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An Engineering Foundation Investigation using the Geoelectric Method. A Case Study: Southwestern Nigeria

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Abstract

The geoelectric method – Schlumberger vertical electrical sounding (VES) technique – was utilised in the geophysical investigation of an engineering site in Ode-Aye Southwestern Nigeria. The aim of the study was to determine the existence of competent and incompetent geologic layers and the depth at which they occur. A total of twenty VES stations were used in this study. Three distinct geoelectric layers were observed- sand, loose sandstone and shale layers respectively. The sand and especially the loose sand /sandstone layers were inferred to be the competent beds in the area from their resistivity values and thickness. They were classified as the stable and suitable beds for engineering construction purposes although their foundations should not extend to great depths – beyond 20 m – due to the presence of an underlying impervious shale bed.

1.0 Introduction

Standard engineering practices requires investigations of the earth's subsurface at the sites designated for engineering construction(s) [1]. Geophysical methods are implemented in a wide range of applications ranging from building site investigation, land reclamation, dam site investigations, bridge construction, among others [2] with the aim of investigating subsurface geologic structures and determining the rocks' physical properties.

Geoelectric methods are thus often used in engineering foundation investigations to evaluate the depth to competent subsurface geologic layers that are stable and suitable for the development of engineering foundations. Geoelectric methods are often used because they usually show a distinct contrast in geoelectric characteristics of subsurface geologic materials. The electrical resistivity of a formation is directly related to the nature, quantity, quality and distribution of the formation water [3]. The two most frequently used electrode configurations are the Wenner and Schlumberger configurations, but this study employed the Schlumberger configuration.

2.0 Theory

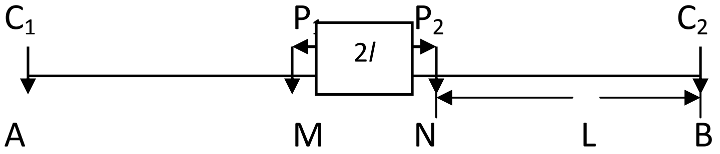

Figure 1: The Schlumberger electrode configuration

$$V = IR \tag{1}$$

$$R = \Delta V/I \tag{2}$$

$$\frac{\Delta V}{I} = \frac{\rho L}{A}$$

$$\rho = \frac{A \Delta V}{IL} \tag{3}$$

$$V = \frac{I \rho L}{A} \tag{4}$$

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For two current electrodes at the surface,

$$V_1 = {}^{A_1}\!/_{r_1} \qquad \text{Where} \qquad A_1 = \frac{I\rho}{2\pi} \tag{4a}$$

The two current in the current electrodes are equal but opposite. Hence the potential difference due to C_2 at P is

$$V_2 = {}^{A_2}\!/_{r_2} \quad \text{Where} \qquad A_2 = {}^{I\rho}\!/_{2\pi} = -A_1 \tag{4b}$$

:. The potential difference

$$\Delta V = \frac{I\rho}{2\pi}\left[\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)\right] \tag{5}$$

For the Schlumberger VES configuration (Figure 1) the apparent resistivity ρ_a becomes:

$$\rho_a = \frac{\pi R L^2}{2l} \tag{6}$$

Where: ρ_a is the resistivity of the material (ohm-m)
R is the resistance of the material (ohms)
V is the potential across the material (Volts)
I is the input current (Amperes)
L (=AB/2) is half the current-current electrode separation (m)
l is half potential-potential electrode separation (m)
A is the cross-sectional Area of the material (m^2)

In this configuration the potential distance MN is kept constant while AB is varied resulting in a rapidly decreasing potential difference across MN that ultimately exceeds the measuring capabilities of the instrument.

3.0 Location and Geology of the study Area

Geographically the study area is located on long $4^0 45^I$E and Lat $6^0 34^I$N and falls within the tropical rainforest belt in Southwestern, Nigeria (Figure 2). It has a gentle undulating terrain to the south with a topographic elevation of approximately 75 m above sea level. The annual temperature ranges from 24-27^0c with a mean annual rainfall of over 2500 mm [4].

