Journal of Applied Geophysics xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Journal of Applied Geophysics

journal homepage: www.elsevier.com/locate/jappgeo

Modified electrical survey for effective leakage detection at concrete hydraulic facilities

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ARTICLE INFO

Article history:
Received 3 March 2017
Received in revised form 17 June 2017
Accepted 17 August 2017
Available online xxxx

Keywords:
Modified electrical survey
Leakage
Concrete dams
Line source

ABSTRACT

Three original electrode arrays for the effective leakage detection of concrete hydraulic facilities through electrical resistivity surveys are proposed: 'cross-potential', 'direct-potential' and modified tomography-like arrays. The main differences with respect to the commonly used arrays are that the current line-sources are separated from potential pole lines and floated upon the water. The potential pole lines are located directly next to the facility in order to obtain intuitive data and useful interpretations of the internal conditions of the hydraulic facility. This modified configuration of the array clearly displays the horizontal variation of the electrical field around the damaged zones of the concrete hydraulic facility, and any anomalous regions that might be found between potential poles placed across the facilities. In order to facilitate the interpretation of these modified electrical surveys, a new and creative way of presenting the measurements is also proposed and an inversion approach is provided for the modified tomography-like array. A numerical modeling and two field tests were performed to verify these new arrays and interpretation methods. The cross and direct potential array implied an ability to detect small variations of the potential field near the measurement poles. The proposed array showed the overall potential distribution across the hydraulic facility which may be used to assist in the search of trouble zones within the structure, in combination with the traditional electrical resistivity array.

1. Introduction

Geophysical electric explorations have generally been applied to assess the safety of hydraulic weirs or dams, and have been proven effective for describing weak or piping regions. A weir is an impervious barrier constructed across a river to raise the water level on the upstream side. The water is raised up to the required height, and the water then flows over the weir. In a weir, the water overflows the weir; but in a dam, the water overflows through a special place, termed a spillway. In the literature, Bergström (1998) focused mainly on leakage problems using the geophysical method, while Oh and Sun (2008) dealt with the correlation between geotechnical measurements and the electrical property of the embankment material. Oh (2012b) highlighted the cause and result of the variation of the electrical properties within embankments, while Panthulu et al. (2001) applied self-potential and electrical surveys together to find the leakage zone of embankments. Oh (2012a) investigated the electrical resistivity response according to the variation of the embankment shape and the reservoir level. Moreover, Johansson and Dahlin (1996) monitored the electrical resistivity for the analysis of seepage. Abuzeid (1994) also used the electrical resistivity method to find the channel seepage areas of existing dams, while Titov et al. (2000) monitored water seepage from a reservoir using electrical resistivity and self-potential methods. Geophysical electric explorations have also been applied to detect leakages through the geomembrane liner of waste disposal sites or landfills. Parra (1988) analyzed the characteristic electrical responses of leaks at geomembrane liners around reservoir and landfill using pole-pole and pole-dipole arrays. Laine and Darilek (1993) used an electrical leak location method to find the location of leakages, in order to solve leakage problems at landfills. White and Barker (1997) installed an electrical monitoring system to detect leak locations in Flexible Membrane Liners.

In spite of the remarkable success of electrical surveys for the safety assessments of hydraulic facilities, the leakage problems that occur in relation to concrete structures like weirs, have remained difficult to effectively investigate. This stems from the fact that electric surveys require the coupling of electrical poles with the ground, which is very difficult when dealing with concrete structures. However, it is very rare for leakage to occur within the material of concrete structures without some noticeable damage. Therefore, it may not be imperative for the safety assessments of concrete hydraulic facilities to probe the electrical property of the concrete material itself. It may be more useful to look for the existence of any fractures in the interfacial boundaries or in the foundation that lies beneath, and which may be the cause of the leakage.

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https://doi.org/10.1016/j.jappgeo.2017.08.006
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In this study, our general goal was to find leakage zones and their paths within and around a concrete hydraulic facility. The zones may be interfacial boundaries within the facility or around the foundation beneath the facility. To achieve this objective, a specifically-designed electrical survey was required. This new survey should provide information as to where the leakage is occurring at both the upstream reservoir and in the downstream area, and be effective in reducing any possible misinterpretation of the anomalous zone. In addition, direct installation of electrodes on the concrete material should be minimized.

To satisfy these requirements, new electrical arrays are proposed. These arrays substitute the established point sources with line sources, to more easily detect any deformation of the electric field around the hydraulic facilities. Moreover, these arrays are comprised of separated individual sources and lines of potential poles, and are placed parallel to the hydraulic facilities, both upstream and downstream. Potential pole lines are installed midway between line sources (Fig. 1), rather than aligned together with source electrodes, as is done in standard arrays. The potential difference between the potential poles is then measured.

The configuration of this array looks similar to that of electrical resistivity tomography (ERT), which can map underground structures using one or two boreholes. However, the suggested arrays devised to efficiently search leakages in hydraulic facilities differ from the standard procedures in array design, and their resultant interpretation. That is, the traditional ERT targets vertical and horizontal variations of material properties between surface and the borehole or more than two boreholes, while this array is designed to find any horizontal variation of electric field at the hydraulic facility. The use of current line-sources and separated potential poles requires different types of data and interpretation to be devised.

