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Geophysical Investigation of Road Failures in the Basement Complex Areas of Southwestern Nigeria

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Abstract: Causes of failures on three roadways located in the Precambrian Crystalline Basement Complex area of Southwestern Nigeria have been investigated in this study. The electrical resistivity method involving dipole-dipole and Wenner Vertical Electrical Sounding (VES) techniques were utilized. The failed segments of the roadways are characterized by relatively low resistivity (mostly < 200 Ω-m) with the stable zones typically resistive (>> 400 Ω-m). Forms of road failures identified from the study are failures arising from differential settlement on road cut sections that intercept clayey saprolite with high moisture content as observed on Igbaraoke-Igbaraodo roadway; failures precipitated by differential settlements associated with significantly thick, low resistivity clay topsoil as observed on Itaogbolu portion of the Akure-Ado Ekiti roadway and failures initiated and sustained by geological features such as lithological contacts/faults, inclined interfaces between basement rocks and or collapse subsurface strata (e.g., cavity or sinkhole structure) as observed on study segment of Igbaraodo-Ikere Ekiti roadway. Pre-construction geophysical studies of roadways could effectively compliment routine geotechnical studies.

Key words: Roadway, failure, resistivity, dipole-dipole, wenner, faults

INTRODUCTION

The spate of failures of highways in Nigeria has reached bothersome proportions in recent times. The trend has aroused the interest of all stakeholders in the usage and maintenance of Nigeria roadways. Rehabilitation of the roadways has constituted some financial burden to the various tiers of government. While road failures have become a common phenomenon in all parts of Nigeria, the problem is apparently more precarious on cut sections of roadways within the Precambrian basement complex terrains of the country.

Several factors are responsible for road failures. These include geological, geomorphological, geotechnical, road usage, construction practices and maintenance (Adegoke-Anthony and Agada, 1980; Ajayi, 1987). Field observations and laboratory experiments carried out by Adegoke-Anthony and Agada (1980), Mesida (1981) and Ajayi (1987) showed that road failures are not primarily due to usage or design/ construction problems alone but can equally arise from inadequate knowledge of the characteristics and behaviour of residual soils on which the roads are built and non-recognition of the influence of geology and geomorphology during the design and construction phases.

The geological factors influencing road failures include the nature of soils (laterites) and the near-surface geologic sequence, existence of geological structures such as fractures and faults, presence of cavities, existence of ancient stream channels and shear zones. The collapse of concealed subsurface geological structures and other zones of weakness controlled by regional fractures and joint systems along with silica leaching which has led to rock deficiency are known to contribute to failures of highways and rail tracks (Nelson and Haigh, 1990). The geomorphological factors are related to topography and surface/subsurface drainage systems.

Subsurface geologic sequence and concealed geological structures can be mapped by geophysical methods (Olorunfemi *et al.*, 1986; Olorunfemi and Mesida, 1987; Ojo and Olorunfemi, 1995), hence geophysics is quite relevant in highway site investigations (Kurtenacker, 1934; Moore, 1952; Nelson and Haigh, 1990). In the present study, geophysical investigation of causes and characteristics of road failures in some basement complex areas has been carried out.

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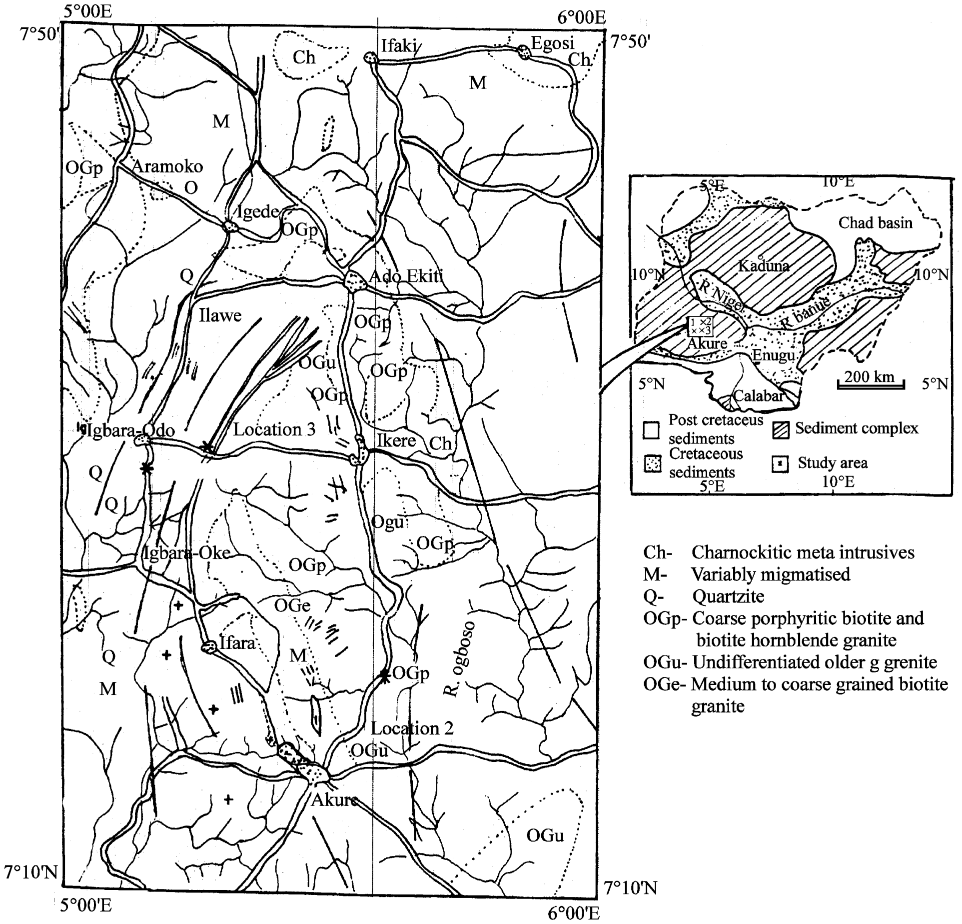

