

Geophysical Investigation of Oba Earth-Fill Dam Embankment using Electrical Resistivity Method

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Abstract

Continual post-construction checks on dam embankment are inevitable to forestall the possible catastrophes associated with its structural failure. In view of this, electrical resistivity (ER) surveys involving vertical electrical sounding (VES) and dipole-dipole profiling were conducted along the Oba dam embankment as a part of routine deformation monitoring for any possible seepage(s) around the dam embankment. Thirty-one vertical electrical soundings and thirty-five dipole-dipole horizontal profiling data were carried out on a 350 m long (west-east trending) traverse established along dam embankment. The iterated VES curves were mainly KH-type suggesting that Oba dam embankment is underlain by four geoelectric layers; topsoil (caprock), fill (granite materials), core (plastic-clay/wet clay) and basement bedrock with resistivity values range of between 53-249 Ω m, 205-1084 Ω m, 15-124 Ω m and 281-1375 Ω m, respectively. The dipole-dipole 2-D resistivity structure along the dam embankment showed no evidence of structural distress/weakness within the underlying sequences. Therefore, by integrating results obtained from geoelectric section and 2D resistivity structure based on the layer resistivity/lithological composition of the core materials (15-124 Ω m/plastic clay/clay/sandy clay), Oba earth-fill dam embankment integrity was good to very good indicating no seepage zone(s).

Keywords

Geophysical, Electrical resistivity, Oba earth-fill dam, Embankment, Ogbomoso

Introduction

Dams are structures that prevent the flow of water and get it accumulated in a reservoir, river or stream, etc. Dams can be constructed from concrete, stones, masonry, loosed rock, earth wood, metal, or a combination of these materials. Hence, gravity, buttress and arch dams are possibly built. Earth-fill dams are examples of gravity dams which consist of an impervious core made up of impermeable earth materials such as clay overlying impervious

bedrock overlain by a less impervious caprock [1]. The Oba dam which is the focus of the present study is an example of an earth-fill dam.

Oba earth-fill dam was constructed in 1964 with a view to supplying the inhabitants of Ogbomoso and its environs potable water through a well-designed waterworks plants established close to the dam. The Oba reservoir (lake) derives its water content from river Oba in the area (Figure 1). The waterworks with expected life

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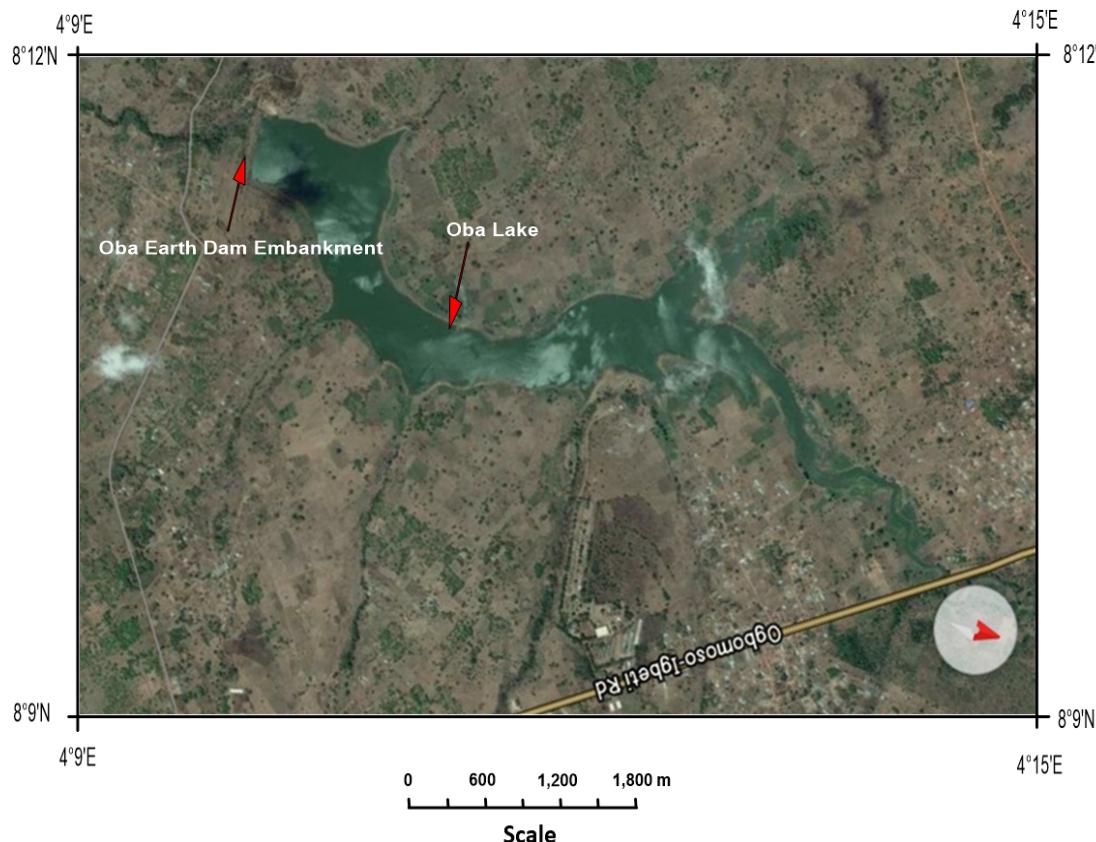


