GEOPHYSICAL INVESTIGATION FOR ANOMALOUS SEEPAGE IN AND AROUND AN EARTH DAM EMBANKMENT IN OGBOMOSO, SOUTHWESTERN, NIGERIA.

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ABSTRACT

The Self-Potential (SP) method, Schlumberger Vertical Electrical Sounding and Wenner resistivity profiling were conducted at the site of Ogbomoso Water Scheme in order to map possible anomalous seepage in and around the dam embankment. The study area is underlain by rocks of the Precambrian Basement Complex typically porphyroblastic gneiss.

119 SP measurements were taken along the dam embankment, parallel axis downstream and the east bank of the reservoir at 5m intervals. Vertical electrical soundings and Wenner resistivity profilings were conducted along the profiles at station spacing of 30-50 m and 5 m respectively. The current electrode spacing (AB/2) for the sounding was varied from 1 to 133m.

The SP total field profile along the embankment identified possible seepage zones at about 20 m to 50 m from the spillway. The geoelectric section revealed three layers defined as the clayey topsoil (caprock), sandy clay (embankment core) and bedrock. The Wenner profiling delineated anomalously low resistivity values, characteristic of suspected seepage zones occur at depths below 4.0 m between stations 46 and 48, and 36 and 38 about 35-45 m and 75-85 m respectively from the west (spillway) end of the profile. These resistivity lows correlate with the SP minima obtained along the dam embankment. The parallel axis downstream and the east bank of the reservoir are underlain by three geoelectric layers composed of clay/sandy clay/clayey sand topsoil, clay/sandy clay weathered layer and bedrock. There is no evidence of seepage beneath both axes.

Two possible seepage zones were identified within the dam embankment. The integrity of the dam embankment is fairly good but the existence of seepage zones beneath it may constitute serious threat to the safety of the dam.

KEYWORDS: Dam embankment, Seepage zones, SP minima, Resistivity lows, Anomalous.

INTRODUCTION

An embankment dam is a large barrier typically built by placing compacted layers of earth materials across a river course to impound water for various uses which include human consumption, irrigation and generation of hydroelectric power. Among the major causes of embankment dam failure, after overtopping at high flooding discharge, are internal erosion and seepage problem in the embankment and foundation (ICOLD, 1995).

Since it is not possible to have seepage-proof dam, provisions are made for expected seepage and its control in the design of earth dams. Sometimes, however, anomalous seepages do occur, which may exceed the drainage capacity provided for in the design of the dam, or occur along path(s) not considered in the seepage design. The integrity of a dam embankment can be undermined by the existence of geological features (e.g. faults, fractures, fissures, jointed or shear zones) and precipitated seepage zones in the bedrock and/or discontinuities in the structure itself (Olorunfemi et al., 2000). Anomalous seepage may constitute serious threat to the integrity of dam embankment and consequently lead to dam failure. Excessive and unplanned seepage may lead to dam failure, especially in unconsolidated or fractured terrains (Panthulu et al., 2001).

Dam failure normally begins with some abnormality in behavior (e.g. an initial fault) which is not detected until it deteriorates and causes disaster. Majority of dam failure in embankment dams occurred because seepages through the dams were not checked and monitored after construction. Regular inspection and monitoring of dams as well as rapid data analyses and interpretation can play a critical role in ensuring dam safety (ICOLD, 1987).

Apart from reducing impoundment in the reservoir, anomalous seepage weakens the dam embankment and renders it unsafe. The consequent failure of an unsafe dam can be deteriorating as lives and property downstream would be lost to the catastrophe. This underscores the importance of routine post-construction investigation of embankment dams for possible spurious seepage and to propose remediation or repair in order to increase the useful life of the structure and insure the safety of lives and property on the downstream side of the embankment (Butler et *al*., 1989; Olorunfemi et *al*., 2000). One important aspect of post-construction studies is the investigation of earth dam for changes within and under the foot of the embankment (Arandjelovic, 1986).

