Excavation of 17km long head race tunnel for 1000MW Karcham Wangtoo hydroelectric project in NW Himalaya

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Abstract

This paper brings out various aspects in respect of excavation of 11.28 m (excavated) diameter, 17 Km long Tunnel for conveying 421 Cumecs of water of river Satluj from Karcham Dam to generate 1000 MW power in an underground Power House at Wangtoo. The tunnel traverses through the lesser Himalayan rock formation comprising ortho and para gneisses of Jeori – Wangtoo Gneissic Complex with number of geological discontinuities in the form of shear zones, high rock temperature zone and high rock stress zone . The tunnel has been excavated by conventional drill and blast method in heading (7.5 m) and benching (3.78 m) sequence. The Norwegian Method of Tunneling (NMT) by using Barton's "Q" system was adopted for rock classification and providing the support system. The support system comprises mainly up to 100 mm thick shotcrete and 25 mm dia 4.5 to 5 m deep rock bolts. In very poor and extremely poor rock conditions, steel rib support made of ISHB – 200 has been provided in the heading section with spacing varying 0.5 to 1.0m c/c and backfilled with M-15 concrete. To ensure safe blasting operations, Nonel detonators have been used.

The tunnel encountered adverse geological conditions in 200 m length in extremely poor and flowing geological conditions wherein face advancement was done by following the "DRESS" technique of tunneling. The HRT also passed through very high temperature zone of up to 98^{0}C in 350 m length wherein the heading excavation was done by multiple drift method and jetting of cold water in drill holes and surrounding areas to bring down the rock temperature below 80^{0}C. During the tunnel excavation, problem of rock bursting was also faced in reaches of high rock cover of up to 700 m depth as well as due to the release of locked up stresses even in rock cover of 300 m depth. These tunneling problems notwithstanding, the tunnel heading excavation has been carried out in an accelerated timeframe of 26 months.

1. Introduction:

Karcham –Wangtoo Hydroelectric Project (1000 MW), the first largest Hydro Power Project in the Private Sector is being executed on river Satluj in Kinnaur District of Himachal Pradesh by M/s Jaypee Karcham Hydro Corporation Limited on "Build-Own-Operate-Transfer basis". The project envisages harnessing of hydro potential of the middle reaches of Satluj river in the form of run of the river scheme by diverting 421 cumec water by placing a 88 m high concrete gravity dam at Karcham through an intake, desilting chamber complex and a 17 Km long Head Race Tunnel to generate 1000 MW (250 x 4) of power in an underground Power House at Wangtoo and then release the water back into Satluj river through a 1.25 Km long Tail Race Tunnel. The layout of project is shown in fig.1. The Project is in advanced stage of execution and is scheduled for generating power during 2011. The real achievement in implementing such a mega project is the breakthrough of the major component i.e. 17 km. long 11.28m dia horse-shoe shaped Head Race Tunnel although through number of geological discontinuities and geothermal gradients.

This paper highlights the excavation methodology adopted by following the optimized drilling pattern, deployment of high capacity equipment and providing the required rock support system besides tackling the adverse geological feature and high temperature zone.

