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RESEARCH ARTICLE

GEOPHYSICAL AND GEOTECHNICAL EVALUATION OF FOUNDATION FAILURE AT ISINKAN OKE-ARO, AKURE SOUTH-WESTERN NIGERIA

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ABSTRACT

The soils in Osinkan, Akure, were evaluated for the likely cause of foundation failure. Integrated geophysical and geotechnical methods was adopted. The data acquired from the geophysical survey was processed into field data pseudo-section and 2-D resistivity structure. The geotechnical analysis involved taking of undisturbed samples from two dug holes at the swampy area in the site of study. Empirical soil test was carried out to determine the grain size analysis, moisture content, Atterberg limit, specific gravity and shear strength. Three layers were delineated, the top soil, clayey sand and weathered basement. The resistivity of the top soil ranges from 2.7 ohm-m to 133.3 ohm-m with a depth ranging from 0.1m to 0.3m. The depth off weathered basement ranges from 0.3m to 0.5m. These variations in the soil resistivity influences corrosion risk, grounding design and overall foundation performances Likewise, the profiling variability indicates heterogeneous subsurface conditions, which may cause differential settlement. For foundation engineering purposes, the soil would require soil stabilisation and foundation design adjustment to ensure stability and durabilityThe geotechnical analysis confirmed that the samples taken were a mixture of clay and sand. From the 2-D Resistivity structure, the depth to fresh basement is 12m. The foundation soil is failing due to the fact that the area is always water-logged after heavy down pour of rain. When the soil is wet the strength reduces and this should be the major cause of some buildings subsiding was authenticated from the geotechnical characteristics of the soils.

KEYWORDS

Geophysical, Geotechnical, Horizontal Profiling, Vertical Electrical Sounding, Foundation Failure

1. INTRODUCTION

Over the years, electrical resistivity method and geotechnical methods have been employed to site characterization and their success to the laid down projects cannot be overemphasized. A group researcher demonstrated the significance of the combination of geotechnical and geophysical tools in engineering site characterization (Anizoba et al., 2015). Their study revealed mechanically unstable soil at depth and hence they were able to give a specific depth of piling that would support the proposed building. Some researcher in their assessment of lateritic soils from a dumpsite using geotechnical methods was able to come out with several conclusive results as provided by the geotechnical evaluation (Kasidi and Victor, 2019). Some of their conclusive results are;

- The overall engineering characteristics of the soil samples collected from test pits, irrespective of the depth of recovery, show that the soils are inorganic clay with low to medium plasticity.
- Generally, these types of soils possess desirable characteristics to minimize hydraulic conductivity of compacted soils.
- The indices properties (liquid limit, plastic limit, percentage fine, and percentage gravel and clay activity) of the soil samples satisfy the basic requirements as barrier materials in landfills.
- The clay portion is inactive; thus, the soils will be less likely to be attacked by waste chemicals.

He recommended higher energy of compaction because it gives lower and better values of coefficient of permeability for the compacted soils.

In other study, researcher using geotechnical methods assessed the use of sand replacement for foundation improvement which were to be used for sensitive storage tanks and ancillary rigid structures and related civil constructions on marginal lands (Emmanuel et al., 2011). They conclusively stated that most marginal lands in the Niger Delta possess poor foundation bearing capacity and large consolidation settlement, thereby making foundation improvement, particularly by sand emplacement imperative. The replacement can increase the bearing capacity by up to 100% and decrease settlement by more than 150%. Ilevbare and Edegbai applied geotechnical methods to road development in the meander belt of the Niger Delta region and conclusively stated that the superficial sediments of the meander belts consist soft and weak silty/sandy clay layers (Ilevbare and Edegbai, 2021). They are exposed to artesian pressure along sections of the road alignment. The sediments exhibit low bearing capacity and significant consolidation settlement. Because of the presence of artesian pressure there is a danger to road construction involving excavations. He developed a chart for the rapid determination of safe depth of excavation to avoid danger. He also stated that to handle the excess hydrostatic pressure under the fill, drain ports or holes maybe required.

