Time and Cost Aspects of Tunnel Construction in Different Rock Mass Conditions

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ABSTRACT

This paper deals with time and cost involved for tunnelling in rock mass conditions varying from class III to VI and adverse geological occurrence (AGO) in 7.2 km reach of 23 km long head race tunnel at Tala Hydroelectric Project in Bhutan Himalayas. There are large variations in time and cost of tunnel construction in different classes of rock mass. Occurrence of extremely poor strata while tunnelling in Himalayas makes the job of construction engineer as most difficult both in respect of time and cost aspects. Further, there is vast difference in time and cost of construction between very poor (class VI) and exceptionally poor (beyond class VI) rock mass conditions.

Keywords: Time and cost aspect; Weak rock mass; Tunnel; Excavation; Support

1. INTRODUCTION

Tala hydroelectric project is a run of the river scheme, located 3 km downstream of the existing 336 MW Chukha hydroelectric project on river Wangchu in South West Bhutan in Eastern Himalayas. The project authorities have 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 head race tunnel (HRT) of 6.8m diameter and 23km in length to carry the water to underground powerhouse and for utilizing a gross fall of 861.5m for generation of 1020 MW of power (6 x 170 MW); a tail race tunnel of 3.1 km length and 7.75m diameter that discharges the water back into river Wangchu. The first unit of the project was commissioned in July 2006 and all the units in March 2007. The layout of the HRT is shown in Fig. 1.

The HRT excavation taken up from 11 faces was completed on 8th November 2004 including 337m reach between Mirchingchu downstream and Kalikhola upstream faces in extremely poor rock mass conditions as called adverse geological occurrence (AGO). Tunnel excavation in 298m length of HRT between Mirchingchu downstream and Kalikhola upstream was carried out by ‘DRESS’ methodology.

This paper presents briefly the time and cost aspects in different classes of rock mass and a comparison with tunnelling in extremely weak rock mass in 23km long HRT at Tala hydroelectric project in Bhutan Himalayas.

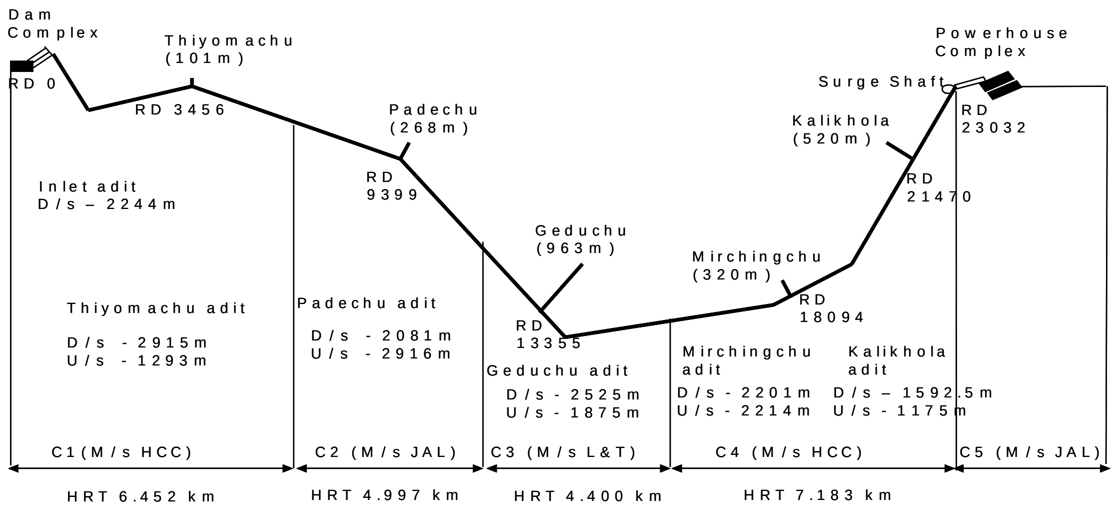

Fig. 1 - Layout of the HRT - Tala hydroelectric project

2. EXCAVATION OF HEAD RACE TUNNEL (HRT)

2.1 Geology

The tunnel alignment passes through bedrocks comprising biotite gneiss, augen gneiss, gnesis with bands of quartzite, biotite schist, muscovite schist, quartz mica schist, calc silicate, quartzite and gneiss with subordinate chlorite schist and sericite schist with acid and basic bands. The tunnel is mostly parallel or sub parallel to the foliation. Rocks are generally folded into open synforms and antiforms. A number of cross and foliation shears were intercepted. Water seepage of the order of 30 to 500 lpm was associated with major shears. The geology encountered along head race tunnel (HRT) has been discussed in detail by Tripathi et al. (2003).

