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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 tunnel constructions require a considerable geological input [1]. The overall engineering design weakens by numerous fractures and cracks developed due to tunneling in hard ground conditions leads to deteriorating the physical condition 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 comprised 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 dominantly constitutes of metapelites and metapsammites of Pre-Cambrian Tanawal Formation (**Figure 1**). The Late Cambrian Mansehra porphyritic granite intruded 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

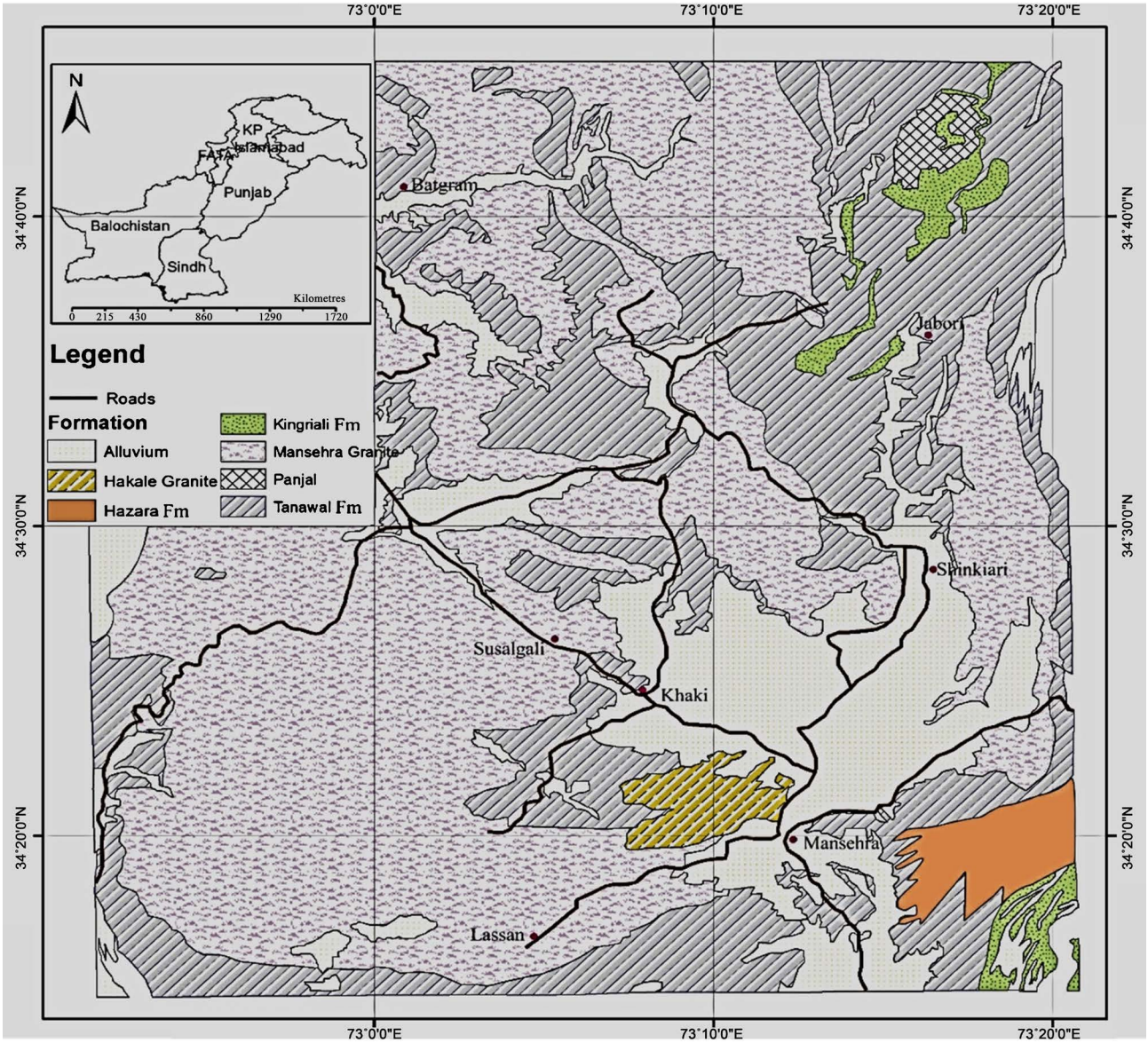

Figure 1. Geological map of Hazara region (Modified after Calkins *et al.* [22]).

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.

$$\mathrm{Q} = \mathrm{RQD}/J_n \times J_r/J_a \times J_w/\mathrm{SRF}$$

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		
			J-1	190	87	25.4	1.4	3	2	1	2
Along the Nullah Downstream	297,962	3,863,277	Foliation	77	78	64.5	18.6	2	3		
			J-1	207	73	40.28	12.95	3	3	1	2
			J-2	47	33	123.5	6.15	2	2		
Along Road Near Bridge	297,952	3,863,038	Foliation	227	73	17.18	2.04	2	4		
			J-1	213	39	25.12	1.41	1	3	1	2.5
			J-2	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)

Continued

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)

Continued

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)

Continued

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	G_QMS + GMS	6.67	0.67	0.35	1.56	
2100	GMS	4.44	0.67	0.40	1.19	Poor (D)
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	Very Poor (E)
2347	QT + QMS	5.00	0.67	0.40	1.33	Poor (D)
2365	QT	3.89	1.00	0.50	1.94	
2376	GMS + M	3.33	0.67	0.40	0.89	Very Poor (E)
2393	M + QMS	4.44	0.67	0.40	1.19	Poor (D)
2400	M	4.44	1.00	0.50	2.22	
2426		3.33	0.67	0.50	1.11	

