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Engineering Geological and Geotechnical Investigations for a Pump House Complex Site – a Case Study from Lift Irrigation Scheme

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ABSTRACT

For the deep underground pump house complex engineering geological and geotechnical investigations were carried out. The area was investigated through detailed engineering geological mapping, exploratory drilling, in-situ stress measurements and laboratory testing. Surface mapping was done on 1:500 scales with 0.5 m contour interval and drill holes logging was done on 1:100 scale. The rock mass properties, i.e. joint sets, weathering grade, RQD etc. of the rock masses to be encountered during the excavation of cavities have been analyzed in detail. Core samples from the exploratory drill holes drilled at the surge pool and pump house area were tested for physico-mechanical properties of rocks in the laboratory. To evaluate the stress regime at the proposed underground pump house complex area, stress measurements were carried out by hydrofracturing method inside the borehole. The mapping details indicated that cavities will be excavated through fresh, coarse to very coarse grained, hard and jointed granites. The average depth recorded of fresh rock from the surface was 15.7 m. The uniaxial compressive strength of the rock mass range from 221 to 246 MPa. The orientation of the long axis of the cavities recommended is N150°. Classification of rock mass using Tunnelling Quality Index Q is attempted and the values are range from 3.58 to 16.40.

INTRODUCTION

For better rock mass classification and for finalization of the longest axis of cavities, engineering geological and geotechnical investigations were carried out for the proposed underground pump house complex site. Pump house complex includes surge pool and pump house cavities. 350 m long, 15 m wide and 44.33 m deep surge pool and 150 m long, 19 m wide and 40.5 m deep pump house is proposed to lift 77.914 TMC of water from Imamabad reservoir to Tadakapally reservoir in Telangana state of India. The detailed investigations include large scale geological mapping on 1:500 scale, geological logging of drill holes, in-situ stress measurements and laboratory testing on rock samples. The main objectives of these studies were to provide the adequate geological and geotechnical data regarding the feasibility of underground cavities. These parameters will be useful for stress analysis of the pump house complex using 3D modelling for a given excavation sequence, and to suggest suitable support system for roof and walls.

Many Indian authors have used these approaches for better rock mass classification and orientation of the longest axis of cavity in many underground deep cavity projects (Nawani, 2011; Mandal et al. 2011; Naithani, 2012; Nanda et al. 2015; Subrahmanyam, 2015; Naithani, 2017; Naithani et al. 2017).

GEOLOGY OF THE AREA AND AROUND

Regionally, the area is predominantly occupied by granite with small patches of supracrustals of Archaean age. The supracrustals occur as enclaves of varying shapes and sizes within granite and predominantly in hornblende granite. They are composed of banded magnetic quartzite which occur as elongated and lensoidal bodies. The present area falls within the geological domain of peninsular gneissic complex represented by granite/gneiss (Ramam and Murty, 2012; Nagaraj, 2012). Hybrid granite gneiss occurs as enclaves within granite and represents older granite – gneiss phase in the south-western parts of the area. The grey hornblende biotite granite gneiss is composed of grey alkali feldspar, plagioclase and quartz with minor biotite and hornblende. Grey biotite granite contains plagioclase, k-feldspar, quartz and biotite and occurs as sheets in younger granite. The other variants of pink hornblende – biotite granite are coarse grained pink hornblende – biotite granite, medium grained pink hornblende – biotite granite and medium grained alkali feldspar granite. The litho ensemble is intruded by dolerite dykes, quartz veins and at places by secondary epidote veins. Regionally the project site falls in the Seismic zone-II as per the Seismic zonal map of India (IS 1893 (Part-1) - 2002).

