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Geophysical and Geotechnical Investigation of Building's Foundation around Crusher area, Lokoja, Kogi state, Nigeria

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Abstract

Integration of geophysical and geotechnical techniques had been utilised to investigate the foundation of a site characterised with building cracks. It was conducted at Muhammadu Buhari Estate, Crusher area in Lokoja, Nigeria, The study aims to delineate geological features responsible for the failure of the building through 2-D resistivity imaging and electromagnetic surveys in conjunction with geotechnical analysis. Seven 2-D electrical resistivity imaging traverse lines, seven electromagnetic profiles were run and seven soil samples were collected and analysed. Each of the sample point were located on each of the 2-D imaging traverse. Traverses 1-7 host samples 1-7 respectively. The findings revealed high conductivity in unstable areas (resistivity ranging from 11-42 Ohm-m, 1-38 Ohm-m, 4-12 Ohm-m, 1-15 Ohm-m, and 11-30 Ohm-m for traverse 1-5, respectively) and low conductivity in stable ones (resistivity ranging from 19-91 Ohm-m and 109-2056 Ohm-m for traverse 6 and 7, respectively) and they occur at near surface to a relatively shallow depths (ranging from 0-6m depth) in all the profile. Geotechnical analysis showed high clay content in the soil, affecting its engineering properties in most of the studied locations. Soil grain oversize data analysis indicated a range between 70.1% and 75.1% for unstable portions (samples 1-5), with an average of 72.22% fines while percentage coarse ranges between 24.9 and 29.9 with an average of 27.78%. Their optimum moisture content ranged from 10.4% to 11.50%, with a mean value of 11.18%. Also, their plastic index averaged at 10.044%, while linear shrinkage varies between 1.79% and 3.60%, with an average of 2.808%. All these are the responsible factors for the soil instability in this axis of the investigated site. But for the stable portions (samples 6 and 7), Soil grain oversize data analysis is between 18.1% and 18.2% with an average of 18.65% fines while percentage coarse range between 81.9 and 80.8 with an average of 81.35%. The optimum moisture content ranged from 10.4% to 11.50%, with a mean value of 11.18%, the optimum moisture content ranged from 11.3% to 12.0%, with a mean of 11.65%, the plastic index equals zero (0), linear shrinkage varies between 5.57% and 5.71%, with an average of 5.64% and all these parameters are responsible for the stability of these two portions. The California Bearing ratio (CBR) results graded the soil samples into different types with the unstable portion characterised with clay, silty clay and sandy clay while the stable portion are classified into well graded sands. The well graded sands are very suitable for the engineering construction and hence the buildings on this portion showed no cracks and failure because of lack of differential settlements unlike that of the unstable portion characterised with cracks due differential settlements that led to structural failure at those sides of the study site. The geophysical results corroborate well with geotechnical results and these highlight the value of combining geophysical

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and geotechnical techniques to evaluate the integrity of the subsurface, providing information that is essential for designing infrastructure foundations and determining stability.

Keywords: Resistivity Imaging; Electromagnetic Surveys; Conductivity; Resistivity; Geotechnics.

1. Introduction

The capacity of soils to hold either temporary or permanent loads that may be placed on them determines whether or not they are suitable for engineering uses. Given the recent wave of collapses of civil engineering facilities, including buildings, roads, and dams, throughout developing nations like Nigeria, the use of pre-foundational studies is becoming increasingly significant (Akintorinwa and Adeusi 2009, Oyedele et al 2011). A structure's foundation is a necessary component that transfers the weight of the building to the earth beneath it. Yet building issues occur when the underlying soil lacks the necessary geotechnical qualities, which eventually affects the structure (Olayanju et al, 2017, Adeoti et al, 2016). Because of this, site investigations are carried out to ascertain the properties of the soil at the specific area and their capacity to sustain structures erected on it. Existing subsurface zones that are considerably unable to support the weight of the structures are frequently covered by anomalous civil and other engineering structures. Also, geological structures such as joints, faults etc underlying a site for construction is very critical as it can have a disastrous impact on the building and hence Abdulbariu et al. (2023a) made use of Frequency-Domain Electromagnetic and VLF data to model basement structures within Ibadan Area to delineate the basement fractures and their orientation and access its impact on any possible future engineering structures. They found out that the fractures were oriented majorly in N-S, NE-SW and NW-SE direction following the regional Pan African orogenic episode. Building directly on such fractures can result into structural failure as a result of movement.

Any structural element failure is frequently caused by a variety of issues, such as

- Inadequate foundation investigation,
- Bad building design,
- Subpar materials, and
- Handling inexperience.

In order to guarantee appropriate design and successful construction of any structure, it is crucial to precisely determine the engineering properties of the soil.

Conventional methods for determining engineering properties such as density, porosity, permeability, moisture content, consistency, compressibility, and shear strength, such as boring, pitting, and trenching (Akintorinwa and Oluwole 2018, Akinlabi and Adeyemi 2014), are intrusive, expensive, and time-consuming. These methods involve collecting field samples using a variety of techniques and arduous laboratory work to determine the fundamental geotechnical parameters (Arora 2008). High geographical and temporal variability affect the characteristics of the soil. High-density sampling will be necessary in order to accurately determine the qualities of the soil. Even so, under these circumstances, borehole sampling can be exceedingly expensive and time-consuming (Akintorinwa and Oluwole 2018). One way for exploring the soil, subsoil, and subsurface for any engineering construction activity is geophysical research. In order to assess if the site is suitable for the proposed construction, the inferred soil properties are used as preliminary data. Failing to do this vital step could result in excessive total or differential settlement caused by hidden geologic features below the surface, which could cause civil structures to fail or collapse. Seismic refraction, electrical resistivity, and gravity are geophysical techniques that have proven helpful in geotechnical investigations conducted before and after construction. The increasing need to explore the earth for scientific and societal issues has led to a high degree of sophistication in geophysical techniques for determining the composition, structure, and nature of the subsurface (Enikanselu, 2008). Abdulbariu et al. (2023b) applied a cheaper way geophysical investigation using Vertical Electrical Sounding (VES) and Two-Dimensional (2-D) Imaging Methods for groundwater exploration and basement configuration study at GOFAMINT Church Camp, Ibadan. They were able to delineate water saturated zones and the basement geometry which can impact on overlying engineering structures and the study can prevent building collapse as it provided relevant information about the subsurface condition. According to Ayedun et al. (2012), Nigerians are embarrassed and feel national concern over the recent spate of building failures and collapses. Such incidents are regularly covered by print and electronic media outlets in the nation. Thirteen of these cases in Lagos State alone were reported in 2006; the numbers for the years prior and following were similarly dismal. The use of subpar building materials, poor workmanship, incompetent contractors, faulty construction methodology, heavy downpours, non-compliance with specifications/standards, inadequate or lack of professional supervision, defective design, and illegal conversion of existing structures were identified as the major causes of building collapse in Lagos State, Nigeria. This prompted a study to empirically ascertain the causes of such building failure and collapse from the perspectives of the stakeholders (comprising of the professionals in the building industry, contractor, and house owners/developers).

Geophysical and geotechnical studies analyze soil and rock properties to assess the stability and suitability of foundations. In geotechnical studies, understanding soil and rock interactions, particularly in areas with cracks, is crucial for assessing foundation integrity. Similarly, geophysical methods (e.g., seismic surveys, electrical resistivity) and geotechnical tests (e.g., soil borings) provide detailed subsurface information, critical for understanding and mitigating issues like soil cracking. In construction, integrating geophysical and geotechnical studies helps in designing foundations that can withstand site-specific challenges, such as cracks in the ground, ensuring safe and stable structures. Geotechnical studies assess how crushed materials (aggregates) behave as part of the foundation, particularly in problematic areas.

Combining geophysical and geotechnical approaches allows for the integration of discrete information obtained from standard engineering soil characterization methods that do provide a complete subsurface imaging picture. When interpreting geophysical data, one can assess the true distribution of geological earth material and see below the surface to the depths of competent layers. By utilizing the 1-D and 2-D resistivity probing techniques, the geologic characteristics can be identified. Cone Penetrometer Test (CPT) is a geotechnical procedure usually use in site investigation. The integrated geophysical and geotechnical techniques study emphasizes the critical role of regulatory frameworks in ensuring infrastructure safety. This is akin to fostering circular economy practices in promoting environmental safety, and sustainable development (Oluwayomi, 2024a, 2024b, 2024c. Babatunde et a., 2022)

While geophysics is not a replacement for geotechnical boring or testing, it is frequently a very economical and effective way to create continuous 2D and 3D images of the subsurface and determine in-situ bulk properties. Assessing and characterizing geotechnical parameters can become complex and expensive in the presence of obstacles like difficult accessibility, erratic terrain and terrain features, or regulatory constraints. Surface geophysical procedures can provide an alternative to wide-area methods for subsurface description and information regarding appropriate material properties (Reynolds, 2011). The porosity and moisture content of the subsoil can lower a material's electrical resistance. Consequently, in order to establish subsoil competency and their engineering properties, it is necessary to merge electrical resistivity and electromagnetic technique (Rungroj, 2015). The site investigation study is usually a non-destructive, economical, and quick geophysical technique to determine the electrical properties of the soil. It involved an electromagnetic survey, a dipole-dipole array, and geotechnical analysis. Ibrahim et al, (2015) studied the geological characteristics of rocks and its petrographic analysis to determine the various rock of Ado-Awaiye and Environs in order to ascertain the various rock types of the area and their structural relationship. Abdulbariu (2016**)** jointly combined Geophysics and Geology as a complimentary approach to investigate the subsurface lithological content in order to deduce the mineralization potential and material strength of the investigated site.

