Case History of Head Race Tunnel of Dulhasti Hydroelectric Project

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ABSTRACT

Dulhasti Hydroelectric Project is being executed by National Hydroelectric Power Corporation Ltd. (NHPC) and is located on river Chenab in District Doda of Jammu & Kashmir. The paper discusses the tunnelling problems faced during construction by tunnel boring machine in the upstream direction of head race tunnel.

Keywords: Dulhasti project, head race tunnel, tunnel boring machine, flowing ground, shear and fault zones.

1. INTRODUCTION

Dulhasti Hydroelectric Project in Himalayas is being executed by National Hydroelectric Power Corporation Ltd. (NHPC) and is located on river Chenab in District Doda of Jammu & Kashmir. The project consists of a diversion dam at Dul with two intakes – one to provide water for the first stage and another to provide water for the second stage. There are two underground sedimentation chambers with necessary flushing conduits and two more sedimentation chambers are to be constructed if and when the second stage is taken up. The head race tunnel is 7.7 m finished diameter and 10.6 km in length. Due to changes in alignment, it doesn't have a uniform slope from upstream to downstream and hence an air-vent shaft of 400 m depth has been provided to avoid airlock. An underground surge shaft of 18.5 m diameter and 117 m depth with air vent and other ancillary tunnels has been provided. Three penstocks of 4.8 m dia and 141 m depth take-off from surge shaft. The underground power house of 390 MW (3x130 MW) with all the appurtenant tunnels is located in the hill at Hasti and with tail race tunnel and control structures.

Geological investigations were done at the time of putting the job into tender in 1989. However, the mountain through which the tunnel was passing was found to be a rock salt mountain. The salt in the mountain melted over a period of years and underground water reservoirs were formed. The mountain cover on the top of the tunnel was in excess of 1000 metres and when intercepted with shear zones it was getting connected to the tunnel at various locations causing huge inflow of water with debris and mylonite (quartzite powder) creating tunneling problems. A Robbins tunnel boring machine which was used for tunneling from upstream face get buried at Chainage 8550 metre and had to be abandoned. All other underground works both on upstream and downstream were executed without any problems.

The work was first awarded to a French consortium Dumez-Sogea-Borie SAE in October 1989, but was abandoned in August 1992. The work was re-tendered and awarded to the Indo-Norwegian joint venture Jaiprakash-Statkraft Anlegg (JSA) on 9th April 1997.

2. CASE HISTORY OF HEAD RACE TUNNEL

The Head Race Tunnel (HRT) of 7.7 m diameter and 10.6 km long is being excavated by drill & blast method from downstream, and by Tunnel Boring Machine (TBM) from upstream. This tunnel had to be excavated through a rock which has a compressive strength of 250 MPa to 400 MPa. The rock was highly jointed and had large quantity of water, which used to bring debris, quartzite powder (mylonite) alongwith water, making the working condition very difficult. The frequency of shear zones and faults was too large.

In a period of one year following things came to light:

(i) Type of the rock and TBM were not compatible, primarily because the machine did not have a protective shield and the total thrust available to push through the rock at a reasonable speed was not adequate. It was about 40% less than what it should have been.

(ii) Five shear zones and faults were encountered in a period of one year and consequently engineers could hardly proceed 1,247 metre in a period of 22 months, which included three months required for changing a weak band. Details of cavities encountered in upstream HRT are given in the Table 1. Crossing further shear zones was also problematic by TBM. The maximum progress achieved by JSA was 177 metre per month in the month of May 1999.

Table 1 - Details of cavities encountered in upstream HRT

Particulars	Chainage	Length of cavity	Date when cavity was punctured	Time taken to get TBM out & negotiate cavity	Amount of water
Cavity 1	1685-1703	18.30 m	07.07.97	65 days	87 lit/sec
Cavity 2	1852	-	09.11.97	8 days	106 lit/sec
Cavity 3	1877-1888	11.65 m	06.12.97	27 days	104 lit/sec
Cavity 4	1953-1958	5.00 m	22.01.98	4 days	Negligible
Cavity 5	1968	-	31.01.98	90 days	81 lit/sec

On 26th of June 1999, the TBM went out of action due to a massive shear zone. The first attempt was tried to see whether engineers could get over the shear zone by use of umbrella arch method. In order to do this, Odex equipment was imported from Atlas Copco, Sweden. During the use of this equipment, the shoe bit was crushed due to highly abrasive rock in a drilling length of less than 5.0 metre and thereby the casing pipes were cracked and jammed. Drilling had to be started from behind the TBM whose length itself was about 8.00 metre and for effective drilling engineers had to drill at least 20 metre as shown in Fig. 1.

