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A COMPARISON OF FOUR GROUND ELECTRICAL RESISTIVITY SURVEY (GERS) ARRAY METHODS USED IN INVESTIGATING INJECTED GROUTING: A CASE STUDY OF THISSA DAM IN SRILANKA

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ABSTRACT: The Thissa reservoir with a capacity of 4.32 million cubic meters is situated in Thissamaharama in Hambanthota district about 250km South from Colombo, Sri Lanka. Geologically, it lies within the litho-techtonic unit of the Vijayan Complex in Sri Lanka. For several years, the Thissa reservoir has experienced seepage issues, posing potential risk to the earthen dam. To address these problems, a rehabilitation study using the two-dimensional Ground Electrical Resistivity Survey (2D-GERS) method and the clay-cement grouting method was conducted. The 2D-GERS method, a geophysical method for detecting subsurface or rock anomalies, was used to compare four electrode array configurations: Dipole-Dipole, Gradient-XL, Schlumberger and Wenner. These arrays helped identify injected grout and seepage zones beneath the Thissa *wewa* earthen dam. The objective of this study was to compare the performance of four arrays, assessing seepage after the clay-cement grouting treatment. The analysis of the 2D-GERS profiles at seepage locations along with the grouting results shows that the 2D-GERS method can serve as a cost-effective investigation method for assessing the seepage locations through earthen dams. The areas of heavy cement-clay grouting are clearly delineated by the 2D-GERS profiles from the different array methods. The Dipole-Dipole array recorded the largest dataset (1149 points) and reached greater depths and was faster compared to the others. In contrast, the Wenner array had the smallest dataset (345 points) and captured shallower depths. The Wenner, Gradient-XL (1030 points) and Schlumberger (748 points) arrays produced relatively similar profiles. However, it was noticed that the Dipole-Dipole array was less sensitive compared to the other three arrays. Overall, the Gradient-XL and Schlumberger arrays captured the grout intake at an acceptable level.

Keywords: dipole-dipole, gradient-XL, schlumberger, wenner

1. INTRODUCTION

Most of the dams in Sri Lanka, built across rivers, are earthen dams, and excessive seepage through these structures has become a recurring issue. The main purpose of most dams is to store water for use in dry periods. Therefore, it is crucial to minimize seepage to ensure both the stability of the dam and the maintenance of secure water storage in the reservoir. The Irrigation Department of Sri Lanka (IDSL) manages most of the country's large dams. Some of the earthen dams maintained by the IDSL were constructed during the reigns of the kings. Recently, seepage has become visible through some of these historic dams including the Thissa reservoir. Geologically, the Thissa reservoir is located within the Vijayan Complex litho-tectonic unit (Fig. 1). Excessive seepage in the dam was investigated using cost-effective geophysical methods. The Ground Electrical Resistivity Survey (GERS) was used to investigate the seepage locations by identifying anomalies in the earthen dam before and after treatments. Based on the recommendations of the Engineering Geology Division (EGD) of the IDSL, clay-cement grouting treatments were implemented to address the seepage issue.

Fig. 1. Location of Thissa dam

The main purpose of grouting is to densify the soil and minimize the voids in soil and gaps in fractures or fissures in rock. Clay-cement grouting involves injecting a slurry mixture of clay, cement, water, and other additives into the voids, cracks, or porous zones within the dam structure or foundation. The process aims to fill these gaps, reducing permeability and enhancing the structural cohesion of the dam. The mixture is injected under pressure through strategically placed boreholes, allowing it to penetrate and fill the targeted areas. Once the grout sets and hardens, it forms a dense, impermeable barrier that strengthens the dam and prevents water seepage. In the grouting industry, various materials can be found which have been used to increase the density and seal the voids in soil. Chun et al (2006) have successfully controlled leakage in an earth- fill dam in Korea through application of permeation grouting.

