Engineering Geological Evaluation of The Underground Water Conducting System of Malshej Ghat Pss Project, Maharashtra, India

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Abstract

The underground water conductor system for the proposed Malshej Ghat Pumped Storage Scheme Project comprises intake for turbine operation, head race tunnel, pressure shaft and tail race tunnel. The components of water conductor system were investigated through detailed engineering geological mapping, geophysical survey, exploratory drilling and laboratory testing. The investigated area was covered by a thin soil cover (from 0.2 to 2.0 m thick). The rock mass properties, i.e., joint sets, weathering grade, RQD, RMR, Q, permeability, P-wave velocity etc. of the rock masses to be encountered during the excavation of intake structure, head race tunnel, pressure shaft and tail race tunnel have been analyzed in detail. Core samples from the exploratory drill hole drilled at the pressure shaft alignment were tested for triaxial tests. The mapping details indicated that the components of water conductor system will encounter greyish black fine to medium grained compact basalts, volcanic breccia, greyish brown amygdaloidal basalts and fine compact basalts with laths of plagioclase. The RMR value varies from 55-70 and Q is 10-17. The uniaxial strength of intact rock as per the lab tests varies from 50-131 MPa for compact basalts and thus can be considered as R4 and R5 grade, very strong to strong rock. On the basis of detailed investigations and laboratory testing, inferences and recommendations have been made for each components which will be helpful during the construction of the project.

Introduction

The proposed Malshej Ghat Pumped Storage (PSS) scheme for generation of 700 MW hydropower is located in Thane and Pune districts of Maharashtra envisages important structures such as concrete dams (upper and lower dam), spillways, head race tunnel (HRT), pressure shaft, underground power house and tail race tunnel. In this paper attempt has been made to bring out the rock mass condition of intake, HRT, pressure shaft and TRT of the proposed scheme on the basis of detailed engineering geological mapping, geological logging of drill holes, rock mass permeability values, geophysical profiling and laboratory test result. The basic purpose of these investigations was to identify / map different rocks and structures like joints, shear zones, faults, fracture zones etc. and to determine engineering properties of rocks by lab testing. In order to forecast the geology along the intake, HRT, pressure shaft and TRT alignment and to estimate the rock mass characteristics, detailed engineering geological mapping has been carried out on 1:1000 scale with 2 m contour intervals by deploying Total Station. The maps prepared during detailed investigation depict the boundaries of different geological units with structural data, areas covered by thin veneer of soil (from 0.2 to 2.0 m thick), vegetations, boulders, river and streams at the project sites. Intake, HRT, pressure shaft and TRT area has been explored by core drilling with five vertical holes and their details are given in Table 1. Water percolation tests were conducted in intake and HRT drill holes, at increasing and decreasing cycles of pressure, to determine rock mass permeability values. Seismic refraction survey was done in the intake area and along

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Table 1: Description of drilling data, drilled along intake, HRT, pressure shaft and TRT

1	2	3	4	5	6	7	8	9	10	11
Intake / HRT										
BHUD-1	677.88	Vertical	30.20	2.0	82 100	42 100	Partial upto 6.0 m then nil	0.45	W-I to W-III	Compact basalt, amygdaloidal basalt and volcanic breccia
BHINT	677.00	Vertical	30.40	0.5	90 100	43 100	Nil	10.6	W-I to W-III	Compact basalt, amygdaloidal basalt and volcanic breccia
Pressure shaft										
BHPS-1	676.03	Vertical	250.15	0.2	>80%	54 100	-	-	W-I to W-IV	Compact basalt, amygdaloidal basalt, volcanic breccia, red bole and porphyritic basalt with laths of plagioclase
TRT										
BHTR-1	293.39	Vertical	70.0	11.5	73 100	60 100	-	-	W-I to W-II	Compact basalt, volcanic breccia and porphyritic basalt with laths of plagioclase
BHTR-2	368.49	Vertical	180.0	19.0	74 100	63 100	-	-	W-I to W-II	Compact basalt, volcanic breccia and porphyritic basalt with laths of plagioclase

1- Borehole number, 2- Ground elevation, 3- Angle with horizontal, 4-Total depth (m), 5- Thickness of overburden (m), 6- Core recovery (%), 7- RQD (%), 8- Drill water loss, 9- Depth of water table, 10- Weathering grade, 11- Rock types

the HRT alignment. Core samples from the borehole BHPS-1 were tested for physico-mechanical properties of rocks in the laboratory. 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.

