

ON THE APPLICATION OF THE ELECTRICAL RESISTIVITY METHOD IN FOUNDATION FAILURE INVESTIGATION - A CASE STUDY

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ABSTRACT

An investigation of the cause(s) of the foundation failure of the buildings in the premises of the Dental Clinic in the campus of the Obafemi Awolowo University (O.A.U.), Ile-Ife, Nigeria, was carried out using the electrical resistivity method. The aim of the investigation was to delineate the geoelectric and geologic parameters of the subsurface, as a means of determining the cause(s) of the foundation failure.

Measurements involving vertical electrical sounding (VES) and horizontal profiling (EHP) techniques were taken along three traverses. The results were presented as geoelectric sections, pseudosections and maps.

The geoelectric sections reveal three subsurface layers, namely the topsoil, the weathered layer and the basement bedrock. Depth to the bedrock map revealed a depression with an approximate N-S trend. The dipole-dipole maps, the pole-pole maps and the pseudosections suggest that clays with pockets of more competent materials underlie the premises.

It is concluded from these that the buildings failed due to the flow of the incompetent clays on which they were founded.

KEYWORDS: Electrical Resistivity, Foundation Failure, Case Study.

INTRODUCTION

All civil engineering structures (e.g. buildings, roads, dams, etc.) are founded on earth materials (soils/rocks). Therefore, one of the priority considerations in the design of such structures is the pre-construction investigation of the subsurface at the proposed site in order to ascertain the fitness of the host earth materials. Even after construction, some structures require timed post-construction monitoring to ensure their integrity. To this end, geophysical methods, besides geotechnical approaches, are routinely used. The geophysical methods that suit such investigations are the electrical resistivity, gravity and seismic refraction methods (e.g. Ako, 1976; Olorunfemi and Meshida, 1987; Boyce and Koseoglu, 1996; Olorunfemi et al., 2000, etc.). Of these methods the electrical resistivity method is the most commonly employed as it combines speed, accuracy and cost-effectiveness in the localization of faults, fractures, buried metallic pipes, vertical rock contacts and leachate/seepage paths. It also provides very reliable results on the general nature of the subsurface.

On the basis of this, the electrical resistivity method was used to investigate the cause(s) of the foundation failure of the buildings in the premises of the Dental Clinic in the campus of the Obafemi Awolowo University (O.A.U.), Ile-Ife, southwestern Nigeria. The foundation failure manifests as major cracks extending from the foundation of the buildings. The investigation had the aim of delineating the subsurface sequence; determining the geoelectric parameters (layer resistivities and thicknesses) of the subsurface layers; mapping of subsurface structures (e.g. faults, joints, fractures, etc.), depth to the bedrock and assessing the nature and competence of the subsoil within the premises of the failed structures.

Location, Geomorphology and Geology

The Dental Clinic is located at the southern part of the Faculty of Health Sciences of the O.A.U. (Figs 1 and 2). The topography is relatively flat. A perennial tributary of the Opa River with a NW-SE orientation drains the southern part of the premises.

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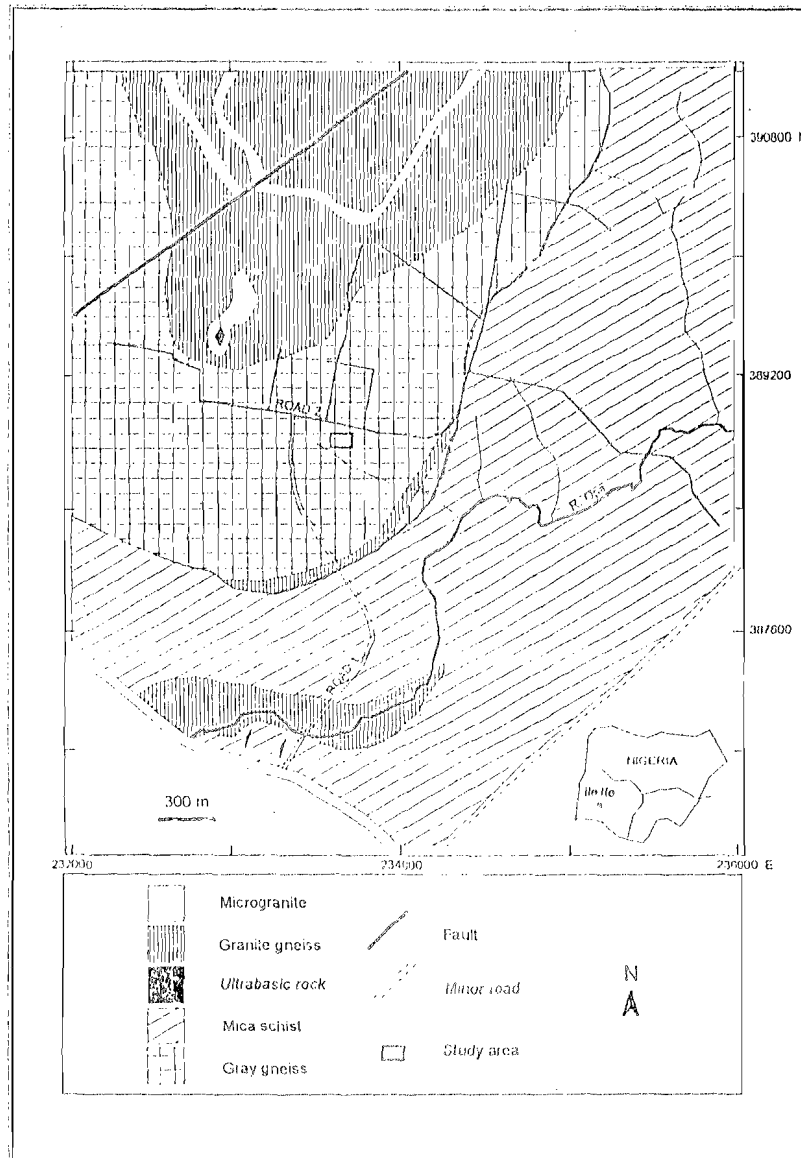


FIG. 1 GEOLOGICAL MAP OF THE OBAFEMI AWOLOWO UNIVERSITY CAMPUS (MODIFIED AFTER BOESSE, 1989) SHOWING THE LOCATION OF THE STUDY AREA.

According to Boesse (1989), the site is underlain by gray gneiss (Fig. 1) of the Precambrian Basement Complex of southwestern Nigeria. The rock has foliation with a general N-S orientation and an average dip of 45°E .

Methodology and Data Presentation

For the geophysical data acquisition, three traverses labeled T1, T2 and T3 were established in the study area (Fig. 2). Each traverse line was 100 m long. The traverses were oriented $\text{N}100^{\circ}\text{E}$, $\text{N}99^{\circ}\text{E}$ and $\text{N}113^{\circ}\text{E}$, respectively. The orientations were constrained

by the underlying geological structure and the disposition of the buildings (B1 and B2) whose foundation failed.

The electrical resistivity measurements were carried out using the vertical electrical sounding (VES) and electrical horizontal profiling (EHP) techniques. Fifteen VES points were occupied using the Wenner electrode array. Sounding was done every 20 m interval along the traverses. The electrode spacing was varied from 1 to 64 m, assuming the bedrock to lie at moderate depth (Olorunfemi and Okhue, 1992).

