Geophysical investigation at the BR dam at the mining complex of Tapira, Minas Gerais, Brazil

Demetrius Cunha Gonçalves da Rocha*[1], Marco Antonio da Silva Braga[1] and Camilla Tavares Rodrigues[2]; [1]UFRJ, [2]Tetra Tech

Abstract

The use of the electrical resistivity geophysical method in the BR dam located at the Tapira mining complex in Minas Gerais state, Brazil operated by Mosaic Fertilizantes, had the main objective to complement the information from the conventional instruments of direct measurement. During the acquisition 10 (ten) longitudinal sections were made along the BR dam embankments totaling 4594 m of electrical resistivity investigation. The electrodes configuration array chosen was dipole-dipole. After processing the geophysical results, were compared with the *INAs* (water level indicator) data using 3 type-sections (C, D, E) in the central region of the dam. Low resistivity zones (LRZ) with values below 250 ohm-m, were interpreted as moisture areas or with a certain moisture content. The position of the internal water table provided by the conventional instruments was later confirmed by the geophysics information. From the results of the electrical resistivity after interpretation of all 2-D geophysical sections it was possible to differentiate dry regions from moisture areas. With the 3D analysis of all sections it was possible to clearly delineate the entire internal moisture distribution of the BR dam.

Introduction

Most of the tailings dams accidents start gradually due to the infiltration of undesirable internal fluid flows, increasing the hydraulic load into the structure, starting the process of material liquefaction. The internal pore pressure will increase and reducing the contact between the solid particles, leading the tailings to a total state of fluidity (Ishihara, 1977).

The BR dam is at the mining complex of Tapira, considered to be the largest phosphate mine in Latin America. It is located at the coordinates: 308,045E / 7,805,260N (crest center), UTM zone 23S, WGS-84 datum at 400 km west of the state capital Belo Horizonte. Currently with 98,000,000 m^3, the BR dam reservoir has a total installed capacity for 190,000,000 m^3. The BR dam is 570 m of long and maximum height is 61 m, reaching 1200 m after the latest heightening. The heightenings were done by the centre line method, using magnetite in the downstream zone, and tailings launched upstream from the crest of the dam, forming beach with more than 100 m of length (Mosaic, 2016) (*Figure 1 and 2*). Currently, inspections and monitoring at the BR dam are done through direct measurement instruments. However, due to the very local nature of their measurements, the traditional equipment can easily fail to show a region of weakness and with unexpected water saturation, being volumetrically un representative of the total mass of the dam.

Geophysics has much to contribute to the investigation and monitoring on all types of dams. Geophysical methods are non-invasive and have the potential of detecting internal erosion and anomalous seepage at an early stage before the safety and integrity of the dam is at stake (GZA et al, 2004).

The application of the electrical resistivity tool in the BR dam had as main objective to develop a complementary methodology for internal investigation and monitoring system. The use of electrical methods generated 10 (ten) continuous 2D sections on the BR dam, making a complete image and providing a precise and spatial evaluation view in 3D of all internal structure.

***Figure 1**: Contact between the flotation tailings and magnetite sand used to make heightening of BR dam.*

Beach material – Flotation Tailings (fine sand)

BR dam body material – Magnetite sand

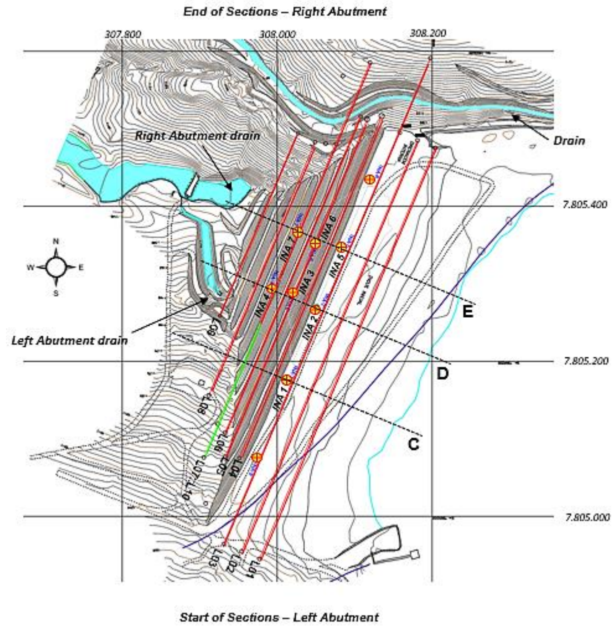
***Figure 2**: The differences between beach floatation tailings and the magnetite sand from the downstream area of the dam.*