Geology of the Area

The Malshej Ghat PSS project lies in the northern part of Western Ghats of Deccan Trap, within the Maharashtra Volcanic Provenance characterized by highly dissected terrain with flat summits, mural slopes, serrated ridges and entrenched valleys. Earlier, geologically the surrounding area was investigated by Bodas et. al. (1985, 1988), Beane et. al. (1986), Hopper et. al. (1988) and Godbole et. al. (1996). The project area is covered almost entirely by Deccan basalt (of Upper Cretaceous to Palaeogene age) except for a few patches of alluvium occurring in the valley portions. The rocks of the project area fall under Salher/ Jawhar and Lower Ratangarh / Igatpuri formations of the Kalsubai sub-Group, separated from each-other by a giant plagioclase phenocrysts horizon at or near the formation boundary. The Jawhar and the Igatpuri formations contain similar looking flows which range in physical characters from aphyric to microphyric to giant plagioclase basalt (GPB) through porphyritic types with occasional flow top breccia. Jawhar formation comprises pahoehoe and simple flows (a'a) while Igatpuri formation comprises pahoehoe flow units. In this area in the compound flow joints are random and irregular with multiple scarps and at the bottom of flow pipe vesicles were reported. Individual rock types constituting the trap sequence are massive basalts, vesicular basalt and amygdaloidal basalts with cavities filled by secondary mineral agglomerates, tuff breccias and layers of red bole. The compound flows contain several units which vary in thickness from less than a meter to several meters and are normally aphyric to feldspar phyric. It is difficult to match and extend small units as they pinch out laterally and do not have uniform thickness. The contacts zone between the successive lava flows are moderately to

highly weathered and marked by presence of flow breccia, predominance of amygdules at the top of the lava flow, pipe amygdalues at the bottom of the upper flow or red-bole bed. Flow breccia contains angular, sub-angular rock fragment of older flow. In general, the flow breccia is moderately weathered to fresh, fine grained and greyish -brown in colour. On the surface of water conducting structures massive basalt, amygdaloidal basalt, fine grained massive basalt with laths of plagioclase and volcanic breccia have been mapped while drilling at this site encountered a sequence of massive basalt, amygdaloidal basalt and volcanic breccias at different depths. In the project area lava flows show various types of structures such as joints, fractures, spheroidal weathering, vesicles, veins, breccias clasts, mafic-dykes and amygdule having different shapes like circular, elliptical and irregular boundary. No curviplanar (fold) structure has been reported from this area. Some of the joints and micro fracture are developed due to cooling of hot lava while some are 'post-cooling' in age and tectonic in origin. Tectonic fractures and joints are playing very important role for the development of the drainage, escarpment and ridges and are traceable over long distances. In and around project site area systematic and non-systematic (curved and irregular joints) joint set are observed. Joint sets of different orientation terminate against lithological contact but many fracture planes are curved and difficult to decide their orientations. In pahoehoe flow of this area, joints are random and irregular with multiple scarps. Three sets of joints are prominent, type 1 are limited to single flow unit, type 2 are master joints – cross many units and drainages are controlled by these joint sets and Type 3 are relieved/ destressed joints, their trends are guided by valleys. The bed rock in general trends sub-parallel to the horizontality and dip (1^0-5^0) generally towards the left bank of the Kalu River. Mafic basaltic dykes showing the prominent columnar joints (horizontal and vertical sections) are very prominent along the Kalu river and its tributaries. The width of dykes varies from ~32 cm to ~3.5 m and the length of the dykes varies from ~ 3.5 to ~4 km. A suspected fault, trending N-S along the nala and disposed very close to MTDC Guest House, was mapped. It is a vertical fault and a displacement of about 1.4 m was recorded in the field. This fault is likely to intersect the proposed penstock alignment and it may intersect at 40 m and 100 m away from the locations of underground Power House and Transformer cavities respectively. This fault needs to be verified during construction of main drift to PH. No significant shear zone was noticed in the area.

