# Electrical Resistivity-Based Geotechnical Evaluation of Subsurface Competence for Structural Foundation Design in Federal University Otuoke

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***Abstract- Resistivity survey was conducted using the Vertical Electrical Sounding (VES) approach at Federal University Otuoke, Bayelsa State, to assess geophysical parameters relevant for evaluating subsurface suitability for building foundations. A total of eight (8) VES stations were investigated, employing the Schlumberger array for data acquisition, with current electrode spacing ranging from 1.0 to 140.0 meters. The acquired VES data were interpreted using IPI2Win+IP software. The Schlumberger array facilitated systematic data collection. A one-dimensional (1D) numerical inversion of the DC resistivity data was applied to improve result accuracy and achieve the study's objectives. The 1D inversion models from each VES point were utilized to generate geo-electric sections, which reveal the primary geo-electrical features of the subsurface geological units within the area. The identified subsurface layers include topsoil, clay, sandy clay, dry sand, and saturated fine/coarse sand. For safe structural development in the region, it is recommended that the topsoil be excavated down to the dry sand layer, which represents a more stable and competent foundation stratum to prevent structural failure or deformation.***

***Indexed Terms- Dry Sand, Schlumberger Array, Subsurface Competency, Foundation Failure***

## I. INTRODUCTION

Over the past ten years, there has been growing interest in the integration of geophysical techniques within civil and environmental engineering practices. In Nigeria, the frequent collapse of engineering structures—including buildings, roads, and bridges—has become a major concern, prompting both Federal and State Governments to mandate their town planning departments to establish building codes, particularly for structures exceeding one storey. Conducting foundation investigations has become a crucial step in construction and engineering projects to mitigate the risk of failure, as tragically demonstrated by the collapse of a 21-storey building in Lagos, which resulted in multiple fatalities.

Various methodologies have been applied in foundation studies, with geophysical methods, especially the electrical resistivity technique, gaining wide recognition for their effectiveness in resolving both engineering and environmental challenges (Zohdy, 1975; Barker, 1980). The electrical resistivity method is increasingly favored due to its cost-effectiveness, speed, simplicity, and capacity to reveal subsurface geological structures (Al-Sayed and El-Qady, 2007). In engineering, it is commonly applied in the assessment of foundations for dams, bridges, and buildings (Adeoti et al., 2008; Mahmoud et al., 2009). Beyond engineering, this method also plays a significant role in groundwater exploration, identification of pollution sources, and assessment of leachate impacts.

The current research is motivated by frequent foundation-related failures within the study area, which lacks adequate subsurface data in the existing literature. To address this gap, this study adopts a non-invasive geophysical approach—Vertical Electrical Sounding (VES) using the Schlumberger configuration—to assess the subsurface conditions of the West Campus, Federal University Otuoke. The goal is to evaluate the strength and reliability of subsurface materials to support future structural developments in the area.

## II. DESCRIPTION OF THE STUDY AREA

Otuoke, located in the southern part of the Niger Delta, lies within the geographic coordinates of latitude 4°46'N to 5°51'N and longitude 6°15'E to 6°23'E (Abadom and Nwakwoala, 2018). The region experiences two main climatic seasons—a wet season that spans April to October, and a dry season from November to March. With an average annual rainfall of approximately 3000 mm, the area benefits from substantial groundwater recharge. However, due to inadequate drainage systems, significant portions of the region become flooded during the rainy months, particularly from April through October or even into November. The area features a generally flat topography.

Geologically, Otuoke is situated within a coastal hydrogeological province made up of alluvial deposits, mangrove zones, and freshwater swamps, which are typical of Bayelsa State (Okiongbo and Ogobiri, 2011). It is part of the Niger Delta formation, and its subsurface composition predominantly consists of gravel, sand, clay, and silt.

