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Engineering geological investigations of Dik Chhu Hydroelectric Project, Sikkim Himalaya, India

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ABSTRACT

The Dik Chhu Hydroelectric Project is located in the Dik Chhu Valley, where the Gorubatham Formation rocks are composed mainly of medium to high-grade metamorphics represented by quartzo-feldspathic gneisses, garnet-mica schists, schistose quartzites, phyllites and biotite gneisses with schist layers. To design the rock support for the underground structures of head race tunnel, surge shaft, and for the foundations of dam, intake of sedimentation tank, penstock, power house and tail race channel, rock mass classifications was attempted following the methods of Bieniawski Rock Mass Rating (RMR) Classification and Tunnel Quality Index (Q) from the surface mapping data to get first hand information about the rock mass condition. The results from the surface mapping indicates that the rock masses of the project area fall under the good, fair and poor rock quality, which is required to be confirmed by drilling and drifting. On the basis of above study drill holes and drifts locations have been suggested and recommendations have been made for the proper and safe construction of the project components.

Keywords: Hydroelectric, rock mass classification, tunnel quality index, Sikkim Himalaya

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INTRODUCTION

The proposed Dik-Chhu hydroelectric project is a run-of-the river scheme on Dik Chhu River, in the Sikkim Himalaya. The Dik Chhu River from Langbu to Dikchu has almost straight course along east-west direction. The length of this river from its source to its confluence with River Tista near Dikchu town is 26.8 km forming the 6th order drainage. The project utilizes a drop of about 150 m, the installed capacity of the scheme is 96 MW (3 x 32 MW) with a design discharge of 4.5 m^3/sec. The project envisages components of a 90 m long and 35 m high dam located about 150 m downstream of confluence of Bakcha Chhu and Rate Chhu, desilting basin, a head race tunnel of 5.6 km long and 3.5 m diameter (circular) to cater for the design discharge of 4.5 m^3/sec, surge tank (110 m high and 6.50 m diameter), one pressure shaft (3.55 m diameter and 310 m length), two surface penstocks (1.75 m diameter each), surface power house on the right bank (90 m x 23 m) and a 3.30 m wide square tail race channel. The general layout map of the project area is given in Fig. 1. The geological observations made on the right bank indicate that the intake structure could be suitably located on the hill slope upstream of dam axis. The rock groups described all along the tunnel alignment coming under good to poor category of rock mass classification. For the major streams (Kholas) cross sections were prepared for ensuring sufficient rock cover for the HRT. Along the proposed surge shaft and penstock alignment quartzitic phyllites will be encountered while the power house area is covered by overburden material. The tailrace channel will be excavated through overburden material and quartzitic phyllite with minor gneissic bands.

Regional geologically this area was investigated by Ray (1947, 1975), Roy (1980), Banerjee and Bhattacharya (1981), Acharyya (1989) and Ravikant (1993). Rock mass classification using Q System (Barton et al. 1974) and Rock Mass Rating (RMR) system (Bieniawski 1979, 1989) was attempted. Rock mass classifications are important indirect requirements for applying numerical procedure in designing underground structures in rock and for recommendations of slope stability measures.

GEOLOGY SETTING

The project area forming a part of Dik Chhu River belongs to Gorubatham Formation of Daling Group. The Daling Group of Sikkim Himalaya is tectono-stratigraphically placed below the high grade gneissic rocks, limited by the sheared belt of mylonitic granitic gneiss and above its own cover of Gondwana equivalent sediments (Permian). The Gorubatham Formation resembles distal meta-flysch with closely linked basics, felsic-volcanism and ignimbrites. It consists of green-slate, phyllite, phyllonite, with which impersistent cherty fine-grained dirty chlorite quartzite; green feldspathic wacks (tuffaceous wacke) and basic metavolcanics and green beds. In Dik Chhu catchment the sulphide mineralization has been reported in high-grade schist. Porphyritic and augen

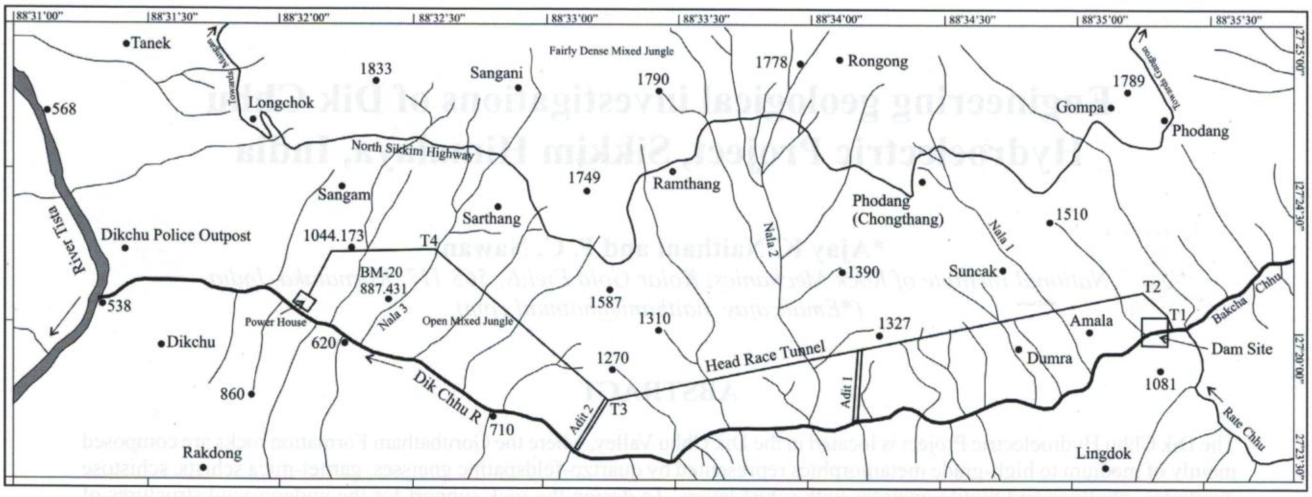

Fig. 1: Layout map of the Dik Chhu hydroelectric project

biotite-granite gneiss (Lingtse granite) emplaced within the Gorubatham Subgroup at number of places. Based on metasomatic contact relations between the Lingtse gneiss and the Gorubatham greywacks and the stromatolites of the Buxa, the Daling Group is dated Precambrian (Acharyya 1989).

