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Efficacy of Grouting in Tail Race Tunnel of 1000MWTehri Pump Storage Plant Hydroelectric Project

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ABSTRACT
This paper deals the grouting operations (contact/consolidation) and permeability tests carried out in TRT of 1000MW Tehri Hydroelectric Project (Pump Storage Plant) in Uttarakhand, India. Efficacy of grouting determined by conducting permeability tests before and after consolidation grouting. Contact grouting is done to fill the cavities/voids between concrete and rock mass on account of shrinkage of concrete and uneven overbreak. Consolidation grouting is done to strengthen the surrounding rock mass by filling up the open joints, fissures, cracks etc. Proper grouting of surrounding rock mass around the opening helps in monolithic behavior of the rock mass. The quality assurance during grouting was ensured by checking the properties of all materials being used and by conducting permeability tests in pre/post grouting stage.
Keywords: Grouting; Permeability; Efficacy; Tail Race Tunnel, Pump Storage Plant.

INTRODUCTION
During underground excavation by drilling and blasting technique the discontinuities in rock mass such as joints, faults, shear planes (major or minor) get further separated. To strengthen and sealing of surrounding rock mass, grouting technique is generally used. Proper grouting by filling open joints, voids and cavity between concrete lining and rock mass around the opening helps in behaving the rock mass monolithically. Sometime ahead of Workfront excavation grouting operation is performed to control ground water inflows and to stabilize the ground. For supplementing the geological findings permeability test conducted in drill holes. By conducting permeability test normally following parameters can be decided: -

a. Pattern of Grouting.
b. Spacing of Grouting Planes.
c. Grout Pressure.
d. Grout Mixes.
e. Efficacy of Grouting.

The Tehri Pumped Storage Plant (PSP) involves construction of an underground Machine Hall housing four reversible pump turbine units

