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Different techniques adopted to tackle the geological adversities during the construction of Rampur hydro power station (412 MW) –A case study of head race tunnel

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Abstract

The Rampur Hydro Electric project (RHEP) with generation potential of 412MW is located on river Satluj, a major tributary of Indus basin, in Shimla and Kullu district of Himachal Pradesh. The project is designed as a cascade tandem operating plant to Nathpa Jhakri project. The design energy approved for Rampur HEP is 1900 million units of electricity per year. The construction of RHEP is completed with generation starting during March 2014. All six unit were commissioned in December 2014. RHEP comprises of 15.117km head race tunnel, 162.5m deep surge shaft open to sky, a multi-junction, three pressure shafts, power house, collection gallery and outfall channel. The RHEP constructed in the lesser Himalayan Zone on Satluj river basin and local geological setup of Project is Rampur- Kullu Group.

The HRT was excavated through different lithologies having varying geophysical and geotechnical characteristics. The entire length of HRT was intercepted by various small scale structural features like shear zones, shear seams, local folds and faults. Beside this, the excavation of the HRT was influenced/ affected by major mechanical adversities viz. intersection of thrust zone, flooding, hot water zone, squeezing conditions and cavity formation. The geo-mechanical adversities were tackled by various techniques practiced world over viz. DRESS methodology, PU Grouting, installation of lattice girder, use of hydraulic hammer for excavation in poor strata. The main focus of present paper is on the strategy, planning, monitoring and execution of various remedial measures adopted to tackle geological adversities.

The experience gained from successful execution of this project is being shared through this paper so that it can serve as a valuable reference for the designing and construction of future hydro power projects.

1. Introduction:

India is endowed with significant hydroelectric potential and ranks fifth in the world in terms of usable potential. As per the latest available data, India has around 44 GW of installed hydropower capacity whereas an additional 13 GW is under construction. This puts the total capacity which is yet to be tapped at around 67% of the potential.

The hydropower potential is mostly available in the Himalayan terrain of India and to harness the 67% of the identified potential, it is pertinent to adopt state-of-the-art investigation and construction techniques to minimize geological risks as well as the overall gestation period of any hydel project.

Highly dynamic physical processes dominate the mountainous terrain of India, and therefore, development of hydropower projects in this terrain is challenging. Construction, maintenance and rehabilitation of infrastructure under the unique Himalayan condition require innovative and more pragmatic approach compared to less critical terrains in other parts of the world. From the tunneling perspective, the Himalayas are continually posing most challenging ground conditions in the World. One of the prime reasons for this is that they are the youngest of the mountain chains and hence most dynamic of all.

Many earlier projects have also faced various problems during investigation, design and construction phases, and in the process invaluable experience has been gained during the last few decades. New concepts, approaches and techniques appropriate to this unique Himalayan terrain are gradually emerging. These techniques and experiences are important and far reaching, and may be applicable in similar regions of the developing world. Over the years, India has gained a significant amount of experience in underground infrastructure development whether it is tunneling for Water conductor systems, transportation and underground storage.

The tunneling works in the Indian Himalayan region is a formidable task with considerable problems caused by formation of major cavities, heavy ingress of water, squeezing rock mass conditions, weak rock zones associated with thrusts; folds; faults, geothermal gradient and high rock covers. The combination of inherently weak geological characteristics and inadequate/insufficient investigations along deep tunnels alignments result in longer delays in scheduled commissioning of projects and escalated cost.The success and failure of the last five decades of engineering practices in India need to be seriously analyzed and lessons learnt must be carried forwards for the future projects.Gradually, realizing the importance of the engineering geological study in a mountainous terrain, such studies were extended also to other infrastructure development.

The main focus of present paper is on the strategy, planning, monitoring and execution of various remedial measures adopted to tackle geological adversities during the construction of 15.157 Km Head Race Tunnel of Rampur HEP.

2. About the Project:

Rampur Hydro Electric Project with an installed capacity of 412 MW, located in Shimla and Kullu district of Himachal Pradesh. The project has been planned and designed in tandem with run of the river NathpaJhakri HE Project (1500 MW) for a design discharge of 383.88 cumecs available at tailrace outfall. The water from Rampur intake structure is conveyed to the right bank through a 10.50 m dia HRT, 15.177 Km long, followed by a 140 m deep, 38 m diameter surge shaft (open to sky) at its tail end. The length of HRT at the left bank is 550 m before it crosses the river Satluj. The water further enter into three partly underground & partly surface penstocks of 5.4 m diameter, which further bifurcated into 6 nos. to feed the each unit in the surface powerhouse.(Figure1).

