Geophysics

FAULT PRESENCE UNDER A FAILING BUILDING COMPLEX MAPPED BY ELECTRICAL RESISTIVITY TOMOGRAPHY

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ABSTRACT

An electrical resistivity tomography supported with Vertical Electrical Sounding (VES) survey was carried out within the precincts of a Faculty building at Olabisi Onabanjo University Main Campus, Ago-Iwoye, Nigeria. The building is intensively affected by dangerous cracks that cause structural instability a few years after its construction. The survey aimed to image the shallow subsurface structures and determine the possible cause of the structural instability. 2D Resistivity imaging using Wenner array with smallest electrode spacing of 10m and VES using Schlumberger electrode configuration were carried out along four traverses extending about 130 meters at the precinct of the building complex. The acquired data were processed and interpreted spatially to expose the shallow structural setting of the site. Integrated interpretation led to the delineation of hazard zone in the area. This zone is interpreted as fault with vertical and sub-vertical linear features having moved both vertically and horizontally with associated resistivity values as low as 5Ωm. This feature is suggested as the main reason of the rock instability that resulted in potentially dangerous cracking of the buildings. Inferred lithologic units which include silty/clayey soil, sandy clay and the basement were mapped out at the site. Compacted lateritic (hardpan) topsoil along traverse 4 (backside of the building), though not a rock unit, constitutes an important factor to the re-construction of geologic unit from ERT model. The possible cause of failure of the building was proposed to result from the underlying fault on which the whole weight of the building rests. It was also discovered that the pre-construction geotechnical investigations possibly failed to capture the zones because they are point investigations that lack continuous imaging of subsurface condition.

Key words: 2-D electrical resistivity tomography, Structural instability, Fault zone, synclinal features, Compressible soil and Springs

INTRODUCTION

Foundation investigation requires the characterization of subsurface soil and determination of soil strength as prerequisites for the foundation design of important civil engineering structures. The usual practice in geotechnical studies is the use of Standard Penetrometer Test (SPT) to determine the resistance of soil to penetration used to evaluate the soil strength in terms of number of blows (N-values). The N-values are defined as the number of blows per 30 cm of penetration into the soil. N-values can be used to obtain the bearing capacity of soils following the procedure of IS 6403 - (1981) code (Sudha et al., 2009). In Dynamic Cone Penetration Test (DCPT), the resistance (i.e. N-value) to penetration of the cone in terms of the number of blows per 30 cm of penetration could be correlated with the bearing capacity of the soil. Over the year, the inefficacy of this geotechnical approach to the characterization of subsurface soil became pronounced through colossal of building failures and collapse in so much that the integrity of engineering soil tests be-

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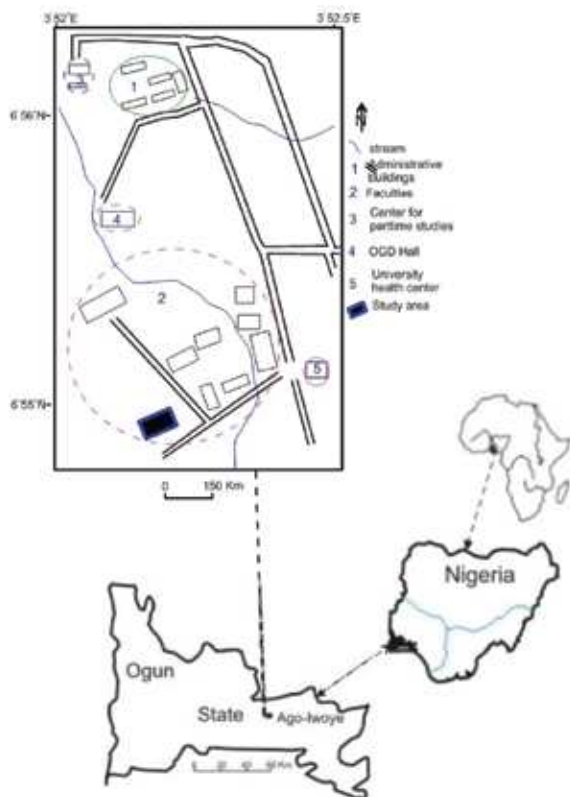
FIGURE 1. Map of OOU campus showing the study area

came questionable. This has led to several attempts in search of complimentary invasive and cost effective geophysical tests capable of continuous imaging of the subsurface. Indeed, engineering soil tests are point method lacking ability to image the subsurface on a continuous basis. In the point method, selection of points for geotechnical survey is not based on any systematic procedure. Thus, points not selected could habour subsurface features inimical to the civil engineering structures.