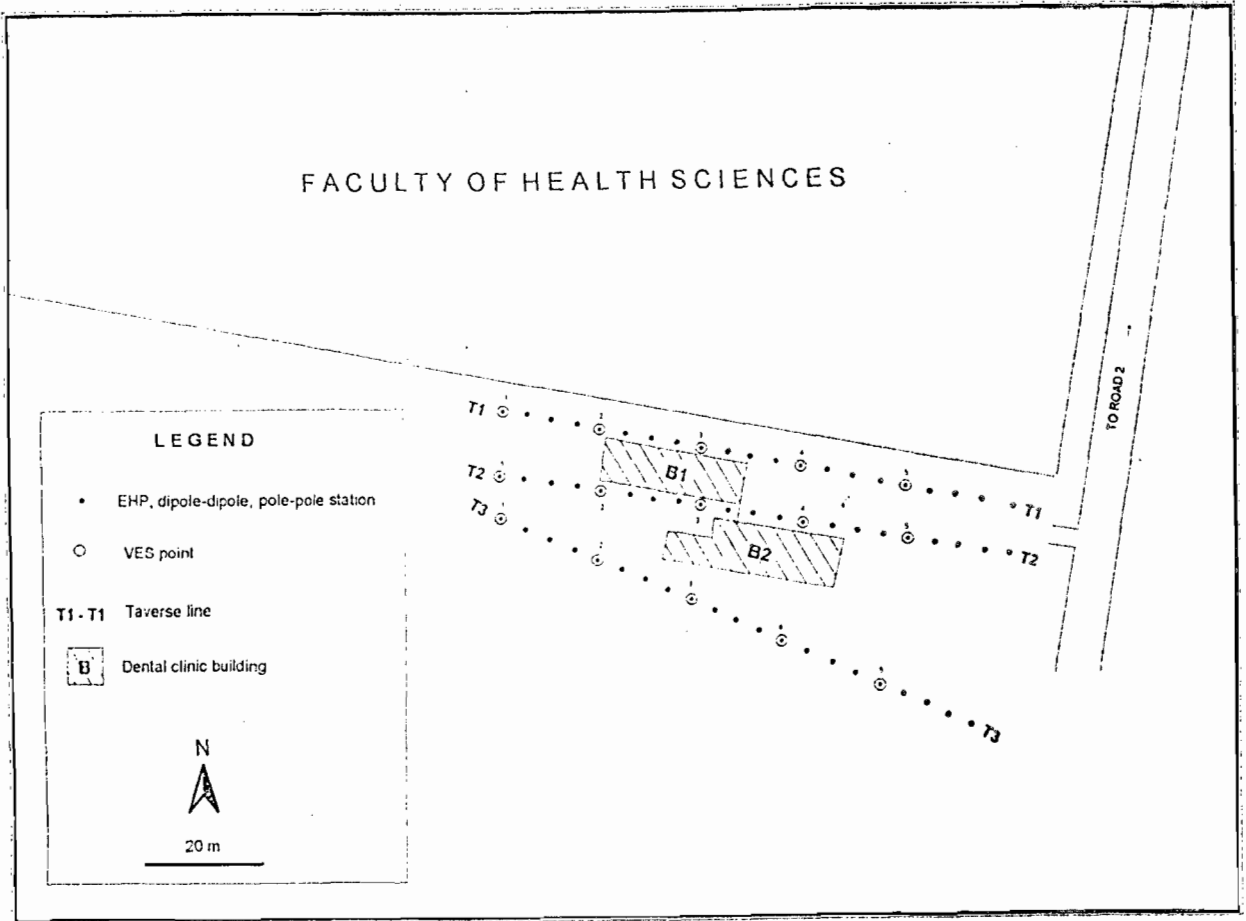


FIG. 2 SITE PLAN SHOWING GEOPHYSICAL TRAVERSE LINES LAYOUT.

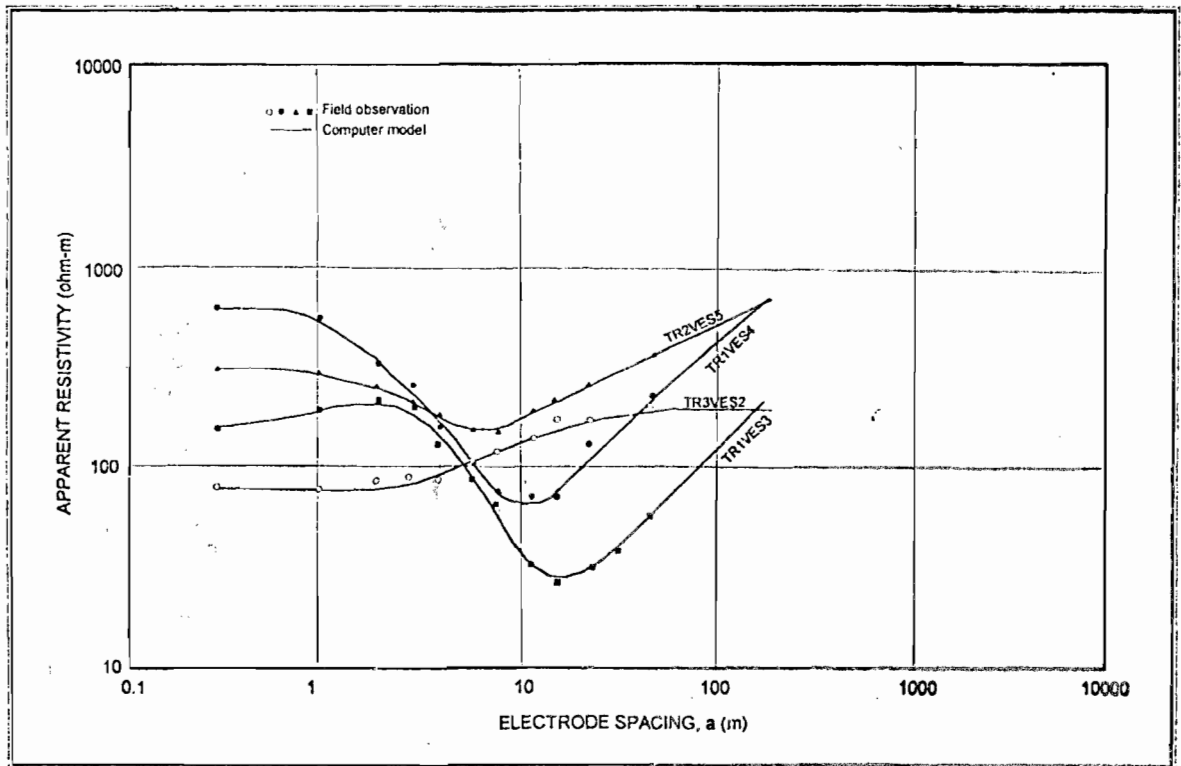


FIG. 3 REPRESENTATIVE TYPE CURVES FROM THE STUDY AREA.

