# Geoelectrical Investigation of a Proposed Dam Site in Okin Village near Ogbomoso, Southwestern Nigeria.

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## ABSTRACT

Geoelectrical investigation was carried out at a proposed dam site in Okin Village, Ogbomoso, southwestern Nigeria in order to determine the foundation characteristics and evaluate the suitability of the site for an earth dam. The study area is underlain by the crystalline basement complex rocks of southwestern Nigeria comprising Migmatite gneiss, Granite gneiss, Quartzites, and Schist.

The Schlumberger Vertical Electrical Sounding and the Dipole-Dipole horizontal profiling techniques were used. Twenty-five VES stations were occupied along four profiles in the E-W direction with half-current electrode spacing (AB/2) varied between 1 and 100m. Dipole-dipole profiling was carried out along the proposed dam axis with a=5m and n=5. The VES data were interpreted by partial curve matching and computer-aided iteration. The layer parameters obtained were used to generate geoelectric sections which provided definitive subsurface information about the dam site. The dipole-dipole data were interpreted with the DIPPRO™ inversion software to produce the 2D resistivity structure beneath the proposed dam axis.

The results of VES interpretation showed that the subsurface is remarkably inhomogenous and comprises three lithologic units defined by the topsoil, clay/sandy clay and fractured/fresh bedrock. The Dipole-Dipole 2D resistivity structure revealed that the bedrock resistivity ranges from 601Ωm to 99881Ωm beneath the proposed dam axis. The bedrock is shallow with depth generally less than 20m.

On the basis of the aforementioned subsurface information, the study location is considered suitable for siting the proposed dam. The clayey layers will make competent materials for both the dam embankment and the reservoir area. The results of the study are expected to guide the geotechnical engineer in planning the construction of the proposed dam.

(Keywords: vertical electrical sounding, dipole-dipole, dam axis, foundation characteristics)

## INTRODUCTION

As a result of the desire to meet the target of the Millennium Development Goals in terms of water requirements and the need to increase the output from the agricultural activities of the inhabitants of Okin village and its environs, the Federal Government of Nigeria, through the Ogun-Oshun River Basin Development Authority has decided to construct a small earth dam across River Okin in Okin village near Ogbomoso, southwestern Nigeria. Since a thorough understanding of the subsoil characteristics is pre-requisite for determining the suitability of a site for the proposed project, detailed site investigation is required in order to ensure that the subsoils can support a stable foundation and that the dam embankment and the reservoir can successfully impound water as proposed.

Two major factors which often lead to dam failure are foundation settlement and seepage, both of which may be caused by incompetence of subsurface materials and concealed structural features (e.g. fracture and fault). A dam must be able to stop water from escaping downstream through uncontrolled channels. It is therefore imperative to obtain adequate subsurface information at the site of the proposed project. Geophysical surveys have been shown to be an efficient and cost effective complimentary technique to borehole drilling in engineering/geotechnical site investigation in areas underlain by crystalline basement complex and sedimentary rocks (Ojo et al., 1990; Olayinka and Oyedele, 2001; Ako et al., 2006).

The electrical resistivity method has been increasingly used in dam site investigation because they are non-invasive, fast and cost effective (Ako,1976; Artsybashev and Aseez, 1977; Ojo et al., 1990; Ako *et al*., 2006; Okwueze *et al*., 1994). The significant resistivity contrast between the different layers constituting a basement complex geoelectric section makes the electrical resistivity method an attractive geophysical technique for engineering site investigation (Olorunfemi and Mesida, 1987). Vertical sounding is more often used because it is quantitative and depicts the vertical variation of resistivity with depth. The technique allows delineation of the subsurface strata and the determination of their thicknesses. A combination with the dipole-dipole array technique can also present the lateral variation of resistivity and thus provide additional information and better resolved picture of subsurface geology.

Based on the afore-mentioned, the Schlumberger Vertical Electrical Sounding (VES) and the Dipole-Dipole profiling techniques were employed to investigate a proposed dam site in Okin village, near Ogbomoso, southwestern Nigeria (Figure 1) with a view to determining its foundation characteristics and hence its suitability for the facility.

The objectives of the investigation included: (i) delineation of the various lithological units beneath the proposed dam axis and its vicinity, (ii) determination of the geoelectric parameters (resistivity and thickness) of the subsurface layers, (iii) determination of depths to the bedrock along the proposed dam axis and in the adjoining area that would eventually impound water, (iv) determination of the nature and thickness of the overburden and (v) determination of the possible presence of subsurface features which may cause structural failure in the dam foundation.

