Efficacy of Grouting in Head Race Tunnel of Tala Hydroelectric Project

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ABSTRACT

This paper deals with quality control assurance of the grouting operations (contact/consolidation) and permeability tests carried out in HRT at Tala Hydroelectric Project in Bhutan. Efficacy of grouting was 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 overbreaks. 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 behaviour 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; Quality assurance; Efficacy; Head race tunnel

1. INTRODUCTION

Rock mass contains discontinuities such as joints, folds, faults, minor/major shear planes etc. These discontinuities get further separated during the excavation by drilling and blasting technique. Grouting the surrounding rock mass in case of underground structures is essential due to various technical reasons viz. to strengthen the surrounding rock mass by filling the open joints and shattered rock mass, to reduce quantity of seepage, filling of voids and cavities between concrete lining and rock mass etc. Proper grouting of the surrounding rock mass around the opening helps in behaving the rock mass monolithically. Sometimes grouting ahead of the working face is also performed to control ground water inflows and to stabilise or modify the ground. Permeability tests conducted in the drill holes are also important for supplementing the geological findings. Permeability tests are the means to decide the pattern of grouting, spacing of grouting planes, grout pressure, grout mixes and finally to check the efficacy of grouting.

Tala Hydroelectric Project is a run of the river scheme in South West Bhutan in Eastern Himalayas, located 3km downstream of the existing 336MW Chukha Hydroelectric Project on river Wangchu. The project has constructed a 92m high concrete gravity dam, three desilting chambers each of 250m x 13.90m x 18.5m size for removal of suspended sediments of 0.2mm and above size coming with the river water diverted through the intake structure; a modified horse shoe tunnel of 6.8m diameter and 23km in length to carry the water to underground powerhouse (206m x 20.5m x 44.5m) for utilising a gross fall of 861.5m, and a horse shoe type tail race tunnel of 3.1 km length and 7.75m diameter to discharge the water back into river Wangchu. The installed capacity of powerhouse is 1020MW (6 x 170MW).

The project was taken up for execution from the zero level of infrastructure development from 1st October 1997 and 1st generating unit was commissioned on 31st July 2006 and all six generating units were commissioned on 31st March 2007. The project was executed by the Tala Hydroelectric Project Authority (THPA) which was a joint venture of the Govt. of India and the Royal Govt. of Bhutan.