GEOLOGY AND GEOTECHNICAL INVESTIGATIONS

Engineering Geological Mapping

For designing the underground cavities, engineering geological investigations are important. Understanding the geological setup of an area constitutes one of the important parameters required for economic and safe designing of a project. This area was mapped on 1:500 scales with 0.5 m contour interval using the total station surveying equipment (Fig. 1). The area was predominantly covered either with reddish brown sandy soils or with light grey/brown, fine to medium grained silty–clayey soils constituting the overburden. However, scattered exposures of grey granite and its variants are discontinuously exposed at places. The granite rocks are weathered to fairly fresh at the surface, generally medium to coarse grained and occasionally fine grained and jointed in nature. They are intruded by basic dykes / leuco veins with emplacements of pegmatite and epidote veins. The prominent sets of joints recorded in the coarse grained granite of the surge pool and pump house area are given in Table 1 and 2.

All the joint sets were close, moderately close to widely spaced. On the basis of spacing of discontinuities, rock mass of this area can be categorized into fractured, blocky/seamy and massive rock mass. The persistence of the joint sets is medium to very high. Prominent joint sets are vertical or steeply inclined. The joint planes are slightly rough and smooth, sometime with minor clay infilling.

Subsurface Exploration

The pump house complex site was explored by core drilling with five vertical holes, two on the surge pool area and three on pump house area. Drilling was planned with the aim to collect adequate required information regarding the extent and thickness of overburden and the type of underlying bedrock, its disposition and depth of

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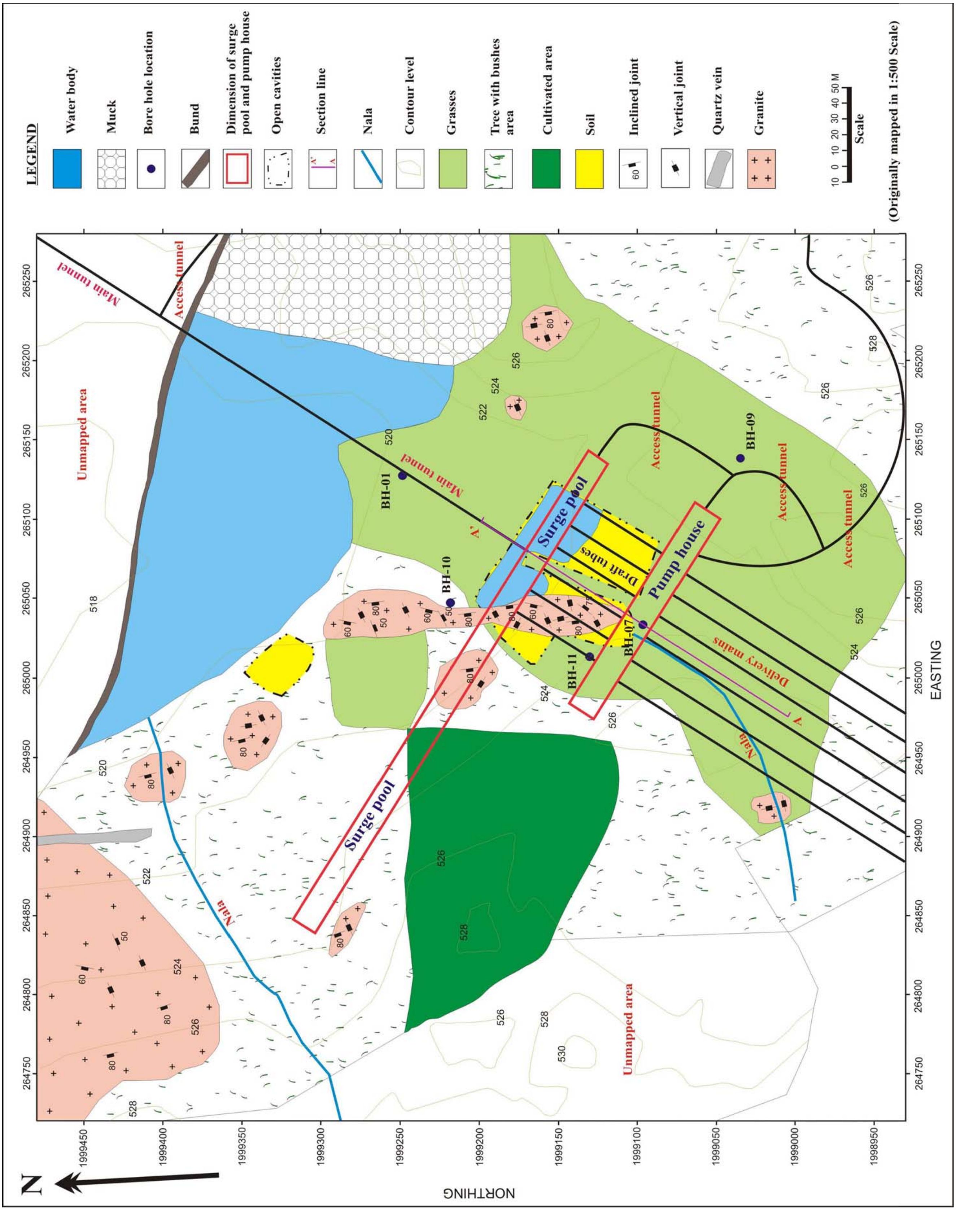