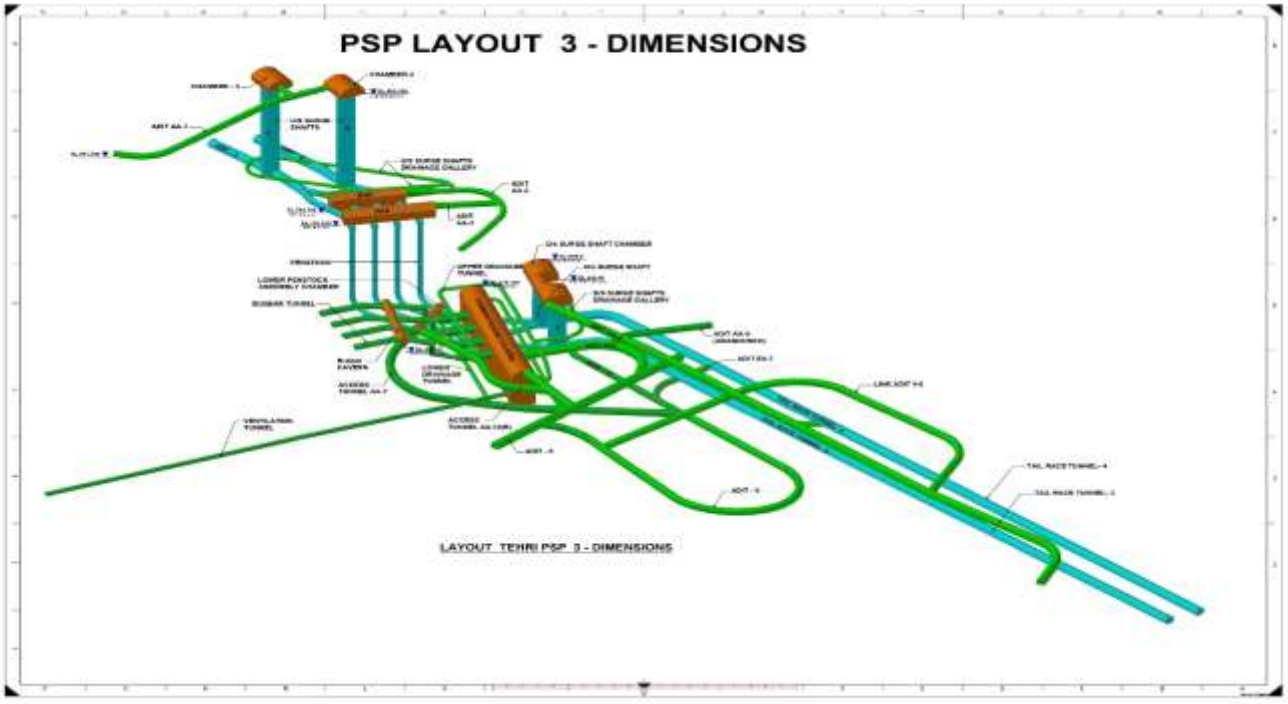
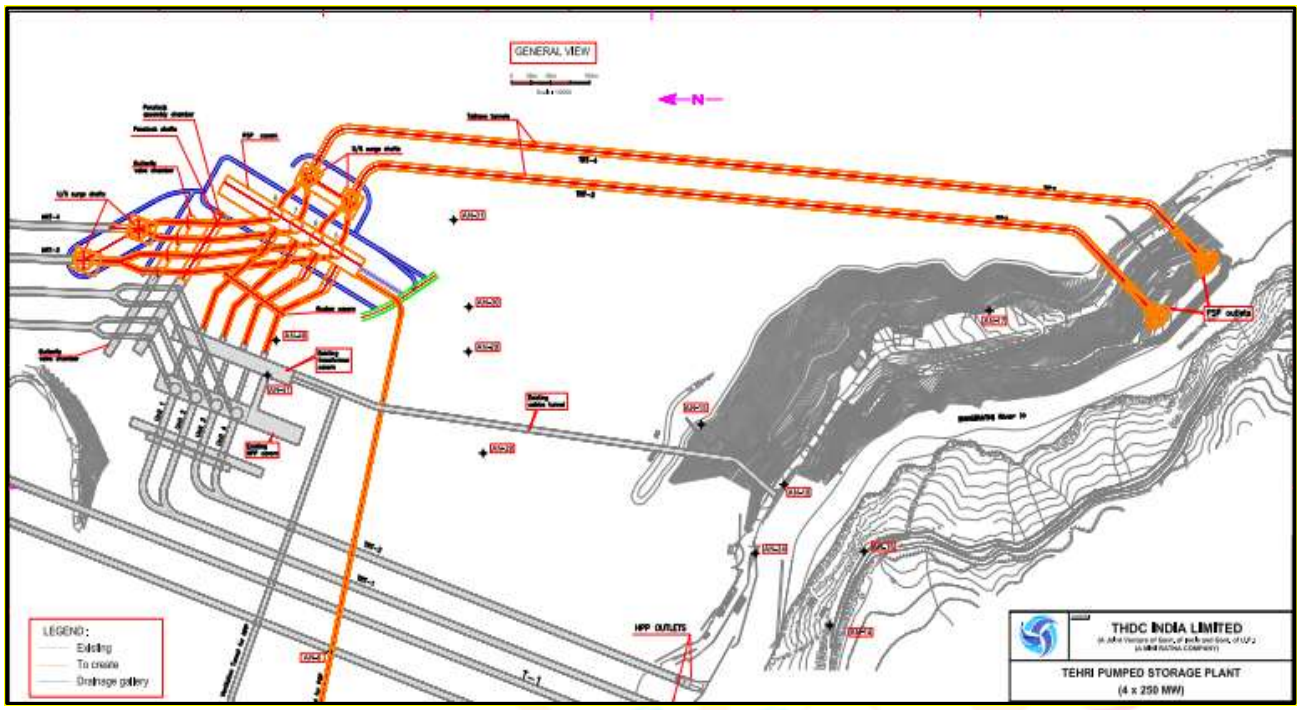


Figure: - 1 1000 MW Tehri Pump Storage Plant Layout



of 250 MW each on left bank of river Bhagirathi.

The Main feature of the Project is the large head variation of about 90.0 M between the maximum and minimum head, under which reversible units shall operate. The operation of Tehri PSP is based on the concept of recycling of water between upper reservoir and lower reservoir. The Tehri Dam reservoir shall function as the upper reservoir and Koteshwar reservoir as lower balancing reservoir.