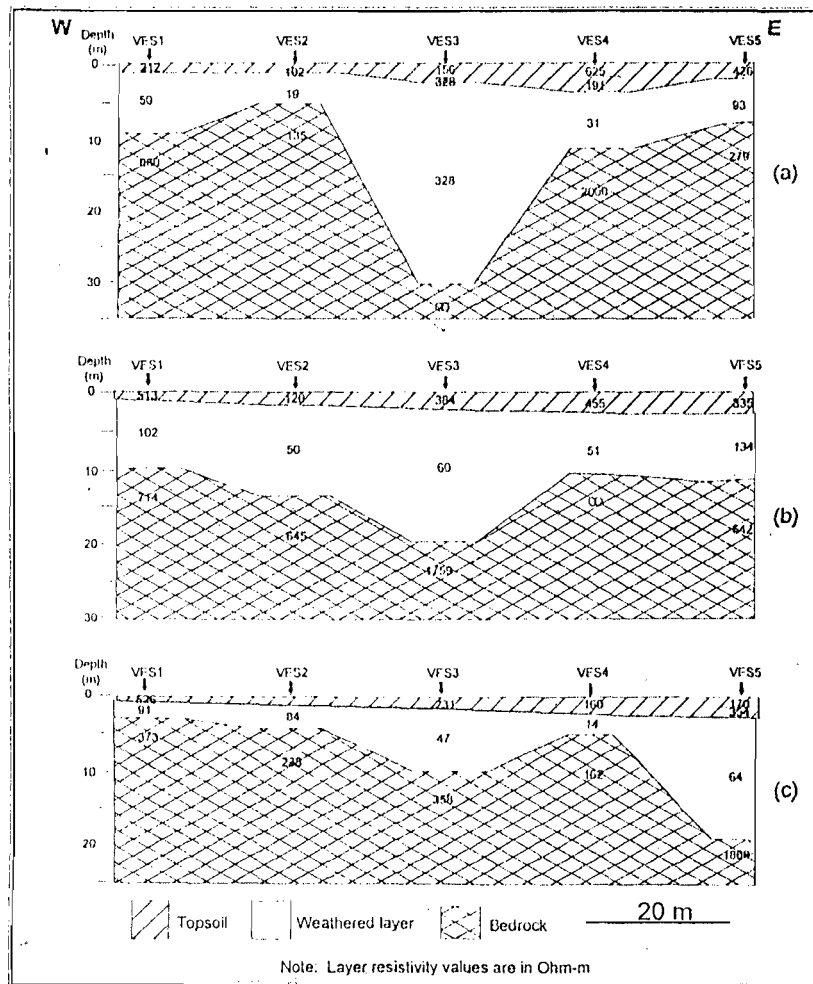


FIG. 4 GEOELECTRIC SECTION BENEATH TRAVERSE 1 (a), TRAVERSE 2 (b) AND TRAVERSE 3 (c).

The recorded data were plotted as depth sounding curves (Fig. 3), and these were qualitatively and quantitatively interpreted. The former involved visual inspection, while the latter was effected by partial curve matching and computer iteration techniques. The depth sounding results are presented as 2-D geoelectric sections (Fig. 4). The depth to bedrock map in the premises is presented in Figure 5.

For the EHP, the dipole-dipole and pole-pole electric configurations were adopted. The dipole-dipole configuration utilized a pair of current and potential electrode dipoles arranged collinearly along the traverse line and separated by a distance na . Parameter a is the pole length (inter-electrode spacing), while n is the expansion factor. In the present study, a was maintained at 5 m, while n was varied from 1 to 5. The results are presented as maps (Fig. 6) and pseudosections (Fig. 8).

The pole-pole configuration utilized two active electrodes (1 current plus 1 potential), while the remaining two electrodes (1 current plus 1 potential) were made passive (dormant) by placing them very far away (assumed to be at infinity) from the two active electrodes. Inter-electrode spacings (between the two active electrodes) of 5 and 10 m were used for the pole-pole electrical horizontal profiling. The results of the survey are presented as maps (Fig. 7).

All the results in the form of maps and pseudosections were automatically generated using the ArcView GIS 3.2 software, and interpreted qualitatively. The 2-D inversion of the dipole-dipole data was carried out using Loke (1998) software.

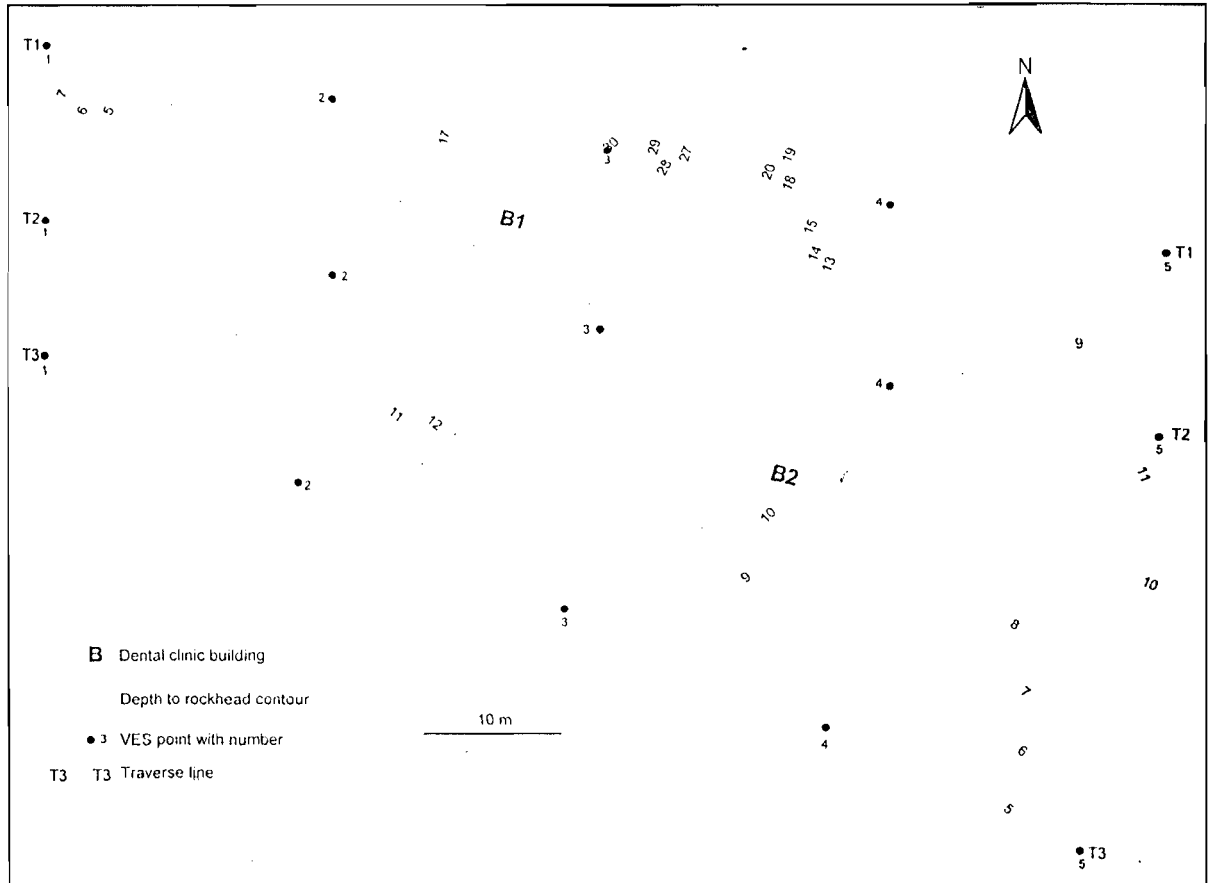


FIG. 5 DEPTH TO BEDROCK MAP OF THE STUDY AREA.

