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Engineering Geological Investigations of Deep Open Surge Pool Area of Lift Irrigation Scheme – A Case Study from Telangana State, India

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ABSTRACT

Engineering geological mapping on 1:200 scale of surge-pool-excavated-vertical walls of Mahatma Gandhi Kalwakurthi Lift Irrigation Scheme-II (MGKLIS-II) was carried out which is being constructed for the irrigation of drought prone upland areas of Mahaboobnagar District in Telangana State, India. For rock mass characterization and for geologic interpretations for deep excavated vertical walls, engineering geological mapping is essential. All the lithological variance and the structural discontinuities in rock mass were identified and mapped. The entire area is made up of Archaean granites belonging to Eastern Block of Dharwar Craton which are intruded by mafic dykes. Rock mass classification was done based on Rock Mass Rating (RMR) and Rock Mass Quality (Q). Investigation shows that the rock masses of the area fall under the fair, poor and very poor rock mass quality. After detailed investigations, geotechnical problems were identified and corrective engineering support measures were suggested.

Keywords: Lift irrigation; Rock mass rating; Rock mass quality; Consolidation grouting; Rock bolt

1. INTRODUCTION

The Mahatma Gandhi Kalwakurthi Lift Irrigation Scheme (MGKLIS) is being constructed in the three stages (I, II & III) for lifting the river Krishna water from Srisailam reservoir (back water) to Gudipallygattu balancing reservoir through channels and tunnels to cater to the needs of irrigation in the drought prone 3,40,000 acres of upland areas of Mahaboobnagar District of Telangana State. In this paper geological investigations are being discussed for the surge pool area of Mahatma Gandhi Kalwakurthi Lift Irrigation Scheme-II (MGKLIS-II). Lift-II scheme is being constructed for lifting the water from Singotam balancing reservoir to Jonnalaboguda balancing reservoir. The FRL of the Singotam and Jonnalaboguda balancing reservoirs are at RL +334.680 m and RL +407.000 m respectively. The capacity of Singotam and Jonnalaboguda balancing reservoirs are 0.55 TMC and 2.14 TMC respectively. The ground elevation varies from RL+382 m to RL+387 m. The major components of the project are: one 4.0 km long gravity canal from Singotam balancing reservoir having bed width of 19.15 m, one 4.533 km long and 6.85 m finished diameter ‘D’ shaped tunnel, one surge pool

(94 m long x 40 m width x 75 m height), five 50 m long draft tube tunnels, one pump house (94 m long x 20 m width x 78 m height) and five (3 m finished diameter) main delivery tunnels, 15 m length horizontal and 305 m length inclined at 45°. Lift height is 86 m and five pumps will be installed in the pump house cavity (30 MW capacity each). Design discharge of the pumps will be 113.2 Cumec. In between the surge pool and pump house a 50 m wide rock ledge is proposed (Fig. 1). For suggesting the suitable engineering measures for stabilizing the excavated walls, engineering geological investigations was carried out. The ground level of surge pool is at RL +382 m and the foundation level is at RL +307 m. The sides of the surge pool will be lined with 500 mm RCC filling from the bed line and floored with 500 mm thick raft foundation to distribute the load as per design specification (Anon, 2012).

