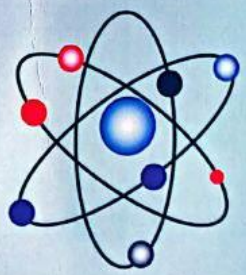
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VIABILITY TEST OF UNIVERSITY OF ILORIN DAM EMBANKMENT USING ELECTROMAGNETIC TECHNIQUE

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ABSTRACT

Very Low Frequency electromagnetic (VLF) technique with inter-data spacing of 5 and 10 m was employed to establishfive traverses around the dam embankment using ABEM WADI VLF model GSM-19Vto determine thefracture system, detect the water-bearingfractured zones in order to infer the possibility of seepage that could lead to the dam failure.The dam, underlain by theNigerian basement rocks, is bounded withinthe coordinate 4° 39'52"EX4° 40' 0"E and 8° 27'5"N X8° 28'5"N.The data were interpreted usingFraser and Karous-Hjelt filter techniques.The results revealed the locations of the water-bearing fracture zones, 2D form the mode of emplacement of the subsurface causative structuresand the depth to the conductive bodies.The 2D models show that most of the water-bearing fractured zones found along traverses 1, 2 and 3are at the depth of about 5 m to 40 m. The most prominent water-bearing fracture zoneslocated at 80-125 m and 130-150 m from the starting point of traverse 1 could signify seepage around the embankment. Notable water-bearing fractures along traverse 2 are at 80-100 m, 150 m, 210-240 m and 300-320 m. Traverse 3 shows only one at 75-150 m. The presence ofwater-bearing fractured zonesbeneath the embankment could lead to failure and collapse.Other minor conductive bodies were detected along all thefive traverses.

Keywords: Very Low Frequency, Dam, Traverse, Water-bearingfracture, Seepage

Introduction

Dams are vital elements in modern society and havelarge economic values. They also represent a potential risk (Johansson,1997). Seepage resulting from water percolating slowly through a dam and its foundation must be controlled both in velocity and quantity (Olatunji and Oladunjoye, 2013). If uncontrolled, it can progressively erode soil from the embankment or its foundation, resulting in rapid failure of the dam. Erosion of the soil begins at the downstream side of the embankment, either in the dam proper or the foundation, progressively works toward the reservoir, and eventually develops a "pipe" or direct conduit to the reservoir (Taft, Samuel, and James, 1994). The pressure of seepage within an embankment is difficult to determine without proper instrumentation.

A slope which becomes saturated and develops slides may be showing signs of excessive seepage pressure.Dam owners and operation and maintenance personnel must be knowledgeable of the potentialproblems which can lead to Dam failure of a dam. Dam failure could be fatal;it couldinvolve destruction of lives, properties and the ecosystem (ICOLD, 1987). Dam failure could be structural, natural

or man-made. It could also be due to prolonged or intensive rainfalls, anomalous seepage, internal erosionand so forth.The failure of a dam is, in general, a complexprocess which normally begins with some abnormality in behaviour (an initial fault) which is not detected. Consequent deterioration, often not observed, leads to further damage or even disaster. This is why inspection and monitoring of dams, as well as rapid data analyses and interpretation, can play a critical role in the field of dam safety. (ICOLD, 1987)

Aim

The focus of this work is to:

- Determine the fracture system in the vicinity of the dam embankment
- Locate water bearing fractures that could be a sign of seepage beneath the embankment
- Hence determine the possibility of failure and collapse.

Principles andTheory

The very low frequency (VLF) technique relies on several electromagnetic wave transmitters located at various places on the earth's surface. The electromagnetic wave frequency is between 15 and 30 kHz. As transmitted, the electromagnetic waves spread throughout the earth and the interaction between them and conducting planes in the earth can be measured. VLF EM waves interacting with buried conductors generate a secondary field. This field can be measured at and above the ground surface (Wrotek and Bujnowska, 2004.)

Low-frequency EM waves have a deep penetration range into the ground and the sea. This is a useful military aspect of VLF, as they are used for submarine communication. Furthermore, the rage of these waves is global, which makes it possible to use them in, for example, Geophysics.

The VLF method is inexpensive, very fast, and well suited to hard rock prospecting. Porous un- consolidated media such as sand are not suitable for this method. However, it enables very large metal objects buried in the ground to be sought. Conductive media, wet clays effectively mask anything lying beneath them.

The resultant waves measured with VLF machine are of two types: that which is in-phase with the primary field whose amplitude is then called In-phase or Real component of the resultant field; and the second component is usually displaced 90^0; thus it is out of phase with the primary, consequently its amplitude is termed the out-of-phase, Imaginary or Quadrature component of the resultant (Olatunji, 1999).

