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Electrical Resistivity Logging for Assessing Nature of Foundation at Kaiga Nuclear Power Plant

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ABSTRACT
The electrical resistivity logging technique is required for assessing the nature of foundation of large power projects. The parameters determined by electrical logging serve as essential input for the design of foundation. The construction of units 3 and 4 of Kaiga Nuclear Power Plant (KNPP) was founded on granitic gneiss of lower and middle Dharwar group overlain by laterites and humus soil. Assessment on nature of the sub-surface formation was required for the design of the foundation on critical structures like turbo-generator and reactor buildings of KNPP. This paper deals with potential of electrical resistivity logging in assessing the nature of the foundation strata at KNPP and its utility of providing parameters for deciding design of the foundation of the structure.

INTRODUCTION

The investigation of the subsurface conditions at a nuclear power plant site is important at all stages of the site evaluation process. This provides information or basic data for deciding the nature and suitability of the subsurface materials. (IAEA Safety Guide, 2004). Adequate geotechnical investigations are needed to establish competency of the foundation medium for the installation of structures under all static and seismic loading conditions (Bishnoi and Basu, 2005). The preliminary investigations provide the information necessary for understanding the subsurface conditions and for identifying potential earthquakes and other geologic hazards (Chung-Chun fu et al, 1980). Detailed investigations provide geological (subsurface soil structure and site geology) and engineering information that serve as an input parameter for the safe design of nuclear power plant structures, systems and components.

Borehole geophysical logging techniques are being increasingly used at large power projects to assess the geological risk. Geophysical logs measure signals that are affected by contrasts in the physical properties of earth materials. Electrical properties of rock are sensitive to factors such as the nature and amount of pore saturant, temperature, and pressure, surface conduction, and micro structural properties such as porosity and tortuosity. Borehole logging methods are important because they, i) sample a larger volume than the core; ii) provide the physical and chemical property of the subsurface in the absence of core recovery; iii) measurements are continuous, throughout the length of the drill hole, and not discrete (Keys, 1990) iv) the methods are non-destructive, rapid and reliable, (Benson, 1991);. v) the extent of geologic knowledge within given horizons, both vertically and laterally, particularly in relation to the resultant effect on the properties of the formation. This paper describes the utility of electrical resistivity logging in assessing the nature of foundation strata and providing the subsurface resistivity variation for deciding the foundation strata of KNPP, Karnataka.

Geology around KNPP

Kaiga Nuclear Power Plant is situated in Kaiga village, Karwar Taluka, Uttar Kannad District, Karnataka and about 13 Km upstream of Khadra dam on the left bank of River Kali. The power generating capacity of the plant is to be increased by constructing of two units 3 and 4, adjacent to units 1 and 2. The project, after completion would generate 220 MWe with steam from Pressure Heavy Water Reactor.

Geologically, the area is covered with an overburden comprising top humus soil, laterites, clay/sand pebbles followed by moderately jointed granitic gneiss. Granite and granitic gneiss of lower and middle Dharwar group constitute the host rock. The granitic gneiss is essentially made up of quartz, feldspar and biotite mica. The groundwater level fluctuates between 0.5 m to 5.0 m from the natural ground level (Technical report: 3758, 2001).

METHODOLOGY

Electrical Resistivity Logging

Electrical Resistivity logs are important component of geophysical logging. In many situations, they are one of the few logs run and thus are a principal source of geologic and hydrogelogcial data. The electric log gives two electrical parameters of the geological formations traversed by the bore hole, viz, the naturally occurring spontaneous potential, which usually is designated as SP, and the resistivity. Resistivity logging is generally used to identify lithology and correlate stratigraphy. Quantitatively, resistivity data can be used to calculate water quality, hydraulic conductivity and porosity. Electric logs include Self Potential (SP), single point resistance, normal resistivity and lateral logs. Resistivity probes collect multiple measurements of formation resistivity by current flow between electrodes or between an electrode and ground. Thus, the resistivity logging with different configurations of electrical arrays can determine the resistivity of subsurface formation and identify the nature and quality of subsurface geological strata (Kamble, 2009).

