Tunneling through weak and water charged strata by ground improvement - A case from Maneri Bhali H.E. Project-II, Uttarakhand, India

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Abstract

Excavation of large diameter tunnels through very weak and water charged strata in the geo-dynamically active terrain like Himalaya has been a very serious problem over the years and still it is a big challenge. This badly affects the project schedule and morale of the team. But with the advent of modern technology and innovative approach, such problems are being tackled successfully, though with long cycle time. This paper highlights about the successful tunneling of 246m long reach of bypass portion of Head Race Tunnel (HRT) passing below the Dhanari *nala* (stream) and exposing very weak and water charged quartzite by adopting pre-injection/pre-grouting techniques. The reach has been excavated by implementing intensive pre-grouting, 10-20m ahead of heading especially above crown portion to increase the modulus of elasticity, to create umbrella arch as pre-excavation support and to minimize the water seepage/inflow in poor grade rock mass and improving the ground condition by using micro cement and special chemicals like colloidal silica and polyurethane.

1. Introduction:

Maneri Bhali Hydroelectric Project is a run-off the river scheme on the River Bhagirathi. The project envisages the utilization of hydraulic head (285m) of the Bhagirathi river between tail of Maneri Bhali project, Stage I (El 1115m) and the tail of proposed Tehri reservoir (El 830m). It involve construction of 81m long barrage, a 16 Km long & 6m diameter horse shoe shaped HRT, 4 Penstocks , 174m high & 14m diameter surge shaft and surface power house to generate 304 MW (4 X 76 MW) of electricity (Figure1, Project Layout).

The HRT passes through the different types of low to medium grade metamorphic rocks. The rock mass encountered during tunneling ranges from fair to very poor grade categories. Most of the contacts of major litho units are either sheared or faulted, which posed stability problems in the form of loose fall and huge water inflows during excavation. The magnitude of such problems and time constraints forced the project officials to take by-passes at four different locations. Earlier tunneling of three by-passes has been tackled by conventional methods, which delayed the scheduled targets. Then with the advent of new technologies regarding ground improvement, restoration of strength of the material and water seepage control by using different mixtures and chemicals, such types of problems have been tackled carefully and smoothly. Excavation of one of such by passes in a reach having low rock cover below Dhanari *nala* and comprising water charged highly sheared and fractured quartzite has been taken as a case to discuss in this paper.