Fig. 1: Local geological map of the study locations

General geology and geomorphology

Location 1: (Igbara Oke-Igbara Odo Roadway): This location is situated at 7 km, along Igbara Oke-Igbara Odo Roadway in Ekiti State. The failed segment at the site selected for this study stretches over a distance of 144 m on a straight portion of the roadway (Fig. 1 and 2). Evidences abound at the site that the pavement structure had been repaired severally. Haunchings, potholes, ruts and cracks characterize the failed segment.

The site falls on low lying undifferentiated migmatite-gneiss complex (Fig. 1). The residual soils belong to the Ondo Association (Smyth and Montgomery, 1962) (Fig. 3).

Location 2: (Akure-Ado Ekiti Federal Roadway): Location 2 is situated at 10 km, along Akure -Ado Ekiti Federal Roadway in Ondo State (Fig. 1). The failed segment selected for studies covers a distance of 71 m on a straight portion of the road (Fig. 4). Potholes, ruts and cracks characterize the roadway within the study area.

The roadway traverses coarse grained porphyritic granites in the south and medium grained porphyritic granite in the north. The granites belong to the Older Granites Group (Fig. 1). The residual soils belong to the Iwo Association (Smyth and Montgomery, 1962) (Fig. 3).

Location 3: (Igbara Odo-Ikere Ekiti Roadway): Location 3 is situated at 3.7 km along Igbara Odo-Ikere Ekiti Roadway in Ekiti State. The selected failed segment which forms part of road cut to grade hillside from Stations 0-12 and embankment over River Omifunfun valley from Stations 12-17 (Fig. 5) is located on a slope. The failed segment covers a distance of 94 m (Fig. 5). Ruts and cracks characterize the roadway at the failed segment.

The site is located on North-South trending narrow quartzite belt which belong to the younger metasediments of the Southwestern schist belt. The quartzites form a distinct topography of steep sided ridge which rises

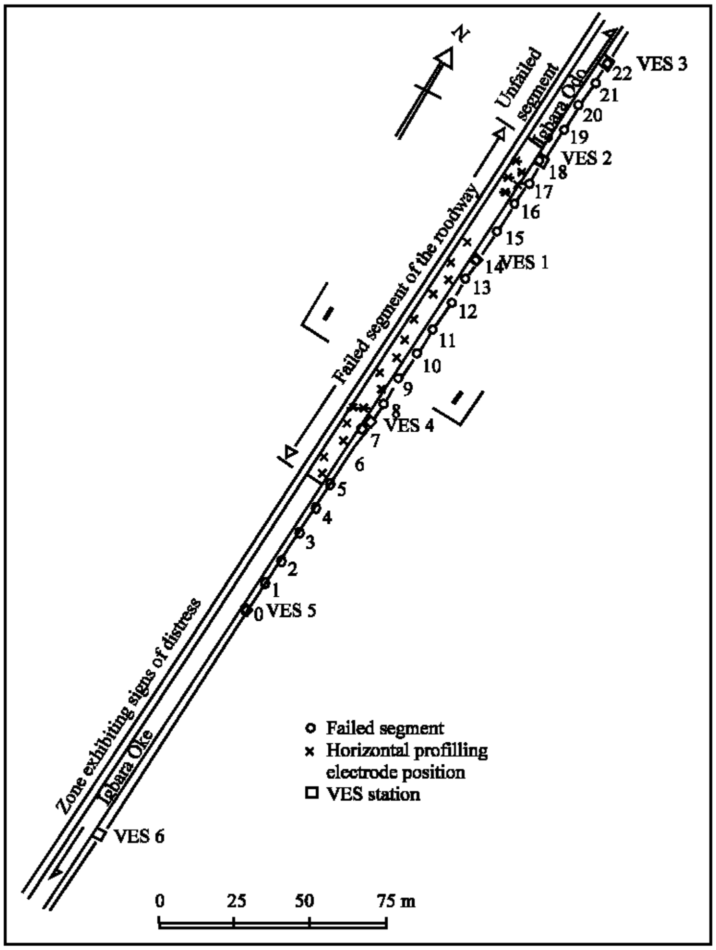

Fig. 2: Site layout at location 1

several metres above the general landscape. The residual soils belong to the Okemesi Association (Smyth and Montgomery, 1962) (Fig. 3).