The principle of the very low frequency (VLF) electromagnetic methods is based on the fact that eddy current is induced in subsurface conductors (rock materials) when primary electromagnetic field from an oscillating current is applied on the rock from the subsurface. Secondary electromagnetic field which will distort the primary field is produced. This flows in opposite direction to the primary field. The resultant of the primary and secondary fields is picked up by a receiver coil at any observation point in the form of variation in amplitude or intensity and phase of the field (Dobrin and Savit, 1988). A pictorial description of the EM induction principle (showing the primary and secondary fields, transmitter and receiver etc.) is shown in figure 3.

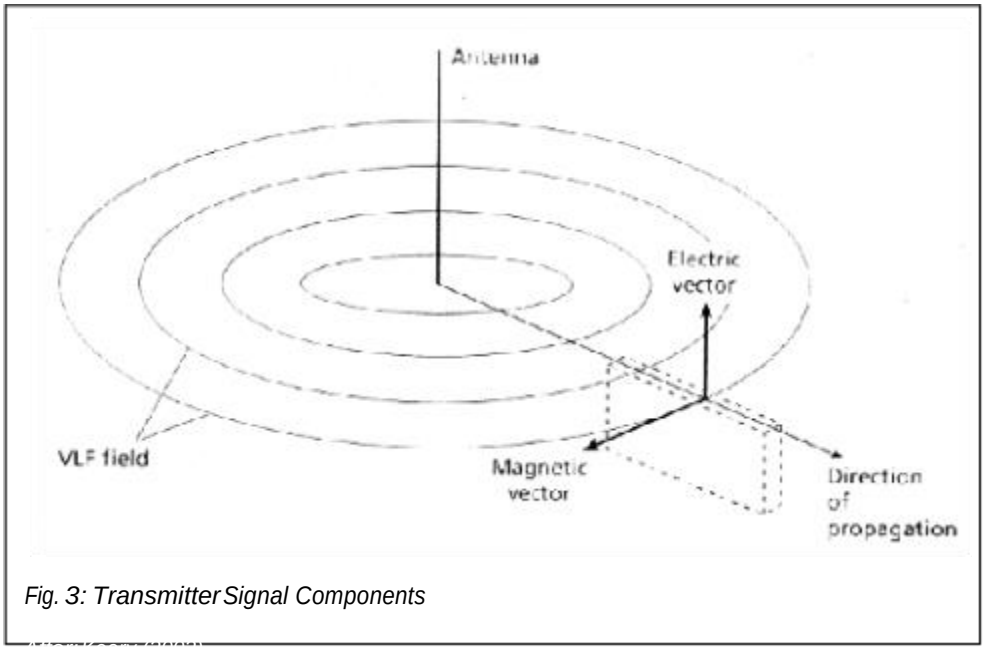


Fig. 3: Transmitter Signal Components

Dashed lines show a tabular conductor striking towards the antenna which is cut by the magnetic vector of the electromagnetic field. The electric component lies in a vertical plane95 and the magnetic component lies at right angles to the direction of propagation in the horizontal plane. A conductor that strikes in the direction of the transmitter is cut by the magnetic vector and the induced currents produce a secondary magnetic field (Keary*et al*., 2002).

When the field emitted by a transmitter strikes a body having low electrical resistivity, secondary circuits are created in the body; this is called induction. These secondary currents, in turn, create a secondary magnetic field that is opposed to the original field emitted from the transmitter (ABEM, 1989). A VLF instrument records the ratio (expressed as a percentage) of the strength of the vertical and horizontal fields at the ground surface. Since the primary field emitted from the transmitter is horizontal, it is evident that a normal reading (taken where there is no anomaly) will be zero (ABEM, 1989).

The depth of penetration of VLF waves depends on the frequencies and the electrical conductivity of the ground. This depth increases as both the frequencies and ground conductivity decreases (Keary and Brooks, 1984). The penetration depth is given by the equation;

$$\delta = \sqrt{2/\mu_o \sigma \omega} \cong 500/\sqrt{\sigma f} = 500\sqrt{\rho/f} \quad (1)$$

where δ =skin depth in meters, μ_o =magnetic permeability (H/m), ω =angular frequency in Hz, σ = Electrical conductivity of the earth material (Mho/m), ρ = resistivity in ohms and f =Signal frequency.

Currents that are caused to flow in the ground by alternating electrical or magnetic fields obtain their energy from the field and so reduce their penetration. Attenuation follows an exponential law governed by an attenuation constant (α) given by:

$$\alpha = \omega [\mu_a \varepsilon_a \{(\sqrt{(1 + \sigma^2/\omega^2\varepsilon_a^2) - 1}\}/2]^{1/2} \quad (2)$$

Where μ_a and ε_a are the absolute values of magnetic permeability and electrical permittivity respectively and $\omega (= 2\pi f)$ is the angular frequency.

sThe reciprocal of the attenuation constant is known as the skin depth and is equal to the distance over which the signal falls to 1/e (37 %) of its original value. Since the base of

natural logarithms e is approximately equal to 2.718, signal strength decreases by almost two-third over a single skin depth. The rather daunting attenuation equation simplifies considerably under certain limitation conditions.