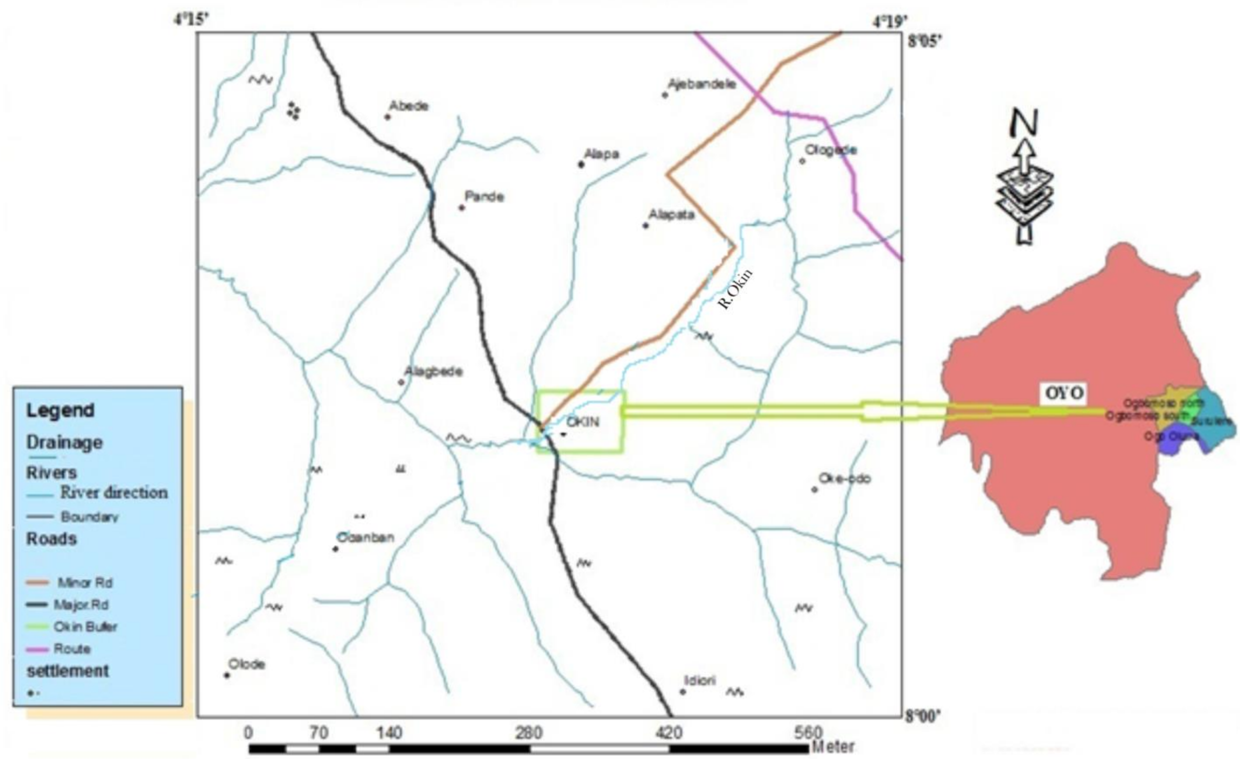


**Figure 1:** Location Map of the Study Area.

The study area is located across river Okin south of Ogbomoso,about 57 kilometres southwest of Ilorin. It lies within longitudes 04° 17.50' E and 04° 17.75' E, and latitude 08° 2.45' N and 08° 2.75' N. The topography varies from 323m above the sea level to 343m at its highest point. The area is well drained by river Okin and its tributaries which jointly form a dendritic drainage pattern. The proposed dam axis is about 350-metre long.

The study area lies within the crystalline basement complex rocks of southwestern Nigeria. Its rock types are those of the Migmatite Gneiss-Quartzite Complex comprising Migmatite gneiss, Granite gneiss, Quartzites, and Schist (Rahaman, 1976). The migmatite-gneiss consists of quartz and feldspar with some noticeable mica. The superficial deposits were formed mainly from the decomposition and disintegration of the existing parent rocks by weathering. They are basically lateritic tropical soils, consisting of a mixture of fine to coarse grained clays, gravels and sands, with varying degree of clay content, depending on the type of parent rock and the degree of decomposition. The color varies from dark brown to reddish brown, depending on the location, depth and moisture content.

## METHODOLOGY

The geophysical techniques employed are the Schlumberger Vertical Electrical Sounding (VES) and Dipole-Dipole horizontal profiling. Twenty-five sounding stations were occupied, 20m apart, along the dam axis and three other parallel profiles (Figure 2). Maximum half electrode spacing (AB/2) was 100m. The VES data were interpreted using partial curve matching in which master curves and their corresponding auxiliary curves were superimposed on the sounding curves to obtain the starting models (Orellana and Mooney, 1966) which were used as input for forward modeling technique carried out by computer software, WINRESIST(R). The layer parameters obtained were then used to generate geoelectric sections.