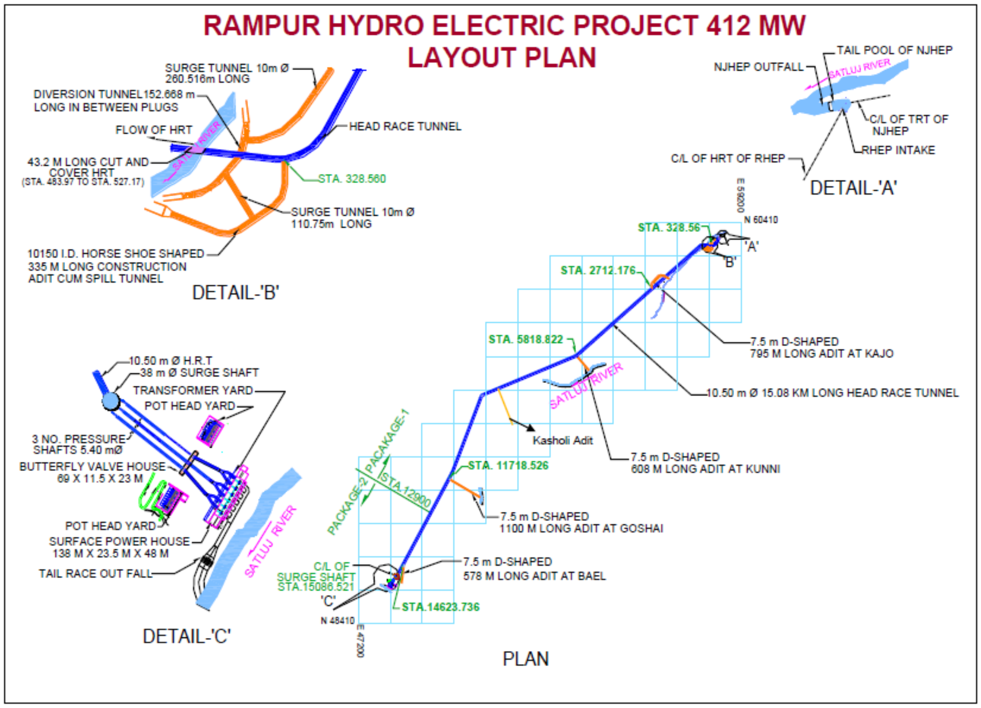


Figure1 General Layout plan of the Project

3. Geology along head race tunnel:

15.177 km,10.50m diahead race tunnel of Rampur HEP is located on the right bank of Satluj river including 484m length on the left bank and about 43.2 m length below the river bed as crossing tunnel from left to right bank. In general the HRT has been excavated under the average cover of less than 600m except a reach of 350m where the cover was 1100m. The HRT alignment intersected three major khads namely Kazo, Kunni and Kasholi. The cover above these HRT- khad crossing was of the order of 80-180m. To ensure sufficient cover above the tunnel underneath two khads (Stream), the tunnel has been provided with two bends, one at Kunni khad and another at Kasholi khad. The excavation of HRT was initially taken up from 4 numbers of adits. Later on an addition 5th adit has been introduced. The maximum distance of HRT between two adits was 6.08 Km.

The tunnel during excavation was expected to pass through three major group of rocks viz., Jeori-Wangtu Gneissic Complex, Kullu Group and Rampur Group of Precambrian age. The various rock types belonging to these Groups intercepted during the tunneling were quartz mica schist, quartzite, quartzitic phyllite, phyllite and amphibolites. These rocks were folded, moderately to closely jointed and have fractured and sheared zones/seams at places. The HRT has also intersected by two major thrust namely: Jhakri thrust and Kullu thrust.

The rocks belonging to Jeori - Wangtu Gneissic Complex occupy a limited stretch of the project area between Rampur Intake and Kajo khad. This stretch is represented by quartz mica schist, which is well exposed on the right bank of Satluj and mostly covered by thick overburden deposits on the left bank.

The Rampur Group of rocks occupied a large segment of the project area extending from Kajo Khad to almost near Bael village (Power House site). The Group is represented by metabasic volcanic flows with minor white quartzite and ortho-amphibolite bodies, quartzite and phyllite.

