### Original Research Article

### GEOPHYSICAL ASSESSMENT OF SUBSURFACE CONDITIONS AND THEIR IMPACT ON BUILDING FOUNDATIONS AT ALAMO, GBONGAN, OSUN STATE, NIGERIA.

**ABSTRACT**

This study assesses subsurface conditions for building foundation suitability in Alamo, Gbongan, Osun State, Nigeria, using an integrated geophysical approach. Vertical Electrical Sounding (VES) and 2D Electrical Resistivity Tomography (ERT) were conducted with ABEM SAS 300C Terrameter along three traverses. Data were processed using DIPROfWIN and WinRESIST software to generate 1D and 2D resistivity profiles.

The results delineated four subsurface layers: topsoil, weathered layer, fractured basement, and fresh basement. Low-resistivity zones (6–60 Ωm), associated with clay-rich and saturated materials, were deemed geotechnically weak. In contrast, zones with resistivity values above 200 Ωm indicated competent basement rock suitable for structural foundations.

The alignment between VES and ERT findings validates the interpretations and emphasizes the effectiveness of combining these methods. The study underscores the value of detailed geophysical surveys in foundation planning, particularly in geologically complex terrains, to reduce structural failure risks.

Keywords: *Electrical Resistivity Tomography (ERT); Foundation Suitability; Precambrian Basement Complex; Subsoil Competence; Vertical Electrical Sounding (VES)*

**1. INTRODUCTION**

The safety and durability of building foundations heavily rely on the nature of the subsurface materials, especially in regions where geological formations exhibit considerable variability. In Alamo, Oke-Ola, Gbongan, Osun State situated in Southwestern Nigeria, there has been a noticeable rise in cases of structural damage and building collapse. These failures are often linked to insufficient assessment of subsurface conditions prior to construction (Bremmer, 1999;Fajana,2021; Fakere et al., 2012). A major contributing factor is the complex interaction between the area's diverse geology and inadequate site investigation techniques, leading to the construction of structures on clay-dominated or extensively weathered soils with poor load-bearing capacity. Consequently, there is an urgent need for the adoption of more dependable methods for subsurface assessment.

Many studies have emphasized the efficiency of geophysical techniques, especially electrical resistivity methods, in mapping subsurface characteristics and detecting areas unsuitable for construction. (Samouëlian et al., 2005; Adepelumi & Olorunfemi, 2000; Akintorinwa & Adeusi, 2009, Ojo *et al*, 2024). Techniques such as Vertical Electrical Sounding (VES) and 2D Electrical Resistivity Tomography (ERT) have been recognized for their non-destructive, cost-effective nature, and ability to provide detailed insights into subsurface stratigraphy, heterogeneities, and moisture variations over large areas. Despite their proven utility in engineering and environmental studies, these geophysical tools remain underutilized in foundation site assessments across Nigeria, where reliance on limited borehole data persists.

A key challenge in Gbongan and surrounding areas is the geological intricacy of the Precambrian Basement Complex. This includes weathered rock profiles, fractured zones, and soil layers that may contain expansive clay. Such conditions contribute to foundation failure but are not always adequately identified through conventional geotechnical approaches (Oyelami & Van Rooy, 2016; Oyelami et al., 2023). Even though integrated geophysical investigations have shown success in comparable geological settings, there remains a notable gap in detailed, location-specific geophysical studies for this region hindering effective construction planning.

Alamo, Oke-Ola in Gbongan, forms part of the **Precambrian Basement Complex** that characterizes much of southwestern Nigeria. Geologically, this region lies within the **Pan-African mobile belt**, bounded by the **West African Craton** to the west and the **Congo Craton** to the east (Tanko & Chime, 2021). The basement rocks in this terrain are diverse and are broadly categorized into four major units: the Archean to Early Proterozoic **gneiss–migmatite–quartzite complex**, the Proterozoic **supracrustal schist belts**, the **Neoproterozoic Pan-African granites and related granitoids,** and the younger **felsic and mafic intrusive rocks** from the late Neoproterozoic to Early Paleozoic periods (Rahaman, 2006).

The **gneiss–migmatite–quartzite complex** dominates the bedrock geology, with schist belts preserved as elongated strips within this framework (Whiteman). These older rock units are intruded by **Pan-African granitic bodies**, including **biotite and muscovite granites** as well as **granodiorites** (Rahaman, 2006). In addition, minor intrusive bodies such as **pegmatites, aplites, dolerites**, and **lamprophyres** occur as dykes and sills, cross-cutting all pre-existing rock types (Fakere et al., 2012; Oyelami & Van Rooy, 2016).

