Applications of resistivity tomography to hydrologic problems in the urban areas of Salvador, Bahia State, Brazil.

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Abstract

Two-dimensional electrical images of resistivity and time-domain induced polarization (IP) in conjunction with standard penetration tests (SPTs) were used to investigate the subsurface drainage patterns in one area of Salvador, Bahia State, Brazil. This area, referred as Luiz V. Filho (LVF), is located along new streets cutting across hill slopes with thick clayed and silt-sand weathering products, which are potentially susceptible to water seepages and landslides. A dipole-dipole array was used to survey three geo-electrical traverses extending across the water-seeping LVF area. The constructed pseudo-sections of apparent resistivity and chargeability were automatically inverted using the RES2DINV software, controlled by SPT and lithological data from samples collected by drilling through the regolith layers. The joint results from these geophysical-geotechnical works were useful for designing engineering structures to drain and contain the earth materials along this dangerous area.

Introduction

Currently in several Brazilian metropolises, the geotechnical problems caused by the construction of roads, avenues and buildings, in places along natural water drainage valleys, become areas of potential danger, especially in the winter seasons where the geological materials change their saturation degree and favor processes of erosion and weathering in constituent materials. This problems mainly of anthropogenic nature, usually need a multidisciplinary approach, based on the use of invasive technologies, such as geotechnical tests (SPT's) employed to investigate the soil mechanic and his competence strength for engineering purposes (Bogoslovsky and Ogilvy, 1977; Godio and Botinno, 2001). The no-invasive techniques such electrical resistivity tomography (ERT), that provide information of the underground geological structure, composition and petrophysical characteristics (porosity and water saturation), as well as to track their more permeable portions (Samouëlian et al., 2005). The study zone is located in a middle class residential expansion area on LVF Avenue and is related to intermittent water filtration outflows along an artificial slopping cut near a large apartment building. The equipment used in this investigation was a SYSCAL R2 system from Iris Instruments (France). The apparent resistivity and chargeability data were processed with RES2DINV software,developed by Loke and Barker (1996) and by Geotomo (2010), which uses the field data to automatically determine a two-dimensional model of resistivity and chargeability for the medium. The RES2DINV is an inversion program for resistivity and induced polarization (smoothing and robust modeling). The final results allowed to know the composition and geomechanical characteristics of the soil, the depths of the static level, as well as the distribution of the saturation and the clay content of the sub-surface. These results provide important information in the design of engineering works.

Field description

Geological aspects

The geology of the municipality of Salvador is characterized by two important geo-tectonics domains, separated by the Salvador Fault, which has an extending over 100 km of extension, with over 6.0 km of total vertical displacement. Associated with this Fault, there is a dense network of fractures with direction oriented in the directions N30-40E, E-W and N30-40W (Marinho, 2013). Other smaller lineaments correspond to the Iguatemi Fault and Morro do Aguia Fault, the last identified during the geophysical surveys made in this work.

The Salvador Fault separates the western limit of the Mesozoic Recôncavo sedimentary rift-basin, located in the lower part. These sedimentary rocks constitute important depositional sequences, characterized by Pre-rift, rift and post-rift events. The eastern part consists by a high rock-terrain, formed with metamorphic rocks of Pre-Cambrian age, including gneisses and migmatites, with a pervasive foliation oriented NNE. This terrain form a structural unit Salvador High, on which the city grew and partly over the sedimentary basin (Nascimento, 2008). Both units experience successive tectonic episodes of brittle failure, with the Salvador Fault being the most impressive faulted controlled zone, appearing big fractures, identified by aerial photos and satellite images of the city, and control the surface water drainage in the area.

The intense fracturing of metamorphic rocks experience deep chemical and physical weathering, and debris transport processes during rainy conditions, controlling the morphology of hills and valleys that cover weathered horizonts soils, defined by lithological data and SPT tests drilled through layers of regolite in the area and characterized by the following layers: (i) A top layer with shows a filling landfill and silty-clay composition (ii) a clay-sand washed horizon (iii) a altered horizon contain textural and feature to the fresh rock (iv) a layer of rock is slightly altered and fractured, which constitutes the embassament crystalline.

ERT Method and Processing data

Electrical Resistivity Tomography (ERT)

The dipole-dipole arrangement is used in mining, geology, engineering geology, groundwater prospecting, environmental studies, among other areas (Telford et al., 1990). In this array the electrodes are arranged in line and the spacing between the two electrodes of current (AB) and potential (MN), remains fixed throughout the surveying. The acquisition of field data performs a series of measures keeping fixed the spacing of the AB emission dipoles and MN reception, increasing the separation between these electrodes. The technical operates by applying a current through two AB current electrodes and measuring the resulting voltage different by two MN potential electrodes.

