Post-Foundation Studies Using Integrated Geophysical and Geotechnical Methods at New Agbor Road, Uromi, Edo State, Nigeria

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Abstract: Globally, the incessant failure of buildings has drastically led to an increase in the loss of lives and properties, posing lots of concerns about the causes of these devastating effects. This research evaluates the immediate and remote causes of probable foundation failure on some buildings at Ohunyon Street, Uromi, Edo State, using integrated geophysical and geotechnical methods. By optimizing the measured field, calculating the apparent resistivity data, and interpreting the generated electrical resistivity tomography by using the SAS 1000 terrameter and RES2DINV software, a variation in soil resistivity and type was established. The geotechnical method required performing Atterberg limit-index studies on the gathered soil specimens in the region as well as geological laboratory grain size analyses. The pole-dipole results showed two weak zones and one moderately competent zone, whereas the dipole-dipole results revealed three primary layers: topsoil (sandy clay), clayey loam, and silty loam. The results also revealed regular clay permeation within the loam at depths ranging from 0.9 to 1.9 m, indicating yearly wetness, volumetric expansion, shrinkage, and uneven ground settlement. The geotechnical survey results provided useful information on both the textural soil test and the Casagrande soil analysis. All of the results were highly correlated, providing pertinent information regarding the factors responsible for the buildings' failure and recommending that the foundations of these buildings be reinforced by piling to depths of 2 m (6.6 ft) below the ground surface in order to prevent future failures. This work has distinctly shown how integrated geophysical and geotechnical methodologies can potentially be used to evaluate subsoil competency.

Keywords: Casagrande soil analysis, Clay, ERT, Foundation failure, Soil integrity

I. Introduction

When a supporting section of a building develops defects that prevent it from supporting and transferring loads to a different part, the building has structural failures. The performance of the material used in a structural component breaks down, leading to structural failure. When a system or material is strained beyond its breaking point and develops cracks or deformation, the structure will fail (CIRIA, 2019). Structural failure and collapse all over the world have been traced to two phenomena: failure caused by any climate condition is classified as a natural phenomenon, while man-made phenomena are failures caused by general geology, incompetent materials, bad or poor structural designs, and poor engineering supervision. A poor foundation will prevent even a structure with superb design and construction from standing. Even though the building will support its weight, the soil that lies underneath it might not (Mohammed, 2017; Ozegin et al., 2013; Fajana et al., 2016). To avoid structural failure of buildings, it is therefore inherent to understand without assumption the geology of any land mass either proposed for engineering works or already utilized where probable signs of structural failure are being noticed, as it reveals the effects of climate in the area, determines the load bearing/uniform load transmitting capacity of the area, recommends suitable designs, and determines the nature of materials needed for the desired construction works. Geophysics can be used to study the geology of any area relating to engineering problems by employing either or both geotechnical and geophysical survey techniques in order to predict or image the subsurface of the earth.

To guarantee the long-term viability of engineering structures and prevent the catastrophic effects of structural failure and collapse, which have become increasingly common in recent years, coordinated efforts must be completely made to establish the on-site soil's characteristics and depth to competent layers for any identified construction site (Ozegin et al., 2013; Eze et al., 2021). As a result, accurate tracking of environmental protection and remediation in impacted regions, as well as building infrastructure, requires an understanding of subsurface geology and the geographical distribution of underlying physical attributes. Additionally, they will help environmental policymakers and administrators make the appropriate decisions needed to protect and maintain an optimal environment for people and ecosystems in general, as well as preserve the resources that we have in an efficient and safe manner (e.g., Ahzegbobor, 2010; Ozegin et al., 2012). Several researchers in the fields of Geophysics, geology, and Civil Engineering have carried out numerous studies using both geophysical and Geotechnical Surveys in order to solve engineering construction problems: Soupois et al., 2007; Sudha et al., 2009; Siddiqui and Osman, 2012; Ozegin et al., 2013; Coker et al., 2013; Oghenero Coker et al., 2014; Boobalan and Ramanujam, 2015; Adeoti et al., 2016; Akintorinwa and Oluwole, 2018; Ozegin et al., 2019; Alaminiokuma and Chaanda, 2020; Aigbedion et al., 2021.

Probable signs of structural failure (cracks) were observed on the walls, compound floor, and fence of a building (figure 1a) at Ohuyun Street in Uromi, Edo State, Nigeria, immediately after its construction. Further examining the building and its environs in order to ascertain the level of damage, it was observed that the failure was not only peculiar to the said building but also to a nearby building (figure 1b) and some others within the neighborhood. The fundamental purpose of this paper is to use 2-Dimensional Electrical Resistivity Tomography and Geotechnical techniques in investigating the foundation failure of the buildings at Ohuyun Street in Uromi, New Agbor Road Esan North-East Local Government Area, Edo State, Nigeria, specifically to obtain the 2-D ERT data, the topographic land form, and the water content of the soil by quickly and thoroughly surveying the physical properties of the near-surface geologic structures, underground strata, and the load bearing capacity, in order to identify the possible causes of the failure, establish their resolutions, and aid in future prevention.

Figure 1a. Cracks on the main building of interest at the study location.

Figure 1b. Signs (cracks) of foundation failure observed on a nearby building.

1.1 Location of Study Area

The area of study is located along Ohunyon Street, Off New Agbor Road, Uromi, in the Esan North East of Edo State, Nigeria (Figure 2). The study area is mostly accessible through the Uromi-Igbanke Road/New Agbor Road (beside Citadel Cinema and Hotels) and is also interconnected to a network of roads and footpaths. Uromi, the headquarters of Esan North East Local Government Area of Edo State. It has a land area of about 2987.52 Km^2 and is about 107 km (66 miles) from Benin City, the State capital (Ezomo and Ajieh, 2013) (Figure 2b). The Atani, Ebhoiyi, Ivue-Obeidu, Uzea, and Amendokhian villages in Uromi are bordered, respectively, with their neighboring towns of Ubiaja on the south, Igueben on the south-east, Irrua on the north-west, Afema by the north, and Ugboha on the far south-west.

