Evaluation of tunnel excavation methods for Neelum Jhelum Hydro Power Project, Pakistan.

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Abstract: Pakistan is passing through a phase of severe energy shortage. To meet the challenge, Pakistan has started a couple of hydropower projects. One of these is Neelum Jhelum Hydro Power Project (NJHPP), which consists of three main components, one diversion dam at Nouseri on Neelum River, 2nd 33-km long tunnel of 82 M^2 cross sectional area for conveying water to obtain 420-M head and 3rd component is power house for generation of 969 MW power. Presently, the major issue of NJHPP is the selection of excavation method which should meet the fast completion of project due to energy crisis in the country & to avoid legal conflict with neighbor country. The selection of excavation method depends upon number of factors such as geology, tectonic setup, strength of rocks, hydro geological conditions of the area, geometry of the tunnel and many other factors. In this study, large number of samples of rocks were collected from the project area and analyzed. On the basis of present work three methods, Drill and blast, excavation through Road Header &excavation through Tunnel Boring Machine (TBM) have been evaluated to determine the suitability for this project. Apparently, the existing status indicates that there is no major problem in the use of drill and blast and road header excavation method except their slow advancement rate. However to meet the fast excavation requirement for achievement of the completion target in 2014, TBM is the only left over option. The results of the strength and the other parameters of rocks are supporting TBM except the disaster expected through the potential fault planes which run along the way of the tunnel & convergence pressures of mud rocks. It is suggested that detail geological investigation should be carried out along the tunnel route to support the final decision for selection of TBM.
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1. Introduction

Pakistan is facing severe energy crisis due to increase in demand and reduction in storage capacity of hydropower producing reservoirs. After the construction of Tarbela Dam in 1974, no large scale project could be initiated over the passed 35 years except Ghazi Brotha Hydral Power Project in 2003. Due to lack of planning and mismanagement day by day, the demand remained increasing and no cheap electricity project could be started. Few expensive options were adopted by the Government with installing thermal Power Projects. Ultimately, the Government issued vision 2025 program in 2000, wherein the stress was to exploit indigenous resources such as Hydropower and coal. Hence, Neelum Jhelum Hydropower project commenced since 2009 to over come the power shortage.

Neelum Jhelum Hydropower project is located in Muzaffarabad, Azad Jamu and Kashmir (Figure 1). It is composed of a diversion dam at Neelum River, 33 km long tunnel and a power house at Jhelum River. Approximately 280 m^3 per second of water will be utilized from Neelum River through a tunnel of cross sectional area 113.5 m^2 (revised) which will pass under Jhelum River and again release water into Jhelum River which meander and gain a total head of 420.5 M from intake.

According to feasibility report by Nonconsult (1996) a concrete gravity dam 135 m Long and 47 m high is being constructed on Neelum River at Nauseri which is designed for over-topping. The dam will create a head pond of 8 million cubic meters which will allow a peaking reservoir of 2.8 million cubic meters to meet daily peaking of power for more than 4 hours.

The total length of head race tunnel is 28.5 km., wherein 15.1 km stretch of the tunnel from the Nauseri be constructed as a twin tunnel system each with x-section of 43 m^2. The remaining head race tunnel down to the surge chamber will be a single tunnel having x-section of 82m^2. The tunnels are shot Crete lined with a concrete invert. The tunnel crosses approximately 380 m below river bed.

The present status of the Neelum Jhelum Hydro Power Project is that 7 adits have been completed 80% of designed length and head race tunnel upto 1.5 km by the drill and blast method. Later these adits will be used as access tunnels for removal of excavated material.

