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Full Length Research

Correlation of geoelectrical and geotechnical parameters of data obtained from geophysical survey conducted at Ahmadu Bello University Phase II, Zaria, Nigeria

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ABSTRACT: Vertical electrical soundings (VES) and standard penetration test (SPT) were carried out at Ahmadu Bello University Phase II, Zaria, Nigeria, with the aim of correlating between transverse resistance (T) and number of blows per counts (N-value) for foundation studies. Two (2) SPT and VES using Schlumberger electrodes array, were conducted within the study area. The VES data acquired from the field were processed and interpreted using AGI earth imager 1D software. Borehole data of exact point, where the VES was carried out were used for calibration. The results obtained from the VES depicts that the depth to basement values ranges between 6.5 and 8.0 m which agree with the borehole data obtained from the SPT results. The results of resistivities and thickness obtained from the VES curve were used to compute transverse resistance. The transverse resistance was used to correlate with the N-values obtained from SPT data. It was observed that the correlation of transverse resistance and N-value was linear and highly positive. The linear relationship that was established between the two parameters can be used to determine the soil strength at any point within the area of study.

Keywords: Foundation studies, number of blows per counts, standard penetration test, transverse resistance, vertical electrical sounding.

INTRODUCTION

In any engineering project, a comprehensive assessment is required at the proposed site. This information can be acquired from the site investigation employing the different technique, which are geophysical and geotechnical methods (Sirles, 2006). As an important element to study, the condition of core material, geophysical survey methods have been broadly adopted (Titov et al., 2002). Normally, drilling of exploratory holes to obtain subsurface materials for identification and laboratory analysis are the ultimate consideration by engineers for construction purpose. Ako (1996) believes that the integration of geophysical method has become crucial in foundation studies since geophysical methods provide subsurface information at a rational price.

Ahmadu Bello University has opened a new site for the construction of massive engineering structures such as student's hostels, academic facilities and communal support facilities. In order to ascertain the safety of lives and properties, engineering properties of the foundation soils has to be carried out on the site. The most suitable method that provides information about the engineering properties of the foundation soils are geotechnical and geophysical methods and they are also cost effective and gives rapid results (Olorunfemi et al., 2005; Fatoba et al., 2017). According to Sudha et al. (2009), it was shown that there is a competence of the electrical resistivity method in association with standard penetration test for soil characterization and geotechnical investigation. The concept of ERT variation with soil strength related to the grain size distribution, cementation, porosity and saturation was used to correlate the transverse resistance of the soil.

In this work, a geotechnical method such as Standard Penetration Test (SPT) was used to provide information about the resistance of soils to penetration in terms of a number of blows per count (N-values) and the Electrical Resistivity method was used in characterizing the soil within the study area. Results from these types of surveys provide better knowledge of the most competent subsurface layer which will be useful for foundation studies within the site. Braga et al. (1999) and Giao et al. (2003) reported that no form of relationship exists between resistivity and geotechnical parameters, however, Sudha et al. (2009) showed that a linear relation exists between a resistivity parameter (such as Transverse Resistance) and a geotechnical parameter (such as N-values) and that such relationship is site dependent. Sudha et al. (2009) also showed that such relationship or model is represented for nearby areas not more than 1 km radius, where the geology is expected not to change significantly.

In this study, the number of blows per 300 mm of penetration (N-values) is used to correlate with the total transverse resistance obtained for the subsurface layers, in order to establish a quantitative measure of relating both parameters. Thus, the objectives of this work are to determine the depth and extent to which the bedrock has been weathered and to develop a useful correlation between SPT (N-values) and transverse resistance in order to establish an empirical relation between them and the relationship will be used to predict soil parameters from the soil resistivity data.

MATERIALS AND METHODS

Location and geology of the study area

The study area falls within the region covered by Ahmadu Bello University, Samaru, Zaria, which is located in Sabon-Gari Local Government Area of Kaduna State, Nigeria (Figure 1). Ahmadu Bello University site II lies between longitudes 7° 37' 58.80"E to 7° 39' 4.42"E and latitudes 11° 7' 51.81"N to 11° 8' 30.13"N and is positioned within the Northwestern part of the Kubanni Dam as shown in Figure 2. It falls within the Nigeria Basement Complex which is underlain by precambrian rocks at an elevation of about 670 m above the mean sea level. The rocks within the Basement Complex consists of granites, gneisses, and schists. The gneisses are found as small belts within the granite intrusions and are also found east and west of the batholiths (Wright and McCurry, 1970). The biotite gneiss extends westwards to form a gradational boundary with the schist belt. The gneiss continues eastwards to some extent and is occasionally broken up by the older granite (Wright and McCurry, 1970).

Geoelectrical investigation

VES is a field technique used to measure the variation of resistivity with depth (Loke, 2000). This was achieved by passing electrical current into the ground through the current electrodes A and B and the resulting potential difference was measured through the other two potential electrodes M and N (Loke, 2000) (Figure 3).

The resistivity survey was carried out using Petrozenith Terrameter. Two vertical electrical soundings using Schlumberger electrodes array were conducted within the study area and the data acquired were processed and interpreted using AGI Earth Imager 1D. The configuration of the electrode array used is shown in Figure 3.