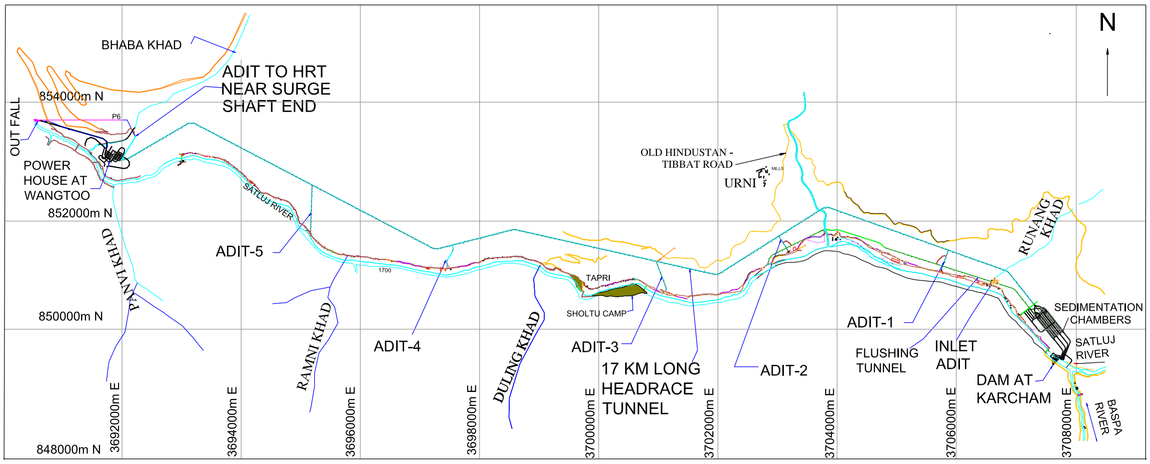

Figure 1 General layout of the project area

2. Geological setting of the area:

The project area is located in Lesser Himalayan Terrain having rock types belonging to Precambrian age and comprising of ortho and para gneisses of Jeori Wangtoo Gneissic complex forming basement of Rampur Group of rocks. This rock group is surrounded by Salkhala and Jutogh group of rock having thrusted contacts and is called Rampur window [1,2,3] which extends from Kulu in the Beas valley in north to Karcham in Satluj valley in the South-East. Three thrusts namely Salkhala thrust, Jutogh thrust and Main Central Thrust (MCT) have been marked about 90 m, 300 m and 10 Km upstream of Dam site respectively. These thrusts have a general N-S trend and dip upstream side i.e. easterly. It is interesting to indicate that, at the locations of the thrusts, the rocks have uniform strike and dip and no large scale shearing normally associated with the Himalayan thrust is present at site.

The Head Race Tunnel is entirely excavated through gneiss and its lithological varieties i.e. Schistose porphyritic and augen gneiss with mica schist bands (from RD 00 to 8.0 Km); Quartzitic gneiss with subordinate biotite schist bands (RD: 8 Km to 9.35 Km) and Granite gneiss with subordinate amphibolites and schist bands (9.35 to 17 Km). The rock stratum is massive as well as foliated and jointed. The major geological discontinuities encountered during tunneling is represented by number of long continuity 10cm to 6.0 m thick shear zones, slip planes, closely spaced joints, rock burst/distressing zones and high temperature zone. The shear zones and joint planes trend at angle varying from 10º to 80º with tunnel alignment which is variable. On the basis of 'Q' system [4,5,6] the rock strata of the HRT has been classified into Good (10.25%), Fair (46.10%), Poor (37.90 %), Very poor (4.10%), extremely poor (0.84%) and exceptionally poor (0.81%) categories.

3. Excavation and support system:

The 17 Km long Head Race Tunnel has been aligned and excavated in NW – SE, direction and is excavated through 7, 7.5 m dia approach adits namely Inlet Adit (280 m) Adit No.-1 (372 m), Adit No.– 2 (310 m), Adit No.– 3 (534 m), Adit No. – 4 (373 m), Adit No. 5 (797 m) and Adit to HRT near Surge Shaft end (467 m long). Excavation of Adits started on 2nd January, 2007. Excavation has been carried out by DBM method in top heading of 7.5 height and benching of 3.78 m depth. In all respect the heading was completed in 26 month on July 27, 2009 and benching subsequently on April 1st 2010.

The major equipment comprises Atlas Copco L2D Drilling Jumbos, Komatsu excavator PC-400, JCB excavator, BL loader, CIFA /Schwing/Aliva Wet Shotcrete Machine, Volvo FM 500 and Tata 2516 dumpers. In addition 5 Drill Jumbos, 4 PC-200, 2 JCB,s, 2 Shotcrete Machines and 2 Loaders were kept standby ready near adjacent adits and deployed if the breakdown of running equipment was > 2 hours.

Major factors for tunnel excavation and its stability are geological discontinuities drilling pattern and the rock support system at every advance. During excavation of HRT, burn cut pattern of drilling was implemented. Special attention was given in drilling and charging of periphery holes, aligned horizontally @ 0.3m c/c spacing and charged alternatively with 25mm dia cartridge filled in PVC pipes for controlled over break. The drilling depth was considered on the basis of rock categories i.e. 4m depth in fair to good rock, 1.5m depth in poor rock and in very poor to extremely poor category, multiple drift method of excavation was implemented by using < 15 Kg gelatin. Likewise, benching was carried out by horizontal drilling which was found suitable from under brake/over break considerations besides enabling speedy construction. In totality the average powder factor achieved was in order of 1.5 Kg/M^3 and the over break remained within 10%. In view of safety the detonators used at site were nonelectric.

On the basis of rock strata at every advance, the required support system was provided concurrent to excavation. The rock support system adopted during excavation in different rock category is given in Table 1.

