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Assessment of Squeezing Potential and Support Estimation Along Headrace Tunnel of a Matiltan Hydropower Project on Ushu River, Kpk Pakistan

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Abstract

Most of hydropower tunnels have squeezing problems due to weak rock mass quality and high overburden. The induced stress level exceeds the strength of rock mass tunnel fails. Stress plays a crucial role in developing brittle fractures, rock strength reduction and rock mass instabilities the critical stress is an indicator for the support design of tunnel. To quantify stress state and deformation of circular tunnel, an empirical, semi analytical and a two-dimensional boundary element numerical analysis have been made in this paper. Initially, rock mass characterization is carried out by using Q and RMR methods which defined rock mass as poor to good and fair respectively. Then for identification of squeezing empirical approaches are used, results shown that there is no squeezing in the tunnel. However, 200 m stretch of tunnel undergoes severe squeezing as identified by Hoek and Marinos approach which is further refined by using Numerical program phase2 which yields displacement values quiet nearer to values obtained by semi-analytical approach by considering rock mass as plastic material. Tunnel support is estimated by using Q and RMR systems respectively which is verified by Numerical analysis.

Keywords: Tunnel; Support system; Squeezing; Hoek and Marinos method

Introduction

High requirement of electricity in Pakistan can be fulfilled by hydropower generation [1]. The enormous capacity of hydropower generation in Pakistan is mostly due to rich water resources and geographical head due to steep rivers. In small hydropower projects, huge quantity of water discharge must be handled from intake to power station and eventually discharged to river again. Due to sharp topography, pipe and canals construction on ground surface could be extremely hard and costly for huge discharges. Therefore, alternative constructions like shafts or tunnels could be the only realistic options of water transportation scheme for huge discharges in steep lands. However, there are higher risks and uncertainties related with subsurface works like instabilities induced by stress, water seepage, mud flows and ultimately the cost of the project increases[2]. When rock stresses go over the strength of rock mass, then stress induced instability will be occur in tunnel. Squeezing phenomenon will be occurring if rock mass is extremely weak, schistose and deformable with the growth of plastic zone in the region of the tunnel which causes too much tunneling deformation. Due to the weak rocks such as mudstone, shale, slate, phyllite, schist, highly schistose gneiss, fracturing and shearing in Himalayan area the rock mass of the tectonic fault zones is incapable to survive the high stresses. In these weak and deformable rock masses squeezing has been ordinary phenomenon in the tunnels.

Matiltan Hydroelectric Project (MHEP)

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Matiltan Hydroelectric Project (MHEP), situated in northern region of Pakistan has been chosen for squeezing assessment [3]. This area lies in district Swat, KPK along Ushu River having tunnel length about 6630 m and approximately 45 km from Kalam. Along the headrace tunnel alignment rock types such as granodiorite, quartzite and phyllite are present. During the geological mapping two main units were identified that are Igneous and meta-sediments. These two units are separated by an intrusive contact. Within the project area meta-sediments can be divided into two sub-units, a quartzite in the downstream end and phyllite in the upstream end. The meta-sediments have a uniform strike NE-SW and NW dip direction which is steep and less steep towards north. Total length of tunnel is 6630 m and tunnel is divided into 400m chainages and maximum overburden encountered is 600 m. Mostly, quartzite has been found along the tunnel alignment and in severe

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squeezing section phyllite is present. Quality of rock mass in squeezed section is of poor quality[4]. The study area is shown in the (Figure 1).

Figure 1: Location map of projected area.

Materials and Methods

The Matiltan Hydropower Project has been chosen for the evaluation of squeezing phenomenon and main purpose is to give solution to the problem caused by squeezing. The data consisted of feasibility reports and other project related reports, field work, photographs, lab test results etc. This data has been collected from the fieldwork of project site. Parameters required for research analysis are comprehensively compiled and then relevant data is gathered from field work[5]. Collection of initial data by performing reconnaissance and scanline surveys is the fundamental purpose of field work. During reconnaissance survey and geological mapping, types of rocks, rocks contacts and other features are observed. As focus of research is squeezing analysis so a discontinuity survey for the collection of rock mass and other strength parameters has done. During this survey parameters such as orientation, persistence, joint spacing, aperture, wall strength, ground water conditions and wall roughness has been observed and noted down for ten various localities along the various tunnel's route. After mapping the discontinuities in the field by scanline survey and marking the contacts. Geological map of the research area was made which is shown in (Figure 2).

