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Geotechnical Investigations for Construction of Onsite Emergency Support Centre of Atomic Power Project Units - A Case Study

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ABSTRACT

To evaluate the design basis foundation parameters for the Onsite Emergency Support Centre (OESC) building being constructed for Atomic Power Project Units 1 to 4 in Gujarat State, engineering geological and geotechnical investigations were carried out. From engineering geological mapping and geotechnical data collected from the field and laboratory investigations, rock mass classification and characterization of the OESC building foundation were done. All the discontinuities in the rock mass with the zone of influence of the foundation have been identified and mapped. The foundation was examined on a grid-to-grid basis and the size of the grid was 1 m x 1 m. All the lithological and structural features were observed and mapped using Total Station surveying equipment. The assessment of RMR for basaltic rock masses, based on the rock joints and their nature, drill holes and laboratory test data has been done while the weathering grade was defined based on International Society for Rock Mechanics (ISRM) method. Entire floor area including the ramp area consists of thick flows of porphyritic and amygdaloidal basalts. No evidence of faulting or shearing was observed along the flow contacts and vertical joints on the surface of the floor area. The floor rock mass was classified into fresh and slightly weathered (W-I to W-II) zones as per the weathering grade classification. Safe bearing pressure was estimated from RMR. Engineering geological and geotechnical data was used for the recommendation of foundation level of OESC building.

Keywords: Onsite emergency support centre; Deccan volcanic province; Foundation floor mapping; Safe bearing pressure

1. INTRODUCTION

Among the three major types of projects producing electricity, i.e., thermal, hydro and nuclear, nuclear projects are better because of providing cleaner energy. Despite of this fact, nuclear projects are very limited (contributing only 10% of global electricity generation) because of being more expensive in terms of constructional, safety and maintenance due to associated severe risks. For example, if any accident happens in the thermal power projects, it affects the limited area around the incident place only. Failure of the dam and any water body constructed for hydroelectric projects affect the area up to far away from the incident place, but mostly it affects in one direction, i.e., downstream and it can be controlled within a limited timeframe. On the other hand side, in case of any accident in the nuclear power site, it affects quickly in all the directions in a radius of many kilometres due to the release of radiation into the atmosphere and sometimes it is beyond the control due to the restriction of human interface, and this will leave imprints of long-lasting damages.

In recent years the Fukushima nuclear disaster was a nuclear accident in 2011 at the Fukushima Daiichi Nuclear Power Plant in Japan. The proximate cause of the disaster was the major earthquake, which triggered a powerful tsunami of 15-metre high waves. Due to this tsunami sea water entered the plant and disabled the power supply and cooling of three Fukushima Daiichi reactors, causing a nuclear accident on 11 March 2011. All three cores largely melted in the first three days. The accident was rated of level 7 on the International Nuclear and Radiological Event Scale. This was the second most severe nuclear accident since the Chernobyl disaster of Ukraine in 1986. During Chernobyl more than 3.5 lakh people were evacuated, and during Fukushima, more than 1.5 lakh people were evacuated. Evacuation of such a large number of people on short notice is very challenging, especially in a country like India where the population density is so high.

Considering the accident at Fukushima Nuclear Power Plants (FNPP), Atomic Energy Regulatory Board (AERB) of India mandated the requirement for establishing the On-Site Emergency Support Centre (OESC) at all NPP sites in the country. This facility will have the capability to withstand earthquakes and floods of magnitudes larger than their respective design basis for the NPP. The building will be designed with requisite shielding for the protected stay of response personnel for extended duration. So that any nuclear and radiological emergency situations can be managed without undue radiological risks to the plant personnel. At present, in India, 22 reactors are operating at 7 locations. The OESC building is of RCC framed structure with shear walls having a basement, ground floor, first floor and second floor. Construction of the first OESC structure in India is started for the Atomic Power Project Units 1 to 4 of Gujarat State.