The ground conductivity σ is much greater than $\omega\varepsilon_a$ under much survey conditions,α is then approximately equal to square root of $\mu_a \sigma\omega$. If the variations in magnetic permeability are small, the skin depth (1/α) in meters, is approximately equal to 500 divided by the square roots of the frequency and the conductivity (Milsom, 2003).

A powerful radio transmitter sourced the time varying electromagnetic field (primary field). A concentric horizontal magnetic field due to the current serving as the primary field is created. The VLF equipment measures the resultant fields due to primary and that from the induced eddy current in the subsurface structures at the survey area. These two waves are of the same frequency but different amplitude and phases. At very large distances from the source of electromagnetic waves, attenuation of this type would control the depth of exploration. Effective depth of exploration, Z_e , defines the maximum depth a body can be buried and still produce a signal recognizable above the noise. It is given as (Keary and Brooks, 1984)

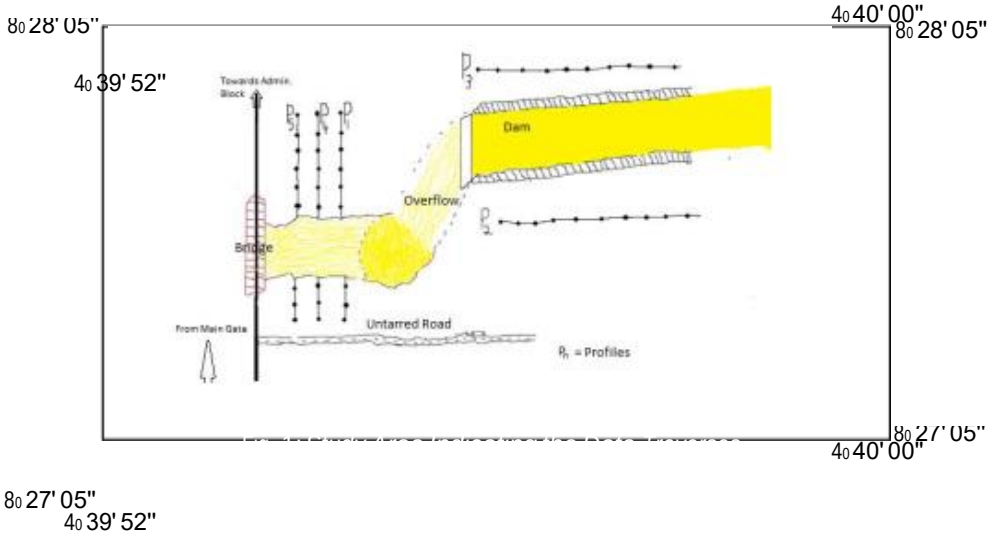
$$Z_e = 100\sqrt{\rho/f} \qquad (3)$$

where: Z_e =effective depth of exploration in meters, ρ = resistivity in Ohms and

