Integrated Geophysical Methods for Post Foundation Studies, Obanla Staff Quarters of the Federal University of Technology, Akure, Nigeria.

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ABSTRACT

Geophysical investigations have been carried out around the Senior Staff Quarters, Obanla of the Federal University of Technology Akure, with a view to establish the possible cause(s) of failure of buildings in parts of the quarters. The geophysical methods used for the investigation were the Very Low Frequency Electromagnetic (VLF-EM) andthe Electrical Resistivity methods (ER). The VLF-EM measurements were taken at an interval of 10m along six (W-E) traverse lines. From the results of the VLF-EM method, thirty four (34) VES stations were occupied in the study area, involving Schlumberger configuration with half current electrode separation (AB/2) varying from 1 to a maximum of 150m.

The 2-D VLF-EM models and the lineament map generated show anomalies that were interpreted in terms of structures, lithology and water saturation, around the distressed buildings and in other parts of the Staff quarters. The VES curve types obtained in the area include H, KH, HA and A with the H type curve dominating. Five subsurface geologic layers were delineated in the study area. These include the topsoil, lateritic/clay layer, weathered layer, partly weathered/fractured basement and the fresh basement with resistivity ranging from 134 – 670 ohm-m, 514 – 756 0hm-m, 45 – 406 ohm-m, 128 to 998 ohm-m and 1138 – 8583 ohm-m respectively. The thicknesses range from 0.4 – 2.1m, 1.0 – 9.5m, 2.9 to 27.6m and 2.9 – 4.3m respectively. Depths to the bedrock are generally less than 31.0m. Around the vicinity of the distressed buildings, the resistivity of the weathered layer beneath the topsoil in which the foundation is seated was found to be low, ranging from 45 – 190 ohm-m typical of clayey materials. From the lineament and resistivity maps generated, the distressed buildings were found to be situated within the areas with a fairly high concentration of fractures, and, relatively low resistivity values (less than 200 ohm-m) typical of incompetent clayey formation.

In conclusion, the results of the investigation show that the possible cause(s) of foundation failure in the study area was due to the presence of geologic features, mapped fractures and clayey formations at the vicinity of the distressed buildings.

(Keywords: very low frequency electromagnetic, VLF-EM, electrical resistivity, distressed buildings, competent formation, depth-to-bedrock)

INTRODUCTION

Maton and Templeton (1973) defined engineering geophysics as an intermediary discipline between engineering geology and soil mechanics. It involves the application of geophysical methods to civil engineering projects. It is frequently used in an initial site investigation to determine subsurface ground conditions prior to excavation and construction work. Engineering geophysics therefore gives detail information on the degree of competence of the subsoil in foundation engineering.

This research examines the use of geophysical methods for post foundation studies at the Federal University of Technology Akure, FUTA – Obanla staff quarters. This is necessitated as a result of gradual failure of buildings (Figure 1) in the University staff quarters. The Federal University of Technology Akure as part of the Basement Complex area of Nigeria is believed to have been affected by various geological events (Rahaman 1976). These geologic events gave rise to such structures as folds, faults and fractures that are geologically associated with zones of weakness. Geophysical methods can however map these geologic structures; hence their application is employed in studying the subsurface geology of the area in order to ascertain if the failure is caused by these geologic structures.

Figure 1: A Distressed Building in the Study Area Showing Cracks at the Base of the Building.

Geophysical methods adopted for this study include the Very Low Frequency (VLF) Electromagnetic method (VLF-EM), and the Electrical Resistivity method.

The use of Very Low Frequency Electromagnetic method and the Electrical Resistivity method become relevant with the aim of:

(i) Mapping the subsurface conductive zones and geologic structures using the VLF-EM method.

(ii) Generating a geoelectric sequence and relevant resistivity maps of the study area using the Electrical resistivity method involving the Vertical electrical sounding, VES.

(iii) Delineating zones of weakness from (i) and (ii) above and thereby evaluate the cause of failure of buildings in the study

SITE DESCRIPTION AND GEOLOGY

The Obanla staff quarters of the Federal University of Technology, Akure is underlain by Precambrian rocks typical of the Basement Complex of southwestern Nigeria (Rahaman, 1976), comprising of undifferentiated granite, Charnokitic rocks, medium to coarse granite and Migmatite gneiss rocks (Figure 2). The site occupies an area of about 1km^2. It lies between latitudes 7^{0}18'21.3''N and 7^{0}18'47.1''N (808000 and 808800 N in the Universal Transverse Mercator scale, UTM), and longitudes 5^{0}07'27.0'' and 5^{0}08'19.2'' (734600 and 736200 E in the Universal Transverse Mercator scale, UTM both in Datum 100 Minna – Nigeria and zone 31N 0^{0}E to 6^{0}E), Figure 2.

The area as part of the Federal University of Technology Akure, lies within the tropical rain forest belt characterized by alternating wet and dry seasons with a mean annual rainfall of 2000mm. Humidity is relatively high during the wet season and low during the dry season. Temperature varies from 22^{0}C to 29^{0}C throughout the year (Asiwaju-Bello, 1999).

MATERIALS AND METHODS

The reconnaissance/geologic mapping of the area entails studying of rock outcrops and their distribution on the study area, road networks and major features so as to produce a sketch map of the study area in order to establish geophysical traverses.

The VLF-EM geophysical method is a quick and powerful tool for the study of shallow conducting lineament features in the near surface earth (Telford et. al., 1977). The method is based on measurement of the secondary magnetic field induced in local conductors by primary electromagnetic fields generated by powerful military radio transmitter in the very low frequency range (15 – 25 KHz).

The instrument employed for this survey was the ABEM WADI, which measures the in-phase (Real) and quadrature (Imaginary) components of the induced vertical magnetic field as a percentage of the horizontal primary field. For the purpose of the investigation, six geophysical traverses (T1–T6) were established within the survey area. The profiling technique was employed for the VLF-EM using a station separation of 10m along the pre cut traverses (Figure 3), perpendicular to established geologic strike of the area and the transmitter signal direction.

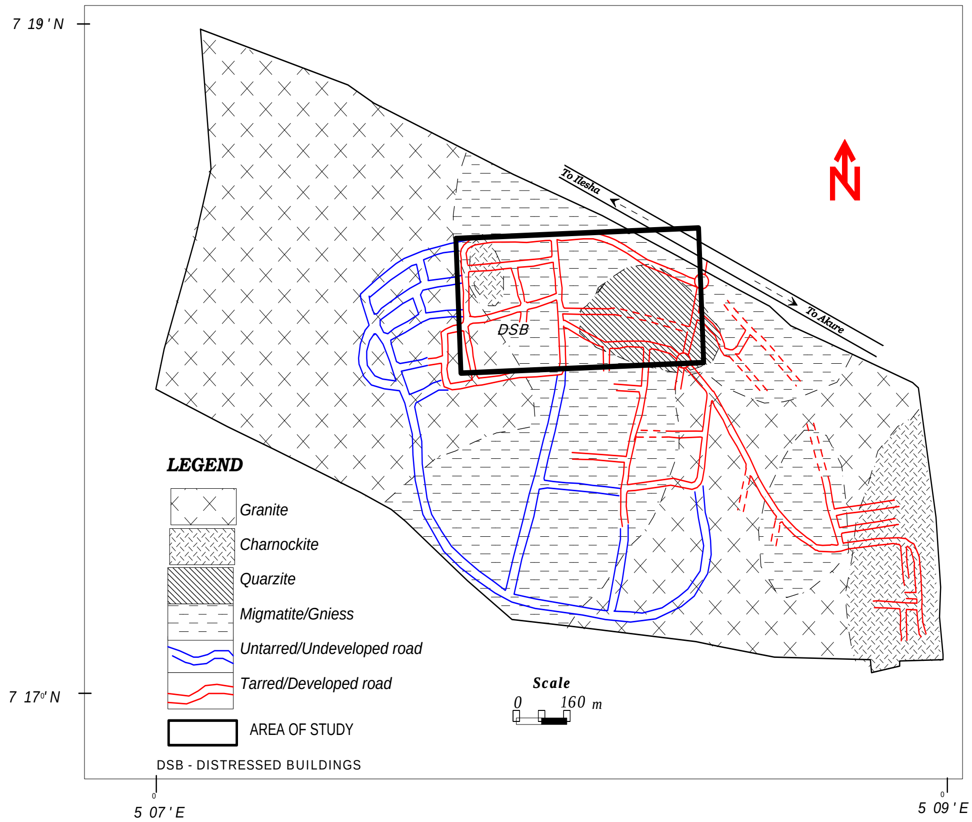

Figure 2: Location and Geological Map of the Study Area (Modified after Kareem, 1995).

