

Geophysical Investigation of Foundation Condition of a Site in Olabisi Onabanjo University, Ago-Iwoye, Southwestern Nigeria

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Abstract: In this study, electrical resistivity techniques were employed to assess the subsurface conditions for the design of foundations at Olabisi Onabanjo University, Ago-Iwoye, in the southwestern part of Nigeria. The terrain of the area is part of the Precambrian Basement Complex terrain. A geophysical survey using Electrical Resistivity Imaging (ERI) and Vertical Electrical Sounding (VES) was conducted. The Wenner array was used to acquire three 80 m-long ERI profiles with 2 m electrode spacing. The Schlumberger configuration was used at each of the profile midpoints to perform three VES stations. The three dominant subsurface lithologic units were identified. A near-surface competent sandy layer (0.5–1.5 m thick) with resistivities ranging from 234–1,680 Ωm , which is too shallow and too laterally discontinuous to provide uniform structural support. Below this is an intermediate resistivity sub-competent sandy clay to incompetent clay (resistivity 53–386 Ωm) to a depth of 1.5–5 m. The high moisture content and low bearing capacity of this layer create a great danger of differential settlements under loading. Lastly, a deeper competent basement interval extending to depths exceeding 642 Ωm and represents partly weathered to fresh crystalline rock that is suitable for deep foundation structures. These lithological divisions were confirmed by the VES results. All three VES curves are of H-type and reveal: (1) a topsoil layer (1.6–1.9 m thick; 290–1,095 Ωm), (2) a clay/sandy clay layer (0.6–9.3 m thick; 55–193 Ωm), and (3) a basement horizon (2.2–13.1 m depth; 274–1,098 Ωm). However, the presence of thin competent sands over weak, moisture-rich clay highlights the need for foundation strategies like deep foundations and ground improvement techniques.

Keywords: Foundation; Subsurface; Resistivity; Structures.

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I. INTRODUCTION

The ability, stability, and longevity of civil engineering structures rely heavily on the competence and integrity of the underlying ground. Nigeria has experienced a troubling trend of collapses and failures of buildings and infrastructure in recent decades, many of which are said to have been caused by inadequate or poorly executed subsurface investigations before the construction of such buildings and infrastructure (Akinbiyi et al., 2021). The result of these structural failures has been loss of life, property damage, economic losses, and environmental consequences. Although poor quality construction materials and workmanship can lead to structural failure, poor assessment of foundation conditions and geology can be a major root cause of structural failure (Akinbiyi et al., 2021; Oyeyemi et al., 2020). The failure of the St. Francis Dam in Southern California on March 12, 1928, brought the value of subsurface exploration to civil engineering practice worldwide to the forefront. The dam's catastrophic collapse,

causing more than 400 deaths, was linked to construction on unstable geological material. Further investigations found that extensive geological and geotechnical investigations were not done before construction, meaning there would have been a chance to have determined the weaknesses within the canyon walls (Rogers, 2006). This event was pivotal in the history of engineering and paved the way for the formalization of engineering geology and geophysical studies for planning and design of civil infrastructure.

Precambrian Basement Complex rocks dominate the subsurface conditions in Southwestern Nigeria, making the conditions highly variable. Banded gneiss, quartz schist, biotite granite, pegmatite intrusions, and thick, deeply weathered overburden characterize the geology of the region. Multiple deformational and metamorphic events occurred during the formation of these lithological units, which created fractures, joints, foliation planes, and other structural discontinuities that have a significant impact on foundation

performance (Adetayo et al., 2013). Moreover, the laterite and clayey soils formed on these basement rocks may have varying engineering properties, including compressibility, plasticity, and moisture sensitivity, which complicates the assessment of the foundation and can be site-specific (Atilade et al., 2024). The objective of this study is to evaluate the condition of the subsurface for the purpose of foundation investigations by means of electrical resistivity techniques. The specific objectives are as follows: to obtain 2D resistivity images of selected profiles to determine the subsurface resistivity distribution; to determine the vertical changes in the subsurface layers using Vertical Electrical Sounding (VES); to identify weak zones, the depth of bedrock, and the competency of the subsurface for foundation works; and to provide recommendations for a safe foundation design based on the interpreted geophysical results.