DISCUSSION OF RESULTS

Goelectric Sections

The type resistivity curves recorded from the survey are the 2-type, H, KH and QH signatures, with the H-types predominant.

The 2-D goelectric sections along the three traverses (Fig. 4a-c) indicate three distinct subsurface geologic layers. The layers are the topsoil, the weathered layer and the basement. The topsoil has resistivity values that vary from 84 to 625 ohm-m, and thicknesses of between 0.5 and 3.7 m. It is composed of clay, sandy clay, clayey sand and laterite. The weathered layer is characterized by resistivity values ranging from 14 to 102 ohm-m and thicknesses varying from 2.5 to 27.5 m. The low resistivity values (<105 ohm-m) are symptomatic of clay. The resistivity values for the third layer vary

between 135 and 11 ohm-m. These range of values suggest partly weathered/fresh bedrock for a sequence characterized by highly conductive weathered layer. The depth to the goelectric bedrock varies from 3.1 to 30 m.

The bedrock relief shows a major depression beneath VES 3 along T1, beneath VES 3 along T2, and beneath VES 3 and 5 along T3. The correlation of the basement depressions indicates a N-S trend as illustrated in a map in Figure 5. The figure shows that the Dental Clinic buildings (blocks B1 and B2) are significantly located within this zone of depression.

Resistivity Maps

Figure 6 illustrates the dipole-dipole resistivity maps at depth levels of 2.9 m, 3.9 m, 4.9 m, 5.9 m and 6.8 m (Roy and Apparao, 1971), corresponding to $n = 1$, $n = 2$, $n = 3$, $n = 4$ and n

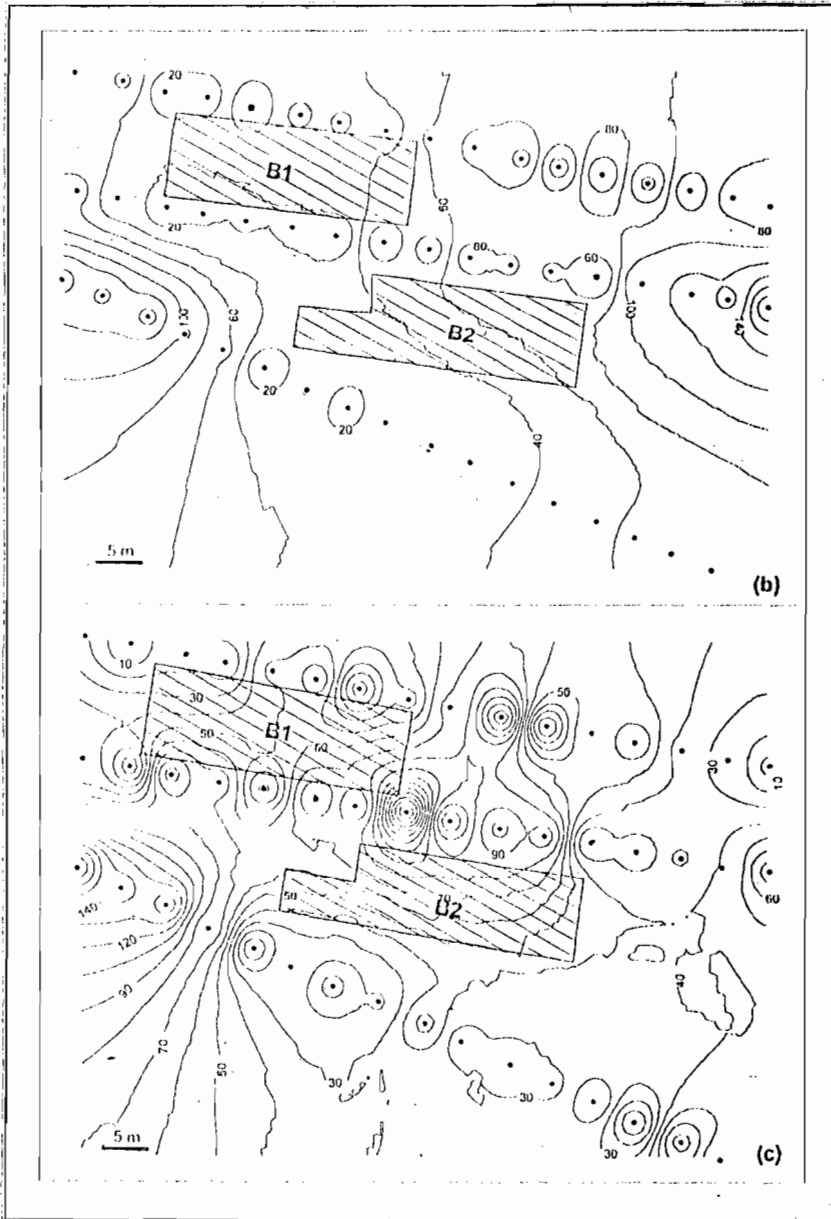


FIG. 6 RESISTIVITY MAP FOR $n = 2$ (b) AND $n = 3$ (c).

= 5. At depth level of 2.9 m (Fig. 6a) block B1 is completely sitting on clays characterized by 20-100 ohm-m resistivity values, whereas block B2 has its western and southern ends sitting on clays with resistivity values ranging from about 40 to 80 ohm-m. The clay grades into sandy clay (indicated by resistivity values of >100 ohm-m) towards its northeastern end. The two blocks are

completely underlain by clay at the 3.9 m depth level (Fig. 6b). At the 4.9 m depth level (Fig. 6c) the situation is virtually the same. B1 and B2 sit on clays at the depth level of 5.9 m (Fig. 6d), but the material underlying the northern end of the latter has become relatively more resistive. A probable clayey sand composition or nearness to the bedrock is suggested by the generally more

resistive underlying material at the depth level of 6.8 m (Fig. 6e).

The pole-pole resistivity map for 5 m electrode spacing, corresponding to 1.8 m depth level (Roy and Apparao, 1971), shows resistivity values ranging from 10 to 200 ohm-m (Fig. 7a). The values are respectively 10-70 ohm-m and 30-140 ohm-m in the premises of blocks B1 and B2. These values indicate that the subsurface is generally clayey, even at relatively shallow depth

levels. The pole-pole map for 10 m electrode spacing, representing 3.5 m depth level (Fig. 7b), shows resistivity values that generally vary from 10 to 220 ohm-m, with the lower values of 10-50 ohm-m recorded in the premises of block B1 and 20-70 ohm-m observed in the premises of block B2.