f =frequency (in Hertz) of the signal

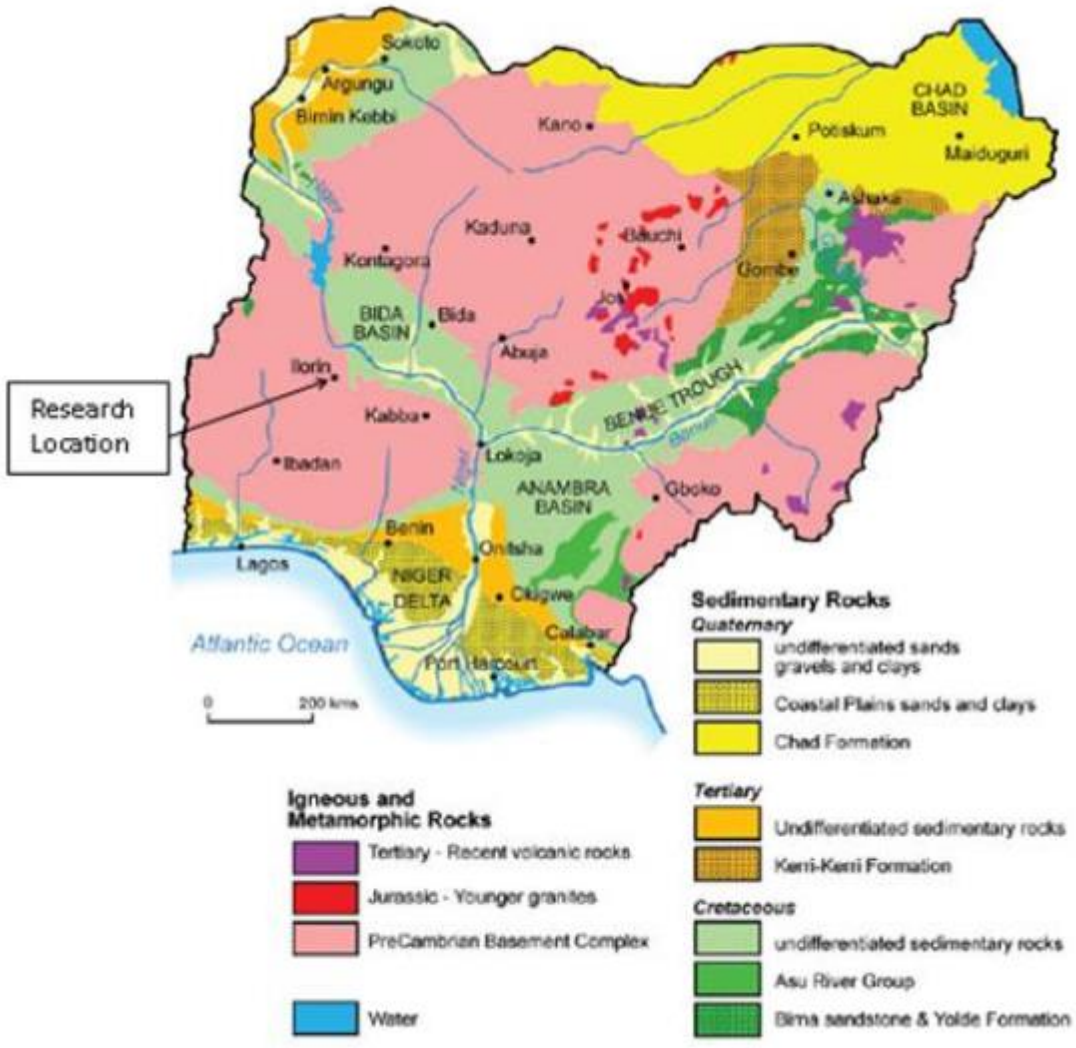
Material and Methods Data Collections

A sketchy picture of the study area is as shown in figure 1. Five traverses were explored to acquire the data using VLF equipment called ABEM WADI model GSM-19V. Two traverses along the river and three traverses along the Dam (Fig. 1). A total of 180 stations (data points) were distributed among the five traverses, with traverse 1 having 44 stations with a total length of 210 m; traverse 2, 36 stations with a total length of 350 m; traverse 3, 25 stations with a total length of 240 m; traverse 4, 39 stations with a total length of 190 m and traverse 5 having 36 stations with a total length of 170 m. The data for traverses 1, 4 and 5 were recorded each at a spacing of 5 m while that of traverse 2 and 3 were recorded at a spacing of 10 m. All the traverses were perpendicular to the direction of the primary transmitted signal. A Global Positioning System (GPS) was used to take the coordinates and elevations at each the data points.



Location and General Geology of the Study Area

University of Ilorin Dam is within the University of Ilorin permanent site in the west central part of Nigeria. The area lies entirely within the basement rocks in the western part of central Nigeria (Fig. 2), bounded by longitudes $4^{0}39'52''$ to $4^{0}40'0''E$ and latitudes $8^{0}27'5''$ to $8^{0}\ 28'5''N$. The study site is easily accessible through a moderately wide motor road that eased the field work. The topography of the area is relatively plain with minor undulations. The city is drained mainly by Asa River and its tributary Rivers such as Aluko, Alalubosa, Okun, Osere, Agba and Oyun River which forms the drainage basin (Jimoh and Ajewole,2009).



The main river within the campus is river Oyun which flows from South-East to North-West ofNigeria.

Generally, the crystalline basement complex of the study area is made up of gneisses and migmatities, schists, quartzites, Pan-African granite, late-stage minor pegmatitic and aplitic intrusives. Olasehinde, Virbka and Esan, (1998) repotted that Ilorin is situated within the Basement Complex rocks of granitic and metamorphic origin These rocks represent the deeper, fractured aquifer which partly lies on top of a shallow, porous aquifer within the

lateritic soil cover (Annor and Olasehinde, 1996). Offodile, 1987 andOlasehinde*et al*., 1998 further emphasized that the rock units form part of the regional South Western highlands of Nigeria running NW-SE parallel to the River Niger.

Results and Discussion

In traverse 1, the excel software indicates both the major and minor conductive zones as cross-over points. A qualitative interpretation of VLF-EM data is based on the cross-over points between the in-phase and imaginary data, which appear as positive peaks in Fraser-filter real curve (Srigutomo*et al*., 2005). The secondary field (in-phase component) generated by the subsurface conductors along these traverse ranges from -50% to 60% while the quadrature component ranges from -40% to 30% (Fig. 4). Fraser filter depicts the prominent conductive zones that may be water bearing fractures along this traverse as major peaks at the distances of 110 m and 130-150 m (Fig.5).Other conductive zones appeared as minor peaks. The Karous-Hjelt filter shows that the water-bearing

fractured zones along traverse 1 extended from the distance of 80 m to 180 m from the starting point with a depth of about 5 m to 30 m from the surface (Fig. 6).

