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Original Research Article

Geophysical Investigation of an Earth Dam: A Case Study of Agba Dam, Ilorin Southwestern Nigeria

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ABSTRACT

Geophysical investigation of Agba dam, Ilorin, Southwestern Nigeria was undertaken to assess the vulnerability of the dam to seepage. The field survey involved very low frequency electromagnetic (VLF-EM) and vertical electrical sounding (VES) techniques with Schlumberger electrode configuration. VLF-EM survey at 10 m and 20 m spacing were conducted along the axis and flanks. Forty VES were carried out on four traverses established in NW–SE direction along the dam axis and NE–SW directions along the right and left flanks. Results of VLF-EM showed conductive zones indicating possible fractured basement. VES data revealed three to four geo-electric layers; topsoil, having resistivity range of 149–1282 Ωm with a mean of 448±315 Ωm, thickness of 0.4–4.2 m with a mean of 2.0±0.8 m, lateritic hardpan with resistivity of 924–1614 Ωm and a mean of 1235±269 Ωm, layer thickness of 1.6–3.2 m with a mean of 2.3±0.5 m, weathered and fractured basement with a resistivity of 12–115 Ωm with a mean of 51±29 Ωm, thickness of 2.5–21.2 m with a mean of 9.4±4.9 m. Fresh basement had a resistivity of 111–1831 Ωm with a mean of 643±380 Ωm. Possible fractured basement occurred in areas of resistivity <400 Ωm. Areas of resistivity >400 Ωm indicated fresh basement rock. The study revealed that the basement rock expected to serve as a sealing barrier for water in the reservoir shows some degree of fracturing which if not properly checked and manage, could lead to the collapse of the dam in the future.

1. INTRODUCTION

A dam is a barrier that impounds water or underground streams. Earth dams are made from compacted earth and designed to operate under steady state seepage. Any excessive seepage may lead to the failure of the dam, especially in unconsolidated or fractured terrains. Despite detailed geotechnical studies preceding the construction of dams, a number of unforeseen problems still appear soon after such structures are put into use. One of such problems may be caused by existence of concealed fractures which can greatly reduce the reservoir capacities of dams (Ojo *et al.,* 1990). These problems are caused by the diversity of geological environments at the proposed and existing dam sites which present unique challenges relating to detailed geological mapping, foundation condition and many others (Camarero and Moreira, 2017). Technological development has provided improvements over time, but there are still reports of problems associated with dams. Between 2000 and 2009, 140 incidents were reported only in Brazil. The recent one in 2019 was that of Brazilian town of Brumadinho, Minas Gerais state which report says has exposed the dangers of Brazil's aging dam system as nearly 1800 Brazilian dams are at risk of failure, according to the Brazilian Government (Olden *et al.,* 2019). A large part of these incidents is associated with problems of infiltration and internal erosion (piping). The largest cause of accidents in earth dams is associated with erosion (Boneli, 2013). Several scientific methods are used in studying both surface and subsurface geology of areas in the world. Amongst these scientific methods are geophysical methods. This is because the method is one method that provides direct answer and valuable additional data to augment other studies and more invasive means of evaluation such as drilling (Kearey *et al.,* 2002). Geophysics has been identified as an important tool for the investigation of structures like dams. In Nigeria and in other parts of the world, several case studies of dams inspected by different geophysical methods such as electromagnetic and electrical methods etc. with different interests and aims have been reported (Medina and Dominguez, 1989; Loh and Wu, 1996; Karastathis *et al.,* 2002; Osazuwa and Chinedu, 2008) but the electrical resistivity method is little exploited for inspections of dams (Al-Fares, 2011; Minsley *et al.*, 2011, Bedrosian *et al.,* 2012; Case, 2012). Olorunfemi *et al.,* (2000) as well as Olayinka and Oyedele (2001) worked on failed dams with the aim of investigating the cause of dam failure. Olawale *et al.,* (2007) investigated geophysical characteristics of bedrock of an existing dam site. Akinlabi and Oladunjoye (2008) investigated the stability of an area for dam construction. Geophysical investigation with the aim of seepage paths/zones delineation was conducted by Panthulu *et al.,* (2001).

In this present work, integrated geophysical investigation was undertaken to assess the vulnerability of Agba dam, Ilorin, Southwestern Nigeria to seepage using VLF-EM and VES techniques. This study is aimed at evaluating the geo-structural setting of the concealed bedrock along the axis and the flanks of the dam. Its objectives include determining the subsurface geometry, the electrical properties of the overburden materials and delineation of bedrock structures. VLF-EM survey conducted along the axis and the flanks of the dam was made at 10 m and 20 m spacing. A total of forty VES were carried out with 30 m spacing between the VES points.