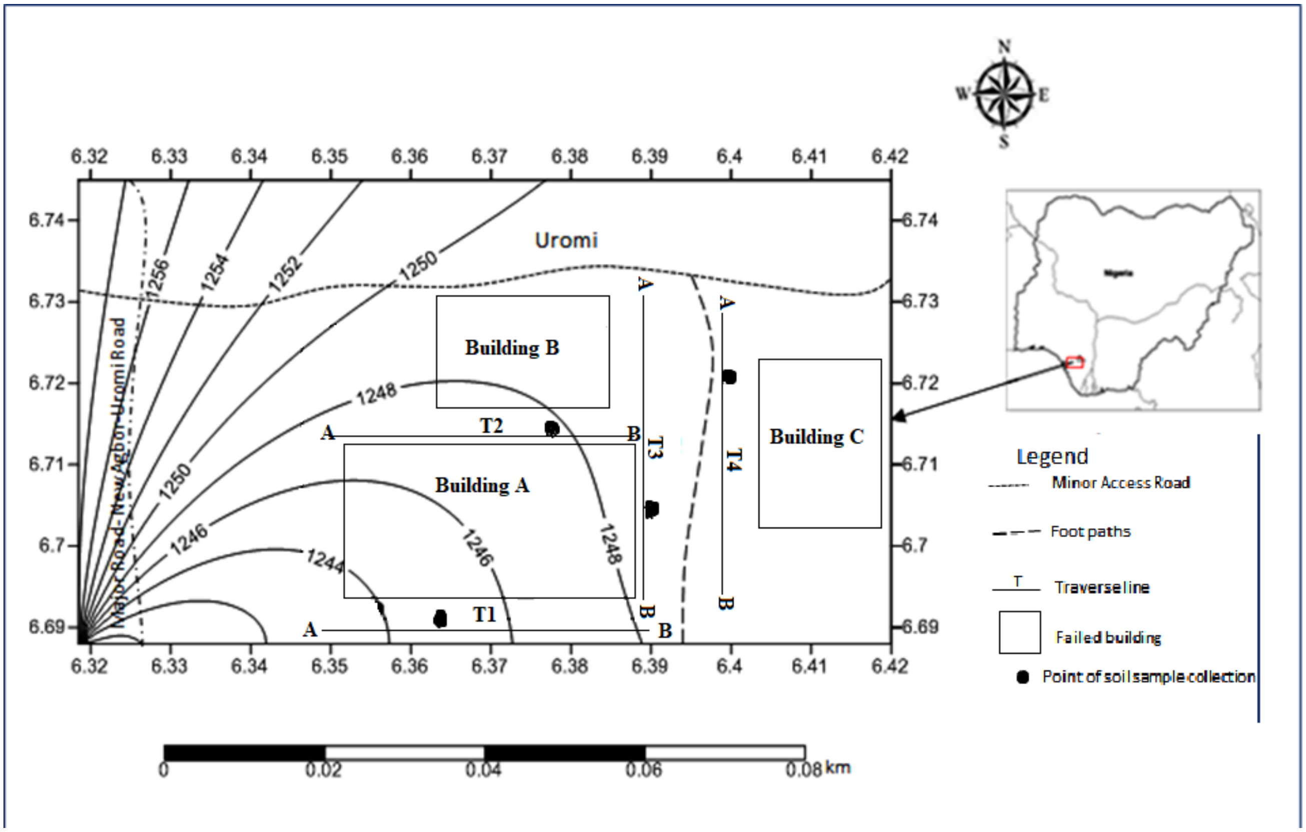

Figure 2. Location/relief map of the study area showing the transverses.

1.2 Geology of the Study Area

The Anambra Basin's Edo State arm includes Uromi. West of the lower Benue Trough is where the Anambra Basin can be found. The Santonian tectonic event that altered the basin bottom is responsible for the basin's development. The Abakaliki Anticlinorium, which was the primary site of deposition in the late Cretaceous–Eocene, was eroded to produce the Anambra Basin sediments (Airewele et al., 2020). According to data from drilled boreholes provided by Shell Petroleum Development Company and government organizations like the Benin-Owenna River Basin Development Authority, the study area is primarily composed of sediments from the Ameki Formation, which were created during the Tertiary's prevalent marine transgression. According to Omonkhodion et al. (2014), the sediments are composed of translucent clayey sandstones and sandy clay with calcareous concretions. The Miocene-aged Benin Formation, which is the lateral equivalent of the Ogwashi-Asaba Formation (Figure 3) and is comprised of fine- to coarse-grained sandstones, forms the southern boundary of the region. The Imo-shale, which is comprised of clayey shale, fine-textured dark gray and bluish-grey shale, and occasionally a mixture of ironstone and thin sandstone bands, forms the northern boundary of the region and outcrops at Irrua and Agbede. The village of Ivue occupies the highest point on the Ishan plateau at around 1,490 feet above sea level, whereas the town of Uromi occupies the top spot among its plateaus at a height of roughly 1000 feet (Ezomo et al. 2013).

With two seasons—the wet and dry seasons—Uromi's climate is comparable to that of southern Nigeria. Its average temperatures in the months of January and July are 27 °C and 25 °C, respectively; March is its hottest month with an average of 29 °C, and the coldest temperature is in July.