Sheet like bodies of coarse to medium grained foliated to strongly lineated granite gneiss and granite mylonite were reported in the Longchok and Ramthang area along the North Sikkim Highway. Augen to porphyroblastic texture is usually very prominent with clear evidence of post-crystalline deformation and recrystallization of feldspar and quartz (Acharyya 1989). A persistent belt of mylonite, Lingtse granite gneiss and diapthoritic phyllonitic schists overlie the topmost level of the Gorubatham and underlie the gneissic formations of the Sikkim Group. In the project area there is no distinct break in the grade of regional metamorphism from the rocks of subjacent Daling Group to those of the high-grade gneisses, although such breaks and diapthorism occur in several sections locally. The Lingtse gneiss is also not restricted to this contact zone but occur well within the Daling. It is thus difficult to define and place the "Main Central Thrust" delineating the upper tectonic limit of the Daling Group and the base of the Central Crystalline in this part of the Himalaya. Tentatively this has been modelised to represent the base of the Lingtse Granite Gneiss occurring at the base of Sikkim Group (Central Crystalline).

In general, the distribution of the Daling Group shows a broad sweep in a north-south antiformal axis plunging gently due north resulting in divergent dips varying in directions from NW in western sector to NE in eastern sector through almost north in the central part. In the eastern and western sectors broad warps with easterly and westerly axial plunges respectively are also responsible for local variation in attitude. The bedding / foliation of rocks are well defined by the preferred orientation of flaky minerals like biotite, sericite, etc. The general strike of foliation is NW-SE near the dam site with dip of 40° to 60° towards NE and in the powerhouse area rocks are generally sub-horizontally laying dipping towards N05° to 15°W. The attitude of beds indicates that this is the central part of the antiformal structure.

Three generation of structures are well documented within this rock unit. First generation folds (F1) are defined by bedding marked by quartzite bands and colour laminations in the phyllites. The axial planes of F1 is at high or right angles near the hinge zone of the second generation folds but away from it they trend to be parallel the F1 folds are invariable isoclinal and occasionally rootless, interfolial types. The stratification and the schistosity / foliation define the second generation (F2) fold form. These folds are invariable isoclinal with the amplitude / wavelength ration varying from 0.8 to 1.8. The thickness (both axial plane parallel bedding surface normal) suggests that the folds are flattened flexure-slip type. In the pelitic rocks F2 linear structure is represented by coarse to fine puckers and is pelite-psammite rhythmite as well developed fold mullions and boudinages. Third generation structures (F3) are the most conspicuous structure manifest in large-scale north-south and complementary east-west cross folds. They are characterized by upright nature and are less penetrative in contrast to F1 and F2. They are represented by broad warps, rolls, kinks and chevron folds signifying brittle stage deformation for the last generation structure.

ENGINEERING GEOLOGY INVESTIGATIONS

Dam Site

Detailed mapping on 1:1000 scale of the dam site has been carried out by deploying Electronic Total Station survey equipment. Geological details on either banks of the river have been picked up for about 200 m upstream and 100 m down stream of the dam site and up to the 100 m towards the hill side. The river channel having the perennial flow section of about 10 m wide is occupied by exposures of biotite gneisses and schistose quartzites. Huge boulders are also lying in scatter form brought from higher altitudes. The river

