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Geotechnical appraisal of water conductor system-Baglihar Hydel Project (Stage- I), J&K

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Abstract

The 2069 m long, 11 m excavated diameter head race tunnel has been driven through Quartzite and phyllitic quartzite (92%) interbedded with slates (8%) to divert 430 cumecs of water to generate 450 MW of power. About 80 % of the tunnel has poor to very poor (Class D/E) tunneling conditions with Q ranging between <0.1 to 2.26 and 12 % through very poor to extremely poor class (E/F) with Q value <0.1 and about 8% through extremely poor Class (F) conditions of rock mass. Poor strength characteristics and squeezing conditions have rendered frequent collapses even after providing supports with systematic rock bolts and S(fr) shotcrete. The paper presents a detailed assessment of the water conductor system

Introduction

The Baglihar hydel project is one of the major run of the river hydel schemes on river Chenab. A 144.5 m high concrete gravity dam is in the advanced stage of construction on Chenab River in the J&K Himalayas (Fig.1) to divert 430 cumecs of water through a circular 2069 m long, 10.15 m (11.00 m excavated) diameter, Head Race Tunnel (HRT) to generate 450 MW (150x3) of power in an under ground power house and release the water back to Chenab river through a 135 m long 10 m diameter Tail Race Tunnel (TRT). The project is targetted to be completed for generation by 2006. Jayprakash Industries Ltd. is constructing the first of it's kind mega-projects in the country under the Engineer-Procure-Construct (EPC) in agreement with Jammu & Kashmir Power Development Corporation. Lahmayer International GmbH are the consultants for the project on behalf of the client.

The power house complex includes construction of a 25 m dia., 80 m high surge shaft, cavern for Gate chamber, Machine hall, Transformer hall and collection gallery. The diversion arrangement for the construction of dam is made through two 11 m dia., flat invert, horse shoe shaped, diversion tunnels (DT1 & DT2) of 398 and 541 m lengths respectively, on the right bank. The tunnels are designed to discharge over 5000 cumecs of water with a peak velocity of 27 m/sec. The construction of stage-II of the scheme for generation of additional 450 MW of power is on the anvil with the common head works and a separate similar layout of water conductor system. The cavities for the Stage-II will be an extension of the Stage I cavities towards the north. The work would be an extension of the existing contract under similar agreements.