Ashioba and Nelson adopted geotechnical evaluation techniques to foundation conditions in Yanagoa in Bayelsa state (Ashioba and Nelson, 2024). The evaluation was carried out by the means of three (3) number of boreholes dug to maximum depth of 30m using percussive cable rigs. They performed field and laboratory analysis from which they were able to draw necessary conclusive statements. Field and laboratory investigations reveal a near surface stratigraphy of clay to an average

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depth of 6m underlain by loose silty sand to a depth of 10m below the existing ground level. The laboratory analysis carried out on relatively undisturbed soil samples of the clay gave undrained shear strength between 40 and 56 kPa with a mean value of 47kPa. However, the 1.0m thick peat embedded in the clay between 3.0 and 4.0m depth will greatly increase the compressibility of the clay. Considering the nature of the intended structure, the anticipated load and the very compressibility of the peat, pile foundation is recommended to take the imposed load from the cellar to the underlying sand stratum. All piles are engaged should be driven and pile load test carried out on them to confirm the working load and the estimated settlement. All piles employed should be driven piles. However, pile load test should be carried out on all driven piles to confirm working load and the estimated settlement.

Using geophysical investigation techniques, a group researcher evaluated structural failure and subsurface characterization at the site of a building (Anudu et al., 2008). Their major aim was to study the causes of stresses in the walls and characterize the soil conditions in the area. Upon care investigation and evaluation, they came with up with the following findings;

- Four geoelectric sequences were delineated within the study area. These include the topsoil, weathered layer, partially weathered/fractured basement and fresh basement. The topsoil and weathered layer are composed of clay/sandy clay formation and the bedrock is generally shallow (less than 3m).
- Two linear features (Suspected fault) were identified by the electrical imaging on bedrock along the S-N direction. This may have been the reason for the cracking of the building walls along this direction, since it was suspected that the foundation of the structure was placed on this weak bedrock.
- The upper 2m in the area where metallic objects can be buried is clayey in nature; hence any metallic object buried within this area without proper protection may be threatened by corrosion. This clayey nature of the upper soil makes the area a good earthing medium.
- The causes of the distress in the walls of the investigated building may not be due to substandard building material or construction practice, but it may have been influenced by the differential settlement resulting from the incompetent subsoil materials and the faulted bedrock on which the foundation of the building was built upon.
- The importance of pre-geophysical investigation of a proposed civil structure cannot be overemphasized, since this will help in designing the foundation of such structures in order to withstand the test of time.

This study aims to integrate a geophysical and geotechnical properties of the soils in Isinkan, Oke road Akure in order to delineate the likely causes for the foundation failure within the region.

1.1 Study Area

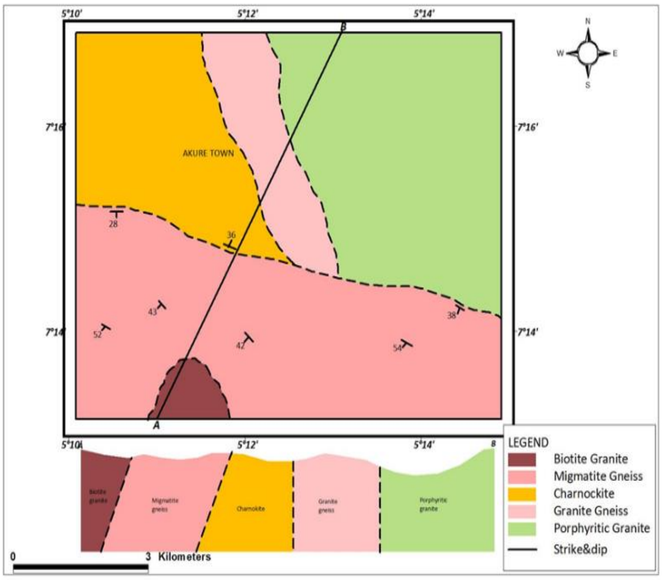

Figure 1: Geological Map of the Akure (After Afolabi, 2010)

Figure 2: Aerial photograph of the study location

2. Materials and Methods

Geophysical investigation carried out at the site is of the study are of two types, the horizontal profiling (dipole-dipole array) and vertical electrical sounding sing Schlumberger configuration. The horizontal profiling covered a distance of one hundred (100) meters. The co-ordinates of station 0, 4 and 9 were taken respectively. The two VES points were located at station 4 and 6 respectively to support the result gotten from the horizontal profiling method. The data acquired from the dipole-dipole array were plotted into pseudo-sections and 2-D resistivity structure using dipro-winresist software. The data obtained from the vertical electrical sounding was plotted on a bi-log. This was interpreted qualitatively by visual inspection and quantitatively by partial curve matching. The interpreted result is fed in the resistivity software for interpretation. The result obtained was used to generate geo-electric sections (Hardianshah and Adul Rahim, 2013).