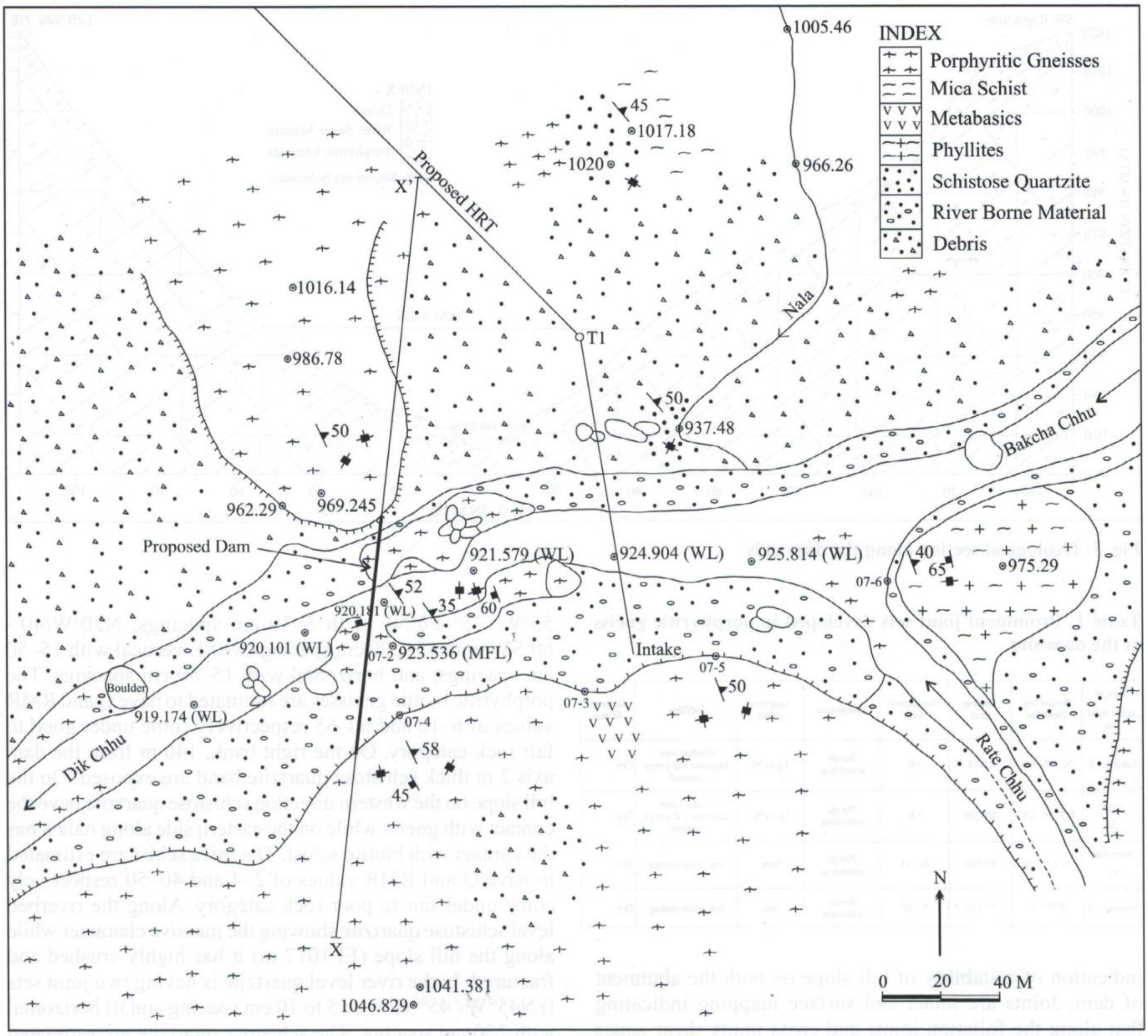

Fig. 2: Geological plan map of the dam site and intake area

on the left bank is marked by an old course along the exiting terrace. The river bed portion is occupied by thin cover of river borne material and prominent patches of terraces were also noted on the left and right bank. Geological plan of the dam site and intake area is given in Fig. 2 and geological cross section along the dam axis is given in Fig. 3.

The rock types exposed at dam site are mainly porphyritic biotite gneisses with minor schist bands and schistose quartzites. On both the abutment prominent escarpment of porphyritic biotite gneisses up to a height of about 150 to 200 m is present. The gneisses are dipping towards NE i.e., upstream direction at 55° to 62° (dip amount). The four prominent joint sets recorded in them have the following attitude (average values): N30W (strike) / 45° to 50° (angle of dip) SW (dip direction) with spacing 200 to 500 cm, N25°W/ 55° to 62° NE with spacing 10-18 cm, horizontal with 80 to 100 cm spacing and N75°E/ vertical with spacing 95 – 150 cm. The surfaces of the all the joint sets are rough-undulating. The sets of joints recorded in the porphyritic biotite gneisses at the dam site area are given in Table 1. The porphyritic biotite gneisses are estimated to have Q and RMR values of 6–10 and 60–65, respectively come under good to fair rock category. Two exploratory pits of 1.5 m depth, along the dam axis on either side of river channel have been put. These pits have proved over-burden, consisting of river borne material, up to the depth of 1.5 m and 0.60 m on the left and right banks respectively. On the right bank side pit, below the overburden, gray compact porphyritic biotite gneisses have been observed up to the bottom of the pit. Foliation joints dipping towards northeast direction at 56° have been recorded. There is no

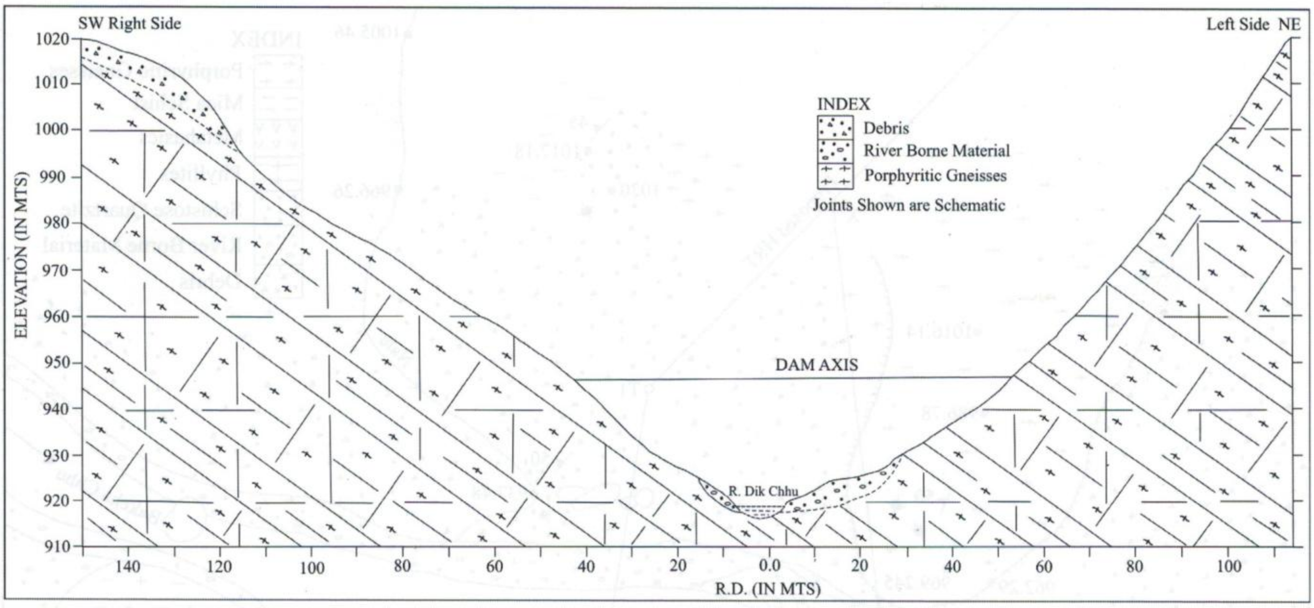

Fig. 3: Geological section along the dam axis

Table 1: Prominent joint sets developed in porphyritic gneiss at the dam site

Type of Joint/ Joint Set	Strike/Dip Direction	Spacing (cm)	Persistence (m)	Roughness	Aperture (mm)	Infilling	Ground Water
Foliation J1	N25°W/NE	10-18	>20	Rough undulating	Up to 50	Crushed rock fragment and gougy material	Dry
Cross J2	N30°W/ SW	200-500	>20	Rough undulating	Up to 50	Crushed rock fragment and gougy material	Dry
Horizontal J3	N75°E / H	80-100	10 - 18	Rough undulating	None	Iron oxide coating	Dry
Vertical J4	N75°/ V	95-150	8 – 20	Rough undulating	None	Iron oxide coating	Dry

indication of instability of hill slope on both the abutment of dam. Joints are intact and surface mapping indicating that along the foliation joints and cross joints shear zones are present but the maximum thickness recorded was 5 cm. The shear zone material should be removed and back filled with concrete followed by consolidation grouting to make the foundation monolithic. River undercutting feature was not observed at the dam site.