The 2062 m long HRT takes off from the

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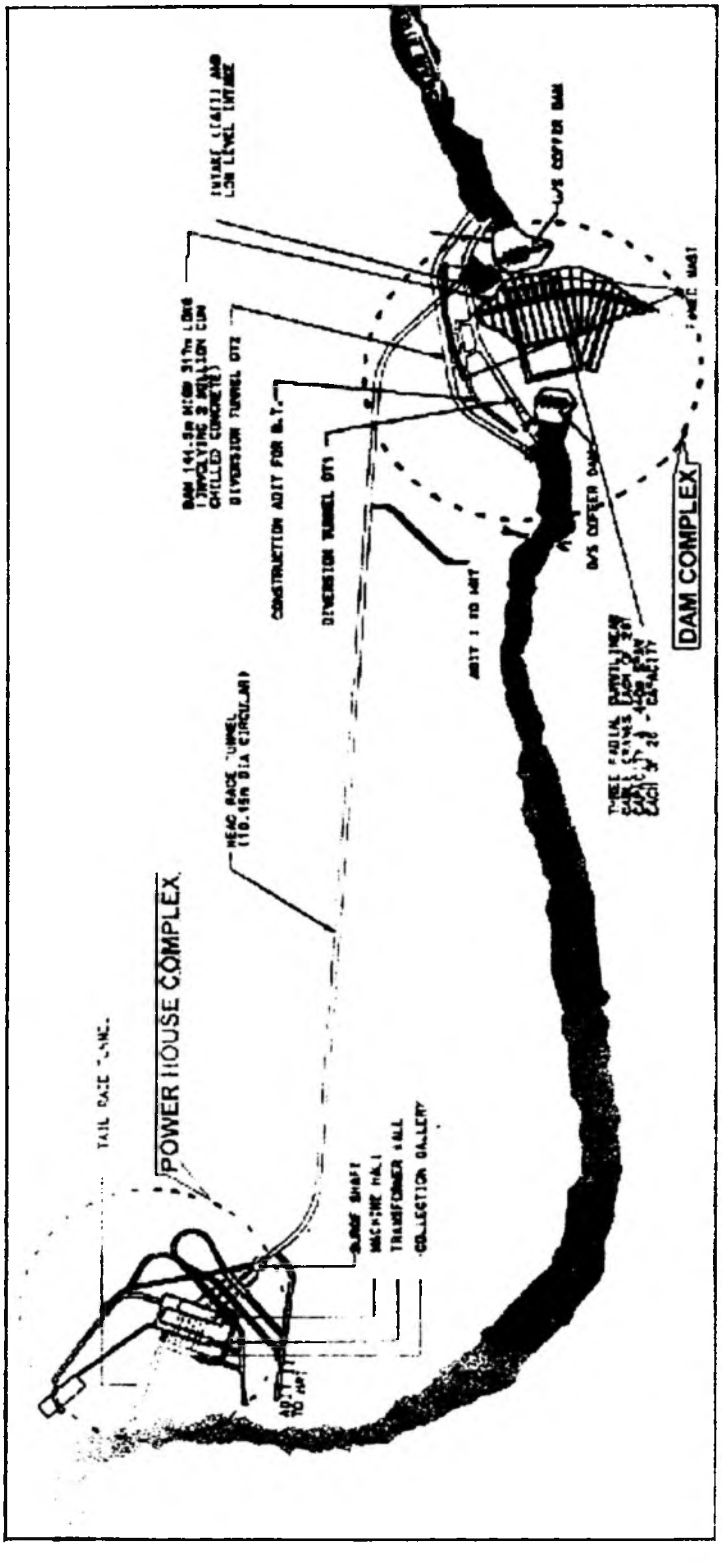

Fig. 1: Layout of Baglihar HE Project

proposed reservoir with a 95 m high intake, on the right abutment, located about 30 m u/s of dam, with a vertical 'S' curve in a length of about 60 m (Fig.2). A 90 m long low level HRT with a low level intake, joining the main HRT about 80 m u/s, is also under construction to meet the requirement of early generation of power. The 95 m high and about 80 m long composite intake structure houses the three intakes for stage-I & II schemes. The HRT is curved in the initial reach of about 286 m and is aligned straight and has a curved layout in the end reach of about 186 m to join the 79 m high 27 m dia. restricted orifice type surge shaft. Three 196 – 197 m long, pressure shafts take off from the surge shaft to join the power house. The pressure shafts are vertical with 15 and 25 m horizontal reaches at the top and bottom levels respectively. A 34m (h)X10m (w) gate chamber with hydraulic hoisting arrangement is located about 10 m d/s of the surge shaft. Three 12 – 15m(d)X45 – 60m(l) tapering draft tubes take off from the power house and cross under the transformer hall cavity to join the collection chamber/gallery. The water from collection gallery is release in river Chenab through 135 m long 10 m dia, 19 – 27 m high tapering tail race tunnel.

Geology

The project area is encompassed by the rocks of Salkhala Series of pre-Cambrian age. The rocks in general are quartzite / inter-bedded phyllitic quartzite with slates and schist and slates. The general trend of the rocks is N30-40°W–S30-40°E with dips of 60–68° due ENE (Fig.2). The project area is located between the Muree and Panjal thrusts of the Kashmir Himalayas. The rocks are strongly influenced by the "*Muree thrust*", which passes in close proximity to the project area (about 800 m SW of HRT). Two sympathetic thrusts trending N-S and dipping 40–55° due westerly (opposite to the general dip of the formations) cut across the project area near the intake (T_1) and mid section of HRT (T_2) respectively (Fig. 2&3). The reverse thrust fault is intercepted in DT-2 in the initial reaches and passes close to the right of DT-1.