Geophysical methods play an important role in mapping seepage paths and monitoring changes in seepage with time, and thereby enable the planning of technically and economically worthwhile remedial measures (Panthulu et *al*., 2001). Previous geophysical studies have shown the effective use of electrical resistivity and self-potential methods to detect and characterize seepage conditions in dams (e.g. Sirles, 1997; Butler et *al*., 1989). Both methods are capable of detecting anomalous seepage at an early stage before the safety of a dam is compromised (Sjödahl et *al*., 2005). The self-potential method offers relatively rapid field data acquisition and is often cost effective for initial investigation of an area prior to more intensive studies using other geophysical methods (Sharma, 2002). By using the electrical resistivity method, seepage through an embankment dam can be detected as resistivity low while the self-potential method can detect the seepage zones by measuring the streaming potential generated by flow of water through the subsurface soil or rock (Schiavone and Quatto, 1984; Erchul and Slifer, 1989; Fournier, 1989; Fagerlund and Heinson, 2003).

In this study, self-potential and methods electrical resistivity were employed with a view to delineating the subsurface layers, determining their geoelectric parameters and mapping anomalous seepage in and around the dam embankment at Ogbomoso Water Works, Ogbomoso, southwestern, Nigeria. The earth dam was built across river Oba in 1964 to provide water for Ogbomoso community. It is situated between the geographic coordinates N 8^0 10’05.5”, E 004^0 11’39.5” and N 8^0 10’06.6”, E 004^0 11’51.0" (Fig. 1). The dam is about 300 m long and about 13.5 m high. The dam is aging and there is no record of post-construction seepage assessment or monitoring program, especially employing the fast and cheap geophysical methods, since the it was built. Dams are known to occasionally fail due to a combination of factors which include age, design defects due to poor understanding of subsurface geology, poor construction materials, and lack of monitoring and maintenance (Olorunfemi et al., 2004). The study area is underlain by Precambrian rocks of the Basement Complex of southwestern Nigeria, composed mainly of porphyroblastic gneiss (Rahaman, 1989).

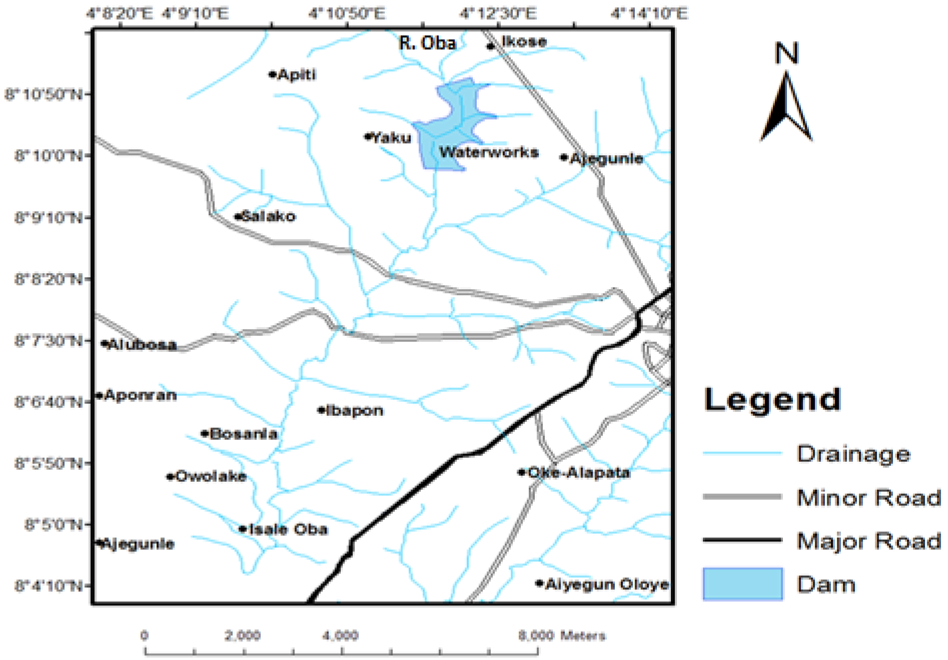


Fig. 1: Location map of the dam site.

