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# Environmental Impact Assessment of Structural Defects Using Geophysical and Geotechnical Methods in Parts of Ekpoma, Southsouthern Nigeria

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**ABSTRACT**

This study has evaluated the immediate and remotes causes of structural/foundation failures arising as a result of geodynamic activities that often bring about weathering/fracturing process. Three geophysical techniques were deployed and complemented with geotechnical analysis. The geophysical techniques include 2-D imaging using Dipole-Dipole, Lateral Horizontal Profiling technique which give useful information on the nature and trends of the sub-surface and structural trends and Vertical Electrical Sounding technique using Schlumberger electrode configuration which gave relevant information on layer sequences/stratification as well as variations in lithology/lithological distributions. The geotechnical analysis gave relevant information on the nature, types, grain size analysis and other soil parameters that has direct impact on foundation integrity. The results obtained from the Dipole-dipole and Wenner techniques indicated six weak zones of major interest while the Vertical Electrical Sounding delineated three major layers which are topsoil, clayey sand/sandy and moderately resistive sandstone formation. The geotechnical analysis indicated the results obtained from both field and laboratory tests which shown that the specific gravity ranged from 2.64 to 2.65; linear shrinkage ranged from 5.0 to 7.1;the amount of fines (i.e. particles less than 0.075mm sieve) from the particle size analysis test ranged from 34.4% to 36.7%; liquid limit varied from 29.4% to 32.2%; Plasticity index varied from 10.2 to 11.9; from the compaction test optimum moisture content and maximum dry density varied from 13.6% to 14.2% and 19.38kN/m$^3$ to 19.49kN/m$^3$ respectively; unconfined compressive strength range from 181kPa to 227kPa. The results obtained from both methods gave relevant information on factors that were responsible for cracks/subsidence and failure of the building.

## 1. Introduction

The global warning doubt is a phenomenon that mankind learns to live with. This is not only because of the unprecedented changes in the climate which has alternatively affected other geodynamic activities, leading to increase in rainfall, erratic distribution of rainfall, sudden changes in erosion pattern, incidence of Earthquake and tremor, sudden rise in sea level, increase in desertification, sudden changes in sea tides and a host of others related with its direct consequences on the safety of man and his environment (Bawallah et al., 2019a; Bawallah et al., 2019b; Ozegin et al., 2019a; Oyedele et al., 2020; Bawallah et al., 2020).

The immediate concern of this research work is to beam a searchlight on the emerging global phenomena and its immediate and remotes consequences on foundation integrity in a typical sedimentary environment of South South Nigeria. This has become very necessary in the face of distressing rate at which structural/failures occurred especially in sedimentary environment which forms the present focus where many causes of foundation/structural failures are fast becoming occurrence (Akintorinwa and Adelusi,2009; Akintorinwa and Adesoji, 2009; Oyedele et al., 2011; Adelusi et al., 2013; Adelusi et al., 2014; Ilugbo et al., 2018a; Adebiyi et al., 2018; Ilugbo et al., 2018b; Adebo et al., 2019; Ozegin et al., 2019b). Therefore, the focus of this research work is to evaluate the geophysical and geotechnical factors and parameters that may put structural integrity into serious doubts when combined with other geodynamic trends/activities occasioned by global warming and their effect on the immediate environment especially as it may affect the rate of foundation failures.

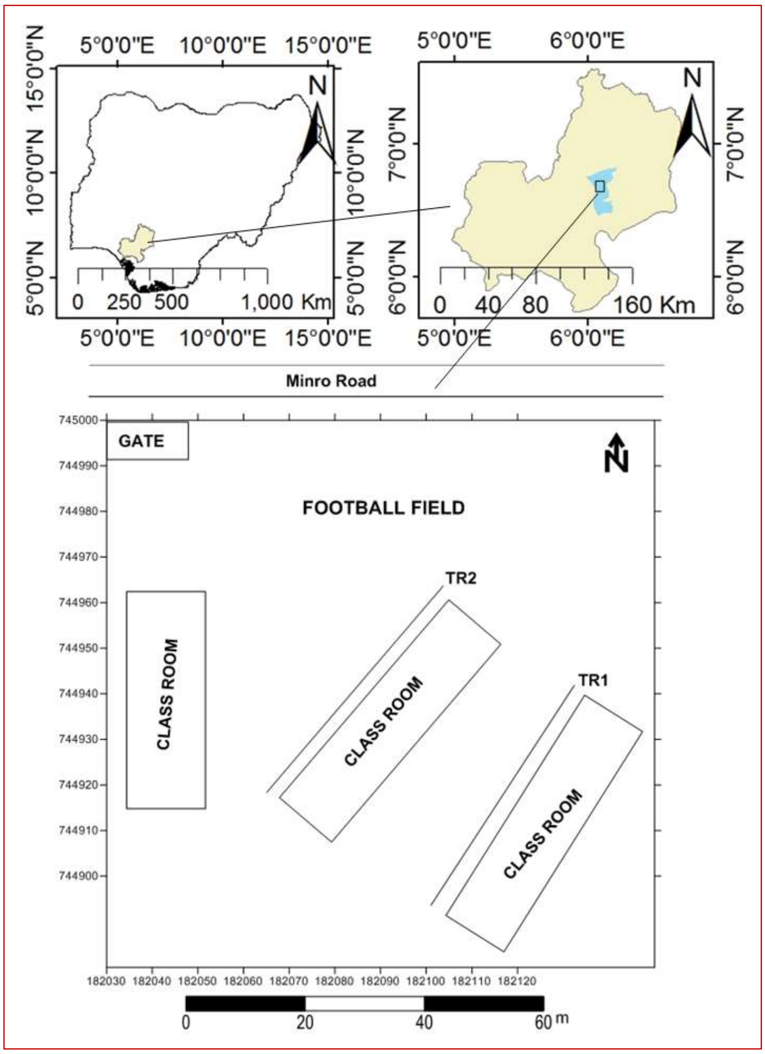


Fig. 1. Base map of the study area

## 2. Site Description and Geology of the Study Area

The study was carried out at Ukpenu Primary School, Ekpoma, Edo State, Nigeria (Fig. 1). It is situated between the UTM coordinates of Eastings 744900 - 745000 m and Northings 182030 - 182150 m. The elevation ranges from 239 to 290 m above the sea level. The accessibility of the study area is mainly by road and footpaths. The study area falls within the Anambra Basin covering Eguare Ekpoma town and Ukpenu extension in Esan West Local Government area of Edo State, Nigeria (Fig. 2). The average annual temperature in Ekpoma is 24.8°C. Precipitation is lowest in January; with an average of 11 mm. The greatest amount of precipitation occurs in September with an average of 303 mm. At an average temperature of 26.6°C, March is the hottest month of the year. The lowest average temperatures in the year occur in August, when it is around 23.0°C.