The OESC building in Gujarat is being constructed 30 km downstream of Ukai dam on Tapi River. The site is in the Southern region of the Gujarat State in Tapi District. The OESC building is being constructed at the southern portion of the existing 2 x 220 MWe operational units and of 2 x 700 MWe commissioning units of Atomic Power Station. Before pouring the concrete, geological mapping of the entire foundation area of the OESC structure was carried out. Detailed investigations which include engineering geological mapping on a 1:100 scale, geological logging of drill holes, in-situ permeability test and laboratory testing on core samples were also carried out in accordance with International Atomic Energy Agency (IAEA) establishes standards for the site evaluation, (Series No. NS-G-3.6, 2004; SSG-35, 2015 and SSR-1, 2019). The primary purpose of the mapping is to provide a permanent record of conditions during the excavation. Mapping data is being used to assess the requirement of any ground improvement before pouring concrete. Exploratory boreholes and confirmatory boreholes were drilled to obtain sub-surface information. Core samples were tested for physico-mechanical properties of rocks in the Laboratory. In-situ permeability tests were conducted in the boreholes. Safe bearing pressure was estimated from RMR. This permanent foundation record will assist in making a better interpretation of post-construction foundation instrumentation data (EM-1110-1-1804, 2001).

2. METHODOLOGY USED FOR OESC FOUNDATION MAPPING

Grid method was used for foundation engineering geological mapping. Grids were prepared on the properly cleaned excavated surface and size of the grid was 1 m x 1 m, which was decided based on the mapping accuracy and resolution required for such investigations in consultation with designer. Mapping was carried out on a 1:100 scale, so that closely spaced geological discontinuities can be mapped. Detailed examination of rock types in each grid was carried out which includes mineralogical composition, texture, classification and nomenclature and degree/grade of weathering. Fracture fillings that have taken place in the study site were examined and recorded. The attitude and structure of the rocks, fractures and joint patterns present in the floor were determined for mapping. ISRM (1981), classification for weathered rock mass was used to characterize the rock mass into different weathering grades. In-situ permeability tests were conducted as per IS 5529 Part-2 (2006). Rock mass exposed at excavated foundation surface was categorized based on the structural characteristics of discontinuities (joints, flow contacts etc.) and the strength of rocks, into the different classes on a grid basis using Rock Mass Rating (RMR) classification system (Bieniawski, 1989; IS: 13365 Part 1, 2010). Rock mass rating (RMR), known as Geomechanics Classification proposed by Bieniawski (1976, 1989) has been found to be quite useful for the nuclear structures foundation mapping (Naithani et al. 2016, 2017).

3. GEOLOGY OF THE PROJECT AREA

The project area is occupied by thick flows of porphyritic amygdaloidal basalts of Deccan Volcanic Province" (DVP), also known as 'Deccan Traps'. The Deccan Volcanic Province covering the Deccan Plateau is one of the most remarkable continental fold basalt provinces of the world. The word 'trap' has come to mean fine-grained, dark-coloured rock, which is usually basaltic in composition. The 'traps' are called 'flood basalts' because of their vast expanse, and as 'plateau basalt' as they often stand out as tablelands. Today, the Deccan Volcanic Province, extended an area of more than 5,00,000 km^2; though, original estimation of the coverage of the lava pile, prior to erosion and possible down-throw on the western side into the Arabian Sea are of the order of one to one and a half million square km. The greatest thickness of the Deccan traps lava pile is more than 1.5 km in the western portions of India and it decreases, a few tens of meters near exposed boundaries of the province. The Deccan extrusions commenced around 68 Ma and continued till 62 Ma (West, 1981; Geological Survey of India, 2008), but radiometric dating has confirmed the late Cretaceous to early Tertiary age for Deccan traps with the bulk of the data clustering around 60–65 Ma (Duncan and Pyle, 1988a, 1988b). However, palaeomagnetic investigations indicate rapid eruption of these lavas coinciding with Cretaceous-Tertiary (K-T) boundary and are being postulated to have been the major cause for Mass-extinction of KT Boundary (Courtillot et al., 1986, 1988). Engineering geological conditions in the Deccan trap were summarized by Jain et al. (2011, 2014) and Naithani et al. (2011).