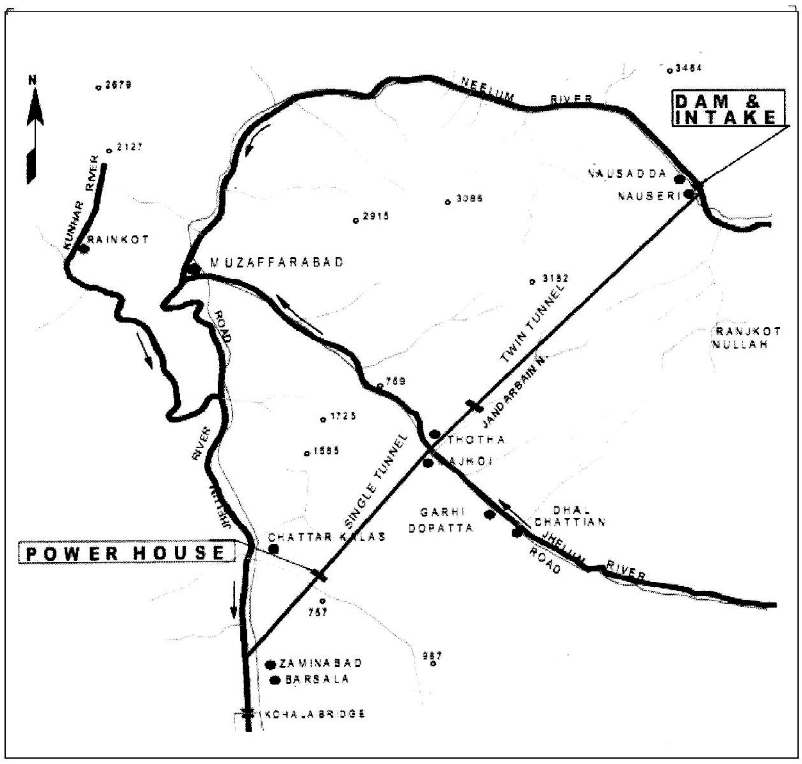

Figure 1: Location map of Neelum Jhelum Hydro Power Project indicating Dam Site, Tunnel Route and Power House (Norconsult, 1996)

The project is required to be completed in 2015 or possibly in 2013 to achieve two targets. Firstly early completion will provide cheep hydropower of 969 MW and secondly to avoid legal complications in the light of Indus Water Treaty.

To achieve the target and objectives of an early completion three tunnel methods in the light of various studies performed by researchers (Doyuran, 1997., Singh, 1998,. Dick, 1995,. Bell, 2007 & Kaneko, et al., 2002) are being evaluated in this study.

2. Geology

The geology of the project area is predominantly composed of Murree Formation of Miocene age. Shah (1997) reported that, "the formation is composed of a monotonous sequence of dark red and purple clay and purple grey and greenish grey sandstone with subordinate intraformational conglomerate, the basal strata of the formation consist of light greenish grey calcareous sandstone and conglomerates with abundant derived Eocene larger foraminifers". Geologically the project area can be divided into two zones. The dam site and intake reservoir nearby the village of Nauseri is the only area where two formations are exposed. On the right side of Neelum River and intake reservoir Punjal Formation is exposed which is lithologically composed of volcanic elastic rocks. In the rest of whole Project area the tunnel and power house only one formation is exposed i.e., Murree Formation.

2.1 Punjal Formation

This formation is only exposed in the reservoir area and composed of three rock units, Green Sandstone, Marble and Limestone. Only diversion tunnel has been successfully excavated in this formation by drill & blast method.

2.2 Murree Formation

It is exposed through out the project area except the dam site & reservoir area. The Lithology of the Murree Formation is composed of alternate beds of hard and soft rock. Four major rock units have been identified as sandstone, siltstone, shale and mudstones (Mubashir, et al., 2009, Khan, et al., 2010).

3. METHODOLOGY

As the execution work of the tunnel has already been commenced since 2009, the methodology is comprised of the field data collection through reconnaissance survey and laboratory testing.

3.1 Field Data Collection

Rock samples were collected from the adits where excavation through Drill and Blast Method was under progress. Geological Mapping and discontinuity survey were also carried out in two adit to assess the field condition and identification of joint pattern.

3.2 Lab Testing

To determine the engineering geological properties of the various rock units through which excavation will be carried out for tunnel, following tests were performed on thirteen samples adopting standard methodology.

Uniaxial compressive strength, dumping constant, slake, durability, Atterberg Limits and clay activity.

4 Criteria adopted for evaluation of Excavation Methods

Generally, the tunnel excavations and other large diameter excavations are based on examination of following parameters:

1. Geology and Tectonics of the area
2. Joint pattern
3. Geometry of the tunnel
4. Strength parameters
5. Porosity and permeability
6. Water conditions
7. Economic parameters

In the light of above parameters, rock samples were collected from the project area and analyzed to find out rock properties necessary for selection of excavation method. Hence, on the basis of various field and laboratory testing, following three excavation methods have been evaluated accordingly.