Two-dimensional electrical images of the resistivity and induced polarization data, obtained with the dipole-dipole arrangement are presented in the form of a section built with pseudo-depths. Each measure is associated with a point located horizontally at the center point between the electrodes and a pseudo-depth equal to the horizontal distance between the center of the arrangement and the center of the dipole AB or MN.

For the dipole-dipole array, the effective depth of theoretical research (z) in each level 'n' investigated, is represented as:

$$Z = \frac{x}{2}, \tag{1}$$

where x is the distance between the centers of the considered dipoles (AB and MN). This way the readings are carried out from the pair of M1N1 potential electrodes that correspond to a theoretical depth n = 1. The apparent resistivity function for the Dipole-dipole array is given by:

$$\rho_a = 2\pi G a \frac{\Delta V}{I}, \tag{2}$$

where;

$$G = \frac{1}{\frac{1}{n} - \frac{2}{n+1} + \frac{1}{n+2}}, \tag{3}$$

being; G the geometric factor of the array, a is the spacing between AB and MN dipoles and n is the theoretical level of investigate.

If n increases, greater depths can be achieved. For the array, all the configuration arrangement is shifted from a distance usually equal to a spacing between dipoles. The dipole-dipole array has better horizontal resolution and better that coverage at the ends of the lines.

Processing data

ERT data has been processed using RES2DINV software. This program is based on the inversion data by least square method with smoothing-constrained. This inversion, uses the optimization method for minimum squares of Gauss-Newton or Quasi-Newton. For two-dimensional model, the program employs a certain number of infinite horizontal rectangular blocks, distributed along a cross section. The sizes of the blocks are automatically generated. The thickness of the first line of blocks is fixed according to the smallest electrode spacing used in the request. The thickness of the subsequent lines is normally increased from 10 to 25.

The configuration of the rectangular mesh of the blocks and its size is automatically generated by the program, being more accurate the modeling of the data the greater the number of points measured in the field. The routine used by the program by applying the method of minimum squares with smoothing, is based on the following equation:

$$(J^T\ J + \lambda\ F)\Delta q_k = J^T\ g - \lambda\ F\ q_k, \tag{4}$$

where;

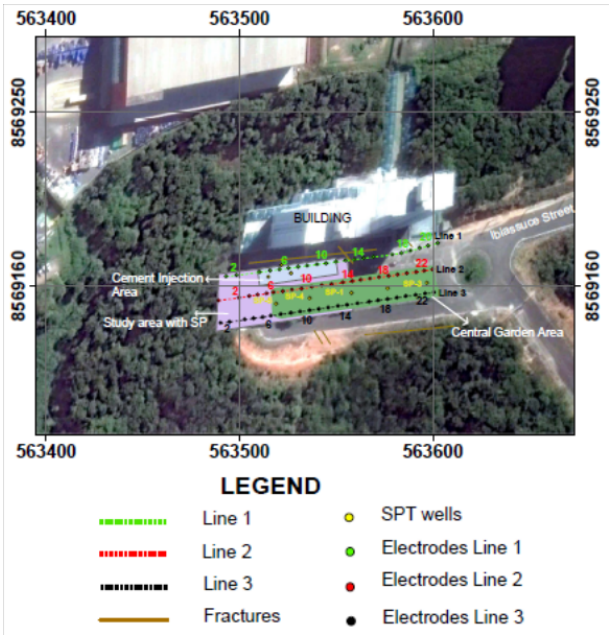
$\mathbf{F}$ s the model spatial smoothing matrix;
$\mathbf{J}$ is a matrix of partial derivatives
λ is the damping factor
$\mathbf{\Delta q_k}$ is the disturbance vector in the model
$\mathbf{g}$ is the discrepancy vector

After the acquisition of the data in the field, are obtain resistivity and chargeability values represented in the form of pseudo-sections. The inversion of these data, allows to obtain a section of real chargeability and resistivity of the subsurface, allowing to obtain a two-dimensional imaging of the internal structure of the rocks. The discrepancy between the apparent resistivity and chargeability sections and true resistivity and chargeability sections is measured through the RMS error, in which one tries to get a minor error after each iteration.

Experimental Results

For the LVF area, electrical and chargeability surveys were carried out using dipole-dipole electrodes array, along three straight lines, keeping the fixed distances between AB current electrodes and MN potential electrodes.

In this technique the transverse sections of electrical resistivity and chargeability were constructed with a basic separation of 5 m, in eight (8) levels of investigations designed to explore the subsurface up to depths of investigation of the order of 15 m, in most of the region of interest of the LVF area on avenue, shown in the Figure 1.



