Mechanized Tunneling in Himalayas: Risk Assessment and Management of Geological Challenges

Dhawan, Gopal
Executive Director (Geotech)
Bhatnagar, Sharad
Chief (Geology)
Engineering Geology & Geotechnical Division,
NHPC Ltd, Faridabad-121003

Abstract

Tunneling is one of the most challenging activities in hydro power construction. The tunnel construction needs meticulous planning as it involves huge investment and has a direct impact on the completion schedule of the project. Quality survey & investigations can help in risk assessment before taking up the construction and making adequate provision in the contract to handle those risks. Today tunnels are being constructed with modern equipment and methodology. With the increasing demand of infrastructure & hydro power development, tunneling industry in India has grown manifold. Major improvement in the methodology of tunnel excavation has been made world over due to technological advancement. Mechanized tunnels using TBM and tunneling in soft rock is now possible. However, in India, utilization of TBM for tunnel construction in Himalayas has been facing problem. Nevertheless, TBM are the only option left for speedy construction particularly in case of long tunnels. Today's trend demand for competency to forecast the tunneling condition, mechanized approach and utilization of state of the art technology to achieve faster rate in construction by tackling the pitfalls effectively.

NHPC, a premier organization in the field of hydropower development has rich experience of tunneling carried out for its various hydro projects located in diverse geological conditions in northwestern, northern and north-east Himalayas. The present paper gives an insight on the experience gained from a series of major tunneling works undertaken for the hydroelectric projects in Himalayas, risk assessment and mitigative measures adopted to manage the adverse geological conditions and recent development in support technology.

1. Introduction:

India has a vast hydro power potential to the tune of 84,000MW, a major part of which lies in the Himalayan region, which provides conducive setting for development of underground hydropower projects. However, the hydro power industry in the country is growing at a slow pace with only 24% of the total potential exploited so far. The ever growing demand of energy in the country has necessitated an increased thrust on accelerated development of hydro power projects. High priority has been accorded by Government of India to harness the huge untapped hydro power potential of the country by launching the ambitious 50,000 MW capacity addition programme and opening up power sector for private developers also. However, the slow pace of hydro power potential development in the Himalayas has to be thoroughly understood. The Himalayas have very diverse geological conditions. Modern tunneling methods such as TBM, road header, etc are being adopted for faster tunneling in challenging geological conditions, however, the desired progress is yet to be achieved.

Over the experience, it is seen that geotechnical problems and related contractual issues are the main bottleneck. It is generally accepted that geological uncertainties and associated construction difficulties lead to significant delay in project commissioning causing cost and time overrun, however, the required technical skills to overcome these hurdles are yet to be achieved. By adopting a pragmatic approach right from the planning stage, adequate geological investigations and their interpretation during project report preparation, identification of probable geological risks and making adequate provisions in the contract documents to tackle such risks, continuous monitoring and predictions by resident geologist, preparedness of implementing remedial measures by the executing agency and prompt decision making process can minimize the time and cost overrun.

Risk management is a vital aspect of project management that is generally overlooked. Success of a project depends, to a great extent, on identification of all possible risks, correct management, and regular review throughout the execution of the project.

While emphasizing on a risk management policy for hydro electric projects this paper, in brief, discusses the geological risks involved in mechanized tunneling in the Himalayas, their management with some case studies where adverse geological conditions were encountered and the way in which they were managed in hydropower projects constructed and commissioned in recent years by NHPC.

2. Modern Tunneling Methods - Opportunities & Challenges:

Today, the focus is on faster completion of projects which demands for an advanced technology, more particularly in tunneling. It is imperative to do safe tunneling with speed and maximize the rate of advance in excavation by adopting modern mechanized method of tunneling.

