



# Integration of SPT and Electrorresistivity data as an efficient auxiliary tool for a geotechnical characterization of a slope

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This paper was prepared for presentation during the 15<sup>th</sup> International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 31 July to 3 August, 2017. Contents of this paper were reviewed by the Technical Committee of the 15<sup>th</sup> International Congress of the Brazilian Geophysical Society and do not necessarily represent any position of the SBGf, its officers or members. Electronic reproduction or storage of any part of this paper for commercial purposes without the written consent of the Brazilian Geophysical Society is prohibited.

## Abstract

An investigation about the instability agents on a slope that uses the Geophysical Electrorresistivity method and also a geological analysis of the investigated area is presented in this work. Two Electrical Resistivity Tomography (ERT) and one Vertical Electrical Sounding (VES) were carried on a slope placed at Federal University of Bahia (*Campus Ondina*). The geophysical data interpretation was made along with SPT soundings and the analysis of ditch samples collected that are placed near the study site. The soil thickness, the saturated zone and the crystalline rocks positions were determined, what proves the efficiency of electrorresistivity methods in defining the evaluation parameters of the mass movement processes. Thus, this work corroborates with the possibility of using Geophysics as a powerful tool to assist in the geotechnical diagnosis of slope stability.

## Introduction

The process of uncontrolled urbanization in Brazil, that happened in of the end of the twentieth century, brought an important theme for a society: slope landslides which put at risk the population life quality, as well as material losses. The suppression of vegetation and the accumulation of garbage in slope areas damage the rainwater drainage, what accentuates the erosion process and, consequently, landslides, especially when it is associated with periods of intense rainfall.

Electrorresistivity geophysical method becomes an operative tool that can be used to investigate the subsurface structure. Besides, when compared to traditional methods was drillings, this method provides more data in a short period of time.

This works aims to integrate the electrorresistivity method with data from ditch samples and SPT surveys, that were carried near the study site, in order to provide a visualization of the subsurface strata, the soil thickness, the saturated and the weathered/fractured zones and also the overburden positions. Besides, the method allows the detection of faults, fractures and boulders.

The geophysical data are constituted by two Electrical Resistivity Tomography (ERT) profiles and a Vertical Electrical Sounding (VES). The surveys were carried at a slope located at the Federal University of Bahia (*Campus*

*Ondina*). The slope has, approximately, 48 meters in length and having the larger measured inclination angle of 41°. Along the slope, the presence of bamboo thickets (*Bambusa vulgaris*) and mature secondary growth and the arboreal forest is intense. Another important aspect that should be mentioned is the large presence of garbage in the area.

## Methodology

Goelectric measurements are based on the injection of a constant current into the ground through two current electrodes and measuring the resulting voltage differences between two potential electrodes at the surface (Sass et al., 2008). The mathematical combination between electric currents and voltage values provides the apparent resistivity values.

The Electrical Resistivity Tomography (ERT) is a geophysical technique that can provide 2D images of the subsurface electrical resistivity distribution. The analysis and interpretation of these tomograms allows the identification of resistivity contrasts that can be found in some areas due to the terrains lithological pattern and the water content variation.

Vertical Electrical Sounding (VES) is another geophysical technique that gives information about the geological structure located several dozen meters below the surface. The acquisition consists in measuring of the resistivity of the rock formations. The measurements allow the separation of areas that are differentiated in terms of resistivity.

In order to determine the subsurface resistivity on different zones or layers from investigated areas, an inversion routine of the measured apparent resistivity values must be carried out. This is performed through the *RES1D software* (for the VES data) and the *RES2DINV* (for the ERT data) *software*.

## Field Survey

The goelectric measurements were carried by using a Sycsal Pro equipment.

The ERT I was conducted by using a dipole-dipole array. With respect to the aimed penetration depth and resolution, the unit electrode spacing was and the total profile length were, respectively, 4 and 80 m. 96 hours before the field survey, a rainfall station (CEMADEN) registered a rainfall index of 0.59 mm near the study site.

Two months after the ERT I, a VES was conducted by using 60 m as the maximum separation among the electrodes. The rainfall index for this period was 9.4 8mm.

The last survey, ERT II was conducted also by using a

dipole-dipole array. Unlike the ERT I, the unit electrode spacing was and the total profile length were, respectively, 5 and 70 m. The rainfall index registered in this period was of 3.35 mm.