Figure 1: Aerial view of oba lake and the embankment from google earth map.

span of 50 years was designed to produce about 4.0 million litres per day. However, at present, the quantity of water being produced was about 2.8 million litres per day [2]. At present, Oba earth-fill dam is about fifty-five (55) years of age, hence, adequate attention is required to check the integrity of its embankment in order to prevent it from sudden collapse.

The catastrophes (loss of human and aquatic lives etc.) usually associated with dams' failure are immense if the structure is breached or damaged. The integrity of a dam embankment can be undermined by the existence of geological features (e.g. faults, fractures, fissures, jointed or shear zones) precipitated seepage zones in the bedrock and/or discontinuities in the structure itself [3]. Earth dams in their natural state experience some degree of seepage and spillage flow from the reservoir and through permeable soils. Age of the dam, poor construction material; defect in the design can also responsible for dam collapse [3]. All the factors may cause the physical properties of the materials in the dam to change.

However, the electrical resistivity methods have the potential of detecting the physical state of such change. The use of electrical resistivity methods is gaining popularity among the geophysicists for post-construction deformation checks of seepage from drains in and around large dams is important to anticipate and permits remedial action to be taken before structural failure occurs. The methods are not only environmentally friendly and inexpensive but also timely [3-13]. As a result, the electrical resistivity survey involving the vertical electrical sounding (VES) using the Schlumberger array and 2-D electrical resistivity imaging using the dipole-dipole array was used along the crest of the of Oba earth dam, Ogbomoso Southwestern Nigeria to check the integrity.

Site Description

Oba Earth Dam is located in the northwestern part of Ogbomoso, Southwestern Nigeria within Latitude 8°9'N and 8°12'N and Longitude 4°9'E and 4°15'E (Figure 2). The dam is constructed within the channel of Oba River from which it sources its water. The dam embankment is 5m