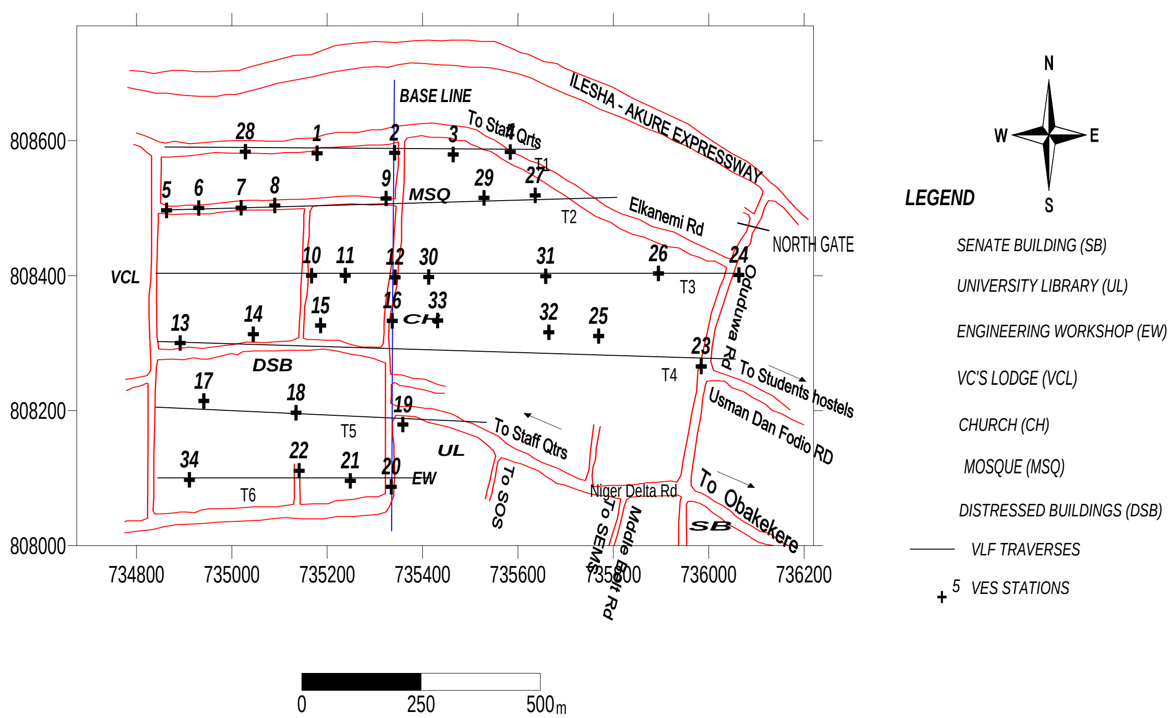

Figure 3: Geophysical Field Layout Map of the Study Area.

Inphase and quadrature values in percentages were plotted against station positions using the Microsoft Excel Program. Qualitatively, the varying amplitude from this anomaly profiles is a measure of the conductivity changes in the subsurface. Also, the Karous - Hjelt and Fraser filter (KHFfilt Version 1.0, Pirttijärvi 2004), program was used to perform Karous - Hjelt and Fraser filtering on the VLF – EM data in order to produce 2-D models along the traverses in the study area. The anomaly inflections appear as peak positive anomalies and false VLF anomaly infections as negative anomalies (Reynolds, 1977) of the profiles.

The equipment employed for the resistivity field data measurements is the R50 DC resistivity meter. The vertical electrical sounding (VES) technique involving the Schlumberger array was adopted at selected points based on the results of the VLF-EM survey along the traverses. Half current electrode separation (AB/2) varying from 1m to a maximum of 150m was used so as to be able to determine the depth to bedrock of the study area. The apparent resistivity values obtained from the vertical electrical sounding (VES) were then plotted against electrode spacing on a bi-log paper. Visual inspection of these curves gave qualitative interpretation of the subsurface resistivity variations. Quantitatively the sounding curves were interpreted by partial curve matching technique (Keller and Frischknecht, 1966) using a 2-layer master curves and the corresponding auxiliary curves.

Geoelectric parameters from this manual interpretation were improved upon through the use of computer iteration technique using the computer algorithm RESIST Version 1.0 (Vander Velpen, 1988). These results were then presented as geoelectric sections and maps.

RESULTS AND DISCUSSIONS

VLF – EM Profiles and Map

The plots of filtered real (quadrature) components are presented as profiles and their corresponding Karous-Hjelt (K-H) pseudo sections are shown in Figures 4-10. The interpretation of both the profiles and pseudo sections was basically qualitative or semi quantitative. The varying amplitude which is a measure of the anomaly changes in the subsurface vary from -55% to 54% generally in the study area, indicating variable conductivity changes of the subsurface materials. From the default on the WADI equipment, the filtered real part will always show a positive peak above a conductor.

Anomalies with a threshold of 10% and above were chosen for further study using the Vertical Electrical Sounding, VES. However a few areas where the threshold is less than 10% was also chosen for even distribution of the VES stations.
Figure 4a shows the filtered real profile along traverse 1, anomalies with positive peaks amplitude on the filtered Real component. These anomalies include those at stations -150 (15W), 0 and 130 (13E). The corresponding K-H pseudo section of the profile which is a measure of conductivity of the subsurface as a function of depth is also shown. This conductivity is shown as color codes with response increasing from left to right (i.e. from negative to positive).

Conductive features of varying degree of conductivity trending in different directions were delineated on the section, for instance, around station -150 (15W), a conductive body of response of 20% is shown. Similarly, around stations 0 and 130 (13E), other conductive features of response of 15% are shown, all trending in the SW-NE directions. Conductive bodies present on the section coinciding with the points already identified on the profile, as fractures/joints. Based on this, VES stations 28, 1, 2, 3 and 4 were established for further study.

The same process of qualitative interpretation was adopted for the remaining profiles and their corresponding pseudo sections. Based on the interpreted VLF-EM profile the points of interest marked as conductive zones were among the points that were further investigated using the Vertical Electrical Resistivity Sounding (VES)

In addition, a lineament map (Figure 7) of the study area was also generated. This map shows the concentration and azimuth direction of the lineaments in the study area. Conductive features of the pseudo-sections from the KHFFILT were marked and their position and orientation drawn on a profile line of traverses one to six using the same scale. From the map, the area with high concentration of lineaments correlates with the conductive zones from the profiles (e.g the eastern flank of traverses 3 and 4, and the south-western part of the study area). These areas of high concentration of lineaments are incompetent areas and are vulnerable to foundation failure.

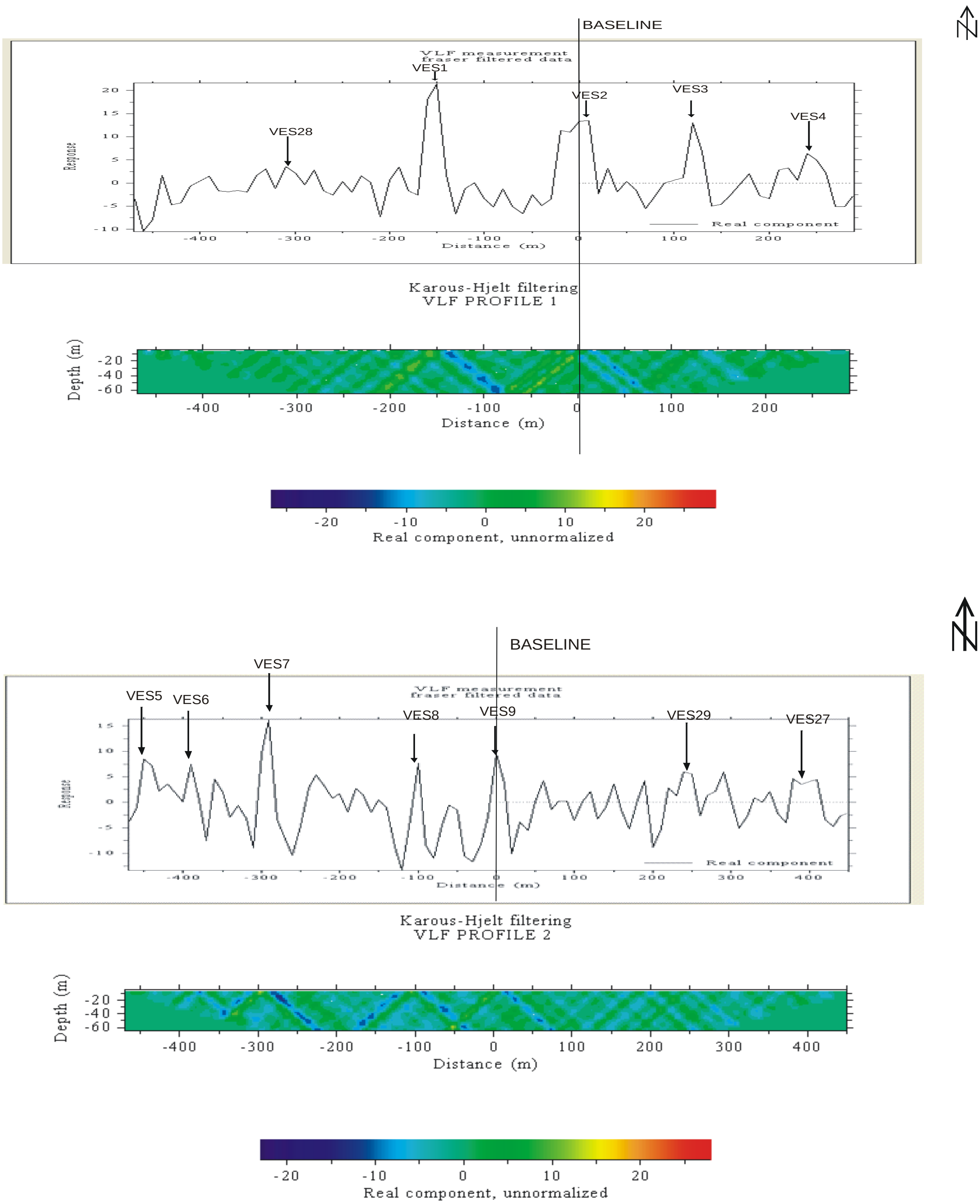

Figure 4: VLF-EM Profile and Karous and Hjelt Pseudo Section along Traverses 1 and 2.