Single point resistance which follows the Ohms law is based on the electrical resistance of the earth. Single-point resistance log measures resistance between a single electrode placed in a borehole and another electrode at the ground surface. Resistance logs are used primarily for lithologic determination, correlation and identification of fractures and washout zones (Benson, 1991; Keys, 1990). Multiple electrode logs like short-and long-normal, and lateral provide better resolution of resistivity and associated properties of individual strata within the subsurface than what can be achieved with the single-point array. The 16″ (short-normal) and the 64″ (long normal) are records of apparent resistivity of the formations adjacent to an electrically conductive fluid filled borehole. The 18′8″ lateral log provides an estimation of the true formation resistivity (Keys, 1990). Calibration of electric logs is carried out by attaching known resistances to the electrodes in the laboratory.

Instrumentation

The electrical resistivity logging was undertaken using Terrameter SAS 300 along with the SAS LOG 200 logging system manufactured by M/s ABEM, Sweden. The equipment consists of a 200 m cable along with a logging probe for measuring the self potential, short normal, log normal and lateral resistivity. The electric probe was calibrated using a standard resistance kit before carrying out the studies.

The portable Well Logging equipment, model 450-E, manufactured by SIE, Australia was used for conducting single point resistance logging. The logging unit consists of logging probes and the output fed to a recorder through a signal processor and a winch with a single conductor armored cable. A logging speed indicator is provided to maintain constant logging speed while recording. The recording unit has two channels with two different colour leak proof ink system having micro cellular tips for continuous recording.

Field Studies

Electrical resistivity logging was carried out in eight Nx - size boreholes drilled at locations where different structures of the atomic power project were expected to come up. For detecting suspicious faults or fracture zones, boreholes should be extended to 50 m for tall buildings or heavy structures (Boominathan, 2004). Resistivity logging was carried out at every half-meter interval in boreholes drilled up to 50 m. and the resulting values plotted. Fig.1 shows the layout of KNPP along with the location of boreholes. In the present study, resistivity logs were obtained using Single Point Resistance, Short Normal (16″), Long Normal (64″), Lateral (18′), Self Potential (SP) and fluid resistivity probes using ABEM SAS 300 and SIE well logging equipments. The results of electrical resistivity logging of four boreholes (BH-79, BH-81, BH-106 and BH-109) drilled at locations proposed for the critical structures like turbo generators and reactor buildings are presented.

RESULTS AND DISCUSSIONS

The results of electrical resistivity logging were interpreted both quantitatively and qualitatively. The single point resistance and the short normal (16″) logs were used to demarcate the different bed

