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Engineering Geophysical Study of the Ebonyi State University Permanent Site, Abakaliki, South-Eastern Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Authors AIO and CNC designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript and managed literature searches. Authors AIO, OPA and PNN managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

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ABSTRACT

An engineering geophysical assessment of the permanent site of the Ebonyi State University, Abakaliki has been carried out to determine the stability of the site for construction projects. Vertical electrical soundings were carried and their interpretation revealed existence of six layers which comprise of laterites, clays and shales; limestone and sandstone occur as lenses within some portions of the campus. From the school gate to about 200 m along the tarred road, towards the university roundabout, the resistivity and thickness of the surface layers suggest a stable surface which is competent enough to carry foundations. However, investigation shows that clays of low stability underlie the area around the faculty of arts and would need to be geotechnically stabilized or foundation in the form of pilling to a depth of 17 m. For foundations in the areas around the Faculty of Management Science and about 200 m after the University roundabout, the topsoil would also require treatment or piled to a depth of about 15 m. Clay deposits occur in most of the areas of the campus; hence deep foundations should be adopted in the form of pilling up to 15 m to avoid the thick pile of clay in the area down to the stable sandstone layer.

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1. INTRODUCTION

The permanent site of Ebonyi State University is still being gradually developed for the purpose of accommodating the entire members of the university community who are currently scattered in three different campuses which serves as the temporary sites for the institution. Aside the geology of the area shown on Fig. 1, it equally gives a display of the site plan for the permanent site, most of which have not been constructed as at the time of this work. Geotechnical survey is a fundamental means of determining the stability of any construction site. In the permanent site of the Ebonyi State University, Abakaliki, southeastern Nigeria such a survey is required to forestall structural failures associated with building on the underlying Abakaliki Shale Formation. Aghamelu et al. [1] had reported structural failure of engineering projects constructed on this shaley formation. The estimated cost of detailed geotechnical assessment is however very exorbitant, hence, this approach was introduced as a good alternative and by so doing provide preliminary information about the subsurface prior to detailed geotechnical study, if the need still be. Previous researchers [2-6] have demonstrated that good geophysical survey data can be correlated with the engineering properties of soils to substitute for detailed geotechnical assessment. This study therefore attempts to employ geophysical approach in the form of vertical electrical soundings (VES), using Schlumberger electrode configuration, to characterise the engineering properties of materials underlying the premises of Ebonyi State University (EBSU) permanent site.

