

Investigation of Earth Dam Seepage using Geo-resistivity Modelling: A Case of Asa Dam, Ilorin-Nigeria

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Abstract

A geo-resistivity modelling has been applied in the investigation of seepage around Asa Earth Dam in Ilorin, Nigeria. The electrical resistivity data were acquired using Wenner configuration. The resistivity values in the surveyed area vary between 0.05 and 1800 Ωm and also suggest two geo-electric layers: a conductive layer interpreted to be clay/wet-to-moist sand, and a more resistivity layer interpreted to be granite intrusions characteristic of Ilorin city. The results further propose anomalous conductive zones within the subsurface, which have lateral extension and therefore interpreted as potential pathways for water seepage from the dam.

Keywords: Geo-resistivity, Wenner, Modelling, Dam, Seepage, Ilorin.

1.0 Introduction

Dams are structures of various forms constructed across streams or rivers to hold back the flow of water, thereby creating a large body of water called a reservoir [1]. They are vital elements in modern society and represent large economic values. For example, millions of people depend on dams and reservoirs for domestic, industrial and agricultural water supply, for flood protection and for electricity. National economies are often highly dependent on the power generated by such dams. Furthermore, even when a dam comes to the end of its economically useful life, ensuring that it remains safe is a continuing economic burden. Prolonging the useful life of a dam is a priority for operators and national governments [2].

Dams require significant investment to build and maintain, and yet their usefulness and integrity are constantly threatened by leakage and sedimentation [2]. The integrity of a dam embankment can be undermined by the existence of geological features, such as faults, fractures, fissures, jointed or shear zones underneath the dam axis or discontinuities in the structure itself [3, 4]. Although, dams are designed to lose some water through seepage for stability, controls should be in place to keep seepage at an acceptably low level because in addition to the designed seepage, impounded water naturally seeks paths of least resistance through the dam and its foundation. Seepage must, therefore, be controlled to prevent erosion of the embankment or foundation or damage to concrete structures [5]. Damages resulting from internal erosion could lead to expensive remediation. Typical dam safety surveillance consists of visual inspections supported by limited instrumentation. However, internal erosion can become quite advanced before the problem is detected via visual methods. Recently, interest has grown regarding the use of non-intrusive geophysical techniques to facilitate early detection of anomalous seepage, piping, or internal erosion. Consequently, several non-intrusive geophysical methods are available but Geo-resistivity modelling provides much more cost-effective tools for dam surveillances [6 -9].

Hence, this study involves the investigation of seepage around Asa earth dam in Ilorin using resistivity modelling for general reconnaissance studies and with a view of contributing to the safety discuss of the dam.

2.0 Study Area

The Asa Dam is located about 5 km south of Ilorin, Nigeria across River Asa (Figure 1). The terrain is gently undulating with topographic elevation from 297 to 301 m. The dam axis is at physiographical confined locations along the course of the river.

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The Dam is a composite dam of earth embankment at its ends, with a central spillway followed to the right by a mass concrete non-overflow gravity section. The dam is 597 m long and 27 m high at its deepest section and a crest width of 6 m. The extent of the lake is 18 km and the storage capacity of water is 43 million cubic metres [10].

The geology of the area consists mainly of the older granite and undifferentiated types that are consistent with the basement complex terrain of Nigeria [11 – 13]. In-situ observations show that the rocks have been greatly weathered with pockets of sandy clay lenses within the area. The geological map of the area is shown in Figure 2.

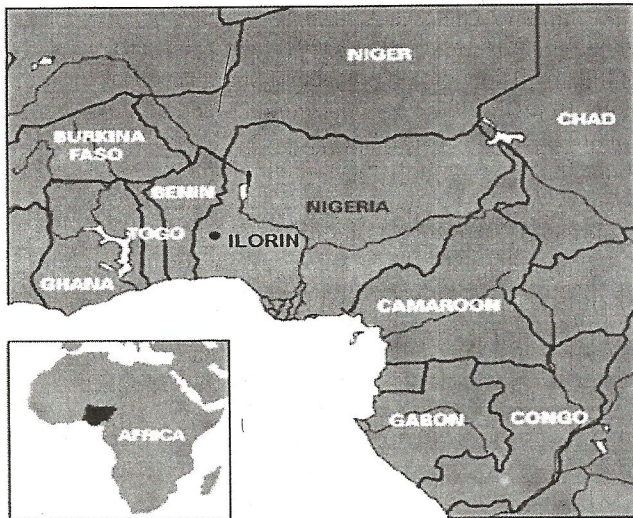


Figure 1: Map of Nigeria showing the city of Ilorin.

