Challenges faced and mitigation measures adopted in construction of head race tunnel of Kameng hydro electric project (600 MW), Arunachal Pradesh, India

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ABSTRACT: Kameng Hydro Electric project (4x150MW), a ROR scheme was constructed by North Eastern Electric Power Corporation Ltd in the West Kameng District of Arunachal Pradesh, India. This project lies in the Lesser Himalaya consisting of Precambrian and Gondwana rock formations. A 14.5 km long tunnel was constructed to convey water from Bichom to Kimi for 600 MW of power generation. This paper deals with the challenges faced during tunnel boring in tectonically disturbed Himalayan terrain and the mitigation measures adopted in overcoming these geological challenges. The challenges comprised cavity formation, blow out, Squeezing, high seepage and very weak rockmass with high rock cover. The mitigation measures adopted to overcome these challenges included fore-poling, umbrella/canopy with channel/joist and chemical/cement grouting etc. After overcoming all these tunnelling challenges, the boring of HRT was successfully completed in March’2015.

Keywords: Mitigation, DRESS, Himalaya, Grouting, Squeezing, Weak rockmass.

1 INTRODUCTION

North Eastern Electric Power Corporation Limited executed Kameng Hydro Electric Project located in West Kameng district of Arunachal Pradesh, India from Lat 27.30°N, Long 92.30°E to Lat 27.17°N, Long 92.69° E. It is a run-of-the-river scheme with a gross head of 536 meters. It was envisaged to generate 3353 MU of electricity annually by constructing two dams across Bichom river and Tenga river. A 69 m high concrete gravity dam with ogee shaped concrete spillway having 6 nos. of radial gates of size 9.00 m x 12.06 m was constructed on Bichom river about 3.00 km downstream of the confluence of Bichom and Digien rivers. Another 24.5 m high concrete dam with 2 nos. of radial gates of size 14.00 m x 14.00 m was constructed on Tenga river. Bichom and Tenga rivers are the tributaries of Kameng river. The reservoir water from Bichom dam is conveyed to Kimi powerhouse through 6.7 m diameter modified horse shoe shaped 14.47 km of Head Race Tunnel, 25 m uniform diameter 60 m deep surge shaft and 3.7 km of high pressure tunnels to feed four vertical Francis turbines having capacity of 150 MW each. The water of Tenga reservoir is used in the lean season. The horseshoe shaped concrete lined HRT of 6.7 M diameter was designed to convey 140 cumecs of power draft. The Tunnel Boring was carried out through 8(eight) faces with the construction of 4(four) adits with a total length of 1095 m. In absence of suitable locations for other adits, the tunnel boring activity was carried out for approx. 4 km in HRT from Face II and Face III each.

