Journal of Himalayan Earth Sciences Volume 49, No. 2, 2016, pp. 75-83

Rock mass characterization along the tunnel axis for Golen Gol hydropower project Chitral, Pakistan

Sajjad Hussain*, Noor Mohammad, Mohammad Tahir, Zahid Ur Rehman and Nisar Mohammad
Department of Mining Engineering,
University of Engineering and Technology, Peshawar
* Corresponding author's email: engr.sajjad@uetpeshawar.edu.pk

Abstract

The characterization of rock mass is an essential part of the preliminary engineering design in the field of civil and mining engineering. It is considered very beneficial when limited geological and geotechnical data of site is available. In the present research, the empirical methods i.e. Rock Mass Rating (RMR), Tunneling Quality Index (Q-System) and Geological Strength Index (GSI) classification systems for assessment and classification of rock mass along the axis of tunnel. These empirical methods were applied on the geological and geotechnical data collected along the axis of tunnel. The strength properties and intrinsic properties of rock samples, which are important for characterization, were determined in the laboratory. The rock mass along tunnel axis was characterized based on the empirical methods, intrinsic and strength properties of the rock mass. After characterization, the rock mass was divided into three geotechnical units i.e. GU-1, GU-2 and GU-3. Different support systems for each geotechnical unit were recommended to stabilize the tunnel. The conventional drilling and blasting technique was proposed for driving of the tunnel.

Keywords: Geology; Strength properties; Deformation modulus; Characterization of rock mass; Support systems.

1. Introduction

The 106 MW Golen Gol Hydropower Project is to be developed on river Golen Gol, Chitral, Pakistan. The location map of project is shown in Fig. 1. The tunnel is the main structure in this project and it requires more attention from stability point of view. The proposed length of the tunnel is 3800 m, diameter 3.7 m. The proposed shape for the tunnel is horse shoe shape as shown in Fig. 2. The geological and geotechnical studies were conducted both in field and laboratory. The field study consists of bore hole logging, geological mapping, sample collections, scan line joint survey and geotechnical data.

The rock mass characterization and design of support systems are the integral part of any engineering design of tunnels, foundations and caverns within the rock mass (Hashemi, 2010; Cai, 2011; Ali, 2014). It is considered very beneficial when limited geological and geotechnical data of site is available (Hoek, 1993). The results from rock mass classification systems depend on the reliability of field data (Biniawski, 1989). The rock mass classification systems are used to classify the rock masses into different categories having more or less similar geological and geotechnical properties on the basis of results obtained from rock mass characterization (Sopac, 2008). For more authentic result of rock mass classification more than one classification systems should be used (Biniawski, 1989; Geni, 2007).

In the present research work the rock mass along axis of tunnel has been assessed and classified using three rock mass classification systems i.e., Rock mass rating (RMR) by Biniawski (1989), Tunneling quality index (Q-system) by Borton et al. (1974), and Geological strength index (GSI) by Hoek et al. (1997-1998). Based on the result obtained from these classification systems the rock masses were divided into three geotechnical units; (each geotechnical unit have the same rock mass behavior). The support systems and blasting method were proposed for each geotechnical unit.

Fig. 1. Golen Gol hydropower project location map (Google earth, 2016).