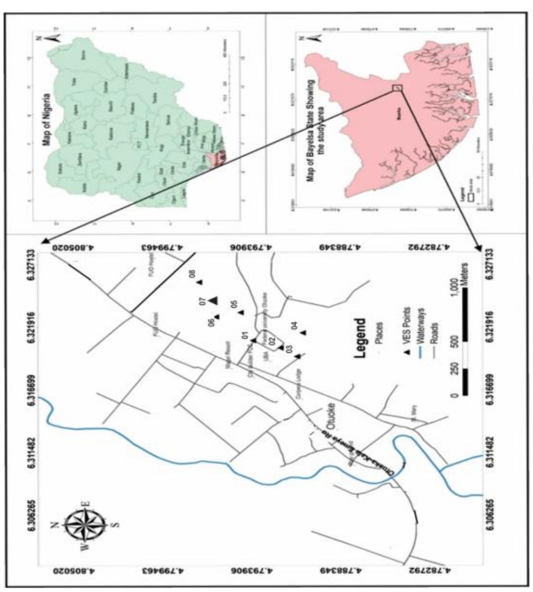


Fig.1.0 Map Showing VES locations

Resistivity measurements were carried out using the ABEM Terrameter SAS 1000 T instrument. The exact locations for each Vertical Electrical Sounding (VES) were recorded with a Global Positioning System (GPS) device. Prior to data collection, a reconnaissance survey was conducted to identify suitable sounding sites, and the coordinate points were plotted on a base map. To assess lateral variations in resistivity near the surface at a relatively constant investigation depth, Electrical Profiling—specifically the Constant Separation Traversing (CST) method—was employed. In this technique, both current and potential electrodes are systematically moved along a predetermined line, maintaining a fixed spacing between them.

Theory of Electrical Resistivity Method

Various electrode arrangements are employed in geophysical surveys to determine the resistivity of subsurface materials. Typically, these setups consist of two electrodes for injecting current, commonly designated as A and B, and two electrodes for measuring voltage, referred to as M and N. In the dipole-dipole configuration, the current electrodes A and B are positioned together on one side with a separation distance indicated as "a."

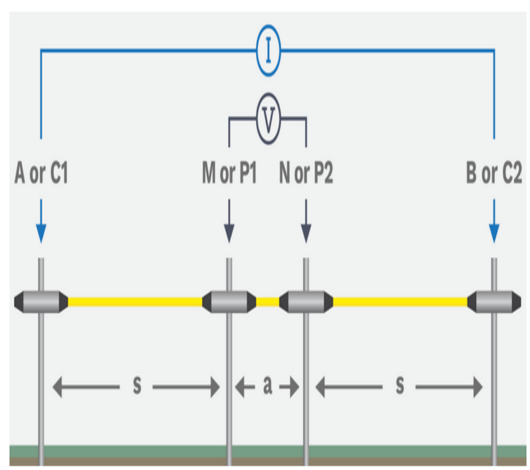


Fig 2 Schematics diagram of the Schlumberger array.

In the Schlumberger array, the current electrodes are typically positioned so that their separation distance is at least five times greater than that of the potential electrodes. This specific arrangement influences the geometric factor, which is calculated based on the general electrode spacing used in Vertical Electrical Sounding (VES), as expressed in the equation below:

$$AM = d_1 = a/2 - b/2;\ MB = d_2 = a/2 + b/2;\ AN = d_3 = a/2 + b/2;\ NB = d_4$$

$$= a/2 - b/2$$

$$G = 2\pi\left[\frac{1}{d_1} - \frac{1}{d_2} - \frac{1}{d_3} + \frac{1}{d_4}\right]^{-1} = 2\pi\left[\frac{2}{(a-b)} - \frac{2}{(a+b)} - \frac{2}{(a+b)} + \frac{2}{(a-b)}\right]^{-1}$$

$$= \pi\left[\frac{2}{(a-b)} - \frac{2}{(a+b)}\right]^{-1} = \frac{\pi}{2}\left[\frac{2b}{(a-b)(a+b)}\right]^{-1}$$