1.1 Statement of problem

The strength of the structure could be seriously jeopardized by the inconsistent structural integrity of the foundation anchorage. For development objectives, site interpretation is crucial since it helps designers to implement sensible safety measures. There are several subsurface geological hazards connected with building structures in locations that have seen volcanic activity, including faults, cracks, voids, and proximity to bedrock. This made the use of electrical resistivity methodologies in the proposed site research necessary. This approach is preferred over geotechnical techniques like trenching, boring, and pitting, which disrupt the soil and require a lot of money and time for sample collection and laboratory analysis. These geophysical techniques reduce the expense and increase the efficiency of geotechnical research.

Aim of Study

The purpose of the research is to delineate the underlying geologic materials and structures beneath the construction site characterise with cracks in the buildings.

Objective of the Study

The study is based on integrating geophysical and geotechnical techniques for foundation condition beneath a site at Muhammadu Buhari Estate, Crusher Area Lokoja, kogi State. The objectives of this work are as follows:

- To carry out geophysical survey on a foundation site using 2D resistivity imaging.
- To integrate Very Low Frequency Electromagnetic Method in delineating structures and materials capable of causing foundation problems.
- To carry out analysis on the results gotten from the above two objectives.
- To carryout geotechnical laboratory analysis such as optimum moisture content, compaction test, California Bearing Ratio, Atterberg Limit test (plastic Limit, Liquid Limit and Shrinkage Limit), sieve analysis on the soil samples collected.

1.2 Geology of the study area

The study area is part of the north-central Nigerian Precambrian Basement Complex and is situated in Crusher area, Lokoja, Kogi state. The sample locations' coordinates are in the range of longitude 06º39'4.36" to 06º40'10.05" and latitude 07º49'49.5" to 07º50'54.49". The region has a very undulating topography. Their protoliths (igneous, psammitic, or felsitic) and the metamorphic (P-T) circumstances in which they originated vary greatly, resulting in significant compositional variances. Three main types of rocks make up this region: granite, gneiss, and migmatite (Ozulu et al., 2021). The structure and mineralogy of the crystals indicate that the granitic rocks are composed of Aplite, medium-grained, and Porphyritic granites. Migmatites are a complicated mixture of dark and light crystals that resemble metamorphic rocks and metamorphosed granitic rocks, respectively. Petrographic data indicates that many of the constituent minerals of the migmatites have partially melted and recrystallized as a result of the Pan-African reworking. The majority of the rocks exhibit metamorphism of the medium to higher amphibolite facies and the rocks are felsic with medium to coarse grains. Owing to a preferential orientation of platy minerals like biotite, the rocks exhibit distinctive gneissose foliation. Biotite, Augen, and Banded gneiss are the three varieties of gneiss (Ozulu et al., 2021). These basement rocks have a foliation pattern that is primarily NE-SW with sporadic E-W variations. It is possible that the rocks originated by granitization because of their gradational contacts with high grade metamorphic rocks (Obiora et al., 2005).

2 Materials and Methods

In order to identify the lithological units of the region and define the stable and unstable portions of the study area, a comprehensive geological mapping exercise was conducted in order to identify the various geology characterising the investigated site. 2-D imaging data were acquired with the Dipole-Dipole array. DIPRO software was used to analyse and interpret the data to obtain lateral and vertical resistivity within the subsurface. The interpretation was initially focused on qualitative assessment. By employing inter-electrode spacing of 5 meters and varying the inter-dipole expansion factor (n) between 1 and 5, the dipole-dipole ER data were collected to visualize subsurface structures. Quantitative inversion of the dipole-dipole data was conducted using DIPPROTM inversion software to generate 2D subsurface resistivity structures. Pseudosections and cross-sections were plotted to offer different perspectives on lateral and vertical variations within the subsurface, providing valuable insights into the distribution of resistivity with depth. In the electromagnetic survey, PQWT-TC Series geophysical prospecting instrument was utilized to acquire soil electromagnetic properties. This instrument relies on natural electric field sources and measures resistivity contrasts underground to study abnormal changes in geological bodies. It utilizes the natural potential frequency method by measuring the electrical component of the earth's electromagnetic field within a selected frequency range. The M, N electrode probe transmits signals to the instrument for data processing, which includes amplification, frequency selection, and A/D sampling. The processed data is displayed on the instrument's LCD screen and can be further analyzed on a computer.

Seven geophysical lines were arranged perpendicular to the constructed buildings under investigation to accurately locate abnormal ground points and detect tectonic features. The data were collected at midpoint between two electrodes and maintaining consistent distances along each measuring line. Seven soil samples were meticulously collected from diverse locations within the study area, guided by the interpretation results of 2-D subsurface resistivity structures. These samples were retrieved from depths ranging between 0.5 to 1.5 meters. Each sampling point's coordinates and elevation were precisely recorded using a global positioning system (GPS). Subsequently, these labeled soil samples were carefully sealed in polythene bags and transported to the laboratory for analysis. Their moisture contents were promptly determined. Upon arrival at the laboratory, the soil samples underwent a 14-day air drying process, following which any lumps were delicately ground. The soil's index and engineering qualities were then evaluated through a series of tests. In addition to engineering property tests like compaction and California bearing ratio (CBR), index property tests were conducted. These included consistency limits, linear shrinkage, specific gravity, and grain size distribution. The British Standard Methods for Civil Engineering Purposes (BS 1377, 1990) and ASTM Standard D1557 (2009) were followed for other tests, while the Atterberg limits tests were carried out in compliance with ASTM D (2017) standards. These thorough studies offered insightful information about the properties and behavior of the soil, which aided in determining whether it was suitable for engineering uses alongside the highway.

3 Results and Discussions

3.1 Geophysical analysis

The results of the electromagnetic and 2-D imaging data carried out at Muhammadu Buhari Estate, Crusher Lokoja Abuja Express way are presented below. This is aimed at determining the competence and suitability of the site where building structures had been imposed.

3.1.1 The 2D resistivity section along Traverse 1

Within the study area, subsurface resistivity is reflected in the 2D electrical resistivity section along Traverse 1 (Figure 1). The first five electrode points have a high resistivity range of 1541-7633 Ωm (red colouration), suggesting the presence of hard rock with a very high resistivity. The next four electrode points have a medium resistivity range of 57-303 Ωm (green colouration), indicating a saturated sandy clay unit with thickness ranging from 2.5m below the surface. The materials that is being studied is along this profile line and it is located in the zone of low resistivity, which is defined at the surface distance on the traverse line between 15 to 45 meters. This zone is almost completely underlain by a very conspicuously very low resistivity of 11-42 Ωm (blue colouration). It occurs at between depths of 2.5m to up to 12.5m. This make the zone even more unstable and undesired for building foundation as shown in the figure 1. The electromagnetic profile found at that same location is shown in figure 2. The very low electromagnetic values in the top soil layer indicates the existence of conductive material and this correlates well the resistivity imaging results.

3.1.2 The 2D resistivity section along Traverse 2

Four (4) geologic units were identified by the 2-D imaging along Figure 3's traverse 2: topsoil, designated as A and typically colored blue, weathered bedrock or zone, designated as B and typically colored green with some yellow, and fractured to fresh dry basement rock, designated as C and colored red and purple. Lateritic clay were found at stations 4 and 6, and sandy clay were also between stations 10 and 12 in the field, therefore the topsoil are typically made up of that units and they are thin. These unstable geologic units are not suitable for foundations as they are incompetent to withstand the imposed load due to building structures. Failures occurred at some portions within this traverse line. At some locations, the weathered bedrock outcrop on the surface as shown by the green colouration on the traverse. This outcrop may seem to possess stable units which may not be too bad for foundation owing to their moderate resistivity value. The top soil with predominant composition of clay, which exhibits very low resistivity has value ranging from 8 to 38 Ωm at a depth of 1.1 to 2.5m. At a depth of 2.5 meters, the weathered bedrock exhibits a medium resistivity ranging from 39 to 803 Ωm. The resistivity values in the last layer, which is in excess of 16260 Ωm with a reddish-purple color, suggest the presence of a large basement platform or plutons. Figure 4 is an electromagnetic data/profile with blue colour from top to 15 m depth from stations 1 to 10 also indicating porous zones.

3.1.3 The 2D resistivity section along Traverse 3

Three geologic boundaries were shown by the 2-D imaging pseudo-section in Figure 5: Unit A, topsoil (blue), unit B, weathered rock (green), unit C, fractured basement (yellowish to red) and unit D, fresh basement (purple colouration). The topsoil spans a depth of 0 to 3 m and is composed of a variety of materials, mostly made up of peat and clay material, with resistivity values ranging from 4 to 12 Ωm. These materials are thought to be degraded organic components. The second geoelectric layer, which is primarily composed of weathered materials, extends from a depth of 3 meters to roughly 6.0 meters and has a resistivity range of 13 to 79 Ωm. highly fractured basement with resistivity range of 80 Ωm to 1500 Ωm while the last layer which is the fresh basement rock has resistivity between 1501 Ωm and 2056 Ωm. This top layer also pose threat to foundation as a result of its geological composition and the entire top unit is prone to instability. The buildings exhibit crack due to differential settlement occasioned by the clayey content of the unit. Furthermore, the electromagnetic data profile (figure 6) indicates an incompetent top geological units too as this confirms the the result of the 2-D resistivity imaging data of figure 5. Therefore, along this entire traverse line, the surface and near-surface lithological contents are detrimental to the base of an engineering construction or building.