Between the driest and wettest months, the in precipitation is 292 mm. The variation in temperatures throughout the year is 3.6°C. The area of study is underlain by Bende – Ameki Formation while the nearby area is underlain with 3 % of Imo shale and Ogwashi – Asaba. The area is underlain by clay, shale, sandstone, limestone and sand. The Niger Delta sediment includes Benin, Agbada and Akata formations and they range in age from Eocene to recent (Kogbe, 1978; Aigbedion, 2007; Okeke, 2011; Salufu, 2014; Aigbedion et al., 2019).

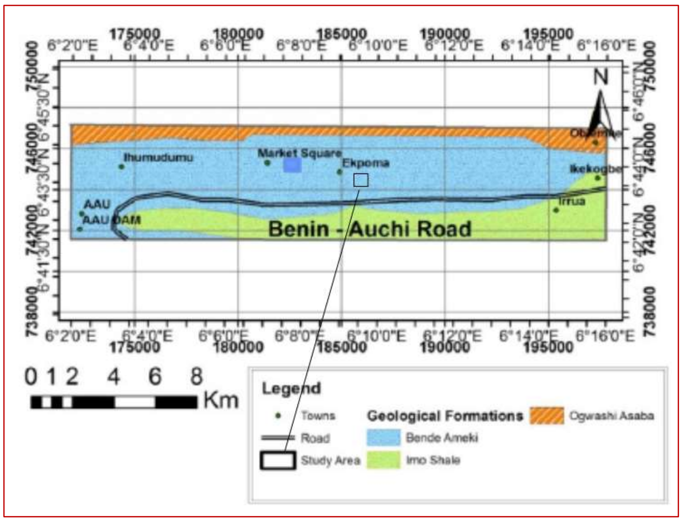


Fig. 2. Geological map of Ekpoma showing the study location (modified after Salufu and Ujuanbi, 2015)

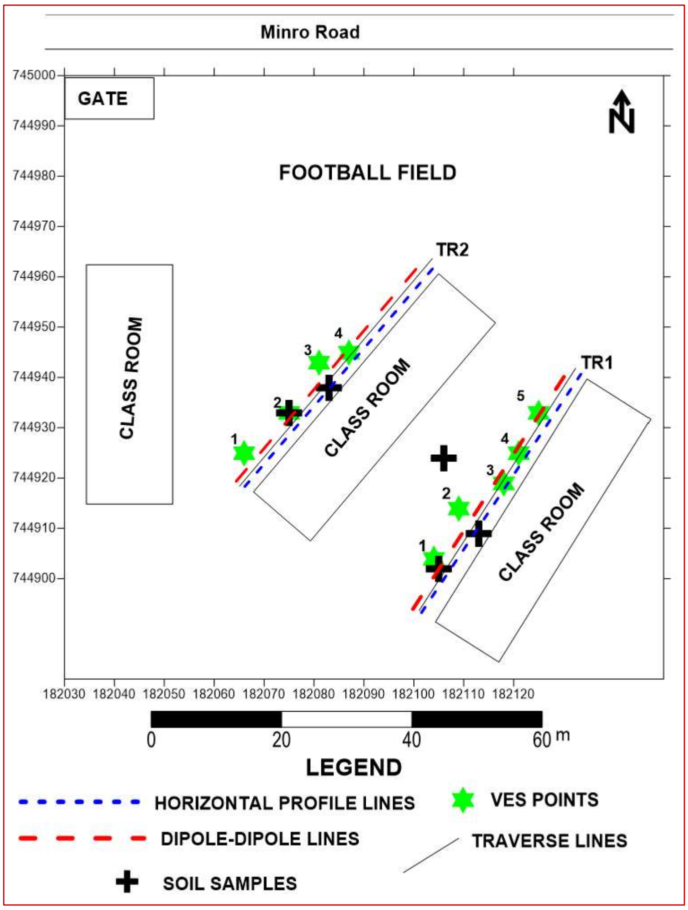


Fig. 3. Data acquisition map of the study area

## 3. Research Methodology

### 3.1. Geophysical investigation

In this method, three electrical resistivity techniques were used, viz; Vertical Electrical Sounding (VES), 2-D Electrical Resistivity Tomography (ERT) and Horizontal Profiling (HP) with corresponding the configurations, Schlumberger, Dipole-Dipole and Wenner configurations respectively (Fig. 3). Nine (9) sounding stations were occupied along the traverses, and the current electrode spacing (AB/2) was varied from 1 to 100 m. To process the electrical resistivity data, the apparent resistivity values were plotted against the electrode spread (AB/2). This was subsequently interpreted quantitatively using the partial curve matching method and computer-assisted 1-D forward modeling with WinResist 1.0 version software.

The results from the VES interpretation were used to determined second order parameters such as the total transverse resistance (T) and the total longitudinal conductance (s). The dipole-dipole data were inverted using 2-D subsurface images using the DIPPRO™ 4.0 inversion software. The inter-electrode spacing of 5 m was adopted while inter-dipole expansion factor (n) was varied from 1 to 5. Lateral Horizontal Profiling (LRP) techniques was taken at a = 5, 10, 15, and 20 m which give useful information on the nature and trends of the sub-surface and structural trends and the data obtained were inverted using 2-D subsurface images using the Resis2D software. Resistivity values were obtained by taking readings using Ohmega resistivity meter.

### 3.2. Geotechnical investigation

The samples for geotechnical test were collected at five different points into a plastic bag and transported to the soil laboratory, the soil was air dried and crushed into small pieces (Fig. 3). The crushed samples were then sieved through various sieves opening ranging from 0.0063 mm to 10.0 mm. The sieved soil was wetted with tap water, the moister soil was sealed in a plastic bag and stored for 2 days to allow moisture equilibrium and hydra soil was later used for other geotechnical tests. Some tests were repeated for some locations to ensure the reliability of the test result.

