histories to recognize the stability and support requirements of tunnels. The RMR system has a wide variety of applications in different engineering projects like tunnels, foundations, slopes and mines.

There are six parameters for RMR system [5]:

- Uniaxial Compressive Strength of rock materials (UCS)
- Rock quality designation (RQD)
- Spacing of discontinuities
- Conditions of discontinuities
- Orientation of discontinuities
- Ground water conditions

RMR system classifies strata along tunnel alignment into several zones, each with more or less similar geological features. In most of the circumstances, boundary of these structural regions will overlap with the main geological features such as shear zones, faults and dykes etc. The Q-system consists of six parameters to calculate Q values by using equation given below and Q values classify the rock mass into poor and good quality to estimate the required support.

\[
Q = \frac{\text{RQD} \times J_n \times J_r \times J_a \times J_w}{\text{SRF}}
\]

The parameters are:
- RQD = Rock Quality Designation
- \( J_n \) = Joint set number
- \( J_r \) = Joint roughness number
- \( J_a \) = Joint alteration number
- \( J_w \) = Joint water reduction number
- SRF = Stress Reduction Factor

3. Rock Mass Classification along Tunnel Route

In this study, all parameters of Q and RMR systems were studied to characterize
the rock mass along tunnel alignment of 2800 m length. Total ten (10) scanline surveys were carried out along the tunnel route to record the joints condition. The rock mass was classified in four classes with respect to RMR and Q values (Good to Very Poor rock). The summary of ratings regarding scanline/discontinuity surveys is given in Table 1.

Table 1. Summary of scanline survey executed in the study area.

| Location | Coordinates | Discontinuity Type | Representative Orientation | Average Value |
|----------|-------------|--------------------|---------------------------|---------------|
|          | Easting     | Northing           | Dip Direction | Dip | Spacing (cm) | Persistence (m) | Jr | Ja | Jw | SRF |
| Tunnel Intake | 295,401     | 3,865,172          | Foliation          | 84  | 56  | 12   | 3.5 | 1  | 4  |
|            |             |                    | J-1                | 286 | 65  | 27   | 2.7 | 1.5| 3  | 1  | 2.5 |
|            |             |                    | J-2                | 234 | 60  | 10   | 1.8 | 1  | 3.5|
| Near Nullah Tunnel Intake | 295,453     | 3,865,150          | Foliation          | 81  | 39  | 14   | 2.94| 2  | 3  |
|            |             |                    | J-1                | 256 | 63  | 15.56| 1.3 | 2  | 2  | 1  | 2  |
|            |             |                    | J-2                | 343 | 76  | 38   | 2   | 1.5| 3  |
| Along Nullah Downstream Intake Structure | 295,545     | 3,865,143          | Foliation          | 69  | 58  | 15   | 3.1 | 2  | 2  |
|            |             |                    | J-1                | 307 | 54  | 2.7  | 0.9 | 2  | 2  | 1  | 2  |
|            |             |                    | J-2                | 234 | 56  | 1.9  | 2.5 | 2  | 3  |
| Along Tunnel In Shear Zone | 295,724     | 3,865,185          | Foliation          | 347 | 77  | 5.8  | 6   | 1  | 4  |
|            |             |                    | J-1                | 70  | 50  | 8.2  | 0.77| 1  | 3  | 1  | 5.5 |
|            |             |                    | J-2                | 210 | 42  | 8.6  | 0.53| 1  | 4  |
| Tunnel Alignment | 296,910     | 3,863,742          | Foliation          | 249 | 61  | 10   | 8   | 1.5| 3  |
|            |             |                    | J-1                | 57  | 58  | 4.5  | 0.5 | 1.5| 3  | 1  | 2.5 |
|            |             |                    | J-2                | 142 | 56  | 2    | 1.5 | 1  | 4  |
| Along Tunnel | 297,307     | 3,863,476          | Foliation          | 258 | 77  | 12.6 | 18.09| 3  | 2  |
|            |             |                    | J-1                | 111 | 21  | 15.69| 3.38| 3  | 3  | 1  | 2.5 |
|            |             |                    | J-2                | 163 | 83  | 50.9 | 9.07| 2  | 2  |
| Near Tunnel Outlet | 297,365     | 3,863,256          | Foliation          | 253 | 60  | 9.1  | 8   | 1  | 3  |
|            |             |                    | J-1                | 131 | 59  | 2.6  | 1.5 | 1  | 3  | 1  | 2.5 |
|            |             |                    | J-2                | 354 | 57  | 0.4  | 0.9 | 1.5| 4  |
| Tunnel Outlet | 297,579     | 3,863,291          | Foliation          | 264 | 87  | 11.28| 2.5 | 3  | 2  | 1  | 2  |
|            |             |                    | J-1                | 264 | 87  | 25.4 | 1.4 | 3  | 2  |
|            |             |                    | J-2                | 77  | 78  | 64.5 | 18.6| 2  | 3  |
| Along the Nullah Downstream | 297,962     | 3,863,277          | Foliation          | 207 | 73  | 40.28| 12.95| 3  | 3  | 1  | 2  |
|            |             |                    | J-1                | 47  | 33  | 123.5| 6.15| 2  | 2  |
|            |             |                    | J-2                | 227 | 73  | 17.18| 2.04| 2  | 4  |
| Along Road Near Bridge | 297,952     | 3,863,038          | Foliation          | 213 | 39  | 25.12| 1.41| 1  | 3  | 1  | 2.5 |
|            |             |                    | J-1                | 350 | 74  | 19.18| 1.45| 2  | 3  |
3.1. Tunnelling Quality Index (Q) of Study Area