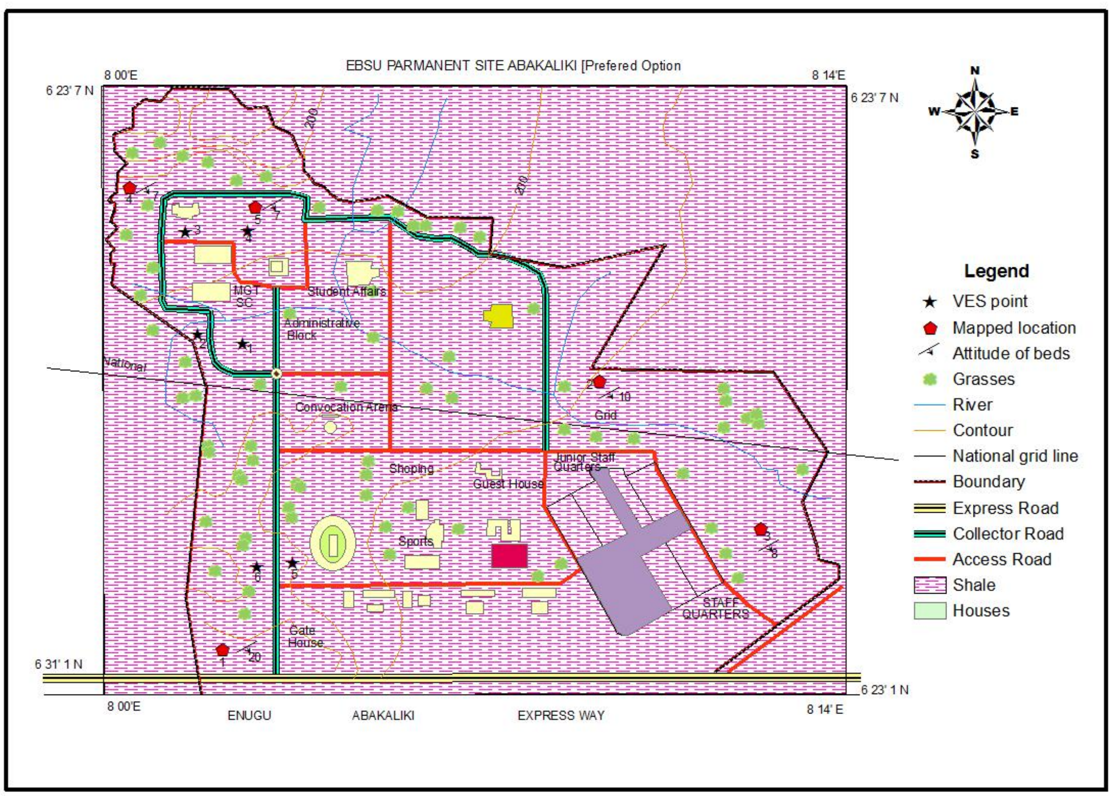

Fig. 1. Geologic map of the study area indicating the VES points

2. GEOLOGY OF THE AREA

The study area falls under the Abakaliki shales [7] of the Asu River Group sediments of Albian age [8]. It is the oldest sedimentary formation within the region. It has been extensively studied on a regional scale geologically by many authors, among whom are Kogbe and Hoque [9,10]. The area is mainly characterized by rather poorly bedded shale, dark grey in colour (weathers to brownish material in the greater part of the formation), blocky, calcareous and non-micaceous in most locations, interbedded with lenses of sandstones, sandy limestones and mudstones. However, within the study area, the geology is predominantly shale (Fig. 1), known as the Abakaliki Shales. The sediments have been folded and fractured particularly following the series of tectonic episodes which have acted on them from the Albian times [11]. The fractures have formed good reservoirs for the lead – zinc deposits in the area. Umeji [12] has argued that the facture systems originated from movement resulting from the rising and cooling of magma, which intruded the sediments in the Santonian time. The high level of induration of the shales, which has made some people use them for construction works, have been interpreted as low grade metamorphism [13].

3. MATERIALS AND METHODS

Equipment used for the geophysical survey include Global positioning system (GPS), Abem terrameter SAS 1000, Four electrodes, four reels of Cables, Direct Current Source, Survey Data sheet and a Measuring tape. Geoelectrical resistivity measurements were performed using the popular Schlumberger electrode configuration (Fig. 2).

In doing this, Six (6) vertical electrical soundings (VES) were carried out at six different locations within the campus, with the half current electrode separation (AB/2) starting from 1m up to 100 m in successive steps, for the current electrodes, and 0.25 m to 10 m for the potential electrodes [14]. The location and distribution of the VES stations were based on the available space and accessibility within the study area. At each VES point, the compass was used to get the direction of the point and GPS was used to record the co-ordinates of the area. The resulting resistance of each VES point were recorded in a survey data sheet and the resulting apparent resistivity were calculated respectively, using equation 1 [15].

$$\rho_{a} = \left[\left(\lambda/_{2I}\right)\times\left(L^2-x^2\right)^2/\left(L^2+x^2\right)\right]xR \ldots\ldots\ldots (1)$$

Where: ρ_a = apparent resistivity, λ = constant (3.143), I = potential electrode spacing, L = current electrode spacing, x = separation of the mid-points of the potential and current electrodes, and R = resistance. The apparent resistivity data were plotted against the electrode spacing ($^{AB}/_2$) in order to generate the relevant geoelectric curves. The processing of the data was enhanced with the use of interpex IX1D software, which enabled the generation of the pseudo sections.

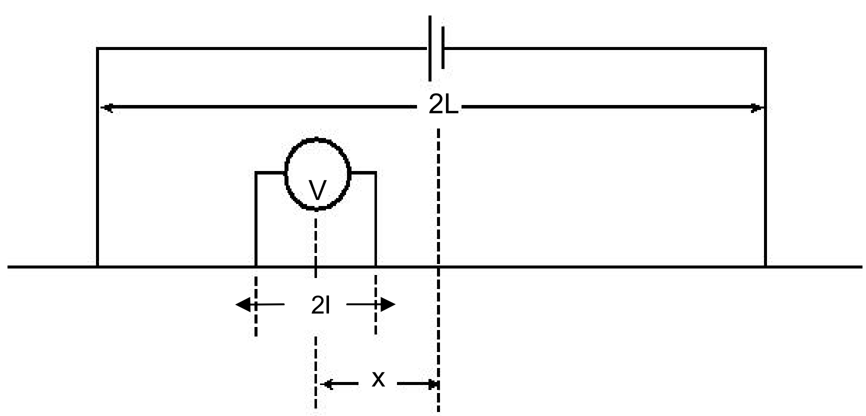

Fig. 2. A sketch of schlumberger field method [15] (After Kearey et al.)

4. RESULTS AND DISCUSSION

4.1 Geophysical Data

4.1.1 VES 1

This VES has the H curve type (Fig. 3). It consists of four layers (Table 1). The first layer is laterite, which is reddish in colour with resistivity value of 1211.2 ohm-m and a thickness of 3.04 m. The second layer consists of silt/soft clay zone with resistivity value of 21.68 ohm-m and thickness of 4.83 m. The third layer is consolidated sandstone lense (i.e. a sandstone lense which is very hard or indurated possibly due to grade metamorphism as described by [13] with a very high resistivity value of 508802.0 ohm-m and thickness of 27.07 m. The fourth layer is shale which is hard with Resistivity value of 96.41 m. The top layer of laterite, which is as thick as 3 m, is stable enough to carry light structures such as buildings of 1 – 3 storeys. However, for superstructures such as higher buildings or bridges, it is our view that foundations should be either laid to an average depth of 8 m (i.e. where the sandstone layer is found), possibly through pilling or the clay zone is treated to increase its shear strength thereby reducing the depth to below 8 m.