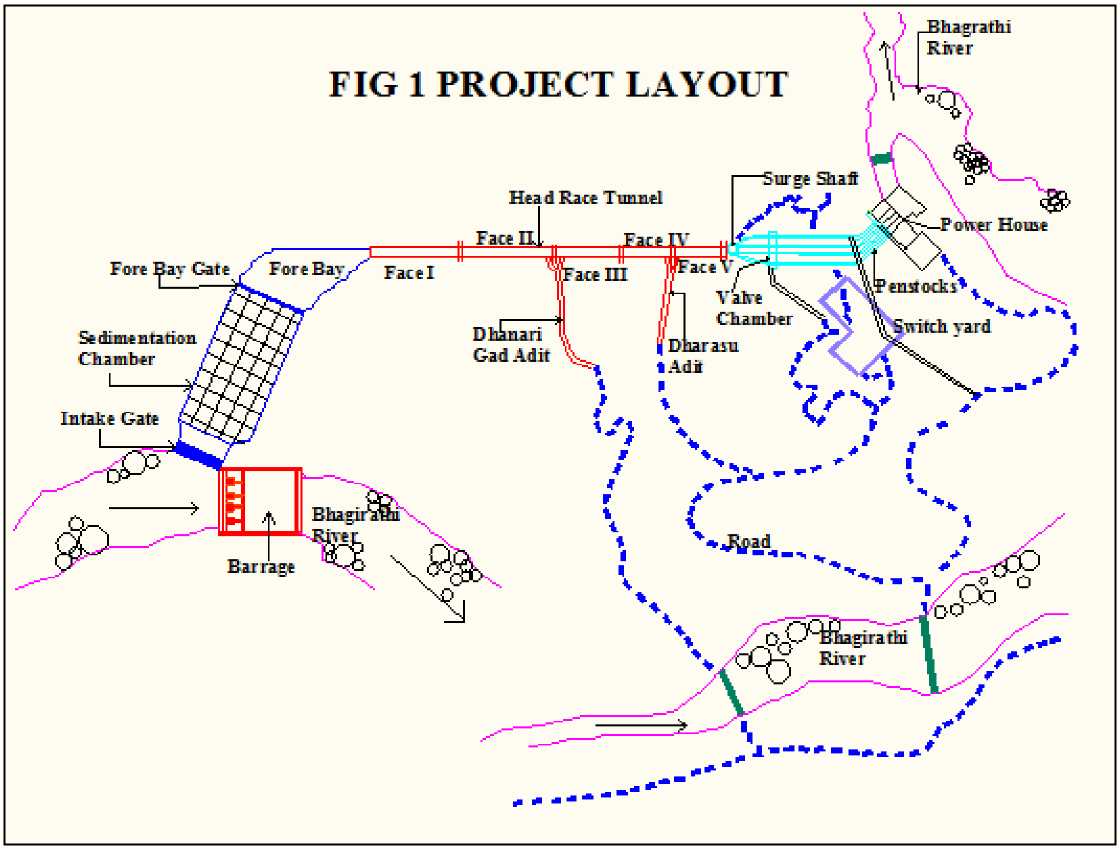


FIG 1 PROJECT LAYOUT

2. Geology of the Project:

The rocks in the project area belong to two major stratigraphic and tectonic units viz Tehri formation of Jaunsar Group and Garhwal Group. These two units are separated by south-west dipping structural dislocation i.e. *Srinagar thrust*, which is north-west extension of North Almora Thrust. The encountered stratigraphic succession in the project area is given in Table 1

Table 1
Stratigraphic succession in the project area

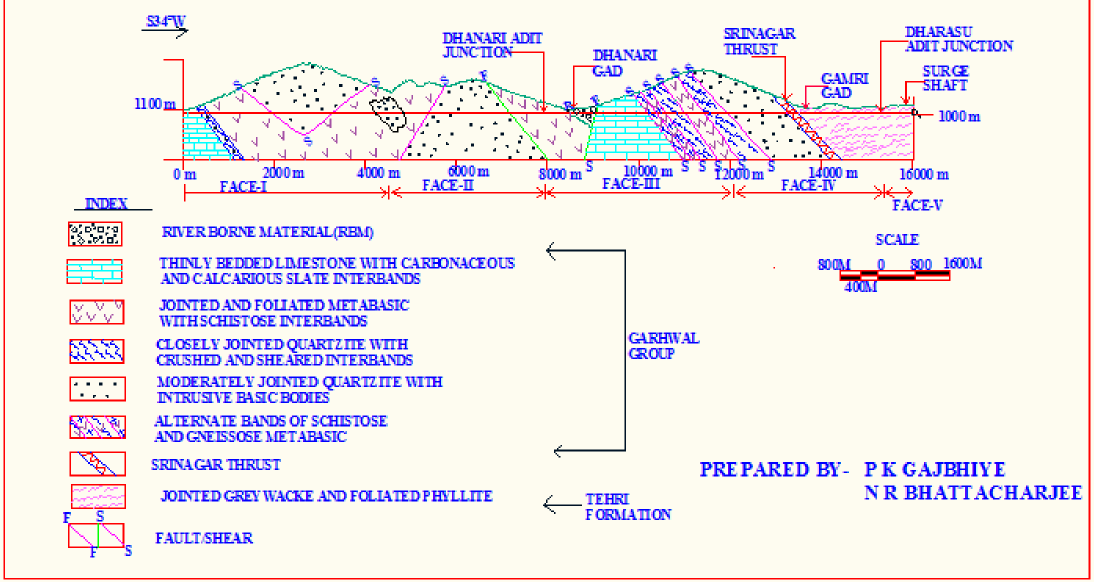
GARHWAL GROUP	Nagni Thank Formation	a) Upper meta-volcanics, amygdoloidal andesites etc.
		b) Gamri quartzite with Basic intrusives (epidiorites)
		c) Lower metavolcanics with slate and Quartzite bands.
	Shyalana Formation	Limestone and dolomite with minor quartzite.
	Uttarkashi Formation	Grey, green and purple slates banded
-------------------SRINAGAR THRUST (NORTH ALMORA THRUST) --------------		
JAUNSAR GROUP	Tehri Formation	Phyllites and greywacke with occasional calcareous lenses and basic intrusives (epidiorites.)

3. General Features and Geology of HRT:

A 6m diameter & 16 Km long Head Race Tunnel (HRT) is aligned on the left bank of River Bhagirathi. To facilitate a speedy progress, the excavation of tunnel was planned from five faces with two intermediate approach adits. It crosses two deeply incised major drainages and south westerly dipping tectonic feature “Srinagar Thrust”. Total thickness of this thrust zone along the alignment was found to be ±210m. The vertical cover over HRT ranges from 21m (min.) to 976m (max.) along the entire length. The entire excavation of the HRT has been done by conventional drill and blast method (DBM).