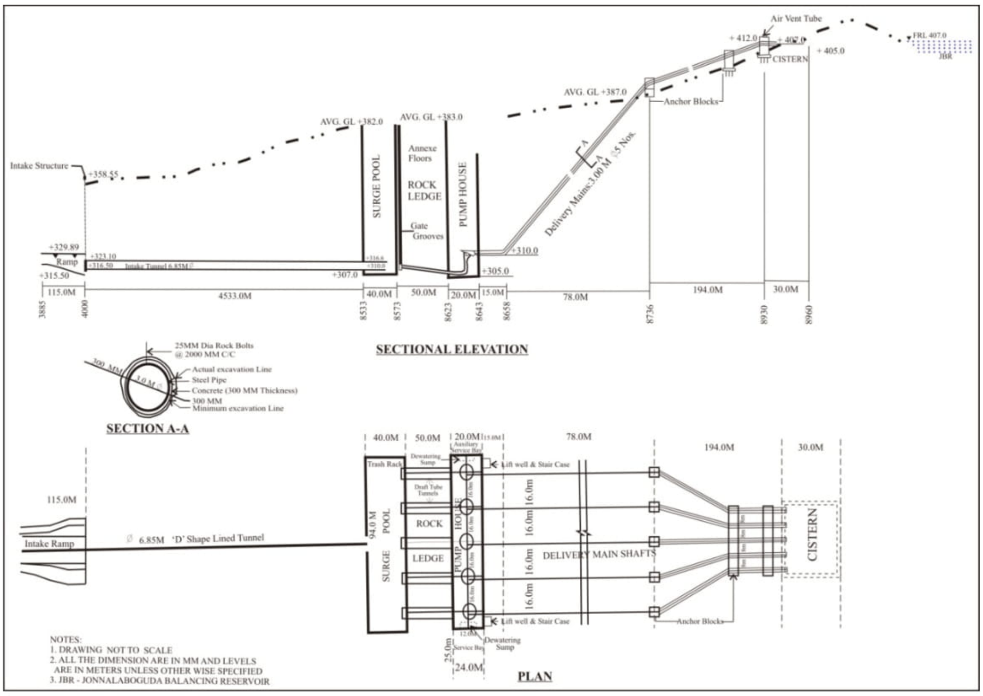

Fig. 1: Plan and elevation of schematic drawing of MGKLIS-II

2. METHODOLOGY

Geological mapping on 1:200 scale was carried out using the crain and traverse method. Crain was used for the mapping of walls, because mapping was carried out after the excavation of surge pool from RL +382 m up to RL +307 m. Grids of 2 m x 2 m dimension were prepared for mapping of the wall, based on the mapping accuracy and resolution required for such investigations. Elevations and chainages were also marked on the walls face using the Total Station surveying equipment. ISRM (1978) classifications for weathered mass was used to characterize the rock mass into different grade. For granites exposed on walls, rock mass classification was done following the methods of Bieniawski (1989) Rock Mass Rating and Barton et al. (1974, 1980) Rock Mass Quality 'Q'. At 2 m x 2 m grids RMR and Q values were calculated and average value at 10 m vertical interval are given for better understanding. The modified Q-values for the immediate and ultimate wall support have been assessed on the basis of Q values (Barton et al., 1974; IS 13365 Part-2, 1992).

3. GEOLOGICAL SETTING OF THE AREA

The project site forms a part of Eastern Block of Dharwar Craton, comprised of Archaean granites which are intruded by mafic dykes, age ranging from Archaean to Upper Proterozoic (Sharma et al.,2008; Ramam and Murty, 2012). Granites and gneisses are exposed in and around the project site over a large area (Fig. 2). Head race tunnel was excavated through fresh and hard grey (porphyritic) granites with medium to coarse grained feldspars, traversed by dolerite dykes and pegmatite veins, while surge pool, pump house, draft tubes, delivery mains and cistern are being excavated through pink and grey granites, traversed by dolerite dykes. Pink granites are coarse grained, hard and jointed and shows phenocryst of alkali feldspar and quartz. Main minerals composition is alkali feldspars, quartz, mica and amphiboles. Grey granites are medium to coarse grained, light colour, hard and jointed. Main minerals composition is feldspars, quartz, mica and amphiboles (Singh and Naithani, 2015). In pink granites three to five prominent joint sets and in grey granites three to four prominent joint sets are developed, which are generally irregular in pattern. Along some joint planes clay coating was recorded. Granites are generally fresh to moderately weathered (WI–WIII). Dolerite dykes are fine grained and greenish-black in colour. Dykes are generally sheared along the contact at the surge pool area. Plagioclase and clinopyroxene (augite/titanaugite) are the main minerals occurring in ophitic to sub-ophitic textures in dolerite. Quartz, epidote and opaques occur as accessories. Amphibole, biotite and sericite occur as alteration products. In a regional perspective E-W trending dykes show greater degree of alteration and are relatively older as established from intersecting features (Naithani and Singh, 2016). Sulphide disseminations are reported in some dykes. Dykes are generally moderately to highly weathered (WIII – WIV).