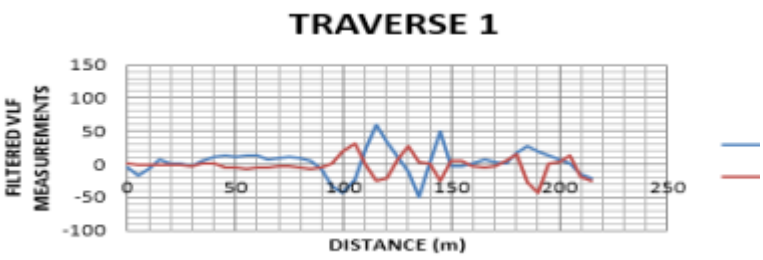


Fig. 4: Filter-Real and Filter-Imaginary Responses along Traverse1

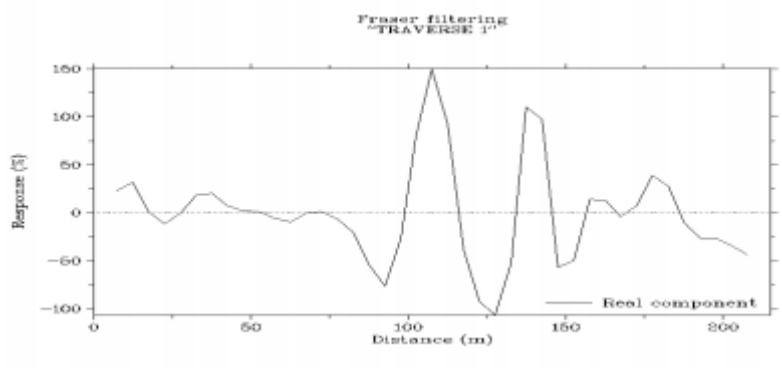


Fig. 5: Fraser Filter Response along Traverse 1

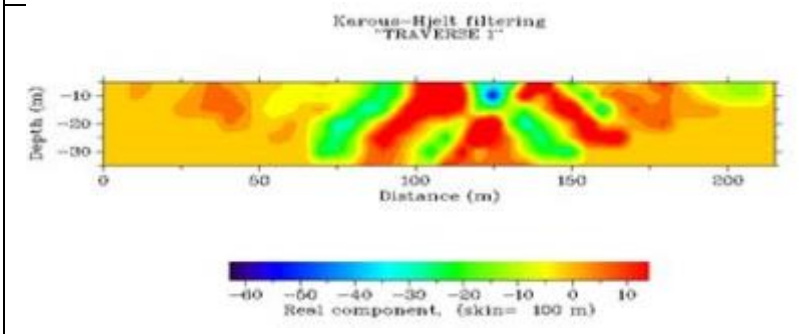


Fig. 6: 2D Cross-section along Traverse 1

The subsurface in-phase conductors along traverse 2 ranges from -25% to 9% while the quadrature component ranges from -7% to 5% as indicated by the response (Fig. 7). The major peaks that may be water-bearing fractured zones occurred at the distances of 80-100 m, 150 m, 210-240 m and 305-320 m (Fig.8) inFraser filter. These regions are also detected by Karous-Hjelt filter (Fig.9). The most prominent conductive zones along this traverse appear at the distance of 80-100 m and 210-240 m with a depth of about 10 m to 40 m from the surface and 305-320 m with a depth of about 10 m from the surface and ended at the depth of 20 m.