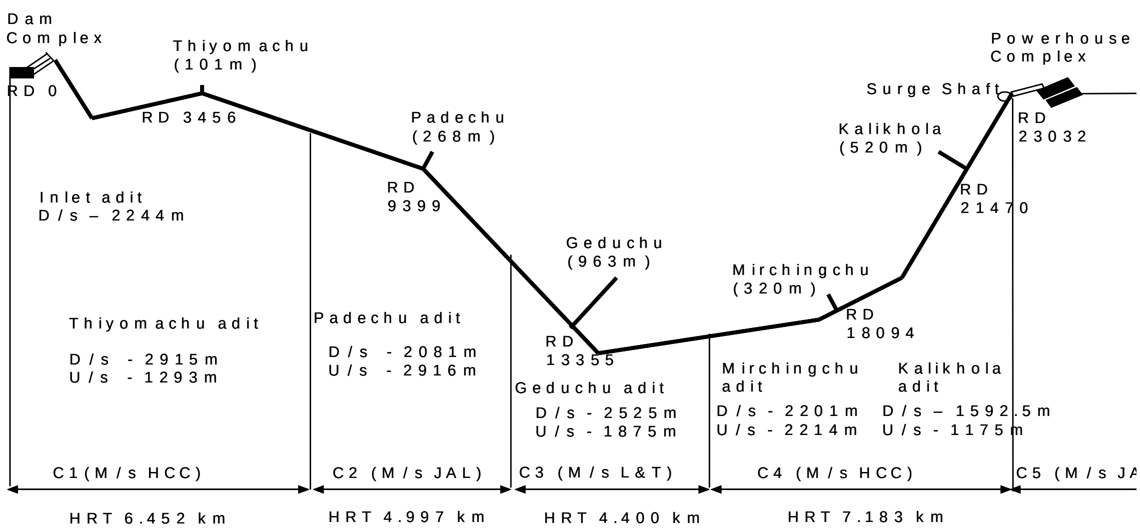

Fig. 1- Layout Plan of Tala Hydroelectric Project

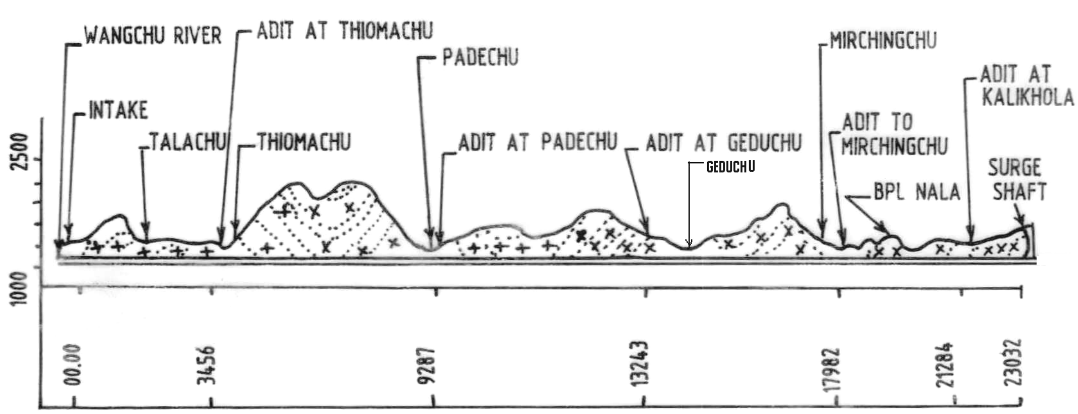

Fig. 2 - Longitudinal section of head race tunnel

The 23km long and 6.8m diameter head race tunnel (HRT) was excavated through various rocks classified by Q system developed by Barton et al. (1974) and further modified by Grimstad and Barton (1993). The total length of HRT was divided into four packages as shown in Fig. 1. Package C-1 comprises of 6.5km length of initial reach of HRT from desilting chambers side. Package C-2 consists of 5.0km length of HRT. Package C-3 comprises of 4.4km length of HRT. Package C-4 with a length of 7.2km was the most typical package with regard to the difficult tunnelling conditions. Because of the poor rock strata, tunnel had to be diverted from Kalikhola U/S from the initial alignment. Longitudinal section of head race tunnel is shown in Fig. 2.

This paper deals with quality assurance during contact/consolidation grouting of 23 km long HRT and checking of efficacy of grouting by conducting permeability tests before and after consolidation grouting along with grout intake.

2. GROUTING

2.1 Need for Grouting in HRT

In underground caverns and tunnels, the grouting is required for various purposes such as:

- Filling of voids and cavities between the concrete lining and the rock mass,
- Strengthening the rock mass by filling up the open joints and cracks,
- Strengthening the shattered rock mass around the excavation,
- Closing up the water bearing passages to prevent the flow of water into tunnel and/or to concentrate the area of seepage into channel from where it can be easily drained out.

Contact and consolidation grouting was performed as per IS 5878 (Part VIII): 1972 in HRT at Tala hydroelectric project as suggested by the designers.

2.2 Contact Grouting

Contact grouting involves the filling of voids between concrete lining and excavated surface of the parent rock. Contact grouting is sometimes referred to as backfill or backpack grouting also. Voids in concrete placed overhead usually occur because concrete behaves like a fluid during placement and consolidation by vibration before it takes an initial set. In this state, concrete tends to maintain a horizontal surface; therefore a void will form at the high point of pour. Voids can also develop due to entrapped air.

