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# Rock Mass Characterization for Diversion Tunnels at Diamer Basha Dam, Pakistan – a design perspective

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**Abstract**

***This research work presents a case study of rock mass characterization on diversion tunnels at Diamer Basha Dam, Pakistan. Geological and geotechnical studies were performed to characterize the rock mass along the axis of diversion tunnel. The core specimens retrieved were tested in laboratory and physical and mechanical properties of the rock mass were determined. Detailed discontinuity survey was carried out to determine the type and orientation of discontinuities with respect to direction of tunnel drive. The rock mass was classified using Rock Mass Rating (RMR), Q-System and Geological Strength Index (GSI). Based on rock mass classification results, the rock mass along the tunnel alignment was divided into three Geotechnical units, where the combined effects of the engineering-geological conditions, the initial stress situation and the ground water conditions were predicted to present consistent tunneling conditions. It was concluded from the rock mass behaviour that conventional drill and blast excavation method can be used, assuming smooth blasting by skilled workers. Ground support system was proposed for the diversion tunnels using Q-System support chart. In order to facilitate the easy classification of the rock mass at the project site, new empirical relationships were developed between Q-system, RMR and GSI by using original field data statistically. The relationship between RMR and GSI was found to have a greater degree of confidence with a higher correlation coefficient ($R^2$= 0.84).***

**Key Words: Characterization; Diversion Tunnel; Basha Dam; Geotechnical units; Gabbronorite; Ultramafic;**

## I Introduction

Rock mass characterization is inevitable in projects involving design, construction and excavation in rocks (Hoek et al., 2005). Efficient characterization provides reliable input for rock mass classification systems and consequently leads the design to a cost effective and time saving transition to implementation. Construction of engineered structures driven in rocks will develop stress induced re-distribution and as a result some discontinuities will be created. In order to reduce the impact of this deformed rock on the stability of the underground structure, a suitable ground support system is inevitable. In order to stabilize the rock mass around a surface or underground opening, rock mass classification systems can provide useful information regarding the stabilizing and destabilizing parameters. The input parameters for Q and RMR (Rock Mass Rating) classification systems have a dominant influence on the rock stability (Plalmstrom, 2009). These parameters can be determined in the field by observations and experiments or laboratory testing of rock specimens. A good practice for understanding the characteristics and behavior of a rock mass is to use several rock mass classification systems (Geni et al., 2007). In this study the rock mass along the axis of diversion tunnels is classified using Q-System, RMR (Rock Mass Rating) and GSI (Geological Strength Index). Based on the results of these classification systems the rock mass along the tunnel axis was divided into three geotechnical units. The rock mass characteristics within a geotechnical unit were found almost similar. Ground support system was recommended for the diversion tunnels using Q-System and RMR. Correlations were determined between the Q-system and RMR, and RMR and GSI. These correlations will facilitate the efficient and time saving classification of the rock mass at the project site. The findings of this research work will also facilitate the numerical modeling.

## 2. Engineering Geological Investigations

When underground engineering structures in rocks are designed, the best way is to apply empirical and numerical methods (Gurocak et. al., 2007), (Basarir et al., 2005) and (Sari and Pasamehmetoglu, 2003).

In order to determine engineering characteristics of rock mass at the project area, a thorough geological study which includes; core drilling, laboratory testing, discontinuity survey, etc. was performed. Core samples from seven boreholes were analyzed in order to investigate the rock mass conditions along the axis of diversion tunnel. Figure 1 shows location map of the study area whereas Figure 2 shows the surface discontinuity survey location map.