In Gbongan specifically, these geological divisions are well represented. The western section of the district is predominantly composed of the **gneiss–migmatite complex**, which appears in two north-south trending zones divided by a linear schist belt (Adepelumi & Olorunfemi, 2000). The schist units include **talc–tremolite–actinolite schists** and **amphibolites,** while Pan-African intrusives such as **biotite granite** and **granodiorite** are widespread throughout the region (Rahaman, 2006). Moreover, **dolerite dykes** intrude various parts of the bedrock, further emphasizing the structural complexity of the area (Burke *et al*., 1971).

This intricate geologic framework underscores the importance of detailed **geophysical investigations,** particularly for foundation studies. Diverse subsurface materials and structural discontinuities in the area may significantly influence foundation behavior and, if not properly assessed, pose serious risks to structural stability (Oyelami *et al*., 2023; Idornigie et al., 2006).

To bridge this knowledge gap, the present study combines VES and 2D ERT methods to evaluate the subsurface integrity of Alamo, Gbongan. By distinguishing between soil layers such as the topsoil, weathered zones, fractured bedrock, and fresh basement, this research aims to provide detailed spatial information on subsoil variability. The findings are intended to guide foundation design, mitigate structural risks, and support safer infrastructure development in geologically complex basement terrains (Oyelami et al., 2023; Cosenza et al., 2006). The aim of this investigation is to evaluate the subsurface geoelectric characteristics of Alamo, Gbongan, using integrated Vertical Electrical Sounding (VES) and 2D Electrical Resistivity Tomography (ERT) techniques. The goal is to delineate weak and competent zones within the subsurface that affect foundation stability, and to provide geophysical data that can guide safe and effective foundation design in the geologically complex terrain of the Precambrian Basement Complex.

### ****2. Materials and Methods****

### 2.1 ****Site location of the investigation****

Alamo community is located in Gbongan, the primary administrative center of Aiyedade local government area of Osun State, southwestern Nigeria. Geographically, Gbongan is positioned at approximately **latitude 7° 28′ 38″ N** and **longitude 4° 21′ 12″ E** (Figure 1).