The joint set number ($J_n$), roughness ($J_r$), alteration ($J_a$), water reduction ($J_w$) and Stress Reduction Factor (SRF) values were assessed during scanline surveys. The Q value varies between 0.01 and 13.33. The rock mass classified as good (B) to very poor (E) rocks. The rock type, rock mass parameters, calculated Q values and rock class are given in Table 2.

**Table 2.** Calculated Q-values and rock class along tunnel alignment.

| Station (m) | Rock Type | RQD/$J_n$ | $J_r/J_a$ | $J_w$/SRF | Q-Value | Rock Class         |
|------------|-----------|-----------|-----------|-----------|---------|-------------------|
| 10         | QMS       | 4.17      | 1.00      | 0.20      | 0.83    | Very Poor (E)     |
| 25         | GMS       | 4.17      | 1.00      | 0.40      | 1.67    | Poor (D)          |
| 40         | QMS       | 4.00      | 1.00      | 0.40      | 1.60    |                   |
| 50         |           | 3.75      | 1.00      | 0.40      | 1.50    |                   |
| 60         | GMS       | 4.44      | 1.00      | 0.26      | 1.17    |                   |
| 67         |           | 3.89      | 1.50      | 0.40      | 2.33    |                   |
| 75         |           | 3.89      | 1.50      | 0.26      | 1.54    |                   |
| 80         |           | 4.44      | 1.50      | 0.26      | 1.76    |                   |
| 90         | CS        | 3.33      | 1.00      | 0.26      | 0.88    | Very Poor (E)     |
| 100        |           | 3.33      | 1.50      | 0.20      | 1.00    | Poor (D)          |
| 105        | GMS       | 4.44      | 1.00      | 0.26      | 1.17    |                   |
| 120        |           | 3.89      | 1.33      | 0.40      | 2.07    |                   |
| 135        |           | 3.89      | 1.00      | 0.20      | 0.78    | Very Poor (E)     |
| 145        |           | 4.44      | 1.33      | 0.33      | 1.96    | Poor (D)          |
| 160        | QT + QMS  | 4.44      | 1.33      | 0.50      | 2.96    |                   |
| 175        |           | 3.33      | 1.33      | 0.26      | 1.17    |                   |
| 183        | GMS       | 2.50      | 1.33      | 0.50      | 1.67    |                   |
| 190        |           | 2.92      | 1.50      | 0.20      | 0.88    | Very Poor (E)     |
| 200        | GMS + SCH_M | 3.89       | 1.50      | 0.20      | 1.17    | Poor (D)          |
| 210        |           | 2.50      | 1.00      | 0.40      | 1.00    |                   |
| 225        |           | 4.44      | 1.00      | 0.50      | 2.22    |                   |
| 230        |           | 5.00      | 1.00      | 0.50      | 2.50    |                   |
| 250        | GMS + M   | 5.00      | 1.50      | 0.40      | 3.00    |                   |
| 260        | GMS       | 3.89      | 1.00      | 0.40      | 1.56    |                   |
| 275        |           | 1.67      | 0.67      | 0.07      | 0.07    | Extremely Poor (F)|
| 286        |           | 2.50      | 0.67      | 0.13      | 0.22    | Very Poor (E)     |
| 294        |           | 1.67      | 0.75      | 0.07      | 0.09    | Extremely Poor (F)|
| 300        | CS        | 2.50      | 0.67      | 0.13      | 0.22    | Very Poor (E)     |
| 311        | CS        | 3.89      | 0.75      | 0.10      | 0.29    | Very Poor (E)     |
| 320        |           | 5.00      | 1.00      | 0.40      | 2.00    | Poor (D)          |
|   |   |   |   |   |   |