The basics test conducted include the plastic index, unconfined compressive strength, hydrometer test, specific gravity, dry unit weight, particle size distribution; compaction test and Atterberg's limit of the soil were performed according to British standard (BS 1377, 1990). The data of these index properties were used to classify the soil following the United Soil Classification System (USCS) classification. The final results from geotechnical test were correlated with geophysical investigation results to provide information on the variation of strata and physical strength across the site.

## 4. Results and Discussion

### 4.1. Characteristic of the VES curves

Curves types identified ranges from A, HA and KH varying from three to four geoelectric layers. The A curve type was predominated.

### 4.2. Geoelectric section along traverses one and two

For the purpose of layer characterization, better understanding of the geoelectric parameters and geological setting; a follow up technique was involved using the VES where nine VES were carried out on traverses one and two (Fig. 4 and 5). The results obtained delineated three geoelectric sequences which comprises of the topsoil with resistivity layer ranged from 73-657 Ωm and thickness ranging from 0.6 to 2.3 m. This is underlain by a clayey sand/ sandy formation whose resistivity varies from 157-1071 Ωm and thickness that ranges from 2.1-9.5 m. The last layer which is considered as the moderately resistive sandstone formation has a resistivity values ranging from 469-3417 Ωm. However, a sudden change was observed in traverse two from the western to eastern part of the study area with a low resistivity values ranging from 73 to 236 Ωm to a depth of 7 m which characterizes weak formation that may threaten foundation integrity. Hence, the evident of a major crack and sinking that were observed along the class rooms in traverse two, this was as a result of the weak formation (high presence of clay).

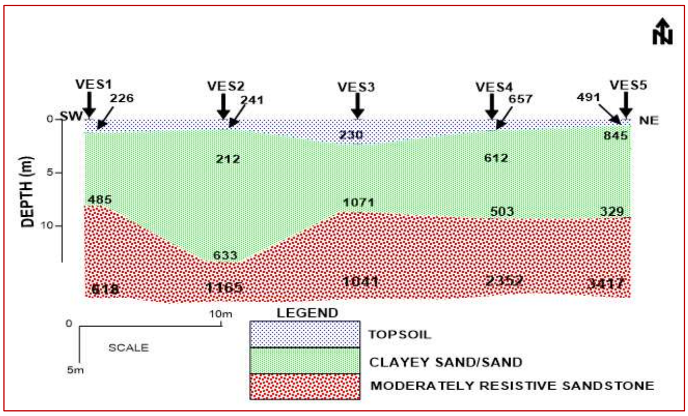

Fig. 4. Geoelectric section along traverse one

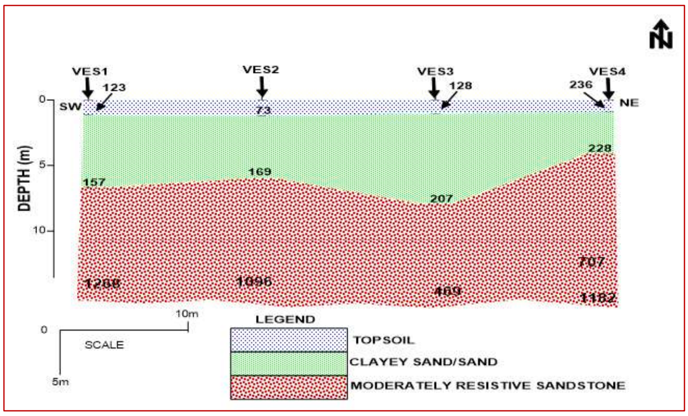

Fig. 5. Geoelectric section along traverse two

### 4.3. Geoelectric maps

#### 4.3.1. Isoresistivity map of topsoil

This map gave useful information on the topsoil apparent resistivity of the study area (Fig. 6). The topsoil consists of clay, clayey sand, sandy clay and sand. The northeastern part of the study area has the highest resistivity values from 300 to 680 Ωm. Northern, northwestern, western, southwestern and southern parts of the study displayed relatively low resistivity values from 60 to 280 Ωm, which indicates apparently weak underlying geologic materials that may be vulnerable to stress and strains occasioned by load that may bring about structural defects leading to foundation vulnerability. These were probably the major reason for the crack and sinking observed towards the northwestern, western and southwestern parts of the study area.

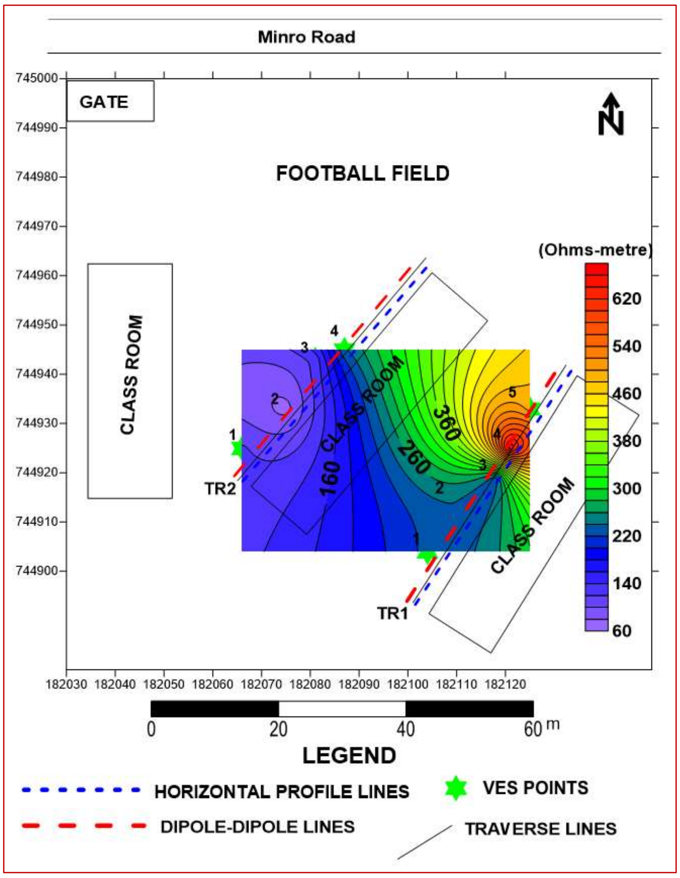

Fig. 6. Isoresistivity map of topsoil

#### 4.3.2. Isopach map of topsoil

This map gives significant information on the relevance of layer thickness of any geologic formation on foundation integrity (Fig. 7). The northeastern, northern and central parts of the study area have a thickness ranging from 0.5 to 1.1 m and the region was a major point of interest with high dominant of clay. The thickness of the topsoil may not be of any considerable interest since topsoil is normally excavated. Therefore, due to the presence of clay with thickness up to 7 m accounts for the major crack and sinking of the classrooms (building).