In the upstream direction, after 80 m from the proposed dam axis on the left bank, gneisses and metabasics are exposed which have the concordant relationship. The thickness of the metabasic band is 5 m and three sets of joints are present. The joint volume (Jv) of the metabasics is 15 while the surfaces of joints are planar and smooth. On the right bank from riverbed level up to accessible ridge top no metabasic band was reported. The rock types exposed at the intake site hill slope are the gray to dark gray biotite porphyritic gneisses with quartz veins. The foliation planes are dipping towards NE at 35° to 50°. Four prominent joint sets recorded in them have the following attitudes: N20°-55°W /35°–50°NE with 5–30 cm spacings, N20°W/40°-60°SW with 15–200 cm spacings, N0°E/vertical with 15–50 cm spacings, and horizontal with 15–50 cm spacings. The porphyritic biotite gneisses are estimated to have Q and RMR values of 6–10 and 60–65 respectively come under good to fair rock category. On the right bank, 140 m from the dam axis 2 m thick schistose quartzite band are exposed. On the hill slope on the western direction schistose quartzite have the contact with gneiss while on the eastern side along nala it has the contact with biotite schist. The mica schist are estimated to have Q and RMR values of 2–4 and 40–50 respectively come under fair to poor rock category. Along the riverbed level schistose quartzite showing the massive character while along the hill slope (El 1017 m) it has highly crushed and fractured. In the river level quartzite is having two joint sets i) N45°W / 45°NE with 5 to 10 cm spacing and ii) horizontal with 250 cm spacing. The schistose quartzite are estimated to have Q and RMR values of 7–10 and 55–60 respectively, come under fair rock category.

Higher levels on both the banks of dam site the area are mostly unapproachable and densely vegetated. Data were collected from the riverbed level and along footpaths. As all the rocks units are dipping upstream direction is quite favorable site for dam foundations. There is no discontinuity in rocks on the right and left bank of river indicating no folding or faulting at the dam site and intake area.

Desilting basins

Two underground desilting basins are proposed on the right bank of the river, before clean water is lead into the head race tunnel. The layout of this area indicates that it is aligned along the river terrace and surfacially it is occupied by river borne deposited materials and fallen rock debris and

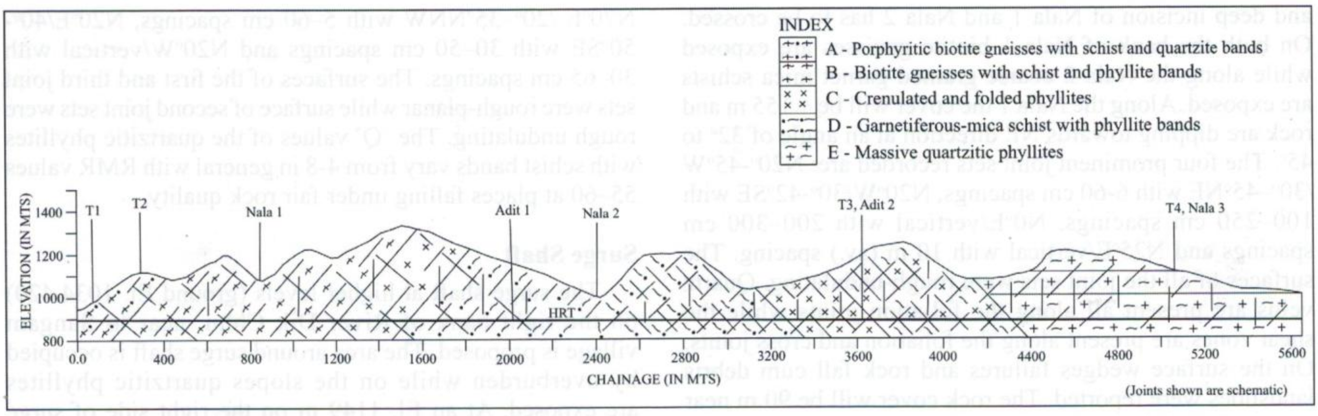

Fig. 4: Longitudinal section along head race tunnel

Table 2: Rock mass classification of the head race tunnel

S.N.	Category	Lithology	Rock mass	UCS in MPa	Q	RMR Value	RMR Class	Length of HRT (in m)
1.	A	Porphyritic- biotite gneiss with schist & schistose quartzite bands	Gneiss & Schist	100-250	6-10	60-65	II-III	220
			Quartzite	100-250	7-10	55-60	III	
2.	B	Biotite gneiss with mica schist and phyllite bands	Gneisses	100-250	6-10	60-65	II-III	960
			Schist	50-100	2-4	40-50	III-IV	
			Phyllite	50-100	3-8	55-60	III	
3.	C	Crenulated and folded phyllite	Phyllite	25-50	2-5	35-45	III-IV	720
4.	D	Garnetiferous-mica schist with phyllite bands	Schist	5-100	4-6	45-50	III	1700
5.	E	Massive fine to medium grained quartzose phyllite	Quartzitic Phyllite	100-250	4-10	55-65	II-III	2000

no rock exposures were noted at the intake for a distance of about 40 m. After 40 m, porphyritic gneisses and schistose quartzites are exposed. Three trail pits were put up to 1.5m in the desilting basin area but rock was not encountered. The intake for water to be conducted to the HRT is proposed immediately u/s of dam site and the geological observations made on the right bank indicate that the intake structure could be suitably located on the hill slope.