Figure: -2 Layout of TRT.

The 1.1km long and 4.5m diameter Tail race tunnel (TRT) was excavated through various rocks classified by RMR developed by Bieniawski ,Z.T. 1976. The total TRT was divided into two packages TRT-3 (1006.00 m) & TRT-4(1117.00 m) as shown in Fig. 2

This paper deals with contact/consolidation grouting of Twin TRT (1006.00m and 1117.00m long) and checking of efficacy of grouting by conducting permeability tests before and after consolidation grouting along with grout intake.

GROUTING

Grouting is a method widely used for strengthening and sealing of rock, soil, and concrete. The aim of grouting (rock, concrete, or soil) is to fill voids, cracks, and pores. The material injected into rock or soil formation gels, stiffens, or sets with time and thereby changes the physical characteristics of the formation.

The purpose of grouting is to improve impermeability of the rock mass which shattered due to poor rock quality and drilling & blasting operation during excavation. Grouting is also used to bring about, as nearly as possible a fully bonded contact between any concrete structure and adjacent rock by way of filling the gaps between structural surface and surrounding rock body by shear presence of shrinkage and/or construction defects otherwise.

The Grouting Operation should aim at satisfying the design requirements economically and in conformity with the rest of the construction schedule.

In case of rock mass, the geo-technical considerations for improving the physical characteristics, by grouting, normally are:

- Safeguard the foundation against erodibility hazard.
- reducing the permeability of the rock mass.
- Improving the mechanical properties
- Void filling

Theory and Assumptions in Grouting Operation

It is well known fact that grouting is complex both in theory and in practice. Grouting as a subject embraces several branches related to Civil Engineering, besides experience in grouting:

a) Geology
b) Soil/rock mechanics
c) Grout Rheology
d) Hydraulic properties of rock and its co-relationship with grout rheology

The complexity of interaction of various areas related to civil engineering and the fact that actual

treatment of the ground is hardly observable, the actual response of the ground to grouting remain open to range of different opinions and concepts.

One of the facts about grouting is that one can't see what is happening. An experienced person can deduce how the grout is flowing and how well the grouting is proceeding, but there is no direct way of knowing this. A variety of methods have been tried, of course and but are no substitute for experienced person.

Despite enormous experience with different grouting material and methods grouting remains a matter of trial and error. International Society for Rock Mechanics Commission on Rock Grouting in 1996 has brought out a report compiling such experience and details effort to turn grouting from realms of trial and error to science. However, such compilation is limited to grouting of rocks with normal to low permeability. As per this report, grouting in comparison with other engineering science, is still in infancy.

In a paper "Application of New Theories and Technology for Grouting of Dams and Foundations on Rock" by H.Stille , G. Gustafson L. Hasseler published in April 2012, authors have stated that till 1990 the understanding on grouting was based on empirical knowledge. One reason for this is the fact grouting techniques developed from practices and not from theory. During recent decades, there has been a substantial increase in deeper understanding of the mechanism behind spreading of grout in jointed rock mass. The Sweden is one country where substantial research has taken place in this area. In Sweden, however, grouting is often used as a permanent sealing solution, which differs from many other countries, where casted lining systems are more often used for permanent support and consequently for sealing.

TYPE OF Grouting

Contact and consolidation grouting was performed as per IS 5878 (Part VIII): 1972 in TRT (TRT-3 & TRT-4) at 1000 MW Tehri Pump Storage Project as suggested by the designers.

Contact Grouting

The process of grouting behind the concrete lining or steel liner, to fill up the shrinkage gap and voids, if any, between the concrete lining and the rock surface and/or between the steel liner and concrete behind it. This is required for fulfilling the design assumption of the rock/concrete taking part of the load along with the lining and to prevent local accumulation of water, if any, and building up local pressures.

Contact grouting in TRT between the concrete lining and the rock mass was carried out in the top portion of tunnel after about waiting range of 25 to 28 days of the concreting of full section to enable concrete to gain full strength before being subjected to grouting pressures. Steel pipes at the locations of grouting holes was installed to eliminate drilling through the concrete lining and to facilitate/guide the drilling work.