From the arrangement above, apparent resistivity ρ_a is related to resistance (R) by

$$\rho_a = RK_f \quad (1)$$

From Ohm's law, resistance R is related to current (I) and potential difference (ΔU) as R = $\frac{\Delta U}{I}$, and K_f is known as the geometric factor = $\frac{2\pi}{\left\{\frac{1}{r_1}-\frac{1}{r_2}-\frac{1}{r_3}+\frac{1}{r_4}\right\}}$, where r_1, r_2, r_3, r_4 are the distances between electrodes. Geometric factor (K_f) depends on the type of arrangement used. For Schlumberger electrode arrangement, the geometric factor is

$$K_f = \pi\left[\frac{\left(\frac{AB}{2}\right)^2-\left(\frac{MN}{2}\right)^2}{MN}\right] \quad (2)$$

Half current electrode spread $\left(\frac{AB}{2}\right)$, half potential electrode spread $\left(\frac{MN}{2}\right)$ and resistance (R) were the parameters measured and recorded on the field. The data obtained were used to evaluate K_f and ρ_a. The evaluated values of the apparent resistivity ρ_a were plotted against $\frac{AB}{2}$ and VES curves were generated. The VES curves obtained depict thickness and resistivity of each layers.

Transverse resistance (T) was used to provide information about the electrical resistance of the layers in the subsurface and it was evaluated from the resulting thickness and resistivity of each layer from the VES curves by using equation 3

$$T = \sum_i^n \rho_i h_i \quad (3)$$

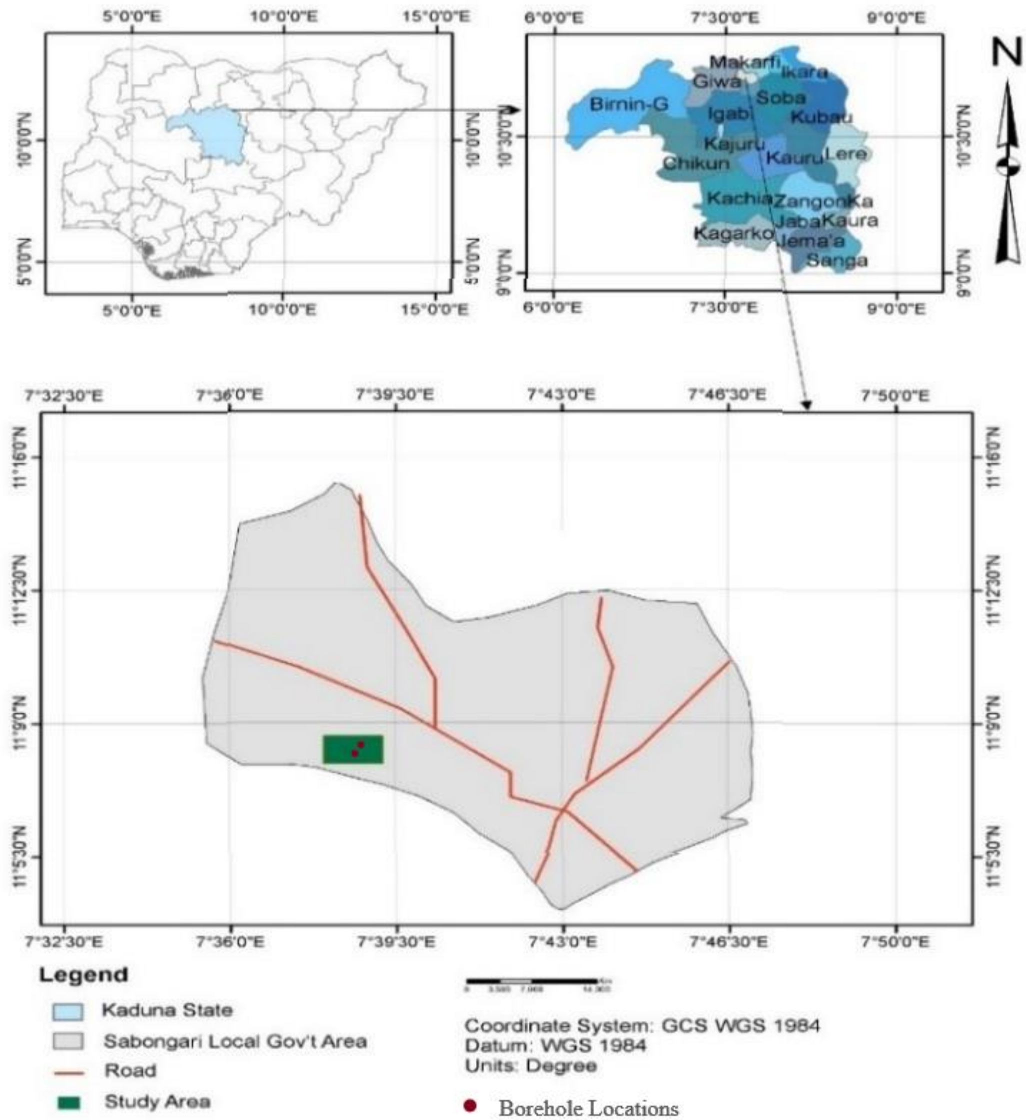

Figure 1. Location of the study area.

Where the ρ_i and h_i are the resistivity and thickness of the i^{th} layer respectively.

The biasedness and non-uniqueness of geoelectrical inversion have made it necessary to source for more additional information about the subsurface of the area. The additional information was obtained from a geotechnical method using the standard penetration test in order to reduce ambiguity.

