Engineering geological and geotechnical assessment of floor of Control Building of Nuclear Reactors-7&8 of Rajasthan Atomic Power Project, Rawatbhata, India

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***Abstract*—To verify whether in-situ conditions have been realistically estimated during investigation and to furnish the permanent data set for the interpretation of geological conditions, foundation floor mapping of important structure like control building of nuclear power plant is essential. At Rawatbhata, adjacent to existing Rajasthan Atomic Power Project (RAPP) units 1 to 6, two units of 700 MWe each Pressurized Heavy Water Reactor (PHWR) type Nuclear Reactors are being constructed. Engineering geological mapping on 1:100 scale was carried out for Control Building of NB-7&8. Geotechnical assessment of the foundation of control building was done on the basis of detailed engineering geological mapping, geological drill holes logging data, rock mass permeability values, geophysical profiling and laboratory test results. Based on the field observations and evidences, it was found that the entire floor area consists of fine to medium grained, compact greyish white quartzitic sandstone and yellowish brown ferruginous sandstone. The floor region was seen to contain certain iron stained and weathered zone. No evidence of faulting or shearing was observed on the surface of the floor area.**

Keywords—nuclear reactor; control building; engineering geological; raft foundation; discontinuity; Rawatbhata

I. INTRODUCTION

The under construction Rajasthan Atomic Power Project (RAPP) consists of two units 7 and 8 of 700 MWe each Pressurised Heavy Water Reactor (PHWR) type Nuclear Reactors, adjacent to the existing RAPS-1 to 6 units. In the plant layout, RB 7 and 8 are located at 108 meter center to center. RAPP-7 & 8 site is located on the right bank of the Chambal River, about 670 m from Reactor Building 5&6, in Kherli block under Tehsil of Rawatbhata in Chittorgarh District of Rajasthan. The site is situated about 64 km from Kota. The approximate latitude and longitude of the site are: N24°52’ and E75°37’ respectively. The site is on a gently sloping terrain and rocks are available within a few centimeters from the surface.

In order to evaluate the design basis foundation parameters for Control Building (CB) of Nuclear Buildings (NB-7&8) engineering geological mapping on 1:100 scale was carried out. A separate Control Building, common for both units, has been provided on the construction east of Nuclear Buildings to house Main Control Rooms (MCR) & Control Equipment Rooms (CER), main steam lines, for both units. In addition, the Control Building acts as a main entrance to the station complex and is located appropriately. The building is a framed structure with a basement/raft at EL 92.00 m and floors at EL 100.00 m, EL106.00 m, EL 111.00 m, EL 116.00 and roof at EL 124.00 m. All the discontinuities in the rock mass of CB with the zone of influence of the foundation and walls were identified and mapped. The primary purpose of the mapping was to provide a permanent record of conditions during the excavation. Mapping data was used to assess the requirement of any ground improvement by adopting suitable engineering measures.

II. METHODOLOGY

Grids of 1 m x1 m were prepared for mapping of the floor, which was decided based on the mapping accuracy and resolution required for such investigations. The vertical and horizontal scale of one grid of construction drawing was 20 m and as the area was mapped in 1:100 scale, the mapping grids (1m x 1m) were marked within one construction grid e.g. 15, 15+1, 15+2,…..15+19, 16 for northing and z, z+1, z+2,….z+19, z2 for easting. Basic nomenclature for northing and easting was adopted from the constructing drawing. All the lithological and structural features were observed and mapped using Total Station surveying equipment. Detailed examination of rock types in each grid were carried out. Fracture fillings that have taken place in the study site were examined and recorded. The attitude of structural elements in the rocks, fracture and joint patterns present in the floor were determined during mapping. ISRM [1] classification for weathered mass was used to characterize the rock mass into different weathering grades (Table I). The assessment of RMR [2] for sandstone rock masses was done based on the characteristics of bedding planes and jointing pattern, drill cores and laboratory test data.