Geotechnical Investigations

Intake Structure

To accommodate the intake arrangement within the silt level and MDDL, vertical circular shaft type intake having 10 m dia and 25 m depth for head race tunnel is proposed at 705 m from left abutment at 672 m RL. One exploratory drill hole BHUD-3 was drilled upto 30.20 m depth located 70 m from Intake in SE direction. Entire intake area is covered by thin soil cover up to maximum 2.0 m depth. Below the soil material up to the bottom of the hole bed rock comprising of gray fine grained compact basalt, brownish amygdaloidal basalt and volcanic breccia are present. The five prominent joint sets recorded in the fine grained compact basalt have the following attitude: vertical/NW-SE (strike) with 20-40 cm spacing, vertical/NE-SW with 20-40 cm spacing, vertical/NEE-SWW with 10-50 cm spacing, vertical/NNE-SSW with 20-60 cm spacing, and vertical/ NW-SE with 10-60 cm spacing. The roughness of the joints surfaces are rough-planar and rough-undulating while aperture is varying from 1 to 2 mm and ground condition reported was dry. Up to 2.0m and from 3.1 to 6.0m water loss are of the partial order, while in the rest of the portion water loss are nil, indicating that the rocks are having close discontinuities. Depth of water table measured at the time of drilling was at 0.45m.

Permeability values low to very low (lugeon 0.00 to 1.12) indicating that condition of discontinuities is very tight to tight. Seismic refraction survey was done in the intake area, also confirmed the maximum thickness of soil layer up to 2m. The weathered basalt was mapped up to 10m while distressed basalt was mapped up to 13m and below the distressed basalt hard basalts were mapped using seismic refraction survey.

From the geological details available from the geological plan and on the basis of exploratory drill holes data, geological section from intake to pressure shaft has been developed on the observed section is given in fig 1. Detailed of rock mass properties to be encountered from El 676.0 m to 646.0 m during the excavation of intake structure, are given in the Table 2.

Head Race Tunnel

A single head race tunnel (HRT) has been proposed, located between Intake and Pressure Shaft and at a 705 m away from left abutment. The length of HRT is 250m and the diameter is 6.5m. The tunnel involves an excavated diameter of around 7.2 m in order to avoid difficulties in construction of large size tunnels has been provided in the design. HRT will be circular type, lined (concrete), inclined at 7° to horizontal and aligned in the S75°03'10"E and N75°03'10"W direction. The centre line of head race tunnel varies from RL 640.00 m at the intake to RL 610.00 m near the beginning of the pressure shaft.

The proposed HRT alignment passes through a flat topography of the Main Deccan Plateau of the Lower Ratangarh Formation. Most of the surface area along the HRT alignment is covered by soil cover up to 2m thick and in some areas compact basalt with thin soil cover upto 0.3 m is present. Rock exposed to the surface normally showing grey or bluish black colour of basalt is turned into shades of brown or red by hydrothermal alteration. One exploratory drill hole BHINT-1 was done in the alignment of this tunnel but it was drilled from the ground elevation of 678.310 m upto 30.40m depth. Therefore, subsurface details from BHPS were taken into account, which was drilled from EL 676.003 m upto 250 m depth. The mapping details indicated that from RL 636.75 m to RL 606.75 m the tunnel will encounter grayish black fine to medium grained compact basalt, volcanic breccia and grayish brown amygdaloidal basalt. The thickness of volcanic breccia will be one meter and it is less jointed and the