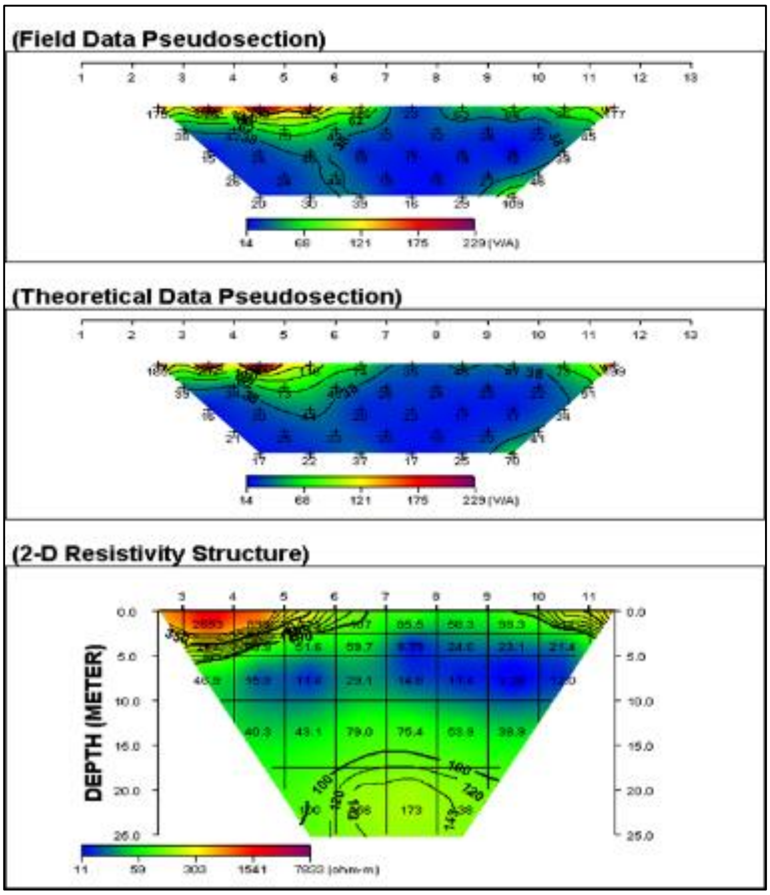

Figure 1 Traverse 1- Pseudo-section of line 1 indicating the apparent resistivity values (coordinate: latitude N7^0 50” 20.3’ and longitude E 006^0, 40” 05.8’

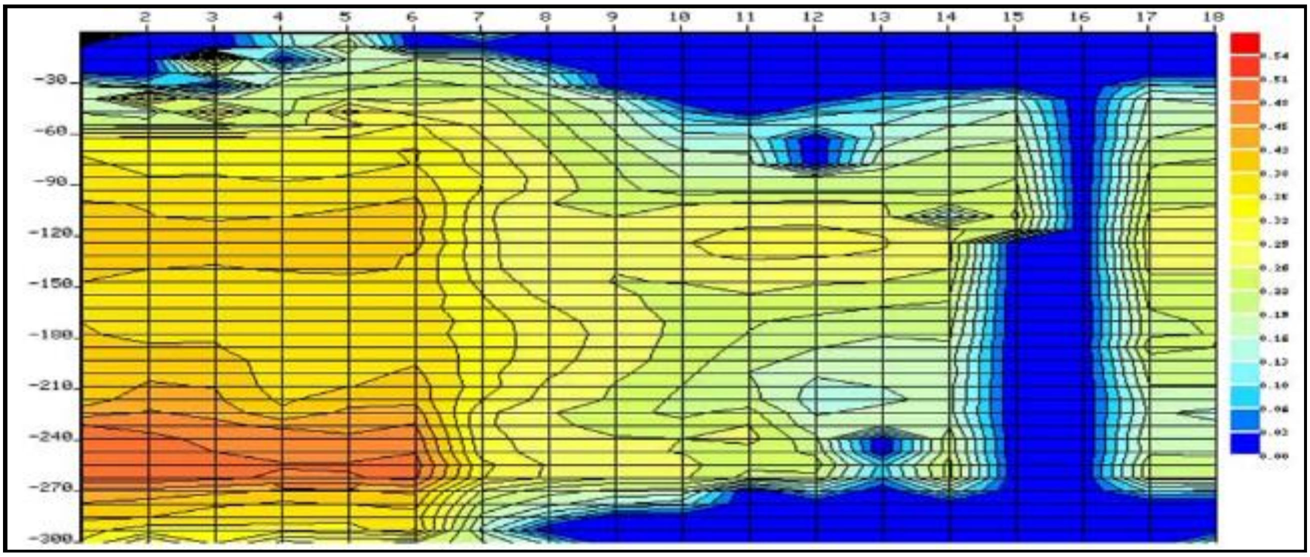

Figure 2 Electromagnetic profile for traverse 1 showing resistivity

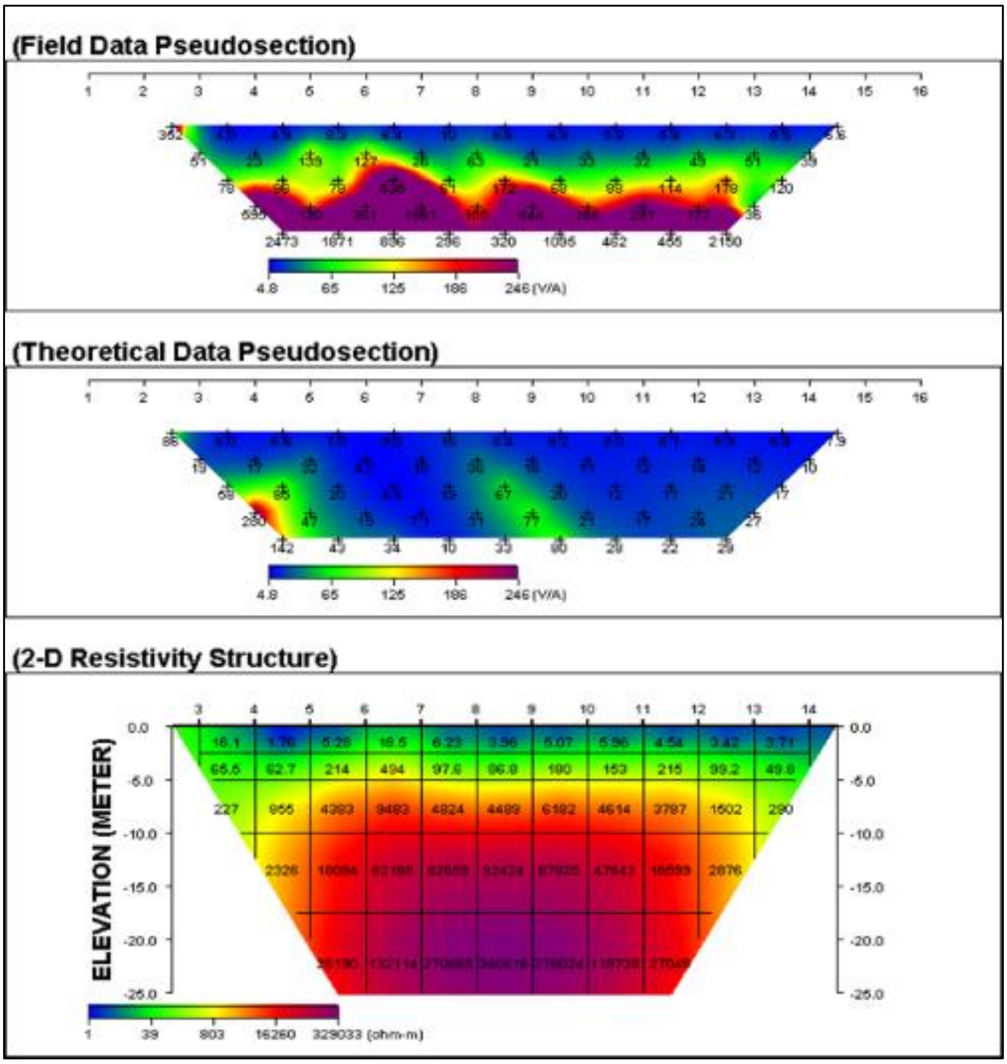

Figure 3 Traverse 2- Pseudo-section of line 2 indicating the apparent resistivity values (Coordinate; latitude N7^0 50" 18.8' and longitude E 006^0, 40" 2.6')