Fig.1. Geological plan map of the surge pool and pump house area around

Table 1. Prominent joint sets recorded in coarse grained granite at the surge pool area

Joint Set	Dip Direction/ Strike	Dip Amount	Spacing (cm)	Persistence (m)	Roughness	Aperture (mm)	Infilling (mm)	Groundwater Condition	Remarks
J1	60-80	Vertical	20-100	>10	Slightly rough to smooth	Tight to 3	Nil to clay	Dry	Joint plane is slightly weathered
J2	250-260	70-85	50-100	10	Slightly rough to smooth	Tight to 1	Clay	Dry	Joint plane is weathered
J3	290	55-65	50-60	5	Slightly rough to smooth	Tight to 1	Nil	Dry	Joint plane is slightly weathered
J4	160	50	35	5	Slightly rough	Tight	Nil	Dry	Random joint, joint plane is slightly weathered
J5	300	Vertical	40	5	Slightly rough	Tight to 2	Nil	Dry	Random joint, joint plane is slightly weathered

Table 2. Prominent joint sets recorded in coarse grained granite at the pump house area

Joint Set	Dip Direction/ Strike	Dip Amount	Spacing (cm)	Persistence (m)	Roughness	Aperture (mm)	Infilling (mm)	Groundwater Condition	Remarks
J1	70-90	Vertical	30-100	>10	Slightly rough to smooth	Tight to 5	Nil to clay	Dry	Joint plane is slightly weathered
J2	130-140	70-80	50-100	10	Slightly rough to smooth	Tight to 1	Clay	Dry	Joint plane is weathered
J3	260-270	55-65	50-60	5	Slightly rough to smooth	Tight to 1	Nil	Dry	Joint plane is slightly weathered
J4	245	Vertical	100	5	Slightly rough	Tight to 1	Nil	Dry	Random joint, joint plane is slightly weathered
J5	350	60	30	5	Slightly rough	Tight to 2	Nil	Dry	Random joint, joint plane is slightly weathered

weathering. All the boreholes were drilled by rotary method using NX size diamond bits employing single tube core barrel. The cores recovered from these drill holes were examined, geologically logged and summary is given in Table 3. On an average overburden thickness was 4 m consisting of fine to medium grained sandy/silty soil occasionally with rock fragments. The average depth recorded of fresh rock from the surface was 15.7 m. In few sections zero RQD was recorded, which may be because of mechanical breaking of core pieces.

Based on surface geological mapping and exploratory drill holes data geological section was constructed on the observed section perpendicular to the centre line of the surge pool and pump house (Fig. 2)

Physico-mechanical Properties of Rocks

Core samples from the boreholes drilled in the surge pool and pump house area were tested for physico-mechanical properties as