Table 2: Properties of rock mass at the intake site of Malshej Ghat PSS, HEP

Elevation (m)	Rock type	Joints	Weathering grade	RQD %	RMR	Q	GSI (From RMR_{89})	Permeability (lugeon)	Type of flow	Vp (km/s)
676 to 663	Compact basalt	Inclined at 75° & 40°, horizontal and vertical joints	W-I to W-III	50 - 100	60 - 66	8.8 to 14	55 to 60	0.04 to 1.12	Void filling	3.0
673 to 661	Amygdaloidal basalt	Unjointed	W-II	100	72	17	67	0.04	Void filling	3.5
661 to 654	Compact basalt	Inclined at 20° & 40°, horizontal and vertical joints	W-I to W-II	94 - 100	65 -70	17	60 to 65	0.00 to 0.07	Dilation and void filling	3.6
654 to 650	Amygdaloidal basalt	Inclined at 20° & 30°, horizontal and vertical joints	W-I	100	65 – 70	15	60 to 65	0.00	Void filling	3.8
650 to 648	Compact basalt	Inclined at 20°	W-I	100	75	17	70	0.03	Void filling	4 0
648 to 646	Volcanic Breccia	Unjointed	W-I	100	60 - 65	13	55 to 60	0.03	Void filling	4.3