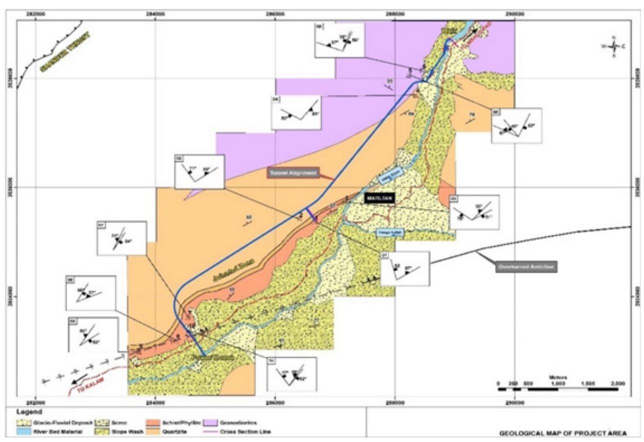

Figure 2: Geological map of area.

From different locations along various routes of tunnel rock samples were also collected and the lithology found was phyllite, granodiorite and quartzite. For the interpretation of results the information gathered during field work was processed, analyze and computed by numerical and empirical methods. For initial design stage studies, detail investigation was carried out in laboratory by performing different test on samples which are collected during the field work from different locations [6]. Concerning rock mass parameters, different tests were performed in lab and some values have been estimated during mapping of projected area such as density, unconfined compressive strength and different rock types and support categories were classified. Further parameters such as, Young's modulus of the intact rock, and Poisson's ratio were estimated by using RocLab software. Petro graphic analysis has been done on the rock samples which are collected during the discontinuity survey along representative locations of tunnel. Based on the available data, squeezing analysis has been done by using different approaches. The empirical methods; Singh et al, Goel criterion, semi analytical method; Hoek and Marinos (2000) and numerical method; Phase2 have been used for the squeezing analysis

Results and Discussion

Total length of tunnel is 6630 m which is divided into different chainages. Scanline survey has been carried out in projected area and their assigned numbers are DS-02, DS-03, DS-04, DS-06, DS-08, DS-09, DS-10. In initial chainage sections there is no sign of squeezing behavior has been recorded according to the empirical and numerical tools. By using Grimstad & Barton rock support has been estimated. For rock mass characterization two methods RMR (Bieniawski 1973) and Q (Barton. are used. Based on RMR, rock mass rating values have been assigned which are given in following table (Table 1).

Rating of tunnel Orientation is taken as 0 and -12.'0' orientation rating is taken for tunnel section having very favorable tunneling condition as tunnel direction drives with dip of strata

While -12 rating is taken for tunnel sections having strike parallel to tunnel axis [7]. Groundwater condition is wet at one section in initial chain age section while at other sections it is damp. Rock mass class for rock units is fair. Based on Q system, Grimstad and Barton (1993) calculated rock mass rating has been given in (Table 2). Stress reduction value is used as 2.5 for overall tunnel [8]. Estimated rock class by using input parameters from various rock units is from poor to fair

Type of rock mass support to be used has been roughly calculated by using Q classification. Rock mass along different chainages has been identified as poor to good quality rock mass [9]. By Grimstad & Barton (1993) chart, rock support has been proposed for different tunnel chainages based on the ratio of span and diameter of the tunnel to excavation support ratio (ESR) versus Q-value as provided in the (Table 3).

RMR-Ratings							
Scanlines No.	DS-06	DS-04	DS-03	DS-02	DS-08	DS-09	DS-10
Chainage	0+876-	1+000-	2+800-	4+000-	5+600-	6+600-	7+000-
	1+000	2+800	4+000	5+600	6+600	7+000	7+506
UCS (Mpa)	7	7	7	7	7	7	2
RQD	20	20	20	20	20	20	3
Spacing	10	10	10	15	10	10	15
Persistence	1	0	0	1	2	1	2
Aperture	1	1	0	1	1	1	1
Roughness	5	3	1	1	1	3	5
Infilling	2	2	6	2	2	2	2
Weathering	5	5	5	5	3	3	5
Ground water Flow	7	10	10	10	10	10	10
Orientation	0	-12	-12	-12	-12	0	0
Adjustment							
Total RMR-Rating	58	46	47	50	44	57	45
Rock Class	III-Fair Rock	III-	III-Fair Rock	III-Fair Rock	III-	III-Fair Rock	III-
		Fair Rock			Fair Rock		Fair Rock

Table 1: Rock mass rating values for rock units along various routes of tunnel.