METHODOLOGY

The electrical resistivity and self-potential methods were employed to detect and map anomalous seepage along the dam embankment, parallel axis, downstream (at the toe of the dam) and the east bank of the reservoir (the west bank was not accessible). The profiles and the distribution of the SP and VES stations along them are shown in Fig. 2. SP field surveys were conducted along the profiles by measuring naturally occurring potentials difference (voltage) between a pair of non-polarizable electrodes (copper-copper sulphate) by a high-input impedance voltmeter on the surface of the earth. The survey employed the Total-field (Fixed-base) by keeping one electrode at the base and moving the other to successive stations at 5 m interval along the profiles. 119 SP measurements were taken in millivolts (mV) with respect to the base station. The SP data were plotted against distance from the base on excel spreadsheet. Negative anomaly peaks were interpreted to indicate water seepage beneath the profiles surveyed.

The electrical resistivity surveys involved the Vertical electrical sounding and Wenner resistivity profiling techniques and were carried out with a resistivity meter. Measurements in an electrical resistivity survey are normally taken by injecting electrical current into the ground through two current-carrying electrodes and measuring the resulting voltage difference at two potential electrodes. The apparent resistivity is calculated using the injected current, the voltage measured, and a geometric factor related to the arrangement of the four electrodes (Telford, 1990; Kearey et al., 2002; Sharma, 2002). Sixteen (16) Vertical electrical soundings (7 along each of the embankment and downstream axis, 2 along the east bank of the reservoir) were conducted using the Schlumberger electrode array with maximum electrode spacing of 133 m and station spacing of 50 m for the embankment and east bank, and 30 m for the downstream axis. The resistivity data were interpreted by initial partial curve matching and computer-assisted iteration (Zohdy, 1989)