|---|---|---|---|---|---|
| 340 | GMS + M | 2.22 | 0.67 | 0.20 | 0.30 | Very Poor (E) |
| 350 |   | 1.25 | 0.50 | 0.13 | 0.08 | Extremely Poor (F) |
| 370 |   | 1.25 | 0.25 | 0.07 | 0.02 |   |
| 396 |   | 1.25 | 0.50 | 0.13 | 0.08 |   |
| 412 |   | 2.08 | 0.67 | 0.13 | 0.18 | Very Poor (E) |
| 435 |   | 0.83 | 0.25 | 0.07 | 0.01 | Extremely Poor (F) |
| 446 |   | 1.67 | 0.67 | 0.20 | 0.22 | Very Poor (E) |
| 460 | GMS + QT | 1.25 | 0.25 | 0.13 | 0.04 | Extremely Poor (F) |
| 470 |   | 2.08 | 0.67 | 0.20 | 0.28 | Very Poor (E) |
| 522 | GMS | 1.25 | 0.25 | 0.13 | 0.04 | Extremely Poor (F) |
| 527 |   | 2.08 | 0.67 | 0.20 | 0.28 | Very Poor (E) |
| 550 |   | 1.67 | 0.25 | 0.13 | 0.06 | Extremely Poor (F) |
| 566 | GMS + M | 2.08 | 0.67 | 0.13 | 0.19 | Very Poor (E) |
| 600 | QMS + M | 1.25 | 0.25 | 0.09 | 0.03 | Extremely Poor (F) |
| 625 |   | 7.22 | 1.00 | 0.50 | 3.61 | Poor (D) |
| 638 |   | 5.00 | 1.00 | 0.40 | 2.00 |   |
| 642 |   | 0.83 | 0.20 | 0.14 | 0.02 | Extremely Poor (F) |
| 670 |   | 3.75 | 1.50 | 0.40 | 2.25 | Poor (D) |
| 687 |   | 6.11 | 1.50 | 0.53 | 4.88 | Fair (C) |
| 692 | GMS + M | 4.17 | 1.50 | 0.26 | 1.65 | Poor (D) |
| 696 |   | 0.83 | 0.25 | 0.09 | 0.02 | Extremely Poor (F) |
| 720 |   | 5.56 | 1.50 | 0.26 | 2.20 | Poor (D) |
| 730 |   | 3.89 | 0.67 | 0.09 | 0.23 | Very Poor (E) |
| 741 |   | 1.67 | 1.50 | 0.09 | 0.22 |   |
| 750 |   | 2.50 | 0.25 | 0.09 | 0.06 | Extremely Poor (F) |
| 757 |   | 7.78 | 1.00 | 0.40 | 3.11 | Poor (D) |
| 784 |   | 7.78 | 1.50 | 0.53 | 6.21 | Fair (C) |
| 800 | GMS + M | 6.67 | 1.00 | 0.40 | 2.67 | Poor (D) |
| 812 | QMS + M | 7.78 | 1.50 | 0.53 | 6.21 | Fair (C) |
| 825 |   | 8.89 | 0.67 | 0.26 | 1.56 | Poor (D) |
| 850 |   | 4.58 | 0.67 | 0.40 | 1.22 |   |
| 890 | MB | 6.11 | 1.50 | 0.53 | 4.88 | Fair (C) |
| 900 | QMS + M | 5.00 | 1.00 | 0.26 | 1.32 | Poor (D) |
| 907 | MS | 5.00 | 1.00 | 0.40 | 2.00 |   |
| 920 | QMS | 3.75 | 0.50 | 0.13 | 0.25 | Very Poor (E) |
| 927 |   | 3.75 | 0.50 | 0.09 | 0.17 | Very Poor (E) |
| 960 |   | 8.33 | 1.00 | 0.67 | 5.56 | Fair (C) |
|    |    |    |    |    |    |    |    |
|----|----|----|----|----|----|----|----|
| 975| 15.00| 1.00| 0.67| 10.00| Good (B) |
| 1008|15.83| 1.00| 0.50| 7.92| Fair (C) |
| 1040|13.33| 0.67| 0.40| 3.56| Poor (D) |
| 1060| 7.78| 2.00| 0.50| 7.78| Fair (C) |
| 1075| 8.89| 2.00| 0.33| 5.87|        |
| 1085| 8.33| 1.50| 0.50| 6.25|        |
| 1100| 8.33| 3.00| 0.33| 8.25|        |
| 1110| 8.89| 3.00| 0.50| 13.33 | Good (B) |
| 1120| 8.33| 3.00| 0.33| 8.25| Fair (C) |
| 1130| 8.33| 1.50| 0.50| 6.25|        |
| 1150| 8.33| 0.67| 0.40| 2.22| Poor (D) |
| 1175| 5.83| 0.38| 0.09| 0.19| Very Poor (E) |
| 1200| 5.83| 0.38| 0.13| 0.29|        |
| 1225| CS| 5.67| 0.25| 0.13| 0.19|        |
| 1260| CS + QMS| 6.67| 0.38| 0.09| 0.22|        |
| 1280| G_QMS + CS| 9.44| 1.50| 0.50| 7.08| Fair (C) |
| 1290| 8.89| 1.50| 0.33| 4.40|        |
| 1315| G_QMS| 9.44| 1.50| 0.50| 7.08|        |
| 1320| 8.89| 1.50| 0.33| 4.40|        |
| 1385| MB + G_QMS + CS| 10.00| 1.50| 0.50| 7.50|        |
| 1425| QMS + G_QMS| 8.89| 0.67| 0.50| 2.96| Poor (D) |
| 1445| GMS + G_QMS| 10.00| 0.67| 0.50| 3.33| Poor (D) |
| 1490| QMS + G_QMS + GMS| 10.00| 1.50| 0.50| 7.50| Fair (C) |
| 1510| QMS| 7.78| 0.67| 0.20| 1.04| Poor (D) |
| 1525| G_QMS + QMS| 6.67| 0.67| 0.53| 2.38|        |
| 1538| G_QMS| 5.56| 0.67| 0.53| 1.98|        |
| 1549| 4.58| 0.17| 0.10| 0.08| Extremely Poor (F) |
| 1555| 5.42| 0.25| 0.13| 0.18| Very Poor (E) |
