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Evaluation of structural defects and the dynamic of stress and strain on a building along Oluwole Area, Southwestern Nigeria

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ABSTRACT: This research was carried out within the Basement Complex terrain along Oluwole, off Akure High School, Akure, Ondo State, Nigeria, with the aim to ascertain the reasons for the major cracks and sign of apparent failures observed in a building few years after its construction and usage. The geophysical investigation involved two electrical resistivity techniques; Vertical Electrical Sounding (VES) using the Schlumberger configuration and 2-D electrical imaging using Dipole-dipole electrode configuration. Three traverses were established E–W direction cutting across geologic strike with a distance of 100 m and of varying inter-traverse spacing. Six (6) VES stations were occupied covering the entire study area for layer stratification and geoelectric parameters. The results were qualitatively and quantitatively interpreted and are presented as sounding curves and geoelectric sections. The 2-D imaging gave information on the subsurface characteristic in the area with generally low apparent resistivity indicating low competence material. The results obtained from the VES delineated four to five geoelectric units which comprise of the topsoil, moderately clayey sand layer, the partially weathered layer, resistive partially fractured basement and fresh basement. The results from the VES were used to determine the second order parameters. The entire results correlate well with one another showing that all the techniques used were complemented. This study has further justified the inevitability of geophysical site investigation for necessary foundation evaluation before embarking on any construction of any kind.

Keywords: Dipole-dipole, geoelectric section, total transverse resistance, total longitudinal conductance, strain, stress.

INTRODUCTION

Structural defect do not just occur without geological processes that have taken place overtime, either as a result of major or minor tectonic events leading to earthquake, tremor, fracture, faults, cracks/joints or high degree of weathering which are geological stress. Therefore, the specific deformation mechanism of any geologic body or materials includes; brittle, fracture of mineral grains, elastic deformation, slip along atomic planes within crystals or along grain boundaries are all the manifestation of geodynamic activities (Bawallah et al., 2019, John, 1985). These aforementioned processes often bring fracturing, weathering and other geological activities which overtime may threaten foundation integrity. In addition, the relationship between stress arising from geological processes and strains as it affect the deformation of rocks or gradual decay that may jeopardize the integrity of foundations are better described by rheological models. There often exist relationships which are valid for particular geologic materials (Ozegin et al., 2019b). These relationships can be better explained by the equation that defines the mechanical behaviour of an idealized material and may be empirical or theoretical in origin, as they describe the net effect of all deformation mechanism. An example is the viscous behavior of material for which stress is proportional to strain rate (John, 1985, Hall, 1999). In addition to more complicated mathematical relationship between stress and strains that have been written to approximate the more complex behavior of many rocks and soil properties (John, 1985). Geological dynamics is a process; where there is a continuous stress, which leads to strain, and when there is a strain, foundation integrity is threaten, under a process that is already in place (weak zones). This is coupled with other geodynamic processes, leading to crack, joints, fault, fracture, weathering and other geodynamic activities that brings foundation vulnerability which most often results to failure (Ozegin et al., 2019a, Ilugbo et al., 2018a, Ilugbo et al., 2018b). Therefore, this research work is an attempt to elucidate the major structural defects that were responsible for major cracks at the centre of a building along Oluwole area, off Akure High School, Akure, leading to the evacuation of human and materials from the building. In order to avoid possible disaster arising from the vulnerability of the building to failure resulting from strain that has manifested as a major crack on the wall of the building cutting across the centre to the back, and almost dividing the building into two equal part.

METHODOLOGY

Site description and geology of the study area

This study was carried out along Oluwole, off Akure High School, Akure, Ondo State (Figure 1). It is situated between the UTM coordinates of Eastings 852700 to 852740 m and Northings 748540 to 748600 m. The accessibility of the study area is mainly by road and footpaths. The area is characterized by uniformly high temperature and heavy well distributed rainfall throughout the year. The average annual temperature ranges between 24 and 27°C, while the rainfall is mostly conventional, with peaks in July and September which varies between 1500 and 2000 mm per annum (Akinbode et al., 2008, Iloeje, 1981). The geology of the investigated area falls within basement rock of Southwestern Nigeria. Major lithological rock units are basically crystalline basement rocks (Figure 2). These are the migmatite-gneiss quartzite complex, charnockitic and dioritic rocks, older granites and unmetamorphosed dolerite dykes. The basement rocks exhibit varieties of structures such as foliation, schistosity, folds, faults, joints and fractures (Odeyemi et al., 1999, Aluko, 2008). Generally, the structural trends in the study area are NNW-SSE and NNE-SSW. Several minor and extensive fractures, joints and fissure zones which generally trend north south are common. These structural trends fall within the principal basement complex fracture direction identified by Oluyide (1988). The dominant rock type within the study area is charnockite.

Method

Three (3) traverses of 1.00 to 100.00 m were established in an approximate E-W direction (Figure 3). The electrical resistivity method utilized the Vertical Electrical Sounding (VES) and the combined Horizontal Profiling and Vertical Electrical Sounding techniques. The combined horizontal profiling (HP) and vertical electrical sounding (VES) using dipole-dipole configuration to determine the lateral and vertical variation in apparent resistivity of the subsurface beneath the three established traverses, electrode spacing of a = 5 m and expansion factor (n) that varied from 1 – 5 was used along the traverses. Resistivity values were obtained by taking readings using the Omega resistivity meter. The dipole-dipole data was inverted into 2-D subsurface images using the DIPPRO™ 4.0 inversion software (Dippro, 2000). The VES data was presented as sounding curves, which are plots of apparent resistivity values against electrode separation (AB/2) on bilogarithmic paper resulting in a VES curve. The VES curve showed the change of resistivity with depth, since the effective penetration increases with increasing electrode spacing. The interpretation of the VES curve is both qualitative and quantitative. The qualitative interpretation involved visual inspection of the sounding curves while the quantitative interpretation utilized partial curve matching technique using 2-layer master curve which was later refined by a computer iterations technique resist version (Vander Velpen, 2004) that is based upon an algorithm (Ghosh, 1971). The quantitatively interpreted sounding curves gave interpreted results as geoelectric parameters (that is, layer resistivity and layer thickness). 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) using below mathematical expressions. The second order parameters were used to generate subsurface integrity model. The results from the techniques were integrated to determine the consequences of the differential settlement and their degree of correlation.

$$S = \sum_{i=1}^{N} \frac{h_i}{\rho_i} \ (\Omega^{-1} \text{or Siemens}) \qquad (1)$$

and

$$T = \sum_{i=1}^{N} \rho_i h_i \ (\Omega m^2) \qquad (2)$$

When a number of layers with thicknesses of h_1, h_2, h_3, ….., transverse resistances of T_1, T_2, T_3, ….., and conductance of S_1, S_2, S_3, ….., respectively, are involved in a