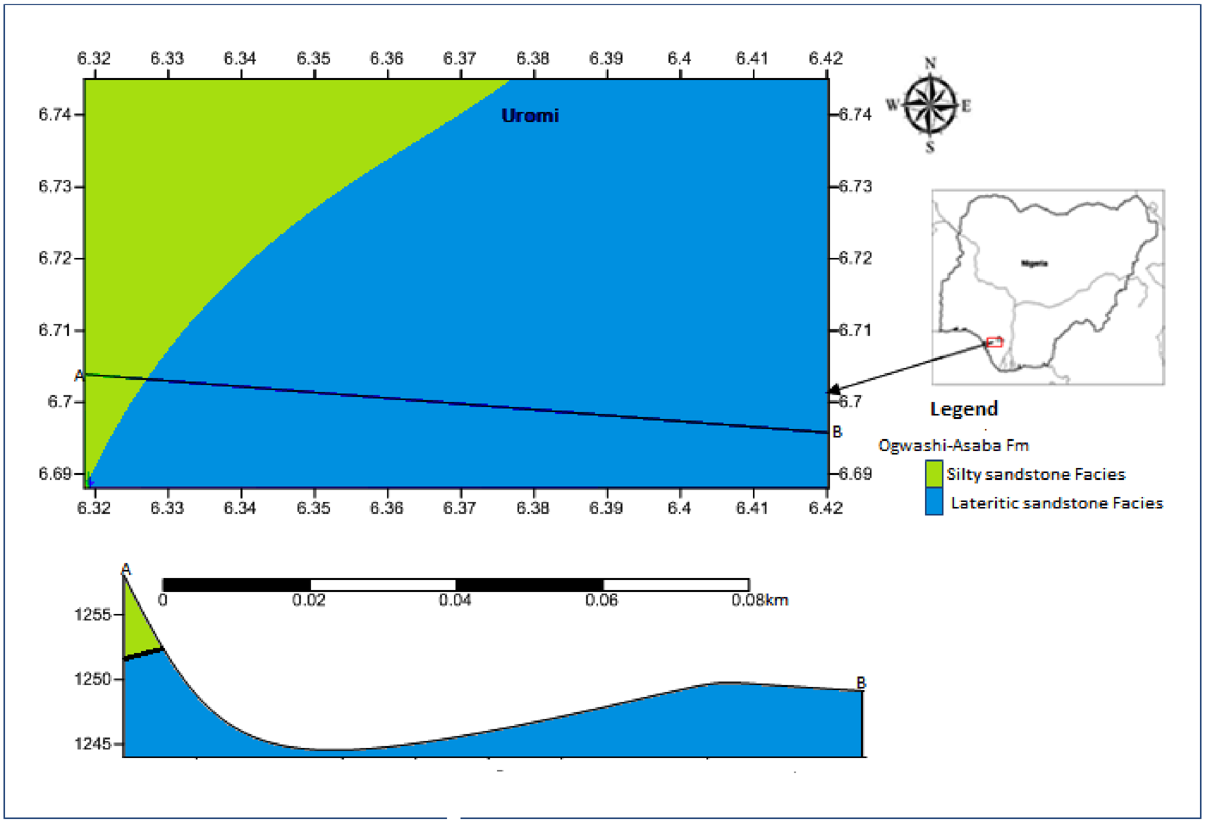

Figure 3. Map displaying the study area's geology

II. Methodology

The electrical resistivity (the inverse of conductivity), a key property of all the elements that make up the earth, is a prerequisite for the geoelectrical resistivity technique, one of the geophysical approaches used to investigate the nature of electrical current in the earth. Four electrodes are embedded in the earth as part of the geoelectrical resistivity exploration procedure. Direct current (DC) or low-frequency current (I) is injected into the earth via each of them, and the earth's potential variation (ΔV) is determined between the other electrodes. The Two-dimensional electrical resistivity tomography was conducted using the SAS 1000 Terrameter (Figure 5), utilizing both the dipole-dipole array (Figure 4a) and the pole-dipole array (Figure 4b) for the field data acquisition.

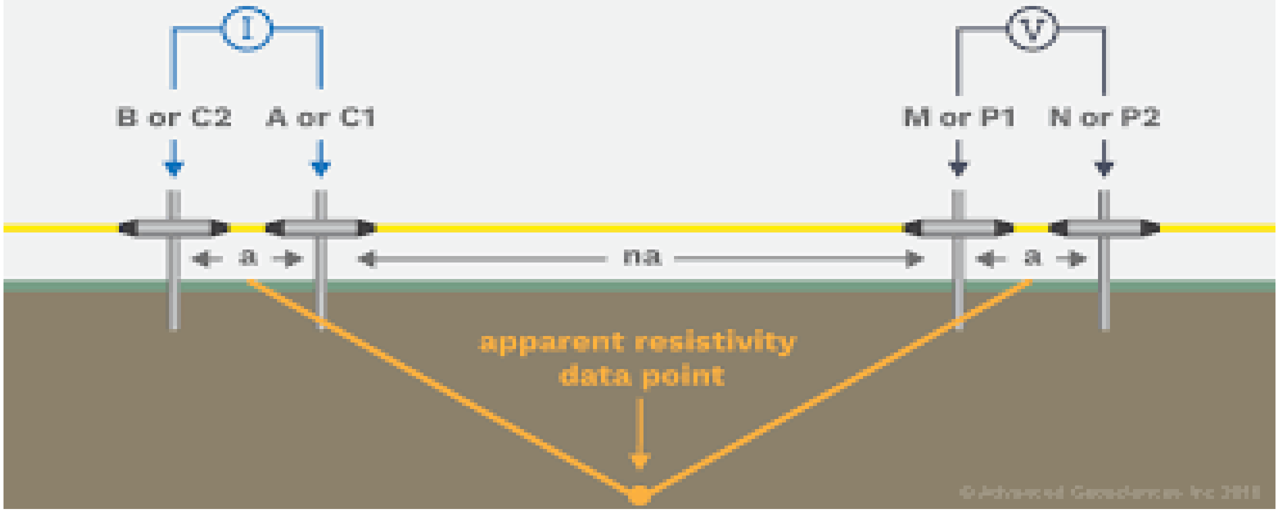

Figure 4a. Dipole-dipole array for data acquisition (Loke, 2004).

