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Soil characterization using electrical resistivity tomography and geotechnical investigations

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ABSTRACT

Electrical Resistivity Tomography (ERT) has been used in association with Standard Penetration Test (SPT) and Dynamic Cone Penetration Test (DCPT) for Geotechnical investigations at two sites, proposed for thermal power plants, in Uttar Pradesh (UP), India. SPT and DCPT tests were conducted at 28 points and two ERT profiles, each measuring 355 m long, were recorded using 72 electrodes deployed at 5 m spacing. Electrical characterization of subsurface soil was done using borehole data and grain size analysis of the soil samples collected from boreholes. The concept of electrical resistivity variation with soil strength related to the grain size distribution, cementation, porosity and saturation has been used to correlate the transverse resistance of soil with the number of blow counts (*N*-values) obtained from SPT and DCPT data. It was thus observed that the transverse resistance of soil column is linearly related with the number of blow counts (*N*-values) at these sites. The linear relationships are site-specific and the coefficients of linear relation are sensitive to the lithology of subsurface formation, which was verified by borehole data. The study demonstrates the usefulness of the ERT method in geotechnical investigations, which is economic, efficient and less time consuming in comparison to the other geotechnical methods, such as SPT and DCPT, used for the purpose.

1. Introduction

Characterization of subsurface soil and determination of soil strength are prerequisite for the foundation design of important civil engineering structures. Electrical characterization of soil was done by conducting surface electrical resistivity measurements and subsequently translating these data in terms of electrical properties of subsurface soil (Israil and Pachauri, 2003). Various attempts have been made in literatures to integrate the ERT and geotechnical data for characterization of subsurface soil (Cosenza et al., 2006; Gay et al., 2006). The application of electrical resistivity for characterization of soil was reviewed by Samouëlian et al., (2005).

Alternatively, in geotechnical studies, Standard Penetration Test (SPT) furnishes data about the resistance of soils to penetration, which can be used to evaluate the soil strength in terms of number of blows (*N*-values). The *N*-values are defined as the number of blows per 30 cm of penetration into the soil. Following the procedure of IS 6403 - (1981) code, *N*-values can be used to obtain the bearing capacity of soils. In Dynamic Cone Penetration Test (DCPT), the resistance, *N*-value, to penetration of the cone in terms of the number of blows per 30 cm of penetration is correlated with the bearing capacity of the soil. The data from these geotechnical tests (SPT and DCPT) in association with the borehole data and laboratory measurement of soil properties (e.g., grain size distribution, degree of saturation and permeability) are used to characterize the subsurface soil.

Geotechnical tests are time-consuming and expensive. On the other hand, geoelectrical methods are faster and comparatively cheap. The use of Electrical Resistivity Tomography (ERT) technique provides the electrical image of subsurface soil and has become an important tool for the electrical characterization of soil. Correlation between electrical parameters and soil strength, derived from geotechnical tests, can be studied by choosing different electrical parameters. It has been reported in literature (Braga et al., 1999; Giao et al., 2003) that the relationship between the electrical parameters such as chargeability, resistivity and *N*-values is poor.

The physics of electrical current flow in the subsurface soil suggests that the possible relationship between the soil strength and electrical resistivity should be based on the parameters which control soil strength as well as electrical resistivity such as grain size distribution, degree of saturation, porosity and cementation. It is so since resistivity is sensitive to the salinity of saturating fluid whereas soil strength is not related with it. Therefore, the relationship between electrical parameters and soil strength will be meaningless if the salinity of saturating fluid changes with depth. On the other hand, clay content in soil matrix can affect both soil strength as well as its

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resistivity with different degree. The ion exchange property of clay forms a mobile cloud of additional ions around each clay particle. These ions facilitate easy flow of electrical current. Thus, in fine-grained soils such as clay, electrical resistivity is always lower than expected on the basis of chemical analysis of water extracted from the soil (Zhdanov and Keller, 1994). Therefore, clay content in the soil may change relationship between electrical parameter and soil strength.

In the present paper, we will report our investigations on two locations having different soil matrix for soil characterization by conducting ERT, SPT, DCPT and laboratory measurements. The sites were proposed for thermal power plant and are located in Aligarh and Jhansi in Uttar Pradesh (UP), India. The locations of these sites along with points of investigation and ERT profile line are shown in Fig. 1. The derived electrical resistivity values are first calibrated with the borehole data of subsurface soil, and subsequently used to compute transverse resistance, which is correlated with the N-values recorded from geotechnical tests at each site.