Several attempts have been made to establish correlation between geotechnical parameters and electrical resistivity methods (Braga et al., 1999; Giao et al., 2003, Sudha et al., 2009). This correlation, if well established, can be applied by ERT method for complete imaging of the underground surface to elucidate its compositional features. This has led to the discovery of linear relationship between transverse resistance derived from DC resistivity data and N-values obtained from geotechnical tests (Sudha, et al., 2009). Consequently, many authors have found the application of different geophysical methods useful for site investigation (Elawadi et al., 2006; Yilmaz and Eser,

2009; Ayolabi et al., 2010), which completely picture the subsurface compositional features while engineers determine the bearing capacity of the soil. Thus, a complimentary geophysics-geotechnical approach proves safe for building construction (Sirles, 2006).

1-D and 2-D DC electrical resistivity method was used for the survey to investigate the subsurface setting of the area. The study site anchors the Faculty building complex of Olabisi Onabanjo University (OOU), Ago-Iwoye (Fig. 1). The two-storey building was defective few years after its construction. Occupants were relocated to allow for amendment to the building. This did not seem to solve the problem as the building soon cracked and show signs of future problem, even after being amended the second time (Fig. 2). Several attempts have been made to salvage the situation but no effort was directed at the subsurface, as no thought of the subsurface been the culprit ever flashed the mind.

GEOMORPHOLOGY AND GEOLOGY OF THE AREA

The entire OOU campus lies to the south-western part of Ago-Iwoye Township between longitudes $3^0 \, 52'$ and $3^0 \, 53'$ and latitudes $6^0 \, 54.5'$ and $6^0 \, 56'$, it is about 3.5km to the town. The topography is rugged with an elevation gradient of about 30m, sloping along NW-SE trend (Fig. 3) and a dendritic drainage pattern. Geologically, Ago-Iwoye lies within the Precambrian basement rock of southwestern Nigeria variously described by many workers as composed of migmatite-gneiss complex (being the oldest), metasedimentary and metavolcanic rocks (The Schist Belts), the Pan-African granitoids (The Older Granites), and the undeformed acid and basic dykes (Jones and Hockey, 1964; Rahaman, 1989 and 2006; and NGSA, 2006).

The campus was recently mapped by Folorunso (2009) who reported four lithologic rock units in the area. The rock units are porphyroblastic gneiss, hornblende-biotite gneiss, banded gneiss and quartzite/quartz schist, which are various types of metamorphic rocks belonging to the migmatite-gneiss complex and the schist belt as classified by earlier workers.

THE PROBLEM AND GEOPHYSICAL INVESTIGATION METHODS APPROACH

The building was erected on the recommendation of building engineers after necessary engineering soil tests. Geotechnical soil test is point test that gives information of the subsurface under the point at which
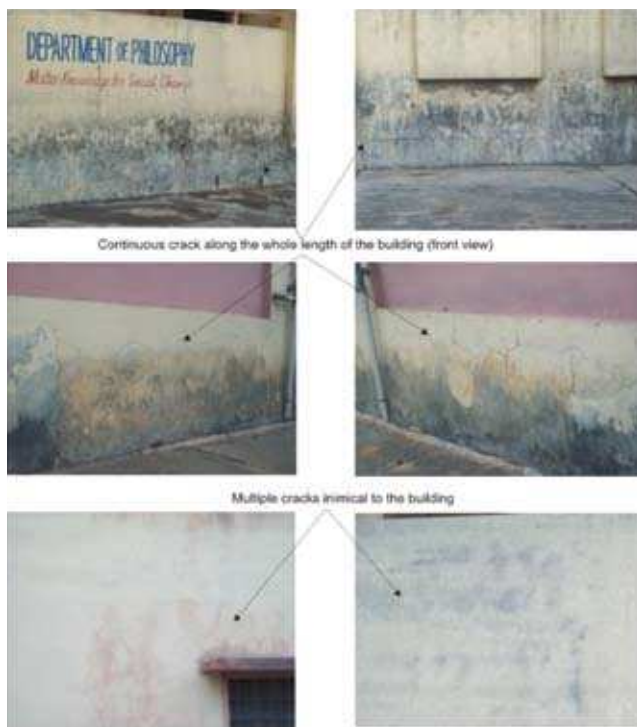
FIGURE 2. *Multiple cracks on the building structure after amendments*

FIGURE 3. *Topographical variation (> 10m) of the area (data map not to scale) indicating NW-SE sloping system.*

the test was carried out. Normally, very few points are selected to represent the total area owing to high cost of the survey. Recent findings and experience from collapsed building structures show that this might not always be enough to characterize the subsurface (Ayolabi et al., 2010). The reason is simple: the subsurface is largely heterogeneous, especially in the basement geologic terrain as the study area. Another possible reason is the development of subsurface structures such as underground voids, fractures (fault and joints), buried river channel and bedrock depression. There is every possibility that these underground structures, if present, may be omitted by the point test method. Hence, there is a need for complementary invasive and cost effective geophysical method capable of continuous imaging of the subsurface. In this study an electrical resistivity method is employed and found a veritable tool as a compliment to engineering soil tests.