#### 4.3.3. Total longitudinal conductance map

Fig. 8 showed the total longitudinal conductance map of the research area. The northeastern, eastern and southeastern regions were characterized by low total longitudinal conductance values ranging from 0.014 to 0.022 $\Omega^{-1}$. This is a reflection of low presence of clayey and high presence of resistive geological materials which are characteristic of good foundation stability. The central part was characterized by moderate total longitudinal conductance with value ranging from 0.022 to 0.03 $\Omega^{-1}$ which is a reflection of moderate foundation stability. Furthermore, the northwestern part has the highest total longitudinal conductance values ranging from 0.38 to 0.048 $\Omega^{-1}$. This indicates region of major weak zone, which leads to major crack and sinking of the classrooms. This is a reflection of very low resistivity attributes characterized by weak geodynamic materials that are readily prone to failure and highly susceptible to stress and strain when load is place on them, especially when combined with the geodynamic effects, tides, rapid erosions and seasonal variations accessioned by global warming.

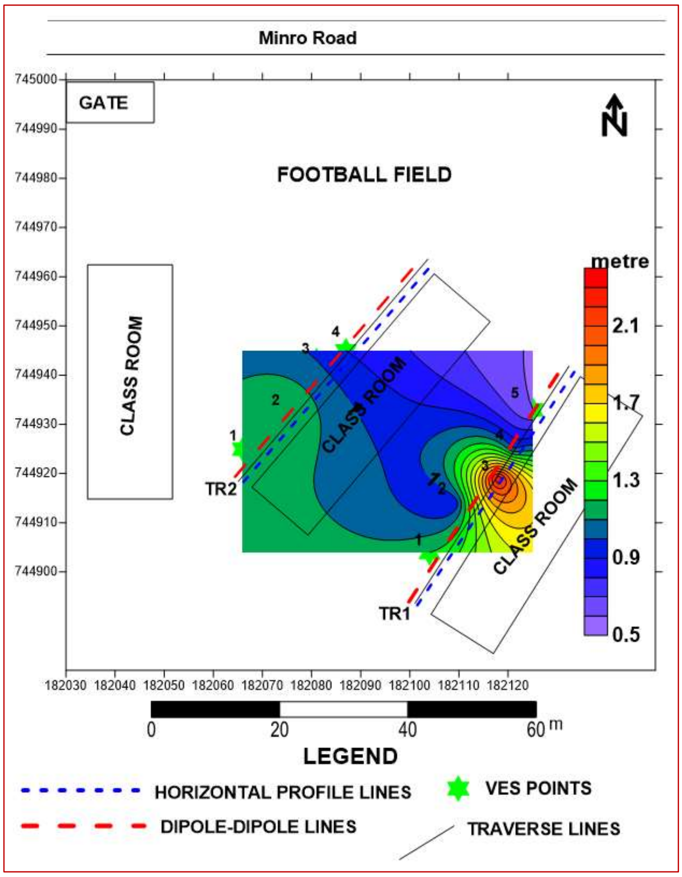


Fig. 7. Isopach map of topsoil

### 4.3.4. Total Transverse Resistance

Fig. 9 showed the total transverse resistance map of the study area which illustrates the foundation and soil integrity. It is a reflection of the ability of the soil to withstand load, as well as an indicator of the load bearing capacity of any study location in terms of foundation and structural parameters within the subsurface (Bawallah et al., 2020). The western, northwestern and southwestern parts of the study area were characterized by low total transverse resistance values ranging from 500 to 3000 $\Omega m^{-2}$ showing regions that are highly susceptible to failure arising from underlying weak geologic materials. Whereas the central, northeastern and southern parts exhibit moderate transverse resistance with values ranging from 3000 to 5500 $\Omega m^{-2}$, which displays region of moderate weak underlying geologic materials. Furthermore, northern and small closure at southeastern parts was dominated with high value ranging from 6000 to 8500 $\Omega m^{-2}$ indicative of high foundation integrity and stability.

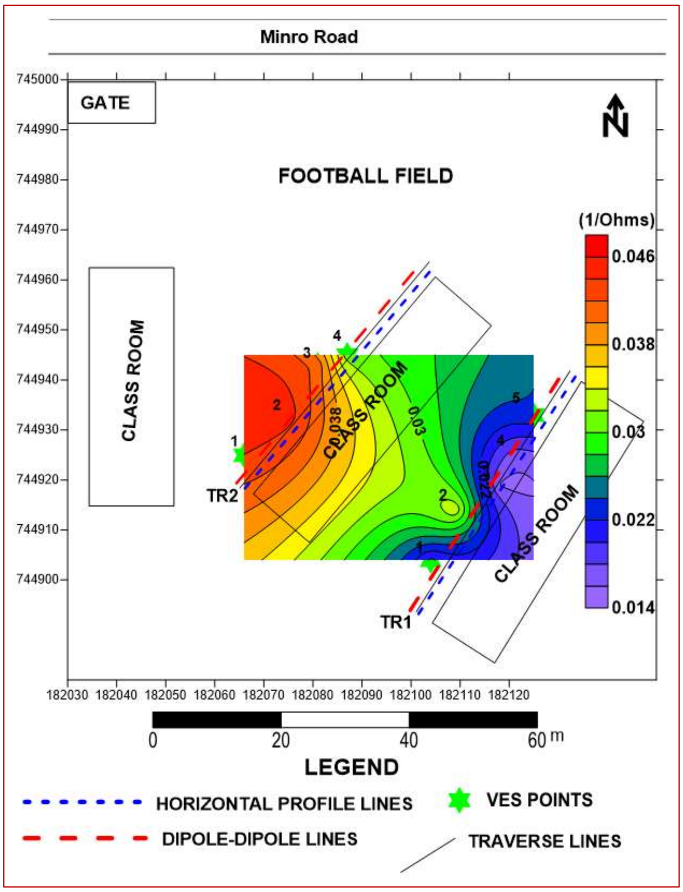


Fig. 8. Total longitudinal conductance map

### 4.4. Dipole-dipole pseudosection

#### 4.4.1. Dipole-dipole pseudosection along traverse one

The imaging reflects the near surface to about 4.5 m indicated a geophysical attribute of a resistivity variations ranging from 230 to 2416 Ωm which exhibits some reasonable elements of a structural stability (Fig. 10). Beyond this layer follow with resistivity attributes varying from 2101 to 10517 Ωm reflecting a higher degree of competence/stability, except for small closure of low resistivity at a distance of 12.5 and 37.5 m with resistivity of 164 and 79.4 Ωm values ranged from 164 to 79.4 Ωm at a distance of 12.5 and 37.5 m. This traverse can be inferred as highly demonstrable competence/stability. Hence, the possible reason for the stability of the building located along the traverse, except for the little crack that was observed at a distance between 12.5 and 37.5 m within the building which may be as a result of near surface low resistivity.

