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Geotechnical site characterization through geoelectrics

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Summary

Point-wise geotechnical site testing in complex geological settings providing refined geo-mechanical information demands costlier drilling budget. Due to absence of suitable transforms geoelectrical imaging results cannot be directly translated to geotechnical knowledge. Here, in a case study we show that 2-D Electrical resistivity tomography (ERT) and induced polarization tomography (IPT) profile data along with projected geotechnical data (Standard Penetration Test (SPT)/Dynamic Cone Penetration Test (DCPT)/Static Cone Penetration Test (SCPT)) from a pair of nearby boreholes/locations can provide 2-D sections of different formation parameters, geotechnical tests and parameters on the same profile.

Our prediction method is based on site-specific regression equations describing actual correlations of geo-electrical and geotechnical data and site –independent well established empirical relations of SPT 'N' with different formation and geotechnical parameters respectively.

Our methodology can easily be extended to other geophysical imaging data also for achieving better comprehensive geotechnical assessment of a site.

Keywords: *Geotechnical tests, Geoelectrical imaging, Geotechnical parameters, Formation Parameters, Lithology Sections, Soil strata, Bearing capacity of soil, Regression analysis*

Introduction

For planning major civil engineering constructions, soil investigations are a must. The traditional geotechnical site investigations are geared towards assessment of various types of bearing capacity of soil through field tests (Murthy 2008) like Standard Penetration Test (SPT), Cone Penetration Test (CPT), Static Cone Penetration Test (SCPT), Dynamic Cone Penetration Test (DCPT) etc. The bearing capacity of soil is in turn used for planning foundation structures. While geotechnical tests provide geo-mechanical information on a very refined depth scales, their advantage is offset by their inherent point-wise information attended by drilling, which is costly. Further, in a complex geological setting, the problems get compounded due to excessive drilling budget to fulfill the geotechnical site investigation needs. So, to meet this need, civil engineers include a very high factor of safety in their 1-D model parameters.

While geoelectrical imaging (resistivity and induced polarization) being non-invasive and cost-effective with proven spatial resolutions at different scales in near-surface exploration, yet its results can't be directly translated to geotechnical knowledge due to absence of site-specific suitable transforms. Accordingly, a leveraged approach is needed to yield better quality subsurface information at a much lesser cost. So, the problem boils down to development of suitable transforms for prediction of different formation and geotechnical parameter images of subsurface on the basis of few geotechnical investigations and ample number of geo-electric image results.

Recent literature (Roth 2002; Roth and Nyquist 2003; Sudha *et al.* 2008; Cosenza *et al.* 2006) shows that efforts

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are limited to site-specific qualitative correlations between geo-electrical and geotechnical data. However, a preliminary attempt has been initiated by (Gautam et al. (2007)) to predict SPT profile using correlation of geo-electric and point geotechnical data (SPT). Even though qualitative correlations are available for shear wave / elastic modulii and SPT (Braga *et al.* 1999; Oh and Sun 2008; Weiher and Davis 2004; Ulugergerli and Uyanik 2007; Iyisan 1996), no worthwhile predictive effort is made to complement the results of geotechnical tests at a site.

Here, 2-D resistivity and IP image profile data along with projected geotechnical data (Standard Penetration Test, SPT / Dynamic Cone Penetration Test, DCPT / Static Cone Penetration Test, SCPT) from nearby boreholes have been used in a case study for predicting different 2-D formation and geotechnical parameter sections along the same profile. This prediction method (Gautam, 2010) is based on site-specific validated regression equations describing actual correlations of geo-electrical and geotechnical data and site-independent well established empirical relations of SPT 'N' with different formation and geotechnical parameters.

Method

It entails in the following steps:

1. Development of regression equations that relate observed geo-electrical (resistivity, IP and fictitious resistivity (Ficres), a product of resistivity and chargeability) logs from respective 2-D image data with geotechnical data referred to boreholes at /in close proximity of geo-electrical profile. The geotechnical test data includes SPT/DCPT/SCPT and formation parameters such as lithology, porosity, water saturation, sand, clay content.
2. At validation stage, consider the match quality between actual and predicted values to choose one among the geo-electrical sections for converting the respective geo-electrical section to SPT and thereby other geotechnical sections. In a similar manner formation parameter sections need to be handled.
3. Develop site-specific regression equations for different formation parameters (porosity, water saturation) including complete lithology and qualitative sand and clay content of subsurface using geoelectric and geotechnical data pertaining to a pair of boreholes in the vicinity of geoelectric profile following Step 2. Here Table 1 serves the purpose.
4. Based on existing empirical relations / Tables/ graphical plots in geotechnical literature (Murthy 2008) regression equations (Table 2) are developed between SPT and shear angle, unit weight of soil cover (dry & saturated), unconfined compressive strength and in turn shear angle versus various bearing capacity factors for both shallow and deep soil investigations (piles).
5. Based on Step 4, developed regression relations (Table 2) are used to transform the SPT section into respective 2-D geotechnical sections along the geo-electrical profile.
6. Steps 1, 2, 3 and 4 have to be repeated for each geo-electric profile in the study region, to yield 3D - volumes of formation and geotechnical parameters.