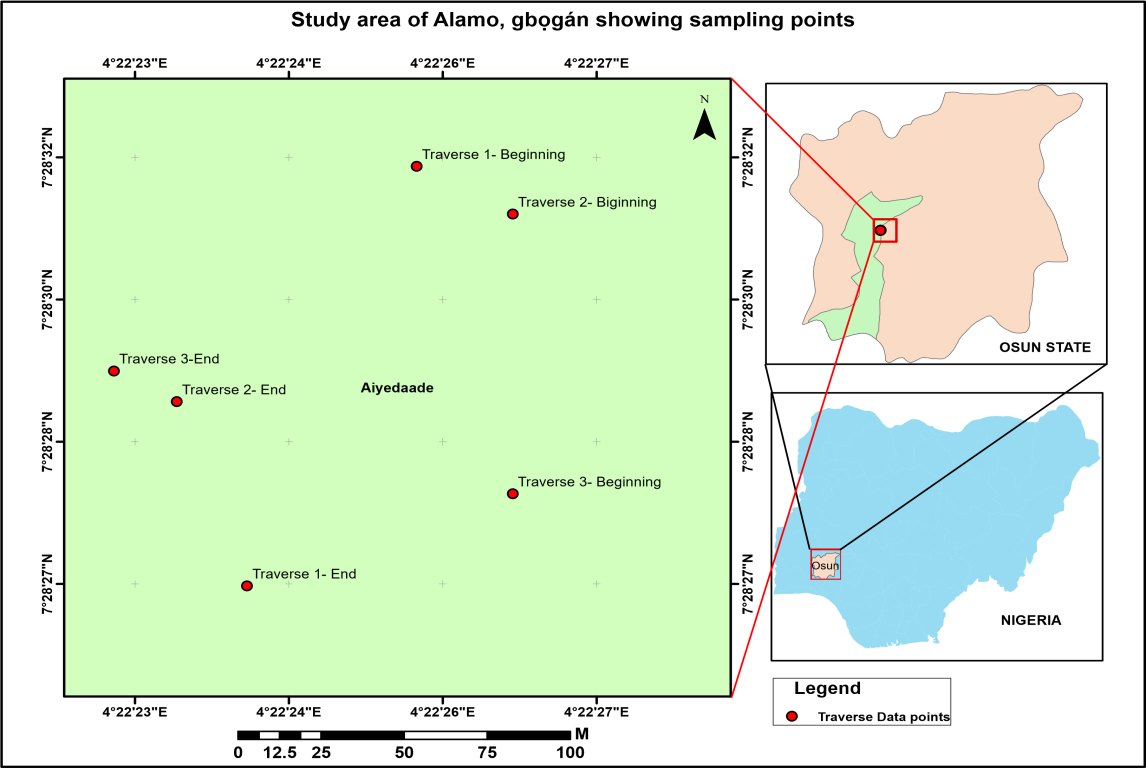


Figure 1: Location and data acquisition map of the study area

This geophysical investigation employed essential tools and equipment for conducting electrical resistivity surveys. The primary instrument used was the **ABEM SAS 300C Terrameter**, a well-regarded resistivity meter suitable for both **Vertical Electrical Sounding (VES)** and **2D Electrical Resistivity Tomography (ERT).** Additional field accessories included **electrodes, connecting cables, measuring tapes,** and **hammers** for electrode installation. A **handheld GPS device** was also utilized to accurately record and geo-reference the coordinates of all survey locations across the study traverses.

### ****2.2 Site Reconnaissance****

An initial site visit to **Alamo, Oke-Ola, Gbongan** was carried out to understand the general geological conditions, soil types, and existing infrastructure. GPS technology was used to plan and demarcate the survey layout. Three **traverses** each spaced **30 meters** apart and approximately **150 meters** long were established in the study area. Along each traverse, **survey stations** were set at **10-meter intervals**.

**2.3 Geophysical data collection**

**To improve the accuracy and reliability of subsurface characterization, data were collected over a 3-month period, encompassing both dry and early rainy season conditions. Geophysical measurements were conducted three times, in late dry season (March), the onset of rains (April), and during early wet conditions (May) to capture short-term hydrological influences on subsurface resistivity.**

**This approach allowed the identification of resistivity variations due to moisture content changes, particularly in clayey and weathered zones, which are sensitive to seasonal water infiltration. Apparent outliers resulting from environmental or instrument-induced noise were identified using statistical filtering, and final interpretations were based on averaged resistivity values across the three measurement sessions. Emphasis was placed on the lowest resistivity values, typically occurring in the early wet period, to ensure foundation recommendations were based on the most critical conditions.**

#### ****2.3.1 Electrical Resistivity Tomography (ERT)****

A **2D electrical resistivity survey** was conducted along the selected traverses to investigate the stratification and physical properties of the subsurface and to locate potentially weak zones. Data acquisition was performed using the **ABEM SAS 300C TERRAMETER** in a **Dipole–Dipole array configuration**. Electrodes were systematically deployed along the profiles. The **Schlumberger configuration** was also employed for specific measurements. Data were processed and inverted using **DIPROfWIN** and **WinRESIST** software, which generated subsurface resistivity models indicating zones of high and low resistivity corresponding to solid and weak ground materials, respectively.

#### ****2.2.2 Vertical Electrical Sounding (VES)****

**One (1) VES** survey was conducted along **Traverse 2** using the **Schlumberger array** configuration. The current electrode spacing (**AB/2**) ranged from **1 meter to a maximum of 40 meters**. In addition to the VES, a combination of **Horizontal Profiling and Vertical Sounding** using the **Dipole–Dipole array** was applied across **Traverses 1, 2, and 3**. This dual approach helped identify subsurface structures and provided both vertical and lateral resistivity variations. An inter-electrode spacing (**a**) of **10 meters** was used, while the **inter-dipole separation factor (n)** varied from **1 to 5**. Apparent resistivity values were plotted at intersection points defined by 45° projections from the midpoints of the current and potential electrodes. These values were used to produce **2D resistivity sections**, which guided the selection of the VES point on Traverse 2 for more focused correlation.

**3.0 RESULTS AND DISCUSSION**

### ****3.1 Electrical Resistivity Method****

#### ****3.1.1 Depth Sounding Curves****

A **single Vertical Electrical Sounding (VES)** was carried out along **Traverse 2** within the study location. The interpreted result of the VES is summarized in **Table 1**, and the curve obtained corresponds to the **A-type** resistivity curve. As shown in **Figure 2**, this curve type is characterized by increasing resistivity with depth.