The rocks are folded in a broad plunging syncline, with a relatively tight complimentary anticline to the NE, and thrusted along the N-S trending thrust lines (T_1 & T_2). The Plunge of the folds is about 25° due North. The dip of the thrust varies between 45° and 60°, which is sympathetic to the regional Muree thrust. The upward throw/displacement varies between 0.50 and 1.50 m.

The HRT is excavated through the folded sequence of rocks. The tunneling medium is mostly fresh to slightly weathered (W_1–W_2) quartzite interbedded with slates. The shear seams are moderately to highly weathered (W_3-W_4). The rocks are intensely/ tightly folded and deformed manifested by four major sets of joints plus 2-3 random sets and shear seams (Table-1). The low angle joints with clay, gouge material /shear seam is a common feature in the tunnel. Discordant shear seams and permeations of vein quartz with higher degree of weathering are the manifestations of shear zone in the rock mass. The joints are invariably clay filled and the shear seams of <0.50 m thickness and shear joints are gougy. The joint volume (J_v) of the rocks ranging between 20 and 30 give rise to small to very small blocks (crushed blocky rock/ sugar cubes). In view of intense folding of the rocks, considerable variation in the attitude and persistence of the joint sets is seen. Besides the above sets, two random sets of joints are also noticed which greatly influence the stability of rock mass locally.

The sheared and weathered contact of quartzite with slates (T_1) cuts across DT-2 askewed to about 40°. The slates exposed in the diversion tunnel-2 covering about 14 % of the tunnel are squeezing in nature. The reach with cover of 130–180 m has shown squeezing of about 157 mm in 19 weeks with an initial convergence of 91 mm in 3 weeks, which stabilized in about 35 days (Ahmed et.al., 2002). These slates were expected to be encountered in the HRT over a length of 100 m along the original alignment. The HRT was realigned in the initial reaches by reducing the curved length to avoid the intersection of this extremely difficult section through the squeezing slates.

It was estimated to encounter 56% of Quartzite and 44% of quartzite with slates/ phyllitic quartzite (Anon., 2002). During actual excavation, about 92% of tunneling is done through the highly fractured / closely jointed quartzite and phyllitic quartzite and rest 8% through sheared, weathered slates.

Rock mass characterization

Based on lithology, weathering and the geo-mechanical properties, the rock mass have been characterized and categorized in to three basic engineering geological units R1, R2 & R3 (Table-2). The percentage of various units encountered in the tunnels is