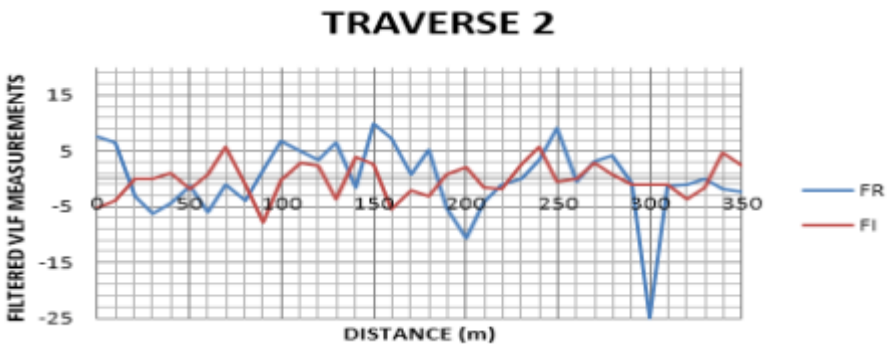


Fig. 7: Filter-Real and Filter-Imaginary Responses along Traverse 2

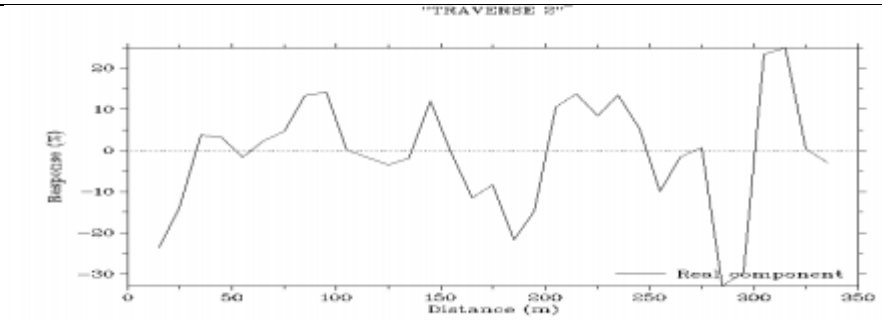


Fig. 8: Fraser Filter Response along Traverse 2

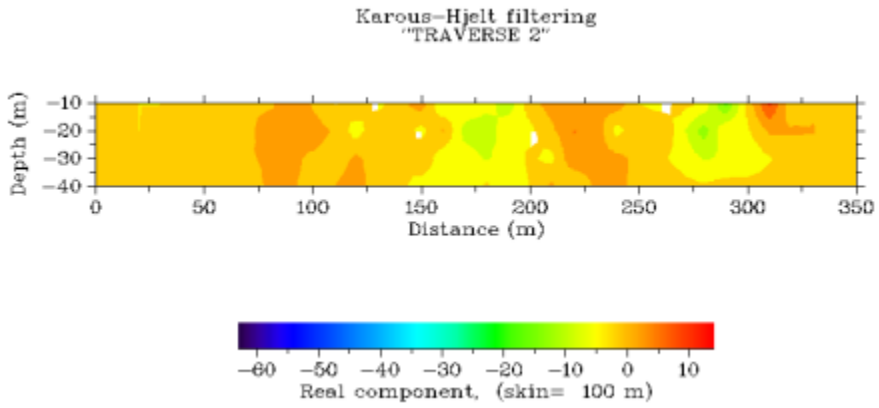


Fig. 9: 2D Cross-section along Traverse 2

In traverse 3, the secondary field generated by the subsurface conductors along the traverse ranges from -11% to +12% while the quadrature component ranges from -9% to +11% (Fig: 10). Only one prominent conductive water-bearing fractured zone is detected by the Fraser-filter (Fig.11). This zone extended from a distance of 75 m to 150 m with a maximum peak at 110 m, almost at the center of the traverse and is located at the depth of 10-40 m from the surface. The picture of this region is shown by the Karous-Hjelt filter in the 2D plot (Fig.12). This region conformed well to the exact location of the conductive zone detected by the Fraser filter (Fig.11 and 12).