#### 4.4.2. Dipole-dipole pseudosection along traverse two

The imaging showed two distinctive characteristics, displaying the nature of the geology of the invrestigated area (Fig. 11). The resistivity values indicated that the greater part of western axis from the near surface horizon to a depth of 12 m and covering a distance of 30 m. This showed low resistivity values ranging from 19.8 to 251 Ωm indicating very weak geological formation that may be readily prone to failure or differential settlement. This is what led to crack and sinking of the building along the traverse. However, the remaining parts of the traverse exhibits high resitivty value ranging from 433 to 42006 Ωm which indicated the zones of high integrity/region of high forundation integrity which showed stability of the building.

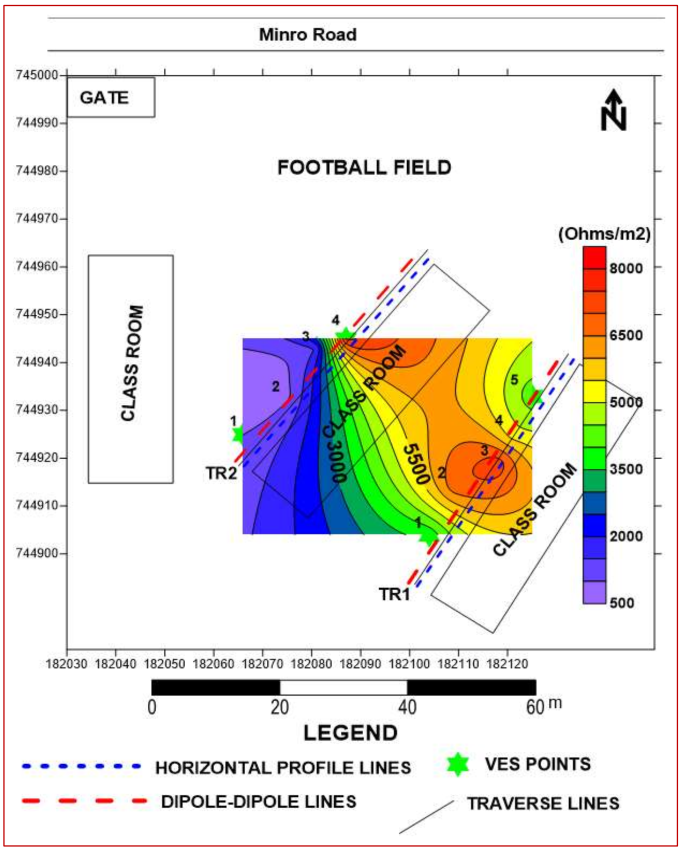


Fig. 9. Total transverse resistance

## 4.5. ERT along traverse one and two

The imaging of the subsurface using Wenner resistivity parameters of a = 5, 10, 15 and 20 m which gave useful information about the subsurface geophysical parameters of the investigated area. Traverse one exhibits the existence of a fairly weak zone from the near surface to a shallow depth from the western part towards the midpoint of the profile (Fig. 12).

Whereas the situation was different for profile two (Fig. 13) which were characterized by major weak zone from the near surface to a reasonably thick depth and covering the greater proportion of the traverse from the western end to far beyond the middle of the profile towards the eastern part. This is an indication that apparent weak geophysical parameters in this traverse subjected the foundation integrity into serious doubt and hence the signs of formation failure that were noticed leads to crack and sinking of the building.

