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# Support design for the diversion tunnel of Diamer Basha Dam, Pakistan, considering the recent developments in empirical systems

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# Support design for the diversion tunnel of Diamer Basha Dam, Pakistan, considering the recent developments in empirical systems

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**Abstract.** The use of rock mass rating (RMR) and tunneling quality index (Q) systems in drill and blast tunneling for support design is necessary in the current practice worldwide as these systems are developed empirically for this particular purpose. However, due to the modifications of individual system, no comparison has been made between their suggested support in tunnel design. Empirical rock mass classification systems are continuously updated to reach a reliable support system for construction of tunnels in rocks. This paper presents the utilization of updated versions of RMR and Q system in empirical support design of a diversion tunnel located at Diamer Basha dam site, Pakistan. The rock mass along the alignment of tunnel is divided into different geological units based on rock mass quality, assessed from borehole data. From comparison of recommended support system by RMR and Q system, it is concluded that the RMR system recommend heavy support as compared to Q system. A linear correlation is also obtained between RMR and Q system for the same rock mass which shows a comparatively better correlation coefficient.

## 1. Introduction

The 4500 megawatt Diamer Basha Dam (DBD) Project comprises of RCC (Roller Compacted Concrete) dam and power production units on the right and left side of the river Indus. This project includes access and diversion tunnels, surge tanks, headrace and tailrace tunnels, underground power cavern, switchgear and transformer cavern.

The proposed DBD project is located at the boundary of Khyber Pakhtunkhwa province and Gilgit-Baltistan in Pakistan, approximately 40 km downstream of Chilas, the headquarter of Diamer district in Gilgit-Baltistan, Pakistan. The location of the project is shown in figure 1.

For the diversion of the river Indus, during the construction of the dam, two numbers of tunnels are foreseen. The 15.4 m span with D-shaped tunnel will be excavated on the right side of river Indus.

Empirical classification systems are frequently used in drill and blast tunneling for support design worldwide, however, they are continuously updated empirically either in the form of support chart or characterization. No comparison is made in the support design for the tunnel, considering these recent developments. Therefore, in this study, the comparison is made for the recommended support for the diversion tunnel of DBD project using rock mass rating (RMR) and tunneling quality index (Q) systems.