Table 3. Summary of the boreholes drilled at the surge pool and pump house area

BH No	Location and structure	Ground Elevation	Total depth	Overburden	Depth of fresh rock (m) / RL	Core recovery %	RQD %	Lithology
BH-1	Along tunnel alignment near to surge pool, at Ch.10.600 km	520.856 m	66.30 m	2.00 m	22.00 m / +498.856 m	83 – 100 (from RL 480.000 to 454.556 m)	29 – 100(from RL 480.000 to 454.556 m)	Fresh and hard, medium to coarse grained, dominantly pinkish grey granite
BH-7	Pump House, at Ch.10.785 km	522.950 m	79.20 m	3.00 m	24.50 m / +498.45 m	88 – 100 (from RL 480.000 to 443.750 m)	54 – 100 (from RL 480.000 to 443.750 m	Fresh and hard, medium to coarse grained, dominantly pinkish grey granite
BH-9	Pump House area, at Ch.10.750 km	525.000 m	95.50 m	3.00 m	15.00 m / +510.00 m	16 – 100 (from RL 480.000 to 429.500 m)	Nil – 91 (from RL 480.000 to 429.500 m)	Slightly weathered and hard, medium to coarse grained, dominantly pinkish grey granite
BH-10	Surge Pool area, at Ch.10.685 km	526.000 m	85.00 m	1.50 m	6.00 m / +520.000 m	75 – 97 (from RL 480.000 to 441.000 m)	15 – 92 (from RL 480.000 to 441.000 m)	Slightly weathered and hard, medium to coarse grained, dominantly pinkish grey granite
BH-11	Pump House Area, at Ch. 10.762 km	523.400 M	70.3 m	11.00 m	11 m / +512.40 m	85 - 100 (from RL 480 to 450m)	Nil - 88 (from RL 480.000 to 450m)	Slightly weathered and hard, medium to coarse grained, dominantly pinkish grey granite