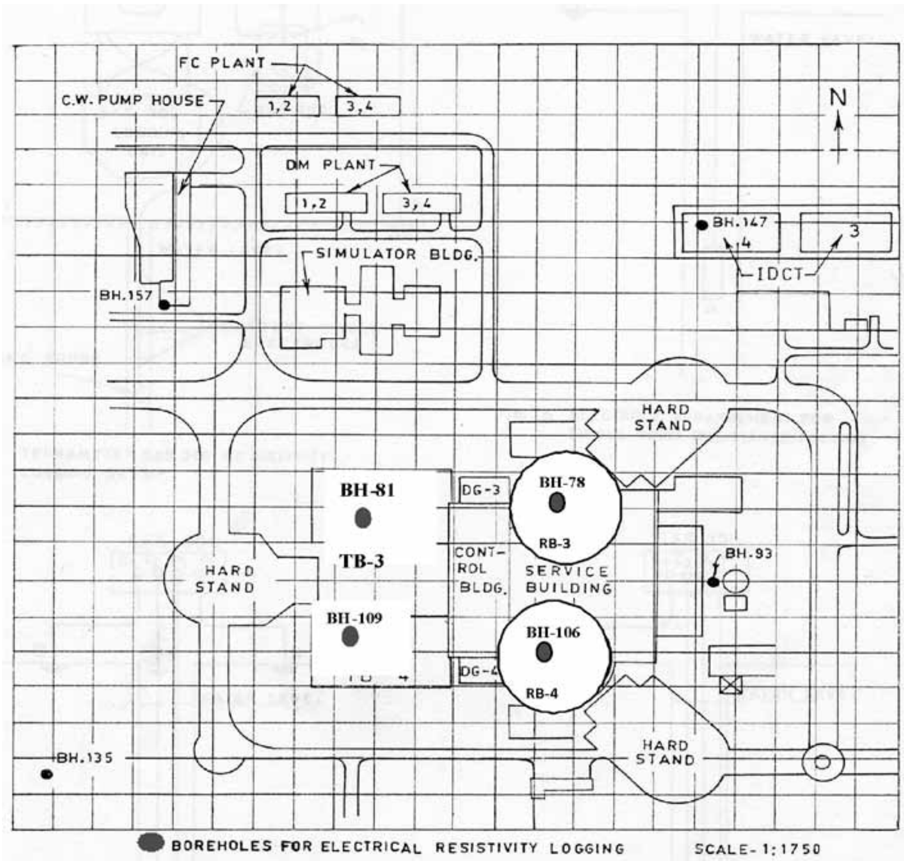

Figure 1. Layout Plan of Kaiga Atomic Power Project Units 3&4 showing location of boreholes for Electrical Resistivity Logging

boundaries. Self Potential (SP) is used in geophysical well logging to locate porous and nonporous beds/ zones and the correlation between wells. Changes in formation water salinity that might occur at large-scale unconformities appear as sudden offsets in the SP base line. The long normal (64″) logs were used for quantitative interpretation of apparent resistivity and were corrected for formation thickness and effects of adjacent formations wherever required. The effects of borehole diameter, invasion diameter, mud resistivity were not considered as all the boreholes were of Nx size and no drilling mud was used for drilling and the formation contained fresh water. Lateral resistivity logs were used for qualitative interpretation together with other resistivity logs (Brown, 1981).

The studies indicated that, in general, the resistivity of the rock varied from 300 Ωm to 7000 Ωm. The overburden resistivity varies from 80 Ωm to 400 Ωm. The zones identified from the resistivity values corroborate well with the geological logs of the borehole. The results of four representative logs in the Reactor building (RB) and Turbine (TB) structure sites are tabulated and shown in Figs. 2-5. The results tabulated in the Table-I to Table-IV show the comparison between the resistivity values interpreted from electrical resistivity logging and the geological log of the respective boreholes supplied by Kaverner Corporation India Ltd.

The electrical resistivity log values for Bore-Hole No 78 drilled at Reactor Building (RB_3) site, shown in Table-I and Fig.2, range from 300-1200 Ωm corresponding to the depths of 19.0-55.0m. This resistivity variation corroborated with the highly to moderately fractured granitic gneiss as obtained from geological log.

Table-II and Fig 3, show the interpreted electrical resistivity values for Borehole No. 81 drilled at Turbo-Generator (TB_3) site. High resistivity values in the range of 4000-6500 Ωm at 13.0-23.0m indicate a fairly compact rock with intermittent fracture zones having resistivity of 2700-5450 Ωm. The geological logs show the presence of a fractured rock along the entire logged depth.

The interpreted electrical resistivity values of

Table - 1: Electrical Resistivity Logging Of Bore Hole No78

Zone Below GL (m)	Geological log of Boreholes Supplied by KCIL		Interpreted Electrical Resistivity Logs	
	Lithology	Structural condition	Resistivity range (Ωm)	Nature of formation
19.0-30.0	Yellowish brown granitic gneiss	Shattered	300-460	Highly fractured rock
30.0-35.0	Reddish brown granitic Gneiss	Highly fractured, vertical joints	300-400	Highly fractured rock
35.0-47.0	Greenish brown granitic gneiss	Shattered	400-950	Moderately fractured rock
47.0-49.0	Granitic gneiss	Shattered	700-800	Moderately fractured rock
49.0-55.0	Greenish granitic gneiss	Shattered	800-1200	Moderately fractured rock