A remarkable physiographic difference exists between Location 2 on one hand (335 m above sea level) and Locations 1 (411 m above sea level) and Location 3 (427 m above sea level). The three study locations are well drained.

The study locations are situated within the tropical hinterland climatic region of Nigeria where rainfall is usually of double maxima regime. Average yearly rainfall ranges from 1000-1500 mm with about four months of dry season (Iloeje, 1981). The monthly average rainfall for December (month of survey) is 15 mm. Average yearly temperature also varies from 22°C (wet season average) to 30°C (dry season average) while humidity varies from 40% (December average) to 80% (July average). The entire zone of study has damp air which comes from the Atlantic Ocean most of the year.

MATERIALS AND METHODS

Geophysical investigation involving the electrical resistivity method was carried out along both failed and stable segments of the roadway at the three locations. One traverse covering both the failed and stable segments of the roadway was established parallel to the road pavement at each locality. The traverse lengths were 220 m for location 1 and 170 m for locations 2 and 3. Station interval of 10 m was adopted (Fig. 2, 4 and 5).

Horizontal profiling involving dipole-dipole array and Wenner Vertical Electrical Sounding (VES) techniques were adopted (Fig. 6-8). The expansion factor (n) for the dipole-dipole array was varied from 1-4. Inter-electrode spacing of 10 m was utilized. For the shallow depth sounding, the inter-electrode spacing was varied from 0.75-6 m. The stepwise expansions of the electrode separations were undertaken parallel to the roadways on the road shoulders to avoid problems of high contact

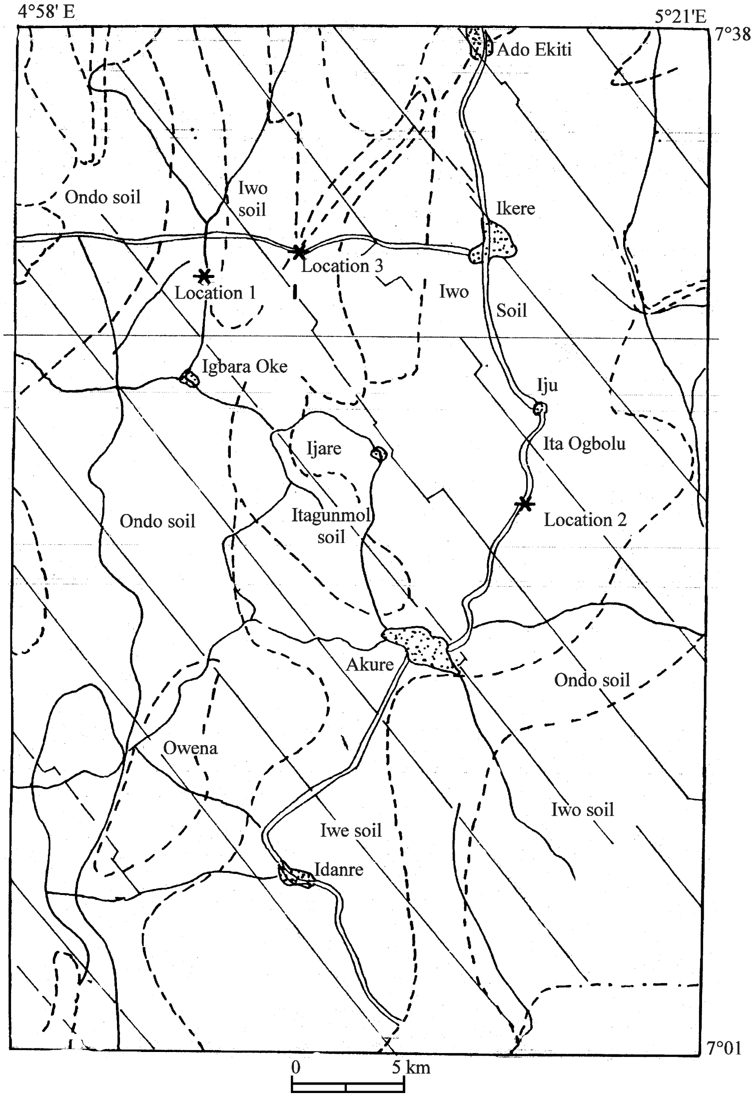

Fig. 3: Soil map of the study area (after Smyth and Montgomery, 1962)

resistance that may arise when electrodes are driven into road pavement materials. VES stations were also located within both the failed and stable segments of the roadway (Fig. 2, 4 and 5).

The dipole-dipole apparent resistivity (ρ_a) are presented as pseudosections (Fig. 9b, 10b and 11 b). The VES data are presented as Wenner pseudosections and geoelectric sections (Fig. 9a and c, 10a and c and 11a and c). VES apparent resistivity values were plotted against electrode separation on log-linear mode and contoured to obtain the Wenner pseudo sections. The sections show resistivity variations at depths of between 0.25 and 2 m.