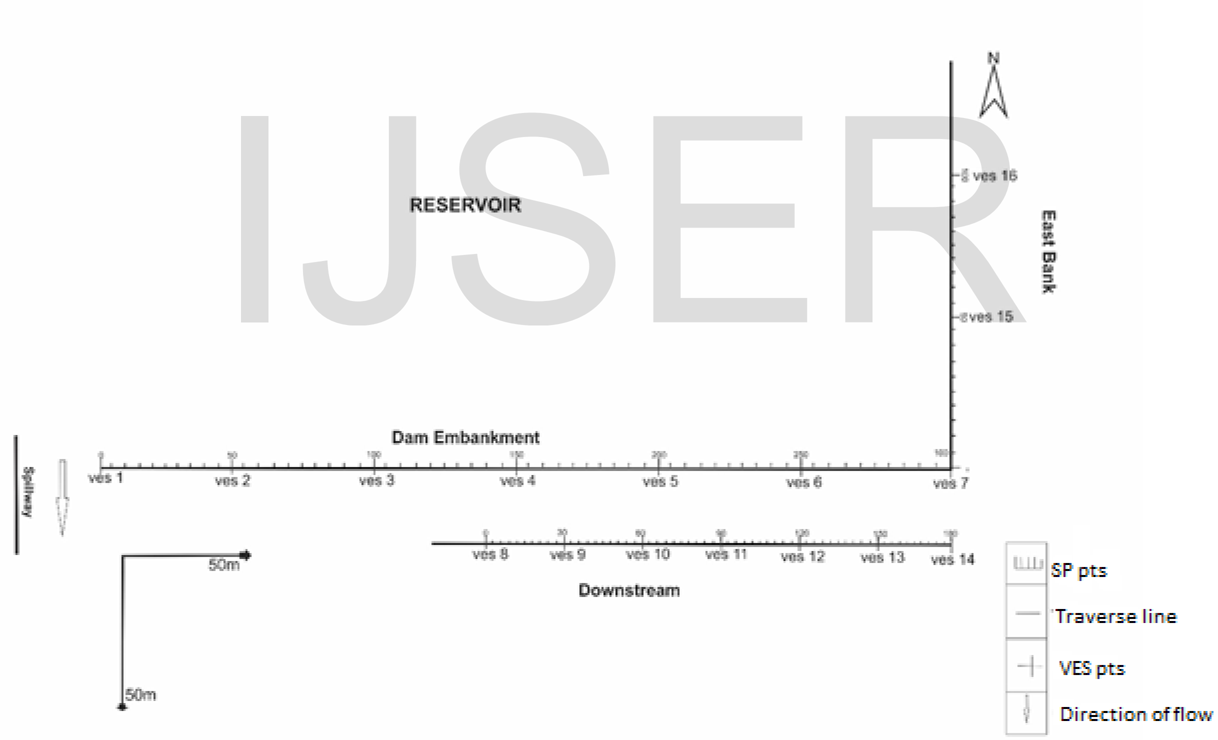


Fig. 2: Field Layout showing VES and SP points along the geophysical profiles.

which generated the VES curves and the geoelectric layer parameters (i.e. resistivity and thickness} used to construct the geoelectric sections along the profiles.

The Wenner resistivity profiling was conducted by keeping all the four electrodes at equal spacing, a =5 m and moving them at the same time along each profile for successive readings. Measurements were repeated along the profiles with electrode spacing, 10 m and 15 m to increase the investigation depth and produce apparent resistivity cross-section. The resistivity data were then inverted using 2D inversion procedures based on the finite element method to generate 2D subsurface structures along the profiles (Dey and Morrison, 1979; Hohnmann, 1982; Loke, 2000).

RESULTS AND DISCUSSION

The profiles obtained from the plots of SP against horizontal distance are shown in Figs 3-5. The seepage zones are located below the trough of the profiles. Total SP profile along the dam embankment shows values ranging from -94.6 mV to 14.07 mV while those along the parallel axis downstream and the east bank of the reservoir vary from -50.8 mV to 15.4mV and 7.7 mV to 15.4 mV respectively. SP anomalies associated with seepage through or under a dam are generally negative when the flow is descending and positive when the flow is ascending and where surface seepage is occurring (Sharma, 2002). The negative SP anomalies of amplitude ranging from -60.8 mV to -94.6 mV, along the dam embankment, at horizontal distance 20-50 m, indicate zones with high streaming potential resulting from water flow (Fig. 3). Prominent SP minima of amplitude -22.6 mV to -50.8 mV observed beneath the parallel axis downstream at distances 10 m, 24 m, 50 m, 80 m, 125 m and 135 m (Fig. 4) while those of amplitude 7.7 mV to 10.3 mV along the east bank of the reservoir at 15 m, 25 m, 40 m, 49 m, 60 m and 89 m (Fig. 5) are suggestive of highly conductive bodies such as clay.

The geoelectric section along the dam embankment (Fig. 6) reveals three distinct layers namely topsoil, weathered layer, and bedrock. The topsoil has resistivity ranging from 3 3 Ωm to 106 Ωm and is 0.2-1.4 m thick. This clay layer constitutes the caprock of the embankment. It is underlain by sandy clay layer with resistivity ranging from 101 to 172 Ωm and thickness from

11.1 m to 23.2 m. This layer constitutes the core of the embankment. Resistivity of the bedrock varies from