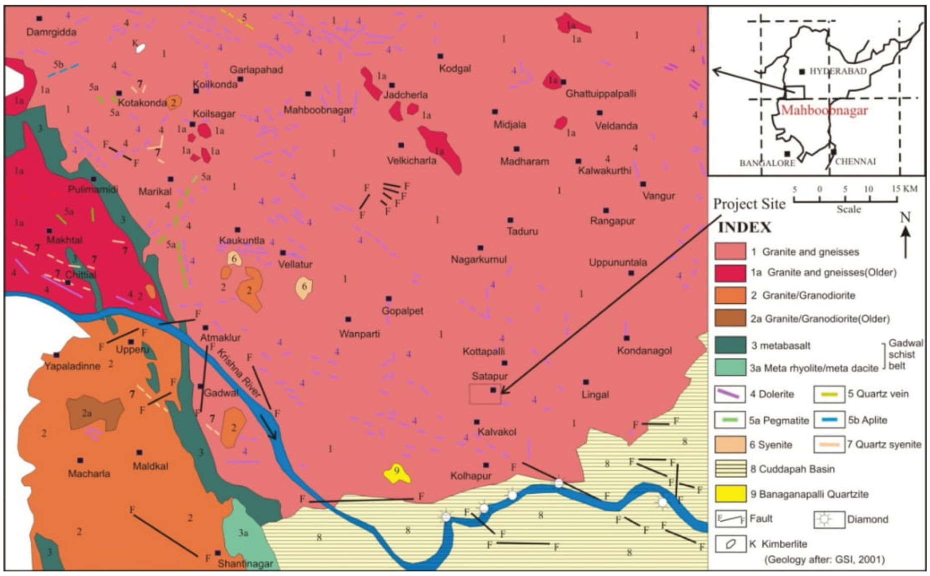

Fig. 2: Generalised geology map of MGKLIS-II project site and area around (GSI, 2001)

4. ENGINEERING GEOLOGICAL ASSESSMENT OF EXCAVATED WALLS

In the surge pool pit, reddish brown gravelly soil is present upto 2 m then coarse grained, compact and jointed granites are exposed upto the foundation level. Granites colour varies from pink to grayish, which is due to varying amount of orthoclase. Granites in the excavated south and east wall sections are generally fresh in nature below RL +377 m while in the west wall, granite is fresh below RL+346 m. The rock mass is characterized by five prominent joint sets, which are continuous and persistent, smooth-planar to smooth-undulating with unaltered to slightly altered joint walls. Staining has been recorded along the joint surfaces where the joints are tight and where opening is up to 4.0 mm, soft clay mineral coating/filling and crushed material filling has been recorded. In general, the rock mass is characterized by the dry condition or minor inflow i.e. < 5.0 litre/min.

The average height of the south, east and west walls is 75.25 m from design foundation level (RL+307.0 m). Design length of south wall is 94.0 m, aligning along the N125°-N305° direction and details of its joint characteristics are given in Table 1 and Fig. 3. During excavation, rock masses were fallen from the central part of this excavated wall. The rock mass failure was due to structural wedge formation between J1 (N020°/65°) and shear zone (N250°/75°) and J1 (N020°/65°) & J3 (N305° /80°) and their depth extended from 1.5 m to 4.0 m in to excavated line of face. A shear zone trending in N250° direction, dipping at 75° having strike length of more than 100 m and average width 20 cm, was mapped on the face of the wall. Four joints viz. N170°(dip direction)/45°(dip amount), N20°/70°, N310°/70° and N150°/60° intersecting this shear zone but displacement was not recorded along this feature. The rock mass is falling under very poor to fair rock mass category (Table 2).

Table 1: Joint sets recorded in granite at the face of south wall

Joint Sets	Dip Direction	Dip Amount	Spacing (cm)	Persistence (m)	Roughness	Aperture (mm)	Infilling (mm)	Groudwater Condition	Remarks
J1	010°- 025°	60°- 70°	5-100	>20	Smooth planar	Tight to 2	None	Dry	Dipping toward surge pool, very unfavorable from stability point of view.
J2	340°- 350°	65°	10-50	>20	Smooth planar	Tight	Clay coating along the joint plane	Dry	Dipping towards surge pool i.e. towards western direction, unfavorable.
J3	300°- 310°	70°- 80°	10-100	>20	Smooth planar/smooth undulating	Tight to 3	Clay coating along some joint plane	Dry	Dipping toward west wall of surge pool, favorable from stability point of view.
J4	150°- 180°	45°- 60°	10-40	2-5	Smooth planar	Tight	None	Dry	Dipping towards hill slope i.e. towards eastern direction.
J5	240°- 250°	60°	7-50	>20	Smooth planar	Tight to 4	Crushed material	Dry	Dipping towards hill slope i.e. towards western direction.
J6	200°	70°	40-100	>20	Smooth planar/smooth undulating	Tight to 1	Crushed material	Dry	Random, dipping towards the hill slope i.e. towards south.
J7	80° -110°	68°	100-200	1-5	Smooth planar	Tight	None	Dry	Random, dipping towards surge pool i.e. towards north eastern direction.
J8 (V1)	065°	Vertical	15-100	>20	Smooth planar	Tight to 2	None	Dry	Random, mainly in the eastern side of the wall.