Method

During data acquisition, ten parallel and longitudinal electrical resistivity sections were made on the BR dam body. Two of them (L01 and L02) were made on the tailings beach, seven (L03 to L09) at the downstream part of the body, consisting of magnetite sand, and one (L10) was made as a complementary section at the left abutment. All sections totaled 4594 m of geophysical data (*Figure 3*). The spacing between the lines was variable, 15 m from the crest to downstream and 25 m in the tailings beach area (*Figure 4*).

Sections	Sections Lenghts (m)
L01	585
L02	583
L03	691
L04	479
L05	475
L06	447
L07	516
L08	365
L09	265
L10	188
Total	***4594***

***Figure 3**: Total in meters of sections raised*



LEGEND:

- ----- Type – Sections (C, D, E).
- All the main electrical resistivity sections on BR dam – L01 to L09.
- Electrical resistivity section on left abutment – L10.
- INAs (Water Level Indicator).

***Figure 4**: All geophysical sections made on BR dam and the type-sections (E, D, C) used to define the water table level by seven water level indicators (INAs).*

The electrode configuration chosen was the dipole-dipole array because it presented the best signal-to-noise ratio with good depth range and satisfactory lateral resolution. In this configuration, several receiving dipoles (MN) arranged along the acquisition line. Each dipole MN corresponds to a level of investigation (Braga, 1999) (Figures 5 and 6).

The equipment used in the acquisition was the R8 resistivimeter manufacture by AGI with 64 channels and 3.0 m spacing between electrodes, using maximum current of 2A and 2s cycle, reaching investigations depths of 49 m. The data processing was done using the: Res2DInv; Google Earth; AutoCAD; CorelDraw and Photoshop software.

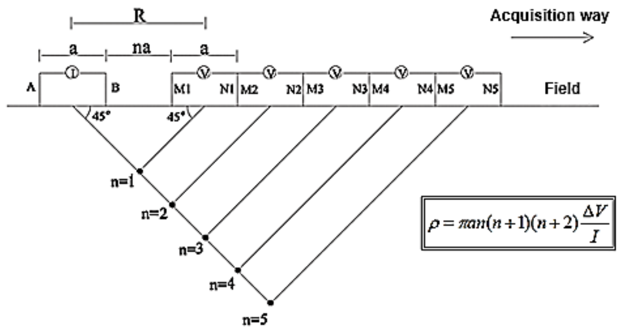


Figure 5*: Dipole-Dipole electrodes (DDP).* For this configuration the resistivity (ρ) can be expressed by the equation above *(Christ and Jorge, 2018).*

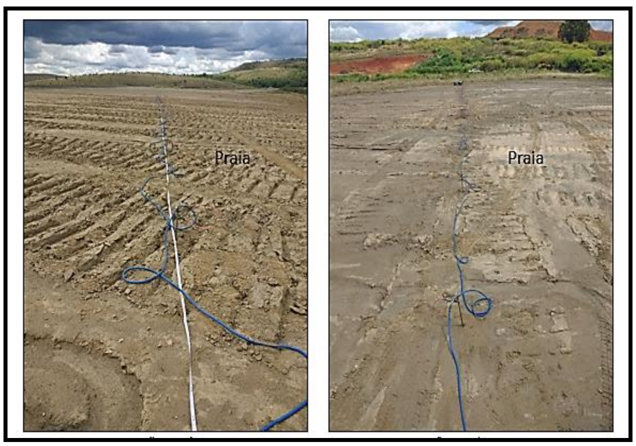


Figure 6*: L01 acquisition section by* electrical resistivity method, dipole-dipole.