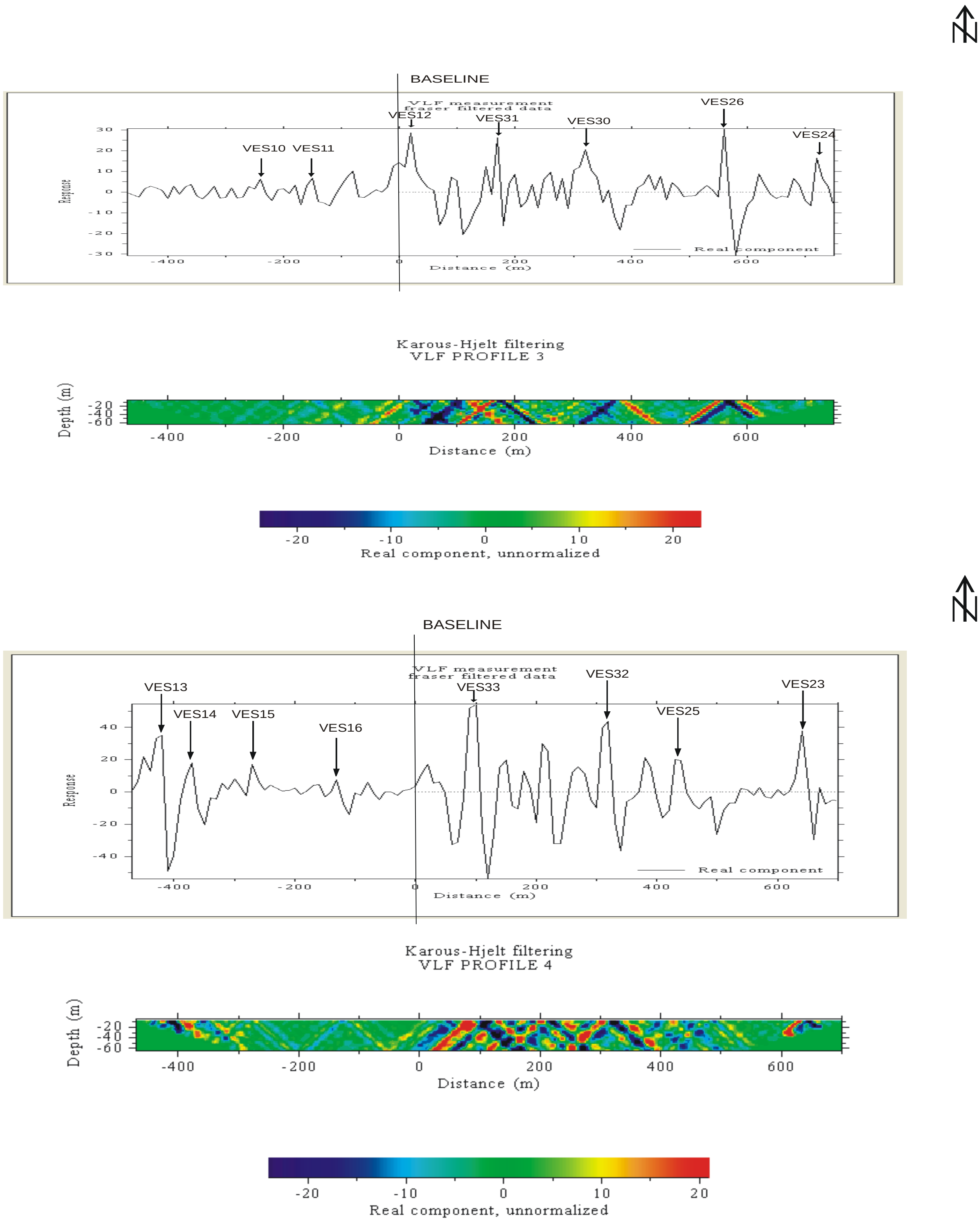

Figure 5: VLF-EM Profile and Karous and Hjelt Pseudo Section along Traverses 3 and 4.

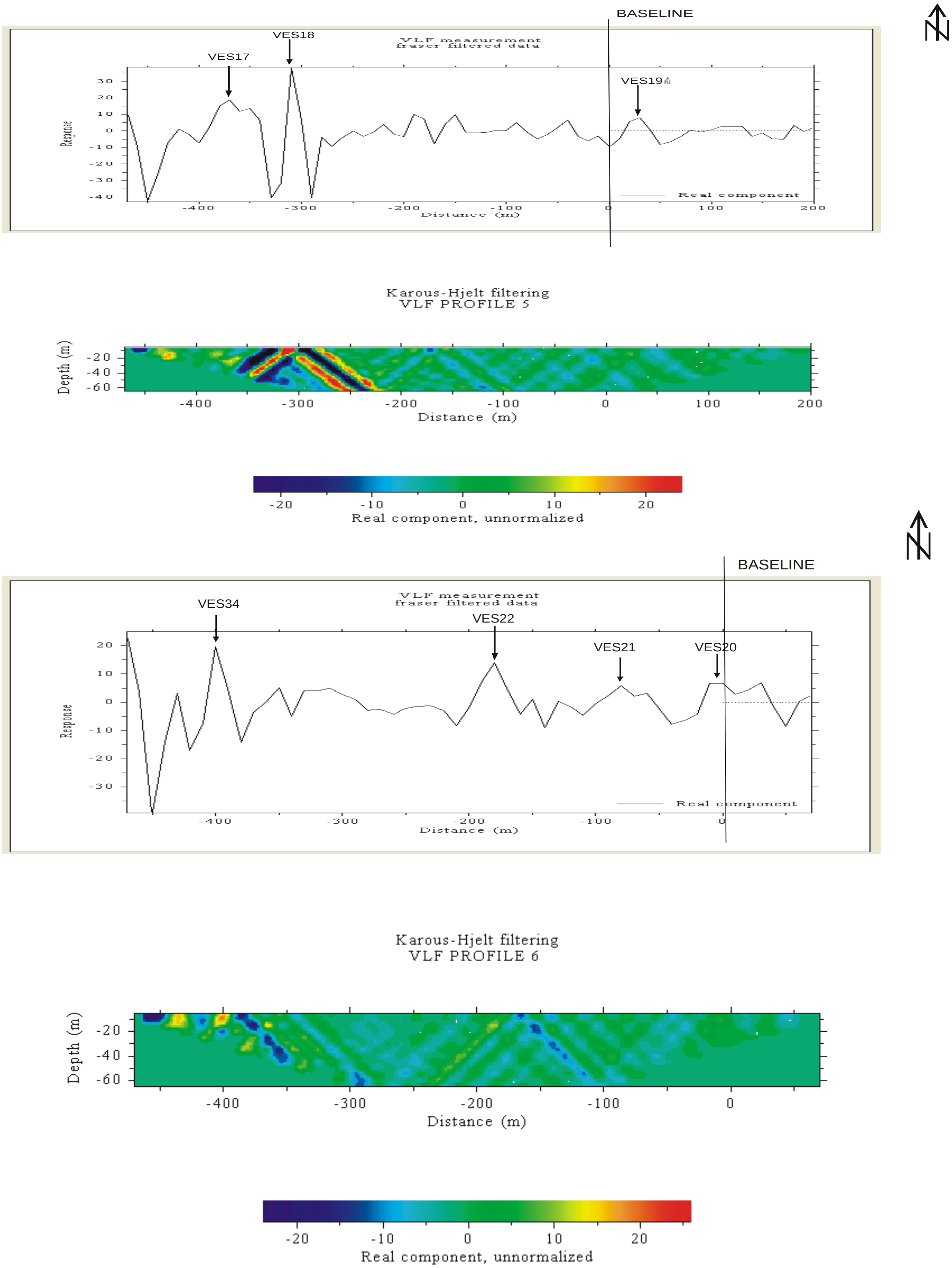

Figure 6: VLF-EM Profile and Karous and Hjelt Pseudo Section along Traverses 5 and 6.

