

Monitoring of Seepage in Agba Dam, Kwara State, Nigeria, Using Vertical Electrical Sounding Technique

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Abstract

Geophysical investigation has been undertaken at Agba Dam, Ilorin, located around the southern flanks of the Nigeria basement complex. It is bounded by longitude E 004°35' 0.72" - E 004°35' 40.6" and latitude N 08° 28' 23.3" - N 08° 28' 40.1". This was aimed at investigating possible seepage along the dam's flank. Vertical Electrical Sounding (VES) technique was used for the field study. Twenty VES station of four profiles were established along the bank of the dam and data were acquired using Schlumberger electrode configuration. The resistivity values in the surveyed area vary from 9.28 Ω m to 9409.37 Ω m. Three major geo-electric layers were delineated which are: topsoil, weathered layer, and the fresh basement. The 2D pseudo-sections along the profiles revealed lowest resistivity of 30 Ω m at the depth of 3 m. This observation could be a signature of seepages around those areas. Also, minor conductive zones that appear close to the dam embankment could signify inceptions of buried erosion. This could be inimical to the future sustenance of the dam. The highest resistivity of 1000 Ω m was discovered at the depth of 10m around VES 13 which is the area of the Dam embankment. This implies that the structure of the Dam embankment is not compromised and is still effective.

Keywords: Seepage, Dam Embankment, Resistivity, Vertical Electrical Sounding

Introduction

A dam is barrier of concrete or Earth that is built across a river or stream to obstruct or control the flow of water, especially in order to create a reservoir (Olasunkanmi *et al.*, 2012). The usefulness of this Dam is provision of water for industrial and domestic uses, for irrigation, flood control, recreation, hydroelectric power station, navigation etc. Despite all these usefulness, dam also presents a risk to public safety. The failure of a large dam has the potential to cause more death and destruction than the failure of any other man-made structure. This is because of the destructive power of the flood wave that would be released

by the sudden collapse of a large dam.

Dams require constant maintenance, monitoring, safety inspections and sometimes even rehabilitation to continue safe service. Dam fails when structural failure occurs along the dam axis and or abutment. This process usually begins as seepages along zones of weaknesses. Seepage is the process in which water flows slowly and in small quantities through the dam. Besides, the design of dam structures must be adapted to the existing site conditions (Ajayi *et al.*, 2005) to minimize the losses. Failure to do any of these may invariably result in unplanned seepage and/or total collapse of the structure (Olorunfemi *et al.*,

2000).

Biswas and Chatterjee (1971) examined causes of dam failures worldwide and discovered that 25% of the failures were due to geotechnical problems associated with seepage, inadequate seepage cut-off, faults, settlements and landslides. After some geotechnical studies preceding the construction of dams there still need of number of problems that dams are prone to, such problems can be caused by existence of concealed fracture/faults, fissures, joints or shears which can greatly reduce the reservoir capacity of dam (Ajayi *et al.*, 2005). There are technical defects at many existing dams which are seepage (process in which water flow slowly in small quantities) through dam foundation rocks, severe erosion on dam's slope, decrease of effective storage due to excessive segment inflow etc. To prevent all these geophysical survey can help in the maintenance of the dam, in which vertical electrical sounding is one of them. For this research vertical electrical sounding technique of electrical resistivity method was used investigation of seepages along the axis and abutment of Agba Dam, Ilorin.

Location, Climate and Geology of the Study Area

Agba dam is located in Ilorin, Southwestern Nigeria. It is bounded by longitude E 004° 35' 0.72" E 004° 35' 40.6" and latitude N 08° 28' 23.3" N 08° 28' 40.1" (Fig. 1).

Climatic condition within the study area is essentially a tropical continental climate characterized by two distinct seasons; the wet and dry seasons. The area is characterized by

two climatic conditions, viz: wet and dry seasons. During these times the aquifer is majorly recharged by precipitation. The wet season extends from April to October while the dry last from November to March. The area lies within the middle belt of Nigeria with a total annual rainfall between 1270 mm and 1524 mm, spread over the month of April to October (Olasinde, 1999). The minimum average temperature throughout the state ranges between 21.1°C and 25.0°C while, maximum average temperature ranges from 30°C to 35°C. The average minimum and maximum temperatures are 30°C and 35°C (Olubode and Ajibade, 2010). The major rivers are rivers Asa, Awon, Oyun and Oshin.