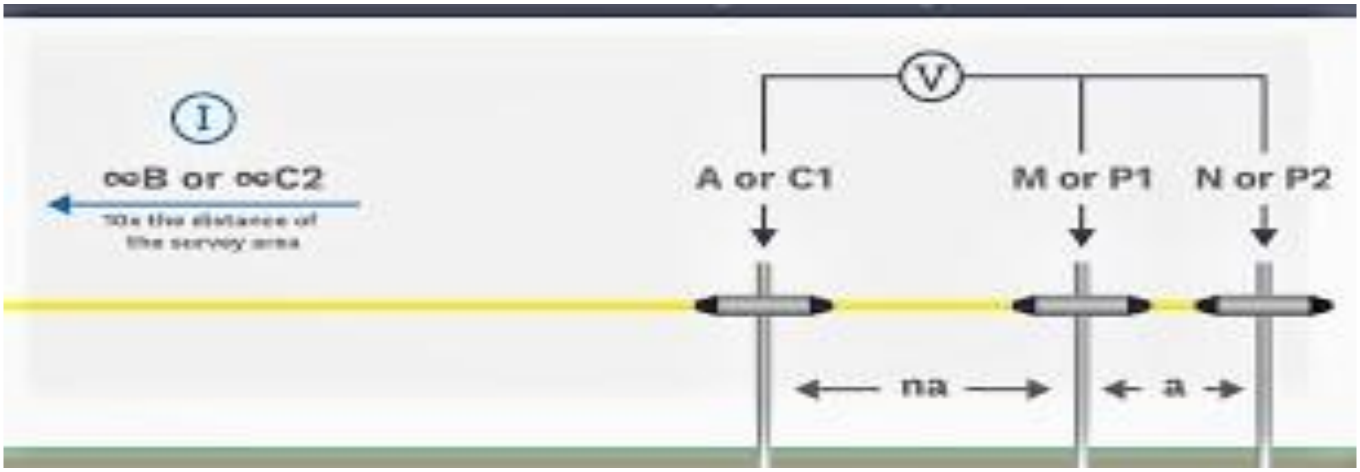

Figure 4b. Pole-dipole array for data acquisition (Loke, 2004).

The three (3) buildings under investigation are relatively close to each other; four (4) traverses were conducted around the study area, with major interest in building A, which was observed to be most affected by cracks.

Figure 5. Instrument arrangement for the field data acquisition

2.1 Measured Apparent Resistivity (ρ_a)

The apparent resistivities (ρ_a) were obtained from field resistance values using Equation 1, which is the bulk average resistivity of all soils and rocks influencing the flow of current. Where R is the measured resistance, and K is the geometric factor, which depends on the arrangement of the four electrodes (Milsom, 2003).

$$\rho_a = 2\pi R/K \tag{1}$$

The resistivity measurements were made by injecting current into the ground through two transmitting current electrodes A and B (C_1 and C_2) and measuring the resulting voltage difference at another two receiving potential electrodes M and N (P_1 and P_2), (Figures 4a and 4b).

$$K = 1/AM - 1/AN - 1/BM + 1/BN \tag{2}$$

2.1.1 Data Optimization

A computer algorithm was used to enhance the values obtained from the field survey to guarantee that the observed resistivity matches the estimated apparent resistivity values. By modifying the resistivity models, this optimization technique decreased the discrepancy between the calculated and measured apparent resistivity values. These discrepancies are measured by the root-mean-square (RMS) error. For each place, the processed data displays the depth and resistivity values.

2.1.2 Data analysis and ERT modeling

The 2-D model of the subsurface, which comprises a variety of rectangular components, served as the foundation for the data interpretation. Using 2-D resistivity inversion software (RES2DINV), the apparent resistivity was converted to the true resistivity, and then an inverse subsurface model was created. The various ERT data were taken from the field data that had been collected. To create the 2-D Electrical Resistivity Tomography, the data produced by the RES2DINV software was griddled.

2.2 Geotechnical Analysis

The geotechnical survey involved taking soil samples from four (4) strategic positions in the study location into plastic bags and sending them to the laboratory for testing in order to get information on the various relevant soil parameters that are essential to foundation integrity. The soil samples were first air-dried and crushed into small pieces. The crushed samples were then sieved through different sieve openings, ranging from 0.0063 to 10.00 mm, in order to get fine grains. The fine-grain sieved soil was wetted with tap water to achieve moisture, the moist soil was sealed in plastic bags and stored for two days to allow moisture equilibrium, and the Hydra soil was later used for other geotechnical soil analysis. The major soil analyses carried out in this research are the Textural soil test, involving particle size characterization (grain size analysis), and the Casagrande soil analysis to obtain the Atterberg limits, which included the liquid limit, the plastic limit, the compaction index, and the plastic index. The test results from the soil analysis served as major guides in making recommendations for this survey.

III. Results and Discussion

3.1 Results

Tables 1 and 2 show results for the textural soil analysis and the Casagrande soil analysis, respectively. Figures 6 to 9 show the 2-D ERT for the four (4) respective profiles around the location of the study. These figures depict measured apparent resistivity pseudo-sections, computed apparent resistivity pseudo-sections, and inverse model resistivity sections that were created following optimization to lower the RMS error between them. The processed pseudo-sections are used to determine the resistivity sections of the inverse model, which are shown as functions of resistivity in ohm-meters vs soil depth in meters. Based on the inverse model of resistivity, the values of resistivity at various depths are calculated. Figure 10 shows the textural soil analysis triangle, and Figure 11 shows the water content plot for the four (4) soil samples.

Table 1. Textural Soil Analysis Result

Soil Samples	Sand (%)	Grain size	Clay (%)	Grain size	Silt (%)	Grain size
borehole 1	20	0.07	55	0.0042	25	0.06
borehole 2	20	0.07	52	0.045	28	0.062
borehole 3	20	0.07	15	0.045	65	0.063
borehole 4	15	0.1	60	0.045	25	0.059

Table 2. Soil Analysis (Casagrande)

Soil Samples	LL (%)	PI (%)	CI (%)	PL (%)
borehole 1	35.9	25.8	1.07	10.1
borehole 2	35.5	25.5	1.05	10.0
borehole 3	30.9	22.8	1.96	8.1
borehole 4	37.8	27.6	1.05	10.2

liquid limit (LL); plastic index (PI); consistency index (CI); plastic index (PL)

