Engineering geological consideration of a deep pump house foundation floor: case study of lift irrigation scheme, India

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***Abstract*—Geological mapping of deep foundation floor is essential to provide permanent data set for geological interpretation. A deep pump house (94 m long x 20 m width x 78 m deep) of Mahatma Gandhi Kalwakurthi Lift Irrigation Scheme-II (MGKLIS-II) wasconstructed at Mahaboobnagar District in TelanganaState for the irrigation of drought prone upland areas. Engineering geological mapping on 1:200 scale of foundation floor of pump house was carried out in order to evaluate the basic design parameters. All the discontinuities in the rock mass of pump house area with the zone of influence of the foundation were identified and mapped. Mapping was done to assess the requirement of any ground improvement by adopting suitable engineering measures. Safe bearing pressure of the foundation was estimated by rock mass rating, rockmass characteristic parameters. Based on investigations geotechnical problems were identified and suitable engineering measures for rock support were suggested to make foundation monolithic.**

Keywords—foundation floor; pump house; lift irrigation; rock mass rating; safe bearing pressure;Telangana state

I.INTRODUCTION

Mahatma Gandhi Kalwakurthy Lift Irrigation Scheme (MGKLIS) is proposed to provide irrigation water to an extent of 3.40 lakhs acres and utilising 25 TMC of water including drinking water facilities to 3,20,000 population (0.73 TMC) to chronically drought prone upland areas in Mahaboobnagar district covering about 303 villages in erstwhile taluks of Kollapur, Nagarkurnool, Achampet, Jadcherla and Kalwakurthy constituencies in 19 Mandals. This scheme (MGKLIS) was constructed having the three stages (I, II & III) for lifting the Krishna water from Srisailam reservoir (back water) to Gudipallygattu balancing reservoir through channels and tunnels(Fig. 1). Water will be lifted to a total height of 289 m in three stages from level +244.40 to +502.00m.

The present investigations were carried out for the foundation of pump house of MGKLIS-II. This deep pump house (94 m long x 20 m width x 78 m deep) is design to install heavy pump machine (~220 tons each pump machine) for the lifting of water[1]. This scheme was constructed near village Sathapur of Mahaboobnagar District, located 195 km away from Hyderabad city, for lifting the water from Singotam balancing reservoir to Jonnalaboguda balancing reservoir. The FRL of the Singotam and Jonnalaboguda balancing reservoirs are 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.

The major components of the project are: one 4 km long gravity canal from Singotam balancing reservoir having bed width of 19.15 m, one 4.53 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), 15 m length horizontal and 305 m length inclined (45°) main delivery tunnels. Lift height is 86 m and five pumps installed in the pump house cavity (30 MW capacity each). Design discharge of the pumps is 113.2 Cumec. This study pertains to large scale engineering geological mapping on 1:200 scale of excavated floor foundation of the pump house. The objective of this study was to advise suitable protective engineering measures of excavated foundation floor of pump house based on detailed engineering geological investigations.

Pump House is the key role in Lift Irrigation Projects, which are facilities including high speed electric pumps and other equipment for pumping fluids from one place to another. The pump machine shall be of the vertical shaft, single stage, Francis Turbine Pump, suitable for direct coupling to motor of (5x30 MW) with 10% over load rating. The direction of rotation shall be anti-clockwise when viewed from top. Each pump shall be so designed of ~220 tons weight including all removable parts including impeller, shaft, guide bearing, shaft seal, guide apparatus etc. They are used for a variety of infrastructure systems, such as the supply of water to high level reservoirs, canals, the drainage of low-lying land, and the removal of sewage to processing sites.

II.METHODOLOGY

Geological mapping on 1:200 scale of the pump house foundation was carried by using the Total Station. Grids were prepared for mapping and the size of the grid was 2 m x 2m, which was decided based on the mapping accuracy and resolution required for such investigations. All the lithological