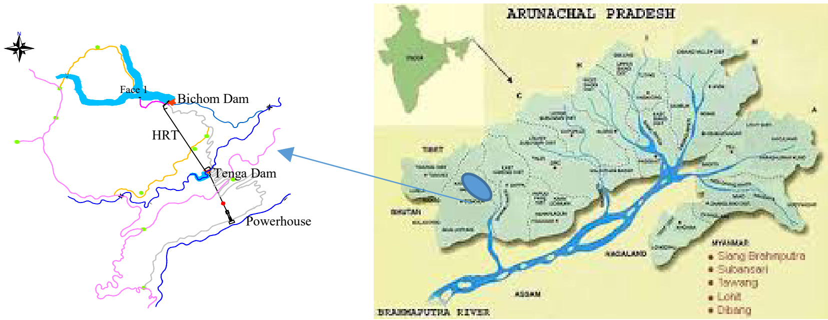

Figure 1. *Project Location.*

2 REGIONAL GEOLOGY

The Kameng Hydro Electric Project area is geologically complex and tectonically highly disturbed, forming part of the Lesser Himalayan range. The area is dissected by a number of major thrusts and faults striking E-W to SW-NE associated with subduction of the Indian plate beneath the Asian plate (CMPDI, 2003). The rock types occurring in the project area belong to the older meta-sedimentaries of Pre-Cambrian age in the northern part, sedimentary rocks of the Gondwana Supergroup in the central and southern part (Sarma, 2014). The Tertiary sedimentary rock of Siwalik Formation occurs in the southeast of the project area in the vicinity of Kimi power house (GSI, 1982). Main Boundary Thrust (MBT) separates Gondwanas from Siwaliks. Topography is steep and actively dissected by the main river systems being the Bichom/Digien, Tenga and Kameng rivers. The major rock units range in age from Pre-Cambrian to the Tertiary. Quaternary sediments are all over the project area.

3 HRT GEOLOGY

The HRT was excavated through a geologically complex and tectonically disturbed area, dissected by a number of major thrusts and shears zones (GSI, 2001). The HRT was expected to encounter Precambrian rockmass comprising mainly of Chlorite-Sericite Schist, Phyllite and Porphyroblastic Granite Gneiss, Quartzite and Slate on Bichom side. Gondwana formation rocks consisting of Quartzitic Sandstone, Slate, Dolomite and Carbonaceous Shale/Siltstone along with Graphitic coaly partings were expected in Tenga and Kimi part of HRT.

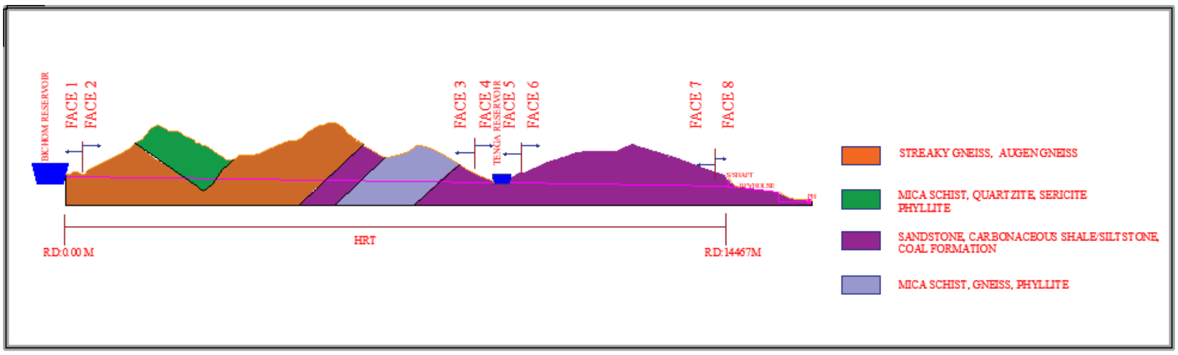

Figure 2. Geological Longitudinal section of HRT.

The initial investigations indicated about 89% of tunnel rockmass to fall in the good to fair rock class (Class- I, II & III) and 11% in poor rock class (Class- IVA & IVB). The rockmass along the tunnel alignment was classified based on the RMR values (Bieniawski, 1989) and divided into five classes i.e. class-I, class-II, class-III, class-IVA and class-IVB. During the excavation it was found that 92% of rockmass came under poor rock category and supported by Class-IV support system. The rockmass encountered in HRT Face I and II were mainly Pre-Cambrian rocks and in Face III, mix of Precambrian metasedimentary and Gondwana sedimentary rocks were encountered. In HRT Face-II/III the thinly laminated Schist and Phyllite rockmass created most of the stability problems along with carbonaceous rockmass. The HRT in between Tenga dam and Surge Shaft (Face IV-VIII) were located in rocks of Gondwana Supergroup which had experienced poly phase deformation due to proximity to the Main Boundary Thrust. The geological Longitudinal section along the HRT with all the faces of boring is displayed in figure 2.