At excavated foundation floor level of the OESC building, basaltic rocks of Deccan Traps mainly amygdaloidal basalt, and porphyritic basalt of fresh (W-I) and slightly weathered conditions (W-II) are present (Figs. 1 and 2). The design foundation floor level was 88.8 m i.e., about 10.0 m below the existing ground level (EGL), whereas excavated levels varied between 87.20 m and 87.50 m. Ten drill holes (BH-01 to BH-06 and RH-01 to RH-04) were drilled at OESC building site during the investigation stage. A review of these drill holes data and physical observations of excavated walls and foundation reveals that from surface up to 2-3 m depth, rock mass is composed of residual soil, then 6 to 7 m rock mass is completely weathered, then slightly weathered to fresh rock mass consisting of a variety of basaltic rocks are present (Fig. 3 & 4). Thin sections petrographic study of the samples of this location also reveals that slightly weathered and fresh rock mass consists mainly of compact, amygdaloidal and porphyritic basalts in and around the foundation area. The typical mineral composition of fine-grained compact black basalt reported is plagioclase-45%, pyroxene-35%, iron oxides-10%, glass-5% and secondary chlorite-5%. The typical mineral composition of fresh porphyritic basalt is plagioclase-45%, pyroxene-30%, iron oxides-10%, glass-10% and secondary chlorite-5%. Typical mineral composition of fresh amygdaloidal basalt is plagioclase-40%, pyroxene-30%, basaltic glass-10%, iron oxides-10%, and secondary chlorite with little calcite/zeolite/quartz-10%. The general description of lithology mapped at the excavated level of OESC is given in Table-1.

Altered/weathered filling of 5 to 40 cm thickness was recorded at flow contacts above the excavated foundation levels. The OESC building foundation area is made up of 30-140 cm thick horizontal basaltic layers. The most prominent joint sets are the flow contacts and a few discontinuous i.e., random vertical joints. The spacing of flow contacts was varying from 10 cm to 140 cm i.e., closely to widely spaced. At the foundation level the exposed surface is characterized by waviness.

Table 1 - Description of lithology mapped at the foundation level

Province	Sub-province	Lithology	Mineral assemblage	Type locality
Deccan Volcanic Province	Saurashtra Plateau	Porphyritic basalt	Plagioclase-45%, pyroxene-30%, iron oxides-10%, glass-10% and secondary chlorite-5%	At and the below excavated level of OESC
		Amygdaloidal basalt	Plagioclase-40%, pyroxene-30%, basaltic glass-10%, iron oxides-10%, and secondary chlorite with little calcite/ zeolite/quartz-10%.	At and below the excavated level of OESC

Fig. 1 - Amygdaloidal basalt exposed at foundation level

Fig. 2 - Porphyritic basalt exposed at foundation level

Fig. 3 - Weathering profile stratum-I, up to 7m depth completely weathered rock mass, Stratum-II moderately weathered to fresh basaltic rocks

Fig. 4 - Collection of engineering geological data of nearly horizontal flow sequence of basaltic rocks

4. ENGINEERING GEOLOGICAL ASSESSMENT

Foundation floor mapping is essential for important structures to provide permanent data sets for geological interpretations. For very important structures like the OESC, the supporting foundation strata must be well studied and documented to provide a data set for credible geologic interpretations. A shallow foundation covers such a type of foundation in which load transfer is through direct bearing pressure of bearing strata. 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 settlements or perhaps sudden failure.

The OESC building is an L-shaped three-storied RC structure. The plan dimensions of the building are approx. 60 m long x 30.0 m wide. OESC will be resting as per the design on a 2.0 m thick raft foundation at an average of about 10.0 m below the existing ground level i.e., 98.0 m, for the functional requirement. Excavation was done up to the average level of EL 87.20 m using mechanical excavators and rock breakers. The over excavated area will be filled with PCC of grade M-15 to achieve the foundation level of EL 88.80 m. Excavated foundation levels were below the designed foundation level because at the design foundation level weathered rock mass was exposed. The average excavated level was about 87.2 m because of the rough undulating nature of the top of the exposed basaltic flow.

Based on the field observations and evidence, it was found that the entire floor area consists of thick flows of amygdaloidal, and porphyritic basalts of Deccan Volcanic Province" (DVP), also known as "Deccan traps" (Fig. 5). It was difficult to demarcate at the site the contacts of different types of flows. No evidence of faulting or shearing were observed along the flow contacts on the surface of the floor area. The rock exhibits massive structures with few tight discontinuous vertical joints (Table 2). The floor rock mass was classified as fresh to slightly weathered rock as per the weathering grade (W-I to W-II). Fractures & cracks due to blasting/excavation were not observed in the floor area. Vertical cuts at the excavated floor between flow units were recorded up to 90 cm because of slightly (4-7°) dipping nature of flows and undulating characteristics of the flow top.