Design of drill holes for contract grouting in HRT between concrete lining and rock mass are shown in Fig. 3 for rock classes I to IV and in Fig. 4 for rock classes V to VI.

Contact grouting was carried out in the HRT at a low pressure of 2.5 to 3.0 kg/cm^2 (0.25-0.3MPa) for filling up of the voids and cavities in between concrete lining and rock. Ordinary Portland cement (OPC) was generally used for contact grouting.

Minimum diameter of drill hole was kept as 38mm and depth of holes was kept 300mm (minimum) into the rock. Grouting was continued without interruption till refusal. Grout mix of 1:1:1 (water: cement: sand) was used for contact grouting. In case of high grout intake, grout mix was thickened up to 0.7:1:1. After 24 bags of cement, the grouting was stopped. The hole was redrilled and grouting started again with cement, sand and water mixture (0.7:1:1) ratio. The grouting was considered complete when intake of grout was less than 1 litre/minute averaged over a period of 10 minutes. The maximum pressure of 2.5 kg/cm^2 (0.25MPa) was maintained by way of closing the valve for sufficient time (1 to 2 hrs) to prevent backflow. After the completion, grout holes were redrilled up to 2/3rd of theoretical thickness of lining and filled with dry pack mortar in the ratio of 0.35:1:2 (water: cement: sand). The mortar was moulded as a ball with the hands and used within 30 minutes. Average 28 days compressive strength of dry pack mortar was 37.36 MPa in the laboratory matching with average 90 days cube compressive strength of concrete and in-situ strength of concrete.

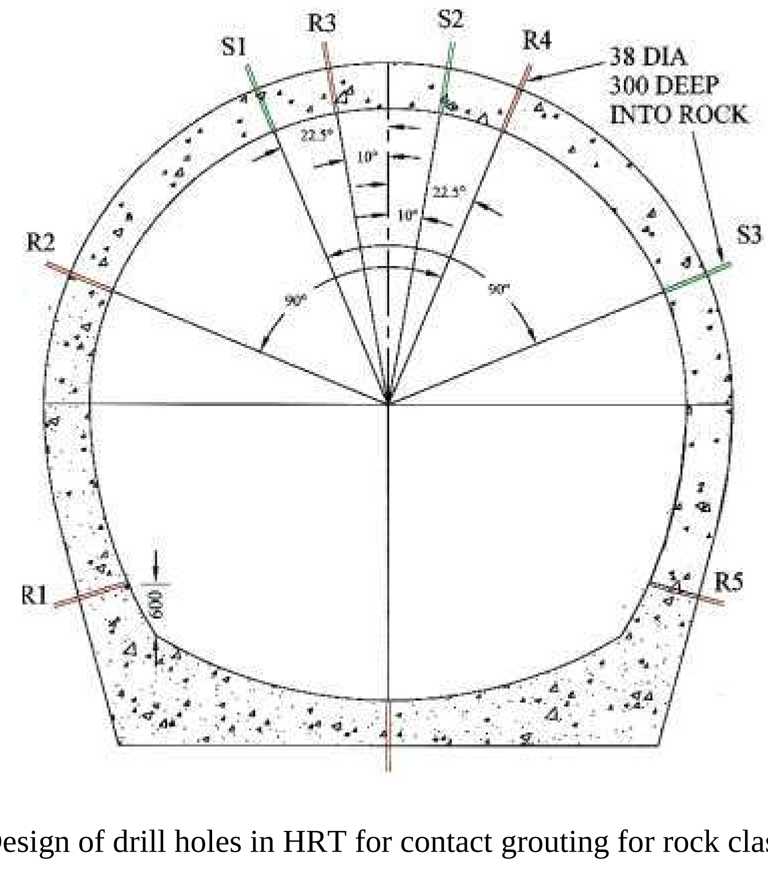

Fig. 3 - Design of drill holes in HRT for contact grouting for rock classes I to IV