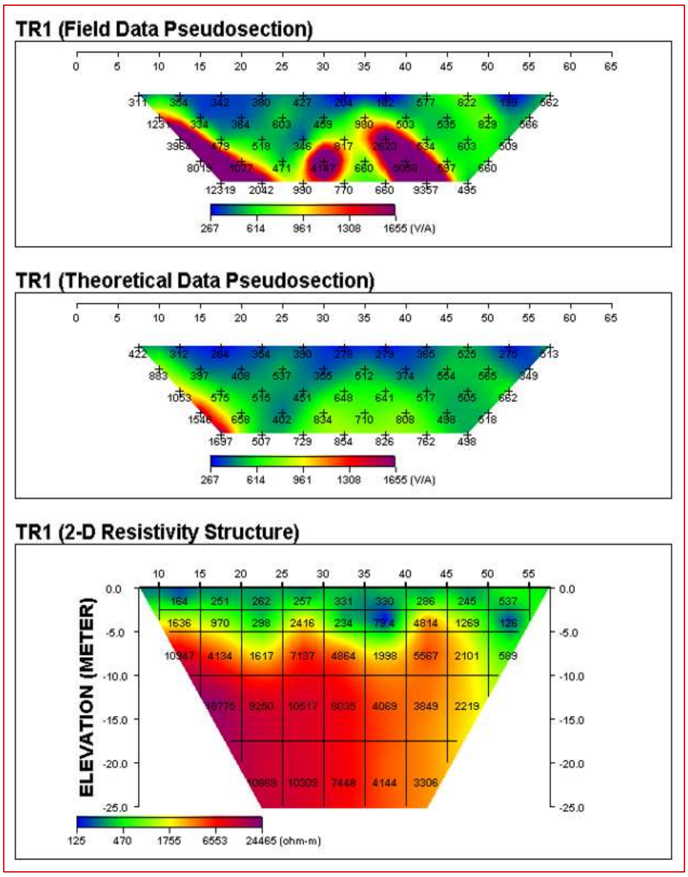


Fig. 10. Dipole-dipole pseudosection along traverse one

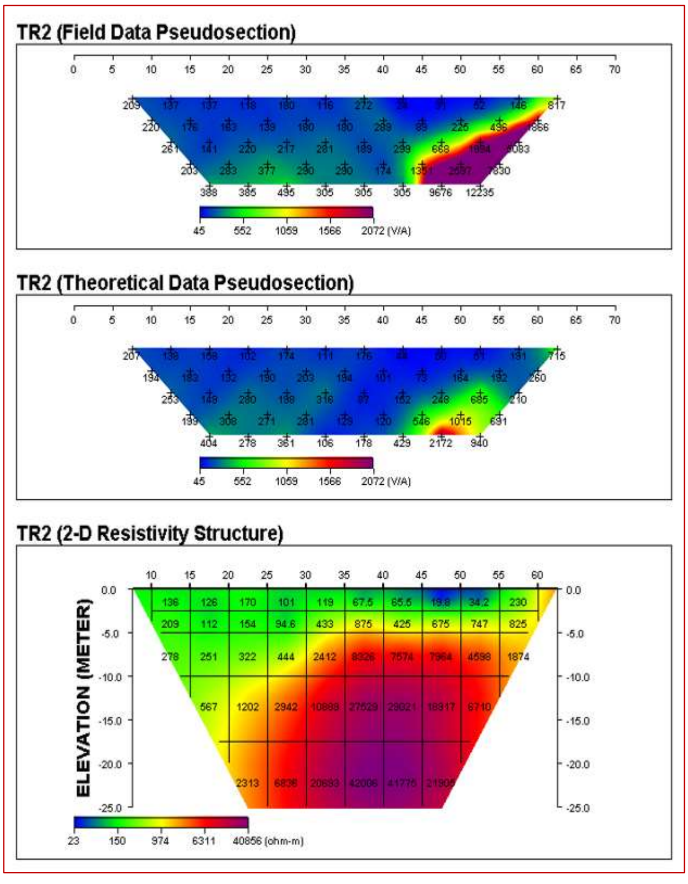


Fig. 11. Dipole-dipole pseudosection along traverse two

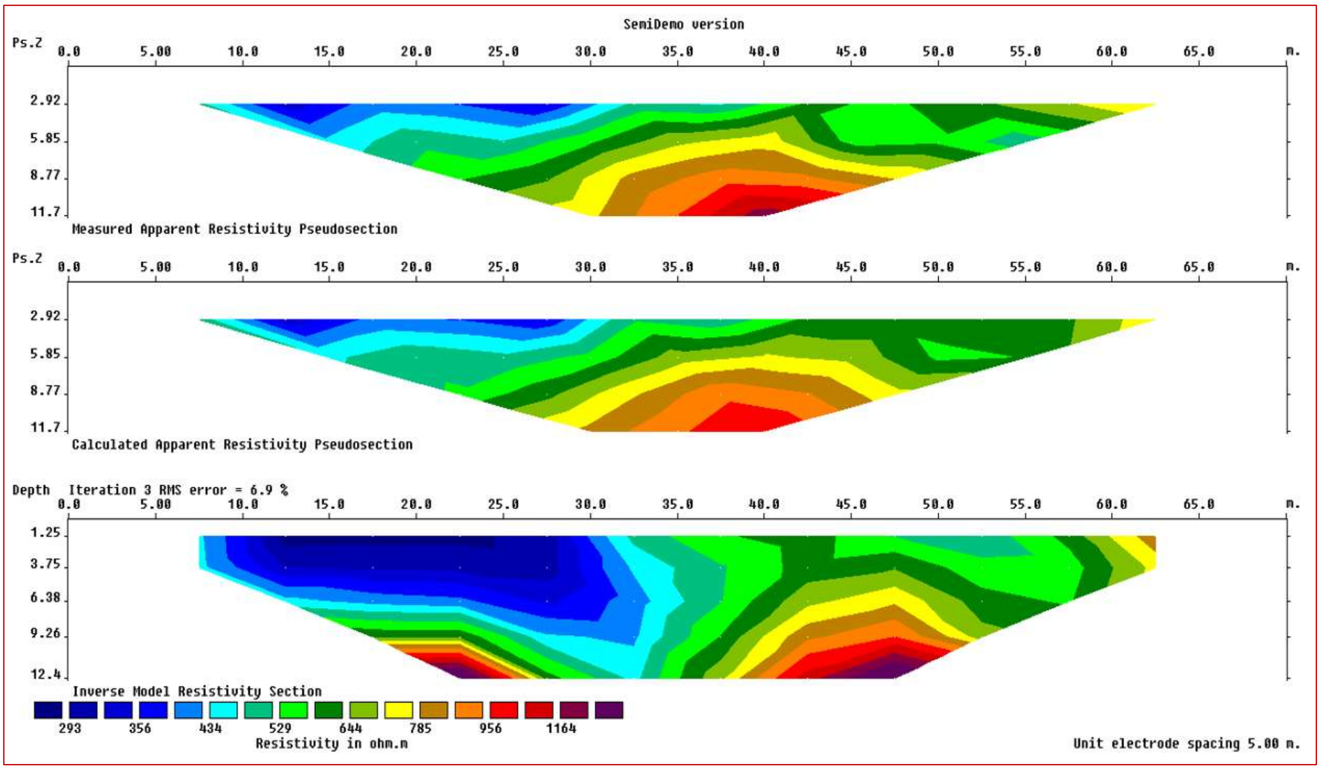


Fig. 12. Lateral horizontal profiling along traverse one

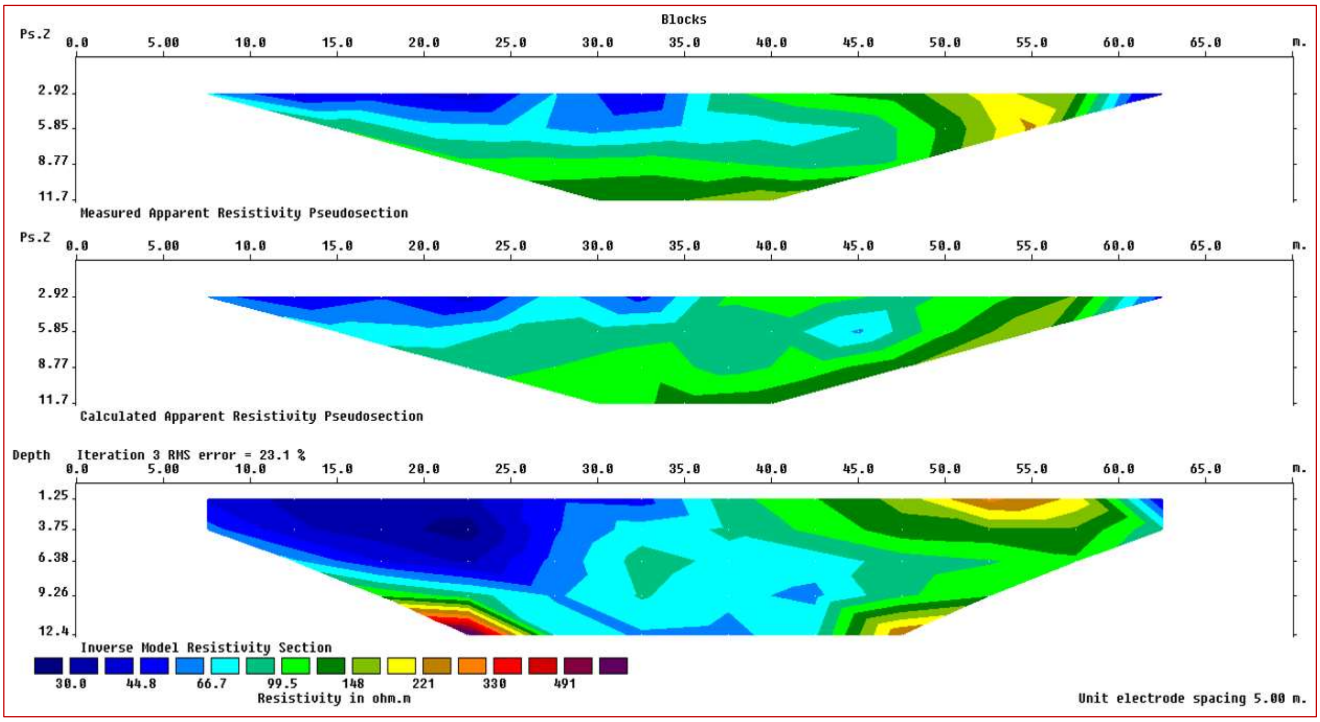


Fig. 13. Lateral horizontal profiling along traverse two

## 4.6. Synthesis of result

### 4.6.1. Traverse one

The dipole-dipole imaging, Wenner resistivity imaging as well as the VES techniques were able to established the existence of near surface partially weak zone, and an underlying competent zone along the traverse one (Fig. 14).