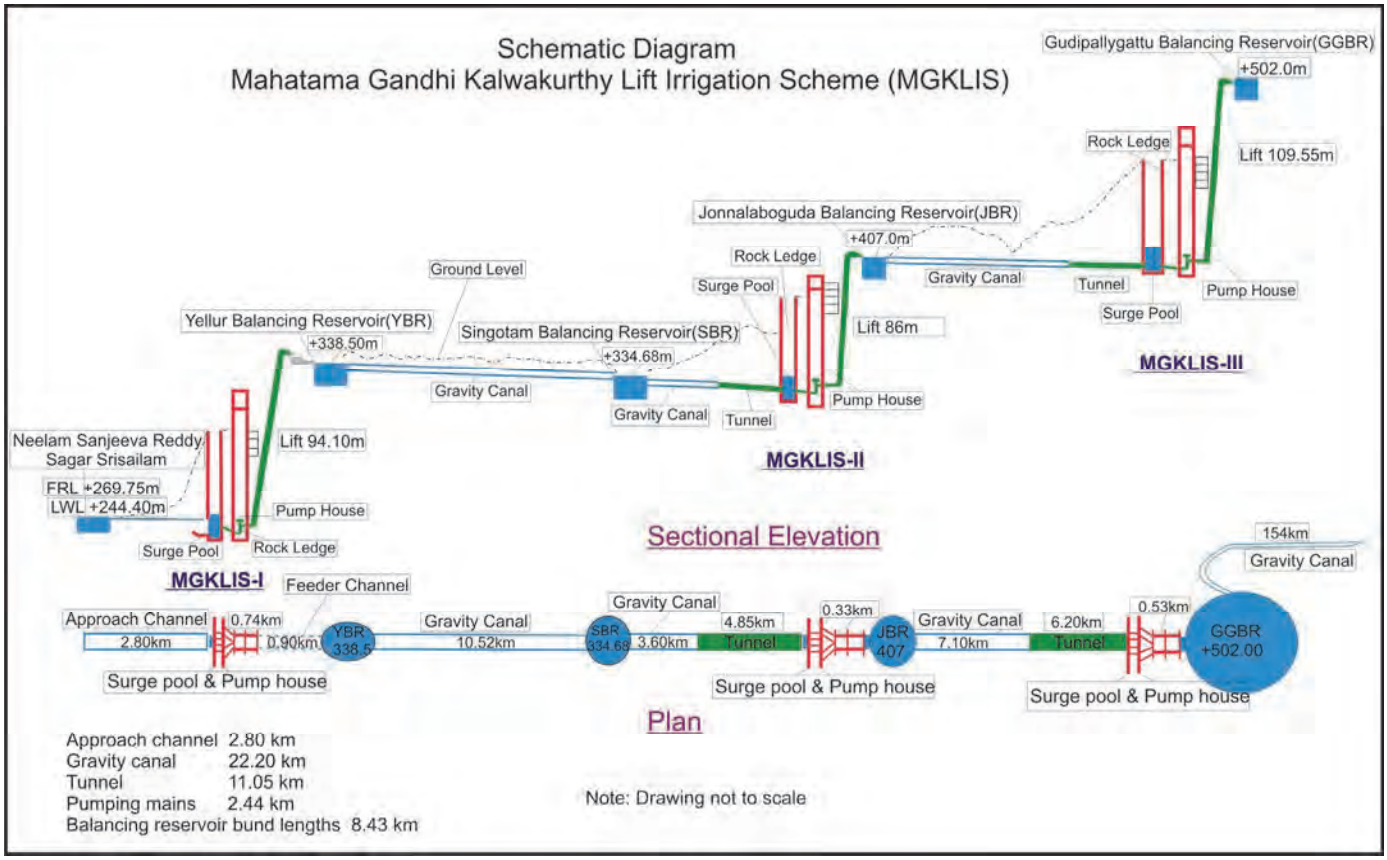

Fig.1. Plan and elevation of schematic drawing of MGKLIS [1]

and structural features were observed and mapped by using Total Station surveying equipment. Detailed examination of rock types in each grid were carried out which includes mineralogical composition, texture, classification and nomenclature and degree/grade of weathering. Fracture filling that have taken place in the study site were examined and recorded. The attitude and structure of the rocks, fractures and joint pattern present in the floor and walls were determined for mapping. ISRM [2] classification for weathered mass was used to characterize the rock mass into different grades. The assessment of Rock Mass Rating [3] for granite rock masses was done based on the rock joints and their nature.