Figure 1: Location map of the study area

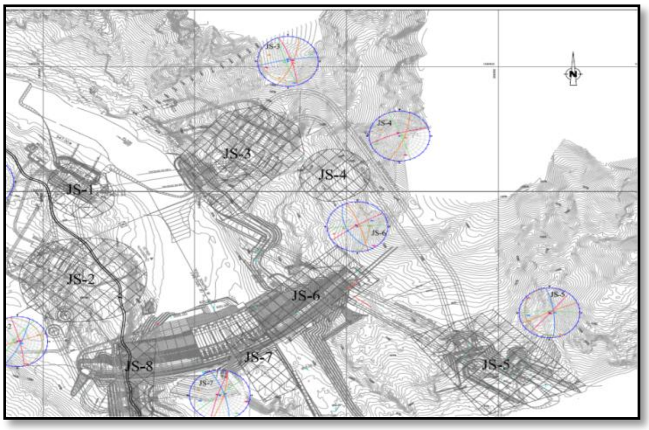


Figure 2: Geological investigations surface discontinuity (Joint) survey location map (DBC, 2008)

### 2.1 Physical and mechanical properties of rocks at the project site

The prevailing rock type at the site is a basic mafic intrusive rock which is petrologically called Norite, or more precisely Gabbronorite. In the field the rock appears very strong and massive. The fresh hand specimen is comparably heavy which is proven by laboratory testing, revealing an average density of 2.9 g/cm$^3$. The rock is quite light colored for a mafic rock. Usually the Gabbronorite is grey to light grey, but it is varying due to changes in quantitative mineral compositions. The full scale of the colors is ranging from very light grey, grey, dark grey to blue-grey. In road cuts, where the rock appears very fresh, it is often overlain by a very thin layer of calcite from evaporation. In such cases the rock seems very bright but in fact when broken with the hammer, real fresh surfaces are darker.

The rock types grouped under Ultramafic Association (UMA) also reveal a very diverse nature. Their common characteristic is that the content of mafic minerals exceeds 90%. Besides that, they are genetically different from the prevailing Gabbronorite. Obviously the ultramafic magmas have been injected into the Gabbronorite while they were still in a molten or partially molten state. Thus both magmas were intermixing with each other. They were intruding each other which is backed by the occurrence of xenoliths of Gabbronorite in Ultramafic rocks and vice versa. Especially at the upstream end of the right bank rock saddle the outcrops of the ultramafic rocks are penetrated chaotically by Gabbronorite xenoliths and vice versa. Despite the presence of virtually unaltered direct contacts between the Gabbronorite and the Ultramafic Association. Sometimes the impression is given that some sort of a coarse to very coarse grained pyroxene rock is developed near contacts of larger ultramafic bodies and Gabbronorite. In the field the Ultramafic rocks can be easily differentiated from the Gabbronorite. They are heavier (3.23 g/cm$^3$), which can be felt in the hand specimen, exceeding the density of the Gabbronorite. Their strength is high but not reaching that of the Gabbronorite. The difference in mechanical properties in the field is pronounced but more in terms that the Ultramafic Association is not reaching the very high strength of the Gabbronorite. Hand specimens of the Ultramafic Association are slightly easily obtained by hammer blows.

Table 1 shows the mechanical properties of the rocks determined at the project site.

Table 1: Summary of mechanical properties of rock at each geotechnical unit

| Parameters | Geotechnical Unit 1 | | | Geotechnical Unit 2 | | | Geotechnical Unit 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Min. | Max. | Mean | Min. | Max. | Mean | Min. | Max. | Mean |
| Unit Weight (KN/m$^3$) | 28.0 | 29.5 | 28.9 | 29.6 | 34.6 | 32.1 | 28.0 | 29.5 | 28.9 |
| UCS (MPa) | 46 | 203 | 110 | 33 | 101 | 63 | 50 | 210 | 110 |
| Elastic Modulus (GPa) | 17.2 | 76.1 | 41.2 | 12.3 | 37.8 | 23.6 | 18.7 | 78.7 | 43.1 |
| Poisson's Ratio | 0.02 | 0.38 | 0.195 | 0.01 | 0.354 | 0.152 | 0.07 | 0.39 | 0.199 |
| Cohesion (MPa) | 0.30 | 0.40 | 0.28 | 0.25 | 1.10 | 0.65 | 0.32 | 0.43 | 0.30 |
| Frictional Angle (Degree) | 20 | 31 | 27 | 23 | 34 | 28.3 | 21 | 29 | 28 |

