Applicability of GPR Technique for Earthen Dam Failures

Arunapriya GGDPI, Liyanage AGSI, Kishanth S, *Premasiri HMR, Ratnayake NP and Abeysinghe AMKB

Department of Earth Resources Engineering, University of Moratuwa, Sri Lanka

*Corresponding author – ranjith@uom.lk

Abstract
A dam is a structure constructed across a river or stream to store water upstream from the obstruction. Dams are susceptible to damage for various reasons, which can lead to many catastrophic disasters. Therefore, identifying the dam's structural failures prior to a disaster is crucial. Drilling can be used for dam failure identification. But it is costly and destructive. Integrated geophysical methods have always helped in identifying subsurface features. In the current investigation, the applicability of ground penetrating radar (GPR) to detect potential failures in earthen dams was assessed. The Uyanwatta Lake earthen dam was selected as the study area during this investigation, considering the reported water leakage in this dam. A GPR survey was conducted with 100 MHz and 300 MHz antennas along five survey paths. Those are the top of the dam, 1.5 m below the top of the dam, and three distinct paths for the lake's spill. During the interpretation process, clay layers, fractured zones, gravel layers, and water seepage areas were identified. Those water leakage areas indicate that there has been a leak in the dam. Those results were compared with exploratory drill hole data from the Uyanwatta Lake Dam. Drill hole data has only presented information about the rock types present in the dam. But GPR data was able to provide information on loose sediments in the shallow depths of the dam as well. That indicates GPR data has the potential to provide additional information related to earthen dams.

Keywords: Geophysical methods, GPRSoft pro, Uyanwatta lake, Water leakage

1 Introduction

Dams are enormous structures erected across rivers or other water bodies to impound water. There are two primary types of dams: earthen dams and concrete dams. For the construction of earthen structures, soil or other earth-based materials are utilised. There are several vital uses for dams. Hydroelectric power generation, flood control, irrigation, and water storage are some examples. The structures are designed and built with the intent of impeding and regulating the flow of water to reduce the danger of flooding in areas located further downstream. Implementing flood protection measures can effectively mitigate the negative effects of flooding on both people and property. In addition, dams can facilitate the accumulation of water for irrigation purposes, allowing farmers to cultivate crops in arid regions [1]. Through the operation of turbines, dams can generate electricity by converting the kinetic energy of falling water into electrical energy. In addition, dams are used to store water for municipal and industrial applications [2]. In order to ensure the accuracy of safety assessments for significant infrastructure projects like dams, it is important to have a deep understanding of both the mechanical properties of the structure and the geological foundation on which it stands. Several factors contributed to the dam's failure, including overtopping, seepage, and human errors such as inadequate maintenance, insufficient inspection, and improper operations [3]. From a global perspective, dam failures have occurred on a significant scale. Instances such as the Belci dam failure [4], Tous dam failure [5], and Taum Sauk dam failure [6] have caused significant infrastructure and human life loss. Therefore, it is advisable to take the necessary precautions to detect potential dam failures before catastrophic events occur.

Several methods are utilised to proactively detect the likelihood of dam failure. Examples include visual interpretations, remote sensing, stress analysis, and core drilling. However, most techniques are characterised by their destructive nature, lengthy duration, and high costs, as well as the difficulties associated with data interpretation. ground penetrating radar (GPR) is a viable technique for proactively detecting dam failures because of its non-invasive nature, efficacy in terms of time and cost, versatility, and capacity for high penetration depth [7].

GPR technology has been commercially available since the beginning of the 1970s [8]. The technique of GPR detection employs electromagnetic waves of high frequency that are emitted as wideband brief pulses [9]. Reflections of these waves help detect hidden objects or underground interfaces. By analysing the time-frequency and amplitude of reflected electromagnetic waves, it is possible to determine the location of a concealed object or the composition of a subterranean medium. Reflecting on the global context, GPR surveys have been conducted on various dams. GPR surveys for the Marathon dam [10], the Medau Zirimils dam [11], and the Monte-Cotungo rock fill dam [12] are some examples. At the El – Elb dam site [13], they have successfully identified cavities, fractures, and the water bodies present in the dam. Prior identification of these features may prevent catastrophic disasters. Despite the widespread success of the GPR method, its potential for use in Sri Lanka to detect earthen dam breaches has not yet been investigated. Taking this opportunity to evaluate the viability of using this method in Sri Lankan dams is vital. Therefore, the objectives of this experiment are to detect probable weak spots or failure locations in the dam's construction and to observe the accuracy of GPR interpretations with drill hole data results.