Geotechnical investigation

Standard penetration test (SPT) is one of the most popular and oldest traditional methods used for evaluating the geotechnical properties of soils. It can also be used to determine the overburden condition and in the evaluation of structural foundations. SPT test was conducted at 15 points to a maximum of 10 m depth, following the procedure laid down in IS:2131-(1981) code. The number of blows (N-values) required for the penetration of every 15 cm depth into the ground, was recorded. Soil samples were collected for grain size analysis, from the borehole drilled near these locations. The N-value is used to provide an empirical measure of the soil strength or competence.

RESULTS AND DISCUSSION

The VES curves from the two positions surveyed in the study area are shown in Figure 4 and 5. Borehole data at the exact positions, where the electrical survey was carried out were used for calibration and the interpreted results indicated the presence of three (3) distinct layers.

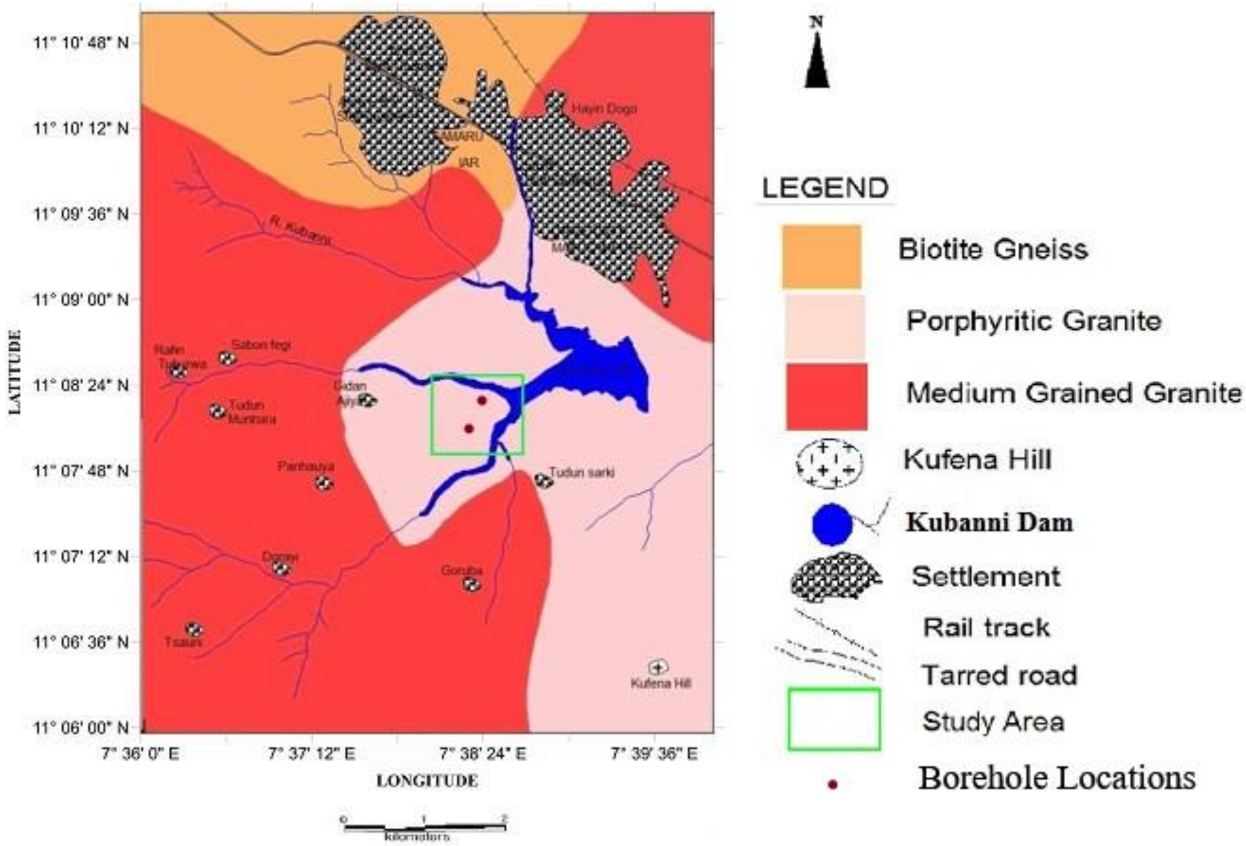

Figure 2. Geological map of the study area (Modified after Garba et al., 2014).