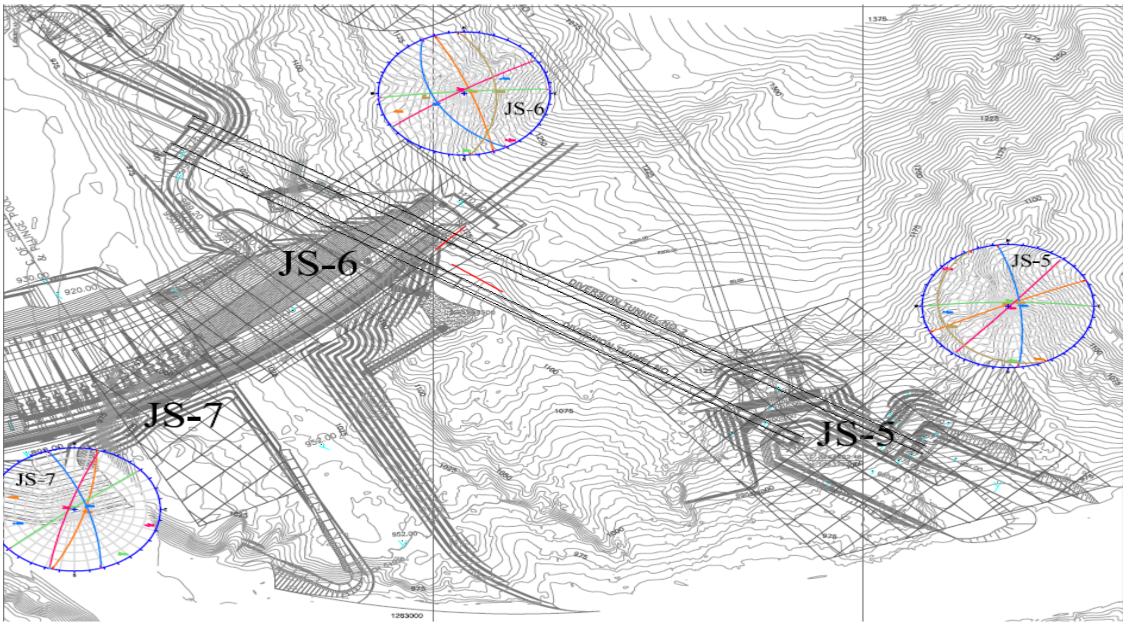
## 2. Materials and methods

### *2.1 Field and laboratory studies*

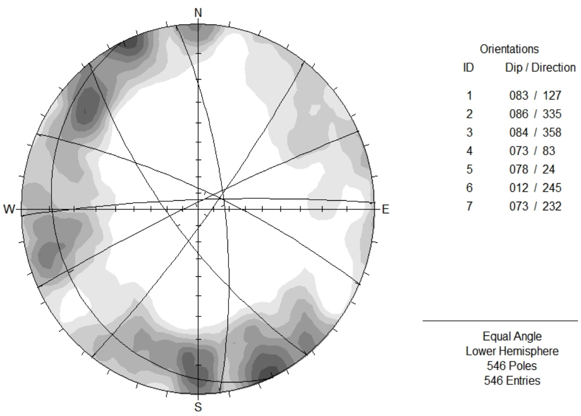
The Water and Power Development Authority (WAPDA) of Pakistan conducted a detailed geological study for the determination of engineering features of rock mass at the project area which includes; core drilling, laboratory testing, discontinuity survey, etc. Out of the total 62 bore hole, drilled for the exploration with 5 exploratory adits and 6 trenches, data of 07 bore holes (BDR-08, 10, 21, 22, 24, 25 and 26) were used in this study as they are drilled along the diversion tunnels axis.

The project area is developed due to the subduction of Indo–Pakistan Plate beneath the Eurasian Plate [1]. Gabbronorite (GN) and Ultramafic Association (UMA) are the major rock types in the project area [2]. The GN is a mafic intrusive rock and the dominant minerals present in it are Plagioclases, pyroxene and amphiboles. The UMA having mafic minerals more than 90 %. The laboratory test reports show that GN and UMA with average uniaxial compressive strength (UCS) of 110 and 80 MPa respectively. For the detailed joint survey (JS), eight location of particular interest were selected. The JS-5 and JS-6 are along the diversion tunnel route, as shown in figure 2.

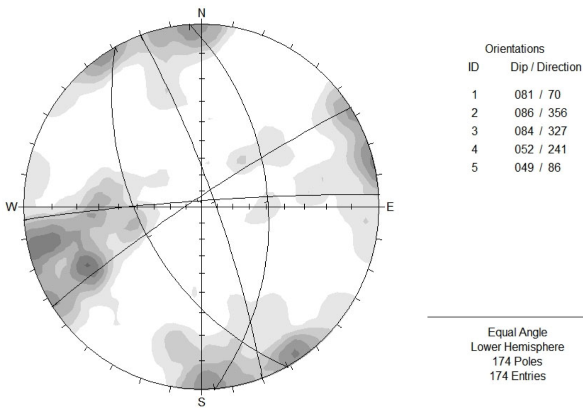

**Figure 1.** Location of Dimer Basha Dam.




Surface discontinuity surveys location.




Discontinuity survey JS-5




Discontinuity survey JS-6

**Figure 2.** Stereographic projection.

*2.2 RMR System*

Bieniawski [3] developed the Geomechanics system for the classification of rock mass on tunnel projects experience, also known RMR system and later on, this classification system has experienced wide alterations. These alterations were incorporated to overcome the limitations of the system for the better use for tunnel support design [4]. The changes included the ratings added for ground water, joint condition and joint spacing. In the current study 1989 form called $RMR_{89}$ is used, although a new version of the system has been introduce called $RMR_{14}$ but it is in the process of development [5, 6].

Rating for UCS ($R_1$) were selected using equations (1) [7].

$$R_1 = 0.126\sigma_c - 0.0004\sigma_c^2, \quad (\sigma_c \leq 110 \text{ MPa}), \tag{1a}$$
$$R_1 = 0.475\sigma_c^{0.626}, \quad (\sigma \geq 110 \text{ MPa}). \tag{1b}$$