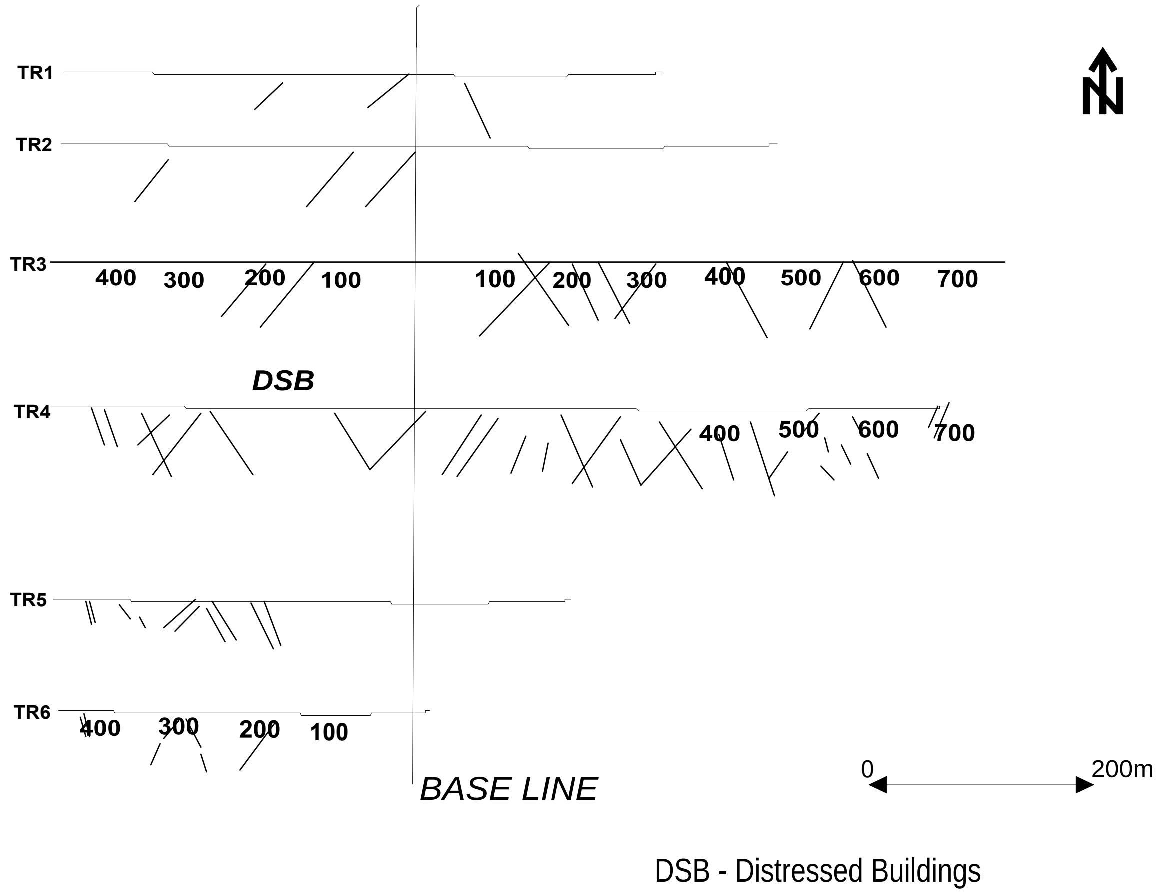

Figure 7: Lineament Map of the Study Area.

This map was also used as a guide in the choice of locating VES points for further investigation in the study area.

RESISTIVITY SOUNDING CURVES AND GEOELECTRIC SECTIONS

The resistivity sounding curves of the 34 VES stations obtained from the surveyed area vary from 3-layer (H and A types) to 4-layer (KH and HA types) as shown in Figure 8. The curves were characterized according to their signatures, which mirror the layering of the subsurface.

The 2-Dimensional view of the geoelectric parameters (resistivity and depth) obtained from the inversion of the electrical resistivity sounding data are presented as geo-electric sections. These geoelectric sections taking along the six traverses (Figures 9 to 11) attempt to correlate the geoelectric sequence across the study area. Five subsurface geologic layers were delineated in the study area. These include the topsoil, lateritic/clay substratum, weathered layer, partly weathered/fractured basement and the fresh basement with resistivity ranging from 134 – 670 ohm-m, 514 – 756 0hm-m, 45 – 406 ohm-m, 128 to 998 ohm-m and 1138 – 8583 ohm-m respectively. The thicknesses range from 0.4 – 2.1m, 1.0 – 9.5m, 2.9 to 27.6m and 2.9 – 4.3m respectively. Depths to the bedrock are generally less than 31m

It was however observed from the geoelectric sections studied and the VES stations around the vicinity of the distressed buildings which include stations 13, 14, 15, 17, 18, 34, 22, and 21 show that the weathered layer has resistivity values of 190, 189, 45, 76, 74, 68, 73, and 121 ohm-m, and thickness of 18.3, 15.4, 4.3, 7.7, 13.9, 12.6, 13.1 and 10.1m respectively. Since the topsoil with thicknesses varying from 0.9 – 1.7m will be excavated during foundation construction, this layer is believed to act as support for the foundation.

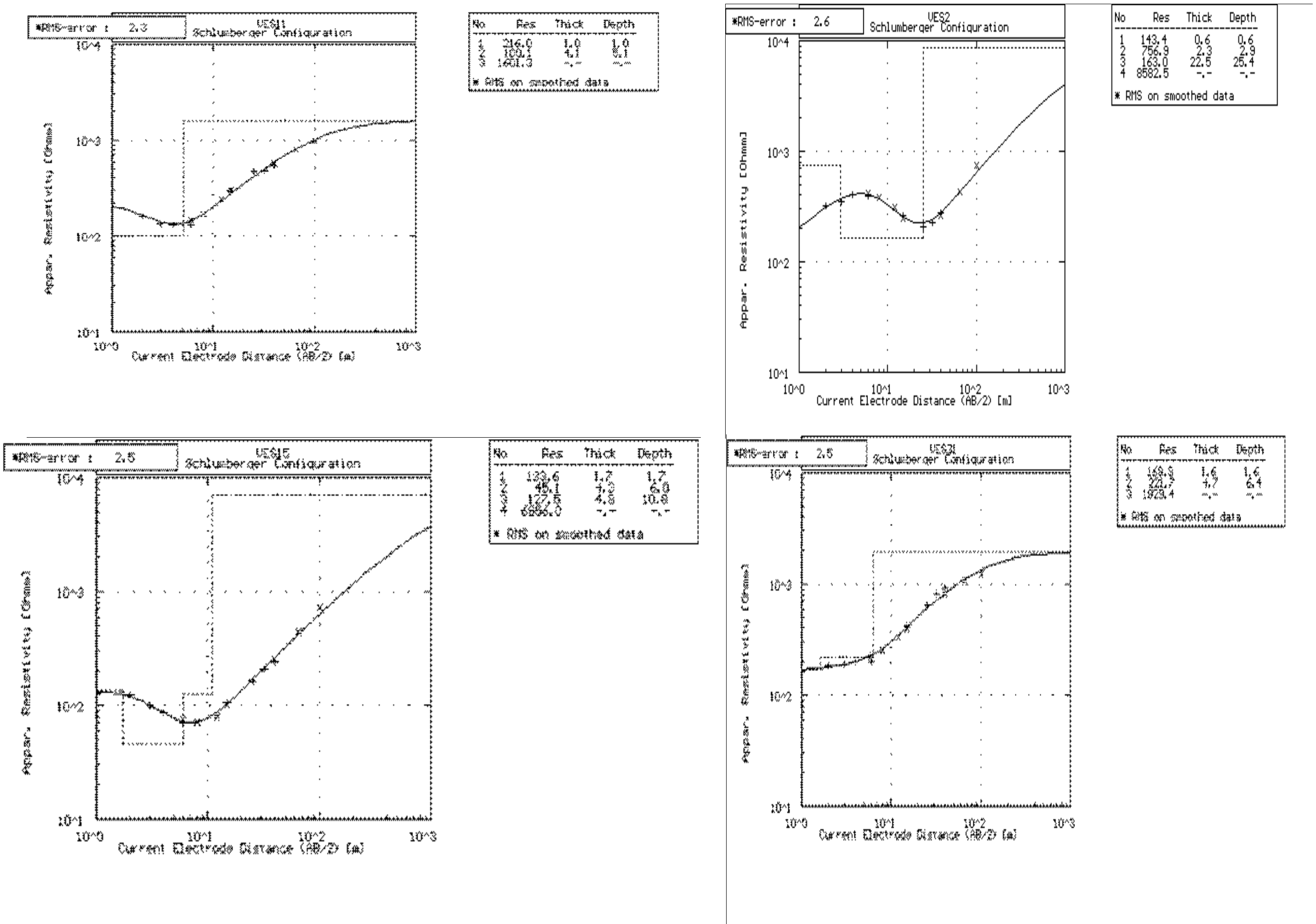

Figure 8: Typical Vertical Sounding Curves obtained from ER Data Acquired in the Study.

From the resistivity values, the weathered layer in this vicinity is seen to be characterized of mainly clayey materials of thicknesses ranging from 4.3 to 18.3m, and which also correspond to area of greatest water saturation. This implies that the region around the distressed buildings is not competent for engineering construction.