The VES data were also plotted as depth sounding curves (Fig. 6-8). The VES curves were quantitatively interpreted by partial curve matching and computer iteration techniques.

RESULTS AND DISCUSSION

Location 1 (Igbara Oke-Igbara Odo Roadway): Except at its extreme northern end, the Wenner pseudosection (Fig. 9a) presents resistivity contours whose values generally increase from less than 400 Ω-m at shallow depths (< 0.5 m) to over 1000 Ω-m at depths of up to 2 m. Such characteristic is possibly synonymous with less competent subgrade and more competent substratum. The contours display a sagging configuration between stations 3 and 15 (zone of failure). This is diagnostic of depression arising from settlement. The virtually horizontal resistivity contours indicate a near homogenous upper 2 m of the superficial layer.

The extreme northern end has a similar subsurface geologic setting overlain by a resistive (up to 797 Ω-m)

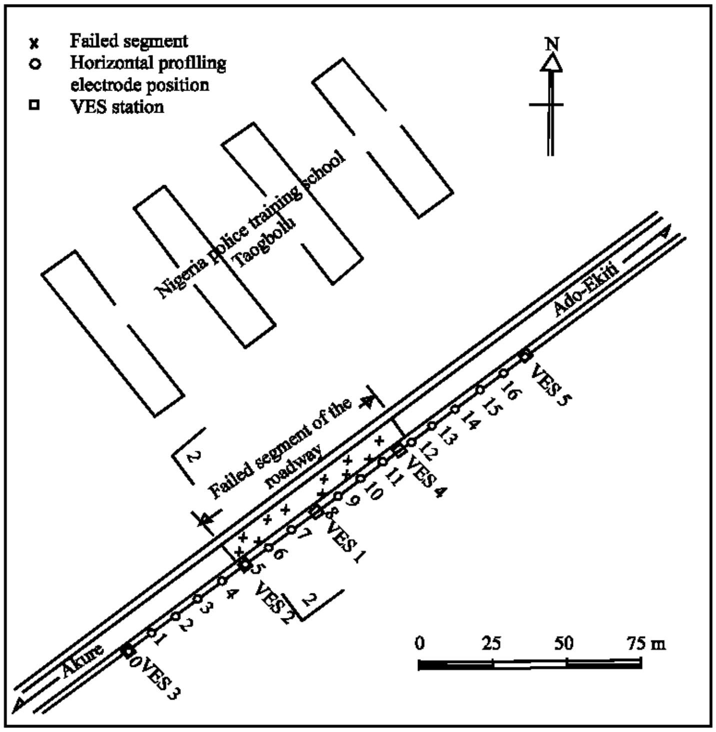

Fig. 4: Site layout at location 2

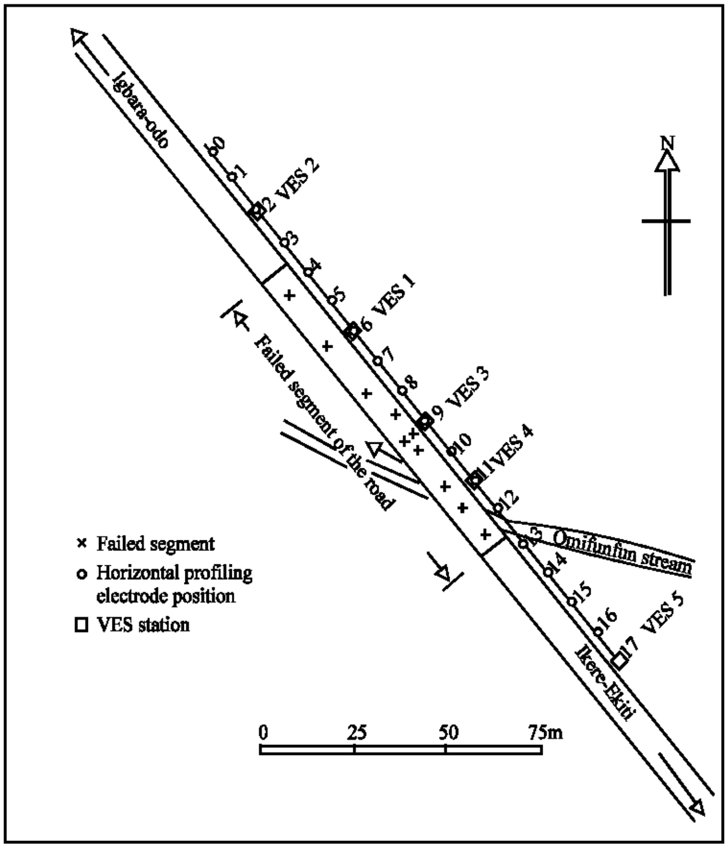

Fig. 5: Site layout at location 3

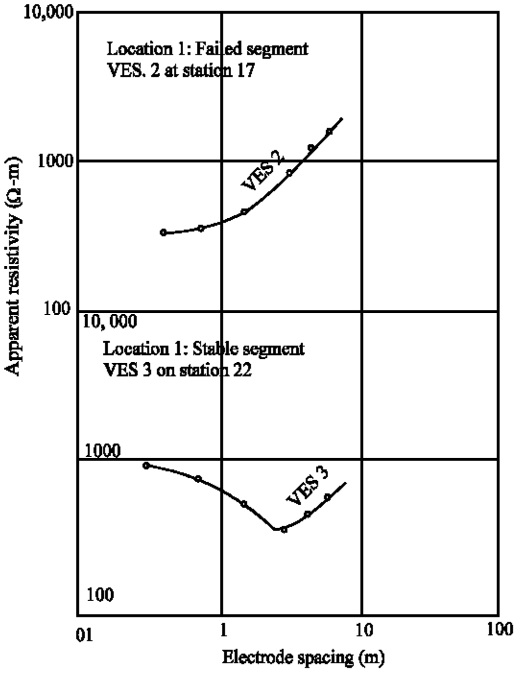

Fig. 6: Typical VES curves obtained at failed and stable segments of location 1

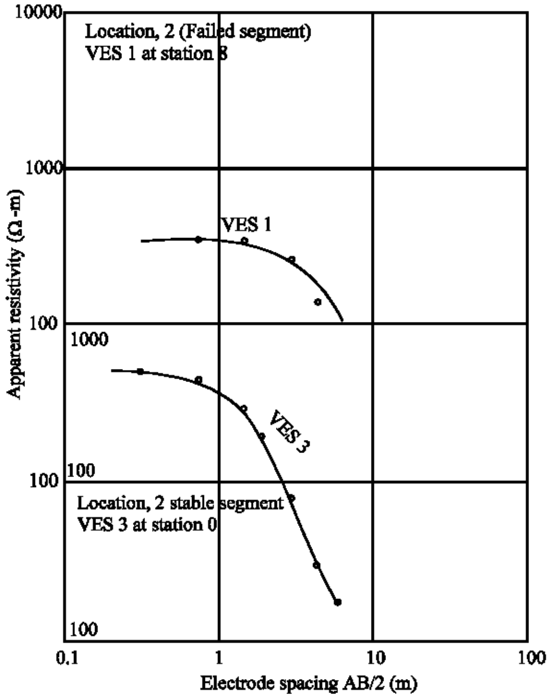

Fig. 7: Typical VES curves obtained at failed and stable segments of location 2

competent lateritic topsoil that was removed due to road cut within the failed segment of the roadway.

