3D Electro Resistivity and Spontaneous Potential Geophysical Data Applied to an Embankment Dam Study

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Abstract (Font: Arial Bold, 9)

This paper introduces a methodology based on two indirect (non-invasive) research techniques applied for monitoring and research in embankment dam. The methods of research are Electro-resistivity geophysical survey and Spontaneous Potential geophysical survey, they were integrated to serve as auxiliary tools in understanding the physical parameters of materials in the subsurface of an embankment dam. The electroresistivity mapped the most conductive and most resistive materials in subsurface, and a scale with three possible zones was defined: low resistivity zone (LRZ - 0 to 1308 Ω.m), intermediate resistivity zones (IRZ - 1308Ω.m to 9765Ω.m), and high resistivity zones (HRZ - 9765Ω.m and higher). From the generated two-dimensional data, it was possible to create a numerical model of electroresistivity. The spontaneous potential (SP) method provided data of the possible fluid flows inside the earth dam, and the possible paths of these flows were defined. The data from the numerical electrorresistivity model was compared with the flow data from the SP method in the embankment dam structure. The results corroborate with the information's commonly found for dams of the same type and were important to understand more about the dam structure and can be used as a complement of direct research data (survey, auscultation instruments, among others) about this dam under study.

Introduction

Currently, the embankment dams used in mining sector have been a recurrent object of study and attention by public agencies and society in general. To effectively monitor and understand the structure of a dam, it is necessary to apply research methods, the most common being conventional monitoring (direct method). To implement conventional monitoring in this type of engineering structure, it involves a high investment. (Silveira, 2006).

In this context, geophysical investigation is an alternative way to supply the increase in demand for safer techniques for research and monitoring of earth dam structures. This type of technique has been widely used in the context of dam geotechnics in the last decades, due to the fact that it is an indirect investigation, that is, without direct sub superficial contact on study object. Precisely because it carries out indirect measurements of the earth massif and attached structures, geophysics, especially shallow methods, meet the definition of monitoring by Penman et al. (1999). It is emphasized, however, that this indirect survey method has effective validation when added to direct survey data, so they are used as a complementary way of understanding the structure.

There are several shallow geophysical methods that can be applied for a geotechnical study of a dam, such as: Resistivity Electroresponse (RES), Spontaneous Potential (SP), Refraction Seismic, Multichannel Surface Wave Analysis (MASW), among others.

On the methods mentioned above, the electroresistivity method (RES) and spontaneous potential (SP) emerge as important study tools, because they can be used in order to complement each other. The electroresistivity can highlight regions with accumulation of conductive materials, regions that are favoring the percolation of fluid in the structure of the massif, therefore, regions containing accumulation of fluid and/or more clayey materials and fractures. Spontaneous Potential in turn provides fluid flow data within an embankment massif. These combined data are important tools to contribute to a geotechnical study of a dam.

Thus, this study aimed to analyze the geophysical data generated from field data collected in a campaign of electroresistivity geophysics and spontaneous potential in order to raise which the main regions in the subsurface need further attention and study. This analysis was built from the generation of a three-dimensional numerical model relative to electroresistivity geophysical data added to the results of spontaneous potential. This information can contribute to the knowledge of the internal dynamics of the dam, understand if there are points that should be monitored carefully, and serve as a complementary basis for future installations of auscultation equipment and geotechnical drilling campaigns.

The object of study of this work was an earth dam built by compacted embankment using the downstream elevation method. The geophysical lines performed make contact with the earth massif and also with nearby natural terrain.

Method

In the present study, the geophysical methods of electroresistivity and spontaneous potential were applied to a large embankment dam. From the data generated, a three-dimensional numerical model of electrorresistivity was built, and compared to the possible flows indicated by the results of the spontaneous potential.

