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Original Article

Geo-Electric Investigation of Sub-soil Competency in Federal University Otuoke Campus in Bayelsa State, Southern Nigeria

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Abstract - *In a bid to investigate the engineering competency of the shallow sub-soil, ten (10) Vertical Electric Sounding (VES) Stations were occupied, and geo-electric data was acquired across the Federal University Otuoke East Campus in Bayelsa State. The data obtained was modelled using IP2WIN resistivity software to obtain information on subsurface geo-electric parameters, layer thickness, and resistivity, which was then used to characterize the shallow geologic material. Results from the ten (10) VES stations investigated revealed four distinct geo-electric trends with results of layer character ranging randomly from incompetent to highly competent; Geo-electric profiles of VES stations 1, 4, 6 and 10 revealed four geologic layers with a trend* $\rho 1 > \rho 2 < \rho 3 < \rho 4$ *associated with the HA-curve type; VES 2 penetrated four geo-electric layers with a trend* $\rho 1 > \rho 2 < \rho 3 > \rho 4$ *associated with the HK-curve type; VES stations 3, 5, 7 and 8 delineated three subsurface layers with a trend* $\rho 1 > \rho 2 < \rho 3$ *associated with the H-curve type and VES 9 which revealed 5 distinct geo-electric layers of the QHA curve type with a resistivity trend* $\rho 1 > \rho 2 > \rho 3 < \rho 4 < \rho 5$*. Results showed high variability in the engineering competence of the subsoil across the campus; also, the thicknesses of layers varied, implying that geologic materials were not laterally continuous. Variations observed may be largely due to sub-soil compaction differentials or other anthropogenic and geologic factors across the area. It is highly recommended that foundations for structures and infrastructures on the campus be designed independently due to subsurface inhomogeneity.*

Keywords - *Competency, Electrical, Otuoke, Resistivity, Sub-soil characterization.*

1. Introduction

The lifespan of an engineering structure or infrastructure is totally dependent on the stability and strength of the foundation on which it is built. The design of the foundation is primarily determined by the competence of the geologic material present; thus, characterization of soil competency is usually carried out either to determine the suitability of the characteristics of a site to host a structure or to investigate the anticipated environmental implication of such structures. [1,2] Mineralogy, the nature of particle contact, rock texture, weathering agents and the degree of compaction and cementation all influence the strength or competence of a geologic material. [3,4] Conventionally, to characterize the competence of sub-surface material, sub-soil boring using an auger or penetrating cone is employed for sample collection, after which laboratory analysis is carried out on samples for geotechnical properties such as grain size distribution, plasticity index property, load bearing capacity and soil compressibility. [5] However, in recent times, engineering geophysics has successfully been employed for insitu sub-soil characterization. The electrical resistivity method is the most commonly used in site investigations because the electrical resistivity of earth materials is determined by the amount and concentration of saturating fluid, degree of fracturing, rock texture, degree of grain cementation, degree of compaction and extent of weathering all which have a significant impact on the competence of such earth materials. [6-9]

Clay with low resistivity values (< 100 ohm-m) are considered incompetent materials due to their tendency to flow under stress; high resistivity laterite, compacted earth material and crystalline rock are considered competent because they can endure stress. [10] Electrical resistivity is also linked to geotechnical index values; soils with a higher liquid limit or plasticity index have lower electrical resistance, implying lesser competence. [11, 12] Geo-electric methods have, thus, proven to be a fast, relatively cheap and non-invasive method for effective subsurface characterization [13].

The Federal University Otuoke campus in Bayelsa state is in its developmental stages; as such, it is an active construction site where new buildings and infrastructures are being developed. There is currently no existing research work on the engineering competency of soils in the area, and there have been several reports of collapse of structures in the area, questionable integrity of structures currently in use with massive cracks due to uneven settlement of soils can be observed around campus. Knowledge of the competency of the sub-soil across the area is thus very crucial in determining the design of the foundation of individual structures and infrastructures and also investigating the environmental impact of such designs on the environment.