III. Geology of the MGKLIS-II Project Site and Area Around

MGKLIS–II project area forms a part of Eastern Block of Dharwar Craton mainly comprised of Archaean granites which are intruded by mafic dykes age ranging from Archaean to Upper Proterozoic [4]. Granites and gneisses are exposed in and around the project site over a large area. In these formation many shears, fractures and faults have affected the terrain controlled the invasion of quartz, pegmatite, apatite and basic dykes along NW-SE, NNW-SSE, WNW-ESE, N-S, NNE-SSW and ENE-WSW directions [5,6,7]. The reactivation is seen especially in WNW-ESE trending features associated with basic dykes and quartz reefs exhibit intense fractures and shears [5]. The regional study of Mahaboobnagar District area based on geology, photogeology and Landsat imageries [8],identified NE-SW, NW-SE, WNW-ESE, NNE-SSW and nearly N-S trending lineaments and major faults trending in NW-SE, WNW-ESE, nearly E-W directions in the eastern and southeastern part of the area. No major lineament or fault is passing through the pump house area of MGKLIS-II project site.

The pump house area is excavated through medium to coarse grained pink 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. Three to five prominent joints set are developed and along the joint plane clay coating/filling was also recorded. Joints are irregular in pattern. Pink granite is generally fresh to slightly weathered (WI–WIII). Dolerite dykes are fine grained and greenish black in colour. The width of the dykes varies from 30 cm to >100 cm and their strike length is more than 50m in excavated part of pump house. Dykes are generally sheared along the contact at the pump house 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, 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. Sulphide disseminations are reported in some dykes. Dykes are generally moderately to highly weathered (WIII – WIV).

IV. Engineering Geological Assessment of the Foundation of Pump House

Geological mapping of foundation floor is essential to provide permanent data input for geological interpretations during construction and also it forms valuable documentation for post-construction stage. For very important structures like deep pump house of lift irrigation, the foundation strata have to be well studied and documented for credible geologic interpretations. Rock is usually recognized as the best foundation material. However, design engineers should be aware of the dangers associated with heterogeneity and unfavourable rock conditions since over-stressing a rock foundation may result in large differential settlementsor perhaps sudden failure. In order to evaluate the design basis foundation parameters for pump house of MGKLIS-II, engineering geological mapping (on 1:200 scale) was carried out.

All the discontinuities in the rock mass of foundation of pump house with the zone of influence of the foundation has been identified and mapped. The primary purpose of the mapping is to provide a permanent record of conditions during the excavation. Mapping will be used to assess the requirement of any ground improvement. This permanent foundation record will assist in making better interpretation of post-construction foundation instrumentation data[9]. The floor of pump house was examined on a grid to grid basis; the size of the grid is 2 m x 2 m. All the lithological and structural features were observed and mapped using Total Station surveying equipment and shown in the final foundation grade geological plan map(Fig. 2).Classification of rock mass using Rock Mass Rating (RMR) of Bieniawski [3] has been attempted and based on investigations, recommendations for the treatment of foundation is given.

A. Geological and Structural Assessment – Floor of Pump House

The design foundation level is at RL +305.40 but in some areas it is excavated up to an average RL +303 and the over excavation was varying from 0.10 m to 2.4 m because of presence of unfavourable discontinuities, and shear zones.The foundation of pump house will be resting as per design on a raft of 300 mm thick at about 78 m below the existing ground level for functional requirement(Fig. 3). Total 1880 sq m excavated foundation area of pump house floor has been geologically mapped. Geological foundation mapping was done after the excavation and before first pore of concrete (Fig. 4). Based on the field observations and evidences, it is found that the entire floor area consists of coarse grained, hard and jointed pink granite (Fig. 5). Total four shear zones are mapped. The width of the shear zones are varying from 1 cm to 30 cm. No displacement has been recorded along shear zones. No evidences of faulting are observed on the surface of floor area. The structural features observed during the mapping indicated the need for consolidation grouting, so that the entire floor is function as single rock mass.On the basis of surface geological mapping the excavated surface is acceptable for foundation.

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. Five prominent joints set are developed and along the joint plane clay filling/coating was also recorded. Joints are irregular in pattern. Granites are generally fresh to moderately weathered (WI–WIII). At the foundation level granites are traversed by dolerite dyke (feature D1 marked in geological plan map). Dolerite dykes are fine grained and greenish-black in colour. The width of the dyke is up to 100 cm and strike length is more than 50 m in excavated part of pump house. Dyke is generally sheared and clay gouge was observed. Plagioclase and clinopyroxene (augite / titanaugite) are the main minerals occurring in ophitic to sub-ophitic textures in dolerite dyke. Quartz, epidote and opaques occur as accessories. Amphibole, biotite, sericite occur as alteration products. Dyke is generally highly weathered (WIV) as per the weathering grade. The rock mass is characterized by prominent five number of joint sets, which are continuous and persistent, slightly rough to smooth with unaltered joint walls. Staining has been recorded along the joint surfaces where the joints are tight and where opening is up to 50 mm, soft clay mineral and crushed material filling has been recorded. In general, the rock mass was characterized by dry condition or minor inflow i.e. < 5.0 l/min. Crack/fractures developed due to excavation / blasting were also recorded during geological mapping. Some of the cracks are tight while some are open with size of the opening varying from 1 mm to 5 mm. Hairline cracks developed due to excavation work were also recorded. The prominent joints recorded in the coarse grained granite at the foundation of pump house are given in Table I.