Pseudosections

The dipole-dipole pseudosections drawn along the three traverses show both lateral and vertical

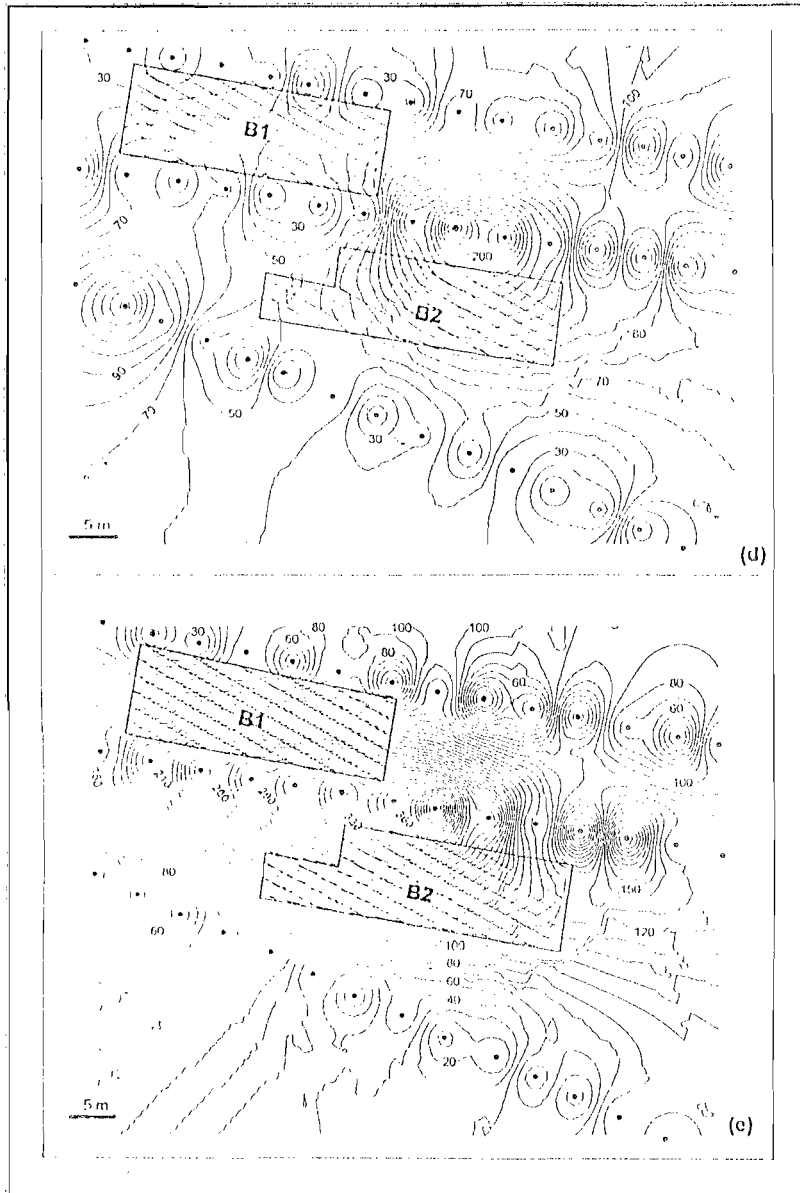
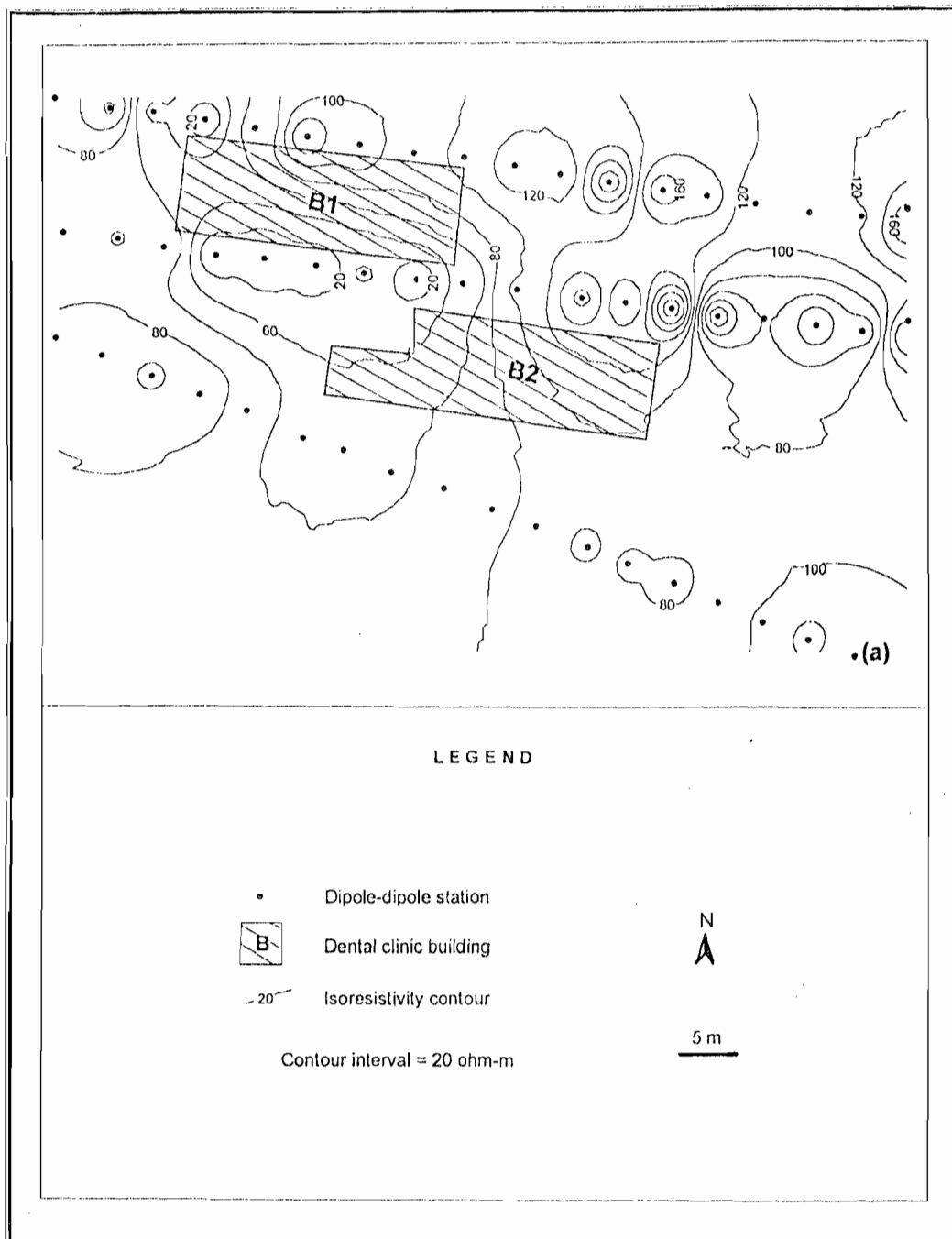


FIG. 6 RESISTIVITY MAP FOR $n=4$ (d) AND $n=5$ (e).

FIG. 6(a) RESISTIVITY MAP FOR $n = 1$.

variations in the apparent resistivity values of the subsurface (Fig. 8). The low values ranging from <20 ohm-m to about 100 ohm-m indicating clays underlie all the area. There are however some pockets of near surface fairly resistive materials (sandy clay) between stations 5 and 7, and 12 and 18 on T1 (Fig. 8a), and between stations 11 and 14 on T2 (Fig. 8b). Figures 9a-c show field, calculated and inverse model resistivity sections

obtained from the inversion of the dipole-dipole data collected along Traverses 1-3 (T1 -T3), respectively. The inverse model resistivity sections confirmed the earlier inference that blocks B1 and B2 are sited on very clayey substratum to depths greater than 8.5 m and with surface/near surface expression along Traverse 2 (T2).