The percentage frequency of rock quality designation (RQD) for the 07 numbers of boreholes are shown in figure 3 as proposed by Deere. The rating for RQD ($R_2$) were selected using the following equation, equation (2) [7];

$$R_2 = 0.22RQD - 0.0002RQD^2 \tag{2}$$

The percentage frequency of joint spacing (χ) and roughness rating are shown for all the 7 boreholes in the figures 3. It is clear from these figures that a joint spacing rating greater than 10 and joint roughness rating from 2-4 are dominant in the study area. The rating for joint spacing ($R_3$) is calculated through equations (3) [7];

$$R_3 = 2.281 \times \ln(x) - 3.41, \quad (x = 5\text{–}200 \text{ mm}); \tag{3a}$$
$$R_3 = 4.175 \times \ln(x) - 13.51, \quad (x = 200\text{–}900 \text{ mm}); \tag{3b}$$
$$R_3 = 6.250 \times \ln(x) - 27.55, \quad (x = 900\text{–}2000 \text{ mm}). \tag{3c}$$

In all bore hole, calcite filling with less than 1 mm were observed and all the joints are un-weathered except BDR-22, where up to 10m depth, the joints are slightly weathered.

Joint orientation is the adjustment parameter and its rating values are applied by comparing the joint orientation with respect to tunnel orientation and expected tunnel excavation from inlet side.

The summary of the parameters rating and rock mass classes are shown in table 1. Data statistics shows that the average $RMR_{89}$ for GU-1 is 63. This value is 60 and 64 for GU-2 & GU-3 respectively. According to RMR classification, GU-1 & 3 are of good quality and GU-2 is the maximum value of fair quality rock mass. The percentage frequency distribution of $RMR_{89}$ for all three geotechnical units are also shown in figure 4.