4 TUNNELING METHODOLOGY

The tunnel excavation was carried out by the conventional drilling and blasting method with Rocket Boomer in full-face or in heading & benching method. The pull was determined on the basis of rock type encountered ranging from 0.50 m to 2.00 m. The rockmass in Class II/III was supported by placing rock anchors/bolts and shotcrete. The rock bolt of Φ 25 mm and 3500 mm length was grouted over their entire length with minimum load capacity of 100kN. The shotcrete of 50 mm thickness was applied on the rock in class II and 100 mm thickness (two shots of 50 mm thickness) in class III with welded wire mesh. The rockmass encountered in Class IVA/IVB was supported by steel ribs with concrete backfilling of M20 grade behind pre-cast RCC laggings between the ribs. DRESS methodology was adopted for advancement of the face in the stretches with considerable seepage and weak rockmass condition. In this method, perforated heavy duty pipe was inserted along the periphery for advance drainage followed by pre-grouting either with MFC or OPC/PPC for strengthening of the rockmass prior to advancement of the face. Further in stretches with loose fall, shotcrete was applied on the face to arrest further deterioration of the face and to facilitate further advancement. The heading was generally carried out for a stretch of 8.00 m followed by benching. Construction niches were provided at an interval of 300-500 meter to facilitate tunnel construction.

5 CRITICALITIES AND REMEDIAL MEASURES

During tunnel advancement, the main challenges encountered were in the form of loose fall with face collapse, heavy seepage, flow of loose / slush during crossing of shear zones, squeezing in erected support etc. Generally, most failures are initiated at the crown portion, when the highly fractured rockmass do not possess the inherent resistive strength.

5.1 *Cavity formation and blowout in HRT Face-I/II*

Boring of HRT Face- I & II was severely affected due to poor geological condition. The rock type encountered in Face I and II was dominated by Mica Schist/Talc Schist, Quartzite with patches of streaky Gneiss and Carbonaceous Phyllite of Pre-Cambrian group. In these critical stretches, DRESS methodology was adopted with available resources including PU (MEYCO MP355A3) and microfine cement (Rheocem 650). The criticality faced, the rockmass encountered and remedial measures adopted in Face II is summarized in Table 1. Some other major cavities also occurred in Face-I at RD: 322.78m and 304.63m and in HRT Face-II at RD: 1370.26m, 1375.91m, 2394.78m and 2489.28m, which were also successfully restored.

Table 1. Summary of problems faced in HRT Face II.

Sl. No.	Location	Rock type	Remedial Measures
1	Blowout at CH. 1208.38 M with 2585.29 Cum slush with water	Shear zone within Banded Quartzite	Face plugging by muckfilling, forepoling of 80/100 mm Φ perforated MS pipes, grouting with 8.47 MT PU and 9.94 MT of MFC, Time consumed- 7 months
2	Blowout at 1402.66 M with 6013.55 Cum slush with 6500 lt/min of seepage water	Shear zone within Banded Quartzite	Face plugging by muckfilling, forepoling of 50/100 mm Φ perforated MS pipes, grouting with 23.65 MT PU and 43.825 MT of MFC, Time consumed- 9 months
3	Blowout at 2122.78 M with 8527.6 Cum slush with water	Quartzite with schist	Face plugging by muckfilling, 5871 RM forepoling of 50mm to 100 mm Φ perforated MS pipes, grouting with 36.65 MT PU and 54.13 MT of MFC, Time consumed- 5 months