GEOELECTRIC CHARACTERISTICS

Topsoil Layer Resistivity Map

Figure 12 shows the topsoil layer resistivity contour map of the study area. It is an attempt to study the layer resistivity trend at a shallow depth. The resistivity of the topsoil varies from 120 – 660 ohm-m while the thickness varies from 0.4 – 2.1m. In the vicinity of the distressed buildings, the topsoil layer resistivity varies from 120 – 280 ohm-m. Zones within the topsoil where the resistivity values are less than 300 ohm-m are considered geotechnically incompetent to carry large engineering structures (Adesida and Omosuyi, 2005). However a large part of this topsoil must have been excavated during foundation construction. Hence it is of less importance as far as foundation study is concerned.

Layer Resistivity Map at Depth of 5m

Layer resistivity map of the study area at a depth of 5m is shown in Figure 13. The map shows a resistivity trend varying from 50 – 1000 ohm-m. Around the distressed buildings the resistivity ranges from 50 – 150 ohm-m, typical of clayey materials. Therefore at this depth, the south-western part of the study area in which the distressed buildings were located is still geotechnically incompetent.

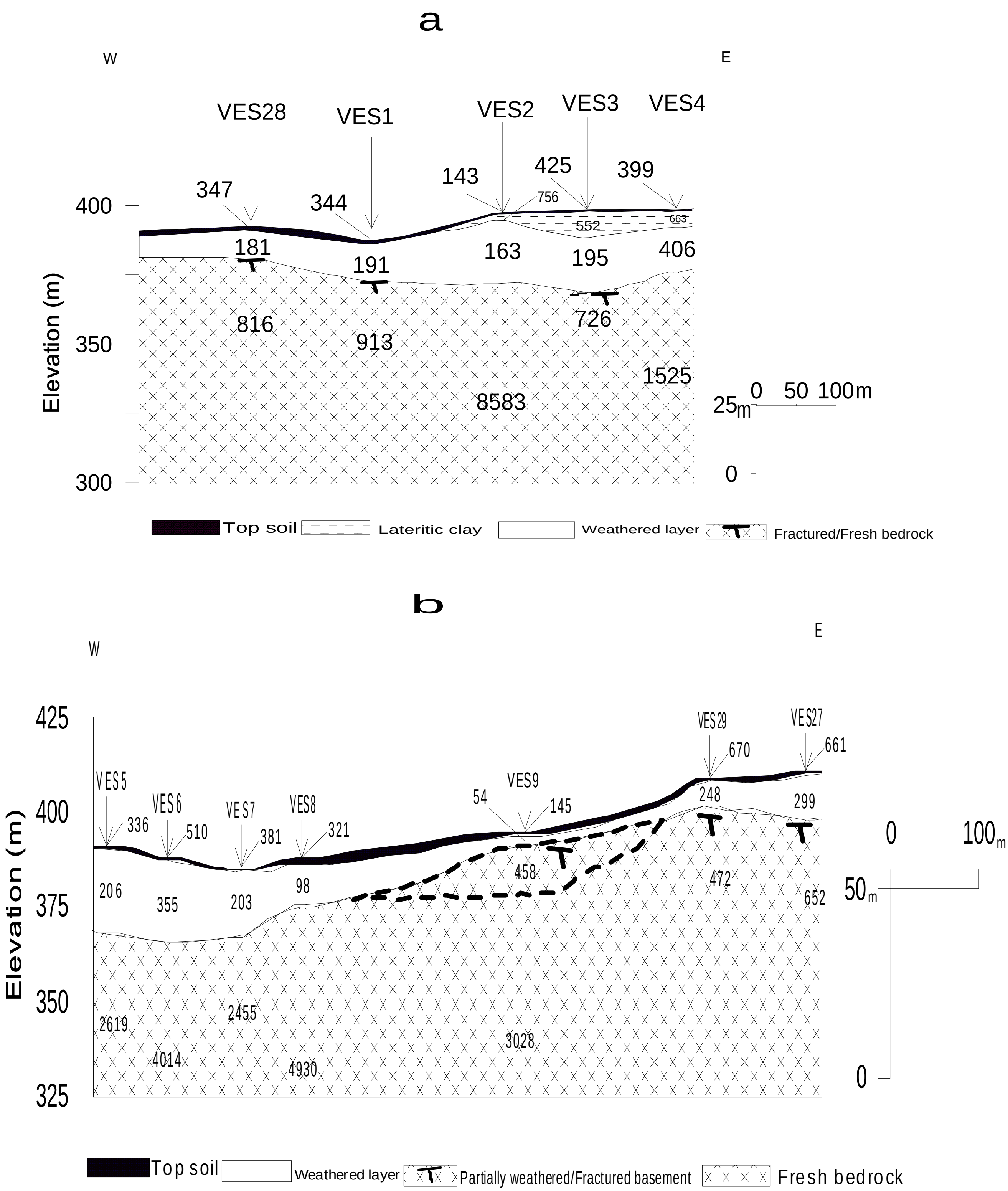

Figure 9: 2D Geo-electric Sections: (a) Along Traverse 1 (b) Along Traverse 2.

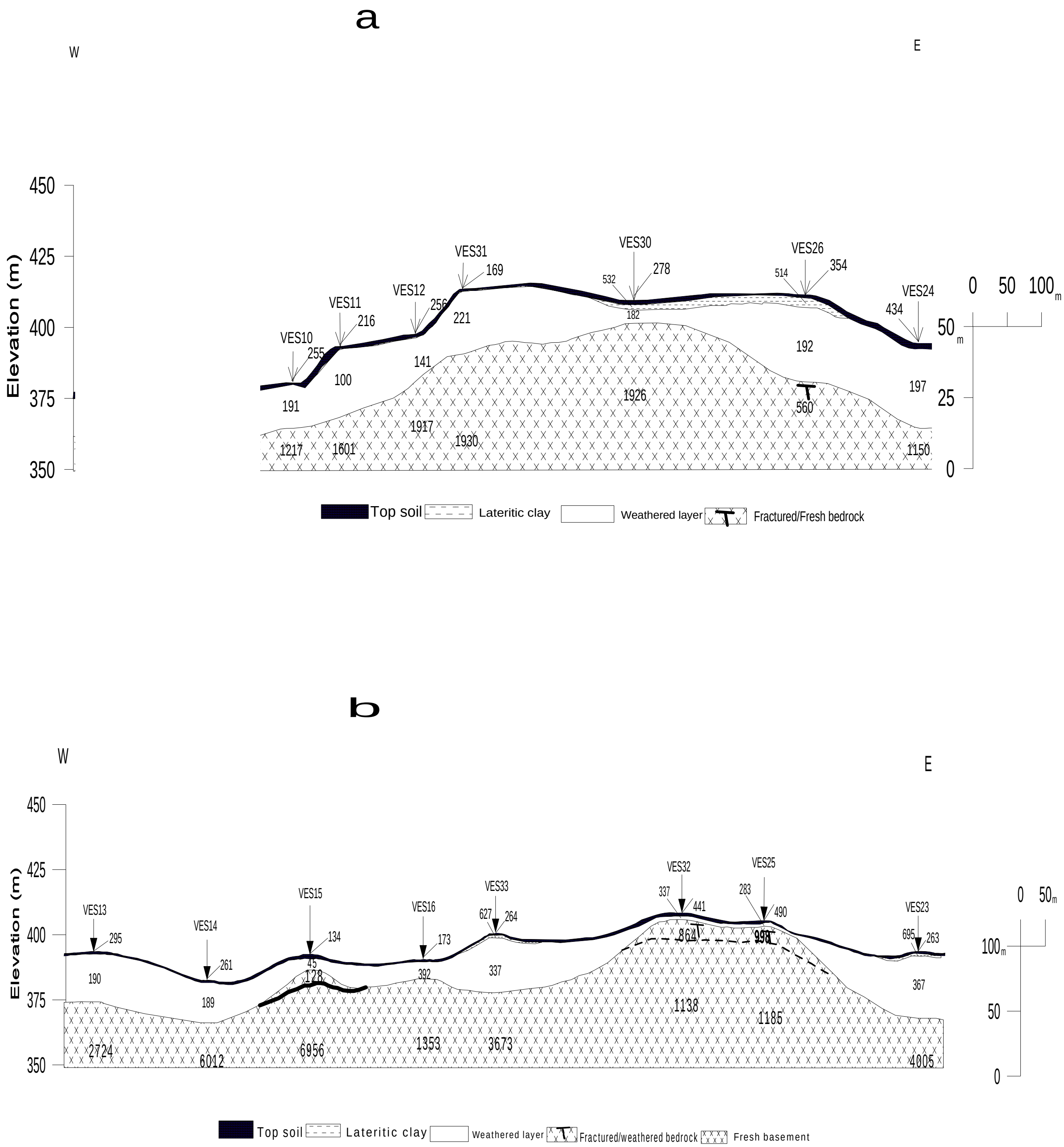

Figure 10: 2D Geo-electric Sections: (a) Along Traverse 3 (b) Along Traverse 4.