Geologically, the area falls within the Dahomey basin and is underlain by the coastal plain sands of the Benin formation (Figure 2). The sands are relatively sorted and non-cemented and the sediments deposited during the late Tertiary-Early Quaternary period [5]. The formation is predominantly shally with outcrops of shale along a spring [6]. The aquifers are characteristically continental sands, gravels or marine sands with the lateritic earth overlying the sands as well as the underlying impervious shale/clay member of the Akimbo formation [7]. Adequate rainfall is however guaranteed in the study area.

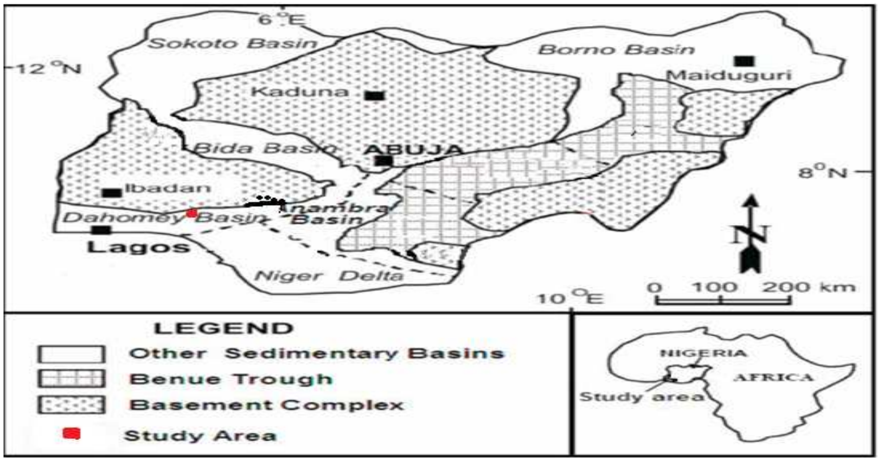


Figure 2. Generalised Geologic map of Nigeria showing the study area.

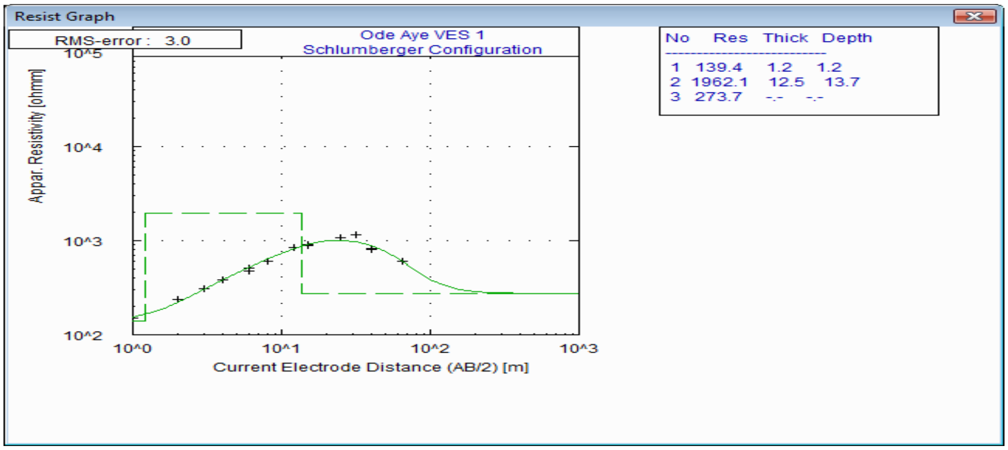
4.0 Method of study

The geophysical study employed the electrical resistivity method – Schlumberger vertical electrical sounding (VES) technique – along a total of six (6) traverses in an S-N direction with inter-traverse and intra-traverse spacing of 100m.

The PASI-E2 DIGIT meter was employed in the data acquisition. The computed apparent resistivity values were partially curve-matched and iterated using the WinRESIST software to generate corresponding geoelectric parameters for interpretation.