The geotechnical analysis involved collection of an undisturbed soil samples from dug holes one and two located close to stations 5 and 9 respectively. The samples were taken at a depth 0.5m and 1.0m respectively. The geotechnical test carried out include Moisture content, Specific gravity, Grain size analysis, Atterberg limit and Shear test using the standard procedures.

3.Results and Discussion

Geophysical and geotechnical techniques were deployed to investigate the failed foundations in this study in order to infer the likely reason for the failure. The results of the geophysical survey carried out at the study area is presented as sounding curves, tables, and geo-electric sections while that of geo-technic analysis carried out are: plastic limit, liquid limit, specific gravity, moisture content test and shear test and are represented as graphs and tables.

3.1 Vertical Electrical Sounding of the Soil

The 2-D resistivity structure (Figure 3) revealed that at depth of 12 m one can encounter the top of fresh basement with a resistivity value of 3,967 ohms-m. The top soil resistivity ranges from 2.7ohms (VES2) to 133.3 ohms (VES1) with a depth ranging from 0.1m (VES1) to 0.3m (VES2). The second layer (clayey sand) has resistivity value ranging from 3.9 ohm-m (VES1) to 6.8 ohm-m (VES2). The third layer is the weathered basement with resistivity value ranging from 23,988 ohm-m to 100,000 ohm-m (Figure 4). The depth to this layer ranges from 0.3m (VES1) to 0.5m (VES2) all represented in Table 1

Table 1: VES 1 of the sampled soil

Station	AB/2	MN/2	Apparent Resistivity
1	1	0.25	40.19
2	2	0.25	3.26
3	3	0.25	22.60
4	4	0.25	46.22
5	6	0.25	135.64
6	6	0.50	113.04
7	8	0.50	227.08
8	12	0.50	1293.18
9	15	0.50	1413
10	15	1.00	162.49
11	25	1.00	10108

From the Vertical Electrical Sounding (VES) results, the soil resistivity values of (2.7-6.8) Ohms-metre indicates a highly conductive soils, typically clayey or water saturated, which may be corrosive to buried foundation elements like steel pies. In contrast, (3.9-133.3) Ohms-metre reveals a low to moderately conductive to resistive soils. These variations in the soil resistivity influences corrosion risk, grounding design and overall foundation performances (Ilevbare and Ogundana, 2022).

The apparent resistivity values (Table 2) from the C1 and C2 horizontal profiling, (2.51-35.7) Ohms-metre reveals a low resistivity soil, mostly clayey, moist or water-logged conditions across the profiles (Mayange et al., 2018). Conversely, (2.5-6.8) Ohms-metre indicates a high moisture content, weak shear strength and as such poises a high settlement risk. The moderate value of 11.57 and higher value of 35.7 are indicators of a localised sandy or well drained zone. This profiling variability indicates heterogeneous subsurface conditions, which may cause differential settlement. For foundation engineering purposes, the soil would require soil stabilsation and foundation design adjustment to ensure stability and durability (Anakwuba et al., 2014).