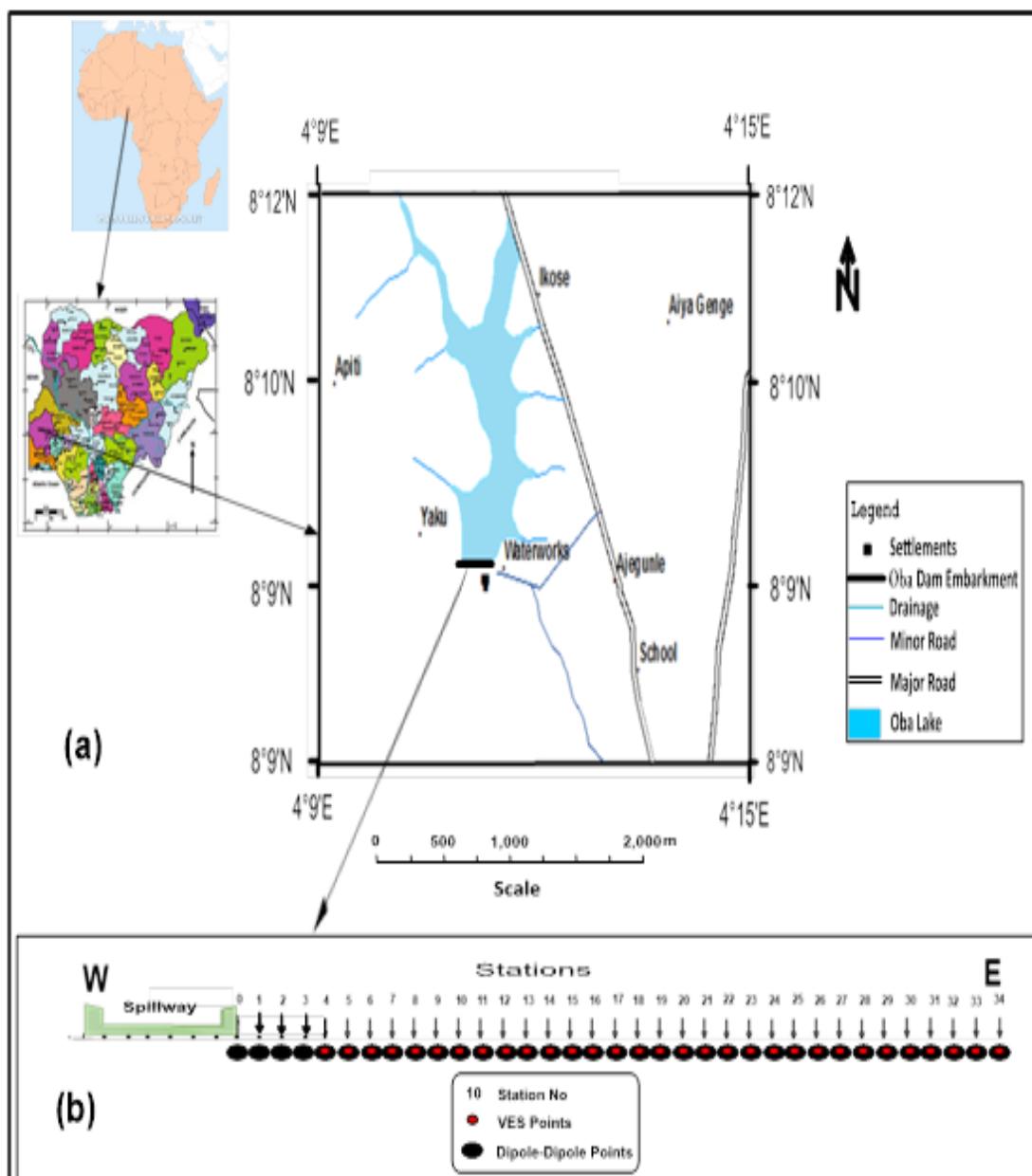


Figure 2: Base map of the study area showing a) Oba lake and dam embankment; b) Geophysical traverse across oba dam embankment.

wide at its crest, 350 m long and 17 m high (Figure 3).

The study area is located within the tropical climatic zone that is characterized by two distinct seasons namely: The raining or wet and the dry seasons respectively. The wet season starts from around the months of March/April through to the month of October even though a little break in rainfall is usually experienced in the month of August. The month of November marks the beginning of the dry season which ends by the end of March. The temperature of the area is usually high throughout the year with an annual mean

of 27 °C. The relative humidity of the area varies from 60 to 80% [14]. The present vegetation of the site is the derived savannah with several baobab trees [15].

Ogbomoso falls within the Precambrian basement complex of southwestern Nigeria which comprises of migmatite-gneiss, banded-gneiss, porphyroblastic biotite-gneiss, granite and quartzite [16]. The porphyroblastic biotite-gneiss is spatially located at the northwestern end of Ogbomoso town towards Ikoyi where the rock is believed to underlie the Oba dam reservoir [17].