The Kullu Group of rocks occupied a limited area towards the downstream end of the project. This formation is represented by Phyllites, carbonaceous-phyllite, slate and limestone/dolomite with quartzite inter beds and Bael Power House has been located in this formation.

4. Major adversities along Head Race Tunnel:

The HRT was excavated through different lithologies having different geophysical and geotechnical characteristics .The entire length of HRT was intercepted by various small scale structural feature like shear zones, shear seams, local folds and faults. Beside this, the excavation of the HRT was influenced/ affected by major mechanical adversities viz. intersection of Thrust zone, flooding, hot water zone, squeezing conditions and cavity formation. Following were the major adversities highly influenced the progress rate of excavation and project completion schedule.

Sr. No.	Location	Adversity	Geology
i	Kazo HRT Reach (±1349m)	Heavy Water Ingress (Unpredicted) @ 180-350 Lit/sec Occurrence of Hot water zone (40°C)	Highly jointed quartzite. Thrust zone in the close proximity. Production loss of two months
ii.	Kazo HRT Reach RD. 1464 – 1508m	Excavation through 44m long thrust zone and about 36m hot water zone with 39°C with water ingress @ 300-350 lit/sec.(Predicted)	Thrusted contact (Thrust Zone) in between older group JeoriWangtoo Gneissic complex and Rampur Group.
iii.	Kunni HRT d/s reach(between RD. 5258 & 7955m)	The squeezing rock conditions resulted in development of failure of support system and deformations like bending and twisting of steel sets and lattice girders and distortion and detachment of face plate of rock bolts and major cavity formation.	Sheared Micaceous phyllite and bands of amphibolite which are highly stained and weathered.
iv.	Kasholi HRT downstream (RD. 52m to 80m)	Numbers of cavities were encountered between RD. 52m to 80m which finally resulted in collapse of the entire reach excavated for a length of 28m.	Sheared MicaceousPhyllite and Quartzite.

i. **Kazo HRT Reach (±1349m):**

The major adversity (unpredicted) during the excavation of this reach of HRT was encountered at RD ± 1349m in the form of heavy ingress of water @180-200 liters/sec from the face & crown. Tunnel was flooded when the discharge suddenly increased to 300-350 liters /sec. The observed physical conditions at face were suggestive of the effect of thrust zone in the close proximity. The rock was highly jointed quartzite with staining along joint surfaces. The seepage water had a temperature of about 33º to 35º. The extent of flooding was so high that it has taken 2 months for restoration of the site.

The major challenges which were identified before the mitigation of the adversity were:

- To overcome flooding of tunnel by increasing pumping capacity or by other means and then establishes access to the site.
- Due to 80m head difference between HRT junction and Adit portal, situation became alarming for proper dewatering operation for such a high ingress of seepage water.
- More water can be expected as we were in the close proximity of the shear zone.
- The cement grouting may not be possible in heavy inflow of water.

Photo1 &2: Flooding in HRT (boat on RHS for monitoring of seepage water.

After detailed studies/analysis,it was apprehended that HRT may be got flooded up to Kunni D/s excavation. Therefore, to tackle excess seepage water, it was decided that a masonry wall will be constructed at RD. 850 m in Kunni U/s to make storage so that gravity flow of water through additional pipe line is carried out up toKunni junction.And after that the water taken at junction will be dewatered through Kunniadit by additional pumps & pipeline.

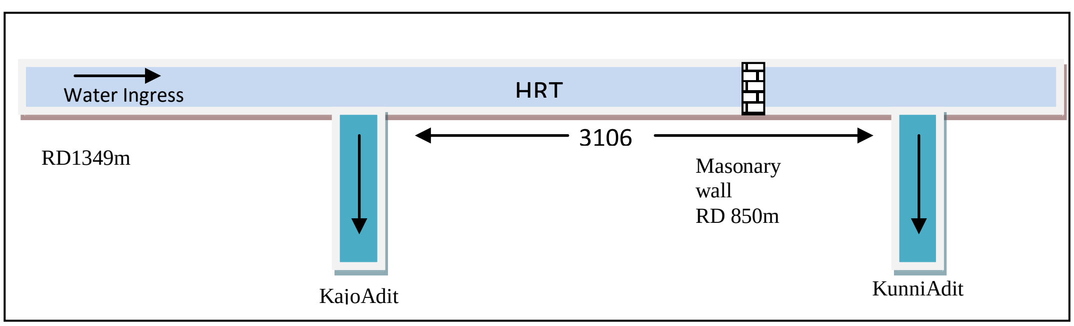


Figure 2 Plan of Dewatering during Flooding in KazoHRT.