2 Methodology

2.1 Study area

The Uyanwatta Lake Dam, located in Bandaragama was chosen as the study area for this research. The approximate coordinates of the selected area are, 60 43′26.26″ N, 800 0′22.64″ E. This lake was constructed in 1538. The dam is an earthen type, reconstructed by the British rulers in 1871. The length of the dam is about 305 m, and the dam's top level is established at 36.27 m above the Mean Sea Level (MSL). The dam height is about 5.8 m. Uyanwatta Lake is considered a medium-scale type of lake. The capacity of this lake is approximately 678,062 m3. The length of the lake's spillway is 23.77 m. In addition to that, it has three sluices. This lake supports a total agricultural area of 141.62 hectares.

2.2 Survey paths identification

During the visual observation, some water leakage places were observed. Therefore, survey lines were chosen to cover those leakage areas and examine these places using GPR. Five survey lines were selected.

(Fig. 1, Table 1). GPR survey was conducted on top of the dam and 1.5 m below the top of the dam. Since the dam height is about 5.8 m, 300 MHz and 100 MHz frequencies were utilised. In addition, another 3 GPR surveys were conducted in 3 different paths of the lake spill utilising the 300 MHz frequency. The acquisition range for the 300 MHz antenna was set to approximately 20 ns, and it was anticipated that it would be able to reach depths of up to 4 - 5 m.

2.3 Data processing from GPRSoft software

GPRSoft Pro was utilised to interpret the collected GPR survey data. The workflow of GPRSoft is simple and straightforward to manage. The first step was the surface correction. After that, a suitable frequency range was selected for interpretation purposes. Then, background noises were removed using 'background removal' function. Finally, 'gain' function was applied, and image was prepared for interpretation. 'velocity analysis tool' was used to determine the dielectric constants.

2.4 Comparison of GPR data with drill hole data

In 2019, a core drilling process was carried out to find dam failure features of the dam. There were 2 drill holes present along the GPR path [14]. Drill hole 1 and 2 were located 122.5 m and 305.5 m away from the initial point of the dam respectively. Therefore, those drill data were compared with GPR data.