Twelve (12) Vertical Electrical Sounding (VES) station were occupied at the building precincts using Schlumberger electrode configuration with a maximum AB/2 of 100m. The direction of electrode line of VES runs from the starting point (0m) to the end of the profile (100m), as indicated in Figure 4. Four VES points were located on each length and two VES points on each width of the building complex. In
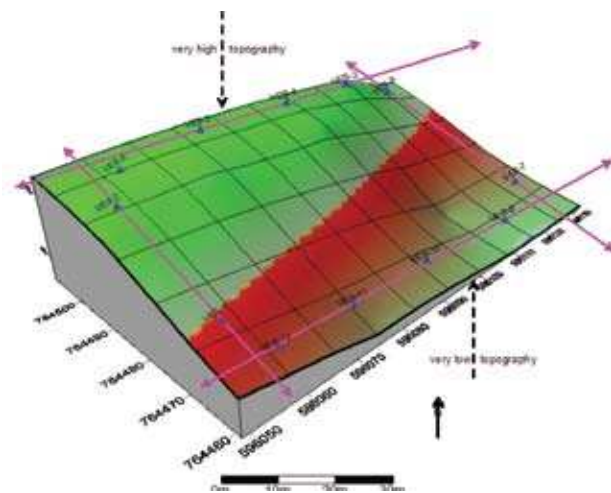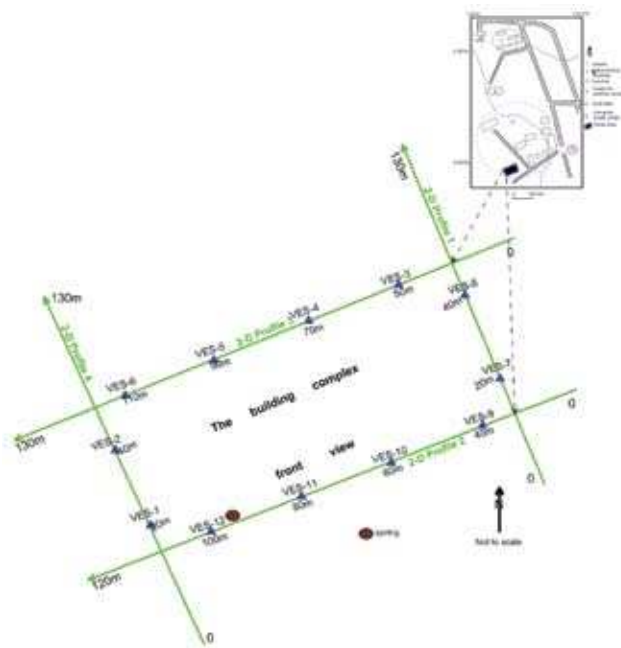

FIGURE 4. *Schematic representation of traverses and corresponding VES points. The direction of electrode line runs from 0 – 130 /120m.*