Q-Ratings							
Scanlines No.	DS-06	DS-04	DS-03	DS-02	DS-08	DS-09	DS-10
Chainage	0+876-	1+000-	2+800-	4+000-	5+600-	6+600-	7+000-
	1+000	2+800	4+000	5+600	6+600	7+000	7+506
RQD (%)	93.61	99.8	96.1	99.81	99.65	98.21	20.97
Jn	9	4	9	4	4	4	9
RQD/Jn	10.4	24.95	10.68	24.95	24.91	24.55	2.33
Jr	3	3	2	2	1.5	1.5	3
Ja	1	2	4	2	2	2	2
Jr/Ja	3	1.5	0.5	1	0.75	0.75	1.5
Jw	1	1	1	1	1	1	1
SRF	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Jw/SRF	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Q-Rating	12.48	14.97	2.14	9.98	7.47	7.37	1.4
Rock Class	Good	Good	Poor	Fair	Fair	Fair	Poor

Table 2: Q -Tunneling index values of rock units along various routes of tunnel.

Support Design Based On Q-system						
		Rock class		Support category	Reinforcement	
Chainage	Q-value		De		Shotcrete (mm)	Bolts
						Systematic bolting, with 2m length and 2.2m spacing
0+876-1+000	12.48	Good	3.125	1	No	
						Systematic bolting,
1+000-2+800	14.97	Good	3.125	1	No	with 2m length and 2.2m spacing
						Systematic bolting, with 2m length and
2+800-4+000	2.14	Poor	3.125	4	40-100	1.8m spacing
						Systematic bolting, with 2m length and 2m spacing
4+000-5+600	9.98	Fair	3.125	1	No	
						Systematic bolting, with 2m length and
5+600-6+600	7.47	Fair	3.125	1	No	1.9m spacing
						Systematic bolting, with 2m length and 1.8m spacing
6+600-7+000	7.37	Fair	3.125	1	No	
						Systematic bolting, with 2m length and
7+000-7+506	1.4	Poor	3.125	4	40-100	1.8m spacing

Table 3: Rock support based on the ratio of diameter of the tunnel to excavation support ratio (ESR) versus Q-value

Conclusion

The instabilities which occur with time are often observed while tunneling in Himalayan region. According to Panthi (autumn 2012) even in lower overburden squeezing potential has been encountered in fragile, highly schistose, broken rock types and tectonically active region [10]. As a result, to find the accurate strain values in this region by squeezing potential analysis could be very complicated to tunnel engineers. The headrace project, Matiltan Headrace Tunnel, has been chosen for the analysis, where in one chainage considerable tunnel squeezing is encountered. Study of projected headrace tunnel revealed that it undergoes severe squeezing in about 200m stretch in chainage 7+000-7+200m from overall length 6630m. In this squeezed section quality of rock mass is poor and type of rock is phyllite. Three approaches are used for squeezing recognition and quantification, i.e. empirical approach, semi-analytical approach and numerical approach [11]. The empirical approach includes Singh et al. Goel, system; semi-analytical approach includes, Hoek & Marinos, method and Phase2 program for numerical modeling. By using different approaches for the squeezing analysis following conclusions has been made; Rock units are identified by petro-graphic analysis in the lab and input parameter and input parameters for all the approaches are collected. Rock mass characterization is done by using empirical approaches Q and RMR. Rock mass classes defined by Q system is poor, fair and good while RMR assigned poor and fair rock mass quality. Rock mass support estimated by empirical approaches is different for various rock units. However, for squeezed section recommended support is systematic bolting, with 2m length and 1.8m spacing and shotcreting of 40-100mm thickness. Squeezing or non-squeezing condition of ground is identified by Singh et al. and Goel, methods but tunnel wall deformation and support pressure are not quantified by using these methods. It is sensitive issue in Singh et al. method to estimate the correct value of SRF for Q-value, which is replaced by Goel, approach by with rock mass number that considers SRF=1. For the quantification of tunnel wall deformation and the support pressure Hoek & Marinos, approach is used. Evaluation of squeezing estimated by this method is in terms of tunnel wall strain/ percentage closure. The limitation of this method is that it does not consider the tunnel wall deformation during the application of support in isostatic stress state that is not based on a reality, because there is considerable difference of stresses encountered in different orientations. Despite of these limitations this approach can be used to assemble initial information for thorough analysis. Tunnel deformation can be visually displayed by the numerical modeling, which can identify the opening geometry and complexity of the rock mass easily and in reality basis. For squeezing analysis, the numerical program, Phase2 has been utilized in three selected tunnel sections. This tool analyzes the convergence in form of tunnel deformation, it does not provide results directly as tunnel convergence. The result obtained from this technique is compared with the results from semi-analytical approach. Severe squeezing is encountered in phyllite while in other rocks granodiorite and quartzite no significant squeezing has been observed.

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