TABLE I. DESCRIPTION OF WEATHERING GRADE [2]

Term	Description	Grade
Fresh	No visible sign of rock material weathering; perhaps slight discolouration on major discontinuity surfaces.	I
Slightly weathered	Discolouration indicates weathering of rock material and discontinuity surfaces. All the rock material may be discoloured by weathering and may be somewhat weaker externally than in its fresh condition.	II
Moderately weathered	Less than half of the rock material is decomposed and / or disintegrated to a soil. Fresh or discoloured rock is present either as a continuous framework or as core stones.	III
Highly weathered	More than half of the rock material is decomposed and / or disintegrated to a soil. Fresh or discoloured rock is present either as a discontinuous framework or as core stones.	IV
Completely weathered	All rock material is decomposed and/or disintegrated to soil. The original mass structure is largely intact.	V
Residual soil	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported.	VI

III. GEOLOGY OF THE PROJECT AREA

The project area is occupied by very hard and competent, fine to medium grained sandstone of Kaimur group of the Upper Vindhyan Supergroup of Proterozoic age (940 ± 40 million years) [3]. Stratigraphically within the 5 km radius area of RAPP-7 & 8, a thick sequence of reddish shale overlain by buff to reddish brown sandstone trending in NW-SE direction and dipping at 4° to 5° towards SW has been reported [4]. Usually, beds are horizontal to sub-horizontal and general slope of the area is towards west. The prevalence of ripple marks in the strata is indicative of shallow water origin; the red sandstones of the Kaimur indicate semiarid and continental conditions. The Vindhyan supergroup is unmetamorphosed and except in the lower part it does not show much effect of tectonism [5].

In this area fine to medium grained, compact ferruginous sandstone and quartzitic sandstones are exposed after excavation. Drill holes data of Control Building (ABH-85, ABH-86, ABH-87, ABH-88, ABH-90, ABH-91) confirmed that control building area is covered by thin soil cover (up to 0.5 m) except in Nallah portion of Control building, where the thickness of overburden upto 2 m has been recorded. In general CB area from RL 90.850 m to RL 88.740 m, fine to medium, fresh, thinly to thickly bedded yellowish-brown ferruginous sandstone and grayish-white quartzitic sandstone with layers of glauconite (up to 1.5 cm) have been recorded during the field large scale (1:100) mapping and logging of drill hole CBH-19, which was drilled from RL 90.05 m (EL 398.35) in control building area.

In the excavated areas of Control Building two major rock types were mapped i.e., grayish-white quartzitic sandstones and yellowish-brown ferruginous sandstones. In grayish-white quartzitic sandstones, quartz content is 98% including crystalline siliceous matrix, chlorite and calcite contents, 2% with accessory cryptocrystalline silica, zircon and apatite and all minerals are very fresh. In ferruginous sandstone spotted appearance of zircon / apatite was recorded during mapping. In ferruginous sandstone quartz contents is 88-89%, iron oxide up to13%, calcite contents 1% mainly as matrix with accessory zircon and apatite and all minerals are fresh. Glauconite coating/layer (up to 1.5 cm) was recorded along the bedding planes of grayish-white quartzitic sandstones.

The Control Building area was characterized by joints and fractures. The most prominent joint sets are the bedding joints dipping at 2-6 degree in WSW direction. The spacing of bedding joints are varying from 1 cm to 70 cm. Along horizontal sheared open master bedding joints (HSMBJ), rock mass crushed material up to 20 cm was recorded. On the basis of persistence and nature/condition of vertical joints recorded at exposed foundation levels of various structural buildings during previous and present mapping they are classified as Master vertical Joint (MVJ) showing strike length more than 100 m with varying thickness of filling and opening. Major vertical Joint (MV_J) showing strike length more than 20 m but less than 100 m with minor filling and opening and Vertical Joint (VJ) for joints having less than 20 m strike length, discontinuous and tight. Master vertical Joints ((MVJ) trending in N260° has been mapped on the foundation surface of CB and this joint was also mapped in RB-7 and RAB-7 [6]. All vertical joints show maximum effects within 1 m zone which are characterized by closely spaced fractures and are slightly weathered (W-II). No displacement has been seen along these joints. These all joints which are having an affected zone of maximum 1 m are considered as the relatively weak zones/moderately fractured zone with no shearing effects. Ripple marks were also mapped in grayish-white quartzitic at foundation level. No structure, other than joints, fractures, shears and ripple marks, was recorded in this area. The general description of lithology, mapped at the foundation level of CB is given in Table II.

IV. ENGINEERING GEOLOGICAL & GEOTECHNICAL ASSESSMENTS OF FOUNDATIONS

A. Geological Mapping

Foundation floor mapping is essential for all important engineering structures to provide permanent data set for geological interpretations. Excavations made during construction provide opportunities for obtaining additional geological and geotechnical data. Geological mapping of floor was done after the excavation of design foundation level and before the placement of concrete or backfill.