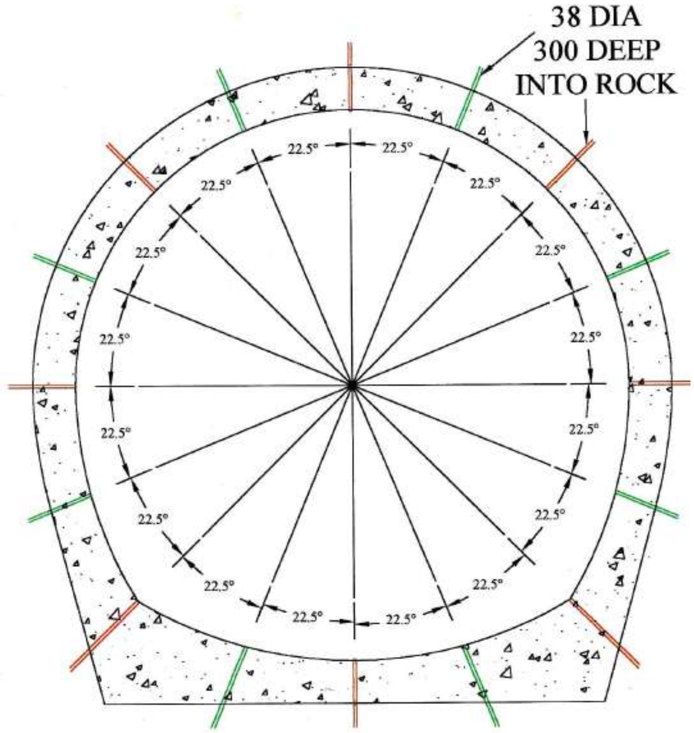

Fig. 4 - Design of drill holes in HRT for contact grouting for rock classes V to VI

2.3 Consolidation Grouting

Consolidation grouting in tunnels is essential to reduce the coefficient of permeability and improving the deformability characteristics of surrounding rock mass around an underground opening. Consolidation grouting in the surrounding rock mass around a tunnel should be carried out up to a minimum depth of one tunnel diameter. Consolidation grouting minimises the flow of water outward through the concrete lining into the rock after the tunnel has been put into service.

Consolidation grouting in HRT was carried out through 38mm diameter and 6m deep drill holes in the rock up to a maximum pressure of 7 kg/cm^2 (0.7MPa). Pattern and depth of drill holes for consolidation grouting as shown in Fig. 5 were governed by the geological and the design requirements.

Consolidation grouting was considered complete when the grout intake reduces to less than 2.0litre/minute averaged over a period of 10 minutes. Grout pressure was maintained for a sufficient time to prevent backflow. The ratio of water: cement was varied from 5:1 to 0.6:1 depending upon the amount of grout intake. Grouting was continued till refusal. After the final setting time of grout, the holes were redrilled up to 2/3rd of theoretical thickness of concrete lining and filled with dry pack mortar of same consistency as that for filling of contact grouting holes.

same consistency as that of being injected. These coupled holes were then capped and combined holes were grouted up to the specified pressure of 7 kg/cm^2 (0.7MPa) and grouting continued till refusal. Such inter connected holes were not grouted again.