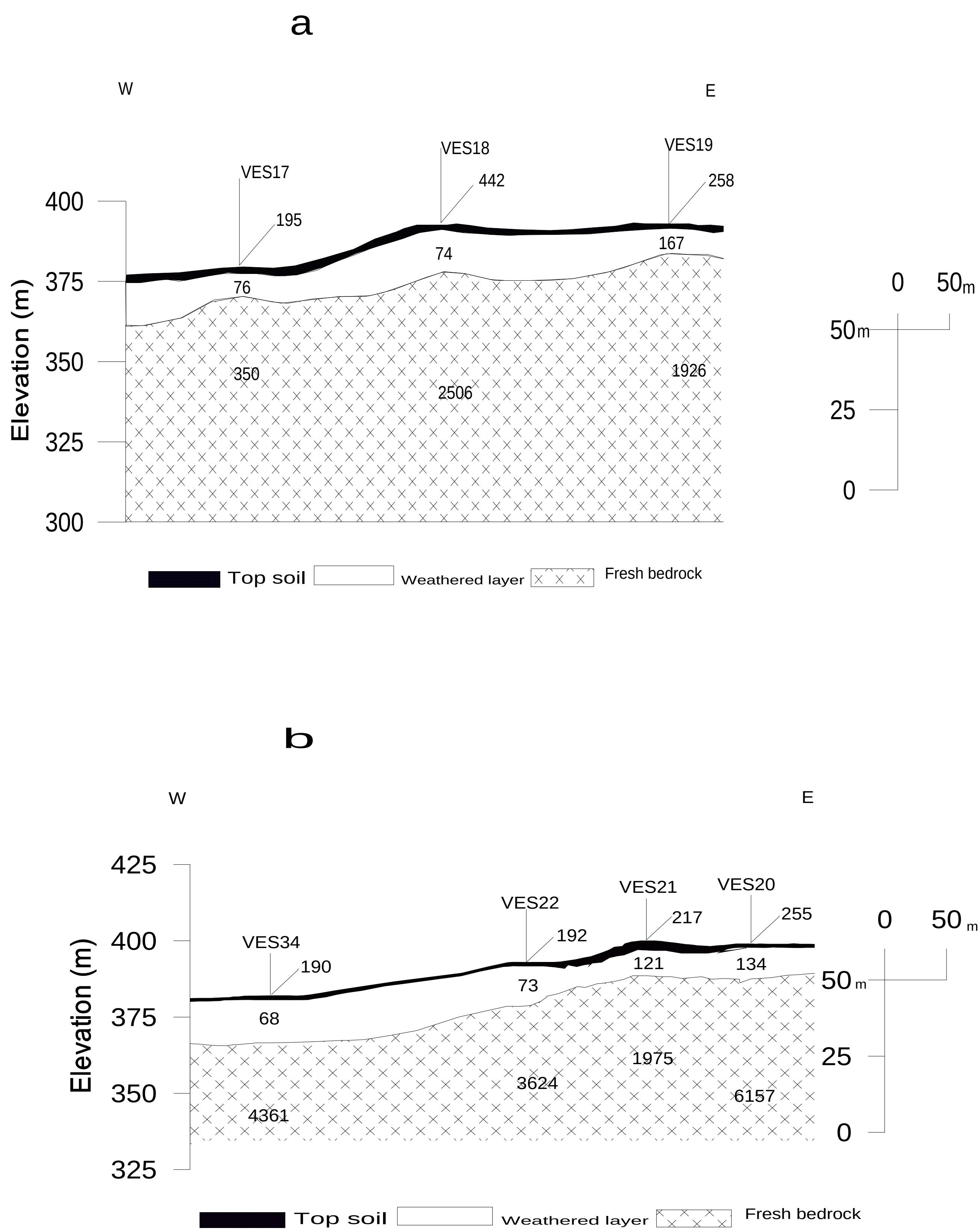

Figure 11: 2D Geo-electric Sections: (a) Along Traverse 5 (b) Along Traverse 6.

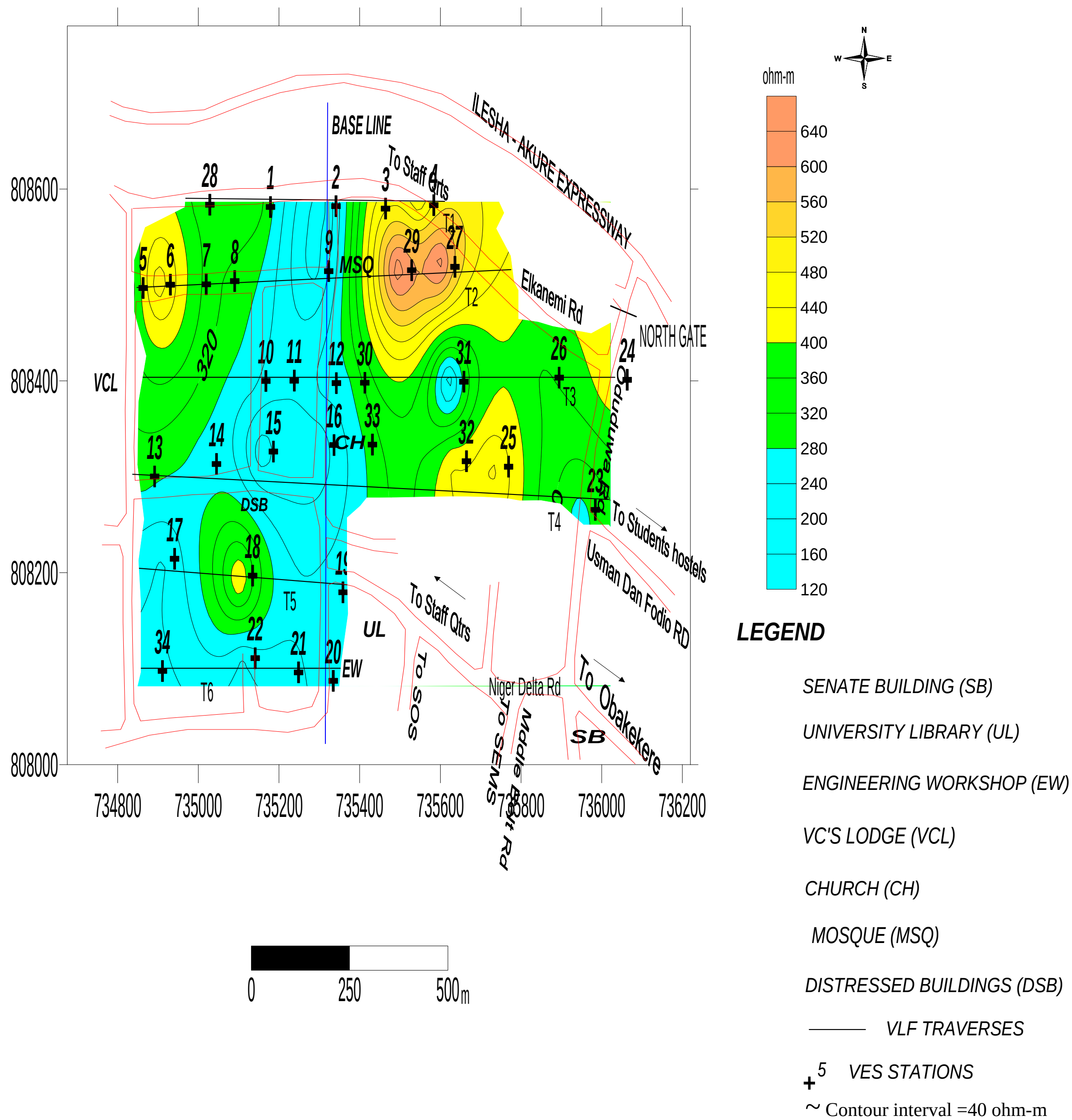

Figure 12: Topsoil Layer Resistivity Map of the Study Area.

<u>Layer Resistivity Map at Depth of 10m</u>

Figure 14 shows the layer resistivity map of the study area at a deeper depth of 10m. The foundation of buildings in the study area will however not get to this depth; it is to further look at the resistivity variation of the materials underlying the foundation. The map further reveals that the materials noticed at a depth of 5m also extend to this depth. Around the vicinity of the distressed buildings the resistivity varies from 50 – 250 ohm-m. By implication, even at a depth of 10m, the material underlying the foundation is also not competent in this region.