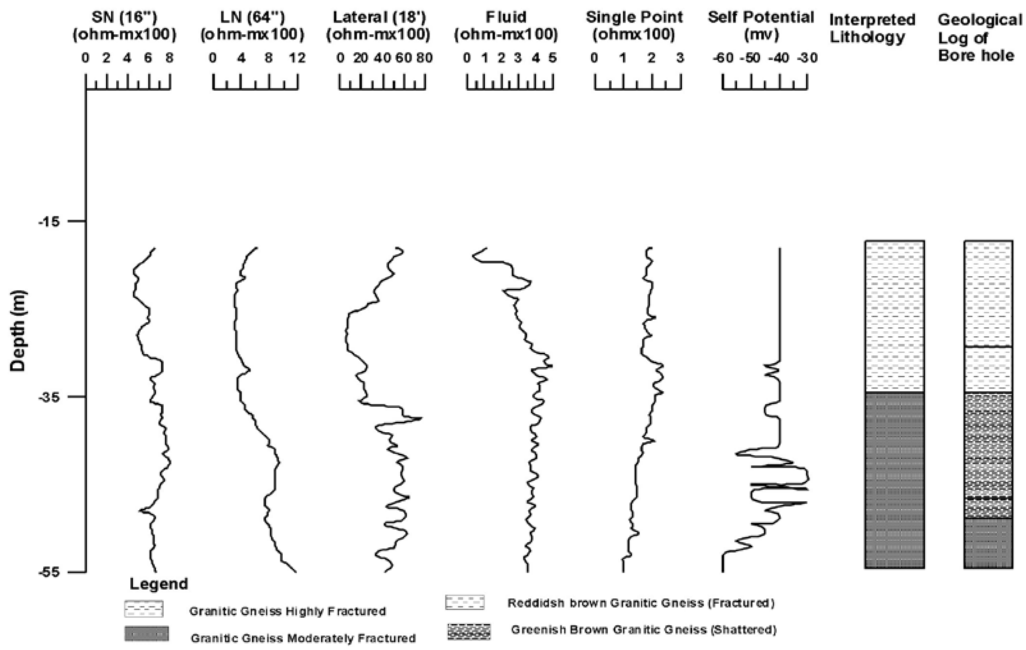

Figure 2. Electrical Resistivity Log at BH-78 (RB-3). KNPP

Table - 2. Electrical Resistivity Logging Of Bore Hole No. 81

Zone Below GL (m)	Geological log of Boreholes Supplied by KCIL		Interpreted Electrical Resistivity Logs	
	Lithology	Structural condition	Resistivity range (Ωm)	Nature of formation
13.0-23.0	Pale grey coarse grained granitic gneiss	A Few fractured zones in between	4000-6500	Fairly sound rock
23.0-30.0	Pale grey granitic gneiss	Fractured to highly fractured	2800-5450	Slightly fractured rock
30.0-32.5	Grey altered granitic gneiss	Highly fractured	2700-3000	Moderately fractured rock
32.0-50.0	Grey granitic gneiss	Fractured	2000-4500	Moderately sound rock

