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Monitoring of seepages around dams using geophysical methods: a brief review

O.T. Kayode[1], A.M. Odukoya[2], T.A. Adagunodo[1], A.A. Adeniji[3]

[1]Department of Physics, Geophysics Unit, Covenant University, Ota, Ogun State, Nigeria
[2]Department of Geosciences, University of Lagos, Lagos State, Nigeria
[3]Department of Physics and Solar Energy, Bowen University, Iwo, Osun State, Nigeria

solajesreign@yahoo.com; olusola.kayode@covenantuniversity.edu.ng; taadagunodo@yahoo.com

Abstract. The slow escape of a liquid or gas through a porous material or small openings is called seepage. It is a process of seeping in soil engineering whereby water in soils move. Seepages often pose a grave problem in building foundations and also a common problem in earth dams (Dams are structures built to retain water/fluild) due to abnormal or excessive leakage. Seepage through or around dams have been responsible for most dam failures. Dam failures are usually catastrophic with many fatalities and causing the destruction of infrastructure and properties. Therefore, monitoring of seepage through and around dams becomes a necessity in other to maintain dam's stability. The main field of application of this investigation is subjected to site characterization and foundation quality assurance. This paper reviews the geophysical techniques which have been considered for the monitoring and control of seepages around dams.

1. Introduction

The incessant incidence of dam failure is becoming an important topic in the past few decades. The improper knowledge about the subsurface geological material, inadequate information about the soil, poor dam foundation design and also seepages around dams have been attributed to the cause of this failure (Lukman et al., 2011). In other to prevent the significant potential hazards that always accompany such failures there is an urgent need for seepage studies (Close et al., 2002). Hence, a need to discuss the importance of geophysical techniques for the thorough mapping of dams, which is a vital factor in civil engineering as well as hydrogeological sectors.
Geophysical methods have contributed immensely to the monitoring of seepages around dams and to various aspects of human endeavours (Adagunodo et al. 2013a; Adagunodo et al. 2014) and more attention should be given to its intrinsic applications in environmental studies. Rapid and cost effective subsurface information/geology of large area are made possible by the applications of geophysical methods (Telford et al., 1976). Generally, dam and reservoirs are basically constructed for irrigation, water supply, hydro-electric power generation, flood control or some combination (Greager and Hinds, 2002). Many advanced countries like USA and China, make use of dams and reservoirs in such

that the development of China's hydropower and its regulation of water resources were as a result of the construction of dam and reservoir projects (Wang et al., 2012).

Major earth dam failures are due to seepages, although if it is within the design limit the stability is not threatened but excessive seepage will eventually lead to dam failure because seepage flow renders dam vulnerable to failure during their staged construction (Wang et al. 2012). The combined ERT results and geotechnical monitoring data are good indicators of likely mechanism for abnormal seepages (Lin et al., 2013). Most of the available seepage monitoring systems are insensitive to small changes in the seepage flow. However, the non-intrusive geophysical techniques have been on high demand to facilitate early detection or diagnosis of anomalous seepage occurences (Voronkov et al., 2004).

However, the relevance of geophysical methods in the investigation of seepage in earth-dam have been established in several works. Among this is the electrical resistivity tomography (ERT) method which have been progressively applied for seepage investigations, dams and buildings stability control (Okko et al. 1994; Abuzeid 1994; Panthulu et al. 2001; Karastathis et al. 2002; Turkmen et al. 2002; Oh et al. 2003; Lim et al. 2004; Sjodahl et al. 2005; Song et al. 2005; Kim et al. 2007 and Cho and Yeom 2007; Adagunodo et al. 2013b; 2015; 2017; Akinwumi 2014; Kayode and Akinwumi, 2014; Adewoyin et al. 2017). Also, Chin-ping et al., (2013) applied ERT to the investigation of seepage in earth dams in Taiwan. This particular dam was reconstructed to increase its water level and two-dimensional (2D) ERT was deployed at the study area to investigate several abnormal leaks that was observed on the downstream portion of the earth-dam. For time-lapse measurements, periodic measurements were collected on the downstream side. ERT results were combined with geotechnical data to indicate clearly the seemly mechanism of the abnormal seepage.

Seepage anomalies can be further enhanced in its capabilities by time-lapse measurement (Johansson and Dahlin 1996; Sjödahl et al. 2010). Also, Ani and Arewa (2013) used 2D electrical resistivity tomography to image suspected seepage channels in an earth dam in Zaria, Nigeria. This method was used to diagnose the variations in the volume of water content in the dam whether it is as a result of an anomalous seepage at the subsurface or a mere seasonal effect. Various zones of relatively uniform resistivity values were mapped and identified from the interpreted acquired data. The results revealed that the rather low resistivity zones within the bedrock represent probable pathways for seepages. Hence, geophysical method was successfully used to detect and map the seepage pathways within the bedrock of the earth dam (Ani and Arewa, 2013; Alemaw et al. 2016).