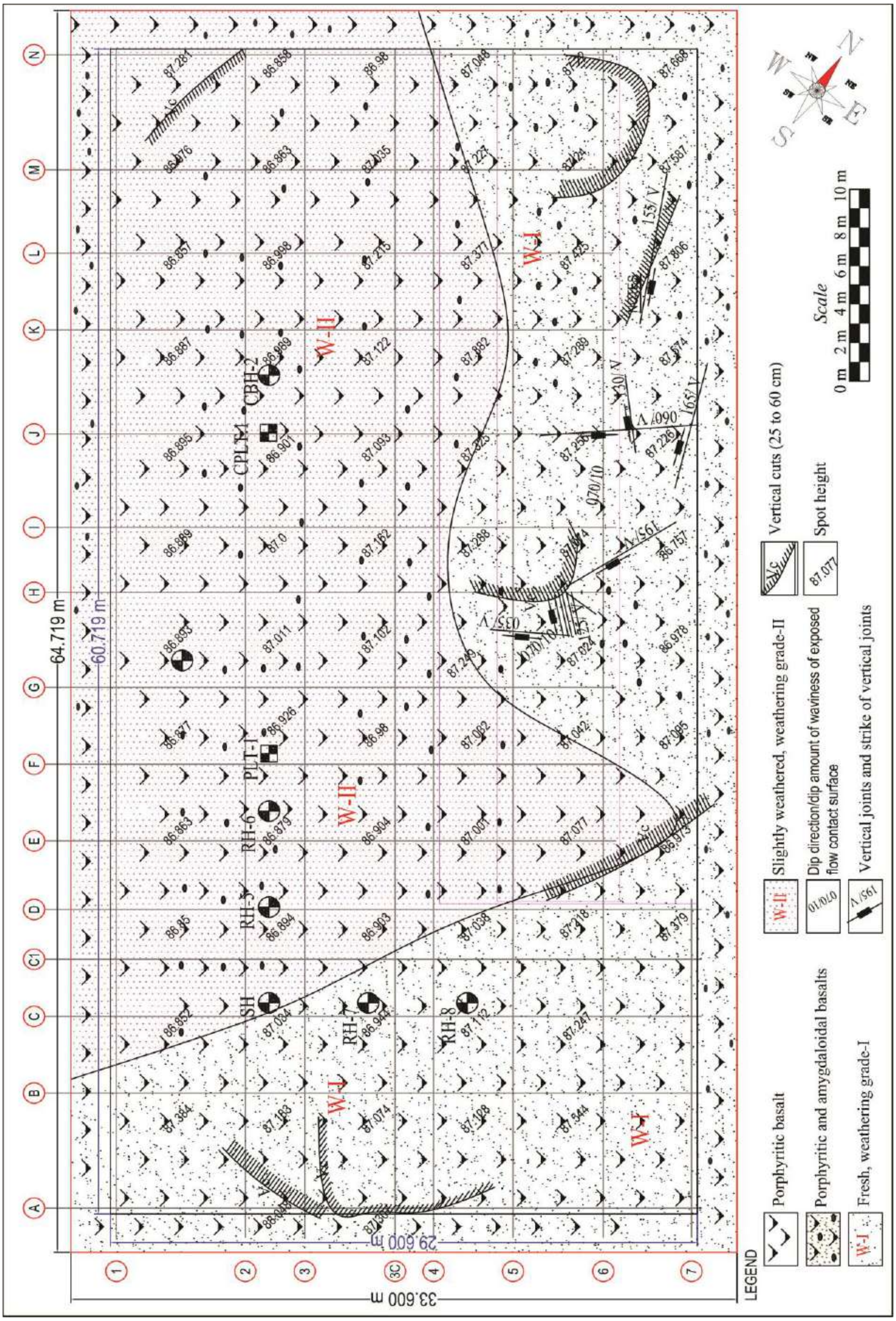

Fig. 5 - Engineering geological plan map

Table 2 - Prominent joint sets recorded in basaltic flow at the foundation level

Joint Order	Dip direction/ dip amount	Spacing (cm)	Strike length (m)	Roughness	Aperture (mm)	Infilling	Ground water condition	Remarks
I	Horizontal	30-140	>50m	rough, undulation	2-400	weathered or altered rock material	dry	layer of lava flows
II	155-165° /vertical	-	>5m	rough, undulation	tight	nil	dry	random joint
III	125-130° / vertical	40	<5m	rough, undulation	tight	nil	dry	random joint
IV	195°/ vertical	-	<5m	rough, undulation	tight	nil	dry	random joint