Results

After the data processing, it was possible to identify 3 zones with different resistivity ranges of values (*Figure 7*):

- High resistivity zones (HRZ), with resistivity values above 1,116 ohm-m.
- Low resistivity zones (LRZ), with resistivity values below 250 ohm-m
- Intermediate resistivity zones (IRZ), where the values are between approximately 1,116 and 250 ohm-m.

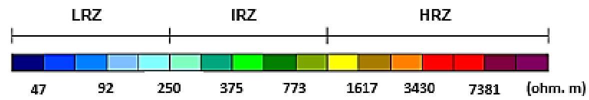


Figure 7*: Electrical resistivity scale in ohm-m.*

Low resistivity zone (LRZ) values are correlated as possibly saturated regions, or with a certain moisture content.

In the central region of the BR dam some characteristic patterns of the resistivity data responses could be identified. It was possible to identify a very superficial zone approximately 3 m thick with intermediate resistivity values (IRZ: 250 to 773 ohm-m). This zone may be correlated to sandy region which is more susceptible to weather effects. It is suggested that the pores are filled with air instead of water.

Below this layer we find a well delimited second zone of approximately 6.0 to 7.0 m thick, continuous to moderately continuous with high values of resistivity (HRZ: 1195 to 3430 ohm-m). Considering there were no changes in the construction materials of the dam, these resistivity increases were interpreted as being due to the difference in grain size or material compaction which influenced directly the water percolation or storage.

Below these zones, we found another zone with intermediate resistivity values (IRZ: 375 to 1195 ohm-m), possibly related to a small humidity increase due to the proximity to the low resistivity zones (LRZ).

These low resistivity zones are associated with a high moisture contents with resistivity values below to 250 ohm-m. The top of this anomaly (LRZ) was interpreted as being equivalent to the top of the water table (WT) and later compared to the seven INAs data and plotted for comparison on the type-sections (C, D, E).

The main objective of the geophysical investigation was to complement the conventional instruments for identifying the water table level and separating dry regions from the areas with certain moisture content inside the BR dam body.

Electrical section L05 was used as representative of the central part of the BR dam. By positioning the water table level determined by the geophysical data on L05 in the "D" type-section, it was possible to observe the blanket drain position below the top of the conductive anomaly (LRZ). Therefore, the blanket drain at the time of the geophysical survey appeared to be positioned 6 m below the top of the LRZ identified by electrical resistivity (*Figure 8*).