2. Field investigation

The field investigations comprise of geoelectrical investigations using Electrical Resistivity Tomography (ERT) technique and geotechnical investigations, which include SPT, DCPT tests and grain size distribution of soil samples collected from these locations. Borehole data were used for calibration and correlation of resistivity values to the subsurface soil. The details of field investigation are discussed in the following:

2.1. Geoelectrical investigations

Electrical Resistivity Tomography (ERT) survey was carried out using multi-electrode system (Syscal Junior). The data were recorded using Schlumberger–Wenner sequence with 72 electrodes deployed along the profile line at an inter-electrode spacing of 5 m. The total length of each profile line was 355 m. Processing and inversion of resistivity image profile data were performed using RES2DINV code (Loke and Barker, 1996; Loke, 1997). For each data sets, L_1 norm was used for the data misfit and the inversion was carried out using the L_1 norm (blocky) inversion method for the model roughness filter (Loke et al., 2003). The method uses a finite difference scheme for solving the 2-D forward problem and blocky inversion method for inverting the processed ERT data. RES2DINV generates the inverted resistivity depth image for each profile line. The quality of inversion result was checked by monitoring absolute error (e_{rms}) between the measured and predicted apparent resistivity given by,

$$e_{\mathrm{rms}} = \sum_{i=1}^{N} \left[\frac{\left| \log\left(\rho_{a_{i_{\mathrm{meas}}}}\right) - \log\left(\rho_{a_{i_{\mathrm{calc}}}}\right) \right|}{N} \right] \tag{1}$$

where $\rho_{a_{i_{\mathrm{meas}}}}$ and $\rho_{a_{i_{\mathrm{calc}}}}$ are the measured and calculated apparent resistivity values at ith data point respectively and N is the total number of data points.

Geophysical inversion suffers from non-uniqueness. One way to reduce non-uniqueness is to use additional data/information from other sources to constrain geophysical inversion. We used borehole data to limit the resistivity values within the acceptable range for different lithological formations. RMS values of 9% and 6% for the two investigated sites indicate that the data are fitted with the computed response and the average error floors are 9% and 6% in the data at Aligarh and Jhansi, respectively. In the present investigation, SPT and DCPT data were recorded up to 16 m depth, therefore, the resistivity model is restricted to a depth of 24 m. Inverted resistivity-depth models are shown in Fig. 2 (a and b) for Aligarh and Jhansi, respectively. Resistivity distribution of subsurface soil in these areas shows a

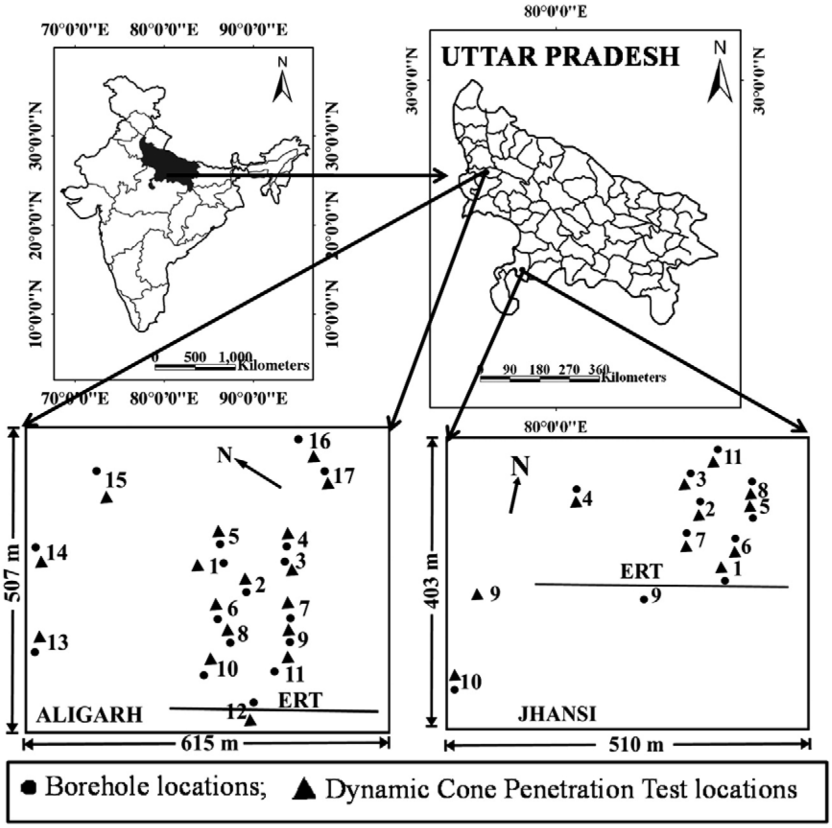

Fig. 1. Location map of the study area, showing the locations of Electrical Resistivity Tomography (ERT), Boreholes (BH) and Dynamic Cone Penetration Test (DCPT) at the investigated sites in Aligarh and Jhansi.