Table 2: Rock mass classification using RMR and Q of the face of south wall

SE side of South Wall From RD 0.00 to + 47.00 m								NW side of South Wall From RD 0.00 to – 47.00 m							
Elevation		RMR		Q		Modified Q (As Per IS: 13365-Part-2)		Elevation		RMR		Q		Modified Q (As Per IS: 13365-Part-2)	
From	To	Value	Class	Value	Description	Immediate Wall Support	Ultimate Wall Support	From	To	Value	Class	Value	Description	Immediate Wall Support	Ultimate Wall Support
279	370	39	IV	0.52	Very Poor	6.50	1.30	379	370	39	IV	0.44	Very Poor	5.50	1.10
370	360	43	III	0.69	Very Poor	8.62	1.72	370	360	38	IV	0.53	Very Poor	6.62	1.32
360	350	-*	-	-	-	-	-	360	350	43	III	0.69	Very Poor	8.62	1.72
350	340	49	III	1.57	Poor	19.62	3.92	350	340	54	III	2.07	Poor	25.87	5.17
340	330	47	III	1.23	Poor	15.37	3.07	340	330	52	III	1.88	Poor	23.50	4.70
330	320	46	III	1.16	Poor	14.50	2.90	330	320	58	III	4.30	Fair	53.75	10.75
320	307	57	III	4.20	Fair	52.5	10.50	320	307	58	III	4.89	Fair	61.12	12.22

*From 382 to 379 and 360 to 350 (SE side) area was shotcreted at the time of mapping

West and east walls are aligning along the N035°-N215°direction. The design length of walls are 40.0 m, but over excavation was mapped, which was due to uncontrolled blasting and unfavourable geological discontinuities. Rock type mapped on the west wall section was granite which was generally fresh in nature below RL +346 m (Fig. 4). The details of the joint characteristics of west wall are given in Table 3. An intrusive dolerite dyke-2 trending in N270° direction with a dip amount of 65°, and a strike length of more than 100 m was mapped on the northeastern side of the wall. The width of dyke varies from 1.0 m to 1.2 m. Three joints viz. N030° /60°, N160°/40° and N250°/80° are intersecting this dyke. The contact between granite and dolerite dyke is unweathered to slightly weathered and no failure scar or displacement was observed along this dyke.