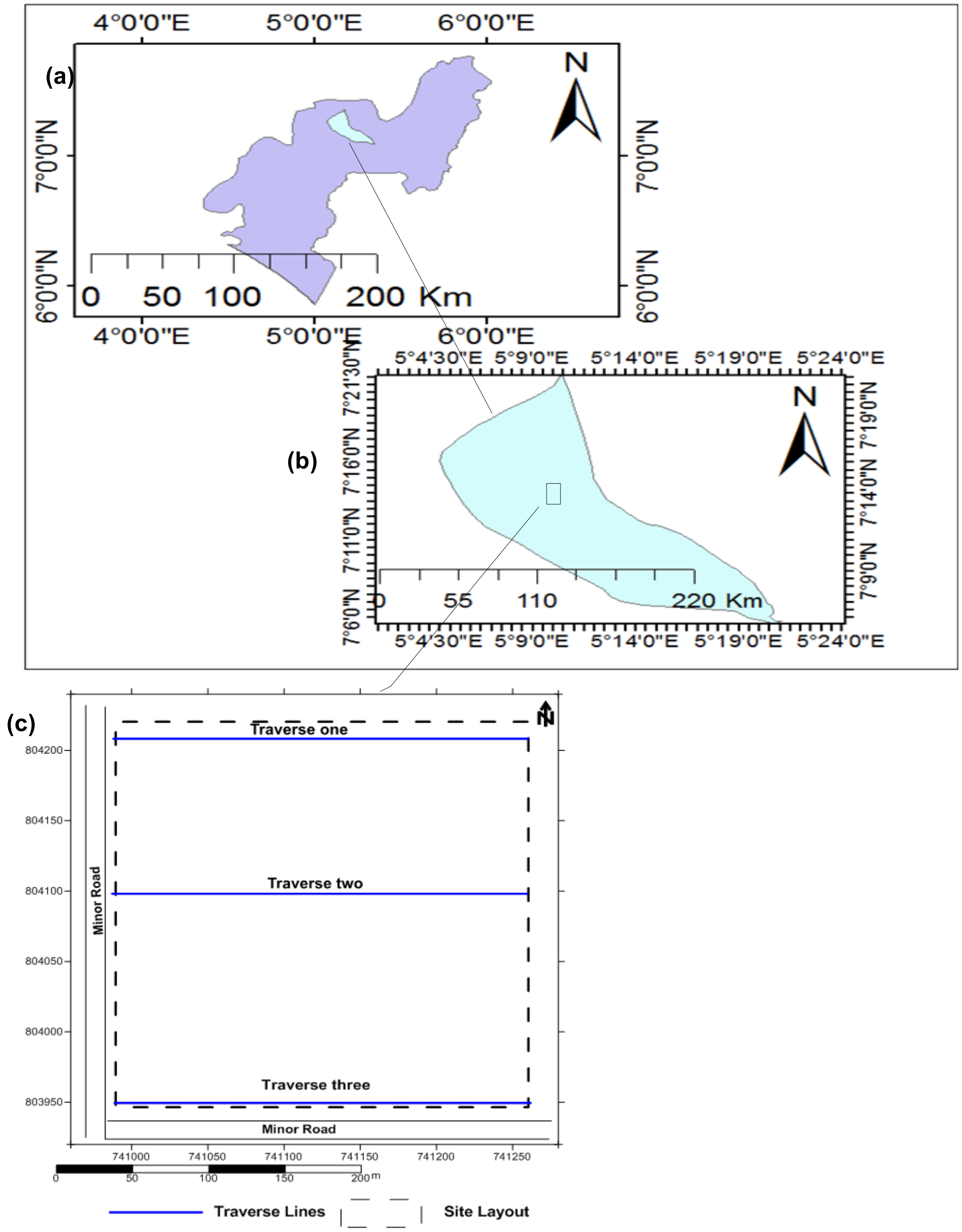

Figure 1. Base map of the study area.

geoelectrical section, their total longitudinal conductance (S) or total transverse resistance (T) may have to be considered (Murali and Patangay, 1998) and are given by:

$$S = S_1 + S_2 + S_3 + \dots \dots \dots \text{ Where } S_1 = \frac{h_1}{\rho_1} \quad (3)$$

$$T = T_1 + T_2 + T_3 + \dots \dots \dots \text{ Where } S_1 = h_1 \rho_1 \quad (4)$$

Where: S = Total longitudinal unit conductance and T = Total transverse unit resistance

RESULTS AND DISCUSSION

Dipole-dipole pseudosection

Dipole-dipole pseudosection along traverse one

Figure 4 displays 2D resistivity imaging of the upper flank of the study area, the northern end covers a distance of 100 m. The findings obtained from the profiles revealed how the activities of stress and strain, vis-à-vis geodynamic activities (Bawallah et al., 2019) has greatly

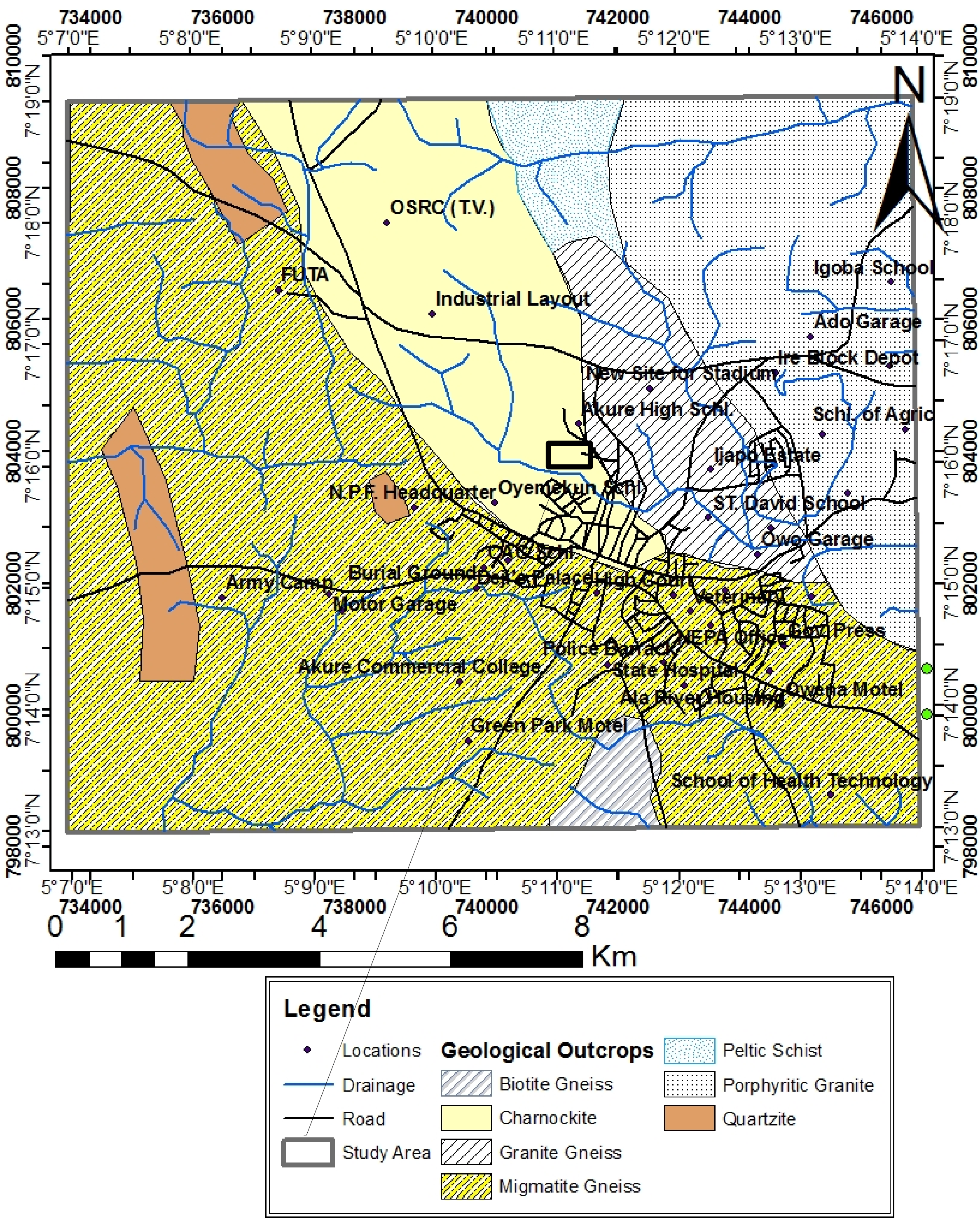

Figure 2. Geological map of Ado-Ekiti showing the study area (modified after Odeyemi et al., 1999).

affected the subsurface formation over which foundation of the study area has been located. The eastern part of the profile was characterized by shallow overburden with majorly sandy clayey material of resistivity distribution varying from 73 to 180 Ωm and overburden thickness ranging from less than 1 m to about 7 m, directly underlain by fresh basement rock, with resistivity between 680 and 1380 Ωm. Beyond this region was characterized by zone of major weakness between 10 to 14 m. This region was characterized by absence of fresh basement and presence