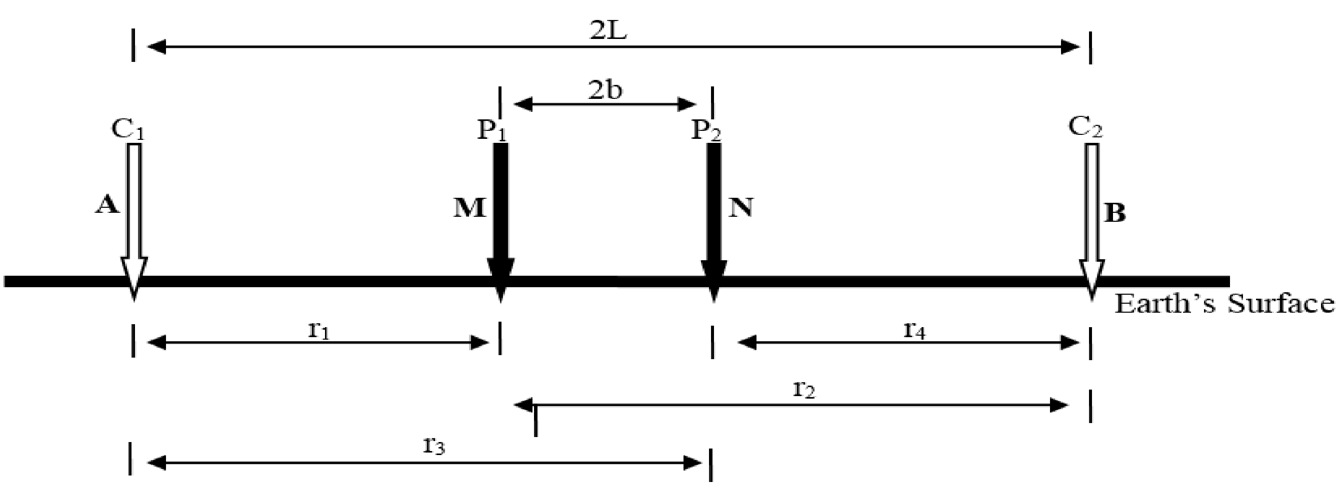

Figure 3. Two current (C_1 and C_2) and two potential (P_1 and P_2) electrodes in the standard configuration (Dogara et al., 2016).

The VES curve for the first location basically depicts twelve (12) layers with resistivities of 60.1, 46.3, 88.9, 152.4, 262.1, 580.1, 95.2, 7.8, 12.7, 24.1, 113, and 18916.8 Ωm as shown in Figure 4. The layers depicted from the VES curve were merged into three as a result of the information obtained from the borehole log for the area (Figure 6). The resistivities of the first layer range between 7.8 to 580 Ωm, the second layer ranges from 12.7 to 113 Ωm and the third layer ranges from 113 to 18916.8 Ωm. The lithological interpretations base on the borehole log

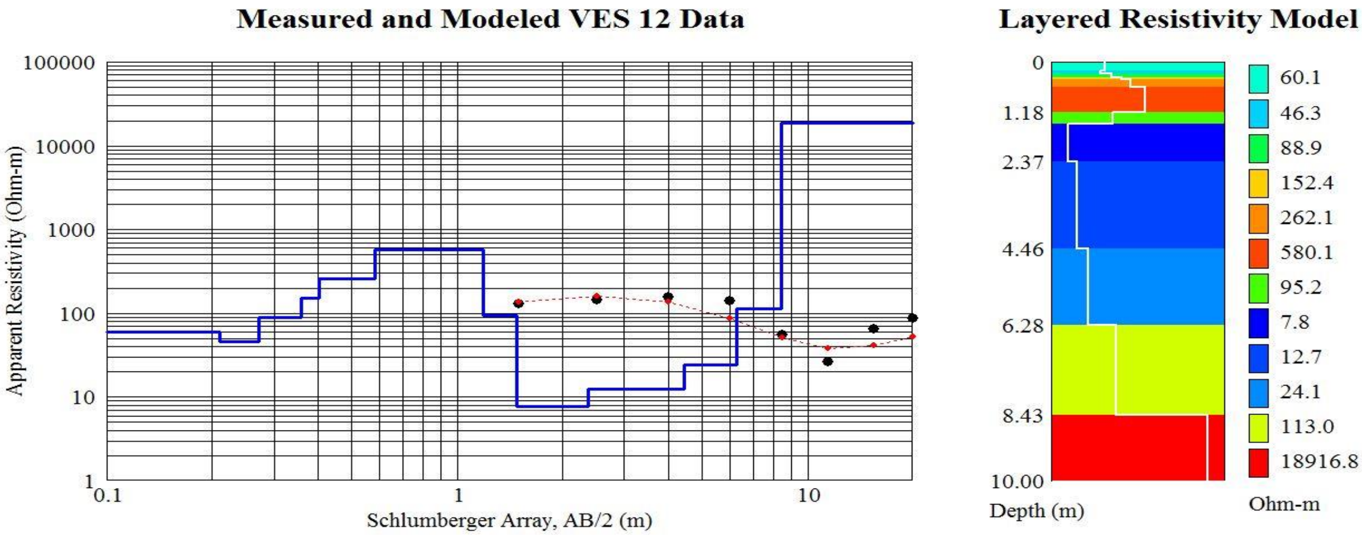

Figure 4. Vertical electrical sounding curve for location 1.