II. GEOLOGIC SETTINGS OF THE STUDY AREA

The study area, which is within Olabisi Onabanjo University (OOU) main campus, lies within the latitudes $6^{\circ} 55'N$ and $6^{\circ} 57'N$ and longitudes $3^{\circ} 52'E$ and $3^{\circ} 54'E$. The physiography of the main campus and environs of Olabisi Onabanjo University is a product of geomorphic processes that have acted on the rocks in the area of Ago-Iwoye and adjacent towns such as Akanni (Akanni, 1992). The rivers in the study area flow from the NW and SE ends of the study area. The OOU main campus area climate is typical of the tropical

region of southwestern Nigeria with its well-defined wet and dry seasons. Rainfall is heavy, with high peaks during the rainy season from March to October, and most likely in June or July, which promotes thick vegetation. The dry season, on the other hand, is November through February when there are less rain and drier weather.

The study area is part of the Precambrian Basement Complex terrain of south-western Nigeria, an important geologic unit in Nigeria. The majority of the gneisses in the study area consist of various grades and suites, as well as granite, porphyroblastic, biotite, banded, and granite gneisses (Bayewu et al., 2017; Rahaman, 1976). Gneiss is found in the north, east, and some parts of the west, while granite is found in the southwest and southeast of the region (Figure 1). In the research region, some structures are observed, such as foliation, joints, and veins. Lateritic soils (silty clayey sand) tend to be finer and loamier than granite and gneiss soils. They have a higher mineral content, including quartz, feldspar, and mica, which provides them with a unique texture and composition. The soils, which include soils from gneiss and granite, have different properties that can help or hinder the longevity and effectiveness of foundations, such as stability, compaction, and drainage. For instance, gneiss soils that have a layered structure may have different levels of compatibility and drainage, and this can influence the way foundations can be constructed and maintained. To determine the composition and properties of the soil, engineers must evaluate the soil in these areas to design a foundation that is suitable.

