Geotechnical challenges in crystalline basement terrain: mapping subsurface conditions with electrical resistivity tomography in Ado-Ekiti, Nigeria

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Abstract

Subsoil investigation constitutes a critical step in the planning and execution of any construction project. It is a prerequisite for the design and construction of safe, stable, and sustainable structures. Subsoil investigation using Electrical Resistivity Tomography (ERT) was carried out in Ado-Ekiti, Nigeria to assess the integrity of foundation soils/near-subsurface geomaterials. The study area is underlain by the crystalline basement terrain of southwestern Nigeria. The study delineated low resistivity zones having as low as 63 Ωm at a depth of about 10 m, localized pockets of clay intercalated by lateritic soil, a stretch of geomaterials of high resistivity values over 10000 Ωm observed at a depth of 6 m, and a structural feature diagnostic of fractured zone with intense weathering at depths stretching beyond 25 m. The presence of an underground water channel within the fractured basement rock is significant. The geological variations along the traverses confirm the heterogeneity of the basement complex rocks, even over short distances. This is crucial for foundation design. A gross assumption of uniformity could be hazardous to the stability of the structure. Geophysics remains a very fundamental tool that can be applied in civil engineering work. Use of integrated geophysical methods would reduce ambiguities and enhance site characterization for construction purposes.

Keywords: competence, geotechnical, imaging, inhomogeneity, resistivity.

Desafios geotécnicos em terreno de embasamento cristalino: mapeamento das condições do subsolo com tomografia de resistividade elétrica em Ado-Ekiti, Nigéria

Resumo

A investigação do subsolo constitui uma etapa crítica no planejamento e execução de qualquer projeto de construção. Ela é um pré-requisito para o projeto e a construção de estruturas seguras, estáveis e sustentáveis. Uma investigação do subsolo utilizando Tomografia de Resistividade Elétrica (ERT) foi realizada em Ado-Ekiti, Nigéria, para avaliar a integridade dos solos de fundação e dos geomateriais próximos à superfície. A área de estudo está situada no terreno de embasamento cristalino do sudoeste da Nigéria. O estudo identificou zonas de baixa resistividade, chegando a valores tão baixos quanto 63 Ωm a uma profundidade de aproximadamente 10 m, além de bolsões localizados de argila intercalados com solo laterítico. Também foi observada uma faixa de geomateriais com valores de resistividade superiores a 10.000 Ωm a uma profundidade de 6 m e uma estrutura característica de uma zona fraturada com intemperismo intenso a profundidades que ultrapassam 25 m. A presença de um canal de água subterrâneo dentro do embasamento fraturado é um achado significativo. As variações geológicas ao longo dos perfis confirmam a heterogeneidade das rochas do complexo de embasamento, mesmo em curtas distâncias. Esse fator é crucial para o projeto de fundações, pois a suposição generalizada de uniformidade pode comprometer a estabilidade das estruturas. A geofísica continua sendo uma ferramenta fundamental para a engenharia civil. O uso de métodos geofísicos integrados pode reduzir ambiguidades e aprimorar a caracterização de sítios para fins de construção.

Palavras-chave: competência, geotécnico, imagem, inhomogeneidade, resistividade.

1. Introduction

The nature of the subsurface of a given site is a common constraint for building construction regarding foundation specifications. Site characterization is essential for construction to determine subsoil structure, strength, and competence, as structures built on inadequate soils are prone to failure (Ugwu; Ezema, 2013; Oyeyemi and Olofinnade, 2016; Hasan et al., 2020). Reliable pre-construction subsurface investigations are mandatory to determine the engineering design parameters and adjudge the most suitable foundation type.

The shear strength of soil, the maximum resistance that a particular soil formation can offer against failure, depends on the nature and composition of the soil. Laboratory methods to determine the parameters are applicable provided undisturbed samples can be extracted from the selected stratum. However, soils are subject to disturbance either during sampling or extraction from the sampling tubes in the laboratory. It is practically impossible to obtain undisturbed samples of cohesionless soils and highly pre-consolidated clay soils. Laboratory methods may be used only in such cases where fairly good undisturbed or remolded samples can be obtained (Andrews et al., 2013; Fajana et al., 2016; Adebo et al., 2021).

However, Electrical Resistivity Tomography (ERT), a non-invasive geophysical technique developed to interpret the nature of the subsurface without altering the dynamic status of the soil mass, offers appreciable imaging of the subsurface. ERT measures the resistivity changes both in the vertical direction as well as in the horizontal direction along a common survey line simultaneously**.** The technique provides the electrical image of subsurface soil. It is well suited to investigate areas with moderately complex geology, such as the crystalline basement complex of southwestern Nigeria (Metwaly; AlFouzan, 2013; Aizebeokhai et al., 2018; Arekumo; Lawrence, 2019).