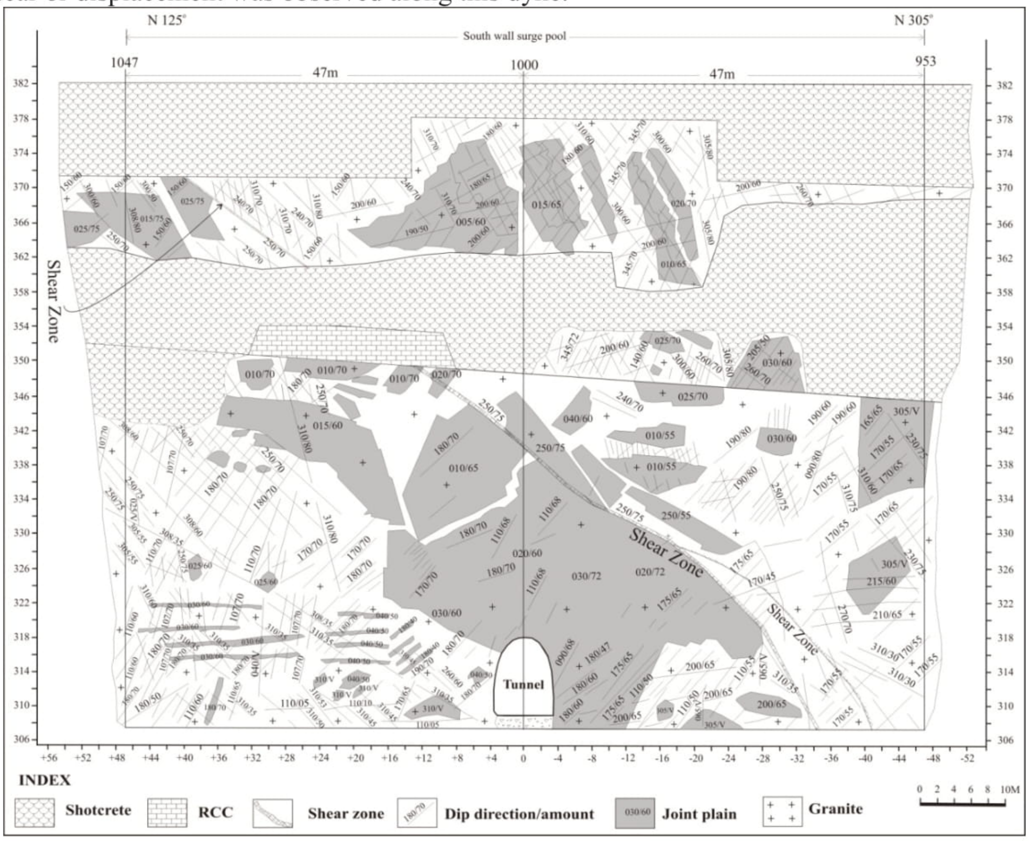

Fig. 3: Geology map of the south wall of surge pool

Table 3: Joint sets recorded in granite at the face of west wall

Joint Sets	Dip Direction	Dip Amount	Spacing (cm)	Persistence (m)	Roughness	Aperture (mm)	Infilling (mm)	Groudwater Condition	Remarks
J1	010°- 025°	70°- 80°	15-50	>20	Smooth planar/smooth undulating	Tight	None	Dry	Dipping toward north wall, not unfavorable.
J2	310°	60°	100-200	>20	Smooth planar	Tight to 1	Clay coating along the joint plane	Dry	Dipping inside the hill slope.
J3	160°	45°- 50°	5-20	1-3	Smooth planar	Tight to 1	Clay coating along the joint plane	Dry	Dipping toward the surge pool.
J4	250°- 260°	60°- 65°	30-100	>20	Smooth planar/smooth undulating	Tight	None	Dry	Dipping towards south wall.
J5	310°	80°	-		Smooth planar	Tight	None	Dry	Random joint, dipping inside the wall i.e. towards the southern direction.
J6 (V1)	340°	Vertical	10-40	10	Smooth planar	Tight	None	Wet	Dripping at the south-west corner of the wall.
J6 (V2)	210°	Vertical	-	>10	Smooth planar	Tight	None	Dry	Random joint

A shear zone-1 trending in N260° direction with a dip amount of 60°, and a strike length of more than 16 m was also mapped on face of the west wall. The average width of shear zone was 20 cm and three joints viz. N10°/70°, N200°/Vertical and N260°/60° are intersected by this shear zone. Shear zone-2, 3 and 4 are orienting towards north-south direction and their average width was 15 cm. No displacement was recorded along these shear zones. The rock mass class is very poor to poor (Q = 0.36 to 3.27) in the entire vertical wall area and the details of the RMR, Q and modified Q-values of at different levels of west wall are given in Table 4.