Contact grouting holes was drilled 300mm beyond the excavated surface into the rock in the respective TRT (TRT-3 or TRT-4).

Design of drill holes for contact grouting in TRT between concrete lining and rock

mass is shown in Fig. 3 for rock classes II to IV.

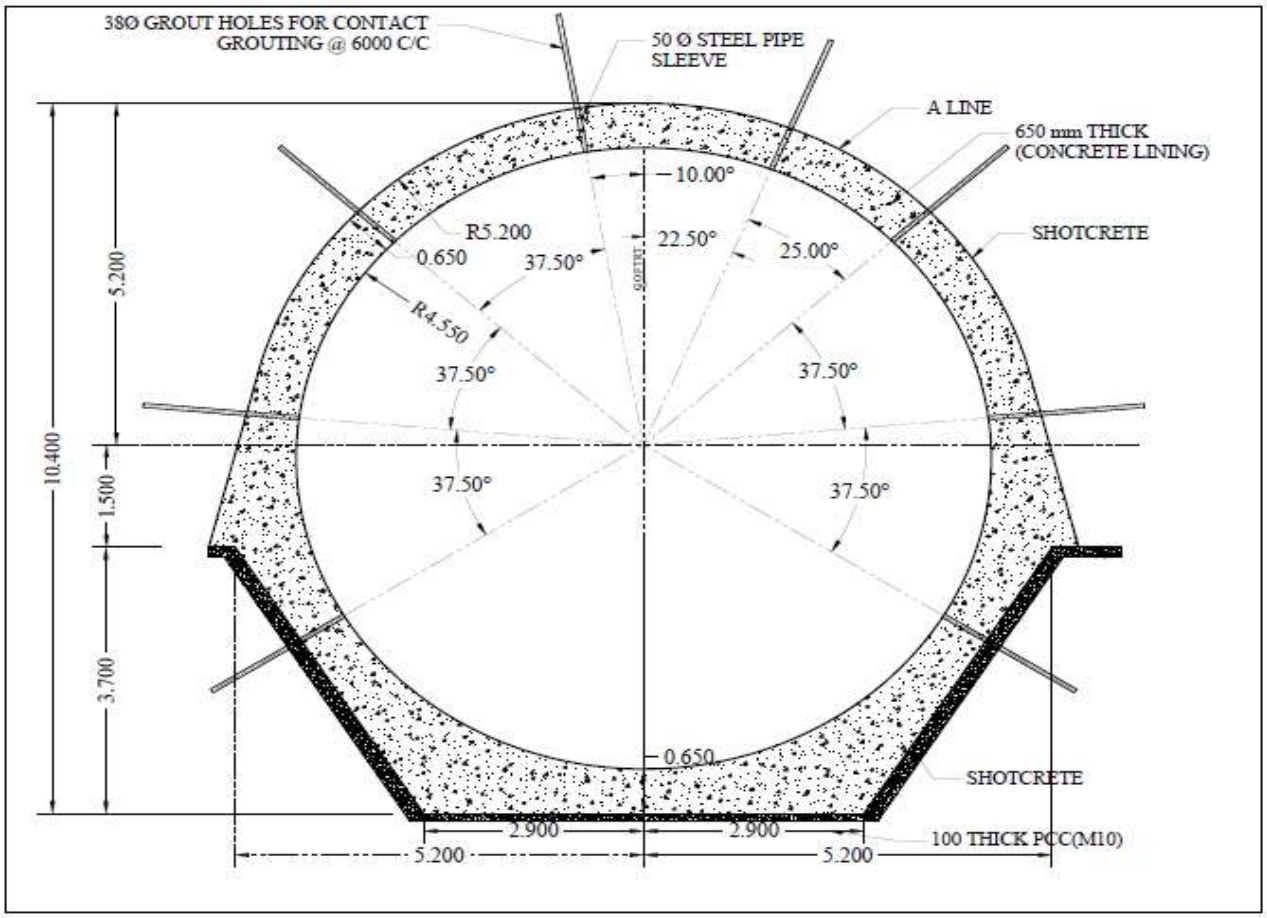


Figure: -3 Contact Grouting Sections in TRT.

