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

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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 Eletrical 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 landslides 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.

In the recent years, application of geophysics for landslides studies has widdely increased, especially for near surface exploration of landslide areas marked by a complex geological setting. (Popescu et al., 2016). According to McCann & Forster (1990), geohysical method can provide the necessary information for hazard assessment of landslides. This considerable attention its is due to a significant progress, in the last 10 years, for some geophysical methods such as Electrorresistivity and Ground Penetration Radar (GPR).

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 growthand and the arboreal forest is intense. Another important aspect that should be mentioned is the large presence of garbage in the area.

Methodology

Geoelectric 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 geoelectric measurements were carried by using a Syscal 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 ($M_{1_{INV}}$) e ($M_{2_{INV}}$) 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 me 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 ($M_{2_{INV}}$).

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 ($M_{2_{INV}}$) 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 continuos 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 an interpretative column with 1D geolectrical model was created (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. The VES was nnot able to reach the last layer due to the presence of the bamboos even with the small opening of the electrodes. Therefore, (Figure 3b) shows a rising trend at the end of the curve. The comparison among the ERTs and the VES confirmed this idea, 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 landslides processes, such as topfill thickness and saturated zone level. From the electric imaging, an anomaly related to a boulder was identified in the slope area. It is necessary to emphasize the loss of refinement in the measurements between the ERT I and ERT II due to the changes between the spacings of the dipoles.

The dense vegetation in the study site acted 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 proved the method efficiency mainly in the delimitation of the topfill and in the indication of the hard rock placement. Therefore, the electrorresistivity method is an excellent auxiliary tool for geotechnical diagnostics, especially when combined with accurate information (e.g: direct tests, rock samples).

Moreover, 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 (SPT).

Therefore, it can be said that geophysics is a operative tool in the study of slope stabilities allowed us to obtain a rich view of subsoil details with low costs and fast execution.

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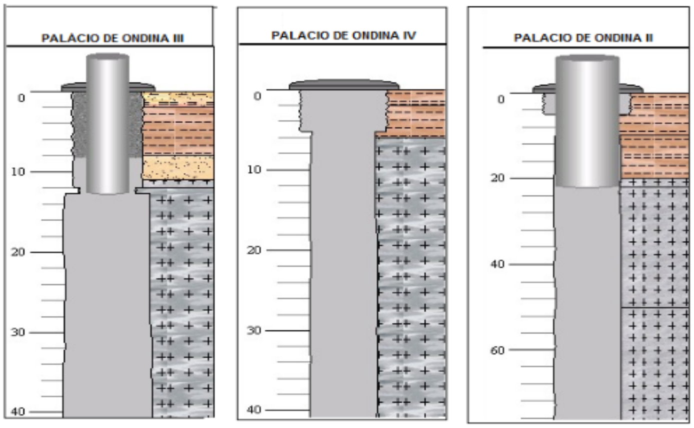

Lithologic Data from the **Palácio de Ondina III well**

(m)	Lithology	Lithologic Description
0-2	Cleyey soil	Cleyey soil with yellow coloration
2-8	Cley	Yellow cley
8-11	Medium sand	White medium sand
11-12	Not identify crystalline rock	Altered crystalline rock
12-80	Granulite	Dark granulite rock composed of quartz and biotite with fine to medium fragmentation

Lithologic Data from the **Palácio de Ondina II well**

(m)	Lithology	Lithologic Description
0-10	Cley	Cleyey soil with yellow coloration
10-20	Cley	Red cley
20-22	Not identify crystalline rock	Altered crystalline rock, grey
22-50	Not identify crystalline rock	Altered crystalline rock
50-80	Not identify crystalline rock	Altered crystalline rock, dark, with amphibole and fine fragmentation

Lithologic Data from the **Palácio de Ondina IV well**

(m)	Lithology	Lithologic Description
0-2	Cley	Yellow cleyey soil
2-6	Cley	Yellow cley
6-80	Granulite	Dark granulite rock