Continued

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)

Continued

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	

Continued

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

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	Fair rock (III)
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	Poor rock (IV)
2347	QT + QMS	42.00	Fair rock (III)
2365	QT	45.00	
2376	GMS + M	39.00	Poor rock (IV)
2393	M + QMS	41.00	Fair rock (III)
2400	M	47.00	
2426		41.00	
2440		42.00	
2455		47.00	

Continued

2468		75.00	Good rock (II)
2475		77.00	
2503	M	84.00	Very good rock (I)
2524		85.00	
2535		82.00	
2557		57.00	Fair rock (III)
2576		74.00	Good rock (II)
2587		44.00	Fair rock (III)
2594		43.00	
2603		51.00	
2610		42.00	
2624	G_QMS + M	45.00	
2635	G_QMS + QMS	44.00	
2652	QMS	26.00	Poor rock (IV)
2673		52.00	Fair rock (III)
2682	QMS + GMS	43.00	
2689	GMS + M	28.00	Poor rock (IV)
2702		43.00	Fair rock (III)
2707	GMS	44.00	
2714		56.00	
2720		58.00	
2727	GMS + M	44.00	
2733		52.00	
2740		44.00	
2746		47.00	
2751		48.00	
2760		47.00	
2773		45.00	
2782	M	48.00	
2788	M + GMS	45.00	
2800	GMS	38.00	Poor rock (IV)

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.

3.2.1. 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

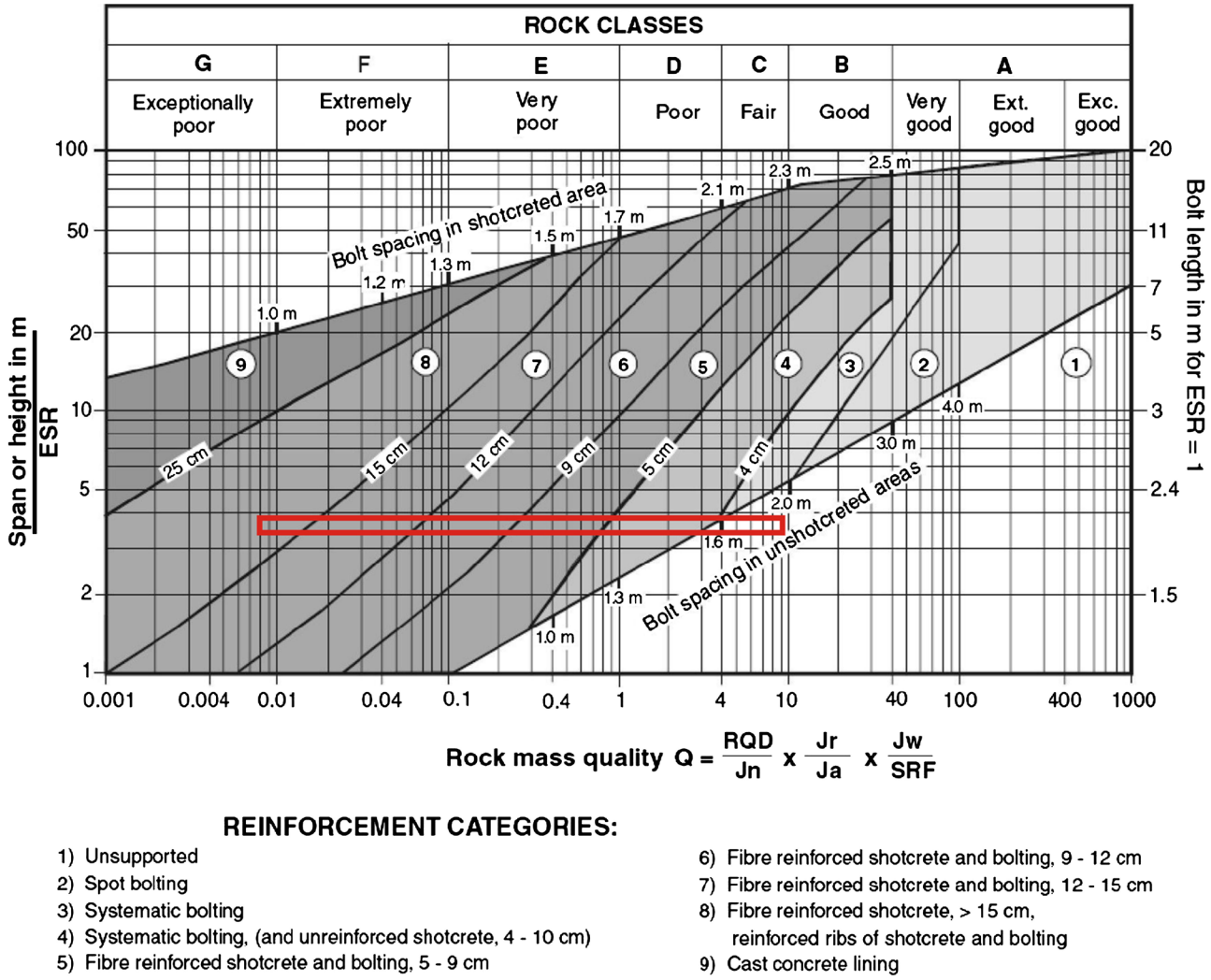

Figure 2. Estimated support categories based on the tunnelling quality index (Q). Red color represents the support categories for the studied tunnel (Modified after Barton [26]).

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

Rock Mass Class	Support Recommendations		
	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 masse 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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