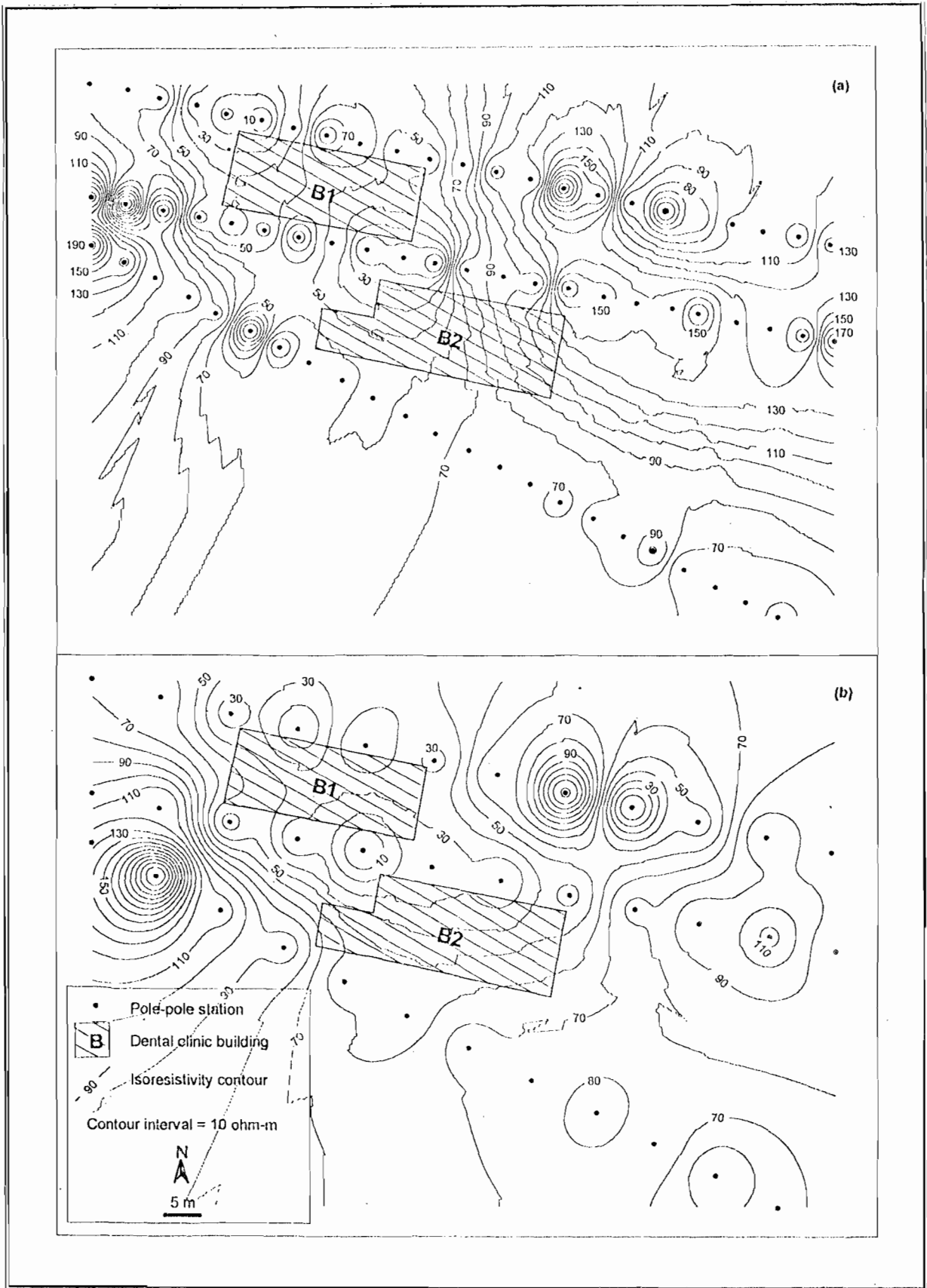


FIG. 7 POLE-POLE RESISTIVITY MAP FOR 5 m (a) AND 10 m (b) ELECTRODE SPACING.

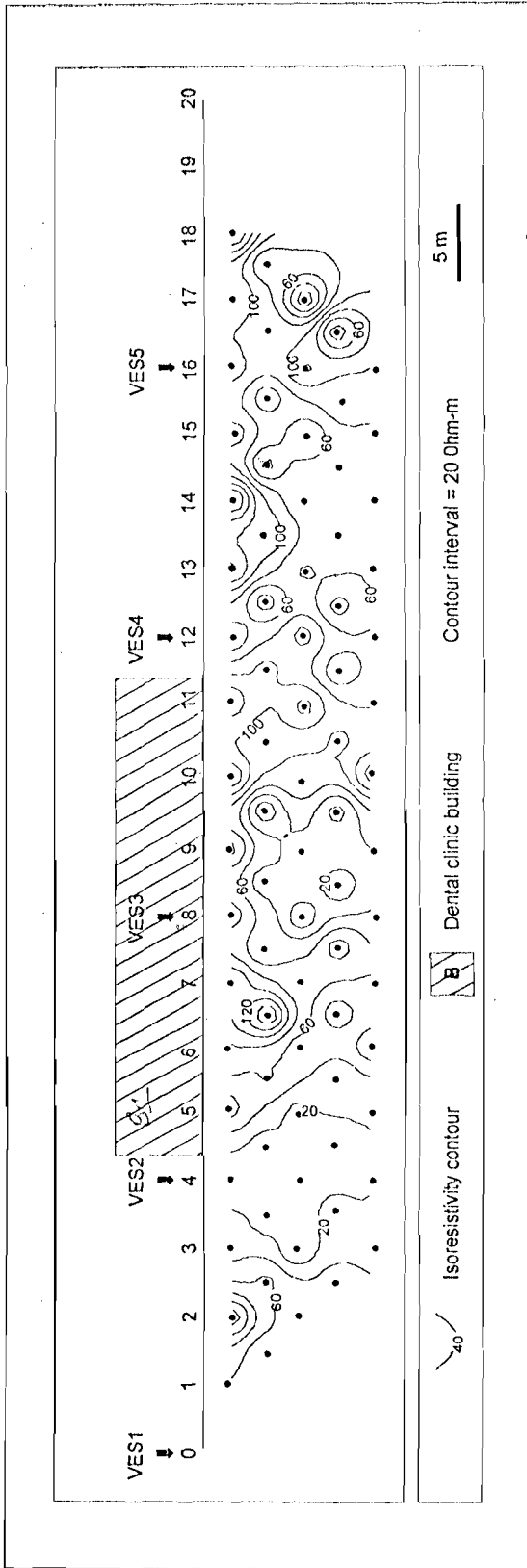


FIG. 8a DIPOLE-DIPOLE PSEUDOSECTION ALONG TRAVERSE 1.