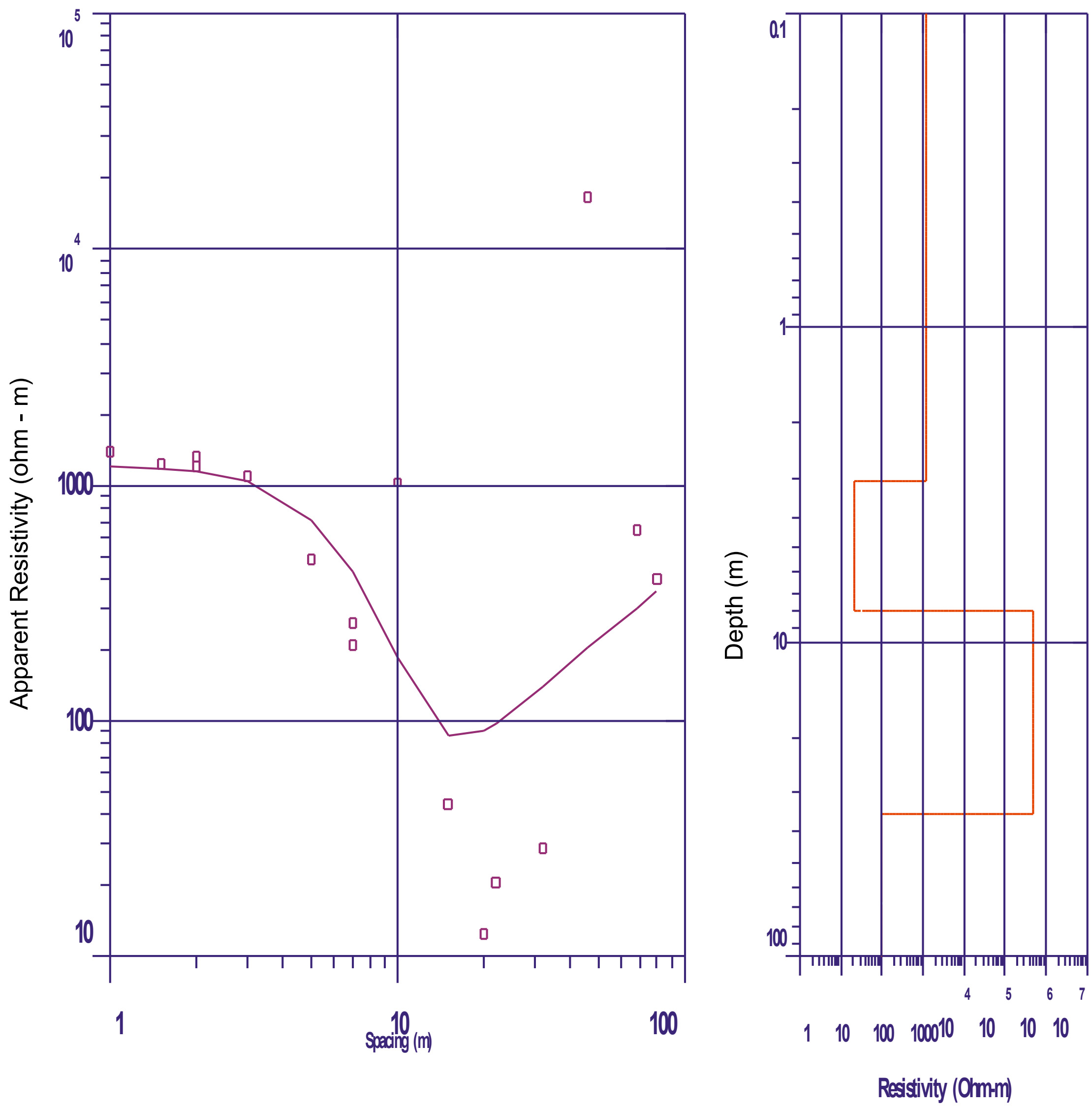

Fig. 3. Log-log plot of VES 1 at the EBSU PERMSITE

Table 1. Layer model of VES 1

Layer no	Resistivity ohm-m	Thickness (m)	Depth (m)	Inferred lithology
1	1211.2	3.04	3.04	Laterite
2	21.68	4.83	7.88	Silt/soft clay zone
3	508802.0	27.07	34.95	Consolidated sandstone
4	96.41			Hard Shale

4.1.2 VES 2

This VES has the Q curve type (Fig. 4). It consists of four layers (Table 2). The first layer is laterite zone; it has resistivity value of 481.6 ohm-m and thickness of 3.79 m. The second layer is wet/soft clay with resistivity value of 16.39 ohm-m and thickness of 2.48 m. The third layer is indurated shale with resistivity value of 1084 ohm-m and thickness of 3.79 m. The fourth layer is moist/soft clay with resistivity value of 0.396 ohm-m. With the presence of the laterite at the top, it is advised that foundations be laid to a depth of 1m for bungalows and a storey building. However, for structures higher than a storey building, it is suggested that the clay which is in the second layer be treated before the foundation is laid.