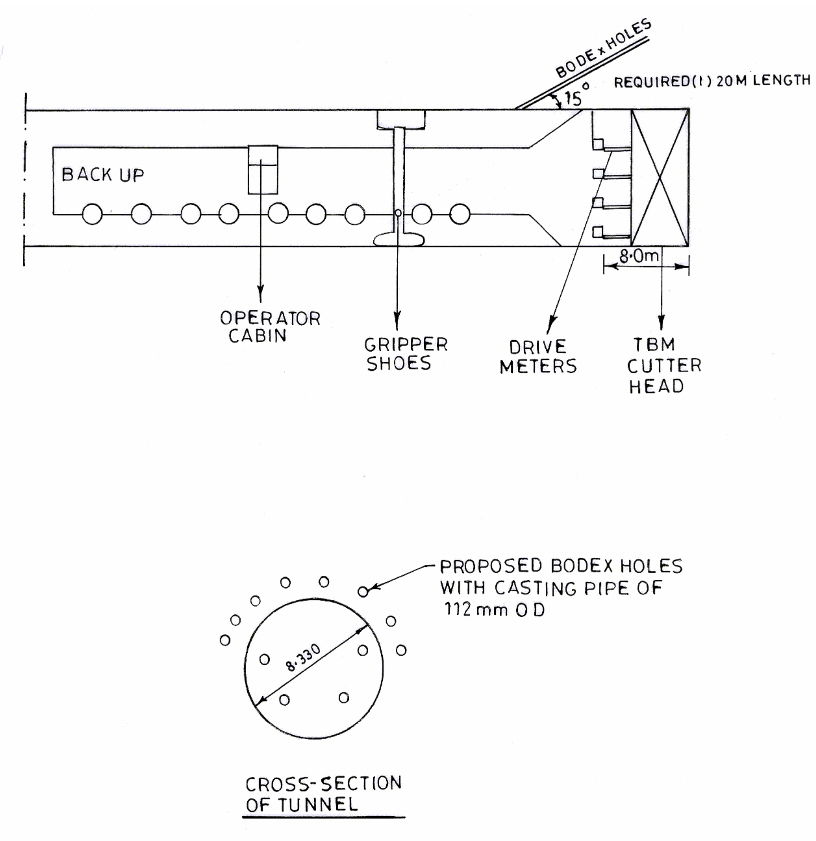

Fig. 1 – TBM at Dulhasti head race tunnel and drainage holes

From 26th June to end of October 1999, the work of release of cutterhead of TBM by hand mining and construction of concrete bulkhead wall in front of it was completed. Also various holes were made for drainage and grouting without much success. In the later part of October, four holes were driven through the gates of the TBM by use of Bodex for lengths upto of 20 metres. Chemical grouting in front of TBM was carried from 11th November to 25th November and about nine tonne of Tacss T-020-NF and one tonne of Tacss T-025-NF alongwith accelerators was injected to consolidate the debris in front of TBM and create a grouted mass canopy at crown. Details of grouting are given in Table 2.

From 25th November to 6th December 1999, removal/ re-fixing of cutters and servicing of TBM for commissioning was carried out. On 7th December, while cutting the bottom portion of concrete bulkhead, some iron pieces cut from concrete came on the conveyor belt of the TBM, which damaged the belt and had to be vulcanized. During this period, the client NHPC directed JSA to drill a 51 mm dia hole of 17 metre length at an angle of 35^o at the crown. Cement grouting was started in this hole and only 17 cement bags went into this hole at a pressure of 40 bar. During this period, lot of water started coming from the holes adjacent to grouted hole. This water was muddy and fine material started flowing through these holes. Also rock pieces upto 40 mm diameter started coming out from the rock joints. The quantity of water coming from holes and rock joints increased to about 50 litres per second.

On 9^{th} December 1999, the cutter head was cleaned and the TBM kept ready for operation. Three drainage holes were drilled on $9^{th}/10^{th}$ December night. One of these holes brought lot of water while these holes were being drilled. At this time, the operating crew heard a big bang caused by rock collapse. With this collapse, lot of water and debris rushed from the bottom and filled up the invert behind the TBM to a height of 2 metres and length of 30 metres. Thereafter, the removal of debris was done and an attempt was made to rotate the cutterhead. The cutterhead was jammed as the muck flowing from the bottom was more than what the TBM could handle. This muck brought pieces of chemical and cement, which did not have any bond with the debris.

After discussions with the client, it was decided that the method to be adopted in the circumstances would be to make 2mx2m drifts on either side of the tunnel allowing the water to drain and consolidate the debris in front of the TBM by further use of chemicals and cement as shown in Fig. 2. Details of the drifts excavated and creation of an umbrella on them is given in Fig. 3.

Geotechnical Note on the Accident at Chainage 2840m, HRT

Excavation of HRT of Dulhasti Hydroelectric Proejct is being carried out by TBM. On 21^{st} February 2000 at about 8.20 hours, there was a major rock burst in the tunnel at RD 2840. Debris with rock blocks of 1 m size and huge quantity of water flowed into the HRT and buried complete TBM upto operator's cabin. Mr. S.P. Jalote, Geologist was asked by Jaiprakash Industries Ltd to examine the accident site and report. He reached Dul site in the evening of 22^{nd} February 2000 and examined the site on 23^{rd} morning. The observations and conclusions are given in the present note. Details of background information have been included from the available records at the site office.

Background Geotechnical Information

Excavation of the tunnel by TBM had reached RD 2811.6 m when it encountered fractured quartzite. Therefore, steel ribs were installed from RD 2811.6 m to 2823.8 m. At RD 2823.8 m probe holes were done and it indicated presence of sheared/ fractured quartzite rock zone from RD 2842 m to RD 2856 m and it was dry. By adopting suitable tunnelling technology such as grouting, fore-poling, concreting and installation of ribs, the tunnel progressed upto RD 2862 m on 24.06.99. The rock in the entire zone, i.e. from RD 2811.6m to RD 2862 m consisted of fractured quartzite or a shear zone where cavity formation had taken place.