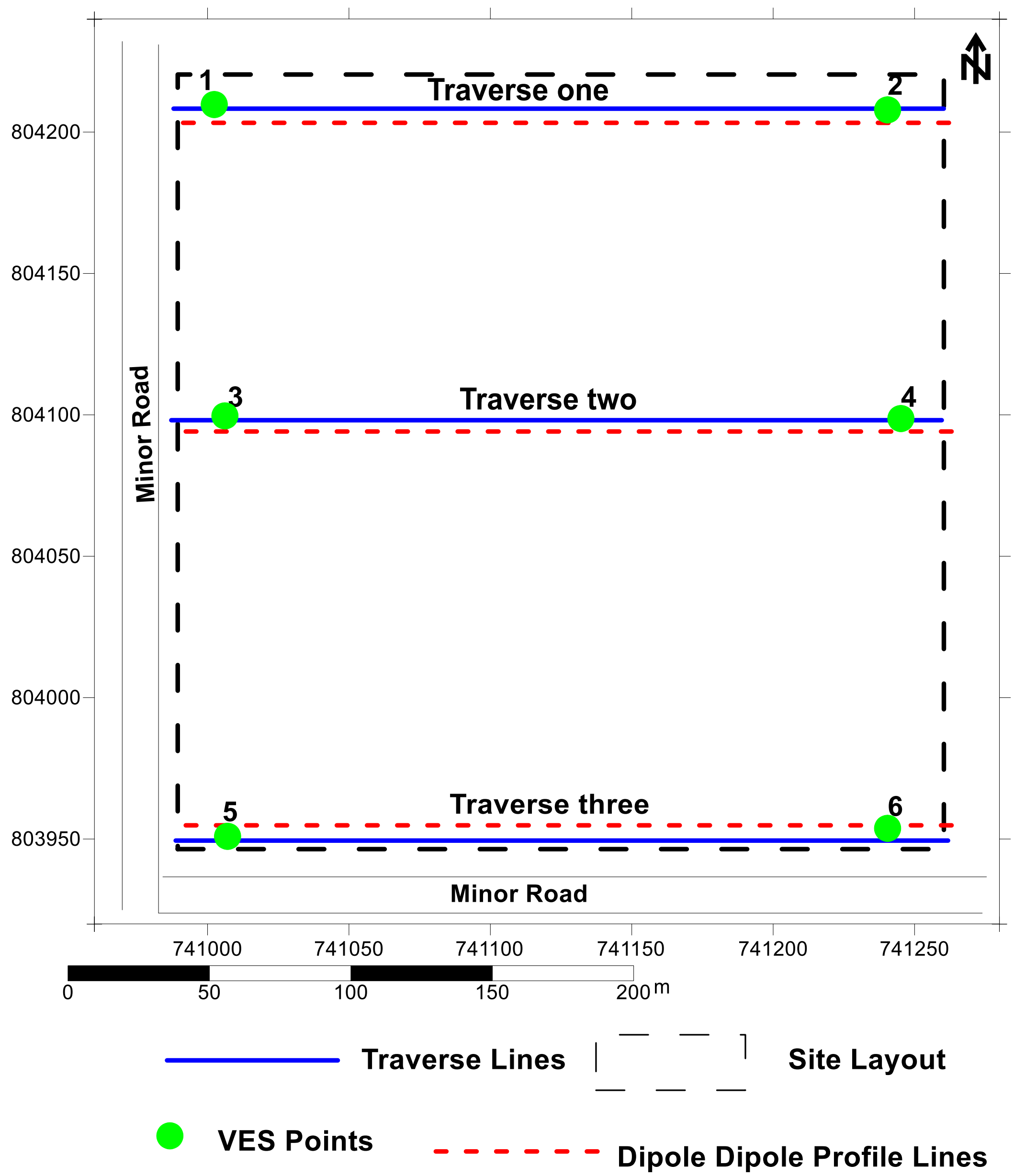

Figure 3. Data acquisitions map of the study area.

of high weathered material that was predominantly clayish in nature with a resistivity variation ranging from 51 to 169 Ωm. This can be described as high region of strain resulting from effect of geodynamic activities into possible structural displacement of crack, joints, fractures, fault or highly weathered material that could not bear the stress occasion by the load that was placed on it thereby resulting into major crack that was observed on the building. Between 72 and 100 m towards the western flanks, a similar event was observed showing the same trend at the eastern end. This region was characterized by shallow overburden made up of mainly clayey material of resistivity ranging from 98 to 146 Ωm, directly underlain by fresh basement with resistivity distribution between 382 and 580 Ωm.

Dipole-dipole pseudosection along traverse two

Figure 5 also cover a distance of 100 m and explains how the activities of stress and strain, coupled with the effect of geodynamic activities, has greatly affected the foundation resulting into cracks and the vulnerability of the building to collapse leading to immediate evacuation from the building. The situation obtained at the middle part of this study area was slightly different in type of geology and structural features. This traverse was characterized into two distinctive events. Mainly the presence of thick overburden but predominantly weak geologic materials of resistivity values varying from 44 to 121 Ωm, indicating heavy presence of sandy clay material that is ready prone

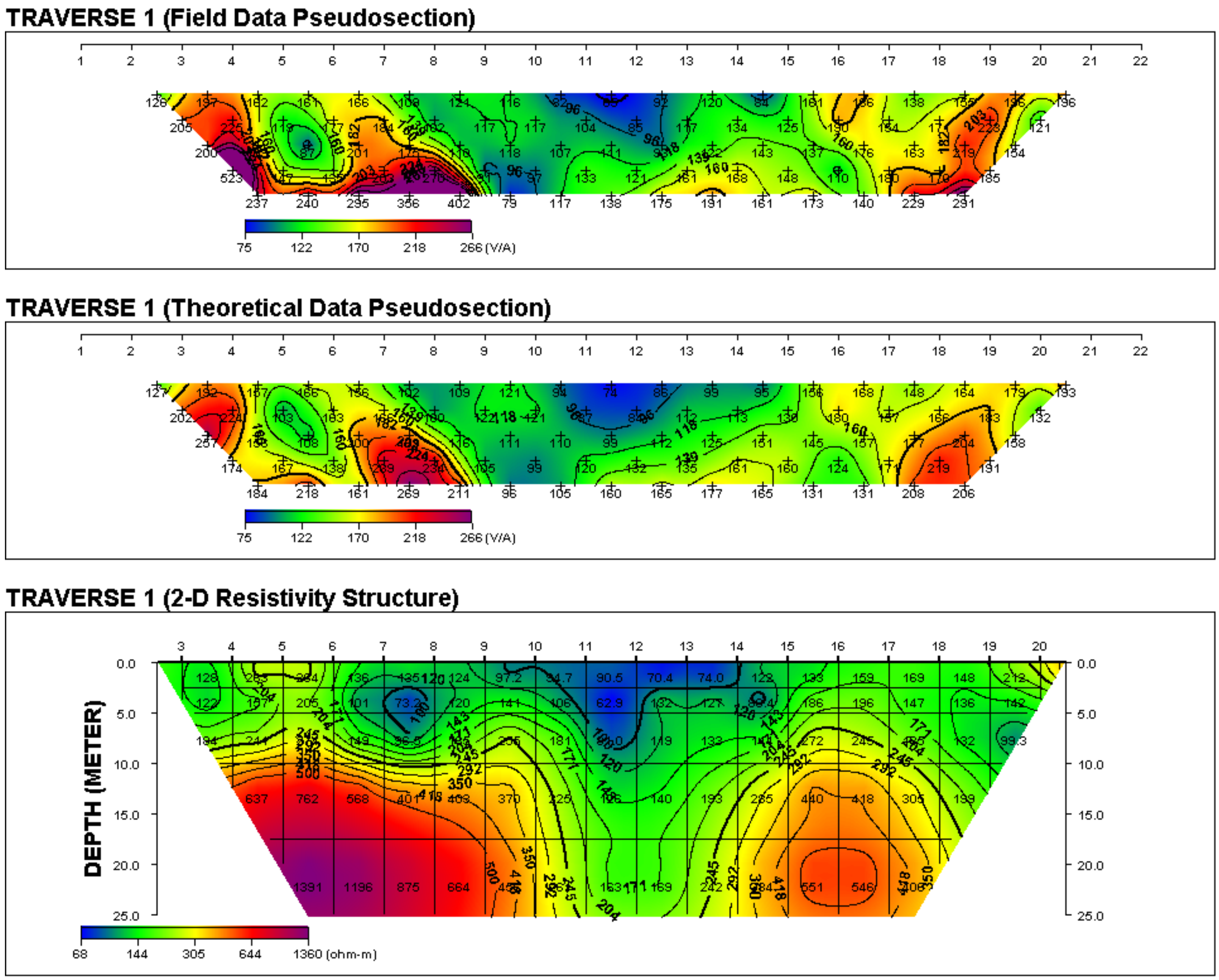

Figure 4. Dipole-dipole pseudosection along traverse one.

to strain as a result of very little stress. The entire traverse was characterized by this trend except between 55 and 75 m which has a thick but weak overburden directly underlain by weak fresh basement rock, whose resistivity layer varies from 240 to 330 Ωm.