Or

$$G = \frac{\pi}{4}\left[\frac{(a-b)(a+b)}{b}\right] = \frac{\pi}{4}\left[\frac{a^2-b^2}{b}\right]$$

Vertical Electrical Sounding (VES) was conducted at eight designated locations within the study area using the Schlumberger electrode configuration (see Fig. 2 and Fig. 3). All eight VES stations were successfully occupied and measured. The collected field data were processed and interpreted with the IP2win software. The results were presented in the form of geoelectric sounding curves and geoelectric sections. Interpretation of these findings indicated a subsurface geology characterized by heterogeneous layers.

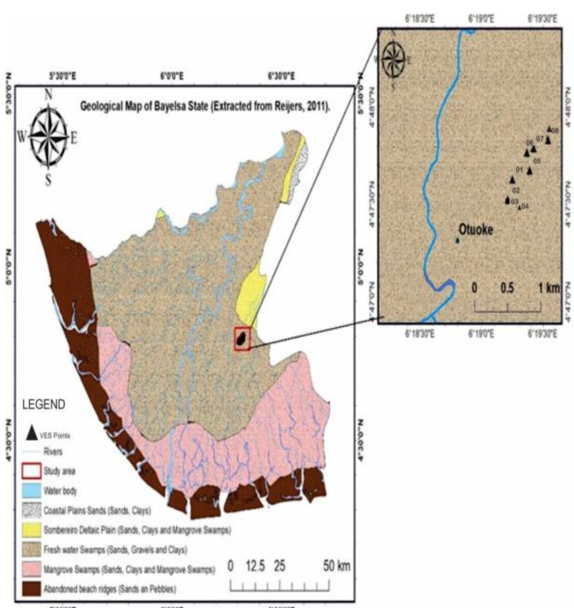


Fig 3: Geological map of Bayelsa State showing the location

## III. RESULTS AND DISCUSSION

The findings from the geophysical investigation are displayed through sounding curves, geo-electric sections, and maps. Layer models derived from all Vertical Electrical Sounding (VES) points are shown in Figures 1 through 8. Interpretation results indicate that VES points 1, 4, and 7 consist of three geo-electric layers, while VES points 2, 3, 5, 6, and 8 exhibit four geo-electric layers. The curve patterns observed include H-type for VES 1, HK-type for VES 2, 3, 5, and 6, K-type for VES 4 and 7, and KH-type for VES 8. A summary of the interpreted data is provided in Table 1.0.

At VES 1 (FUO NASU Secretariat), three layers were identified. The first layer has a resistivity of 133 Ωm, followed by a second layer at 13.5 Ωm, and a third layer with a higher resistivity of 568 Ωm. Thickness and depth values are 9.35 m for the first layer, 14.1 m thickness with 23.49 m depth for the second layer, and the third layer extends beyond the measured depth. These layers correspond to dry sand, clay soil, and saturated fine/coarse sand respectively, with an H-type curve pattern ($\rho_1 > \rho_2 < \rho_3$).

At VES 2 (Beside Faculty Building II, Humanity), four layers were detected: the first layer has resistivity of 124 Ωm, the second 10.4 Ωm, the third 316 Ωm, and the fourth 56.1 Ωm. The soil profile shows dry sand to a depth of 1.32 m, clay soil extending to 6.74 m with 5.41 m thickness, dry sand with a thickness of 17.7 m at 24.4 m depth, and saturated fine/coarse sand below. This station's curve is HK-type ($\rho_1 > \rho_2 < \rho_3 > \rho_4$).

For VES 3 (Faculty of Education), four layers with resistivities of 89.7 Ωm, 17.5 Ωm, 1010 Ωm, and 102 Ωm were recorded. The layers consist of dry sand (1.44 m depth), clay (7.14 m depth with 5.75 m thickness), dry sand (42.6 m thickness at 49.7 m depth), and saturated fine/coarse sand extending infinitely. The curve type matches HK ($\rho_1 > \rho_2 < \rho_3 > \rho_4$).