## 3. Rock mass classification along the Tunnel alignment

When the available information regarding the rock mass is limited then it is advisable to use more than one rock mass classification systems. This practice may define the rock mass composition and characteristics in a more descriptive manner. Also for preliminary tunnel design, apply at least two classification systems (Bieniawski, 1989). For the assessment of rock mass quality at the project area three empirical rock mass classification systems, namely the Q-system (Barton, 1974), (Grimstad and Barton, 1993) and (Barton, 2013), Rock Mass Rating (RMR) (Bieniawski, 1989) and Geological Strength Index (GSI) (Hoek et al., 2005) were used and a summary of the rock mass classification results is shown in table 2.

Table 2: Rock mass classification results summary for each GTU in study area

| GTU | Chainage (m) | Borehole No. | Rock Type | Average Ratings | | |
|---|---|---|---|---|---|---|
| | | | | RMR | Q | GSI |
| 1 | 0+000–0+633 | BDR-25 | Gabbronorite | 68.52 | 81.96 | 74.54 |
| | | BDR-24 | Gabbronorite | 53.67 | 47 | 74.45 |
| | | BDR-10 | Gabbronorite | 57.53 | 36.4 | 60.79 |
| | | BDR-8 | Ultramafic | 52.04 | 21.75 | 60.43 |
| | | | Gabbronorite | 63.16 | 79.66 | 66.13 |
| 2 | 0+633 – 0+800 | BDR-22 | Ultramafic | 52.24 | 19.93 | 57.64 |
| | | BDR-21 | Gabbronorite | 52.98 | 25.59 | 60.34 |
| | | | Ultramafic | 51.88 | 19.35 | 53.75 |
| 3 | 0+800 – 0+911 | BDR-26 | Gabbronorite | 66.94 | 23.50 | 73.42 |

The rock mass long the tunnel axis was divided into three Geotechnical Units, based on the rock mass quality. The geological section F-F' (DBC, 2008) which covers the rock mass along the axis of the diversion tunnel – 1, has been prepared from the available data. Because of the close

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distance between the diversion tunnels and the expected similarities in terms of geological conditions the discussion on the rock types will be done for Diversion Tunnel-1only. Figure 3 represents the section of diversion tunnel composed totally of sound Gabbronorite rock. This section which is 633 m long is named as Geotechnical Unit – 1. Four boreholes namely BDR-8, BDR-10, BDR-24, BDR-25 (BDR means Basha Dam Right Bank) were drilled in this section. Based on the borehole data the rock mass was categorized as good rock by both Q-System and RMR.

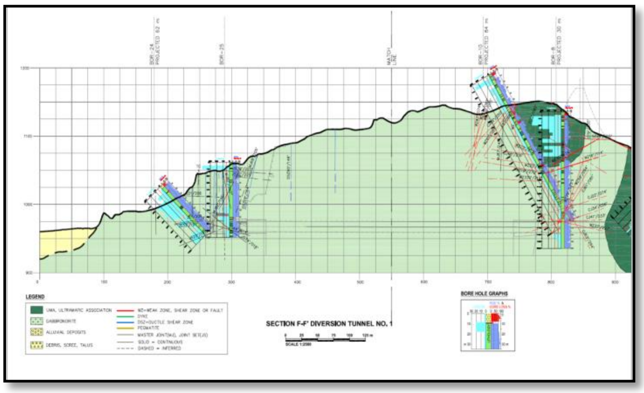

Figure 3 Geological section F-F' sheet 1 of 2 (DBC, 2008)

In figure 4 the geological section F-F' passes through a rock mass which is composed of Ultramafic rock. Two boreholes namely BDR-21 and BDR-22 were drilled long this section.