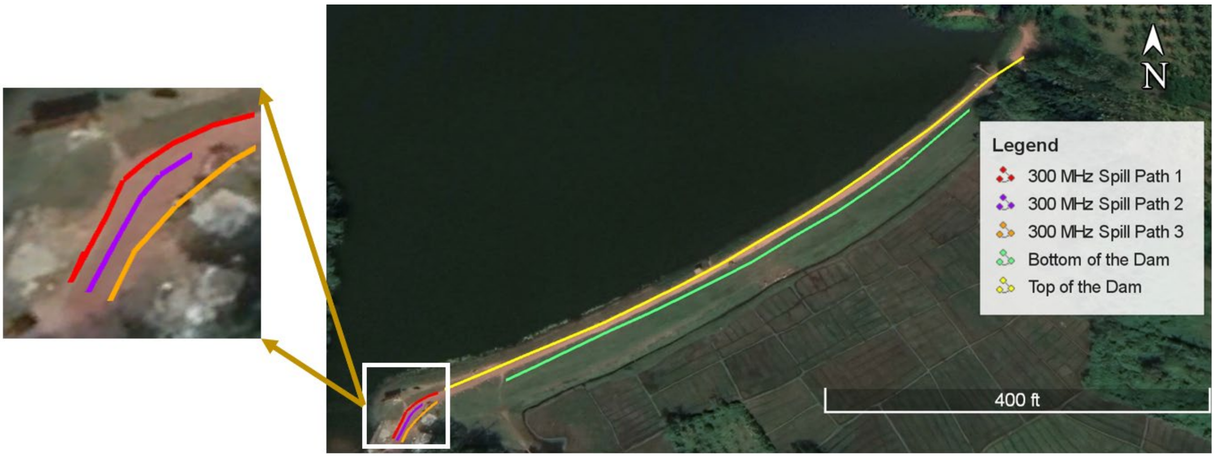

Figure 1: GPR survey paths of Uyanwatta lake dam

Table 1: Description of the GPR surveys

GPR path names with colours	Starting coordinates		Ending coordinates		Length (m)
	Easting	Northing	Easting	Northing	
Spill Path 1 (Red)	80^0 00′ 22.72″	6^0 43′ 25.88″	80^0 00′ 22.96″	6^0 43′ 26.44″	18.51
Spill Path 2 (Purple)	80^0 00′ 22.78″	6^0 43′ 25.89″	80^0 00′ 22.88″	6^0 43′ 26.32″	11.88
Spill Path 3 (Orange)	80^0 00′ 22.85″	6^0 43′ 25.93″	80^0 00′ 23.15″	6^0 43′ 26.45″	18.52
Top of the Dam (Yellow)	80^0 00′ 22.81″	6^0 43′ 26.25″	80^0 00′ 29.36″	6^0 43′ 31.03″	314.12
Bottom of the Dam (Green)	80^0 00′ 29.37″	6^0 43′ 30.74″	80^0 00′ 23.22″	6^0 43′ 26.37″	243.22

3 Results

Fig. 2 illustrates that the GPR profile exhibits the same kind of reflection from a depth of 0 to 0.8 m. That indicates that there are no lateral variances present. Since this is a dam made of earth material, it can be interpreted that there is a homogeneous material layer present in that depth [13]. Considering the reflections, it can be observed that reflections are less in that depth. The presence of water is the primary factor for that. Because of this, the dielectric constant goes up, while the amount of electromagnetic waves that are reflected goes down [13]. That indicates the material layer which presents in 0 - 0.8 m depth has the capability of absorbing water. When considering the dielectric constant of that area, it was 9.41. Therefore, it can be interpreted that the layer is a wet clay layer [15]. In addition, Fig. 2 shows that a significant amount of reflection occurs in the depth range of 1.3 – 2.8 m. The dielectric constant was 5.21. This can be interpreted as gravel being present in that area [15]. In the Fig. 3, there is a fracture pattern that can be seen from 2 m depth. Within those two fractures, a considerable reduction in reflection can be observed. It occurs when a material with a high dielectric constant is present. The dielectric constant obtained for that area was 12.45. It is an indication that there is water may present in that region [15]

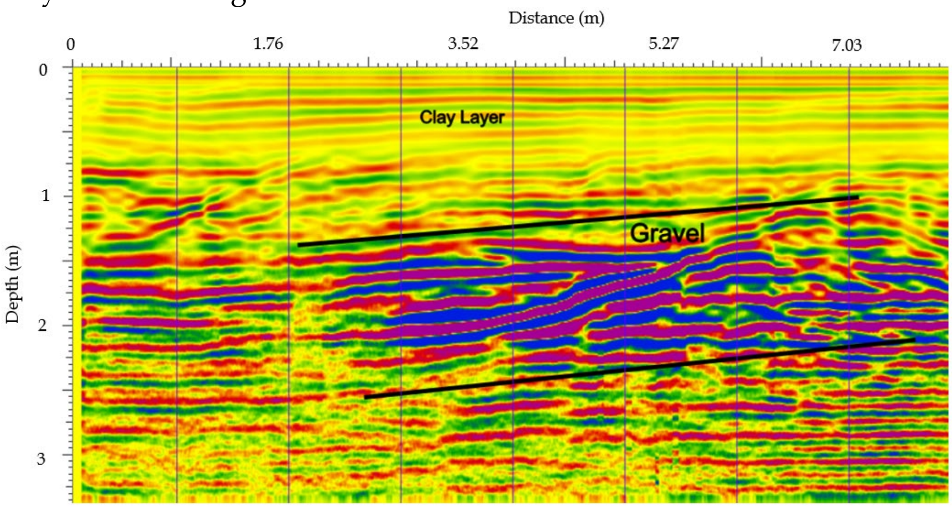

Figure 2: Identified gravel, clay layer (Top of the dam, 300 MHz)