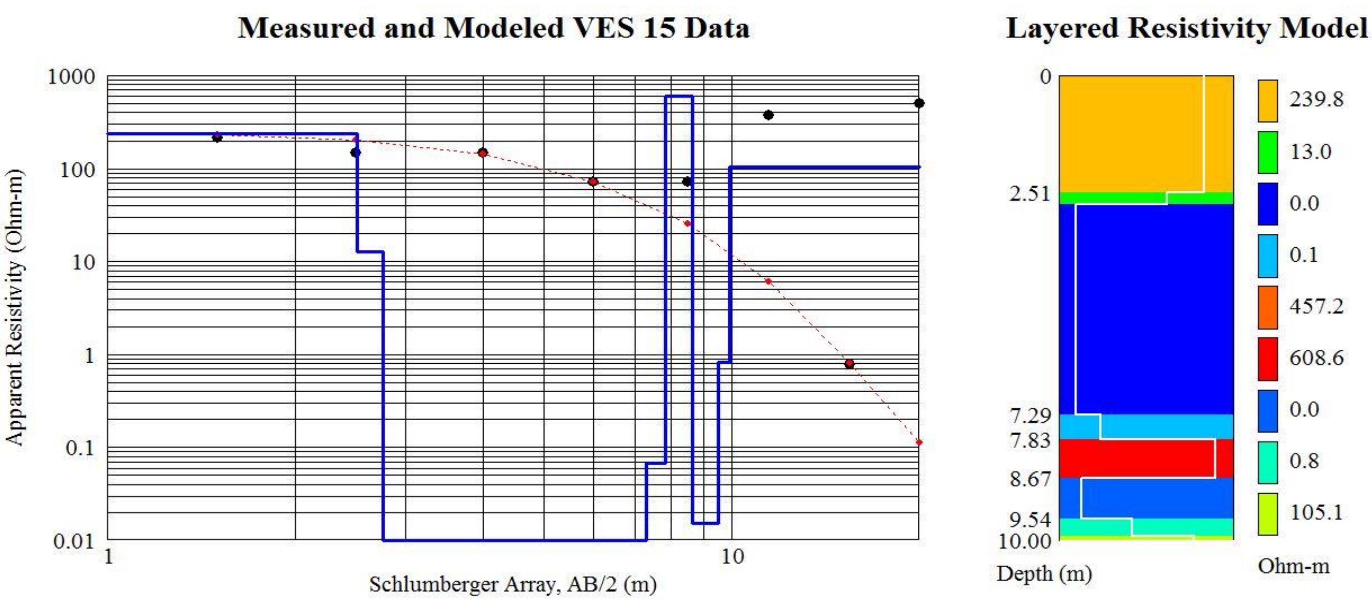

Figure 5. Vertical electrical sounding curve for location 2

data is brownish lateritic sandy lean clay, light brown lateritic clayey sand, and brownish lateritic weathered rock. The thicknesses of the layers are 0 to 1.56 m, 2.0 to 6.5 and 6.5 to 10 m respectively.

The VES curve for the second location depicts eight (8) layers with resistivities of 239.8, 13, 0, 0.1, 457.2, 608.6, 0.8, and 105.1 Ωm as shown in Figure 5. The layered resistivity model for the second location was also merged together to form three layers due to the information obtained from the borehole log data as shown in Figure 7. The resistivity of the first layer is 239.8 Ωm, the second layer ranges from 0 to 13 Ωm and the third layer ranges from 0.8 to 608.6 Ωm. The lithological interpretations base on the borehole log data is brownish lateritic sandy lean clay, light brown lateritic clayey sand, and greyish concretionary lateritic weathered rock. The thicknesses of the layers are 0 to 1.6 m, 2.51 to 7.80 and 7.83 to 10 m respectively.

The results of resistivities and thicknesses obtained from the VES curve (Figures 4 and 5) were used to compute transverse resistance of an n-layer section using equation 3. The transverse resistances were calculated at the depth for which the N-values were recorded, in order to correlate both parameters.