Factors often linked to building collapse and foundation failures have been bad design, faulty construction, overloading, non-possession of approved drawings, non-compliance with approved drawings, and unethical practices. Remarkably, the subsurface condition of the site is less frequently mentioned. The presence of natural voids, cavities, near-surface depth to water, fractures/faults, and discontinuities in the subsurface constitutes severe problems for civil engineering structures. Such geologic features within the subsurface, if unaccounted for, may precipitate excessive total or differential settlement and eventual failure or collapse of structures (Andrews et al., 2013; Coker, 2015).

Electrical resistivity tomography is increasingly becoming an essential tool in geotechnical site investigations as it provides high-resolution electrical images of subsurface geomaterials (Hasan et al., 2021). Alhussein and Nouran (2022) utilized electrical resistivity tomography (ERT) and shallow seismic refraction geophysical methods to achieve a soil study for foundational and construction purposes. Jabrane et al. (2023) employed Electrical Resistivity Tomography and Seismic Refraction Tomography to investigate subsiding sinkholes in Karst Areas. Recently, Alam et al. (2024) demonstrated the main features and applications of the ERT technique in geotechnical and geoenvironmental engineering, including investigation of the possible flow paths and areas of moisture accumulation in a bioreactor landfill, determination of the moisture variation along highway pavement, and slope failure investigation. According to the study, ERT exhibited promising performance.

The study area is located within latitudes 7º 42′ 37.84 and 7º 42′ 43.67 and longitudes 5º 15′ 2.39 and 5º 15′ 10.00 in Ekiti State University, Ado-Ekiti, Southwestern Nigeria (Figure 1). The study area is underlain by the Precambrian Basement Complex, which comprises the migmatite gneiss quartzite complex; the slightly migmatised to unmigmatised metasedimentary schists and metaigneous rocks; the charnockitic, gabbroic, and dioritic rocks; and the members of the older granite suite. Migmatite constitutes the main rock unit at the location (Figure 2). The area is associated with two distinct seasons (wet and dry seasons) typical of the tropical climate. The annual rainfall in the area is about 1300 mm (Ademilua et al., 2015; Oyedele, 2019).

Initial desk study and reconnaissance indicated the possibility of existence of difficult ground conditions occurring at the site. The desk study informed the field exploration. This paper presents a geoelectrical investigation of the near-subsurface geomaterials and subsoil integrity evaluation using electrical resistivity tomography in the crystalline basement terrain of Ado-Ekiti, Southwestern Nigeria.