The GERS is a geophysical method used to investigate subsurface properties by measuring the ground electrical resistance. Several array methods are available, each suited to different types of investigations, including Wenner, Schlumberger, Dipole-Dipole and Gradient-XL arrays. Each method offers distinct advantages and limitations, with the choice depending on the survey's specific objectives and conditions. Wickramasooriya et al (2023) carried out a GERS in Uyanwewa Dam in Sri Lanka and successfully investigated seepage locations during clay-cement grouting. Even though Wickramasooriya et al (2024) assessed the applicability of GERS for identification of seepage in an earthen dam, a comparison of the array methods has not been performed yet for the Thissa Dam. Furthermore, Wickramasooriya (2024) concluded that the Schlumberger method is well accepted for delineating the subsurface materials in the Ellewewa Reservoir Project in Sri Lanka and has identified GERS as a more economical method for investigating subsurface materials, compared to traditional borehole drilling. In contrast, the Wenner array was identified as superior over the Dipole-Dipole array by Neyamadpour et al. (2010) during a three-dimensional electrical resistivity imaging study aimed at determining an underground cavity in Malaysia. Moreover, three array methods were compared by Al-Saady et al. (2022) in a 2D resistivity survey in Iraq to determine subsurface weak zones and concluded that the Dipole-Dipole array is the optimum method for mapping subsurface weak zones. Himi et al. (2018) successfully detected seepage and injected mortar zones by geophysical methods. However, it appears that a comprehensive study of all four methods in GERS along with an assessment of their applicability has not been sufficiently carried out in the Sri Lankan context.

2. METHODOLOGY

A few years after leakages were observed along the downstream (DS) face of the Thissa dam, as a quick and economical investigation method in geophysics, the GERS along the bund top was used here to identify leakage paths. These investigations identified three locations (Fig. 2) with significant seepage issues.

The EGD of IDSL recommended grouting the identified bund sections (Sections A, B and C) up to a maximum depth of 12 m in overburden with proper ratios of clay and cement, and in rock up to 24 m with cement grout to arrest water leakages as necessary. Two rows of grout holes were planned in a zigzag pattern with 3 m spacing between two holes within a row and 1.5 m spacing between the rows. The shortest distance between nearest holes was 2.12 m. After grouting, only section C was investigated using the four different GERS methods of fixing electrodes as in Fig. 3. ABEM Terrameter LS2 instrument and RES2D software were used for the GERS analysis. All four GERS profiles were compared to the actual amounts of grout and assessed, each with different levels of acceptance.

Fig. 2. Seepage locations

Fig. 3. GERS at Thissa dam

3. RESULTS AND DISCUSSION

The locations where the dam received peak grout values were marked and compared with the GERS profiles. A total of ten peak points were identified and they were categorized based on how accurately each method captured grout injection into the dam as shown in Table 1. It was assumed that the clay grout had a resistivity value ranging from 0 to 30 Ωm.

Table 1. Capturing of Grouting by Each Method of Arrays

Peak point	Dipole-Dipole	Gradient-XL	Schlumberger	Wenner
A	NC	NC	NC	NC
B	NC	MC	NC	NC
C	MC	NC	MC	MC
D	MC	WC	WC	WC
E	WC	WC	WC	MC
F	WC	WC	WC	WC
G	WC	WC	WC	WC
H	WC	WC	WC	WC
I	MC	WC	WC	WC
J	MC	MC	MC	MC