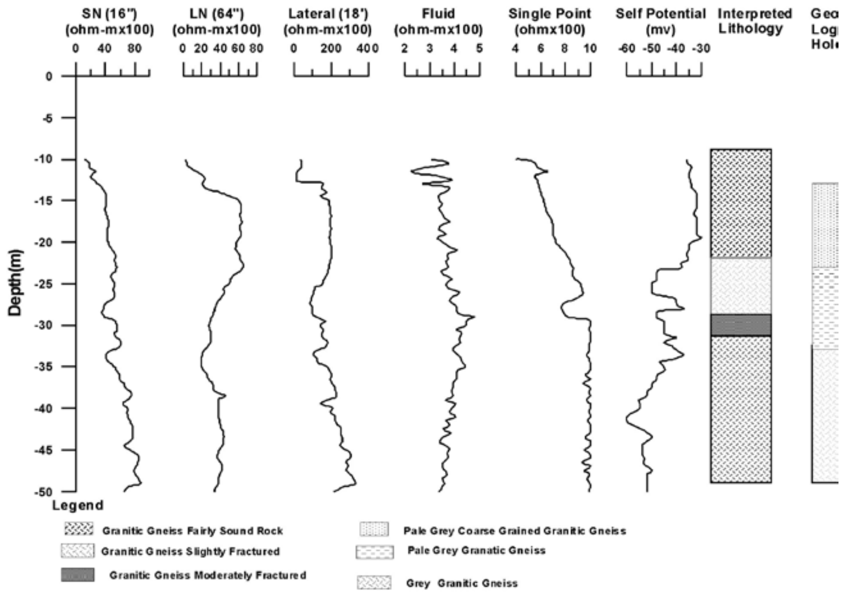

Figure 3. Electrical Resistivity Log at BH-81 (TB-3). KNPP

Table - 3: Electrical Resistivity Logging Of Bore Hole No. 106

Zone Below GL (m)	Geological log of Boreholes Supplied by KCIL		Interpreted Electrical Resistivity Logs	
	Lithology	Structural condition	Resistivity range (Ωm)	Nature of formation
18.0-34.0	Greenish altered granite	Shattered	450-1500	Highly fractured rock
34.0-43.0	Greenish grey granitic gneiss	Highly fractured and shattered	1380-3800	Moderately fractured rock
43.0-49.0	Greenish grey granitic gneiss	Shattered	380-1580	Highly fractured Rock
49.0-55.0	Greenish grey granitic gneiss	Shattered	1860-7050	Fairly sound rock

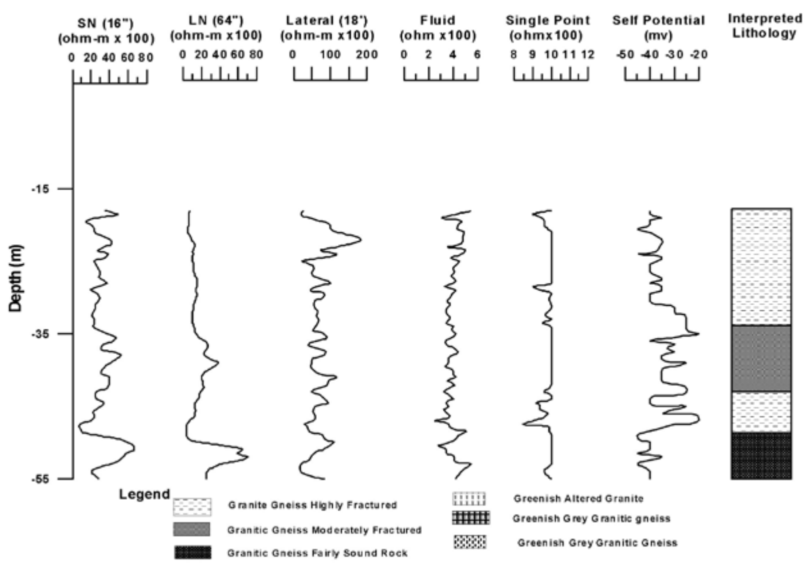

Figure 4. Electrical Resistivity Log at BH-106 (RB-3). KNPP

Table - 4: Electrical Resistivity Logging Of Bore Hole No. 109

Zone Below GL (m)	Geological log of Boreholes Supplied by KCIL		Interpreted Electrical Resistivity Logs	
	Lithology	Structural condition	Resistivity range (Ωm)	Nature of formation
11.5-19.0	Pink brown altered coarse granitic gneiss	Shattered and highly fractured	550-1050	Highly Fractured rock
19.0-27.5	Pink-grey altered granitic gneiss	Slightly fractured to Highly fractured	600-1400	Moderately fractured Rock
27.5-42.5	do	Highly Fractured and Shattered	450-800	Highly fractured rock
42.5-52.5	Pink greenish grey granitic gneiss	Shattered a few thin zones with no fractures observed in between	750-2450	Moderately fractured rock