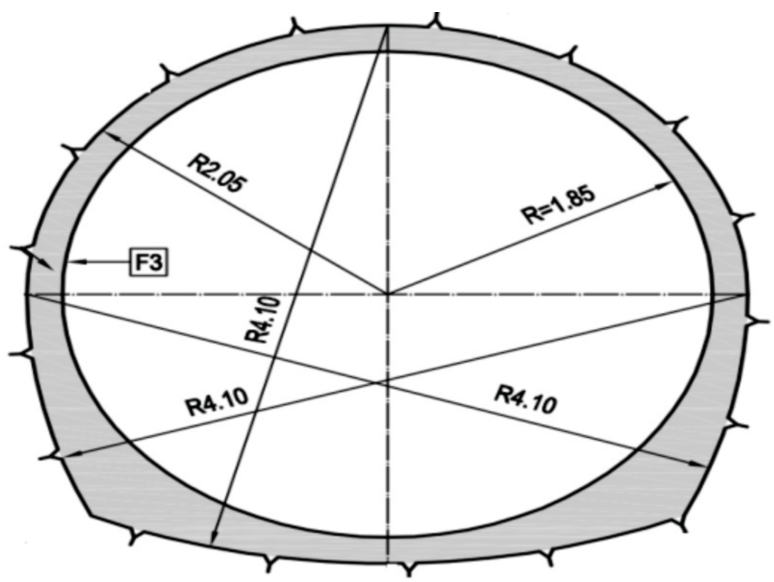

Fig. 2. Cross-sectional view of the tunnel (Water and Power Development Authority, 2011).

2. Geology of the project area

The Golen gol hydropower project lies mainly in igneous and metamorphic rocks. The project area is consists of high and uneven mountains. According to the published literature the area is tectonically effected and disturbed (Water and Power Development Authority, 2011). Regionally the project area is part of Hindu Kush.

To know about subsurface geology of area three holes GGT-3, GGT-4 and GGPH-7 were drilled at different chainages along the axis of proposed tunnel. The geology of rock units lies in surface and subsurface of project area was observed the same. It was noted from the surface geology that it has been projected down according to dip angle, strike and rock units as noted on the surface along the axis of the tunnel. The rock mass surrounding of bore hole GGT-4 was observed weak due to presence of Ayun Fault in the area, as compared to rock mass surrounding bore holes GGT-3 and GGPH-7 along the axis of the tunnel. The greater part of the tunnel (2775m) will be passing through Granites of igneous nature and the remaining (825m and 200m) will be passing through metamorphosed rocks i.e. Quartz Mica Schist, and Calcareous Quartzite (Water and Power Development Authority, 2011).

The Granite unit in chainage 0+2775m was observed generally whitish grey to greenish, hard and weathered on the exposed surface. The nature of granite rock appears to be changing at places and looks like granodiorite. The granite rock in this chainage was observed massive and blocky (Water and Power Development Authority, 2011).

The Quartz Mica Schist unit in chainage 2275-3600m was observed generally light grey to grey in colour, moderately hard, and weathered at the surface. Thin layers of dark color minerals as well as bands of quartz have been observed at place. The Marble units are well exposed, which are light grey to grey in color, moderately hard to hard, and generally thin to medium bedded and are steeply dipping (Water and Power Development Authority, 2011).

The Calcareous Quartzite unit in chainage 3600-3800m was observed light grey to grey, generally quite hard with quartz bands, contains dark colored thin bands of minerals and weathered at the surface. The geology and design plan of project area are shown in Fig. 3.

The scan line joint survey was carried out to determine the numbers of joints sets along the tunnel axis in each rock region (Water and Power Development Authority, 2011). The results of scan line joint survey are presented in Table 1.

3. Engineering geology

The main rock types along the axis of tunnel are granite, quartz mica schist, and calcareous quartzite. The engineering geological data includes field data collected at site (geological and geotechnical) and strength properties of the representative rock samples determined in the laboratory.

The major rock is granite. The average uniaxial compressive strength (UCS) of granite is 125 MPa; the average RQD is 87 %; joints spacing range from greater than 2m to less than 60mm; joints encountered are rough and, are slightly weathered, joint persistence range from less than 1m to 3m, and joint apertures are less than 0.1mm in width filled by hard filling materials. Fair to very favorable orientations of discontinuities were observed.

For the quartz mica schist the average uniaxial compressive strength (UCS) is 54 MPa, the average RQD is 42%, joints spacing range from 200mm to less than 60mm, joints encountered are rough to slightly rough and, are unweathered, joint persistence range from less than 1m to 10m, and joint apertures range from 0.1mm to 5mm in width filled by hard and soft filling materials. Favorable very favorable orientations of discontinuities were observed.