According to Kearey et al. (2002), the electroresistivity method promotes the determination of electrical resistivity in the subsurface distribution, through an artificial source of electric current application. The electrical resistivity parameter is intrinsic to the various materials that make up the subsoil and is inversely proportional to electric current that propagates through the physical media.
In this study, the electroresistivity method was done through electric walking, by dipole-dipole arrangement. The equipment used was a SuperSting resistivity meter from AGI (Advanced Geosciences Inc.) with an 8-channel configuration and 3.5 m electrode spacing for a total of 38 geophysical lines.
The Spontaneous Potential or Self Potential geophysical method is considered the oldest geoelectric method, according to Orellana (1972). This method is based on the measurement of a potential difference between two electrodes located on the ground surface, independent of the existence of an artificial electric field. According to Telford et al. (1978) and Lowrie (1997) the natural potentials that occur in the subsurface are the result of electrochemical activity or mechanical activity, and groundwater is the factor responsible for this.
Regarding the geophysical method of spontaneous potential, it shows the susceptibility of fluid percolation in a terrain contained in the dam but does not contain data on depth and velocity of the water flow. Currently, it is mostly applied in conjunction with another methodology, being a great auxiliary method, according to Oliveira et al (2002). Its great advantage is that it is relatively simple to instrument and execute, and has a low operational cost (Gallas, 2005).
The equipment used for this SP survey was the SAS1000 resistivimeter from manufacturer ABEM with 1-channel configuration and 3.5m spacing. The electrodes, non-polarizable, were copper, immersed in a solution of Copper Sulfate ($CuSO4$). A total of 27 SP sections were made in this research.
Using the two-dimensional data from the electroresistivity sections, it was possible to generate a three-dimensional numerical model using Leapfrog Works software, with the RBF (Radial Basis Function) interpolation technique.
The SP data were processed, and on the generated map preferential lines of the possible existing flows were drawn. Finally, the data cited above were overlaid on the three-dimensional model and analyzed.

Results

The electroresistivity geophysical survey is spatially arranged in Figure 1:

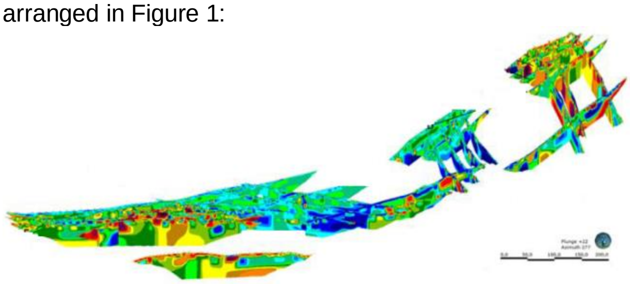

Figure 1 – Map with the spatially distributed two-dimensional lines from the electroresistance survey (view from Leapfrog Works modeling software).

For scaling purposes, three zones were defined, those with resistivities between 0 and 1308 Ω.m were classified as low resistivity zones (LRZ). Resistivities between 1308 and 9,765 Ω.m intermediate resistivity zones (IRZ). Resistive values greater than 9,765 Ω.m were considered as high resistivity zones (HRZ).
During the three-dimensional modeling process, an implicit modeling of regions with continuity and higher concentration of lower resistivity values, therefore, more conductive, was performed (Figure 2). Such regions were called "Low Resistive Concentration Zones" or LRCZ. Sites with resistivity lower than 850 Ω.m were classified as zones of higher humidity and/or clay content, therefore, are within the range of Low Resistivity Zones (LRZ).

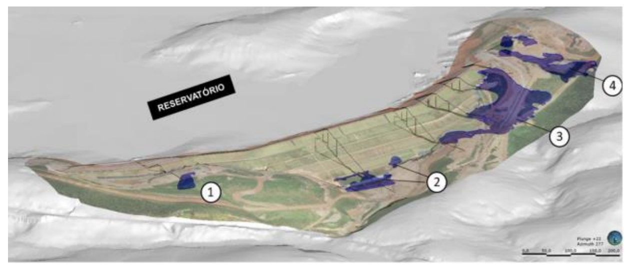

Figure 2 – Volumes of the "Low Resistive Concentration Zones" highlighted in blue, modeled in area orthophoto context.