5.2 *Cavity formation and Squeezing problem in Face-III*

The rockmass encountered in HRT Face-III was found to have squeezing characteristics in some stretches due to presence of highly fractured and jointed carbonaceous material and coaly bands with very low compressive strength below 2.00 MPa and high rock cover extending upto 800 m – 1150 m. The frequent roof collapses with heavy over-breaks and cavity formations of 3.00 m to 9.00 m height were experienced during tunneling. The thickness of shear zones varied from few centimeters to few meters. The rock experienced gradual squeezing tendency of deformations generally after a period of about one month from excavation at several places. This was manifested by development of cracks in the laggings and twisting of steel ribs as shown in Figure 3, resulting in opening up of concrete lagging from steel ribs. The strain in the rockmass was observed by MPBX (Multi Point Borehole Extensometers) installed in the tunnel walls with 0.5m, 1.50m and 3.00m long anchors inserted in the rockmass. The convergence readings were also taken by the plastic survey reflectors of the Geodata Bireflex type. The tunnel deformation at SPL of HRT has been recorded up to 0.48 m. The Unconfined Compressive strength (UCS) values of the rock samples from different stretches of HRT was determined at site laboratory. The UCS values of the rock samples from the disturbed zones is shown in Table 2. The strain percentage in the squeezing zone ranges from 4.11 to 13.15 indicating severe to very severe squeezing problem. The values of In-situ stress in distressed zone of HRT was estimated from the curve in Figure 4. and was found to be in the range of 10.31 to 20.56 MPa with about 800-1000 m rock cover.

Table 2. Strain (%) and UCS (MPa) as observed in distressed zone of HRT Face III.

HRT Face III CH.(m)	Rockmass strength (UCS) in MPa)	Deformation at SPL (m)	Tunnel Radius (m)	Strain (%)
2472.47	2.15	0.165	3.65	4.52
2475.72	2.45	0.150	3.65	4.11
2486.22	1.85	0.480	3.65	13.15
2490.22	1.85	0.283	3.65	7.75
2500.97	1.25	0.450	3.65	12.33
2555.47	1.75	0.280	3.65	7.67
2560.47	1.95	0.230	3.65	6.30
2565.47	1.75	0.250	3.65	6.85
2569.72	1.65	0.150	3.65	4.11

Modifications in the tunnel section was incorporated by increasing unlined tunnel diameter from 7.3 m to 7.6 m to tackle the problem of squeezing in some stretches of HRT.

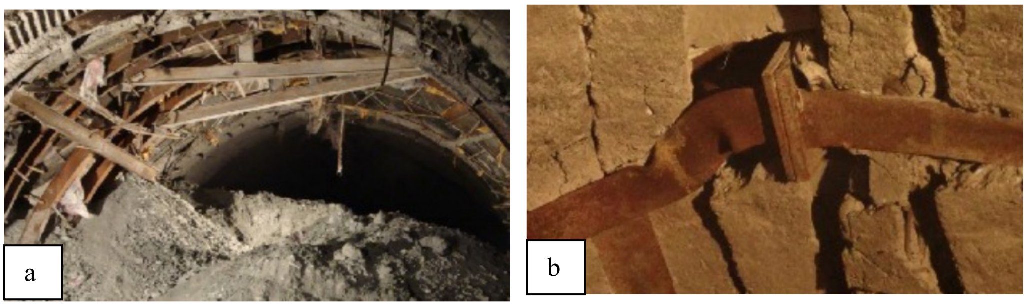

Figure 3. a. Crushed sheared material in shear zone, b. Twisted ribs in shear zone in Face III.

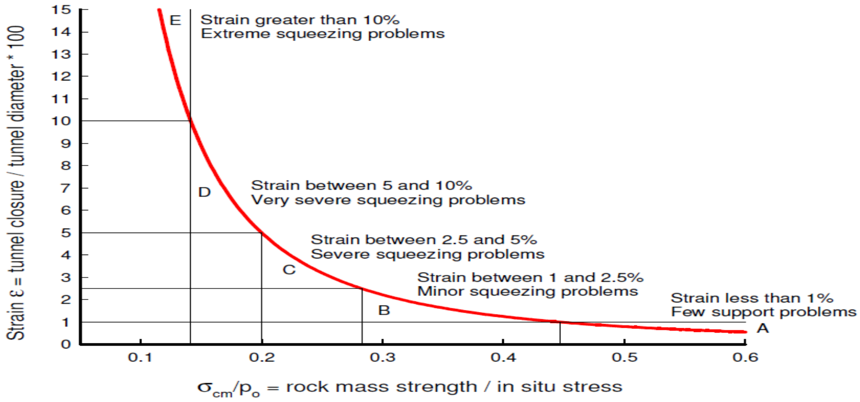

Figure 4. *Relationship between* tunnel *strain and ratio of rockmass strength to in situ stress* (Proposed by Dr. Evert Hoek and Marinos, 2000).