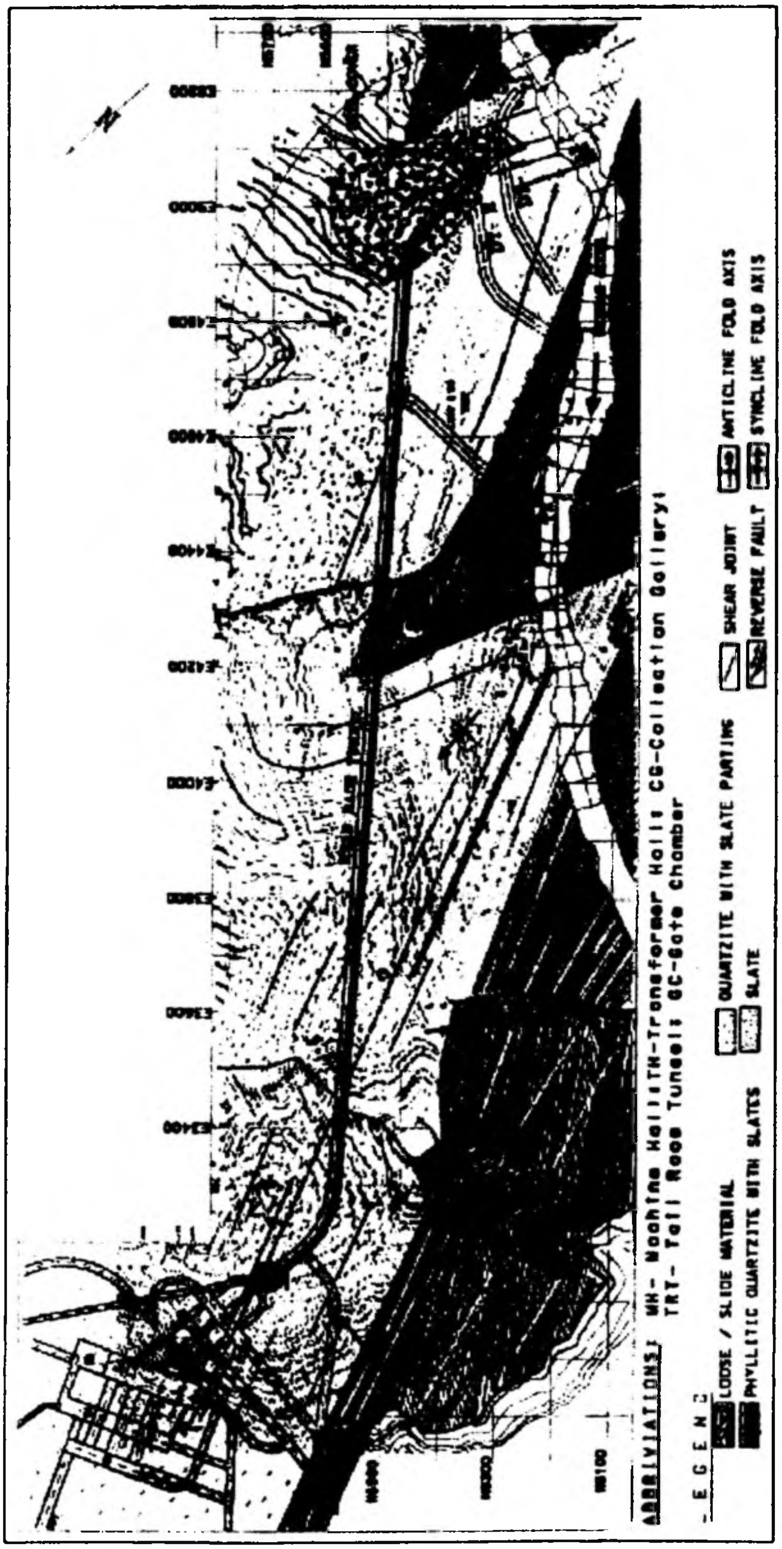

Fig. 2: Geology and layout of Baglihar HE Project

Table-1: Discontinuity characteristics

Sl. No.	Joint set	Direction/ amount	Spacing (mm)	Persistence (m)	Aperture/ Filling (mm)	Remark
1	J_1	$60^0/62^0$	10-300	>10	Clay	Foliation/ bedding shear seams
2	J_2	$270\text{-}280^0/30^0\text{-}65^0$	10-100	<20	Open with Clay, gouge to granular	Joint / shear seam
3	J_3	$190\text{-}200^0/30^0$	40-100	<10	Granular	Joint / shear seam
4	J_4	$350^0/20\text{-}60^0$	10-100	<10	-	Joints /shear seams
5	*J_{R1}	$290^0/28^0$	300-500	<10	Clay gouge	Joint / seam
6	*J_{R2}	$330^0/40^0$	30-400	<10	Granular	Joint / seam

* Random sets

given in Table-3.