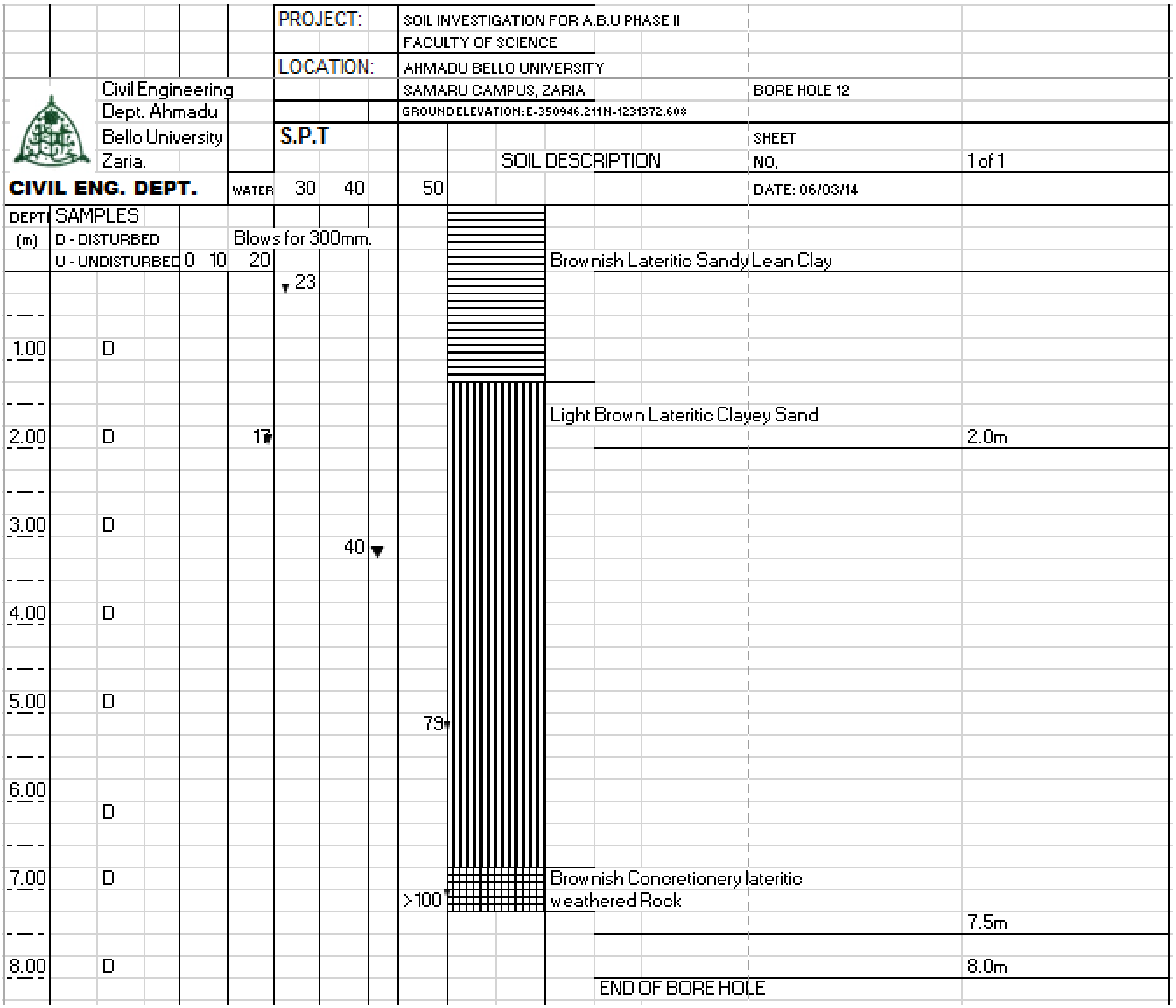

Figure 6. Borehole log of Location 1.

Corrected N-values with a depth of 8 and 10 m are shown in Figures 8 and 9. The N-value in general increases with depth; the rate of increase varies with depth, which depends on the soil strength parameters such as grain size distribution, porosity, degree of saturation and cementation of the soil matrix.

The values of transverse resistance obtained from equation 3 were plotted against depth as shown in Figures 10 and 11. The variation of transverse resistance with depth in Figure 10 shows that an increase in depth results in an increase in transverse resistance while in Figure 11 there is a slightly different at the depth of 3 to 8 m and 9 to 10 m, as the values of transverse resistances were constant at these depths.

The N-values were also plotted against the transverse resistance for both location and a straight line was fitted through the points (Figure 12 and 13). According to Sudha et al. (2009), the coefficients in the linear relations are sensitive to clay content and the lithology at the site of investigation. This is as a result of the salinity of saturating fluid in each of the lithological units which may differ from one site to another, and this can facilitate an easy movement of ions, which will, in turn, decrease the value of electrical resistivity results. In addition, soil strength can be affected by the clay content due to its ability to retain water which will, in turn, decreases the value of number of blows per counts.

The linear relationship that was obtained from the two locations is given by equation (4) and (5).

