Tunneling in Soft Rock- Subansiri Hydroelectric Project, Arunachal Pradesh, India.

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Abstract

The 2000 MW Subansiri Lower Hydro Electric Project on Subansiri River, a major tributary of Brahmaputra River, located across the border of Assam and Arunachal Pradesh is under advanced stage of construction. For construction of dam the river has been diverted by constructing five diversion tunnels of 9.5 m diameter. The rock type in the project area comprises of weak sandstone of Middle Siwalik group of rocks. The project, located in the fragile Outer Himalayas, is bounded in the north by Main Boundary Fault and to the south lies Main Frontal Fault. The rocks have a UCS range of 15 to 20 Mpa in dry condition and 4 – 7 Mpa in saturated condition. Because of the soft nature of rock mass, 'non-blasting' technique using road header and twin cutter heads, mounted on excavator bases are used for excavation by grinding. The Low cutting rate is mainly attributed to the massive nature and lack of fissility in the rock mass. Presence of higher percentage of fine gained matrix in the rock mass has lead to generation of large quantities of dust due to the grinding effect. Use of water for suppression of dust has further been a detrimental effect, due to the formation of large quantities of slush which makes difficult to handle the generated muck. RMR and Q – system of classification were adopted for the tunnel grade assessment. Significantly high values for the rock mass were noticed. The massive and weak nature of the rock mass limited the use of these systems of classification. The tunnels with a moderate superincumbent cover (200m), has given spallings on the walls at a number of places. Relatively recent alternative classification system for tunneling grade assessment, based on hindrances during tunneling has been discussed in the paper.

Introduction

The Subansiri River a major tributary of the Brahmaputra River, originates from Tibet, where it is known as Tsari Chu. The Subansiri basin is one of the largest sub-basins of the Brahmaputra valley and contributes about 10% of the discharges of Brahmaputra River, (measured at Pandu near Guwahati). Subansiri Basin extending from tropical to temperate zones, exhibits a great diversity in the rainfall characteristics. The maximum observed discharge at Gerukamukh is 12939 cumecs on 14th June 2008.

The Subansiri Lower H.E. Project is located 2.3 Km upstream of Gerukamukh village on Assam/Arunachal Pradesh border on the Subansiri River. The Project envisages a 116 m high concrete gravity dam with surface power house of 2000 MW capacity. Eight horse shoe shaped Head Race tunnels of 9.5 m diameter would supply water to the Power house (fig.1). For construction of the dam, five horse shoe shaped diversion tunnels of 9.5m diameter are constructed for a flood diversion of 4550 cumec (1 in 25 years non monsoon flood).

Geological Set-up of the area

The Eastern Himalaya in Arunachal Pradesh forms the highest mountain belt in the north eastern part of India. Wide varieties of rock types have been reported from this belt (Krishnan, 1956; Wadia, 1957; Le Fort, 1977; Sinha Roy, 1976). The Eastern Himalayan

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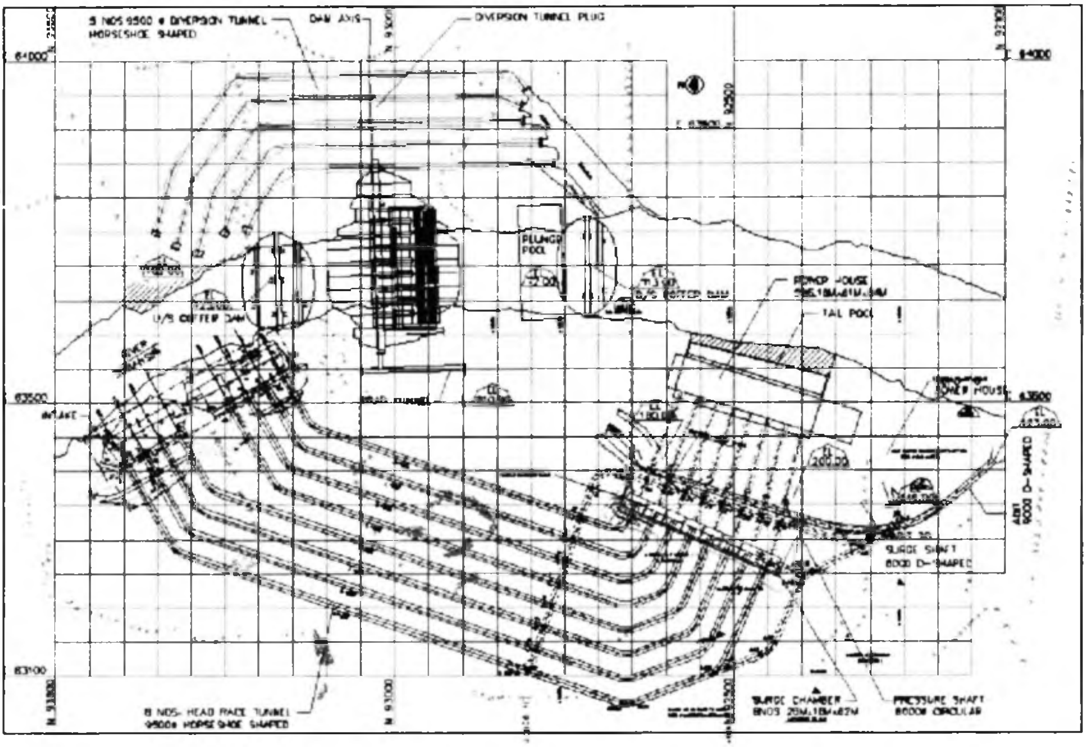