4.1.3 VES 3

This VES has the combination of the Q and K curve types, therefore the curve type is QK (Fig. 5). From the result (Table 3), this VES point has five (5) layers. The first layer is with resistivity value of 830.8 ohm-m and thickness of 1.88m and was interpreted as compacted laterite. The second layer is uncompacted laterite with resistivity value of 548.6 ohm-m and thickness of 1.03 m. The third layer is of soft clay lithology, with resistivity value of 16.33 ohm-m and thickness of 1.48 m. The fourth layer is of indurated shale lithology with resistivity value of 3827.6 ohm-m and thickness of 2.19 m. The fifth layer is wet/soft clay with resistivity value of 0.583 m. Considering the result above, structures like a storey building or less could be sighted on the laterite zone, while projects heavier than that should be laid at about 4m below the laterite surface.

4.1.4 VES 4

This VES has the H curve type (Fig. 6). It consists of four (4) layers. From the result (Table 4), the first layer is uncompacted laterite, with resistivity value of 321.8 ohm-m and thickness of 2.40 m. The second layer is of clay lithology, it has resistivity value of 58.80 ohm-m and thickness of 9.38 m. The third layer is compacted limestone lense with a very high resistivity value of 335471.4 ohm-m and thickness of 308.1 m. The fourth layer is compacted clay with resistivity value of 39.83 ohm-m. With the thickness of the clay as high as 9 m, it is not advisable to lay foundation on the laterite overburden. Consequently, foundation within this area should be laid at a depth of not less than 12 m deep through pilling in other to reduce cost.

4.1.5 VES 5

This VES has the H curve type (Fig. 7). It consists of four (4) geoelectric layers (Table 5). The first layer is compacted laterite with resistivity of 723.6 ohm-m and thickness of 2.50. The second layer is soft clay zone with resistivity of 26.81 and the thickness is 3.82. The third layer is indurated shale with resistivity value of 2025.9 ohm-m and thickness of 14.66 m. The fourth is wet/soft clay with resistivity value of 10.78 ohm-m. At this area, foundations for all structures are suggested to be laid at a depth not less than 7m (i.e. on the compact shale).

4.1.6 VES 6

This VES has the A curve type (Fig. 8). It shows some changes in gradient but the Apparent Resistivity increases with electrode separation, indicating that the true resistivities increase with depth from layer to layer (Table 6). The first layer is soft clay zone, with resistivity value of 49.78 ohm-m and thickness of 0.219 m. The second layer is hard shale with resistivity value of 467.9 ohm-m and thickness of 41.84 m. The third layer is soft shale with resistivity value of 230,066.8 ohm-m. Hence, a foundation of 1 m deep is recommended.