R-I

The unit with quartzite are light gray coloured, predominantly hard, relatively strong, compact, unweathered to slightly weathered ($W_{1\&2}$), blocky (with small blocks) rock mass with thin slate partings. The strength parameters (Table-2) relates to rather competent rock mass (Q >1-2.2)

R- II

The unit is predominantly a dark gray coloured, foliated, phyllitic quartzite interbedded with lenses of thinnly foliated slates/bands. It is slightly to moderately weathered ($W_{2\&3}$), blocky (small tabular blocks) with moderate to low strength characteristics (Table-2). The strength parameters indicate it to be a less competent rock mass (Q 1-0.1)

R- III

The unit is predominantly identified as a dark gray coloured, thinly foliated, moderately to highly weathered ($W_{2\&3}$), relatively soft, crushed rock with clay infilling and shear seams. The rock mass has occasional competent ribs of fine-grained sandstone to quartzite. The rock breaks perfectly along foliation joints with a phyllitic sheen. The rock mass is intensely jointed to sugar cube like/ very small blocks to crushed rock. The rock mass is less competent to incompetent.

Table-2: Rock mass characteristics

Sl. No.	Lithology	Eng. Geol. Unit	Weathering Grade	Rock Mass Parameters		Geo-mechanical properties				
				J_v	Q	CS	E_d	E_e	C	Ø
1.	Quartzite	R -I	W1 & W2	20 – 25	1– 2.5	775-819	7-19	13-27	7	41
2.	Phyllitic quartzite	R -II	W2	30	<1	571-636	8-17	12-26	6	38
3.	Slates	R -III	W2 & W3	30->60	<0.1	< 100	4-6	-	<1	<30

NB: Jv- Joint Volume; Q- Tunneling quality; CS- Crushing strength in Kg/cm²; E_d- Deformation modulus in Gpa; E_e Elastic modulus in Gpa; C- Cohesion in Kg/cm²; Ø- Angle of internal friction in °.