Fig. 1: Project layout

ranges which are believed to have formed during major mountain building orogenies in the Miocene include thrust, fault and over-folding as major structural elements.

The Indus-Tsangpo Suture Zone (ITSZ) marks the Collision boundary of Indian and Tibetan plates. The rock unit south of ITSZ are the high grade metamorphics and gneisses of the axial belt , separated from the Precambrian Sedimentary sequences and its equivalents by the Main Central Thrust (MCT). The Main Boundary Thrust (MBT) separates the Siwalik rocks from Pre-Tertiary rocks. Beyond MBT different stratigraphic units are disposed in intricate thrust slices.

The Siwaliks on the foothills of the Arunachal Himalayas, are represented by a thick pile of Mollassic Sub-greywacke. The belt is continuous all along the Himalayan foot hills. The Siwalik sequence was deposited during Mio-Pliocene in an unstable sinking basin developed along E – W fractures north of the Shillong Plateau and south of the rising Himalayas. The Siwaliks are folded and thrusted over by the older rocks

Site Geology

The Subansiri Lower project site is occupied by sandstone of Middle Siwalik Formation (Subansiri Formation). The sandstones are medium to fine grained with typical salt and pepper texture and are soft in nature. The sandstone is massive to bedded at places. Stringers and lenses of carbonaceous material are also present. The sandstone occasionally. The characteristics of the sandstone are embedded rounded pebbles of quartzite and lenses of pebbles and the presence of concretionary nodules, of diagenetic origin.

Petrographic analysis shows, the rock contains quartz (3-5%), feldspar (5-8%), chlorite, biotite and muscovite (3-5%) with fine grained matrix of quartz, calcareous and carbonaceous material (15-25%).

Table 1A : Uniaxial compressive strength determined during investigation stage.

Sl. No.	Name of Laboratory	Results		Condition
		Min (Mpa)	Max (Mpa)	
1	CWPRS(1981)	4.2	23.1	Dry
2	NEHARI (1998)	2.058	10.11	Dry
4	NEHARI (1999)	7.01	40.30	Dry
5	NEHARI (2000)	7.21	33.07	Dry
		4.12	7.21	Wet
6	NEHARI (2000)	7.01	40.30	Dry
		1.24	6.59	Wet
7	CSMRS (2001)	10	25	Dry
		1.5	6.0	Wet
8	IIT New Delhi	13.88	14.04	Dry
		2.45	6.90	Wet

Table 1B: Uniaxial compressive strength determined during construction stage.

	DT-5	DT-4	DT-3	DT-2	DT-1
UCS (Mpa) Wet condition	12.47 (max)	15.41(max)	12.47(max)	12.47(max)	11.69(max)
	5.02 (min)	8.16(min)	10.0(min)	6.19(min)	6.62(min)
UCS (Mpa) Dry condition	23.38 (max)	30.39(max)	24.41(max)	35.02(max)	35.26(max)
	8.89 (min)	15.01(min)	20.40(min)	14.49(min)	19.48(min)
Average UCS	Dry condition	7.2 (min).		12.9 (max.)	
	Wet condition	15.65 (min)		29.7(max).	