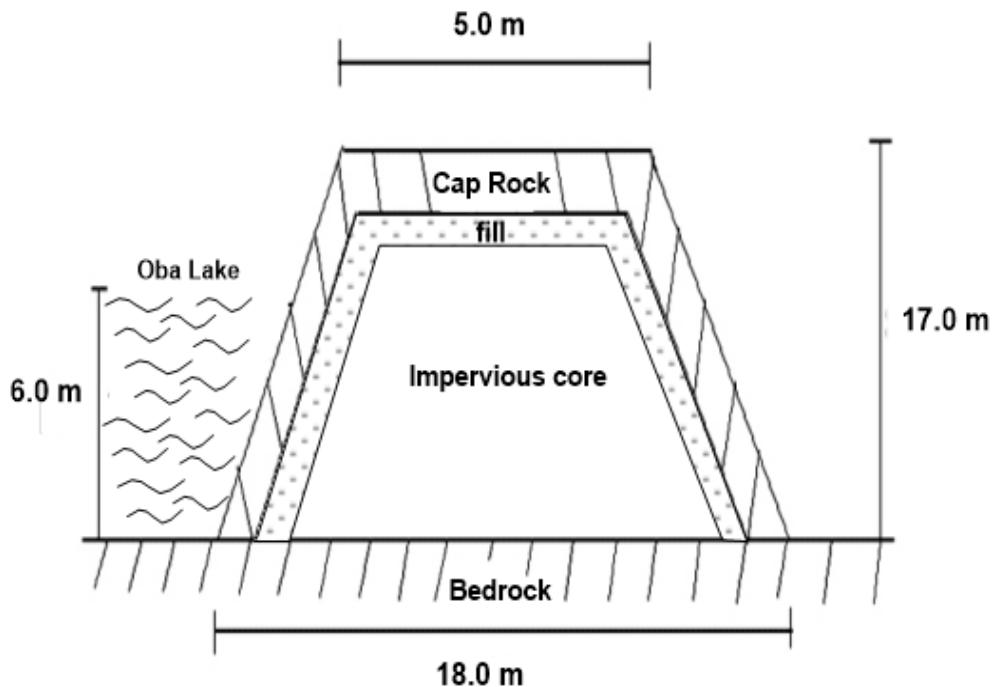


Figure 3: A cross section of oba earth-fill dam embankment.