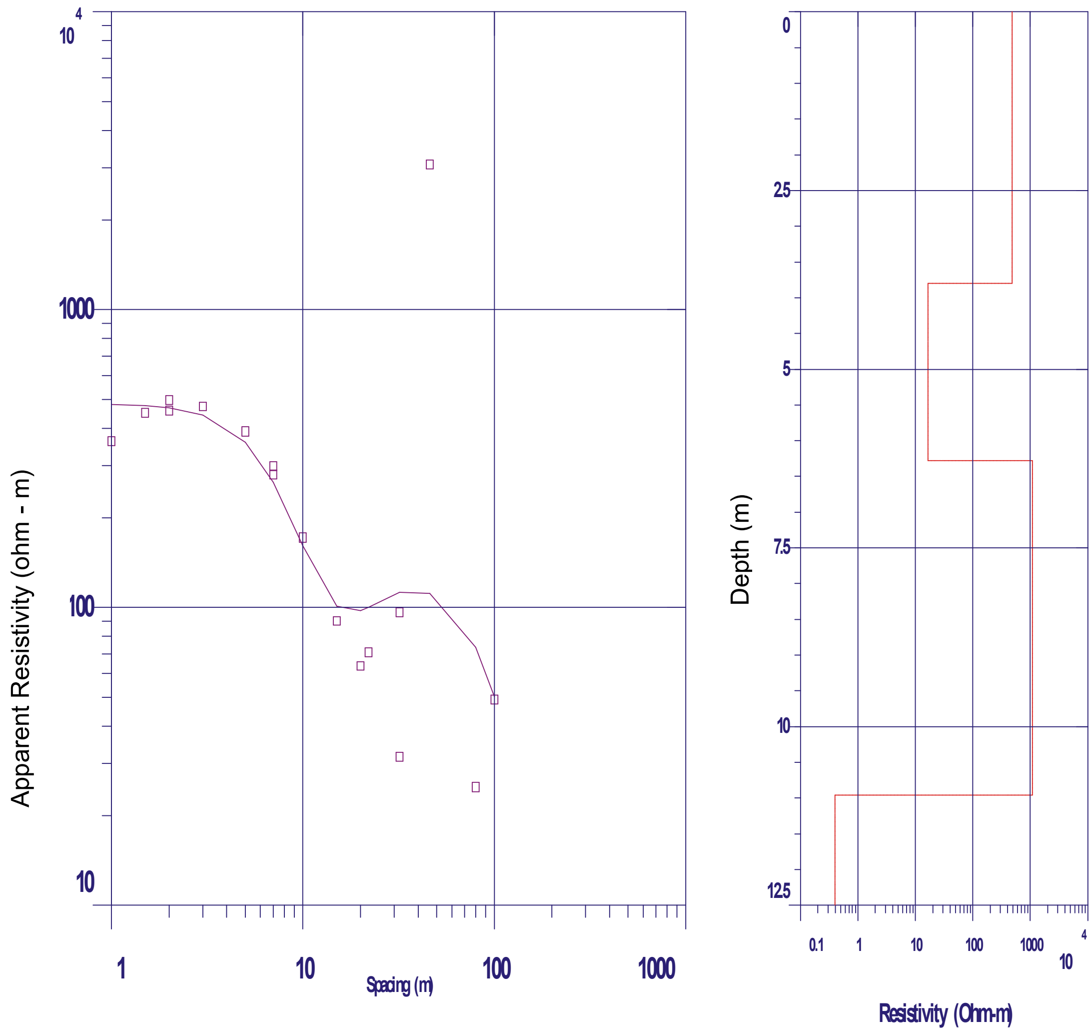

Fig. 4. Log –log plot of VES 2 at the EBSU PERMSITE

Table 2. Layer model of VES 2

Layer No	Resistivity (ohm-m)	Thickness (m)	Depth (m)	Inferred lithology
1	481.6	3.79	3.79	laterite
2	16.39	2.48	6.27	Wet/soft clay
3	1084.8	4.67	10.95	Indurated shale
4	0.396			Wet/soft clay

Table 3. Layer model for VES 3

Layer No	Resistivity (OHM- M)	Thickness (m)	Depth (m)	Inferred lithology
1	830.8	1.88	1.88	Compacted laterite
2	548.6	1.03	2.92	Uncompacted laterite
3	16.33	1.48	4.40	Soft clay
4	3827.6	2.19	6.59	Indurated Shale
5	0.583			Wet/ soft clay