Further during the deliberations an alternate route to dewater through 2nos., 100mm dia. holes for a length of about 120m was also considered. But due to some limitations viz. chances of connection with river through these holes resulting into more ingress of water, difficulties to drill 120m long holes at an angle of about 17º upward and requirement of more than 100mm dia holes for effective dewatering ruled out the proposal.

Finally it was decided to dewater the tunnel by installing additional 05 nos. pumps of 60HP each and 8” pipeline in addition to existing dewatering system. In total, the dewatering was done by about 997 HP capacity water pumps. Seepage at face was tackled by making a ramp in the central portion of HRT.Keeping in view the ingress of seepage water, instead of backfill concrete, porous concrete or shotcrete with wire mesh rolls in layers up to the crown was adopted so that seepage water does not block behind the ribs & create pressure.

Photo3 Wire mesh rolls filling in cavities

Photo4 Shot creting being done to embed ribs

In addition PU grouting to strengthen the face & crown was carried out before further advancement. Material used for PU grouting U-res (Urethane), M1and Unicat-2C was injected by 45mm¢ hole at an angle of about 30º to 35º (Periphery Hole).

ii. Excavation through 44m long thrust zone and Hot water zone:

During the investigation stage of the project a 27m thick thrust zone with highly sheared sericitic, chloritic, muscovite quartz mica schist having 100% water loss with very low RQD was predicted between RD 1300 m to RD. 1500m by an 160 m deep exploratory hole. It was also apprehended that there will be a possibility of encountering high temperatures along this thrust zone during the excavation of tunnel.

During the actual excavation, Kazo HRT has encountered 44 m long thrust zone and about 36 m hot water zone having water temperature up to 39°C with ingress of water ranging from 300-350 ltrs/sec between RD. 1464m to 1508m. The tunneling through this zone was very challenging task because of very friable nature of rock associated with thermal gradient. As it was known therefore proper planning and resources management have already been done before the actual excavation. A vigorous planning along-with deployment of state of the art equipment, machinery, techniques and interpretation of geological data helped in crossing this adverse zone without eventuality of any mishap. The methodology adopted to cross the thrust zone and hot water zone is as follows:

- **Multi-drifting:** A drift of size 2mx2m was excavated manually to know the rock conditions ahead in temperature of about 40º C.
- **Injecting PU grout:** The face condition was improved by injecting PU grout by drilling 45mm¢, 5m long holes all along the periphery and in the face keeping an overlap of 2m.
- Excavation was done with hydraulic hammer only for a step of 1m of each. No drilling & blasting was advisable due to extremely poor rock conditions.
- **Pipe roofing:** 50mmϕ, 5.00m long pipes were inserted along the periphery as pipe roofing after keeping an overlap of 2m.
- **Steel Fibre Shotcreting (SFRS):** Steel Fibre Shotcreting(SFRS) was applied so as to embed whole of the steel ribs &wire mesh rolls into shotcrete
- Consolidation cement grouting was further injected for final strengthening of the reach along with additional bolting of 32mm c/c, 5m long bolts were also provided.

Photographs 5 & 6 Multidrifting along thrust zone

Photographs 7 & 8 Application of hydraulic hammer and impression of fore poling

iii) Kunni HRT d/s reach (between RD. 5258 & 7955m):