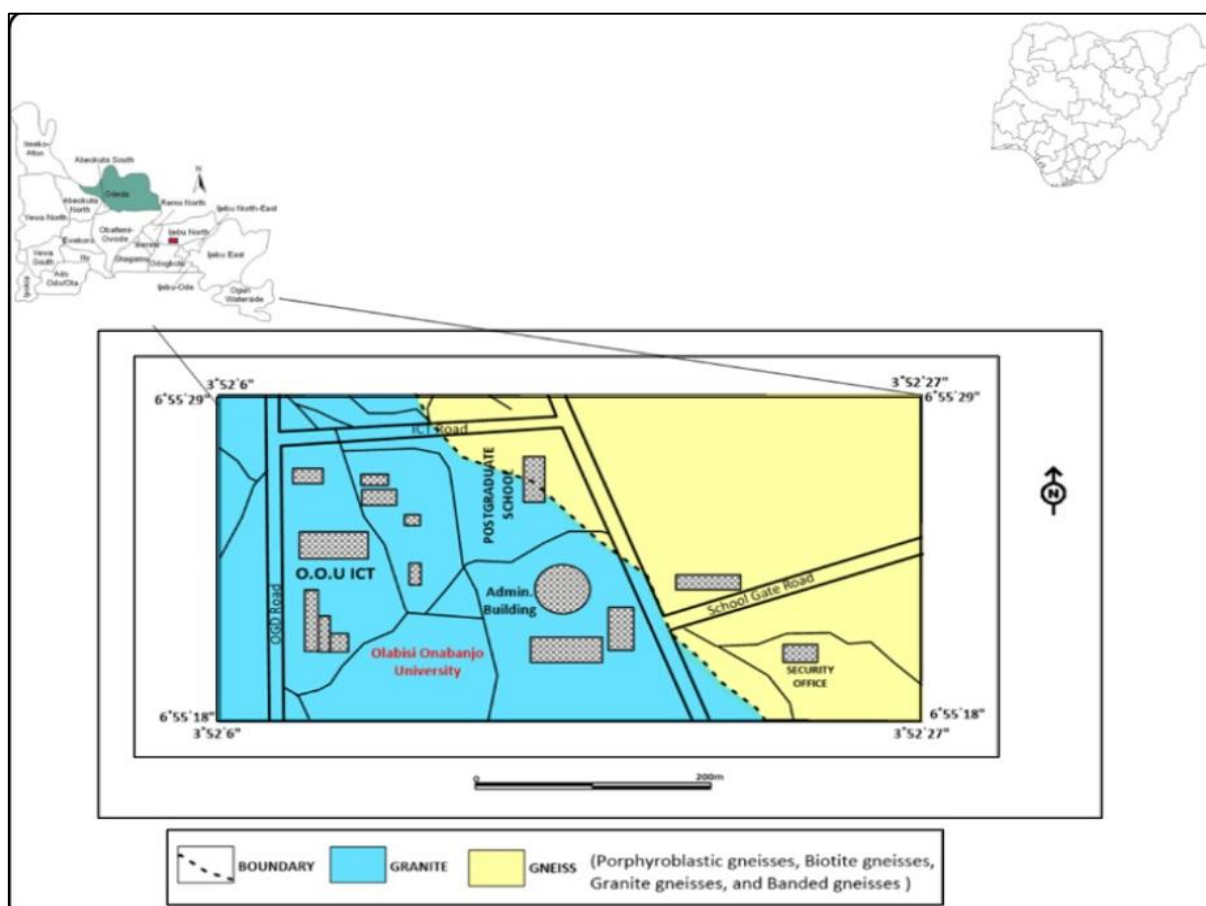


Fig 1 Geological Map of the Study Area Showing Rock Types (Bayewu et al., 2022).

III. METHODS

The geophysical methods employed in this study include:

- Vertical Electrical Sounding (VES) using the Schlumberger array configuration.
- Two-dimensional (2D) electrical resistivity imaging using the Wenner array configuration.

Three (3) 2D resistivity profiles were deployed to cover the lateral subsurface extent of the study site with an inter-profile spacing of 50 m. These profiles were 80 m long and are suitable for a good depth of investigation for foundation assessment in crystalline basement terrains. The 2D resistivity survey was done using the Wenner array configuration. This array consists of four electrodes arranged linearly at equal spacing. The outer electrodes are current electrodes through which direct current (DC) is passed into the ground, and the inner electrodes are potential electrodes that measure the voltage difference. The Wenner array was chosen because it had a high S/N ratio, was easy to deploy in the field, and was sensitive to vertical and lateral resistivity differences. The initial electrode spacing (a) was 2 m, and then measurements were taken at increments of 4 m, 6 m, 8 m, and 10 m. These spaced profiles enabled the acquisition of depth-sensitive data for five levels per profile. The greater the distance between the electrodes, the deeper the current penetration, allowing resistivity changes at various depths beneath the surface to be measured in the survey. This helped to improve the resolution of the subsurface features and gave useful information on lithological changes and foundation competency.

A Vertical Electrical Sounding (VES) survey was carried out, as well as 2D resistivity imaging to explore the variations in resistivity with depth and to estimate the depth to bedrock or to other competent layers. Unlike 2D imaging, the VES method also offers complementary information with regard to the vertical layering under a particular location. The Schlumberger array configuration was used for the VES measurements because it was sensitive to vertical resistivity changes and was easy to use in the field. This arrangement consists of a relatively stable inner pair of potential electrodes (MN) and a progressively expanded outer pair of current electrodes (AB) to enable deeper subsurface probing with little or no movement of the potential electrodes. The survey was conducted at three (3) VES stations. Each VES point was located at the midpoint (40 m mark) of the corresponding 2D resistivity profile to ensure correlation between lateral and vertical resistivity data. A central reference point was set at each of the VES stations, and electrode spacings were measured in a symmetric manner (with a measuring tape) around the central point. The present electrode spacing (AB/2) was gradually increased to explore deeper layers of the subsoil, with the potential electrode spacing (MN/2) being fairly stable and expanded only when the potential difference measured was too weak to be recorded. As the current was injected further away from the existing electrodes, the depth of the current in the subsurface was increased, giving measurements of the resistivity change with depth.

Apparent resistivity data from the 2D Electrical Resistivity Imaging (ERI) survey were processed and interpreted using 2D Electrical Resistivity Imaging (ERI) software, called RES2DINV, which is used for 2D inversion of resistivity data to make 2D resistivity models. The raw field data were first entered in a spreadsheet (Microsoft Excel) before being imported into RES2DINV. Three essential parameters were created for every profile:

- Midpoint – average position of the two possible electrodes.
- Electrode spacing (a) – distance between the adjacent electrodes.
- Apparent resistivity (ρ_a) – calculated from the field measurements.