2. Geology of Study Area

The area under study is within the East Campus of the Federal University Otuoke in Ogbia LGA of Bayelsa State, and it is located on Latitude 04°42´23.4” N and Longitude 06°19´44.5” E within the coastal area of the sedimentary Niger Delta basin in the southern axis of Nigeria (Figure 1). The area is generally low-lying and drained by creeks and tributaries of the River Nun, which empties into the Atlantic Ocean. It is accessible by a network of major and minor roads.

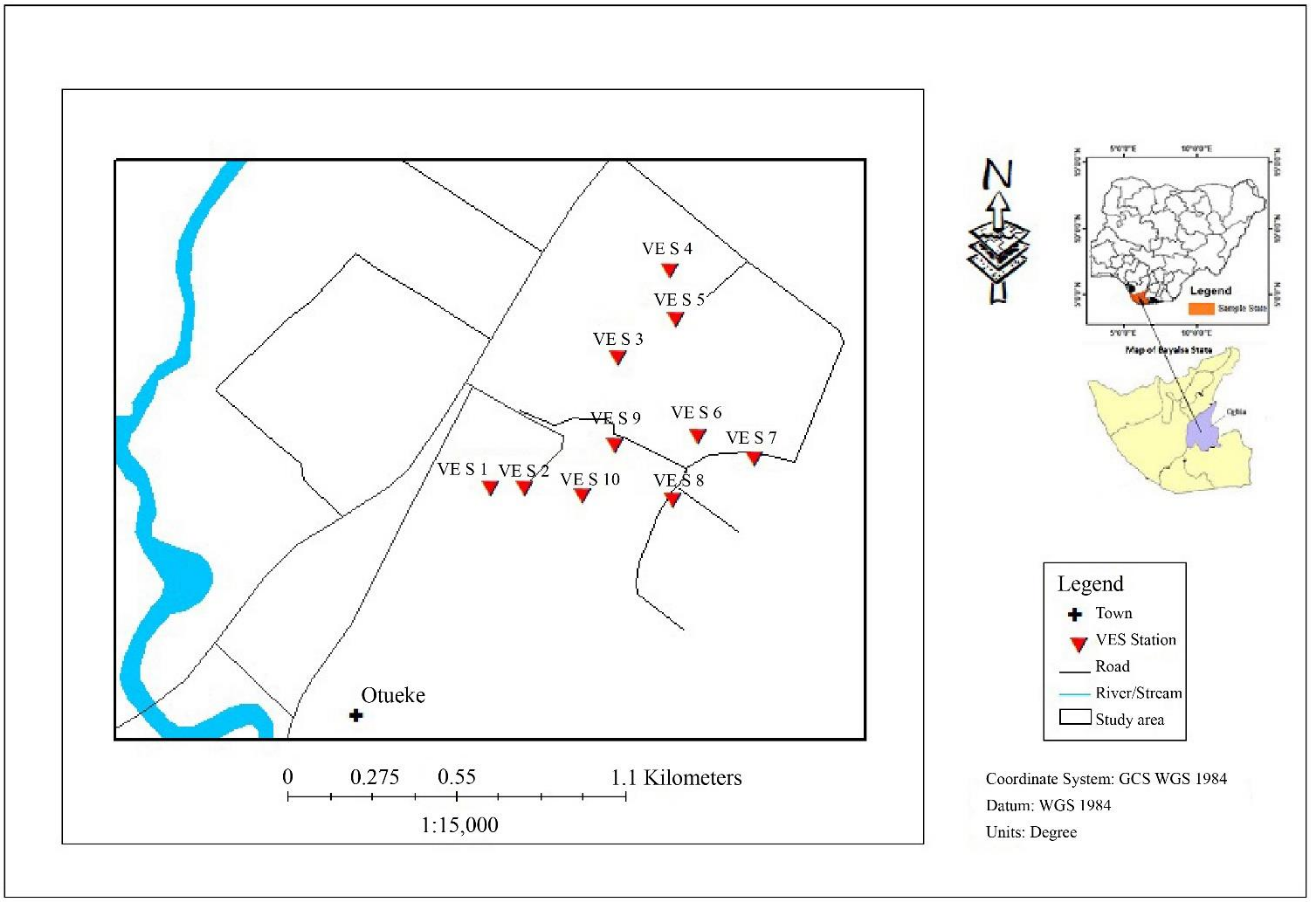

Fig. 1 Location map of study area showing VES stations

According to [14,15], the Niger Delta basin comprises sediments spanning over an area of seventy thousand square kilometres extending to a vertical profile of about twelve kilometres to the basement complex at the middle. It is flanked on the Northwest by the Benin flank, the Calabar Flank to the east and the Atlantic to the Southern [16]. The sediment assemblage in the basin was generated a the side of a failed arm of a triple junction “RRR” fault system when South American and the African plates were pulled apart by tectonism opening up the Atlantic Ocean during the Late Jurassic [17]. The Niger Delta is made of a single petroleum system called the Akata-Agbada petroleum system which formed in the Mid-Eocene [18]. Three lithostratigraphic units exist in the Niger Delta basin, namely the Akata Formation, which is characterized by a marine depositional environment comprising dark grey shales, which are the potential source rock material of the petroleum system. The Agbada Formation overlies the Akata FM, and it is composed of a sequence of sandstones and shales characteristic of a transitional or deltaic depositional environment. The sandstones that make up the Agbada Formation are good potential hydrocarbon reservoirs due to their high effective porosity. The Benin Formation, which is the youngest lithostratigraphic unit, overlies the Agbada FM, it is composed chiefly of sandstones with some intercalations of shales characteristic of a continental depositional environment. [19-21]

Table 1. Relationship between apparent resistivity and soil competence

Apparent Resistivity	Lithology	Competence Rating
<100	Clay	Incompetent
100 – 350	Sandy Clay	Moderately competent
350 – 750	Clayey Sand	Competent
>750	Sandstones	Highly competent

3. Materials and Methods