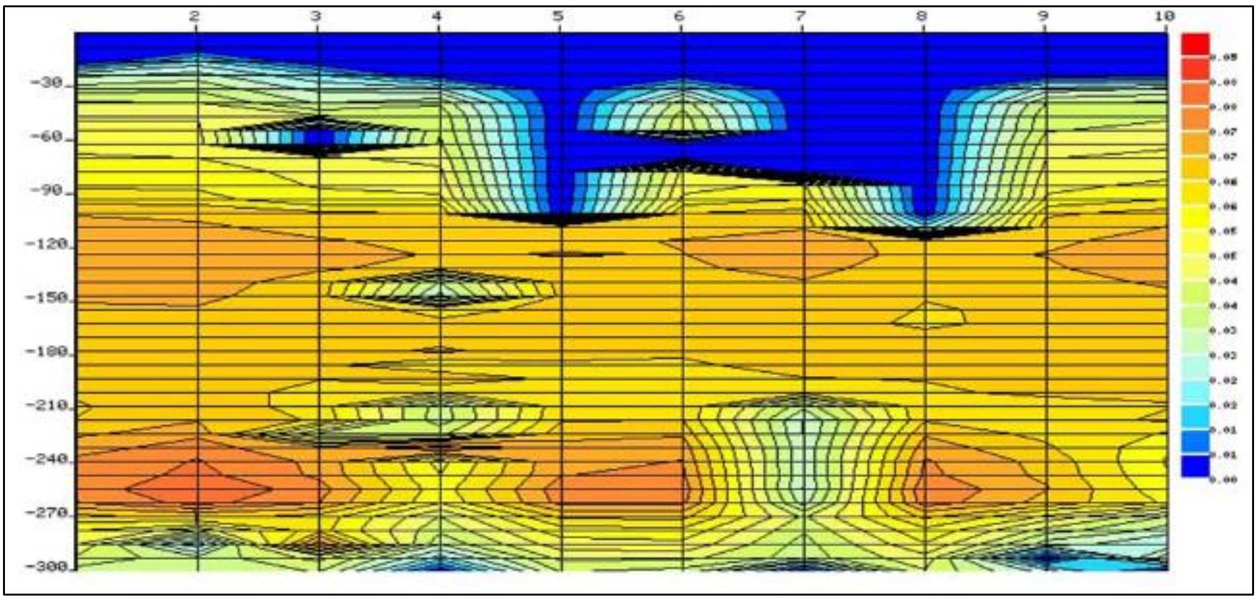

Figure 4 Electromagnetic profile for traverse 2 showing resistivity

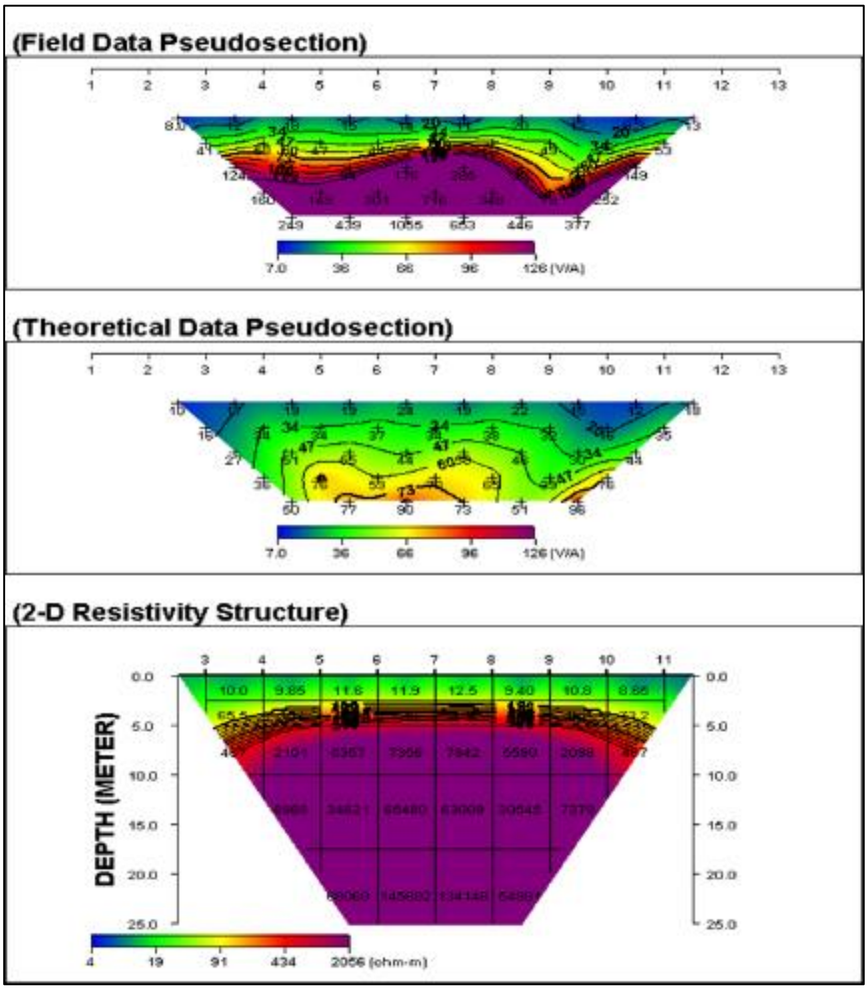

Figure 5 Traverse 3- Pseudo-section of line 3 indicating the apparent resistivity values (Coordinate: latitude N7^0 50” 09.4’ and longitude E 006^0, 39” 47.3’)

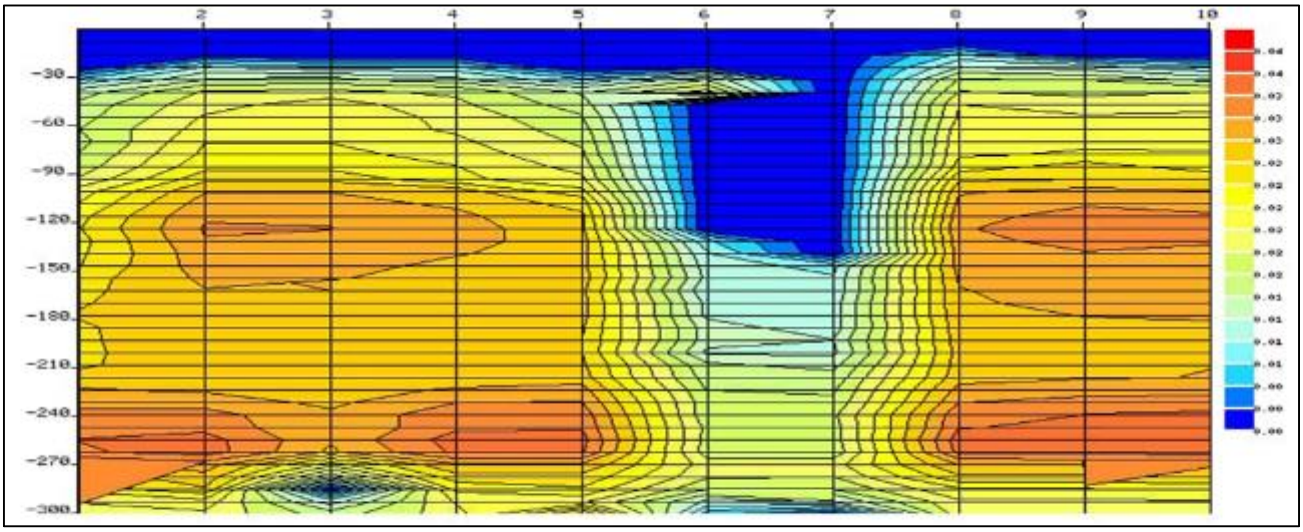

Figure 6 Electromagnetic profile for traverse 3 showing resistivity

3.1.4 The 2D resistivity section along Traverse 4

The topsoil varies in depth from 0 to 5 m and is formed of material with varied resistivity (1.0 to 15 Ωm), which is presumed to be composed of degraded organic components, vegetable residues, sand infill materials, etc as shown in the 2D resistivity section along Traverse 4 (Figure 7). The second geoelectric layer is composed primarily weathered zone and at some points, it spans from the surface to depth of about 8.5 m (represented by green colour). Its resistivity ranges from 16 to 320 Ωm. It varies in thickness and depth. The next layer is fractured basement extending below 8.5 meter to depth range of 15 to 20 meter depending on the location with characteristic resistivity between 321-6150 Ωm (yellow to red). This layer is finally underlain by a fresh basement knoll extending from 15 meter to 25 meter and even beyond with resistivity between 6151 Ωm to 90230 Ωm (purple). The surface layer is not good for engineering structure as it is incapable to hold the load and effectively support the buildings. Though deeper layers are a very resistant and piling can be introduced to transmit the load to this stable high resistant zones. Additionally, the electromagnetic data/profile (figure 8) indicates a low resistant zone at the surface as earlier seen in the 2-D imaging profile (figure 7) along the entire profile length confirming good data integration. Again, the topsoil is not a good engineering materials as the soil permits differential settlement and building failure.

3.1.5 The 2D resistivity section along Traverse 5

The fifth traverse (Figure 9) shows that the topsoil is formed of material with varied resistivity (11 to 30 Ωm) that is thought to contain decomposed organic materials, vegetable remnants, and sand filler. The depth of the unit ranges from 0.0 to 6.0 meters below the surface represented by blue colour. This layer is incompetent. The second geoelectric layer is primarily made up of weathered material and spans a depth range of 6.0 to 7.0 m with a resistivity range of 31 to 159 Ωm (green). This can be seen to be a capable layer for the engineering structure's foundation along this traverse. The third geoelectric layer has depth range of 7.0 to 10 meter or even more especially at their two extremes and this zone is characterised with resistivity between 151 to 1541 Ωm (yellow to red colour) and it is a fractured geologic basement rock. The last lithology is the fresh basement extending from 8.0 meter to beyond 25.0 meters with resistivity between 1542 to 1633 Ωm. Additionally, the electromagnetic data/profile (figure 10) indicates a low near surface geologic layer throughout the entire profile length and it is not a good engineering construction material as earlier pointed out from the 2-D imaging line.

3.1.6 The 2D resistivity section along Traverse 6

The topsoil in this traverse (Figure 11) is composed of material with varied resistivity between 19 to 91 Ωm (green), which represent top soil is made up of sand. The depth ranges from 0.0 to 5m below the surface. The second geoelectric layer is weathered zone made up of coarse sand material and spans a depth range of 5 meters to about 10 meters and even more in the extreme right hand side of the traverse. Its resistivity ranges from 91 to 120 Ωm (yellow colour). Fractured basement rock has resistivity of 121 to 434 Ωm (red) and the fresh basement rock has resistivity of 434 to 2056 Ωm (purple). Both the fractured and fresh basement form the subsurface conical hill at depth and together with surface geological units will provide support and stability for any imposed loads without any case of differential settlement. Additionally, from station 1 to 11, the electromagnetic profile (figure 12) displays stable zones near and below the surface. It can be observed that competent zones of moderate resistivity even at the surface at some locations exist. These locations will support buildings and are advantageous for the engineering structure's foundation along this profile line.

3.1.7 The 2D resistivity section along Traverse 7

The top units are lateritic pan (red and patches of purple colour) directly on top of the near surface basement rock, and weathered basement rock (green). They both occur at the surface as shown in figure 13. The lateritic pan has resistivity between 109 to 256 Ωm while the weathered basement is characterised with moderate resistivity between14 to 46 Ωm. they provide stable platform for the buildings. The clayey unit has resistivity between 8 to 13 Ωm and occur at depth and this may not affect the foundation.

The absence of cracks in the building at this traverse indicates stable geologic materials that is appropriate for construction. The electromagnetic data/profile (figure 14) showed some isolated portion with high resistivity from geologic materials capable of bearing load at surface or near surface depth especially at station points 2 and 5.