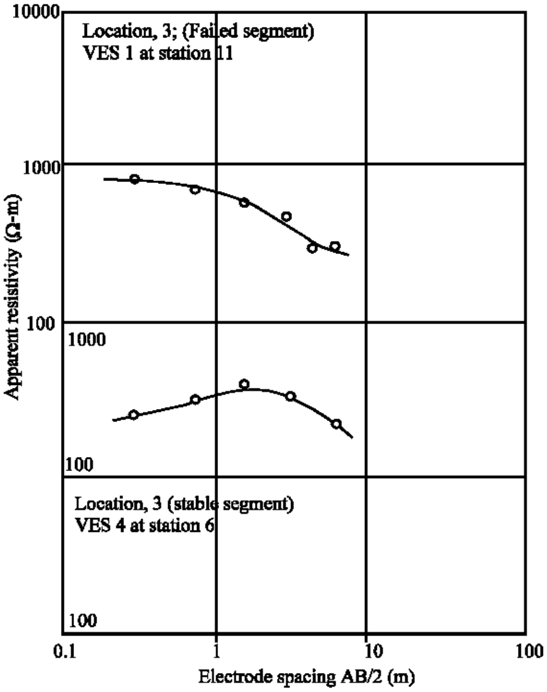

Fig. 8: Typical VES curves obtained at failed and stable segments of location 3

The various degrees of moisture content and presumably the stages of decomposition of the subsurface rocks are manifested in the variable resistivity distribution pattern (37 - 7163 Ω-m) of the pseudosection (Fig. 9b). Intensely weathered rocks of high moisture content are manifested as very low resistivity values which characterize the southern flank of the road section. High resistivity values are manifestations of low moisture content near-surface partially weathered or fresh bedrock. The concealed bedrock relief is irregular. Low bedrock relief may have aided settlement of the subgrade within zones of relatively thick weathered layer and a consequent failure of the roadway.

The geoelectric section (Fig. 9c) shows a topsoil with resistivity values varying between 224 Ω-m (sandy clay) at VES 4 (failure zone) and 950 Ω-m (laterite) at VES 3 (stable zone). The thicknesses generally vary between 0.49 m at VES 6 and 1.60 m at VES 2. The layer resistivities within the failed segment (224 - 335 Ω-m) are slightly less than those obtained (345 - 950 Ω-m) within the stable zone.

The second layer beneath VES 5, 4, 1 and 2 (Fig. 9c) is presumably the basement rock with resistivity values ranging from 1530 Ω-m to infinity. A sandy clay weathered layer with layer resistivities between 213 and 238 Ω-m overlies the basement rock beneath VES 6 and 3.

