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Electrical Resistivity and Geotechnical Attributes and The Dynamics of Foundation Vulnerability

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Abstract: This research evaluates the significance of geotechnical and Electrical Resistivity methods in studying structural integrity as fundamental factors that may account for failure in a typical sedimentary environment of Ukpenu Primary School, Ekpoma, Edo State, Nigeria. Two methods were used in this study such as the Electrical Resistivity approach involving the use of Lateral Horizontal Profiling (LHP), 2D Electrical Resistivity Tomography (ERT), and Vertical Electrical Sounding (VES) techniques. While geotechnical method involved the collection of soil samples from the study locations for the characterization of the soil properties that are very vital to foundation studies. Nine VES were carried out using Schlumberger array with current electrode spacing varying from 1 to 40 m, with 2-D ERT using Dipole-Dipole electrode array with inter-station separation of 5 m and an expansion factor varied from 1 to 5 while LHP involve Wenner array with an electrode spacing of 5 m interval and was used to determine the vulnerability factors for the building sustainability. The VES interpretation results were used to determine the second-order parameters for the determination of vulnerability. The results obtained from the two methods review that both are very fundamental to foundation dynamics. However, electrical attributes were found to give better information in terms of depth, lateral extent, layer stratification, and nature of materials which make it an indispensable tool over geotechnical attributes whose depth of investigation is up to a maximum of 5 m which poses great limitation in the evaluation of structural integrity, against stress, and strain occasion by geodynamic activities that often result into fracture, crack, highly weathered formation that usually goes beyond the shallow depth of investigation. Therefore, it can be stated that resistivity attributes account for 90% of the major contributing factors that affect foundation vulnerability.

Keywords: Geotechnical Studies, 2D ERT, Lateral Horizontal Profiling, VES, Vulnerability Factor, Structural Integrity

INTRODUCTION

The issues concerning foundation studies have remained a burning concern in the mind of geoscientists and civil engineers (Bawallah et al., 2020). Whereas, the spates of foundation vulnerability and subsequent failures that were reported in some parts of African and especially Nigeria has assumed a worrisome dimension, hence to evaluate the factors that are responsible for this foundation vulnerability in terms of depth of investigations, nature of materials, structural trends, geodynamic factors, the relevance of Electrical Resistivity and Geotechnical attributes and their significance in evaluation of foundation sustainability (Ilugbo et al., 2018; Ozegin et al., 2019a; Bawallah et al., 2019a; Bawallah et al., 2019b; Bawallah et al., 2020; Oyedele et al., 2020).

Moreover, the Electrical Resistivity attributes take into consideration the nature of geological materials i.e. structural settings, both lateral and depth extent from the topsoil to a depth of 100 meters and sometimes beyond, whereas, civil engineering site investigation takes into account geotechnical attributes such as nature of the soil, stratification, and settings up to a maximum depth of 3 – 5 meters. Therefore, it brings to mind the pertinent issues of which among these attributes is most fundamental and inevitable, which most times the civil engineers do not seem to appreciate the inevitability of Electrical resistivity attributes in foundation studies (Akintorinwa & Adesoji 2009; Adebiyi et al., 2018; Ilugbo et al., 2018; Adebo et al., 2019).

Therefore, this study is a direct consequence of the need to harmonize this school of thought to evaluating both Electrical Resistivity and geotechnical attributes, to establish the indispensability of both approaches to foundation studies. Over the years, geophysicists have found the Electrical Resistivity Method to be of major application in the identification of soil type, layer stratification, delineation of structural settings, structural disposition, lateral and depth extent of geological materials, and its disposition to foundations in terms of integrity and vulnerability to failure (Akintorinwa & Adeusi, 2009, Oyedele et al., 2011, Adelusi et al., 2013, Adelusi et al., 2014, Ozegin et al., 2019b).

However, in recent times, it has become a matter of public interest, the need for foundation sustainability and the most appropriate and relevant approach to be used in other to reduce or minimize failure arising from building constructions. However, the focus of these present studies is to carry out an evaluation of Electrical Resistivity attributes in the sedimentary environments of Nigeria, where most of the reported cases of foundation failures occurred and compare it with geotechnical attributes to be able to determine the significance of geophysical investigation in engineering construction purposes.

METHOD

Site Description and Geology of The Study Area

The study was carried out at Ukpenu Primary School, Ekpoma, Edo State, Nigeria (Figure 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 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 (Figure 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 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).

Geotechnical Investigation

The samples for the geotechnical test were collected at five different points into a plastic bag and transported to the soil laboratory for analysis, the soil was air-dried and crushed into small pieces (Figure 3). The crushed samples were then sieved through various sieves openings 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 the geotechnical test were correlated with geophysical investigation results to provide information on the variation of strata and physical strength across the site.