The geophysical data were integrated with analysis of rock sample at boreholes (Palácio de Ondina II, Palácio de Ondina III and Palácio de Ondina IV) and SPT soundings that were collected near the study site (Figure 1).

## Results

The ERT I and II allowed the generation of inverted models of resistivity, I and II ( $M_{1INV}$ ) e ( $M_{2INV}$ ) 2D, that show subsurface lateral and vertical resistivity variations, as it can be seen in Figure 2.

It is possible to suggest the following information about lithology: The orange-reddish colors refers to the lithological materials of high resistivity corresponding to the topfill (unsaturated soil) and they correspond to the Weathering Mantle. This area corresponds to a zone of intense vegetation. Besides, the orange-reddish colors also correspond to the top of the crystalline hard rock. The ERT I identified an anomaly located at approximately 53 m from the zero mark that was interpreted as a boulder.

Two meters bellow the top fill, there is a water-saturated zone that can be interpreted as saturated clay (blue tones) and saturated clayey silt (greenish tonality), what is consistent with the local geology. Below this saturated zone, lithological materials related to the top of the altered crystalline rock were found .

The hypothesis that the material that corresponds to the yellow tonality could be sandstones has arise, since this lithology appears in the boreholes rock samples data and the resistivity presented in the section are also in agreement with values for sandstones.

The ERT II was conducted with a bigger spacing between the dipoles than the first ERT (5 in 5 m) and 70 m as the maximum opening between the electrodes. As a results of this changes one can expect a less refined coverage of the measurements in subsurface, due to the fact that the dipoles are further away from each other, and the number of data collected is smaller.

An important factor that should be highlighted is the increase in the contact resistance values at the ERT II. The contact resistance at the ERT was around 200 Ohm.m and at the second survey these values at some dipoles had an increase of 1 KOhm.m This drastic values can be the possible cause of the high RMS error value presented in ( $M_{2INV}$ ).

Months after the ERT I survey, the slope suffered some antropic alterations as it had a part of the bamboo thickets in the top removed, what made the topfill more exposed to the action of the rainwater, which allowed the rainfall infiltration in more superficial zones and deep down the slope. It is possible to see in increase of saturation in the shallower portions of the ( $M_{2INV}$ ) due to a decrease of resistivity of this area.

It is possible to make a second hypothesis about the lithology corresponding to the resistivities of yellowish coloration of ERT I. It was previously said that it could be a sandy material due to the presence of this lithology in

rocks samples from boreholes near the study area and the values of resistivities consistent with this hypothesis, but it was observed that the same region in ERT II has low resistivity values when compared to the values of the first survey.

Therefore, it can be said that this zone corresponds to a clayey or silty-clayey material that was not yet saturated when ERT I was conducted, a fact that changed with the greater exposure of the slope and more intense rainy season to which it was subjected, allowing rainwater to infiltrate at greater depths and saturate previously unsaturated areas.

Another disagreement that is observed between the two ERTs is that the ERT I indicates a large amount of clay concentrated 32 m away from the beginning of the profile and 7 m below the surface while ERT II shows a continuous area. In this way, it is possible that this area also became saturated after ERT I and before ERT II.

Despite the difference in the electrode spacing of the ERT I and ERT II, the latter ERT also shows the anomaly related to the boulder that was identified in the first tomography.

The VES was placed at 49 m along the ERTs (starting from zero mark) and from it is measurement it was possible to analyze the vertical variation of resistivity at a point on the slope. These data allowed to obtain the inverted 1D model (Figure 3a). Through this result it was possible to create an interpretative column of the 1D geoelectric model (Figure 3b).

The interpretation of the 1D model showed the existence of three layers: The first layer which has thickness of 4.2 m corresponds to the topfill and the clayey silt with little degree of saturation. The second layer had a thickness of 8.5 m and it was interpreted as saturated clayey silt and the last layer was considered to be the modified hard rock. Despite the fact that the opening of the Vertical Electrical Survey was too small, it was not possible to reach this layer due to the difficulties of entering the bamboo, it is observed in (Figure 3a) a rising trend at the end of the curve. The comparison between the ERTs and the VES allowed such confirmation, in addition to comparing this data with the SPT surveys conducted near the slope.

## Conclusions

The electrorresistivity method proved to be efficient in defining the main evaluation parameters of the mass movement formation processes, such as thickness of the topfill and level of the saturated zone. From the electric imaging an anomaly related to the presence of a boulder was identified in the slope area. It is necessary to emphasize the loss of refinement of the measurements of the ERT I and ERT II due to the changes between the spacings of the dipoles.