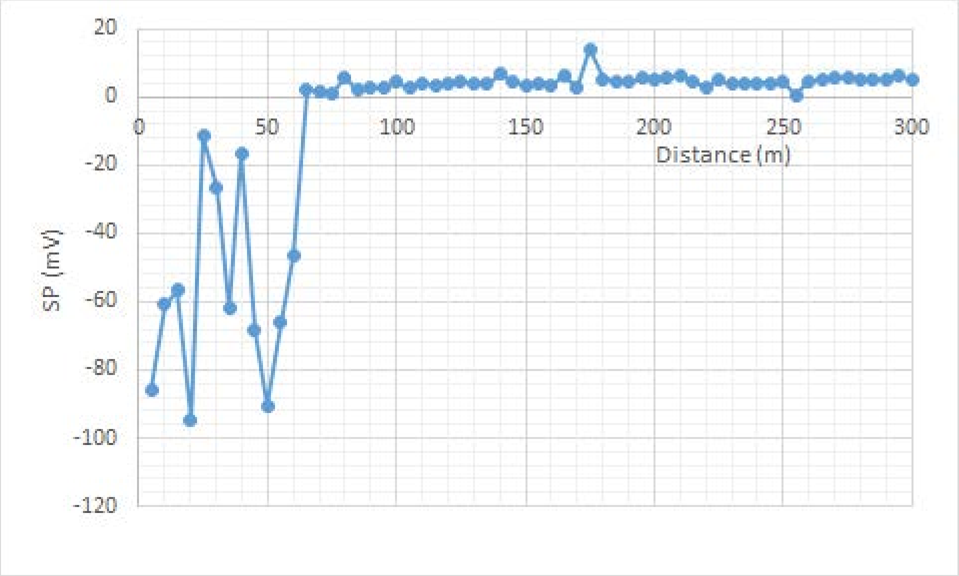


Fig. 3: SP profile along the dam embankment.

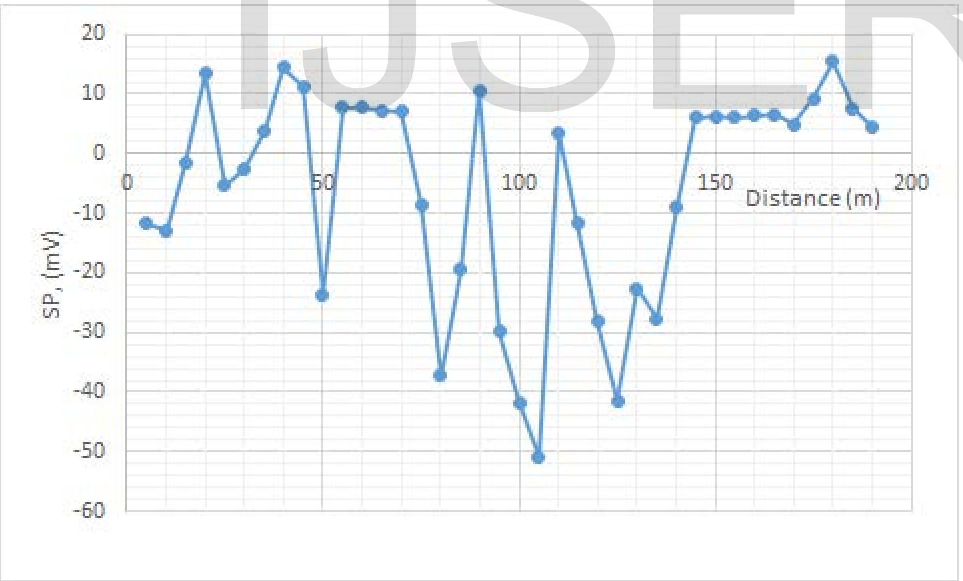


Fig. 4: SP profile along the parallel axis downstream.