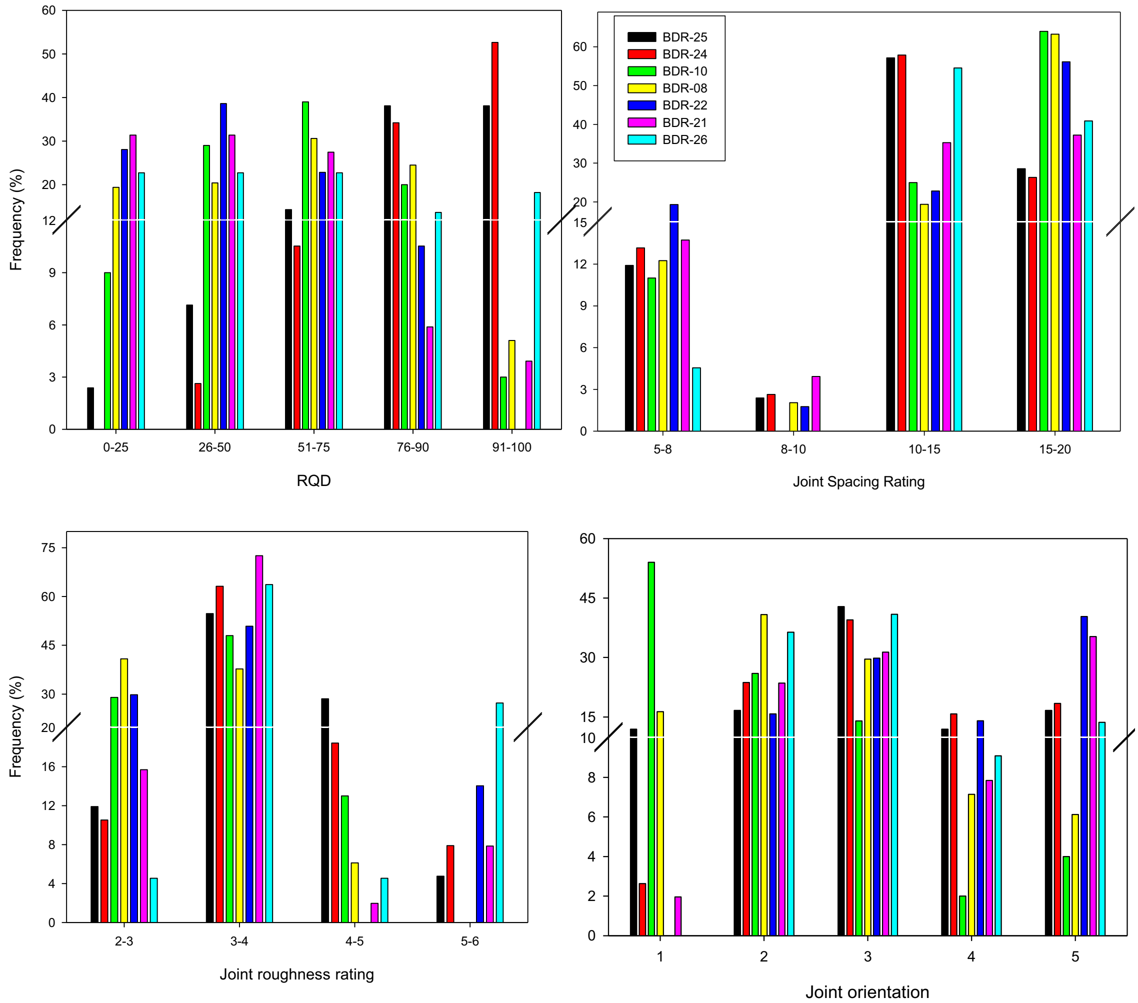



**Figure 3.** Percentage frequency of RMR parameters.

**Table 1.** RMR rating for three geological units

| **Parameter** | **Rating** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **GU-1** | | | **GU-2** | | | **GU3** |
| | **DBR-25** | **DBR-24** | **DBR-10** | **DBR-08** | **DBR-22** | **DBR-21** | **DBR-26** |
| UCS [MPa] | 9 | 9 | 9 | 7.33 & 9 | 7.33 | 7.33 & 9 | 9 |
| RQD [%] | 4.8-20 | 9.2-20 | 0.8-18.4 | 0-19.4 | 0-17.8 | 0-18.4 | 2-19.8 |
| Joint Spacing [mm] | 6-20 | 6-18.8 | 6-20 | 4-18.8 | 6-16.75 | 2-17.28 | 7.07-20 |
| Persistence [m] | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Aperture [mm] | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Roughness | 3-6 | 3-6 | 1-5 | 2-5 | 2-6 | 2-6 | 3-6 |
| Filling [mm] | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Weathering | 6 | 6 | 6 | 6 | 5-6 | 6 | 6 |
| Ground water | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Joint Orientation | -12-0 | -12-0 | -12-0 | -12-0 | -10-0 | -12-0 | -10-0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| RMR (min-max) | 56.97-77.1 | 64-75 | 48.8-70.6 | 42.3-70.6 | 44.3-69.93 | 45-71 | 55.8-73.8 |
| Avg. RMR | 69 | 70.5 | 59.6 | 59.73 | 60.17 | 59.9 | 64 |
| Rock Mass Quality (Avg. RMR) | | Good rock mass (63) | | | Fair rock mass 60 | | Good rock mass (64) |

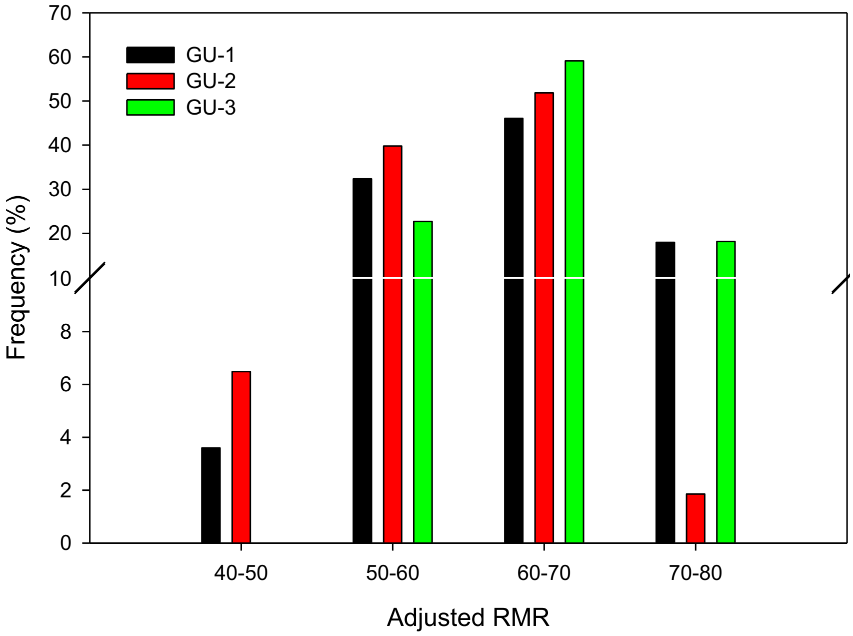



**Figure 4.** Percentage frequency of RMR for three geological units.

*2.3 Q-system*

The Q-system of classification for the rock mass in underground excavations was developed in 1974 [8]. This system divides the rock mass into nine classes after calculating Q value from equation (4). The relative block size (first quotient in equation (4)) is defined through RQD and $J_n$ (rating for the joint sets). The middle quotient is the inter block shear strength and defined as the ratio of rating for the joint roughness ($J_r$) alteration of joint ($J_a$). The last quotient of equation (4) is the active stress component and is the ratio of two stress components. These components are the groundwater pressure and SRF (stress reduction factor).