Highly mechanized tunneling using TBM are well known throughout the world for achieving very high tunneling rates and adoption of such methods in our projects can speed up considerably the completion of the project within the stipulated time schedule. Tunnel Boring Machine (TBM) has been proved to be a cost effective and faster alternative to conventional Drilling and Blast method (DBM), particularly for long tunnels. TBM has been found suitable for its adaptability to tunneling in any type of rock with varying degree of ease. Though deployment of TBM involves high capital cost, one of the most positive factors in favour of TBM is faster and smooth tunneling without much disturbance to surrounding rockmass. However, TBM could not gain a wider acceptance in the country due to complex geological conditions, especially in the Himalayas. In the following paragraphs, the experience gained by NHPC in two of its projects namely Dulhasti in J&K and Parbati Stage-II Project in Himachal Pradesh has been briefly discussed.

2.1 Dulhasti Hydroelectric Project, (J&K):

Dulhasti hydroelectric project, the first major hydroelectric venture of NHPC using TBM was contemplated as a run-of-the-river scheme over Chenab river. The project is located in Kishtwar district of Jammu & Kashmir, India. The main features of the project include a 65m high, 186m long concrete gravity dam near Dul village, a 10.6 km long and 7.46 / 7.7 m diameter headrace tunnel, a "Dufor-type" desilting basin having 240 m of length, a 90-metre-high surge shaft, a 311.6 meter long pressure shaft, an underground powerhouse near Hasti village accommodating three Francis turbines of 130 MW each utilizing 235m of gross head to generate 390 MW of power.

The project lies within lesser Himalayan zone and is characterized by a unique plateau like feature with schist/ gneiss on western side and quartzite/phyllite on eastern side. Kishtwar Regional fault divides the plateau into two lithological units. The power house and part of downstream HRT lies within schist / gneiss formation whereas the dam complex and upstream HRT rest in quartzite/phyllite sequence. The main interesting geomorphic feature of the project was fossil valley. The detailed investigation carried out by NHPC revealed that the fossil valley is filled up with deep lacustrine deposits comprising sand, silt, clay and pebbles.