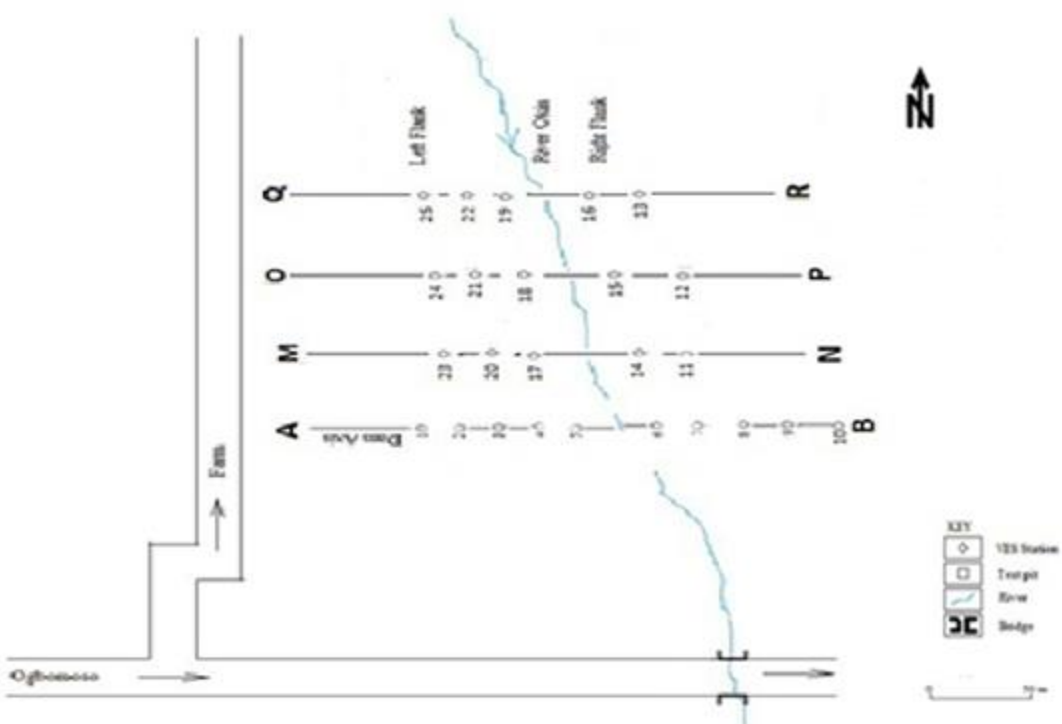


**Figure 2:** Locations of VES Stations along the Profiles in the Study Area.

The dipole-dipole profiling was carried out along the proposed dam axis with electrode spacing a=5m and expansion factor n=5. The data were processed using the DIPPRO™ inversion software which iteratively computes the resistivity response of a two-dimensional model until a reasonable match is achieved between a theoretical pseudosection and the observed pseudosection, based on the finite element method (FEM) of modeling using a 2nd order smoothness constraint {(Dey and Morrisson (1979) and Hohnmann (1982)}.

## RESULTS AND DISCUSSIONS

The summary of the VES interpretation is presented in Table 1. The results show that the subsurface is remarkably inhomogenous in geological composition comprising three lithologic units defined by the topsoil, clay/sandy clay and fractured/fresh bedrock.

The VES curves are the H type; typical of the basement complex (Figure 3). The geoelectric section along the dam axis (Profile AB) is presented in Figure 4.

**Table 1:** Summary of VES Interpretation in the Study Area.

| Layer No. | Layer Resistivity (Ωm) | Thickness(m) | Depth(m) | Inferred Lithology |
|---|---|---|---|---|
| **VES 1 Long. E 04° 17.736´, Lat. N08° 2.759´** | | | | |
| 1 | 1891 | 2.1 | 2.1 | Topsoil |
| 2 | 39 | 8.0 | 10.1 | Clay |
| 3 | 472 | - | - | Bedrock |
| **VES 2 Long. E 04° 17.740´, Lat. N08° 2.751´** | | | | |
| 1 | 1084 | 2.1 | 2.1 | Topsoil |
| 2 | 25 | 7.8 | 9.9 | Clay |
| 3 | 239 | - | - | Bedrock |
| **VES 3 Long. E 04° 17.744´, Lat. N08° 2.741´** | | | | |
| 1 | 1072 | 1.1 | 1.1 | Topsoil |
| 2 | 617 | 1.0 | 2.1 | Laterite |
| 3 | 32 | 6.0 | 8.1 | Clay |
| 4 | 923 | - | - | Bedrock |
| **VES 4 Long. E 04° 17.745´, Lat. N08° 2.729´** | | | | |
| 1 | 1410 | 1.8 | 1.8 | Topsoil |
| 2 | 26 | 7.4 | 9.2 | Clay |
| 3 | 399 | - | - | Bedrock |
| **VES 5 Long. E 04° 17.746´, Lat. N08° 2.731´** | | | | |
| 1 | 1672 | 1.7 | 1.7 | Topsoil |
| 2 | 26 | 5.0 | 6.7 | Clay |
| 3 | 1461 | - | - | Bedrock |
| **VES 6 Long. E 04° 17.773´, Lat. N08° 2.572´** | | | | |
| 1 | 1477 | 1.0 | 1.0 | Topsoil |
| 2 | 202 | 12.2 | 13.2 | Sandy clay |
| 3 | 1950 | - | - | Bedrock |
| **VES 7 Long. E 04° 17.776´, Lat. N08° 2.583´** | | | | |
| 1 | 709 | 1.7 | 1.7 | Topsoil |
| 2 | 133 | 11.4 | 13.1 | Sandy Clay |
| 3 | 1701 | - | - | Bedrock |
| **VES 8 Long. E 04° 17.783´, Lat. N08° 2.591´** | | | | |
| 1 | 830 | 1.0 | 1.0 | Topsoil |
| 2 | 163 | 12.2 | 13.2 | Sandy Clay |
| 3 | 801 | - | - | Bedrock |
| **VES 9 Long. E 04° 17.781´, Lat. N08° 2.601´** | | | | |
| 1 | 843 | 1.0 | 1.0 | Topsoil |
| 2 | 133 | 14.6 | 15.6 | Sandy Clay |
| 3 | 400 | - | - | Bedrock |