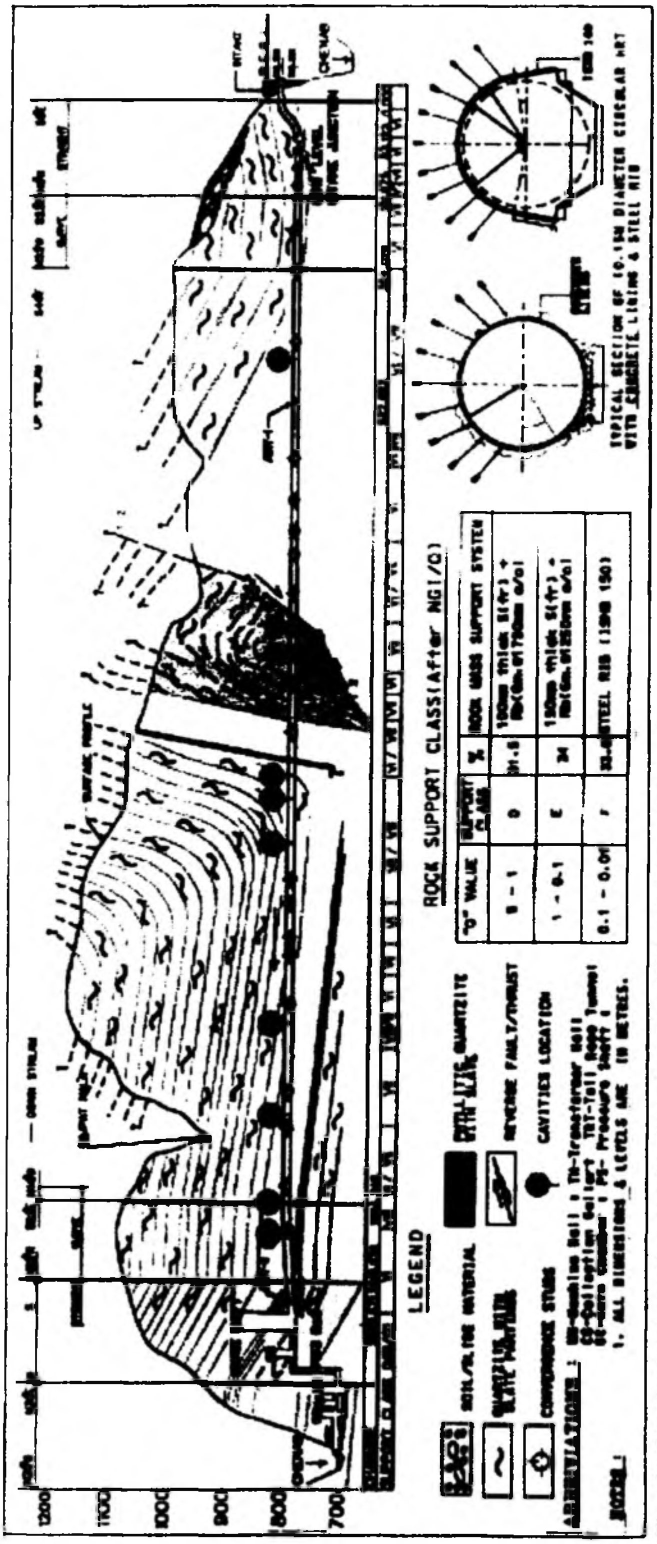

Fig. 3: Geological section and other details of Head Race Tunnel

The tunnels in this unit show bone dry to damp condition. The unit is squeezing in nature. The unit requires heavy supports. About 12% of tunneling is done through the extremely Poor rock mass, Q<0.1

Excavation and support system

The 2069 m long, 11 m excavated dia. HRT with a discharge capacity of 430 cumecs has been excavated by 10.5 m span 7 m high top heading and 3.5 m high benching with DBM method, through two 7.5 m span, 'D' shaped inclined (1:10) adits with three faces (Fig.3). The tunnel is to be lined with 400 mm thick plain concrete (Fig.3).

The intersection of adverse joint sets resulted in local over breaks / loose falls and formation of deep chimneys of 3 – 5 m depth. In addition to the primary supporting with rock bolts and S(fr) shotcrete, steel rib supports (ISMB 150) at 1 m c/c with blocking concrete have also been provided to support the selective reaches (Table-4). The excavation vis-à-vis support system of some major chimneys / collapses, which were critical to progress, are shown in Table -4.

The estimated support categories were Cat. I – 0.5 m long rock bolts at 1.25 m c/c with 100 mm thick S(fr)

Table-3: Support system adopted for water conductor system

Sl. No.	Eng. Geol. Unit	Length in m (%)	Tunneling class/ Q value	Treatment / support measures	Remarks
1.	R-I	1355 (65.5)	E /1 – 2.22	* Rb+ S(fr)	
2.	R-II	558 (27.5)	F/ 0.1 – 0.88	# Rb+ S(fr)	
3.	R-III	170 (8)	G/ 0.1 – 0.01	@Rb + S(fr) + PSS	Steel supports in addition to primary supporting.

NB: * - 6 m long, expansion shell type, tensioned, grouted, Fe 500, rock bolts at 1.5m c/c, 150 mm steel fiber reinforced shotcrete.

\# - 6 m long, expansion shell type, tensioned, grouted, Fe 500 rock bolts at 1.25m c/c, 150 mm steel fiber reinforced shotcrete.

@ - 6 m long, expansion shell type, tensioned, grouted, Fe 500 rock bolts at 1.25m c/c, 150 mm steel fiber reinforced shotcrete and steel supports at 1 m c/c with blocking concrete.

shotcrete. and Cat. II- ISHB steel ribs at 50–75 cm c/c or as needed Based on actual excavation and assessment of the quality of rock mass using the Norwegian Method of Tunneling (Ahmed et.al., 2002) and the practical difficulties the support system was reviewed progressively (Table- 3).

Systematic rock bolting with 6 m long (Fe-500), tensioned, grouted, rock bolts (shell type) at 1.25 - 1.5 m c/c and 100 – 150 mm thick S(fr) shotcrete has been adopted as the reviewed support system in general.