2. METHODOLOGY

2.1. Geology of the Study Area

The study area location is a part of the Nigerian Basement Complex of South-Western Nigeria. Agba dam is situated on the basement complex and found within latitudes $8^0$28' 28.5'' and $8^0$28'42.7'' and longitudes $4^0$35'07.1'' and $4^0$35'33.8'' (Figure 1). The bedrock is identified as migmatite gneiss and is concealed in most parts of the site. The textural characteristic observed in this rock is coarse grained texture. Alternations of light and dark colored minerals define a clear banding. Common structures observed on the rocks are minor folds and joints. Intrusions of concordant and discordant quartz veins were also observed on the rocks. Tectonically, these rocks trend in the NE-SW direction. Rip-raps are present at the lower portion of the embankment near the reservoir. These are large fragments of migmatite gneiss which function to reduce the waves of the impounding water thereby reducing surface erosion of the basement.

2.2. Geological Investigation

Geological investigation of the study area was carried out using equipment such as Base map, Global Positioning System (GPS), Compass clinometers, Camera, Field note book etc. Geophysical methods adopted include very low frequency electromagnetic (VLF-EM) and vertical electrical sounding (VES). In the field procedure, ABEM Wadi instrument was mounted on a belt and worn by the user. Low frequency of 16.1 kHz was used to carry out the VLF survey. The survey was conducted along the dam axis, left and right flanks which are approximately 330 m, 470m and 330 m in length respectively (Figure 1). Measurements were made at 10 m and 20 m intervals. Readings and remarks were recorded in field note book. After data had been acquired, the filtered real and raw imaginary data were downloaded from wadi instrument. Both the real and imaginary components of VLF anomalies were recorded. Only the real component data were processed for interpretation. Data used for this present work was partly acquired using VES method with Schlumberger configuration. A total of forty vertical electrical soundings were carried out, (ten along the dam axis, twenty along the left flank and ten along the right flank) (Figure 1) The number of VES carried out along the dam axis and the left flank was reduced due to restriction of space. The Schlumberger electrode configuration was used with half electrode spacing AB/2 varying from 1 to 30 m and station spacing is 30 m.