### 4.6.2. Traverse two

The dipole-dipole imaging, Wenner resistivity imaging as well as the vertical electrical sounding techniques exhibited effective correlation, as the three techniques showed the existence of major weak zone especially from the western part of the traverse towards the centre (Fig. 15).

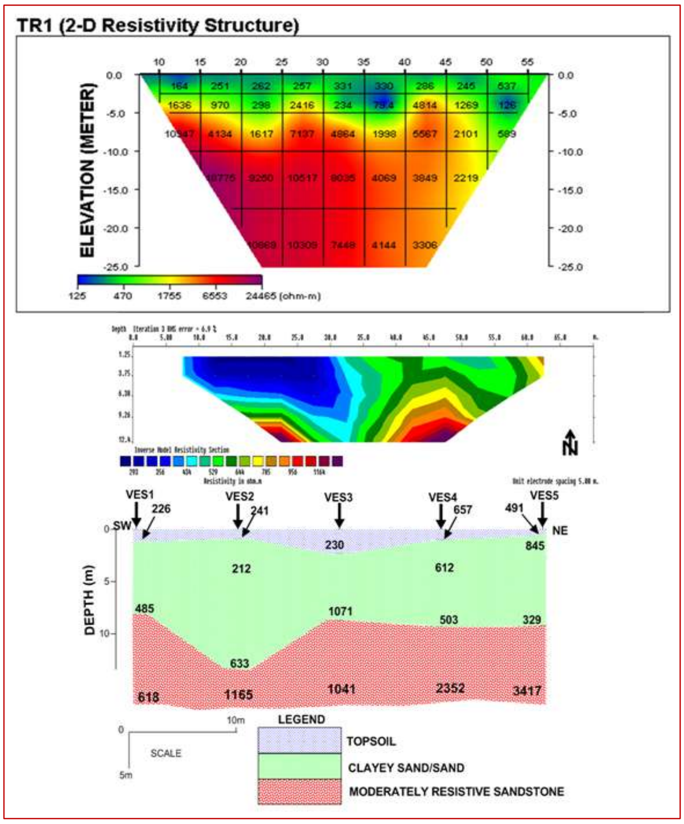


Fig. 14. Correlation of results along traverse one

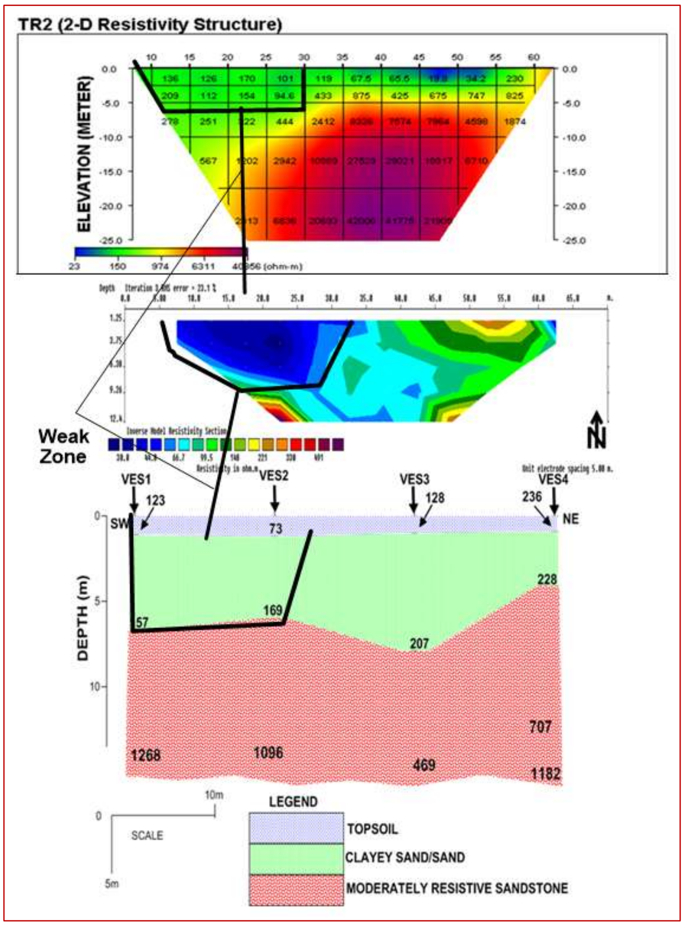


Fig. 15. Correlation of results along traverse two

This has negatively affected the integrity of the area, hence, leads to the major crack and gradual sinking observed on the building.