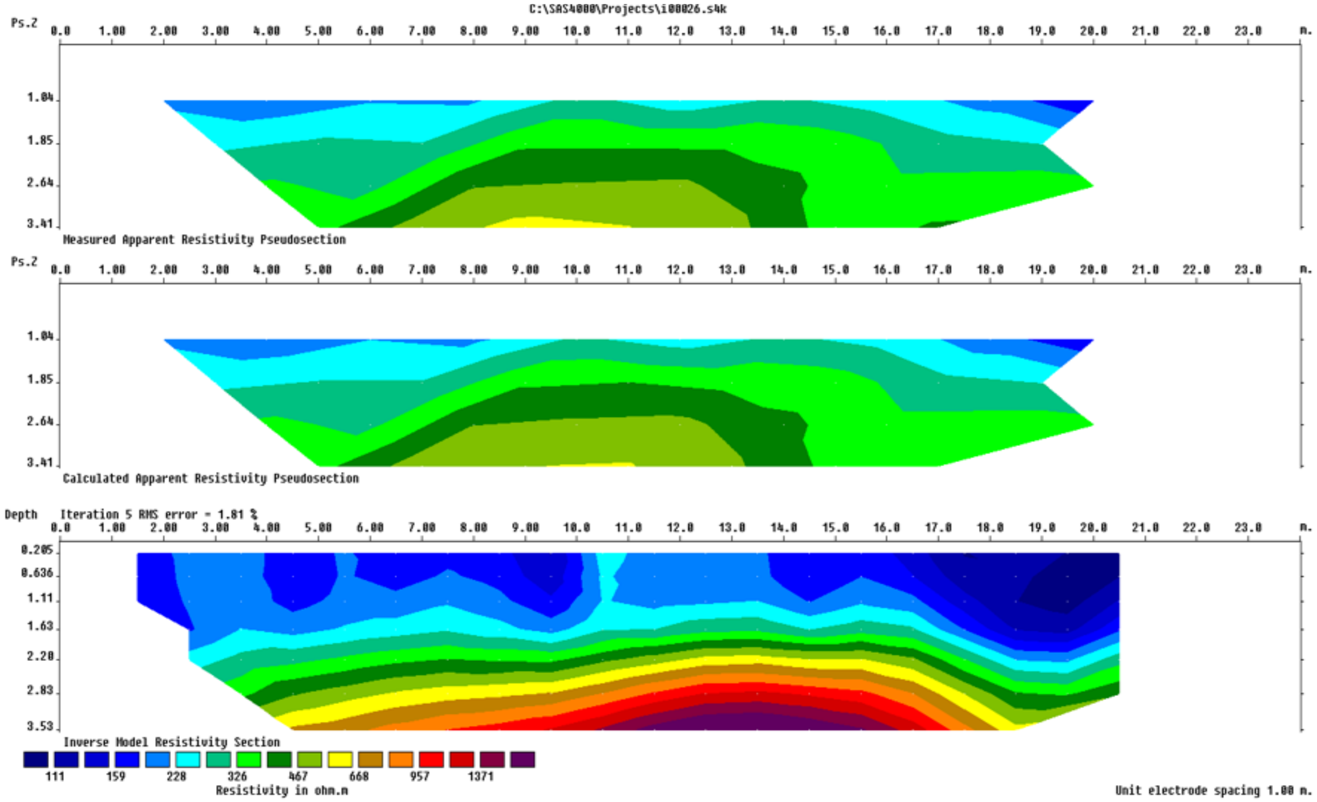

Figure 6. Pole-dipole pseudo section T1

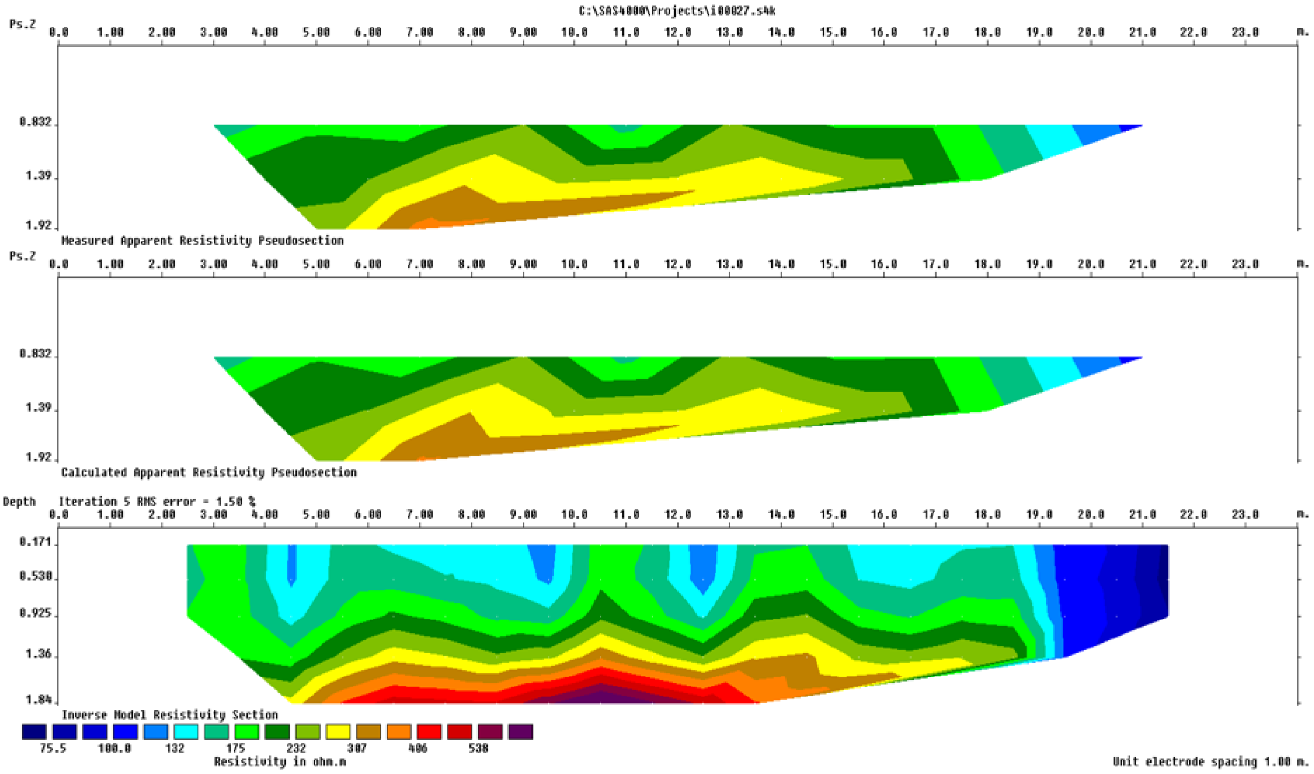

Figure 7. Dipole-dipole pseudo section in T2

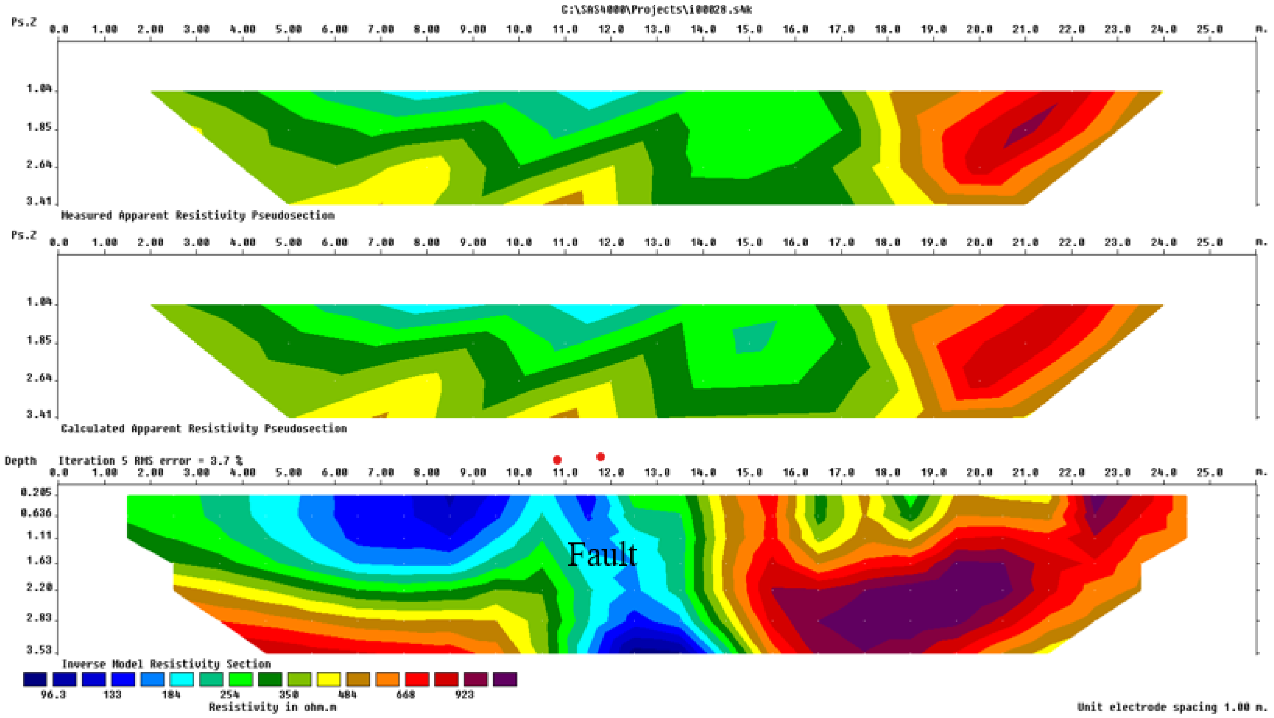

Figure 8. T3 Pole-dipole pseudo section

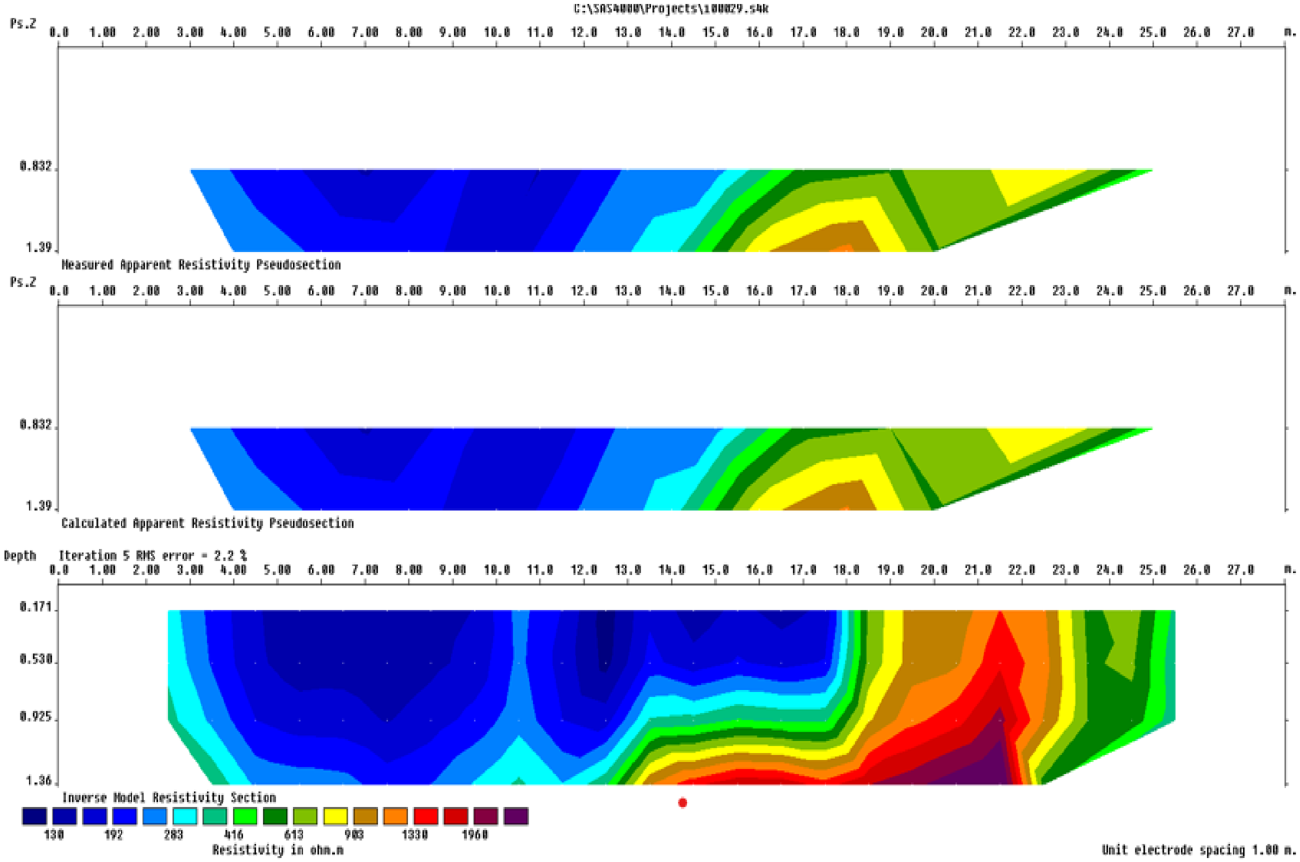

Figure 9. T4 Dipole-dipole pseudosection

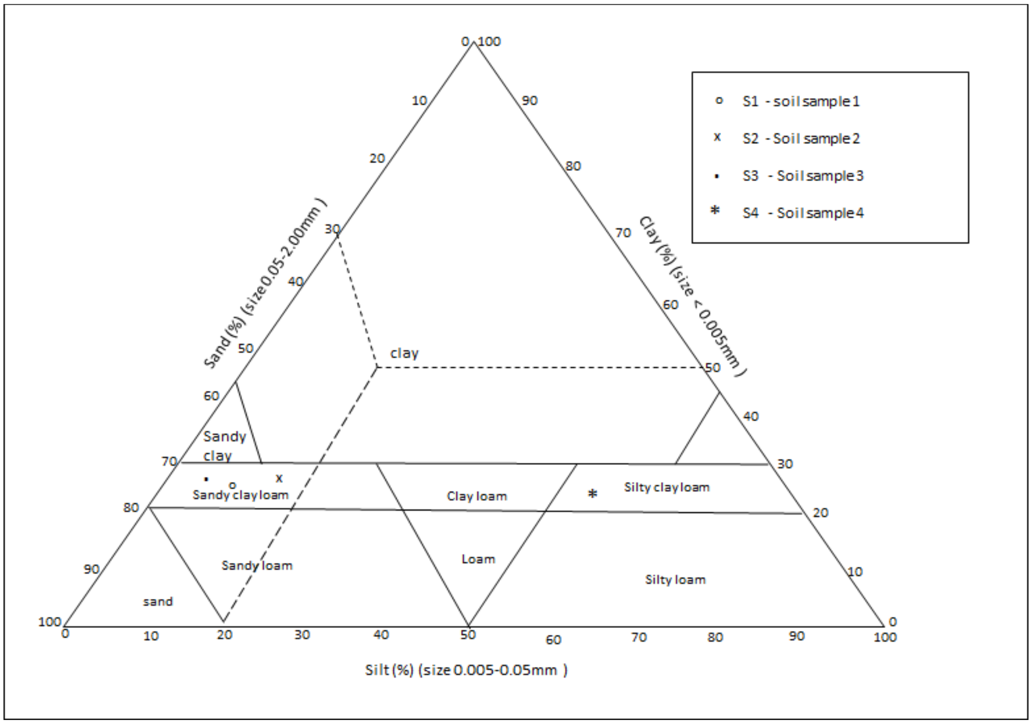