At VES 4 (road behind Faculty of Science, FUO), three layers were found: sandy clay at the surface, dry sand underneath, and saturated fine/coarse sand below. The aquifer lies at 35.9 m depth. Resistivity values are 74.4 Ωm, 829 Ωm, and 90.6 Ωm for the respective layers, showing a K-type curve pattern ($\rho_1 < \rho_2 > \rho_3$).

VES 5 (Behind FUO Female Hostel) shows four layers: surface sand (327 Ωm), clay soil (41.2 Ωm), dry sand (1374 Ωm), and saturated fine/coarse sand (327 Ωm). This station exhibits an HK curve type ($\rho_1 > \rho_2 < \rho_3 > \rho_4$).

At VES 6 (New PG Building site, FUO), four resistivity layers were noted: dry sand (231 Ωm), clay soil (60 Ωm), dry sand with high resistivity (2450 Ωm), and saturated fine/coarse sand (283 Ωm), also presenting an HK-type curve ($\rho_1 > \rho_2 < \rho_3 > \rho_4$).

VES 7 (FUO Engineering site) consists of three layers: sandy clay (9.57 Ωm) at 2.13 m depth, dry sand (9427 Ωm) with 30.4 m thickness at 32.6 m depth, and saturated fine/coarse sand (164 Ωm) extending infinitely. The curve pattern corresponds to K-type ($\rho_1 < \rho_2 > \rho_3$).

Finally, VES 8 (FUO back gate) displays four layers with a KH-type curve: sandy clay (41.2 Ωm) to 3.19 m depth, dry sand (1020 Ωm) with 10.4 m thickness at 13.6 m depth, saturated fine/coarse sand (11.6 Ωm) with 35.7 m thickness at 49.2 m depth, and clay (28.1 Ωm) extending beyond measured depth.

Table 1.0: Location of VES Stations

| VES NO | VES Stations/locations | Latitude | Longitude | Elevation (m) |
|---|---|---|---|---|
| 01 | Beside FUO NASU Secretariat building | N $04^0$ $47^l$ $37.7^{ll}$ | E $006^0$ $19^l$ $14.9^{ll}$ | 6 |
| 02 | Beside Faculty building II humanity | N $04^0$ $47^l$ $31.5^{ll}$ | E $006^0$ $19^l$ $12.7^{ll}$ | 6 |
| 03 | Beside Faculty of education | N $04^0$ $47^l$ $27.8^{ll}$ | E $006^0$ $19^l$ $10.1^{ll}$ | 3 |
| 04 | Behind Faculty of science | N $04^0$ $47^l$ $26.5^{ll}$ | E $006^0$ $19^l$ $17.2^{ll}$ | 9 |
| 05 | Behind FUO female hostel | N $04^0$ $47^l$ $40.5^{ll}$ | E $006^0$ $19^l$ $23.3^{ll}$ | 8 |
| 06 | FUO new PG building | N $04^0$ $47^l46.0^{ll}$ | E $006^0$ $19^l$ $22.0^{ll}$ | 6 |
| 07 | FUO Engineering site | N $04^0$ $47^l47.3^{ll}$ | E $006^0$ $19^l$ $25.3^{ll}$ | 7 |
| 08 | FUO new site back gate | N $04^0$ $47^l$ $49.8^{ll}$ | E $006^0$ $19^l$ $32.4^{ll}$ | 1 |