Diversion Tunnels

The Subansiri River is diverted by five diversion tunnels with a cumulative length of 2954 m. The tunnels are aligned parallel to each other with a wall to wall separation of about 23 m. The tunnels are negotiated through weak sandstones of Subansiri Formation (Middle Siwalik). The rock is slightly to moderately jointed with intermediate zone of massive rock.

The Uniaxial compressive strength of the rock was determined by conducting a number of laboratory tests in different laboratories, during investigations as well as construction stages. The values of UCS obtained are giving in table 1A & 1B.

The rock has an average UCS value of 12 to 20 Mpa in dry condition and 4 – 7 Mpa in saturated condition. As the Diversion Tunnels were negotiated through weak sandstones with marginal lateral space between the tunnels, conventional drilling and blasting method was not adopted. The tunnels were excavated using rock cutting machines with drag pick cutter.

In the Diversion Tunnels Webster W/S 120 and Voest Alpine ATH 150 twin cutter header drums machines mounted on an excavator base (Photo-1) and Paurat E242 road header mounted on crawler loader bases (Phote-2) are utilized. The expected performance of rock cutting machines using picks in different rock mass with different UCS values provided by manufacturers are given in Table 2.

Photo 1: A view of the Road header

Photo 2: A view of mounted twin cutter in operation.

cutting process. The rate of cutting of the machine depends signifi-cantly on the presence of discontinuities, and their spacing and orientation with respect to the direction of tunneling (Gehring, 1997; Thuro and Spaun, 1996a & 1996b; Verhoef, 1997).

b. Due to presence of 15 – 20 % of fine grained matrix and carbonaceous matter considerable energy is lost due to the cushioning effect of the matrix i.e., the sample need very high energy to break the rock. Further, it leads to poor propagation of fractures during the cutting process.

Table 2: Performance of rock cutting machine in different value of UCS.

UCS (Mpa)	Cutting rate m^3/hr	Cutting rate m^3/hr	Cutting rate m^3/hr
	Webster W/S 120	Voest Alpine ATH 150	Paurat E242
L 20 (12)	51-100 (85)	60-75	120-200
20	51		122
30	33		112
40	25		98
50	18	10-11	77

The cutting rate of the twin cutter machines and road header were observed to be significantly lower than the predicted rates by manufacturers. The cutting rates of different rock cutting machines in Siwalik sandstone, which comprises the tunneling media for the diversion tunnels. are summarized in table 3.

Table 3: Cutting rates of different rock cutting machines in Siwalik sandstone

Machine type	Cutting rate m^3/hr		Average cutting rate m^3/hr
	Max	Min	
Voest Alpine ATH 150	7.9	4.3	5.8
Webster W/S 120	11.9	5.2	7.16
Paurat E242	18.5	14.6	16.65
Paurat T134	11.6	9.9	12.0

The low cutting rates are mainly attributed to following reasons:

a. The rock is slightly jointed to massive and devoid of fissility. Hence, the rock cutting machine grinds the rock instead of chipping; the machine utilizes more energy in the

c. generates large quantities of dust. Near the face of the tunnel measurements of fine dust are as high as 88 mg/ m^3. Because of the high generation of dust, the visibility becomes very poor at the face and excavation has to stop intermittentl for removal of dust through the ventilation system provided in the tunnel. This is one of the major causes for lower productivity of the rock cutting machines.

b. The use of water for dust suppression had a detrimental effect as it lead to formation of slush and made difficult to handle the generated muck.

Engineering characteristics of rock mass

The engineering classifications of rock mass both RMR (Bieniawski, 1976) and Q-system (Barton et al., 1974) were adopted for the Diversion Tunnels. The percentage of rock classes at the negotiated tunnel grade is given in table 4A & 4B. From the table it is apparent that. in about 18.2% of the cumulative length of tunnels, the classification of rock mass could not be adopted due to the massive nature of the rock mass. Further, major part of tunnel shows Good rock condition as per Q-system where as Class-II as per the RMR system. The tunnels with a maximum superincumbent cover of approximately 200 m, have shown spallings at a number of places, which indicates presence of over stressed zones in the tunnels. The over stressed zones have been tackled by installing systematic rock support and providing some dummy holes to release the stresses.