There has been large variations in anticipated rock mass as per contract and as actually encountered rock mass in the HRT excavation. The variation in geological projections in contract package # C4 (about 7.2 km reach from surge shaft end) is given in Table 1.

HRT length of 337m (298m with DRESS methodology) was excavated in adverse geological reach in completely weathered garnetiferous quartz-sercite schist with intermittent quartzite bands rock mass from Mirchingchu d/s and in completely weathered quartz-biotite schist and amphibolites rock mass between Mirchingchu downstream and Kalikhola upstream. The geology encountered in HRT around Kalikhola shear zone was the worst.

As will be seen from Table 1, 75% of the HRT was expected to be excavated through class-I to class III (very good to fair tunnelling medium) and 25% in class IV and in class V (poor to very poor tunnelling medium). However, 26.80% of tunnel length was excavated in class III and 73.20 % was excavated in class IV, V, VI and in exceptionally poor tunneling medium.

Table 1 - Variation in anticipated and actually encountered rock mass in HRT

Rock Mass Classification	Anticipated (as per contract)		Actually encountered		Remarks
	Length m	%	Length m	%	
Class-I	0.00	0.00	0.00	0.00	Rock not encountered
Class-II	430.95	6.00	0.00	0.00	Rock not encountered
Class-III	4955.93	69.00	1924.91	26.80	-
Class-IV	1508.33	21.00	2977.15	41.45	-
Class-V	287.30	4.00	1515.51	21.10	-
Class-VI	0.00	0.00	428.15	5.96	Rock encountered
AGO*	0.00	0.00	336.80	4.69	Rock encountered
Total	7182.50	100.00	7182.50	100.00	

*AGO-Adverse Geological Occurrence (beyond class VI)

2.2 Excavation

Based on rock class, support system as per design and Barton's classification (Barton et al. 1974) was provided as given in Table 2.

Table 2 - Support system for HRT

Q Value	Rock Class	Type of Rock Support				
		Rock Bolts		Steel Ribs	SFRS	
		Pattern	Spacing mm	Section and Spacing mm	Shotcrete Thickness mm	Extent/Level
100-40	I	Spot bolting	-	-	50	Spot SFRS
40-10	II	Spot bolting	-	-	50	Up to Haunch
10-4.0	III	Pattern bolting	1750	-	50	Up to SPL
		Staggered both ways	1750			Above SPL
4.0-1.0	IV	Pattern bolting	1500 -	ISMB 250 750 c/c	50	Above invert level
1.0-0.10	V	Spot bolting	-	ISMB 250 600 c/c	100	Above invert level
0.10-0.01	VI	Spot bolting		ISMB 250 500 c/c	100	Above invert level

The HRT was excavated in rock class III to VI without much difficulty except some chimney formation on the crown and loads were more than expected on the steel ribs in class VI rock mass. Convergence of some steel ribs took place and some steel ribs were rectified during concreting.

Excavation from Kalikhola adit upstream progressed through fair rock mass (Q=4.1-9.2) up to RD 618m with excavation progress at times of more than 200m/month with rock supports of bolts and SFRS only. No rib was provided in this reach of HRT. The rock mass (Q=1.6-2.5) slightly deteriorated from RD 618 onwards. During excavation of HRT from Kalikhola u/s face, the rock mass conditions started deteriorating from RD 662m with unstable crown and face, large over breaks, flowing and squeezing rock mass conditions (Q=0.05-0.14). Jeur et al. (2003) discussed in detail the methodology adopted to tackle shear zone in original alignment of HRT.

The tunnel finally collapsed at RD 709m on 16th July 2002 infilling 70m already excavated HRT with about $3500m^3$ of fallen muck. It was, thereupon, decided to divert HRT from RD 607m at 45^0 from the original alignment and 110m inside the hill abandoning 102m of already excavated HRT. The excavation was started on 17th July 2002 in diverted alignment. However, similar adverse geological occurrence (AGO) was encountered form RD 1008.25 in Kalikhola U/s during March 03 and from RD 2030.55m in Michingchu d/s during July 2003.