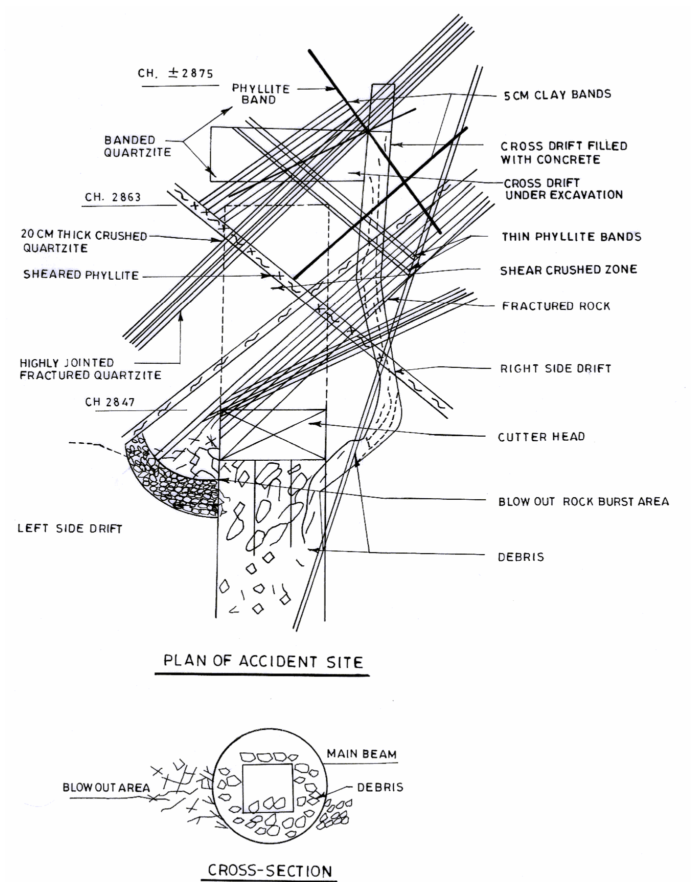

Fig. 2 – Side drifts to tackle face collapsed problems in TBM driven section

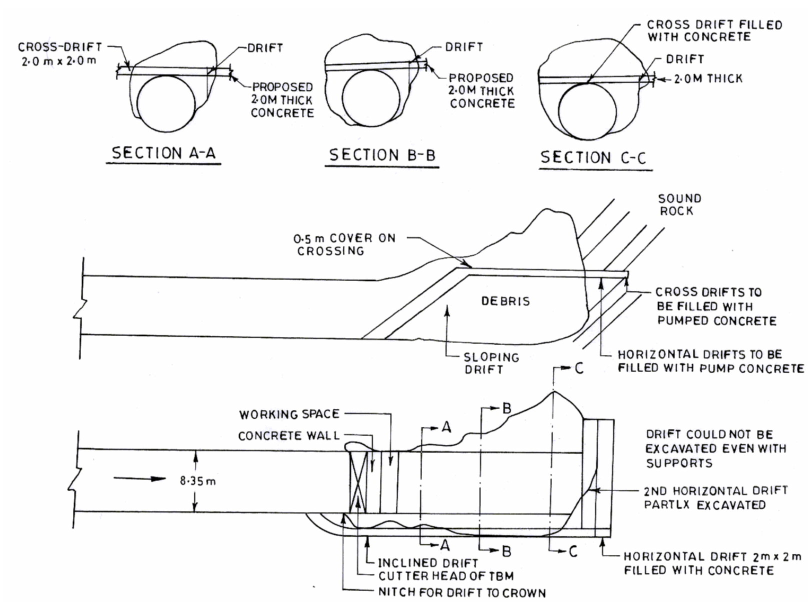

Fig. 3 – Proposed method for crossing shear zone, Ch. 2846 to 2865m in HRT

While progressing further, jamming of TBM cutter was observed and TBM had to be pulled back after removing 2 ribs already installed as support to rock as TBM cutters cannot move inside the ribbed section due to smaller size. Boring advanced to 0.9 m, at this stage about 15-20 lps water was observed. It was further observed that cavity formation has taken placed ahead of TBM upto about 4 m in the direction of the tunnel and about 2 m on the right side and about 2 m above the crown.

On 29.06.99, collapse of rock mass ahead of face took place with formation of cavity on all directions. Huge blocks of quartzite (2-2.5 m in size) jammed the cutters. After progressive removal of ribs and segments, retraction of TBM started on 30.06.99. Upto 03.07.99, retraction of TBM was done by 3.85 m. On 03.07.99, ingress of water amounting to about 7 lps increased to 18 lps on 04.07.99 with substantial inflow of sediments. The invert upto the back up system got filled with debris flow from face. The muck was removed by 07.07.99. The flow of material continued further.

Up to 14.07.99, TBM has been retracted for 16.3 m i.e. upto RD 2840.0 m after removal of 18 ribs installed at 90 cm spacing and a total of 928.32 m^3 of solid muck had been removed during the period 29.06.99 to 14.07.99 (the TBM cutter resting at RD 2840 m).

From 11.11.99 to 28.11.99, attempts were made to consolidate the material in front of TBM by chemical and cement grout from RD 2840. The holes were drilled by Boodex 90 system within tunnel profile and on the periphery, outside the profile, with 51 mm diameter holes by Atlas Copco boomers.

In view of the fact that removal of ribs for rotation of TBM for effective advance was not proving meaningful, it was decided by concerned authorities on 10.12.99 that TBM should not be further retracted. A decision was taken that a 2,x2 m drift may be made starting from behind the cutterhead to determine the extent of crushed rock zone ahead of cutter face on the right side of the tunnel face. Subsequently, it was decided that a second drift should be made on the left side also.