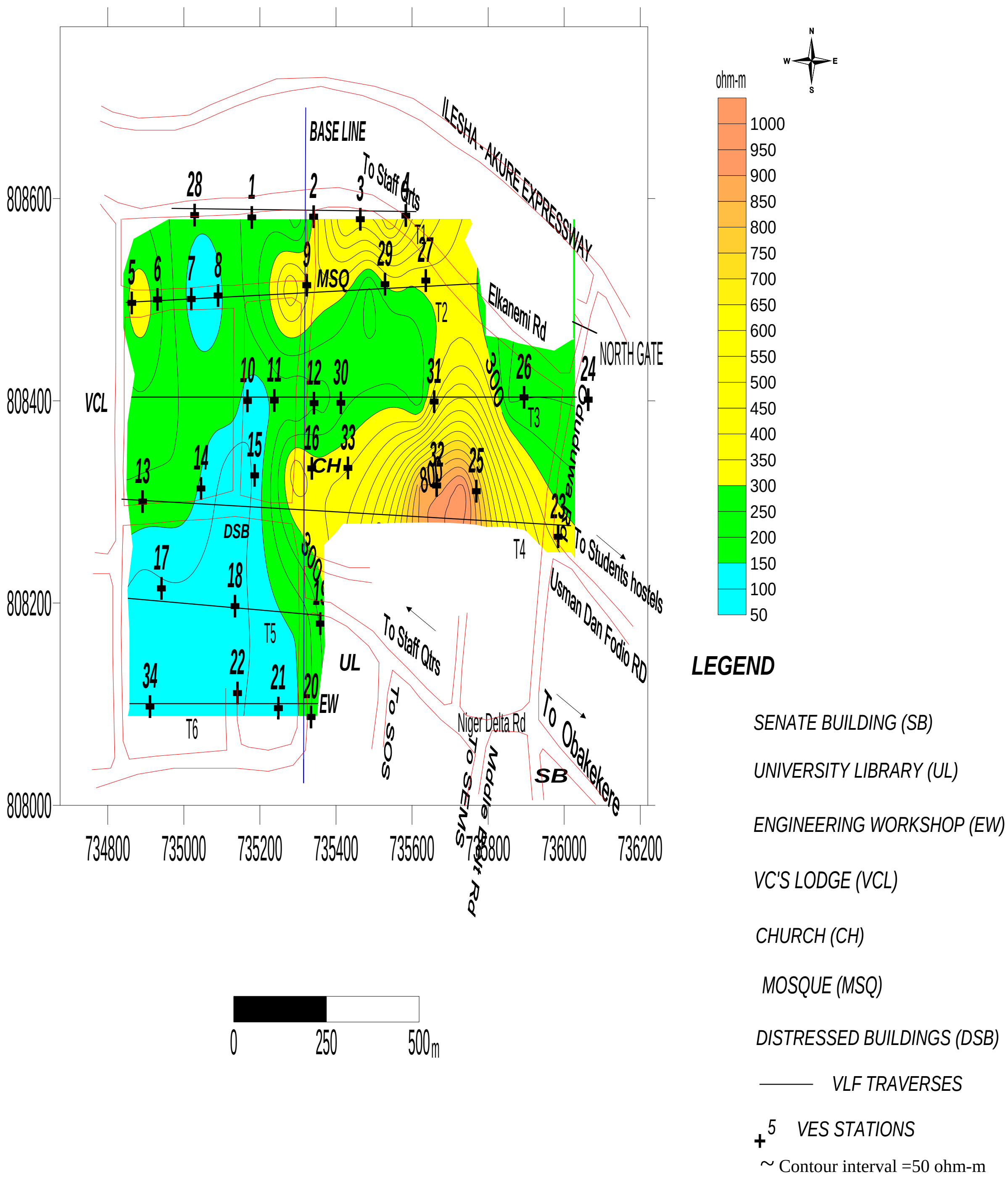

Figure 13: Layer Resistivity Map of the Study area at Depth of 5m .

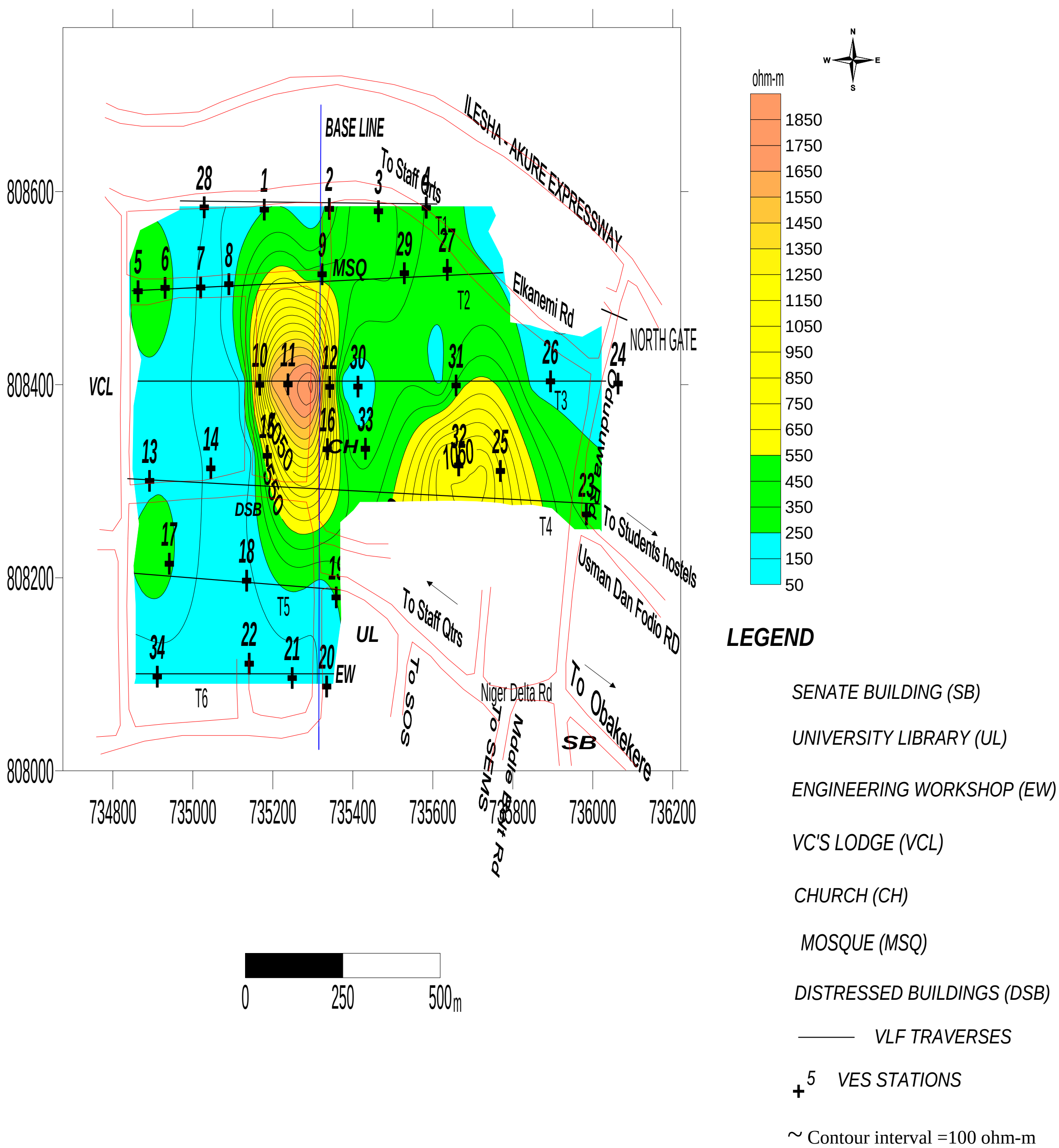

Figure 14: Layer Resistivity Map of the Study Area at Depth of 10m.