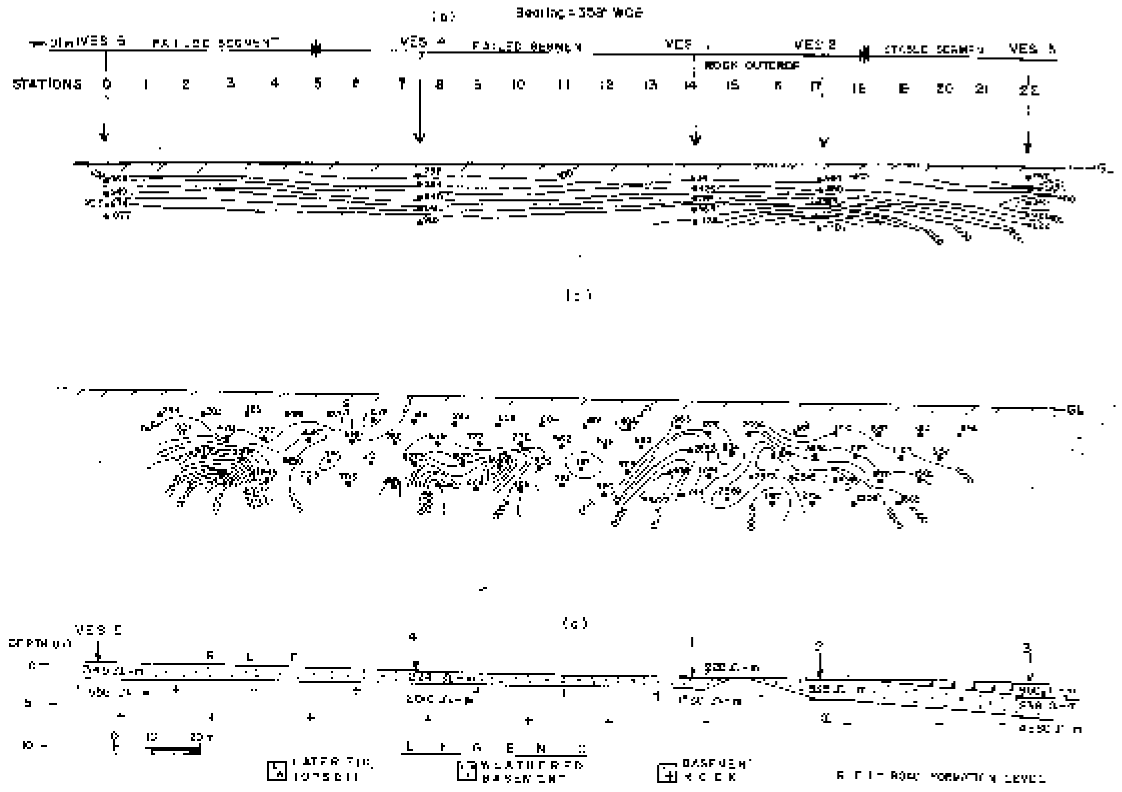

Fig. 9: (a) Wenner pseudosection (b) dipole-dipole pseudosection and (c) geoelectric section at location 1

Location 2 (Akure -Ado Ekiti Roadway): The Wenner pseudosection (Fig. 10 a) presents apparent resistivity whose values range from 50-1062 Ω-m. The resistivity values generally decrease with depth. Such characteristic is diagnostic of decrease in layer competence with depth. Beneath stations 5-12, low resistivity contour lines are predominant indicating high moistening. This zone coincides with the southwestern end of the failed segment of the roadway.

The pseudosection (Fig. 10b) shows resistivity variations that ranged from 31-5805 Ω-m. The northeastern flank of the traverse beginning from station 4 is characterized by low resistivities (mostly < 200 Ω-m). The low resistivity zone has relatively shallow depth extent between station 0 and 6 and significant depth (minimum of 11.7 m, using Roy and Apparao (1971) depth of investigation equation) from station 6 north-eastwards. These low apparent resistivities are typical of clay/sandy clay. The failed segment of the road is typified by low resistivity values. The existence of thick column of clay/sandy clay beneath a significant stretch of the investigated roadway probably accounts for the incessant failure of the roadway in the area. However, high apparent resistivity values (up to 5805 Ω-m) were recorded beneath station 0 to 5 at depth. This is presumably due to presence of near surface basement rock which invariably accounts for the stability of the road pavement structure in the southwestern section.

The geoelectric section along the investigated segment of the road is shown in Fig. 10 (c). The topsoil resistivities range from 330-1150 Ω-m while its thickness varies from 1.05 m beneath VES 5 to 2.9 m beneath VES 1. The lithology varies from clayey sand to lateritic topsoil. The failed segments of the roadway recorded lower topsoil resistivities of 330-460 Ω-m.

The topsoil is underlain by clay/sandy clay whose resistivity values range from 21-128 Ω-m. The bottom of the layer could not be delineated because of the short sounding spread. The failure along this segment of the road is apparently precipitated by differential settlement induced by the clayey substratum.