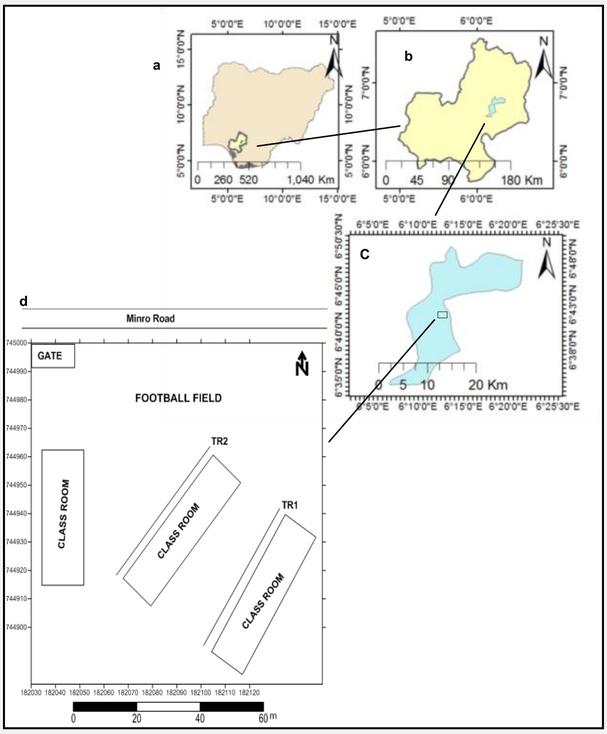

Figure 1. (a) Map of Nigeria and Edo State (b) Map of Edo State and Esan West Local Govt. (c) Map of Esan West Local Govt. Showing the Study Area (d) Base Map of the Study Location.

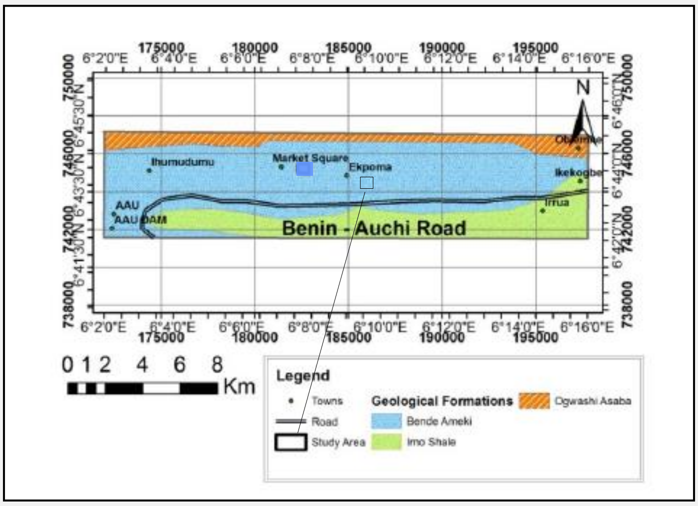

Figure 2. Geological Map of Ekpoma Showing the Study Location (modified after Salufu and Ujuanbi, 2015)

Geophysical Investigation

In this method, three Electrical Resistivity techniques were used, viz; Vertical Electrical Sounding (VES), 2-D Electrical Resistivity Tomography (ERT), and Lateral Horizontal Profiling (LHP) with corresponding configurations such as Schlumberger, Dipole-Dipole, and Wenner (Figure 3).

Nine (9) sounding stations were occupied along the traverses, and the current electrode spacing (AB/2) was varied from 1 to 40 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 determine 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 the inter-dipole expansion factor (n) was varied from 1 to 5. Lateral Horizontal Profiling (LRP) techniques were 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.

The data from Dipole-dipole and Lateral Horizontal Profiling were used to determine the vulnerability factor for each of the length spread. The final results from both geotechnical and Electrical Resistivity techniques were correlated with each other.