DRESS methodology was applied in tackling HRT excavation Mirchingchu d/s from RD 2064.15m. The HRT reach of 337m was excavated in extremely weak rock mass conditions, out of which 298m was excavated with DRESS methodology as discussed by Goyal and Khazanchi (2004), Jeur and Kumar (2004) and Singh et al. (2004).

The DRESS (drainage, reinforcement, excavation and support solution) methodology mainly involves:

- Drainage in advance of rock mass ahead of the face with long drainage holes (done up to 27m long). Face stabilisation was also done by placing layers of SFRS.
- Reinforcement of rock mass by installation of long forepoles of 114mm diameter and 12-15m length followed by extensive grouting to create an umbrella arch as pre excavation support,
- Excavation of tunnel with varying diameter, and
- Support solution by installation of steel ribs of varying dimensions and other rock support measures like bottom struts, shotcrete, concrete etc.

The placement of forepole umbrella as shown in Fig. 2 was carried out with a special drilling rig Casagrande PG 175 - Italian make. A complete view of excavation and supporting sequence under forepole umbrella is shown in Fig. 3.

Thirty seven forepole umbrellas, having 9m to 15m forepole length were successfully completed for excavating 298m shear zone using this method (Fig. 3). Further, 43 to 50 pipe forepoles have been used in an umbrella depending upon the rock strata.

2.3 Construction Schedule

The C-4 package of HRT was awarded to M/s Hindustan Construction Company (HCC) on 1st October, 1998. Time required for completion of HRT of this package was envisaged as 66 months in the contract, i.e. up to 31st March 2004. Due to various projected geology, occurrence of AGO conditions and road closures due to unprecedented rainfall in the year 2000. This delay, besides geological variations/AGO occurrence, has resulted into extraordinary increase of cost from Rs. 132 crores as per contract to about Rs. 420 crores for 7.2 km length of HRT in this package.

Fig. 2 - A view of forepole umbrella and drainage holes at the HRT face in AGO reach

Fig. 3 - View of excavation and supporting sequence under forepole umbrella

3. TIME AND COST

Time and cost are two very important factors in construction of any hydroelectric project. A comparison of time and cost between different classes of rock and AGO reach has been brought out in this paper as experienced at Tala Project.

Table 3 - Construction schedule of HRT in contract package C4

Milestones	Completion schedule as per Contract		Actual date of completion	Delay months	Reasons for delay
	Time months	Date			
Excavation for both adits and 1500m of HRT	18	31.03.2000	21.07.2000	4	Variation in rock mass Classification and execution of additional length
Excavation for 4500m of HRT	33	30.06.2001	20.08.2001	2	Due to change in projected geology
Excavation for full HRT	48	30.09.2002	08.11.2004	25	Due to closure of Highway and approach roads during year - 2000 monsoon and AGO conditions
Completion of the works	66	31.03.2004	31.10.2005	19	Due to change in projected geology and occurrences of AGO reach

3.1 Excavation

Time and cost involved in excavation of HRT is given in Table 4. Average time taken for excavation of 7.5m diameter (for 6.8m finished diameter) tunnel and per running meter (rm) length is 5.33 hours/rm and corresponding cost is Rs. 59,330.00 (1US$=Rs.48.00) in class III rock as compared to time taken 13.50 hours/rm and cost of Rs.168,255.00 in class VI rock. Due to immediate support before and during excavation, time and cost could not be separated out in AGO reach.

Table 4 - Time and cost of excavation for different rock classes in HRT

Rock Class	Excavation			
	Time hrs/rm	Volume m^3/rm	Rate Rs/m^3	Cost Rs./rm
Class-III	5.33	50.28	1180	59330
Class-IV	5.00	53.822	1820	97964
Class-V	8.42	54.34	2385	129599
Class-VI	13.50	54.90	3065	168255

3.2 Support System Installation

Time and cost involved for installation of support system of HRT is given in Table 5. The time and cost involved in class III rock were 3 hrs/rm and Rs. 29043.00 per rm. The time and cost involved in class IV rock were 6.85 hrs/rm and Rs. 110623.00 per rm as compared to 15.50 hrs/rm and Rs. 274028.00 per rm in class VI rock which was about 2.5 times more than class IV rock mass.