The area has a vegetation characteristic of transition zone between tropical rainforest and savannah zone. The natural vegetation comprises guineas and derived savanna. The vegetation is characterized by shrubs, tall grasses and sparsely distributed trees. The vegetation is denser in places especially around river courses.

The study area lies within the southwestern part of the Precambrian Basement Complex of Nigeria (Fig. 2). Rahaman (1988) grouped the rocks in this region as migmatite-gneiss complex comprising largely of sedimentary series with associated minor igneous rock intrusions which have been altered by metamorphic, migmatitic and granitic processes. Qdeyemi (1999) suggested that almost all the foliation exhibited by rocks of south western Nigeria excluding the intrusives

are tectonic in origin, because pre-existing primary structures have been obliterated by subsequent deformation. Boesse and Ocan (1992) also reported that the south western basement complex of Nigeria has been affected by two phases of deformation namely D1, D2, the first phase (D1) produced tight to isoclinal folds while the second phase (D2) is characterized by more open folds of variable style and large vertical NNE-SSW trending fault.

The detailed geology can be grouped into surface and subsurface geology (Ige, 2013). The surface geology is characterized by clay, lateritic soil and the crustal top layers. This differs from place to place but in most places, the lateritic soil obscure most of the underlying geology of the area. The subsurface geology is made up of rocks of the crystalline basement complex including gneisses, granites, migmatites and quartzites.

Figure 1: Location Map of the Study Area



Figure 2: Geology Map of the Study Area

Methodology

Principle and Theory

The electrical resistivity method involves the passage of electric current (I) into the ground through a pair of current electrodes (C₁ and C₂) and measuring the resultant potential (ΔV) between another pair of electrodes called the potential electrodes (P₁ and P₂) (Fig.3).

The potential for a 2-electrodes system (Fig 3a) is given by

$$V = I\rho/2\pi r \quad (1)$$

In practice, a minimum of four electrodes are used and the potential difference between a pair of potential-electrodes is measured (Fig. 3b).

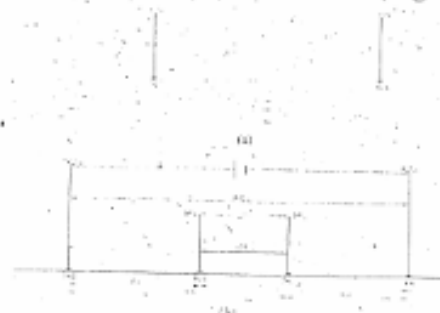


Figure 3: (a) Two Electrodes System (b) Schlumberger Electrode

From equation 4 the potential at P_1 due to current

$$C_1, V_M^A = \frac{I\rho}{2\pi r_1}$$

Also the potential at P_1 due to current C_2

$$V_M^B = \frac{-I\rho}{2\pi r_2}$$

The potential at P_1 due to C_1 and C_2 is of the form

$$V_M^{AB} = \frac{I\rho}{2\pi} \left(\frac{1}{r_1} - \frac{1}{r_2} \right)$$

Similarly, the potential at P_2 due to C_1 and C_2 is of the form

$$V_N^{AB} = \frac{I\rho}{2\pi} \left(\frac{1}{r_3} - \frac{1}{r_4} \right)$$

Therefore, the potential difference, ΔV between P_1 and P_2 is given by

$$V_M^{AB} - V_N^{AB} = \frac{I\rho}{2\pi} \left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4} \right)$$

So,

$$\Delta V = \frac{I\rho}{2\pi} \left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4} \right)$$

From Ohm's law,

$$\Delta V/I = R$$

Therefore the equation 5 becomes

$$\rho = 2\pi R \left\{ \frac{1}{\left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4} \right)} \right\} \quad (6)$$

Alternatively,

Suppose G is a geometric factor, which is typical of the electrode array (configuration) system.

Then,

$$\rho = R.G \quad (7)$$

ρ is apparent resistivity in Ωm .

R is resistance in Ω .

G is a geometric factor which varies from one electrode array to the other.