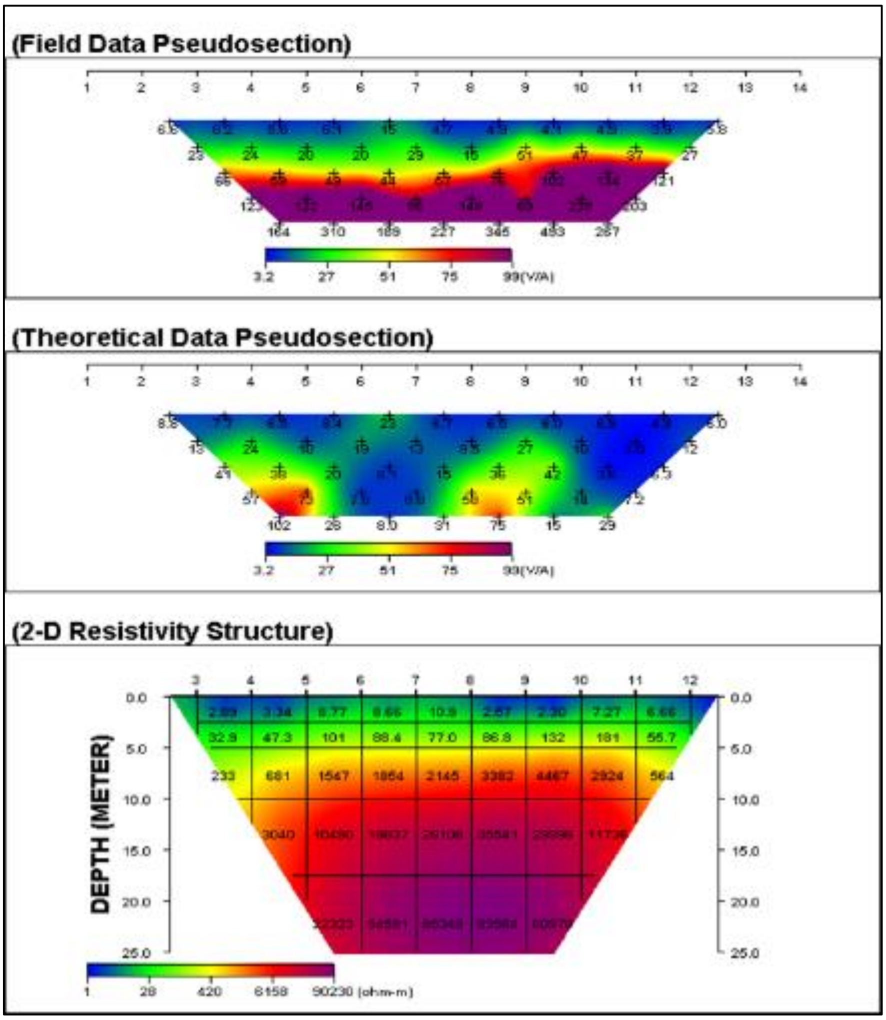

Figure 7 Traverse 4- Pseudo-section of line 4 indicating the apparent resistivity values (Coordinate; latitude N7^{0} 50” 06.5’ and longitude E 006^{0} 39” 43.9’)

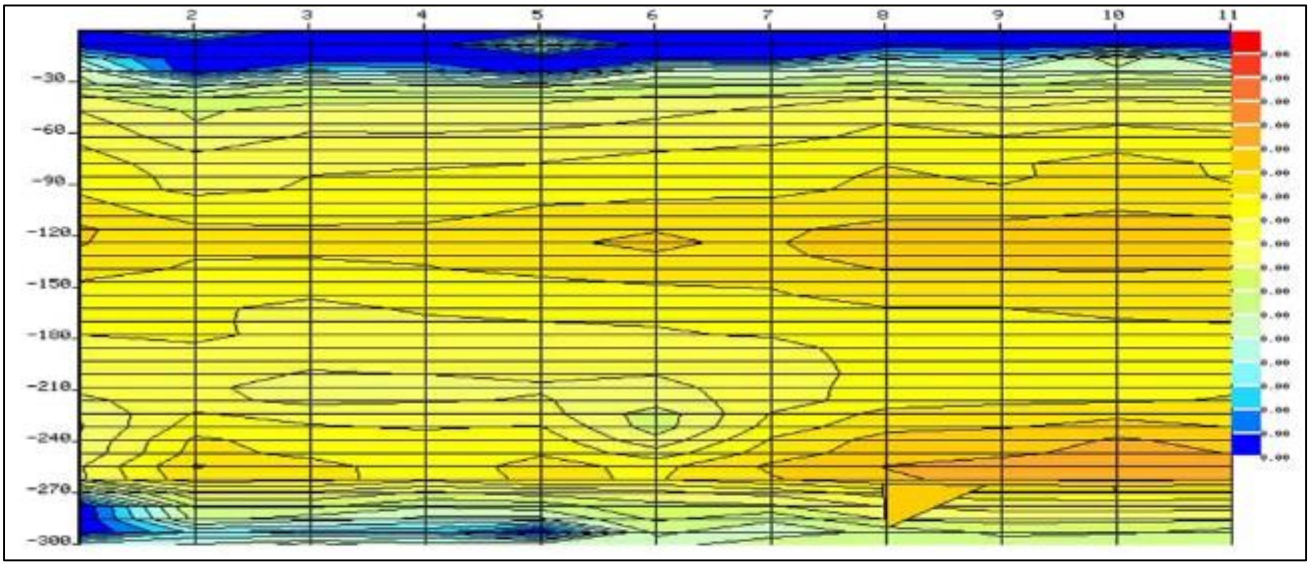

Figure 8 Electromagnetic profile for traverse 4 showing resistivity

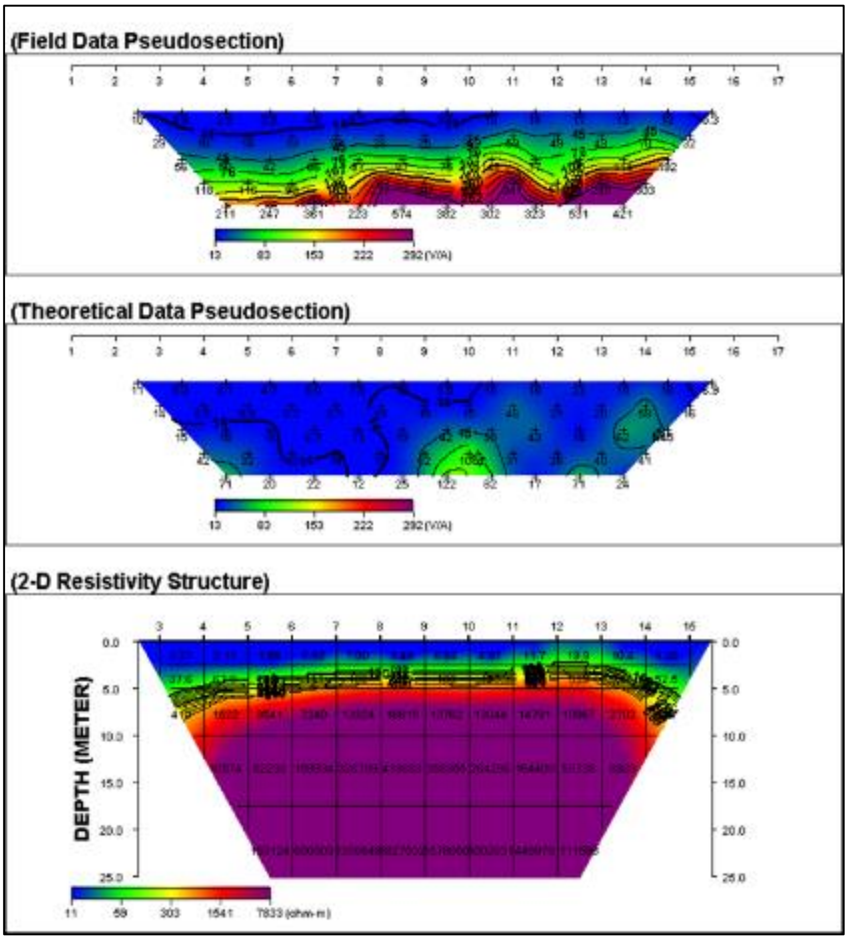

Figure 9 Transverse 5- Pseudo-section of line 5 indicating the apparent resistivity values (Coordinate; latitude N7^0 50” 03.0’ and longitude E 006^0 39” 30.0’)