In a subsequent meeting held on 16.12.99 with NHPC authorities, the methodology for negotiating the shear zone was outlined as given below:

a) Construction of two drift on each side of the tunnel alignment as described above.

b) Construction of 2m x 2m cross drift between the above drifts spanning the tunnel. These cross drifts were to be excavated in the rock just above the proposed profile of tunnel, it was supposed to be sloping right and left side having highest point at the centre line of HRT. This cross drift was to be filled with concrete and next cross-drift was to be made adjoining the previous one.

c) By making a number of cross-drifts and filling them with concrete, a canopy of concrete was to be created in advance above the projected crown of HRT to be excavated by TBM subsequently.

The construction of drifts was started on 14.12.99. These were located at RD 2840 behind the cutterhead at about EL 2840, i.e. roughly 4 o' clock and 8 o' clock position on the right and left side respectively. The left side drift was abandoned after some excavation due to continuous flow of material from shear zone. It was plugged with sand bags.

The right drift was excavated from RD 2840 to RD 2874 m and it was stopped after it had entered in the sound rock for four metres. It recorded active dripping of water at RD 2872.5 m. At RD 2869m, a cross cut on left side was made extending sufficiently beyond the limit of HRT left side. This cross drift was filled with concrete on 11th and 12th February. On 13th February 2000, work on second cross drift was started between RD 2866-2868m just before the cross cut already concreted. The work was in progress.

The right side drift crossed the shear zone between RD 2856 m to 2871 m. The rock of the shear zone consisted of largely highly crushed quartzite. It also encountered between approx RD 2870.5 m – 2871 m a gougy shear seam containing gouge of sand apparently developed due to extensive crushing of quartzite. The gougy shear seam had struck N50^{o}E–S50^{o}W and dip 88^{o}N 40^{o}W. The drift required timber support. It recorded minor seepage and dripping at RD 2850.0 m, RD 2859.5 m, and RD 2863.0 m. In the left cross cut, seepage was met at a number of places from the crown and sides. The left side cross cut (already concreted) also recorded the gougy shear seam at RD 2869, beyond which the rock was highly blocky quartzite.

Stress Conditions in HRT

The HRT from Dul end has been excavated mainly in quartzites with some bands of phyllites. The formation has a general dip of about 20^{o} dipping towards portal side.

The rock cover over the tunnel rises gradually, it is 1050 at RD 2840m (the present heading). The maximum rock cover of the order of 1350 m is at Dul Dhar at about RD 3100 m, further onwards between RD 3100 m to RD 4800 m, it is in the range of 1000 m.

Some measurements of rock dilations are reported to have been carried out, their results, if any, could not be made available for study. Load cells have also not been installed behind steel ribs for measurement of load being exerted by rock on steel ribs. Therefore, any data of rock behavior by instrumental measurement in the tunnel is not available.

Steel supports have been installed at about 1.0 m spacing and less at other places. A quick measurement indicated that (out of 2840 m length of tunnel) at about 18% length, steel supports are existing. It is revealed that steel ribs are intact, any bending or distortion due to rock pressure could not be observed. However, in the TBM assembly area (RD 2765 m – RD 2840 m) where quartzite is present along with bedding partings (indicated by presence of 1-2 cm thick slate layers), some rock bolts with about ½ m long channels have been provided as rock supports apparently to prevent spalling. Channels are intact without any indication of bending due to rock pressure. Rock bolting in tunnel execution is a normal requirement. The tunnel excavated by TBM, rock bolts have been given whereever there was need in view of smooth cut (due to no disturbance by blasting). Therefore, it is apparent that excavated part of tunnel has no visible signs of rock stress problem. Rock is giving metallic sound on hammering, there is also no indication of gradual spalling or progressive slab formation. If this phenomenon is existing, rock gives hollow sound which is generally not observed in the present tunnel.

It is reported that near RD 2759 when cutterhead was at RDS 2785, small rock chips came out with sound. This is an indication of popping. This was however controlled by rock bolting.

The Accident

On 21st February 2000, at about 8.20 hours, when shift people were going for work, they saw about 3 m high column of water gushing from the tunnel head. The following significant points were noted on examination of TBM area up to cutterhead on 22nd February:

(i) The TBM is embedded by debris flow from the heading area. Debris accumulation is 7.0 m high behind the cutterhead, 4 m high at operator's cabin and 2 m high at the start of TBM assembly.

(ii) On the back side of the cutterhead, big blocks of rock (100x60x60 cm) and smaller blocks are lying, indicating that these are fallen from the left side.

(iii) The boomer mounted on the back side of cutterhead turned left side by about 20o from the tunnel alignment from the point of its anchor indicating that the thrust was from the left side beyond the anchor point (i.e. towards heading).

(iv) A walk way was lying turned and shifted from original position which indicated that flow of debris material came from left side as well from the right side.

(v) Shri Dinesh, Geologist (Trainee) informed that he was going on foot to TBM. When he was at RD 1800 m, he saw that some (work) labourers are running out and shouting that flood has come. When he went at RD 2200 m where a loco was standing, he saw a wave of water coming towards loco. Timber supports used in the right drift were floating as well as one drum was floating.

(vi) On the left side behind the cutterhead and the first rib, there is a gap where GI sheets and other bulkhead had been provided. It indicates that considerable material had flowed into tunnel from this point and tilted the boomer clockwise.

(vii) Right side drift portal was not visible, it was buried under debris. The debris consisted of rock fragments of white and grey quartzite rock fragments 1.0 cm to 3.0 cm size embedded in very fine to fine whitish sand. The material became so compact that seepage water flowed over this and about 1.0 lit/sec water was flowing.