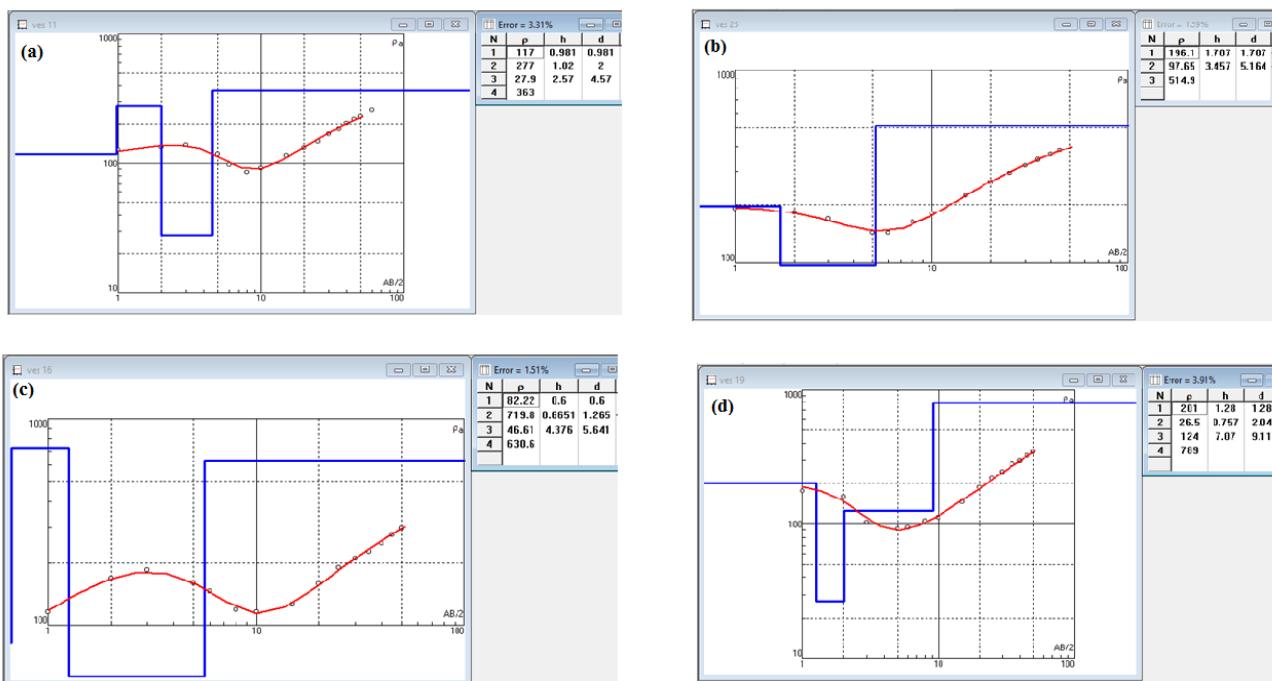


Figure 4: Typical sounding curves from the VES data acquired along oba earth dam embankment a) KH-type; b) H-type; c) KH-type and; d) HA-type.

Methodology

A total of thirty-six geophysical stations at 10 m interval were established on a 350 m long, west-east trending traverse along the Oba dam embankment (Figure 2). All the stations were

geo referenced using the Geographic Positioning System (GPS) for accurate positioning of the points. Thirty-one vertical electrical soundings (VES) were conducted on the established stations along the traverse with the Digital Direct Resistivity Meter (DDR3 Terrameter) using the

Schlumberger electrode array, with the current electrode spacing (AB/2) having a maximum spread of 60 m. The obtained apparent resistivities (ρ) at each station were plotted against corresponding current electrode spacing (AB/2) on a log-log graph. while adopting partial curve matching technique [18] to generate initial layer earth model. The initial model was then iter-

ated using IP2 win 1-D forward modelling software package to reduce the interpretation error to acceptable level. The final layer parameters (resistivities and thicknesses) were then used to prepare 2D geoelectric section across the dam embankment.

Thirty-six dipole-dipole profiling were also conducted on the established stations. Expansion fac-

Table 1: Summary of layer parameters and the inferred lithological description.

VES No.	No. of layers	Resistivity (Ωm) ($\rho_1 / \rho_2 / \rho_3 / \rho_4$)	Depth (m) ($D_1 / D_2 / D_3$)	Type Curve	Lithological Description
1	4	115/349/43/333	0.6/1.4/3.5	KH	Topsoil/fill/clay/basement
2	4	116/893/37/622	0.6/1.2/5.4	KH	Topsoil/fill/clay/basement