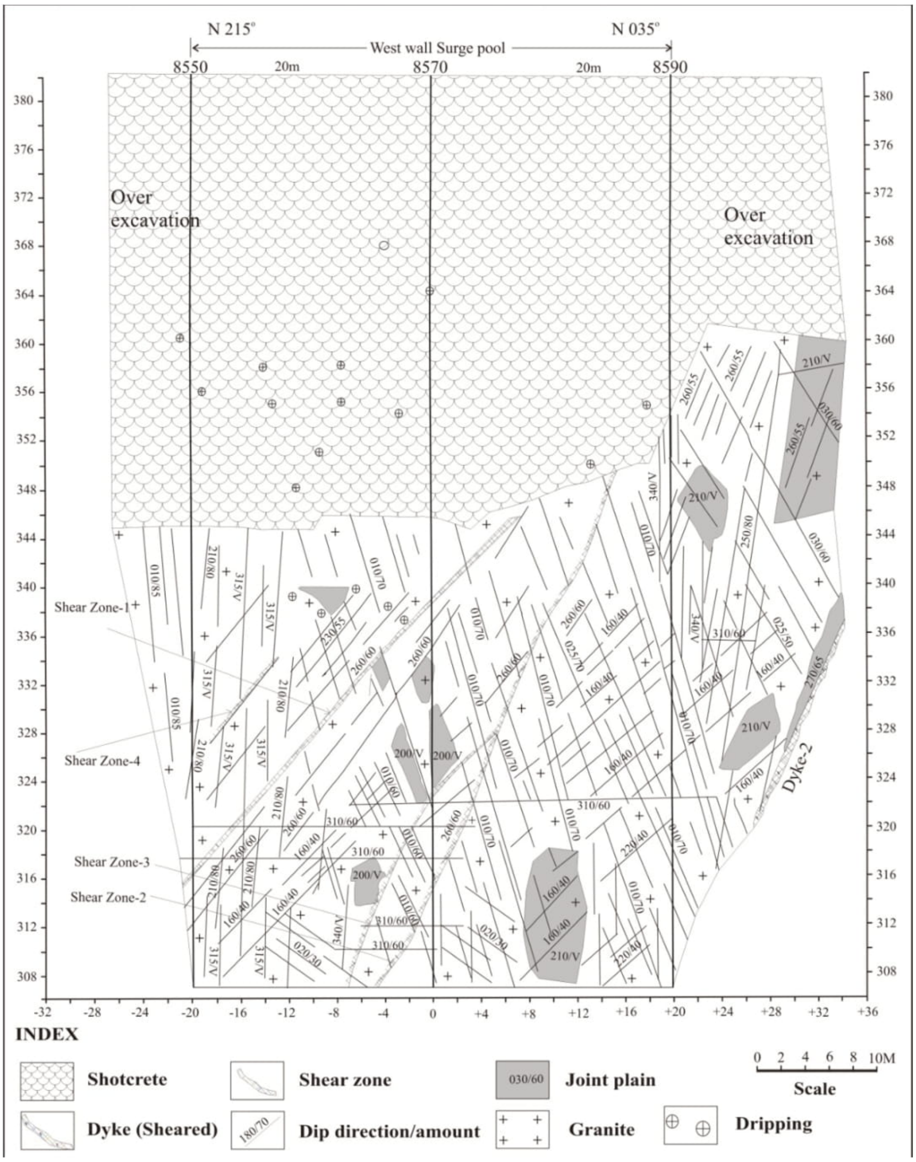

Fig. 4: Geology map of the west wall of surge pool

Fresh, hard and jointed granite was mapped on the east wall section (Fig. 5). Cavity was formed in southern side of east wall because of intersection of dyke-1, J1 (005°-025°) and J2

(300°-330°). The details of the joint characteristics are given in Table 5. The dolerite dyke trending in N260° direction with a dip amount of 65°, and a strike length of more than 100 m was mapped almost on the centre of the wall. The width of dyke varies from 0.80 m to 1.0 m and three joints viz. N240° (dip direction)/ 65° (dip amount), N300°/65° and N060°/55° are intersected this dyke. Dolerite dykes are fine grained, jointed, fractured and sheared in nature and dark gray in colour. The contact between granite and dolerite dyke is unweathered to slightly weathered and no failure scar was recorded along this dyke.

Table 4: Rock mass classification using RMR and Q of the face of west wall

SW side of West Wall								NE side of West Wall							
From RD 0.00 to -20.00 m								From RD 0.00 to +20.00 m							
Elevation		RMR		Q		Modified Q (As Per IS: 13365-Part-2)		Elevation		RMR		Q		Modified Q (As Per IS: 13365-Part-2)	
From	To	Value	Class	Value	Description	Immediate Wall Support	Ultimate Wall Support	From	To	Value	Class	Value	Description	Immediate Wall Support	Ultimate Wall Support
-	-	-	-	-	-	-	-	360	350	42	III	0.83	Very Poor	10.37	2.07
345	340	52	III	3.27	Poor	40.87	8.17	350	340	42	III	0.80	Very Poor	10.00	2.00
340	330	40	IV	0.62	Very Poor	7.75	1.55	340	330	35	IV	0.39	Very Poor	4.87	0.97
330	320	59	III	5.12	Fair	64.00	12.80	330	320	50	III	2.05	Poor	25.62	5.12
320	307	59	III	5.20	Fair	65.00	13.00	320	307	58	III	4.56	Fair	57.00	11.40
Above RL 345 m in SW side and RL 360 in NE side was shotcreted at the time of mapping															

Table 5: Joint sets recorded in granite at the face of east wall

Joint Sets	Dip Direction	Dip Amount	Spacing (cm)	Persistence (m)	Roughness	Aperture (mm)	Infilling (mm)	Groudwater Condition	Remarks
J1	005°- 025°	60°- 67°	10-50	>20	Smooth planar/smooth undulating	Tight to 1	None	Dripping	Dipping towards northern side.
J2	300°- 330°	55°- 65°	40-100	>20	Smooth planar	Tight to 1	Clay coating along the joint plane	Wet	Dipping towards surge pool side.
J3	150°-180°	60°-70°	10-40	1-5	Smooth planar	Tight	None	Wet	Dipping towards wall i.e. towards ENE direction.
J4	240°- 260°	65°- 70°	5-30	5-10	Smooth planar/smooth undulating	Tight	None	Wet	Dipping towards south wall, parallel to dyke.
J5	060°- 070°	45°- 55°	30-100	10	Smooth planar/smooth undulating	Tight to 1	Clay coating along the joint plane	Wet	Dipping inside slope i.e. towards northern side.
J6	250°	Vertical	-	2-7	Smooth planar	Tight	None	Wet	Random vertical joint

Two shear zones were mapped on the face of east wall. The average width of shear zone-1 is 25 cm, trending in N180° direction with a dip amount of 65°, and a strike length is more than 100 m. Two joint set viz. N025°/50° and N070°/68° are intersecting this shear zone. Shear zone-2 trending in N60° direction with a dip amount of 65°, and a strike length of more than 10 m is having average width of 10 cm. No displacement was recorded along these shear zones. The rock mass was classified as very poor to fair rock mass (Q = 0.39 to 2.98) and the details of the RMR, Q and modified Q-values of east wall are given in Table 6.