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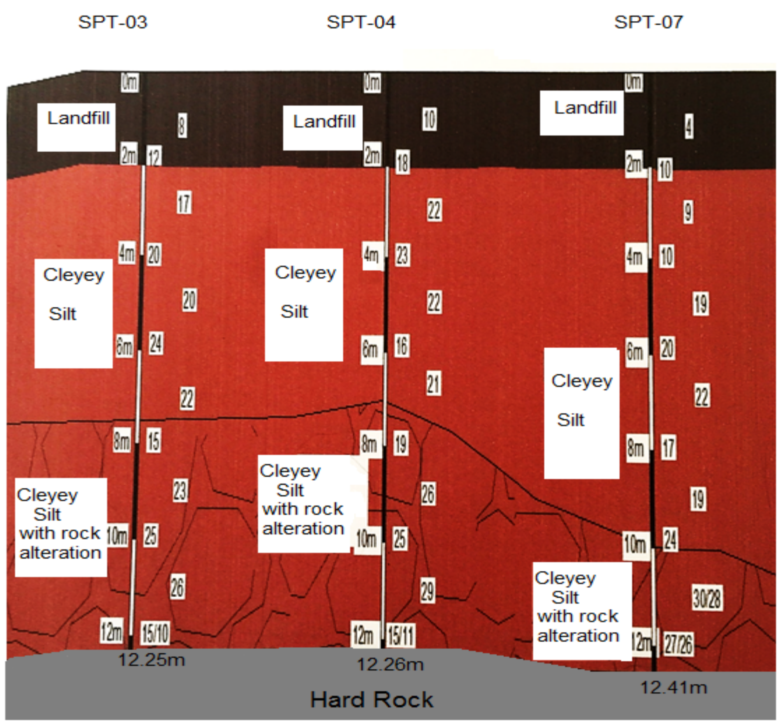

Figure 1: (a) Constructive profiles and lithological data of the wells of Palácio de Ondina II, III, IV modified from SIAGAS website, 2007 (b) Geotechnical profile obtained through the SPT survey data generated by Santos (2016).

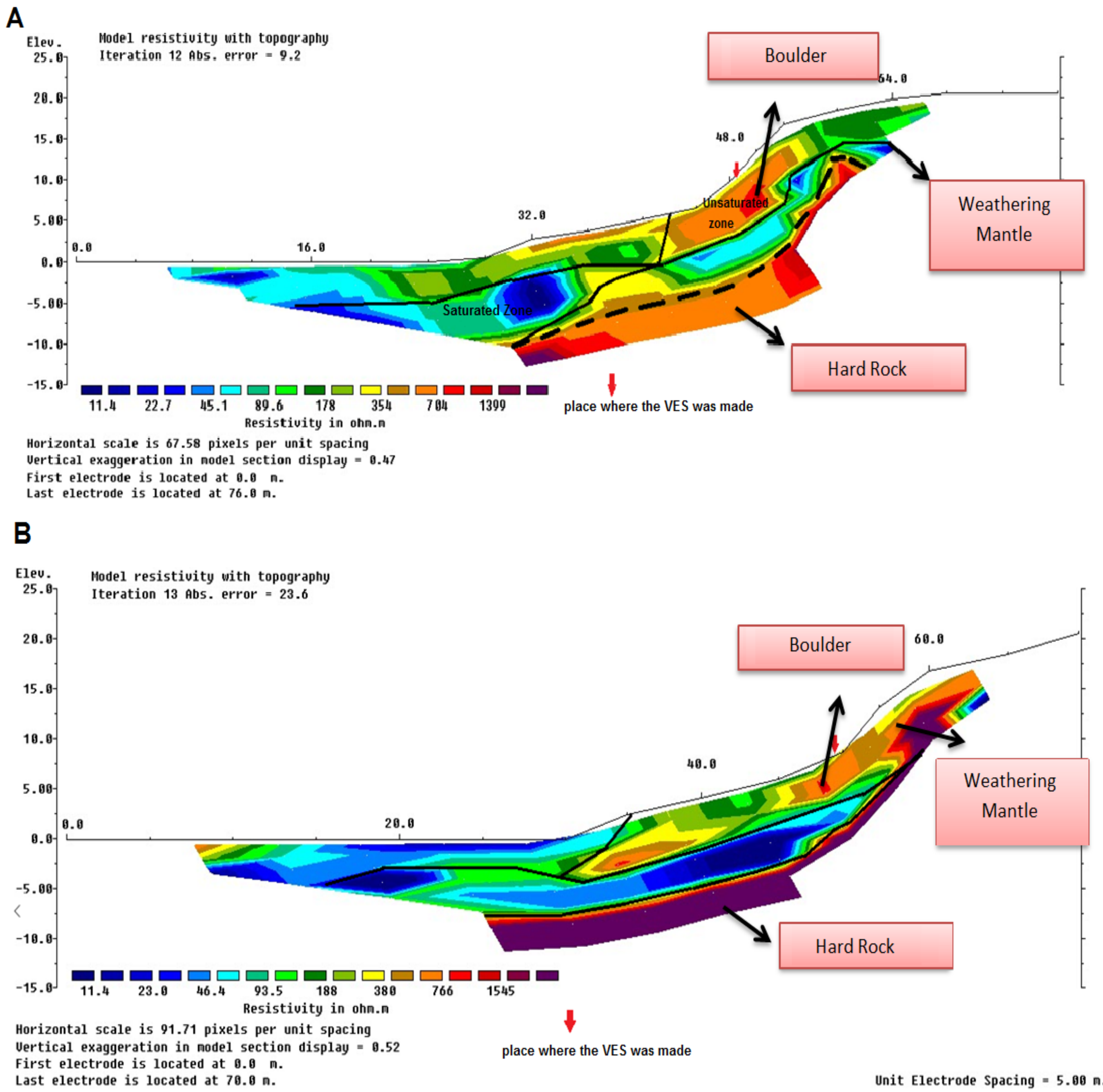

Figure 2: (a) Inverted 2D resistivity model ($M_{1_{INV}}$) for the ERT I,using the dipole-dipole array. The spacing between the dipoles was 4 m. This model presented the RMS error, between the calculated and the observed data, of 9.2 % (b) Inverted 2D resistivity model ($M_{2_{INV}}$) for the ERT I,using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