Consolidation Grouting

Consolidation grouting is done to bind and densify the natural foundation strata to make it capable of supporting the load by sealing cracks and gaps so as to behave as monolithic mass and to improve the overall elastic behavior and bearing capacity of foundation.

In case of tunnels, the process of consolidation grouting (pressure grouting) is to fill up voids in rock or to consolidate the rock mass around the periphery, generally to a uniform distance from the finished surface of the concrete lining. This is done under relatively under high pressure.

In TRTs (TRT-3 & TRT-4) Consolidation grouting is carried out in rock class IV and V. For rock class II and III, requirement was assessed by site geologist as per site conditions.

As per approved GFC drawings, consolidation grouting for some of holes was carried out through the same holes those was used for contact grouting. However, few holes were drilled and grouted only for consolidation grouting.

As per the standard practice, consolidation grouting was done in stages starting with half of maximum pressure near lining and increasing pressure with depth and ultimately maximum pressure at maximum depth.

In order to reduce the pressure of consolidation grouting near to lining. Grouting was done in stages with pressure reducing from far end towards concrete lining. Consolidation grouting was done after

the contact grouting is completed in a length of at least 60m ahead of the point of grouting. Consolidation grouting pattern is shown in Fig-4.

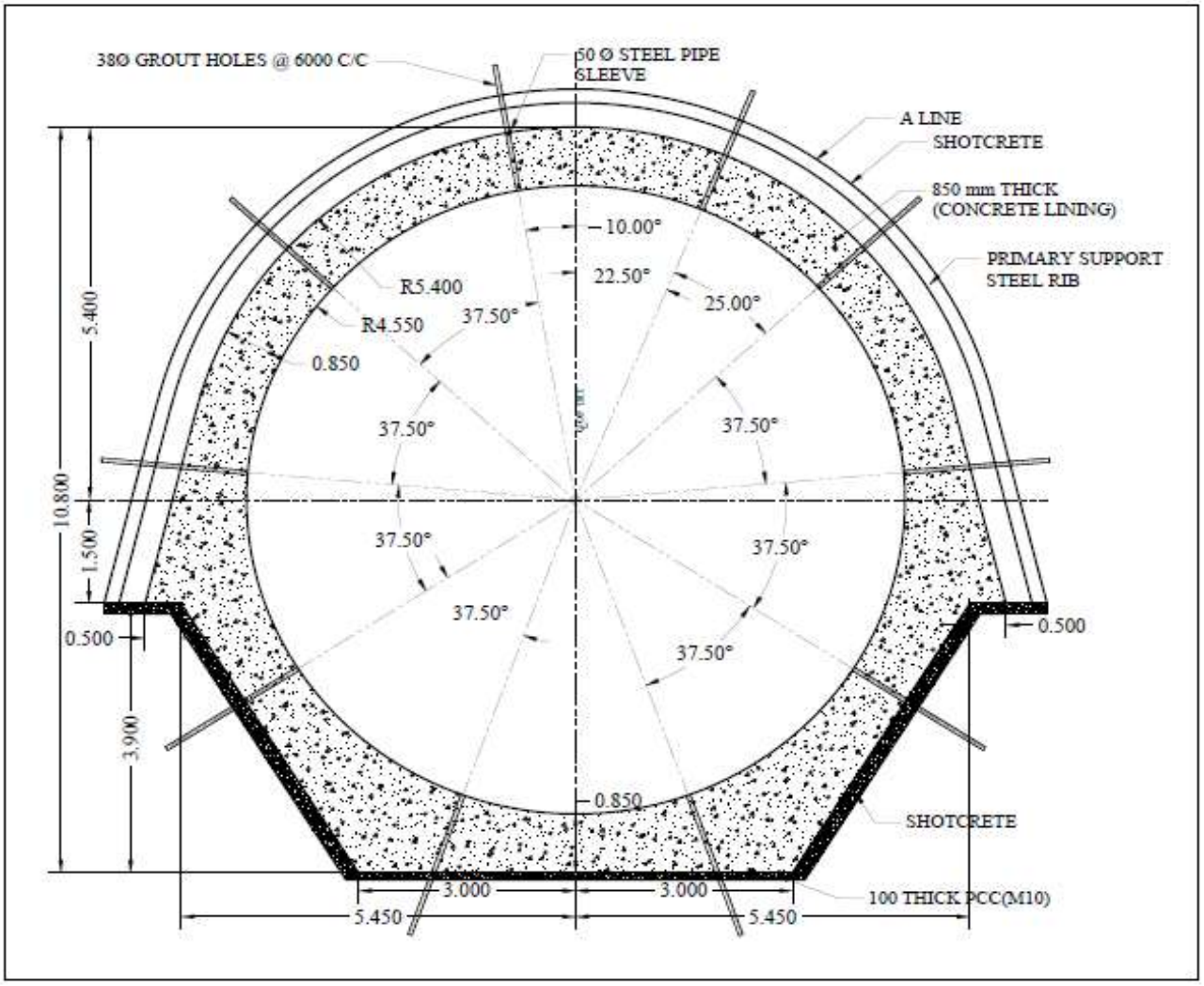


Figure 4: - Consolidation Grouting Sections in TRT.

Grouting Material

Followings materials were used in Grouting Operation in TRTs

(a) Portland Cement Ordinary Portland Cement
As per IS code recommendations, generally contact and consolidation grouting shall be done using mixture of cement and water only.