Table 2.0: Summary of Interpreted VES Data Results

| VES Names / numbers | Layer no. | Apparent Resistivity ρ (Ωm) | Thickness (m) | Depth to Bottom (m) | Inferred Lithology | Curve Type |
|---|---|---|---|---|---|---|
| Beside FUO NASU Secretariat building / 1 | 1 | 133.00 | 9.35 | 9.35 | Dry Sand | H |
| | 2 | 13.50 | 14.10 | 23.50 | Clay | |
| | 3 | 568.00 | ******* | ******* | Saturated Fine Coarse Sand | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Beside Faculty Building II Humanity/ 2 | 1 | 124.00 | 1.32 | 1.32 | Dry Sand | HK |
| | 2 | 10.40 | 5.40 | 6.74 | Clay | |
| | 3 | 316.00 | 17.70 | 24.40 | Dry Sand | |
| | 4 | 56.10 | ******* | ******* | Saturated Fine Coarse Sand | |
| Faculty of Education / 3 | 1 | 89.70 | 1.44 | 1.44 | Sand | |
| | 2 | 17.50 | 5.72 | 7.16 | Clay | HK |
| | 3 | 1010.00 | 42.60 | 49.70 | Dry Sand | |
| | 4 | 102.00 | ******* | ******* | Saturated Fine Coarse Sand | |
| Behind Faculty of Science/ 4 | 1 | 74.40 | 7.02 | 7.02 | Sand Clay | K |
| | 2 | 829.00 | 28.90 | 35.92 | Dry Sand | |
| | 3 | 90.60 | ******* | ******* | Saturated Fine/ Coarse Sand | |
| Behind FUO Female Hostel /5 | 1 | 327.00 | 1.30 | 1.30 | Sand | HK |
| | 2 | 41.20 | 1.91 | 3.21 | Clay | |
| | 3 | 1374.00 | 26.50 | 29.70 | Dry Sand | |
| | 4 | 327.00 | ******* | ******* | Saturated Fine Coarse Sand | |
| FUO new PG building /6 | 1 | 231.00 | 12.20 | 12.20 | Dry Sand | HK |
| | 2 | 60.00 | 7.96 | 20.20 | Clay | |
| | 3 | 2450.00 | 62.30 | 82.50 | Dry Sand | |
| | 4 | 283.00 | ******* | ******* | Saturated Fine Coarse Sand | |
| FUO Engineering Site /7 | 1 | 9.5700 | 2.13 | 2.13 | Sandy Clay | K |
| | 2 | 9427.00 | 30.40 | 32.60 | Dry Sand | |
| | 3 | 164.00 | ******* | ******* | Saturated Fine Coarse Sand | |
| FUO new Site back Gate /8 | 1 | 41.20 | 3.19 | 3.19 | Sandy Clay | |
| | 2 | 1020 | 10.40 | 13.60 | Dry Sand | |
| | 3 | 11.60 | 35.70 | 49.20 | Saturated Fine Coarse Sand | KH |
| | 4 | 28.10 | ******* | ******* | Clay | |

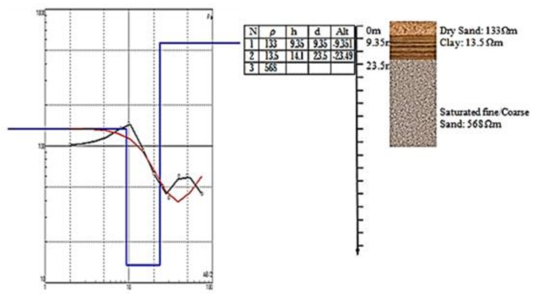


Fig 1.0 (a)VES 1 Plot of apparent resistivity against half electrode spacing (AB/2) and (b) geo-electric section of beside FUO NASU Secretariat building

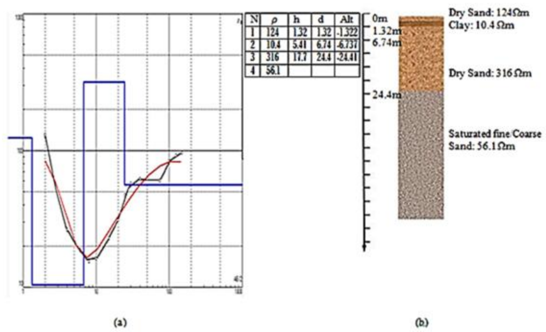


Fig 2.0 (a)VES 1 Plot of apparent resistivity against half electrode spacing (AB/2) and (b) geo-electric section of beside Faculty building II Humanity