The intense vegetation in the study site works as a barrier to rainfall erosion and makes the pluvial infiltration more difficult in the subsurface. After the removal of this protection, superficial infiltration began to occur along the slope (ERT II)

A comparison between the inverted 1D model and some SPT soundings suggests that the method proved to be effective mainly in the delimitation of the topfill and in the

suggestion of the location of the hard rock. Therefore, the electrorresistivity method is an excellent auxiliary tool for geotechnical diagnostics, especially when combined with accurate information (e.g: direct tests, rock samples).

The main advantage of the geophysical method was the possibility of imaging the subsoil laterally through the ERTs. It was possible to obtain a continuous view of the study area, considering the horizontal and vertical variations of resistivity and lithology, when compared to the conventional methods of investigation (direct methods).

Finally, the use of geophysics in the study of slope stabilities allowed us to obtain a rich view of subsoil details with low costs and fast execution.

### **References**

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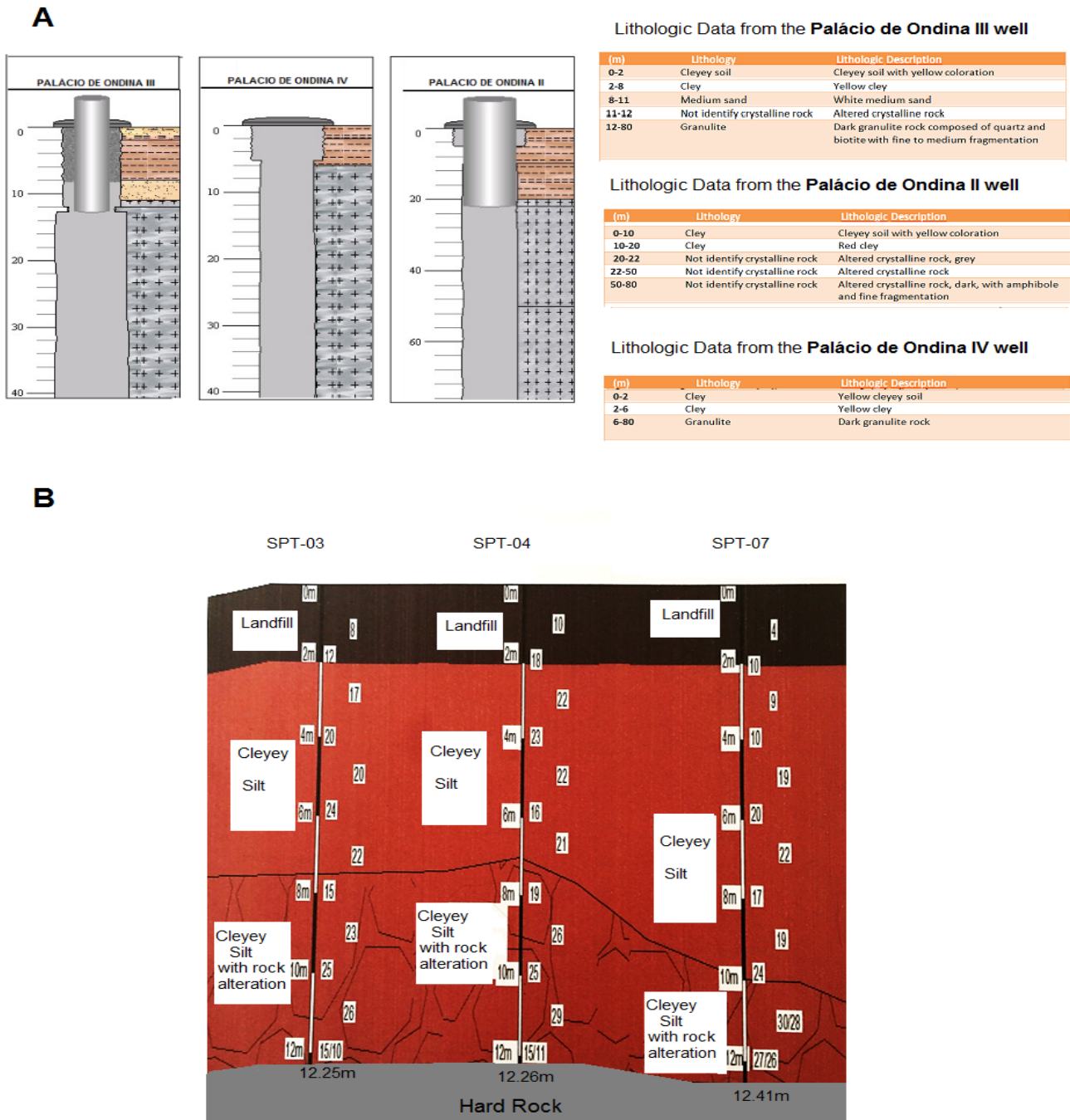