Figure 02 shows the "Low Resistive Concentration Zones" highlighted in blue, four focal points, denoted by 1,2,3 and 4. LRCZ 1 is the smallest of them, and is located near the right shoulder, covering a small volume of area. LRCZ 2 is located in the center of the earthen dam structure and is in a position posterior to the vertical filter and above the horizontal mat, and anterior to the foot drain, and also has a relatively small volume. LRCZ 3 is the largest of all in the model, is located near the left shoulder (covering a portion of the dam and also natural terrain), despite its considerable size, it is noteworthy that this portion has a large area without geophysical data of electrorresistivity, so it is possible that part of the most conductive resistivities visualized are related to statistical calculations of the modeling software during the generation of the model. LRCZ 4 is contained only in natural terrain and has a more expressive volume than 1 and 2.
In addition to the "Low Resistive Concentration Zones", the processing of the two-dimensional data from electroresistivity geophysics, resulted in a three-dimensional numerical model, which is shown below in Figure 3:

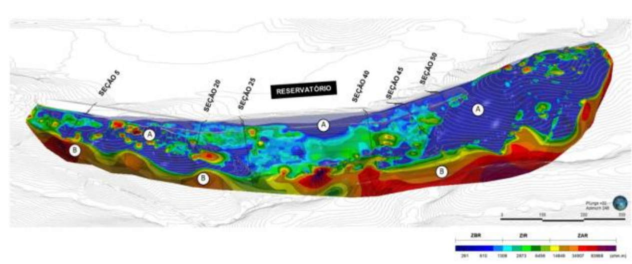

Figure 3 – Three-dimensional numerical model of the resistivity of the dam under study with an indication of the most conductive (A) and most resistive (B) areas.

As can be seen in Figure 3, the most conductive regions have the denotation "A", and are dominant in the image, having higher concentrations in the center-north, center-right and center-left portions of the map (these regions are relative to the dam embankment, left shoulder and downstream ridge). It should be noted, however, that as seen in Figure 1, this is a region with a lower density of geophysical lines, and therefore it is possible that the very conductive resistivities in this section are correlated to the interpolation of data during the numerical model processing. More conductive regions may be related to wetter materials in the embankment and/or with more clayey accumulations, in this sense, one can verify in this dam the tendency common to dams in general, in which the most conductive regions are increasing from upstream to downstream, usually associated with the drainage system of the structure.

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Regarding the results obtained with the spontaneous potential method, they can be seen below in Figure 4:

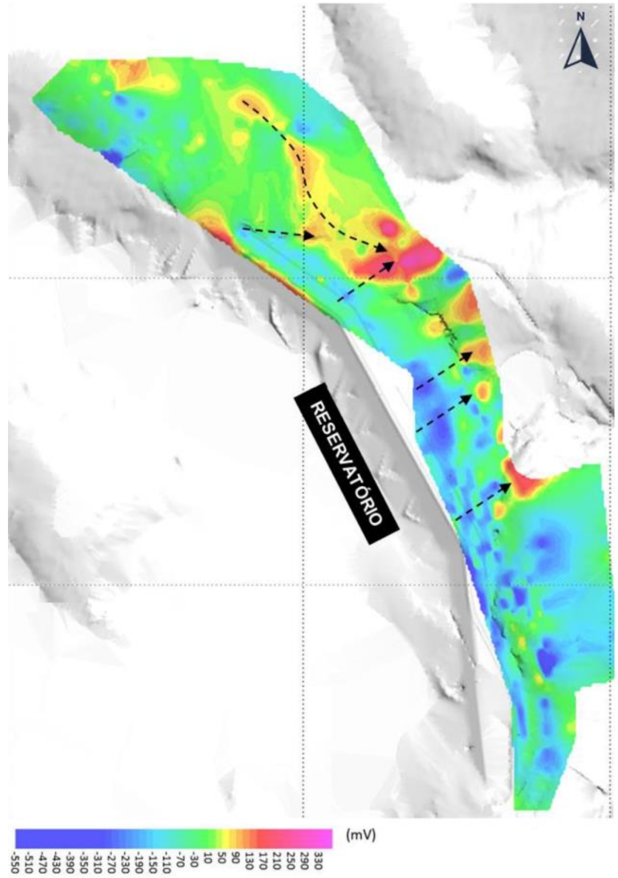

Figure 4 – Spontaneous Potential (SP) Map.