5. GEOTECHNICAL ASSESSMENT

Based on detailed engineering geological mapping, geological drill holes logging data, rock mass permeability values and laboratory test results, a geotechnical assessment of the foundations was done. The intact rock properties at/near the foundation levels are given in Table 3. The rock core samples from BH-1 to BH-6, RH-1 to RH-8 were tested for unconfined compressive strength. The average values of unconfined compressive strength (UCS) in soaked condition at/near excavated foundation levels vary from 30.72 to 89.79 MPa. Its specific gravity ranges from 2.78 to 2.85. The grade of the rock mass as evaluated from the UCS, drill holes cores, core recoveries, RQD and conditions of discontinuities, has RMR values vary from 53 to 67, and falls under the Fair to Good rock mass category (Fig. 6, Table 4a & b). During confirmatory subsoil investigations, the safe bearing capacity (SBC) of the foundation strata was evaluated based on Rock Mass Rating (IS 12070, 2010)). As per RMR, the allowable bearing pressures (q_{allow}) are varying from 228.60 to 336.00 t/m^2. As per the design, the safe bearing capacity of the founding strata shall be ensured as 200 t/m^2. After reaching at the design foundation level, confirmatory tests were conducted and tests results are summarized in Table 5. Based on details investigations, average excavated level i.e. EL 87.20 m was accepted for the foundation of OESC structure and pouring of concrete.

Table 3 - Physico-mechanical properties of intact rock at/near foundation level

Rock type		Dry density (g/cc)	Specific gravity	Porosity (%)	Water absorption (%)	Uniaxial compressive strength (MPa)	Point load strength index (MPa)	Modulus of elasticity (GPa)	Poisson's ratio
Porphyritic and amygdaloidal basalts	Min	2.47	2.78	1.54	0.30	30.72	2.12	6.74	0.13
	Max	2.72	2.85	15.07	5.67	89.79	5.72	68.5	0.23
	Ave	2.63	2.81	6.44	2.49	55.94	3.84	36.67	0.19
	Note: Dry density and specific gravity values are different because these were tested for different rock samples.								