V. Geotechnical Assessment Floor of Pump House

The foundation of the pump house is falling under weathering grade WI - WIV. The grade of the rock mass as evaluated from the UCS and conditions of discontinuities has RMR values are varying from 49 to 63 and fall under fair to good rockmass category (Table II). Randomly 20 samples were selected from the pump house area for the unconfined compressive strength. Tests were conducted at site and specimens were tested at a moisture content close to field conditions. The values of uniaxial compressive strength (UCS) is varies from 132 to 291 MPa. The average value of Uniaxial compressive strength (UCS) is 210 MPa.

A. Safe Bearing Pressure for Foundation Floor

Safe Bearing Pressure is an important factor for the design of foundation for large engineering structures. The Bearing Pressure of the foundation in jointed rock masses can be estimated by Rock Types, Rock Mass Rating (RMR), Uniaxial Compressive Strength (UCS), Point Load Strength, Rock Quality Designations (RQD), Pressure Meter Test and Plate Load Test [10,11]. The Rock type and Rock Mass Rating (RMR) parameters are used to evaluate the Safe Bearing Pressure of the pump house foundation. Average RMR 56.73 of the foundation floor of the pump house was taken for the estimation of Safe Bearing Pressure. The Allowable Bearing Pressure was also estimated as given in the Table III

The Safe Bearing Pressure and Allowable Bearing Pressure calculated from the above two methods viz. by rock characteristic and RMR method are summarized in Table IV for the pump house.