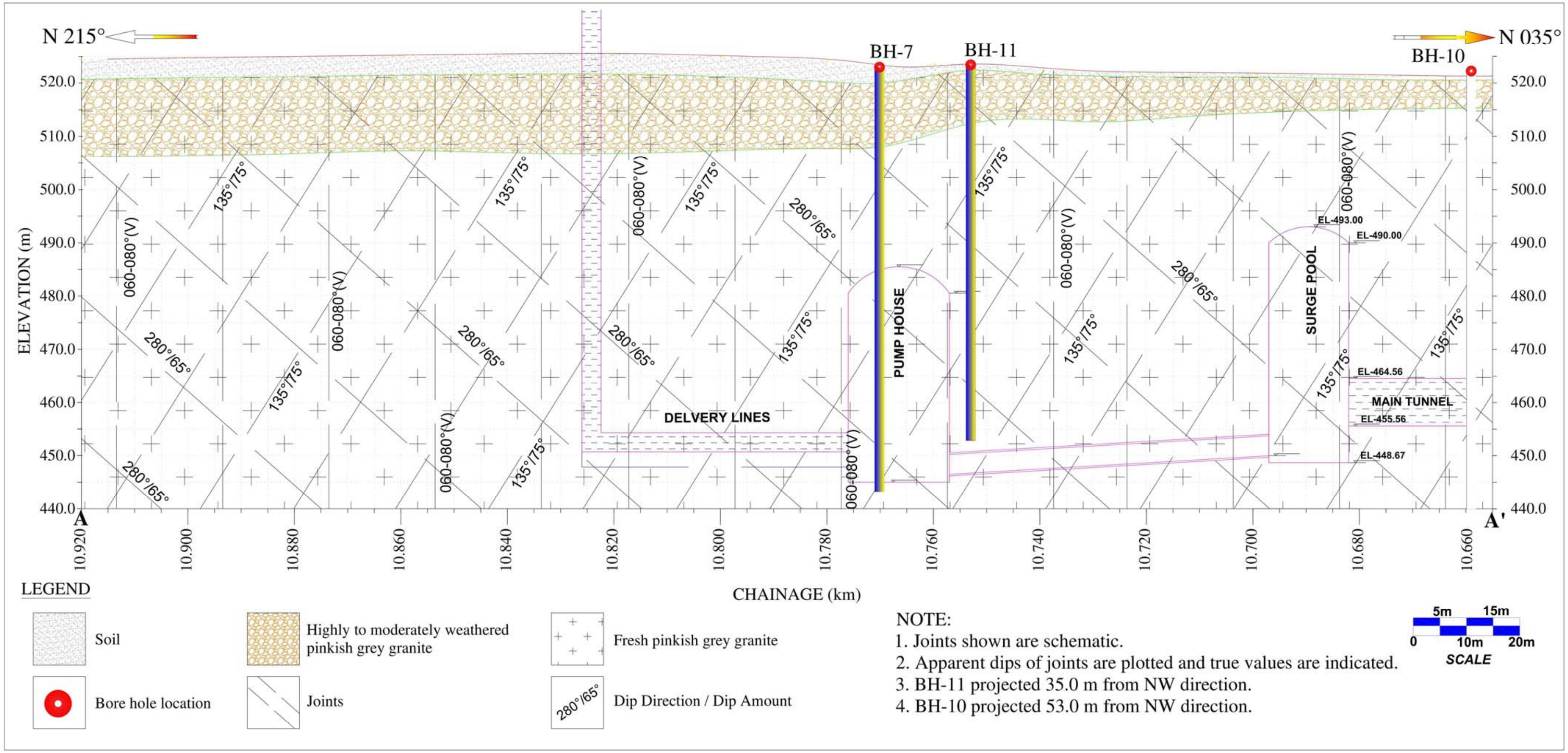

Fig.2. Geological section perpendicular to the centre line of the surge pool and pump house

Table 4. Results of lab tests to rock core samples

BH No	Rock Type	Reduce Levels (m)	Density (kg/m^3)		UCS (MPa)		Young's modulus (GPa)		Poisson's ratio		Cohesion (MPa)		Friction angle (deg.)	
			Dry	Saturated	Dry	Saturated	Dry	Saturated	Dry	Saturated	Dry	Saturated	Dry	Saturated
7	Granite	501.95	2669	2668	231	246	80.01	78.43	0.20	0.23	-	-	-	-
10	Granite	511.80 - 501.90	2657	2657	236	240	79.29	75.71	0.21	0.21	56.88-59.71	63.10	50.42-51.45	51.42
		496.16 - 491.50	2671 - 2677	2672	217-248	221-231	80.79-81.62	80.36 - 80.52	0.21 - 0.22	0.22 - 0.24	-	64.06	-	49.04
11	Granite	490.90 - 501.60	2667	2672	240	241	79.52	80.17	0.27	0.22	57.59	61.39	52.67	48.38

per the standard procedures. The test results are summarized in Table 4. The rock samples were tested for their density, uniaxial compressive strength, Young's modulus, Poisson's ratio, cohesion and friction angle. The uniaxial compressive strength of the rocks at the surge pool and pump house cavities ranges from 221 to 246 MPa in saturated condition. In general the difference between dry and saturated strength is negligible, probably because rock is coarse grained and isotropic. In granite the silicate minerals (mainly quartz and feldspar) of uniform grain size are randomly oriented and distributed. It has been observed that in saturated condition (water increases) strength is reducing with increasing amount of dark minerals (biotite, amphibolite, pyroxene) and for increasing schistosity (anisotropy) (Broch, 1979). According to strength classification criterion for rock substance, proposed by Deere and Miller (1966) and ISRM (1981), the rocks are of very high strength. The density values of granite are 2657 to 2672 kg/m^3 in saturated conditions belong to high density category (Kesavulu, 2009). Density values are indicating that microfissures equivalent to largest grain or pore size, which causes erratic results are absent in the representative samples. In saturated condition Poisson's ratio values are varying from 0.21 to 0.24 and as per intact rock classification proposed by Gercek (2007) it falls under medium category.