3	4	172/227/61/281	0.6/2.6/5.3	KH	Topsoil/fill/clay/basement
4	4	86/603/40/491	0.6/1.2/5.3	KH	Topsoil/fill/clay/basement
5	4	64/489/15/622	0.6/1.2/2.5	KH	Topsoil/fill/plastic clay/basement
6	4	154/369/59/492	0.6/2.6/5.3	KH	Topsoil/fill/clay/basement
7	4	140/379/48/562	0.6/2.6/5.3	KH	Topsoil/fill/clay/basement
8	3	107/1084/84/586	0.6/1.3/5.9	KH	Topsoil/fill/clay/basement
9	4	74/403/23/797	0.6/2.6/5.3	KH	Topsoil/fill/clay/basement
10	4	223/320/78/624	0.6/2.6/5.3	KH	Topsoil/fill/clay/basement
11	4	117/277/28/363	0.98/2/4.6	KH	Topsoil/fill/clay/basement
12	4	98/298/30/865	1.2/2.6/5.3	KH	Topsoil/fill/clay/basement
13	4	142/610/46/550	0.6/2.2/4.2	KH	Topsoil/fill/clay/basement
14	4	74/157/56/323	0.6/2.7/5.7	KH	Topsoil/fill/clay/basement
15	4	80/334/57/405	0.6/1.2/5.6	KH	Topsoil/fill/clay/basement
16	4	82/720/47/631	0.6/1.3/5.7	KH	Topsoil/fill/clay/basement
17	4	94/184/33/529	0.6/2.6/5.3	KH	Topsoil/fill/clay/basement
18	4	95/209/15/327	1.0/2.5/3.8	KH	Topsoil/fill/plastic clay/basement
19	4	201/27/124/789	1.3/2.0/9.1	HA	Topsoil/fill/sandyclay/basement
20	4	113/205/39/296	1.2/2.6/5.5	KH	Topsoil/fill/clay/basement
21	4	92/447/20/720	0.6/1.3/2.7	KH	Topsoil/fill/plastic clay/basement
22	4	70/425/34/510	0.6/1.4/3.5	KH	Topsoil/fill/clay/basement
23	4	56/788/57/1375	0.6/1.2/5.3	KH	Topsoil/fill/clay/basement
24	4	53/738/46/998	0.6/1.2/5.7	KH	Topsoil/fill/clay/basement
25	3	196/98/515	1.7/5.2	H	Topsoil/clay/basement
26	4	96/562/65/501	0.6/1.2/5.2	KH	Topsoil/fill/clay/basement
27	3	249/56/384	1.8/3.6	H	Topsoil/clay/basement
28	4	112//709/60/454	0.6/1.2/5.4	KH	Topsoil/fill/clay/basement
29	4	88/247/26/985	0.6/2.6/5.3	KH	Topsoil/fill/clay/basement
30	4	103/236/43/327	0.6/2.7/5.6	KH	Topsoil/fill/clay/basement
31	4	103/227/46/704	0.6/2.7/5.6	KH	Topsoil/fill/clay/basement