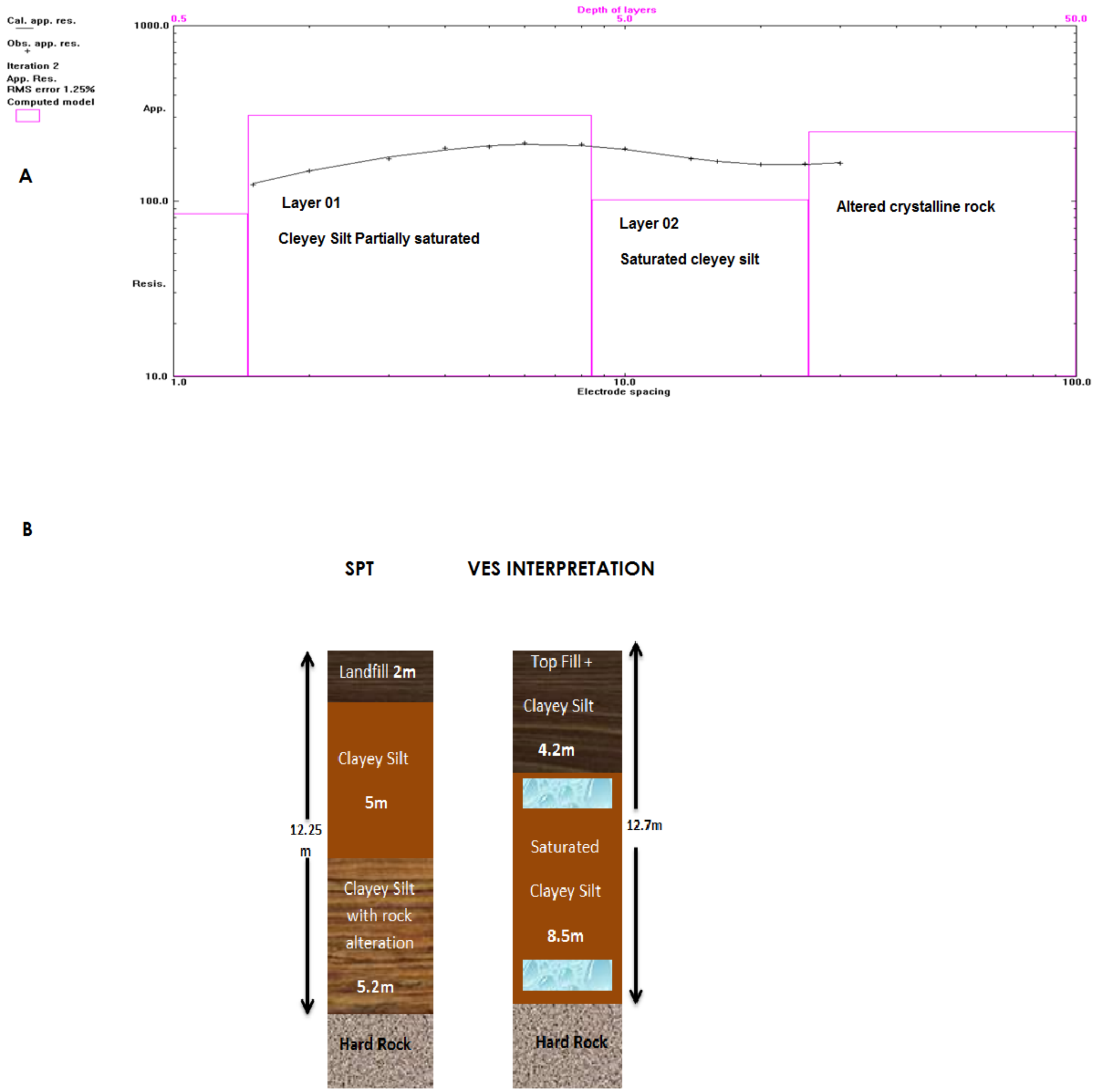

Figure 3: (a) Observed and calculated data of the VES, 1D inverted resistivity model made in the *RES1D software* (b) Description of the samples from one of the SPT surveys located near the study site, modified from (Santos, 2016) and interpretation of VES 1D geological model.