1. Drill and Blast Method
2. Road Header
3. Tunnel Boring Machine (TBM)

4.1 Drill and Blast (D&B) Method

Presently, Drill and Blast method has been adopted for excavation of tunnels in the Neelum Jhelum Hydro Power Project and approximately 7.3 kms tunnel (in total) have been successfully completed. Our results regarding strength (Table 1) and other parameters given in Tables 2 & 3, are also supporting this method except slow progress.

4.2 Boom Type Machines (Road Header)

A variety of tunnel excavators are available in the market. The selection of tunnel excavation depends on the strength of the rock and diameter of the tunnel to be excavated. Mainly two types of road header are being deployed for tunnel excavation. For medium to hard rocks ripping type road headers are suitable where as for soft geology milling type road headers are used. Generally compared to D&B method for medium size tunnel average rate of progress per day is of 30% more by road headers compared to drill and blast method..

Normally road headers are no good for working in areas where compressive strength of rock is greater than 14 KSI. Some of our rock units have high compressive strength as 94 MPa, where excavation may be problematic through road header.

Table 1: Uniaxial Compressive Strength

Sample No.	Strength (MPa)			Average Value of UCS (MPa)
	First sample	Second sample	Third sample	
A	46.5	57.7	56.5	53.6
B	51.7	54.2	53.3	53.3
E	87.2	88.0	94.5	89.9
F	94.6	99.2	88.6	94.1
G	74.0	90.7	97.0	87.2
H	77.9	74.9	74.9	75.9
I	55.2	52.9	56.9	54.7
J	40.4	42.7	42.67	41.82
K	84.0	72.8	72.4	76.4
L	73.4	63.0	68.0	88.00
M	41.6	40.3	39.1	40.3
N	60.5	68.4	57.7	62.2
O	75.4	64.5	84.3	74.7
P	72.7	72.8	58.5	74.7
Q	17.0	15.6	16.9	16.5
R	53.13	35.5	44.8	44.5

Taheri (2008) reported that, "one of the main limitations for using the boom type machines is high bit consumption according to high abrasive mineral (such as quartz content). Only few authors have worked on the correlation between abrasively and the mineral content of the rocks and the relationship is not fully understood by now." Our results show that quartz content are in highest ratios upto 85% among all the rock units exposed in the study area. This situation apparently does not favor and suit excavation through road headers. Probably due to this factor the Project Authorities of NJHPP have not considered adaptation of road header for this project.

4.3 Tunnel Boring Machine (TBM)

This method has advantage to achieve fast completion target and safety. The major limitation for the selection of this method is that of convergent soil which may stick the machine. Another potential hazard area for TBM is the presence of a number of faults, through which tunnel has to be crossed which need detailed investigation. The project authorities are actively considering this option to adopt for early completion of the project.