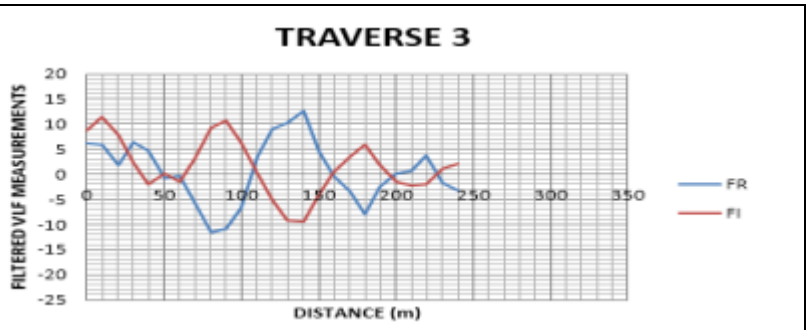


Fig. 10: Filter-Real and Filter-Imaginary Responses along Traverse 3

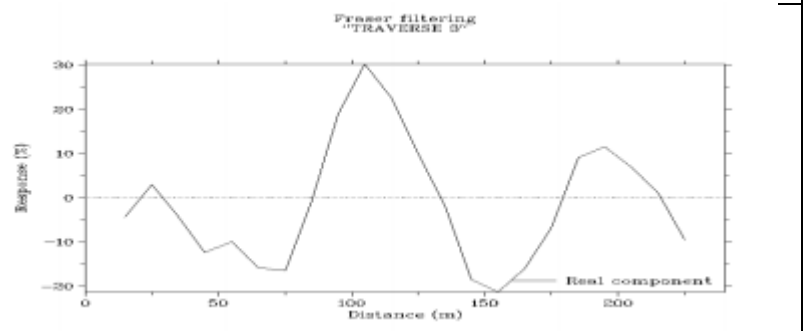


Fig. 11: Fraser Filter Response along Traverse 3

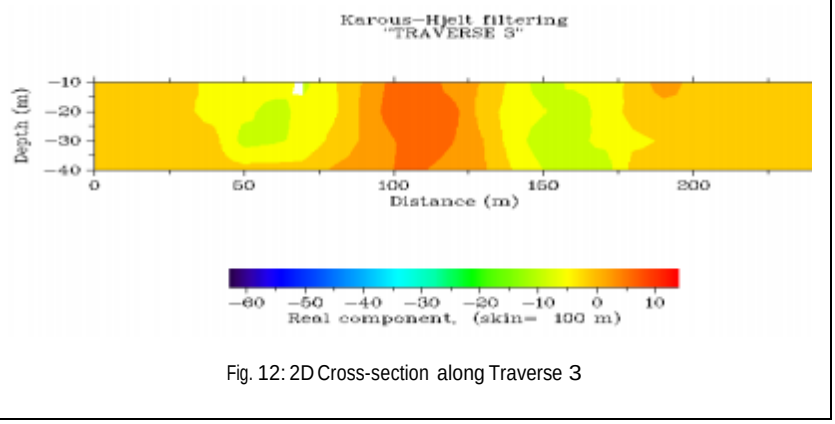


Fig. 12: 2D Cross-section along Traverse 3

The subsurface conductors along traverse 4 shows that the in-phase conductivity ranges from -6% to 7% while the quadrature component ranges from -1.8% to 2% (Fig. 13).The conductive zones detected by Fraser filter along traverse 4 are at the distances of 34 m, 70-80 m, 118 m and 150 m with percentage conductivity ranging from 10 to 15% (Fig. 14). These regions conformed with those detected by the Karous-Hjelt filter appearing within the distances of 30-38 m, 64-72 m ,110-120 m and 142-147 m from the starting point of the traverse (Fig: 15). These zones are found at 5-15 m depth. The Karous-Hjeltfilter shows that these zones are not water-bearing fractures but may be either metallic objects or other conductive bodies lying in the subsurface along the traverse.