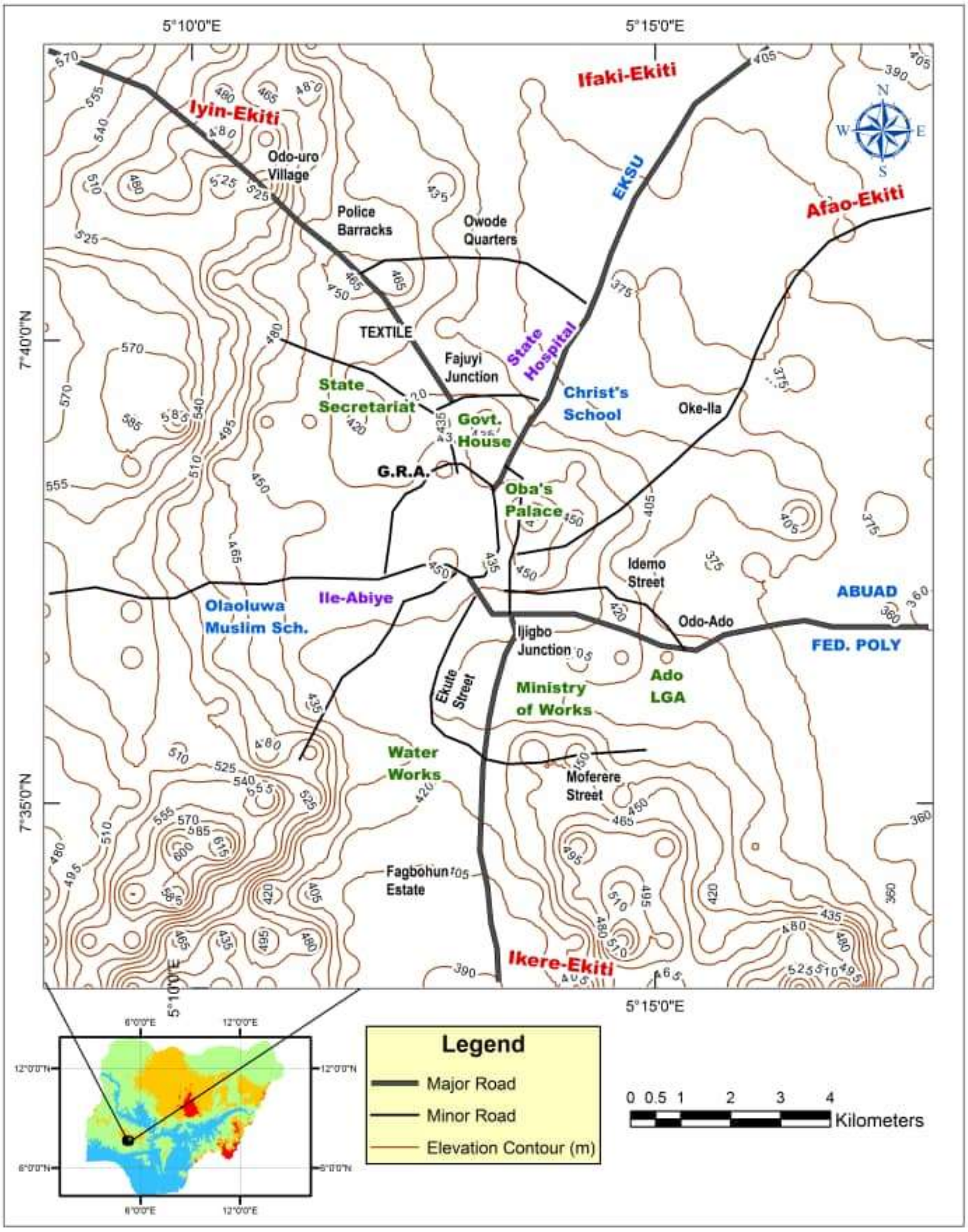

Figure 1. Location map of the study area. Source: Oyedele, 2019.

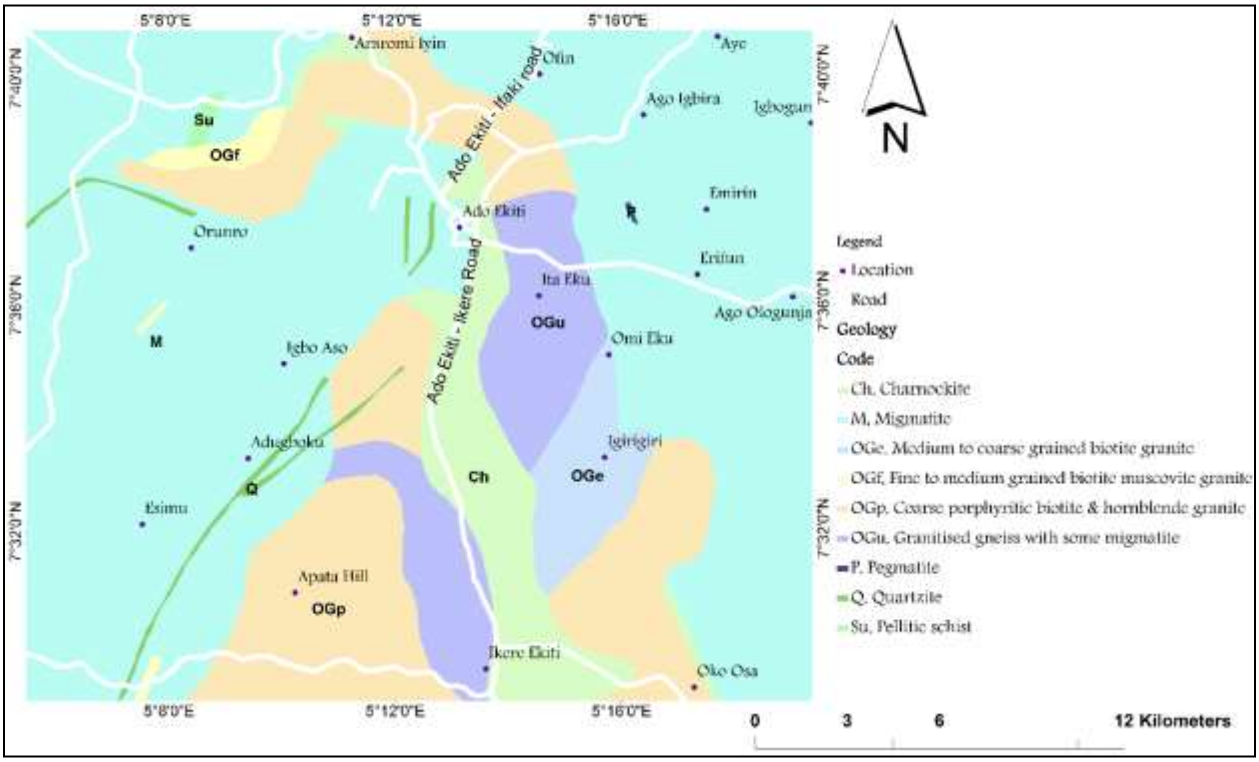

Figure 2. Geological Map of Ado-Ekiti, SW Nigeria. Source: Oyedele, 2019.