This configuration suggests that the **topsoil,** typically ranging from **0 to 0.4 meters**—the zone where shallow foundations are often placed—exhibits **lower resistivity values** compared to the layers beneath. Such low near-surface resistivity values indicate that the topsoil has **poor geotechnical strength** and may not be ideal for supporting engineering structures.

Table 1: Summary of findings from VES interpretation

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| VES S/No | Layers | Resistivity Value (Ωm) | Thickness(m) | Lithological  Characteristics | Curve Type |
| 1 | 3 | 13.0  53.2    552.1 | 1.0  1.0    …. | Topsoil    Weathered Layer    Fresh Basement | A |

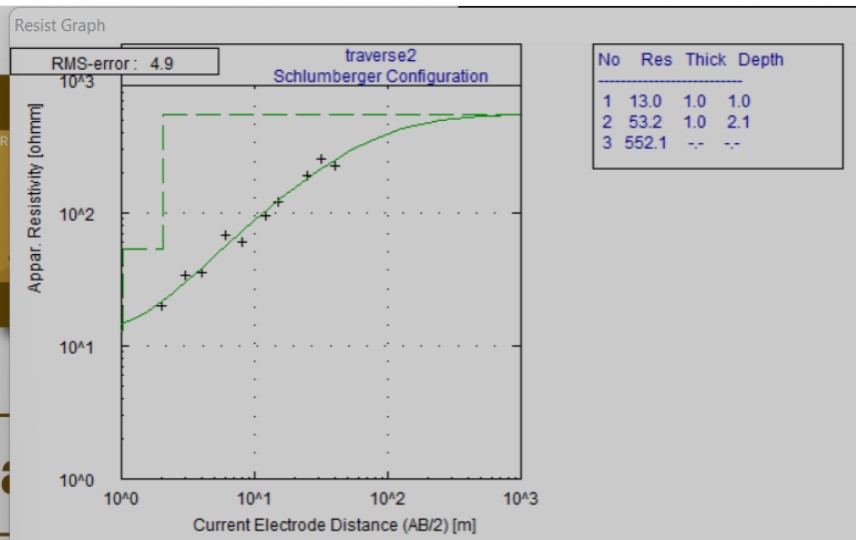


Figure 2:VES graphic interpretation (This study)

### ****3.2 Two-Dimensional (2D) Resistivity Structure****

The 2-D resistivity profiles derived from traverses 1, 2, and 3 in the study area are presented in Figures 3, 4, and 5. These profiles delineate four distinct subsurface layers: the topsoil, a weathered layer, a partially weathered or fractured basement, and the fresh basement rock. The topsoil is overlain by or merges with the low-resistivity weathered layer and exhibits very low resistivity values ranging between 6 and 60 ohm-m. This layer is represented by deep blue to green colour bands and occurs at depths and stations such as 2–7 (0–5 m), 7–9 (0–16 m), and 9–13 (0–6 m) along traverse 1 (Fig. 3); 2–6 (0–5 m), and 6–10 (0–5 m) along traverse 2 (Fig. 4); and 2–3 (0–5 m), 3–4 (0–5 m), 4–6 (0–9 m), 6–8 (0–5 m), and 8–11 (0–5 m) along traverse 3 (Fig. 5). These zones, dominated by clayey materials with high conductivity, are regarded as structurally weak and unsuitable for engineering foundations.

The second layer is the weathered zone, also marked by deep blue to green bands with resistivity values ranging from 6 to 54 ohm-m. The thickness of this layer varies across the profiles, ranging from 5 to 10 m at stations 7–8 on traverse 1; 1–3 m at stations 2–3, 4–6, and 6–10 on traverse 2; and 1–5 m at stations 2–3, 4–6, and 9–11 on traverse 3. Within this weathered layer, certain segments exhibit extremely low resistivity (8–27 ohm-m), indicating the presence of conductive clay-rich zones. These conductive features extend to depths between 1 and approximately 15 m at locations such as stations 7–9 (1–16 m) and 9–13 (1–6 m) along traverse 1; 2–6 (1–5 m) and 6–10 (1–5 m) on traverse 2; and 4–6 (1–9 m) on traverse 3. These highly conductive zones are also deemed geotechnically unstable for construction purposes.