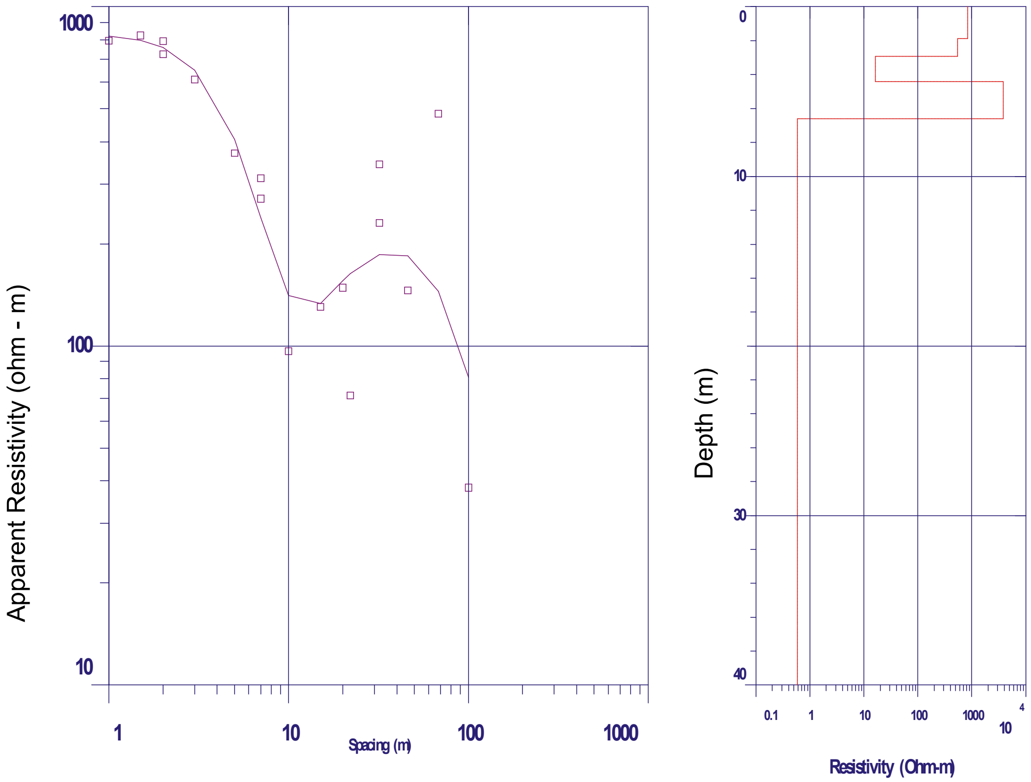

Fig. 5. Log–log plot of VES 3 at the EBSU PERMSITE

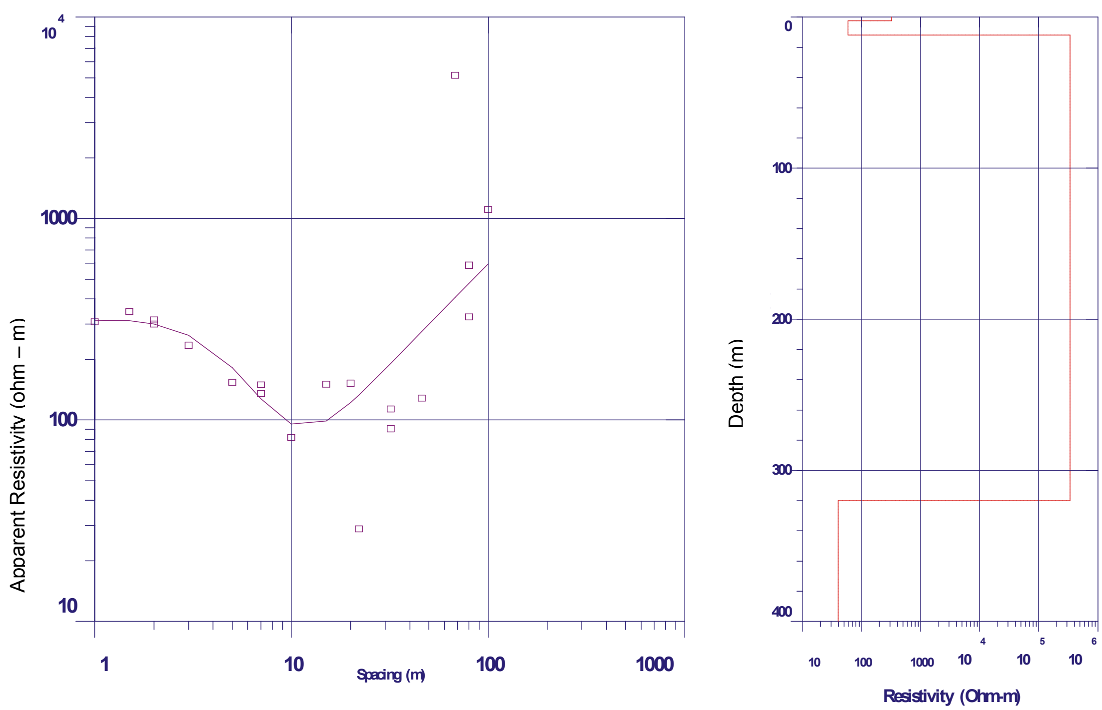

Fig. 6. Log –log plot of VES 4 at the EBSU PERMSITE

Table 4. Layer model for VES 4

Layer No	Resistivity (ohm-m)	Thickness (m)	Depth (m)	Inferred lithology
1	321.8	2.40	2.40	Uncompacted Laterite
2	58.80	9.38	11.78	Clay
3	33571.4	308.1	319.9	Compacted
4	39.83			Compacted clay

Table 5. Layer model for VES 5

Layer No	Resistivity (ohm-m)	Thickness (m)	Depth (m)	Inferred lithology
1	723.6	2.50	2.50	Compacted
2	26.81	3.82	6.32	Wet/soft Clay
3	2025.9	14.66	20.99	Indurated shale
4	10.78			Wet/soft clay