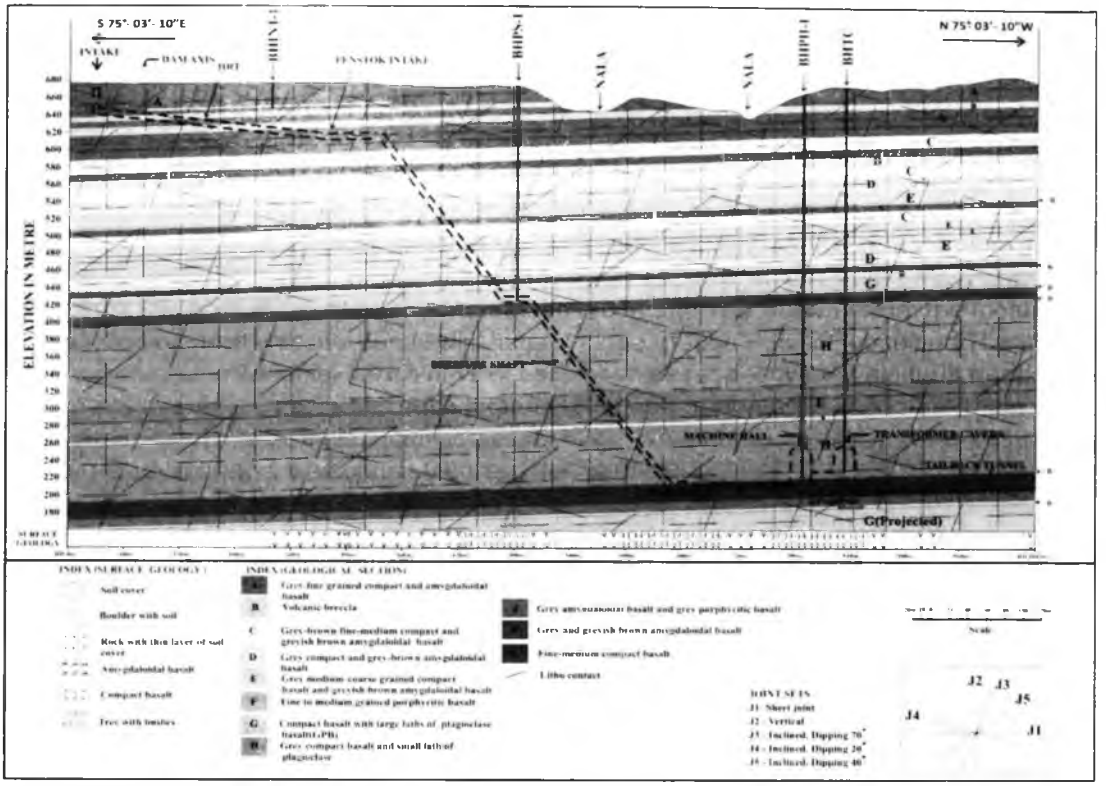

Fig. 1 Geological section of intake, HRT and pressure shaft

average core recovery and RQD of breccia is 95%. In compact basalt sheet joints and vertical to subvertical joints are very prominent, surface are generally rough-planar to rough-undulating and core recovery is varying from 97 to 100% and RQD is 95 to 100%. In case of amygdaloidal basalt sheet joints are very prominent and surfaces are rough-planar to rough-undulating. The core recovery is varying from 98 to 100% and RQD is 70 to 100%. The five prominent joint sets recorded in the compact basalt have the following attitude: vertical/NW-SE with 30-60 cm spacing, vertical/NWW-SEE with 30-60 cm spacing, vertical/NNE-SSW with 20 cm spacing, vertical/NNW-SSE with 80 cm spacing, and vertical/NE-SW with 80 cm spacing. Joints are generally closed but calcite filling upto 2 mm were also reported along some joint sets. The five prominent joint sets were also recorded in the amygdaloidal basalts have the following attitude: vertical/ E-W with 25-60 cm spacing, vertical/NNW-SSE with 25-40 cm spacing, vertical/NE-SW with 20 cm spacing, vertical/NW-SE with 10-60 cm spacing, and vertical/NNE-SSW with 20 cm spacing. Aperture upto 2 mm was reported along the joint surfaces filled with weathered rock material. Ground water condition of the area was dry.

Depth of water table measured at the time of drilling in BHINT was at 10.6m. Permeability test have been carried out from 3.0 to 30.0 m. In the test section 9.0 m to 12.0 m lugeon values are low (1.649) indicating that conditions of discontinuities are tight. In the test section 21.0 m to 24.0 m lugeon values are medium (26.544) indicating that some discontinuities are open. In the test section 24.0 to 27.0 m lugeon values are moderate (8.35) indicating that few joints are open. In rest of the sections lugeon values are very low (0.0 to 0.981) indicating that conditions of discontinuities are very tight.

All along the HRT alignment seismic

refraction survey was done. This section is characterised by a thin top soil layer which was mapped with a maximum thickness of 2m. The weathered basalts is mapped with a minimum of 1-2m thickness from RD 75m to 130m from intake and is mapped up to 8-10m below the surface near either ends. The de-stressed zone exists just below the weathered basalts except that its thickness is more in the first 30m stretch with a maximum thickness (13m) and at RD 325m to 335 with a thickness of 35m. The assessment of RMR (Bieniawski, 1989) and Q (Barton et.al., 1974), for basaltic rock mass, based on the information available of the rock joints and their nature and drill holes data, is tabulated in Table 3.

Pressure Shaft

One inclined and steel lined pressure shaft has been proposed to convey water from headrace tunnel to the powerhouse. The pressure shaft is inclined at 52° to the horizontal till the level of centre line of the distributor at the bottom. The total length of pressure shaft will be 525 m and its optimum diameter is 7.0 m and the clear or finished diameter of the pressure shaft has been fixed at 6.5 m. The pressure shaft bifurcates near the powerhouse into two branches to covey water to each of the pump-turbines of 350 MW capacities. The diameter of each branch of the pressure shafts is 4.4 m and the centre line is at RL 221m i.e. the centre line of turbine so as to match with the size of the inlet valves. The total length of each branch is about 100 m up to the inlet valve including the bifurcation. The length of Upper portion of pressure shaft will be 235 m and will be excavated bottom-up i.e. from RL 430.00 m up to RL 610.00 m. It is proposed to transport muck from the upper portion of pressure shaft through the intermediate adit. The lower portion which has a length of about 290 m will be excavated bottom-up from the powerhouse end i.e. from RL 221.00 m to RL 430.00 m and the muck will be transported from main access tunnel.