(a) $\rho = 500$ m

Figura 1: Survey line locations in the LVF area with hydrological and geotechnical problems

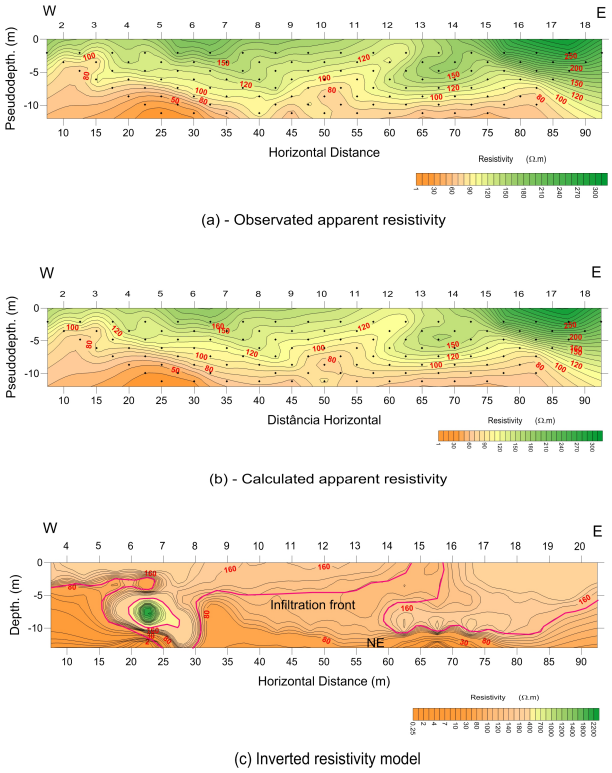


Figura 2: Resistivity distribution along line 2 (LVF area) and the interpreted geo-electrical models.

The observated, calculated, and computed apparent resistivity and chargeability data, obtained by dipole-dipole array are displayed as pseudo-sections and in the Figure 2 and Figure 3, respectively. These sections were skirted using Surfer 12 package. The geophysical results were complemented by lithological data and SPT tests drilled through layers of regolite, under control of internal structures and samples of different types of soil, collected in the area. The qualitative results of one of the lines, reflected in line 2, and shown in the resistivity and chargeability sections, is at the base of the figures. In such sections are delineated:

- A top layer of low water saturation and resistivity above 160 $\Omega.m$ between the surveys (4-9) and (16-20);
- An intermediate zone with resistivity values between (60 $\Omega.m$-100 $\Omega.m$) indicating a saturation front in the NE-SW direction, in the central portion of the profile;
- A low resistive block (2000 $\Omega.m$) between the electrodes (6-7), reflecting the lateral influence caused by the injection of cement in the holes of this region of the central garden;
- A capillary area located at a depth of 12.5 m, best indicated in the chargeability section, depending on the increase in the value of m_a;
- Drilling holes for the percussion SPT located in the Central garden area (SP-4 and SP-2), indicate the existence of clay silts and clays and sands with boulders, which correspond to the model of true resistivity obtained in the two-dimensional geophysical modeling.

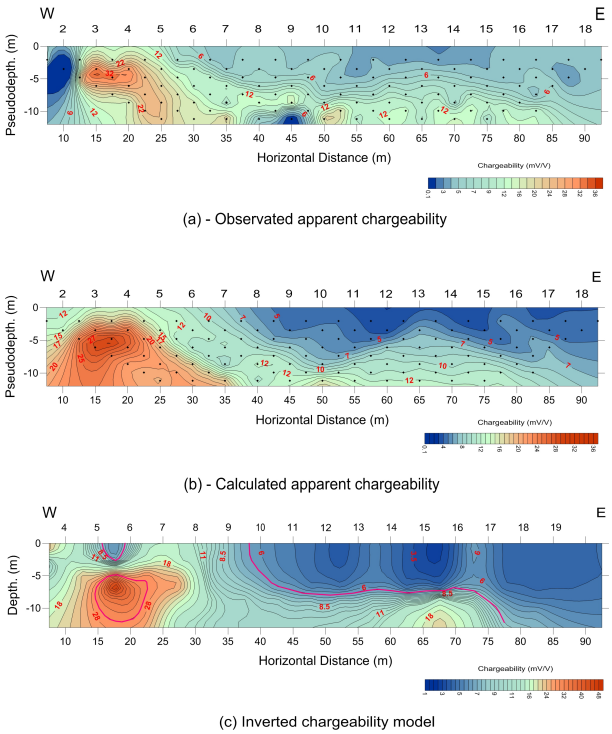


Figura 3: Resistivity distribution along line 2 (LVF area) and the interpreted geo-electrical models.

Conclusions

- The geophysical results obtained from Consil, located in the LVF avenue, suggests that filtration, checked under the building site, results from a drainage and a wide infiltration of rainwater located in the central region in front of the garden.
- The geophysical results obtained on the Consil area, show the heterogeneity in the resistivity and chargeability sections, interpreted as variations of porepermeability and saturation of water, due to the contrast in the lithology of regolith horizons, according to the results presented in the geotechnical tests done in the area.

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