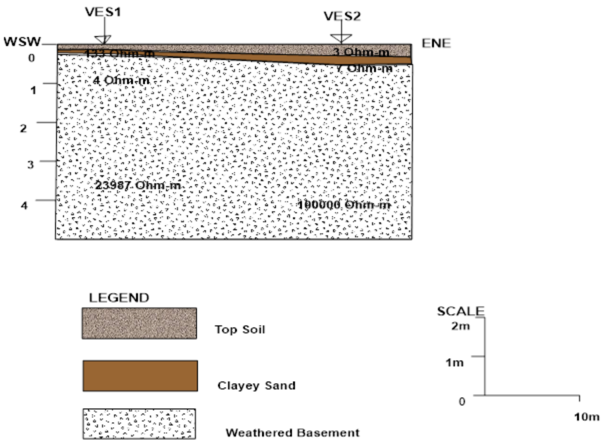

Figure 3: Geoelectric Section of VES 1 & 2

3.2 Horizontal Profiling of the Soil

Table 2: Horizontal Profiling (Dipole-Dipole)				
C1	C2	P1	P2	Pa
0	1	2	3	3.2609
		3	4	16.5816
		4	5	2.4504
		5	6	4.9008
1	2	3	4	3.5060
		4	5	2.4881
		5	6	3.7699
		6	7	133.0778
2	3	4	5	5.1459
		5	6	3.0159
		6	7	4.9008
		7	8	12.4407
3	4	5	6	4.2600
		6	7	4.9762
		7	8	2.4504
		8	9	4.9008
4	5	6	7	3.6379
		7	8	2.4881
		8	9	2.4504
		9	10	37.6991
5	6	7	8	453.7699
		8	9	5.5040
		9	10	3.7699
		10	11	
6	7	8	9	1.2440
		9	10	6.4842
		10	11	
		11	12	
7	8	9	10	2.5069

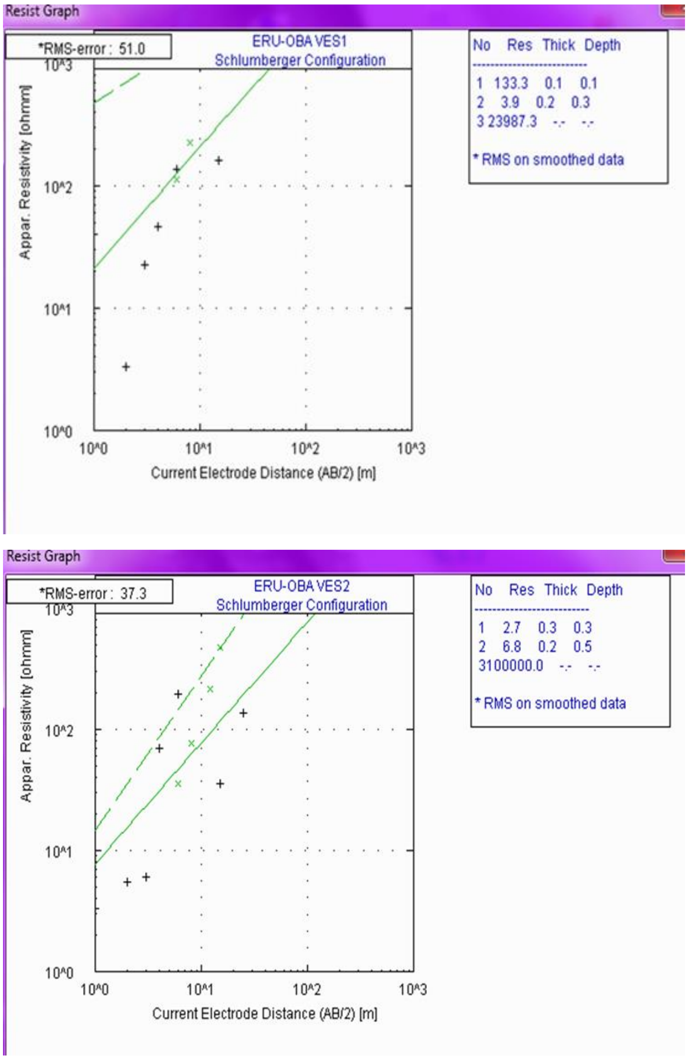

Figure 4: Depth Sounding Curves of VES 1 & 2

3.3 Geotechnical Properties of the Soil

The result for moisture content of both DH1 and DH2 soil samples indicates the average moisture content of DH1 sample is 12.8% while for DH2 sample is 21.6%. The specific gravity for DH1 is 2.6 and DH2 is 2.1 accordingly. For the grain size analysis of DH1, the % passing of the sieve ranges from 1.5% (sieve no 0.063) to70.5% (sieve no 3.35) while the % passing of the sieve ranges from 5.5% (sieve no 0.063) to 77% (sieve no 3.35). For the Atterberg limit, the average liquid limit is for DH1 on table 7 is 5.825 and the average plastic limit is 0.6, with a plasticity index of 5.225. While the average liquid limit for DH2 on table 8 is 4 and an average plastic limit is 0.5. The plasticity index is gotten to be 3.5.