The proposed pressure shaft area passes through a flat topography of the Deccan traps on the surface and two deep nalas. At the surface along the pressure shaft alignment compact basalts, amygdaloidal basalts and volcanic breccia beneath very thin cover of soil are present along with isolated patches of dense vegetation. Along the nalas, which is controlled by master joints, compact basalts are exposed. One exploratory drill hole BHPS-1 was done in the alignment of pressure shaft but it was drilled from the ground elevation of 677.00 m upto 250 m depth. Therefore, subsurface details from BHPH-1 were taken into account, which were drilled from EL 667.07 m upto 450 m depths. Subvertical to vertical and sheet joints are prominent while two sets of oblique joints dipping at 20° and 40° are also present in the rocks of pressure shaft area. The surfaces of the joints are rough-planar, rough-undulating and smooth-planar. Mostly the joint are closed, ground water condition was dry and persistence of joints recorded was from 3 m

Table 3: Assessment of the rock mass parameters in HRT alignment

Elevation (m)	Rock type	Number of joint sets	Weathering grade	RQD (%)	RMR	Q	GSI (From RMR_{89})
652.00 to 641.00	Volcanic Breccia	One	W-I to W-II	90-100	55-60	13	50-55
641.00 to 630.00	Fine to medium grained compact basalt	Three	W-I	97-100	60-65	17	55-60
630.00 to 628.00	Volcanic Breccia	One	W-II	90	55-60	12	50-55
628.00 to 626.50	Amygdaloidal basalt	One	W-I	100	60-65	15	55-60
626.50 to 625.30	Compact Basalt	One	W-I	100	65-70	17	60-65
625.30 to 621.50	Amygdaloidal basalt	Two	W-I to W-II	100	60-65	12	55-60
621.50 to 614.60	Fine to medium grained compact basalt	Three	W-I to W-II	95-100	60-65	15	55-60
614.60 to 611.00	Amygdaloidal basalt	Two	W-I	98	60-65	12	55-60
611.00 to 608.50	Fine grained compact basalt	Three	W-I to W-II	100	60-65	15	55-60

to more than 20 m. Volcanic breccia is mostly unjointed. Mostly the rocks are fresh (W-I) but in some area rocks are slightly (W-II) to moderately (W-III) weathered. The pressure shaft will have a lateral cover of about 650 m from the rock slope of Malshej Ghat, which should be adequate to permit the rock surrounding the lining to carry maximum portion of the internal pressure load. Core samples from the exploratory hole drilled at the pressure shaft alignment were tested at NIRM for triaxial tests. The test results are summarized in the Table 4.

Mapping and borehole data in the area indicate that the pressure shaft will be driven through very good compact fine grained massive basalts, amygdalidal basalts, basalts with laths of plagioclase and volcanic breccia. The RMR value varies from 60-70 and Q is 10-17 and basaltic media could be considered as competent and good from all standard. At El 599.50 m, 0.5 m red bole, and at 431.00 m tuff layer of 0.5 m may encounter during excavation of pressure shaft. The uniaxial strength of intact rock as the lab tests varies from 50-131 for the compact basalts and thus can be considered as R4 and R5 grade, very strong to strong.

Table 4: Results of lab tests to rock samples – Pressure Shaft

Rock Type	Location	Depth (m)		Cohesion, MPa		Friction angle, Deg	
		From	To	Dry	Saturated	Dry	Saturated
Fine to medium grained compact basalt	BHPS-1	198.12	198.37	28.52	24.41	20.82	16.49
Volcanic breccia	BHPS-1	240.47	240.71	29.23	22.57	19.71	20.15
Volcanic breccia	BHPS-1	240.71	241.10	27.61	24.83	26.29	22.99