$$N = 0.0776T - 16.917 \qquad (4)$$

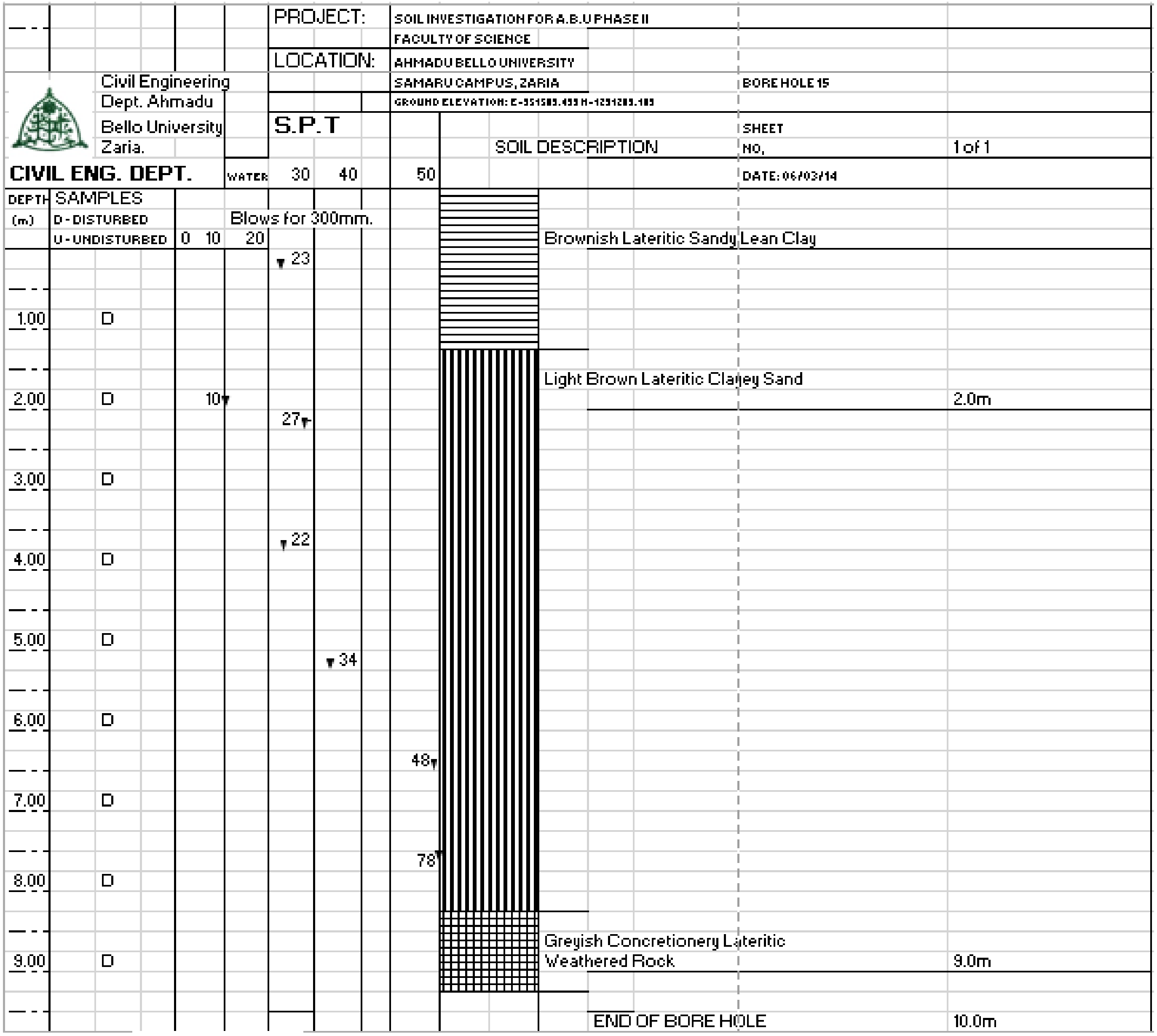

Figure 7. Borehole log of Location 2.

$$N = 0.0215T + 11.595 \qquad (5)$$

Where N is the number of blow counts (N-values) and T is the transverse resistance (Ωm^2).

Equation (4) and (5) demonstrate that the Number of blow count (N-value) is linearly correlated with transverse resistance at the site of investigation. The coefficients of correlation are positive value for both equation (4) and (5) and the values are 0.8003 and 0.6892 respectively. The result of these linear correlations can, therefore, be used to estimate the N-values within the area where transverse resistance values are known. The positive correlation between the two parameters N and T is the major outcome of the present investigation.

Conclusion

The geotechnical investigation has been carried out at Ahmadu Bello University site II, Zaria Nigeria, the SPT has been integrated with the ERT results. A linear relationship has been presented between transverse resistance derived from the ERT data and N-values obtained from geotechnical tests at these sites. The findings show that the transverse resistance and SPT N-values depict positively correlated pattern as expected. That is, zones

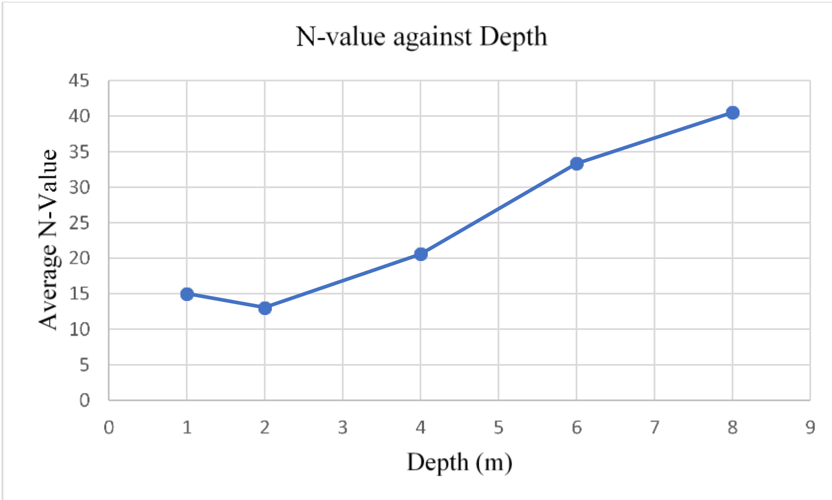

Figure 8. Relationship between Average N-values and depth at location 1.

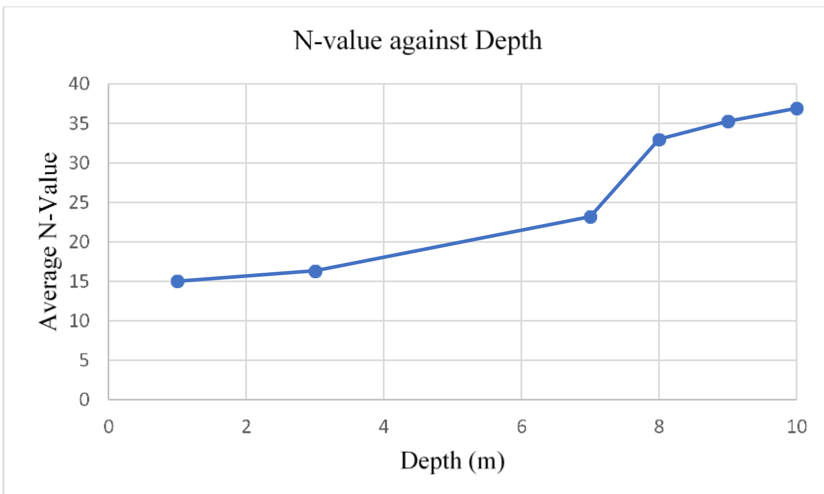

Figure 9. Relationship between Average N-values and depth at location 2.