HRT passes through bedrocks comprises limestone with slate interbands, metabasic with schistose interbands & quartzite of Garhwal Group and metagreywackes and phyllites of Jaunsar Group. The tunnel alignment is mostly perpendicular to foliation/bedding of the rock strata. A Geological section along HRT is given as Figure 2

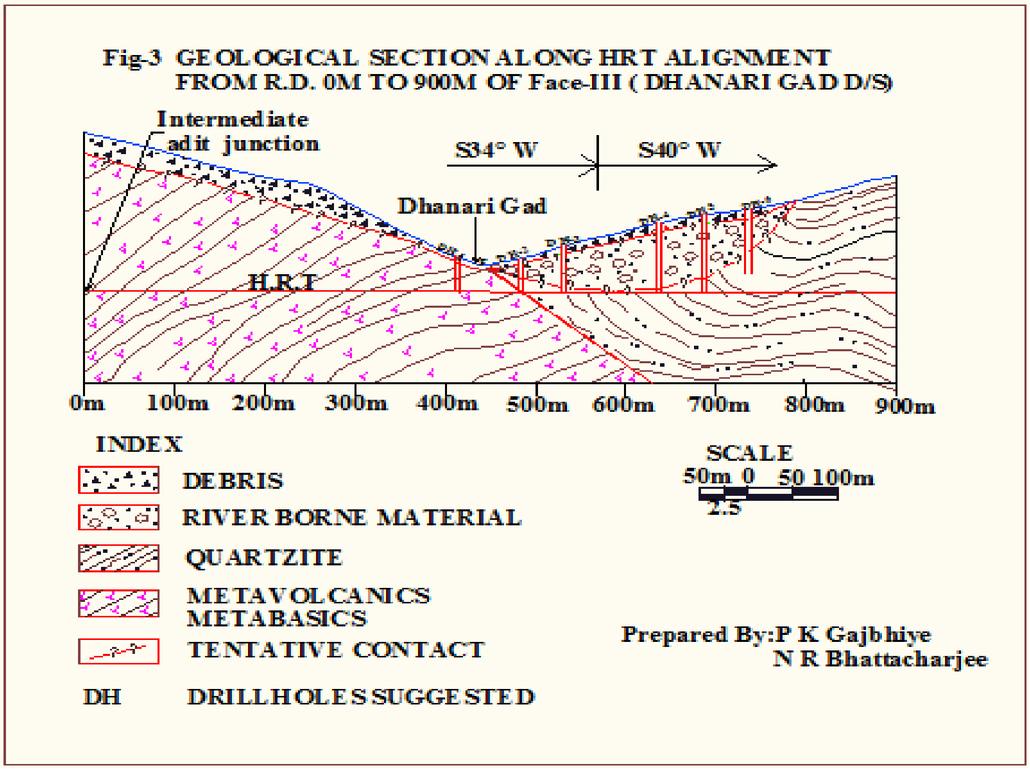
FIG 2 GEOLOGICAL SECTION ALONG HRT



4. By Pass in RBM Zone of HRT Face-III:

4.1 Rock mass condition:

In the main HRT (Face III), a reach between RD 520 to 690m passes below Dhanari *nala* and comprises highly jointed, sheared and fractured quartzite of Garhwal Group and River Borne Material (RBM) of Dhanari *nala* comprising pebbles of quartzite, gneiss and metabasic and sandy/silty clay. Five prominent sets of the joints were recorded with bedding/foliation showing warping at places. The rock mass falls in poor to very poor grade (Q value: 0.5 to 1.8) category. As far as vertical cover is concerned, reach between RD 570 to 640 was critical, where only 1-5m of rock (sheared quartzite) was available over crown and rest above it was RBM (Fig-3). Beyond RD 590m, RBM of *nala* exposed at many places with heavy in-rush of water. Due to very less rock cover and adverse geological condition, this reach posed severe stability problems in the form of loose fall and water inflows during excavation of main HRT. This lead to hampering of the progress many times even the installed ribs also started buckling and could not allow rectifying the support. Finally tunnel got filled up with the muck and RBM at places and reduced the tunnel section from 6.8m (excavated dia.) to 5.4m at few places.



4.2 Geotechnical Problems:

Highly jointed rock mass with water seepage, small block size, occurrence of RBM and frequent sheared planes, low inter-block shear strength along joints due to shearing and seepage, formation of potential structural wedges and less stand-up time due to low cohesive material were some of the geotechnical problems encountered during the tunneling.