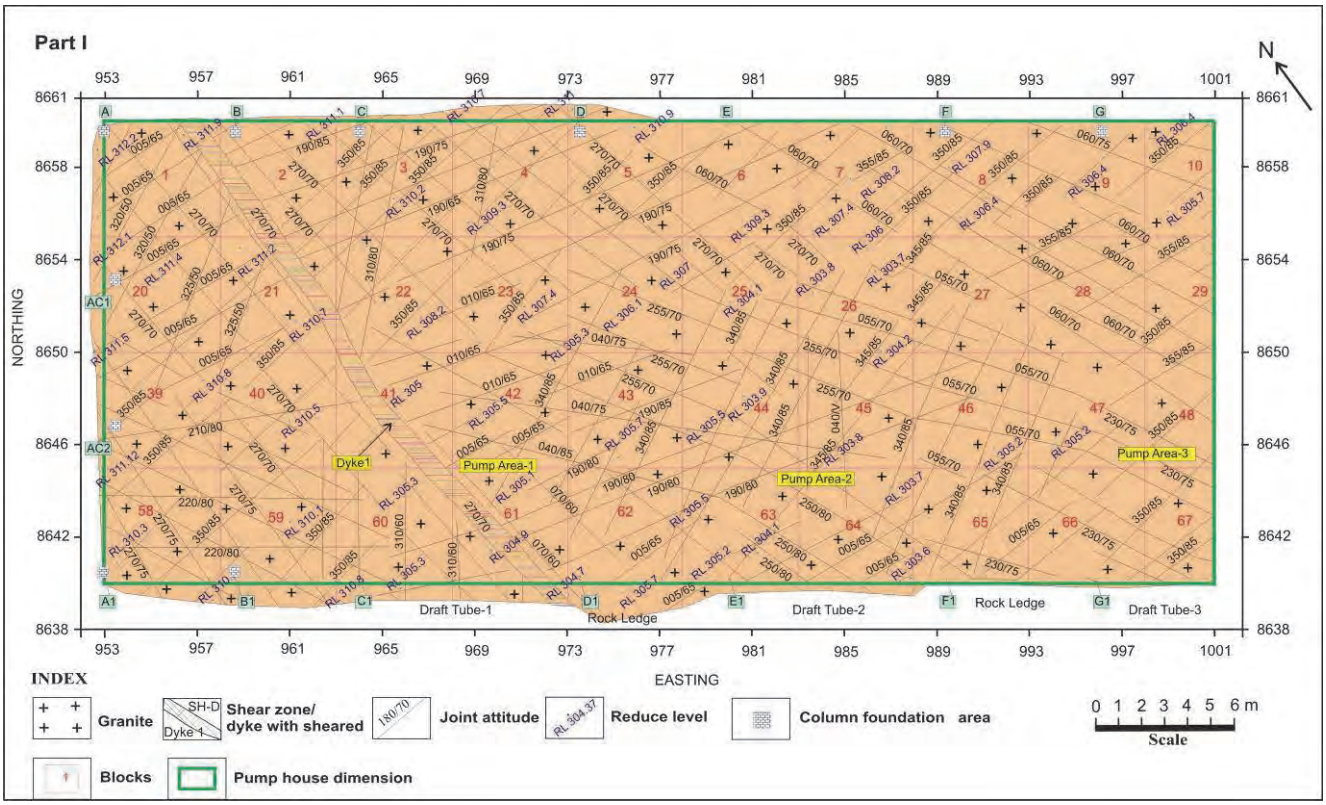

Fig. 2 (part I). Geology map of foundation of pump house of MGKLIS-II

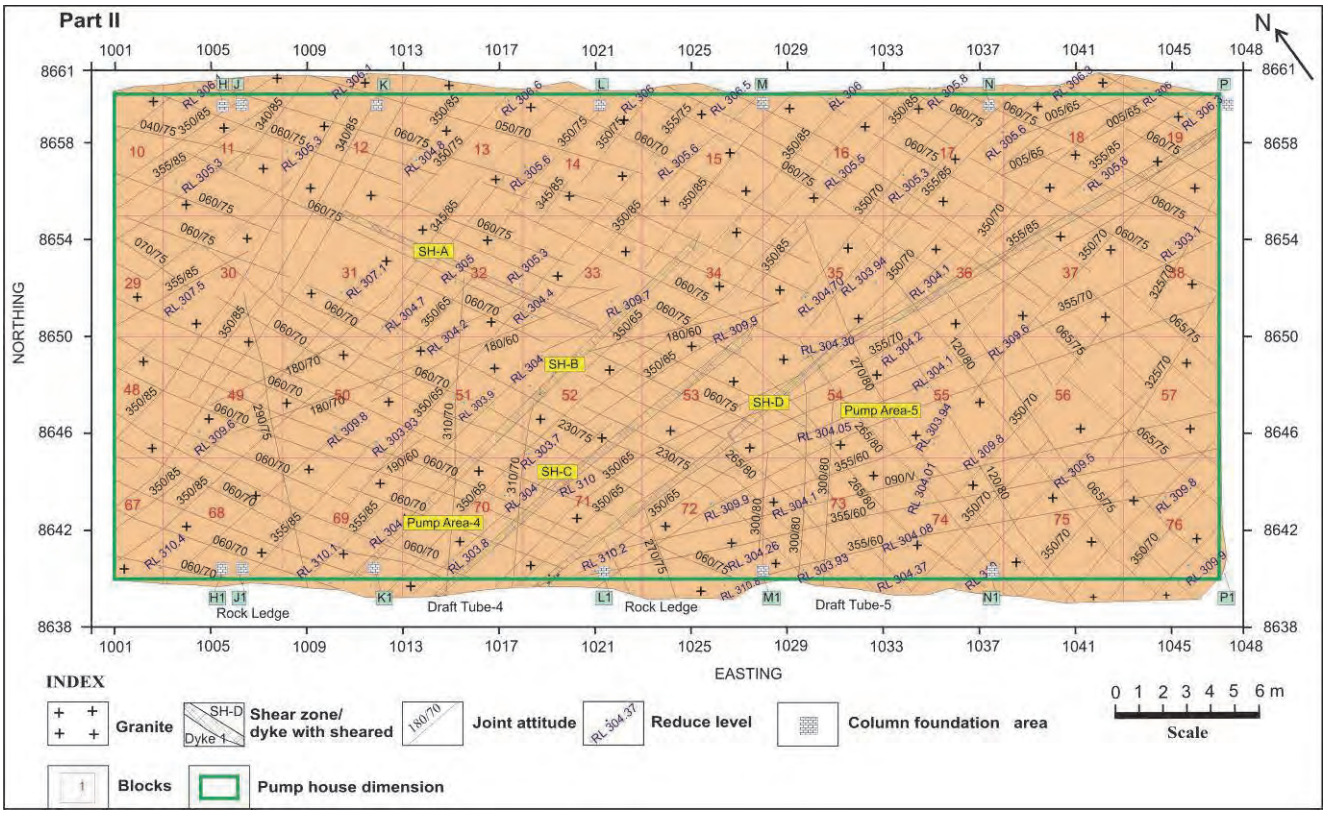

Fig. 2 (part II). Geology map of foundation of pump house of MGKLIS-II

Fig. 3. Pump house area, viewing towards left side i.e. western direction

Fig. 4.Pink granite mapped at the foundation of pump house

TABLE I. PROMINENT JOINTS RECORDED IN COARSE GRAINED GRANITE

Joint set	Dip direction	Dip amount	Spacing (cm)	Persistence (m)	Roughness	Aperture (mm)	Infilling (mm)	Groundwater condition	Remarks
J1	340-355	60-85	10-50	>20	Slightly rough to smooth	Tight to 50	Nil-clay	Damp	Joint plane is stained
J2	040-070	70-75	50-100	>20	Slightly rough	Tight to 2	Nil-clay coated	Damp	Joint plane is stained to fresh
J3	220-270	75-80	30-70	20	Slightly rough	Tight to 1	Nil-clay coated	Damp	Joint plane is stained to fresh
J4	180-220	60-80	50-100	20	Slightly rough	Tight to 2	Nil-clay coated	Damp	Joint plane is stained to fresh
J5	290-325	70-85	70-100	10	Slightly rough	Tight to 2	Nil-clay coated	Damp	Joint plane is stained to fresh
J6	005-010	65	30-50	10	Slightly rough	Tight	Nil	Damp	Joint plane is fresh
J7	120	80	40-60	5	Slightly rough	Tight	Nil	Damp	Joint plane is fresh
J8	090	Vertical	30-80	10	Slightly rough	Tight to 2	Nil	Damp	Joint plane is fresh
J9	040	Vertical	-	10	Slightly rough	Tight to 1	Nil	Damp	Joint plane is fresh