| Layer No. | Layer Resistivity (Ωm) | Thickness(m) | Depth (m) | Inferred Lithology |
|---|---|---|---|---|
| **VES 9** | | **Long. E 04° 17.781´, Lat. N08° 2.601´** | | |
| 1 | 843 | 1.0 | 1.0 | Topsoil |
| 2 | 133 | 14.6 | 15.6 | Sandy Clay |
| 3 | 400 | - | - | Bedrock |
| **VES 10** | | **Long. E 04° 17.776´, Lat. N08° 2.580´** | | |
| 1 | 591 | 1.6 | 1.6 | Topsoil |
| 2 | 112 | 16.6 | 18.2 | Sandy clay |
| 3 | 1356 | - | - | Bedrock |
| **VES 11** | | **Long. E 04° 17.783´, Lat. N08° 2.604´** | | |
| 1 | 985 | 0.5 | 0.5 | Topsoil |
| 2 | 106 | 6.5 | 7.0 | Sandy clay |
| 3 | 671 | - | - | Bedrock |
| **VES 12** | | **Long. E 04° 17.770´, Lat. N08° 2.609´** | | |
| 1 | 645 | 1.2 | 1.2 | Topsoil |
| 2 | 94 | 11.3 | 12.5 | Clay |
| 3 | 911 | - | - | Bedrock |
| **VES 13** | | **Long. E 04° 17.780´, Lat. N08° 2.438´** | | |
| 1 | 1480 | 2.3 | 2.3 | Topsoil |
| 2 | 37 | 14.3 | 16.6 | Clay |
| 3 | 100000 | - | - | Bedrock |
| **VES 14** | | **Long. E 04° 17.785´, Lat. N08° 2.438´** | | |
| 1 | 438 | 2.2 | 2.2 | Topsoil |
| 2 | 23 | 7.0 | 9.2 | Clay |
| 3 | 277 | - | - | Bedrock |
| **VES 15** | | **Long. E 04° 17.787´, Lat. N08° 2.433´** | | |
| 1 | 645 | 1.2 | 1.2 | Topsoil |
| 2 | 94 | 11.3 | 12.5 | Clay |
| 3 | 100000 | - | - | Bedrock |
| **VES 16** | | **Long. E 04° 17.780´, Lat. N08° 2.434´** | | |
| 1 | 203 | 1.0 | 1.0 | Topsoil |
| 2 | 22 | 4.6 | 5.6 | Clay |
| 3 | 299 | - | - | Bedrock |
| **VES 17** | | **Long. E 04° 17.780´, Lat. N08° 2.427´** | | |
| 1 | 213 | 0.8 | 0.8 | Topsoil |
| 2 | 27 | 5.4 | 6.1 | Clay |
| 3 | 260 | 12.9 | 19.0 | Sandy clay |
| 4 | 9853 | - | - | Bedrock |
| **VES 18** | | **Long. E 04° 17.785´, Lat. N08° 2.430´** | | |
| 1 | 326 | 0.5 | 0.5 | Topsoil |
| 2 | 587 | 1.6 | 2.2 | Laterite |
| 3 | 66 | 5.8 | 8.0 | Clay |
| 4 | 3403 | - | - | Bedrock |
| **VES 19** | | **Long. E 04° 17.782´, Lat. N08° 2.431´** | | |
| 1 | 1176 | 2.5 | 2.5 | Topsoil |
| 2 | 54 | 15.9 | 18.4 | Clay |
| 3 | 779 | - | - | Bedrock |
| **VES 20** | | **Long. E 04° 17.784´, Lat. N08° 2.429´** | | |
| 1 | 851 | 1.2 | 1.2 | Topsoil |
| 2 | 142 | 6.9 | 8.1 | Sandy clay |
| 3 | 360 | - | - | Bedrock |

| Layer No. | Layer Resistivity (Ωm) | Thickness(m) | Depth(m) | Inferred Lithology |
|---|---|---|---|---|
| | **VES 21** | **Long. E 04° 17.740´, Lat. N08° 2.439´** | | |
| 1 | 794 | 0.6 | 0.6 | Topsoil |
| 2 | 102 | 4.8 | 5.4 | Sandy clay |
| 3 | 714 | - | - | Bedrock |
| | **VES 22** | **Long. E 04° 17.742´, Lat. N08° 2.488´** | | |
| 1 | 1018 | 1.3 | 1.3 | Topsoil |
| 2 | 48 | 9.5 | 10.8 | Clay |
| 3 | 961 | - | - | Bedrock |
| | **VES 23** | **Long. E 04° 17.749´, Lat. N08° 2.727´** | | |
| 1 | 2042 | 1.5 | 1.5 | Topsoil |
| 2 | 65 | 12.0 | 13.5 | Clay |
| 3 | 147 | - | - | Bedrock |
| | **VES 24** | **Long. E 04° 17.765´, Lat. N08° 2.758´** | | |
| 1 | 272 | 2.1 | 2.1 | Topsoil |
| 2 | 119 | 14.5 | 16.6 | Sandy clay |
| 3 | 4492 | - | - | Bedrock |
| | **VES 25** | **Long. E 04° 17.736´, Lat. N08° 2.759´** | | |
| 1 | 239 | 0.8 | 0.8 | Topsoil |
| 2 | 70 | 7.1 | 7.9 | Clay |
| 3 | 2176 | - | - | Bedrock |