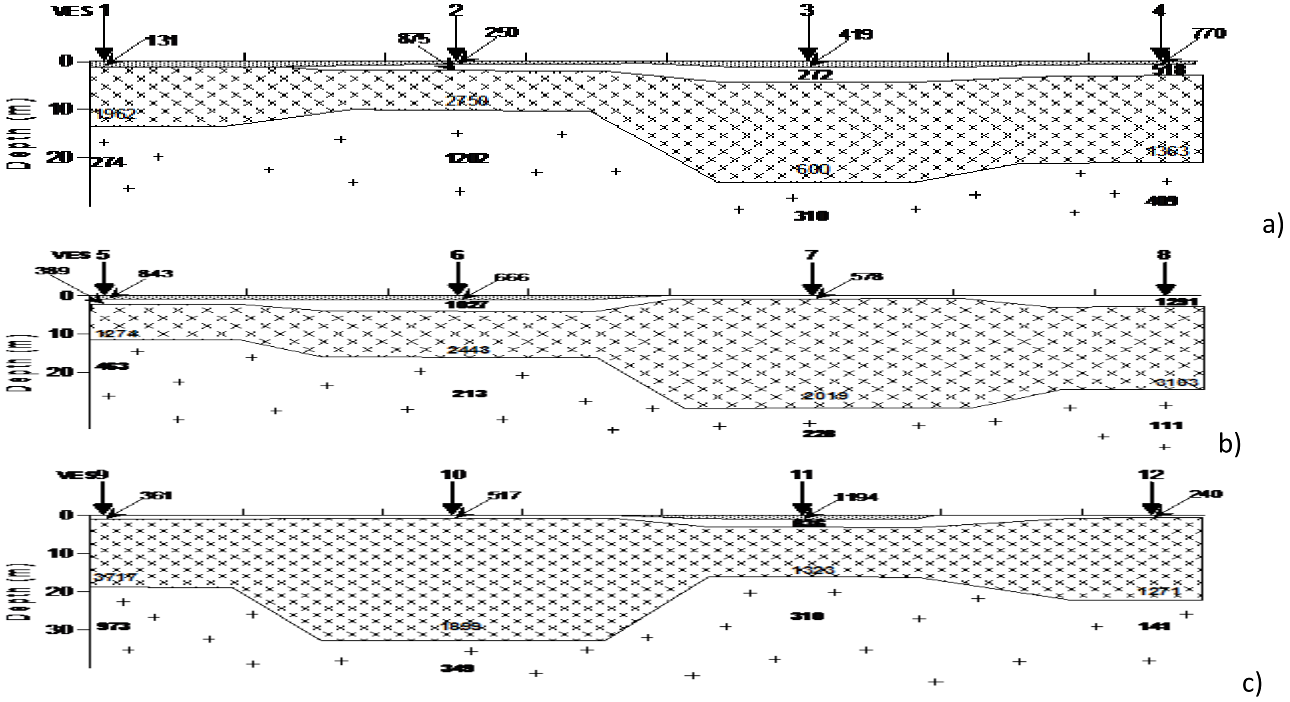
5.0 Discussion of results

The typical VES curve obtained from the area is the K – type (Figure 3) and the subsequent subsurface geoelectric sections (Figure 4) displays three distinct geologic layers. From the geoelectric sections (Figure, 4 a-e), the upper most layers can be seen to have resistivity values in the range of 139.4– 1290.6 ohm-m and thickness in the range of 0.4-2.8 m consisting mainly of sandy topsoil which is the alluvium deposit in the area. The second layer has resistivity values in the range of 918.3 – 3717 ohm-m and thickness in the range of 7.5 – 32.1 m, and comprises of loose sand/sandstones. The third layer has resistivity values in the range of 111 – 973.6 ohm-m and an undetermined thickness; comprising of sandy shale/shale.



No	Res	Thick	Depth
1	139.4	1.2	1.2
2	1962.1	12.5	13.7
3	273.7	-.-	-.-

Figure 3. Typical depth sounding curve for the area.