(viii) It is confirmed from field observation that at the time of accident, the gush of water and debris flow was very high. It continued for about 15-20 minutes, afterwards it became very little. At the time of examination, the flow of seepage water was guessed to be about 25 lit/sec.

It is concluded from the above observations that there was considerable built of water pressure in the cavity beyond the cutterhead. When the water pressure exceeded the shear strength of grouted mass which was 2.5MPa, it burst and flowed whereever it got opening or weak points. Apparently, it flowed from left lower corner from behind TBM cutterhead and other places which could not be seen since the area was full of debris. The pressure exerted by underground water as judged from flow of material could be close to 10MPa.

Utility of TBM in Dul HRT

While driving HRT from Dul end by TBM, four zones have been encountered where heavy water discharge with flow of crushed rock material has taken place. There was considerable time loss in tackling these zones. In each zone, the tunnel had to be supported by steel ribs. As the current technological advancements in the tunnelling technology have certain limitations. Wherever high discharge of water with sheared rock flow is encountered, rib support is the only answer.

The Dul HRT is to be excavated further up to air-vent point and more such shear zones with water bodies are anticipated with possibly higher hydrostatic head as the rock cover increases with further advancement of tunnel. It is, therefore, concluded that the present TBM will be of no use for tunneling further even if the buried TBM is retrieved which seems an impossibility. The present TBM which has been in the tunneling humid conditions for the last nine years and buried under saturated debris since 21st February 2000 onwards until the time it is retrieved, after recovery will be totally deteriorated beyond repair after recovery.

The above conclusion does not rule out the possibility of use of TBM in Himalayan Terrain. It can certainly be used provided a TBM is manufactured which can bore the tunnel about 15 cm extra radius than its normal boring radius where ever it is required. This may be required in poor rock reaches where rock support by steel ribs is essential. This is necessary where rib support is provided so that TBM can move freely in the rib supported area wherever necessary. In case of Dul HRT, rib support had to be removed while moving the TBM backwards.

Since the TBM got buried, it was decided to divert the tunnel from Ch. 2676m as given in Figs. 4, 5 & 6 and excavate it by drill and blast method. The rock mass quality of this area was grey quartzites with thin phyllite bands (2-5mm) alongwith foliation. The rock quality in terms of Q ranges from 2.6-6. The rock support system (from Ch. 2702 to 2895m) was by full length adhesive anchors of 5.0 and 6.0 m length alternate at 1.0 m centre to centre staggered with wire-mesh. The thickness of the shotcrete was 10 cm. From Ch. 2895 to 2928m, ribs spaced at 1.0 m centre to centre with legging and blocking concrete was executed. From Ch. 2928m onwards, since the quality of rock improved, the system of support was again full length adhesive anchors 5.0 to 6.0 m length at 1.0 m centre to centre staggered with wire-mesh and 10 cm thick shotcrete. The method followed for crossing the shear zone in the diverted area was by drilling forepoles and providing drainage holes as shown in Fig. 7 and Table 3.