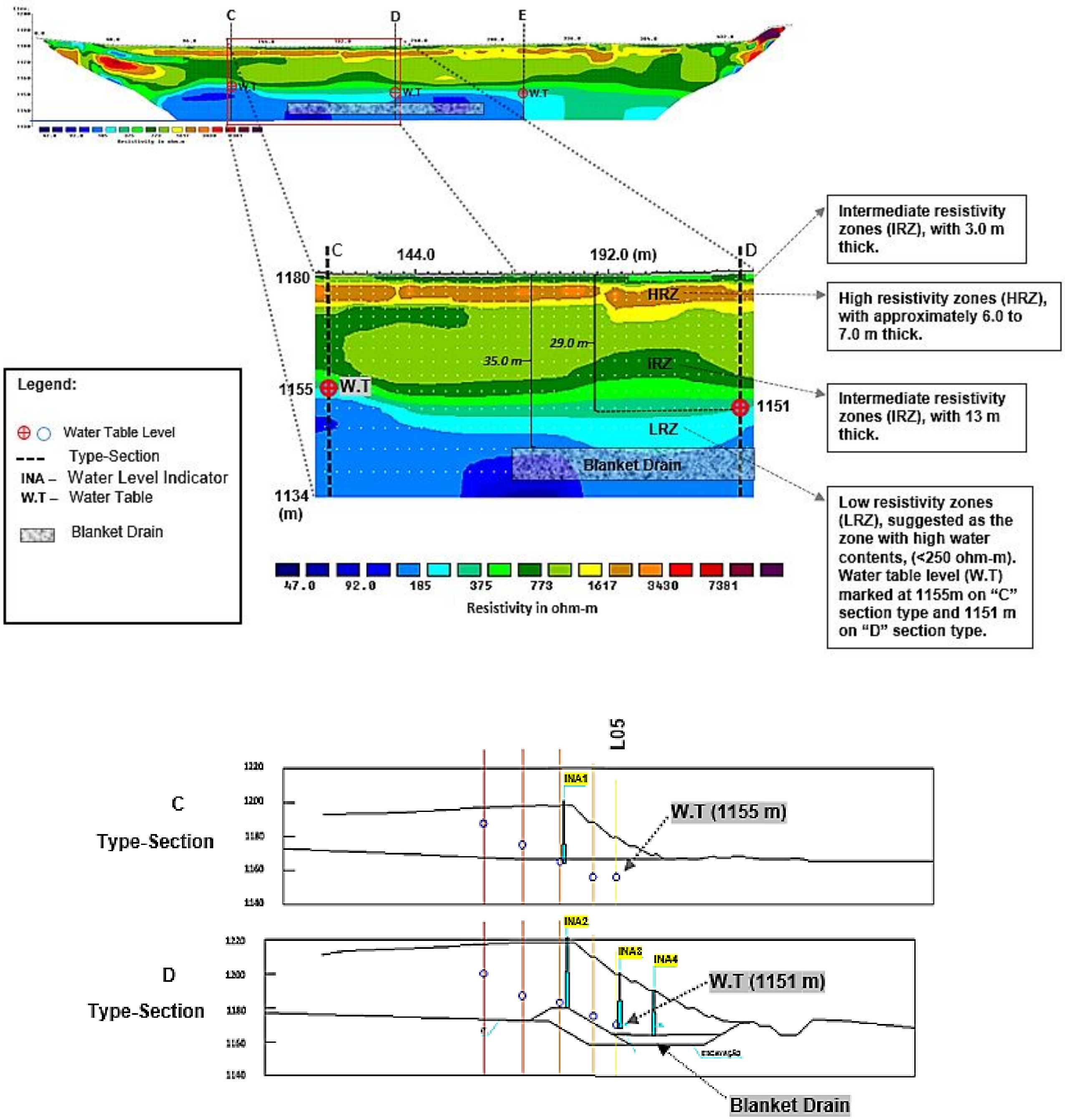
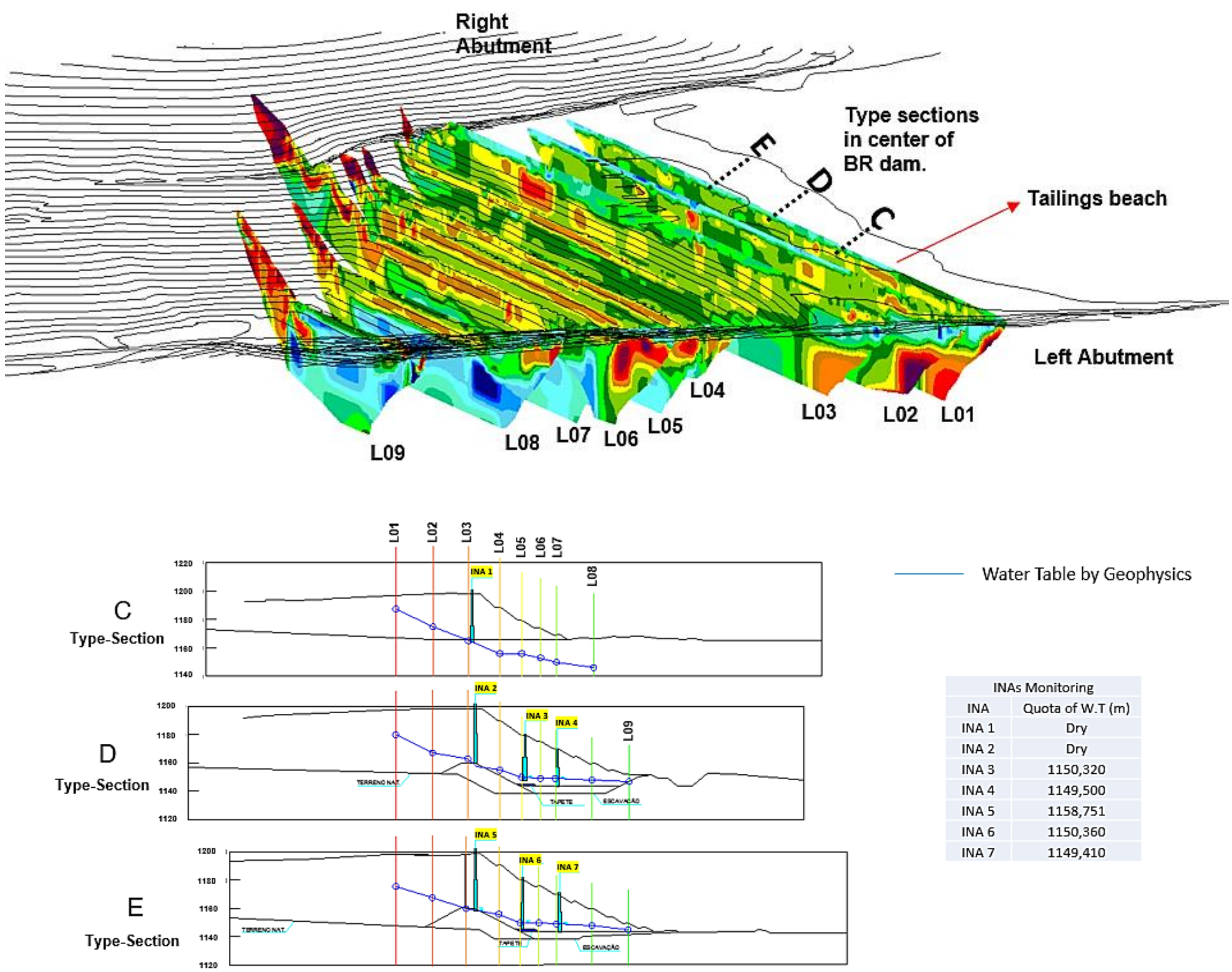