From Figure 3b

$$r_1 = L - l,$$

$$r_2 = L + l,$$

$$r_3 = L + l,$$

$$r_4 = L - l$$

If we substitute these for r_1 , r_2 , r_3 and r_4 in equation 6

Apparent resistivity for Schlumberger array the is given by;

$$\rho = 2\pi R \left\{ \frac{1}{\left[\frac{1}{(L-l)} - \frac{1}{(L+l)} - \frac{1}{(L+l)} + \frac{1}{(L-l)} \right]} \right\}$$

$$\rho = 2\pi R \left\{ \frac{1}{\left[\frac{4l}{(L^2 - l^2)} \right]} \right\} \quad (8)$$

Since $AB \geq 5MN$, L is much bigger than l such that

$$L^2 - l^2 \approx L^2$$

Therefore, the apparent resistivity equation for Schlumberger becomes

$$\rho_s = 2\pi R \cdot L^2 / 4l$$

$$\rho_s = \pi R L^2 / 2l \quad (9)$$

But from Figure 3b

$$AB = 2L \text{ and } MN = 2l$$

This can be written as

$$\rho_s = \pi R (AB/2)^2 / MN \quad (10)$$

Data Acquisition and Processing

Four multi-VES profiles were established along the axis and flanks of Agba Dam using Schlumberger electrode configuration. Each profile contained 5 VES points, making a total of 20 vertical electrical sounding points. The resistivity data were acquired using DDC-8 automatic resistivity meter. The VES data were processed as profiles using computer iteration software IP2Win developed by Bobachev (2008), Moscow State University. Co-linear VES points were also processed to obtain resistivity pseudo-section in the study area. The profiles were further overlapped in order to be able to establish "tie" between adjacent profiles.

Results and Discussion

The results of the VES data plots show that the

study area is underlain by a system of three to five geo-electric layers which are topsoil, lateritic layer, clayey soil (sandy clay and clayey sand), weathered basement and fresh basement. Sample field curves are shown in Figures 4(a and b) while summary of the results are presented in Table 1. VES 2, VES 3, VES 5, VES 10, VES 13, VES 15, VES 16, VES 17, VES 18, and VES 19 have three layers while VES 1, VES 4, VES 6, VES 8, VES 9, VES 11, VES 12, VES 14 and VES 20 has four layer. Only VES 7 depicts five layers.

The 2-D resistivity pseudo-section along the four profile presented in Figure 5 (a-d) show that for profile 1; the water tends to seep laterally from VES 2 and VES 5 into the surrounding and cut across VES 4, VES 3 and VES 1. This is obvious from the relatively low resistivity ($100 \Omega m$) along the transverse at VES 2 and VES 5 at the depth of 10 m. For profile 2 there is a trace of seepage from VES 11 signified by its low resistivity of $30 \Omega m$ at depth range of 7.2 m-10 m depth. This spread northwards across VES 10, VES 9 and VES 8.

3 is made up of VES 1, VES 13, VES 14, VES 15 and VES 16. It cut across the dam axis and it is the least affected by seepage. However, impact of seepage is observable on the right flank close to profile 1. The resistivity (about $100 \Omega m$) is observed across VES 14, VES 15 and VES 16 at a depth range of 5 m-18 m while VES 13 located directly on the dam axis has the highest resistivity range of $268 \Omega m$ - $1589 \Omega m$ at the depth range of between 1 m-40 m. Along profile 4, VES 20 has the lowest resistivity of $30 \Omega m$ from the surface to a depth

of 19 m. However, observation shows that the low resistivity could be because the recharge of water from the upstream into the reservoir flows across this point.