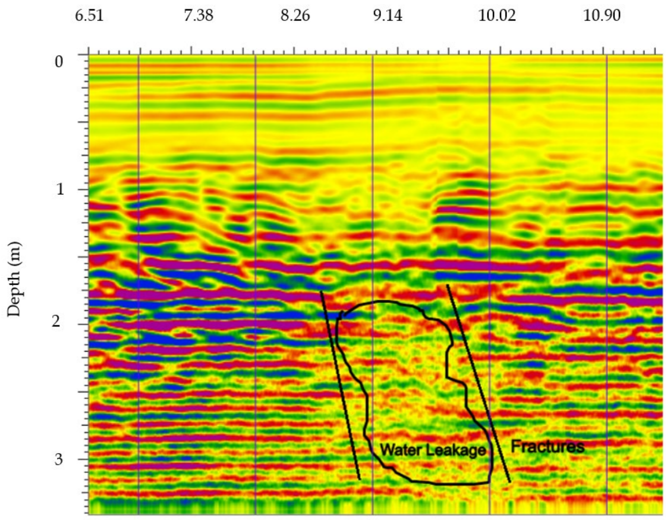

Figure 3: Identified fractures, and water leakage (Top of the dam, 300 MHz)

When comparing GPR data with drill hole data, drill hole data indicating the presence of loose sediments in the shallow depth level (0 - 3 m) [14]. GPR data also indicates the presence of clay and gravel at that depth level.