Photographic records of foundation mapping and treatment was also carried out.

Control Building will be resting as per design on a raft of 2.0 m thick at about 10 m below the grade level for functional requirement. On the basis of surface geological mapping and drill core log data of ABH-85, ABH-86, ABH-87, ABH-88, ABH-90, ABH-91 and CBH-19 the maximum portion of CB site has been excavated up to the foundation level because rock mass was competent and acceptable for foundation, but in some areas excavation has been done beyond the foundation level because of the layering of quartzitic sandstone and blasting. The total excavated area i.e. 6331.080 m^2 of CB foundation was mapped. Based on the field observations and evidences, it was found that entire floor area consists of fine to medium grained, compact grayish-white quartzitic sandstones and yellowish-brown ferruginous sandstone (Fig. 1). No evidences of faulting or shearing were observed on the surface of floor area. However, there were some isolated patches of weathered / altered rock and small fractures in the rock. The exposed foundation surface is coated with glauconite. The structural features observed during the mapping exercise indicated the need for consolidation grouting so that the entire floor are function as single rock mass.

The floor rock mass was classified to fresh rock as per the weathering grade (W-I). In the southern portion of the CB floor, set of master vertical joints trending between N260° and N290° direction with a strike length more than 100 m was mapped. This feature shown the maximum effects within 1 m, which was characterized by closely spaced fractures and slightly weathered (W-II). Joints are intersected by vertical minor (up to 1m) joint sets at an acute angle. Because of the presence of these criss-cross joints the floor area here is disintegrated. Filling of 1-5 cm was recorded along this feature may be due to brittle nature of rock mass. No displacement has been observed along this feature. Along this feature the rock mass is relatively weak and moderately fractured in the isolated patches on the surface was observed and no shearing effects was observed on the surface. Joint is tight and crushed rock masses are also well cemented. No cavity or soft material was observed along this joint. Iron staining was recorded along this vertical joint. Along these vertical joints consolidation grouting is required to make the foundation monolithic.

Ripple marks, primary structures produced by the water action at the time of deposition of rock, were also mapped at the foundation level of CB mainly in the northern part. Apart from the above mentioned structural features, scattered presence of small to medium (1-3 m) and shallow fractures & cracks due to blasting / excavation was observed in the floor area. These cracks are generally tight but opening up to 2 mm has been mapped in some areas. Loose and detached rock fragments lying along the vertical cuts on the southwestern portion of the floor area has to be removed before the final treatment. The prominent sets of joints recorded in the fine-medium grained compact grayish-white quartzitic sandstones and yellowish-brown ferruginous sandstone at the foundation of CB are given in Table III.

TABLE II. DESCRIPTION OF LITHOLOGY MAPPED AT THE FOUNDATION OF CONTROL BUILDING

Super Group	Group	Lithology	Mineral Assemblage	Type locality
ō	Kaimur Group Proterozoic age (940 ± 40 million years)	Grayish-white quartzitic sandstones	Quartz content is 98% including crystalline siliceous matrix, chlorite and calcite contents 2% with accessory cryptocrystalline silica, zircon and apatite and all minerals are very fresh	South portion of CB
		Yellowish-brown ferruginous sandstones	Quartz content is 86% to 89%, chlorite contents 1%, iron oxide 10% to 13% with accessory zircon and apatite and all minerals are very fresh	North portion of CB
Mineral Assemblage based on Sohams Foundation Engineering Pvt. Ltd., Mumbai Report [7]				

B Laboratory Testing and Geotechnical Assessment

Selected rock core samples from the boreholes drilled in the control building area were tested for physico-mechanical properties of rocks in the laboratory of Sohams Foundation Engineering Pvt. Ltd [7]. The intact rock properties at the foundation levels given in Table 4 were evaluated considering the necessity in the overall context of the design requirements of the foundations. The values for the dry density of ferruginous/quartzitic sandstones are 2.40 to 2.60 g/cc belongs to moderate to high density category. The water absorption values are quite low. Uniaxial compressive strength and deformability characteristic i.e. Modulus of Elasticity and Poisson's ratio were determined.