The Electrical Resistivity method is based on the response of the earth to the flow of electrical current. It involves introducing an electrical current into the ground via current electrodes. Using two potential electrodes, we record the resultant potential difference between them, giving us a way to measure the electrical impedance of the subsurface geology. The apparent resistivity measured is then a function of the measured impedance and the geometry of the electrode array. This research employed the Schlumberger electrode configuration with a maximum current electrode spread (AB) of 200 m. A total of Ten (10) Vertical Electrical Soundings (VES) were carried out on the East Campus of the Federal University Otuoke in Ogbia LGA of Bayelsa State to investigate a 1-D variation of geo-electric properties of the earth.

The ABEM Terrameter SAS 1000, a self-averaging digital device, was used for the field operation. The field procedure was carried out by applying current to the ground through two electrodes (A and B) and then measuring the resultant potential difference (ΔV) between the potential electrodes (M and N), which were fixed between the current electrodes. The centre point of the electrode array remained fixed, but the spacing of the current and, at times, potential electrodes was increased in line with the sounding programme for deeper sampling. The positions and surface elevations of the investigated points were also recorded during the survey with a GPS receiver.

The calculated apparent resistivity data were inverted using a computer-aided 1-D inversion modelling software known as IP2Win, which generated geo-electric profiles for sampled points. All depths were constrained with secondary lithological information obtained from boreholes in the vicinity of the study area. The Schlumberger configuration was employed in this study because it is fast and less likely to be influenced by lateral sub-surface variations. The correlation of subsoil resistivity and rating of the engineering competence of a geologic material was made by [1, 22].

This put forward that there is a direct proportional relationship between the resistivity of a geologic media and competence; as such, as the resistivity of a material increases the competence of the material for engineering purposes also increases. Clay layers are incompetent geologic materials because they tend to flow under stress; moderately competent layers, such as sandy clay, can endure stress partially. Clayey-sand layers are competent, which implies they can endure stress and would not flow under stress, while sandy layers are highly competent and can endure extreme levels of stress. The relationship between resistivity and soil competence by [1, 22] is presented in Table 1.