Head race tunnel

The traverse, in the area on the left and right banks of the River Dik Chhu indicated that tunnel could belocated on right bank due to availability of rock exposures whereas on left bank, rock exposures are discontinuous and possibility of tunnel day lighting exist. HRT will encounter the Gorubatham Group of rocks comprising quartz feldspathic gneisses, garnet-mica schists, schistose quartzites, phyllites and biotite gneisses, with schist layers. Two possible locations for intermediate adits have been identified from the point of minimal length, suitable geological setup and are located near Nala 2 and 3.9 km from intake. Due to inaccessibility at the adit sites rock exposures have been noted from the right bank and a detailed assessment has to be made at the construction phase.

In order to project geology along the tunnel alignment, geological mapping on 1:10000 scale along North Sikkim Highway has been carried out to pickup the different rock units and estimated the Q and RMR values by taking the RQD and other joint properties. In addition, geological traverses were taken in Sangam, Dikchu, and Amala areas in and around the tunnel alignment. The geological details so gathered have been projected to tunnel grade and forecast section prepared (Fig. 4). The rock mass classification of different rocks at the head race tunnel has been given in Table 2 and their characteristics with respect to the tunnel alignment is given in Table 3.

Table 3: Characteristics of lithology along the tunnel alignment of head race tunnel

Location	Rock Type	Dip direction / amount	No of joint sets	Roughness*	Angle between strike of rocks and central line of HRT	Tunneling Condition
From intake to T2	Quartz mica gneisses	NE/ 40°-60°	Three	Smooth-undulating Smooth-planar	Parallel	Unfavorable
From T2 to Nala 2	Biotite gneisses, phyllites, mica schists	NE/32°-60°	Four	Rough-undulating	70°-80°	Favorable
From Nala 2 to T3	Mica schists and phyllites	NE/NW/ 35°-60°	Four	Rough-undulating	70°-80°	Favorable
From T3 to T4	Quartzose phyllite	NNW/N/30°-55°	Three	Rough-planar Rough-undulating	60°-70°	Favorable
From T4 to surge shaft	Quartzose phyllite	NNW/N/30°-55°	Three	Rough-planar Rough-undulating	Parallel	Unfavorable

*For the roughness of each joint set refer the text part of sub-heading head race tunnel

The quartz mica gneisses with schistose quartzites and schist bands are exposed along the tunnel alignment from intake point up to T2 for distance of about 220 m. The rocks are dipping towards NE at 40° to 60°. The rocks are grey to dark grey in colour foliated strongly intruded by quartz veins along with foliation. Three prominent joint sets recorded are: N25°W/30°-60°NE with spacings 10-50 cm, horizontal with spacings 20-50 cm and N20°W/40°-60°WSW with spacings 35-80 cm. The joint surface for the first joint was smooth-undulating while other two were smooth-planar. The rock cover along this section is about 270 m. The strike of the rocks here parallel with the central line of the tunnel alignment and against the dip of rocks and is considered to be unfavorable tunneling direction. The estimated 'Q' and RMR value vary from 6–10 and 60 to 65 respectively come under the fair to good rock category.

From T2 upto Nala 2 the tunnel will pass through biotite gneisses with mica schist and phyllite bands, crenulated and folded phyllite and mica chlorite schist. In this reach the tunnel will have a surface cover of 425 m at the maximum and deep incision of Nala 1 and Nala 2 has to be crossed. On both the bank of Nala 1 biotite gneisses are exposed while along the Nala 2 coarse grained garnet mica schists are exposed. Along the Nala 1 the cover will be + 155 m and rock are dipping towards NE direction at an angle of 32° to 45°. The four prominent joint sets recorded are: N20°-45°W /30°–45°NE with 6-60 cm spacings, N20°W/30°-42°SE with 100–250 cm spacings, N0°E/vertical with 200–300 cm spacings and N25°E/vertical with 10 m (av.) spacing. The surfaces of all the joint sets were rough-undulating. Quartz veins are present all along the foliation joints while the shear zones are present along the foliation and cross joints. On the surface wedges failures and rock fall cum debris landslides were reported. The rock cover will be 90 m near at Nala 2 and the rocks are dipping towards NE direction at an angle of 45° to 60°. The garnet biotite schists are well foliated, jointed and from as thin parting to layer of 2-3 m thickness. Three prominent joint sets recorded in them are: N20°W /40°–60° NE with 50–400 cm spacings, N60°E/35°-40° NNW with 2–20 m spacings and N0°E/vertical with 300–500 cm spacings. The surfaces of all the joint sets were rough-undulating. In this reach the tunnel is aligned in N75°E direction and will cut-a-cross the strike of the rocks making an angle of 70° to 80° with the direction of the tunnel and tunneling should be favorable either from downstream or upstream. The estimated 'Q' and RMR values of the schist will be in the range of 2-5 and 35-45, respectively.

From Nala 2 to T3 the tunnel will passes through mica schists with phyllite bands and folded and crenulated phyllites. The rocks are dipping towards NE and NW i.e. in the upstream and downstream directions of the river flow at an angle of 35°–60°, which shows a small anticlinal structure. The tunnel direction makes an angle of 70° – 80° with strike of the rocks. The rock cover in this section will reach a maximum of 300 m and the cover at Nala crossing is the minimum (+75 m). Since the phyllites are highly crenulated, possibility of existence of weak zones with crushed shear zones should be expected in the tunnel length. The four prominent joint sets recorded in phyllites are: N20°W /30°–45°SW with 5–20 cm spacings, N45°E/35°-53°SE with 100–200 cm spacings, N30°E/vertical with 100–300 cm spacings and horizontal with 20–200 cm spacings. The surfaces of all joint sets are rough-undulating. The estimated 'Q' values are 2-5 and RMR is 35-45 come under fair to poor rock category for tunneling.