$$Q = \left(\frac{RQD}{J_n}\right) \times \left(\frac{J_r}{J_a}\right) \times \left(\frac{J_w}{SRF}\right) \tag{4}$$

As UCS of intact rock have a dominant role in the strength of rock mass, UCS adjustment factor were applied in this study as per procedures of Barton and the revised Q value called $Q_c$ were find which is given by the following equation, equation (5);

$$Q_c = \left(\frac{RQD}{J_n}\right) \times \left(\frac{J_r}{J_a}\right) \times \left(\frac{J_w}{SRF}\right) \times \left(\frac{\sigma_c}{100}\right) \tag{5}$$

The percentage frequency of RQD from the exploratory drill holes are shown in the figure 3 and adjustment were made as per instruction of Q-system. The percentage frequency distribution of joint set number for exploratory drilled holes along the diversion tunnels are shown in figure 5 which shows that the highest number of joint set were calculated in BDR-10 and the lowest in BDR-25. Joint roughness number of 3 and 2 were used as almost all the joints are in the category of rough, undulating and smooth, undulating respectively except DBR-10 where smooth joints were observed at two points. A value of 2 were assigned in all the cases as calcite coating were observed from the core logs. No water was observed in all number of bore holes. Due to the presence of shear zones in tunnel vicinity, and as the Q-system is unable to assign value for multiple shear zone in competent rock for excavation depth greater than 50 meter, the trend of the table shows that a value of 5 will be suitable in such circumstances. SRF value of 1, 1.25, 2.5 and 5 were used per the instruction for SRF calculation. A UCS correction factor of 1.1 & 0.8 to Q value were used in according to equation (5) for GN &UMA respectively.

The summary of rating parameters and rock mass class based on Q-system are shown in table 2. The average Q values are 21.4, 8.8, and 17.5 for GU-1, GU-2, and GU-3 respectively. The GU-1 and 3 are of good quality and GU-2 is of fair quality according to Q-system. The average $Q_c$ values are also shown with 23.54, 7.07 and 19.25 respectively for GU-1, GU-2 & GU-3.

**Table 2**. Q and $Q_c$ rating for three geological units.

| **Parameter** | **Rating** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **GU-1** | | | | **GU-2** | | **GU3** |
| | **DBR-25** | **DBR-24** | **DBR-10** | **DBR-08** | **DBR-22** | **DBR-21** | **DBR-26** |
| RQD [%] | 25-100 | 45-100 | 10-90 | 10-95 | 10-90 | 10-90 | 10-100 |
| Jn | 2,4&9 | 2,4&9 | 2,4&9 | 2,4&9 | 4&9 | 2,4&9 | 2,4&9 |
| Jr | 2&3 | 2&3 | 1,2&3 | 2&3 | 2&3 | 3 | 2&3 |
| Ja | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Jw | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| SRF | 1,1.25,2.5 | 1 | 1,2.5,5 | 1,2.5,5 | 1&5 | 1&5 | 1 |
| Q (min-max) | 4-82 | 10-82 | 0.4-25 | 0.33-25 | 0.22-34 | 0.75-35 | 3.67-78.4 |
| Avg. Q | 36 | 39 | 5.4 | 5.3 | 9 | 8.66 | 17.5 |
| Rock Mass Quality (Avg. Q) | Good rock mass (21.4) | | | | Fair rock mass (8.8) | | Good rock mass (17.5) |
| Avg. $Q_c$ | 23.54 | | | | 7.04 | | 19.25 |