Dipole-dipole pseudosection along traverse three

Figure 6 was taken at the west eastern part of the investigated area with a distance of 25 m from traverse two and located at the lower path (southern end) of the study area. It covers a distance of 100 m and also exhibits a unique characteristic of having a shallow overburden of extremely weak material that cannot withstand the activities of stress and strain. The resistivity layer varies from12 to 25 Ωm and overburden thickness less than 5 m. This is underlain by competent fresh basement rock with resistivity layer varying from 1066 to 7800 Ωm which characterize the entire traverse.

Vertical electrical sounding

Characteristic of the VES Curves

Curves types identified ranges from HKH and HA varying between four to five geoelectric layers. The HKH curve type predominates. Typical curve types in the area are as shown in Figure 7(a) and Figure 7(b).

Geoelectric and lithological characteristic along the three traverses

Geoelectric section along traverses one

For the purpose of layer characterization, better

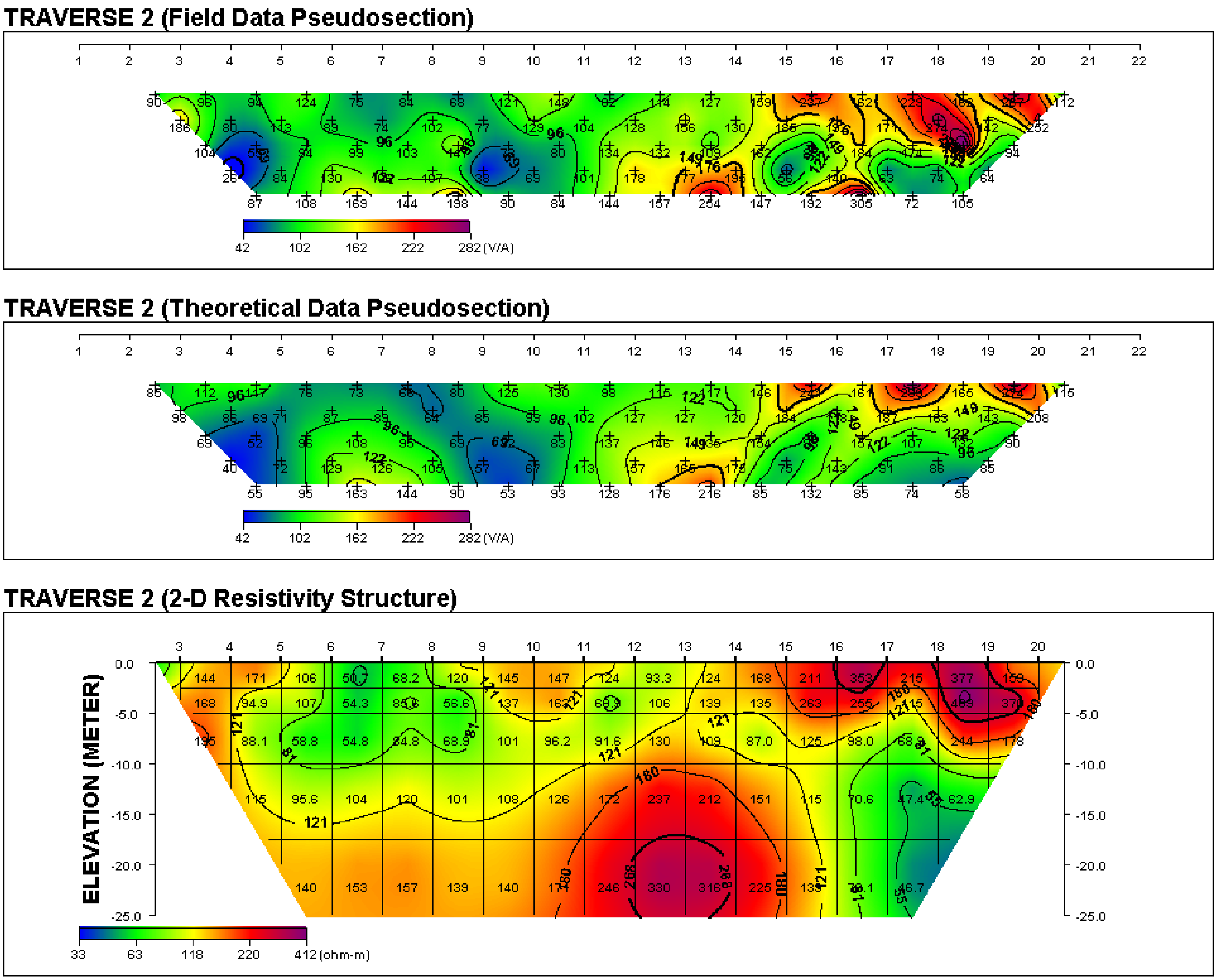

Figure 5. Dipole-dipole pseudosection along traverse two.

understanding of the geoelectric parameters and geological setting; a follow up technique was involved using the Vertical Electrical Sounding (VES) where two (2) VES were carried out along each traverse (Figure 8). The results obtained from VES one (1) and two (2) delineated four to five geoelectric layer sequence comprising topsoil with 0.5 m thickness and resistivity layer ranging from 388 to 1067 Ωm. This is underlain by a moderately clayey sand layer with thickness varying from 1.4 to 4.8 m and resistivity layer ranging from 112 to 144 Ωm. The weathered layer has a thickness varying from 4.8 to 11.3 m and resistivity ranging from 328 to 450 Ωm, underlain by fractured basement with resistivity from 160 to 273 Ωm. The thickness varies from 9.0 to 9.8 m, while the fresh basement has resistivity that ranges from 8858 to 10675 Ωm.

Geoelectric section along traverses two

VES three (3) and four (4) points were taken along traverse two located 20 m at an interval of 25 m away from traverse one (Figure 8). The result obtained delineated five geoelectric sequence which comprises of the topsoil with resistivity layer ranging from 577 to 737 Ωm and thickness of 0.6 m. This is underlain by a moderately thin layer whose resistivity varies from 195 to 251Ωm and thickness that ranges from 3.1 to 6.2 m, and constitutes partially clayey sand formation; directly followed by a resistive formation with resistivity value ranging from 1413 to 2043 Ωm and thickness that varies from 1.8 to 2.8 m which is considered as partially weathered fresh basement. The fourth layer has a resistivity layer ranges from 177 to 241 Ωm and thickness varies from 9.0 to 11.6 m, which is the