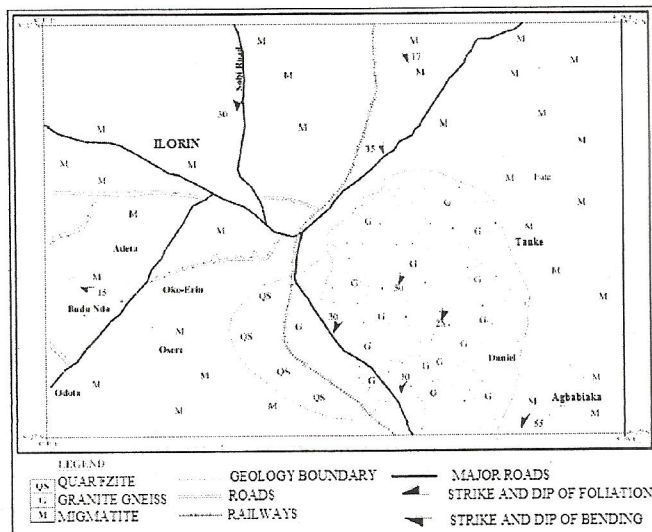


Figure 2: The Geological Map of Ilorin (after [11])

3.0 Theoretical Considerations

The basis of geo-resistivity modelling is the Ohm's law [14 - 17]:

$$\rho = \frac{RA}{L} \quad (1)$$

where ρ is resistivity, R is resistance, L is length of homogenous conducting cylinder and A is cross sectional area.

The solid earth is not like a straight uniform wire which equation (1) applies to strictly, therefore, there is a need to derive the ohms law which is equivalent to the semi-hemisphere that electrical conductor in the ground represents. Consequently, a current density j is defined, which is proportional to electrical field strength E with resistivity ρ as proportionality constant:

$$j = \frac{I}{2\pi r^2} \quad (2)$$

$$E = \rho j \quad (3)$$

$$E = \frac{\rho I}{2\pi r^2} \quad (4)$$

where r is radius of the hemisphere, which also represents the radius of current electrode's small hemisphere in geo-electric field survey.

The electrical field strength E is also defined by the derivative of potential difference V , therefore,

$$V = - \int E dr \quad (5)$$

The solution of equation (5) results into:

$$V = \frac{\rho I}{2\pi r} \quad (6)$$

Consequently,

$$\rho = \frac{\Delta V}{I} \cdot 2\pi r \quad (7)$$

where ΔV is change in voltage.

Since the earth is not homogeneous, equation (7) is used to define an apparent resistivity ρ_a which is the resistivity the earth would have if it were homogeneous [14]:

$$\rho_a = \frac{\Delta V}{I} \cdot 2\pi r \quad (8)$$

where $2\pi r$ is then defined as a geometrical factor G that describes the geometry of the electrode configuration being used.

The Wenner configuration was used in this work; as a result, the geometric factor G is given as:

$$G = 2\pi a \quad (9)$$

where a is spacing between electrodes.

Wenner configuration has the simplest geometry, with all of the electrodes equally spaced as shown in Figure 3.

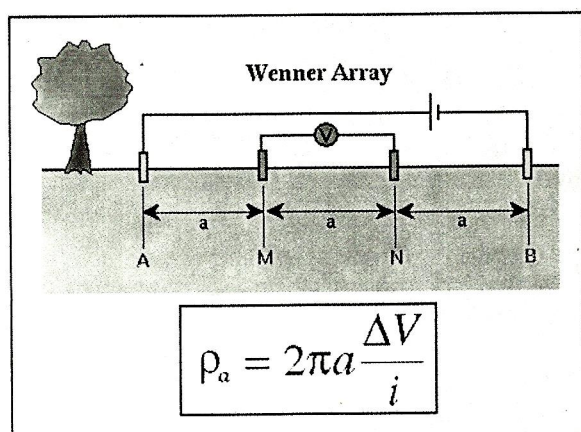


Figure 3: Configuration of Wenner electrodes as used in the study

4.0 Field Survey

Electrical resistivity field measurements were carried out along 5 profiles (A-A', B-B', C-C', D-D' and E-E') with 10 m station intervals around the bank of Asa River and across the embankment of Asa dam. A resistivity profile is used to detect lateral variations of resistivity, and for this application, the electrode spacing is fixed while the center of the array is varied. However, in order to also unravel the formations at different depths and structural variations across the dam, the electrode spacing was varied between 5 and 15 m at equal interval of 5 m.