Figure 10. Textural soil analysis triangle.

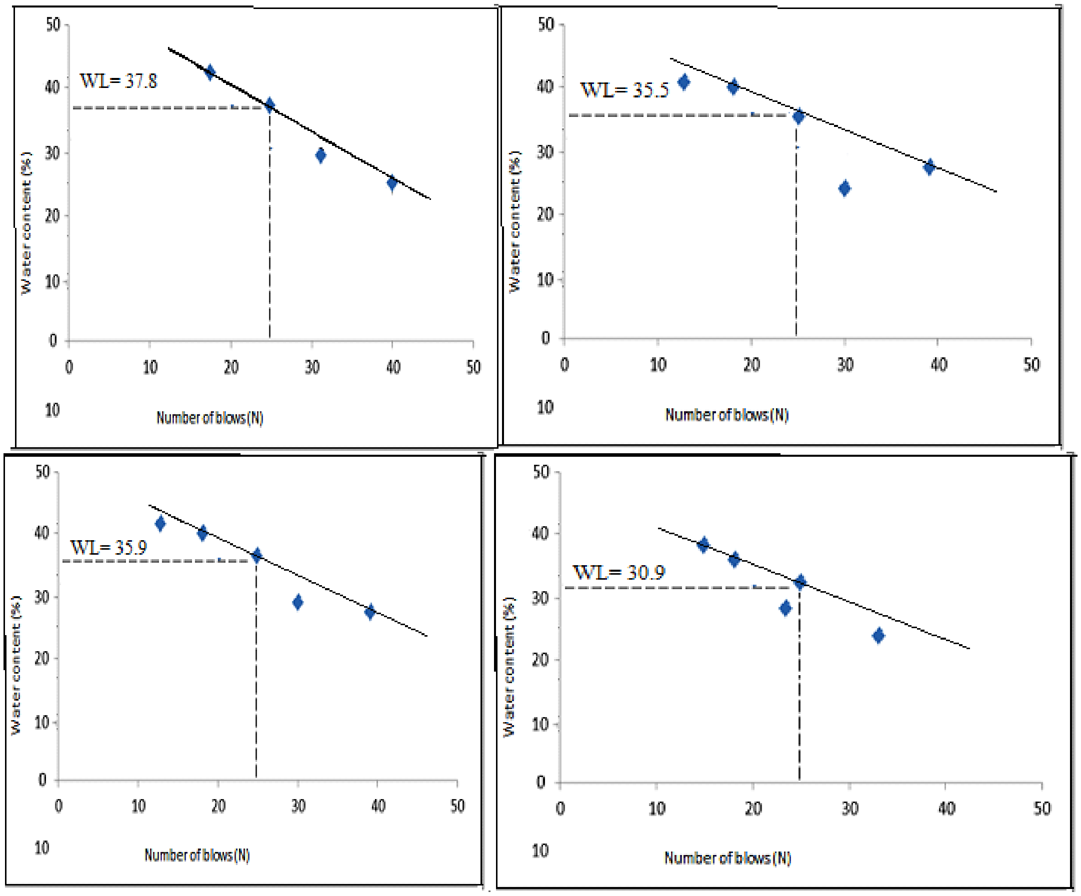

Figure 11. Water content plot for the four (4) soil samples.

IV. Discussion

This study reveals that the top soil (sandy clay), clayey loam, and silty loam are the three main sub-soil layers in the study area with low resistivity values. These layers are geotechnically suggestive of poor material for foundations with water-filled voids, as determined by the Textural and Casagrande soil analyses. Given their high compressibility, insufficient bearing capacity, inadequate drainage, excessive ground and surface water, and various settlements, among other issues, they present significant engineering challenges.