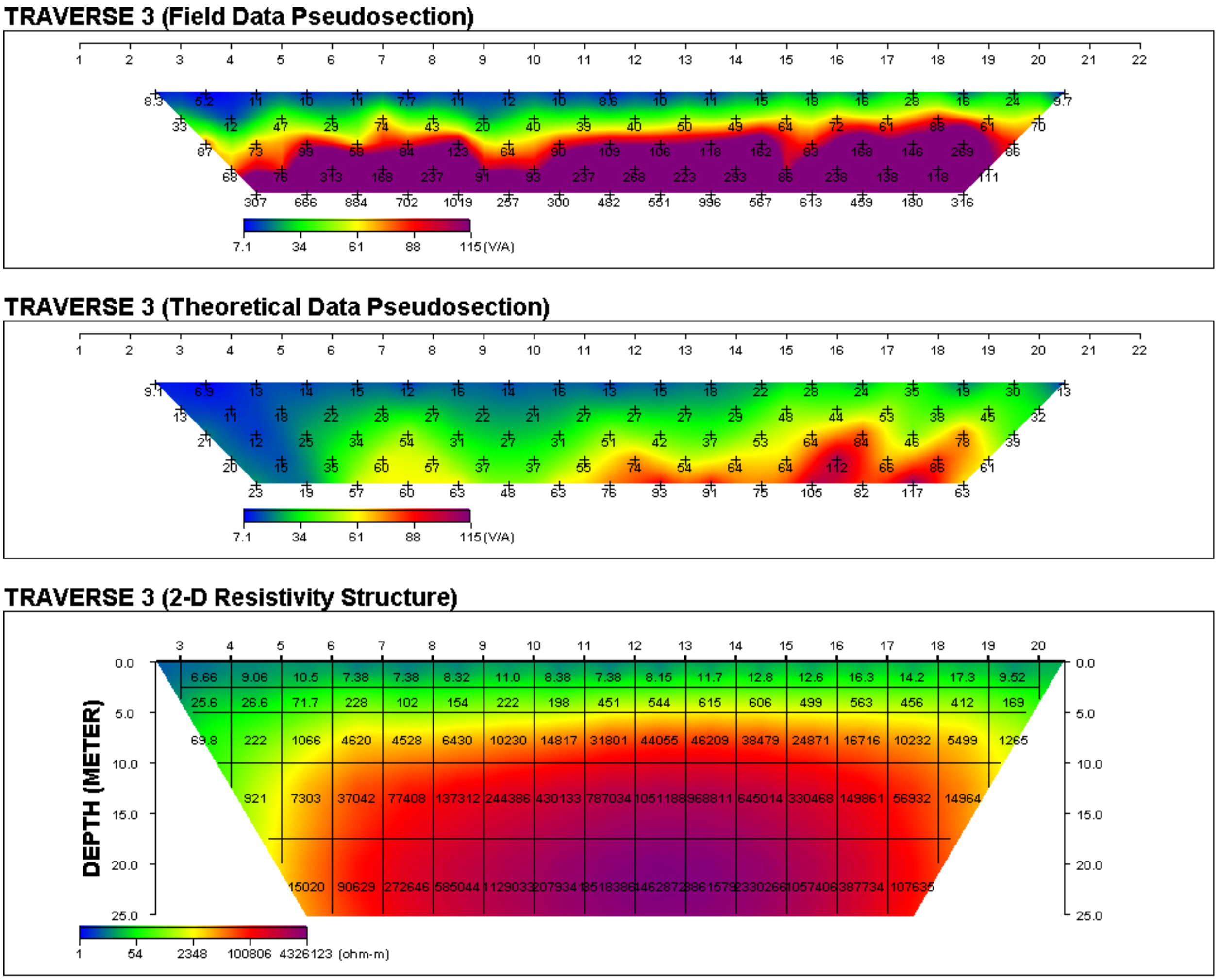

Figure 6. Dipole-dipole pseudosection along traverse three.

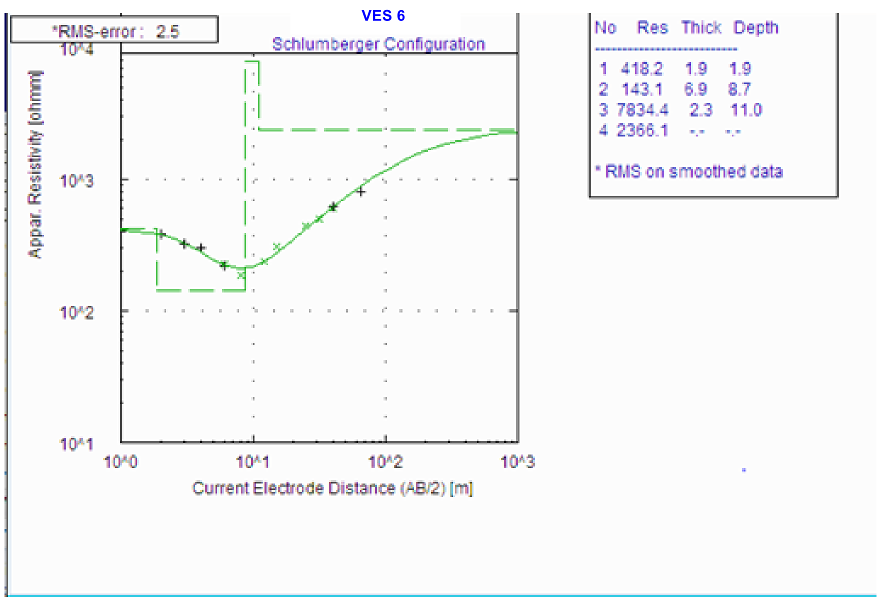

Figure 7a. Typical 'HA' sounding curve.

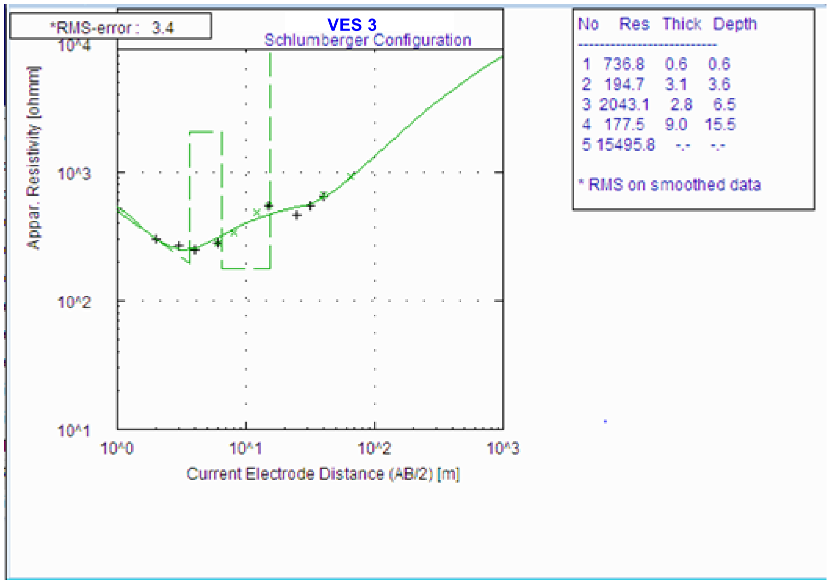

Figure 7b. Typical 'HKH' sounding curve.

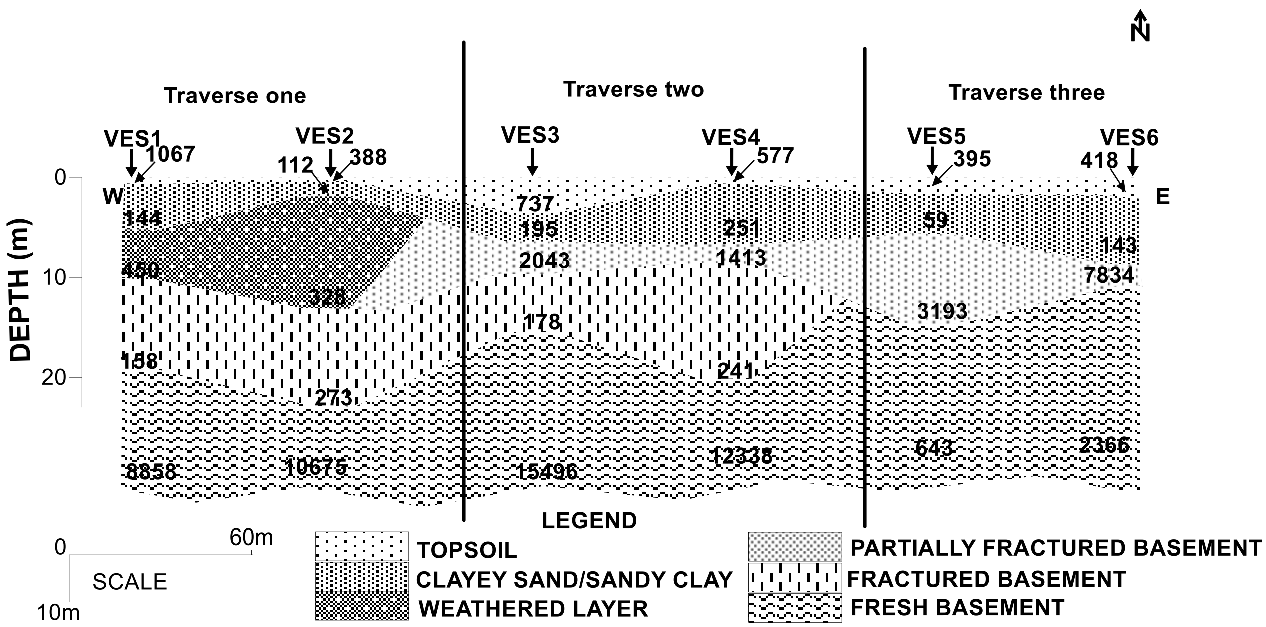

Figure 8. Geoelectric Section along the three traverses.

fractured basement. The last layer which is considered as the fresh basement has a resistivity layer between 12338 and 15496 Ωm.