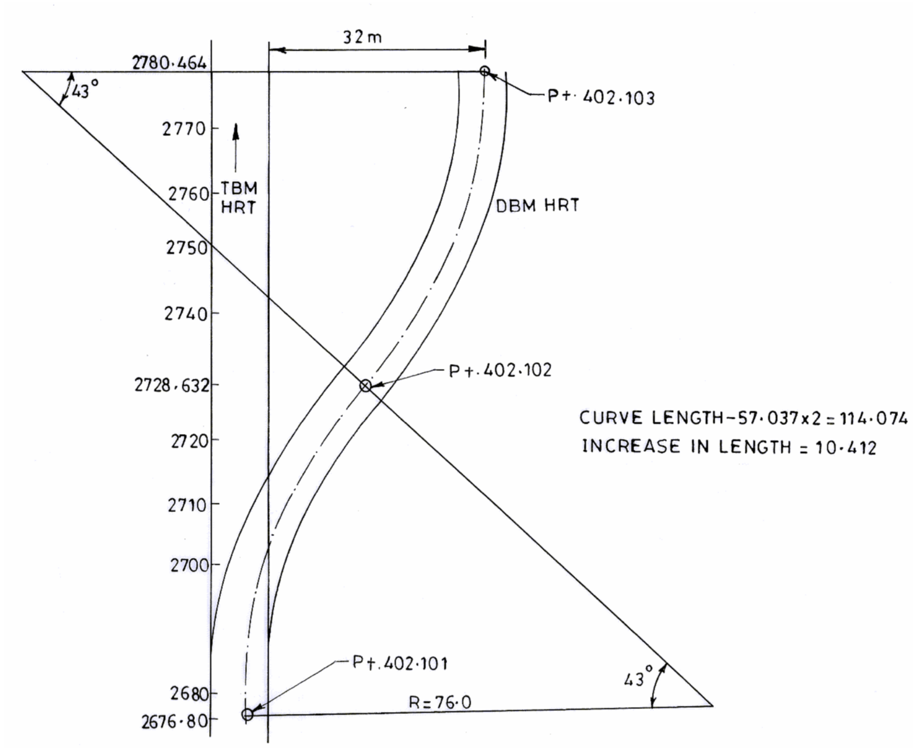

Fig. 4 – Plan of proposed HRT - 402

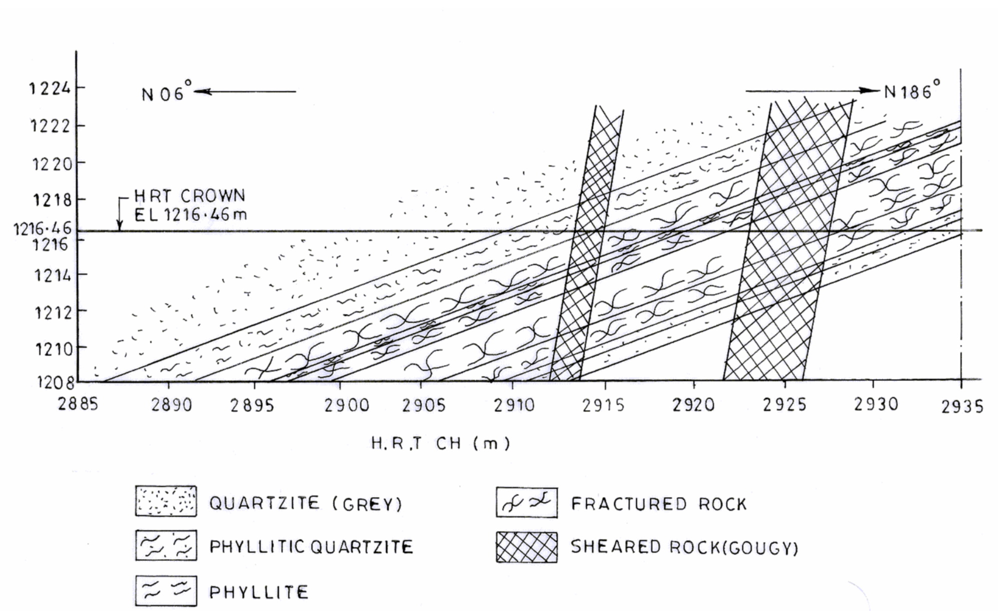

Fig. 5 – Geological section along C.L. of HRT 402

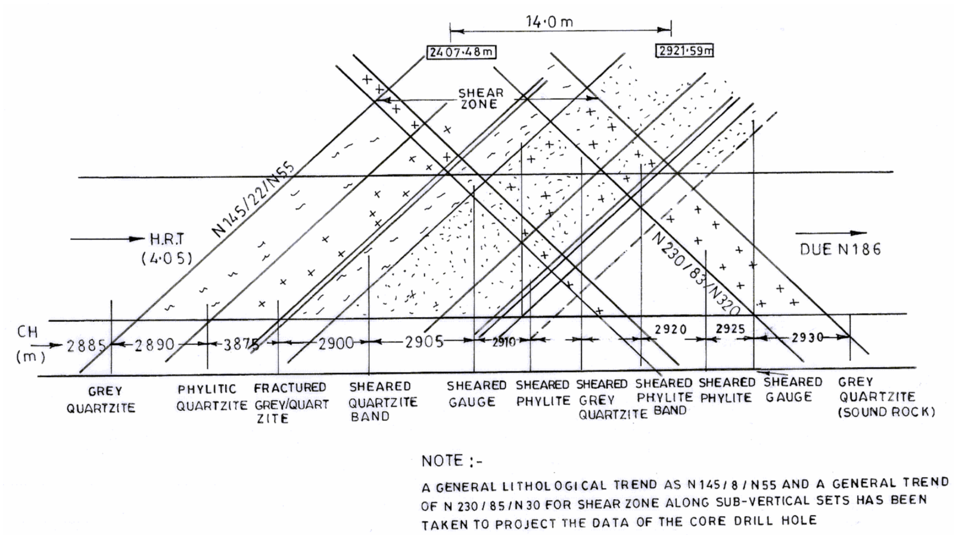

Fig. 6 – Geological plan at EL 1210.9m along core drill hole showing location of shear zone

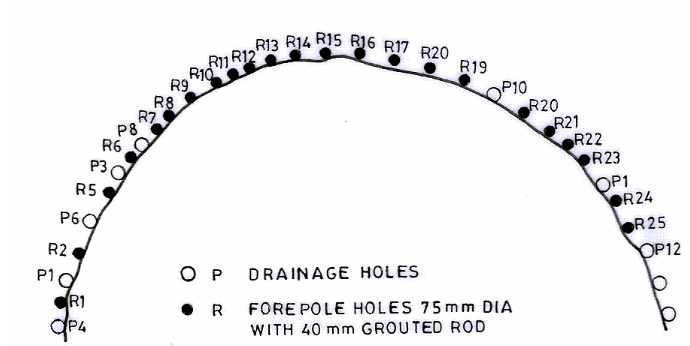

Fig. 7 – Details of pre-treatment carried out in HRT 402 at Ch. 2913m

Table 3 – Details of pre- treatment in HRT at Ch. 2913m

Hole No.	Hole dia.	Position w.r.t. crown	Angle with HRT Axis	Inclination of Hole	Depth of Hole	Pipe (dia 40mm)/Rod Length
P1	76mm	08:30	Due N 146	6° up	14.20m	12.00m pipe
P2	76mm	08:40	Due N 136	8° up	14.20m	12.00m pipe
P3	76mm	08:50	Due N 116	10° up	14.20m	12.00m pipe
P4	76mm	09:15	Due N 136	6° up	14.20m	12.00m pipe
P5	76mm	09:30	Due N 136	6° up	9.52m	9.50m pipe
P6	76mm	10:00	Due N 146	6° up	14.25m	14.00m pipe
P7	76mm	10:20	Due N 147	8° up	11.95m	11.80m pipe
P8	76mm	10:40	Due N 170	10° up	11.75m	11.60m pipe
P9	76mm	10:50	Due N 176	18° up	11.90m	12.00m pipe
P10	76mm	01:00	Due N 216	14° up	17.01m	18.00m pipe
P11	76mm	02:00	Due N 236	6° up	17.01m	18.00m pipe
P12	76mm	02:45	Due N 240	6° up	21.57m	21.57m pipe
P13	76mm	03:00	Due N 240	6° up	16.80m	12.00m pipe