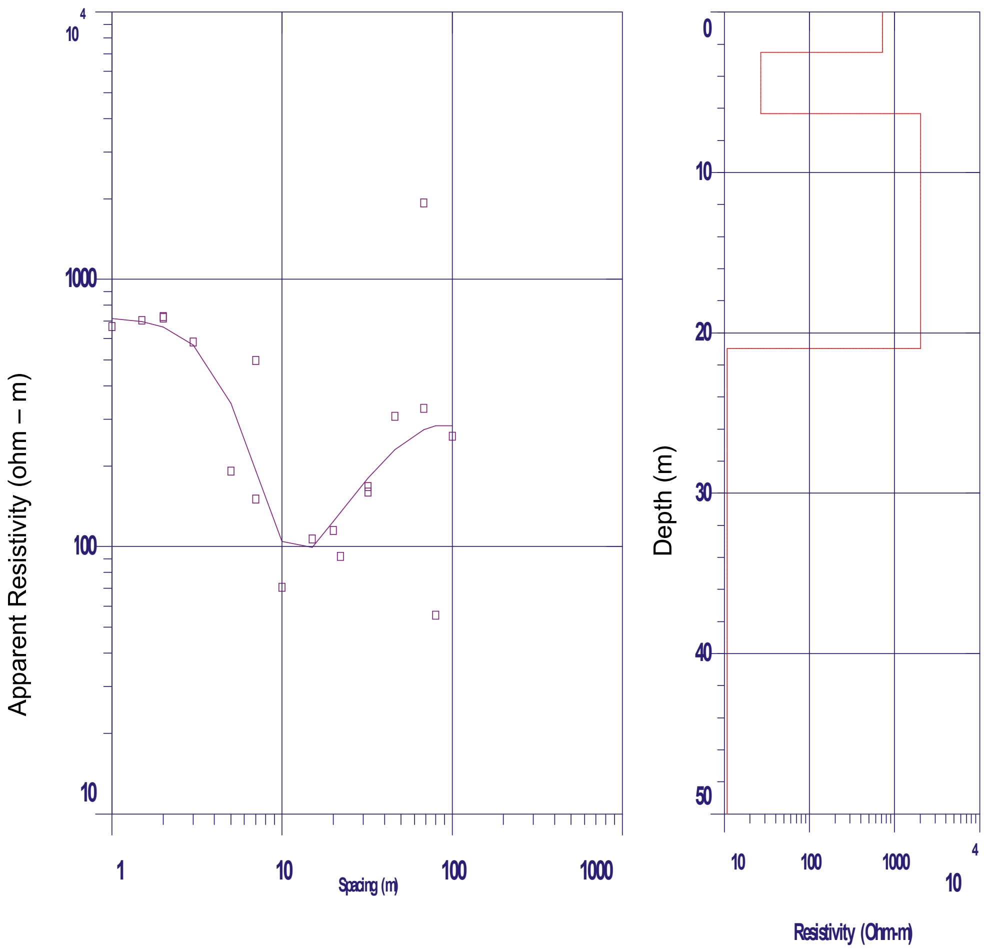

Fig. 7. Log–log plot of VES 5 at the EBSU PERMSITE

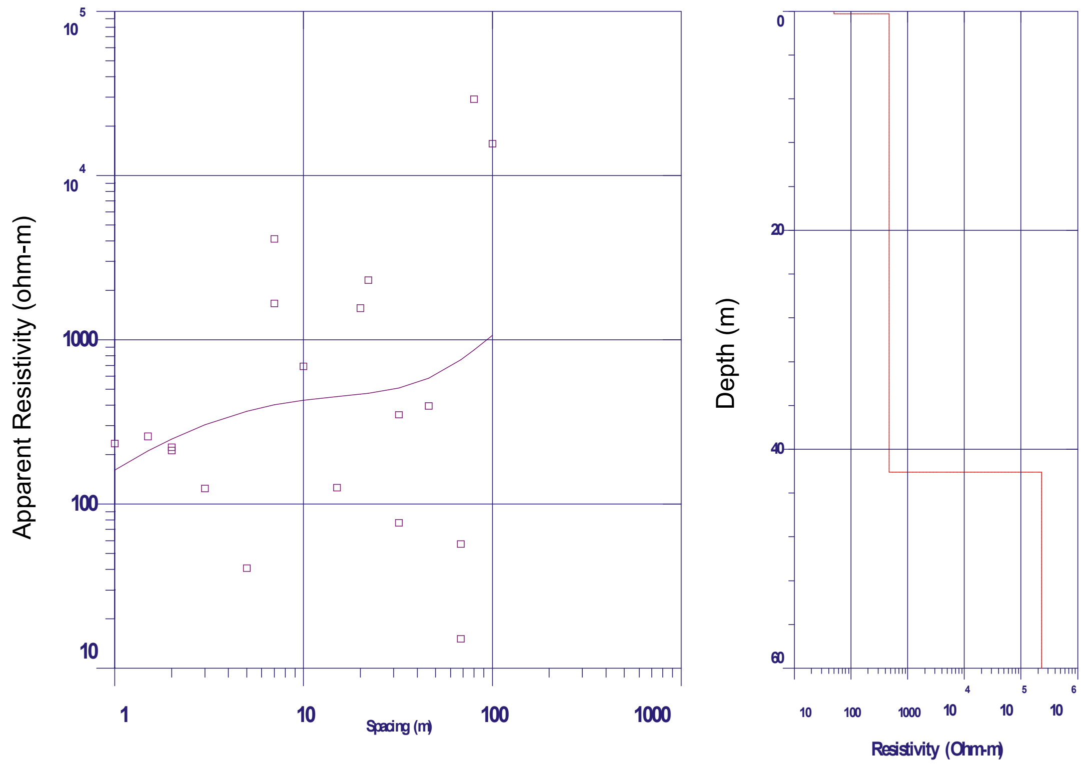

Fig. 8. Log–log plot of VES 6 at the EBSU permanent site

Table 6. Layer model for VES 6

Layer No	Resistivity (ohm-m)	Thickness (m)	Depth (m)	Inferred lithology
1	49.78	0.219	0.219	Soft Clay
2	467.9	41.84	42.06	Hard shale
3	230066.8			Soft shale

4.2 2D Resistivity Pseudo Section

A 2D pseudo section was generated using a combination of the six (6) VES data points. It is a form of contouring which was digitally done using the Interpex software. From the Pseudo section (Fig. 9), VES 5 and 6 are close to the permanent site gate but on either sides of the tarred road. Looking at Fig. 8, the 2D inversion resistivity shows that from the school gate to the point marked ‘A’, the resistivity and thickness of the surface layers suggests a stable surface which is strong enough to carry foundations. Between point A and the VES 1 (i.e. the area marked Z or shortly before the roundabout up to the front of the Faculty of Management science), there is a thin deposit of a weak zone in between the stable ones (the thin yellow line) which reduced the thickness of the stable blue layer. Again there is another weak zone of about 5 m thick across this zone. These two observations suggests that for foundations to be laid between the Faculty of Management Science and about 200 m after the University roundabout, the top soil should be treated to a stable point or the foundation pilled to a depth of about 15 m. In the same vein, the area marked B comprises VES 1, VES 2, VES 3 and VES 4. VES 1 is located opposite the university roundabout, VES 2 is found opposite faculty of arts where as VES 3 and VES 4 are respectively located behind faculty of social sciences and faculty of management science towards the back of the university.