4. Results and Discussion

The modeled curve type and layer parameters generated from field data of the Ten (10) VES points occupied in this study are presented in Figure 2 and Table 2 below:

4.1. VES 1

This profile showed a total of 4 geo-electric layers. The type of curve associated with this VES is the HA-curve type represented by a resistivity trend $\rho1 > \rho2 < \rho3 < \rho4$. The competency of the subsoil from the top ranged from incompetent to competent. The geo-electric section showed a resistive topsoil with a thickness of 2.38 m and resistivity of 43.9 Ωm; this layer is incompetent and would not respond positively to stress. The second layer is composed of clay with a resistivity of 34 Ωm; it has a thickness of 13 m and extends to a depth of 15.4 m; like the topsoil, this layer is incompetent and, therefore, cannot endure stress. The third layer is comprised of sandy clay with a resistivity of 186 Ωm and thickness of 4.14 m, extending to a depth of 19.5 m; this layer is moderately competent and, therefore, can partially endure stress. The fourth layer is comprised of clayey sand, with a resistivity of 644 Ωm and thickness of 20.1 m extending to a depth of 39.6 m; it is competent and can withstand stress.

4.2. VES 2

This VES delineated 4 geo-electric layers having a resistivity trend of $\rho1 > \rho2 < \rho3 > \rho4$ represented by the HK-curve type. The competency of the station ranged from highly competent to moderately competent from the top. The geo-electric section showed a resistive topsoil to a thickness of 1.9 m with a resistivity of 1130 Ωm characteristic of sand, which is highly competent. Thus, the topsoil can endure extreme stress. The second layer is composed of clay with a resistivity of 44.5 Ωm; it has a thickness of 5.9 m and extends to a depth of 7.25 m. The second layer is incompetent and, therefore, cannot endure stress. The third layer comprised sand with a resistivity of 3055 Ωm and thickness of 17.5 m, extending to a depth of 24.8 m. This layer is highly competent and can endure extreme stress. The fourth layer is composed of sandy clay, with a resistivity of 183 Ωm, a thickness of 35.2 m extending to a depth of 60 m. This layer is moderately competent and, therefore, can endure partial stress.