According to strength classification criterion for rock substance (ISRM, 1981), the rocks are of very high strength. The Modulus of Elasticity values are ranging from 28.00 GPa to 44.70 GPa and fall under very good rock mass category. Poisson's ratio is 0.30 which is high. Quartzitic sandstone shows higher cohesion. Friction angle is varying from 45° to 63° possible due to variation in roughness of the fractured surface. The rock mass properties at the foundation levels, combining geological data, drilling data and geophysical are given in Table 5. Lugeon values are very low indicating that conditions of rock mass discontinuities are very tight. Maximum part of the floor area of the CB is falling under weathering grade 1 (W-I). The grade of the rock mass as evaluated from the UCS, drill holes cores, core recoveries, RQD and conditions of discontinuities, has RMR values are varying from 65 to 70 and fall under the good rock.

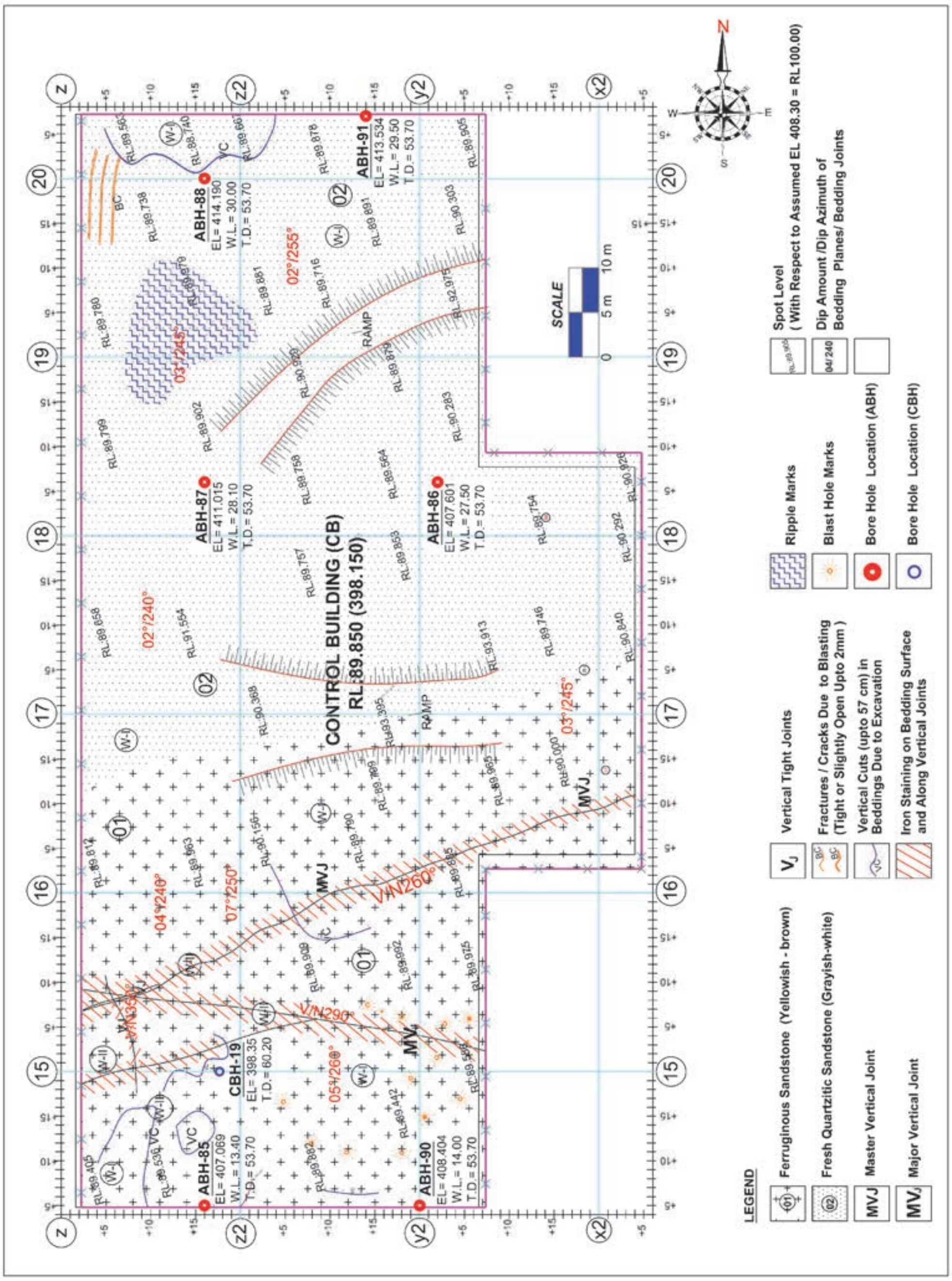

Fig. 1. Geological plan map of Control building of RAPP unit 7&8

TABLE III. PROMINENT JOINT SETS RECORDED IN SANDSTONES AT THE FOUNDATION OF CONTROL BUILDING AREA

Joint Order	Dip Amount/ Azimuth/	Spacing (cm)	Strike length (m)	Roughness	Aperture (mm)	Infilling	GW	Remarks
I	V/N260	-	>100	Rough	2–10	Crushed rock fragments and iron oxide coating	Dry	Master Vertical Joint (MVJ)
II	V/N290	-	>45	Rough	1–5	Crushed rock fragments and iron oxide coating	Dry	Major Vertical Joint (MV$_J$)
III	V/N350	-	Up to 15	Rough	< 2	Crushed rock fragments and iron oxide coating	Dry	Vertical Joint (VJ)
IV	2–6 /N240–260	15–90	>100	Slightly rough	None	Glauconite layer up to 1 cm & coating	Dry	HTMBJ
V	2–9 /N240–265	5–15	5–25	Slightly	None	None	Dry	Traces of bedding planes
V- Vertical joint, HTMBJ- Horizontal tight master bedding joint, GW-Ground water								

TABLE IV. PHYSICO-MECHNICAL PROPERTIES OF INTACT ROCK AT FOUNDATION LEVELS OF CONTROL BUILDING

Rock Type	Dry Density (g/cc)	Water Absorption (%)	Specific Gravity (g/cc)	Uniaxial Compressive Strength (MPa)	Modulus of Elasticity (GPa)	Poisson's Ratio	Shear Strength Parameter	
							Cohesion (MPa)	Friction Angle (Degree)
Ferruginous Sandstones	2.40–2.55	0.30–2.00	2.49–2.90	100.20–112.80	28.00–43.00	0.30	0.95–3.10	45–62
Quartzitic Sandstones	2.45–2.60	0.24–2.15	2.59–2.98	103.20–116.60	28.02–43.70	0.30	0.95–3.10	45–63

TABLE V. PROPERTIES OF ROCK MASS AT THE FOUNDATION LEVELS OF CONTROL BUILDING