Geoelectric section along traverses three

VES five (5) and six (6) points were located 20 and 80 m away from the origin, 25 m away from traverse two (Figure 8). The result obtained displays four layer case comprising the topsoil, the partially weathered layer, resistive partially fractured basement and fresh basement with layer resistivities and thickness ranging from 395 to 418 Ωm; 1.6 to 1.9 m, 59 to 143 Ωm; 4.1 to 6.9 m, 3193 to 7834Ωm; 2.3 to 8.9 m and 643 to 2366 Ωm, respectively.

Dar Zarrouk parameters

The results from the VES were used to determine the second order parameters (Table 1).

Table 1. Result Showing Dar Zarrouk Parameters

VES	1	2	3	4	5	6
Total Longitudinal Conductance (Ω^{-1})	0.100812	0.084137	0.068644	0.075148	0.07633	0.069026
Total Transverse Resistance (Ωm^{-2})	4931.4	6732.6	8369.1	7241.4	29291.6	6146.3

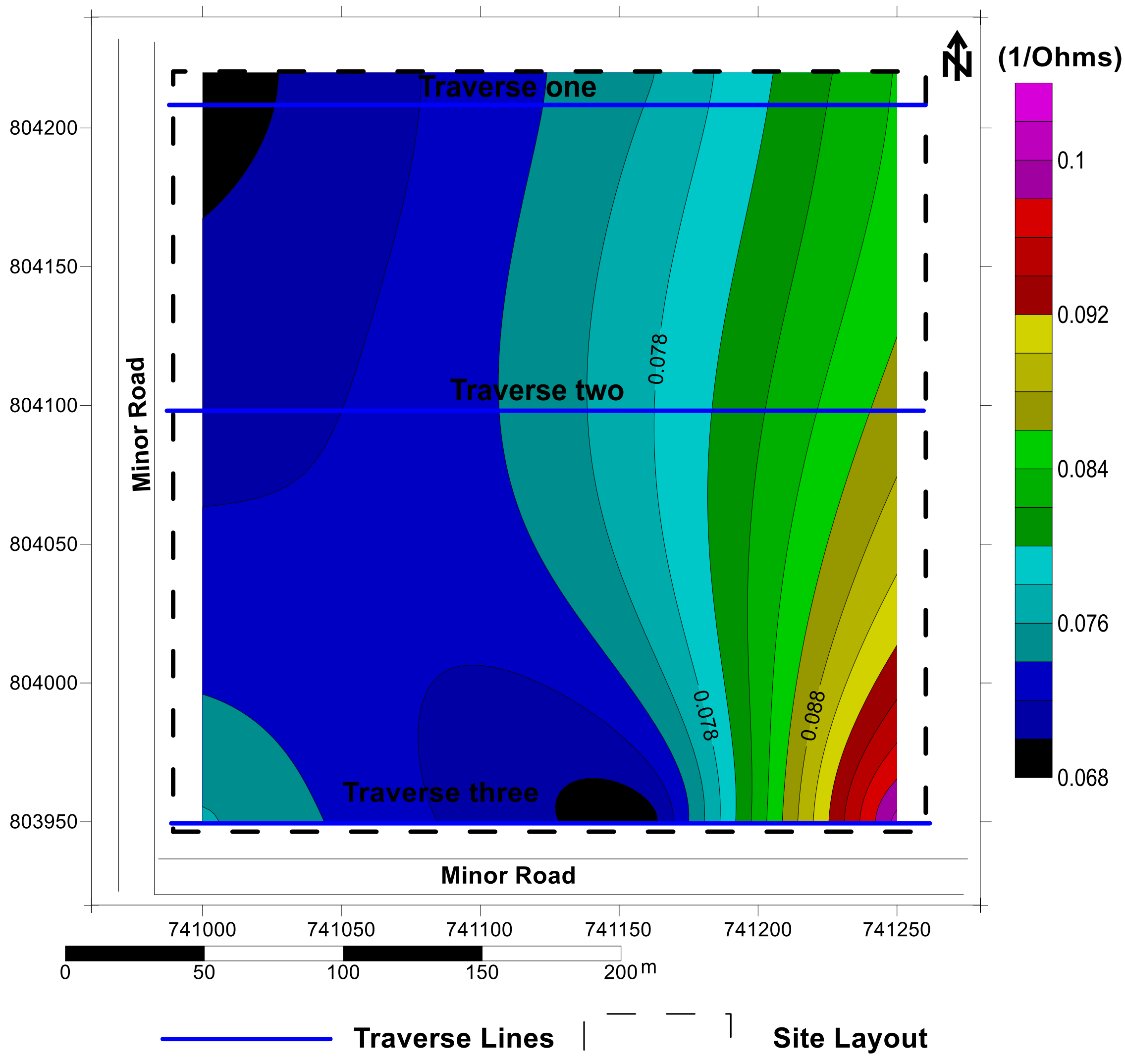

Figure 9. Total longitudinal conductance map of the study area.

Total longitudinal conductance

Figure 9 shows the total longitudinal conductance map of the research area. It shows that more than seventy-five percent (75%) of the study area was characterized by clay with total longitudinal conductance value ranging between 0.068 and 0.076 Ω^{-1}, while about twenty-five percent (25%) of the investigated area were fairly competent longitudinal conductance with a values ranging from 0.092 to 0.1 Ω^{-1} making vulnerability to failure high. 3D subsurface view of longitudinal conductance and the dynamics of stress and strain (Figure 10) shows the geological events that led to the major crack that developed from the building after construction leading to the evacuation of staffs few years after completion and usages. The greater percentage of the study area of more than 75% was under intense pressure from the load (building), as a result of the heavy presence of clay/clayey materials been the dominant factor and given the dynamics of stress which is very active in a clayey dominated environment. The factor of strain