Processed data were saved in a compatible format (.dat) and later imported into the program RES2DINV. The inversion procedure employed was based on an optimization method, in which least squares was used. The resistivity model was obtained by an iterative inversion that minimizes the difference between measured and calculated apparent resistivity values. The final product was 2D resistivity sections that displayed lateral and vertical resistivity changes. The geologic interpretation of these sections was used to delineate subsurface layers, to identify weak zones, to determine depth to bedrock, and to assess foundation competence in the study area.

The data from Vertical Electrical Sounding (VES) were processed using WinRESIST version 1.0 software. The two main parameters were prepared in Microsoft Excel, as follows:

- AB/2 – one-half the current electrode spacing.
- Apparent resistivity (ρ_a): Field values that are measured.

Data were plotted on a log–log graph to reveal the characteristics of the curves and make an estimate of the number of subsurface layers. At all three VES sites, a 3-layer geoelectrical structure was noted. Layer resistivities and thicknesses were first estimated by visual inspection of the curves and then fed into a computer model (WinRESIST).

IV. RESULTS AND DISCUSSION

The data from the three VES points are interpreted to indicate three layers; their resistivities indicate the presence of topsoil, sandy clay, and fresh basement.

➤ Interpretation of Vertical Electrical Sounding Results

- *Interpretation of VES point on Profile 1:* Profile 1 is made up of one Vertical Electrical Sounding (VES) point, which is VES 1. The resistivity of topsoil in the study area is 1095 Ωm , which is classified as highly competent; it is possible that dry lateritic or sandy soil with low moisture content and high bearing capacity. The second layer, which is interpreted as a weathered layer, has a resistivity of 55 Ωm , which is of low competency. This value is normally associated with the clayey or water-saturated weathered zone that is weak and compressible, and may result in differential settlement if foundations are placed in or above

this zone unless it is improved (Akinbiyi et al., 2021). The third layer, with a resistivity value of 274 Ωm , suggests a partially competent formation, possibly fractured bedrock or a moderately weathered basement, which can offer moderate to good bearing capacity depending on the degree of weathering and fracture density.

- **Interpretation of VES point on Profile 2:** Profile 2 is made up of one Vertical Electrical Sounding (VES) point, which is VES 2. The first layer has a resistivity value of 549 Ωm , corresponding to a relatively good topsoil, probably lateritic or sandy. The layer is relatively dry; it can be said that it has moderate to high bearing capacity and can be used for shallow foundations (Ozegin et al., 2012). The second layer has a resistivity of 110 Ωm ; this layer is weathered or clayey and is a low-competency layer. This is generally taken as an indication of a saturated or clay-rich horizon with low shear strength, high plasticity, and prone to settlement on loading. An unimproved foundation located directly over or close to this layer might experience instability or differential settlement (Akinbiyi et al., 2021). This is a very thin layer (0.6 m) and will probably not have a significant geotechnical effect, as the overlying and underlying layers are competent. The third layer shows a resistivity of 1098 Ωm , which is quite high and implies a competent to highly competent material, most likely fresh basement rock. This layer can be used for deep foundations

and may provide adequate support for structural loads, but should not be too deep (Omolaiye et al., 2024).

- **Interpretation of VES point on Profile 3:** The third Vertical Electrical Sounding (VES 3) indicates the presence of a three-layer subsurface sequence having different geoelectrical properties along the third profile in the study area. The resistivity of the first layer is 290 Ωm , and its thickness is 1.7 m. The material in this layer is believed to be lateritic topsoil of moderate competency. Resistivity indicates that the material is fairly dry and compact; thus, it will most likely have a satisfactory bearing capacity. This layer has a thickness of more than 1 m and may be used for shallow foundations such as structures under light to moderate loading conditions (Ozegin et al., 2012). The second layer below has a resistivity of 193 Ωm and a thickness of 0.9 m. This layer is interpreted as being a sandy clay, which is interpreted as having low to moderate geotechnical strength. This layer, however, is relatively thin (less than one meter) and will not significantly affect the overall performance of the foundation unless the imposed load is very high or if differential settlement is very critical (Akinbiyi et al., 2021). The final and third layer has a resistivity of 387 Ωm , typical of a weathered basement rock. The value of this resistivity indicates a partly competent subsurface material.