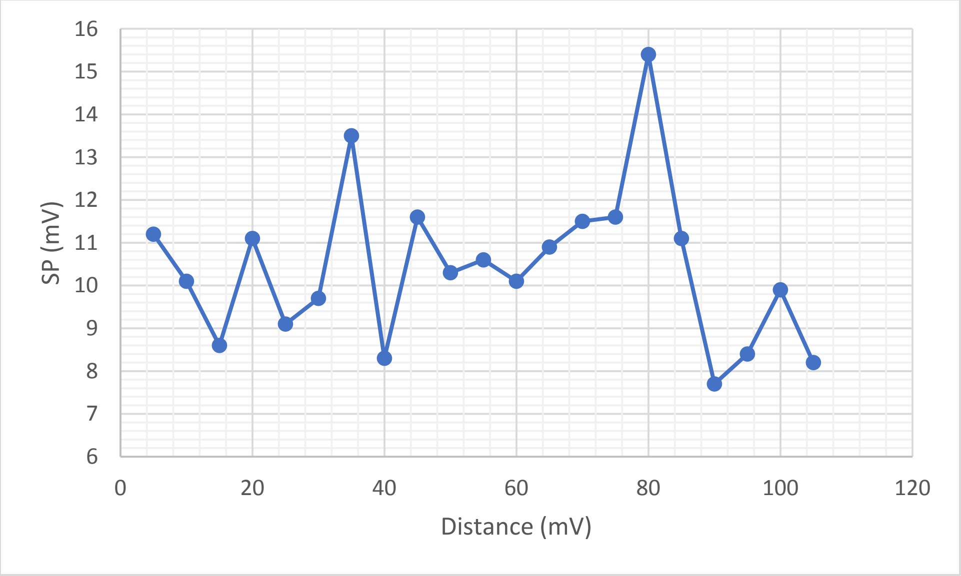


Fig. 5: SP profile along the east bank.

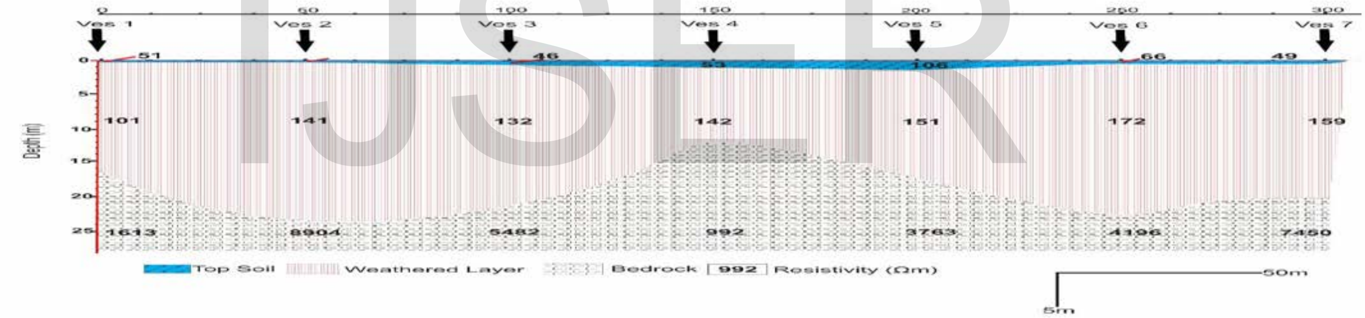


Fig. 6: Geoelectric section along the dam embankment.

992 Ωm to 74509 Ωm indicating fresh bedrock. Depth to the bedrock ranges from 12.1m to 23.4m.

Fig. 7 shows the geoelectric section along the parallel axis downstream in the E-W direction. The topsoil has resistivity ranging from 152 Ωm to 619 Ωm and thickness from 0.6 m to 1.8 m. It is composed of clayey sand eastward and sandy clay toward the west. The resistivity of the weathered layer ranges from 35 Ωm to 283 Ωm suggesting clay/sandy clay and its thickness is 2.7 m to 12.5 m. Bedrock resistivity ranges from 498 Ωm to 9017 Ωm while depth to the bedrock is 3.5-13.1 m.

The results of interpretation of electrical soundings along the east bank of the reservoir show topsoil resistivity values of 98 Ωm to 233 Ωm indicating clay/sandy clay 1.4 m-1.6 m thick. The topsoil is underlain by clay layer of resistivity 29-96 Ωm and thickness 1.9-4.0 m. Resistivity of the bedrock ranges from 2365 Ωm to 2596 Ωm while depth to the bedrock varies from 3.3 m to 5.6m.