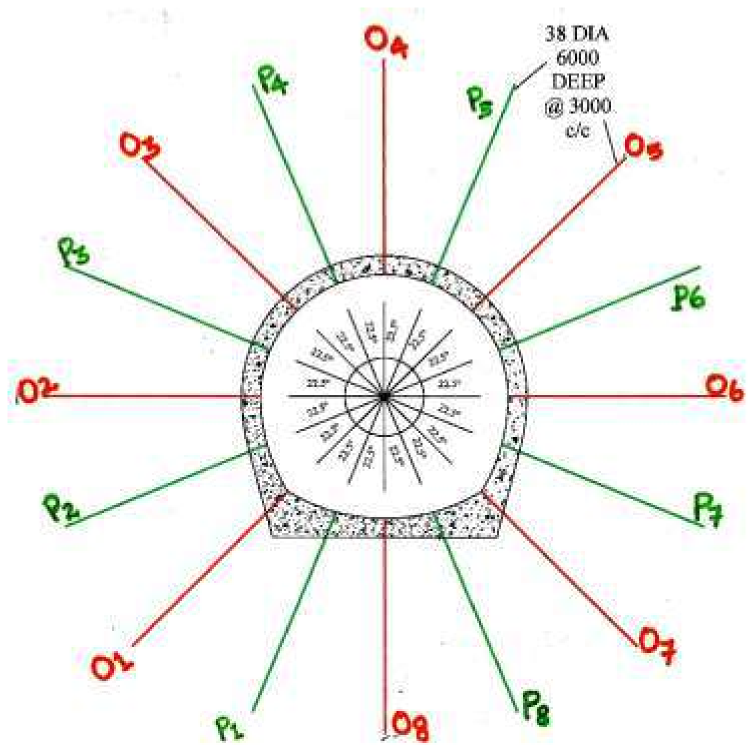

Fig. 5 - Design of drill holes in HRT for consolidation grouting (all classes of rock)

3. GROUT MATERIALS

Grout materials include cement, sand, water and admixtures, if any. The quality of these materials needs to be checked from time to time. The tests on the cement such as consistency, setting time and compressive strength were performed regularly. Sand passing through 2.36 mm sieve was used in the contact grouting. Water to be used in grouting should be free from organic matter and deleterious materials. Generally water suitable for drinking purpose is also suitable for use in grouting. Water for use in the grouting operation was got tested from CSMRS, New Delhi (2002) and it was found to be harmless for use.

4. TESTING OF GROUT MIX

Laboratory testing is used to evaluate the proposed grouting materials for chemical and physical properties of the grout mix. Chemical analysis of mixing water and sieve analysis of sand are the two common tests. Laboratory testing of the grout mix is also done to evaluate properties such as viscosity, sedimentation, shrinkage, density and compressive strength. The quality of grout in its fluid state was tested for density, viscosity and sedimentation or bleeding. Density tests were used to check proper mix proportioning. ASTM Marsh funnel viscosity test was used to determine the viscosity for grout mix proportion of 3:1 (water: cement) and richer mixes. For thicker grout, ASTM flow cone test was used. Viscosity was measured in time (seconds).

The properties of grout mix and dry pack mortar such as compressive strength, viscosity, density and shrinkage were evaluated in the laboratory before use at site, so as to have a check on grouting operations. The laboratory results of different mixes have been given in Table 1.

Table 1 - Results of laboratory tests on grout mixes at different water cement ratio

S. No.	Water Cement Ratio	Density, g/cc	Average Viscosity by Marsh Cone Seconds	Shrinkage at 28 days, %	Equivalent Cube Compressive Strength at 28 days age, MPa
Grout Mix (Water: Cement)					
1	0.5:1	1.750	68	11.17	31.68
2	0.6:1	1.734	47	16.10	26.72
3	0.7:1	1.695	43	17.45	23.66
4	0.8:1	1.582	39	21.93	18.89
5	1:1	1.492	35	33.18	8.37
6	2:1	1.190	33	60.02	-
7	3:1	1.068	31	66.67	-
Dry Pack Mortar (Water: Cement : Sand)					
1.	0.35:1:2	2.28	-	-	37.36

It is seen from Table 1 that 28 days cube compressive strength and density decrease with increase in water cement ratio. The compressive strength of 31.68 MPa was obtained with water cement ratio of 0.5:1 and it reduced to 8.37 MPa at a water: cement ratio of 1:1. However, shrinkage increases from 11.17 % to 33.18 % with increase in water cement ratio from 0.5 to 1.0.

Based on the above study, thickest grout mix was designed with water cement ratio of 0.5:1. The dry pack mortar in the ratio of 0.35:1:2 (Water: Cement: Sand) was used at site to plug the grout holes.