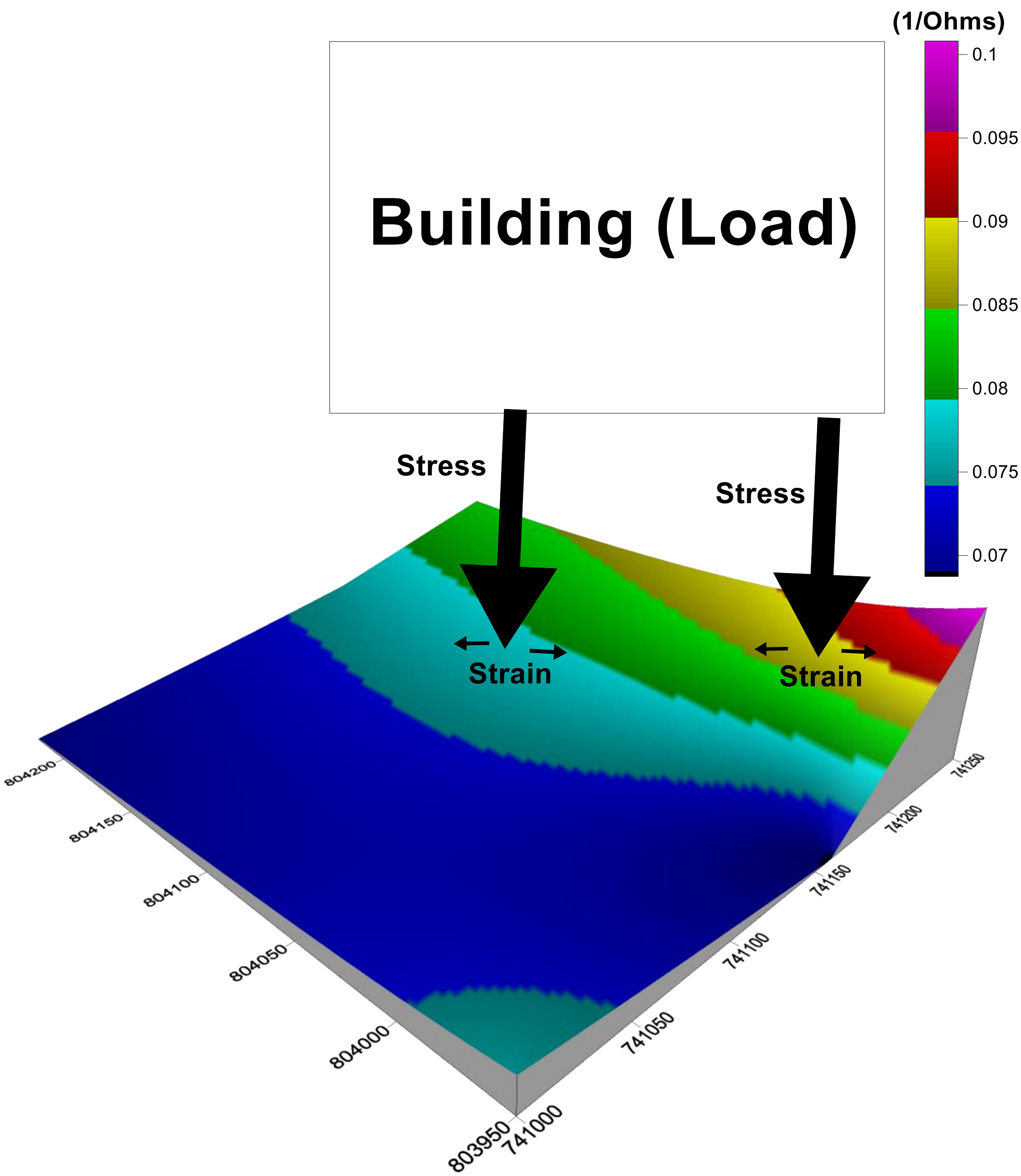

Figure 10. Total longitudinal conductance map and the dynamic of stress and strain of the study area.

becomes inevitable as a result of the poor load bearing capacity of the clay/clayey material, and hence, vulnerability to failure leading to major cracks, which is a pointer to the reality of apparent failure of the building.

Total transverse resistance

Figure 11 shows the total transverse resistance map of the study area which illustrates the foundation and soil integrity. It is a reflection of the ability of the soil to withstand load, as well as an indicator of the load bearing capacity of any study location in terms of foundation and structural parameters within the subsurface. Therefore, finding from the map reveals that more than eighty five percent (85%) of the study area has a low total transverse resistance value ranging between 4000 and 19000 Ωm^{-2} which is a measure of its vulnerability to failure, arising from the heavy presence of clayey material. Fifteen percent (15%) of the study area is fairly competent in term of load bearing capacity and soil integrity. The 3D subsurface view of total transverse resistance map and the

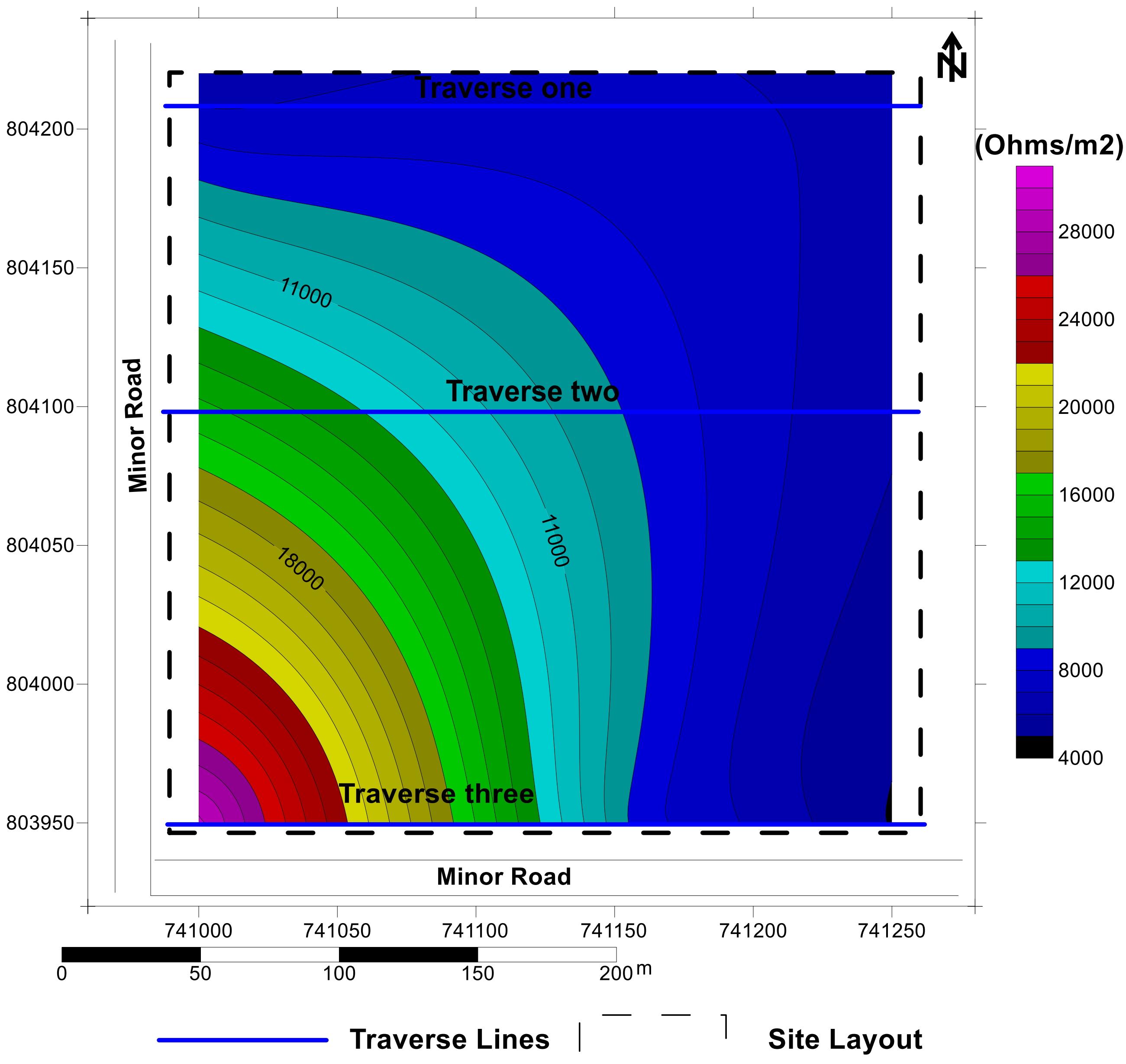

Figure 11. Total transverse resistance map of the study area.

dynamics of stress and strain (Figure 12), indicate that the highest transverse resistance value obtained within the investigated area ranges from 22800 to 25600 Ωm^{-2} and this constitute fifteen percent (15%) of the study area, while the remaining eighty five percent (85%) has a value ranging between 6000 and 20000 Ωm^{-2}. From weak transverse resistance (soil integrity/incompetence/weak geologic materials), it is obvious that vulnerability to failure is high, and eventual failure is inevitable as a result of continuous stress resulting from geodynamic activities (Bawallah et al., 2019), which can be attributable to the major cracks that was noticeable at the building of the study location.

Synthesis of results

Figure 13 indicates the correlation of dipole dipole pseudosection, geoelectric section, 3D total longitudinal conductance and 3D total transverse resistance along the three traverses. The 2D imaging along the three traverses indicates the presence of near surface weak zone and clayey materials. A major weak zone was observed at the middle region underlain by shallow bedrock along traverse one while traverse two was characterized by weak subsurface geologic materials diagnostics of highly weathered/fractured basement throughout the profile, except for part of the middle region that exhibited the