Table 5: Assessment of the rock mass parameters in pressure shaft alignment

Elevation (m)	Rock type	Number of joint sets	Weathering Grade	RQD (%)	RMR	Q	GSI (From RMR_{89})
621.50 to 614.60	Fine to medium grained compact basalt	Three	W-I to W-II	95-100	65-70	15	60-65
614.60 to 611.00	Amygdaloidal basalt	Two	W-I	98	65-70	12	60-65
611.00 to 608.50	Fine grained compact basalt	Three	W-I	100	65-70	17	60-65
608.50 to 463.00	Alternate flows of compact and amygdaloidal basalts	Three	W-I to W-II	89-100	65-70	15	60-65
463.00 to 459.50	Volcanic breccia	One plus random	W-II	96-99	60-65	12	55-60
459.50 to 440.00	Fine grained basalts with laths of plagioclase basalt	Three	W-II	54-96	65-70	15	60-65
440.00 to 428.00	Volcanic breccia with layer of tuff and white vein	Two	W-I to W-II	85-100	60-65	10	55-60
428.00 to 417.07	Fine grained compact basalt	Three	W-I	62-100	65-70	12	60-65
417.07 to 415.80	Volcanic breccia	One plus random	W-II	100	60-65	12	55-60
415.80 to 317.90	Grey-brown compact basalts with laths of plagioclase basalt	Three	W-I	91-100	65-70	15	60-65
317.90 to 274.80	Compact and amygdaloidal basalts	Three	W-I to W-II	95-100	65-70	12	60-65
274.80 to 269.10	Volcanic breccia	One plus random	W-I	100	60-65	12	55-60
269.10 to 217.07	Grey compact basalts with laths of plagioclase basalt	Three	W-I	83-100	65-70	15	60-65

The assessment of RMR (Bieniawski, 1989) and Q (Barton et.al., 1974), for basaltic rock mass, based on the information available of the rock joints and their nature and drill holes data is tabulated in the Table 5.

Tail Race Tunnel

The water discharging from draft tubes will

be collected through a Y-piece and will be let out through a single circular tailrace tunnel. The TRT is 985 m long and is 9.0 m in diameter and tail race channel of 150 m length and 60m width. Tunnel will be aligned in the S75°03'10"E and N75°03'10"W direction. The invert level of tailrace tunnel at powerhouse is at 208m and at lower intake 300 m. The tunnel has a maximum static head of 82 m and will be supported by 300 mm thick cement concrete (M175) lining for the full length of tunnel.

TRT traverses initially below the escarpment then through steep to moderately steep slope covered by dense to moderately dense forest and small bushes. Detailed surface geological information was collected from the transformer cavern upto the cliff and from lower dam reservoir area Kalu river to cliff portion upto accessible area i.e. for a length of 1180m along the TRT and TRC alignment. The rocks exposed on the surface are compact basalt and amygdaloidal basalt. Sheet joints and vertical joints are very prominent in compact basalt while in amygdaloidal basalt sheet joints are prominent. The joints are mostly closed, ground water condition was reported dry and persistence varying from 2 m to more than 20 m. The six prominent joint sets other than sheet joints recorded in the compact basalt have the following attitude: vertical/N-S with 30-60 cm spacing, vertical/NWW-SEE with 30-40 cm spacing, vertical/NNE-SSW with 20-30 cm spacing, vertical/NW-SE with 30-40 cm spacing, N (dip direction)/37° (dip amount) with 40-55 cm spacing and SW (dip direction)/55° (dip amount). The two prominent joint sets were also recorded in the amygdaloidal basalts have the following attitude: vertical/NE-SW with 30-40 cm spacing and vertical/NW-SE (strike) with 20-30 cm spacing. Two drill holes BHTRT-1 and BHTRT-2 were drilled along the TRT alignment upto 70 m and 180 m respectively. Drilling data indicate that vertical and sheet joints are prominent while two sets of oblique joints dipping at 15° (av.) and 45° (av.) are also present in the rock mass of TRT area. The surfaces of the joints are smooth-planar, rough-planar and rough-undulating. Mostly the rocks are fresh (W-I). The assessment of RMR and Q for basaltic rock mass, based on the information available of the rock joints and their nature and drill holes core is given in Table 6.