Moreso, Walid Al-fares (2011; 2014) carried out survey involving various geophysical methods such as the superficial electromagnetic (EM), electrical sounding and ERT to identify and discern the cause of the water losses problem in the Afamia B dam located at Al- Ghab basin in Syria. He noted that the ERT technique was more effective and convenient to detect water infiltration problems and leakages through the bedrocks. The integrated results of the methods revealed some geological structures that have adverse effect which may eventually lead to leakages in the dam foundation. The vertical infiltration in the dam was later detected as the principal cause for the seepage problem.

Also, Oladapo et al. (2013) carried out a feasibility study for constructing a dam on Gurara dam phase II using seismic refraction method. Off-end/reverse and split spread shootings were the seismic field techniques employed on the field. The study site is on the crystalline basement complex rocks of North Central Nigeria. The results showed significant seepage features within the bedrock, that is, on the western flank of the proposed dam axis. Significant fractured bedrock with probability for seepage was delineated on the eastern flank of the dam. The overall result revealed the competence and suitability of the materials investigated within the dam.

The present day seepage pattern and hydrogeological mechanisms that influence seepages were carried out in Raymond, California (Burke et al. 2011) using the self-potential and direct current resistivity surveys. The background knowledge of the hydrogeology and the information of a typical subsurface structures from resistivity surveys aided the interpretations as several flow scenarios were investigated. Evidence of seepage was discovered from the self-potential data interpretation of the dam which is consistent with past observations (Sjodahl et al. 2009). When properly integrated geophysical surveys, well data and numerical modeling can provide better understanding of seepages at sites. (Burke et al. 2011). In view of the above, this article utilizes the performance of ERT and other related geophysical methods to detect the abnormal seepage at earth dams and to further understand the possible ways of monitoring abnormal seepage in earth-dams.

2. Causes of seepage

So many factors have been researched to lead to the cause of seepage in dams. They include; open scams, joint in rocks, unconsolidated rocks in the foundation, poorly compacted soil, rat holes, digging of drains, deep rooted trees, cracks, frost action, shrinkage cracking in the environmental soil, uprooted trees, earthquakes; excessive uplift pressure and trapped groundwater and insufficient structural drainage (Greager et al. 2002; FERM, 2006; Flores-Berrones et al. 2011; Lukman et al 2011; Omofunmi et al. 2017).
Seepage is peculiar to all earth dams because water percolates slowly through dams and foundations. If seepage forces are large enough they may lead to eroded soil which may weaken the soil and eventually result in landslides. Seepage may result in environmental failure if not properly monitored (Auvinet et al 2010).
Other recognizable signs of seepage according to Auvinet et al. (2010) and Omofunmi et al. (2017) are

i. Seasonal temperature variation inside the dam.
ii. Rapid water level decrease below the level expected with normal use.
iii. Accumulated portion of water in areas around the dam site.
iv. Reduced growth rate in vegetation around the dam compared with other places far away.
v. Change of vegetation colour with distorted growth.

2.1 Effects of seepages on earth dams
Dams and embankments are most vulnerable to seepage during water conditions. Piping, excessive internal pressure or saturation, solutioning of soluble rocks such as gypsum, limestone and rock-salt, internal erosion, excessive uplift and heave or blowout, are some of the common seepage problems which could lead to dam failures (Alberro, 2006; Omofunmi et al. 2017).

2.1.1 Piping
Piping is a kind of seepage failure mode that occurs under the influence of seepage force in soil materials. The poor soils formed channels which transport materials downstream. These channels (hollow) grow wider as a result of infiltration of materials downstream and if not quickly checked it may eventually lead to subsidence of the dam. (Wang et al. 2017; Omofunmi et al. 2017).

2.1.2 Internal erosion
Internal erosion is another common way that water can damage embankment dams. This is the movement of water in cracks or other defects along borderlines of soil and bedrock (FERC, 2006; Fell et al. 2003; Flores-Berrones et al. 2011). Failures of internal erosion are commonly found in areas with slicken slides, careless construction, cracks and horizontal piping (FERC, 2006).

2.1.3 Solutioning
Dam foundation on soluble rocks that dissolve in groundwater can cause seepage problems. Rainfall dissolves soluble rocks in zones above the water table and below by the groundwater movement. Extreme caution should be taken on dams to be constructed on materials prone to solutioning such as gypsum, rock salts and limestone rocks (FERC, 2006; Flores-Berrones et al., (2011). The dissolved salts if not checked may gradually lead to the loss of strength of subsurface formations.

2.1.4 Internal pressures and saturations

Seepage normally takes place at the foundation soil of the dam especially when water is stored in the dam. Pore pressure, reduced shear strength are some of the adverse effects of seepages (FERC, 2006). The dam becomes so attenuated to withstand the water pressure as a result of continuous saturation and slumping processes and this may eventually leads to dam failure (FERC, 2006).