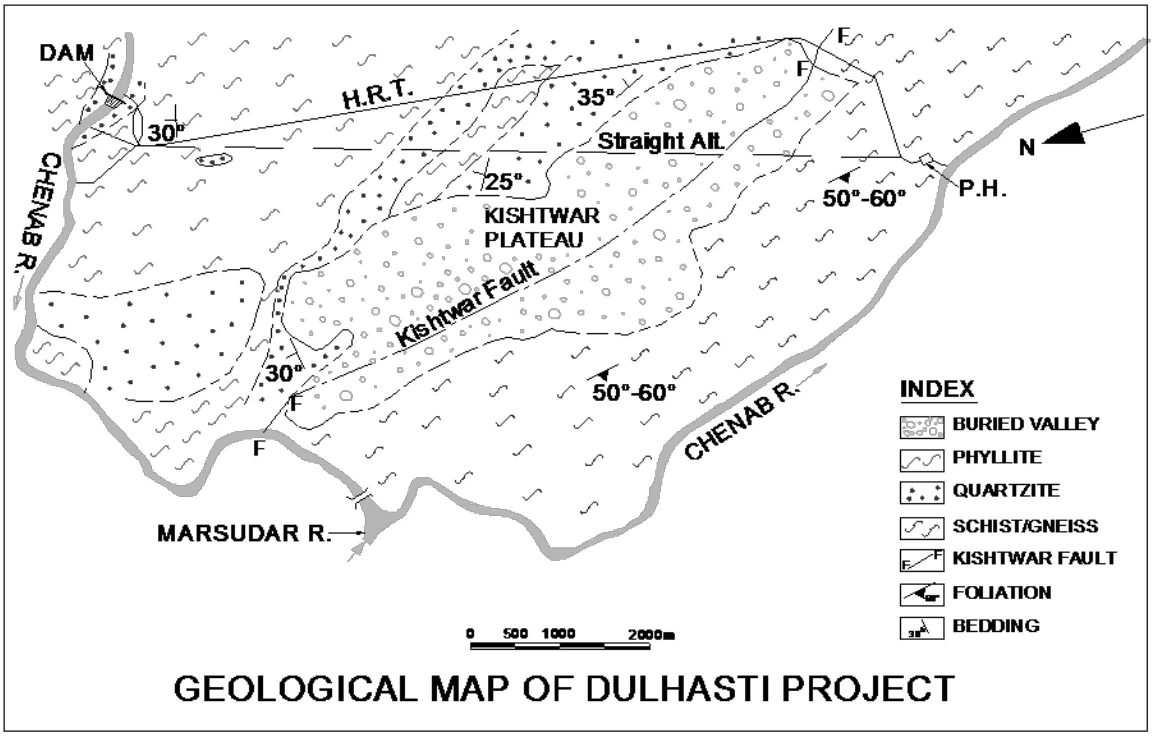


Figure 1 Geological Map of Dulhasti Project, J&K

Originally, the HRT was conceived as 9.6 km long straight alignment wherein 300-500 m length of HRT was passing through fossil valley area. It was apprehended that the adverse geological conditions may lead to tunneling problems. Hence, an alternative layout of length 10.6 km with a loop alignment to avoid fossil valley area was chosen. The topography of the area was such that there was no scope for an intermediate adit. Hence, it was decided to bore 6.75 km upstream portion of tunnel using TBM and remaining portion by DBM.

The TBM used was hard rock TBM manufactured by M/S Robbins having 8.3m diameter and 59 disc cutters. The machine had the ability to bore into hard rock and fractured zones as well. The precast segments were laid in the invert concurrent with the progress of excavation. A trench was provided in the central part of segmental lining for dewatering. The machine had the facility of installing rock bolts, wire mesh, shotcreting and erection of steel ribs. The TBM also had the facility of drilling probe hole of 50 mm diameter about 50 m ahead of the face.[1]

Extensive geotechnical investigations including surface mapping of rock exposures, aerial photo, satellite imageries, geophysical surveys, exploratory drift, etc. had been carried out to ensure smooth functioning of TBM. However, the unpredictable Himalayan geology resulted in severe geological conditions which were encountered in many reaches. As a result, the TBM excavation ran into many geological as well as contractual problems resulting in considerable time and cost overrun.

The major problems encountered were:

- High cutter consumption requiring frequent stoppage of works for replacement of cutters resulting in slow progress rate
- Frequent occurrence of shear zones ranging from few centimeters to 5-6 meters. These shear zones were often associated with water under high hydrostatic head posing extremely difficult tunneling condition. Precautionary/ remedial measures such as probe drilling, drainage holes, application of Boodex technique, forepoling, installation of steel girders and grouting were adopted for treatment of shear zones.
- Heavy flow of the order of 1100 liters per second under high hydrostatic pressure and cavity formation due to artesian aquifer like conditions. The alternating sequence of jointed quartzite being good receptor of subsurface water and phyllite forming the impervious barrier was found to be conducive of artisan condition. Interception of these zones during tunneling caused sudden ingress of water with heavy silt flow, causing burial of the TBM at Chainage ± 2863 and further excavation by TBM had to be abandoned. The TBM could bore only 2.86 km and finally abandoned. Balance tunneling was completed by conventional drill & blast method. This situation coupled with grim law and order (in the state of J & K) was a major jolt to the project and the work remained standstill for couple of years. The project finally got commissioned in 2007.

Overall, this experience in Himalayan geology was not encouraging.

2.2 Parbati Hydroelectric Project, Stage II , HP:

The Parbati Hydroelectric Project is located in Himachal Pradesh on river Parbati which is a major tributary of Beas River. It is a cascade scheme planned to be developed in three stages with an aggregate generating capacity of 2070 MW. However, Stage-I of the Parbati hydropower project which envisaged 750 MW was abandoned in 2001 due to environment-related concerns. Stage II of this scheme is a run-of-river scheme comprising an 85m-high & 113m long concrete gravity dam near village Pulga in Parbati valley. A discharge of 116 cumec from Parbati River and Tosh stream is diverted through a 6 m diameter, 31.5 km long headrace tunnel on the left bank of Parbati to an underground 17 m in diameter surge shaft that will feed two steel lined pressure shafts each of 3.5m diameter having length of 1542 m and inclined at 30° to the horizontal. A gross head of 862 m so formed shall be utilized to generate 800 MW of power through 4 generating units of 200 MW each in the surface powerhouse located on the right bank of the Sainj river near Suind village, 200 m downstream of the confluence of the Jiwa nala and Sainj rivers. Short tailrace channels will discharge the water from the powerhouse to Sainj River.