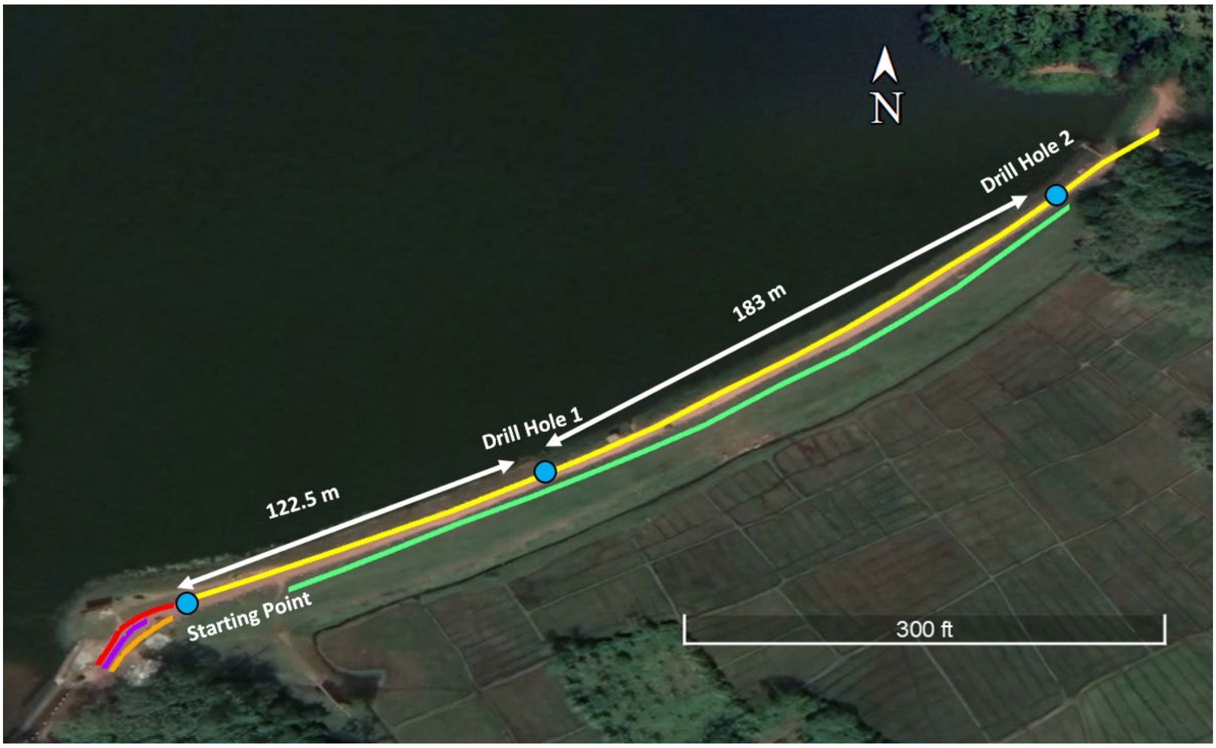

Figure 2: Drill hole locations (not to scale)

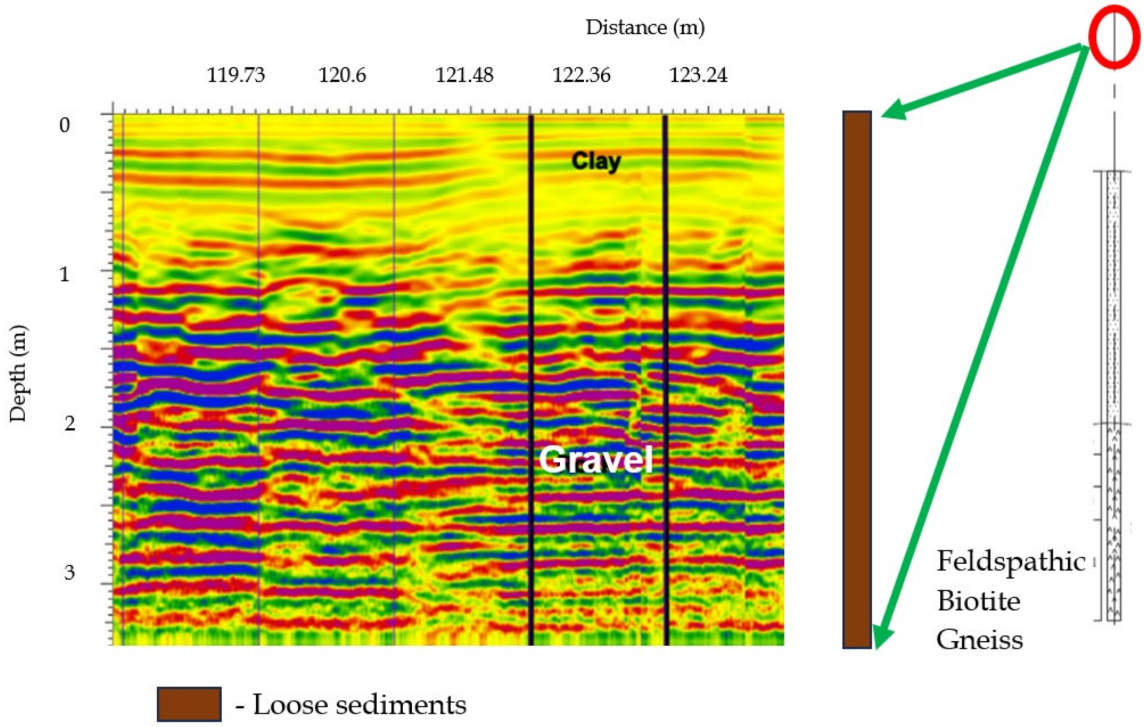

Figure 3: Comparison of GPR data and drill hole data for the same place of the dam at drill hole 01