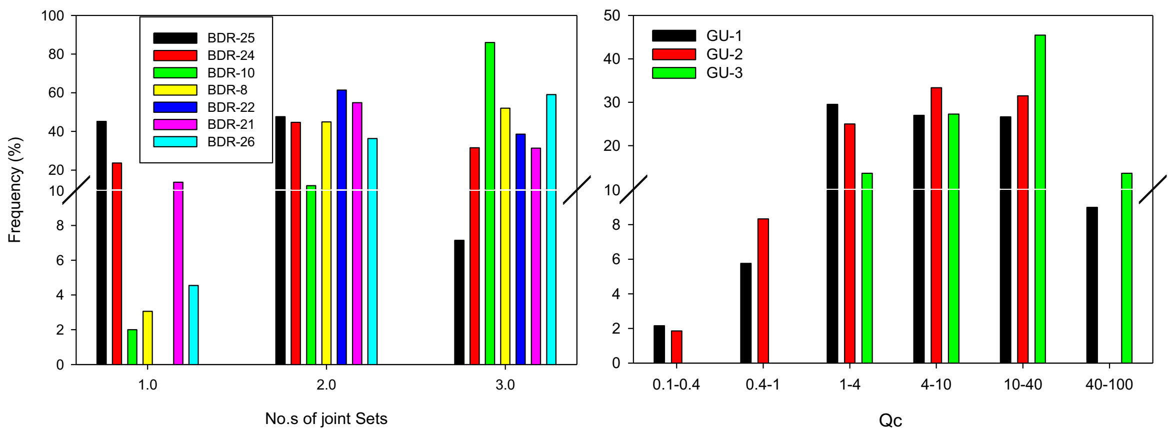



**Figure 5.** Percentage frequency of joint set numbers and $Q_c$.

*2.4 Correlation between RMR & Q-system*
The range of practice possessed by a company or consultant, it is possible to utilize the correlation between RMR and Q systems. To do so, various studies, have suggested a linear relationship between the two systems in the following form:

$$RMR = A.\ln Q + B \tag{6}$$

A number of correlation have been presented to find RMR from Q and vice versa. These relations were not used universally due to the old version of RMR & Q system, differences in the parameters and the rating methods used, and the manner in which the final RMR and Q values are computed [4, 7]. An attempt has been made at Basha Dam site to correlate RMR & Q [9] but with low co-efficient ($R^2$=0.59). After characterizing SRF for fault and using $Q_c$ value, a better correlation is developed between RMR & $Q_c$ (equation (7)) which is shown in figure 6.