From T3 to surge shaft all along the tunnel alignment the area is highly inaccessible and the rock type to be encountered in the tunnel will be fine to medium grained quartzose phyllites with minor gneisses bands. From T3 to T4 the strike of the rock makes an angle of 60° to 70° with the tunnel alignment and is considered favorable for tunneling while from T4 to surge shaft the tunnel alignment is parallel to the strike of the rocks, which may not be very favorable tunneling direction. The topographic cover is maximum in the Ramthang ridge, which is about 300 m, at Nala 3 it is 180 m and it gradually reduces towards surge shaft. The rocks are dipping towards NNW to north direction at an angle of 30°–55°. The three prominent joint sets recorded in them are: N70°E /20°–35°NNW with 5–60 cm spacings, N20°E/40°-50°SE with 30–50 cm spacings and N20°W/vertical with 30–65 cm spacings. The surfaces of the first and third joint sets were rough-planar while surface of second joint sets were rough undulating. The 'Q' values of the quartzitic phyllites with schist bands vary from 4-8 in general with RMR values 55–60 at places falling under fair rock quality.

Surge Shaft

The surge shaft at higher levels (ground El. 1034.420) on the right bank of River Dik Chhu, near to Sangam village is proposed. The area around surge shaft is occupied by overburden while on the slopes quartzitic phyllites are exposed. At an El. 1149 m on the right side of surge shaft, along the Nala contact between quartzitic phyllites and gneisses was observed. Along the contact gneisses are highly crushed and folded. Quatzitic phyllites are exposed all along the ridge to the south of Sangam village and it is up to riverbed level. The rocks are dipping towards north at 40° to 55°. Three prominent joint sets are present in quartzitic phyllites and along the foliation joints shear zones up to 4 cm were reported while vertical joints are very prominent. Joint sets are having the following attitudes: N70°- 90°E /25°–35°NNW with 6–20 cm spacings, N20°E/45°-55°SE with 25–55 cm spacings and N0°E/vertical with 75–1000 cm spacings. The surfaces of the first joint sets are rough-planar while surface of second and third joint sets are rough undulating. The quartzitic phyllites are estimated to have Q and RMR values of 2-5 and 35-45, respectively come under poor to fair rock category. The plan map and L-section along the surge shaft, penstock alignment and power house are given in Figs. 5 and 6.

Penstock slopes

The penstock slopes have reasonably good gradient and quartzitic phyllites are exposed along the penstock alignment. The rocks are dipping towards north at 35° to 50°. The four prominent joint sets recorded in them have the following attitudes: N70°- 80°E /40°–45° NNW with 5–20 cm spacings (foliation), N70°E/45°SE with 2 m spacings (cross), N25°E/50°-60° NW with 1-2 m spacings and N50°W/vertical with an average spacing of 5 m. The quartzitic phyllites are estimated to have Q and RMR values of 4-8 (av. 6) and 55-60, respectively come under poor to fair rock category. The rock exposures form the apparent dip slope on which the anchors / saddles have to be located. No signs of instability have been observed during the field investigations. The geological setup and attitude of joints indicating that there will be hardly any slump limits in the penstock alignment.

Power house

The power house (PH) is proposed as a surface structure, is at a distance of + 1250 m towards the western side from the confluence point of River Tista with River Dik Chhu on its right bank. The area is just below the escarpment of Sangam village towards the south, which is covered by debris material and whole area is densely vegetated. At the middle portion of power house few rills and gullies were reported

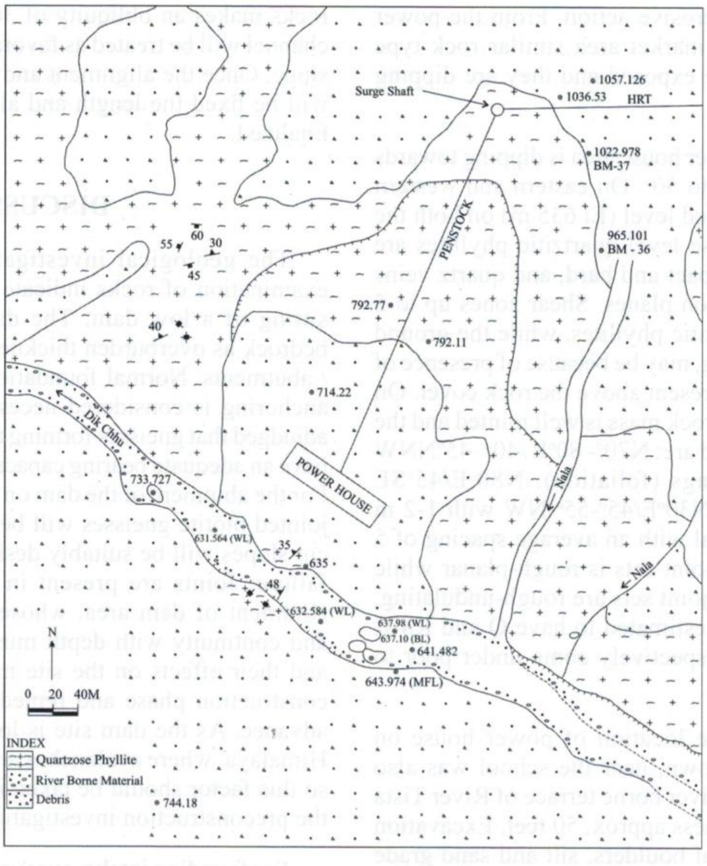

Fig. 5: Geological plan map of surge shaft, penstock and power house area

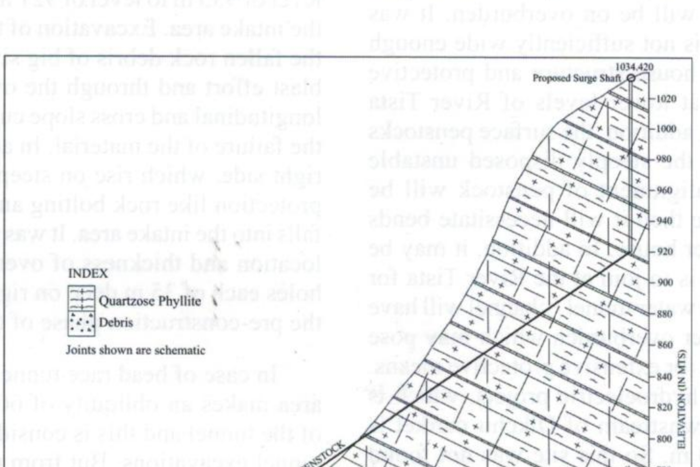

Fig. 6: Geological section along surge shaft, penstock and power house area

which may formed due to erosive action. From the power house grade up to Dikchu market area similar rock type having the similar trend are exposed and they are dipping upstream of River Tista.