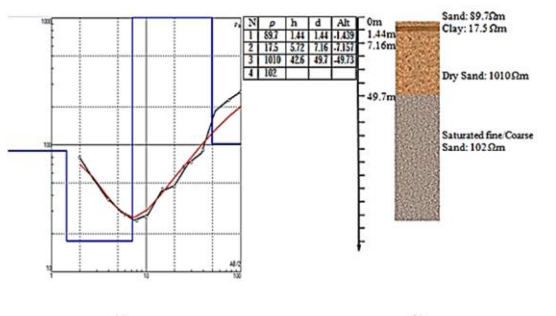


Fig 3.0 (a) VES 3 Plot of apparaent resistivity against half electrode spacing (AB/2) and (b) geo-electric section of road beside Faculty of Education

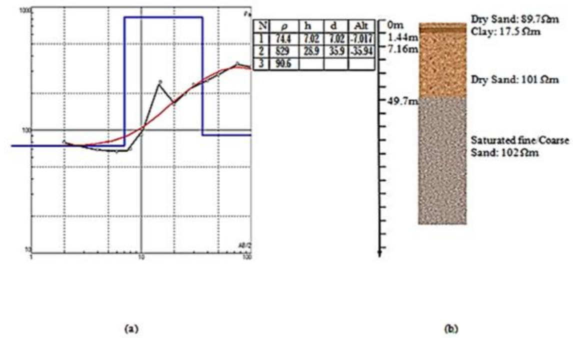


Fig 5.0 (a) VES 5 Plot of apparaent resistivity against half electrode spacing (AB/2) and (b) geo-electric section of road beside FUO Female Hostel .

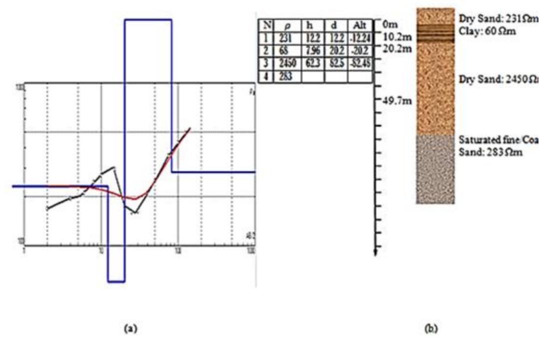


Fig 6.0 (a) VES 6 Plot of apparent resistivity against half electrode spacing (AB/2) and (b) geo-electric section for new PG Building site .

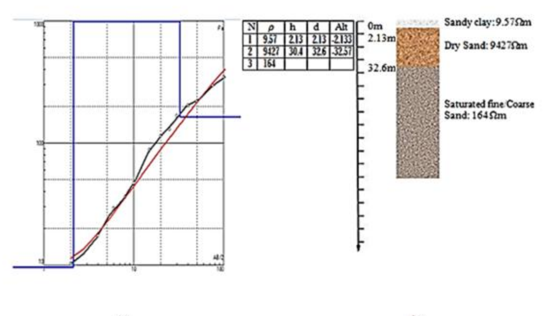


Fig 7.0 (a) VES 7 Plot of apparaent resistivity against half electrode spacing (AB/2) and (b) geo-electric section for FUO Engineering site .

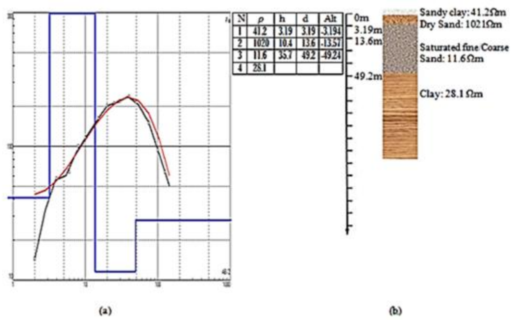

Fig 8.0 (a)VES 8 Plot of apparent resistivity against half electrode spacing (AB/2) and (b) geo-electric section for FUO Back gate .