The third subsurface unit is the fractured basement, identified by low resistivity values situated between solid basement rocks, particularly visible in Figures 3(iii) and 5(iii). These zones appear as bluish to greenish bands and have resistivity values ranging from 4 to 9 ohm-m. They occur within stations 7–8 (5–10 m depth) on traverse 1, 2–6 (1–5 m) on traverse 2, and 4–6 (1–9 m) on traverse 3. The fractured basement layer has a variable thickness of approximately 1 to 10 m and occurs at shallow depths (5–10 m), posing minimal risk to foundation integrity.

The fourth and deepest layer is the fresh basement bedrock, characterized by moderately high to very high resistivity values ranging from 66 to 252 ohm-m, indicated by yellow to red colouration. The depth to this competent basement rock ranges from less than 1 m to about 5 m across the traverses.



Figure 3: Traverse 1 2-D Dipole Dipole Interpretation

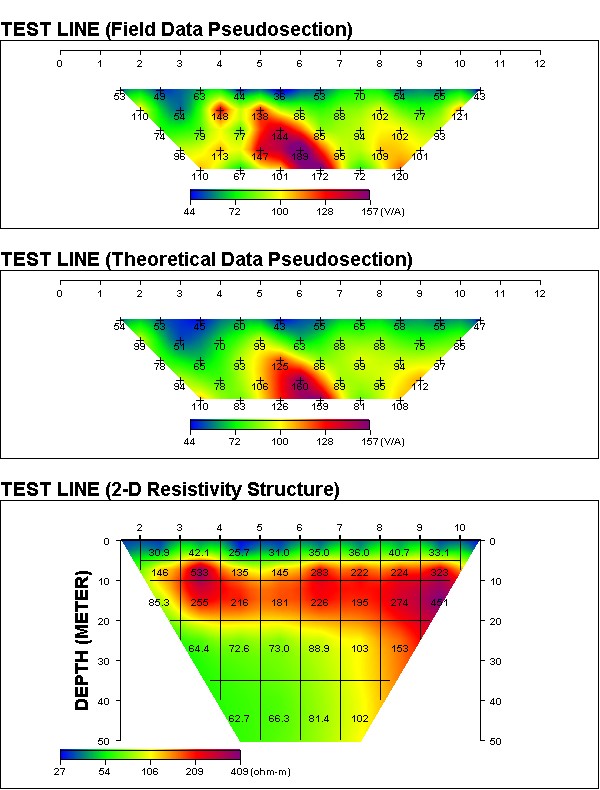


Figure 4: Traverse 2 2-D dipole dipole Interpretation

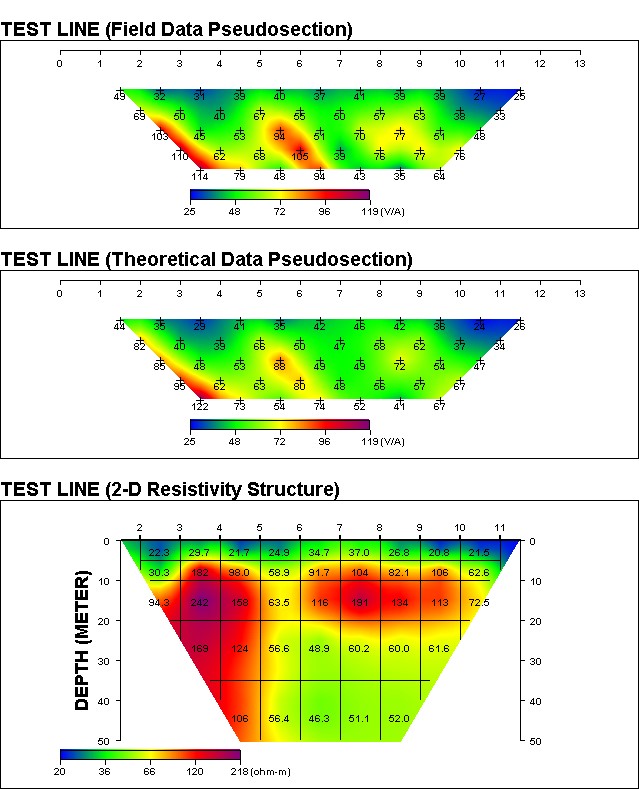


Figure 5: Traverse 3 2-D dipole dipole Interpretation

### ****3.3 Comparison of geophysical findings****

The outcomes from the **Vertical Electrical Sounding (VES)** and the **2D dipole–dipole resistivity imaging** were compared to validate the subsurface interpretation. The correlation is supported by data presented in **Tables 2 and 3** of the study. The VES results successfully outlined **partly weathered and fractured basement zones** beneath **Traverses 1, 2, and 3,** consistent with the anomalies identified in the 2D resistivity profiles.