The average uniaxial compressive strength (UCS) of calcareous quartzite is 106 MPa, and the average RQD of is 75%. Joints spacing range from 200mm to less than 60mm, joints are rough to slightly rough and, are slightly weathered, joint persistence range from less than 1m to 3m, and joint apertures range from 0.1mm to 1.0mm in width filled by hard and soft filling materials. Favorable very favorable orientations of discontinuities were observed.

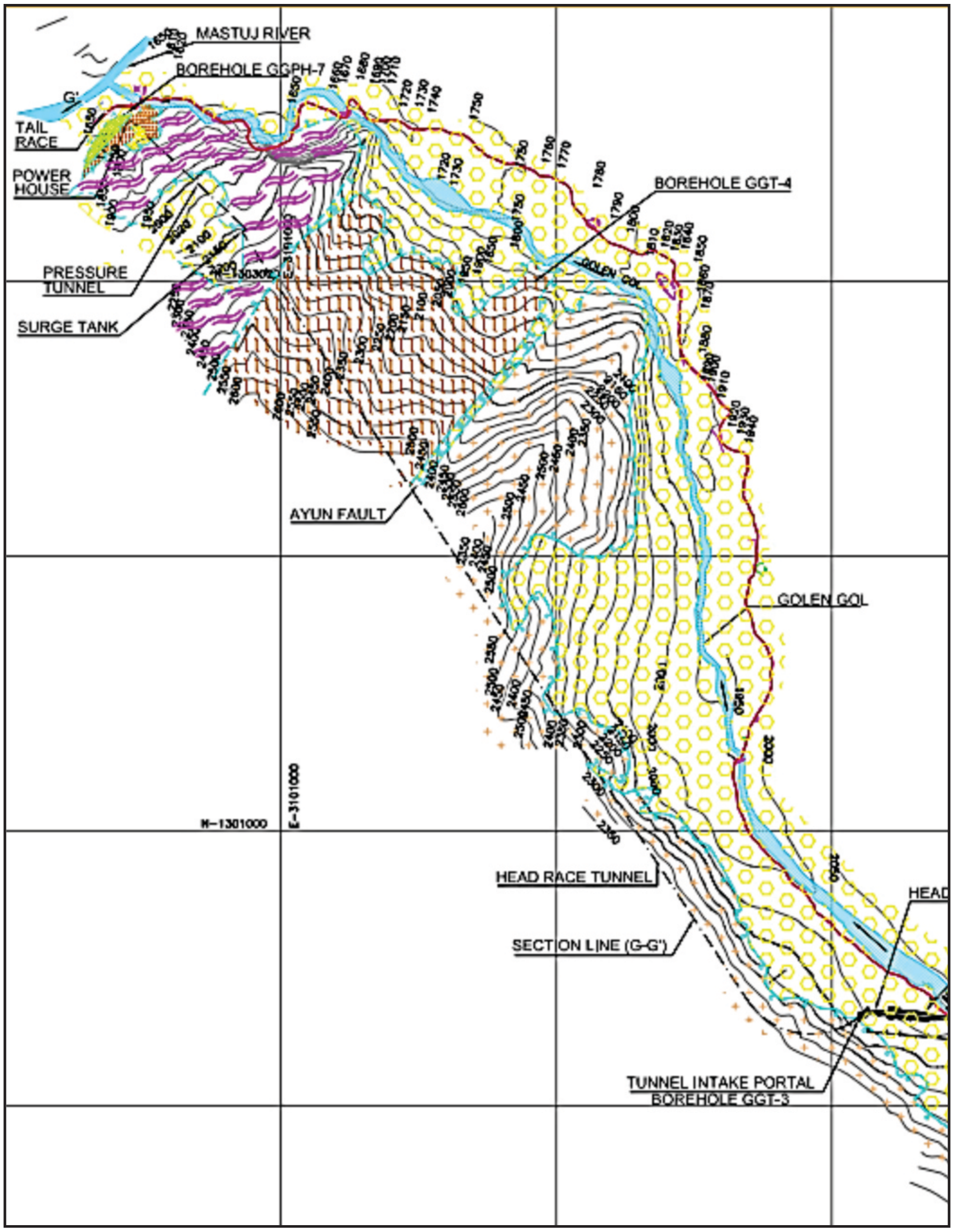

Fig. 3. Geology and Design plan of the project area.

Table 1. Rock types and number of joint sets.

S.No	Rock Type	Joint sets	Dip	Strike
1	Granite	3	26° W	NS
			58° NE	N20W
			85° NW	N80E
2	Quartz Mica Schist	2	80°SW	N 40W
			37° NW	N40E
3	Marble	2	75° to 90° SW	N 30 to 50 E
			25° to 40° NW	N 25 to 40 E
4	Calcareous Quartzite	1	65° to 75° SE	N 5 to 20 E

4. Estimation of deformation modulus for the rock mass

The deformation modulus is determined by two methods, one from in-situ test data and the other war to deduce it from empirical equations. When in-situ data is not available then the accurate and alternate method is to estimate the deformation modulus from published empirical equations. The deformation modulus for rock masses is very important design input parameter for characterization of rock mass, numerical modeling and to analyze the rock mass behavior at the initial stage of any engineering design within the rock mass environment (Cai, 2004; Hoek, 2006; Shen, 2012).

