willowstick

Dam decisions: *past experiences, future challenges*

The use of innovative groundwater seepage detection techniques

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Numerous challenges complicate the effort to identify the source and character of groundwater seepage. Traditional investigative techniques which involve the chance intersection of drilled bore holes and seepage paths can become very expensive when required to cover large areas. The Willowstick diagnostic method detailed in this paper significantly mitigates these problems. By charging the subsurface with a low voltage, low-frequency electrical current and then mapping the resulting magnetic field, this method effectively and efficiently charts groundwater flow in complex environments, at significant depths, and over large areas.
This paper will detail the method and examine its application at a site in Sri Lanka.

The method was deployed at the Samanalawewa Dam, a large and important hydroelectric power project on Sri Lanka's Walawe River. The Samanalawewa Dam is surrounded by karstic geology, which has long complicated the effort to account for and remediate seepage through the dam. The mapping method proved effective at mitigating the particular challenges associated with groundwater seepage. The results represent an important advancement in the ongoing quest for better ways to monitor and remediate seepage. This paper discusses the Willowstick diagnostic tool which allows individual seepage points to be mapped at depths of more than 100 metres to an accuracy of less than 100 millimeters.

Introduction

Groundwater seepage can exacerbate environmental pollution through contaminant transport, pose a threat to dam safety and can also be associated with valuable mineral deposits.

Dam safety, environmental remedial works and mineral location normally involve comparatively expensive techniques but if the extent and location of groundwater seepage can be accurately predicted then the amount of works and thus costs can be dramatically reduced.

This paper describes the Willowstick technique and how it was used to locate leakage and target the proposed remedial works at a 200 metre high rockfill dam in Sri Lanka.

The Willowstick technique

Equipment

The equipment used to measure the magnetic field induced by electrical current flowing in the groundwater of interest includes: three magnetic sensors oriented in orthogonal directions (X, Y, and Z-axes); a data logger used to collect, filter and process the sensor data; a Global Positioning System (GPS) used to spatially define the field locations; and, a Windows-based handheld computer used to couple the GPS data with the magnetic field data and store it for subsequent reduction and interpretation. All of this equipment is attached to a surveyor's pole and hand carried to each field station (see Figure 1).

Figure 1 - Willowstick Instrument

Interpretation and modelling

After data is collected, one or more footprint maps are created to reveal the patterns of electrical current flow in the subsurface by showing contrast between areas of high and low electrical conductance.

Interpreting magnetic field contour maps could be compared to reading a topographic map. On a topographic map, the ridge lines connecting the peaks could be thought of as the pathways offering the least resistance to traverse. In the same way, these lines in the magnetic field maps represent paths of least resistance for electrical current to follow. By identifying these high points and ridges and connecting them together through the study area, the center position of strong preferential electric current flow can be identified.

In some cases electric current flow paths produce very tight and revealing anomalies that can be modeled with a fairly high degree of accuracy (depths to within 10% error). Other times electric current flow patterns are not as distinctive and the depth and character can only be roughly estimated—in which case it is very important to have additional data to help characterize the groundwater zone of interest, such as, well logs, piezometric data, or other geophysical or hydrological data. In any case, the horizontal position of electric current flow paths is generally determined with a high degree of consistency and accuracy.

The results obtained from a Willowstick geophysical investigation is to be used to make informative decisions concerning how to further confirm, monitor and possibly remediate groundwater problems through a given area of investigation.

Example of the Willowstick system in practice

The Samanalawewa Dam is located in Sri Lanka approximately 160km southeast of the capital city, Colombo (see Figure 2).

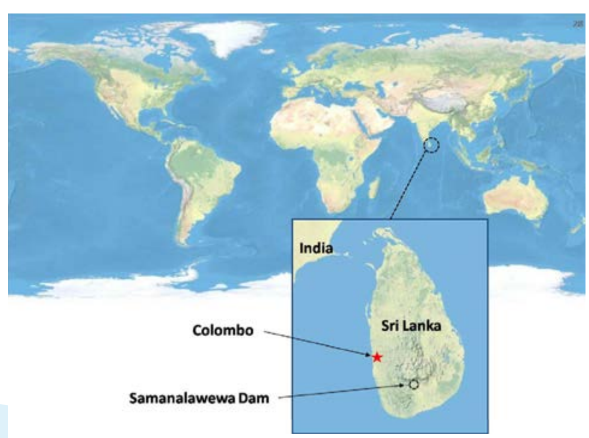

Figure 2 - Samanalawewa Dam location map

The construction of the Samanalawewa Dam was started in 1986 and completed in 1991. The dam and resultant reservoir are one of the largest storage facilities created in recent times in Sri Lanka. The dam is a zoned rockfill embankment with clay core. The dam is roughly 105m high and 530m long and retains a reservoir with a capacity of 254 Mm^3. The catchment area of the dam covers nearly 350km^2.