2. Materials and Methods

Desk study and site reconnaissance provided valuable insights into the site conditions. These enabled the identification of potential geotechnical issues and the planning of the fieldwork.

The field investigation utilized the Electrical Resistivity Tomography (ERT) technique. Measurements were conducted along three 2-D ERT traverses using the dipole-dipole array (Figure 3). The dipole-dipole electrode array consists of two sets of electrodes, the current (source) and potential (receiver) electrodes. The field work was run with a unit of OMEGA CAMPUS SAS 1000 RESISTIVITY METER and its accessories. Point coordinates and elevations were recorded using a hand-held Garmin GPS device.

A controlled current (I) was injected into the ground using two steel electrodes, while the potential difference (V) was measured using two potential electrodes. The terrameter gave the apparent resistivity values digitally as computed from Ohm's law. The inter-electrode spacing of 5 m was adopted while the inter-dipole expansion factor (n) was varied from 1 to 5. The dipole-dipole data were inverted into 2-D subsurface images using the DIPPRO(TM) 4.0 inversion software. The procedure yielded the field data pseudo-section, the theoretical data pseudo-section, and the 2-D resistivity structure images of the subsurface (Loke et al., 2013; Aizebeokhai et al., 2018; Adebo et al., 2021).

Geophysical methods such as electrical resistivity tomography (ERT) are non-invasive, user-friendly, and fast. The methods produce quite continuous data over vast areas and in a less expensive way (Hasan et al., 2021; Jabrane et al., 2023; Alam et al., 2024).