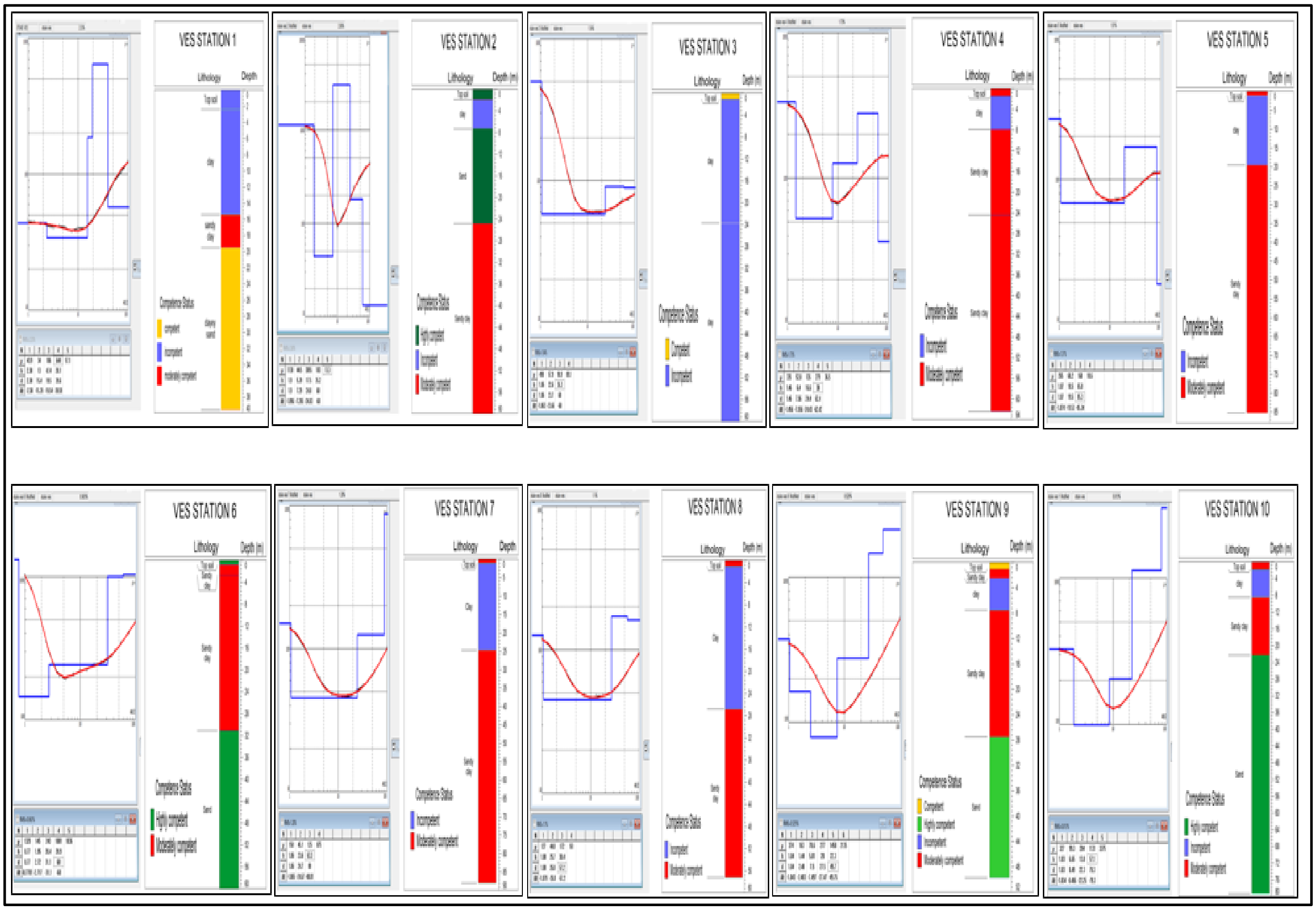

Fig. 2 Geo-electric curves and profiles showing variable classes of sub-soil competence for VES 1 – 10

Table 2. Geo-electric layer parameters of VES stations 1 – 10 and assigned class of competence of layers

VES NO.	LAYERS	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	CURVE-TYPE	LITHOLOGY	COMPETENCE
VES 1	1	43.9	2.38	2.38	HA	Topsoil	Incompetent
	2	34	13	15.4		Clay	Incompetent
	3	186	4.14	19.5		Sandy Clay	Moderately competent
	4	644	20.1	39.6		Clayey Sand	Competent
VES 2	1	1130	1.9	1.9	HK	Sand	Highly competent
	2	44.5	5.39	7.29		Clay	Incompetent
	3	3055	17.5	24.8		Sand	Highly competent
	4	183	35.2	60		Sandy Clay	Moderately competent
VES 3	1	498	1.06	1.06	H	Clayey Sand	Competent
	2	57.9	22.6	23.7		Clay	Incompetent
	3	90.9	36.3	60		Clay	Incompetent
VES 4	1	335	1.46	1.46	HA	Sandy Clay	Moderately competent
	2	52.8	6.4	7.86		Clay	Incompetent
	3	126	16.6	24.4		Sandy Clay	Moderately competent
	4	279	38	62.4		Sandy Clay	Moderately competent
VES 5	1	265	1.07	1.07	H	Sandy Clay	Moderately competent
	2	68.2	18.5	19.5		Clay	Incompetent
	3	168	65.8	85.3		Sandy Clay	Moderately competent
VES 6	1	1320	0.77	0.77	HA	Sand	Highly competent
	2	145	1.95	2.72		Sandy Clay	Moderately competent

	3	243	28.4	31.1		Sandy Clay	Moderately competent
	4	1001	28.9	60		Sand	Highly competent
VES 7	1	150	1.06	1.06	H	Sandy Clay	Moderately competent
	2	45.1	23.6	24.7		Clay	Incompetent
	3	125	63.3	88		Sandy Clay	Moderately competent
VES 8	1	127	1.08	1.08	H	Sandy Clay	Moderately competent
	2	44.8	25.7	26.8		Clay	Incompetent
	3	172	30.4	57.2		Sandy Clay	Moderately competent
VES 9	1	374	1.04	1.04	QHA	Clayey Sand	Competent
	2	163	1.44	2.48		Sandy Clay	Moderately competent
	3	78.6	5.01	7.5		Clay	Incompetent
	4	277	20	27.5		Sandy Clay	Moderately competent
	5	1458	22.3	49.7		Sand	Highly competent
VES 10	1	327	1.83	1.83	HA	Sandy Clay	Moderately competent
	2	99.3	6.65	8.49		Clay	Incompetent
	3	204	13.8	22.3		Sandy Clay	Moderately competent
	4	1131	57.1	79.3		Sand	Highly competent