Instrumentation/Monitoring

The convergence measurements of the excavated sections were done progressively at fixed locations with tape extensometer (AIMIL type). In general the ground convergence studies were carried out with three studs (Figs.4&5). The convergence measurements were taken every alternate days initially which were extended conveniently to weekly basis. Studs have been put on the rock line initially which were transferred on to the steel ribs, for further monitoring soon after erection with back fill concrete,. In the excavated reaches of the HRT, progressive convergence measurements at the fixed locations, at an average interval of 70 m, were taken during the month as per schedule of measurements. Some typical convergence curve of the tunnel is given in Fig.4. The observations based on the studies carried out in about 150 days are as follows.

- The maximum convergence observed in R-I type of rock mass was about 22 mm in about 32 weeks, with an initial convergence of 18 mm in 5 weeks with a rate of 3.6 mm/week (Fig.4).
- The maximum convergence observed in the slates R-III type rock mass was about 157 mm in about 19 weeks, with an initial convergence of 91 mm in 3 weeks (Fig.5). The convergences stabilize in about 5 – 14 weeks with a rate falling to <0.5 mm/week.

In view of the squeezing tendency of the rock mass and the large dia./span of the tunnel additional support measures with permanent steel supports with blocking concrete in the overt portion has been provided prior to benching operations in identified reaches with Q values lying at <0.4 ie. Class E/F rock mass.

Table-4: Account of deep over-breaks/chimneys formed in head race tunnel

Sl. No.	EG Unit R	RD. (length) in m	Q value / Class	Depth in m	Treatment measures	Remarks
1.	II&III	450–462(12)	0.06/ F	3 – 5	FP,S(fr)S, PSS-12	Low angle shear joints and seams.
2.	II	900–905(5)	0.53 /E	2	FP,S(fr)S, PSS-5	-do-
3.	II	950-956((5)	0.1–0.6/E	2.5	FP,S(fr)S, PSS-5	-do-
4.	II/III	1160-1173(18)	0.09/F	3.5 – 4	FP,S(fr)S, PSS-18	Sheared slates with dripping condition, ***thrust zone***
5.	II	1186-1190(5)	0.09/F	2	FP,S(fr)S, PSS-4	Low angle shear joints and seams.
6.	II/III	1250 – 1268(18)	0.06/F	2-3.5	FP,S(fr)S, PSS-12	Sheared slates with dripping condition, core of syncline
7.	II	1578- 1581(3)	0.1-1.0/E	1.5	S(fr)S, PSS-03	Low angle shear joints and seams.
8.	II/III	1715-1751(37)	1.00-1.6	2- 4	S(fr)S,Rb' PSS-37	Sheared slates,clay filled joints. Gajpat nalla crossing
9.	II/III	1876-1885(14)	1.0-1.6/F	2–3	S(fr)S,Rb' PSS-10	Sheared slates,clay filled joints.
10.	II	1912-1916(5)	0.66-1.00	2.5	S(fr)S,Rb' PSS-5	Low angle shear joints and seams.
11.	II	1930-1945(10)	1.0-2.0	5-7	S(fr)S,Rb' PSS-17	Adverse orientation of joints, wedge failure
12.	II/III	Draft tube-2	0.01	5–6	S(fr)S,Rb' PSS	Sheared slates,clay filled joints. Low rock cover

NB: FP- Fore polling; S(fr)S- Steel fiber reinforced shotcrete; Rb- systematic rock bolting; PSS- Permanent steel supports.