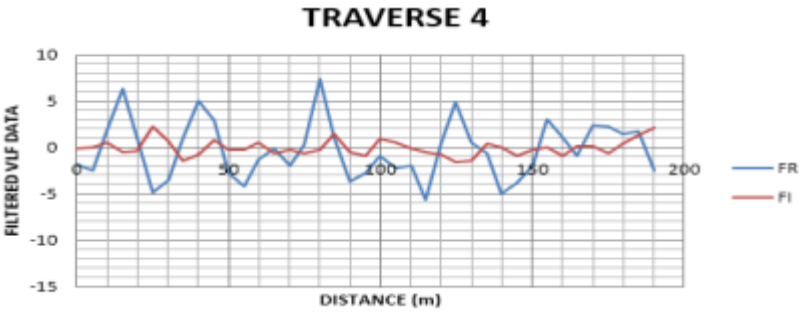


Fig. 13: Filter-Real and Filter-Imaginary Responses along Traverse 4

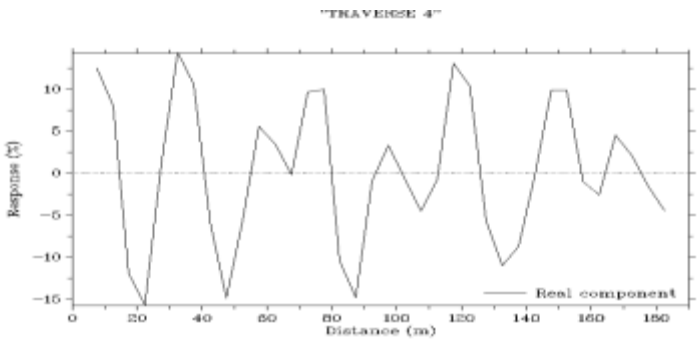


Fig. 14: Fraser Filter Response along Traverse 4

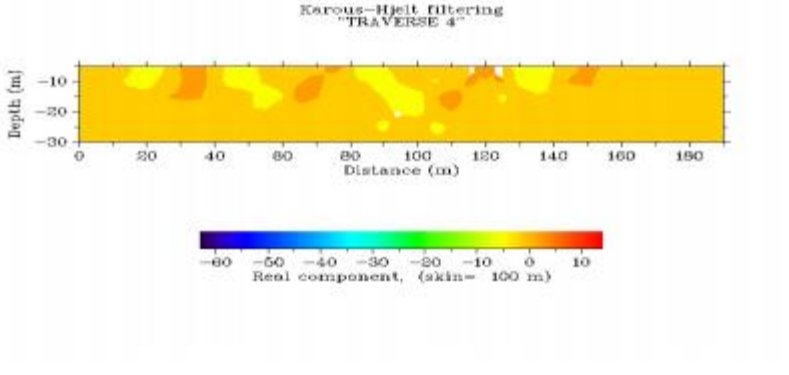


Fig. 15: 2D Cross-section along Traverse 4

Similarly, in traverse 5, the excel graph shows that the in-phase component generated by the subsurface conductors along the traverse ranges from -6% to 4% and the quadrature component range from -2% to +2% (Fig: 16). The peaks detected by the Fraser filter are found at the distances of 32 m, 62 m, 82 m and 148 m. The prominent minor peak which is of low conductivity (1%) or resistive region appear at 110 m from the starting point on the traverse (Fig.17). The most conductive zones depicted by the Karous-Hjelt filter appeared at the distance of 35-40 m and 140-145 m along the traverse with a percentage conductivity of about 15% (Fig.18).

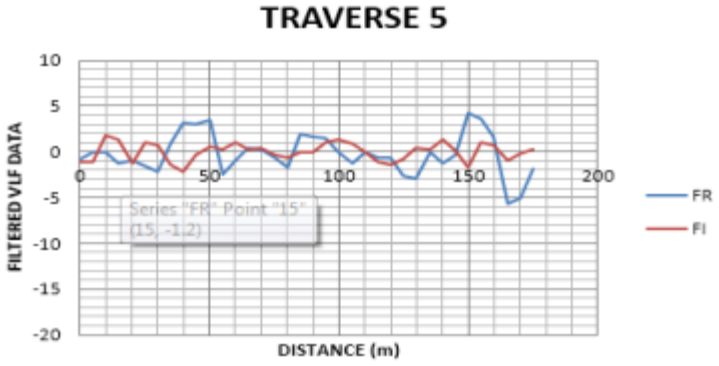


Fig. 16: Filter-Real and Filter-Imaginary Responses along Traverse 5

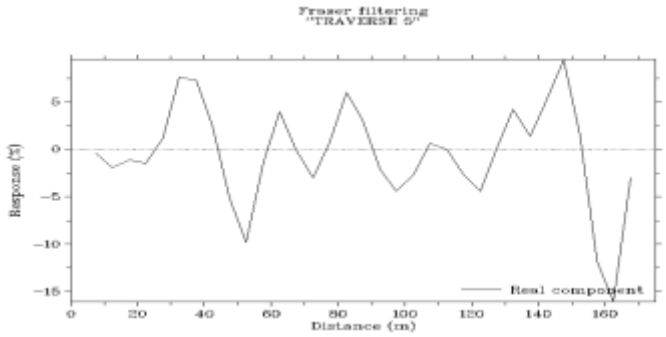


Fig. 17: Fraser Filter Response along Traverse 5

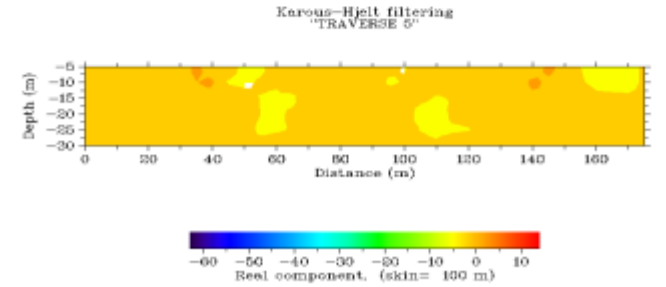


Fig. 18: 2D Cross-section along Traverse 5

Conclusion

VLF electromagnetic method used was found adequate, as fracture and water bearing zones were detected. The results obtained from the data show that there are water-bearing fractured zones and other conductive bodies along and across the dam axis. These water-bearing fractures are found along traverses 1, 2 and 3 as detected by Fraser filter and Karous-Hjelt filter in figures 5, 6, 8, 9, 11 and 12respectively. The most prominent water bearing fractures along traverse 1 were found at the 80-125 m and 130-150 m from the beginning of the traverse. On the traverse 2, the water bearing zones appear at 80-100 m, 150 m, 21o-240 and 300-320 m from its beginning and Water bearing zone appears only at 75-150 m from the starting point of traverse 3.The presence of water-bearing fractures around these areas is an indication that there is possible seepage of water from the dam. This is actually confirmed by those conductive zones that extend from the surface to a great depth of 40 m (Figures. 6, 9 and 12). Further, these traverses are closer to the dam wall. The aforementioned fact could be a warning signal to dam collapse as it could result into internal erosion as explained by Johansson 1997; whereby the underlain basement of the dam wall is washed away, the consequence of which is collapsing. There is no water-bearing fracture detected along traverses 4 and 5 but some confined conductive zones are also detected as seen in figures 15 and 18 respectively. This could not depict seepage in these areas.

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