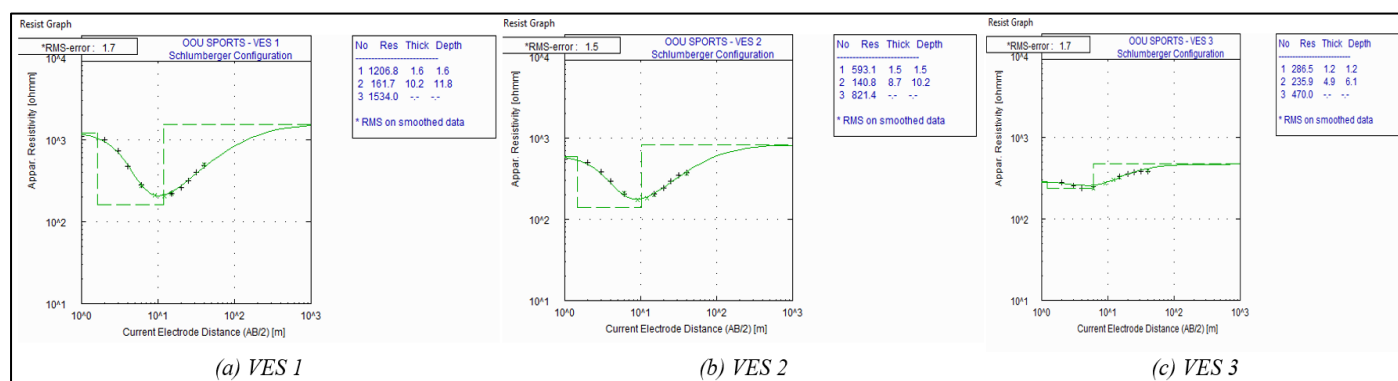


Fig 2 Iterated VES Curves Showing H-Type Curves for (a) VES 1, (b) VES 2, and (c) VES 3.

Table 1 Geoelectric Parameters for the Three VES Stations

VES NO	No of Layers	Resistivity (Ω)	Thickness (m)	Depth (m)	Inferred Lithology	Curve Type
1	1	1095	1.9	1.9	Topsoil	H
	2	55	9.3	11.2	Clay	
	3	274			Partially weathered basement	
2	1	549	1.6	1.6	Topsoil	H
	2	110	0.6	2.2	Sandy clay	
	3	1098			Fresh basement	
3	1	290	1.7	1.7	Topsoil	H
	2	193	0.9	2.6	Sandy clay	
	3	387			Weathered basement	

➤ Interpretation of 2D Resistivity Imaging Results

- **Interpretation of 2D Resistivity Profile 1:** The 2D resistivity section for Profile 1 shows that there is a multi-layered subsurface with high lateral and vertical resistivity changes. The highest resistivity values (642 to more than 1680 Ωm) are seen in the topmost layer, and it is observed

to spread laterally throughout the profile to a depth of about 1.5 m. This layer is interpreted as dry, compact, well-graded sand, indicating good engineering competence. But because of its thinness, it may not be able to bear heavy foundation loads by itself. The second layer has a noticeable lateral heterogeneity. Resistivity in the range of 246 Ωm to 642 Ωm from 16–24 m and 48–64 m along the

profile indicates good competence clayey sand, which is moderately suitable for foundation support. A low-resistivity zone (58.1–152 Ωm) is, by contrast, present between 32–48 m and deepens to shallow depths. The zone has been interpreted as being water-saturated and incompetent clay that has weak mechanical properties and can cause differential settlement, thus making it a potential geotechnical hazard. The zone of transition between 24–32 m, with a resistivity range between 152–246 Ωm , is interpreted to be sandy clay of sub-competent quality. The contrast in lateral resistivity is great in the second layer, reflecting strong facies variability, and highlighting the necessity of site-specific foundation design rather than uniform structural design. Resistivity also rises (>642 Ωm) at greater depths (beyond ~4.5 m), especially under the flanks of the profile. These zones are all considered to be fresh basement, which is mechanically competent material that can support stable foundations where overlying incompetent materials exist.