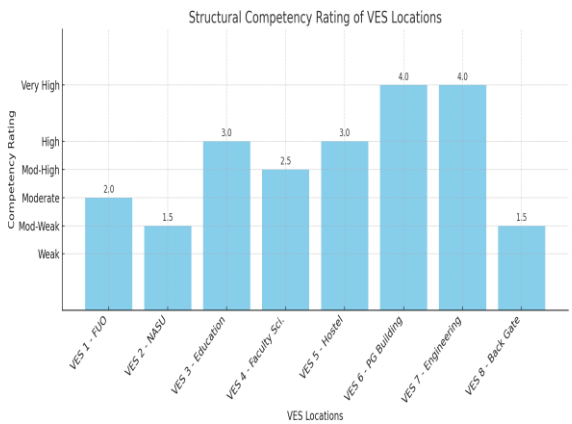


Fig 9.0 Structural competency rating of VES locations.

Table 3 showing layers of structural competency

| VES Station | Layer Composition | Layer Resistivity (Ωm) | Layer Competency | Suitability for Structure |
|---|---|---|---|---|
| VES 1 | Dry sand, Clay, Saturated sand | 133, 13.5, 568 | Moderate, Weak, Strong | Moderately suitable |
| VES 2 | Dry sand, Clay, Dry sand, Saturated sand | 124, 10.4, 316, 56.1 | Moderate, Weak, Moderate, Strong | Moderately suitable |
| VES 3 | Dry sand, Clay, Dry sand, Saturated sand | 89.7, 17.5, 1010, 102 | Moderate, Weak, Strong, Strong | Highly suitable |
| VES 4 | Sandy clay, Dry sand, Saturated sand | 74.4, 829, 90.6 | Moderate, Strong, Strong | Moderately - Highly suitable |
| VES 5 | Sand, Clay, Dry sand, Saturated sand | 327, 41.2, 1374, 327 | Strong, Weak, Strong, Strong | Highly suitable |
| VES 6 | Dry sand, Clay, Dry sand, Saturated sand | 231, 60, 2450, 283 | Strong, Moderate, Very Strong, Strong | Highly suitable ( very high competence) |
| VES 7 | Sandy clay, Dry sand, Saturated sand | 9.57, 9427, 164 | Weak, Very Strong, Strong | Highly Suitable ( very high competence) |
| VES 8 | Sandy clay, Dry sand, Saturated sand, Clay | 41.2, 1020, 11.6, 28.1 | Weak, Strong, Weak, Weak | Poorly suitable |

## CONCLUSION

The geoelectrical investigation carried out across eight Vertical Electrical Sounding (VES) stations within the Federal University Otuoke campus has provided a clear insight into the subsurface lithological distribution and its suitability for structural foundations. The resistivity data and interpreted geologic layers show a consistent pattern of alternating sand, clay, and sandy clay layers, with significant variation in thickness and resistivity values across the different locations.

At most VES points, the topmost layers are composed of dry sand or sandy clay, often with moderate to high resistivity values. These top layers are generally favorable for shallow foundations in light structural development, especially when the thickness is beyond 1.5 meters. However, the presence of underlying clay layers, which are widespread and vary from 1.9 to over 14 meters in thickness, poses a considerable engineering challenge. These clay units are characterized by low resistivity values and are known to have poor load-bearing capacities. They are also prone to water retention and differential settlement, which could compromise the integrity of structures founded directly on or within them.

Beneath the clayey zones, most locations reveal the presence of dry or coarse sand units with significantly high resistivity values, some extending deeper than 30 to 60 meters. These sand layers are highly competent, offering excellent structural support and stability. They serve as reliable load-bearing strata for deep or pile foundations, especially where surface and intermediate clay zones are unavoidable. In a few locations, notably behind the Faculty of Science, at the new PG building site, and the Engineering site, these competent sand layers are either shallow enough or thick and laterally extensive, making them particularly ideal for heavy or multi-storey structures.