4.1 The Geotechnical Results

Almost all facets of soil administration and application are influenced by soil texture (Ozegin et al., 2019). The soil's fineness (clayey) or coarseness (sandy), which affects a number of its physical and chemical qualities, except for soils that undergo severe erosion, accumulation, or elimination, is a lasting characteristic. From the results of the textural soil study (Table 1), a textural soil triangle (Figure 10) was established. A soil with 30% sand, 20% silt, and 50% clay is shown. These three lines connect within the "Clay" textural class's boundaries, indicating that the soil is clay-based. These values indicated the high quality of clay soil material present in the location of the study, which indicates that in the event of a rise in the water table beneath the surface, the subsoil within these buildings will be susceptible to swelling and will be faced with shrinkage during the dry season. They are also indicative of a weak mass of interlocking particles with low shear strength and high compressibility as a result of the large spaces between the particles of the excessive clay soil material (Adejumo et al., 2015; Fajana et al., 2016).

The liquid limit for the soil samples in the study (Table 2) ranges from 30.9 to 37.8%, indicating that the soil is not good enough to support foundation integrity, as it is relatively close to the maximum 40% recommended by the Nigerian Federal Ministry of Works and Housing, (FMWH, 1997). The water content present on each specific moist soil sample at which 25 blows cause the groove to close as required is taken to be the liquid limit of the respective soil samples. As the soil paste would be stiffer with a low water concentration, it would typically result in more blows, whereas the abundance of water would result in fewer blows. Figure 11 shows the liquid limit flow curve graph of the four (4) respective soil samples, with the different specific water content (30.9 to 37.8%) on each moist soil sample plotted on the vertical axis and the specific number of blows required to close the groove created on each of the respective moist soil samples plotted on the horizontal axis. The plastic limit of the material showed values ranging from 22.8 to 27.6%, indicative of a poor foundation material, as it is relatively low when compared with the maximum of 30% recommended for safe foundation materials (FMWH, 1997). The plastic index of the results of the four soil samples ranges from 8.1 to 10.2%. This is again relatively lower than the 12% maximum plastic index value recommended in Nigeria (FMWH, 1997) for good foundation or engineering properties, thus showing the soil as a less competent foundation material. This also shows the high presence of clay soil content within the study area. The consistency index of the four soil samples showed values ranging from 1.05 to 1.96%, indicative of very low competent foundation soil materials, because the higher the consistency index of a soil, the stronger and higher the competency of the soil (Adejumo et al., 2015).

4.2 The Geophysical Results

Figure 6, traverse one (T1), revealed low resistivity values ranging between 111 and 228 Ωm, at depths from about 0.201 to 1.63 m and 326 to 467 Ωm at depths from about 1.64 to 2.79 m in the deep near-surface layer classified respectively as sandy clay and clayey loam (weak zones). T1 also showed high resistivity values ranging from about 668 to 1371 Ωm, at depths of about 2.80 to 3.53 m, and soil within these deep-surface layers is characterized as competent zones. Comparable results have been reported by Egbeyale et al. (2019).

T2 (Figure 7) showed low resistivity values ranging from 75.5 to 175 Ωm, at about depths of 0.171 to 1.60 m and 176 to 232 Ωm, at depths of 1.61 to 1.78m in the shallow near-surface layer. These varying topsoil resistivities suggest sandy clay and clayey loam, respectively. High resistivity values at T2 were observed between 307 and 538 Ωm, at depths ≥ 1.84 m, with the soil at these competent layers classified as clayed sand and laterite.

Figure 8: T3 showed low resistivity values ranging from 96.3 to 184 Ωm, at depths of 0.205 to 1.63 m and 254 to 350 Ωm, at depths of 265 to 215 m. The soil within these near-surface layers is characterized as sandy clay and clayey loam, respectively. High resistivity values at T3 were observed between 484 and 932 Ωm, at depths of 2.20 and 3.53 m. The lithology and resistivities of this layer indicate clayed sand and laterite (a competent zone). However, a fault was observed within 11 to 12 meters on this traverse.

Figure 9, T4, showed low resistivity values ranging from 138 to 283 Ωm, at about depths of 0.171 to 0.925 m, and 284 to 416 Ωm, at depths of about 0.927 to 1.20 m, with the varying topsoil resistivities characterized as sandy clay and clayey loam, respectively (indicative of weak zones), and competent zone with high resistivity values between 903 and 1960 Ωm, at depth ≥ 1.30 m, classified as lateritic.

The results also show that there is regular clay permeation within the loam at depths ranging from 0.9 to 1.9m with low resistivity values ranging from 96.3 to 283 Ohm meter in the study area. These clayey soils experience seasonal volumetric variations that cause them to either substantially enlarge in volume when filled with water or significantly contract when drained (Ozegin et al., 2012). Variable settlements may result from these modifications to clayey soils. Different loads placed on various components of the foundations of these buildings may be the cause of these differential settlements brought on by the expanding clayey soil in the study region. Where the foundations of these structures are constructed within this stratum or zone, from 3.3 to 6.6 feet (1 to 2 m) in the research location, such variations in the displacement of the foundations may result in defects, especially around the expansion joints of these structures.

V. Conclusion

This study strongly suggests using integrated geophysical and geotechnical studies to investigate foundation failures. Both methodologies produced highly correlated findings, particularly because the places of the major cracks found on the structures were approximately at equal distances on the pseudosections, where both lateral and vertical fractures were visually observed. The ERT study showed that resistivity levels vary within different soil layers surrounding the three analyzed buildings. According to the geotechnical assessment, different soil types have varying degrees of expansivity with seasonal volumetric variations. This analysis discusses the elements that are most likely to be the causes of the structural collapses in these structures. Clayey soils have been shown to intercalate the underlying sand or loam soil of these buildings within the top shallow layers of 0.9 to 1.9 m, which mostly contributes to the soil's expansive nature, with low resistivity values ranging from 96.3 to 283 Ohm meter. As a result, the crumbling and fractures on the researched buildings at Ohunyon Street, Uromi, Edo State, can be attributed to the clayey soil type underlying the area. Long-term monitoring of reinforced foundations for evaluating sustainability and similar research in other regions for contrasting geotechnical circumstances and failure developments are recommended.

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