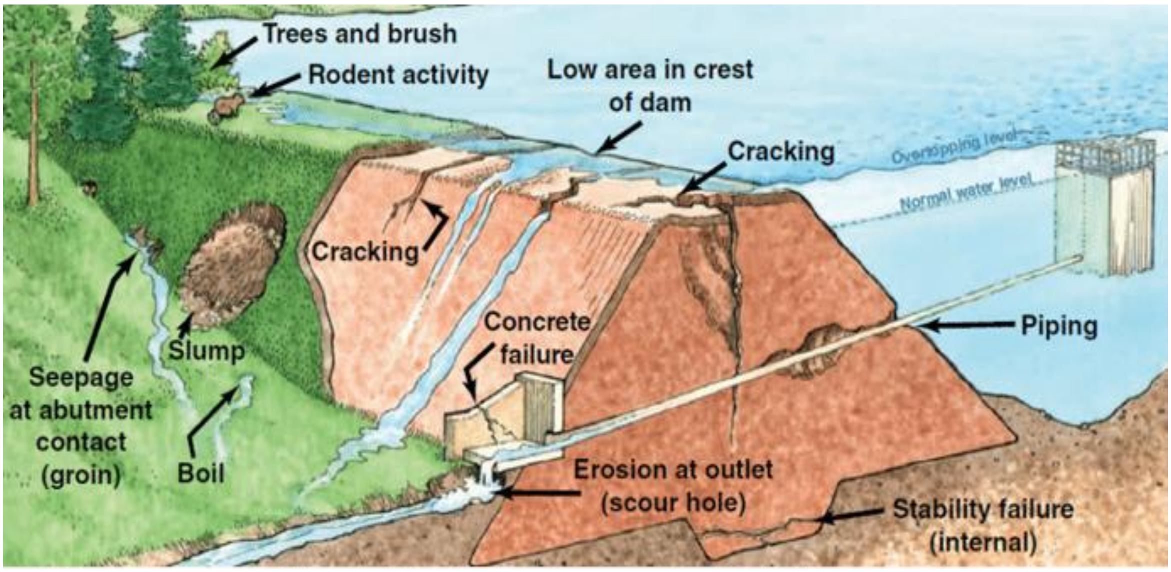

Figure 1: Effects of seepages in dams. Courtesy: the constructor

2.1.5 Blowout, uplift or heave

This is one of the symptoms of internal pressure and saturation. It occurs when there is an excessive uplift pressure, that is, the previous layer apply an excessive force on an overlying confining layer at the seepage foundation. Dam failure occurs when the pore pressure on the underlying confining layer surpasses the overburden pressure of the overlying soils. This scenario eventually results into a blowout, commonly forming a boil as it breaks through or breaches the confining layer (FERC, 2006).

3. Methodology and Applications

3.1 Electrical Resistivity Tomography (ERT)

Electrical resistivity method is non-intrusive geophysical method whereby profiles of the length of the proposed dam of investigation were spread in up and downstream sides, parallel and close to the dam embankment. Resistivity profiles have been successfully used to detect seepage paths in dams (Panthulu, 2001). The intrinsic electrical resistance of materials and the resistance contrasts between them is basically what the geophysical resistivity methods rely on. The resistivity of earth materials is determined by injecting electrical current into the ground and measuring the resulting potential difference. Self -potential (SP) or Induced polarization (IP) method is another proven method for monitoring seepage in the subsurface (Panthulu, 2001). Electric potential generated from fluid flow can be recorded on the surface survey lines. Hence, a comparison of SP/IP surveys from different reservoir levels can actually reveal seepage flow path. However, a combination of SP/IP and resistivity profiles can facilitate the detection and delineation of seepage path in dams (Brosten et al. 2005).

3.2 Electromagnetic method (EM)

This is also a non-intrusive geophysical method commonly used for seepage monitoring in dams. Low or high conductivities produced from air filled subsurface features and water or clay-filled features respectively are good indicators for seepage pathways using EM (Boston et al. 2005). EM can be used selectively to correlate survey results to known and existing seeps or groundwater seepage sources. Understanding of site hydrogeology of the study area is necessary when using EM so that the presence of power lines, buried cables, weak electrical conductors and clay layers in the soils can be delineated. Changes in water conductivity due to changing ion concentration and other related changes in groundwater should also be considered when using this method (Montgomery and Kofoed 2001).

3.3 Seismic refraction method

This geophysical method has also been used for seepage monitoring in dams but rarely used because of its high cost implication. The method has possibility to give an image of the subsurface and map lateral and vertical variations in the subsurface geology of the required site under investigation (Mustafa et al. 2012). A combination of seismic refraction and resistivity methods will give robust information of the seepage pathways in and around dams.

4. Conclusion

Monitoring of seepages around embankment dams is very important in civil engineering and hydro-geophysical structures. Generally, the effects of seepage on dams are functions of soil water retention capability which is a vital factor in engineering geology. Geological mapping and field investigations for dam projects should delineate soil properties and rock formations that could cause seepage failures. An in depth study of the geological and geotechnical properties of these materials should be carried out. A combination of electrical resistivity and other tools such as self-potential/Induced polarization have proven to give quantity and quality interpretation of seepage flow. Performing resistivity and self-potential profiles along several lines across the abutment permits a quasi-three dimensional view of the seepage pattern to be obtained (Brosten et al. 2005). Lastly, geophysicists and the civil engineers should work hand in hand in other to build and maintain dam structures to avoid the damage and waste of resources that may eventually result in the project if done otherwise.

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