The Below equation was generated to determine vulnerability factors

$$\text{Failure index} = A \tag{1}$$

where A = addition of all the percentage ratings for failure index

$$\text{Stability Index} = B \tag{2}$$

where B = addition of all the percentage ratings for stability index

$$\text{Vulnerability Factor} = A/B \tag{3}$$

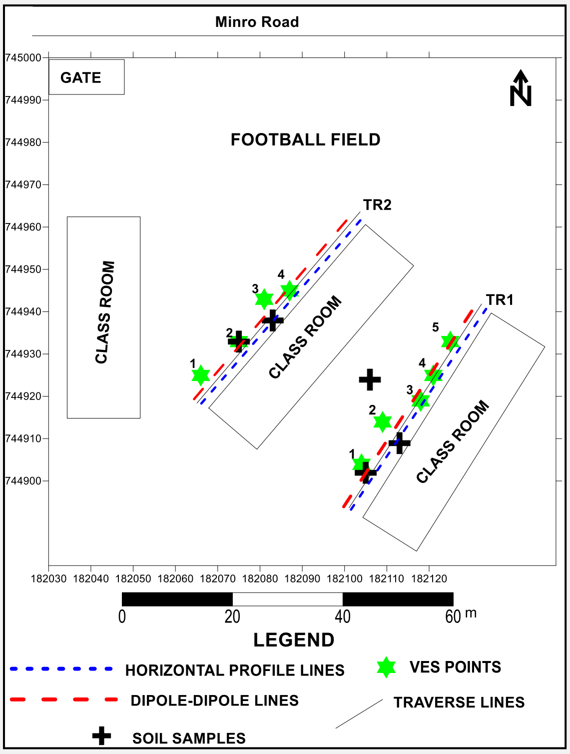

Figure 3. Data Acquisition Map of the Study Area

RESULTS AND DISCUSSION

Geotechnical Results

The details of various results obtained from both field and laboratory tests are shown in (Table 1). The dry unit weight ranges from 19.38 to 19.60 kilo Newton per cubic meter (KN/m^3), which suggests a density index less than the required standard of 85% index stability and hence may also account for partial vulnerability or structural failure. The plasticity index obtained from the soil analysis ranges from 10.2 to 11.9 % which implies that compressibility is low (Burmister, 1997) and encourages cracks that may lead to foundation vulnerability to failure. Grain size analysis for the five sample points gave relevant information on the number 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. The specific gravity was used to determine the rate of voids within the soil sample which ranges from 2.64 to 2.65. This is the water content at which the soil will behave like a viscous mud flowing under its weight. The liquid limit test has values ranging from 29.4 to 32.2 % which is fairly good enough to support foundation integrity. 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.

The unconfined compressive strength value varies from 181 to 227 kilo Pascal (Kpa) (Table 6 to 10) which may be good but not the best for foundation/structural strength and hence may be partly responsible for foundation vulnerability.

Table 1. 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

Geophysical Results

Dipole-dipole pseudosection

The analysis of the 2D resistivity imaging using dipole-dipole gave relevant information on the structure settings along the study areas (Figure 4a). Two distinctive formations were obtained from the structural settings, a shallow layer horizon of fewer than 5 m with resistivity variations ranging from 184 to 870 Ωm, reflecting resistivity attributes of moderate structural stability and integrity. While below this layer is an underlying formation of about 25 m thickness with high resistivity attributes values ranging from 1617 to 10899 Ωm, indicative of a layer formation with high structural integrity.

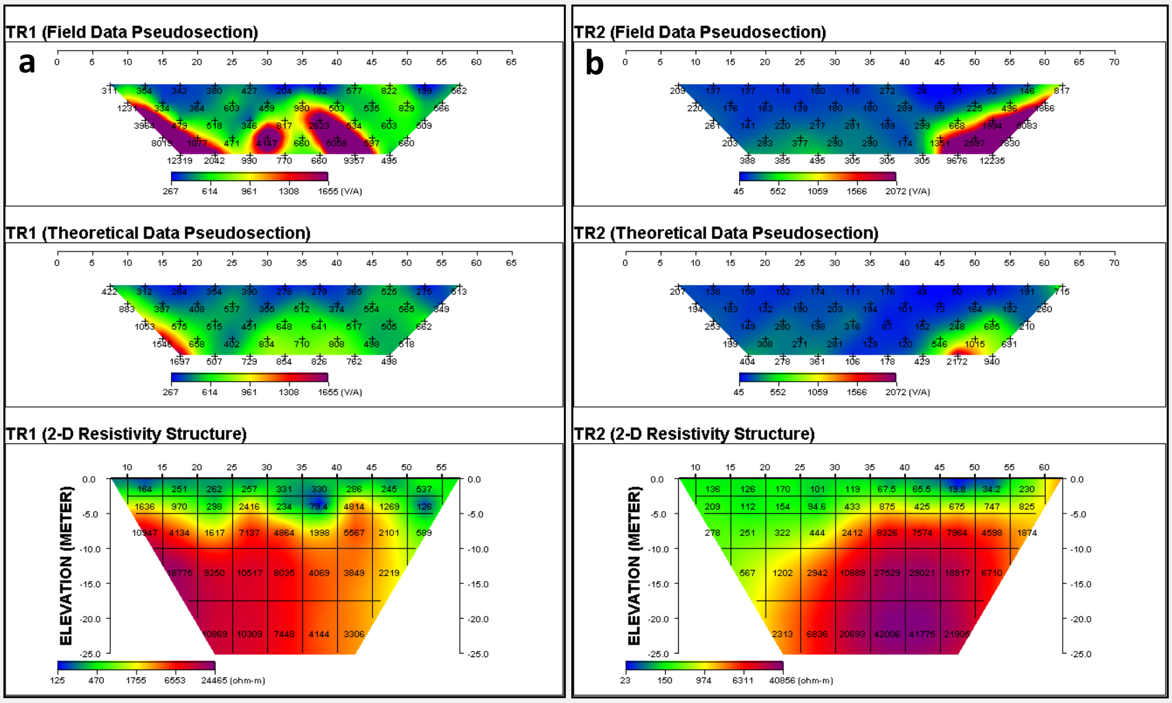

Figure 4. Dipole-Dipole Pseudosection along traverse one(a), traverse two(b)