This section which extends from chainage 633–800m is named as Geotechnical Unit – 2. The rock mass in this section is termed as Fair rock by RMR and Good rock by Q-System. It was determined from BDR – 26 that from chainage 800m till the end of the tunnel the rock mass is again composed of Gabbronorite. This section of the tunnel is named as Geotechincal Unit – 3. The rock mass in this section is termed as good rock by both Q-System and RMR.

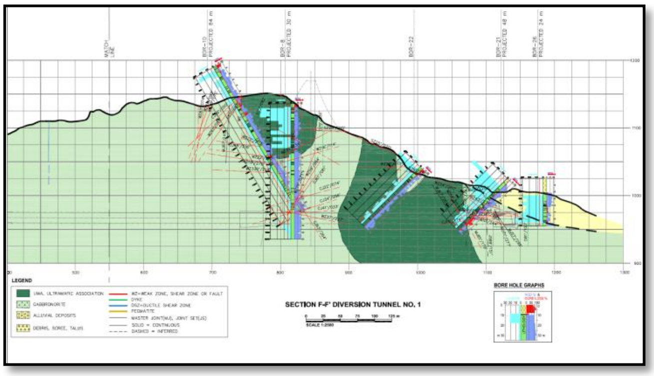

Figure 4 Geological section F-F' sheet 2 of 2 (DBC, 2008)

## 4. Correlations among RMR, Q System and GSI

To improve the impact of rock mass classification one of the approaches is to take parameters of each classification system separately and then superimposing them (Laderian and Abaspoor, 2012).

RMR, Q and GSI classification systems are based on the principal properties of a rock mass such as intact rock strength, discontinuity conditions (roughness, filling, weathering etc.), geometry of intact rock blocks. Also various empirical relationships have been developed among these classification systems.

In this study at each borehole location, rock masses were classified according to RMR, Q and GSI classification systems. Results of rock mass classification systems were compared and relationships among them were developed carrying out statistical analysis and regression equations were obtained.

The earlier empirical relationship between RMR and Q-system available in the literature (Bieniawski, 1989) is represented by equation 1.

$$RMR = 9 \ln Q + 44 \quad \text{(Original Equation)} \qquad 1$$

For the Diversion tunnels at Diamer Basha Dam site, the empirical relationship can be expressed by equation 2.

$$RMR = 2.8709 \ln Q + 48.713 \; (R^2=0.2096) \qquad 2$$

(Modified Equation)

This equation was obtained from 423 data points which relate the geotechnical units. The low correlation coefficient ($R^2$ value) indicates the inherent scatter in the respective data as shown in figure 5.

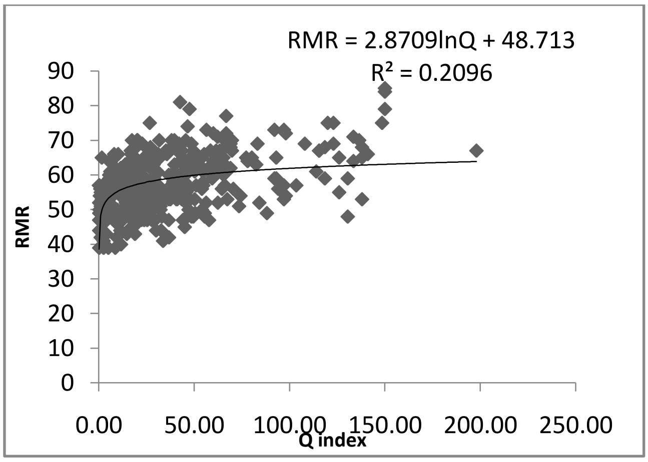


Figure 5: Relationship between RMR and Q index

Similarly the empirical relation between Dry basic RMR and GSI that is proposed in literature (Marinos et al., 2005) is represented by equation 3.

$$GSI = RMR - 5 \qquad 3$$

For the present study area the empirical relationship was determined and expressed as;

$$GSI = 0.9932RMR - 4.913 \; (R^2 = 0.84) \qquad 4$$

(Modified Equation)

This equation is almost same as proposed by (Marinos et al., 2005) as shown in the Figure 6.