Conclusions

Based on the above studies, the following inferences and recommendations have been made:

- For the intake, the RQD values of the rock mass fall under very good class and

Table 6: Assessment of rock mass parameters in TRT alignment

Elevation (m)	Rock type	Number of joint sets	Weathering Grade	RQD (%)	RMR	Q	GSI (From RMR_{89})
320.50 to 309.00	Fine compact to porphyritic basalts and grey brown amygdaloidal basalts	Three	W-i to W-Ii	94-100	60-65	12	55-60
309.00 to 302.50	Grey and greyish brown amygdaloidal basalts	One plus random	W-I to W-II	91-94	60-65	17	55-60
302.50 to 278.00	Fine to medium grained compact basalts	Three	W-I	79-99	65-70	17	60-65
278.00 to 273.00	Volcanic breccia	One plus random	W-II	84-88	55-60	12	50-55
273.00 to 214.50	Grey fine compact basalt with laths of plagioclase	Three	W-I	82 -100	60-65	15	55-60
214.50 to 213.50	Volcanic breccia	One plus random	W-II	86-94	55-60	12	50-55
213.50 to 193.00	Fine to medium grained compact basalts	Three	W-i to W-Ii	89-100	65-70	17	60-65
193.00 to 188.50	Grey and greyish brown amygdaloidal basalts	One plus random	W-I	96-99	60-65	17	55-60

the laboratory tests indicate the UCS values varying from 40-105 MPa. Geological mapping and drilling results in the area (BHUD-3) indicate that the intake will be driven through very good compact fine basalts, amygdaloidal basalts and volcanic breccia and no major geotechnical problems are anticipated.

- HRT will be driven through very good compact fine grained basalts, volcanic breccia and amygdaloidal basalt. RMR has been estimated as 55 to 70 and Q is varying from 12 to 17. It can be said that the rock mass could be considered as competent and good tunneling medium. The uniaxial strength of intact rock as per the lab tests varies from 50-131 MPa for compact basalts and thus can be considered as R4 and R5 grade, very strong to strong rock. As per the estimated support categories based on the Tunneling Quality index Q (Grimstad and Barton 1993), the tunnel is expected to be self-supporting; however, rock bolting will be necessary at the crown portion, since tunnel will be excavated through the horizontal basaltic flows.
- The pressure shaft will have a lateral rock cover of about 650 m from the hill slope, which should be adequate to bear the maximum portion of the internal pressure load. The Tunneling Quality Index 'Q', of rock mass suggests that the shaft is expected to be self supporting; however, some active supports at places will be required. A fault has been interpreted along the natural drainage and the pressure shaft excavation in this reach should be carefully done with concurrent supporting and monitoring. The water table is expected to play an important role during excavation of the pressure shaft and TRT and water seepage is expected inside the shaft and TRT. A nala rivulet is also to cross the alignment at the lower reaches of pressure shaft. Thus suitable drainage arrangement should be provided.
- Geological mapping and drilling results indicate that the TRT will be driven through very good compact fine grained massive basalts, amygdaloidal basalts, gray fine compact basalt with small laths of plagioclase and volcanic breccia. The RMR value varies from 60-70 and Q is 12-17 and basaltic media could be considered as competent and good from all standard. The support measure for the TRT should be designed based on the above rock mass properties and the load should be worked out as per Barton's 'Q' (1980) system. The location of tunnel portals in a favorable geological and physiographic setting is of prime importance in any tunneling project. Although in the present case the country rock is hard compact and amygdaloidal massive basalts, volcanic breccia with intervening layers of thinly bedded basalts are supposed to be good tunneling media in dry and fresh state but the presence of adversely oriented planes of discontinuities coupled with weathering poses the slope stability problems near the tunnel portals. Another criteria is to have at least 2D (dia) sound rock in the tunnel portal area. As per the drill holes data, the rock cover at the portal location is only 3-4 m, so there should be structural portal or false portal for a length of approximately 45 m.

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