Figura 1: (a) Constructive profiles and lithological data of the wells of *Palácio de Ondina II, III, IV* modified from SIAGAS website, 2007 (b) Geotechnical profile obtained through the SPT survey data generated by Santos (2016).

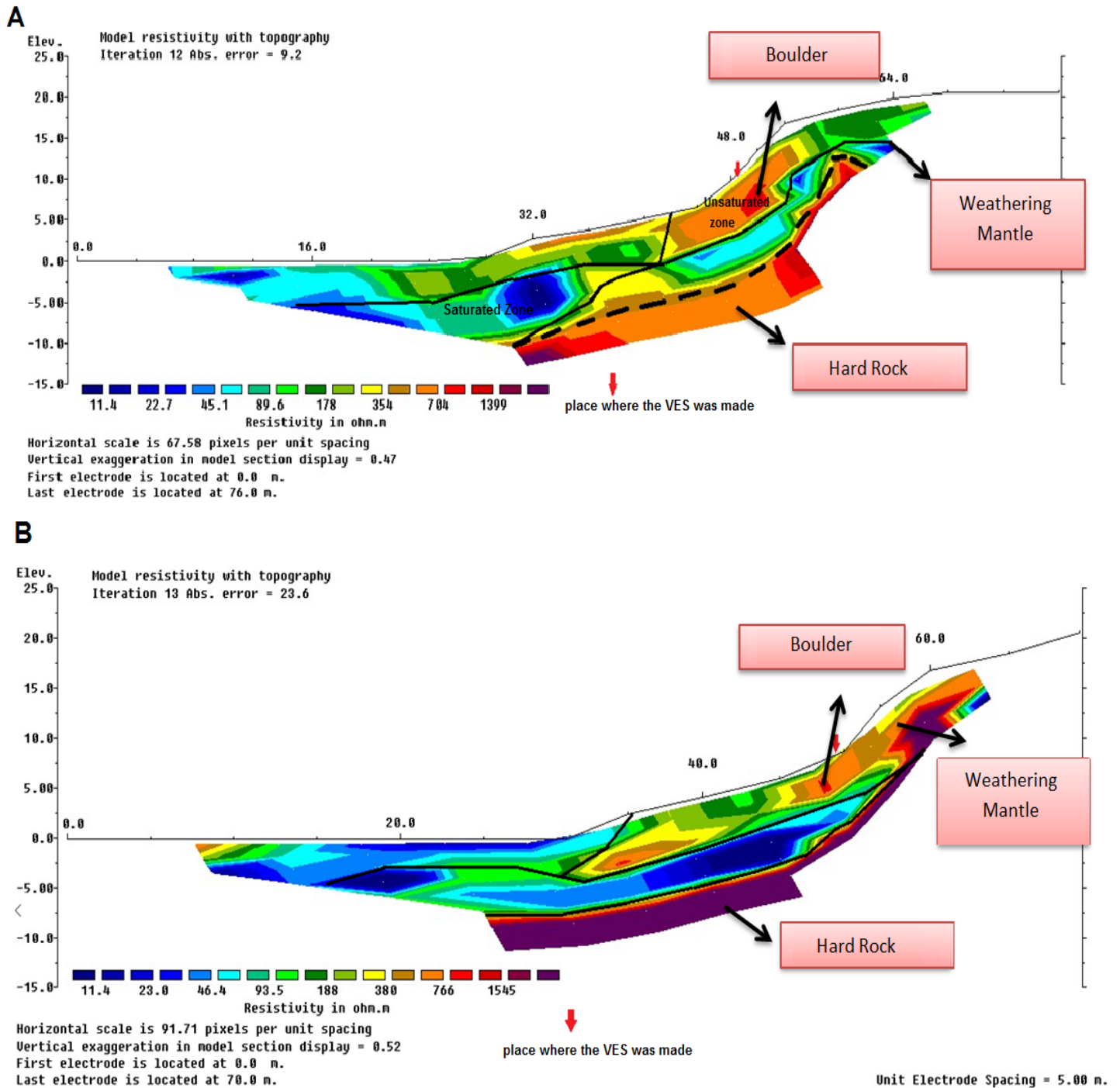
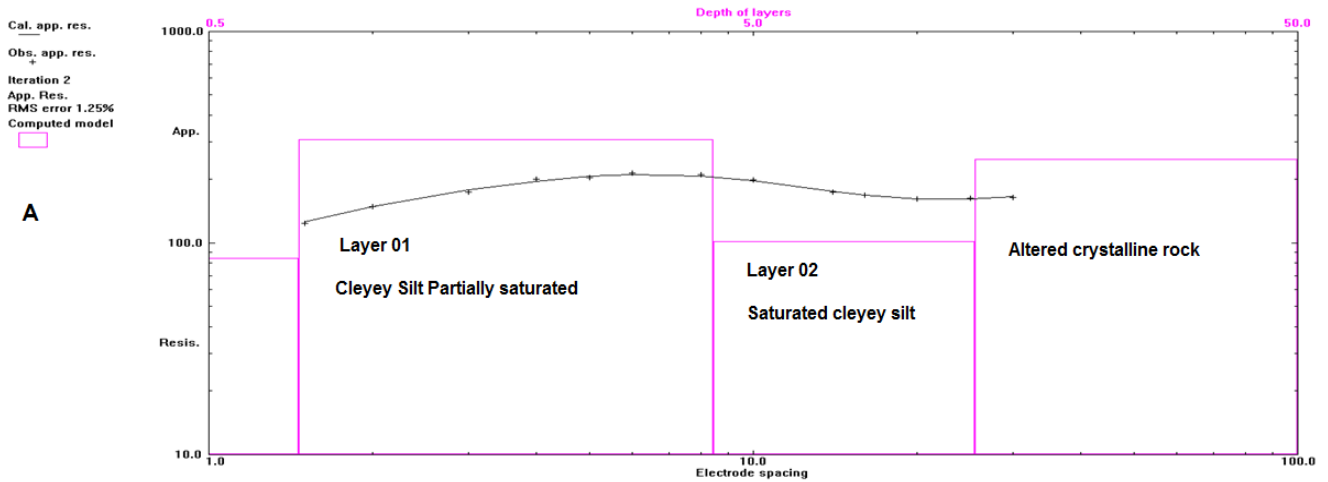