(b) Fine sands (IS 383: 1970).

(c) Water.

Equipment for Mixing and Injecting Grout

The grout pump shall be capable of developing in a uniform manner the desired pressure at the grout hole connection up to the maximum pressure required. The equipment and lines shall be kept clean by constant circulation of grout and by periodic flushing with water.

Following equipment was used for grouting:
1) Mai Grout Pump
2) Unigrout 100 - 12EH or Equivalent Grout Pump

Record of grouting operations

The information was recorded in daily is as follows:
(a) Result of the pressure test

(b) Grouting feature, for example, contact / consolidation.

(c) Date,

(d) Shift:

(e) Name of foreman.

(f) Grouting method, packer grouting or full depth grouting and stage whether first, second or third.

(g) Hole station number or co-ordinates.

(h) Time grouting begun,

(i) Time of each change in mix, pressure, or pumping rate.

(j) Time of hole completion.

(k) Total quantity of cement used for each pressure or mix change.

(l) Water-cement ratio at the start and each change thereafter,

(m) Grout consumption and time required for consumption of each batch.

(n) Pressure recorded at 3 min to 15 min intervals and on completion.

(o) Rate of injection

(p) Cement washed:

(q) Total quantity of cement injected into the hole.

(r)Reason for abandoned holes,

(s) Number and depth of holes left for redrilling and grouting.

Geology of TRT

The Phyllites along the TRT have been classified into mainly four lithological variants. The nomenclature has been based on variable proportions, and quality of Quartzite and Phyllite. The four variants are as follows:
PQM – Phyllitic Quartzite Massive.
PQT – Phyllitic Quartzite, Thinly Bedded.

QP – Quarzitic Phyllite.
SP – Sheared/ Shattered Phyllite.

TRTs (TRT-3& TRT-4) are crossing through inconsistent rock variant which are PQM+PQT, PQT+SP, QP+SP & SP.