Note: For vertical joints strike direction is given									

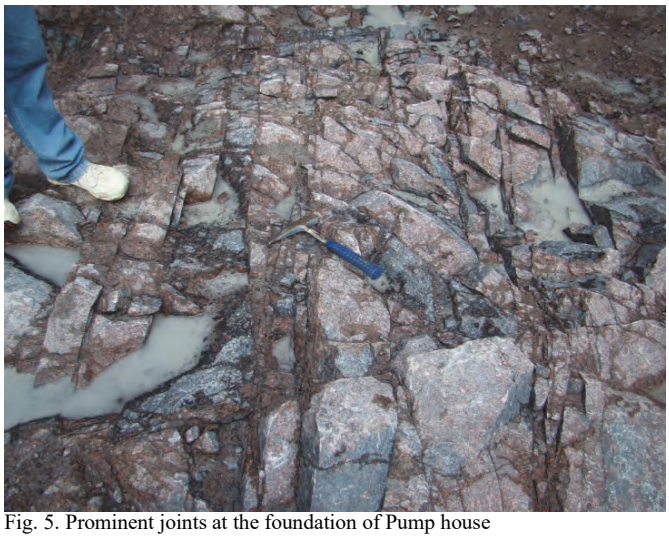

Fig. 5. Prominent joints at the foundation of Pump house

TABLE II.ROCK MASS CLASSIFICATION USING RMR OF THE FOUNDATION OF PUMP HOUSE

Block No.	Rock type	RMR		
		Value	Class	Description
1	Coarse pink granite	52	Class-III	Fair
2	Coarse pink granite	49	Class-III	Fair
3	Coarse pink granite	57	Class-III	Fair
4	Coarse pink granite	57	Class-III	Fair
5	Coarse pink granite	57	Class-III	Fair
6	Coarse pink granite	57	Class-III	Fair
7	Coarse pink granite	57	Class-III	Fair
8	Coarse pink granite	57	Class-III	Fair
9	Coarse pink granite	63	Class-II	Good
10	Coarse pink granite	57	Class-III	Fair
11	Coarse pink granite	63	Class-II	Good
12	Coarse pink granite	61	Class-II	Good
13	Coarse pink granite	61	Class-II	Good
14	Coarse pink granite	61	Class-II	Good
15	Coarse pink granite	52	Class-III	Fair
16	Coarse pink granite	57	Class-III	Fair
17	Coarse pink granite	57	Class-III	Fair
18	Coarse pink granite	52	Class-III	Fair
19	Coarse pink granite	52	Class-III	Fair
20	Coarse pink granite	57	Class-III	Fair
21	Coarse pink granite	49	Class-III	Fair
22	Coarse pink granite	49	Class-III	Fair
23	Coarse pink granite	57	Class-III	Fair
24	Coarse pink granite	63	Class-II	Good
25	Coarse pink granite	63	Class-II	Good
26	Coarse pink granite	57	Class-III	Fair
27	Coarse pink granite	63	Class-II	Good
				(continued)