Note: WC = Well Captured, MC = Moderately Captured, NC = Not Captured

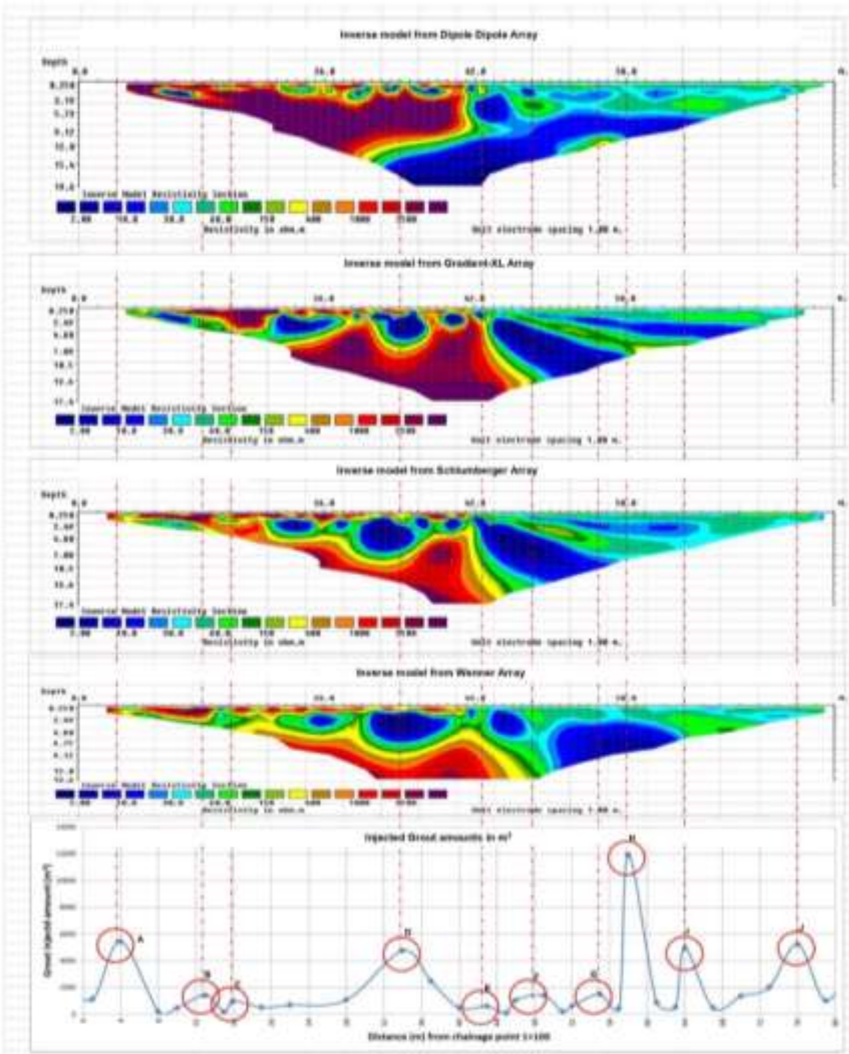

Fig. 4. Comparison of GERS performance with the injected grout amount

It was observed (Fig. 4) that none of the four array methods was able to detect the peak grout intake at the starting edge of the profile. As noted by Wickramasooriya (2024) the GERS method is less suitable to get subsurface materials in the edges of the profiles. The Dipole-Dipole array method captured well only the middle area of the profile while the other array methods captured a comparatively wide range of areas effectively. However, the Dipole-Dipole array method reached the greatest depth recording 19.6 m depth, which is the maximum among the methods. It was noticed that non-grouted areas between 24 m to 28 m were incorrectly shown in Gradient XL, Schlumberger and Wenner arrays as low resistivity areas. This is due to the existing high moisture content of the soil due to the availability of trees on the dam.

Table 02 tabulates the WC, MC and NC values as per their identification of the injected grout zones. As tabulated in Table 02, the dipole-dipole array method was identified as less sensitive than the other three arrays, because it has a smaller number of Well Captured (WC) zones. The WC zones are higher (Table 02) in the Gradient XL and Schlumberger method arrays for identifying the injected mortar.

Table 2. Capturing Performance of Each Array Method

	Dipole-Dipole	Gradient-XL	Schlumberger	Wenner
WC	4	6	6	5
MC	4	2	2	3
NC	2	2	2	2

The GERS method was very cost-effective; one GERS profile would cost around 0.1 Mn (LKR) approximately (without the instrument cost) while traditional borehole drilling costs about 1 Mn (LKR) approximately for one bore hole. Furthermore, GERS provides comparatively broad, continuous coverage over a large area and traditional bore hole drilling provides point-specific data with high accuracy at each point.

4. CONCLUSION

The areas where cement-clay grouting was heavily applied were clearly identified using 2D-GERS profiles from various array methods. The Gradient-XL and Schlumberger methods proved to be superior compared to the others. The dipole-dipole array captured comparatively greater depths and was quicker than others but less sensitive, while the Schlumberger array took a longer time compared to other methods.

In conclusion, GERS can be identified as a more economical method of investigation compared to traditional borehole drilling. However, there are limitations in the level of acceptance in each array type. Further studies could compare the grout injection variation with depth to enhance precision. Furthermore, GERS can play a critical role in the planning, design, construction, operation, decommissioning, and closure of water resources or tailings dams.

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