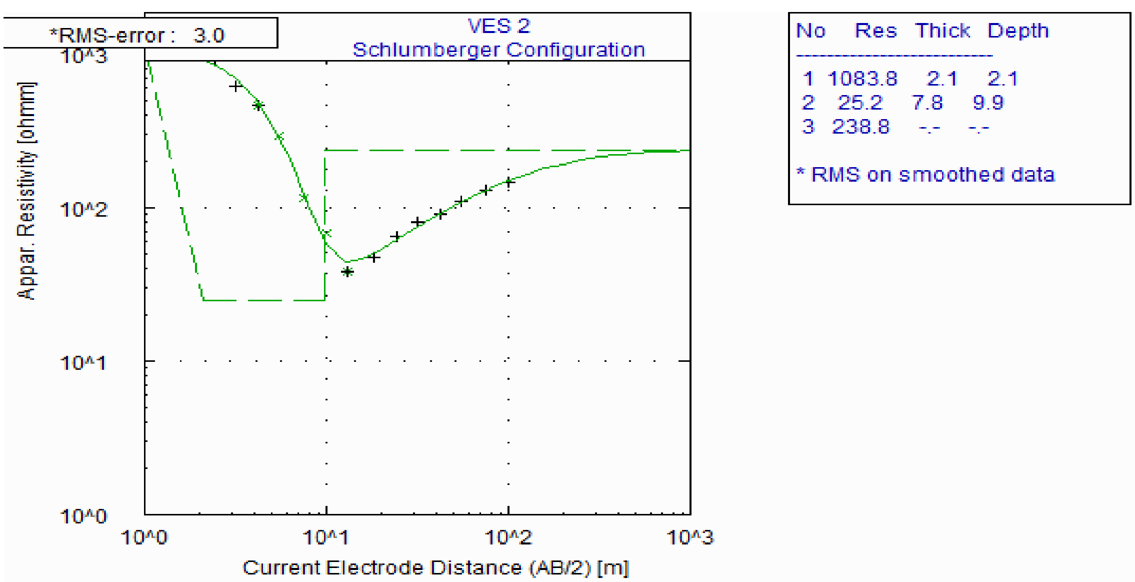


**Figure 3:** Typical Resistivity Curves Obtained in the Study Area.

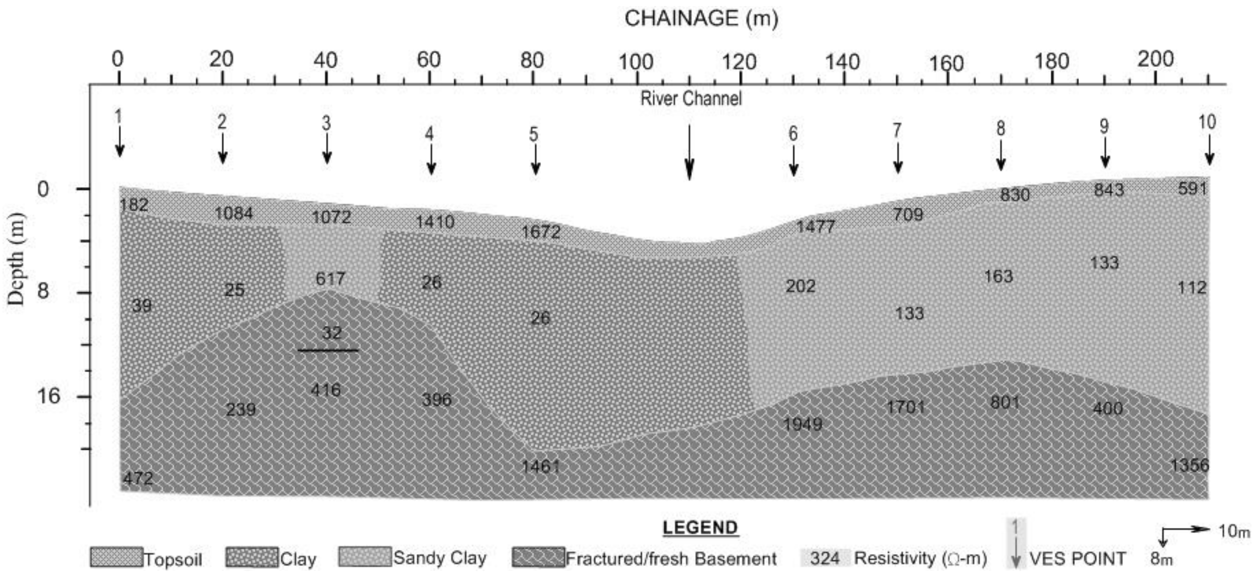


**Figure 4:** Geoelectric Section along the Dam axis AB.

The resistivity of the topsoil varies from 709Ωm and 1891Ωm. while its thickness varies from 1.0.m to 2.1m. The topsoil is underlain by clay layer beneath VES 1-5 and sandy clay beneath VES 6-10. The clay layer has resistivity and thickness which range from 26Ωm to 60Ωm and 5.0m to 8.0m respectively, while the resistivity and thickness of the sandy clay layer range from 112Ωm to 202Ωm and 11.4m to 16.6m respectively. Bedrock resistivity ranges from 239Ωm to 1949Ωm while depth to the bedrock varies between 6.7m and 18.2m.

Figures 5, 6 and 7 show the geoelectric sections along profiles MN, OP and QR, respectively. The sections reveal mainly three geoelectric layers defined by topsoil, clay/sand clay and fractured/fresh bedrock. The resistivity of the topsoil ranges from 203Ωm to 2042Ωm and its thickness from 0.5m to 2.5m. The resistivity of the clay/sandy clay layer ranges from 22.1Ωm to 142Ωm while its thickness ranges from 4.6m to 15.9m. Bedrock resistivity varies from 146.5Ωm to 10,000Ωm. All the sections are underlain by bedrock ridges on both flanks and depressions beneath the river channel.

The results of the dipole-dipole data interpretation along both flanks of the dam axis are presented as 2D resistivity structures in Figures 8 and 9, respectively. Bedrock resistivity ranges from 4219Ωm to 99881Ωm on the eastern/right flank and 1510Ωm to 36025Ωm on the western/left flank. The relatively low resistivity zones (601Ωm to 1420Ωm) at depths between 6m and 9m beneath the latter indicate low to moderate fracturing (Olayinka and Oyedele, 2001). The low resistivity zones within the weathered layer, at depths between 3m and 4m beneath the left flank of the dam axis is indicative of groundwater which was actually encountered in the 3m deep test pits dug at VES points 2 to 5 along the dam axis.

The Isopach map of the overburden shown in Fig. 10 presents the variation in overburden thickness in the study area. The overburden thickness varies between 5.4m and 19.0m. The relatively high values (> 10m) were obtained from the eastern, northeastern and southeastern parts of the study area while the western, northwestern and southwestern parts showed relatively thin overburden (<10m).