The results obtained revealed the presence of two distinctive formation/structural settings characterized by fairly thick upper layer horizon with apparently low resistivity attributes, characterized of a weak zone/formation with layer resistivity varying from 94.6 to 230 Ωm and layer thickness ranging from 5 to 15 m. this was underlain by a fairly competent but thin layer formation with resistivity attributes ranging from 444 to 8328 Ωm. The characteristic feature of this formation that makes it vulnerable is the drastic fall in the apparent resistivity attributes with depth (Figure 4b).

Lateral Horizontal Profiling

The lateral profiling conducted at a = 5 m, 10 m, 15 m, and 20 m was processed using RES2D software for a better understanding of its resistivity attributes (Figure 5a). The result obtained showed high structural integrity with layer resistivity variations ranging from 293 to 1164 Ωm. The result explained the reasons for the high vulnerability, low structural integrity failure, and subsidence that occurred along the traverse with apparent resistivity attributes as low as 30 to 99.5 Ωm characterizing more than 85 % of the entire profile (Figure 5b).

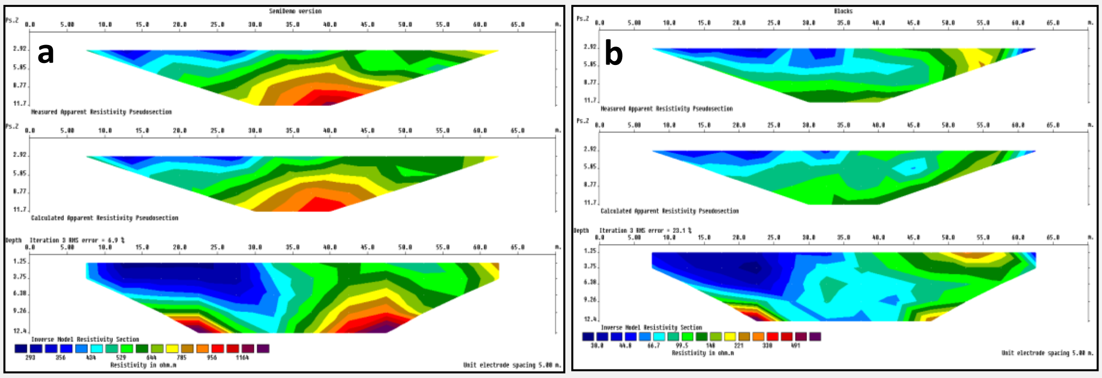

Figure 5. 2D Lateral Horizontal Profiling along Traverse one(a), Traverse two(b)

Geoelectric Section

Following the results obtained from the Wenner profiling and dipole-dipole, further investigation was conducted using Vertical Electrical Sounding (VES) based on suspended anomalous zones as identified by the two techniques (Figure 6a). The geoelectric section along this traverse indicated a topsoil horizon that was made up of competent materials with resistivity values ranging from 226 to 657 Ωm, while next layer material was also considered to be made up of competent materials with layer resistivity variations ranging from 212 to 1071 Ωm.

The third layer formation was considered to be made up of competent materials with resistivity variations ranging from 618 to 3417 Ωm. This reflected the effective correlation with both the lateral resistivity and dipole-dipole techniques.

The finding obtained from traverse two characterized the area into very weak, moderately weak, and competent formation. The topsoil, clayey sand/sand formation, and moderately resistive sandstone with resistivity variations ranging from 73 to 236 Ωm, 157 to 228 Ωm, and 469 to 1268 Ωm (Figure 6b). Thereby justifying the reason for failure and subsidence that occurred and showing effective correlation with the two other techniques used along the traverse.