addition, four (4) 2-D Electrical Resistivity Topography profiles were equally established around the building, maintaining the same profile line with VES. One of the new developments in recent years is the use of 2-D electrical imaging/tomography surveys to map areas with moderately complex geology (Griffths and Barker, 1993; Loke, 2000). This is to allow for continuous imaging of the subsurface in order to capture areas the VES and engineering soil test would generally not cover and to reveal 'hidden' structures. Wenner electrode array and smallest electrode spacing
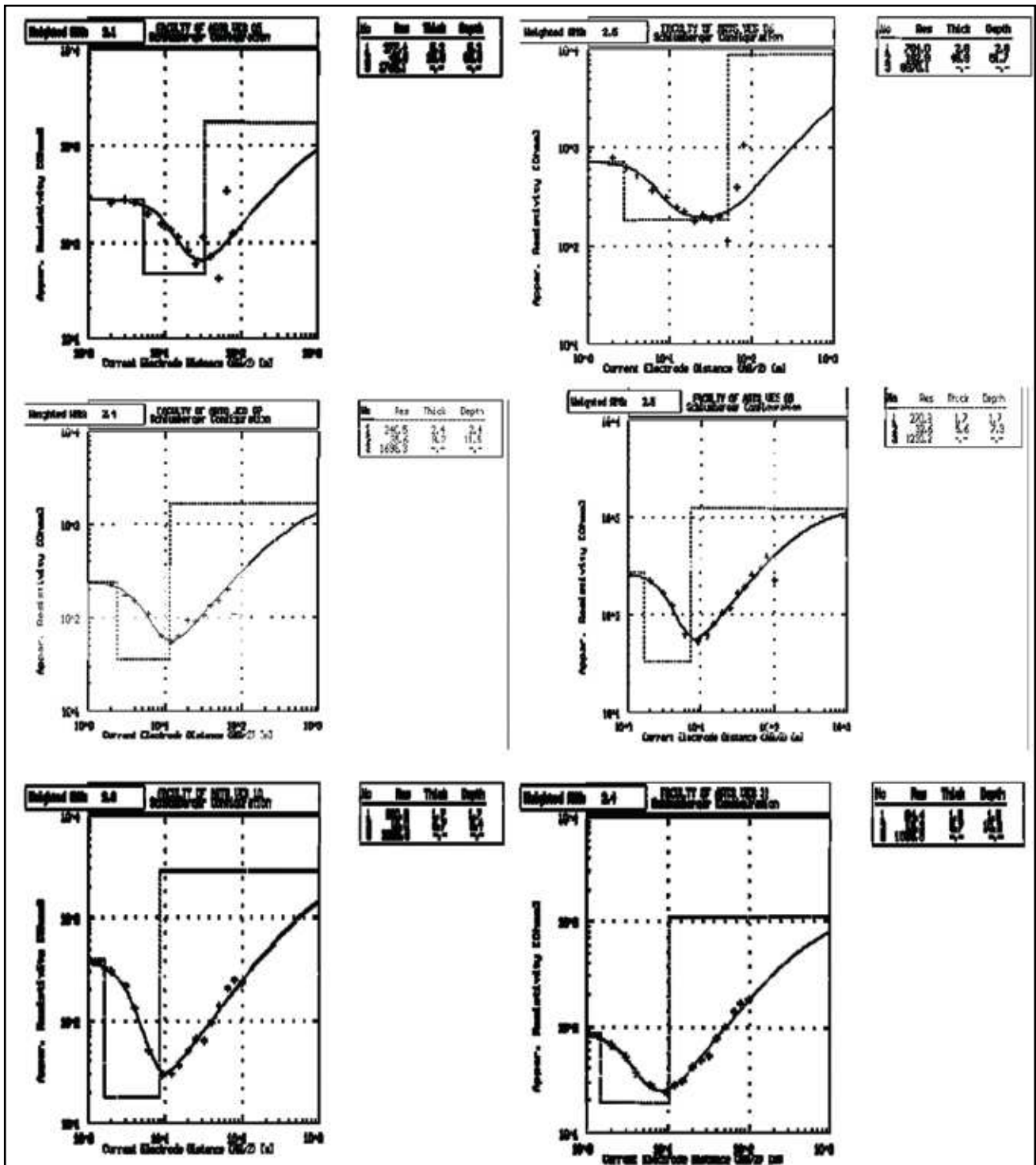
FIGURE 5. Typical resistivity-electrode spacing graphs for the area

of 10m were used along a maximum length of 130m (Fig. 4). The use of Wenner electrode configuration for 2D Resistivity Imaging was popularized by the University of Birmingham research group (Griffiths and Turnbull, 1985; Griffiths, et al 1990) for better resolution of horizontal structures (Loke, 2000).

The VES data were inverted using RESIS inversion software after curve matching based on the work of Vander Velpen (1988) to obtain the geoelectric parameters (the layer resistivity and the layer thickness). The values obtained from curve matching were used as initial model parameters for the inversion process to generate the geoelectric parameters read off from resistivity-electrode spacing graph (Fig.5).