Behaviour of grouting materials with proposed admixture was also evaluated in laboratory. Preconstruction testing was performed in the laboratory and field tests were performed during the grouting operation. The results of testing for grout mix with flowcable 50 (MBT make) at different water cement ratio (0.45 to 0.70) are given in Table 2.

Compressive strength test was performed in the laboratory on specimen of grout. A set of three grout cubes of 50mm x 50mm x 50mm is the most common type of specimen used. The cubes were cast, cured and tested as per IS: 4031- (Part-6) - 1988. The requirement of compressive strength tests of grout is not common for geotechnical grouting application. However, it is more common for structural grouting such as contact grouting.

Table 2 - Tests on grout mix with flowcable 50

W/C ratio by weight	Admixture (% by weight of cement)	Flow time for 1000 cc (sec) at		Bleeding at 1 hr, (%)	Shrinkage at 24 hr, (%)	Compressive Strength, MPa		
		0 min.	30 min.			3 days	7 days	28 days
0.70	NIL	31.5	32.75	4.90	19.00	7.14	12.45	18.50
0.70	0.75	29.41	30.48	2.40	12.00	9.09	14.28	18.00
0.60	NIL	36.00	37.50	5.20	14.12	7.65	11.20	19.85
0.60	1.25	33.00	34.50	2.00	9.40	5.61	14.50	19.30
0.50	NIL	54.17	54.68	6.66	9.33	6.00	11.00	22.00
0.50	1.25	44.17	48.67	1.70	8.48	7.25	13.50	19.33
0.45	NIL	102.66	104.58	1.50	3.04	9.45	14.00	23.75
0.45	1.25	65.59	82.32	0.50	2.40	10.00	13.00	22.00

5. PERMEABILITY TESTS

Field permeability test is the most important tool for checking the effectiveness of grouting operation at all stages of execution. For in-situ water pressure testing, a section of hole is isolated with a double packer or single packer. Water is injected at specified pressure into the test hole section. The amount of water loss to the geological formation at a particular pressure over a time interval is recorded. This is used to evaluate permeability coefficient (k) as per IS 5529(Part 2): 1985 is expressed in terms of cm/sec or Lugeon.

The unit of measuring the co-efficient of permeability is called Lugeon, which is defined as percolation of 1 litre of water per minute per meter length of drill hole test section at a pressure of 10 kg/cm^2 (1 MPa).

5.1 Criteria for locations of permeability tests

Locations for conducting the permeability tests before consolidation grouting were decided on the basis of grout intake in the contact grouting and the available geological data of the reach. On the basis of results of the permeability tests conducted in the pre-consolidation stage as well as amount of grout intake during the consolidation grouting, the locations for conducting the permeability test in the post consolidation grouting stage, were finalised. In general, the locations for permeability tests were fixed above the springing line level in all rock classes. In the regions of low permeability values during the pre-consolidation grouting stage, certain holes can be skipped during the consolidation grouting.

5.2 Efficacy of Grouting in HRT

Efficacy of grouting was checked by conducting permeability tests before and after grouting. Permeability tests were conducted after contact grouting and before consolidation grouting to decide the pattern of drill holes, grouting planes, consistency of grout mix and finally to check the efficacy of grouting operation. Permeability tests were conducted up to a maximum pressure of 7 kg/cm^2 (0.7MPa) in the drill holes drilled up to 6 m depth into the rock. Coefficient of permeability was determined in Lugeon at 7 kg/cm^2 (0.7MPa) water pressure.

Permeability test results and the degree of efficacy of grouting at some of the typical locations in HRT are given in Table 3. The coefficient of permeability varied from 6.55 to 148.57 Lugeons before grouting. The maximum value of coefficient of permeability after consolidation grouting was only 1.55 Lugeon.