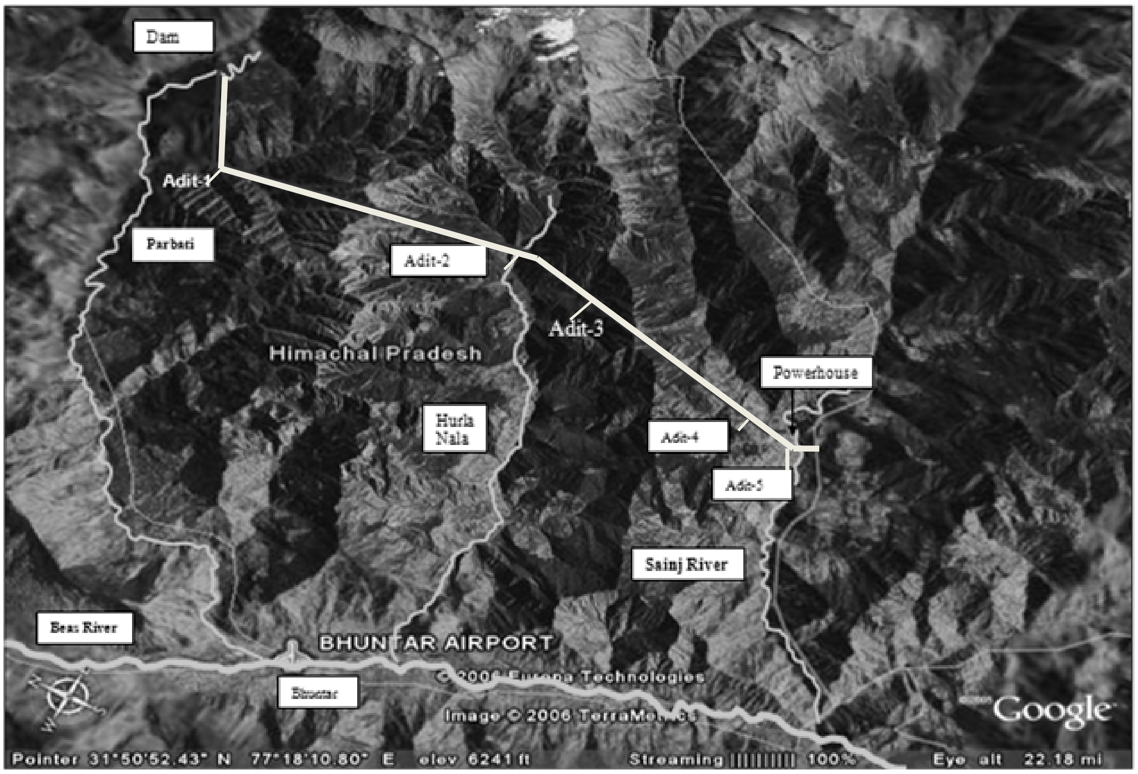


Figure 2 Layout of Parbati HE Project, Stage-II

The 31.5 km long HRT of this project is the longest tunnel in any hydropower project in the country and perhaps one of the longest in the world. The HRT had been planned to be excavated through six adits. In absence of the possibility of an intermediate adit in the reach between adit 1 and adit 2, it was decided to excavate this stretch of 9km of HRT by the open type hard Rock TBM and balance 22.476 km tunnel by the conventional DBM with finished diameter of 6.0 m.

The inaccessible terrain restricted the amount of investigations in comparison to size of the project. Investigations revealed that the headrace tunnel will broadly pass through seven lithological units of two geological formations, separated by a regional thrust known as Jutogh (Kullu) Thrust. The rocks encountered were expected to be granite/gneissose granite, quartzite, biotite schist with subordinate schistose quartzite. The superincumbent cover over the tunnel ranges from 400 m to 1200 m.