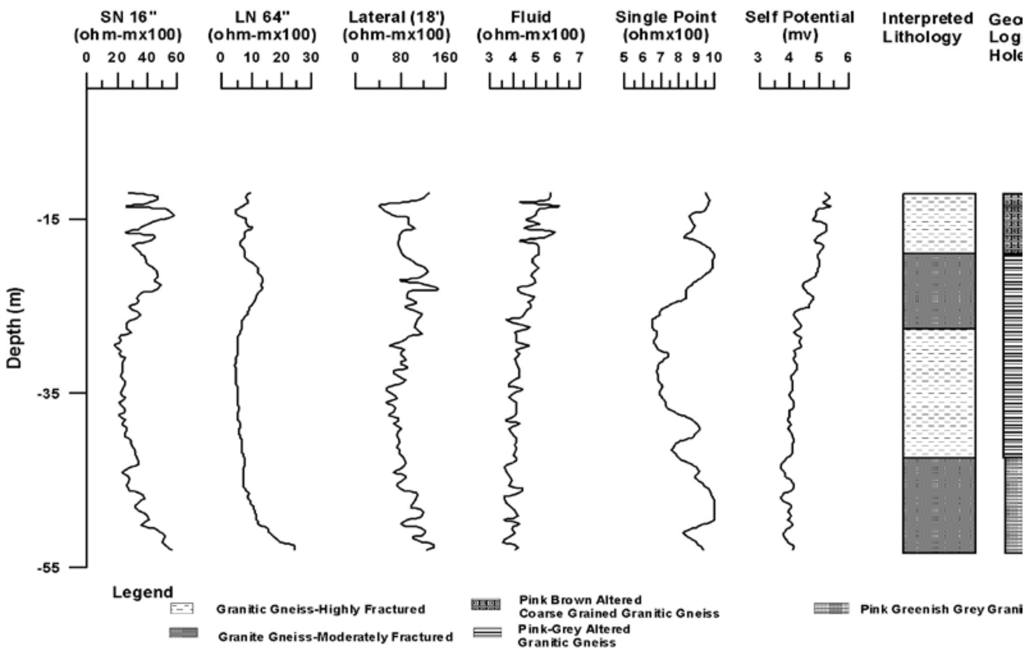

Figure 5. Electrical Resistivity Log at BH-109 (TB-4). KNPP

Borehole No. 106 (RB_4), in Table-III and fig 4, are in the range of 300-1580 Ωm at depths of 18.0 - 34.0 m and 43.0 - 49.0 m, indicating a fractured rock. This corroborates with the shattered granitic gneiss obtained from the geological log value at corresponding depths. The high electrical resistivity values of 1860-7050 Ωm at a depth of 49.0-55.0 m indicate fairly sound rock, whereas the geological log shows shattered granitic gneiss at the same depth.

Table-IV and Fig 5, shows the variation of the electrical resistivity values at Borehole No.109 (TB_4). The resistivity ranges from 450-2450 Ωm corresponding to the depth of 11.5-52.5m indicating fractured rock which corroborates with the shattered/ fractured granitic gneiss obtained from geological log at the same depth.

CONCLUSIONS

The electrical resistivity logging has established its potential to determine the lithology and assess the nature and quality of rock at KNPP. The electrical resistivity logging was particularly useful in identifying weathered and fractured rock zones. Fairly good correlation was observed between the electrical resistivity and geological logs. Low Resistivity encountered indicated slightly fractured to highly fractured rock. In some zones, high resistivity values of the order of 2000 Ωm to 7000 Ωm were observed, thereby indicating the presence of fairly compact rock. The resistivity determined and nature of formation assessed by electrical resistivity logging was utilized in designing the foundation of crucial structures like turbo generators and reactor buildings of KNPP.

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