For foundations being laid between the Faculty of Management Science backwards across the tarred road towards the back of the University, pilling should be applied up to 15 m to bouycourt the thick pile of clay in the area down to the stable sandstone layer.

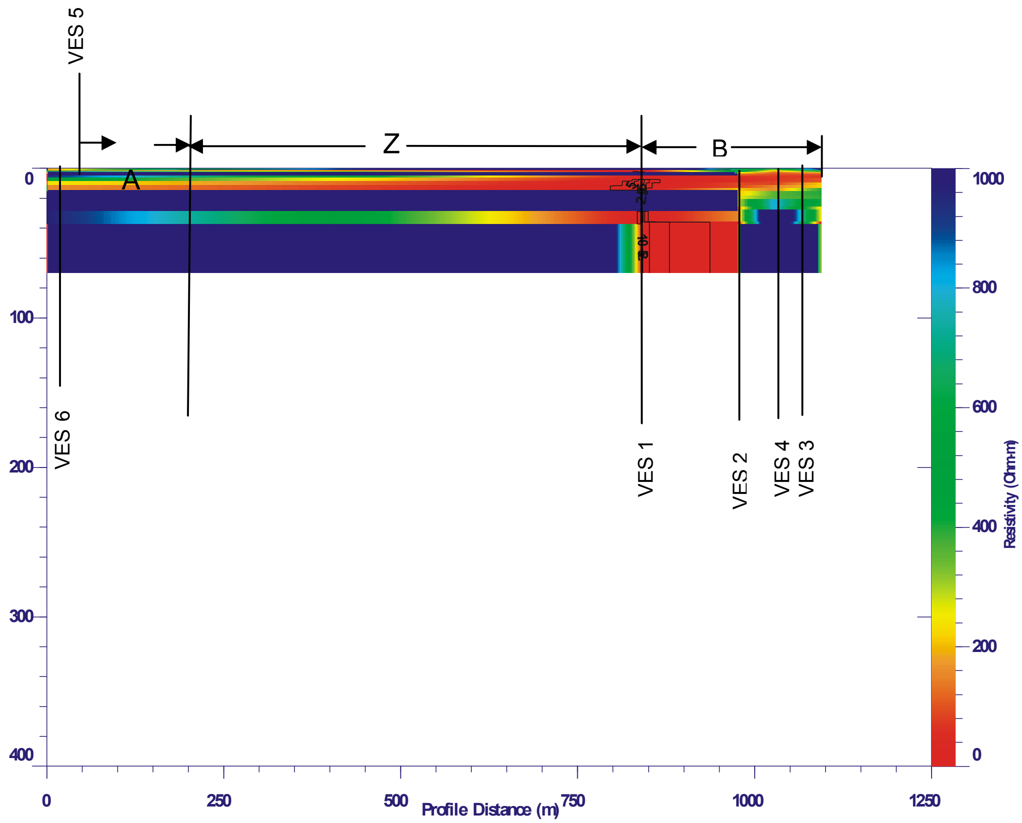

Fig. 9. A 2D pseudo section of the VES plots across the EBSU Permanent site

4.3 Data Correlation and the Suitability of the Site for Construction Purposes

The results of investigation reveal that clays of low stability underlie the area around the faculty of arts. In this area, the subsurface need to be geotechnically stabilized or foundation in the form of pilling to a depth of 17 m is required in order to erect structures. Foundations in the areas around the Faculty of Management Science and about 200 m after the University roundabout should go below the clayey topsoil which would also require treatment. Piling to a depth of about 15 m may be the most appropriate measure here. Clay deposits occur in most of the areas of the campus, suggesting that deep foundations should be adopted generally in the form of pilling up to 15 m for all high-rising structures to avoid the thick pile of clay in the area down to the stable sandstone layer.

5. CONCLUSION

The interpretation of six electrical vertical soundings revealed the existence of six layers within the limit of survey in the study area which comprise laterites, clay, shales. In addition to the above mentioned, limestone was also observed at VES 4 and sandstone observed at VES 1 and VES 6. From the school gate to about 200 m along the tarred road (i.e. towards the university roundabout) the resistivity and thickness of the surface layers suggest a stable surface which is competent enough to carry foundations. From the school roundabout towards faculty of arts (VES 1 and VES 2 respectively), the surface layers should be geotechnically stabilized or foundation in the form of pilling to a depth of 17 m should be applied due to the presence of clay in the area. For foundations to be laid between faculty of management science and about 200 m after the university roundabout (VES 3 and VES 4), the topsoil should be treated to a stable point or the foundation piled to a depth of about 15 m. For foundations being laid between the faculty of management science backwards across the tarred road and towards the back of the university, deep foundations should be adopted in the form of pilling up to 15 m to avoid the thick pile of clay in the area down to the stable sandstone layer.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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