The TBM designed for HRT was refurbished Robbins TBM MK 27 of 6.8 m dia (Photo 1). The machine is equipped with 49 x 432 mm diameter cutters. Maximum cutter head rotation speed is 5.77 rpm and maximum machine thrust is 18550 KN which is considered suitable for hard rock machine. The machine is equipped with ring-mounted probe drilling equipment, which has the capacity to drill in any corner of the tunnel. The probe drills with the maximum probing length of 120 m are also intended for use in drilling drain holes and for grouting. TBM also has arrangements for rock bolting, wet & dry shotcreting and ring beam erector for erection of heavy steel arches.

Photograph 1 Open mode TBM assembled outside Adit-II

The TBM section of HRT mainly comprises of granite/gneissose granite (RD 19354m-15700m) followed by Manikaran quartzites (RD 15700m -10,340m). Initial reach of the tunnel boring comprised gneiss with schist bands and minor quartz lenses which were supported by rock bolts and wire mesh. The rock formation then changed to schistose gneiss with bands of chlorite schist, sometimes weak and highly jointed. A wedge failure occurred at chainage 748 m u/s of Adit-2 and a large block of 6.0 m x 2.5 m separated from the crown. The cavity was backfilled with concrete. The treatment caused a loss of nearly three weeks. With this experience, modifications were made in TBM to provide extension drilling system to access the cavities and arrangement of manual shotcreting just behind the cutter head. The next 250 m reach was marked with rock/wedge failure forming cavities up to 5m above the crown which required a lot of concrete backfilling. The excavation rate dropped significantly. However, this condition soon improved and best weekly rate of 90 m could be achieved. [2]

The increased excavation rate of best of 250 m/month and 24 m /day could also be achieved. However, this condition could not prevail for long and soon after the unfavorable rock conditions like rock bursts and large over break were encountered due to high superincumbent cover ranging between 800m to 1000m, requiring rock support by wire mesh secured to the rock surface with 150mmX75mmX(2.6-3m) long channels , 2.7m long rock anchors and 2.4m long swellex anchors. In situations where higher risks were anticipated heavy steel rib supports varying from 400-800mm spacing were provided. The support system almost removes the use for shotcrete.

As the work progressed, the rock conditions became worse, as several weak zones consisting of weak mica schist bands were encountered. These adverse geological conditions resulted in numerous severe over break requiring closely spaced (0.4 m c/c) steel ribs, fore poling and shotcrete application immediate behind the cutter head.

Significant deterioration of tunnel wall behind the grippers was observed as well, requiring additional rock support. These measures resulted in substantial decrease of progress rates. During November 2006 there was heavy ingress of water with immense quantity of silt and sand from a routine probe hole drilled, which flushed into the tunnel and buried the TBM. The ingress of water was initially of the order of 8000 lpm but decreased later to about 2500 lpm. The content of silt and sand decreased by January 2007. The work of silt removal was carried out during December 2006 to March 2007 by making special arrangements after which TBM was finally repaired and refurbished. Various proposals such as detouring of tunnel alignment were discussed at length. Investigation by Tunnel Seismic Prediction test was also carried out to predict such water bearing zones lying ahead of tunnel face. Efforts are being made to treat the cavity/water ingress zone, by grouting, for which a specialized International agency has been identified and the work of tunneling was resumed in June, 2010. Since then no major problem is being faced and the tunneling is under progress with an average progress rate of10 m/month.

2.2.1 Excavation in pressure shaft:

The twin pressure shafts having an internal diameter of 3.5 and length of 1542 m, inclined at 30° to the horizontal were planned to be excavated with double shield TBM with a nominal excavated diameter of 4.88 m. The boring of shafts was done from bottom to top.

These shafts, inclined at 30 degree, are world's steepest shafts to be excavated using Tunnel Boring Machine. The inclined shafts encountered moderately foliated to massive metavolcanics with moderately to closely jointed and moderately strong to weak chloritic phyllite zones and intermittent bands of chlorite schist. As a consequence of shearing, the strength of the rock mass varies from moderately strong to weak.