- *Interpretation of 2D Resistivity Profile 2:* The 2D resistivity section of Profile 2 shows up to three distinct layers within the subsurface with significant lateral variations. The top layer lies between 0 and about 0.5–1.5 m deep with medium resistivity values of 234 to 628 Ωm . This layer is interpreted as competent sandy topsoil, but it is laterally discontinuous in thickness and resistivity. The relatively high resistivity values (>628 Ωm) along the eastern end (64–80 m) indicate drier, more consolidated sand; the relatively low values (0–16 m) indicate greater moisture or finer-grained materials. The layer is moderately competent, but too thin to bear structural loads and can only be used as an overburden layer. The 2nd layer is found between 1.5 m and 5 m depth with lower resistivity values of 53–234 Ωm , especially between 16–64 m. This zone is considered to be saturated clayey sand and thus a possible geotechnical problem. It has a relatively low resistivity and lateral heterogeneity, indicating high moisture retention and low load-bearing capacity. Structures constructed directly on or in this layer could experience differential settlement and instability unless

suitable ground improvement works are undertaken. There is a third layer below this with moderately high to high resistivity values, rising from over 383 Ωm at shallower depths to over 1030 Ωm at greater depths. The layer, which is clearly visible starting at about 5 m downwards, is taken as a partially weathered to fresh basement rock. The higher resistivity and depth continuity suggest better mechanical competence. If this unit is sufficiently shallow and laterally continuous, it could be considered as a bearing stratum for deep or pile foundations.

- *Interpretation of 2D Resistivity Profile 3:* Three main subsurface units of the 2D resistivity section are identified for Profile 3, offering significant engineering implications. The highest resistance values (633 to 1037 Ωm) are found in the uppermost layer of soil, extending from 0.5–1.5 m below the surface. This layer is identified as competent, well-compacted sand, especially in profile edges (0–8 m, 72–80 m). The zones are deemed to be suitable for shallow foundation systems because of their potential to be dry and their strength. Like the other profiles, however, the layer is relatively thin and may not be able to support heavy structural forces independently. This is underlain by a wide subcompetent sandy clay which underlies the central part of the profile (8–72 m) and has resistivities ranging from 144 to 386 Ωm . The moisture content of this unit is likely to be moderate, and there is reduced compaction, which will lead to lower bearing capacity. The lateral extent and thickness of this layer are very important, and it has been known to cause geotechnical problems for shallow foundations built in it, as it can lead to differential settlement and stability problems over time. A higher-resistivity zone (>1037 Ωm) is present in the center of the profile (around 36–44 m) at a depth of ~4.5–6.3 m. This zone is interpreted as a competent load-bearing zone of fresh crystalline basement rock. The technical scope of this unit provides a suitable foundation base for deep or pile-supported structures, particularly in locations where the overlying subcompetent layer is not suitable for shallow foundations and where suitable and accessible at moderate depth.