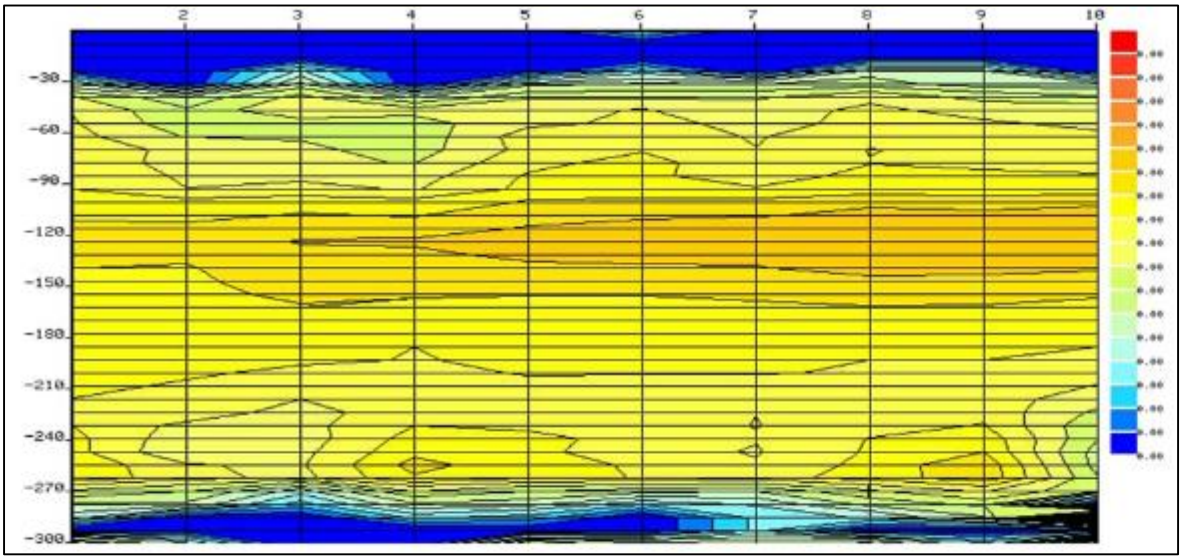

Figure 10 Electromagnetic profile for traverse 5 showing resistivity

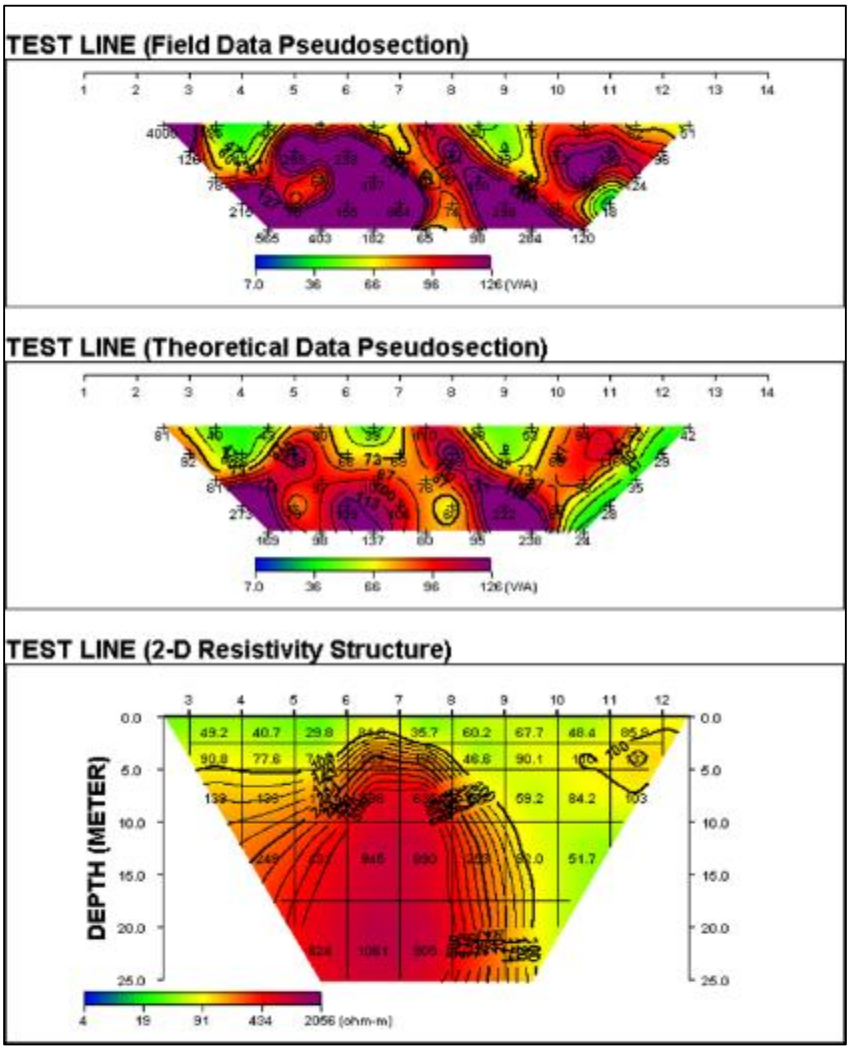

Figure 11 Traverse 6- Pseudo-section of line 6 indicating the apparent resistivity values (Coordinate; latitude N7^0 49” 57.1’ and longitude E 006^0 39’ 12.2’)

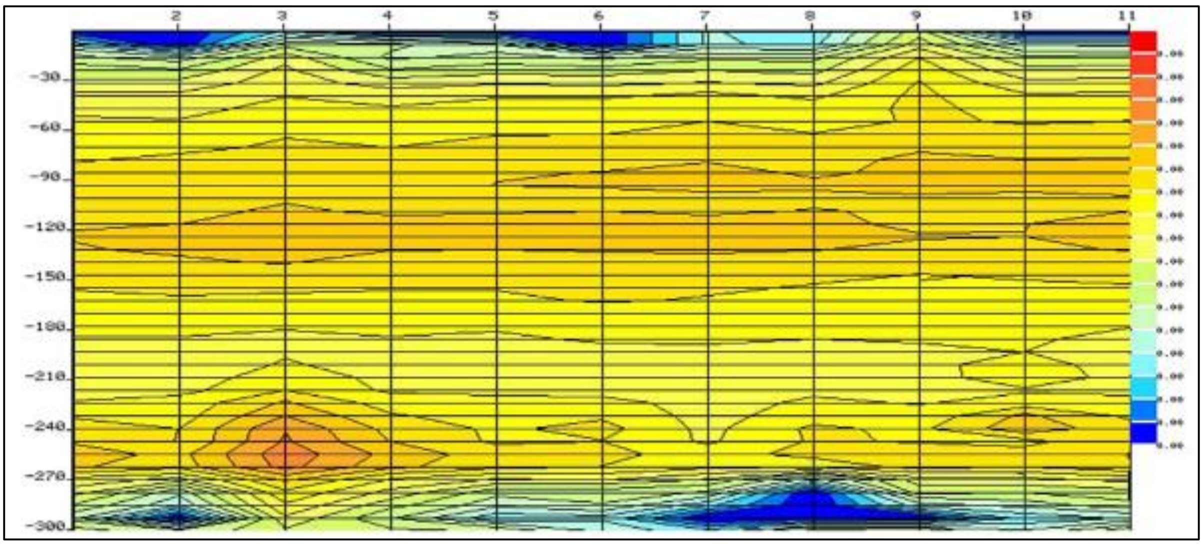

Figure 12 Electromagnetic profile for traverse 6 showing resistivity

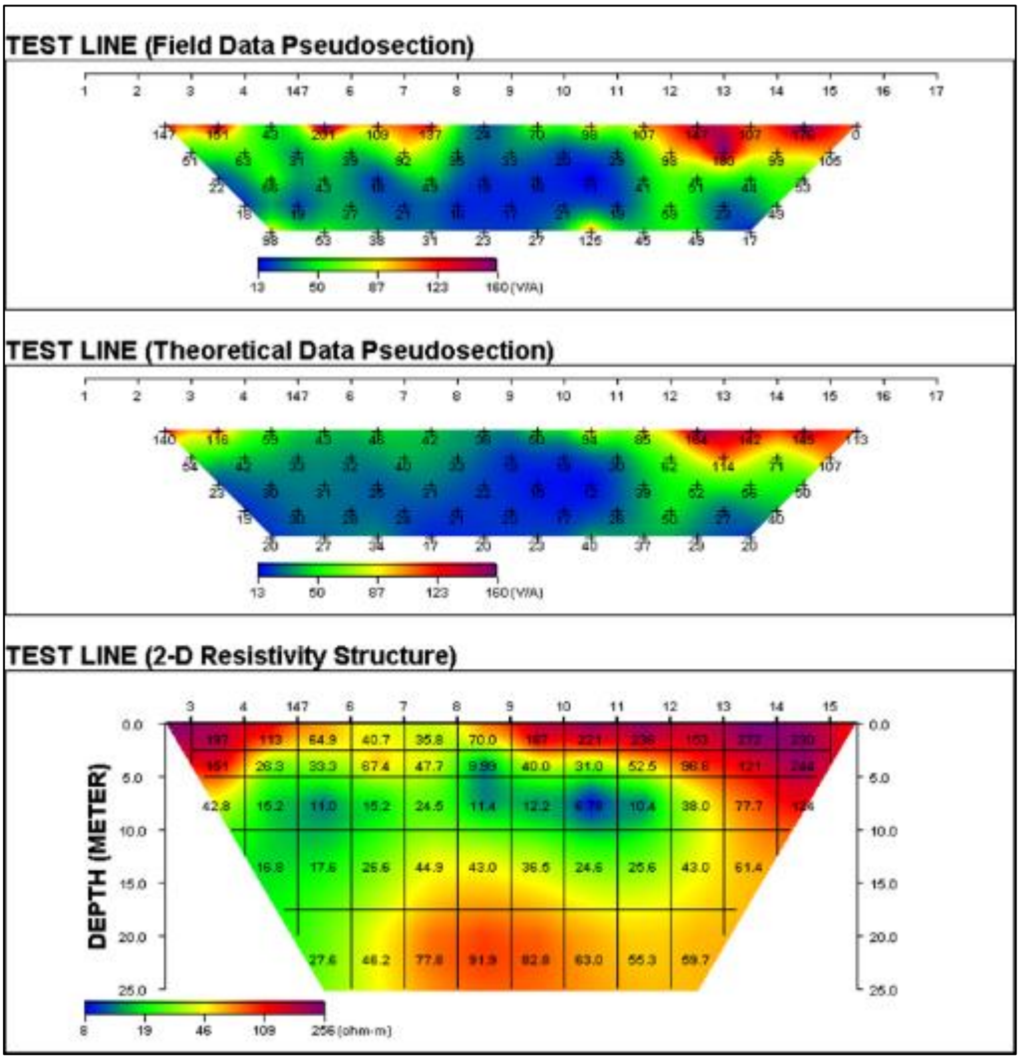

Figure 13 Transverse 7- Pseudo-section of line 7 indicating the apparent resistivity values (Coordinate; latitude N7^0 49" 59.0' and longitutde E 006^0 39" 09.8')