Many researchers have used rock mass classification systems and established the empirical equations for estimation of deformation modules for rock masses. The rock mass deformation modulus was estimated by using the published empirical equations of Biniawski, (1978); Shen, (2012); serafem and pereira, (1983); tahir, (2014) for each rock at the tunnel axis. The results are presented in Table 2 and Fig. 4.

Table 2. Estimation of deformation modulus.

Empirical equation	Researcher	Bore hole	Rock type	Chainage	Estimated deformation modulus (GPa)
Em= 2*RMR-100	Biniawski, 1978	GGT-3	Granite	0+00-2+775	43.00
		GGT-4	Quartz mica schist	2+775-0+825	19.65
		GGPH-7	Calcareous quartzite	3+600-3+800	44.00
$Em=10^{(RMR-10)/40}$	Serafem and Pereira, 1983	GGT-3	Granite	0+00-2+775	36.40
		GGT-4	Quartz mica schist	2+775-0+825	19.11
		GGPH-7	Calcareous quartzite	3+600-3+800	37.50
$Em=113*e^{-((RMR-113)/39)^2}$	Mohammad Tahir and Noor Mohammad, 2014	GGT-3	Granite	0+00-2+775	33.73
		GGT-4	Quartz mica schist	2+775-0+825	19.12
		GGPH-7	Calcareous quartzite	3+600-3+800	38.66
$Em=110*e^{-((RMR-110)/37)^2}$	Jiaya Shen et al., 2012	GGT-3	Granite	0+00-2+775	38.63
		GGT-4	Quartz mica schist	2+775-0+825	19.13
		GGPH-7	Calcareous quartzite	3+600-3+800	39.62