Table 3 - Permeability test results and degree of efficacy of consolidation grouting

S. No.	Contract Package	Location/ RD,m	Rock Class as per Q System	Coefficient of Permeability Lugeon		Efficacy of Consolidation Grouting, %
				Before grouting	After grouting	
1	C-1	150	III	12.06	0.48	96.0
2	C-1	Thyomachu D/S 802.5	IV	47.74	0.00	100
3	C-1	Thyomachu D/S 4500	III	6.55	0.81	87.6
4	C-2	Padechu U/S 2550	III	75.83	0.0	100
5	C-2	Padechu U/S 2424	IV	32.78	1.55	95.3
6	C-2	Padechu D/S 1772	IV	54.17	0.89	98.3
7	C-2	Padechu D/S 1664	V	35.42	0.71	98.0
8	C-3	Geduchu U/S 1505	III	9.87	0.0	100
9	C-3	Geduchu U/S 300	IV	25.50	0.0	100
10	C-3	Geduchu U/S 333	IV	31.43	0.57	98.2
11	C4	M/Chu U/S 982	IV	148.57	0.39	99.7
12	C4	M/Chu U/S 1750	VI	14.46	0.71	95.1
13	C4	M/Chu U/S 1993	IV	52.56	1.48	97.2
14	C4	M/Chu U/S 2017	IV	8.33	0.02	99.8

The Lugeon values obtained after consolidation grouting were compared with those determined in the pre-consolidation grouting stage. This was used as a measure for checking the effectiveness of grouting operation. The Lugeon values obtained in the post consolidation stage testing were correlated with the geological data of that reach and amount of grout intake during the consolidation grouting. The locations where high value of coefficient of permeability was obtained after consolidation grouting, the drill holes were regrouted and the permeability tests were conducted again to confirm the efficacy of grouting. It can be seen from Table 3 that proper grouting of surrounding rock mass helps in sealing of cracks/joints and other discontinuities present in the geological strata.

6. QUANTITY OF GROUT INTAKE

The amount of grout intake in HRT depends upon many factors, viz. nature and extent of overbreaks, nature and pattern of discontinuities, method of excavation, seepage in the tunnel, grout pressure and finally the consistency of the grout. The amount of grout intake in HRT during contact and consolidation grouting has been given in Table 4. It is clear from Table 4 that there is no fix rule for quantity of grout intake. In general, grout intake in contact grouting was lesser than in consolidation grouting. However, in C-3 Package of HRT where in general rock mass condition was better than other packages, grout intake in contact grouting was more than in consolidation grouting.

Table 4 - Grout intake in HRT

Sl. No.	Contract Package	Total Grout Intake, MT (length, m)		Grout Intake, MT/m Length	
		Contact Grouting	Consolidation Grouting	Contact Grouting	Consolidation Grouting
1.	C-1	1800.12 (4932)	10513.88 (4932)	0.365	2.132
2.	C-2	2055.20 (4473)	7644.30 (4386)	0.460	1.743
3.	C-3	8163.65 (4400)	3564.15 (4400)	1.855	0.810
4.	C-4	11918.70(6835.20)	12007.60 (6835.20)	1.744	1.757

7. CONCLUSIONS

Based on these studies, the following conclusions have been drawn:

- Proper grouting of the surrounding rock mass is essential for sealing of cracks/joints and other discontinuities present in the geological strata. This helped not only in minimising the seepage of water from tunnel to the geological mass but also helped in behaving the rock mass monolithically around the hydraulic tunnel.
- Permeability tests conducted before and after consolidation grouting proved to be an important tool for checking the efficacy of grouting. It also helped in taking decisions for re-grouting certain sections of HRT where coefficients of permeability even after grouting were found to be high.
- Properties of the grout mix such as shrinkage, bleeding and viscosity determined in the laboratory before the grouting operation proved to be useful. These properties of the grout improved considerably with the use of non shrink compound.
- In general, the design criteria given were followed for grouting. However, based on the permeability tests conducted during pre consolidation stage, some holes were skipped during consolidation grouting after few trials at site. This procedure resulted in saving of grouting time which also added to financial savings.

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