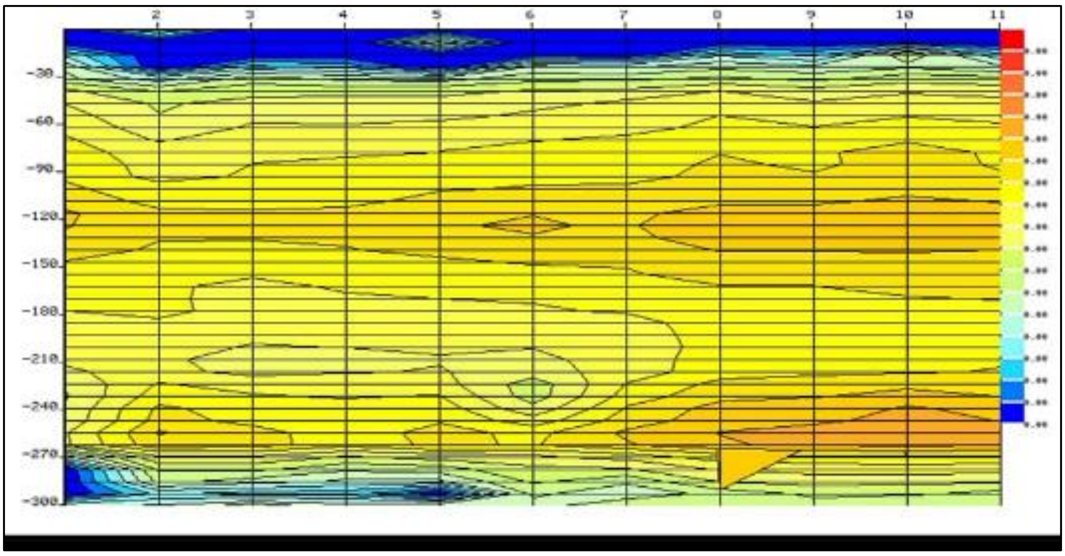

Figure 14 Electromagnetic profile for transverse 7 showing resistivity

3.2 Geotechnical Analysis

The following are the geotechnical data obtained and they include; Grain Size Analysis, Compaction and moisture content, California Bearing Ratio and Atterberg Limits.

3.2.1 Granulometric Analysis Result

Table 1 Summary of the Sieve analysis result for the seven samples

Sample ID	**% Wt. Passing**	**% Wt. Passing**	**% Wt. Passing**	**% Wt. Passing**	**% Wt. Passing**	**% Wt. Passing**	**% Wt. Passing**
Sample Name	SAM 1 (unstable portion)	SAM 2 (unstable portion)	SAM 3 (unstable portion)	SAM 4 (unstable portion)	SAM 5 (unstable portion)	SAM 6 (stable portion)	SAM 7 (stable portion)
10mm	100	100	100	100	100	100	100
5mm	100	100	100	100	100	96	96
2.5mm	99	99	97	99	99	86	85
1.25mm	85	92	92	94	94	47	49
0.6mm	76	70	74	76	78	19	19
0.3mm	48	42	45	39	46	5	6
0.15mm	23	20	19	16	21	2	2
Passing	1	0	0	0	0	0	0
Σ	100	100	100	100	100	100	100

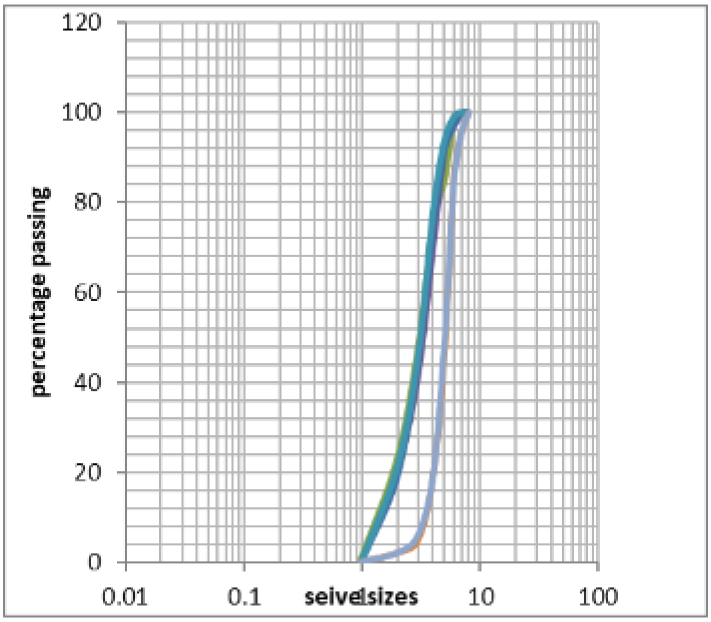

Figure 15 Granulometric analysis plot showing plotted percentage passing against sieve sizes

The plotted grain size analysis of the soil samples taken at seven different locations at a depth of 1.5 meters is displayed in the graph above. Plotting the sieve sizes (phi values) versus the cumulative weight % was done. More than 50% of the grain sizes in samples 1 through 5 (the unstable portion of the research regions) are less than 0.3 mm in diameter, suggesting the presence of silt and clay. In contrast, samples 6 and 7 demonstrate that 80% of the grain sizes are less than 0.6 mm in diameter. Grain distributions were even, making them appropriate for use in civil engineering projects. This interpretation is in line with the interpretation from both 2-D imaging and the EM data that indicated that instability of geologic materials for traverse 1-5 and Electromagnetic profile 1-5 and stability for traverse 6 and 7 and Electromagnetic profile 6 and 7.

3.2.2 Compaction Test Result

The soil compaction test result is displayed in the table below. The purpose of this compaction was to determine the highest dry density that could be achieved for a particular soil with a typical level of compaction effort. The optimum moisture level of the oil samples was determined by plotting the dry density against the moisture content. The optimal moisture content of samples 6 and 7, which are from the stable part of the site, are 12.0% and 11.3% respectively, while samples 1 through 5, which are from the unstable portions, have the optimal moisture content of 11.3%, 11.7%, 10.4%, 11.0%, and 11.5%, respectively.

Table 2 Summary of the Compaction Test Result Analysis

SAMPLE 1		**SAMPLE 2**		**SAMPLE 3**		**SAMPLE 4**		**SAMPLE 5**		**SAMPLE 6**		**SAMPLE 7**	
MC %	DD g/cm3	MC %	DD g/cm3	MC %	DD g/cm3	MC %	DD g/cm3	MC %	DD g/cm3	MC %	DD g/cm3	MC %	DD g/cm3
8.8	1.57	9.0	1.60	6.8	1.55	8.6	1.68	7.9	1.62	9.3	1.67	8.3	1.57
9.6	1.58	10.4	1.61	8.1	1.57	9.6	1.69	9.5	1.65	10.2	1.68	6.9	1.58
11.3	1.60	11.7	1.63	10.2	1.61	11.0	1.71	11.1	1.68	12.0	1.70	11.3	1.60
12.5	1.58	13.1	1.60	12.8	1.59	14.6	1.68	12.2	1.67	14.0	1.68	12.5	1.58
OMC %		OMC %		OMC %		OMC %		OMC %		OMC %		OMC %	
11.3		11.7		10.4		11.0		11.5		12.0		11.3	

NOTE: MC= Moisture Content, DD= Dry Density, OMC= Optimum moisture Content

Table 3 Oversize data Analysis

S/N	**SAMPLE ID**	**% finer**	**% coarser**	**Moisture content**
1	SAM 1 (unstable portion)	71.1	28.9	11.3
2	SAM 2 (unstable portion)	70.8	29.2	11.7
3	SAM 3 (unstable portion)	70.1	29.9	10.4
4	SAM 4 (unstable portion)	75.1	24.9	11.0
5	SAM 5 (unstable portion)	74.0	26.0	11.5
6	SAM 6 (stable portion)	18.1	81.9	12.0
7	SAM 7 (stable portion)	19.2	80.8	11.3

Samples 1 through 5 in Table 3 contain percentage fines of 71.1, 70.8, 70.1, 75.1, and 74.0, respectively, with corresponding percentage coarse of 28.9, 29.2, 29.9, 24.9, and 26.0. This demonstrated the existence of highly water-retaining clay particles in the soil sample. While sample six and seven have percentages of coarsening of 81.9 and 80.8, respectively, and finer of 18.1 and 19.2 respectively. These research areas is stable and the structures here exhibited no cracks. This is due to the soil's inability to retain water for an extended period of time, the high percentage coarse values explain why there was no crack on this building. These interpretation also corroborate with those geophysical results earlier analysed above.

3.2.3 Atterberg Limit Result Analysis

A high clayey content in the soil samples is also indicated by the liquid and plastic limit values. The samples' average plastic index (PI) value, as measured by column 5, is 11.2%. In contrast, the linear linkage shrinkage (LS) values (table 4), range from 1.79% to 5.71%, with an average value of 2.78%. This LS number indicates that the soil type in the area is shrinking and active. Sand can be used to describe samples 6 and 7, which exhibit non plasticity and this is what is responsible for their stability as revealed from the two geophysical profiles (2-D resistivity imaging traverse and Electromagnetic profiles)

Table 4 Summary of the Result for Atterberg Limit Test of Soil Samples

S/N	SAMPLE ID	PL (%)	LL (%)	PI (%)	LS (%)	Degree of Plasticity	Soil Type
1	SAM 1 (unstable portion)	15.5	23	7.5	1.79	Medium plasticity	Silt clay
2	SAM 2 (unstable portion)	16.44	33	16.56	3.60	Medium plasticity	Silt clay
3	SAM 3 (unstable portion)	6.28	12	5.72	3.07	Low plasticity	Silt
4	SAM 4 (unstable portion)	5.78	17	11.22	2.78	Medium plasticity	Silt clay
5	SAM 5 (unstable portion)	6.78	16	9.22	2.8	Medium plasticity	Silt clay
6	SAM 6 (stable portion)	0	13	0	5.57	Non plasticity	Sand
7	SAM 7 (stable portion)	0	8	0	5.71	Non plasticity	Sand

Note: PL= Plastic Limit, LL= Liquid Limit, PI= Plasticity Index, LS=Linear Shrinkage and SAM= Sample

3.2.4 California Bearing Ratio result

The summary of the California Bearing Ratio result obtained from the seven (7) samples examined is displayed in the table below (Table 5). Figure 16 shows a plot of the plunger load in KN against the penetration rate in mm.