Block No.	Rock type	RMR		
		Value	Class	Description
28	Coarse pink granite	63	Class-II	Good
29	Coarse pink granite	63	Class-II	Good
30	Coarse pink granite	61	Class-II	Good
31	Coarse pink granite	57	Class-III	Fair
32	Coarse pink granite	52	Class-III	Fair
33	Coarse pink granite	57	Class-III	Fair
34	Coarse pink granite	61	Class-II	Good
35	Coarse pink granite	57	Class-III	Fair
36	Coarse pink granite	52	Class-III	Fair
37	Coarse pink granite	52	Class-III	Fair
38	Coarse pink granite	57	Class-III	Fair
39	Coarse pink granite	61	Class-II	Good
40	Coarse pink granite	57	Class-III	Fair
41	Coarse pink granite	49	Class-III	Fair
42	Coarse pink granite	52	Class-III	Fair
43	Coarse pink granite	61	Class-II	Good
44	Coarse pink granite	57	Class-III	Fair
45	Coarse pink granite	52	Class-III	Fair
46	Coarse pink granite	63	Class-II	Good
47	Coarse pink granite	63	Class-II	Good
48	Coarse pink granite	63	Class-II	Good
49	Coarse pink granite	61	Class-II	Good
50	Coarse pink granite	57	Class-III	Fair
51	Coarse pink granite	52	Class-III	Fair
52	Coarse pink granite	52	Class-III	Fair
53	Coarse pink granite	52	Class-III	Fair
54	Coarse pink granite	52	Class-III	Fair
55	Coarse pink granite	57	Class-III	Fair
56	Coarse pink granite	57	Class-III	Fair
57	Coarse pink granite	57	Class-III	Fair
58	Coarse pink granite	57	Class-III	Fair
59	Coarse pink granite	57	Class-III	Fair
60	Coarse pink granite	57	Class-III	Fair
61	Coarse pink granite	49	Class-III	Fair
62	Coarse pink granite	61	Class-II	Good
63	Coarse pink granite	57	Class-III	Fair
64	Coarse pink granite	57	Class-III	Fair
65	Coarse pink granite	57	Class-III	Fair
66	Coarse pink granite	57	Class-III	Fair
67	Coarse pink granite	57	Class-III	Fair
68	Coarse pink granite	52	Class-III	Fair
69	Coarse pink granite	52	Class-III	Fair
70	Coarse pink granite	52	Class-III	Fair
71	Coarse pink granite	57	Class-III	Fair
72	Coarse pink granite	57	Class-III	Fair

Block No.	Rock type	RMR		
		Value	Class	Description
				(continued)
73	Coarse pink granite	57	Class-III	Fair
74	Coarse pink granite	57	Class-III	Fair
75	Coarse pink granite	61	Class-II	Good
76	Coarse pink granite	57	Class-III	Fair

TABLE III. CALCULATION SAFE BEARING PRESSURE (Q_{NS}) AND ALLOWABLE BEARING PRESSURE (Q_{ALLOW})

Base on rock characteristic	
Rock Type	Coarse grained Granite
Net Safe Bearing Pressure (q_{ns})	1000 t/m^2
Correction factor (for rock mass with continuous joints with aperture up to 5 mm and clay filled)	0.50
Allowable Bearing Pressure (q_{allow})	q_{ns} * correction factor
	1000 * 0.50 t/m^2
	500.0 t/m^2
Based on Rock Mass Rating, (RMR)	
Average RMR	56.73
Classification of rock mass	Class III
Description of rock mass	Fair
Net Safe Bearing Pressure (q_{ns})	**250.5 t/m^2**
Correction factor (for rock mass with continuous joints with aperture up to 5 mm and clay filled)	0.50
Allowable Bearing Pressure (q_{allow})	q_{ns} * correction factor
	250.5 * 0.50
	125.25 t/m^2