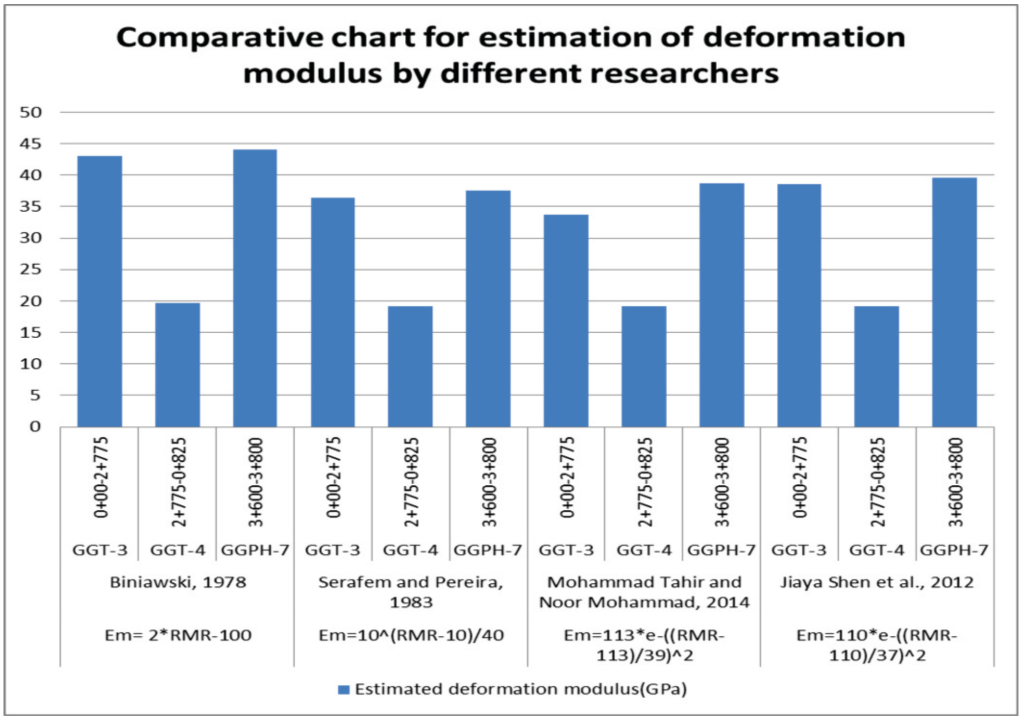

Fig. 4. Comparative chart for estimation of deformation modulus using different empirical equations.

Table 2 and Figure 4 shows that the deformation modulus is over estimated by the empirical equation of Biniawski, (1978), as compared to Serafem and Pereira, (1983), Tahir and Noor Mohammad, (2014), and shen et al. (2012), for this particular indigenous rock mass. From the designing and stability point of view, it is better to use the lower estimated value as compared to the high value in the analysis of tunnel and for the recommendation of support system. For this indigenous rock mass the proposed equation of Tahir and Noor Mohammad, (2014) is appropriate for estimation of deformation modulus.

5. Intrinsic and strength properties of intact rocks along the alignment of tunnel

Different intrinsic properties and strength properties of representative rock samples (five from each rock unit) collected along tunnel axis were determined in the laboratory, and some properties were estimated using the established empirical equations. The intrinsic and strength properties important to be considered in the empirical and as well as numerical design of tunnel and support systems are unit weight, porosity, deformation modulus, UCS, poison ratio (υ), and Hoek and Brown constants. The Hoek and Brown constants were determined from Rocklab software developed by Rockscience (Rockscience, 2015). The average values of each intrinsic and strength property of rock samples are presented in Table 3.

Table 3. Laboratory test results and Rocklab software results.

Bore hole	**Rock Type**	**Unit weight**	**Porosity [%age]**	**UCS [MPa]**	**Modulus of elasticity [MPa]**	**Poison ratio (υ)**	**Hoek and Brown constants**		
							mb	**s**	**a**
GGT-3	Granite	2.71	1.17	125	$3.41e^4$	0.188	7.669	0.0117	0.503
GGT-4	Quartz Mica schist	2.76	0.57	54	$3.42e^4$	0.051	1.934	0.0060	0.504
GGPH-7	Calcareo us Quartzite	2.69	1.44	106	$5e^4$	0.277	6.154	0.0256	0.502

6. Rock mass classification systems

Three empirical methods namely RMR, Q-System and GSI were used to assess and classify the rock mass along axis of tunnel namely.