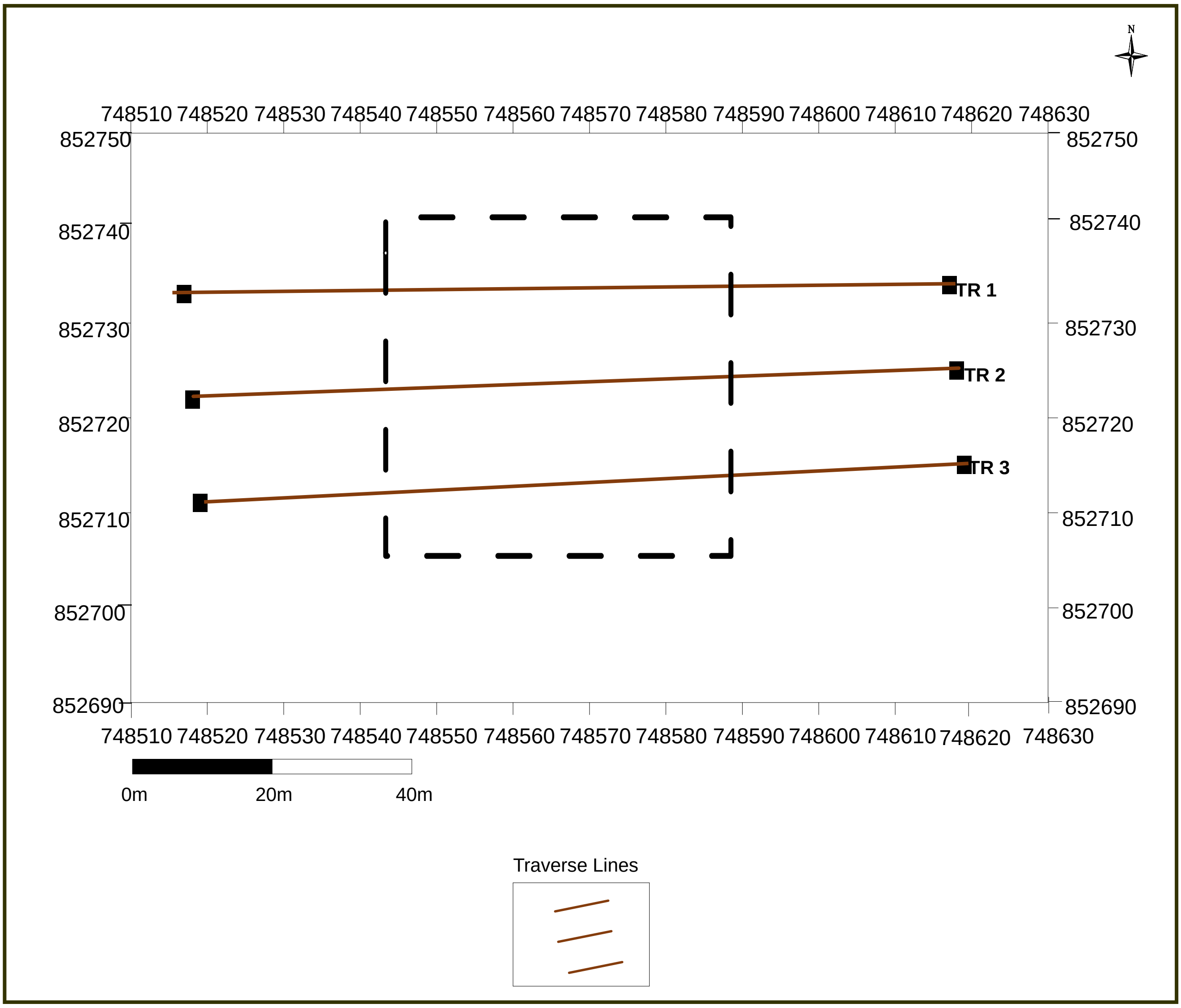

Figure 3. Data acquisition map showing the profiles. Source: Authors, 2025.

3. Results

The results of the resistivity imaging are presented in Figures 4 – 6, showing the measured, calculated apparent resistivity pseudosections and resistivity structures.