The **2D resistivity sections** provided broader lateral and vertical coverage, mapping distinct **subsurface layers** across the three traverses. These layers include **topsoil, weathered zones, fractured basement**, and the **underlying fresh basement rock**. Within the weathered and fractured layers, several **low-resistivity anomalies** were detected typically associated with **conductive soils such as clay** or **moisture-rich materials**. These conductive zones, found at **relatively shallow depths**, are considered **geotechnically weak** and unsuitable for direct foundation siting.

Table 2 VES resistivity interpretation

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| VES  S/No | Layering | Resistivity Value (Ωm) | Thickness (m) | Lithologic Description |
| 1 | Topsoil  Weathered layer  Basement rock  Fractured basement  Basement Bedrock | 13.0  53.2  552.1    6 - 72  840 | 0.4  1 - 5    …  5 - 10 | Sand and gravel, Clayey sand and Lateritic  Clay/Sandy Clay, Clayey sand and Lateritic  Fresh basement  Partly weathered and Fractured basement rock.  Fresh basement |

Table 3: Assessment of topsoil strength in the study area based on resistivity values

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Layering | RESISTIVITY RANGE (ohm-m) | THICKNESS(M) | LITHOLOGIC DESCRIPTION | COMPETENCE  RATIING |
| Topsoil | 20 – 66    27 -106    6 - 75 | 0.4 – 3    3 – 4    4.5 - 5 | Clay    Silty sandy gravel    Basement | Incompetent    Moderately competent    Competent |

### ****3.4 Subsoil Characterization of the study area****

Both the **VES** and **2D dipole–dipole resistivity imaging** techniques delineated four key subsurface layers beneath the study location: the **topsoil, weathered layer, partly weathered/fractured basement,** and the **fresh basement rock.** The **topsoil,** typically found within a **depth range of 1–4 meters**, is the most common foundation zone for civil engineering projects. This layer primarily consists of **clay, sandy clay**, and **clayey sand** materials.

Across the study area, **resistivity values** range from as low as **6 ohm-m** to as high as **840 ohm-m**, reflecting significant variability in the subsoil's physical and geotechnical properties. The **resistivity values in the topsoil** were used to assess **subsoil competence,** following the classification system developed by **Idornigie (2006).**

Based on the data summarized in **Table 3**, much of the central portion of the study area displays **moderately low to moderately high resistivity values**, particularly in the range of **66–252 ohm-m** at depths of up to **5 meters**, indicating the presence of **fresh basement rock**. This section of the subsurface is considered **moderately competent to competent** and is therefore suitable for foundation support.

However, in areas where **lower resistivity values** dominate, caution is strongly advised for civil engineers involved in **foundation design and structural planning**. These **weak zones**, often saturated or clay-rich, present a higher risk of instability. Therefore, it is essential to exercise **increased care and precision** in foundation siting to prevent future structural problems.

**4.0 Conclusions**

The integrated use of Vertical Electrical Sounding (VES) and 2D Electrical Resistivity Tomography (ERT) revealed four distinct geoelectric layers: topsoil, weathered layer, fractured basement, and fresh basement. The topsoil and weathered zones exhibited low resistivity values (6–60 Ωm), indicating clay-rich, moisture-laden materials with poor geotechnical properties, aligning with findings by Oyelami et al. (2023). These layers pose high risks for shallow foundations due to their susceptibility to seasonal moisture variation and associated volume changes.

In contrast, higher resistivity values (>200 Ωm) identified in the fresh basement signify stable, competent zones suitable for structural loads, consistent with Akintorinwa & Adeusi (2009). The A-type VES curve indicates increasing resistivity with depth, reflecting the transition from weak near-surface materials to stable subsurface formations.

The 2D ERT profiles provided enhanced resolution, revealing discontinuous low-resistivity features within the weathered and fractured basement often linked to clay seams or saturation zones highlighted by Samouëlian et al. (2005)

Overall, the study confirms the effectiveness of combining VES and ERT for subsurface evaluation in basement terrains and reinforces the need for detailed geophysical surveys in engineering site investigations (Adepelumi & Olorunfemi, 2000; Akintorinwa & Adeusi, 2009).

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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