Table 5 - Time and cost of support system for different rock classes in HRT

Class	Length m	Support System	
		Time, hrs/rm	Cost, Rs/rm
Class-III	1924.91	3.00	29043
Class-IV	2977.15	6.85	110623
Class-V	1515.51	10.50	129773
Class-VI	428.15	15.50	274028

Average actual time in excavation and support involved in AGO reach as given in Table 6 was 68 hours/rm from Mirchingchu side and 90 hours /rm from Kalikhola side which is very high as compared to even 29 hrs/rm in class VI rock mass. The cost of excavation and support system in AGO reach by using Dress methodology was Rs. 2480,000.00 per rm which was 5.60 times higher than Rs. 442,283.00 per rm in class VI rock.

Table 6 - Time and cost of excavation and support system for different rock classes

Class	Length m	Excavation and Support System	
		Time, hrs/rm	Cost, Rs/rm
Class-III	1924.91	8.33	88373
Class-IV	2977.15	11.85	208587
Class-V	1515.51	18.92	259367
Class-VI	428.15	29.00	442283
AGO	336.80	Mirchingchu 68.00 Kalikhola 90.00	2480000

3.3 Concrete Lining

After completion of excavation and temporary support, RCC lining was done done in HRT. The approximate average cost of steel reinforcement used in different classes of rock is given in Table 7.

Table 7 - Cost of steel reinforcement in concrete lining in different rock mass classes

Rock Class	Steel Quantity MT/rm	Rate Rs/MT	Cost Rs/rm
III	0.4456	27831	12402
IV	0.4586	27831	12763
V	0.6301	27831	17536
VI	1.368	27831	38073
AGO	6.261	27831	174251

Reinforcement of 16mm diameter 200 mm c/c both ways was provided in class III and class IV and 20 mm diameter 200 mm c/c main bars and 16 mm diameter 200 mm c/c distribution bars was provided in class V rock. However, 32 mm diameter 200 mm c/c main bars and 16 mm diameter 200 mm c/c distribution bars was provided in class VI rock. It was proposed to use 32 mm diameter 75 mm c/c on both faces towards rock as well as lining sides and 16 mm diameter 200 mm c/c as distribution bars in AGO reach.

Concrete grade of M20A20 was used with cement content of 325 kg/m^3 for kerb, overt and invert stage II and 300 kg/m^3 for invert stage I concrete. Cement content in concrete was optimized from 375 kg/m^3 which was used to start with concrete lining. Portland slag cement was used to avoid alkali silica reaction (Singh and Sthapak, 2003, Singh et al., 2006) as all the aggregates were found reactive with ordinary Portland cement. Average quantity of concrete in HRT lining was 19 m^3/rm. Cost of RCC lining was Rs. 89471 per rm as the RCC lining rate was Rs. 4709/m^3.

3.4 Grouting

Due to joints in rock mass, cost involved in contact and consolidation grouting was high. Cement consumption in contact grouting varies from 0.040 t/rm in class III rock to 0.098 t/rm in class VI rock. However, cement consumption varies from 1.40 t/rm in class III rock to 5.61 t/rm in class VI rock for consolidation grouting. Total cost of contact and consolidation grouting including cost of drilling, grout placement, cement consumption and permeability tests varied from Rs. 26461 per rm in class III rock to Rs. 57116 per rm in class VI rock.

Table 8 - Cost of contact and consolidation grouting

Rock Class	Contact Grouting		Consolidation Grouting		Total Cost Rs/rm
	Cement MT/rm	Cost* Rs/rm	Cement MT/rm	Cost* Rs./rm	
III	0.040	5737	1.40	20724	26461
IV	0.056	5827	1.62	22063	27890
V	0.094	7882	2.73	32654	40536
VI	0.098	7849	5.61	49267	57116

* Includes cost of cement, drilling and placing

3.5 Cost of Instrumentation

Average cost of instrumentation was Rs. 231 per rm in HRT including AGO reach. However, additional instruments were installed in AGO reach as compared to other classes of rock. Thus cost of instruments installed in AGO reach was Rs. 6721 per rm.

4. TIME AND COST OF HRT CONSTRUCTION

The time of excavation and support of HRT was about 8.33 hours/rm in class III rock mass and 29.00 hours/rm in class VI rock mass. However, average time in AGO reach was 68 to 90 hours/rm.

The total cost of HRT construction per running meter has been calculated for C-4 package and given in Table 9 which includes cost due to excavation, support, steel reinforcement, RCC lining, grouting and instrumentation. Bar chart of cost of construction in different rock classes is shown in Fig. 4.