R1	76mm	09:20	Due N 180	6° up	9.60m	11.00m Rod
R2	76mm	09:50	Due N 181	8° up	9.70m	10.00m Rod
R3	76mm	10:10	Due N 178	8° up	9.72m	11.00m Rod
R4	76mm	10:30	Due N 172	10° up	14.50m	14.00m Rod
R5	76mm	10:40	Due N 172	18 up	14.55m	14.00m Rod
R6	76mm	10:50	Due N 178	28° up	14.56m	14.00m Rod
R7	76mm	11:00	Due N 170	22° up	14.58m	14.00m Rod
R8	76mm	11:07	Due N 174	20° up	14.30m	14.00m Rod
R9	76mm	11:15	Due N 172	18° up	14.58m	14.00m Rod
R10	76mm	11:30	Due N 178	22° up	14.08m	14.00m Rod
R11	76mm	11:37	Due N 182	24° up	14.38m	14.00m Rod
R12	76mm	11:45	Due N 180	28° up	14.00m	14.00m Rod
R13	76mm	11:50	Due N 182	24° up	14.18m	14.00m Rod
R14	76mm	12:00	Due N 186	28° up	14.08m	14.00m Rod
R15	76mm	12:50	Due N 194	28° up	14.13m	14.00m Rod
R16	76mm	12:07	Due N 190	26° up	14.18m	14.00m Rod
R17	76mm	12:12	Due N 190	26° up	16.71m	17.00m Rod
R18	76mm	12:25	Due N 194	26° up	16.60m	17.00m Rod
R19	76mm	12:50	Due N 198	22° up	16.81m	17.00m Rod
R20	76mm	01:12	Due N 206	18° up	18.09m	17.00m Rod
R21	76mm	01:25	Due N 208	18° up	20.45m	20.00m Rod
R22	76mm	01:37	Due N 220	18° up	20.65m	21.00m Rod
R23	76mm	11:45	Due N 226	16° up	14.20m	14.00m Rod
R24	76mm	21:50	Due N 191	16° up	21.60m	21.00m Rod
R25	76mm	02:30	Due N 192	6° up	22.87m	22.00m Rod
R26	76mm	02:45	Due N 193	6° up	18.31m	18.00m Rod

3. CONCLUSIONS

Dulhasti hydroelectric project was an engineering & geological experience. On one side there was a problem of life of drill bits which was less than 20 metres as they had to drill quartzite mass which had a compressive strength of about 400 MPa, and on other side the quartzite was highly jointed and crushed forming into mylonite powder which used to flow with water blocking the drainage holes in less than 24 hours thereby developing water pressure causing bursting the face rock. This happened almost 10 times. This was a unique feature in the world tunnelling history and somehow with great difficulty the project would be completed in a month’s time. Since the mountain cover was very high it was not possible to do geological investigation except by inferred geology. Satellite imagery method was followed. Based on the overall engineering geological mapping and investigations done by eminent geologists including ex-Deputy Director of GSI, results were arrived at. Trials of contents of salt in water in upstream and downstream of river were made. This proved that rock salt portions in the mountain was progressively melting and forming underground water reservoirs. This conclusion was drawn out because of differential percentage of salt content between upstream and downstream river water indicating that the process of melting of salt continues even today. There was less salt in upstream and more salt in downstream. Hence, if and when we need to bore tunnels in this type of ground, we should decide the methodology well in advance to reduce construction time.