Table 4A: Rock mass class based on RMR-System

	Massive Rock (%)	Class II (%)	Class III (%)	Class IV (%)
DT-1	25	50	25	0
DT-2	20	52	28	0
DT-3	17	42	40	1
DT-4	15	48	33	4
DT-5	14	37	49	0
Average	18.2	45.8	35	1

Table 4B: Rock mass class based on Q-System

	Massive rock (%)	Good (%)	Fair (%)	Poor (%)
DT-1	25	57	18	0
DT-2	20	53	27	0
DT-3	17	48	34	1
DT-4	15	48	32	5
DT-5	14	33	51	1
Average	18.2	47.8	32.4	1.4

In RMR system the compressive strength is taken as rock mass parameter but active stresses to which the rock mass is subjected is not considered, which limits the use of RMR system in this type of sandstone. On the contrary, the Q-system considers strength as it relates to in-situ stress in competent rock mass. Therefore, there are limitations to the uses of Q-System in the weak Sandstones of the project. Hence, massive and weak nature of rock limits the use of these systems of rock mass classifications.

Classification as Per Hindrance

In view of the above limitations, the classification of underground excavation as per hindrance is adopted. Underground excavation is divided into different classes in order to differentiate the difficulties and hindrance during excavation work, which has to cope with due to the properties of material encountered. The class of excavation is defined in relation to the hindrance in the progress of the excavation works caused by the type and amount of rock supports installed during excavation within the tunnel heading zone.

The underground excavation classes are specified as follows

Class IIIA: Installation of supports causes some hindrance and slowing down of the excavation work. Support system consist of shotcrete in one or more layers and pattern rock anchoring in heading, with or without wire mesh as shotcrete reinforcement.

Class IIIB: Installation of supports causes substantial hindrance on the excavation work of heading, such that support installation becomes a part of the work cycle. Support system consists of shotcrete in one or more layers and pattern rock-anchoring in heading and benching, with or without wire mesh, as shotcrete reinforcement.

Class IV: Installation of support causes a heavy hindrance both during excavation work of heading as well as benching. Support system consists of steel ribs (in heading and benching), wall plate and lagging placed continuously at the face immediately after excavating any part of the cross-section; steel ribs and lagging shall be complemented with systematic rock anchoring and the steel ribs may have to be completely encased in shotcrete, with wiremesh reinforcement as required, when lagging is not used.

Class V: Excavation is only possible by heading and benching with the simultaneous installation of supports, and under their protection. Support system consists of steel ribs in heading and benching with invert bracing/ struts, and placement of wall plates and lagging. Continuously at the face, immediately after excavating any part of the cross-section; steel ribs and lagging shall be Complemented with systematic rock anchoring.

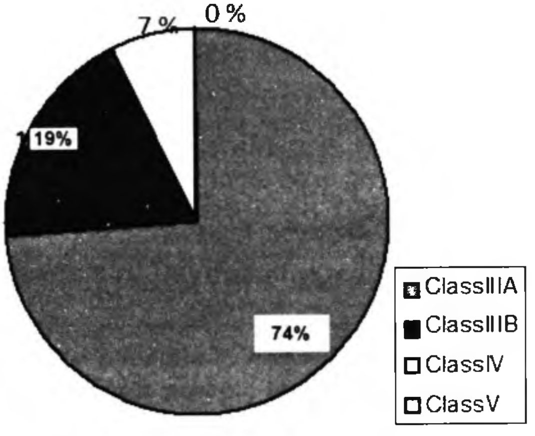

Fig. 2: Percentage of hindrance class

Steel ribs may have to be completely encased in shotcrete, with wiremesh reinforcement as required, when lagging is not used. The percentage of the diversion tunnels to which different underground excavation classes as per hindrance is assigned is shown in figure2. No strong correlation between percentage of engineering classifications of rock mass and percentage of hindrance class, could be observed, in the Diversion Tunnels.

Conclusions

During site investigations of the project, prediction of tunnel stability is usually the main concern. The level of geological and geotechnical investigation required for ascertaining suitable methodology for excavation of tunnels are not addressed properly. If mechanical excavation is to be adopted, proper investigations are to be carried out for establishing relationship between geological/ geotechnical characteristics of rock mass and the cutting performance, wear and tear of bits etc. While adopting mechanical excavation, proper ventilation in the tunnel needs to be planned, as large quantity of fine dust is generated during excavation.

The geology is unique for every project and the geotechnical characteristics of rock vary widely. Therefore, while using any system of classification of rock mass care is to be taken keeping in view the limitations, as these systems are originally based upon case histories drawn from civil engineering projects.

The recent trend of classification of underground excavation, based on hindrances has been used. The classification would be more useful, if the assigned class is properly correlated with the geotechnical characteristics of the rock mass.

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