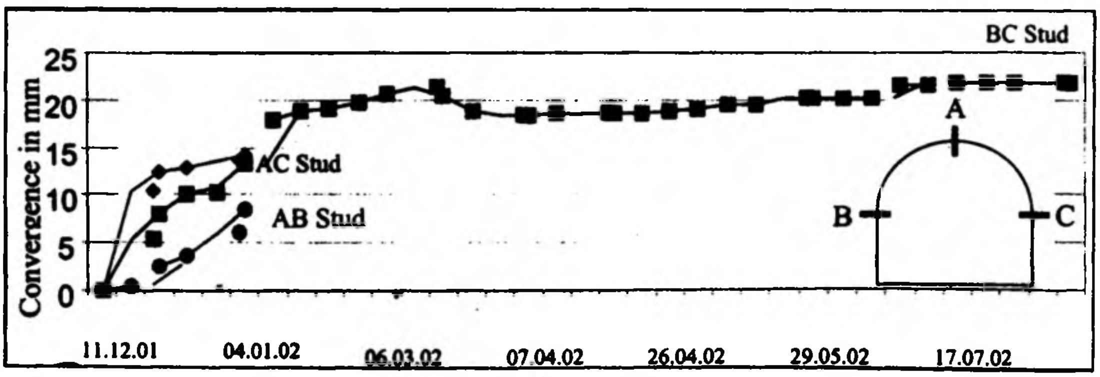

Fig. 4: Typical convergence graph in phyllitic quartzite.

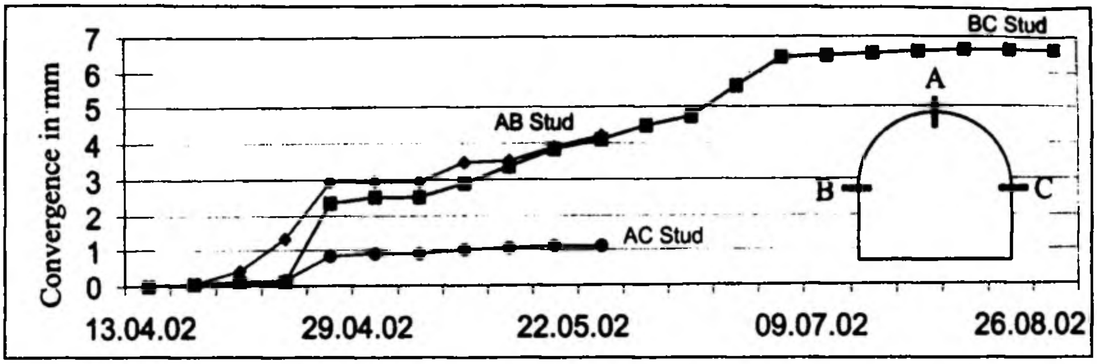

Fig. 5: Graph showing convergence in sheared slates

Conclusions

1. The rock mass is greatly influenced by the close location of the project (about 800 m) to the regional 'Muree thrust' by it's stress regime manifested by a high degree of jointing (Jv +20), presence of repeated shear seams, clay filled shear joints and squeezing conditions. The features have greatly influenced the strength parameters of rock mass and hence the stability in both underground and surface excavations.
2. About 92% of the 11 m dia water conductor tunnel is driven through quartzite /phyllitic quartzite and rest 8 % is through the sheared and crushed slates. Tunneling was accomplished with a top heading of 7.5 m and benching of 3.5 m height, through two adits with three headings followed by benching and adopting the DBM method of excavtion.
3. About 80 % of the tunnels have poor to very poor (Class D/E) tunneling conditions (Q ranging between <0.1 to 2.26), 12 % through very poor to extremely poor (Class E/F) conditions (Q value <0.1) and about 8% through the extremely poor (Class F) conditions of rock mass.
4. Poor strength characteristics and squeezing conditions have rendered frequent collapses even after providing supports with systematic rock bolting and S(fr) shotcrete. The above uncertainties warranted a review of excavation vis-a-vis the support system to adopt permanent steel supports with blocking concrete in the cavity reaches of very poor to extremely poor (F/G) tunneling class of rock mass.
5. The maximum convergence was observed to be about 22 mm in about 32 weeks, in the R-I type of rock mass, with an initial convergence of 18 mm in 5 weeks with a rate of 3.6 mm/week and about 157 mm in R-III type of rock mass in 19 weeks. The convergences stabilized in 5 – 14 weeks with a rate falling to <0.5 mm/week

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