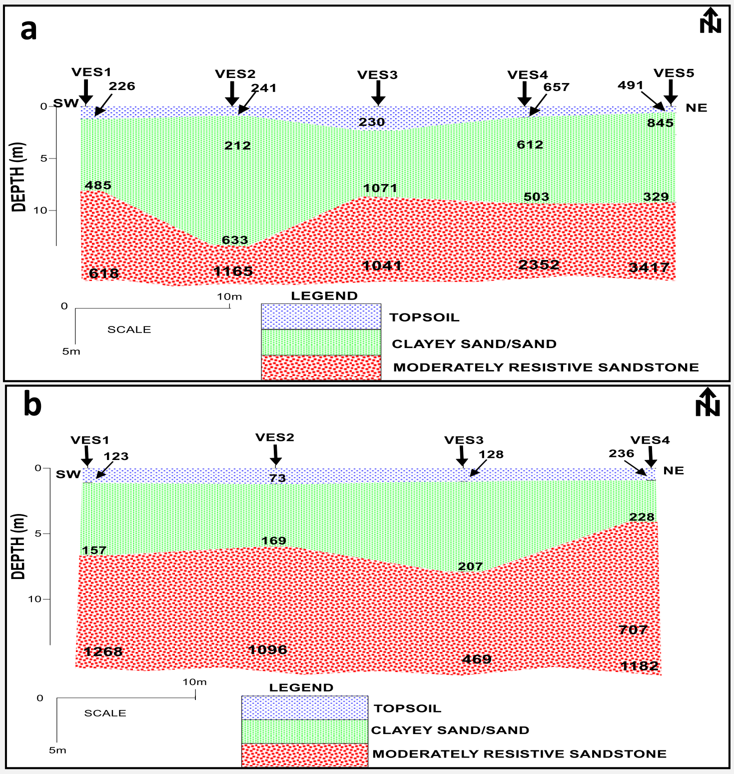

Figure 6. Geoelectric Section along Traverse one(a), Traverse two(b)

Dar-Zarrouk Parameters

Total Longitudinal Conductance & Total Transverse Resistance

The result obtained from the second-order parameters using the Da-zarrouk principle demonstrates the reason for the failure that occurred mainly as a function of resistivity attributes (Figure 7a). The map was classified into three distinctive regions, mainly regions of high longitudinal conductance with values ranging from 0.038 to 0.046 Ω^{-1}, reflecting zones of high vulnerability at Northwestern, western and central parts of the study area.

The second region falls within the central, northern, and southern regions with values ranging from 0.025 to 0.038 Ω^{-1}, indicating region/zone of moderate weakness, while the third region reflects high resistivity attributes with very low total longitudinal conductance values ranging from 0.014 to 0.022 Ω^{-1}, reflecting areas of high stability/foundation integrity which correlate effectively with previous results.