TBM for pressure shaft was specially designed by Mitsubishi to work in an inclined tunnel. The 4.88 m diameter double-shield TBM was equipped with 33 x 432 mm cutters and gripper pads with an anti-skidding device (Photo 2). The machine was also equipped with a probe drilling machine and segment erector. The machine was assembled inside the inclined pressure shaft in two 35 m-long 12m high chambers, constructed for this purpose. After boring the first, left pressure shaft which took almost 13months to complete, the TBM was dismantled at the top and taken out again to be assembled for the second pressure shaft. Hexagonal precast segments were installed for supporting the ground. Precast segmental lining was backfilled with gravel. The excavated muck was transported through a steel trough and flushed with a jet of water from the working face down to the adit bottom in a hopper where water and muck were separated.

Photograph 2 Breakthrough in Inclined Pressure

Barring some minor problems like clogging of muck, etc. no major problems were encountered and the second, right shaft successfully holed through in a record period of 136 days (Photo 2). Although initial experiences of NHPC with the TBM are not encouraging, all efforts are on to make TBM a successful venture in India. Undeterred, and having gained experience from these challenging conditions, NHPC has lead a contract to construct the 16km long Kishanganga HEP (J&K) headrace tunnel to be driven by TBM in similarly extreme conditions.

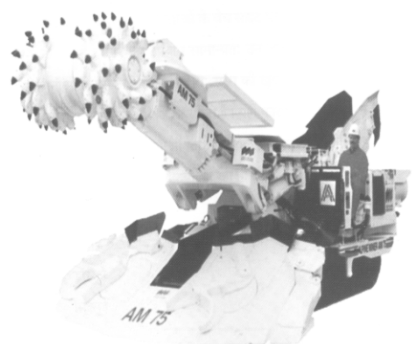
With an exponential growth in hydropower development, mostly in Himalayas, the tunneling activity in India is bound to gather momentum. While the excavation using TBM has been quite successful in other parts of India, Delhi Metro, Srisailam Left Bank Canal tunnel scheme and Bombay Malabar Hill tunnel to name a few, the Himalayas remain a major challenge. The experience suggests that many of the problems can be avoided if sufficient advance information ahead of face is available. Faced with cost and time constraints, detailed investigations before selecting a tunnel alignment are often compromised resulting in encountering very disturbed geological conditions. It is essential that detailed exploration work is carried out before the start of the project and exploration ahead of the face should be undertaken on a continuous basis. Probe holes of at least 75 - 100 mm diameters with perforated pipes at crown level ahead of a tunnel face and the use of geophysical exploration techniques such as Tunnel seismic profiling could be used to ascertain the presence of groundwater.

The choice of TBM is another important factor. A TBM can be designed for every type of geological conditions. The design and special construction characteristics of each TBM need to be project specific. The shield TBM has a definite edge over open TBM as they are not as sensitive to the instability. By pushing against the lining it is thus possible for the TBM to advance independent of the instabilities. Treatment of the fault zones from inside the shield becomes possible. The shielded TBM has a wider range of application than open TBM, more so with the increased diameter of the tunnel. The properly designed TBM can significantly reduce the problems arising due to adverse geological situations.

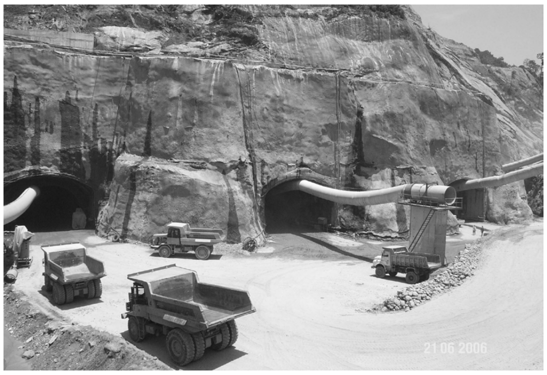
3. Tunneling in Soft Rock by Road Header:

The 2000MW Subansiri Lower H.E. Project in Arunachal Pradesh, located close to its border with Assam on Subansiri river, a major tributary of Brahmaputra river, is under advance stage of construction. The Project comprises of 5 nos. 9.5m dia. horseshoe shaped Diversion Tunnels varying from 491m to 688m length, 116m high concrete gravity Dam, 8 nos. Head Race Tunnels of 9.5m dia, horseshoe shaped varying from 630 m to 1130 m length, 8 nos. Pressure Shafts, circular shaped, having a dia of 7.5m/8 m/9.5 m and length varying from 209 m to 231m, a surface Power House to accommodate 8 units of Francis turbines of 250MW capacity each for generating 2000 MW of power.

The rock type in the project area comprises weak sandstone of middle Siwalik. In view of the soft nature of rock having low UCS in the range of 15-20 MPa in dry condition and 4-7 MPa in saturated condition, a non blasting technique by means of road header (Photo3) is being carried out for tunneling.[3] Problem of frequent spalling of rockmass was encountered while tunneling. The massive but weak nature of rockmass limited the use of RMR & Q system of rock mass classification. In view of the above a support based Hindrance classification has been adopted wherein the rock class is defined in relation to the hindrance in progress of excavation caused by type & amount of support installed.



Photograph 3 Road Header



Photograph 4 Outlet portals of Diversion tunnel

The average cutting rate by twin cutter machine and road header was between 5.8m^3/hrs to 16m^3/hrs which was significantly lower than the predicted rate of 51m^3/hrs to 104m^3/hrs. The main reasons of slow progress were massive nature of sandstone lacking fissile planes. In addition, crushing of rock resulted in large quantity of dust which was difficult to handle. Spraying of water to control the dust was also proved detrimental as it resulted in slush, making the working conditions difficult.

Nevertheless, the river has been successfully diverted through 5 diversion tunnels; each of 9.5m dia, having a cumulative length of approximately 3km (Photo 4).The tunneling was carried out through heading & benching method. The scheduled time for completion of diversion tunnels was between 5.5 months to 7.5 months whereas actual time taken varied between 17 to 26 months. The construction of 8 numbers of HRTs, each of 9.5m dia, is under advance stage.

4. Risk assessment and management plan for underground works:

The risk management plan implies identifying risks for particular projects and helps in the quantification and mitigation of such risks. The risk management system must be implemented as an integral part of the overall project management system, to provide assurance that the project shall be completed on time, on budget and in compliance with the specified contract and statutory requirements

Risk management essentially consists of five steps - risk identification, analysis, formulation of tackling measures, implementation, and review. The four steps, viz., risk identification, formulation of remedial measures, implementation and review, are normally carried out, albeit in an ad hoc manner, in most of the projects. The fifth one, i. e. analytical part, is an important but normally a weak, if not missing link in the chain of risk management.[4]

Tunnelling and underground construction works impose risks to the owner as well to the contractor. Due to the inherent uncertainties, including geological and groundwater conditions, there might be significant cost overrun and delay risks as well as environmental risks. Also, as demonstrated by tunnel collapses and other disasters in the recent past, tunneling works are subject to high risk. Geotechnical risks in conventional tunneling are stress related problems resulting in squeezing ground condition in weak rocks and rock burst condition in massive rocks under high cover, cavity formations, water ingress and geothermal conditions. Traditionally, these risks are being managed indirectly through the engineering decisions taken during the project development. However, risk management processes can be significantly improved by using systematic risk management techniques throughout the tunnel project development. By using these techniques, potential problems can be clearly identified and an appropriate risk mitigation measures can be implemented in a timely manner.

5. Conclusions:

Fast track tunneling is need of the time for accelerated development of hydropower. The use of mechanized tunneling, viz. TBM and road header deployed in some of the NHPC projects have met with partial success mainly due to geological complexities typical of Himalayan region. Nevertheless, with a proper site investigation programme and Risk assessment many of the geotechnical problems can be predicted and handled successfully.

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