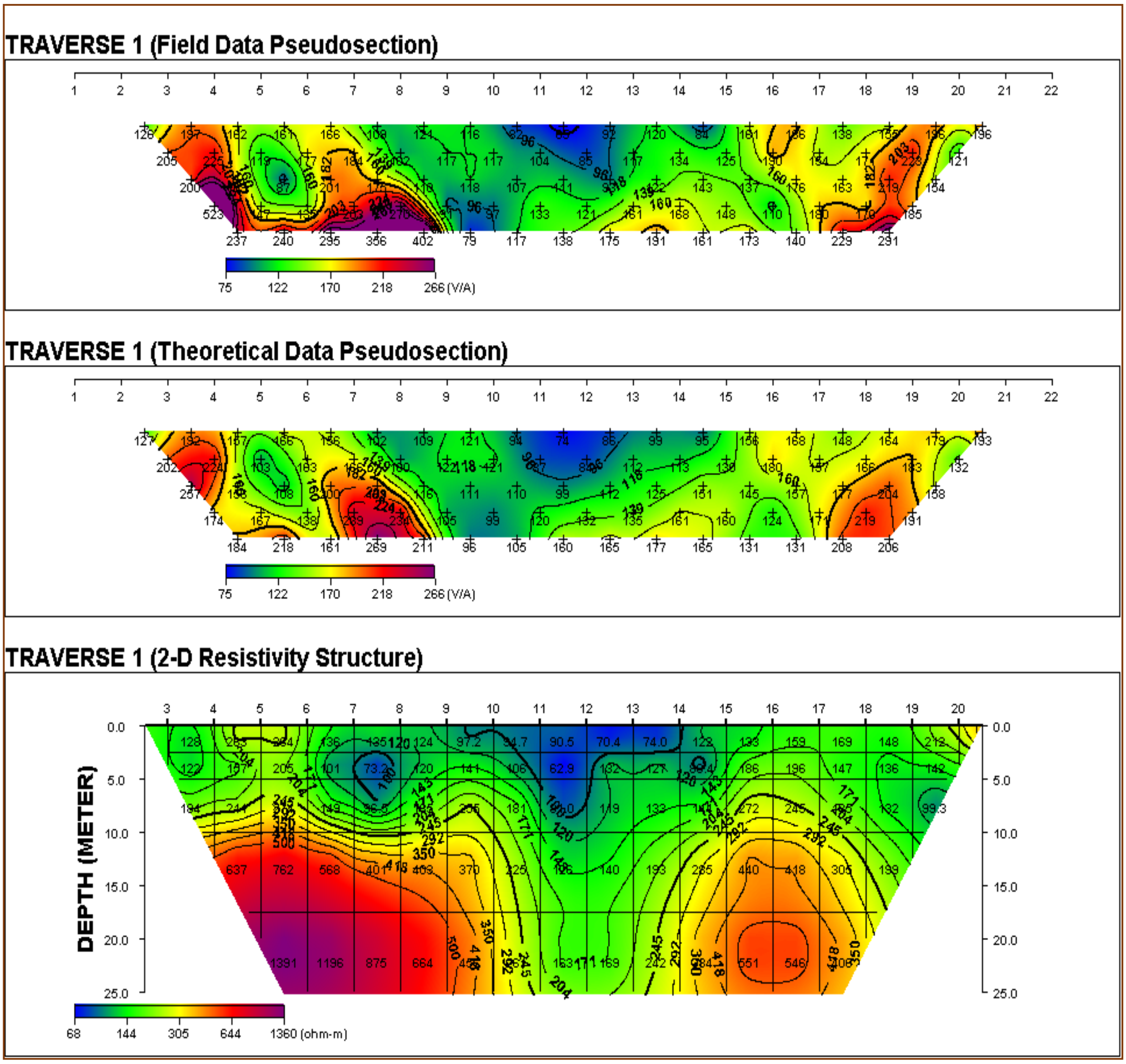

Figure 4. Inverse resistivity model of traverse 1. Source: Authors, 2025.

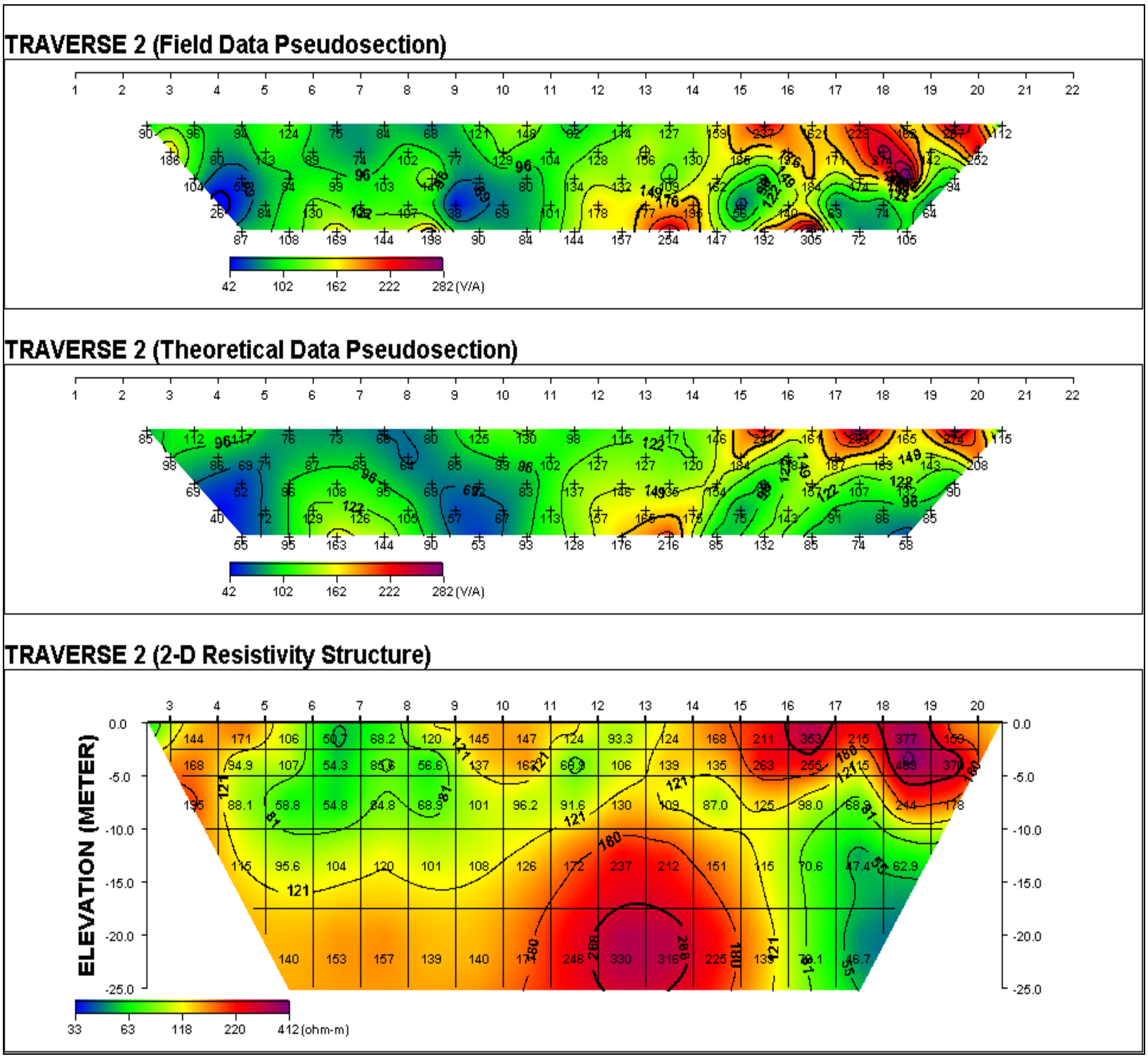

Figure 5. Inverse resistivity model of traverse 2. Source: Authors, 2025.