### 4.7. Geotechnical results

The results of the geotechnical parameter such as plastic index, unconfined compressive strength, hydrometer test, specific gravity, dry unit weight, particle size distribution; compaction test and Atterberg's limit of the soils samples from the trial pit is attached to the scope of this study in form of table and graphs**.**

#### 4.7.1. Dry unit weight

The dry unit weight ranges from 19.38 to 19,60 kilo Newton per cubic meter (KN/m$^3$), which suggest a density index less than the required standard of 85 % index stability and hence may also account for partial vulnerability or structural failure.

#### 4.7.2. Specific gravity

The specific gravity was used to determine the rate of voids within soil sample which ranges from 2.64 to 2.65 as seen in the Table 1.

#### 4.7.3. Plasticity index

The plasticity index obtained from the soil analysis ranges from 10.2 to 11.9 % which implies that compressibility is low (Burmister, 1997) and encourage cracks that may leads to foundation vulnerability to failure (Table 2).

Table 1. Specific Gravity for Sample one to five

| Sample points | Average specific gravity |
|---|---|
| 1 | 2.642 |
| 2 | 2.648 |
| 3 | 2.645 |
| 4 | 2.652 |
| 5 | 2.651 |

#### 4.7.4. Grain size analysis

The grain size analysis for the five sample points gave relevant information on the amount of fines i.e., less than 0.075 mm sieves, these ranges from 34.4% to 36.7 % which is good enough to support stability (Table 2).

#### 4.7.5. Liquid limit

This is the water content at which the soil will behave like a viscous mud flowing under its own weight. The liquid limit test has a value ranging from 29.4 to 32.2 % which is fairly good enough to support foundation integrity (Table 2).

#### 4.7.6. Compaction test

The compaction test/analysis indicated that the optimum moisture content (OMC) and maximum dry density (MDD) ranges from 13.6 to 14.2 % and 19.38 to 19.49 kilo Newton per meter cube (KN/m$^3$) which is good enough to support stability (Table 2).

#### 4.7.7. Unconfined compressive strength

The unconfined compressive strength value varies from 181 to 227 kilo Pascal (kPa) (Table 2) which may be good but not the best for foundation/structural strength and hence may be partly responsible for foundation vulnerability.

### 4.8. Result summary and soil classification

The details of various results obtained from both field and laboratory tests are shown in (Table 2). The specific gravity ranges from 2.64 to 2.65; linear shrinkage range from 5.0 to 7.1; the amount of fines (i.e. particles less than 0.075mm sieve) from the particle size analysis test range from 34.4 to 36.7 %; liquid limit range from 29.4 to 32.2 %; plasticity index range from 10.2 to 11.9; from the compaction test the compaction parameters OMC and MDD range from 13.6% to 14.2% and 18.25 kN/m$^3$ to 18.52 kN/m$^3$ respectively. The unconfined compressive strength values range from 181kPa to 227 kPa.

### 4.9. Correlation of both methods

As stated earlier under precious discussion of results, the results obtained from both methods gave relevant information on factors that were accountable for the cracks/subsidence and failure. The areas that were diagnostic of anomalous zones from geophysical method were found to have failed one geological test or another in terms of soil integrity especially information obtained along traverse two.

Table 2. Results summary and soil classification

| Sample code | L1 S1 | L1 S2 | L1 S3 | L1 S4 | L1 S5 |
|---|---|---|---|---|---|
| Natural moisture content (%) | 13.25 | 14.15 | 14.1 | 14.15 | 14.15 |
| Specific gravity | 2.64 | 2.65 | 2.65 | 2.65 | 2.65 |
| Linear shrinkage value | 7.1 | 6.4 | 5.7 | 6.4 | 5.0 |
| Liquid limit, $W_L$ (%) | 32.2 | 31.3 | 31.2 | 30.4 | 29.4 |
| Plastic limit, $W_P$ (%) | 20.5 | 19.4 | 19.4 | 19.9 | 19.2 |
| Plasticity index, PI (%) | 11.7 | 11.9 | 11.8 | 10.5 | 10.2 |
| % of soil passing 2.36mm sieve | 98.5 | 98.6 | 98.6 | 98.7 | 98.8 |
| % of soil passing 425μm sieve | 71.4 | 75.4 | 76.3 | 72.4 | 76.9 |
| % of soil passing 75μm sieve | 35.6 | 34.5 | 35.4 | 34.4 | 36.7 |
| Optimum moisture content, (%) | 13.6 | 14.0 | 13.9 | 14.2 | 14.0 |
| Maximum dry density, (kg/m$^3$) | 1852.1 | 1834.0 | 1838.6 | 1825.0 | 1834.0 |
| Unconfined compressive strength, (kPa) | 212.1 | 212.9 | 227.2 | 211.2 | 181.8 |
| Group index, GI | 1.8 | 1.7 | 3.4 | 1.0 | 0.7 |
| AASHTO classification | A-2-6 | A-2-6 | A-2-6 | A-2-6 | A-2-6 |
| USCS Classification code | CL | CL | CL | CL | CL |
| Degree of expansion based on linear shrinkage value | Marginal | Marginal | Marginal | Marginal | Non - critical |

## 5. Conclusion

The two methods that were engaged in this study justifiably gives relevant information on the contributing factors that are accounted for the vulnerability and subsequence failure that occurred at the location of the study. Therefore, it is strongly recommended that these two approaches should be adopted as a major tool for foundation studies.

## Data Availability Statement

The authors confirm that the data supporting the findings of the study are available within the article and its supplementary materials. Authors have declared that no competing interests exist and the data was not use as an avenue for any litigation but for the advancement of knowledge.

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