| 1586| 3.33| 0.17| 0.04| 0.02| Extremely Poor (F) |
| 1645| QMS| 2.50| 0.17| 0.10| 0.04|        |
| 1653| 2.08| 0.17| 0.07| 0.02|        |
| 1660| 2.50| 0.67| 0.09| 0.15| Very Poor (E) |
| 1690| 2.08| 0.17| 0.07| 0.02| Extremely Poor (F) |
| 1745| GMS| 4.44| 0.50| 0.10| 0.22| Very Poor (E) |
| 1760| 2.08| 0.38| 0.09| 0.07| Extremely Poor (F) |
| 1800| 3.33| 0.50| 0.13| 0.22| Very Poor (E) |
| 1808| QMS| 5.56| 0.67| 0.35| 1.30| Poor (D) |
| Year | Code    | Value1 | Value2 | Value3 | Value4 |
|------|---------|--------|--------|--------|--------|
| 1835 |         | 5.56   | 0.67   | 0.53   | 1.97   |
| 1865 |         | 5.00   | 1.00   | 0.35   | 1.76   |
| 1875 |         | 5.56   | 0.67   | 0.53   | 1.97   |
| 1892 |         | 5.56   | 0.67   | 0.40   | 1.48   |
| 1908 |         | 3.89   | 0.67   | 0.40   | 1.04   |
| 1925 |         | 8.33   | 0.67   | 0.53   | 2.96   |
| 1934 |         | 8.33   | 0.67   | 0.35   | 1.95   |
| 1960 | GMS     | 8.33   | 0.67   | 0.53   | 2.96   |
| 1980 |         | 9.17   | 0.67   | 0.53   | 3.25   |
| 2000 |         | 9.17   | 0.67   | 0.35   | 2.15   |
| 2025 | GMS + QMS | 8.33 | 1.00 | 0.35 | 2.93 |
| 2050 | QMS     | 8.33   | 0.67   | 0.35   | 1.95   |
| 2065 |         | 8.33   | 0.67   | 0.53   | 2.96   |
| 2086 | Q, QMS + GMS | 6.67 | 0.67 | 0.35 | 1.56 |
| 2100 | GMS     | 4.44   | 0.67   | 0.40   | 1.19   |
| 2125 | QT + MM | 5.83   | 0.67   | 0.40   | 1.56   |
| 2141 | MM      | 8.33   | 1.00   | 0.40   | 3.33   |
| 2150 | G, QMS  | 6.67   | 1.00   | 0.40   | 2.67   |
| 2162 |         | 6.67   | 1.00   | 0.53   | 3.55   |
| 2175 | M       | 5.83   | 1.00   | 0.40   | 2.33   |
| 2186 |         | 6.67   | 1.00   | 0.53   | 3.55   |
| 2200 | QMS + QT| 6.67   | 0.67   | 0.40   | 1.78   |
| 2216 |         | 7.50   | 0.67   | 0.40   | 2.00   |
| 2236 | QT      | 6.67   | 1.00   | 0.53   | 3.55   |
| 2252 |         | 7.50   | 0.67   | 0.40   | 2.00   |
| 2265 |         | 6.11   | 1.00   | 0.50   | 3.06   |
| 2275 |         | 6.11   | 0.67   | 0.50   | 2.04   |
| 2292 |         | 8.33   | 1.00   | 0.40   | 3.33   |
| 2352 |         | 8.33   | 1.00   | 0.26   | 2.20   |
| 2317 |         | 6.67   | 1.00   | 0.50   | 3.33   |
| 2330 |         | 4.44   | 0.67   | 0.26   | 0.78   |
| 2347 | QT + QMS| 5.00   | 0.67   | 0.40   | 1.33   |
| 2365 | QT      | 3.89   | 1.00   | 0.50   | 1.94   |
| 2376 | GMS + M | 3.33   | 0.67   | 0.40   | 0.89   |
| 2393 | M + QMS | 4.44   | 0.67   | 0.40   | 1.19   |
| 2400 | M       | 4.44   | 1.00   | 0.50   | 2.22   |
| 2426 |         | 3.33   | 0.67   | 0.50   | 1.11   |
5.00  0.67  0.33  1.10  
8.33  0.67  0.40  2.22  
8.33  1.50  0.80  10.00  Good (B)  
8.33  1.50  0.53  6.60  Fair (C)  
4.44  1.50  0.80  5.33  
4.44  1.50  0.50  3.33  Poor (D)  
5.00  1.50  0.80  6.00  Fair (C)  
6.11  1.00  0.26  1.61  Poor (D)  
6.11  1.00  0.20  1.22  
4.44  1.50  0.40  2.67  
5.00  1.00  0.26  1.32  
5.00  1.00  0.40  2.00  
6.67  1.00  0.26  1.76  
3.33  0.38  0.20  0.25  Very Poor (E)  
6.11  1.00  0.40  2.44  Poor (D)  
4.17  1.00  0.26  1.10  
3.33  0.50  0.20  0.33  Very Poor (E)  
4.17  1.00  0.26  1.10  Poor (D)  
4.17  1.00  0.40  1.67  
7.22  1.00  0.40  2.89  
6.67  1.33  0.40  3.56  
5.56  0.67  0.40  1.48  
6.67  1.00  0.40  2.67  
5.56  0.67  0.40  1.48  
5.56  1.00  0.40  2.22  
7.22  1.00  0.40  2.89  
6.67  1.00  0.40  2.67  
6.67  1.00  0.26  1.76  
7.22  1.00  0.40  2.89  
7.22  1.00  0.26  1.91  
6.67  1.00  0.13  0.88  Very Poor (E)  