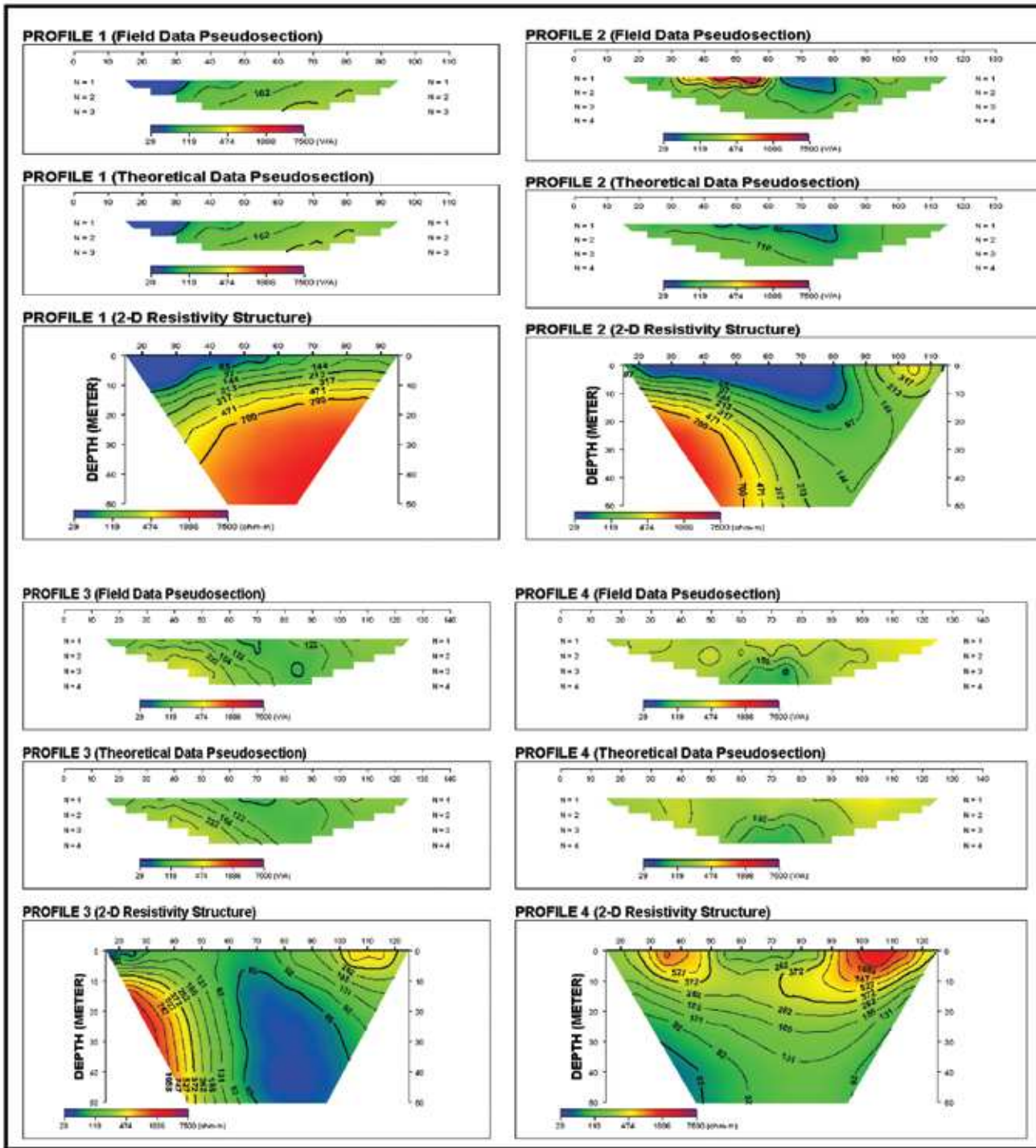The ERT data were inverted using DIPPRO for window program – a 2-D forward modelling program

FIGURE 6. Resistivity-depth models for the traverses

which calculates apparent resistivity pseudosection for 2-D subsurface model (Loke, 2000). The program is designed to allow for choosing the finite-difference (Dey and Morrison 1979) or finite-element (Silvester and Ferrari 1990) method to calculate the apparent resistivity values. The resistivity model obtained are displayed as resistivity variation again depth, where both field and theoretical data pseudosections are displayed along with the inverted 2-D resistivity structure (Fig. 6).

