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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 catastrophe 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 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

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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 (Jackson, 2009). The Oba dam in this context is a typical 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 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 (Ojoawo and Ogunrombi, 2014). 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 (Foster *et al.*, 2000).

The strength of the embankment of a dam dictates its integrity and how much water it holds in economic quantity. The presence of geological features such as fractures, faults, joints or shears could precipitate seepage in the basement bedrock. Planar discontinuities in the embankment itself are possible (Olorunfemi *et al.*, 2000). However, it is possible that earth dams lose water through permeable soils and spillage flow from the floor of the dam reservoir in its natural state. The age of a dam, substandard construction materials and faulty design strategies can also be responsible for dam collapse (Olorunfemi *et al.*, 2000 and Fell, *et al.*, 2003). All the factors may culminate into change in the materials' physical properties of the dam.

Figure 1: Aerial view of Oba Lake and the Embankment from Google Earth Map

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 (Olorunfemi *et al.*, 2000; Tedd *et al.*, 2000; Buselli and Lu, 2001; Panthulu *et al.*, 2001; Batayneh *et al.*, 2004; Olorunfemi *et al.*, 2004; Sjudahl *et al.*, 2005; Song *et al.*, 2005; Sjudahl 2006; Sjudahl *et al.*, 2009; Osazuwa *et al.*, 2010; Bayowa *et al.*, 2011; Bedrosian *et al.*, 2012; Revil *et al.*, 2012 and Sentenac *et al.*, 2012). As a result, the electrical resistivity survey involving the depth sounding using the Schlumberger array and two dimensional electrical resistivity subsurface imaging using the double-dipole configuration was employed along the crest of the of Oba earth dam, Ogbomoso Southwestern Nigeria to check the integrity. Our primary goal in this study is to investigate Oba earth-fill dam embankment for possible seepage zone(s) within its embankment that could undermine its integrity using the electrical resistivity method.

Site Description and Geological Context

Oba Earth Dam is located in the northwestern part of Ogbomoso, Southwestern Nigeria within Latitude $8^{\circ}9'N$ and $8^{\circ}12'N$ and Longitude $4^{\circ}9'E$ and $4^{\circ}15'E$ (Figure 2). The dam is constructed within the channel of Oba River from which it sources its water. The dam embankment is 5m wide at its crest, 350 m long and 17 m high (Figure 3).

The study area is part of the tropical climate of southwestern Nigeria which consists of the raining/wet season (from March/April

through October with little break in rainfall in the month of August) and the dry season (the month of November to March) respectively. The annual mean temperature of the area is about $27^{\circ}C$ while the relative humidity variation is between 60 and 80%. Derived savannah with several baobab trees constitutes the vegetation type in the study area (Ogunfolakan *et al.*, 2006).

Ogbomoso and environs are underlain by the Precambrian basement complex of southwestern Nigeria. The rock types include the migmatite gneiss complex, banded-gneiss, porphyroblastic biotite-gneiss, granite and quartzite (Afolabi *et al.*, 2013). 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 (Afolabi *et al.*, 2013).

Materials and Method

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 depth sounding data were carried out on the established stations along the traverse with the Digital Direct Resistivity Meter using the Schlumberger configuration. The current electrode spacing (AB/2) was varied from 1m to a maximum spread of 60m. The obtained apparent resistivities (ρ) at each station were plotted against corresponding current electrode spacing (AB/2) on a bi-log graph paper while adopting partial curve matching technique to generate initial layer earth model. The initial model was then iterated using IP2win 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 double-dipole profiling were also conducted on the established stations. The expansion factor n was varied from 1 to 6 for greater depth attainment. 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

Typical depth sounding curves obtained along the dam embankment are presented 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 shown 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 (Olorunfemi *et al.*, 2004; Bayowa, *et al.*, 2011; Jones *et al.*, 2014).

2-D Electrical Resistivity Structures

Figure 6 shows the field data pseudo section, theoretical data pseudo section and 2-D resistivity structures along the dam embankment. The 2-D resistivity structure represent 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 (Bayowa, *et al.*, 2011, Li, *et al.*, 2013 and Jone, *et al.*, 2014).

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

Figure 5: Geoelectric Section along Oba Earth-fill Dam Embankment

Figure 6: (a) Field Data Pseudo section (b) Theoretical Data Pseudo section and (c) 2-D Resistivity Structure along Dam Embankment

Evaluation of the Dam Embankment Integrity

Figure 3 shows that Oba earth dam embankment was 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 (Olorunfemi *et al.*, 2004, Bayowa, *et al.*, 2011, Minsley, *et al.*, 2011 and Pedro and Cesar, 2017).

Table 2: Dam Embankment Integrity Rating based on Layer Resistivity and Lithological Composition of the Core (modified after Olorunfemi *et al.*, 2004)

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	.	Fair/Poor

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. 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. In conclusion, Oba earth-fill dam integrity was good to very good as judged from 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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