5.0 Results and Discussion

The results of the survey are presented as resistivity images in Figures 4 – 8. The images show 2D resistivity variation along each traverse in the study area. The resistivity values in the surveyed area vary between 0.05 and 1800 Ωm . This shows that both high and low resistivity areas exist along the surveyed traverses. The data also suggests two geo-electric layers: a conductive layer interpreted to be clay/wet-to-moist sand, and a more resistivity layer interpreted to be granite intrusions characteristic of Ilorin city. For example, profile A – A¹ (Figure 4) is about 10 m away from the dam edge. It is characterized with high resistivity values (200 – 1800 Ωm) at the top left flank, which extend to the middle of the profile and to a depth of about 3.5 m. This layer resistivity is typical of igneous rocks; however, coarse sand or gravel, if it is dry, may also have resistivity values like that of igneous rocks. A dominant layer of low resistivity (5 – 20 Ωm) is also observed on the 2D resistivity structure, characteristic of wet-to-moist sand, however with intruding very low resistivity (0.8 – 2 Ωm) cavities sited at both lower extremes of the image with a thickness of more than 6 m. These cavities are interpreted to be filled with clayey materials, and could act as potential pathways for water seepage from the dam.

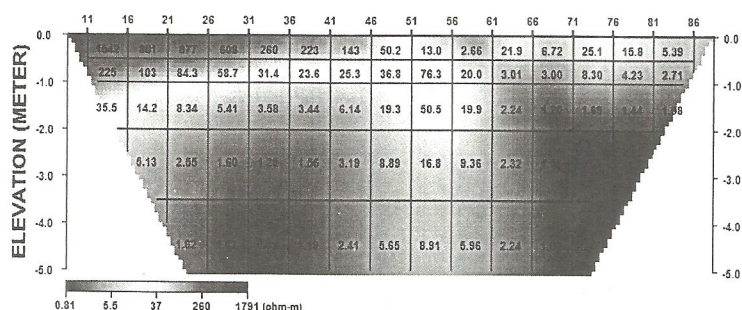


Figure 4: Pseudosection along Traverse A – A¹ (elevation is multiplied by 3)

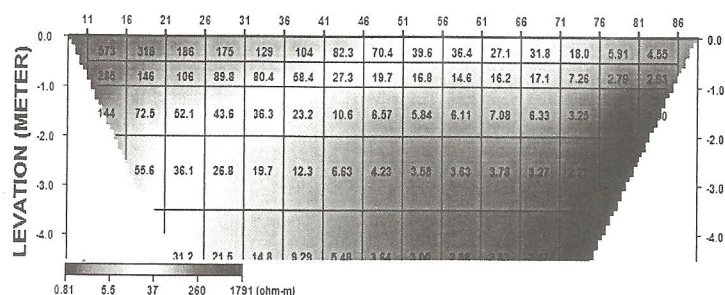


Figure 5: Pseudosection along Traverse B – B¹ (elevation is multiplied by 3)

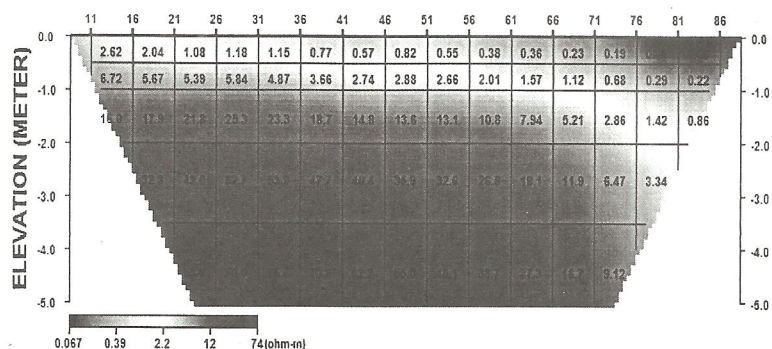


Figure 6: Pseudosection along Traverse C – C¹ (elevation is multiplied by 3)