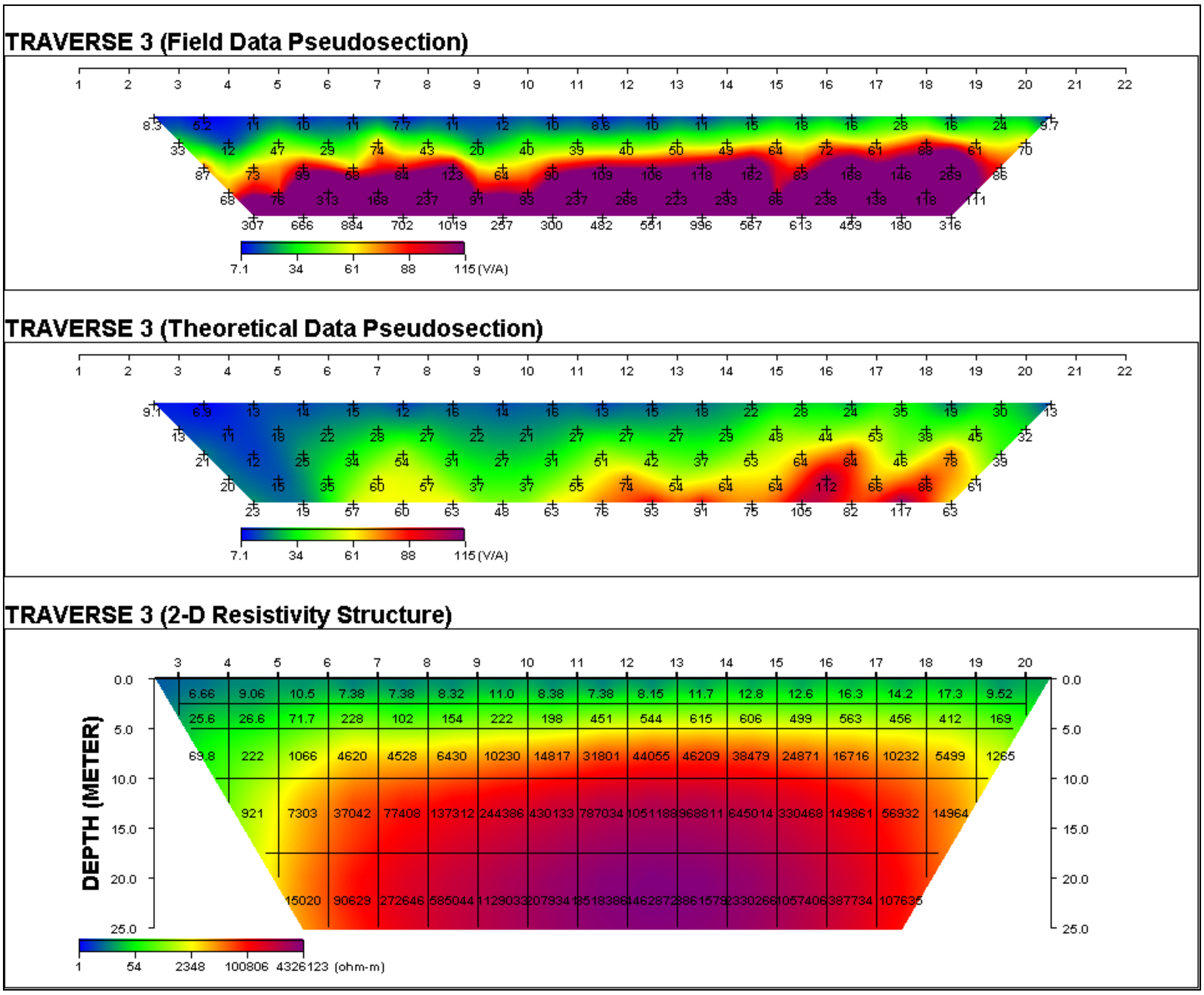

Figure 6. Inverse resistivity model of traverse 3. Source: Authors, 2025.

4. Discussion

The inverse resistivity model (Figure 4) highlights low resistivity zones between 50 m and 70 m, reaching 62.9 Ωm at a depth of 10 m and a localized pocket of clay occurring at a depth of about 5 m. The clayey topsoil is underlain by a structural feature diagnostic of the fractured zone with intense weathering at depths stretching beyond 25 m. The geological condition indicates the presence of an underground water channel within the fractured basement rock. This region of groundwater accumulation demands adequate geotechnical attention and could be inimical to foundation stability given the enhanced secondary porosity and permeability (Coker, 2015; Hasan et al., 2020; Alam et al., 2024).