Table 2 – Drilling and grouting record of Dulhasti hydroelectric Project

Description of Hole								Grouting										Remarks
Date	Hole No.	Dia of Hole (mm)	Clock Position	Inclination Angle with Horizontal (Deg.)	Initial Drilling/ Redrilling	Depth (m)	Time Taken for Drilling (min)	Type of Packer Used	Grouting Time		Pressure Applied (Bars)	Grouting Pump Used	Grouting Chemicals Consumed (litres)		Cement Grouting			
11.11.99	29	51	10.30	30º	Redrilling	9.72	35.00	Hydraulic	10.30	10.40	136	Chemical	125.00	15.00	-	-		
	28	51	11.30	28	-do-	9.72	40.00	-do-	16.10	16.13	136	-do-	62.50	7.50				
12.11.99	31	51	10.45	60	Drilling	13.30	65.00	-do-	7.00	7.12	136	-do-	50.00	5.00				
	31A	51	9.30	30	-do-	12.15	90.00		-do-									
14.11.99	31	51	10.45	60				-do-	11.30	11.37	136	-do-	57.50	7.50				
	01	76	11.00		Previous drill.	20.65		-do-	6.30	7.05	136	-do-	37.50	25.00				
15.11.99	32	51	11.00	60	Drilling	16.51	135.00	-do-	9.00	9.10	68	-do-	50.00	2.50				
	33	51	11.15	25	-do-	18.20	140.00	-do-	-	-	68	-do-	210.00	20.00				Time not recorded
	34	51	12.15	15	-do-	10.00	50.00	-do-	-do-		68	-do-	200.00	15.00				-do-
	02	76	10.00		Previous drill.	21.87			-do-		68	-do-	100.00	10.00				-do-
16.11.99	33	51	11.15	30	-do-	19.44	100.00		-do-		68	-do-	50.00	2.50				-do-
	32	51	11.00	60	Redrilling	9.72	30.00		Mechanical		68	-do-	50.00	2.50				-do-
17.11.99	03	5	11.45	40	Drilling	9.72	40.00	Hydraulical	13.00	13.30	130	-do-	275.00	13.75				Ch.2840.15
	36	51	11.45	60	-do-	9.72	45.00	-do-	15.25	15.30	136	-do-	75.00	3.75				Ch.2839.75
	37	51	11.30	-	-do-	17.01	45.00	-do-	11.32	11.39	68	-do-	120.00	6.25				Ch.2839.75
	38	51	11.55	250	-do-	21.87	90.00	-do-										Ch.2841.00
18.11.99	38	51	11.55	25		-do-		-do-	23.15	23.30	68	-do-	50.00	2.50				Ch.2845.00
	31A	51	9.30	30				-do-	0.11	0.15	68	-do-	25.00	1.25				Ch.2840.00
	39	51	11.55	9	-do-	14.40		-do-	1.45	6.00	68	-do-	2975.00	153.75				Ch.2840.00
19.11.99	40	51	11.45	20	-do-	21.47	60.00	-do-	4.15	4.25	136	Chemical	25.00	1.25 Cement	311	150		Ch.2840.00
	40	51	11.45	20				-do-	1.10	4.00	68	Ch/Cem.	2275.00	67.50	200	6		Ch.2840.00
20.11.99	B4	102	Rt hand bottom	12	Previous drill.	17.00		Mechanical	11.00	13.15	136	Ch/Cem.	325.00	16.25	1 600	800		Ch.2839.75 Hole by Bodex cased
	11	57	11.15	-	Drilling	12.15		-	2.00	7.20	5 to 18		-		38 500	7700		-
22.11.99	B2	102	Rt hand top	10	Previous drill	10.50		-	2.30	Onward	136	Ch/Cem.	250.00	13.15	20 500	4100		
	B3	102	LS bottom	12	-do-	7.50		-do-	11.15	12.30	102	-do-	225.00	12.25	200	40		
	B3	102	Re-drilling	12	-do-	18.37		-do-	21.15	22.15	136	-do-	25.00	1.25	2 400	800		
23.11.99	B2	102	11.00	15	-do-	16.59		-do-	12.15	1300.00	102	-do-	250.00	5.00	1800	600		
	B1	51	1 o"clock	10	Redrilling	11.43	2.50	-do-	9.30		68	-do-	275.00	5.50	24 900	8 300		
24.11.99	B1	51	1 o"clock	10	-do-	11.43	2.50	-do-			68		-do-		1350	450		
	B3	51	Near Bodex	12	-do-	9.00	0.30	-do-	0.30 LH Bottom	100	136	-do-	7.50	7.50	450	150		By the side of Bodex holes
	B2	51	LH Top	15	-do-	16.00	0.45	-do-	0.50	7.00	136	-do-	100.00	10.00	1050	350		
	Holes "B" are in the body of the TBM and are done by use of Bodex with 102mm casing																	

25.11.99	B4	51	RH Bottom	12	-do-	14.84	20.00	-do-	15.45	18.00	103	-do-	75.00	3.75	2700	900	
	42	51	1 o"clock	10	drilling	21.87	89.00	-do-	0.10	8.15	136	-do-	25.00	1.50	13350	4100	Sodium silicate 41 lit
26.11.99	43	51	11.45	15	-do-	24.30	75.00	-do-	11.00	15.00	68	Cement only			4050	350 1350	Ch.2839.50
	B1	51	RH Top	10	Redrilling	14.40	75.00	-do-	18.00	21.00					9600	3200	
	44	51	1.15 o"clock	20	Drilling	14.56	120.00	-do-	6.00	7.00					1500	500	Sod.sillicate 3.00 lit
27.11.99	45	51	RH Bottom Near Bodex	10	-do-	9.00					-do-				11550	3850	Close to Bodex hole
	46	51	2 o"clock	20	-do-	19.40									5250	1750	Ch.2839.50
	46	51	2 o"clock	20	Redrilling	21.87									3750	1250	
29.11.99	47	51	Near Bodex	15	Drilling	9.58									4950	1650	
	48	51	RH Top Near Bodex	10	-do-	7.15									5850	1950	
	49	51	11.45	20	-do-	14.28	135.00	-do-	6.20	6.30	136	Chem/Cem	100.00	10.00	400	100	
	50	51	2.30	10	-do-	7.29									12600	4200	
30.11.99	51	51	1 o"clock	25	-do-	13.20	60	-do-	14.30	18.30	136		Cement		20850	5950	Sod. Silicate 9.70 lit
	52	51	1 o"clock	20	-do-	21.87	90.00	-do-	20.30	0.30	68		-do-		6000	2000	Sod. Silicate 32.00 lit
1.12.99	50	51	2.30	10	Redrilling	13.20		-do-	8.00	10.00	68		-do-		7500	2500	
	52	51	1 o"clock	20	-do-	14.40	120	-do-	16.00	18.00	68		-do-		7050	2350	
	53	51	11.15	15	-do-	21.87	120	-	0.00	100.00	68		-		750	250	
	54	51	11.50	15	Drilling	19.44	120.00	-do-	5.00	6.00	68		-		1500	500	
2.12.99	55	51	Adjacent to	20	-do-	9.72	90	-do-	9.00 LH Bodex	11.00	68		-do-		4800	1600	
	P1	51		10	Probe drill	12.00	120										Check holes Near Bodex
	P2	51		15	-do-	14.40	120										