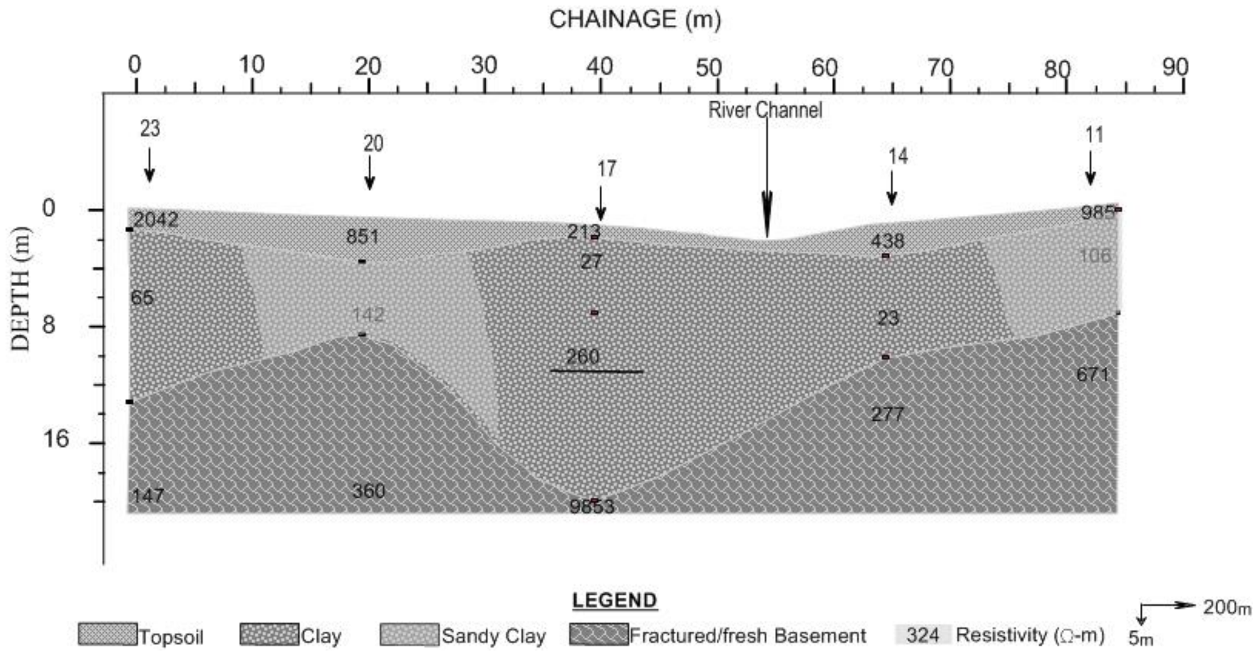


**Figure 5:** Geoelectric Section along Profile MN.

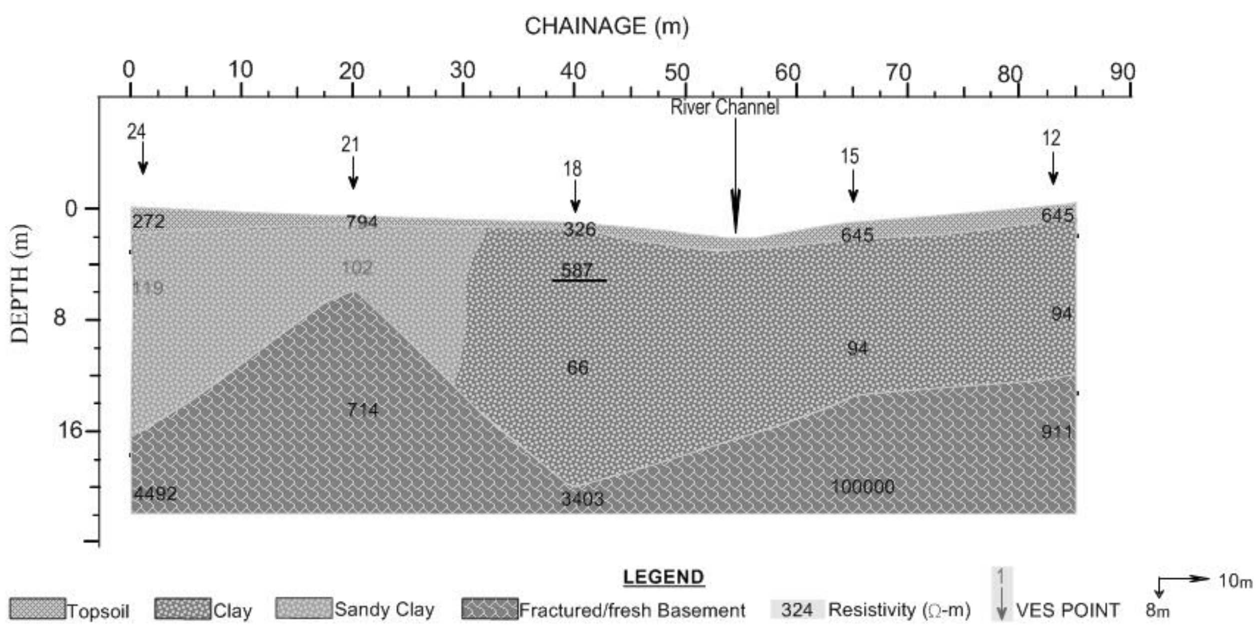


**Figure 6:** Geoelectric Section along Profile OP.

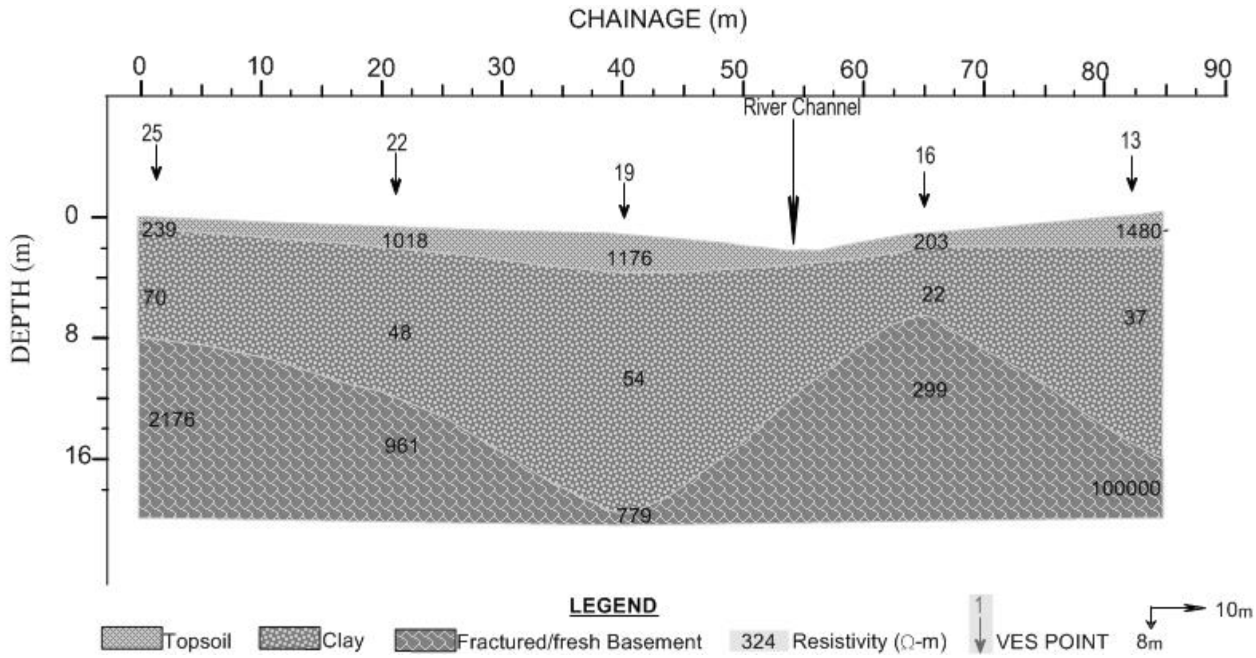


**Figure 7:** Geoelectric Section along Profile QR.

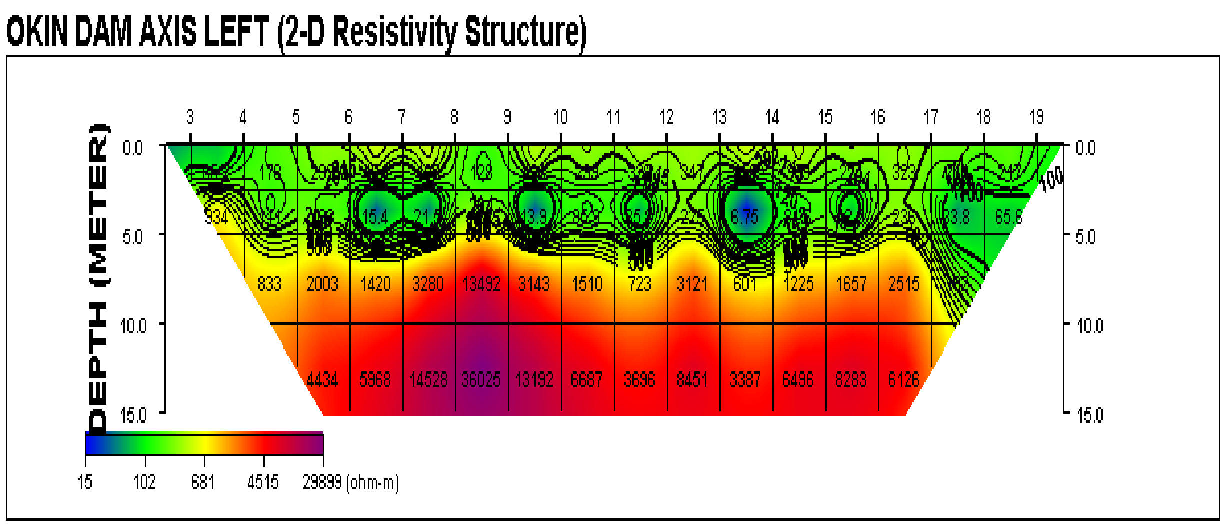


**Figure 8:** Dipole-Dipole 2-D Resistivity Structure along the Western/Left Flank of the Dam Axis.

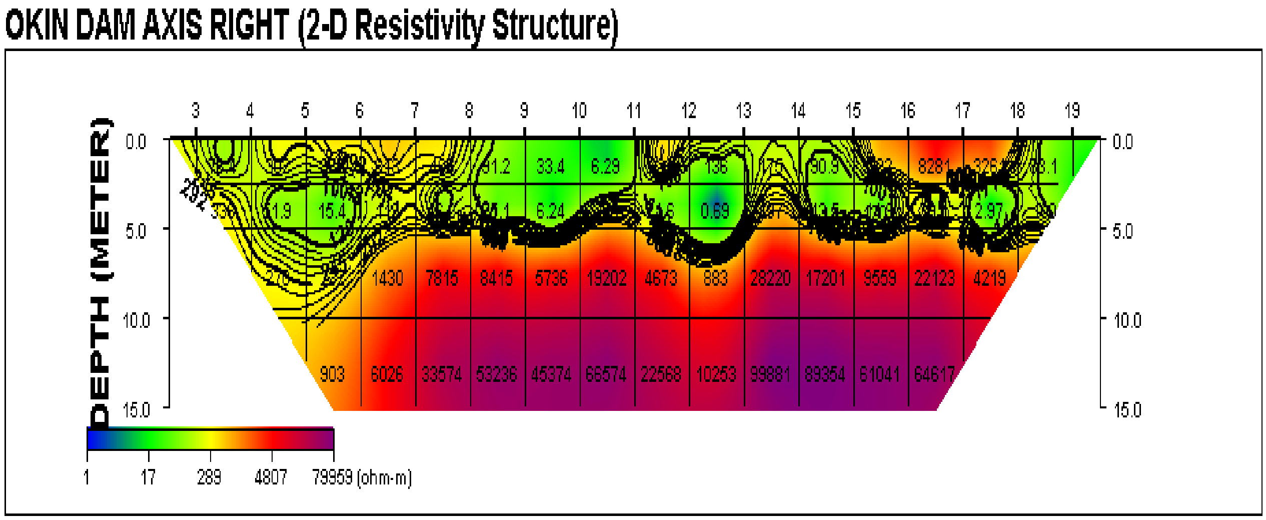


**Figure 9:** Dipole-Dipole 2-D Resistivity Structure along the Eastern/Right Flank of the Dam Axis.

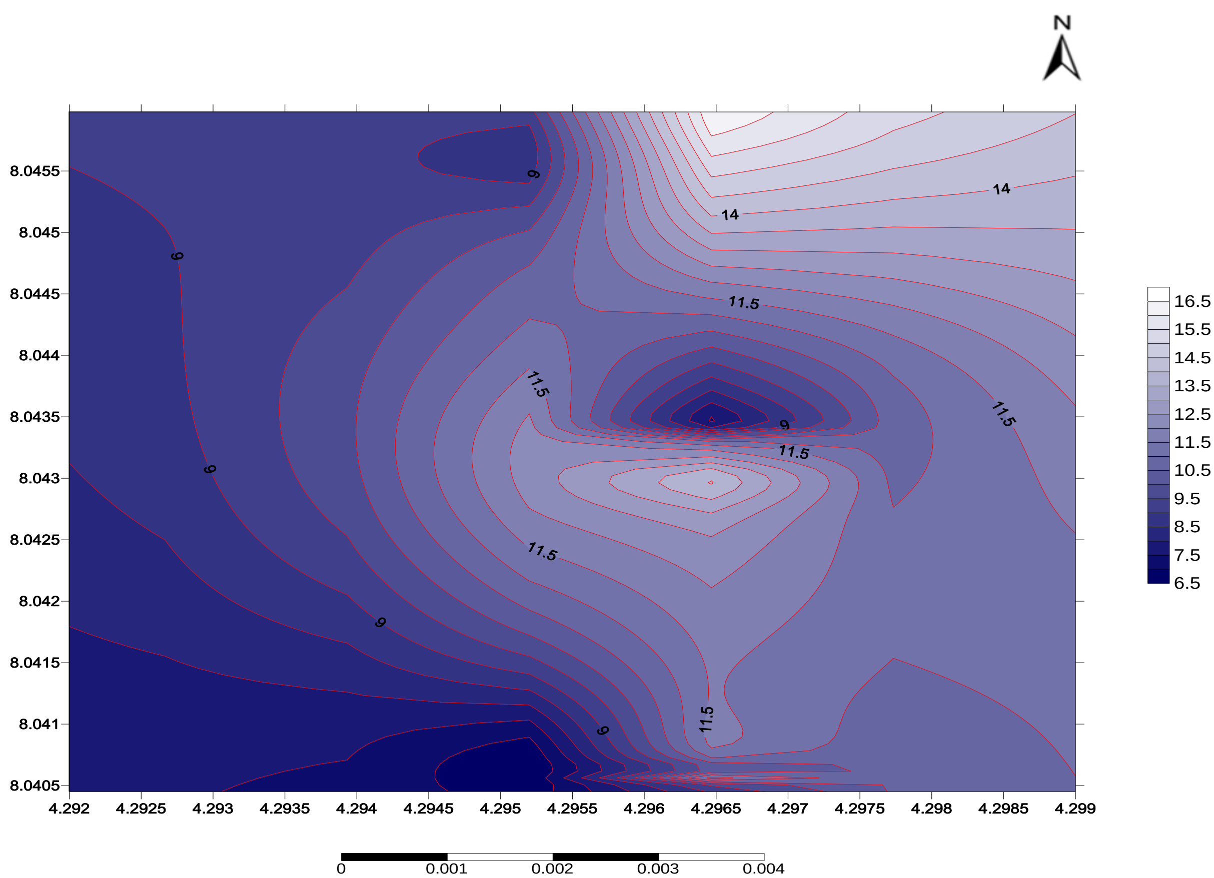


**Figure 10:** Isopach map of the Overburden.

## CONCULSIONS

A proposed dam site across river Okin located in Okin village south of Ogbomoso, southwestern Nigeria was investigated using the Schlumberger vertical electrical sounding and dipole-dipole horizontal profiling techniques in order to determine its foundation characteristics and suitability for an earth dam. The results of VES interpretation showed that the subsurface is inhomogeneous and consists of three geoelectric layers namely: the topsoil, weathered layer and weathered/fresh bedrock. The topsoil is underlain by low resistive layer inferred to be clay/sandy clay mixture. It is predominantly clay beneath the left flank and sandy clay beneath the right flank of the dam axis.

The bedrock is generally shallow; overburden thickness varies between 5.4m and 19.0m. The right flank and the river channels are underlain by relatively thick (> 10m) overburden compared to that of the left flank which is relatively thin overburden (<10m). Groundwater was encountered beneath the left flank of the proposed dam axis at depths less than 3m.

The clayey layers beneath the proposed reservoir area would provide suitable construction materials. There are no indications of major structural features which may threaten the stability of the foundation. The fracturing suspected beneath the western flank of the dam axis is not prevalent. It could therefore be concluded that the subsurface characteristics of the study area is suitable for the construction of the proposed earth dam.

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