The distribution of resistivity within the dam embankment is presented in Fig. 8. The inverse resistivity model shows resistivity values varying between 43.7 Ωm and 499 Ωm. The dam embankment is mainly underlain by materials of low resistivity values (generally less than 250 Ωm) suggestive of clay and sandy clay. Anomalously low resistivity values, characteristic of suspected seepage zones occur at depths below 4.0 m between stations 46 and 48, and 36 and 38 about 35-45 m and 75-85 m respectively from the west (spillway) end of the profile. These resistivity lows correlate with the SP minima obtained along the dam embankment. The integrity of the dam embankment is fairly good, based on layer resistivity/lithological composition (Olorunfemi et al., 2000), but the existence of seepage zones beneath it may pose serious threat.

The inverse resistivity model along the parallel axis downstream near the dam toe shows resistivity values varying between 14.0 Ωm and 33078 Ωm (Fig. 9). The subsurface is heterogeneous comprising clay/sandy clay/clayey sand mixture. The low resistivity values ranging from 14.0 Ωm and 38.1 Ωm observed in the topsoil between stations 10 and 15, 16 and 19, 22 and 30, and 32 and 33 up to about 2m depth from surface is suggestive of wetness from surface rain water, as the survey was conducted during the rainy season. The bedrock is shallower at the west end, occurring at about 2.5 m beneath the surface, while its depth is 5.0 m and more toward the east end.

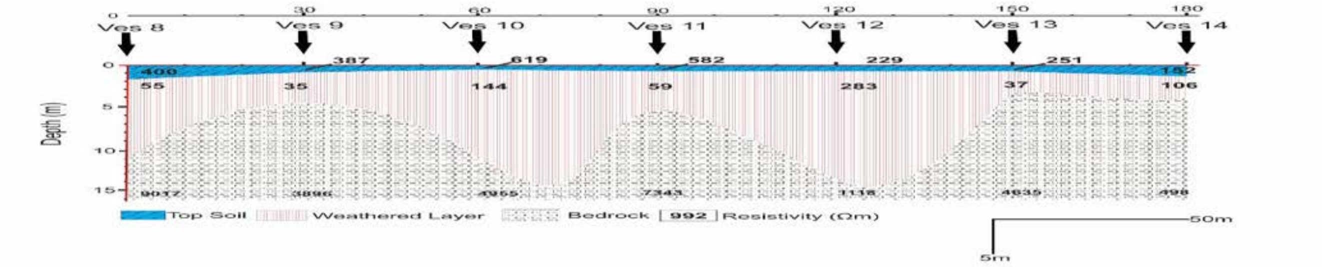


Fig. 7: Geoelectric section along parallel axis downstream.