| RMR | UTS 1 | UTS 2 | UTS 3 | UT | Classification |
|-----|-------|-------|-------|----|----------------|
| 2440| 5.00  | 0.67  | 0.33  | 1.10|                |
| 2455| 8.33  | 0.67  | 0.40  | 2.22|                |
| 2468| 8.33  | 1.50  | 0.80  | 10.00| Good (B)       |
| 2475| 8.33  | 1.50  | 0.53  | 6.60 | Fair (C)       |
| 2503| 4.44  | 1.50  | 0.80  | 5.33 |                |
| 2524| 5.56  | 1.50  | 0.80  | 6.67 |                |
| 2535| 4.44  | 1.50  | 0.80  | 5.33 |                |
| 2557| 4.44  | 1.50  | 0.50  | 3.33 | Poor (D)       |
| 2576| M     | 5.00  | 1.50  | 0.80 | 6.00 | Fair (C)       |
| 2587| 6.11  | 1.00  | 0.26  | 1.61 | Poor (D)       |
| 2594| 6.11  | 1.00  | 0.20  | 1.22 |                |
| 2603| 4.44  | 1.50  | 0.40  | 2.67 |                |
| 2610| 5.00  | 1.00  | 0.26  | 1.32 |                |
| 2624| G_QMS + M | 5.00 | 1.00 | 0.40 | 2.00 |                |
| 2635| G_QMS + QMS | 6.67 | 1.00 | 0.26 | 1.76 |                |
| 2652| QMS   | 3.33  | 0.38  | 0.20 | 0.25 | Very Poor (E) |
| 2673| 6.11  | 1.00  | 0.40  | 2.44 | Poor (D)       |
| 2682| QMS + GMS | 4.17 | 1.00 | 0.26 | 1.10 |                |
| 2689| GMS + M | 3.33  | 0.50  | 0.20 | 0.33 | Very Poor (E) |
| 2702| 4.17  | 1.00  | 0.26  | 1.10 | Poor (D)       |
| 2707| GMS   | 4.17  | 1.00  | 0.40  | 1.67 |                |
| 2714| 7.22  | 1.00  | 0.40  | 2.89 |                |
| 2720| 6.67  | 1.33  | 0.40  | 3.56 |                |
| 2727| GMS + M | 5.56  | 0.67 | 0.40 | 1.48 |                |
| 2733| MB + GMS | 6.67 | 1.00 | 0.40 | 2.67 |                |
| 2740| 5.56  | 0.67  | 0.40  | 1.48 |                |
| 2746| 5.56  | 1.00  | 0.40  | 2.22 |                |
| 2751| 7.22  | 1.00  | 0.40  | 2.89 |                |
| 2760| 6.67  | 1.00  | 0.40  | 2.67 |                |
| 2773| 6.67  | 1.00  | 0.26  | 1.76 |                |
| 2782| M     | 7.22  | 1.00  | 0.40  | 2.89 |                |
| 2788| MB + GMS | 7.22 | 1.00 | 0.26 | 1.91 |                |
| 2800| GMS   | 6.67  | 1.00  | 0.13  | 0.88 | Very Poor (E) |