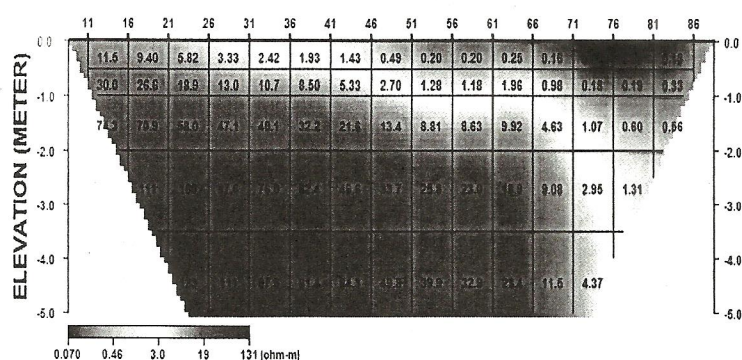


Figure 7: Pseudosection along Traverse D – D¹(elevation is multiplied by 3)

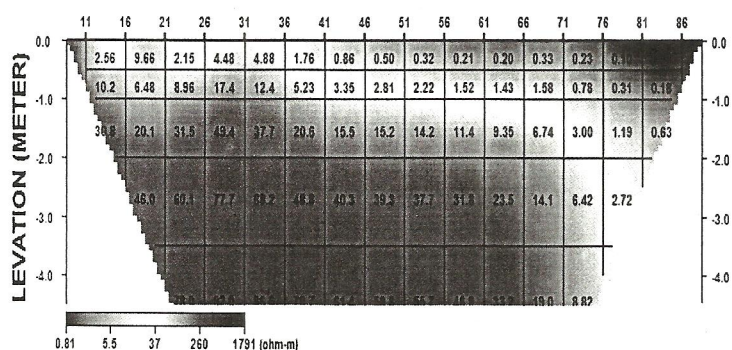


Figure 8: Pseudosection along Traverse E – E¹(elevation is multiplied by 3)

The resistivity structure of profile B – B¹ in Figure 5 is similar to that of profile A – A¹, except that the left flanked cavity observed in A – A¹ is not evident in B – B¹. The beginning of profile B – B¹ is about 15 m away from the dam. The shallow low resistivity zone found in this profile narrowed down in width and subtends between 41–71 m with depth of about 12 m. More so, a weak zone (less than 2 Ωm) is observed towards the right edge of the profile which depicts presence of water saturated soil. The lithology conspicuously shows low resistivity distribution at the top-soil. The resistivity distribution is relatively high at the left edge compared to the middle of the profile. The interface could be inferred as a fractured area.

The 2D resistivity structure in profiles C – C¹, D – D¹ and E – E¹ are similar. Except that a portion of likely intruding igneous rock with resistivity value above 100 Ωm and situated in the lower left flank is more evident in profile D – D¹. Excluding this observation, the three 2D resistivity structures show low values ranging from 0.05 to 90 Ωm with the least values (less than 1 Ωm) situated at 71 – 86 m along the transverse of the three profiles. These values are representative of clay layers and could infer water saturation at those points.

Consequently, the results suggest anomalous conductive subsurface zones within the surveyed area, which are interpreted as a subsurface space filled with water or clay. These anomalous areas have lateral extension and therefore interpreted as potential pathways for water seepage from the dam.

6.0 Conclusion

This study is intended to reveal the potential seepage zones around Asa dam in Ilorin, north-central Nigeria. The resistivity values in the surveyed area vary between 0.05 and 1800 Ωm and also suggest two geo-electric layers: a conductive layer interpreted to be clay/wet-to-moist sand, and a more resistivity layer interpreted to be granite intrusions characteristic of Ilorin city. The results further propose anomalous conductive zones within the subsurface, which are interpreted as a subsurface space filled with water or clay. This anomalous area has lateral extension and therefore interpreted as potential pathways for water seepage from the dam. Therefore, it is recommended that these anomalous conductive zones should be monitored closely for adequate dam safety measures.

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