The Biniawski, 1989 version of RMR was used in the present study. The six parameters of RMR as listed below were used for assessment of rock mass quality along the axis of tunnel. The results of RMR are presented in Table 4.

i. Uniaxial compressive strength,
ii. Rock quality designation (RQD),
iii. Spacing of discontinuities,
iv. Condition of discontinuities,
v. Ground water condition
vi. Orientation of discontinuities

The rock mass quality along tunnel axis was evaluated by tunneling quality index (Q-System) developed by Borten et al. (1974) based on the six parameters of Q-System listed below.

i. Rock quality designation (RQD)
ii. Number of joints (Jn) ,
iii. Roughness number for joint (Jr) ,
iv. Joint alteration number (Ja) ,
v. Joint water reduction factor (Jw) ,
vi. Surface reduction factor (SRF)

The value of Q was determined using the following formula, and the results of Q-System are presented in Table 4.

$$Q = RQD/Jn*Jr/Ja*Jw/SRF$$

The GSI value was estimated quantitatively for rock mass along tunnel axis based on structure rating (SR) and surface condition rating (SCR) for the estimation of GSI suggested by sonmez and Ulusay was used (Sonmez, 2002; Cai, 2004). The results are presented in Table 4.

7. Recommendation of support system

The design of optimum support system for tunnel in order to stabilize the tunnel is the demand of the day. It is not an easy task. The best design support system depends on the reliability of the input parameters and the geological data of site. For more accurate and reliable design of support systems the input parameters and geological data of site should be precise. The support systems and shear strength parameters for each geotechnical unit of tunnel at Golen Gole hydropower project were designed based on the rock mass classification results and support charts developed by Biniawski, 1989 and Borten et al. (1974). The support system, shear strength parameters for each geotechnical unit of the tunnel are shown in Table 5.

Table 4. Summary of rock mass classifications for rock mass in each geotechnical units.

Geotec. Unit	**Chainage [m]**	**Bore holes**	**Rock types**	**Rock mass classification**					
				RMR	**Rock mass Class**	**Q**	**Rock mass Class**	**GSI**	**Rock mass Class**
GU-1	0+00-2+775	GGT-3	Granite	71	Good rock	11	Good rock	60	Good rock
GU-2	2+775-0+825	GGT-4	Quartz mica schist	59	Fair rock	20	Good rock	54	Fair rock
GU-3	3+600-3+800	GGPH-7	Calcareous quartzite	72	Good rock	17	Good rock	67	Good rock

Table 5. Recommendation of support systems for each geotechnical unit of tunnel.

Geotec. Unit	RMR Support Systems	Q-System Support systems	Cohesion (MPa)	Angle of internal friction
GU-1	Locally, 3m long bolt in crown of 20mm diameter and fully grouted, spacing between bolts 2.5m with occasionally wire mesh, 50 mm thick shotcrete where necessary and no steel set required	2m long systematic bolting (fully grouted with 20mm dia) of spacing between bolts 2.32 m, and Fibre reinforced sprayed concrete of 50 -60mm thick in crown of the tunnel.	3-4	35°-45°
GU-2	4m long Systematic bolts of 20mm diameter and fully grouted, spacing between bolts range from 1.5m to 2m in crown and walls with wire mesh in crown, thickness of shotcrete range between 50mm to 100m in crown and 30mm in the sides of the tunnel and no steel set required	2m long systematic bolting (fully grouted with 20mm dia) of spacing between bolts 2.5 m, and Fibre reinforced sprayed concrete of 50 - 60mm thick in crown of the tunnel.	2-3	25°-35°
GU-3	Locally, 3m long bolt in crown of 20mm diameter and fully grouted, spacing between bolts 2.5m with occasionally wire mesh, 50mm thick shotcrete where necessary and no steel set required	2m long systematic bolting (fully grouted with 20mm dia) of spacing between bolts 2.48 m, and Fibre reinforced sprayed concrete of 50 -60mm thick in crown of the tunnel.	3-4	35°-45°