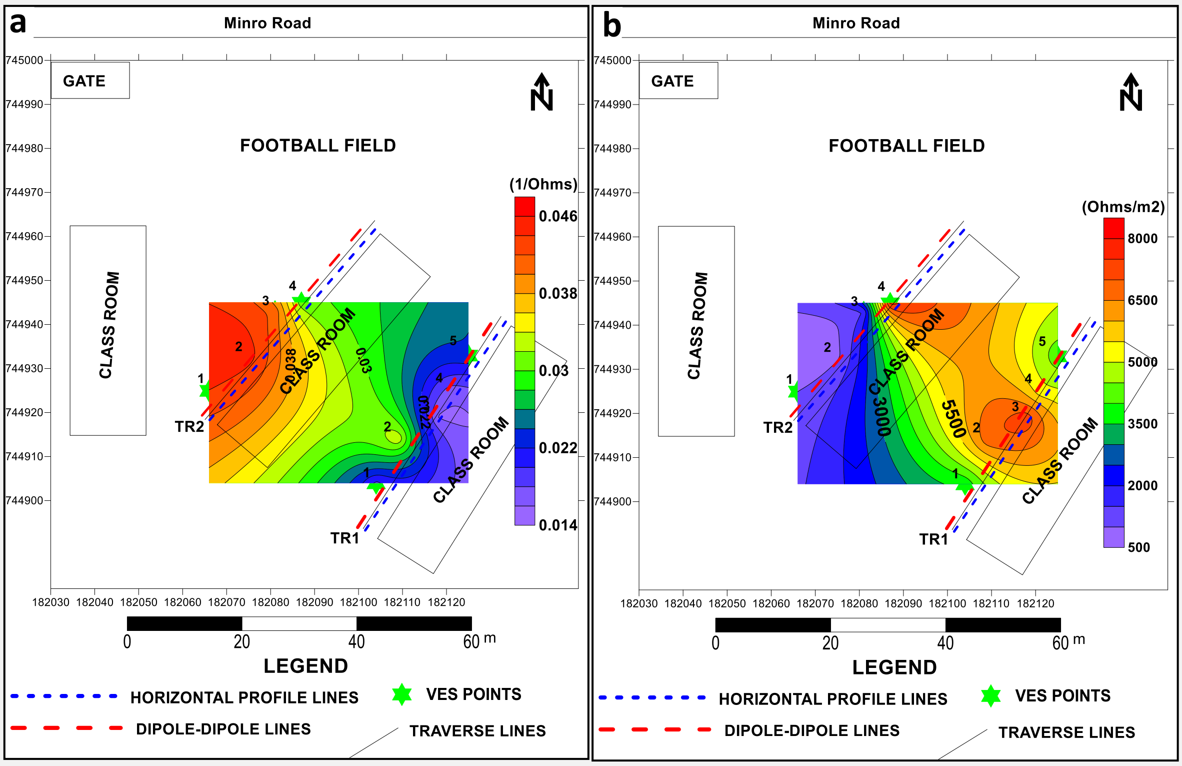

Figure 7. Total Longitudinal Conductance(a), Total Transverse Resistance(b)

Figure 7b showed the total transverse resistance map which clearly explains resistivity attributes of the study area indicative of the structural integrity and was classified into four regions. The western, northwestern, and southwestern part has very low structural integrity with values ranging from 500 to 1500 Ωm^{-2}, while the southwestern and northwestern are indicative of low structural integrity with values ranging from 1500 to 2500 Ωm^{-2}.

The moderate structural integrity with transverse resistance values ranging from 2500 to 3500 Ωm^{-2} was observed at the southwestern and central of the investigated area while the region of high structural integrity with resistivity attributes of transverse resistance values ranging from 4500 to 8500 Ωm^{-2} was observed at the northern, northeastern, eastern and southeastern part of the study area.

Synthesis of Results

Figure 8a displays the correlation of dipole-dipole 2-D resistivity imaging, Wenner 2-D resistivity imaging, and Vertical Electrical Sounding along traverse one, which gave relevant information on the characteristic signature of the resistivity attributes. It reveals a near-surface resistive material underlain by thick layer formation of highly resistive materials of high structural integrity which reflected the stability of the structure placed along the profile.

Figure 8b evaluated the resistivity attributes along the traverse from the western part toward the centre of the study area, as revealed that all the three techniques were characterized by near-surface with highly vulnerable materials, and further underlain by materials of very low structural integrity with low resistivity values which justifying the reason for failure and subsidence that occurred along the traverse.

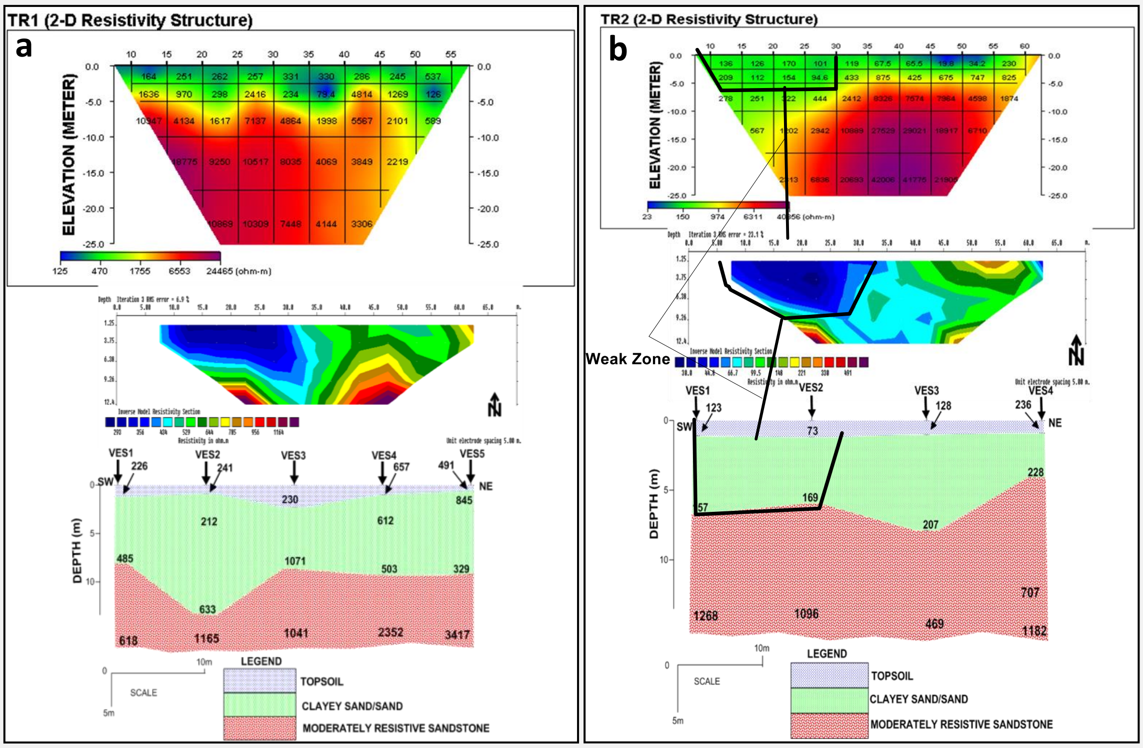

Figure 8. Correlation of Results along Traverse one(a), Traverse two(b)