RESULTS AND DISCUSSION
VES

The result of twelve VES stations established at the precincts of the building structure reveal three geo-electric layers beneath each VES station. The top soil varies in resistivity between 84 to 889Ωm which marked sharp contrast in soil cover of the back side (Profile 3) made of compacted laterite and the front side (Profile 2) composed of silty/clayey soil, highly
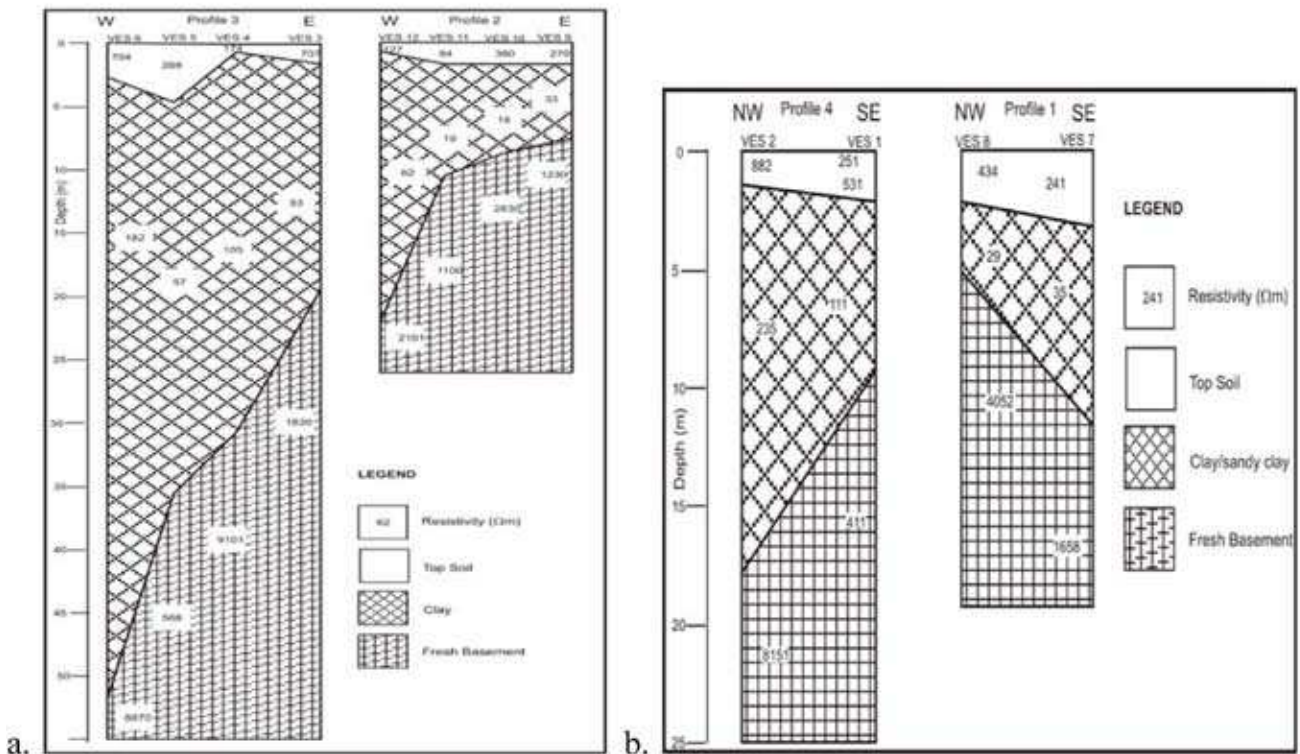
FIGURE 7. Geoelectric sections along the (a) rear and front sides (b) both widths of the building
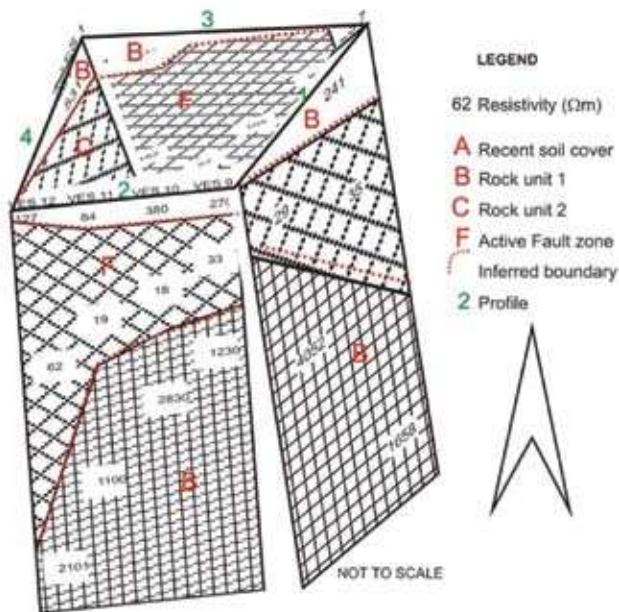

FIGURE 8. 2-D block model for the VES Traverses. Note that depth differences exist between the profiles. It can be best viewed from figure 7 vis a vis the lithology. Post fault deposition could be seen right from resistivity contrast from both profile 2 and 3 where clay was mapped along the fault plane

marshy. The thickness of the top layer ranges between 0.7 and 4.64m (Fig. 7). The second layer is made of materials of very low resistivity beneath most of the VES stations as low as 18Ωm. An important observation worth noting is the fact that on ground surface, the back side appears to be an uplift made up of hard pan (compacted laterite). Vivid examination of the resistivity variations beneath the VES points shows a wide zone of low resistivity deep beneath the VES points in the rear side of the building extending across the building but shallow in the subsurface of the front view (Fig. 5). This region is interpreted to be either subsurface void, fault or abandoned river channel which probably has been taken over by highly saturated and compressible clay/clayey soil inimical to building structure.