The rock mass at the power house area is dipping towards N10°-20°W to north at 40° to 50°. On eastern and western side of PH and at the river bed level (El 635 m) on both the bank below the power house level quartzitic phyllites are exposed which is very compact and hard, and quartz veins are present along the foliation planes. Shear zones up to 5 cm are present in the quartzitic phyllites, while the ground water condition was dripping, may be because of presence of thick overburden material present above the rock cover. On the either side of the PH the rock mass is well jointed and the prominent joint sets recorded are: N70°- 80°E /40°–45°NNW to N with 5–20 cm spacings (foliation), N80°E/45°SE with 2 m spacings (cross), N30°E/45°-55° NW with 1-2 m spacings and N45°W/vertical with an average spacing of 5 m. The surface of the first joint sets is rough-planar while surface of second and third joint sets are rough-undulating. The quartzitic phyllites are estimated to have Q and RMR values of 4-8 and 55-60, respectively come under poor to fair rock category.

An alternate site for the location of power house on the right bank of Dikchu town, near the school was also examined. At this location, river borne terrace of River Tista exist with the vertical thickness approx. 50 feet. Excavation through terrace consisting of boulders, silt and sand grade will have to be done to reach the power house grade and the foundation of power house will be on overburden. It was also noted that the location is not sufficiently wide enough to accommodate the power house structure and protective measures will be required at lower levels of River Tista from effect of toe erosion. In addition, the surface penstocks will have to be located on the steeply disposed unstable ridge (slump unit) and if alignment of penstock will be further north on stable slope then it will necessitate bends in penstocks to lead to power house. In addition, it may be stated that the tail race, if it is to join at the River Tista for utilizing the full head, the tail water tunnel / channel will have to be excavated through river overburden which may pose problems of stability, calling for extensive protective means. The MFL of Tista Phase V hydroelectric project, which is being constructed in the downstream of Dikchu market is 580.72 m and FRL is 579.0 m. So this site was not found suitable for the construction of power house.

Tail race channel

The tail water from the power house will be flowing through a channel about + 300 m (approx.) long downstream of River Dik Chhu on its right bank. The tail race channel areas on the surface are occupied by quartzitic phyllite with minor gneissic bands near to the exit portal below the Rakdong village. The study indicates that initially the alignment will be through overburden and then the channel will pass through quartzitic phyllites. The rock type strikes E-W with dip of 40° to 60° towards north. The strike of the rocks makes an obliquity of 30° with the alignment of the channel will be treated as favorable direction for channel cut slope. Once the alignment and location of the power house will be fixed the length and alignment of the TRC will be finalized.

DISCUSSIONS

The geological investigations of the dam area and examination of rocks indicate that this site is suitable for sitting of a low dam. The dam will be founded on the bedrock as overburden thickness is less in the river section / abutments. Normal foundation treatment of grouting and anchoring is considered necessary at this stage. It is also adjudged that gneisses forming the foundation of the dam will have an adequate bearing capacity for the low dam envisaged. For the abutment of the dam on the right bank excavations of jointed biotite gneisses will be involved for which suitable cut slopes will be suitably designed for averting rock mass failure. Joints are present in the rocks of left and right abutment of dam area, whose geometry, intensity, nature and continuity with depth must be thoroughly established and their effects on the site must be evaluated during the construction phase and remedial measures should take in advance. As the dam site is located at the high altitude of Himalaya, where avalanches are common during the winter, so this factor should be taken into the consideration during the preconstruction investigation.

For founding intake, excavation from the existing surface level of 935 m to level of 921 m will have to be carried out in the intake area. Excavation of the order of 8 to 10 m through the fallen rock debris of big sizes which may need drill and blast effort and through the overburden for which suitable longitudinal and cross slope cuts have to be designed to limit the failure of the material. In addition the rock slopes on the right side, which rise on steep slopes, will require suitable protection like rock bolting and shotcreting to prevent rock falls into the intake area. It was proposed to explore the intake location and thickness of overburden by putting three drill holes each of 35 m deep on right bank of River Dik Chhu in the pre-construction phase of the project.

In case of head race tunnel the strike of the rocks in the area makes an obliquity of 60° to 80° with the central line of the tunnel and this is considered as a favorable factor for tunnel excavations. But from the intake to T2 as the tunnel alignment is parallel to the strike so it should be excavated with proper method of tunneling practice. In the reach from T4 to surge shaft the strike of the rock group follows very close to the tunnel direction, which is considered as not very favorable since any weak zone along the foliation will be met for a longer length during tunneling. The rock groups described all along the tunnel alignment form fair to good quality coming under good to fair category of tunneling media with a 'Q' value ranging from 6 – 10 and RMR value of 55 – 65 for major length of the tunnel (3.20 km approximately) the remaining 2.4 km is expected to encounter mica- schist foliated, crenulated with shear zone at places with a poor to fair 'Q' value of 2 – 6 and RMR value of 35-45 coming under fair to poor rock category, which will necessitate careful tunneling operations including shorter pulls, closer supporting etc. The group of gneissic rocks also are inter banded with schist layers which are reduced to shear zones at places (0.5-1.5 m) will also require suitable tunneling practice along with support measures. The tunnel alignment has to pass under perennial streams like Nala 1, Nala 2 and Nala 3 which all carry considerable discharge during the rainy season. It is felt that seepage of water in the tunnel reaches below the above streams should be anticipated which would call for adequate drainage measures and precaution during tunneling including advance probe holes. The support measure for the tunnel reach wise has to be designed based on the above rock properties and the load worked out as per Barton's 'Q' system. Appropriate lining will be required at various parts of the tunnel where there may be the deep cuts or sheared ones because the prime responsibility of HRT is to convey the water safely throughout the life of the project, without detrimental effects on the surroundings. As the diameter of the tunnel is small, there is a greater need for a smooth lining to maintain acceptable head losses.