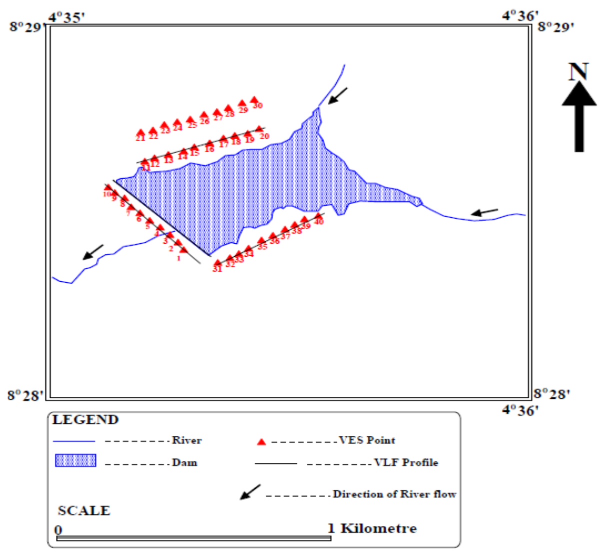

Figure 1: VES points and VLF profiles of Agba dam

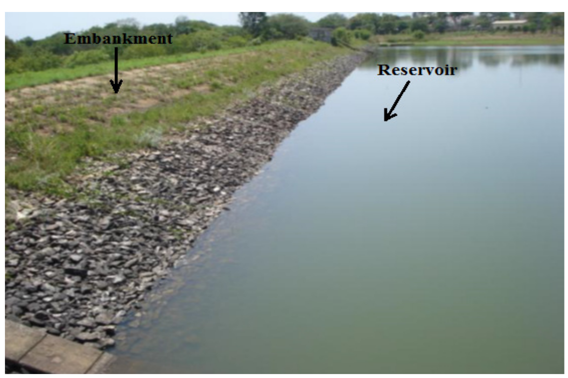

Plate 1: Photograph of Agba Dam showing the embankment and the reservoir

3. RESULTS AND DISCUSSION

The VES data obtained revealed three to four geo-electric layers comprising topsoil, lateritic hardpan, weathered basement (sandy clay) and the fractured/fresh basement rock (Figures 2a-2d). The topsoil resistivity ranged from 149–1282 Ωm with a mean of 448 ± 315 Ωm and thickness varying from 0.4–4.2 m with a mean of 2.0 ± 0.8 m. Lateritic hardpan had high resistivity ranging from 924–1614 Ωm with a mean of 1235 ± 269 Ωm. The range of the layer thickness was from 1–3.2 m with a mean of 2.3 ± 0.5 m. The weathered basement (sandy clay) had resistivity ranging from 12–115 Ωm with a mean of 51 ± 29 Ωm and thickness varying from 2.5–21.2 m with a mean of 9.4 ±4.9 m. The basement rock had resistivity ranging from 111–1831 Ωm with a mean of 643 ± 380 Ωm. Possible fractured basement occur in areas with resistivity <400 Ωm while areas having resistivity >400 Ωm indicates fresh basement rock. Depth to bedrock ranged from 4.3–14.6 m along the dam axis, 4.1–21.2 m along the left flank and 4.9–14.6 m along the right flank.

The results of VLF-EM survey along the dam axis, the left and right flanks show conductive zones indicating possible fractured basement. The plot of filtered real against station distances is shown as profile as presented in (Figures 3a-3f). Conductive targets are denoted with positive Fraser and Karous-Hjelt filtered anomalies. Red color is suggestive of presence of conductive (weak) zones. Such points were identified on the profiles.

Low resistivity and the presence of conductive zones within the basement revealed by the VES and VLF-EM are indications of possible fractures which are usually caused by seepage. This fractured basement occurs in areas with resistivity <400 Ωm while areas having resistivity >400 Ωm indicates fresh basement rock. The presence of these fracture zones can greatly reduce the reservoir capacity of the dam. Seepage in dam body in most cases at the dam foundation can lead to the formation of reed erosion which can eventually result in landslide and possible collapse of a dam.