Table 1
Summary of rock support system adopted at site

Class	Q value	Rock category	Rock Support system
2	10 - 40	Good	25 mm dia (Fe 500) 4.5/5.0 m long (alternate) resin end anchored and fully cement grouted rock bolts @ 2.5 m c/c both ways (staggered) with 25 mm thick plain shotcrete.
3	4 - 10	Fair	25 mm dia (Fe 500) 4.5/5.0 m long (alternate) resin end anchored and fully cement grouted rock bolts @ 2.25 m c/c both ways (staggered) with 50 mm thick plain shotcrete.
4	1 - 4	Poor	25 mm dia (Fe 500) 4.5/5.0 m long (alternate) resin end anchored and fully cement grouted rock bolts @ 2.0 m c/c both ways (staggered) with 75 mm thick plain SFRS (Steel fibre reinforcement shotcrete).

5	0.1 – 1.0	Very poor	25 mm dia (Fe 500) 4.5/5.0 m long (alternate) resin end anchored and fully cement grouted rock bolts @ 1.5 m c/c both ways (staggered) with 100 mm thick SFRS and ISHB 200 Ribs @ 0.75m t0 1 m c/c with backfill concrete.
6	0.01 – 0.1	Extremely poor	Fixing of 89 mm dia and 6 m long perforated seamless fore pole pipes @ 0.3 to 0.5 m c/c with cement grouting, Drainage holes, followed by tunneling with Multiple heading and supporting with ISHB 200 Ribs @ 0.5 m to 0.75m c/c with backfill concrete and drainage holes.
-	0.001-0.01	Exceptionally poor	Fixing of 89 mm dia and 6 m long perforated seamless fore pole pipes @ 0.3 to 0.5 m c/c with cement grouting, Drainage holes, followed by tunneling with Multiple heading and supporting with ISHB 200 Ribs @ 0.5 m c/c with backfill concrete and drainage holes.

3.2 Excavation through Weak Zones:

Major weak zones encountered during HRT are in the form of 2 to 6 m thick gougy shear zones with flowing conditions and rock bursting/distressing zones. The account of major geological discontinuities encountered and the treatment is presented in Table 2.

Table 2
Account of some typical weak zones in HRT and their treatment measures

Location	**RD (In meter)**	**Rock quality**		**Feature/ Discontinuity**	**Treatment adopted**	**Days taken**
		“Q”	**Category**			
HRT d/s from Inlet	390 - 440, 465 - 468.5, 474 -512.2 884 - 895.25	0.087 – 0.95	Very poor to extremely poor	0.5 - 4.5m thick multiple gougy shear zone with seepage condition, created 2-3m. deep cavity at crown and wall	32 mm dia, 5.0 , 6.0 &7.0 m. long rock bolts with 100 mm thick shotcrete (390-440) and ISHB 200 Ribs @ 0.5 m to 0.75m c/c with backfill concrete.	82
HRT d/s from adit - 1	1081 - 1105	0.06 - 0.08	Extremely poor	Long continuity 6.0 m thick gougy shear zone with flowing condition created 10 m deep cavity.	Concreting of the cavity followed by fore-polling, grouting and ISHB 200 ribs @ 0.5 – 0.75 m c/c with backfill concrete.	60
HRT u/s from adit - 2	458 – 470,	0.085	Extremely poor	2.0 to 4 m thick gougy shear zone created 5m to 7m deep cavity at crown.	Plugging and concreting/grouting of cavity portion followed by ISHB 200 Ribs @ 0.5m to 0.75 m c/c with backfill concrete.	50
HRT d/s from adit - 2	169 - 179.5, 431.5- 434 772 - 798, 850.5 - 872 1066 - 1115	0.2 – 2.8	Poor to very poor	Multiple shear zones and long continuity schist band. with seepage.	Additional rock bolts with 100mm thick SFRS & ISHB 200 Ribs @ 0.75 - 1 m c/c with backfill concrete.	87