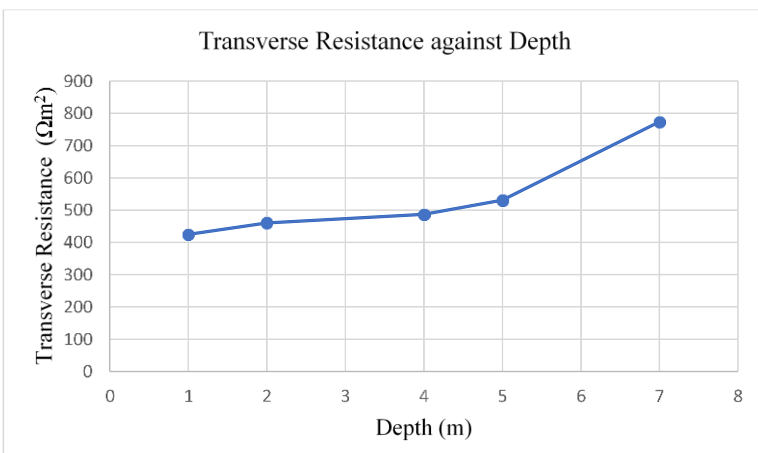

Figure 10. Variation of transverse resistance with depth at location 1.

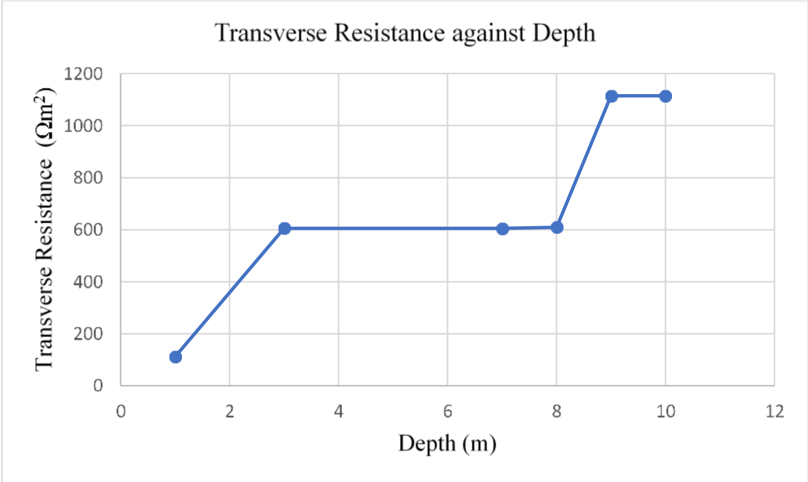

Figure 11. Variation of transverse resistance with depth at location 2.

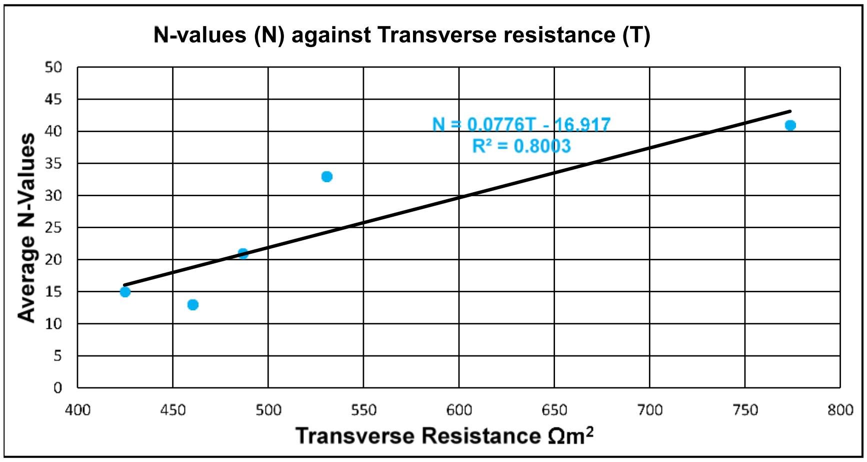

Figure 12. Relationship between Average N-values and Transverse resistance at location 1.

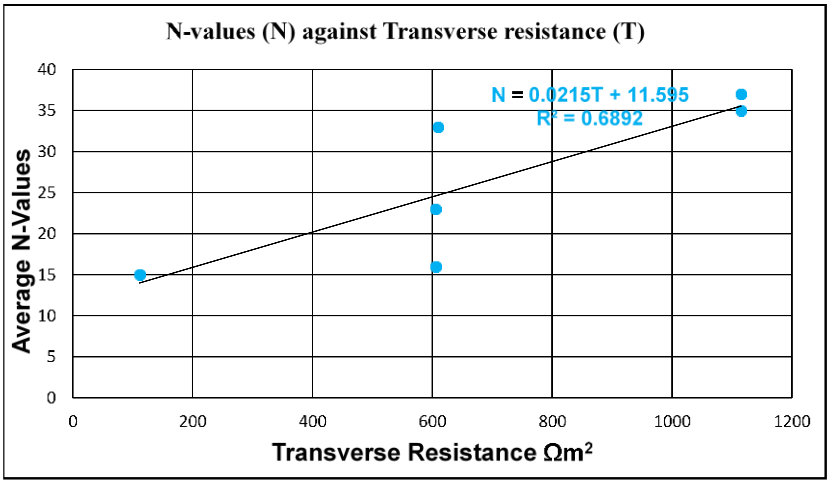

Figure 13. Relationship between Average N-values and Transverse resistance at location 2.

showing low transverse resistance values generally have low N value and vice versa. The linear relationship obtained from these correlations can be used to estimate N-values within the area, provided that the transverse resistance is known. This study has been used to determine the depth to basement and linear relationship between transverse resistance and N-value using both geoelectrical and geotechnical investigation.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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