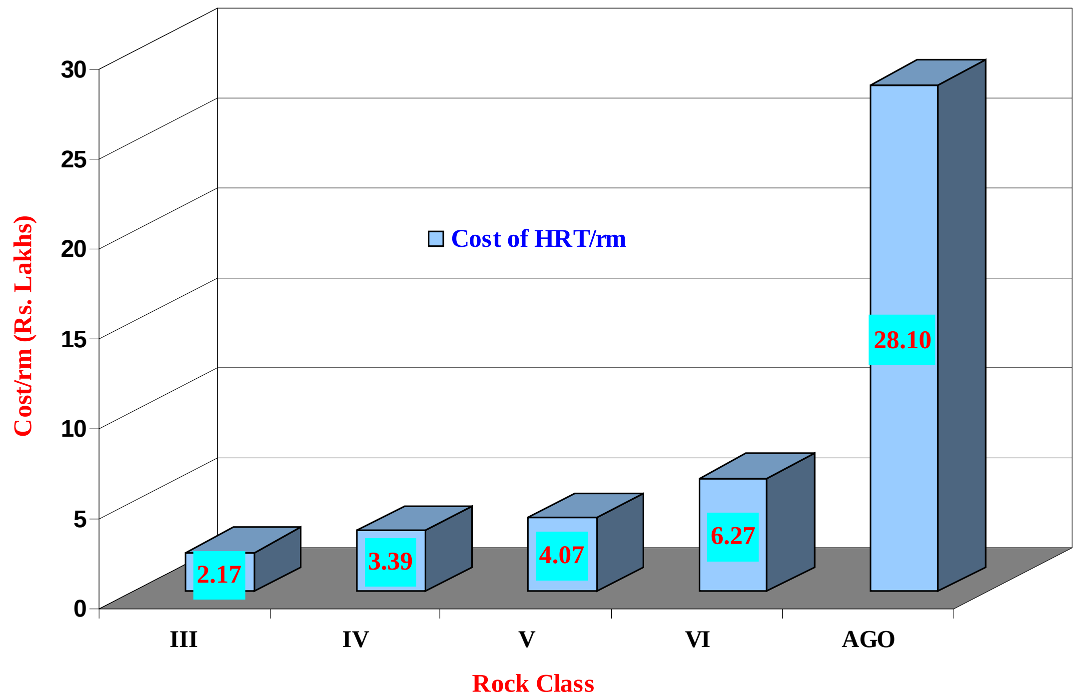

Fig. 4 - Cost of HRT construction in different rock mass classes

The cost of construction was Rs. 2.17 lakhs/rm in class III rock and it went up to Rs. 6.27 lakhs in class VI rock. However, the cost of construction was Rs. 28.10 lakhs/rm in AGO reach which was tackled with DRESS methodology. For 337 m AGO reach, the cost of HRT construction was about Rs. 95 crores as compared to about Rs. 21 crores of HRT construction even in class VI rock and it would have been between Rs. 7.31 crores and Rs.13.72 crores in class III to V rock mass.

Table 9 - Cost of HRT construction

Rock Class	Cost of HRT Rs/rm due to					
	Excavation and Support	Steel	Concrete	Grouting	Instrumentation	Total Rs./rm
III	88373	12402	89471	26461	231	216938
IV	208587	12763	89471	27890	231	338942
V	259367	17536	89471	40536	231	407141
VI	442283	38073	89471	57116	231	627174
AGO	2480000	174251	89471	60000	6721	2810443

5. CONCLUSIONS

Based on this case study and experience of tunnelling at Tala hydroelectric project in Bhutan, the following conclusions are drawn:

- Time and cost involved in HRT construction is dependent on rock mass class encountered during actual excavation. It is, therefore, pertinent that rock mass class for tunnels may be projected properly in the tender documents before actual construction through proper and detail investigation.

- The head race tunnel in 337m reach in the shear zone adverse geological occurrence (AGO) was excavated successfully including 298m using 'DRESS' methodology. Cost of excavation in DRESS methodology in tackling exceptionally poor rock mass conditions was, however, very high.
- The time and cost of excavation and support of HRT were about 8.33 hours/rm and Rs. 216938/ rm in class III rock 29.00 hours/rm and Rs. 627174/rm in class VI rock mass respectively. However, time and cost in AGO reach was 68 to 90 hours/rm and Rs. 2810443/rm, respectively.
- For 337 m AGO reach, the cost of HRT construction was about Rs. 95 crores as compared to about Rs. 21 crores of HRT construction even in class VI rock mass and it would have been between Rs. 7.31 crores and Rs.13.72 crores in class III to V rock mass, respectively.

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