The four VES traverses were justaposed for a better three dimentional view of the soil condition under the building. It was noted from resistivity contrast from both profile 2 and 3 that post-fault deposition has resulted in the fault plane being occupied by material of very low resistivity interpreted as clay (Fig. 8).

ERT

The ERT resistivity models obtained from the survey site reveal that the electrical resistivity values increase with depth from surface to the bedrock in profile 1 where no subsurface structure was mapped. Resistivity distributions increase with depth beginning with a silty/clayey top soil (5-25 Ωm) through sandy
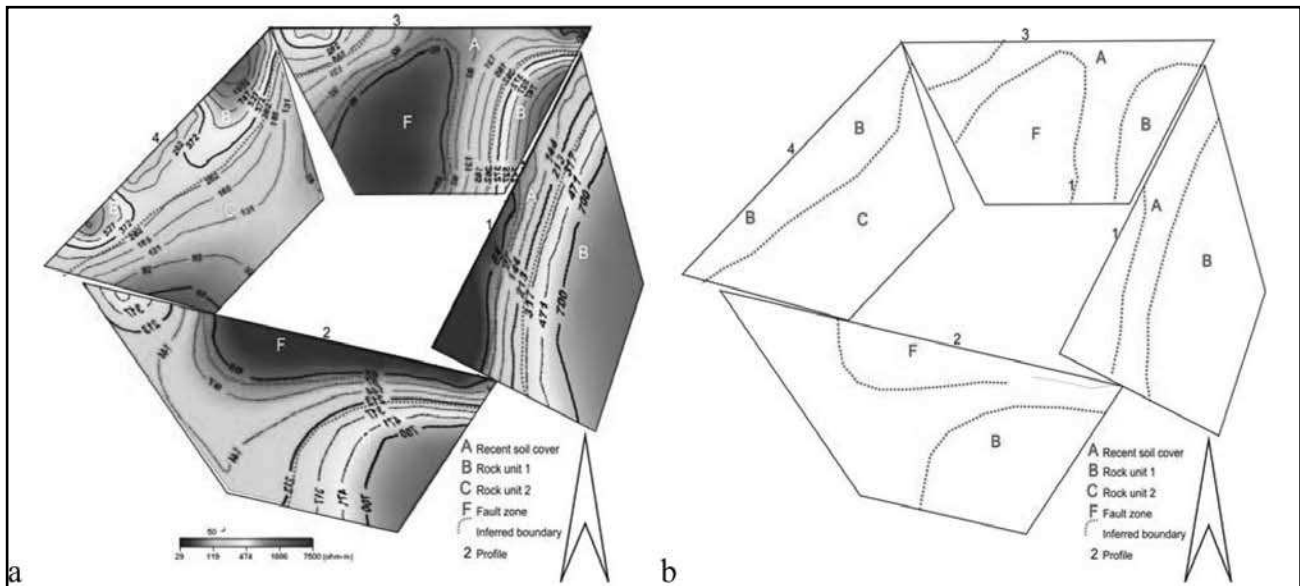
FIGURE 9. ERT resistivity model of the profiles (a) resistivity structure (b) inferred lithology and structure

clay (55-250 Ωm) to the basement. Electrical resistivity, ER under profile 2 maps out a synclinal structural feature interpreted as a fault, having a low resistivity of <65 Ωm between surface position 20-85m. The front view is topographically lower than the backside. Putting this into consideration, the same synclinal structure can be mapped from profile 3 (<80 Ωm), between surface positions 62-90m at a depth of >10m extending across the building to profile 2. We notice that the >10m thickness above the synclinal structure (fault) in profile 3 matches the elevation differences between the two sides of the building (see Figure 3). Moreover, the structure (fault) is sandwich between two competent subsurface units with high resistivity, increasing away from the center. The topsoil in the first part of profile 3 is sandy clay while the later part is hard pan (compacted and dry laterite) as observed in the field. The later unit is highly non-conductive having resistivity comparable to basement mapped at surface position 30m (>15m depth) and under VES 3. Profile 4 well depicts the soil cover around the site as observed on the field. It is a near-hilly topography made of compacted hardpan. The reason for its low conductive behaviour may be attributed to non permeable nature, though porous.

A 3-D view of the site from 2-D ERT models (Fig. 9) was constructed to enable an understanding of the subsurface conditions under the building. It clearly illustrates a fault zone whose separating blocks (B – rock unit 1) have moved wide apart, and the fault zone became an active zone for the deposition of materials possibly residual soil (from the underlying bedrock and adjacent topsoil) and exotic materials due to erosion. It is observed that the separated blocks moved both horizontally and vertically downward to achieve the present status. This was very similar to 3-D view constructed from VES survey as shown in figure 8. A second proof of the proposed fracture is the groundwater springing out beneath the building as indicated on Figure 4. Generally, underground water seep out as a spring using available fracture as conduit.