The above figure shows higher positive potential differences directed to the downstream region of the dam structure, while the more negative potential differences are located further upstream. Since the potentials rise in the direction of flow and their intensities are directly related to the hydraulic gradient, which is related to the percolation velocity of the fluid. We can identify that there is a tendency in this SP profile of flow direction from upstream to downstream, which corroborates with the natural tendency in dam structures (flows from upstream to downstream; low potentials in direction to high potentials). The arrows shown are relative to the preferential direction of the possible fluid flows, which are preferentially from upstream to downstream.

Once the results of the three-dimensional electroresistivity model and those of spontaneous potential are defined, it is possible to perform a correlation between them. As previously mentioned, the (SP) method has been applied as an auxiliary method. Thus, Figure 5 is presented, in which the flows pointed out in Figure 4 are being compared to the resistivities applied by the electroresistivity method (RES) in a three-dimensional model (Figure 3). It is verified that the concentrations of the low resistivity in some downstream regions coincide with the arrows of preferential flows indicated in Figure 04, therefore, the preferential flows pointed out by the SP corroborate with the RES resistive anomalies:

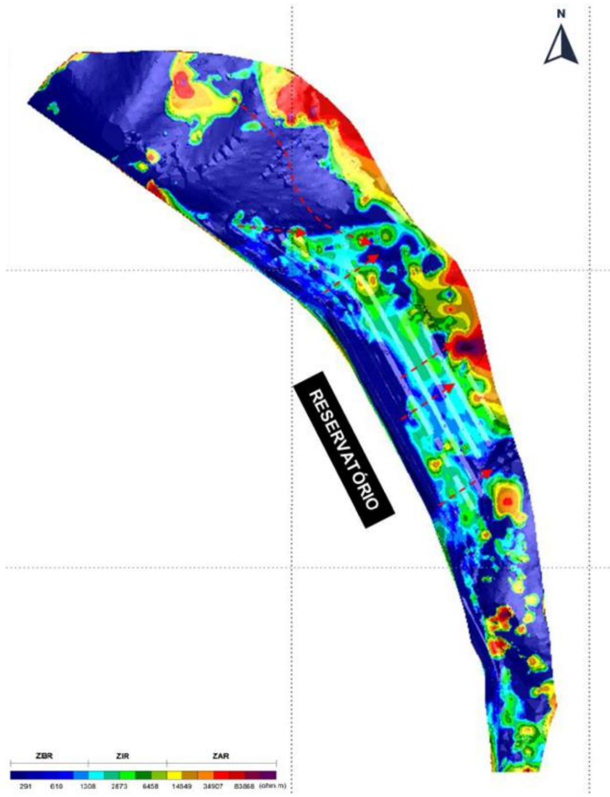

Figure 5 – Comparison between flows from the Spontaneous Potential map and the three-dimensional numerical resistivity model (B).

Conclusions

As the results denote, the three-dimensional electroresistivity model confirms results usually found in earth dams, in which regions with lower resistive values (more conductive) tend to be increasing in the direction from upstream to downstream, possibly due to the influence of the structure's drainage system. These more conductive regions are commonly associated with wetter embankment materials or more clayey accumulations, therefore, regions of great interest in understanding the stability dynamics of a dam. It should be noted that the "Low Resistive Concentration Zones" are in regions with a low density of geophysical lines made, therefore, the values at the site may be related only to statistical issues during data processing, and do not necessarily compose the real existing situation.

Specifically, about LRCZ, that is, regions of conductivity less than 850 Ω.m, therefore zones of low resistivity, it was possible to identify four prominent zones.

It was found that LRCZ 3, closest to the left shoulder, is the one with the highest concentration and continuity of low resistivity compared to the other zones. This LRCZ 3 has no correlation with drains or mats, as occurred in LRCZ 2 for example. Therefore, it is possibly this zone is correlated to flow contributions associated with hydrogeological conditions (Figure 5). However, it is again emphasized that this area has a lower concentration of geophysical lines, and this concentration of conductive values may be associated with the data interpolation process during model generation.

Finally, to validate the data found and contribute to the understanding of the dam dynamics and stability in this study, it is interesting to combine these geophysical results with direct survey data, such as geotechnical borehole data, water level meters, and piezometers. It is also possible to combine these results with a geological model, whereby it is possible to identify contacts of the natural terrain with the earth massif.

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