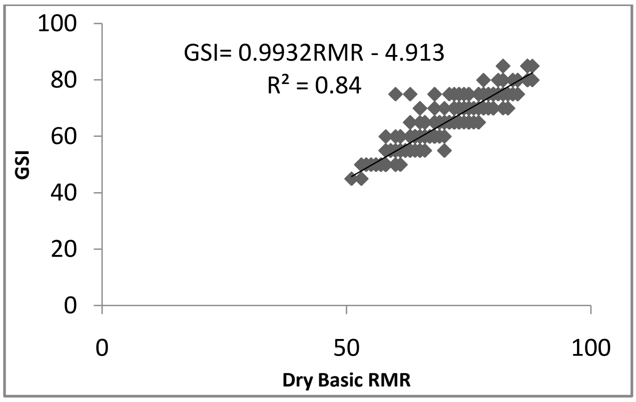


Figure 6: Relationship between Dry Basic RMR and GSI

## 5. Ground Support recommendations

The potential for instability in the rock surrounding underground openings is a chronic threat to both the safety of men and equipments (Hoek et al., 1995). That is why optimized ground support system is necessary. In this study the ground support system was proposed for each geotechnical unit using RMR and Q-System support charts. In geotechnical unit-1 (Km: 0+00 – 0+633) the empirical support determined was 4 m long and 25 mm diameter rock bolts with wire mesh and 40 mm thick layer of shotcrete. In Geotechnical Unit-2 (0+633 – 0+800) the support determined was systematic bolts 4 m long and 25 mm diameter, spaced 1.5 – 2 m in crown and walls with wire mesh and 50-100 mm shotcrete in crown and 30 mm in walls. In Geotechnical Unit-3 (0+800 – 0+911) the support determined was 4 m long and 25 mm diameter bolts, spaced 3.1 m with occasional wire mesh and 40 mm shotcrete where required. The determined support system is summarized in Table 3.

Table 3: Summary of Q and RMR support recommendations

| GTU | Q | RMR | Maximum Unsupported Span (Q) | Stand-up Time (RMR) |
|---|---|---|---|---|
| 1 | Spot bolting with no shotcrete | Locally, 4 m long and 25 mm diameter bolts, spaced 3.1 m with wire mesh and 40 mm shotcrete where needed. | 11.82 m | 3 weeks |
| 2 | Spot bolting with no shotcrete | Systematic bolts 4 m long and 25 mm diameter, spaced 1.5 – 2 m in crown and walls with wire mesh and 50-100 mm shotcrete in crown and 30 mm in walls. | 9.16 m | 4 days |
| 3 | Systematic bolting | Locally, 4 m long and 25 mm diameter bolts, spaced 3.1 m with occasional wire mesh and 40 mm shotcrete where required. | 8.38 m | 6 months |

## 6. Conclusions

In this paper the rock mass quality along the axis of diversion tunnel was assessed by using empirical methods. By making use of applying more than one rock mass classification systems, it was concluded that there is very little variation in the rock mass quality determined from three different rock mass classification systems. Based on the rock mass quality the diversion tunnel was divided into three geotechnical units. In each geotechnical unit the rock mass quality and characteristics were found almost similar. Ground support system was determined for each geotechnical unit. Also the original data of the three rock mass classification systems 'Q', 'RMR' and 'GSI' from the proposed project area was analyzed in order to get a best fit relationship with higher correlation coefficient. The most fit relationships found were GSI = 0.9932RMR – 4.913 ($R^2$ = 0.84) and RMR = 2.8709 lnQ + 48.713 ($R^2$=0.2096). It seems that the relation GSI = 0.9932RMR – 4.913 shows more confidence relationship between GSI and RMR with correlation coefficient 0.84.

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