In the direct shear test of DH1 sample, for a load of 500g, the shear strain varies with the shear force producing it. It ranges from a shear force of 0.024 to 0.0318 producing 5% to 35% respectively. While for DH2 samples, for the same load of 500g, the shear strain varies with the shear force producing it. It ranges from a shear force of 0.0504 to 0.0894 producing 5% to 40% respectively.

3.4 Natural Moisture Content of the Soil

Natural moisture content influences soil strength, compressibility and shrink-swell behaviour. Low moisture content improves stability, while high moisture content reduces bearing capacity and risks of foundation failure. Accurate assessment guides foundation type, depth, and soil stabilisation for durable foundations (Unamba et al., 2024). According to a study, these percentages of moisture content (12.8 and 21.6) % have significant implications for foundation studies because it reflects different soil behaviours (Ashioba and Nelson, 2024). At 12.8. the soil is relatively dry exhibiting higher Shear strength and lower compressibility which favours stable foundation support. However, moisture content of 21.6% typifies a wetter soil which reduces shear strength and increases plasticity and compressibility. This can lead to the settlement bearing capacity failure or soil expansion in clayey soil.

3.5 Specific Gravity of the Soil

Specific gravity helps to determine soil density, porosity and compaction, which influences compressibility and bearing capacity of soils. The values allow engineers to evaluate risks of foundation failure under applied load. Soil specific gravity (S.G) affects foundation design by indicating mineral composition and void ratio. A soil with S.G. of 2.6 (typical for quartz rich sand) suggests higher density and strength, suitable for supporting structures. Conversely, S.G of 2.1 is relatively low and suggests the presence of organic matter or lightweight materials, which are often compressible and weaker. This can lead to higher settlement and reduced bearing capacity. For engineering purposes, soils with S.G. of 2.1 may require stabilisation, replacement, or deep foundations while S.G. of 2.6 soils are generally more reliable (Oladipupo, 2025).

3.6 Grain Size characteristics of the Soil

Grain size determines soil permeability, compaction, and load – bearing capacity, coarse soils drain well and support heavier structures, while fine soils may compress, settle or require stabilization for safe foundation design (Figure 5). A medium to coarse grained soils with percent passing of 1.5 and 5.5 (typically through a fine sieve like 0.075 mm) indicates soils with very low fines content. Such soils are predominantly coarse-grained, like sand or gravel. Low fines (1.5%) suggest excellent drainage, high permeability and minimal cohesion, but reduced binding between particle, which may affect stability under load (Adamu et al., 2024). At 5.5%, there is slightly more fines content, offering marginally improved cohesion while still maintaining good drainage. For foundation engineering, these soils generally provide good bearing capacity and low compressibility but may require compaction and confinement to prevent excessive settlement or particle displacement (Adamu et al., 2024).