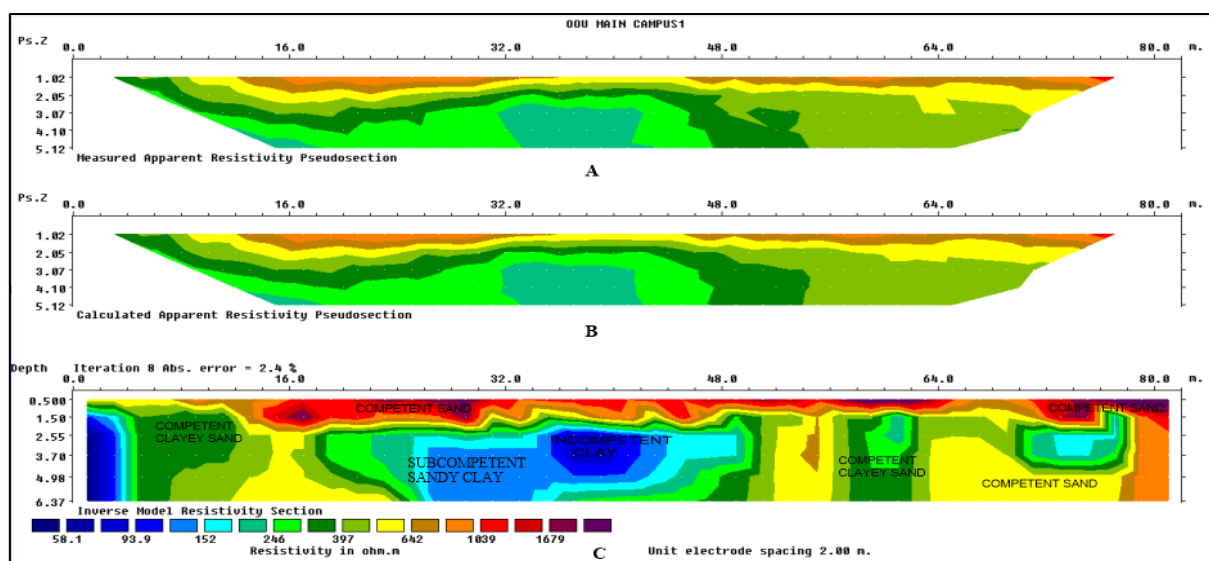


Fig 3 Inversion Model for Profile 1: (A) Field Data Pseudosection, (B) Theoretical Pseudosection, and (C) 2D Resistivity Structure.

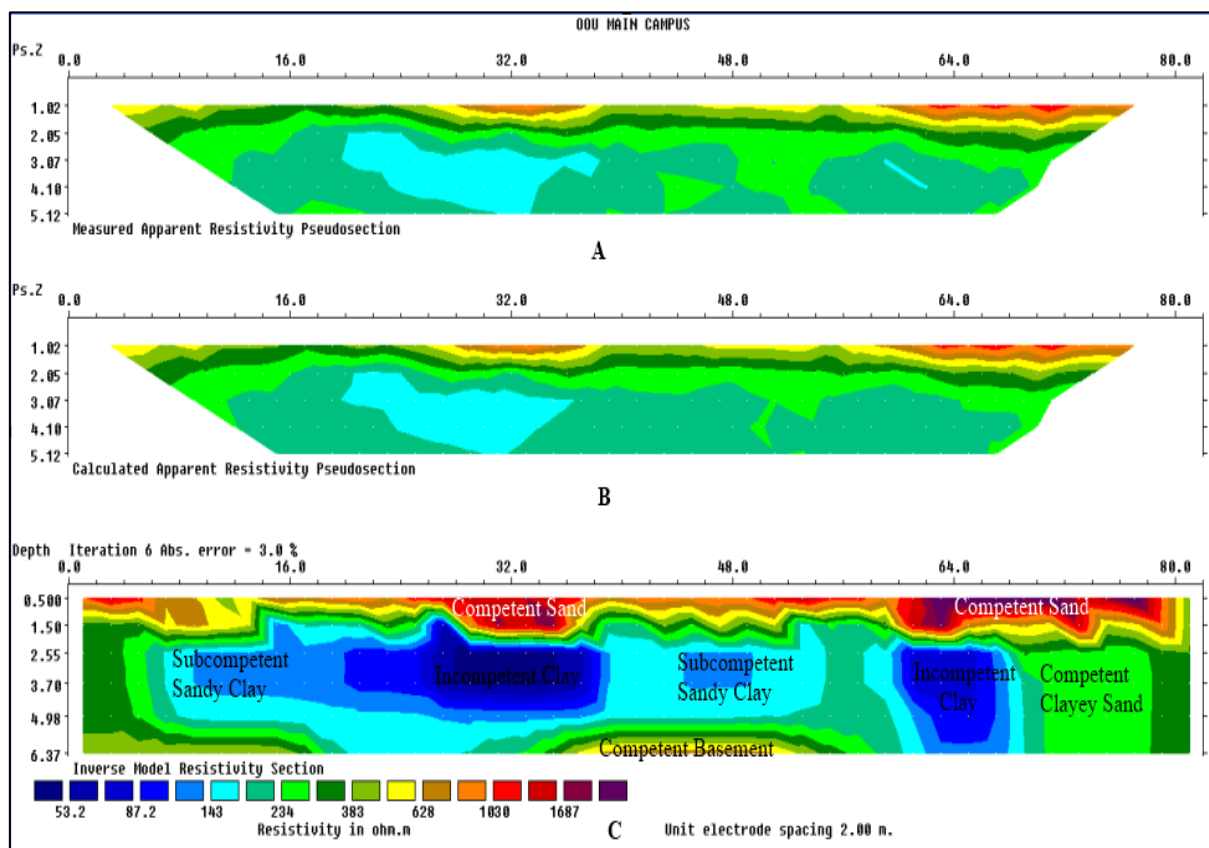


Fig 4 Inversion Model for Profile 2: (A) Field Data Pseudosection, (B) Theoretical Pseudosection, and (C) 2D Resistivity Structure.