HRT d/s from adit - 3	385.5-407.3	0.008 – 0.07	Extremely poor to exceptionally poor	1.5 – 3 m thick shear zones filled with gougy material.	Fore-polling, grouting and ISHB 200 Ribs @ 0.5 to 0.75 with backfill concrete.	35
HRT u/s from adit - 4	1063–1413	7.5	Fair	Hot zone with rock temperature ranging from 78° C to 98° C.	Initially the blasting work was suspended due to high rock temperature (w.e.f. 19-12-09 to 26-12-09). However, the face was advanced by jetting and injecting cold water and getting short pulls in multiple drift method.	142
HRT u/s from adit - 5	710 - 797.5, 806 - 812, 865 - 884, 893 - 906	0.008 – 0.1	Extremely poor to exceptionally poor	4m. to 6 m thick gougy shear zone with flowing condition created 4m to 25m deep cavity at crown and wall	Concreting of the cavity followed by fore-polling, grouting and ISHB 200 Ribs @ 0.5-0.75 m c/c with backfill concrete.	142
	828 - 856, 967-972, 986 - 995, 1003-1007, 1017 - 1020	1.2 – 1.7	Poor	Rock burst/Distressing zone manifested by 05mm to 40 mm open cracks, bending of rock bolt plates and detachment of 32mm dia rock bolts.	32mm dia, 5.0 & 6.0 m deep additional rock bolts with 100mm thick SFRS and ISHB 200 Ribs @ 1 m c/c with backfill concrete.	35
HRT d/s from adit - 5	716 – 740	0.005 – 0.01	Extremely poor to exceptionally poor	4.0 m to 5.5 m thick Shear zones filled with crushed quartz and gougy material created flowing condition and 4m to 15 m deep cavity.	Concreting of the cavity followed by fore-polling, grouting and ISHB 200 Ribs @ 0.5 to 0.75 m c/c with backfill concrete.	62
HRT u/s from S/Shaft end	1241–1245, 1791 - 1798	1.4 – 2.8	Poor	Rock bursting zone	32mm dia, 5.0 & 6.0 m deep additional rock bolts with 100mm thick SFRS and 13 nos. ISHB 200 Ribs @ 1 m c/c with backfill concrete.	16

The problem of adversely oriented 0.5m to 6m thick shear zones associated with seepage, cavity formation and flowing condition was encountered in all faces of HRT. The shear zones were filled mainly with crushed, clay and gougy material (Photo 1 to 4) and trend at an angle varying from 10^0 to 80^0 with tunnel alignment which is variable.

Photograph 1 Treatment of gougy shear zone and 10m high cavity by channel fore-poles

Photograph 2 Shear zone gushing down crushed material and created about 8m deep cavity at crown.

Photograph 3 Long continuity 4m to 6m thick gougy shear zone tackled with fore- polling technique.

Photograph 4 Close – up view of 5.5m thick gougy shear zone with flowing condition tackled with fore- polling and multiple drift que.

3.2.1 Measures taken:

Following measures were implemented to negotiate the shear zones/cavity zones:

(a) Shotcreting of exposed part of shear zone and cavity.
(b) Filling and consolidation of the cavity and loose muck with concreting and extensive grouting.
(c) Fixing 89mm outer dia, 6m long perforated seamless fore pole pipes in two pieces of 3m length with the L2D boomer, which was converted by Atlas Copco fore - polling conversion kit with high torque motor and pilot/scarify bits.
(d) Grouting through fore-pole pipes repeatedly upto pressure of $10Kg/cm^2$
(e) Re-mining/tunneling through grouted muck/sheared strata selectively by multiple heading, immediate shotcreting and followed by supporting with ISHB 200 Ribs @ 0.5 to 1m c/c with backfill concrete.
(f) Hard strata within shear zone was excavated by getting short pull of <0.5m with <15kg of gelatin.
(g) Drainage holes of 76mm dia were also provided at suitable intervals to negotiate seepage and pore water pressure.
(h) In highly flowing conditions, ribs were also extended during benching (Photo no 5 & 6).

Photograph 5 Benching through gougy shear zone.

Photograph 6 Extension of ribs concurrent to benching through gougy shear zone.

3.3 Tackling of high temperature zone:

The major surprise faced during excavation of HRT was in the form of unpredicted high rock temperature zone between Adit -3 and Adit -4 for a length of 350m. Wherein drill hole temperature ranging from 78º to 98ºC was encountered (fig.2). Such high temperature in the heading made the tunneling very difficult specifically when tunnel excavation had been proposed to be advanced by drilling and blasting method.

Due to extremely high rock temperature, work was temporarily suspended considering safety of men and machinery. An emergency visit of mining [7] and geology [8] experts was made in between 22nd February & 1st March, 2009 to assess the problem and evolve a site specific blasting procedure.