5.3 *Cavity formation and water ingress in HRT Face- VI, VII & VIII*

Heavy seepage of underground water was encountered along with very poor geology from RD 10026.00 m to 10038.00 m, RD 10227.00 m to 10290.00 m and from RD 10446.74 to 10477.14 m. The rate of seepage recorded in the stretches of tunnel varied from 6500 to 9000 liters/min as shown in Figure 5.

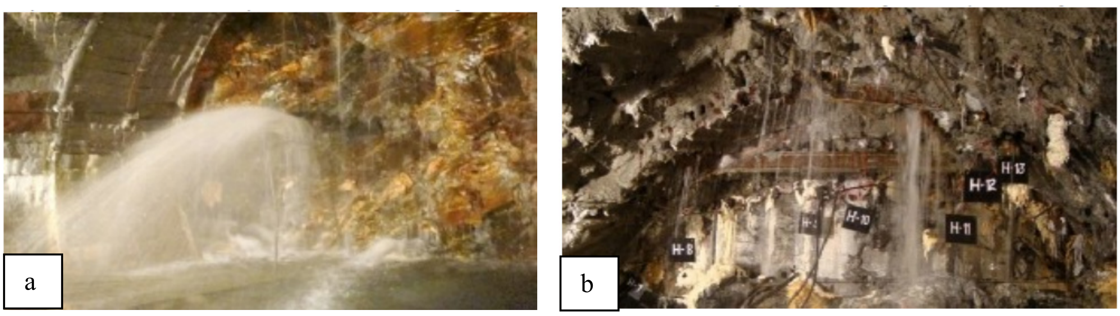

Figure 5. a. Gushing seepage water in Face VI, b. PU grout in Face VI.

In order to stabilize the rockmass and to divert the excessive seepage water, extensive cement/colloidal silica grouting was carried out. Finally, Polyurethane (PU) grouting of about 10 MT was carried out. Polyurethane grouting was done under high pressure up to 60 Bar in HRT Face-VI, by drilling 45 mm diameter, 5.00 m long holes all along the HRT periphery and in the face keeping an overlap of 2.00 m to divert seepage water from the tunnel at two locations at RD 10479.99 m and RD 10653.99 m for further face advancement. During excavation of HRT Face-VII, heavy seepage was encountered at RD 14301.50 m. The cavity formation in the form of crown collapse occurred at several stretches due to weak rockmass. Methane gas (more than 5%) was also encountered in some stretches leading to fire in the tunnel face. The work was resumed by blowing sufficient air and water jet until the methane content diluted to the acceptable limit.

6 CONCLUSIONS

In coming days, we are going to develop more of hydropower in the fragile Himalayan rocks. We completed this tunnel even after facing so many challenges. The magnitude of HRT mishaps and criticalities could not be predicted during investigation stage due to inaccessibility throughout the tunnel alignment for detailed geo-technical investigation. The experience in tunnel boring activities of Kameng HEP covering different engineering and geological issues may be taken as an eye opener for hydro structures being planned in geo-technically sensitive lesser Himalayan region. The tough and challenging task of tunneling in such poor geological formation could be successfully completed by evolving strategies involving engineering skills and innovative ideas. It is also a fact that with all the challenging tasks and geological criticalities, the project tunneling fraternity of Kameng HEP could accomplish tunnel boring for a length of 4.5 kilometers with conventional tunneling methodology by Full Face and Heading & Benching method through one face i.e. face – III which itself is a remarkable milestone achievement in Indian Hydro Tunneling Industry. The criticalities encountered and remedial measures adopted during boring works of 14.47 km tunnel of Kameng Hydro Electric Project (600 MW) shall therefore be of valuable reference for tunneling in similar conditions of sub-Himalayan area.

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