4.3. VES 3

This VES profile showed a total of 3 geo-electric layers. The curve in this station showed a resistivity trend of ρ1> ρ2< ρ3 associated with the H-curve type. Interpretation of the geo-electric section showed a resistive topsoil with a thickness of 1.06 m and resistivity of 498 Ωm, and this layer is competent and, as such, can endure stress. The second layer is composed of clay with a resistivity of 57.9 Ωm; it has a thickness of 22.6 m and extends to a depth of 23.7 m. The second layer is incompetent and cannot respond well to applied stress. The third layer comprised clay with a resistivity of 90.9 Ωm and thickness of 36.3 m, extending to a depth of 60 m. The third layer is incompetent and, therefore, cannot endure stress.

4.4. VES 4

This VES profile delineated 4 geo-electric layers of the HA-curve type with a resistivity trend ρ1> ρ2< ρ3<ρ4. Geo-electric section showed a resistive top soil with a resistivity of 335 Ωm and thickness of 1.46 m. The first layer is moderately competent and can endure stress to a considerable extent. The second layer is composed of clay with a resistivity of 52.8 Ωm. It has a thickness of 6.4 m and extends to a depth of 7.86 m. The second layer is incompetent and, thus, will not respond well to external stress. The third layer comprises sandy clay with a resistivity of 126 Ωm and thickness of 16.6 m extending to a depth of 24.4 m. This layer is moderately competent and, therefore, can partially withstand extreme stress. The fourth layer is also composed of sandy clay, with a resistivity of 279 Ωm and thickness of 38 m, extending to a depth of 62.4 m. The fourth layer is moderately competent and, therefore, can endure moderate stress.

4.5. VES 5

This profile revealed 3 geo-electric layers of the H-curve type with a resistivity trend ρ1> ρ2< ρ3. The geo-electric section showed a resistive topsoil with a thickness of 1.07 m and a resistivity of 265 Ωm, which is moderately competent. The second layer is composed of clay with a resistivity and layer thickness of 68.2 Ωm and 18.5 m, respectively, extending to a depth of 19.5 m. The second layer is incompetent and cannot endure stress. The third layer comprises sandy clay with a resistivity of 168 Ωm and a thickness of 65.8 m. The third layer is moderately competent and, therefore, can moderately withstand stress.

4.6. VES 6

This profile delineated 4 geo-electric layers of the HA curve type representing a resistivity trend ρ1> ρ2< ρ3<ρ4. The competency of the station ranged from moderately competent to highly competent. The geo-electric section showed a resistive top soil with a thickness of 0.77 m with a resistivity of 1320 Ωm. This layer is highly competent. The second layer is composed of sandy clay with a resistivity of 145 Ωm; it has a thickness of 1.95 m and extends to a depth of 2.72 m. This layer is moderately competent, and therefore, it endures stress partially. The third layer comprises sandy clay with a resistivity of 243 Ωm and thickness of 28.4 m, extending to a depth of 31.1 m. this layer is moderately competent and, therefore, can endure moderate stress. The fourth layer is composed of sand, with a resistivity of 1001 Ωm and thickness of 28.9 m, extending to a depth of 60 m. This layer is highly competent and, therefore, can endure extreme stress.

4.7. VES 7

This VES profile showed a variation of 3 geo-electric layers. The type of curve associated with this VES is the H-type, representing a trend in the form of ρ1> ρ2< ρ3. The competency of the station ranges from incompetent to moderately competent. The geo-electric section showed a resistive topsoil with a thickness of 1.06 m and resistivity of 156 Ωm. This layer is moderately competent and will respond moderately to stress. The second layer is composed of clay with a resistivity of 45.1 Ωm. It has a thickness of 23.6 m and extends to a depth of 24.7 m. This layer is incompetent, and therefore, it cannot withstand stress. The third layer comprises Sandy Clay with a resistivity of 125 Ωm, thickness of 63.3 m, extending to a depth of 88 m; this layer is moderately competent and, therefore, can endure stress to an extent.