tor n (i.e. distance between the leading and trailing potential electrodes) was varied from 1 to 6. The measured resistivity values are plotted against the points of intersection of two 45° inclined lines from the mid - points of the current and potential dipoles. The Dippro™ (version 4.01) software was

used to produce 2-D resistivity structure beneath the dam embankment.

Results and Discussion

VES and geoelectric section along oba dam embankment

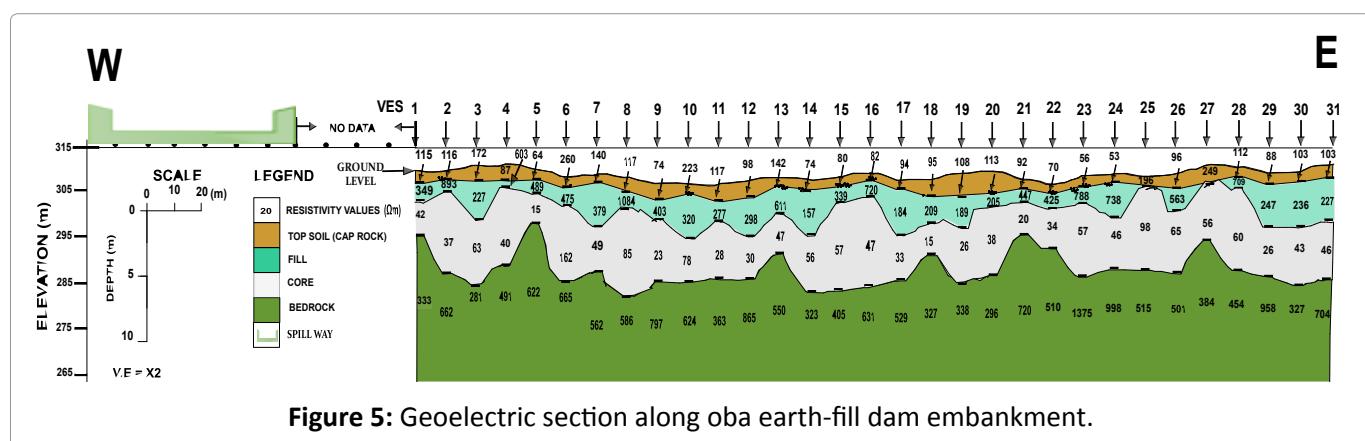
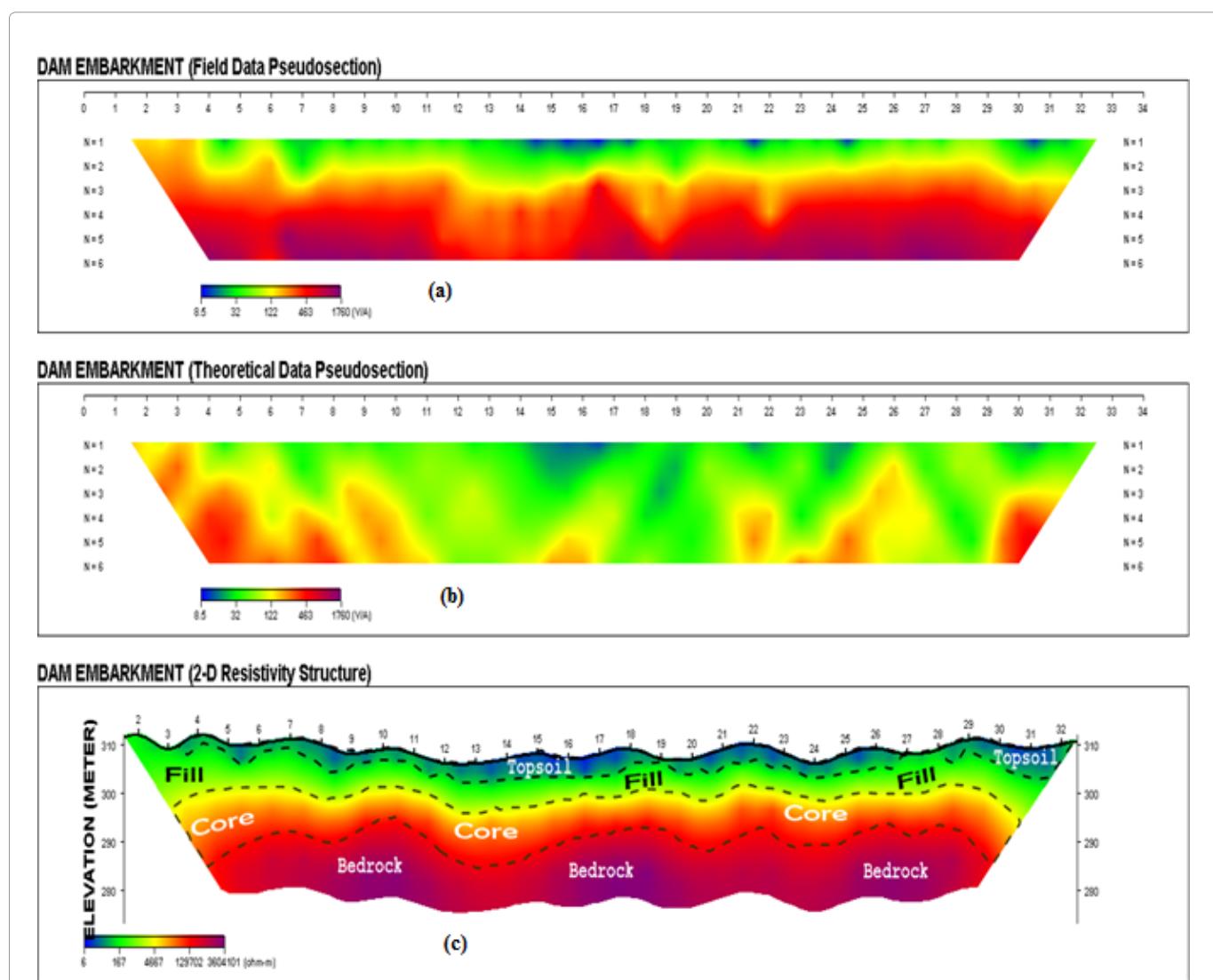


Figure 5: Geoelectric section along oba earth-fill dam embankment.



Figures 6: a) Field data pseudosection; b) Theoretical data pseudosection and; c) 2-D resistivity structure along dam embankment.