Figure 8*: L05 section, used as being representative of the central part of the BR dam, showing the different resistive zones delimited through the results obtained from the electrical resistivity survey. The blanket drain was positioned at 6 m below of the top of the LRZ identified by the electrical resistivity survey. The water table was marked as the top of the low resistivity zones (LRZ) (<250 ohm-m).*

Water Table Position

For investigation of the properties of the dam body the direct measurements data provided by the INAs (water level indicator) were compared with the electrical resistivity data. The water table in the central region of the BR dam identified as the top of the low resistivity zones (LRZ) in the 3 type -sections (C, D, E). It is important to notice that the readings of the water level indicators (INAs) present on the type-sections for the central dam region (Section C - INA 1, Section D - INA 2, INA 3 and INA 4 and Section E - INA 5, INA 6 and INA 7), are very close to the responses obtained from the geophysical data on the same site. This fact can be observed from the correlation of the top-level conductive anomalies with the water-level readings measured by the INAs, which are approximately coincident (*Figure 9*).



INAs Monitoring	
INA	Quota of W.T (m)
INA 1	Dry
INA 2	Dry
INA 3	1150,320
INA 4	1149,500
INA 5	1158,751
INA 6	1150,360
INA 7	1149,410

***Figure 9**: 3D view of the electrical survey (L01 to L09), showing the position of the water table in the type sections (C, D and E) interpreted from the electrical resistivity data in the central region of the BR dam. The water table from geophysics is very close to the position suggested by the readings of the water level indicators (INAs).*

Conclusions

Applied geophysics contributed significantly to geotechnics, complementing the conventional instruments of direct measurement used in the BR dam. Geophysics generated continuous 2D and 3D view sections of the BR dam, where it made a complete imaging along all the structure. The electrical resistivity method showed a good ability to identify the water table, internal hydraulic dynamics, local saturations, anomalous seepage and to identify the main discontinuities of the materials used during the all heightening stages. In general, this method proved capable of identifying dry zones (HRZ), saturated zones (LRZ) or zones with some moisture.

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- Mosaic Fertilizantes S.A.

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