Table 2: Determination of Damping Constant Using Various Resonance Frequencies

Sample	Obs. No	Frequency Range	Resonance Frequency F_r	Low Frequency F_i	High Frequency F_h	Damping Constant Q
A-1	1	2.5-4.5	3.60	3.39	3.89	7.20
	2	3.0-5.0	3.59	3.27	3.89	5.29
	3	3.5-5.5	3.59	3.51	3.88	9.7
	Avg	-	-	-	-	7.39
A-2	1	2.5-4.5	2.54	2.51	2,82	8.19
	2	3.0-5.5	3.55	3.3	4.03	4.86
	3	3.5-5.5	3.54	3.51	3.81	11.8
	Avg	-	-	-	-	8.28
E-1	1	3.0-5.0	3.04	3.01	3.31	10.13
	2	3.5-5.5	3.54	3.51	3.89	9.32
	3	4.0-6.0	4	4	4.29	13.79
	Avg	-	-	-	-	11.08
F-1	1	2.5-4.5	2.54	2.51	2.81	8.47
	2	3.0-5.0	3.84	3.41	4.14	5.26
	3	3.5-5.5	3.54	3.51	4.10	6.00
	Avg	-	-	-	-	6.57
F-2	1	2.5-4.5	3.49	3.3	3.7	7.27
	2	3.0-5.0	3.69	3.49	3.97	7.69
	3	3.5-5.5	3.54	3.51	3.81	11.83
	Avg	-	-	-	-	8.93
H-1	1	2.5-4.5	3.59	3.45	3.88	8.35
	2	3.5-4.5	3.58	3.51	3.86	10.23
	3	3.0-5.0	3.59	3.46	3.88	8.54
	Avg	-	-	-	-	9.04
K-1	1	3.0-5.0	3.04	3.01	3.31	10.13
	2	3.5-5.5	3.63	3.51	3.91	9.07
	3	4.0-5.5	4.40	4.37	4.69	13.75
	4	4.0-6.0	4.39	4.36	4.69	13.30
	Avg	-	-	-	-	11.56
L	1	3.0-5.0	3.04	3.01	3.31	10.13
	2	3.5-5.5	3.62	3.51	3.91	9.05
	3	3.5-6.0	3.7	3.51	4.0	7.55
	4	4.0-6.0	4.04	4.01	4.30	13.9
	Avg	-	-	-	-	10.15
M	1	3.0-5.0	3.04	3.01	3.30	10.48
	2	3.5-5.5	3.54	3.51	3.80	12.21
	3	3.5-6.0	3.54	3.51	3.80	12.29
	4	4.0-6.0	4.04	4.01	4.30	13.93
	Avg	-	-	-	-	12.09
N-1	1	3.0-4.5	3.0	3.0	3.29	10.34
	2	3.0-5.0	3.6	3.5	3.89	9.23
	3	3.5-5.5	3.6	3.5	3.89	9.47
	4	4.0-6.0	4.04	4.01	4.29	14.43
	Avg	-	-	-	-	10.86
N-2	1	3.0-5.0	3.7	3.5	4.08	6.38
	2	3.5-5.5	3.79	3.51	4.18	5.66
	3	3.5-6.0	3.79	3.51	4.19	5.57
	4	4.0-6.0	4.04	4.01	4.29	13.47
	Avg	-	-	-	-	7.77

Table 3: Determination of Slake Durability Index for Two Cycles, on the Rocks Samples Collected from Outcrops and Under-ground Excavations from the Study Area

Sample No.	Durability Index		
	1st Cycle (%)	2nd Cycle (%)	Average (%)
A	97.97	98.79	98.38
B	99.00	99.6	99.3
D	93.38	98.48	98.43
E	99.8	99.6	99.7
F	98.8	98.69	98.7
G	99.8	99.39	99.59
H	98.6	98.4	98.5
I	98.4	98.2	98.3
J	97.6	97.8	97.7
K	97.57	97.26	97.41
L	99.19	98.9	99.09
M	98.4	98.4	98.4
N	98.5	99.1	98.8
R	98.15	98.25	98.20

Table 4: Determination of Clay Activity based on mudstone / clay stone samples.

Samples	Initial Weight (g)	Weight of Clay Particles (g)	Percentage Fraction (P.F.) %	Plasticity Index (PI) %	Clay Activity (A) (PI/P.F.)
B	23.498	6.702	28.52	12.85	0.45
C	17.499	4.903	28.01	7.72	0.27
D	13.253	3.424	25.83	10.40	0.40
J	11.068	2.714	23.3	13.20	0.56
R	12.674	3.502	27.63	12.62	0.45

Table 5: Results of Atterberg's Limits for the Selected Samples of Mudstone/ Clay stone.

Sample No.	Lithology	Average Values for 3 Tests	
		Liquid Limit %	Plastic Limit %
B	Mudstone	24.14	11.25
C	Clay stone	19.52	11.80
D	Mudstone	25.68	15.40
J	Clay stone	27.05	13.85
R	Mudstone (Sheared)	25.97	13.35

The results given in Tables 4 & 5 to determine clay activity indicate that there is no threat of convergence of soft formation during excavation by TBM. These results are based on limited samples collected from adits, however the situation may be quite different where the tunnel passes through over burden of more than 1800 M along the course of tunnels which may increase convergence to dangerous levels.

Although it is a costly option but the project authorities have recently decided to use TBM for major section of the tunnel to achieve fast completion of the project. Until now no detail geological investigations to meet the requirements for design criteria are available but investigations along the route of the tunnel are under progress.

5 Conclusion and Recommendation

The Drill & Blast method is working well except slow progress which can be accelerated to start tunnel excavation from a number of locations through access tunnels which are already complete. The road header method has not been considered useful by the project authorities due to high ratio of quartz content in sandstone formation.

Recently decision has been made by the project authorities to use TBM which requires detail investigations for its design. Special considerations are required after 2005 earthquake to accommodate the potential hazards associated with active faults through which tunnel will cross.

6 Acknowledgement

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