3.3.1. Geology of the face and exploration of high temperature zone:

The rock strata in the hot zone was fair granite gneiss with foliation strike N10ºW-S10ºE dipping 25º to 30º in north easterly direction It was noticed that the face was dry without any hot water dripping or flowing. The hot rock in the tunnel was initially observed from RD 770 m upstream from Adit No. 4 with 50º to 65ºC temperature. This range of temperature was recorded up to RD 1060 m. On 18th February, 2009 at RD: 1063 m the rock temperature showed increasing trend (78ºC) and rose up to 98ºC at RD 1067 m. No structural features/fault zone was observed near the hot zone. The tunnel in this part was completely dry with absence of any dripping or water seepage.

To demarcate any hot water body/springs, a traverse was made in surrounding areas, as a result of which three hot water springs were observed below NH-22 which are connected to right bank of Satluj river about 400 m. laterally outside of hot reach zone of HRT. As a part of exploration of hot rock zone, six probe holes of 51 mm dia and 20 m to 51 m deep were drilled at suitable locations along and across the heading. All the holes were found dry but steam/vapors having temperature ranging from 80ºC to 98ºC was observed (photo 7). On basis of the probe holes, nature of rock strata anticipated up to 51 m depth was continued to be sound with absence of any shear zone or any water bearing zone. It was therefore, decided to advance the face with effective ventilation, injecting and jetting cool water into drill holes as well as on the face with round the clock/practice (photo 8), which was able to bring down the temperature of the face and holes below 80ºC to make the face ready for blast in multiple drift method.

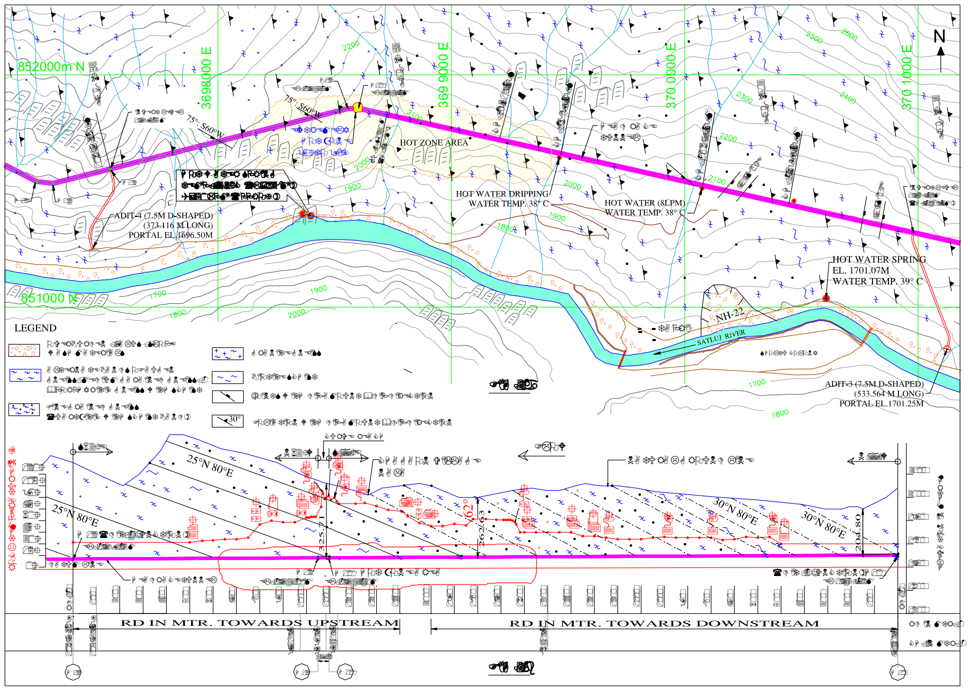

Figure 2 a. Geological plan; 2b Geological cross section of HRT between adit 3 and adit 4 showing high rock temperature zone (modified after Kadkade, 2010)

Steam vapors with 98^0C temperature

Photograph 7 View of high rock temperature reach of HRT.

Photograph 8 High rock temperature zone treated with cool water jetting.

3.3.2 Experimental Test of Explosive:

Temperature sensitivity test of the explosive and detonators was also performed at site with the help of hot water and blazing fire. On basis of the experiment it was revealed that the nonel detonators could not detonate even up to a temperature of 80ºC. However, it detonated when it received blazing fire. The experimental tests were performed in excavated portion of tunnel. The exact nature of detonator inside the drill holes with accumulation of high temperature and pressure was not precisely known. Likewise during testing/burning of the explosive, there was a continuous release of its energy to the atmospheres without subjecting to confinement /pressure accumulation. As per the Directorate General of Mine Safety regulation, blast holes with temperature above 80ºC should not be charged & detonated.