The above methodology is illustrated with the help of following case study.

Case Study

This study region namely the site of construction of New I.I.T Roorkee Library structure belongs to Indo-Gangetic Alluvial Plains and falls in Uttarakhand State, India. Our study region is located on a river terrace of the Solani River (Fig. 1a). Different field geoelectrical and geotechnical study locations are included in Fig. 1(b). The geoelectrical investigations pertain to resistivity and IP imaging data acquisition.

Data acquisition and processing

By using a multi-electrode resistivity and IP chargeability system of IRIS make geoelectric data is gathered with Wenner-Schlumberger electrode configuration of two meters inter-electrode configuration along profiles indicated in Fig.1. Both apparent resistivity and IP data are inverted using Loke & Barker's (1995) inversion algorithm. As a result, Fig. 2a and 2b are respectively the true resistivity and chargeability sections along profile A-B (Fig. 1). As illustrated in Fig.1, SPT boreholes, B-1 and B-3 correspond to electrode positions, EL-16 and EL-24 respectively. The SPT data for B-1 and B-3 are shown in Fig. 3a and 3b respectively. Though not considered here, Fig. 1 also contains locations of DCPT and SCPT and their projected positions on geoelectric profile A-B.

Further, both resistivity and IP logs for projected SPT locations at EL-16 and EL-24 (Fig. 2) are considered for further analysis.

Results

All major results are summarized below in terms of following illustrations including data acquisition details:

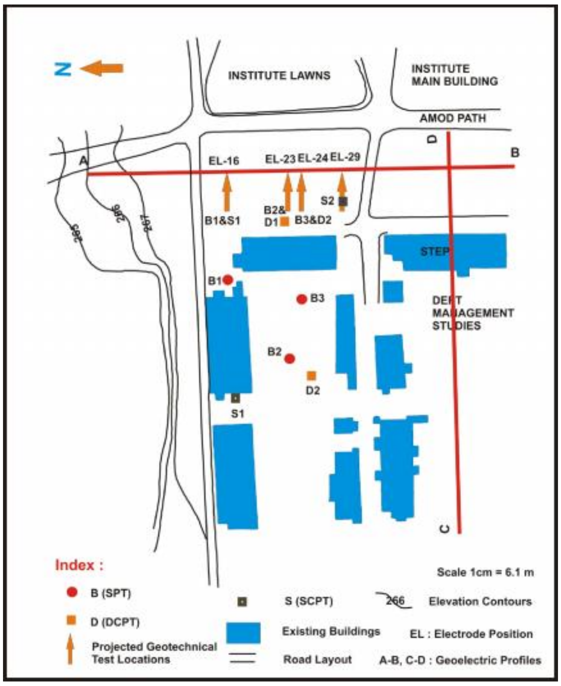

Fig.1 Data acquisition details at site location on IIT Roorkee campus.

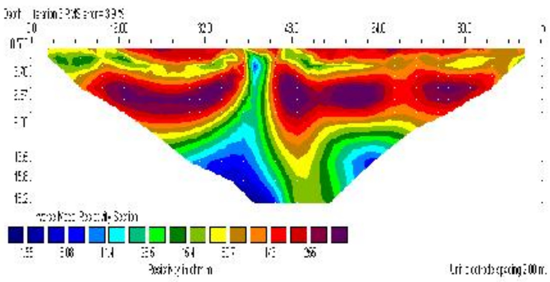

Fig. 2a True restivity section along Profile AB (Fig.1)

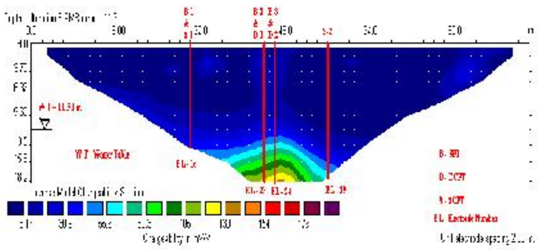

Fig. 2b True chargeability section along Profile AB (Fig.1)