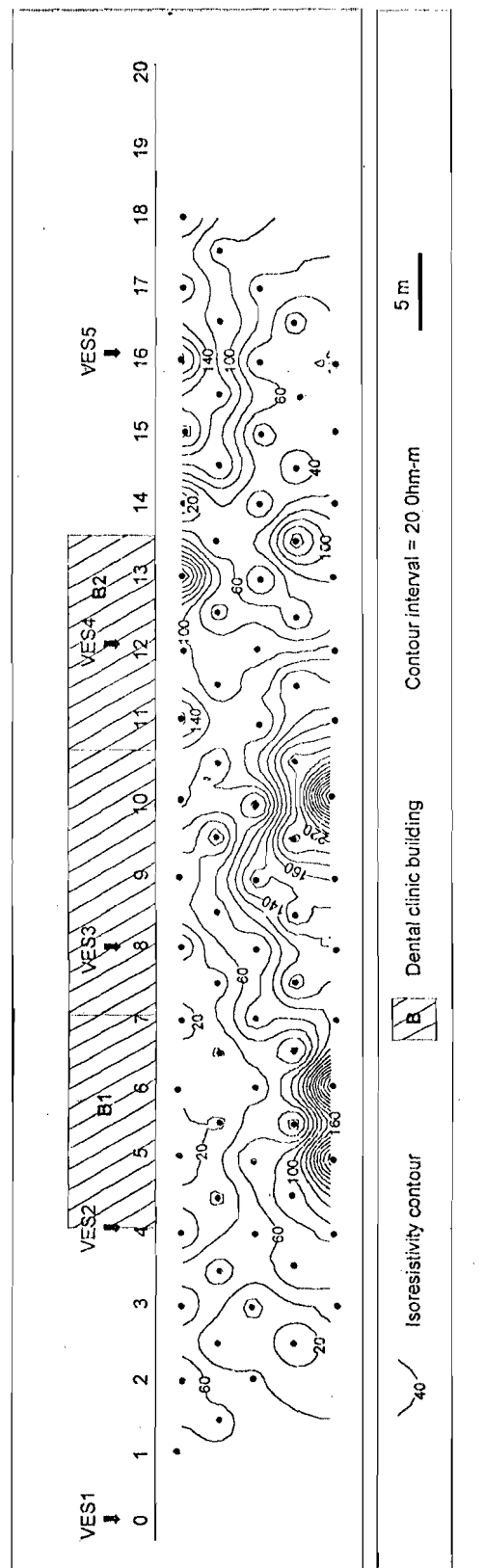


FIG. 8b DIPOLE-DIPOLE PSEUDOSECTION ALONG TRAVERSE 2.

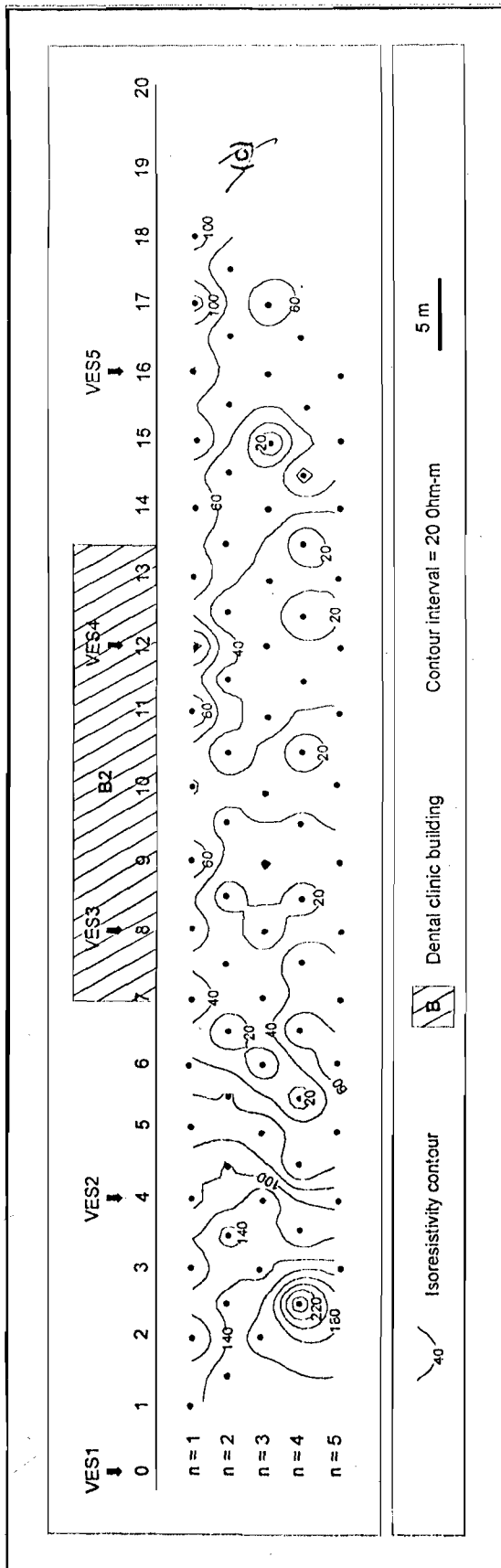


FIG. 8c DIPOLE-DIPOLE PSEUDOSECTION ALONG TRAVERSE 3.

CONCLUSIONS

The Dental Clinic premises in the Obafemi Awolowo University (O.A.U.) campus was investigated using the vertical electrical sounding, dipole-dipole and pole-pole profiling. Measurements were taken along three traverses established with an approximately E-W orientation across the premises.

The geoelectric sections reveal three distinct subsurface layers, which include the topsoil, the weathered layer and the bedrock. The topsoil is composed of clay, sandy clay, clayey sand and laterite, whereas the weathered layer is composed of clay. The depth to the electrical bedrock varies between 3.1 and 30 m. The bedrock depressions along the traverses could be correlated to define a zone with approximate N-S trend. It probably represents an ancient stream channel. Blocks of the clinic (B1 and B2) lie significantly within this zone of depression.

The electrical resistivity maps prepared from the dipole-dipole data delineate highly incompetent clay layer between depth levels of 2.9 and 6.8 m. Conclusions from the pole-pole profiling maps corroborate those from the dipole-dipole maps. Thus, the two blocks (B1 and B2) within the premises are entirely floated on clays. The dipole-dipole pseudosections and inverse model resistivity sections also suggest that the whole premises is underlain by clay, with some patches of sandy clay/clayey sand.

Consistency limit test carried out on few samples from the near-surface clayey substratum (at depth of 1.6 m) gave mean liquid limit (LL) of 30.8 and plastic index (PI) of 15.2, indicating a plastic/incompetent substratum.