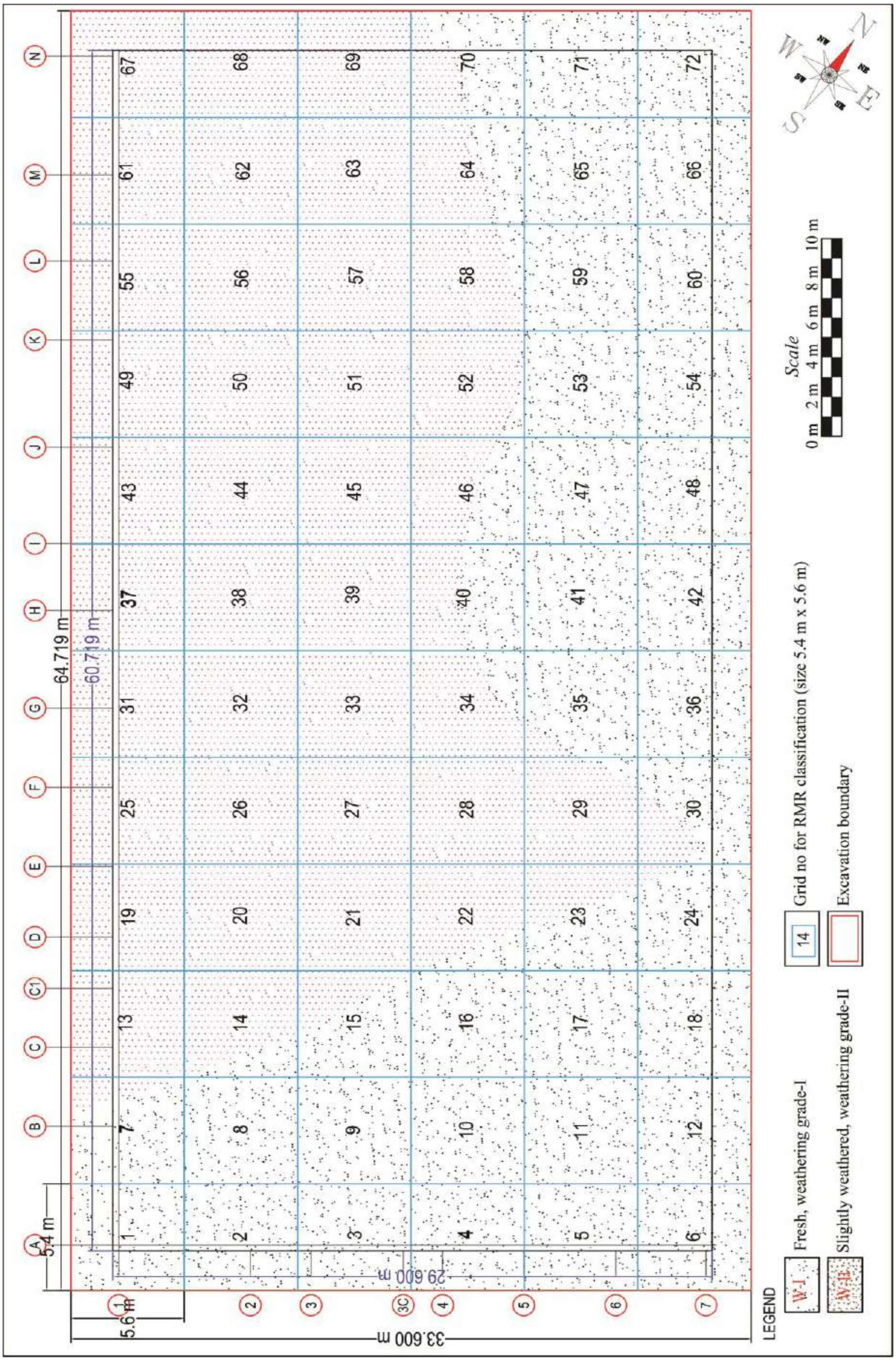

Fig. 6 - Plan of map in a grid of 5.4 x 5.6 m of the foundation for rock mass classification

Table 4a - Rock mass rating classification of OESC building foundation

Grid No.	UCS		RQD		Spacing		Condition of discontinuity									
							Persistence		Aperture		Roughness		Infilling		Weathering	
	Value (MPa)	R	Value (%)	R	Value (cm)	R	Value (m)	R	Value (mm)	R	type	R	type	R	Grade	R
1 to 12	85-90	7	90-100	20	21-60	10	>30	0	0.1-1	4	SR	3	SF<5	2	W-I	6
13 to 14	30-49	4	75-90	17	10-20	8	>30	0	0.1-1	4	SR	3	SF<5	2	W-II	5
15 to 18	85-90	7	90-100	20	21-60	10	>30	0	0.1-1	4	SR	3	SF<5	2	W-I	6
19 to 23	30-49	4	75-90	17	10-20	8	>30	0	0.1-1	4	SR	3	SF<5	2	W-II	5
24	55-85	7	90-100	20	21-60	10	>30	0	0.1-1	4	SR	3	SF<5	2	W-I	6
25 to 29	30-49	4	75-90	17	10-20	8	>30	0	0.1-1	4	SR	3	SF<5	2	W-II	5
30	55-85	7	90-100	20	21-60	10	>30	0	0.1-1	4	SR	3	SF<5	2	W-I	6
31 to 34	30-49	4	75-90	17	10-20	8	>30	0	0.1-1	4	SR	3	SF<5	2	W-II	5
35 to 36	55-85	7	90-100	20	21-60	10	>30	0	0.1-1	4	SR	3	SF<5	2	W-I	6
37 to 39	30-49	4	75-90	17	10-20	8	>30	0	0.1-1	4	SR	3	SF<5	2	W-II	5
40	55-85	7	90-100	20	21-60	10	>30	0	0.1-1	4	SR	3	SF<5	2	W-I	6
41 to 42	55-85	7	75-90	17	21-60	10	>30	0	0.1-1	4	SR	3	SF<5	2	W-I	6
43 to 45	30-49	4	75-90	17	10-20	8	>30	0	0.1-1	4	SR	3	SF<5	2	W-II	5
46	55-85	7	90-100	20	21-60	10	>30	0	0.1-1	4	SR	3	SF<5	2	W-I	6
47 to 48	55-85	7	75-90	17	21-60	10	>30	0	0.1-1	4	SR	3	SF<5	2	W-I	6
49 to 52	30-49	4	75-90	17	10-20	8	>30	0	0.1-1	4	SR	3	SF<5	2	W-II	5
53 to 54	55-85	7	90-100	20	21-60	10	>30	0	0.1-1	4	SR	3	SF<5	2	W-I	6
55 to 58	30-49	4	75-90	17	10-20	8	>30	0	0.1-1	4	SR	3	SF<5	2	W-II	5
59 to 60	55-85	7	90-100	20	21-60	10	>30	0	0.1-1	4	SR	3	SF<5	2	W-I	6
61 to 64	30-49	4	75-90	17	10-20	8	>30	0	0.1-1	4	SR	3	SF<5	2	W-II	5
65 to 66	55-85	7	90-100	20	21-60	10	>30	0	0.1-1	4	SR	3	SF<5	2	W-I	6
67 to 69	30-49	4	75-90	17	10-20	8	>30	0	0.1-1	4	SR	3	SF<5	2	W-II	5
70 to 72	55-85	7	90-100	20	21-60	10	>30	0	0.1-1	4	SR	3	SF<5	2	W-I	6
R= rating, SR=slightly rough, SF=soft filling, VF=very favourable																