Vulnerability Factors

Vulnerability Factor for Lateral Horizontal Profiling (LRP) along Traverse One

For a better understanding of the structural setting in order of their various soil horizons, the integrity and vulnerability factor were considered as one of the major contributing resistivity attributes to foundation studies at various lateral resistivity traverse spread of a = 5 m, 10 m, 15 m, and 20 m. The soil integrity and vulnerability to failure was evaluated, and these various spreads of "a" were considered as a function of the various depths and lithological integrity variations along the various layer formations.

Therefore, at L.R.P of a = 5, considering the resistivity attributes responsible for the failure, six (6) factors were considered in order of soil lithologies. These were classified into A, B, C, D, E, and F as it affects foundation integrity. Based on lithologies occurrence, the various lithology distribution against the total number of sampled points, the percentage rating of resistivity attributes for the vulnerability was determined.

The failure index was determined from the summation of the percentage per data points that are contributing to failure which was considered as A, B, and C, while the stability index is determined by the addition of all the contributing factors to stability which are D, E, and F. The vulnerability factor was determined by dividing the attribute failure index with the stability index. This procedure was repeated for all the various spread of a = 5 m, 10 m 15 m, and 20 m which enabled the determination of vulnerability or stability at various layers.

Based on analysis, the following results were obtained at a = 5 m, 10 m, 15 m, and 20 m (Table 2). The analysis of the results obtained indicated that the vulnerability factor for the building to fail was zero.

Table 2. Vulnerability Factor for a of 5, 10, 15 and 20 m along Traverse One

S/N	A	B	C	D	E	F
Resistivity Value Range	0 – 50	50 – 150	150 – 250	250 – 500	500 – 1000	>1000
Lithologies	Clay/Silt	Sandy Clay	Clayey Sand	Sand	Resistive/Dry Sand	Sandstone
a = 5 m	-	-	-	7	6	-
Percentage Rating (%)	-	-	-	53.8	46.2	-
a = 10 m	-	-	-	3	8	-
Percentage Rating (%)	-	-	-	27.27	72.73	-
a = 15 m	-	-	-	-	9	-
Percentage Rating (%)	-	-	-	-	100	-
a = 20 m	-	-	-	-	3	4
Percentage Rating (%)	-	-	-	-	42.86	51.14

Vulnerability Factor for Lateral Horizontal Profiling along Traverse Two

The same approach was carried out along this traverse for the various spread length. The analysis of the results obtained indicated that vulnerability factor for the building to fail was 100 % at a = 5 m, 10 m, 15 m, and 20 m (Table 3). Hence, this was what leads to a major crack and sinking that were observed along the classrooms in traverse two.

Table 3. Vulnerability Factor for a of 5, 10, 15 and 20 m along Traverse two

S/N	A	B	C	D	E	F
Resistivity Value Range	0 – 50	50 – 150	150 – 250	250 – 500	500 – 1000	>1000
Lithologies	Clay/Silt	Sandy Clay	Clayey Sand	Sand	Resistive/Dry Sand	Sandstone
a = 5 m	5	6	2	-	-	-
Percentage Rating (%)	38.46	46.15	15.39	-	-	-
a = 10 m	-	8	2	-	-	-
Percentage Rating (%)	-	80	20	-	-	-
a = 15 m	-	7	2	-	-	-
Percentage Rating (%)	-	77.78	22.22	-	-	-
a = 20 m	-	5	2	-	-	-
Percentage Rating (%)	-	71.43	28.57	-	-	-

Vulnerability Factor for Dipole-Dipole along Traverse One

The analysis of the data obtained was also carried out using the same guiding principle adopted for Wenner profiling to reflect on the resistivity attributes contributing to failure at various soil horizons of dipole-dipole configurations, representing n of 1 = 5 m, n of 2 = 10 m, n of 3 = 15 m, n of 4 = 20 m and n of 5 = 25 m.

The data distribution points also followed the same principle and data distribution range of A, B, C, D, E, and F, from the results obtained at n of 1, the vulnerability factor indicated 0.38 % which reflects a weak topsoil horizon, while at n of 2, the result obtains indicated that the resistivity attribute for failure is zero. Furthermore, for n of 3, 4, and 5, the vulnerability factor for the building to fail is zero (0%) (Table 4).