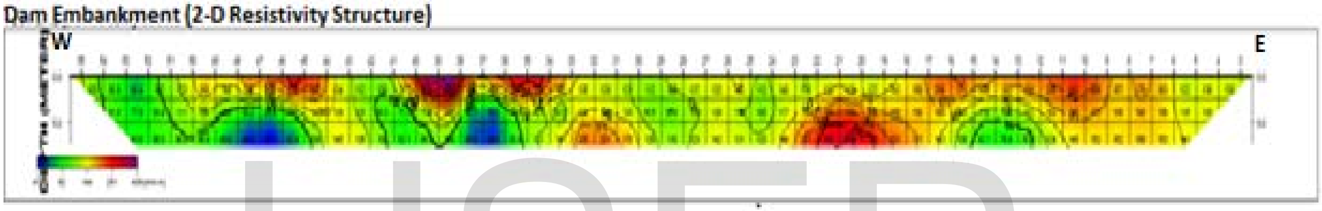


FIG. 8: Inverse resistivity model along the dam embankment

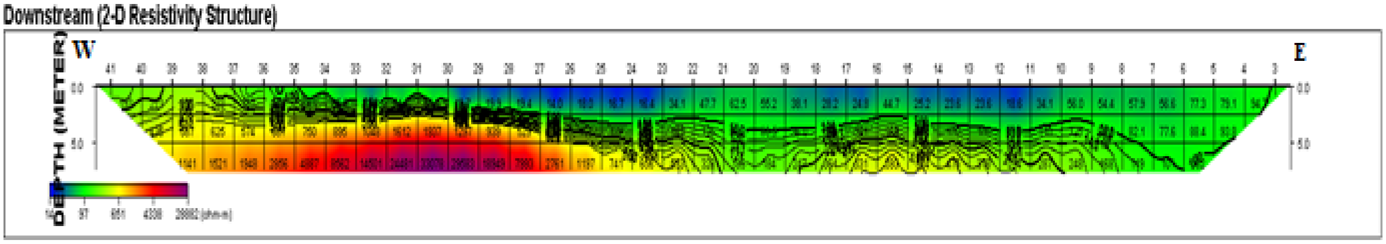
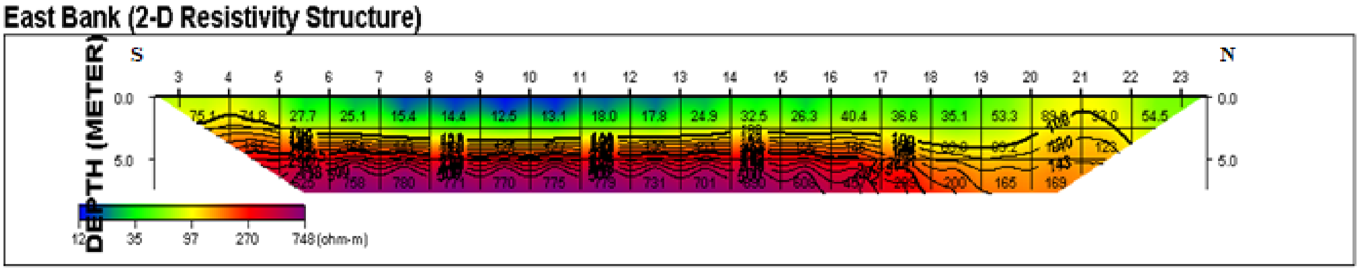


FIG. 9: Inverse resistivity model along parallel axis downstream.

The inverse resistivity model along the east bank of the reservoir (Fig. 10) reveals resistivity ranging from 14.4 Ωm to 780 Ωm. The low resistivity zone occurring between stations 7 and 13, at the surface indicates wetness from rain water. The bedrock is shallow at about 3.0-4.0 m.



East Bank (2-D Resistivity Structure)

FIG. 10: Inverse resistivity model along east bank of reservoir.

CONCLUSIONS

Seepage assessment has been made on the earth dam at Ogbomoso waterworks using vertical electrical sounding, and self-potential and Wenner resistivity profiling. The dam embankment comprises three layers defined as low resistivity caprock underlain by the clay/sandy clay embankment core and a resistive basement bedrock. The Wenner inverse resistivity model of the dam embankment is consistent with the three-layer model of the resistivity sounding. The integrity of the embankment is fairly good, based on the resistivity/lithological composition of its core. However, there are anomalously low resistivity values characteristic of possible seepage zones at depths below 4.0 m between stations 46 and 48, The results of vertical sounding and Wenner profiling for the parallel axis downstream and east bank of the reservoir revealed clay/sandy clay/clayey sand topsoil underlain by low resistivity weathered layer (clay/sandy clay) and high resistivity basement bedrock. The low resistivity clay layers are indicated by the SP minima on the total field SP profiles. There is no evidence of seepage beneath both profiles. Regular post-construction investigation for potential seepage is recommended at the damsite in order to put in place remedial measures where necessary.

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