Table 6: Rock mass classification using RMR and Q of the face of east wall

NE side of East Wall								SW side of North Wall							
From RD 0.00 to + 20.00 m								From RD 0.00 to - 20.00 m							
Elevation		RMR		Q		Modified Q (As Per IS: 13365-Part-2)*		Elevation		RMR		Q		Modified Q (As Per IS: 13365-Part-2)*	
From	To	Value	Class	Value	Description	Immediate Wall Support	Ultimate Wall Support	From	To	Value	Class	Value	Description	Immediate Wall Support	Ultimate Wall Support
370	360	38	IV	0.43	Very Poor	5.37	1.07	370	360	36	IV	0.40	Very Poor	5.00	1.00
360	350	36	IV	0.42	Very Poor	5.25	1.05	360	350	54	III	2.07	Poor	25.87	5.17
350	340	43	III	0.77	Very Poor	9.62	1.92	350	340	44	III	0.83	Very Poor	10.37	2.07
340	330	37	IV	0.39	Very Poor	4.87	0.97	340	330	57	III	2.98	Poor	37.25	7.45
330	320	55	III	3.27	Poor	40.87	8.17	330	320	50	III	1.72	Poor	21.50	4.30
320	307	58	III	4.56	Fair	57.00	11.40	320	307	58	III	4.89	Fair	61.12	12.22
Above RL 370 area was shotcreted at the time of mapping															

*Note: *IS code is based on the observationa that the wall support pressures are found to be negligible in the tunnels in the non-squeezing ground conditions. The Q_{wall} is recommended for the shafts.*