On basis of the exploration and experimental tests conducted at site, following methodology was finally implemented to negotiate the hot zone.

(a) Provided extra ventilation system up to face and kept minimum 4 oxygen cylinders and masks nearby face.
(b) Continuous injecting and jetting of cool water into drill holes, face and surrounding area to lower down the temperature well below 80ºC.
(c) Excavated face with multiple drift method by getting short pulls which involved advancement of 3 x 4 m size pilot blast of 2 m depth. Limited depth of 2 m was adopted only to reduce the charging time within 30-40 minutes.
(d) Before conducting the widening blast, blast holes and existing tunnel face was again treated with cool water to drop down the temperature below 80ºC and charged and blast within 40 minutes to avoid any deflagration and immature detonation.
(e) Placement of detonator within holes was strictly prohibited. Only detonating cord was connected for the corresponding rows/delays. Nonel detonators of required number were tied on the surface of tunnel face with detonating cord surrounded by moist/chilled cotton to restrict temperature within acceptable rang
(f) The 350m hot zone reach was negotiated in 142 days in this manner.

3.4 Rock Bursting Zone:

During excavation of HRT, problem of rock bursting was faced mainly in granite gneiss below 300 m to 700 m rock cover in form of sudden separation and throwing of a rock chunks with great force. This phenomenon was caused in fresh openings where rock cover was high and accumulated rock stress exceeded tensile strength of rocks. However localized rock bursting was observed at shallow depth (<350 m rock cover) also where a portion of rock was generally massive and un-jointed due to which the rock contained locked up stresses and were suddenly released on getting exposed in an opening. In some places the rock bursting continued even after 7 days of excavation and manifested popping and separation of rock layer behind tensioned rock bolt plates thronging off shotcrete with thin rock layer and also detachment of rock bolt plates and thread. On examination wherein the rock burst took place, the area produced hollow sound on mild hammering. This phenomenon was observed mainly in valley side wall of tunnel and died out in due course of time which varied from few days to few months.

3.5 Measures Taken:

In view of rock burst in massive rock and damage to men and machinery, excavation of HRT in this reach was carried out by providing additional rock bolts of 32 mm dia and 100mm thick shotcrete up to face at every advance with pressure relief holes at suitable intervals to negotiate popping sound and failure of rock chunks due to bursting. However, in some highly rock burst zone, additional bolts with shotcrete could not be effective, and as a result steel rib support was provided to check the popping of rock strata. In addition close monitoring of bursting zones was carried out and unnecessary movement of men's and machinery especially towards valley side wall was restricted.

4. Conclusions:

- For execution of 1000MW Karcham - Wangtoo H.E.P. on River Satluj, a 17Km. long and 11.28m (excavated) dia horse – shoe shaped HRT has been successfully excavated through Lesser Himalayan terrain comprising gneisses and its lithological varieties by using 7, 7.5m. dia approach adits.
- The Norwegian Method of Tunneling by using Barton's "Q" system was adopted for classifying and supporting the rock strata. The support system adopted in general was 25 mm dia 4.5 to 5 m deep pattern rock bolts with shotcrete up to 100 mm thick. Steel ribs made of ISHB – 200 were used to support the weak zones.
- The tunnel was excavated by conventional drill and blast method in two sequences, heading (7.5m) and benching (3.78m). However, the tunneling through highly sheared and flowing zones in 200 m. length was carried out by multiple drift and DRESS methodology. The major equipments deployed at site comprises Atlas Copco L2D Drilling Jumbos, Komatsu excavator PC-400/200, JCB excavator, BL loader, CIFA /Schwing/Aliva Wet Shotcrete Machine, Volovo FM 500 and Tata 2516 dumpers.
- Severe tunneling problem in the form of very high rock temperature zone of up to 98^0C was faced in 350 m. length. The problem was successfully tackled by continuous injecting/ jetting of cool water into drill holes to lower down the temperature in multiple drift method of excavation.
- The problem of high rock stress was also faced specially in granite gneiss. The excavation of HRT in this reach was carried out by providing additional rock bolts of 32 mm dia and 100mm thick shotcrete with pressure relief holes at suitable intervals to negotiate popping sound and failure of supported rock chunks due to bursting. However, in some highly rock burst zone, steel rib support was also provided to check the popping of rock strata.
- Smooth drilling and blasting pattern was implemented at site and minimized the over break under 10% and powder factor of the order of 1.5 Kg/M^3.
- In all respects, the heading was completed within 26 month on July 27, 2009 and benching subsequently on April 1st 2010.

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