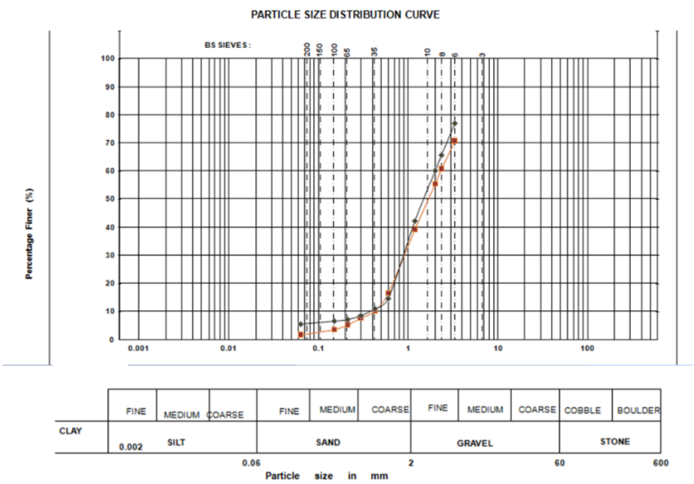

Figure 5: Particle Distribution Curve for the Soils

3.7 Atterberg Limit Determination of the Soil

Atterberg limits (comprising of liquid limit, plastic limit and shrinkage limit) are important in foundation studies because they describe the consistency and behaviour of fine-grained soils under varying moisture conditions. It helps to ascertain how soil would perform under structural load. A plasticity index (PI) of 5.23 and 3.5 indicates low plasticity soils, typically Silty or slightly Clayey materials. These low values of PI indicate low shrinkage behaviour although beneficial, but the soil may lose strength when wet. Consequently, foundations of these soils risk bearing capacity failure if not properly compacted, drained or designed with adequate load distribution measures (Ashioba and Nelson, 2024). They are generally stable under moisture variation but may have moderate compressibility and lower cohesion. For foundation designs, this implies shallow foundations are feasible, but proper compaction and drainage control are essential to prevent settlement and maintain bearing capacity.

3.8 Shear Strength Determination of the Soil

Shear strength is a fundamental property of soil that determines its ability to resist deformation under applied loads. In foundation engineering, failure occurs when imposed stresses exceed the soil's shear resistance, causing shear deformation or collapse (Table 3). This can lead to tilting, or structural instability in loose or water-saturated soils supporting foundations.

Table 3: Direct Shear of the Soil (DH 1)

Horizontal Reading	Proving Ring Reading	Shear Deformation (mm)	Shear Force (KN)	Shear Stress (KN/m²)	Shear Strain %
0	0	0	0	0	0
100	4.0	1	0.024	0.0066	5
150	4.4	1.5	0.0264	0.0073	7.5
200	4.8	2	0.0288	0.008	10
250	4.8	2.5	0.0288	0.008	12.5
300	5.0	3	0.03	0.0083	15
400	5.0	4	0.03	0.0083	20
500	5.2	5	0.0312	0.0086	25
600	5.2	6	0.0312	0.0086	30
700	5.3	7	0.0318	0.0088	35
800	5.2	8	0.0312	0.0086	40

$$\text{Shear deformation} = \frac{\text{horizontal reading}}{100}$$

$$\text{Shear stress} = \frac{\text{shear force}}{\text{area}(L\times B)} \times 1000$$

$$\text{Shear strain \%} = \frac{\text{shear deformation}}{\text{thickness}} \times 100$$

$$\frac{\Delta L}{20} \times 100$$

A Shear Stress of 0.02 typifies a low force combined with a shaer strain of 18.3 indicates extremely soft, weak soil that undergoes large deformation under minimal loading. This suggests low shear strength and poor resistance to applied foundation loads. In foundation studies, such soil is highly compressible and prone to excessive settlement or failure. It is unsuitable for shallow foundations without improvement. Ground stabilisation, soil replacement or deep foundations would be required to ensure structural stability and Safety (Ilevbare and Edegbai, 2021). This soil strength result shows loss of stiffness and possible failure conditions. This is a red-flag as a characteristics of reduced bearing capacity with potential instability that would require soil improvement to ensure structural safety and prevent further failure.

4.Conclusion

Two (2) vertical electrical sounding (VES) were carried out along with one (1) horizontal profiling using the R-50 and two (2) pits were hand dug to a depth of 1.1m. Two (2) disturbed samples were collected from two hand dug pits in the study area. These samples were further subjected to geotechnical tests in the laboratory which included the moisture content, Shear test, Atterberg's limits, Specific gravity and Grain size analysis. The geophysical results revealed three (3) geoelectric sequences in the study area, which comprises of sandy-clay as top soil, clayey-sand as subsoil, and weathered basement/ rock head that is highly compacted (no fracture). The overburden is generally thick and majorly composed of sandy clay and clayey sand. The low resistivity recorded in the clayey sand section (second layer) may be due to its moisture content as it has high water retaining capacity. Concrete water channel is not present around site of study. The geo-electric sections depict depth of rock head to be between 0.3m and 0.5m. The site of study is a valley, it might have been filled with transported sediments as the place is usually water logged whenever there is heavy down pour of rain. The depth for foundation layer is from 0.3m to 0.5m which is high enough to reveal the compactness of the third layer. The geotechnical results show that the soil has a fairly high natural moisture content. The deduction from the investigation is that the sub-soil formation is adequate to act as foundation material but soil stabilisation is highly recommended to improve the geotechnical properties of the soil for engineering use.

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