Location 3 (Igbara Odo -Ikere Ekiti Road): The Wenner pseudosection (Fig. 11 a) displays two distinct resistivity characteristics within the study section. The northwestern flank (stations 0-10) is generally characterized by

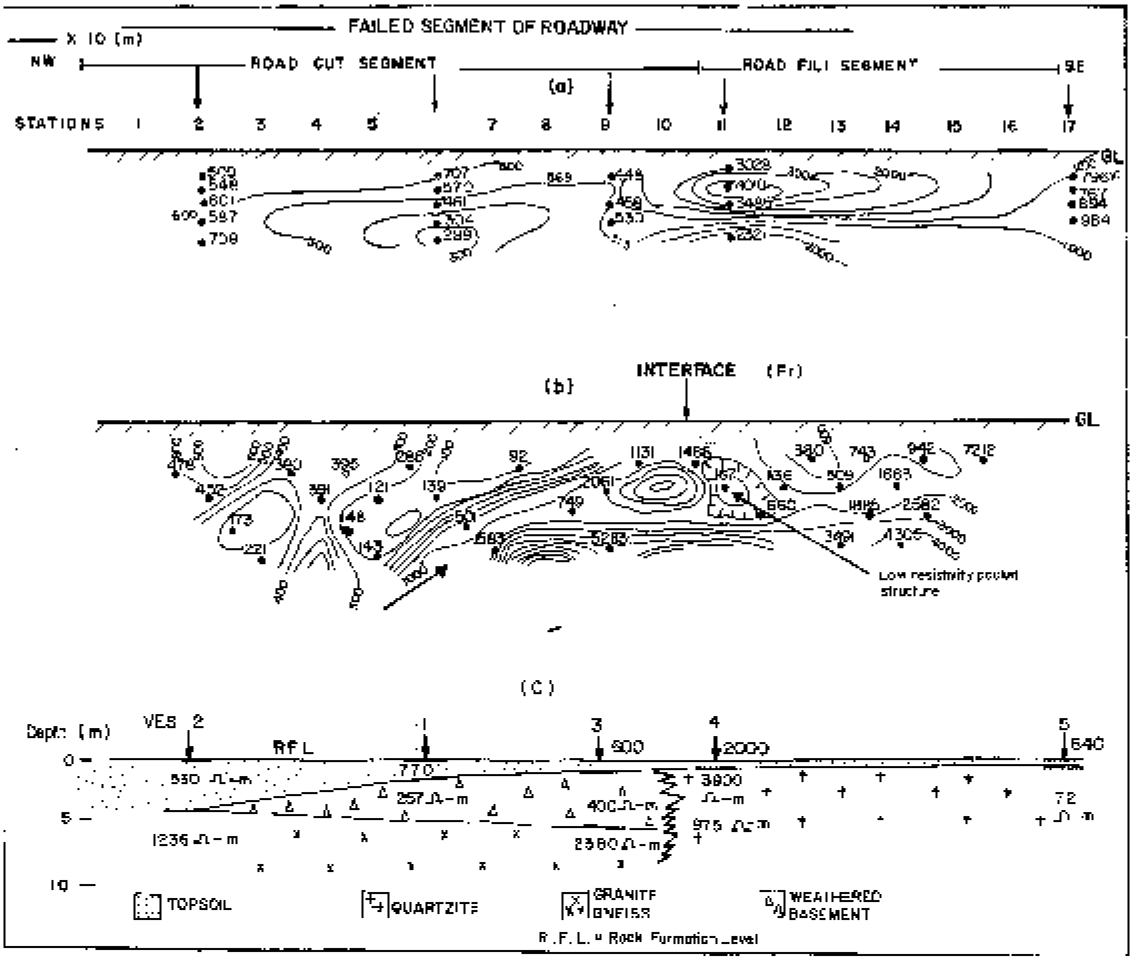

Fig. 10: (a) Wenner pseudosection (b) dipole-dipole pseudosection and (c) geoelectric section at location 2

resistivity values that are lower than 800 Ω-m while the southeastern flank (stations 10-17) is characterized by higher resistivity values (> 1000 Ω-m). The northwestern flank is underlain by gneiss while quartzite underlies the southeastern segment. A lithological boundary exists around station 10.5 (southeastern end of the failed segment) of the study segment of the road. Hence, the road failure is most probably precipitated and sustained by this geological feature which is a plane of weakness where high moisture is retained in all seasons.

The pseudosection (Fig. 11 b) shows a resistivity distribution that varies from 50-12923 Ω-m. A sharp resistivity contrast exists between the low resistivity (mostly < 500 Ω-m) residual soils of the northwestern flank and the high resistivity (up to 12923 Ω-m) quartzite of southeastern flank. The interface F (marked with arrow in Fig. 11b) is a lithology contact which is possibly a fault plane. The plane has a surface expression at around station 10.5 about the southeastern end of the failed segment. Within the high resistivity zone in the southeast is a low resistivity zone that delineates the buried stream channel of River Omifunfun. The southeastern end of the failed segment of the roadway is located on this geological structure.