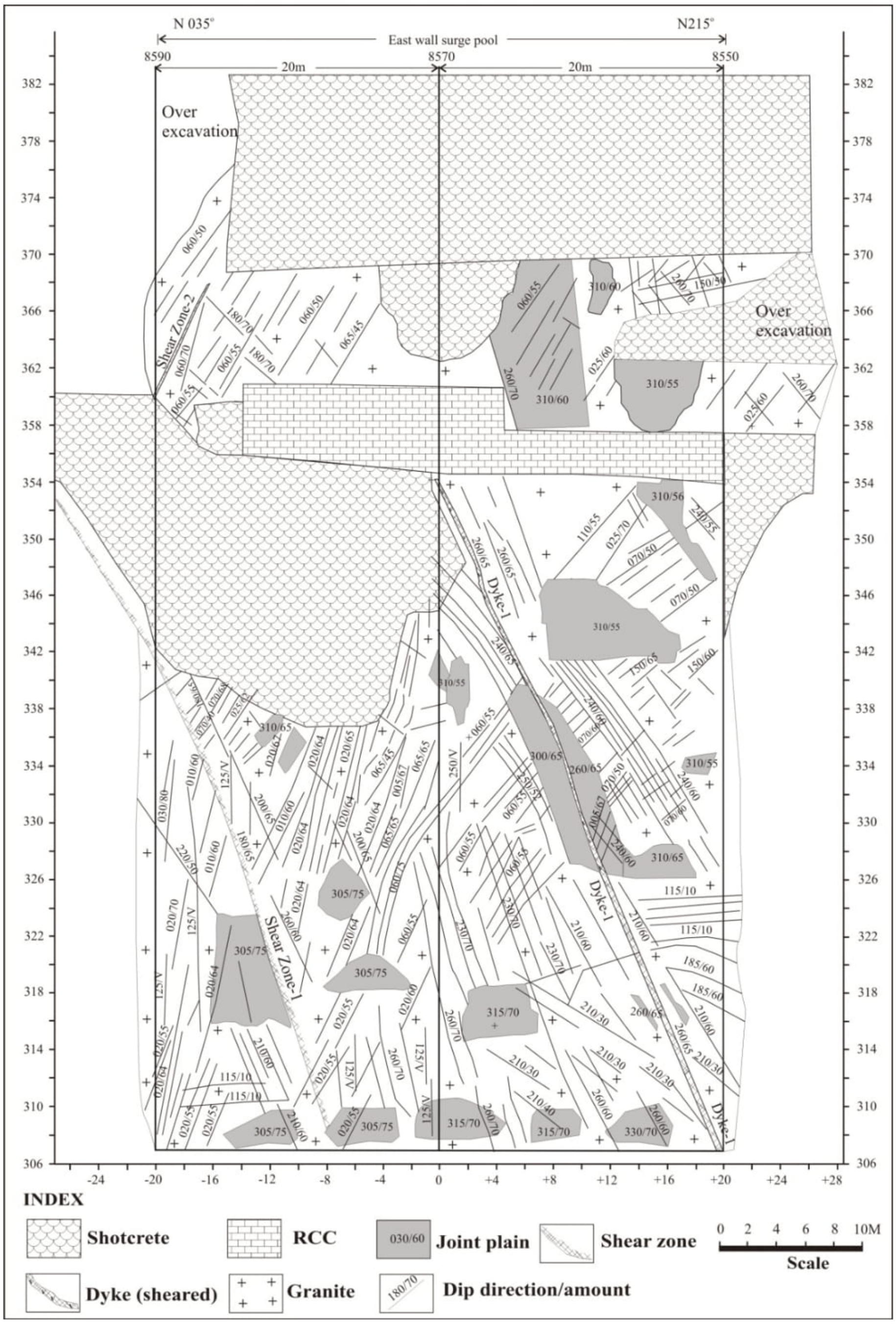

Fig. 5: Geology map of the east wall of surge pool

5. OBSERVATIONS AND RECOMMENDATIONS

The stability of the cut slopes/vertical walls depends upon the geometry, frequency and orientation of joint sets, dip of slope and its plane of weakness. Based on field observations and evidences, it was concluded that the site condition, particularly the south and east walls of surge pool are not stabile, particularly along the shear zone due to its interplay with a joint set forming a wedge. Other major joint sets, dipping inside the wall or towards opposite sides of the wall i.e. those joint sets not dipping towards the pits do not tend to cause unfavourable condition. Generally the rocks are fresh, hard and jointed in nature. But the top level is fractured/jointed, and the joints are open, due to uncontrolled blasting. The top layer will require proper treatment either by removal of loose material or consolidation grouting once the lining of wall is provided.

Rock support arrangements were recommended based on rock mass quality Q and site geological conditions. A 3.0 m wide berm in 1:1 slope at the contact of overburden soil/highly weathered and disintegrated granites at RL +380 m was constructed along all the sides during benching down of the cavity. For this bench 100 mm thick shotcrete with chainlink/wiremesh and weep holes is recommended. Turfing in the overburden top soil slope, which will not be covered by shotcrete is also recommended. Second 3.0 m wide berm is recommended at RL +368 m and 1:1 slope is suggested between RL +380 m and RL + 368 m. Spot rock bolting and 100 mm thick shotcrete with properly anchored chainlink/wiremesh and weep holes is suggested for this slope. The third 6.0 m wide berm is suggested at RL +357 m with 1:8 slope between RL +368 m and RL + 357 m. 25 mm dia and 5.0 m length rock bolt with 1.0 m c.c. spacing in staggered fashion is recommended for this berm. Chute drains along the berms are also recommended. It is recommended that at every berm, the inner slope should be provided with toe drain and connected to the chute drain. Below RL +357 m upto foundation level, 25 mm dia and 5.0 m long rock bolt in staggered fashion and 100 mm thick SFRS is recommended. For south wall spacing of rock bolt will be 1.5 m centre to centre and for east and west walls it will be 2 m. The rock bolt should be full-column-grouted with resin or quick setting cement capsules. The rock bolts shall be oriented normal to the side wall, angled for about 20° from horizontal, inclined into the wall face.

On the wall portion, shear zones and dykes are present. Some of the dykes are sheared. It is suggested that the sheared material should be removed by mechanical excavator and the excavated portion should be back filled with concrete. The shear zone should be cross-stitched with rock bolts and covered with shotcrete, before regular support is applied. RCC (design) lining of 500 mm thick will be constructed along all side walls from the foundation level up to the maximum surge level i.e. RL +332.680 m. Above this level lining shall be done following the cut slope, maintaining the minimum thickness of lining with sufficient anchorage. After providing lining in the area, consolidation grouting (with 0.25 to 0.35 MPa pressure) up to maximum 20 m depth shall be done from the top surface using primary, secondary and tertiary holes so that the openings created due to blasting are filled and the area functions as the monolithic rock mass.

6. CONCLUSIONS

The engineering geological mapping was done after the final excavation of the surge pool which should be done concurrently with the excavation. For these types of deep excavations, the unsupported depth should not be more than 10 m, because the poorest rock mass qualities almost always cause appreciable deformation in the periphery zone. In these cases, it is important to provide a temporary support which is flexible, but strong enough to increase stand-up time and prevent collapse, while allowing the rock mass to gain a new stress distribution (Grimstad and Barton, 1993). The final support should be installed based on observations and the temporary support must be a part of final support. For very important structures like deep surge pool, the vertical walls and foundation strata have to be well studied and documented to provide data set for credible geological interpretations. This permanent record will assist in making better interpretation of post-construction instrumentation data.

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