The schedule time can be improved for construction of HRT by providing two access adits. Adit 1 is recommended on the left bank of Nala 2 on the rock face. The rock type is garnet-biotite schist dipping upstream side generally in NE direction. Sometimes the schist is massive/ compact and at times loose and fractured. The three prominent joint sets (averaged values) recorded in the schist are: N15°W /60°NE with an average spacing of 400 cm, N75°E/45°NNW with an average spacing of 200 cm and N0°E/vertical with an average spacing of 350 cm. The second set of joint dipping inside of slope is very prominent and intersecting the foliation joints. During the construction of this adit the failures may be in the form of blocks, so suitable tunneling technique is recommended. Adit 2 is recommended on the right side of Ramthang ridge at an elevation of about 923 m. Adit will be through quartzitic phyllite dipping towards SW direction. Foliation joints and cross-joints are very dominating, one is dipping downstream and other in upstream direction so the wedge may form during the construction of adit. Vertical horn types of structure are present along the slope above the adit level, which are controlled by vertical joints. During the construction phase their stability should be checked. The four prominent joint sets recorded in them are: N15°W /45°SW with 500 cm (av.) spacing, N45°E/35°SE with 120 cm (av.) spacing, horizontal with 10–200 cm spacings, and N30°E/ vertical with 150 cm (av.) spacing.

For the detail assessment of the surge shaft foundations, condition of the rock and to have an idea of the penstock tunnels to be driven, an exploratory drift from the rock face up to the bottom of surge shaft and drill hole from its surface location up to the bottom level is recommended. As surface mapping indicate that there are hardly any major shear zones but drifting and drilling will prove the presence or absent of major shear zones and if present their characteristics will be find out. Water permeability tests should be conducted and rock cores tested for their properties like UCS, water absorption, Sonic wave velocity, modulus values, porosity for design purposes. At the proposed location the geological mapping assessment indicated that this area is prima-feasible topographically and attitude of the beds are suitable for locating the surge tank. The support measure for the surge shaft has to be designed based on the above rock properties and the load worked out as per Barton's 'Q' system. No special measures will be required during excavation except on a normal scale. The cross section across the surge shaft indicated that the rock cover is adequate.

In order to prove the nature of rock for designing the anchor blocks and saddles for penstock slopes, a bore hole may be put along the slope to prove the bed rock and collect rock core samples for the laboratory tests. Approximately 100 m length of the penstock will be on the overburden material, so this should be checked by putting a bore hole to know about the nature and thickness of overburden.

The surface observations and traverses indicated that power house may have to be located on debris material. In order to prove the depth of this debris material, it is necessary to drill three bore holes at the power house area. These drill holes should be drilled to power house grade and in case bed rock is met with, water permeability tests should be carried out as per standard procedure. In the course of investigation the hydrogeological condition of the area was dry, the reason may it is rocky slope and south facing slope. But as the area is densely vegetated and thick debris cover is there so seepage of water during excavations and even after completion of the power house structure should be anticipated for which suitable drainage measures will be a requisite.

The major part of the tail race channel will be through overburden material so slope protection measures will be taken during the construction of TRC. The open channel section of the TRC will also have to be assessed in further details along with exploration. The location of the exit portal for the tail race channel will have to be assessed in further details once the alignment is finalized.

It is recognized that for the concrete dam, power house complex and for lining of head race tunnel, coarse (rock) and fine aggregates (sand) will be required. The traverses in the area and observations made indicate that coarse aggregates in the form of boulders will be available in Dik Chhu channel bed and its tributaries and in main Tista River. Samples of different rock types like the quartzites, gneisses and quartzose phyllites should be tested for their suitability. Fine aggregate (sand) appears not to be copious in the tributaries of main Dik Chhu and may have to be brought from lower reaches of River Tista, near Rongphu. At the Dam site and at suspension bridge near to Dam site on both the banks of river pockets of river borne material deposits are present, which can be explored during the construction period. In Tista Phase-V Hydroelectric project massive quartzitic phyllites and slates are being used for coarse aggregates and river borne material deposits after crushing for fine aggregates, which can also be used for this project.

CONCLUSIONS

In this paper Q and RMR values are estimated for the rock types, which will be encountered at the project during the construction phase. Q and RMR are most essential indirect inputs required for the design of underground structures and cut slopes. The investigation shows that the foundation of dam will be on rock only exhibit very good shear strength but to be verified by testing of core samples. Three categories i.e poor, fair and good of rock mass conditions were identified and expected to be encountered in the HRT, surge shaft and TRC. For the fair rock mass category, support by shotcreting and systematic bolting concurrently with excavations is recommended before final lining of the concrete. For good rock, spot bolting and shotcreting are recommending while for poor rock mass category, steel fibers reinforced shotcrete (CFRS), systematic bolting and steel ribs with small pull are recommended before final lining. In the portal of intake and adits prominent joint sets were reported during the investigations and will require suitable protection like rock bolting and shotcreting to prevent rock falls. In general the strike of the rocks makes obliquity of 60°-80° with the central line of the HRT and this is considered as a favourable factor for tunnel excavations but from intake to T2 and from T4 to surge shaft the central line of head race tunnel is parallel to the strike of rock, so it should be excavated with proper method of tunneling practice. Profile of the streams shows that there are sufficient rock covers at all the perennial nalas at the HRT crossing point. In the HRT and at power house seepage of water during excavation through the joints in rock mass is anticipated, which would call for adequate drainage measures and precaution during the excavation.

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