GMS = Garnet Mica Schist, M = Marble, MM = Micaceous Marble, QMS = Quartz Mica Schist, G_QMS = Garnet bearing Quartz Mica Schist, CS = Calcareous Schist, QT = Quartzite, MS = Micaceous Schist.

### 3.2. Rock Mass Rating (RMR) of Study Area

The parameters including the Uniaxial Compressive Strength (UCS) [30], RQD,
joint spacing, orientation, persistence, joint surface conditions and ground water conditions were determined to calculate RMR for each rock type section as discussed below and final calculated values of RMR are given in Table 3 with rock quality ranged between very good (I) to very poor (V) rock.

**Table 3.** Calculated values of RMR and rock class along the tunnel route.

| Station (m) | Rock Type       | RMR-Value | Rock Class       |
|-------------|-----------------|-----------|------------------|
| 10          | QMS             | 38        | Poor rock (IV)   |
| 25          | GMS             | 43.00     | Fair rock (III)  |
| 40          | QMS             | 42.00     |                  |
| 50          |                 | 42.00     |                  |
| 60          | GMS             | 41.00     |                  |
| 67          |                 | 46.00     |                  |
| 75          |                 | 43.00     |                  |
| 80          |                 | 44.00     |                  |
| 90          | CS              | 38.00     | Poor rock (IV)   |
| 100         |                 | 42.00     | Fair rock (III)  |
| 105         | GMS             | 41.00     |                  |
| 120         |                 | 46.00     |                  |
| 135         |                 | 39.00     | Poor rock (IV)   |
| 145         |                 | 44.00     | Fair rock (III)  |
| 160         | QT + QMS        | 55.00     |                  |
| 175         |                 | 41.00     |                  |
| 183         | GMS             | 43.00     |                  |
| 190         | GMS             | 38.00     | Poor rock (IV)   |
| 200         | GMS + SCH_M     | 41.00     | Fair rock (III)  |
| 210         |                 | 41.00     |                  |
| 225         |                 | 47.00     |                  |
| 230         |                 | 48.00     |                  |
| 250         | GMS + M         | 55.00     |                  |
| 260         | GMS             | 43.00     |                  |
| 275         | GMS             | 16.00     | Very poor rock (V)|
| 286         |                 | 24.00     | Poor rock (IV)   |
| 294         |                 | 18.00     | Very poor rock (V)|
| 300         | CS              | 18.00     |                  |
| 311         |                 | 27.00     | Poor rock (IV)   |
| 320         |                 | 23.00     |                  |
| 340         | GMS + M         | 24.00     |                  |
| 350         |                 | 17.00     | Very poor rock (V)|
|   |   |   |
|---|---|---|
| 370 | 13.00 |   |
| 396 | 18.00 |   |
| 412 | 22.00 | Poor rock (IV) |
| 435 | 15.00 | Very poor rock (V) |
| 446 | 24.00 | Poor rock (IV) |
| 460 | GMS + QT | 14.00 | Very poor rock (V) |
| 470 | 27.00 | Poor rock (IV) |
| 522 | GMS | 13.00 | Very poor rock (V) |
| 527 | 28.00 | Poor rock (IV) |
| 550 | 16.00 | Very poor rock (V) |
| 566 | GMS + M | 26.00 | Poor rock (IV) |
| 600 | QMS + M | 15.00 | Very poor rock (V) |
| 625 | 58.00 | Fair rock (III) |
| 638 | 45.00 |   |
| 642 | 12.00 | Very poor rock (V) |
| 670 | 49.00 | Fair rock (III) |
| 687 | 86.00 | Very good rock (I) |
| 692 | GMS + M | 44.00 | Fair rock (III) |
| 696 | 13.00 | Very poor rock (V) |
| 720 | 44.00 | Fair rock (III) |
| 730 | 26.00 | Poor rock (IV) |
| 741 | GMS + M | 27.00 | Poor rock (IV) |
| 750 | 15.00 | Very poor rock (V) |
| 757 | 50.00 | Fair rock (III) |
| 784 | 87.00 | Very good rock (I) |
| 800 | 46.00 | Fair rock (III) |
| 812 | QMS + M | 88.00 | Very good rock (I) |
| 825 | 43.00 | Fair rock (III) |
| 850 | 42.00 |   |
| 890 | M | 85.00 | Very good rock (I) |
| 900 | QMS + M | 42.00 | Fair rock (III) |
| 907 | MS | 45.00 |   |
| 920 | QMS | 26.00 | Poor rock (IV) |
| 927 | 22.00 |   |
| 960 | 87.00 | Very good rock (I) |
| 975 | 95.00 |   |
| 1008 | 93.00 |   |
|   |   |   |
|---|---|---|
| 1040 | 58.00 | Fair rock (III) |
| 1060 | 92.00 | Very good rock (I) |
| 1075 | 86.00 | |
| 1085 | 88.00 | |
| 1100 | 91.00 | |
| 1110 | 98.00 | |
| 1120 | 91.00 | |
| 1130 | 88.00 | |
| 1150 | 47.00 | Fair rock (III) |
| 1175 | 23.00 | Poor rock (IV) |
| 1200 | 26.00 | |
| 1225 | CS | 23.00 |
| 1260 | CS + QMS | 24.00 |
| 1280 | G_QMS + CS | 90.00 | Very good rock (I) |
| 1290 | | 82.00 |
| 1315 | G_QMS | 90.00 | Very good rock (I) |
| 1320 | G_QMS | 83.00 | |
| 1385 | M + G_QMS + CS | 91.00 | |
| 1425 | QMS + G_QMS | 55.00 | Fair rock (III) |
| 1445 | GMS + G_QMS | 56.00 | |
| 1490 | QMS + G_QMS + GMS | 91.00 | Good rock (II) |
| 1510 | QMS | 42.00 | Fair rock (III) |
| 1525 | G_QMS + QMS | 47.00 | |
| 1538 | G_QMS | 45.00 | |
| 1549 | | 18.00 | Very poor rock (V) |
| 1555 | | 22.00 | Poor rock (IV) |
| 1586 | | 13.00 | Very poor rock (V) |
| 1645 | QMS | 15.00 | |
| 1653 | | 13.00 | |
| 1660 | | 22.00 | Poor rock (IV) |
| 1690 | | 13.00 | Very poor rock (V) |
| 1745 | GMS | 23.00 | Poor rock (IV) |
| 1760 | | 16.00 | Very poor rock (V) |
| 1800 | | 24.00 | Poor rock (IV) |
| 1808 | QMS | 42.00 | Fair rock (III) |
| 1835 | | 45.00 | |
| 1865 | | 44.00 | |
Continued