The geoelectric section is shown in Fig. 11c. The topsoil has layer resistivities and thicknesses of 600-2100 Ω-m and 0.24-4.2 m, respectively. The relatively high topsoil resistivity values may have arisen from its high sand/gravel content. The second layer of the geoelectric section has variable resistivity values occasioned by the structural setting of the underlying basement rocks. On the southeastern flank, the second layer is quartzite with expressions of fractures manifesting as relatively low resistivity values (721-975 Ω-m) within highly resistive (2100-3900 Ω-m) host rock. On the northeastern flank, the second layer resistivity values are

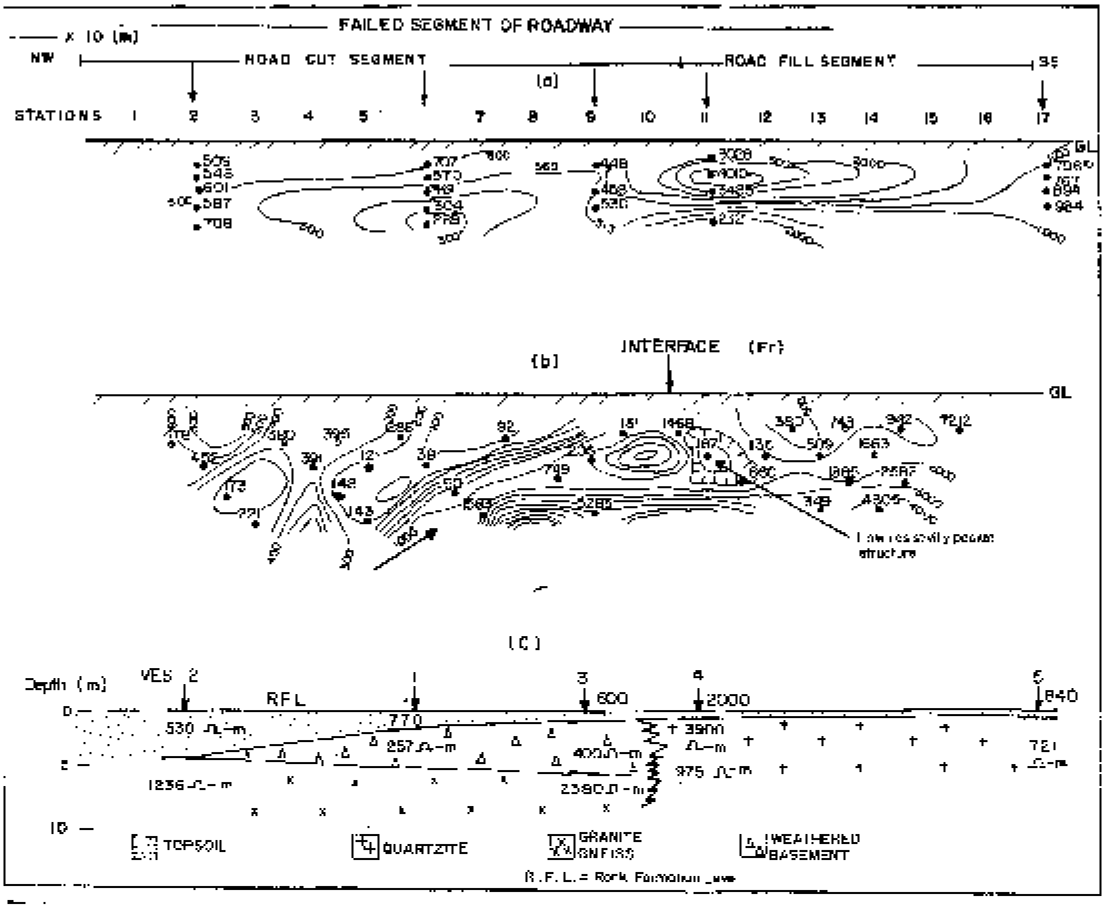

Fig. 11: (a) Wenner pseudosection (b) dipole-dipole pseudosection and (c) geoelectric section at location 3

relatively lower (257-400 Ω-m) thus indicating possibility of presence of weathered granite gneiss basement rocks.

CONCLUSION

Three forms of road failures have been identified from the present study. These are:

- Failures arising from differential settlement on road cut sections that intercept clayey saprolite with high moisture content as observed in location 1.
- Failures precipitated by differential settlements associated with significantly thick, low resistivity clay topsoil as observed in location 2.
- Failures initiated and sustained by geological features such as lithological contacts/faults, inclined interfaces between basement rocks and or collapse subsurface strata (e.g. cavity or sinkhole structure) as observed at location 3.

The investigated zones of failure are generally characterized by relatively low apparent resistivity (mostly < 200 Ω-m and sometimes up to 400 Ω-m). The stable zones are typically resistive (>> 400 Ω-m).

The above analyses are clear demonstrations of the relevance of geophysical investigations in pre-highway route feasibility studies and roadway performance evaluations.

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