In the light of these results, it becomes clear that the failure of the foundations of the two blocks is due to differential settlement precipitated by the flow of the clay at depth. Block B2, at the time of investigation, appeared to have been more severely affected by the failure, as could be observed from more pronounced cracks on its walls. These more severe cracks with a N-S disposition may have arisen from the more pronounced settling of its western end (underlain by thicker layer of clay) in comparison with the eastern end. The settlement at the western and eastern ends of this block was recorded at the time of investigation to be 40 mm and 5 mm,

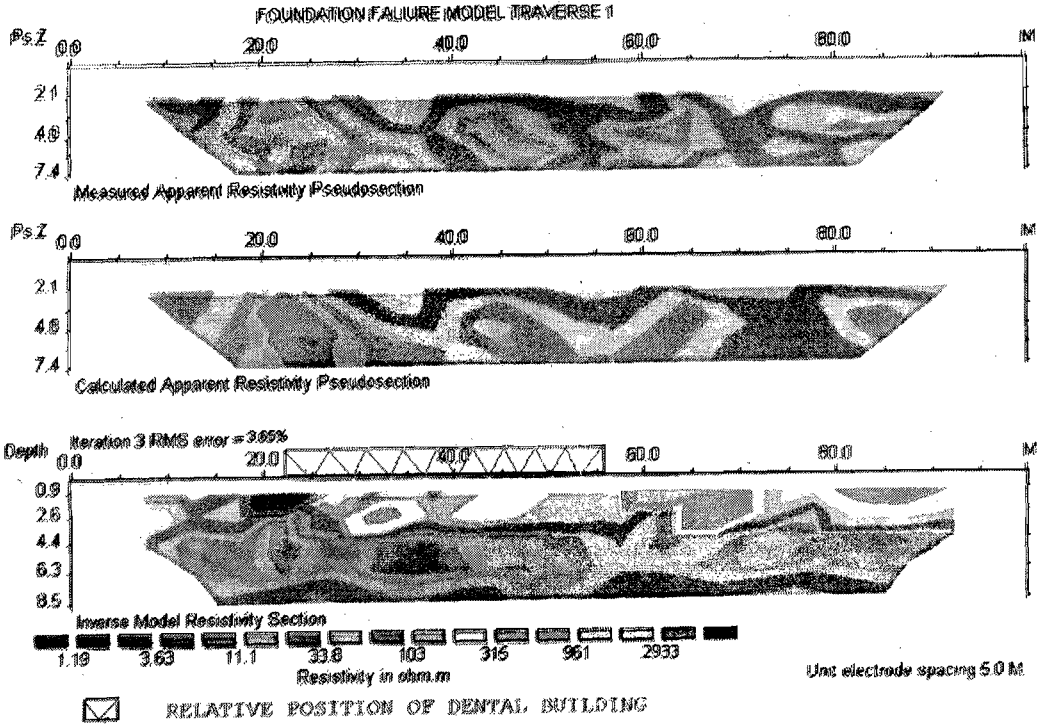


FIG. 9(a) INVERSE MODEL RESISTIVITY SECTION OF DIPOLE-DIPOLE DATA ALONG TRAVERSE 1.

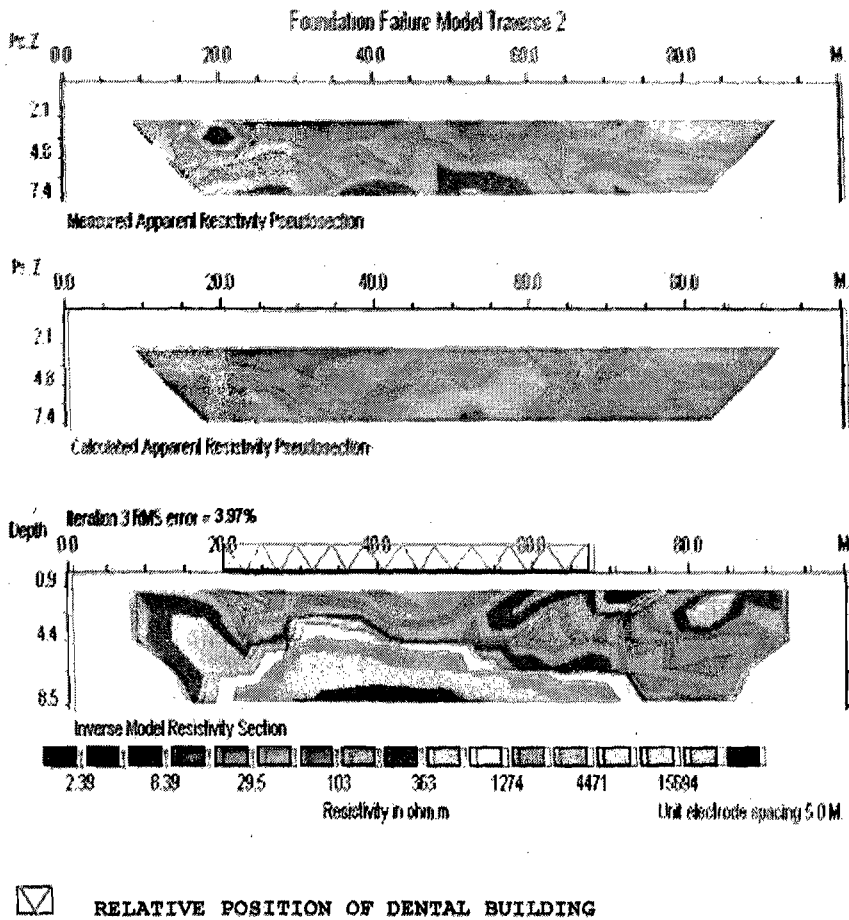


FIG. 9(b) INVERSE MODEL RESISTIVITY SECTION OF DIPOLE-DIPOLE DATA ALONG TRAVERSE 2.

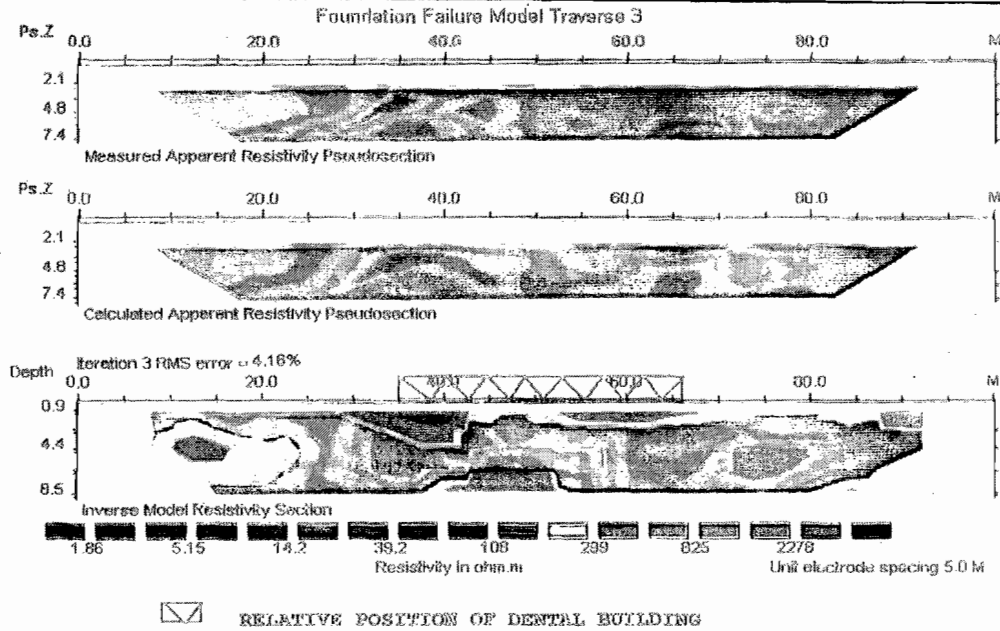


FIG. 9 (c) INVERSE MODEL RESISTIVITY SECTION OF DIPOLE-DIPOLE DATA ALONG TRAVERSE 3.

respectively. On the other hand, the distress of the foundation of block B1 appears less severe, most likely because the thicker and more uniform clay layer underneath it made for more uniform settlement. However, it is envisaged that the integrity of this block will also become severely disturbed as a consequence of continuous settlement over a long time.

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