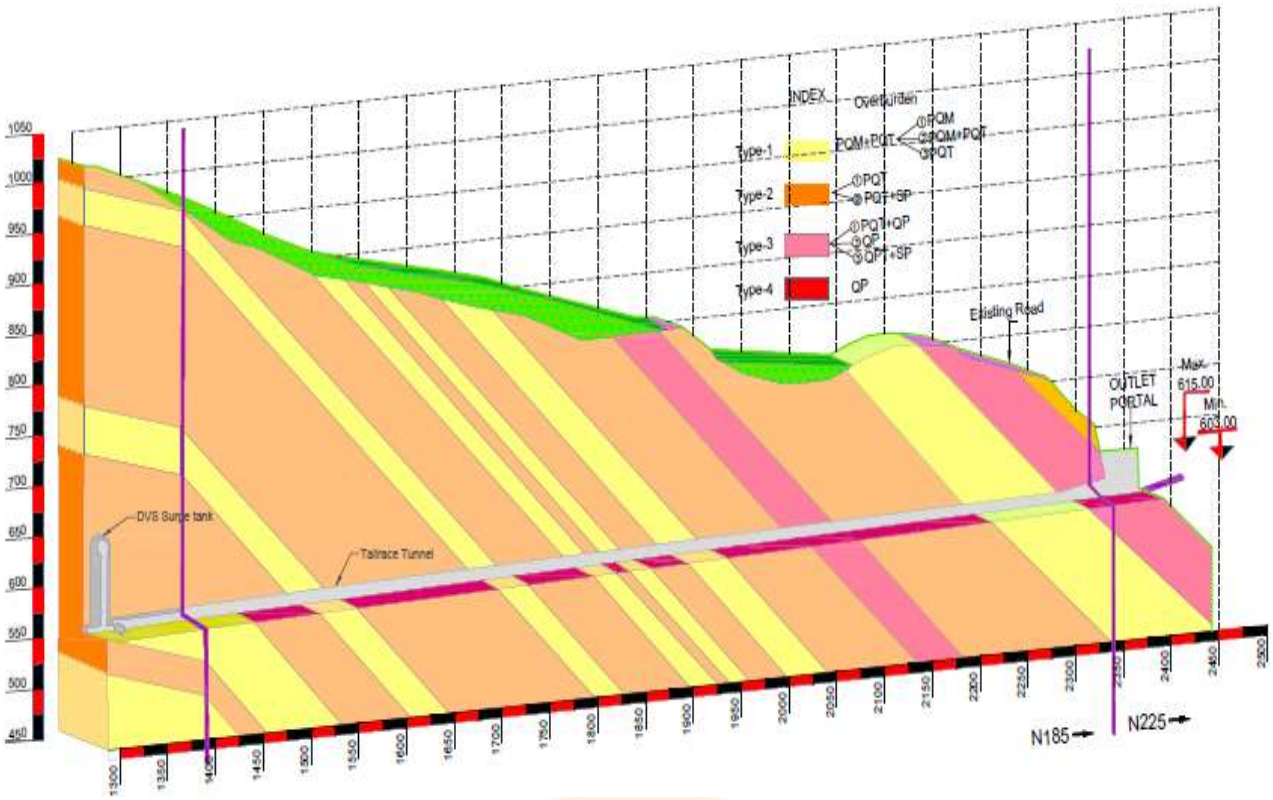


Fig: - 5 Geological model of Tail Race Tunnel in Tehri PSP.

Rock mass along the TRTs have been classified using RMR system proposed by Bieniawski, 1989. Presence of shear zones and weak Phyllite bands in the rock mass almost always associated with loose falls and cavity formations. The percentages of classes as per Bieniawski's Rock Mass Rating (RMR) system evaluated in the TRTs are shown in the following graph (Figure: - 6).