Figura 2: (a) Inverted 2D resistivity model ( $M_{1\_INV}$ ) for the ERT I, using the dipole-dipole array. The spacing between the dipoles was 4 m. This model presented the RMS error, between the calculated and the observed data, of 9.2 % (b) Inverted 2D resistivity model ( $M_{2\_INV}$ ) for the ERT I, using the dipole-dipole array. The spacing between the dipoles was 5 m. This model presented the RMS error, between the calculated and the observed data, of 23.6 %.



**B**

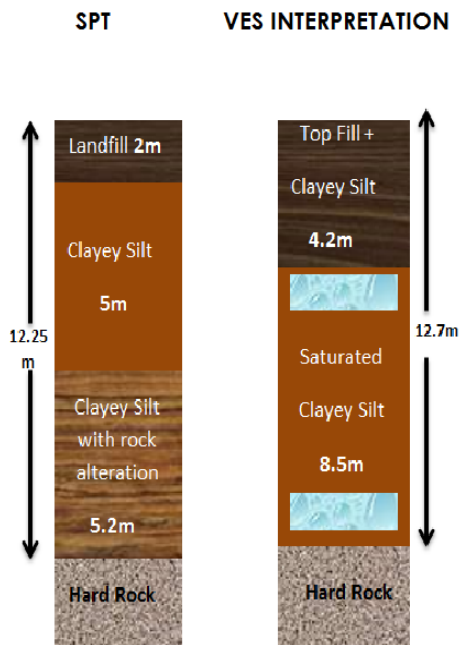


Figura 3: (a) Observed and calculated data of the VES, 1D inverted resistivity model made in the *RES1D software* (b) Description of the samples from one of the SPT surveys located near the study site, modified from (Santos, 2016) and interpretation of VES 1D geological model.