8. Conclusion and recommendations

Three empirical methods i.e Rock Mass Rating (RMR), Quality Index (Q-System) and Geological Strength index (GSI) classification systems were applied using geological and geotechnical data collected along the axis of tunnel. The intrinsic properties, strength properties and deformation modulus of rock mass along tunnel axis were determined. The rock mass was evaluated and classified based on the result obtained from rock mass characterization. The rock mass along the axis of tunnel was divided into three geotechnical units, namely GU-1, GU-2 and GU-3. The support systems for each geotechnical unit were recommended based on the support design charts developed by Biniawski (1989) and Borten et al. (1974), in order to stabilize the tunnel. Keeping in view the estimated behavior of rock mass, the conventional drilling and blasting by skilled worker was recommended for driving of the tunnel. It is also recommended for future studies to apply numerical modeling techniques should be applied for investigating deformation around the tunnel and support performance.

References

Biniawski, Z.T., 1989. Classifcation of Rock Masses for Engineering: The RMR System and Future Trends, USA.

Cai, M., 2011. Rock Mass Characterization and Rock Property Variability Considerations for Tunnel and Cavern Design. Rock mechanics and rock engineering , 44, 379-399.

Cai, M., Kaisera, P.K., Unob, H., Tasakab, Y., Minamic, M., 2004. Estimation of rock mass deformation modulus and strength of jointed hard rock masses using the GSI system. International Journal of Rock Mechanics & Mining Sciences, 41, 3-19.

Geni, M., Basarir, A., Ozarslan, E., Bilir, E., Balaban, 2007. Engineering Geological appraisal of the rock masses and preliminary support design, Doorukhan Tunnel,Zonguldak, Turkey. Engineering Geology, 92, 14-26.

Google Earth map, 2016. Golen Gol Hydro Power Project Chitral location map, downloaded from myearthonline.blogspot.com/

Hashemi, M., Moghaddas, S., Ajalloeian, R., 2010. Application of Rock Mass Characterization for Determining the Mechanical Properties of Rock Mass: a Comparative Study. Rock Mechanics and Rock Engineering , 43, 305-320.

Hoek, E., Diederichs, M..S., 2006. Empirical estimation of rock mass modulus. International Journal of Rock Mechanics & Mining Sciences, 43, 203-215.

Hoek, E., Kaiser, P.K., Bawden, W.F., 1993. Support of Underground Excavations in Hard Rock.

Marinos, V., Marios, P., Hoek, E., 2005. Gelogical strength index: applications and limitations . Bulletin of Engineering Geology and Environment, 55-65.

Rockscience, 2015,https:www.rocscience.com

Shen, J., Karakus, M., Xu, C., 2012. A comparative study for empirical equations in estimating deformation modulus of rock masses. Tunnelling and Underground Space Technology, 32, 245-250.

Sonmez, H., Ulusay, R., 2002. A discusion on the Hoek and Brown failure criterion and suggested modifications to the criterion verified by slope stability case studies. Bulletin of Earth Sciences, 77-99.

Sopac, E., Akgun, H., 2008. Engineering geological investigations and the preliminary support design for the proposed Ordu Peripheral Highway Tunnel, Ordu, Turkey. Engineering Geology, 96, 43-61.

Tahir, M., Mohammad, N., 2014. Prediction performance and generalization of the empirical estimation of rockmass deformation modulus based on rockmass classification systems. International Journal of Scientific Engineering and Technology, 3, 1488-1495.

Wahid, A., Mohammad, N., 2014. Rock Mass Characterization for Diversion Tunnels at Diamer Basha Dam, Pakistan– a design perspective. International Journal of Scientific Engineering and Technology, 3, 1292-1296.

Water and Power development Authority (WAPDA), 2011. Geology and Geotechnics of Golen Gol Hydropower Project Chitral, Pakistan, 1-30.