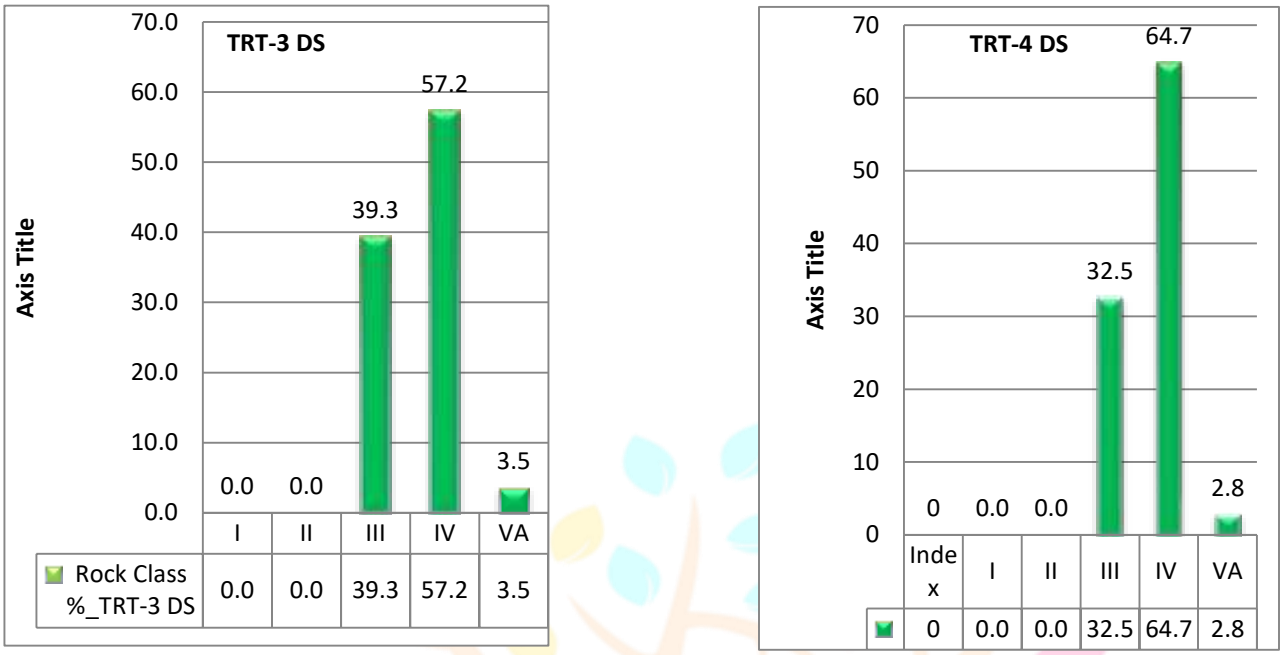


Figure: -6 Percentage of rock class encountered during excavation in TRT-3 and TRT-4

Efficacy of Grouting in TRT

Efficacy of grouting was inspected by conducting permeability tests before and after grouting operation at typical location of TRT. Permeability tests were conducted after contact grouting and before consolidation grouting to check the efficacy of grouting operation. Permeability tests were conducted in the drill holes drilled up to 6 m depth into the rock.

The coefficient of permeability was less than 3 Lugeons where rock was class III and in rock class IV location the coefficient of permeability was ranging from 5 to 10 lugeons before grouting. The maximum value of coefficient of permeability after consolidation grouting was only 1.25 Lugeon.

Time Cycle

The time duration for consolidation grouting per hole depends upon the average time requirement can be assessed. Below is the cycle time for contact and consolidation grouting in TRT.

Consolidation Grouting				
Sl no.	Activity	Unit	Qty.	Remar
	Consolidation Grouting at TRT (TRT-3 & 4)			
	Stretch Length 15m, No. of hole rows = 6 rows			
A	Drilling			
1	Drilling of holes 38mm dia. 6m length	Nos. per row	6	
2	Stretch Length	m	15	Parallel Activity
3	No. of holes for six rows	Hole No.	35	
4	Depth of each hole	Rmt	6	
5	Drilling Rmt	Rmt	216	

6	Rate of Drilling	m/hr	90	
7	Drilling duration	min	144	
B	Consolidation Grouting			
1	Fixing of manifold, connections, grout preparation	min	180	
2	Grouting Duration per hole assumed	min	30	
3	Time for grouting holes	min	1260	
4	Duration in hours	hours	25	
5	Working hours per day	hours	20	
6	Working days per month	days	25	
7	Cycle per Day	cycles	0.8	
8	Progress per day	m/day	12	
9	Progress per month	m/month	300	

Safety Precaution

Following Safety Precaution were taken as per Safety Management Plan.
a) Ensure all persons have sufficient PPE, before starting the work.
b) All machines shall be completely insulated from the ground and other conductors.
c) Ensures proper lighting arrangements at a safe distance surrounding the area.
d) In addition to the above listed precautionary and safety measures, certain IS codes for safety norms enlisted below shall also be followed.
The amount of grout intake in TRT depends upon many factors, viz. nature and extent of over breaks, nature and pattern of discontinuities, method of excavation, seepage in the tunnel, grout pressure and finally the consistency of the grout.

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