The analysis indicated that the vulnerability factor for the building to fail is zero percent reflecting a high degree of stability along this traverse which exhibited an effective correlation with Wenner array configuration. From the analysis of dipole-dipole, any vulnerability factors greater than one percent (1%) represents various degree of weakness while less than one percent present stability.

Table 4. Vulnerability Factor for n = 1 to 5 along Traverse One

S/N	A	B	C	D	E	F
Resistivity Value Range	0 – 50	50 – 150	150 – 250	250 – 500	500 – 1000	>1000
Lithologies	Clay/Silt	Sandy Clay	Clayey Sand	Sand	Resistive/Dry Sand	Sandstone
n = 1	-	-	3	5	3	-
Percentage Rating (%)	-	-	27.27	45.46	27.27	-
n = 2	-	-	-	3	6	1
Percentage Rating (%)	-	-	-	30	60	10
n = 3	-	-	-	2	5	2
Percentage Rating (%)	-	-	-	22.22	55.56	22.22
n = 4	-	-	-	1	3	4
Percentage Rating (%)	-	-	-	12.5	37.5	50
n = 5	-	-	-	1	3	3
Percentage Rating (%)	-	-	-	14.29	42.86	42.86

Vulnerability Factor for Dipole-Dipole along Traverse Two

The result obtained using the same approach indicated that vulnerability of resistivity attributes to fails at n of 1 which is equivalent to 5 m was 5%, reflecting major weak zone with a failure index of 83.34 % and stability index of 16.67 % while at n of 2 which is equivalent to 10 m. The failure index was 72.73 % and the stability index was obtained to be 22.22 %, while the resistivity attribute characterizing the vulnerability factor for failure was 3.67 % indicative of the high vulnerability factor that the building will fail.

At n of 3 which corresponds to 15 m, the result obtained indicates a failure index of 40 % and a stability index of 60 %, while the vulnerability factor for the building to fail was 0.67 % which implies a moderately weak formation/horizon. At n of 4 which corresponds to 20 m, the results obtained from the analysis of resistivity attributes at that horizon indicated that the failure index was 22.22 %, while the stability index was 77.77 %. Subsequently, the vulnerability factor for failure was reflected partly weak formation and at n of 5 which represents the highest thickness and depth, the failure index obtained was 0% while the stability index was 100 %.

Furthermore, the vulnerability factor for failure was zero percent (0%), implying a high degree of soil stability and competence. Since the foundation of the building was laid within the upper 5 m, the vulnerability factor that the building will fail was high within the upper 10 m, which leads to a major crack and sinking that were observed along the classrooms (Table 5).

Table 5. Vulnerability Factor for n of 1 to 5 along Traverse Two

S/N	A	B	C	D	E	F
Resistivity Value Range	0 – 50	50 – 150	150 – 250	250 – 500	500 – 1000	>1000
Lithologies	Clay/Silt	Sandy Clay	Clayey Sand	Sand	Resistive/Dry Sand	Sandstone
n = 1	2	6	2	1	1	-
Percentage Rating (%)	16.67	50	16.67	8.33	8.33	-
n = 2	-	2	6	2	-	1
Percentage Rating (%)	-	18.18	54.55	18.18	-	9.09
n = 3	-	1	3	3	1	2
Percentage Rating (%)	-	10	30	30	10	20
n = 4	-	-	2	4	-	3
Percentage Rating (%)	-	-	22.22	44.44	-	33.33
n = 5	-	-	-	6	-	2
Percentage Rating (%)	-	-	-	75	-	25

Correlation of Vulnerability Factor of Wenner Profiling and Dipole-Dipole Along Traverse One and Two

The result obtained from the vulnerability factor of Lateral Horizontal profiling and 2D ERT along traverse one and two at the various spread length of a = 5, 10, 15 20 m, and n of 1 to 5 showed effective correlation. The results were able to explain as well as justify the reason for the high degrees of stability of the structure along traverse one and the reason for structural failures and subsidence that occurred along traverse two (Figure 9).

Correlation of Geophysical and Geotechnical Methods

The results obtained from the two methods advance that resistivity attributes give better information in terms of depth, lateral extent, layer stratification, layer lithology, and nature of the material which makes it indispensable over geotechnical attributes. The geotechnical attributes give relevant information but are all limited to a maximum depth of 5 m, which has a great limitation in the area of carrying out a complete evaluation of structural integrity against subsurface weak zones that often goes beyond the shallow depth of investigation.

Figure 9. Structure along traverse one and two

CONCLUSION

The advantages and overriding benefits of Electrical Resistivity investigation over geotechnical method in terms of depth, lithological evaluation, and structural integrity have been advanced in this study. It has justified that the Electrical Resistivity method gives better information and major contributing factors that account for vulnerability and structural integrity to failure.

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AUTHORS NOTE

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 used as an avenue for any litigation but the advancement of knowledge.

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