Typical iterated curves generated from the VES data are shown in [Figure 4](#). The curve type includes the 3-layers H-type (6%) and 4-layers KH- (90%) and HA-types (3%). The geoelectric parameters and lithological description of the inferred geoelectric layers at each sounding point along the dam embankment are presented in [Table 1](#). The geoelectric section ([Figure 5](#)) provides an insight into the geological sequence and structural disposition beneath the dam axis.

The geoelectric interpretation revealed that the area along the dam embankment is underlain by a maximum of 4 geoelectric layers ([Table 1](#) and [Figure 5](#)). The topmost layer constitutes the topsoil and is made up of sandy clay/clay/clayey sand with layer resistivity ranging between 53 and 249 Ωm. The layer depth ranges between 0.6 and 1.8 m. The second layer is the fill (granite materials) having resistivity values that range between 205 and 1084 Ωm. The depth of the layer ranges between 1.2 and 2.7 m. The third layer has a resistivity value range of between 15 and 124 Ωm with depth range of between 2.5 and 9.1 m. This layer is presumably plastic-clay/clay/sandy clay. The fourth layer is suspected to be the basement bedrock. The resistivity values range between 281 and 1375 Ωm. Depth to rock head varied between 2.5 and 9.1 m.

2-D electrical resistivity structures

[Figure 6](#) shows the field data pseudosection, theoretical data pseudosection and 2-D resistivity structures along the dam embankment. The 2-D resistivity structure represents the true picture of the geological structural disposition within the dam embankment. The image revealed a continuous blue colour band which indicates the topsoil (cap rock). The second layer (fill) is characterized by green colour band with resistivity values range from 35-1074 Ωm and layer thickness of between 4.2-11 m. The Third layer (yellow to light red) colour band is the presumed core. There is no any remarkable interface discontinuous observable in

this layer. The fourth layer which is the basement bedrock is characterized by deep red colour bands. The resistivity values of the layer generally ranged between 57484-650628 Ωm.

Evaluation of the dam embankment integrity

[Figure 3](#) shows the cross-section of the Oba earth dam embankment which is made up of a caprock/topsoil (low resistivity) overlying a resistive granite material (fill). The granite material overlies an impervious clay core sitting on high resistive competent bedrock. The characteristic geoelectric sounding curves across the embankment are the H, KH (about 90% of total type curves) and HA-type. The core material has resistivity values ranging from 15-124 Ωm typical of plastic clay/clay/sandy clay. However, plastic clay/clay constitutes 97% of the core material while the sandy clay constitutes 3% ([Table 1](#)). The 2-D resistivity structure shows no remarkable interface discontinuity among the subsurface sequences which could precipitate structural failure later on. The rating of the embankment integrity is based on layer resistivity/lithological composition as shown in [Table 2](#) below. The Oba dam embankment integrity is good to very good with a pocket of fairly good at station 19 which is suspected to be a potential weak zone within the dam embankment [[19](#)].

Conclusions

The electrical resistivity method involving the dipole-dipole and VES data interpretation has been used to investigate the integrity of the Oba earth-fill embankment for possible structural distress within the dam embankment. The H, KH and HA-type curves constitute the characteristics sounding curves across the dam embankment. The geoelectric section and 2-D resistivity structure revealed four (4) distinct geoelectric subsurface sequences with no significant interface discontinuity within the dam embankment.

Table 2: Dam embankment integrity rating based on layer resistivity and lithological composition of the core (modified after Olorunfemi, et al.) [[7](#)].

Lithology of Core	Layer Resistivity Range (Ωm)	Embankment Integrity Rating
Plastic Clay	1-20	Very Good
Clay	20-100	Good
Sandy Clay	100-250	Fairly Good
Clayey Sand/Sand	> 250	Fair/Poor

The subsurface sequences delineated include the topsoil (caprock) which is presumably clay/sandy clay/clayey sand, the fill (granite materials), the core/weathered horizon made up of plastic clay/clay/sandy clay and the fourth layer suspected to be fresh basement bedrock. The plastic clay/clay constitutes 97% of the materials that constitute the dam embankment. The study concluded that Oba earth-fill dam integrity was good to very good based on the layer resistivity/lithological composition of the core materials obtained from the geoelectric section and the 2-D resistivity structure along the dam embankment.

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