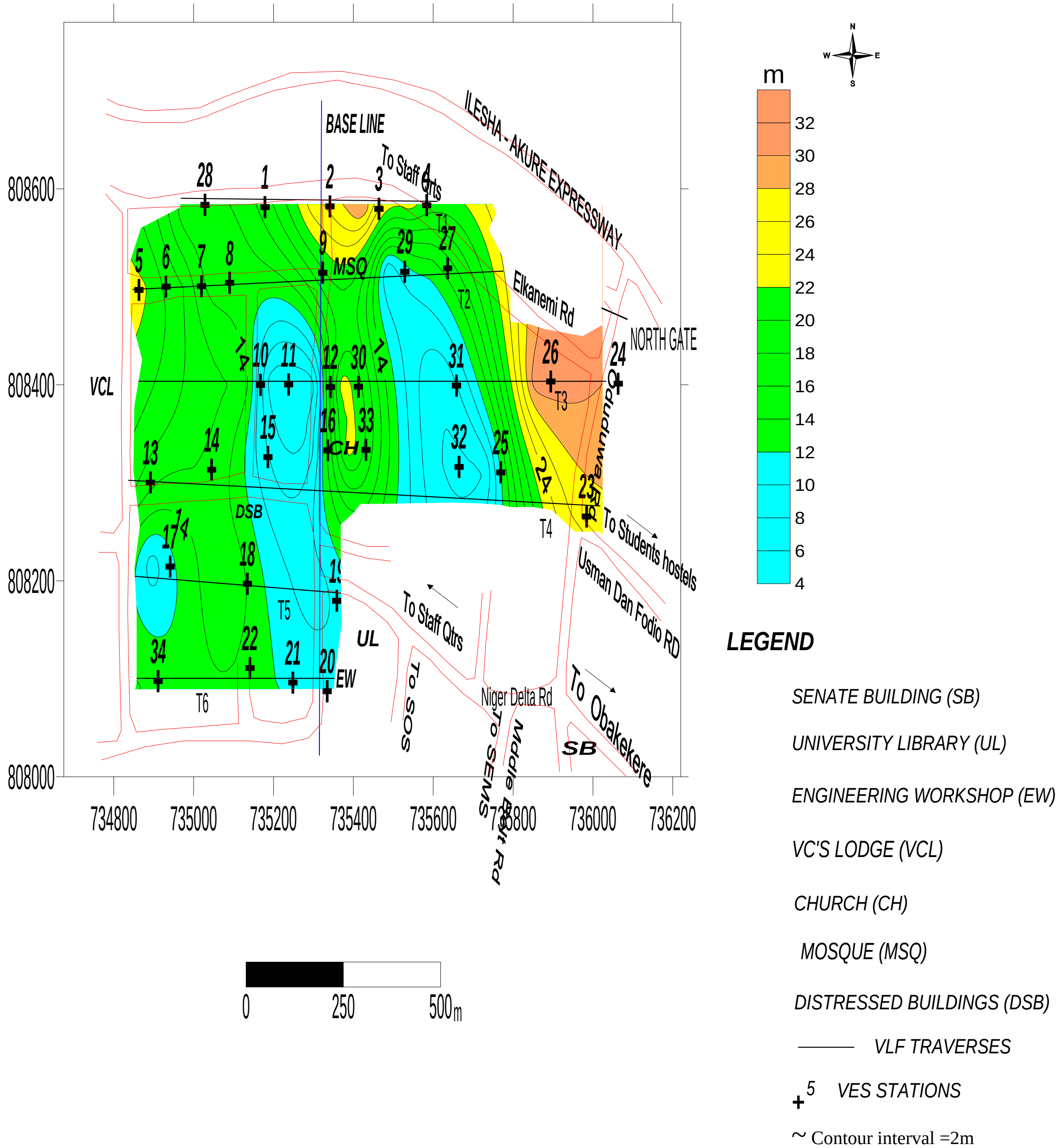

Figure 15: Isopach Map of the Overburden of the Study Area.

Isopach Map of the Overburden

Depth to the bedrock beneath all VES stations were plotted and contoured. The overburden thickness map (Figure 15) shows that the depth to bedrock varies from 4 – 32m in the study area. The map shows areas with thick overburden and areas with thin overburden.

The central part is characterized with fairly thick overburden of 12 – 26m in between two areas of thin overburden of 4 – 12m towards the east around stations 31, 32 and 25, and towards the west around stations 11, 12 and 16. Around the failed buildings, depth to bedrock varies from 10 – 22m.

Areas with fairly thick/thick overburden are considered to be incompetent, most especially when it is composed of geotechnically weak overburden materials.

CONCLUSIONS

Geophysical investigations were carried out within the staff quarters of The Federal University of Technology Akure in order to unravel the possible cause of failure of buildings in the area. The staff quarters occupy an area of about $1km^2$ in the Obanla campus of the University. The geophysical survey involves the Very Low Frequency Electromagnetic method (VLF-EM), and the Vertical Electrical Sounding (VES).

Six traverses (T1 – T6) of varying lengths (570 – 1230m) were established for the VLF-EM survey with an inter traverse separation of 100m and station separation of 10m. The profiling technique was adopted along the traverses and the results were presented as profiles, 2D models and lineament map.

Anomaly responses which may be due to conductive clayey material and weathered basement/ fracture zones were identified. The lineament map shows a fairly high concentration of fractures around the vicinity of the distressed buildings. These fractures correspond with the conductive zones observed on the VLF-EM profiles.

Around the vicinity of the distressed buildings, the resistivity of the weathered layer beneath the topsoil in which the foundation is seated was found to be low ranging from 45 – 190 ohm-m typical of clayey materials. The geoelectric parameters obtained from the VES data interpretation were used to generate isoresistivity maps, overburden thickness map and relief map of the bedrock.

These maps show a general trend of low resistivity in the south-western part of the study area in which the failed buildings were located. This is in agreement with the results of the geoelectric sections and also the lineament map generated from the VLF-EM survey.

From the resistivity maps, low resistivity (<600 ohm-m) within the bedrock, and, low average resistivity (<300 ohm-m) within the overburden are considered geotechnically incompetent to bear significant engineering structures (Adesida and Omosuyi, 2005).

RECOMMENDATIONS

The Very Low Frequency Electromagnetic method (VLF-EM) and the Vertical Electrical Sounding (VES) appear to be valuable tools for geotechnical studies.

The regions delineated as geotechnically incompetent require engineering reinforcement to be determined by the proposed load in order to enhance the bearing capacity of the soil/rock.

In order to avert future geotechnical problems in the University, the services of the geophysicist should be engaged for pre foundation studies, which will act as a guide for the civil engineers before and during construction.

It is, however, recommended that the seismic refraction method be carried out in the geotechnically incompetent zone in order to see the extent of faulting in the area where it exists. Engineering geological studies can also be adopted to complement the geophysical techniques so that the most suitable foundation design can be adjudged.

APPENDIX - Summary of the geoelectric parameters over the study area

VES STN.	NO. OF LAYERS	RESISTIVITY (Ohm-m) $\ell_1/\ell_2/\ldots\ell_{n-1}$	CURVE TYPE	THICKNESS (m) $h_1/h_2/\ldots h_{n-1}$	DEPTH (m) $d_1/d_2/\ldots d_{n-1}$
1	3	344 / 191 / 913	H	1.3 / 13.5	1.3 / 14.9
2	4	143 / 757 / 163 / 8583	KH	0.6 / 2.3 / 22.5	0.6 / 2.9 / 25.4
3	4	426 / 552 / 196 / 726	KH	0.6 / 9.5 / 20.0	0.6 / 10.2 /30.2
4	4	399 / 663 / 406 / 1525	KH	0.6 / 5.8 / 16.1	0.6 / 6.4 / 22.5
5	3	336 / 206 / 2619	H	0.6 / 22.6	0.6 / 23.2
6	3	510 / 355 / 4015	H	0.9 / 21.5	0.9 / 22.4
7	3	381 / 203 / 2455	H	0.4 / 17.5	0.4 / 18.0
8	3	321 / 98 / 4930	H	2.0 / 11.0	2.0 / 13.0
9	4	145 / 53 / 458 / 3028	HA	1.1 / 2.9 / 12.5	1.1 / 4.0 / 16.5
10	3	255 / 181 / 1218	H	0.7 / 15.4	0.7 / 16.1
11	3	216/ 100 / 1601	H	1.0 / 4.1	1.0 / 5.1
12	3	256 / 147 / 1918	H	1.1 / 3.5	1.1 / 4.6
13	3	295 / 190 / 2724	H	0.9 / 18.3	0.9 / 19.2
14	3	261 / 189 / 6012	H	0.9 / 15.4	0.9 / 16.3
15	4	134 / 45 / 128 / 6956	HA	1.7 / 4.3 / 4.8	1.7 / 6.0 / 10.8
16	3	173 / 392 / 1353	A	0.8 / 6.6	0.8 / 7.4
17	3	195 / 76 / 350	H	1.3 / 7.7	1.3 / 9.0
18	3	448 / 74 / 2507	H	1.6 / 13.9	1.6 / 15.5
19	3	259 / 167 / 2129	H	1.6 / 7.8	1.6 / 9.4
20	3	255 / 134 / 6157	H	1.2 / 10.3	1.2 / 11.5
21	3	217 / 121 / 1975	H	1.7 / 10.1	1.7 / 11.8
22	3	192 / 73 / 3624	H	1.3 / 13.1	1.3 / 14.4
23	4	263 / 695 / 367 / 4005	KH	0.7 / 1.0 / 23.8	0.7 / 1.7 / 25.5
24	3	434 / 197 / 1151	H	2.1 / 27.6	2.1 / 29.7
25	4	490 / 283 / 996 / 1185	HA	0.8 / 1.0 / 4.3	0.8 /1.8 / 6.0
26	4	354 / 514 / 192 / 560	KH	1.1 / 2.1 / 27.6	1.1 / 3.3 / 30.8
27	3	662 / 299 / 652	H	0.9 / 12.4	0.9 / 13.4
28	3	347 / 181 / 816	H	1.4 / 10.5	1.4 / 11.9
29	3	670 / 284/ 472	H	0.9 / 6.6	0.9 / 7.5
30	4	278 / 532 / 183 / 1926	KH	0.6 / 2.0 / 20.6	0.6 / 2.6 / 23.2
31	3	169 / 222 / 1929	A	1.6 / 4.7	1.6 / 6.4
32	4	441 / 337 / 864 / 1138	HA	0.7 / 1.2 / 3.8	0.7 / 2.0 / 5.8
33	4	264 / 627 / 337 / 3673	KH	0.7 / 1.3 / 20.7	0.7 / 2.0 / 22.6
34	3	190 / 68 / 4361	H	1.4 / 12.6	1.4 / 14.0

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