$$RMR = 4.7\ln Q + 53.1 \qquad (R^2 = 0.76) \tag{7}$$

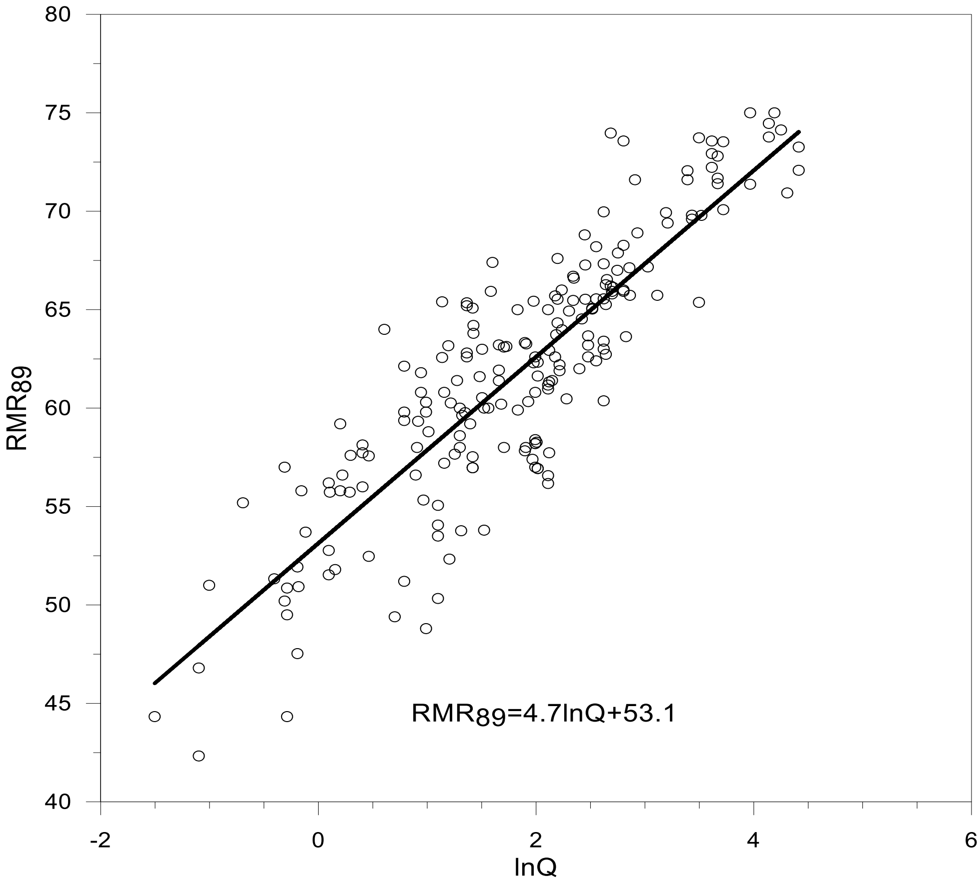



**Figure 6.** Linear correlation between lnQ and $RMR_{89}$.

## 3. Recommended Support System by Empirical Approach
The recent development in the support charts of the two systems indicate that rock mass quality is the single indicator for rock bolt spacing [10, 11]. The fully grouted rock bolt length is a function of tunnel size and

RMR, although according to Q-system, rock bolt length is a function of tunnel span and Excavation Support Ratio (ESR). The tunneling practice in Pakistan show that ESR=1 is the suitable rating for hydroelectricpower tunnel also [12].

The latest development for the shotcrete thickness specify that the role of tunnel size and rock mass quality is inconstant [7].

As from the maximum unsupported span proposed by Q-system [13], which is given by equation (8), and stand-up time proposed by RMR system [14], top heading and bench is the suitable excavation approach for the excavation of this project.

$$Max.Span = 2.ESR.Q^{0.4} \tag{8}$$

Barton et al. (1980) [13] and Lowson and Bieniawski (2013) [10] provide information on rock bolt length by equation (9) and (10) respectively. Rock bolt length is limited to 6m using equation (10) [10];

$$L = 2 + \frac{0.15 \times B}{ESR} \tag{9}$$

$$Span = \frac{(L+2.5)^{\frac{RMR+25}{52}}}{3.6} \tag{10}$$

Where Span is width of excavation in meters, L is the inserted bolt length in meters and ESR is the Excavation Support Ratio (ESR=1 for current study). The spacing of fully grouted rock bolts can be obtained from RMR value using equation (11) [10] and Q system support chart [11].

$$S_b(m) = 0.5 + 2.5\frac{RMR-20}{65} \qquad (20 < RMR \leq 85) \tag{11}$$

Where $S_b$ is rock bolt spacing in meters.

Keeping in mind the guidelines for excavation and support of 10 m span, horseshoe shaped rock tunnels constructed using drill and blast method with the RMR system[14], support recommendations are shown in table 3;

**Table 3**. Estimated support for the diversion tunnel using RMR and Q system support charts.

| **GU** | **1** | | **2** | | **3** | |
|---|---|---|---|---|---|---|
| Classification System | RMR | $Q_c$ | RMR | $Q_c$ | RMR | $Q_c$ |
| Rating | 63 | 23.54 | 60 | 7.04 | 64 | 19.25 |
| Rock Bolt Length (m) | 6 | 4.31 | 6 | 4.31 | 6 | 4.31 |
| Rock Bolt Spacing (m) | 2.15 | 2.5 | 2.04 | 2.2 | 2.2 | 2.5 |
| Shotcrete Thickness (cm) | 10 | 5-6 | 12 | 6 | 10 | 5-6 |
| Recommended Support | L=4-6m, $S_b$=2.15m in crown & 2.5 m in sidewall with 8 cm thick shotcrete | | L=4-6m, $S_b$=2.0m in crown & 2.5 m in sidewall with 9cm FRS | | L=4-6m, $S_b$=2.2m in crown & 2.5 m in sidewall with 8cm thick shotcrete | |

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## 4. Conclusion

1. The rock along the diversion tunnel route for the DBD project is jointed. Using the exploration data as input in the updated versions of the two systems, the rock mass along the tunnel route is classified into three geotechnical units. The GU-1 and GU-3 belongs to the good rock mass quality while GU-2 belongs to fair rock mass quality using the two rock mass classification systems.
2. The comparison of suggested support by the two systems, considering the recent developments in these systems, indicate that while using their updated version, the RMR system suggests comparatively heavier support than Q system.
3. Using the SRF values for fault effect and normalized factor for intact rock strength in Q system, a better linear correlation exists between RMR and Q system, however, the correlation coefficient is still low. This low correlation coefficient is due to the difference rating procedure of each classification system and the structure for the calculation of the RMR and Q value.

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