In order to verify the usefulness of the proposed method, numerical modeling for two types of hydraulic concrete facility models was carried out, and two field tests were conducted on a concrete weir and dam in order to obtain field data.

2. Modified electric array

A geophysical electric survey measures the potential difference between two electrodes to infer the electrical properties of subsurface material. Traditionally the current electrode providing the electrical source and the potential electrode are aligned and each electrode should be carefully installed on the ground to maintain low contact resistance. The new array is designed to achieve both convenience and effectiveness to perform surveys close to a concrete hydraulic facility. The electrodes may not be installed on the facility. The line current sources are floated upon the water far from the facility, anticipating that the steady-state currents flow parallel, and the potential pole lines are located directly next to the facility. This ensures that potential measurements accurately reflect the internal condition of the facility as precisely as possible. However, in some cases of low levels of downstream water, which frequently occurs at concrete dams, the potential pole lines may be attached to the facility, and the negative line source should be substituted by a point source located sufficiently distant from the dam to reduce the near field effect. The use of line sources makes the interpretation of data very convenient and simple. Since line sources permit the maintenance of a constant distance between electrodes that are symmetrical with respect to the facility, there is no need to consider any geometric factors. For example, if the dam is intact and linear, the equipotential lines generated by line sources around the target area will be parallel to the facility, and the potential difference of the electrodes will maintain a steady pattern, without any local variation. On the other hand, if leakage occurs through a fracture or a damaged part of the dam, the equipotential lines will show deformation around the anomalous zone, and the potential difference of the electrodes will show an anomalous value around the leakage zone. Therefore, the piping flow or leakage zone can easily be found. As this paper has proposed, having the line source buoyed upon the water can avoid the difficulty of installation, and the need of good electrical conditions between the coupled materials (Fig. 2).

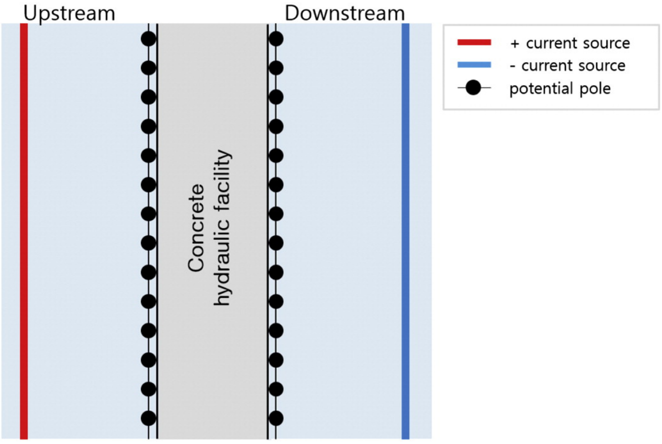

Fig. 1. Plan view of the installation of current line sources and potential poles according to the new arrays of an electrical resistivity survey that is being suggested for the detection of water leakage in concrete hydraulics.

In the modified array, three different kinds of potential differences are measured. The first method is called the “cross potential array”, and measures the potential difference between symmetric electrodes across the facility (Fig. 3(a)). The aim of the cross potential array is to search for a zone where electrical current flows toward a leakage zone. If there is any piping flow or leakage at the foundation of the facility, most of the electrical flow will focus on the leakage flow or path, and the value of the cross potential differences measured near the leakage will be relatively very low compared to other safe zones. This measurement will be very effective when the piping flow occurs directly perpendicular to the facility. The feature of this data is that the potential difference is always a positive value, and the value at the leakage zone is a minimum. Therefore, when plotting potential difference vs. electrode number, a graph as shown in Fig. 3(b) is obtained.

The second method is the “direct potential array”, and is based on the measurement of the potential difference between adjacent electrodes on the same line (Fig. 3(c)). As described above, if the hydraulic facility is safe, the equipotential line will be parallel to the facility, and so the potential difference between neighboring electrodes should be zero. However, if there are any problems in and around the hydraulic facility, the field will be distorted, and the potential difference will not be zero. Gathering data using the direct potential array can be acquired upstream and downstream. Fig. 3(d) shows a representative graph illustrated through the data measured by direct potential array.

The last measurement, mimicking the tomography array in a borehole, is named the “D-Lux array”. Fig. 3(e) shows how the D-Lux array measures potential differences at the hydraulic, and the measurement looks very similar to traditional tomography. However, unlike traditional tomography, current sources and potential poles are separated, and line sources are used. This new array has the advantage of providing results that are very straightforward and easy to analyze, especially for troubled structures. The data obtained using the D-Lux array are represented through the color matrix of Fig. 3(f), and referred to as the “D-Lux view”. Each row and column of the D-Lux view includes information about the pole

Please cite this article as: Lee, B., Oh, S., Modified electrical survey for effective leakage detection at concrete hydraulic facilities, Journal of Applied Geophysics (2017), https://doi.org/10.1016/j.jappgeo.2017.08.006