| Year | Rock Type   | Price |
|------|-------------|-------|
| 1875 |             | 45.00 |
| 1892 |             | 43.00 |
| 1908 |             | 42.00 |
| 1925 |             | 56.00 |
| 1934 |             | 46.00 |
| 1960 | GMS         | 57.00 |
| 1980 |             | 56.00 |
| 2000 |             | 45.00 |
| 2025 | GMS + QMS   | 48.00 |
| 2050 | QMS         | 46.00 |
| 2065 |             | 51.00 |
| 2086 | G_QMS + GMS | 44.00 |
| 2100 | GMS         | 42.00 |
| 2125 | QT + MM     | 43.00 |
| 2141 | MM          | 57.00 |
| 2150 | G_QMS       | 50.00 |
| 2162 |             | 57.00 |
| 2175 | M           | 49.00 |
| 2186 |             | 57.00 |
| 2200 | QMS + QT    | 46.00 |
| 2216 |             | 47.00 |
| 2236 | QT          | 58.00 |
| 2252 |             | 47.00 |
| 2265 |             | 53.00 |
| 2275 |             | 47.00 |
| 2292 |             | 55.00 |
| 2352 |             | 46.00 |
| 2317 |             | 58.00 |
| 2330 |             | 36.00 |
| 2347 | QT + QMS    | 42.00 |
| 2365 | QT          | 45.00 |
| 2376 | GMS + M     | 39.00 |
| 2393 | M + QMS     | 41.00 |
| 2400 | M           | 47.00 |
| 2426 |             | 41.00 |
| 2440 |             | 42.00 |
| 2455 |             | 47.00 |

Fair rock (III)

Poor rock (IV)
### 3.2.1. Quartz Mica Schist (QMS)

The recommended Uniaxial Compressive Strength (UCS) of QMS is *i.e.* 80 MPa; RQD is 75%, joints spacing ranging from 10 - 60 cm, joints encountered are smooth-slicken sided and undulating-planar, persistence 3 - 10 m and joint apertures are <1 mm in width with soft filling of materials. Fair to unfavorable
orientation of discontinuities conditions were observed.

3.2.2. Garnet Bearing Quartz Mica Schist (G-QMS)
The average values UCS for G-QMS is 95 MPa with average RQD 75%, joints spacing ranges from 10 - 50 cm, joints are undulating, planar and smooth, persistence of 3 - 10 m and joint apertures are <1 mm in width with soft filling materials. Discontinuities attitude reveals fair to unfavorable tunnel drive conditions.

3.2.3. Garnet Mica Schist (GMS) and Micaceous Schist (MS)
The GMS has average UCS of 80 MPa and RQD of 50%, joint spacing range is 10 - 22 cm, joint apertures <1 mm in width with soft filling materials with undulating, planar, smooth & slickensided joints, persistence of 0.3 - 3 m.