TABLE IV: SAFE BEARING PRESSURE AND ALLOWABLE BEARING PRESSURE FOR PUMP HOUSE FOUNDATION

Sl. No.	Method	Safe Bearing Pressure, t/m^2	Allowable Bearing Pressure, t/m^2
01	Base on rock characteristic	1000.0	500.0
02	Based on Rock Mass Rating	250.5	125.25

It is recommended to adopt the Allowable Bearing Pressure value obtained from RMR, that is 125.25 t/m^2 for the design of foundation on this stratum for pump house.

VI. TREATMENT AND RECOMMENDATIONS FOR FOUNDATION FLOOR

The rocks exposed at the foundation grade of the pump house are jointed pink granite interspersed with sheared dolerite dyke. Shear zones having the varying thickness are mapped which are having differential mechanical behavior due to varying physical properties leading to differential settlement. In order to overcome the problem of differential settlement shear zones treatment plan as given in Table V was suggested.

Based on the structural features mapped, consolidation grouting up to 6.0 m depth using primary, secondary and tertiary holes was recommended so that the entire floor area functions as a single rock mass. The pressure and proportion of grout mixes to be used for injection shall be based on water pressure test and the results of trial grouting operation. Special care to be taken to consolidate rock mass along the

TABLE V. TREATMENT PLAN FOR SHEAR ZONES AND DYKE WITH SHEAR AT THE FOUNDATION LEVEL OF PUMP HOUSE

Shear zone/ dyke	Thickness	Recommended excavation depth	Treatment plan
D1	Upto1.0m	1.5 m	Dolerite dyke is crushed and sheared, should be excavated up to 1.5 m depth by mechanical breakers and backfilled with concrete (M≥25) up to the foundation level after systematic cleaning, washing and jetting to make the rock mass monolithic. The concrete should be allowed to cure for 10-12 days before rock bolting. The length of rock bolt will be varying from 4 to 5 m as per the site condition.
SH-C, SH-D	20.00 to 30.00 cm	0.60 m	Shear zones area should be excavated up to 0.60 m depth by mechanical breakers and backfilled with concrete (M≥25) up to the foundation level.
SH-B	Up to 15.00 cm	0.50 m	Shear zones area should be excavated up to 0.50 m depth by mechanical breakers and backfilled with concrete (M≥25) up to the foundation level.
SH-A	Up to 10.00 cm	0.30 m	Shear zone having clay gauge should be excavated up to 0.30 m depth by mechanical breakers and backfilled with concrete (M≥25) up to the foundation level.

weak zones/shear zones. The holes which absorb water greater than 3 lugeons, shall invariable be grouted. (1 Lugeon is water loss of 1 lit/m/min at a pressure of 10 kg/sq cm) [12,13]. The grout holes shall be laid out in line with secondary holes staggered with reference to the primary holes on the adjacent lines. Spacing between holes initially shall be 6 m centre to centre. After completing the grouting through these primary holes intermediate holes will be taken in between primary holes. The number of holes for further grouting (tertiary grouting – which will be determined based on results of drilling and grouting of intermediate holes) will be such that a continuous consolidated area of satisfactory water tightness is achieved.

It was recommended to complete blasting before taking up grouting operation. Ifblasting after grouting is unavoidable, through testing and regrouting will be essential after blasting. Plain Cement Concrete (PCC) of M15 grade lining up to the design foundation level (i.e. RL+305.40 m) was recommended before 300 mm thick raft foundation. On the floor detached rock-masses were laying in scattered form, which were recommended to remove before any protective measure is applied.

VII. CONCLUSIONS

Base on detailed engineering geological investigation, it was observed that area in the floor of pump house site is characterized by coarse grained, hard and jointed pink granite traversed by sheared dolerite dyke. The floor region was fresh to moderately weathered (W-I to W-III) but prominent vertical/inclined joints were present. The grade of the rock mass as evaluated from the condition of discontinuities has RMR values varying from 49 to 63 and falls under fair to good rock mass. Allowable Bearing Pressure value obtained from RMR is 125.25 t/m^2 for the design of foundation of pump house. Treatment plan i.e. grouting etc. for the foundation of pump house is discussed in this paper to overcome the problem of differential settlement and to make floor monolith. The rock mass was quite competent and accepted for the first pour of concrete.

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