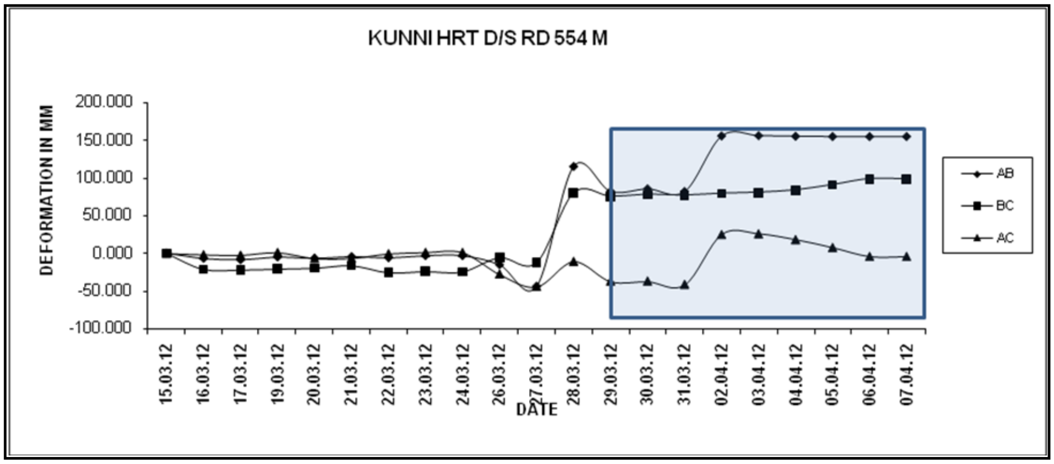
The main tunneling hazards during the construction of Kunni HRT were development of instabilities in rear zone of HRT, Squeezing Conditions, Rock Fall, Cavity formation during benching. Failure of lattice girders which were installed in downstream posed a great challenge and squeezing conditions enhanced the quantum of failure. Bending of face plate of the rock bolts, bending and twisting of lattice girders and detachment and development of huge cracks in shotcrete layers was also a common phenomenon observed during execution of downstream reach of HRT.(Photos: 9&10). The modification in design of rock support was adapted later to counter this problem.

Apart from this, large cracks were also observed in shotcrete and the installed support system was encroached into the final section of concrete lining from crown, left wall and right wall portion.

Photographs 9 & 10 Deformation in lattice girders and bending of steel ribs.

In order to counter the squeezing rock, HRT section was depressed by $\pm$1m and envisaged for a length of 500m between RD. 500m to 1000m in order to avoid scaling of encroached and deformed support system which resulted in implementation of safe and effective methodology for tackling the severe squeezed rock conditions. The strain percentage varies from 2.5% to 5% in squeezing rock zone and 1% to 2.5% in other reaches.

The monitoring of deformation was carried out at number of places before and after the appearance of squeezing rock condition. The representative deformation data at RD554 m is plotted in the graph shown below. This data incorporates relative displacements between the Bi-reflex paper targets installed at crown, left SPL and right SPL after the refurbishment of squeezed rock conditions. The relative displacements shown in box were measured during benching excavation.



In order to tackle the squeezing rock conditions following methodology was adopted at site in consultation with the design department.

- Passive support of steel sets.
- Installation of Bi-reflex paper targets for monitoring at regular interval of 12m.
- Additional rock- bolts of longer length of 7.5m.
- Drain holes of longer length & size of 89/102mm.
- Additional shotcrete in the cracked areas.
- Rock-bolts which were initially of 25mm Ø was increased to 32mm Ø.
- Rock-bolts which were initially of 4m to 4.5m length were changed to 5m to 7.5m.

iv) Kasholi HRT downstream (RD 52m to 80m):

The main rock types encountered during the excavation of HRT were; Amphibolite, bands of Phyllitic Amphibolite, sheared Micaceous Phyllite, Mica Schist with moderately jointed hard Quartzite with prominent fracturing at the contact of sheared Micaceous Phyllite and Quartzite. The rock cover in this reach varies from 130m to 500m.Extremely poor rock conditions were encountered between RD 52-80m, which resulted in formation of three major cavities prior to the collapse of entire excavated and supported reach of 28m in downstream. The sequential occurrence of major cavities between RD. 52m to 80m along Kasholi HRT d/s are tabulated below:

S.No.	Date	RD(m)	Extent of Cavity
1	06-11-2009	52	cavity of around 6.0-7.0m height formed in the crown.
2	10-11-2009	54	Loose fall of around height 7-8m damaged 2no. Ribs and forepole umbrella.
3	01-12-2009	63	Damaged 3 sets of steel ribs and channel fore poles.
4	01-01- 2010	55-79	Whole reach got collapsed.

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Photograph 11 & 12 Extent of cavities formed at RD's 52 and 63m respectively

For the treatment of this cavity, many methodologies were used like pre grouting, pipe fore poling, multi drift excavation etc.