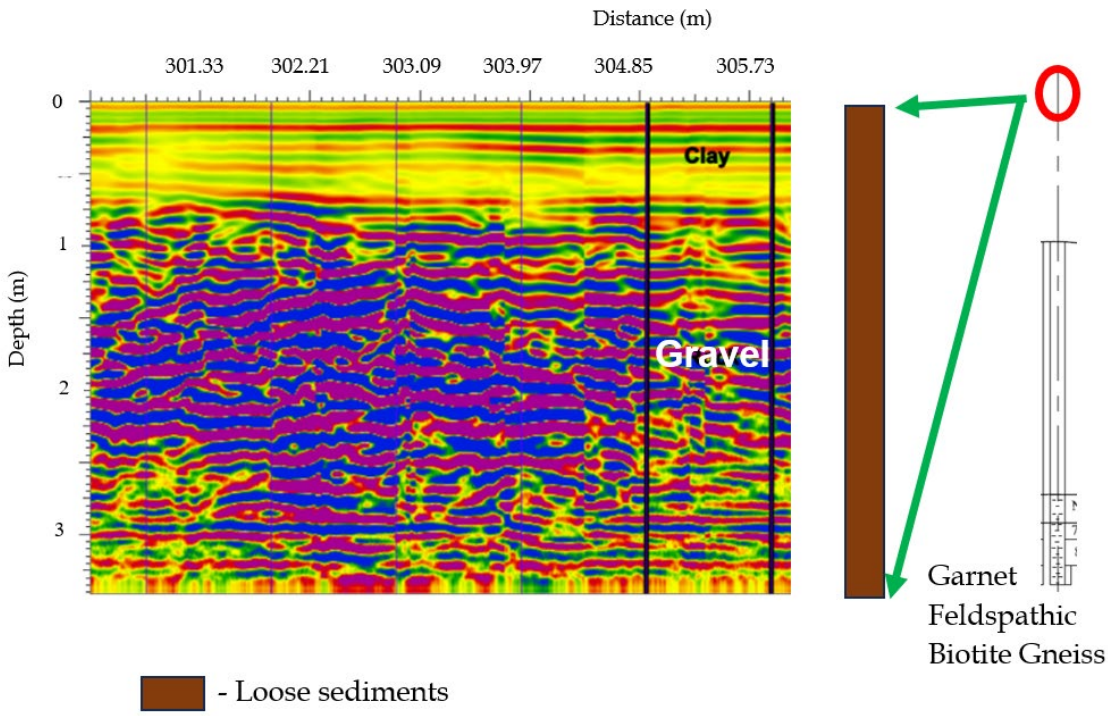

Figure 6: Comparison of GPR data and drill hole data for the same place of the dam at drill hole 02

4 Discussion

The GPR investigation revealed features like, clay layers, gravel layers, fractures, and water leakage areas within the earthen dam. Several features of the Uyanwatta dam were identifiable at GPR frequency of 300 MHz, which proved to be an effective choice during this investigation. At 100 MHz, the penetrating depth was greater, but recognising of features was difficult due to the limited resolution of data collected at that frequency. Within the dam, some water seepage areas were identified. That means water is penetrating through the dam in certain areas. During the interpretation process, both clay and gravel material were identified as loose sediments. There were several obstacles encountered during the conduct of this GPR survey. The depth restriction is one issue. The frequency of 300 MHz was adequate for this dam as its height was 6 m. Nonetheless, as the dam's height continues to rise, lesser frequencies will be required. Consequently, the resolution will be reduced, making it difficult to discern certain features. Below the water table, there will be minimal reflections from the features [16].

5 Conclusion

According to the results, it can be concluded that the 300 MHz frequency was adequate in recognising a wide variety of features in this earthen dam, and 100 MHz frequency was not sufficient in this procedure. The reason was that the resolution of images was not sufficient for interpretation. There are water leakage areas identified within the fractured zones. Those areas must be grouted or filled using an earth material. GPR data have provided the detail that there are loose sediments present at shallow depth levels (0 – 3 m). Also, that detail was able to be certified with drill hole data as well. It can be concluded that GPR can be applied to earthen dams as a supportive method for drilling because it helps to identify exact drilling locations. As a result of that, GPR helps to reduce the cost by reducing the number of required drill holes.

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