4.3 Tackling and strengthening of Critical Zone:

To get more vertical cover and full tunnel section of 6.0m finished diameter the RBM zone was negotiated by taking a by-pass on conventional left side. The excavation of the 246m reach of the by-pass has been done from both the ends i.e. from RD 720m end towards upstream and RD 490m end towards downstream of HRT face -III with conceptual planning and design. Considering the experience of the main tunnel, similar geological conditions were anticipated in the bypass tunnel also. Therefore, an extensive plan was devised to tackle the anticipated problems of heavy inrush of water and loose fall. A special impetus was given to strengthening of the rock mass in the reach ahead, excavation and support system.

The reach has been excavated by implementing intensive pre-grouting, 10-20m ahead of heading especially above crown portion to increase the modulus of elasticity, to create umbrella arch as pre-excavation support and to minimize the water seepage/inflow in poor grade rock mass.

- **Pre-grouting:**

In case of the RBM zone and fractured/sheared strata expected in by-pass tunnel, it was necessary to have stable grout with less than 5% bleeding, thixotropic behavior, marsh cone viscosity of less than 35 seconds, quick setting to allow uninterrupted construction sequences and good pressure stability. Therefore, combination of Rheocem micro-cement complimented with MEYCO MP320 colloidal silica gel to achieve final sealing and range of one and two component polyurethane foams (MEYCO MP355 series products) for control of water seepage problems were recommended by M/s Degussa.

Micro cement is very fine and colloidal silica has very low viscosity which penetrates easily into fine cracks, joints and pores, whereas polyurethane forms a thick foam immediately after coming in contact with the water thus helping in minimizing the water inflow and strengthening the ground.

a) Drilling:

Drilling of probe holes and grouting holes was done with multi boom drilling boomers with 54mm -64mm drill bits. A total of 3 probe holes were drilled in a section located in the crown and spring lines of the tunnel at an outward inclination of 7^0 to 14^0 and were also used for subsequent grouting. Outside the RBM zone, 21m long probe holes and grout holes were drilled after every 15m reach with overlap of 6m with next round, whereas inside the RBM zone the holes were drilled for maximum 21m length or less depending upon the stability of the hole after every 6m reach with sufficient overlap. At least 16 numbers of holes were drilled in a section and the same was followed after each overlap. The typical spacing of holes and grout fan around the perimeter is given in Figure 4 & 5

FIG NO 4-
TYPICAL GROUT FAN PROBE HOLE LOCATIONS

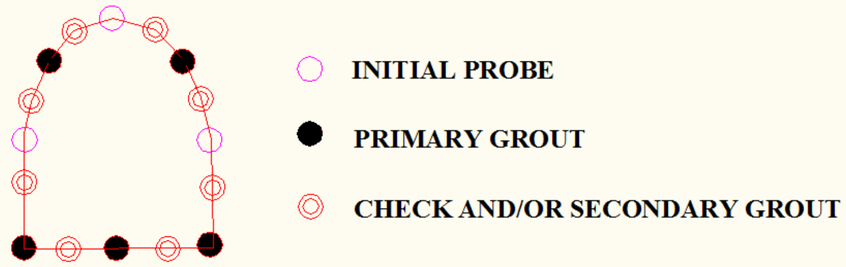
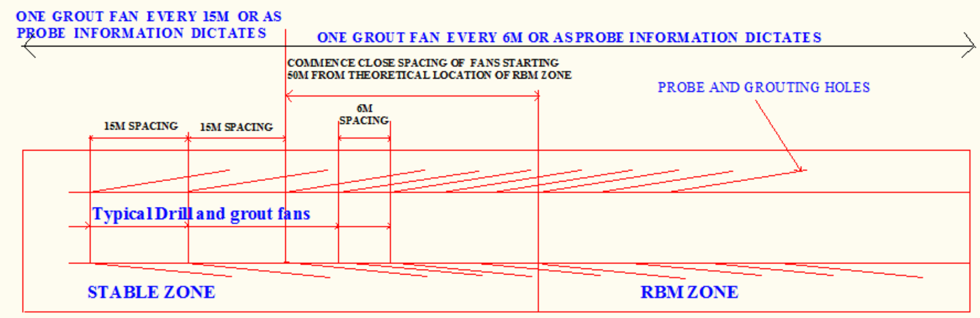


FIG NO 5- LONGITUDINAL PLAN IDENTIFYING GROUT FAN SPACING



b) Flushing of boreholes:

Flushing and cleaning of the hole is very important in the areas of weak rock mass and fissures/joints filled with sheared material as all the joints/fissures have to be open to ensure the penetration of the injected grout to the bottom of the fissures/joints. Flushing of the hole was done by using water at 10 bar pressure, combined with some compressed air from bottom to neck of the hole.

c) Placing of Packers:

The utmost care is taken while placing and tightening of the packer to ensure the proper grouting. Normally packers were placed near to the collar of the borehole (1.5m to 2m from neck) and the gout was injected over its entire length in one single step. But sometimes very poor rock and high water pressure provoked a face failure and placement of the packer was very difficult. In such cases packers were placed at suitable location in depth.

d) Injection:

Pre-injection criteria were classified in two categories viz i) Outside the RBM zone and ii) inside the RBM zone. For first category, observational Pre-injection and for second category systematic Pre-injection approaches were followed respectively. The decision criteria for injection was based on measured water in-leakage in the form of number of l/min from a single hole or as per zones of weakness identified in the probe drilling record. Outside the RBM zone, the decision was based on the observational method with the following criteria below

Water out-leakage	Grouting decision	Stop Criteria
< 2 lit/min	No grouting	----
2 to 10 lit/min	Grouting with Rheocem 650	80 bar or 4 tonnes/hole
>10 lit/min	Grouting with OPC	80 bar or 4 tonnes/hole

Inside the RBM zone the systematic method was conducted with full drill fans fully grouted as per the water out-leakage below.

Water out-leakage	Grouting decision	Stop Criteria
< 2 lit/min	Colloidal Silica MP320	20 minute gelling time
2 to 10 lit/min	Grouting with Rheocem 650	80 bar or 4 tonnes/hole
>10 lit/min	Grouting with OPC	80 bar or 4 tonnes/hole

The cement mixture has to be a state of the art colloidal mixture with an impeller speed of not less than 1500 rpm. Mixing of material was done for two minutes, which should neither be exceeded, as intensive high shear mixing generates heat and increases the temperature of the mixture, nor shortened as micro cement does not work properly if flocculated clusters are not completely broken. In case of leakage of the grout and high water pressure conditions, quick setting and hardening of the grout was needed, which was done by adding MEYCO SA 160 an alkali free accelerator for cement . Also polyurethane was used in case of heavy seepage zones as it transforms into foam just after coming in contact with the water and seals the cracks, thus reducing the water seepage considerably.

In this particular case the maximum grouting pressure allowed was 50 bars above the static ground water head from beginning. Sometimes it was done alternatively until one of the following occurred i) No more grout accepted by the ground at maximum allowed pumping pressure ii) The maximum specific grout quantity has reached, regardless of pressure used, whichever happens first.

Injection of the gout was done starting from lowest hole in the face followed by holes located upward. The typical setting time of the Rheocem is about 2 hours as per the standard specification and was allowed to proceed the work without breaks.

4.4 Sequence of excavation and support:

Intensive Pre-grouting with chemicals → Drainage and Pressure relief holes prior to blast → Controlled blasting with less pull → Application of protective layer of shotcrete on heading → Rock bolts and shotcrete in excavated section → Concurrent Steel rib support → RCC lining.

Pre-grouting helped in strengthening the rock mass and reducing the water pressure in the rock mass ahead. This was followed by providing 5m to 7m long drainage and pressure relief holes around periphery, prior to blast for further reduction of water seepage and pressure if any. The blasting was done for full face in a controlled way with maximum pull of 1.5m only to avoid the undesired over breaks and loose fall. Support system was initiated with the application of 50-100mm thick shotcrete on the face itself followed by pattern rock bolts (L- 4 to 4.5m, dia- 25mm @ 1.75m staggered spacing) and 100-150mm thick shotcrete in the fair grade and poor grade (having Q values closer to 4) rock mass. Steel ribs ISMB section has been provided @ 50-100cm spacing in very poor and lower poor grade rock mass with complete backfilling. Finally the tunnel section was supported by providing concrete lining as permanent support.

The bypass tunnel directly influenced by low rock cover, occurrence of RBM over the crown, sheared & fractured rock mass and heavy water seepage has been negotiated successfully. Though it took much cycle time but compared to the problems occurred during excavation of the main HRT reach, the tunneling in bypass tunnel has been completed carefully and smoothly and only minimal water seepage was observed at places and there were no blow-outs, loose falls and uncontrollable collapse during excavation.

5. Discussions:

- Geological and geotechnical risks in the form of unforeseen geological conditions occur as surprises during construction, especially in the Himalayan terrain.
- The amounts of money involved in claims and time over runs arising from adverse geological conditions are enormous and needs to be taken very seriously.
- The advanced ground strengthening techniques and water seepage control by chemical grouting are very successful in negotiating the poor to very poor tunneling media.
- Considering the past history and experiences of the other projects about cost & time over runs, unnecessary hindrances and escalations, comparably this is not a costly affair at all.

6. Acknowledgement:

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