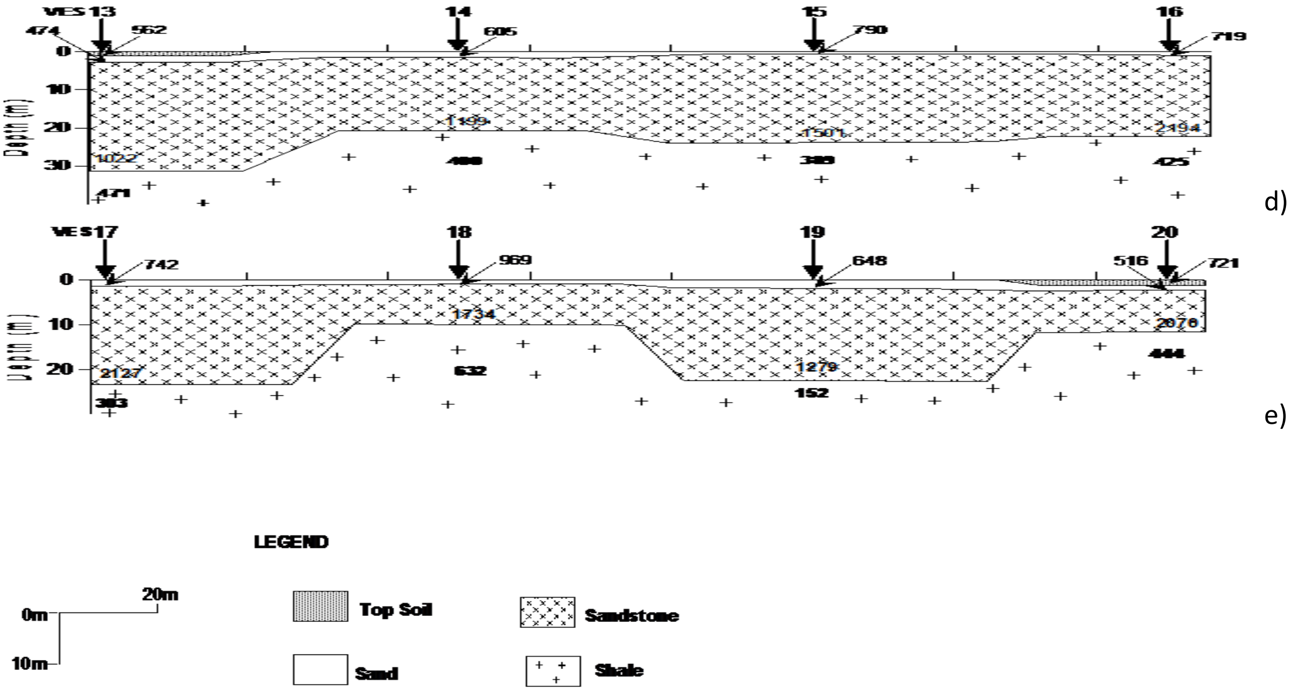


Figure 4(a – e). Geoelectric Sections along traverses 1 – 5 in an S – N direction.

The sandy topsoil and the loose sand/sandstone layers which constitute the competent geologic layers in the survey site vary in thickness from 8.6 – 32.9 m and it is composed of permeable geologic materials as seen from the resistivity values across the layers. The shale/sandy shale layer with undetermined thickness is a porous and relatively permeable material as observed from the resistivity distribution across the layer. Also from geoelectric section (Figure 4), the underlying porous and impervious shale layer can also be observed to be undulating along the traverses except along traverse four which is relatively gentle (flat) .

6.0 Conclusion:

Conclusively, the first and especially the second layers are the competent bedrocks in the area due to its relative thickness and permeability of its constituent materials.

These layers are therefore stable and suitable for engineering structures' foundation development. However, the foundations should not be too deep whenever possible to avoid water percolation in the foundations due to capillary action because an impervious shale bed underlies the competent bedrock.

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