Rock Type	Major Joints	Weathering Grade	Core Recovery (%)	RQD (%)	Vp (km/sec)	Water Level (m)	Permeability (lugeon)	RMR		Level of Acceptable Foundation (m)
								Values (Range)	Class	
Ferruginous Sandstones	HTMBJ, MVJ,	W-I to W-II	100	75–95	3.50–4.20	9.10–12.5	0.06–0.09	65 - 70	Good Rock	El +398.150 m (RL 89.850) for control building
Quartzitic Sandstones	HTMBJ, MVJ,	W-I to W-II	100	75–100	3.85–4.40	9.10–12.5	0.05–0.09	65–70	Good Rock	El +398.150 m (RL 89.850) for control building

V. OBSERVATIONS AND CONCLUSIONS

Based on the field observations and evidences, it was established that area in the floor of CB site is characterized by grayish-white quartzitic sandstones (containing quartz including crystalline siliceous matrix, chlorite and calcite) and yellowish-brown ferruginous sandstone (containing quartz and calcite as matrix with accessory zircon and apatite). Depth persistence and lateral prevalence of bed rock was established. The floor region is unweathered but prominent vertical joints are present. The floor is falling in W-I weathering grade, and drilling data confirming the same beyond the foundation. The test results and field observations indicate that the rock mass was quite competent and acceptable for the foundation of the CB. It was recommended that only fractured and loose rock material from all along the Vertical Joints should be removed by mechanical breaker and back filled with concrete (>M20, grade having either normal density or heavy density) up to the foundation level to make the foundation monolithic. The structural features observed during the mapping exercise indicated that consolidation grouting up to 9-10 m should be done in the foundation of CB using primary, secondary and tertiary holes so that the entire floor area function as single rock mass. Regarding the final depth, spacing and pattern of grout holes, trials for the establishment of depth and spacing was recommended at the initial stages of the work. Vertical holes for the grouting were recommended because beds are horizontal to sub-horizontal lying. It was recommended to complete blasting before taking up grouting operation. If blasting after grouting is unavoidable, through testing and regrouting is essential after blasting. As in the foundation, compact, massive and hard sandstones were lying, so chance of upheaving was negligible.

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