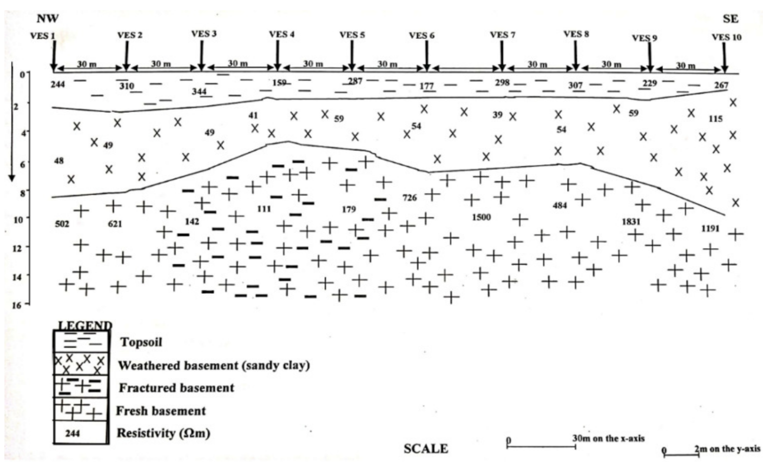

Figure 2a: Geo-electric cross-section along the dam axis

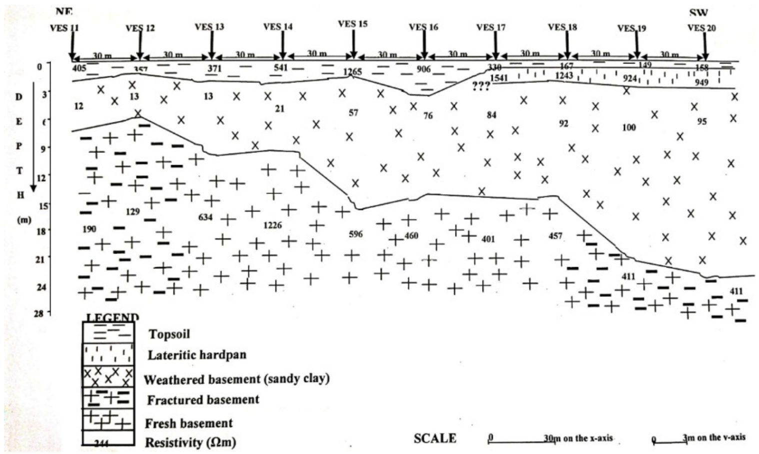

Figure 2b: Geo-electric cross-section 1 along the left flank

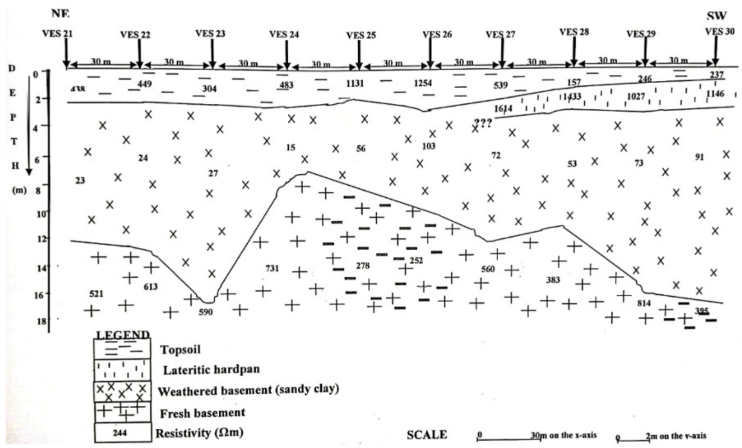

Figure 2c: Geo-electric cross-section 2 along the left flank

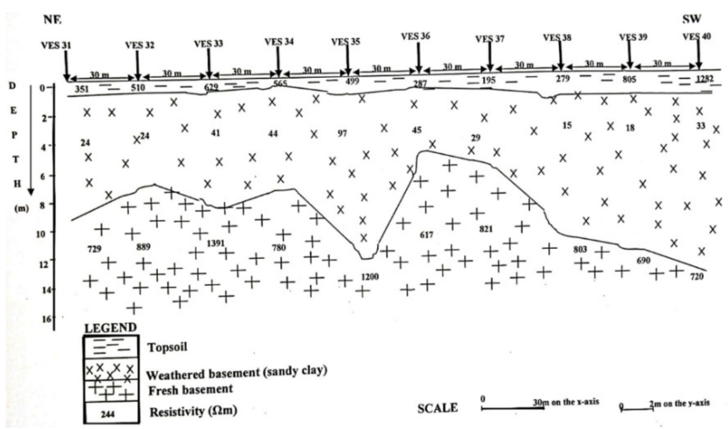

Figure 2d: Geo-electric cross-section along the right flank

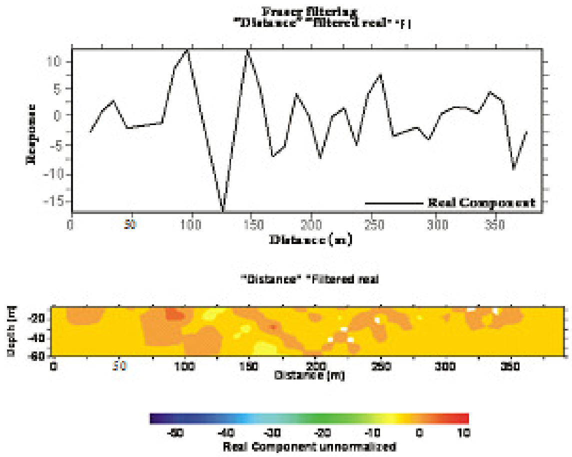

Figure 3a: VLF profile for dam axis at 10 m spacing and corresponding KH section

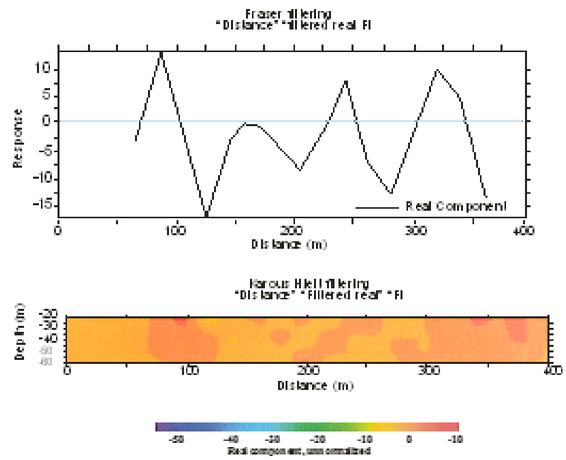

Figure 3b: VLF profile for dam axis at 20 m spacing and corresponding KH section

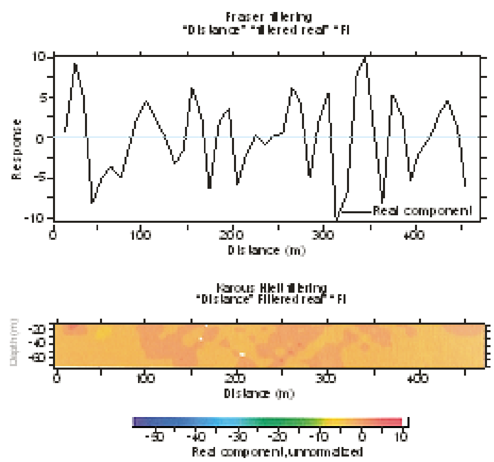

Figure 3c: VLF profile for left flank at 10 m spacing and corresponding KH section

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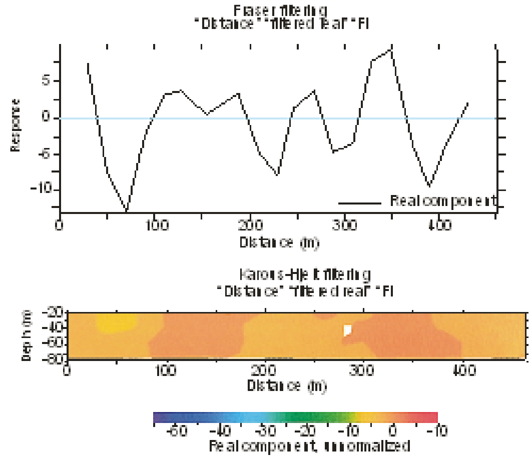

Figure 3d: VLF profile for left flank at 20 m spacing and corresponding KH section

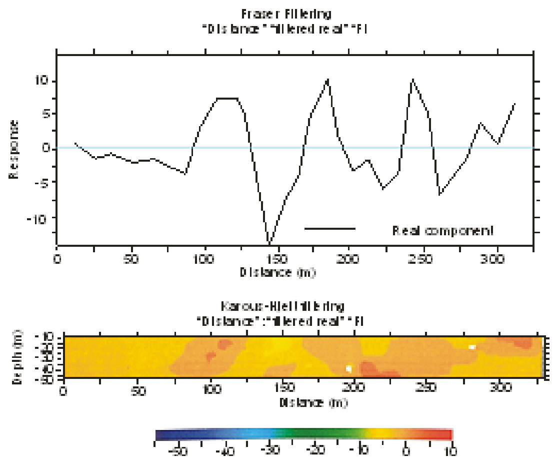

Figure 3e: VLF profile for right flank at 10 m spacing and corresponding KH section

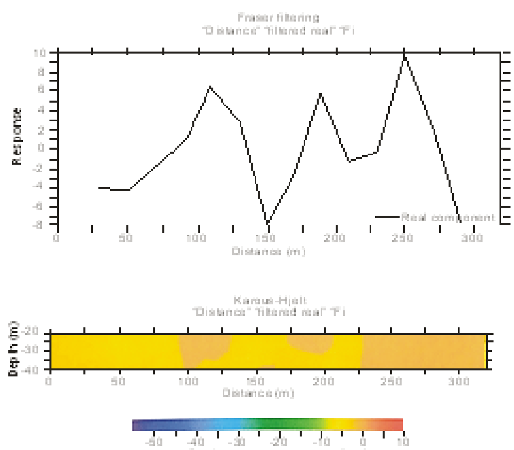

Figure 3f: VLF profile for dam axis at 10 m spacing and corresponding KH section

4. CONCLUSION

An integrated geophysical investigation of Agba dam in Ilorin Southwestern Nigeria has been carried out. The study revealed that the basement rock which is near the surface by a depth ranging from 4.1–21.2 m expected to serve as a sealing barrier for water in the reservoir show some degree of fracturing. Fractures may vary in width depending on the quality of the original rock and the intensity of relative displacement. Fractures characterized by very low resistivity were observed along the dam axis and the left flank. These are considered inimical to the continued retention of water in the reservoir. Significant reduction in reservoir water may be experienced. However, no surface manifestation of their effects exists; these zones are suspected to be current zones of anomalous seepage. They also represent potential failure zones even before any relative displacement has occurred, especially if they are affected by weathering and decomposition. In spite of the inherent problems sometime encountered using geophysical methods in surface investigations, the methods remain an invaluable tool for the investigation of subsurface geology and occupies a key role in exploration programmes for geological resources.

5. ACKNOWLEDGEMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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