Saturated sand and clay layers were also observed at greater depths in some profiles. These layers exhibit low resistivity due to their water content and tend to have poor geotechnical characteristics. Such water-bearing zones should be avoided as founding horizons. Where they occur below thick competent sand layers, their presence has minimal impact; however, if they lie closer to the surface or are only separated by a weak clay layer, structural amendments such as deeper foundation design or soil treatment become necessary.

Among the surveyed locations, the Engineering site stands out as the most structurally competent, with an exceptionally thick and highly resistive dry sand layer underlain by a moderately resistive water-bearing layer. The new Postgraduate Building site follows closely, offering more than 60 meters of high-resistivity dry sand, ideal for deep pile foundations. The area behind the Faculty of Science also shows a promising profile, with a thick, resistive sandy clay overlying moderately competent sand. These three locations present the most favorable geotechnical environments for both shallow and deep foundations, depending on the specific structural requirements.

Other locations, such as the Secretariat Building, NASU, and the area behind the female hostel, also show promise but require specific foundation designs to overcome the presence of intermediate clay. Structures can be erected in these areas with proper engineering design such as raft or pile foundations to transfer loads to deeper competent zones. Conversely, the location at the new site back gate exhibits the poorest conditions for shallow foundations, with weak and water-logged layers dominating the profile. Any development in such areas would require substantial soil improvement or avoidance altogether.

In conclusion, the VES study has identified zones of high structural competence and others requiring soil remediation or deep foundation systems. The understanding of resistivity-derived lithologies—particularly the recognition of dry sand and clay zones—plays a crucial role in guiding building foundation choices across the campus. For optimal structural integrity, careful geotechnical design should accompany the resistivity findings, especially in zones affected by clay and saturated layers.

Foundation Suitability Comparison: Engineering Site vs. Postgraduate (PG) Building Site

A comparison of subsurface conditions at the Engineering and Postgraduate (PG) Building sites reveals distinct advantages at each location. The PG Building site is characterized by a notably thick dry sand layer, approximately 62.3 meters in depth, with a resistivity value around 2450 Ωm. In contrast, the Engineering site has a thinner dry sand layer—measuring about 30.4 meters—but with a significantly higher resistivity of approximately 9427 Ωm.

This contrast points to a key engineering consideration: while the PG site provides a greater sand thickness, beneficial for very deep foundations, the Engineering site features a higher resistivity, which typically suggests lower moisture content, better compaction, and enhanced soil strength. In foundation design, high resistivity values are often indicative of more stable and load-bearing subsurface materials.

Although both sites contain saturated layers at greater depths, the Engineering site's combination of elevated resistivity and adequate sand thickness presents a strong and dependable foundation base. This makes it particularly suitable for moderate to deep foundations where strength and stability are essential. On the other hand, the PG site's thicker sand sequence is advantageous for very deep foundations or structures requiring substantial load-bearing capacity over extended depths.

In conclusion, selecting between these two locations should be guided by the structural demands of the proposed development. The PG Building site is more appropriate for extremely deep or heavy-load foundations, while the Engineering site provides superior material quality for moderately deep yet structurally demanding foundations.

## RECOMMENDATIONS

Although geophysical methods are not a direct replacement for geotechnical investigations—since they do not provide detailed soil strength parameters—they remain valuable for preliminary assessments. Their use can significantly reduce the number of boreholes required and lower the overall cost and duration of subsurface investigations. It is essential, however, to conduct geotechnical tests on the identified competent layers to evaluate their load-bearing capacity and determine suitable stabilizing additives. Therefore, integrating geophysical and geotechnical methods will lead to a more precise understanding of the subsurface stratigraphy within the study area.

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