3.2.4. Marble (MB), Siliceous Marble (SM) and Micaceous Marble (MM)
The average UCS for these rocks is 80 MPa with RQD of 60%, joint apertures are <1 mm - 5 mm with non-softening fillings and clean also, rough, irregular, undulating & smooth, 0.5 - 2.8 m of persistence and tunnel drive situation is favorable & very favourable.

3.2.5. Quartzite (QT)
The average value of 145 MPa were calculated as UCS strength for QMS with RQD is 47%, joints spacing ranging from 10 - 20 cm, joints encounter are irregular, smooth and undulating-planar, persistence of joints are 6 - 4 m and joint apertures are <1 mm - 3 mm in width with soft filling materials and few joints are clean. Very favorable to favorable orientation of discontinuities along tunnel route was observed.

3.3. Estimated Support Recommendations
The support estimation was calculated by both RMR and Q system. The Q-values and other required parameters (tunnel height and excavation support ratio) have been evaluated in the support estimate chart (Figure 2). The estimated support by Q system falls in category 1, 3, 4, 5, 6 and 7 which have support requirements of unsupported, systematic bolting, systematic bolting (shotcrete, 4 - 10 cm), fiber reinforced shotcrete and bolting, 5 - 9 cm, fiber reinforced shotcrete & bolting, 9 - 12 cm and fiber reinforced shotcrete & bolting, 12 - 15 cm respectively as shown by red color square (Figure 2).

According to calculate values of RMR, rock masses characterized in following classes: Very good (I) and Fair (III) to Very poor (V). Based on support recommendation chart after Bieniawski, type and amount of support estimates are listed in the (Table 4).

3.4. Correlation between Petrography and Rock Mass Parameters
The detailed petrographic studies of rock samples revealed that tunnel majorly consist of five major rock types namely QMS, GMS, G-QMS, M and CS. The collected samples of QMS, M and G-QMS are fine to medium grained, compact
Figure 2. Estimated support categories based on the tunnelling quality index (Q). Red color represents the support categories for the studied tunnel (Modified after Barton [26]).

Table 4. Support recommendation based on RMR [2].

| Rock Mass Class | Rock bolts | Shotcrete | Steel sets |
|----------------|------------|-----------|------------|
| Class I Very good rock | No support required except spot rock bolting | | |
| Class II Fair rock | 3 m long bolts in crown, spaced 2.5 m with occasional wire mesh | 50 mm in crown where required | None |
| Class III Poor rock | Systematic bolt 4 m long, spaced 1.5 - 2 m in crown and walls with wire mesh in crown | 50 - 100 mm in crown and 30 mm in sides | None |
| Class IV | Systematic bolt 4 - 5 m long, spaced 1 - 1.5 m in crown and walls with wire mesh | 100 - 150 mm in crown and 100 mm in sides | Light to medium ribs spaced 1.5 m where required |
| Class V Very poor rock | Systematic bolt 5 - 6 m long, spaced 1 - 1.5 m in crown and walls with wire mesh, bolts invert | 150 - 200 mm in crown and 150 mm in sides and 50 mm on the face | Medium to heavy ribs spaced 0.75 m with steel lagging and forepoling if required. Close invert |
Table 5. Average RQD, Q value and RMR rating with respect to main rock types.

| Rock types | Average RQD | Average Q-value | Average RMR rating |
|------------|-------------|-----------------|-------------------|
| GMS        | 40%         | 1.29            | 40                |
| CS         | 41%         | 0.43            | 29                |
| G-QMS      | 57%         | 3.91            | 62                |
| QMS        | 43%         | 1.14            | 38                |
| M          | 45%         | 3.08            | 47                |

and are cross cut by few discontinuities having greater spacing. As a result, these rocks have greater average RQD, Q values, RMR ratings (Table 5). The remaining two rock types such as GMS and CS are relatively medium to coarse-grained with many closely spaced discontinuities. The average RQD, Q values and RMR ratings of these segments are comparatively low (Table 5).

4. Conclusion

The main objectives of the current research work are the rock mass categorization along proposed tunnel alignment using RMR and Q system and comparison of rock mass quality with mineralogical composition of rocks. The results were further materialized to predict and assess applicable rock reinforcement requirements for tunnel. Tunnel was divided into five major geological segments on the bases of rock type: quartz mica schist (QMS), garnet mica schist (GMS), garnet bearing quartz mica schist (G-QMS), calcareous schist (CS), marble (M). Q values vary between 0.01 and 13.33 that depicted rock mass quality ranges from good to extremely poor in case of Q-system, while very good to very poor according to RMR. Geological segments comprised of following rock type quartz mica schist, marble and garnet bearing quartz mica schist having fine to medium-grained texture, compact and having large spacing. Therefore, these geological segments have greater average RQD, Q values, RMR ratings as compared to garnet mica schist and calcareous schist.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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