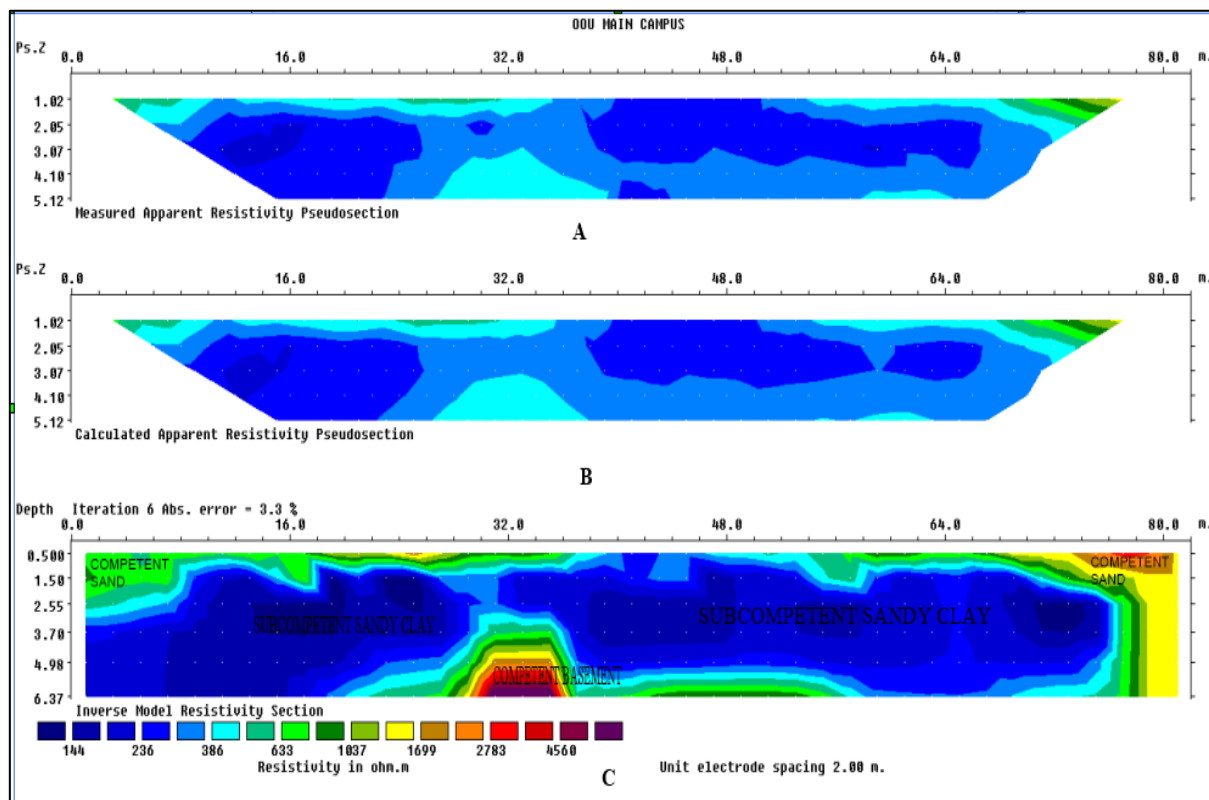


Fig 5 Inversion Model for Profile 3: (A) Field Data Pseudosection, (B) Theoretical Pseudosection, and (C) 2D Resistivity Structure.

V. CONCLUSION

The data from 2D resistivity imaging and VES show that there is variation in the subsurface in both the lateral and vertical directions in the study area. A thin competent sandy topsoil layer is present in places throughout the site but in most cases is too thin to sustain structural loads, especially where underlain by weak, moisture-sensitive clayey and sandy clay layers. The subcompetent material in the middle of the profiles dominates and carries a risk of differential settlements and reduced bearing capacities. Basement rock units at greater depths are the more stable and dependable foundation horizons, but vary in depth throughout the site. Thus, the foundation design should be site-specific and based upon geophysical results. In areas underlain by competent sandy soils, which are also laterally continuous enough, shallow foundations may be used; in areas where competent sandy soils exist but are extremely thin or discontinuous in their lateral extent, the use of deep foundations and ground improvement is recommended. In addition, borehole drilling and Standard Penetration Tests (SPT) should be performed to confirm the geophysical interpretations and to provide key engineering data for the safe and sustainable design of the structures.

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