- **Pre-grouting and Pipe fore poling:** These methods were followed to tackle this cavity reach. For the pre-grouting 50mm diameter & 5m long holes were drilled at a spacing of 0.5m in 2-3m behind the face. PVC pipes were inserted in those holes & grouted. Then Pipe fore poling was performed at the face & grouting was done in those pipes.
- **Multi-drifting:** After the pre-grouting and pipe-fore poling, multi drift excavation was started at RD 55m by excavating two drifts at bottom (LHS & RHS). These drifts were of size around 2m X 2m. Another drift of similar dimension was excavated at the crown of length about 15m. After this the space between two drifts was manually excavated and supported by steel ribs one by one. This method was followed up to the RD 68m.

Photo 13 Multi drifting in progress

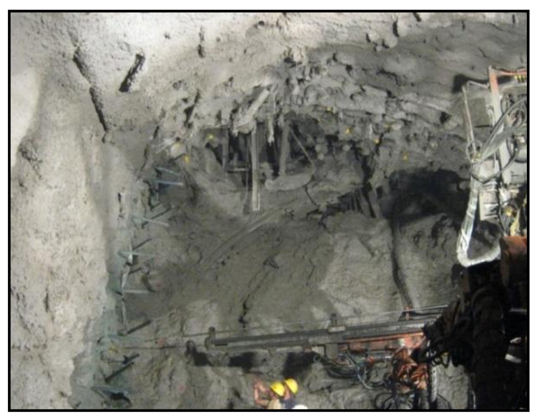

Photo 14 Pre-grouting at face

From RD 68m onwards excavation was followed in Adit shape (D-shape) as it was difficult to excavate the full section in loose muck. In parallel grouting was continued to consolidate the loose muck in crown and sides. In this method crown segments of steel rib of size ISHB 150 X150mm @ 34.60 kg/m were used and verticals of about 6m were used having section ISHB 200 X 200 mm @ 40 kg/m. This method remained very much successful for us. Both sides and crown was well consolidated by intensive grouting and smaller section of excavation helps a lot. This method followed till the end of cavity i.e. up to RD 80 m.

Photo 15 Excavation of HRT through D- Shaped Adit

Photo 16 Drift from Bye pass junction (U/S Side)

After that excavation as drift shape from bye pass junction (U/S side) commenced of having dimensions 2m X 2m.

Due to occurrence of this cavity the face was stand still for many days. As a result it was proposed to treat the cavity by introducing a bye-pass adit as well as to complete the excavation of HRT in schedule time. Alignment of this adit, having a diameter of 7.5 m is kept parallel to HRT. During the excavation of bye pass adit drill and blast methodology was adopted for initial reach having hard Amphibolite rock. After the disappearance of hard rock, the weak sheared Micaceous Phyllite rock was excavated by Twin Cutter and installing of pipe fore poles. The lattice girders have also been installed from RD 60m onwards up to junction.

5.Conclusion:

From the tunneling perspective, the Himalayas are continually posing most challenging ground conditions almost anywhere in the world. In addition to this, long deep seated tunnels through mountainous terrain, it is generally neither physically nor economically feasible to drill a sufficient number of boreholes and exploratory drifts to investigate all the rock units and weak zones along the entire alignment. Further it is difficult to interpolate the geological conditions between widely spaced boreholes or adits consequently resulted in tentative estimation of geotechnical parameters. Sometime this will skip many important weak zones, shear zones and other geological structures which during actual execution of the tunnels pose lot of problems result into cost and time over run of a feasible project.

To overcome the adversities it is imperative to have a blend of adequate investigations by means various latest techniques, interpretation of geological data, vigorous planning along-with deployment of state of the art equipment, machinery, techniques as well as involvement of geologists at site, close liaisoning with construction engineers, and their team together during the construction of any tunneling project which can help in timely completion of project without eventuality of any mishap and in cost effective manner. The construction of RHPS was done with the same approach to tackle various adversities by adopting different innovative and simple proven remedial measures. Geotechnical techniques viz. use of twin cutter in weak rock zones, multi-drifting during the restoration of cavities and thrust zone, use of PU grout in established adverse geological zones (Thrust zones) and use of geotechnical instruments to identify the behaviour and interaction between applied design support and rock mass during excavation as a whole etc. are successfully applied in RHPS during the construction stage of the project.

The experiences and lesson learnt during the application of these simple and prudent geotechnical techniques as applied in RHPS must be carried forwards for the future projects.

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