Table 5 Classification of the soil samples using the typical CBR values

S/N	SAMPLE ID	CBR %	At 2.5mm	At 5.0mm	Soil type
1	SAM 1 (unstable portion)	2.34	3.5	4.3	Clay
2	SAM 2 (unstable portion)	2.33	4.6	5.2	Clay
3	SAM 3 (unstable portion)	1.99	2.9	3.4	Silty Clay
4	SAM 4 (unstable portion)	3.26	4.8	6.2	Sandy Clay
5	SAM 5 (unstable portion)	2.15	4.9	6.1	clay
6	SAM 6 (stable portion)	21.89	23.7	21.0	Well graded sand
7	SAM 7 (stable portion)	28.60	29.1	28.1	Well graded sand

Table 6 Summary of the California Bearing Ratio Result

"PEN	SAM. 1	SAM. 2	SAM. 3	SAM. 4	SAM. 5	SAM. 6	SAM. 7
	UNS.	UNS.	UNS.	UNS.	UNS.	ST.	ST.
mm"	LOAD(KN)	LOAD(KN)	LOAD(KN)	LOAD(KN)	LOAD(KN)	LOAD(KN)	LOAD(KN)
0.5	2.2	2.5	2.05	2.2	2.2	2.05	1.9
1	2.65	3.24	2.5	2.8	2.5	2.5	2.05
1.5	3.09	3.69	2.95	3.39	2.95	2.65	2.2
2	3.24	4.14	3.39	4.14	3.39	3.09	2.65
2.5	3.54	4.59	3.99	4.89	3.84	3.24	2.95

3	3.84	4.89	4.29	5.49	4.29	3.54	3.24
3.5	3.99	5.04	4.59	5.93	4.89	3.84	3.39
4	4.14	5.19	5.04	6.08	5.34	3.99	3.39
4.5	4.29	5.19	5.49	6.08	5.78	4.14	3.39
5	4.29	5.19	5.78	6.08	6.23	4.14	3.39
5.5	4.29	5.19	5.93	6.16	6.53	4.14	3.39
6	4.29	5.19	6.23	6.16	6.98	4.14	3.39

Note: Uns= Unstable Portion and St= Stable Portion

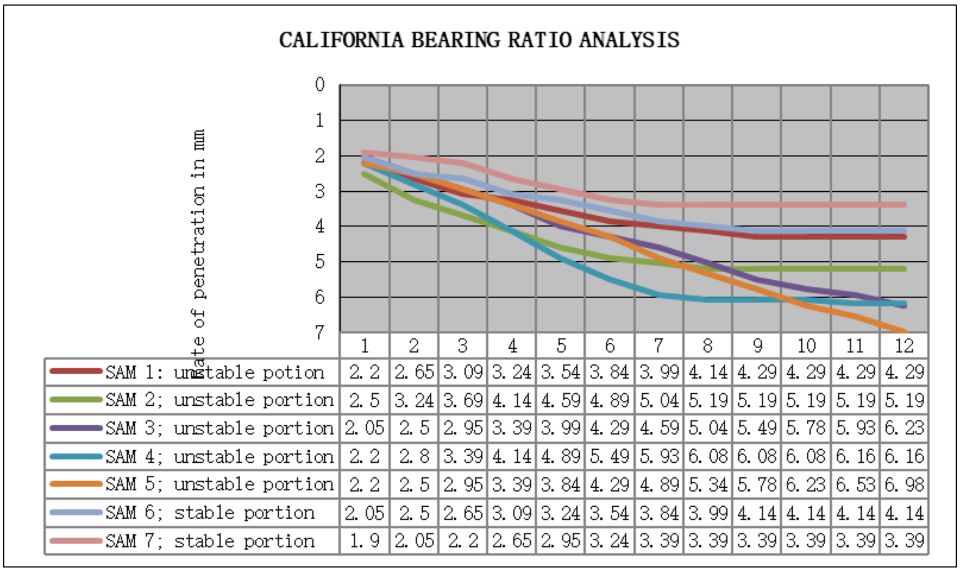

Figure 16 California Bearing Ratio plot for the seven analyzed samples showing there penetration rate

4 Discussion

The foundational integrity of the subsurface materials in a typical crystalline basement complex terrain has been evaluated using geophysical and geotechnical techniques, specifically to identify the reasons for some obvious cracks on some of the buildings in the study region. Two types of rocks migmatite and porphyroblastic gneiss were recognized from the geological mapping that was conducted. These sorts of rocks are composed of mafic minerals, which, when worn out, become clay-rich top soil. The subsurface geology complexity, structural mapping, and pertinent geotechnical parameters for foundation layer reliability have all been assessed using the proper techniques.

Seven (7) traverses were chosen, two from the section showing no fracture and five from the location where the buildings are exhibiting cracks. The analysis of the geophysical data reveals that the top soil in the five problematic areas (traverses 1-5 and samples 1-5) contains clay materials with a very low resistivity, which contributes to the breakdown of the engineering structures. Extremely high resistivity zones are shown in the results from the stable region (traverse 6 and 7 and samples 6 and 7), suggesting the presence of hard rock. The evaluated soil samples' optimum moisture content (OMC) for unstable portions range from 10.4% to 11.50% with average of 11.18% (samples 1-5) while it ranges from 11.3% to 12.0%, with a mean of 11.65% for stable portions based on the geotechnical study results (Row 8 of Table 2). According to Jegede (2000), this range of OMC values for samples 1-5 suggests that the soil sample at 1.5 m deep is naturally medium compacted and may be seriously threatened by heavy rains. This is most likely due to the fact that the OMC parameter of soil is mostly influenced by the amount of rain, the depth at which samples are collected, and the soil's texture.

The unstable portion of the buildings (table 3) has values in the range of 70.1 to 75.1 according to the findings of the soil oversize grain data analysis test (% finer passing). 72.22% is the calculated average value for the samples' passing percentage. According to the results, the soil samples were categorized as having fine particles and a poor grade, which is indicative of a high clay material concentration and low silt content. In a similar vein, the soil samples 1-5 have high clayey content as shown by the liquid and plastic limit values (Table 4). The average value of the determined plastic index (PI) for the samples is 10.044%. According to Jegede (2000), these PI results are also within the 20% of the technical standard for foundation materials and hence they exhibited low to medium plasticity and are not good for foundation. As a result, for foundation materials subgrade at shallow depth, the soil samples 1-5 were interpreted as having fair to poor engineering qualities. But samples 6 and 7 have zero plasticity as revealed by their PI values and they are good foundation materials. In contrast, the linear linkage shrinkage (LS) values (table 4) range from 1.79% to 3.60%, with an average value of 2.808%.

4.1 Foundational integrity assessment of the area

The integrated findings from both geophysical and geotechnical studies serve as the basis for the evaluation of the area's foundation competency. It has been determined and understood that the area's geoelectric parameters allow for the subsurface lithological characterization and the potential absence of major linear features like fractures and faults, which indicate weak zones. The research area subsurface is made up of fresh bedrock, fractured basement, partially or totally soaked weathered layer, clayey substratum, and silty/clayed topsoil, lateritic soil and lateritic pan (figures 1 to 14). The foundational integrity of civil engineering structures can be significantly impacted by both shallow or intermediate depth structures as well as the topsoil and near-surface representation of these weak features.

The topsoil in the region is primarily made up of clay materials geoelectrically. Furthermore, it was determined that the high porosity, low permeability, and low resistivity properties of the topsoil in the area typified a clayey composition medium that is a weak foundation material based on the geotechnical evaluation results of this layer (mainly the OMC, grain oversize data, PI parameters determined, etc.; Tables 2 and 3). Akintorinwa and Adeusi (2009) and Adeoti et al (2016), found out that a layer's competency increases with its resistivity value and vice versa from the perspective of engineering and geoscience applications. Therefore, from all the analysis, the subsoil is comparatively incompetent as a foundation material, unless it undergoes some form of treatment like cut and fill, grouting etc to improve its quality for perfect suitability for foundation structures except at sample points 6 and 7 which seems to be naturally good and suitable for building.

which may be the cause of the building cracks, according to the geotechnical characteristics gathered from the site.

5 Conclusions

In order to ensure appropriate building plans for civil engineering structures, geophysical and geotechnical techniques have been used to evaluate the foundational integrity of subsurface materials in a typical crystalline basement complex terrain. These techniques have been used to assess the structural mapping, subsurface geology complexity, and pertinent geotechnical parameters for foundation layer reliability. The 2D imaging showed the underlying geologic layer of fresh/fractured bedrock, partially/fully soaked weathered layer, clayey substratum, and silty/clayed topsoil and lateritic clay and lateritic pan. This result is complimented by electromagnetic data which also offer information about weak points in the subsurface layers. Due to the degree of weathering and the underlying porphyroblastic gneiss in the hybrid rocks, the geophysical data suggest that the subsoil at the site has a poor to low competency grade for foundational material except at few locations. The area's subsoil's natural moisture content, liquid limit, plastic limit, plastic index, linear shrinkage, compact test, and California Bearing Ratio are among the geotechnical criteria that have been assessed. Practically speaking, the geotechnical study of these values indicates that the subsurface in the area is unsuitable as a foundation material at that depth except with pre-engineering treatment. There was a good complementarity between the geophysical and geotechnical results.

Additionally, this study showed that because of their limited spatial dimensions (size, lateral extent, and depth) and discontinuity across the area of interest, geologic features that have a significant impact on the structural integrity and competency of the foundation materials are frequently overlooked or overlooked during conventional geotechnical evaluations. As this study shows, this issue can be more fully resolved by utilizing the complementary strengths of geophysical and geotechnical methods.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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