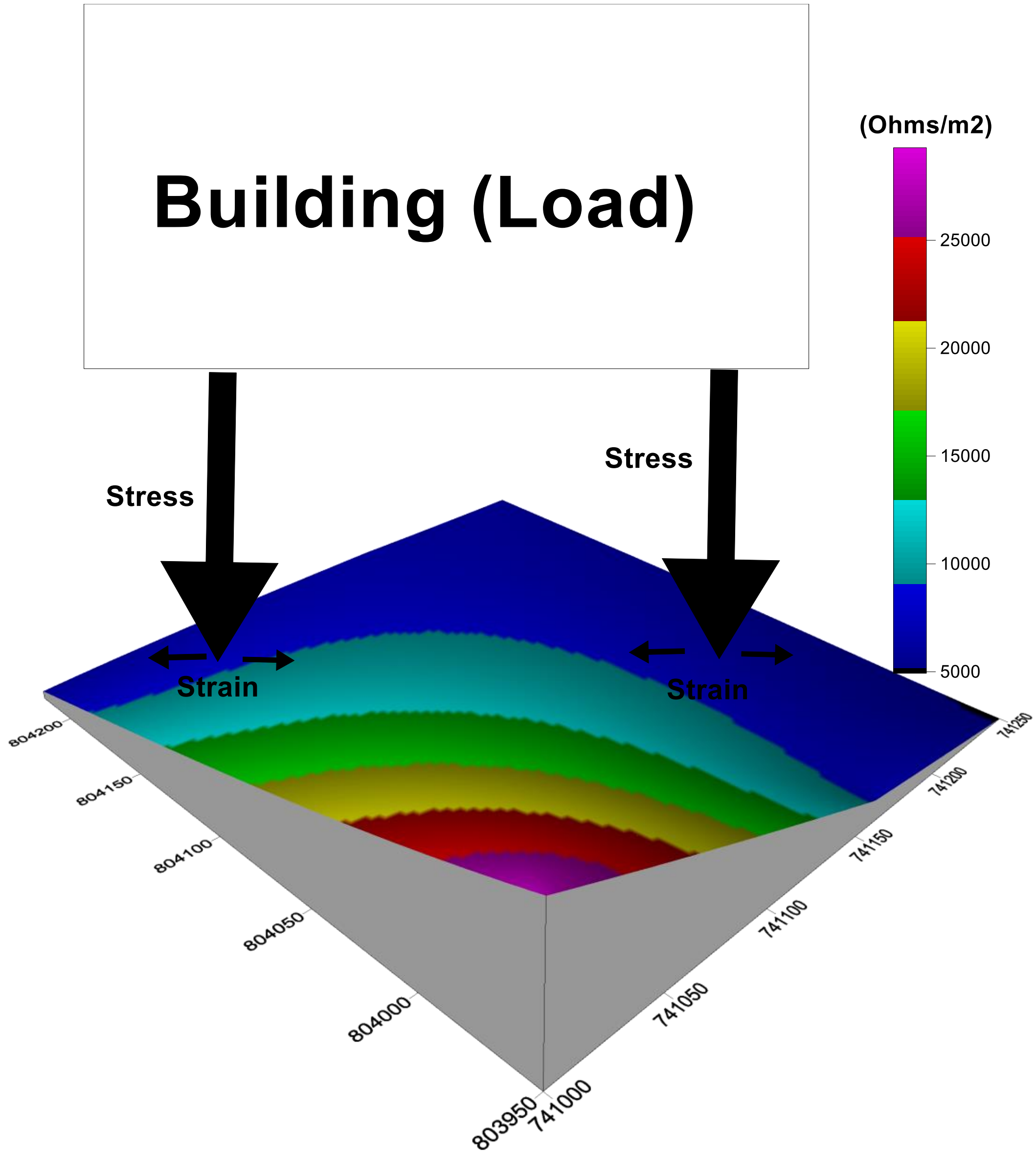

Figure 12. Total Traverse Resistance Map and the dynamic of stress and strain of the study area.

presence of fresh basement rock underlain by shallow/moderately thick overburden. Traverse three was characterized entirely by near surface weak material, underlain by shallow partially weathered/fractured basement before the bedrock. The VES carried out along these traverses correlate effectively with the informationobtained from the 2D imaging. The result obtained from the total longitudinal conductance indicated a predominantly weak geologic material with the average value of 0.084 Ω^{-1} and total transverse resistance of average of 16500 Ωm^{-2}, implying geologic material of low integrity. Both of these exhibited effective correlations and were also in complete agreement with the information obtained from the 2D and the Vertical Electrical Sounding (VES).

Conclusion

This study has been able to confirm the causes of the major cracks and subsequent vulnerability of the building to failure. Findings showed that geodynamic forces of fracturing, faulting and high degree of weathering processes coupled with pressure from the load (building) resting on inherent subsurface weak zones lead to stress which resulted to strain on the weak geologic material within the subsurface. Therefore, in the absence of little or no elastic property, the result is vulnerability and the resultant major crack that cut across the entire building, which was an indicator or a pointer to apparent failure of the building. This study has further justified the need for geophysical site investigation as pre-condition before any

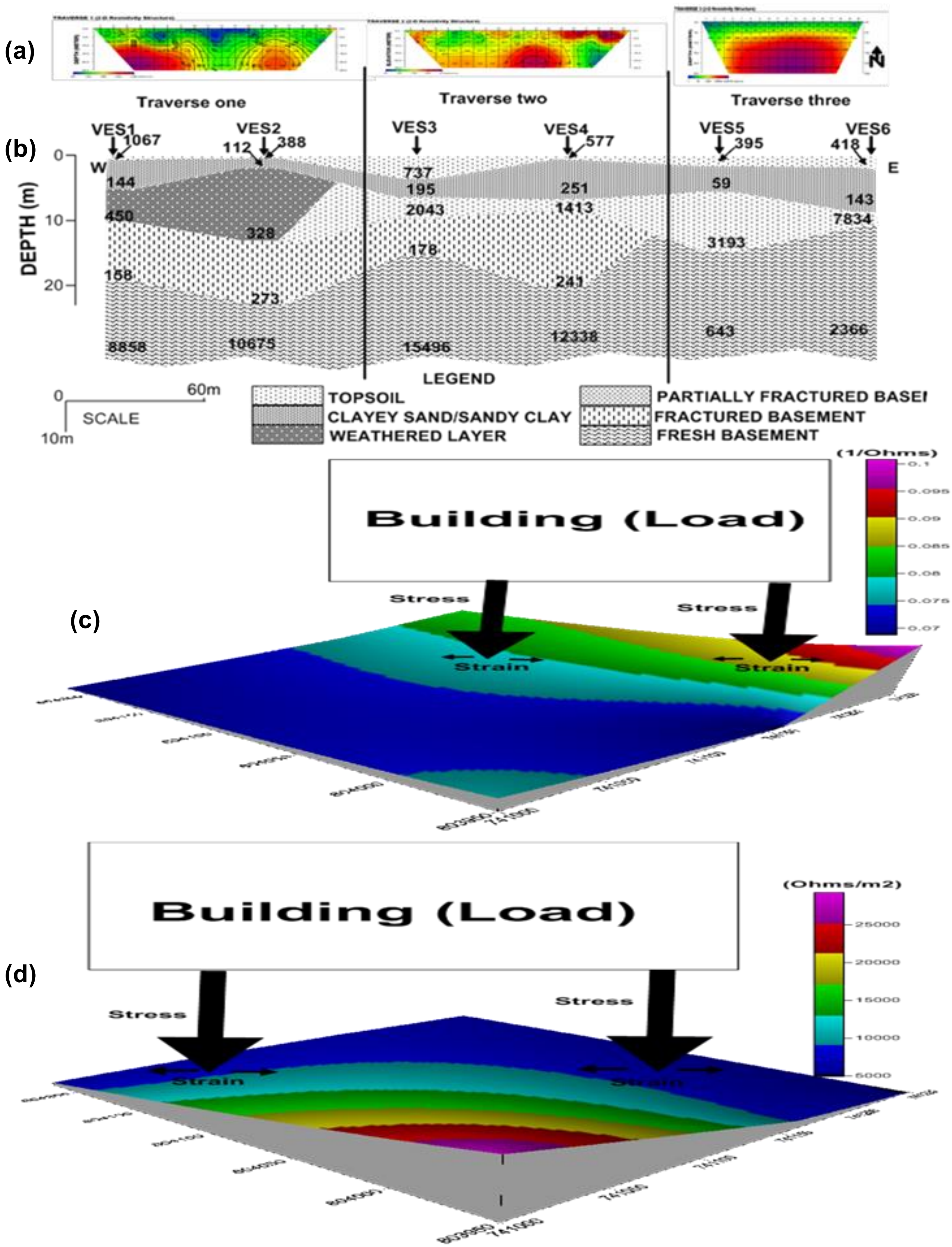

Figure 13. Correlation of (a) Dipole-dipole pseudo-section, (b) Geoelectric section, (c) 3D total longitudinal conductance and (d) 3D total tranverse resistance.

construction to avoid problems of this nature. It was also show that there is a consequence for negligence or ignorance considering the colossal loss, resulting from failures of this magnitude. It is highly recommended that efforts should be put in place to ensure that studies of this type are carried out before embarking on any construction of any kind, especially major project. Geophysics remains a very cheap and viable approach to complement studies of this nature, especially where there is structural displacement.

DATA AVAILABILITY AND CONFLICT OF INTEREST STATEMENT

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

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