Figure 3 - Photograph of Samanalawewa Dam

Geological setting

The dam's right abutment and right rim areas consist of karstic terrain. Karst conditions develop from the dissolution of the host rock along fractures, joints and/or bedding planes which become enlarged over time from the saturation and flow of groundwater along these features.

During the investigation and construction phases of the reservoir it was recognised that karstic features were likely to be common in the right bank.

A karstic feature, a cave, was discovered during the construction phase 300 metres upstream of the proposed axis of the dam on the right abutment.

This and other signs of possible leakage through the right abutment area resulted in an extensive grouting program. Six large cavities, were found and sealed with concrete during construction.

Measures to limit water losses

During the construction of the dam 4 adits were driven along the axis of the dam.

Despite the effort to cut off seepage through the right abutment area, a small spring appeared downstream of the dam upon initial filling of the reservoir (June 1991). The seepage was large enough to suspend filling the reservoir. Additionally, a flat water table was observed responding to the reservoir levels up to a distance of 2.5km from the dam (along the reservoir's right rim). As a remedial measure, a 1,880m-long tunnel was drilled beneath the right rim area. From inside the tunnel, a 100m-deep by 1,600m-long grout curtain was constructed.

'Leakage incident' and subsequent remediation

An effort to remediate the leakage consisted of installing a dumping of clay from barges in an attempt to slow seepage from flowing out of the reservoir into suspected ingress areas. However, after installing nearly 50,000m3 of clay, the leak was not stopped.

Willowstick survey layout

The Willowstick investigation of the right abutment study area initially employed one electrode configuration to energize the subsurface study area.

Shortly after the fieldwork was initiated and based on preliminary results, Willowstick suggested a second survey. This second survey was targeted to investigate possible seepage through the right rim grout curtain area. The intention of the additional work was to identify if major seepage path(s) exist through the grout curtain.

Figure 4 presents an interpretation of Survey 1 results. This figure 4 shows the positions of the modelled flow paths (vertical and horizontal alignment).

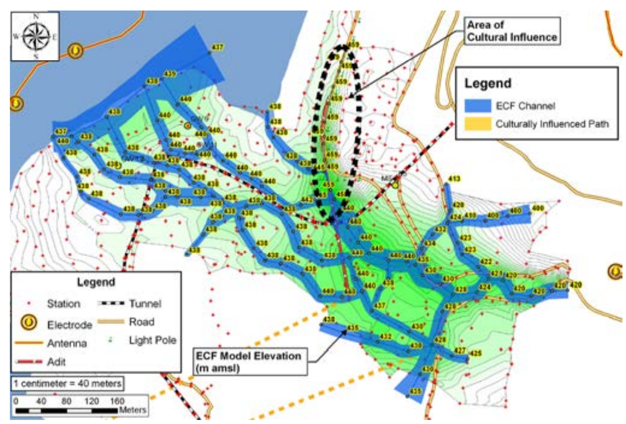

Figure 4 - Electric Current Flow Model with Posted Elevations

The model suggests that seepage north of the tunnel occurs above the tunnel and finds an opening in the adit's grout curtain very near the 440m elevation.

In conclusion the results of the investigation suggest that there are a series of braided seepage flow paths north and south of the tunnel that run beneath the right abutment study area. Seepage appears to concentrate around the right side of the dam rather than underneath or through the dam's earthen embankment. There is some seepage occurring along the right rim grout curtain, but not to the extent that it is flowing through the right abutment study area. It has been recommended any seepage through karst topography needs to be carefully characterised, monitored and possibly remediated to ensure the integrity of the reservoir as well as the safety of those residing downstream of the dam.

Remedial Works

The Willowstick survey has confirmed two main areas where the cut-off is compromised – one on the bend of the tunnel and the other where the original cut-off crosses the tunnel. Having identified the location of what we believed to be the two largest sources of leakage through the right abutment area, it is possible to undertake cost effective remedial works at Samanalawewa Dam to ensure the safety and integrity and to bring the reservoir back to its proposed top water level and retain its ability to generate energy.

The work will involve measures:-

1) to close 2 significant gaps in the existing supplementary grout curtain
2) to locate and fill major karstic features at approximate elevation of 438m.