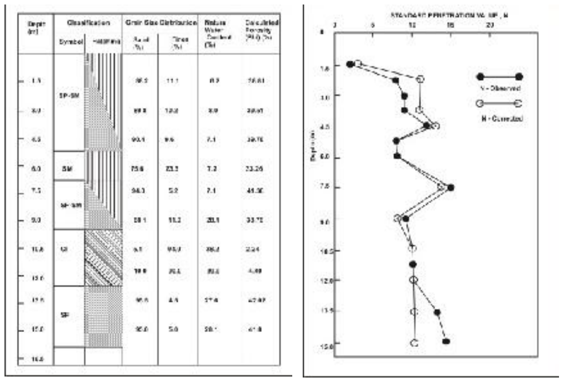

Fig. 3a SPT data at Borehole 1. Its projection on Profile AB (Fig. 1) coincides with electrode 16.

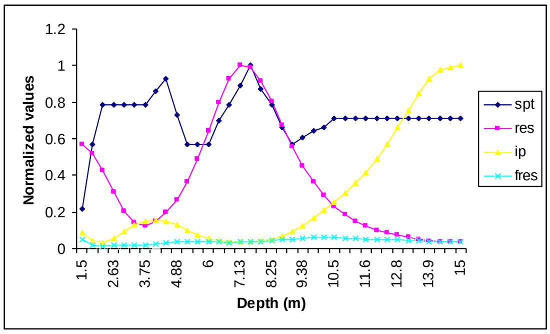

Fig. 3b Normalized plots of true resistivity, IP chargeability, fictitious resistivity and SPT 'N'

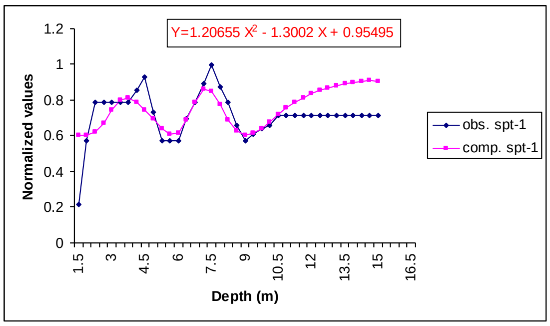

Fig. 4a Predicted and actual SPT

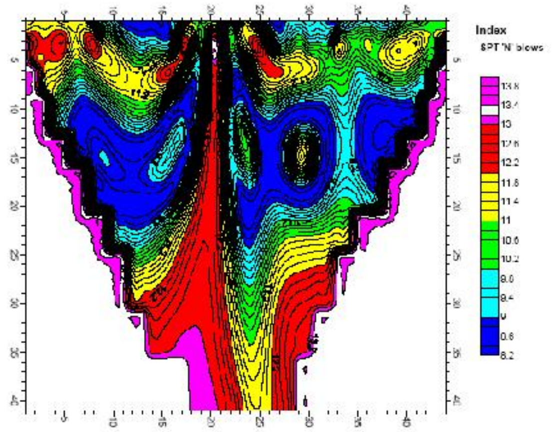

Fig. 4b Predicted 2-D SPT section as per our methodology

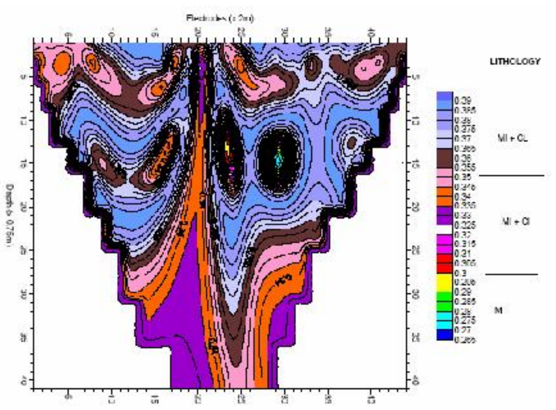

Fig. 4c Inferred lithology section by our methodology

Summary and conclusions

A practical methodology has been devised to infer 2-D sections of lithology, formation and geotechnical parameter sections. Here, a pair of boreholes in the vicinity of geo-electric profile is used for arriving at regression equation. But the procedure remains unaltered if more boreholes are available for this analysis and in such an event prediction quality improves. Our methodology is applied in a case study and arrived results support the efficacy and cost-effectiveness of the approach. By a careful scrutiny of achieved results suggest that geo-electric imaging could be implemented at pre-investigation stage leading to better location of requisite number of boreholes for carrying out conventional geotechnical field tests. Further, our methodology can be utilized in the next stage to infer 2-D image sections of lithology, formation and geotechnical parameters. Such a scheme optimizes the entire site investigation procedures, minimizing both cost and time by providing quality information to a geotechnical engineer for refining his models.

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