Table 4b - Rock mass rating classification of OESC building foundation

Grid No.	Ground water		Orientation		RMR
	Condition	R	Value	R	Value
1 to 12	Dry	15	VF	0	67
13 to 14	Damp	10	VF	0	53
15 to 18	Dry	15	VF	0	67
19 to 23	Damp	10	VF	0	53
24	Dry	15	VF	0	67
25 to 29	Damp	10	VF	0	53
30	Dry	15	VF	0	67
31 to 34	Damp	10	VF	0	53
35 to 36	Dry	15	VF	0	67
37 to 39	Damp	10	VF	0	53
40	Dry	15	VF	0	67
41 to 42	Dry	15	VF	0	64
43 to 45	Damp	10	VF	0	53
46	Dry	15	VF	0	67
47 to 48	Dry	15	VF	0	64
49 to 52	Damp	10	VF	0	53
53 to 54	Dry	15	VF	0	67
55 to 58	Damp	10	VF	0	53
59 to 60	Dry	15	VF	0	67
61 to 64	Damp	10	VF	0	53
65 to 66	Dry	15	VF	0	67
67 to 69	Damp	10	VF	0	53
70 to 72	Dry	15	VF	0	67

6. CONCLUSIONS

During the review of the safety of Indian Nuclear Power Plants (NPPs) against external events of natural origin, the Atomic Energy Regulatory Board (AERB) Committee recommended the creation of an onsite facility at each Nuclear Power Plant site for handling emergencies. This facility will have adequate radiation shielding and will be seismically qualified. This type of structure will be constructed at seven locations of all operational nuclear power plant sites across the country. After successful construction of this structure at nuclear power plant site of Gujarat State it can be replicated in other places.

At foundation level (EL 96.69m), porphyritic and amygdaloidal basalts of weathering grades I-II was observed. According to core log data, core recovery and RQD was observed to be 78-100% and 57-100% respectively. The permeability of the rock mass was determined to be zero as the joints were tight. RMR of the rock mass was obtained as 53-57. It exhibited P-wave and S-wave velocities as 4258-5437 m/s and 2222-2895 m/s respectively.

After systematic and confirmatory stages investigations of foundation, depth persistence and lateral prevalence of bedrock were established. The foundation was found suitable to locate an OESC building, meeting all the safety norms, as prescribed in national and regulatory standards. Above excavated levels thin to thick altered/weathered material fillings between flow contacts were recorded which were removed up to certain depth and backfilled with concrete during excavation. The floor region was fresh to slightly weathered and no significant persistent vertical joints were recorded during geological mapping. Semidetached/fractured rock mass which were present in scattered form on the foundation was removed using mechanical breakers before PCC. Over excavated areas were filled with PCC of grade M-15 to achieve the design foundation level of EL 88.80 m. Systematic cleaning, washing, and jetting was done at the foundation area before the first pour of concrete.

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