4.8. VES 8

3 geo-electric layers were delineated by this profile, a resistivity trend ρ1> ρ2< ρ3 representing the H-type curve. The geo-electric model showed a resistive topsoil with a thickness of 1.08 m and resistivity of 127 Ωm. The layer is moderately competent and, thus, can endure partial stress. The second layer is composed of clay with a resistivity of 44.8 Ωm. It has a thickness of 25.7 m and extends to a depth of 26.8 m. This layer is incompetent, and therefore, it cannot endure stress. The third layer comprises Sandy Clay with a resistivity of 172 Ωm, thickness of 30.4 m, extending to a depth of 57.2 m. this layer is moderately competent and, therefore, can endure partial stress.

4.9. VES 9

This VES profile showed a vertical section of 5 geo-electric layers. A resistivity trend of ρ1> ρ2> ρ3<ρ4< ρ5 representing the QHA-curve type. The competency of the station ranges from incompetent to highly competent. The geo-electric section revealed a resistive topsoil to a thickness of 1.04 m with a resistivity of 374 Ωm; this layer is competent and can endure stress. The second layer is composed of sandy clay with a resistivity of 163 Ωm; it has a thickness of 1.44 m and extends to a depth of 2.48 m. This layer is moderately competent, and therefore, it can endure extreme stress moderately. The third layer comprises clay with a resistivity of 78.6 Ωm and thickness of 5.01 m, extending to a depth of 7.5 m. This layer is incompetent and, therefore, cannot endure stress. The fourth layer comprised sandy clay with a resistivity of 277 Ωm and thickness of 20 m, extending to a depth of 27.5 m. this layer is moderately competent and, therefore, can endure partial stress. The fifth layer is comprised of sand with a resistivity of 1458 Ωm and thickness of 22.3 m, extending to a depth of 49.7 m. this layer is highly competent and, therefore, can endure extreme levels of stress.

4.10. VES 10

This VES delineated 4 geo-electric layers of the HA-curve type. The curve is associated with the resistivity trend ρ1> ρ2 <ρ3<ρ4. Interpretation of the geo-electric section above showed a resistive topsoil with a thickness of 1.83 m and resistivity of 327 Ωm; this layer is moderately competent and can endure partial stress. The second layer is composed of clay with a resistivity of 99.3 Ωm. It has a thickness of 6.65 m and extends to a depth of 8.49 m. This layer is incompetent, and therefore, it cannot endure stress. The third layer comprises sandy clay with a resistivity of 204 Ωm and thickness of 13.8 m, extending to a depth of 22.3 m. this layer is moderately competent and, therefore, can endure partial stress. The fourth layer comprises sand with a resistivity of 1131 Ωm and thickness of 57.1 m, extending to a depth of 79.3 m. This layer is highly competent and, therefore, can endure extreme stress.

5. Conclusion

This study was carried out with a view to characterize the vertical competency profile of the sub-soil using the Electrical Method in the study area. Geo-electric models obtained from the ten (10) stations occupied revealed four distinct geo-electric trends with results of layer character ranging randomly from incompetent to highly competent; Geo-electric profiles of VES stations 1, 4, 6 and 10 revealed four geologic layers with a trend ρ1> ρ2 <ρ3 <ρ4 associated with the HA-curve type; VES 2 penetrated four geo-electric layers with a trend ρ1> ρ2< ρ3> ρ4 associated with the HK-curve type; VES stations 3, 5, 7 and 8 delineated three subsurface layers with a trend ρ1> ρ2 < ρ3 associated with the H-curve type and VES 9 which revealed 5 distinct geo-electric layers of the QHA curve type with a resistivity trend ρ1> ρ2> ρ3< ρ4 < ρ5.

The study established the use of the Electrical Method to investigate sub-soil competence at Federal University Otuoke East Campus in Bayelsa State. Results showed high variability in the engineering competence of the subsoil across the area; also, the thicknesses of layers varied, implying that geologic materials were not laterally continuous. Variations in thickness observed may be due to sub-soil compaction differentials or other anthropogenic and geologic factors across the area. It is highly recommended that foundations for structures and infrastructures in the campus be designed separately due to subsurface inhomogeneity across the area as what might constitute a good structural foundation design in one area within the campus might not necessarily be suitable and safe in another area.

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