POSSIBLE CAUSE
OF THE BUILDING FAILURE

Figure 10a illustrates a pictorial condition under the building. It is noted that the building (>70m in length) rests on competent soil layer at the western side but the eastern side rests on incompetent layer made up of saturated compressible clay as a result of post tectonic erosion and deposition on the active fault zone. From gravitational force, the weight of an object acts at the center of the object. This implies that the overall weight of the building complex rests on the fault zone (compressible and saturated clay, Fig. 10b). This is inimical to the building and hence, the possible cause of its failure. Emergency evacuations of occupants for two times have been reported here. Each time, the building is amended with more cement as if the root cause is usage of incompetent building materials, as no one thought of the possibility of subsurface being the cause.
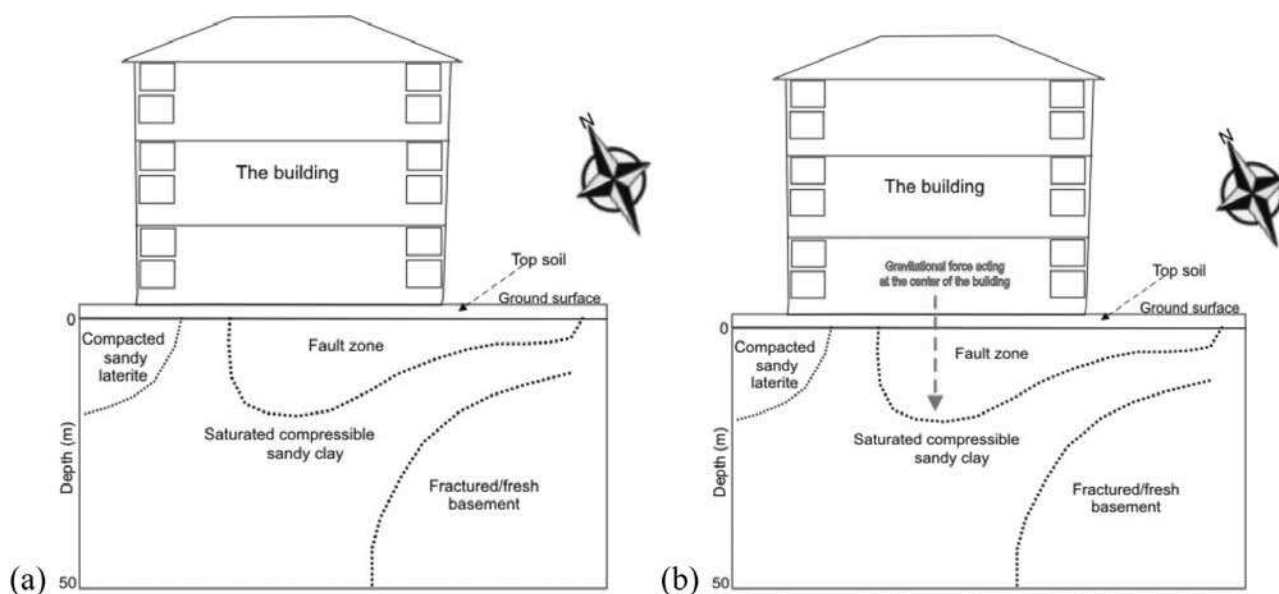
FIGURE 10. Model showing the subsurface under the building

CONCLUSION

Electrical resistivity tomography with vertical electrical sounding has been employed in this study to unravel the cause of persistent failure of a Faculty building in Olabisi Onabanjo University. The building has collapsed partially about two times. ERT conducted at the precincts of the structure unveiled a dynamic fault zone where the two opposite blocks have moved both horizontally and vertically paving way for deposition of recent soil possibly residual and exotic materials due to consequent erosion. Generally, a low resistivity zone of <80Ωm was attributed to the fault zone, which formed a synclinal feature, in contrast to the adjacent material. Topography at the site varies widely, which was reflected from the ERT models. Inferred lithologic units include silty/clayey soil, sandy clay and the basement. Compacted lateritic (hardpan) topsoil along traverse 4, though not a rock unit, was equally mapped by ERT as it constitutes an important factor to the understanding of the study. The possible cause of failure of the building was proposed to result from the underlying fault on which the whole weight of the building rests. Pre-construction geotechnical investigation failed to capture the fault zone being a point test lacking continuous imaging of the subsurface. So, it is therefore recommended that geotechnical tests should be supported with geophysical survey for foundation investigation.

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