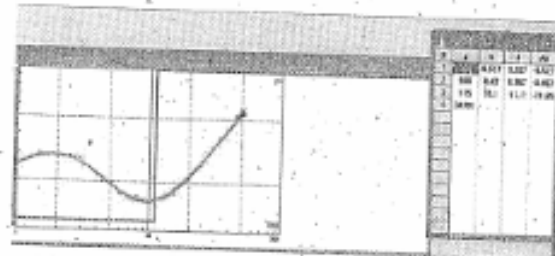


Figure 4a: Resistivity Curve for VES1



Figure 4b: Resistivity Curve for VES5

Table 1: Summary of Results

VES POINT	NUMBER OF LAYERS	RESISTIVITY	THICKNESS (m)	GEOLOGY EQUIVALENT TO THE GEO-ELECTRIC LAYERS
1	4	100, 100, 100, 100	12.5, 12.5, 12.5, 12.5	Topsoil, lateritic soil, weathered basement, fresh basement
2	3	100, 100, 100	12.5, 12.5, 12.5	Topsoil, weathered basement, fresh basement
3	3	100, 100, 100	12.5, 12.5, 12.5	Topsoil, weathered basement, fresh basement
4	4	100, 100, 100, 100	12.5, 12.5, 12.5, 12.5	Topsoil, lateritic soil, weathered basement, fresh basement
5	3	100, 100, 100	12.5, 12.5, 12.5	Topsoil, weathered basement, fresh basement
6	4	100, 100, 100, 100	12.5, 12.5, 12.5, 12.5	Topsoil, lateritic soil, weathered basement, fresh basement
7	5	100, 100, 100, 100, 100	12.5, 12.5, 12.5, 12.5, 12.5	Topsoil, lateritic soil, weathered basement, fresh basement, fresh basement
8	4	100, 100, 100, 100	12.5, 12.5, 12.5, 12.5	Topsoil, lateritic soil, weathered basement, fresh basement
9	4	100, 100, 100, 100	12.5, 12.5, 12.5, 12.5	Topsoil, lateritic soil, weathered basement, fresh basement
10	3	100, 100, 100	12.5, 12.5, 12.5	Topsoil, weathered basement, fresh basement
11	3	100, 100, 100	12.5, 12.5, 12.5	Topsoil, weathered basement, fresh basement
12	3	100, 100, 100	12.5, 12.5, 12.5	Topsoil, weathered basement, fresh basement
13	3	100, 100, 100	12.5, 12.5, 12.5	Topsoil, weathered basement, fresh basement
14	3	100, 100, 100	12.5, 12.5, 12.5	Topsoil, weathered basement, fresh basement
15	3	100, 100, 100	12.5, 12.5, 12.5	Topsoil, weathered basement, fresh basement
16	3	100, 100, 100	12.5, 12.5, 12.5	Topsoil, weathered basement, fresh basement
17	3	100, 100, 100	12.5, 12.5, 12.5	Topsoil, weathered basement, fresh basement
18	3	100, 100, 100	12.5, 12.5, 12.5	Topsoil, weathered basement, fresh basement
19	3	100, 100, 100	12.5, 12.5, 12.5	Topsoil, weathered basement, fresh basement
20	4	100, 100, 100, 100	12.5, 12.5, 12.5, 12.5	Topsoil, lateritic soil, weathered basement, fresh basement

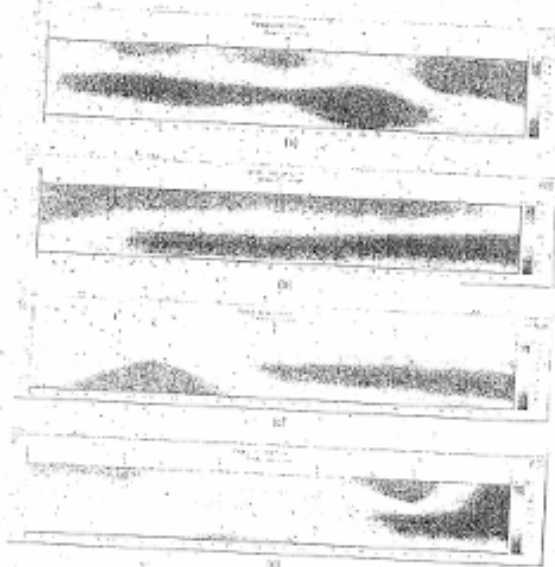


Figure 5: 2-D Pseudo Section along (a) profile 1, (b) profile 2, (c) profile 3, and (d) profile 4

Conclusion

Integration of the interpreted structures from the vertical electrical sounding data suggests the presence of geologic conditions suggestive of seepage along the flanks of embankment. This is particularly obvious along profile 1, 2 and 4 where low resistivity zones were observed to advance on radial fronts. The low resistivity areas may indicate areas where the host rock has been lowered by faulting and/or fractures and thus contains water, making the area less resistive to electrical current. Hence, the bank of the Dam shows low resistivity which could be interpreted as there is seepage along the Dam banks in the study area. For instance, along profile 1, the water tends to seep laterally from VES 2 and VES 5 into the surrounding and cut across VES 4, VES 3 and VES 1. This is obvious from the relatively low resistivity ($100\Omega m$) along the transverse at VES 2 and VES 5 at the depth of 10m.

Areas of high low resistivity were identified along the Agba Dam axis. The high resistivity areas could be a signature of gravel, sand, and rock fragment lying on top of elevated solid rock. Close study of profile 3 which lies across the dam axis revealed that the structure of the dam is not compromised. That is, it is still effective to some extent because of its high resistivity, but there is trend of underground water flowing towards it.

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