In-situ Stress Measurement

To evaluate the stress regime at the proposed underground pump house complex area, stress measurements were carried out by hydrofracturing method inside the borehole by NIRM (Subrahmanyam, 2015, Anon, 2015). From this test magnitude of the principal stresses as well as the direction of maximum horizontal principal stress were determined. The hydrofracture stress measurements were conducted in six zones between RL 497.40 m and RL 418.40 m. A sophisticated data interpretation method, viz. Psi (shut-in-pressure) method was used under the analysis program GENSIM to calculate the magnitude and the direction of principal stresses. The test results are given in Table 5. After detailed analysis it is concluded that the K value indicates a medium stress magnitude and the principal horizontal stress direction N150°, which is recommended for the orientation of the long axis of the cavities to reduce ground control problems.

Table 5. Test results derived from *GENSIM* analysis (source: Anon, 2015)

Principal stresses	Result
Vertical Stress (σ_v) in MPa	1.11
Maximum Horizontal Principal Stress (ó$_H$) in MPa	1.84
Minimum Horizontal Principal Stress (ó$_h$) in MPa	1.24±0.25
Maximum Horizontal Principal Stress direction	N 150°
$K = \sigma_H/\sigma_v$	1.65

CHARACTERIZATION OF ROCK MASS

The assessment of tunnelling quality index 'Q' (Barton et al., 1974) for the granitic rock mass, based on the information available of the rock joints and their nature from surface mapping and drill holes data was done (Table 6). This is one of the best methods being used for classification of the rock mass around an underground opening (Naithani et al. 2009, Naithani and Singh 2013). Q-values are being used to predict engineering behaviour of rock masses with reasonable accuracy including the prediction of support pressure in underground opening. The Q-system can be used as a guideline in rock support design decisions. The rock mass at the crown portion of surge pool (from RL +493 to RL +503.00) has the Q value of 3.58 to 15.00 and it comes under poor to good rock mass category. The rock mass at the crown portion of pump house (from RL +483 to RL +493) has the Q value of 6.30 to 16.40 and it comes under fair to good category.

OBSERVATIONS AND CONCLUSIONS

Surge pool and pump house cavities will be excavated through medium to very coarse grained, hard and jointed granites, which will be generally fresh in nature. Sufficient lateral rock cover is available, and the vertical rock cover is 29 m and 42 m above the surge pool and pump house cavities respectively. In general core recovery and RQD values fall in fair category and uniaxial compressive strength of the rock is very high, thus supporting the feasibility of underground excavations of pump house and surge pool. The orientation of the long axis of cavities recommended is N150°. In view of the presence of jointed granites over the crown portion, geotechnical problems may arise during the excavation of the proposed underground surge pool and pump house. The presence of prominent low dipping joints in the granite may cause separation of blocks in the crown portion, which needs to be tackled by installing long rock bolts for ensuring effective

Table 6. Summarized data of the 'Q' system for the proposed pump house complex

BH No	Cover (m)	Rock Quality Designation (%)	Joint Set Number	Joint Roughness Number	Joint Alteration Number	Joint Water Reduction Factor	Stress Reduction Factor	Rock Mass Quality (Q)	
								Value	Class
BH-1	27.85	42.50 (av.)	6 – 9	1.5	2.0	1.0	1.0	3.58 - 5.35	Poor to Fair
BH-7	39.95	75.63 (av.)	4 – 9	1.5	2.0	1.0	1.0	6.30 - 14.18	Fair to Good
BH-9	42.00	82.8 (av.)	4 – 9	1.5	2.0	1.0	1.0	6.90 - 15.53	Fair to Good
BH-10	29.46	80.00 (av.)	4 – 9	1.5	2.0	1.0	1.0	6.67 - 15.00	Fair to Good
BH-11	40.40	87.50 (av.)	4 – 9	1.5	2.0	1.0	1.0	7.29 - 16.40	Fair to Good

stitching of rock mass. Moreover, combination of vertical joints and low dipping joints may at places result in block falls at the crown level, which also needs to be tackled by rock bolting and shotcreting. The vertical joints on the walls of cavities might at times pose some problems related to convergence or bulging during benching down, which ought to be arrested by rock bolting.

For underground deep cavities, these types of detailed investigations are required for better rock mass classification and orientation of the longest axis of cavity. These parameters will be the main input data required for structural design of supporting system.

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