The 2-D resistivity structure along traverse 2 (Figure 5) delineated patches of clay/clayey materials, lateritic formation, and weathered basement. The tomography image shows clayey materials with low resistivity values (54.3 – 68.7 Ωm) between distances 23 m and 45 m stretching down to a depth of about 10 m. The lateritic formation occurring as topsoil between distances 70 m and 95 m is underlain by clay/clayey material of an average resistivity value of 46.7 Ωm (Fajana et al., 2016; Arekumo & Lawrence, 2019). The bearing capacity of these rocks depends on various factors, including rock type, degree of weathering, mineralogical composition, rock association, faults/fractures, and water infiltration. The nature of the bedrock, lithological type, structural disposition, lateral changes in lithology, and fractures/faults system are essential to designing formidable foundations (Olayanju et al., 2017; Hasan et al., 2021; Joseph et al., 2023).

Along traverse 3, the 2-D tomography delineated four geologic formations: clay, lateritic formation, weathered basement, and fresh basement (Figure 6). The topsoil along the traverse is composed of material characterized by low resistivity values ranging from 6.66 to 20 Ωm. The thin topsoil with an average thickness of about 2.5 m is underlain by a lateritic formation of about 5 m thickness. The weathered basement is indicated by resistivity values ranging from 1026 – 1265 Ωm. This horizon is underlain by the fresh basement of very high resistivity. The stretch of the fresh basement occurring at a depth of about 8 m extends from a distance of 25 m to 95 m. It indicates a baseline high with a very high degree of competence.

The geological variations along the traverses confirm the heterogeneity of the basement complex rocks, even over short distances. This is crucial for foundation design. Points of low geotechnical competence are indicated by the low resistivity spectrum. Competent zones are inferred across the high end of the resistivity spectrum (Ademilua et al., 2015; Adelekan et al., 2017; Adebo et al., 2021).

A stretch of geomaterials of high resistivity values over 10000 Ωm observed at a depth less than 8m and extending beyond depths of 25 m is very significant. The clayey layer and the fractured basement constitute the weak zones at the location. Features produced by weathering and tectonic processes may render the normally impermeable crystalline rocks suitable for the ingress and storage of water. These features render geomaterials in such regions geotechnically weak. Settlements can be anticipated given a combination of clayey topsoil and weathered/fractured basement (Olayanju et al., 2017; Joseph et al., 2023)

The presence of very thick clayey materials underlying a traverse, intense weathering, and fracturing occurring within the shallow basement constitutes geological complexities. The peculiarity should be factored into the foundation design to stem foundation-related failures.

Subsoil investigations using integrated tools are becoming mandatory to avoid potential foundation-related failures and/or structural deformations (Jabrane et al., 2023). The application of non-invasive and economical ERT in geotechnical investigation provides subsurface imaging that would guide the location of drilling points and reduce the number of requisite tests (Oyeyemi & Olofinnade, 2016; Adobo et al., 2021; Hasan et al., 2021).

5. Conclusions

The study demonstrated the significance of geophysical site investigation in civil engineering work. Electrical resistivity tomography was used to provide a geoelectric image of the subsurface sequence. The study delineated patches of clay/clayey materials, lateritic formations, fractured basement rock, and a stretch of geomaterials of high resistivity values. The high resistivity variations are attributable to the heterogeneity and unpredictable nature of the geology of a typical crystalline basement terrain. Electrical resistivity imaging provides subsurface conditions and lithological characteristics both laterally and vertically.

The presence of clay/clayey materials, lateral inhomogeneity, near-surface geological structures, and underground water channels within the fractured basement rock would promote foundation failures. The economic waste associated with failed structures and other attendant catastrophic consequences can be avoided if a thorough subsurface investigation is put in place. Geophysical studies provide a relatively rapid and cost-effective means of deriving aerially distributed information on subsurface geology. Detailed geophysical investigations are versatile tools in engineering site investigation and should readily be incorporated in geotechnical investigation to secure reliable subsoil information. This will aid foundation design and material selection. Enhanced resolutions are achieved when ERT is applied jointly with other techniques. Use of integrated geophysical methods would reduce ambiguities.

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7. Authors' Contributions

Taofeek Olubunmi Ewumi: conceptualization, methodology, investigation, discussion of results, writing – original draft, writing– review and editing, resources, supervision, and approval of the final text. *Funmilola Olusola Ogunlana*: conceptualization, methodology, investigation, discussion of results, writing – original draft, writing– review and editing, resources, supervision, and approval of the final text. *Akintunde Akinola Oyedele*: methodology, investigation, discussion of results, resources, and approval of the final text.

8. Conflicts of Interest

No conflicts of interest.

9. Ethics Approval

Not applicable.

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